EXHIBIT 1311

EXPERT DECLARATION OF JEFFREY A. MILLER

("MILLER DEC.")

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Paper No. ___

UNITED STATES PATENT AND TRADEMARK OFFICE

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BEFORE THE PATENT TRIAL AND APPEAL BOARD

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TRW AUTOMOTIVE US LLC

Petitioner

v.

MAGNA ELECTRONICS INCORPORATED

Patent Owner

Case IPR 2015-00____

Patent 8,599,001

____

DECLARATION OF JEFFREY A. MILLER

I declare under penalty of perjury under the laws of the United States of America that the statements in this declaration are true and correct.

Executed on 12-16-2014

[signature]

Jeffrey A. Miller, Ph.D.

I, Jeffrey A. Miller, declare:

1. I am an adult individual and make this Declaration based on personal knowledge.

2. I have been retained by TRW Automotive US LLC ("Petitioner") to provide analysis regarding U.S. Pat. No. 8,599,001 ("the '001 Patent"). I have personal knowledge of the facts set forth in this Declaration unless otherwise stated. If called as a witness, I could and would competently testify to the facts set forth in this Declaration.

A. BACKGROUND AND QUALIFICATIONS

3. I am an Associate Professor of Engineering Practices in the Department of Computer Science at the University of Southern California. I was awarded a Ph.D. in Computer Science from the University of Southern California in 2007. I have authored numerous publications and a supplement to a book. I have given many presentations. I have assisted in developing curricula for the Computer Science and Computer Systems Engineering programs at UAA. I am a named inventor on one U.S. Patent Application. A copy of my *curriculum vitae* ("CV") is attached hereto as Exhibit A.

4. I was the Editor-in-Chief of the *IEEE Intelligent Transportation Systems Magazine* through 2013. I was previously an Associate Editor of the same magazine. I am presently an Associate Editor of *IEEE Transactions on Intelligent Transportation Systems*.

5. I have conducted research on the software and network architectures and algorithms used in mobile and wireless communication. Since 2008, I have secured over $930,000 for projects concerning Intelligent Transportation Systems networks and architectures.

6. I was the General Chair for the IEEE 69th Vehicular Technology Conference in fall 2009, the IEEE 15th Intelligent Transportation Systems Conference in fall 2012, and the IEEE 77th Vehicular Technology Conference in fall 2013. I was also a Program Co-Chair and Technical Program Chair for the IEEE 73rd Vehicular Technology Conference in fall 2011. I was on the IEEE Intelligent Transportation Systems Society Board of Governors for the term from January 2009 – December 2011 and was elected as Vice President for Administrative Activities in the same society from January 2011 – December 2012. I was also on the IEEE Vehicular Technology Society Board of Governors for the term from September 2011 – December 2013. From October 2011 – December 2013, I was the Editor-in-Chief of the IEEE ITS Magazine. Within the ITSS, I am an Associate Editor for the *IEEE Transactions on Intelligent Transportation Systems* since 2010. In 2010, I was the treasurer for the Alaska section of the IEEE and was the chair of the section from January 2011 – December 2011. During my time as chair of the IEEE Alaska Section, the section won the 2011 Outstanding Section Award for the Region 6 Northwest Area. In addition to being a member of the Intelligent Transportation Society of Alaska, I was also the president from January 2010-December 2011.

7. I have reviewed the patent at issue as well as the prior art patents and printed publications discussed in this Declaration and Petitioner's Request for *Inter Partes* Review of that same patent. I am familiar with state of and nature of the art at the time of the invention by virtue of my review of contemporaneous materials, including, but not limited to the prior art patents and printed publications addressed in this Declaration. I am also familiar with the state of and nature of the art at the time of the invention based on my own studies, research, publications, and experience as explained in the attached CV (Ex. A). For example, my studies, research, publications, and experience related to intelligent vehicles has included significant study of references of the time period of, before, and after the time of the claimed invention.

B. PERSON OF ORDINARY SKILL IN THE ART

8. A person of ordinary skill in the art relevant to the claims of the '001 patents at the time of the alleged inventions would have had at least the qualifications of or equivalent to either an undergraduate degree in electrical engineering or mechanical engineering with course work or research in automobile accessory systems and with at least two years of work making automobile accessory systems (sometimes referred to as the "POSITA").

C. STANDARDS GOVERNING OBVIOUSNESS

9. Petitioner's counsel has explained to me that a patent claim is invalid for obviousness under 35 U.S.C. 103 if the differences between the subject matter

sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains.

10. I have also been informed that various rationales may be used to find a patent claim obvious. For example, a combination of familiar elements according to known methods is likely to be obvious when it does no more than yield predictable results. And when a work is available in one field, design incentives and other market forces can prompt variations of it, either in the same field or in another. Rearranging parts in a manner that does not change operation of the device is also not a patentable improvement. And still further, where a skilled artisan merely pursues known options from a finite number of identified, predictable solutions, the result was merely obvious to try. Obviousness also exists when a claimed improvement is but a predictable use of prior art elements according to their established functions.

11. I have been further informed that to determine whether there was an apparent reason to combine the known elements in the way a patent claims, it is often necessary to look to interrelated teachings of multiple patents; to the effects of demands known to the design community or present in the marketplace; and to the background knowledge possessed by a person having ordinary skill in the art. In addition, I understand that a validity analysis need not seek out precise teachings directed to the specific subject matter of the challenged claim, as the inferences and creative steps that a person of ordinary skill in the art would employ can be

recognized, and that the legal determination of obviousness may include recourse to logic, judgment, and common sense.

12. Petitioner's counsel has also informed me that an obviousness analysis under 35 U.S.C. 103(a) proceeds by setting a background against which obviousness is measured. In this analysis, the inquiry is to: (1) determine the scope and content of the prior art, (2) ascertain the differences between the prior art and the claims at issue, and (3) resolve the level of ordinary skill in the art. Petitioner's counsel has further informed me that known mathematical algorithms are considered abstract ideas, and the step of programming an abstract algorithm into a computer, in and of itself, does not render a claim patent eligible under 35 U.S.C. 101.

D. THE '001 PATENT

13. I have been asked to consider the meaning of certain claim terms appearing in the '001 Patent. The '001 Patent is entitled "Vehicular Vision System." The '001 Patent was filed on November 19, 2012, issued on December 3, 2013, and has not yet expired.

14. For at least for the reasons discussed below, all of claims 1-24, 28, 32, 34-40, 42-69, 71, and 73-109 of the '001 patent are obvious in light of several prior art references, considered with respect to different combinations thereof, under 35 U.S.C. 103(a). A copy of the '001 Patent is attached as Exhibit B.

Claim Construction

15. Although I am not a lawyer, I understand that the words appearing in the claims of a patent are normally given their ordinary meaning from the perspective of a person of ordinary skill in the art ("POSITA"). I further understand that the perspective of the person of ordinary skill is discerned with reference to the time of filing of an earlier patent application within the '001 patent family. In this case, I am considering the '001 Patent from the perspective of the POSITA as of June 7, 1995. By using this date I do not intend to express an opinion that any of the claims of the '001 patent were actually conceived or reduced to practice on or before this date. I am simply adopting a date I understand has been identified by the Patent Owner for the purpose of establishing the reference point for a POSITA.

16. Petitioner's counsel has informed me that construing claims is a matter of law, and has asked me to construe the term "plurality", which appears in claims 1, 7, 36, 56, 61, 79, and 96 in the phrases "plurality of photosensor elements," "plurality of exposure periods," "plurality of light beams," and "plurality of sub-arrays," to mean, at a minimum, "greater than one." My analysis and conclusions use this construction.

17. Petitioner's counsel has further informed me that the claim phrase "pattern of light", which is present in claims 8, 62, and 83, to mean, at a minimum, the choice of light intensity and/or direction, *i.e.*, high beam or low beam, for the

equipped vehicle headlights. My analysis and conclusions use this construction.

Vehicular Machine-Vision Systems in June 1995

18. As discussed further below with regard to specific prior art references, a conventional machine-vision system from June 1995 all shared a basic hardware configuration: (A) a camera or image sensor positioned in a desired location; (B) an image processor to process image data captured by the camera/sensor; and (C) a controller to execute a desired function based on the results from the image processor of the processed data. Although, in June 1995, CCD-type photosensor cameras had been prevalent in the field for a number of years, as of 1993, CMOS photosensor array cameras had come to be a recognized replacement or substitution for CCD cameras.

19. "CCD" refers to Charge Coupled Devices, and CCD-type photosensor imager arrays (also known as "CCD image sensors" or "CCD cameras") were solid-state, that is, semiconductor, arrays of light-sensitive photosensors that generate an electrical signal in response to light incident on the photosensor. In a CCD image sensor, the individual photosensors, or pixels, in the array utilize a p-doped or n-doped Metal Oxide Semiconductor (MOS) elements capacitors to generate the electrical charge from the incident light. "CMOS" refers to Complimentary Metal Oxide Semiconductor, which are a variant of MOS technology. CMOS imager photosensor arrays (also known as "CMOS image sensors" and "CMOS cameras") are similar to CCD image sensors in many ways,

but utilize both a p-doped and an n-doped MOS elements together. CMOS arrays generally operated at lower power than CCD arrays, but there were many tradeoffs between the two variants.

20. By 1993, many of the tradeoffs negatively affecting the use of CMOS arrays as image sensors, as opposed to the more prevalent CCD image sensors, had been overcome, as particularly described in detail by Vellacott (Ex. C), for example.

Overview of the Claimed Subject Matter

21. The claims of the ‘001 Patent all claim a “system,” but in fact each claim actually requires a mixture of not only structural, that is, hardware, components of a device, but also functional methods of and operating such a device. This distinction is significant because, as discussed in the preceding section, typical machine-vision system devices of June 1995 all shared the same basic camera/image processor/controller configuration, and these typical processors and controllers were easily capable of being programmed to perform a variety of different functional algorithms without altering the electronics or structure of the device.

22. With regard to the actual structural device requirements of the ‘001 Patent, all of the claims require at least a CMOS photosensor array and a control having an image processor that processes image data captured by the CMOS array. Several dependent claims define various functional capabilities of the claimed

CMOS array/image processor/control configuration, but none of the claims deviate from this basic vehicular vision system configuration.

23. The basic configuration is important, because the written description of the '001 Patent expressly acknowledges how this claimed hardware configuration of its vehicular vision system was not actually new to the listed inventors of the '001 Patent, but instead an off-the-shelf machine-vision system made by VLSI Vision Limited ("VVL") for several years prior to the claimed June 1995 priority date of the '001 Patent. Specifically, the '001 Patent admits that the "photosensor array 32 is the VLSI Vision Limited (VVL) Single Chip Video Camera Model #ASIS 1011." (Ex. B, col. 13, lines 30-37).

24. The written disclosure of the '001 Patent further describes various specific details of a logic and control circuit (Ex. B, col. 18, line 30, for example), but none of the claims require such details. Where a logic and control circuit appears in the claims, only its generic presence is required in connection with the control and image processor. The claims are not limited to the particular descriptions of the logic and control circuit in the '001 Patent.

25. A similar issue arises with respect to the various operational capabilities (*e.g.*, headlight detection, fog detection, collision avoidance, etc.) featured in the '001 Patent claims. Whereas the written description of the '001 Patent includes some details of particular algorithms used to allow such operation, the claims themselves require no such detail. The claims merely feature the

generic ability to perform such function, but require no specifics as to how such functionality is accomplished. I note in particular that the '001 Patent includes no method claims.

E. SUMMARIES OF RELEVANT PRIOR ART

Vellacott

26. The primary reference is Vellacott (Ex. C). Vellacott is of particular relevance because it provides significant detail about the very device that the '001 Patent admits to use as its "light sensing device," namely, the VVL model #ASIS 1011 (Ex. B at 13:36-37), in a vehicular vision system. As shown by Vellacott, VVL's single-chip "Peach" camera model #ASIS 1011 was much more than simply a light sensing device. The ASIS 1011 was an integral component of "a complete standalone machine-vision system" sold by VVL as "The imputer." (Ex. C, page 3, Fig. 4). The imputer was specifically programmed for use in automotive vision systems. (Ex. C at page 4, col. 3). "ASIS" refers to an "Application-Specific Interconnect Structure."

27. In addition to the Peach/ASIS camera chip structure, Vellacott states that the imputer also included "A full library of machine-vision functions … including morphological (shape) filters, transforms, correlators, convolvers, image segmentation, frequency filtering rotation, reflection and logical operators."

28. Paradiso (Ex. D) provides a more detailed analysis of the VVL imputer, its capabilities, and several known applications in the field. Paradiso

confirms that the Peach camera and ASIS 1011 were a unified package where the reference explicitly states that "As of last year [1993], the Peach chip[14] (ASIS-1011-B) was separately available for under £30." (Ex. D at page 4, last two lines, emphasis added). Paradiso is thus describing the same Peach camera with supporting electronics (ASIS 1011) that constitutes the VVL imputer described by Vellacott.

29. Paradiso further illustrates the electronic schematics of the camera, processor, and control of the VVL imputer. (Ex. D, page 6, at Figure 5). Paradiso states that "The complete camera (with housing) measures 3.5 x 3.5 cm. The CMOS monolithic inside integrates the sensor (operating down to 5 Lux @ F1.8) with all video formatting and signal processing." (Ex. D, page 4, last paragraph).

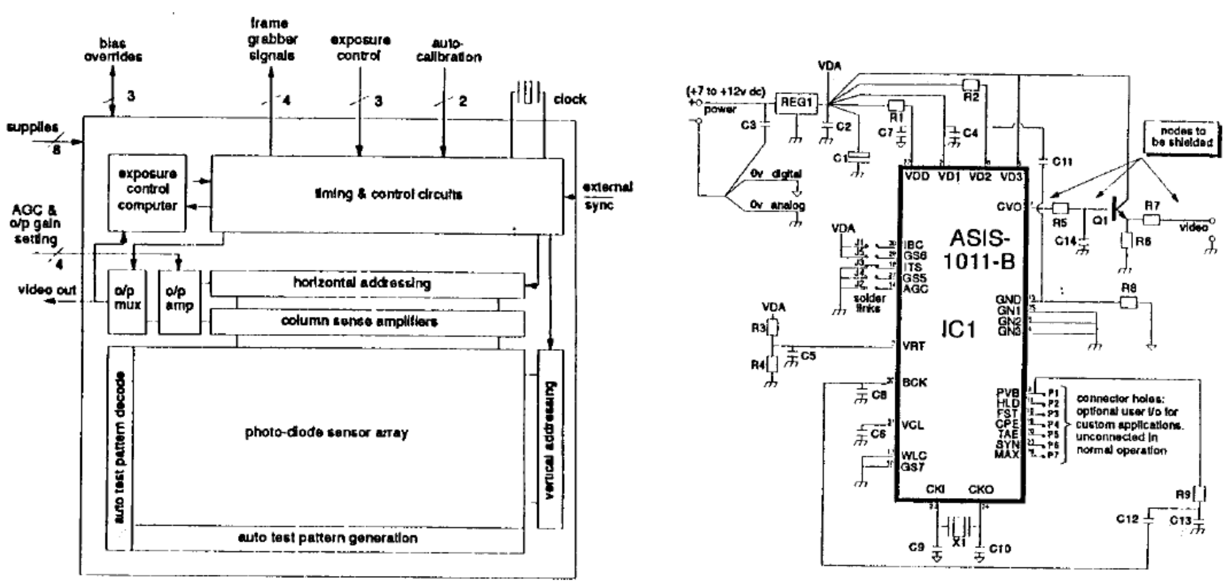


Figure 5: Block diagram of the VVL chip (left) and its recommended support electronics (right)

30. As shown above, Paradiso clearly demonstrates VVL imputer further

included exposure control as an integral function of the camera that forms the nucleus of the Vellacott imputer. (Ex. D, page 6, at Figure 5). Paradiso further confirms that the Peach CMOS photo-diode sensor array was not only available in the 256x256 or 512x512 arrays mentioned by Vellacott as examples, but also in an asymmetric "1/2" array of 312x287 photodiode pixels," which would, by definition, have a greater width than height to the array. (Ex. D, page 4, last paragraph). Fletcher (Ex. M) further confirms that the hardware of VVL imputer, disclosed by Vellacott, was capable of supporting lenses and lens mountings of different sizes. Given this known capability of the VVL imputer, choice of a compatible photosensor array having different dimensions would have been an obvious matter of design choice by the POSITA.

31. The GEM reference (Ex. E), discussed further below, also analyzes the Peach camera chip and confirms that the Peach camera chip with ASIS 1011 electronics was unified package at the time of the invention. (Ex. E, page 109). GEM specifically states that "Along with a 1/2" format image sensor array, <u>ASIS-1011-B includes the circuits which control and read the array, plus a comprehensive control input and output set for digital video applications</u>." (Ex. E, page 109, emphasis added). GEM further confirms that the Peach camera, together with the ASIS 1011 processor/control was on sale to the public as early as at least June 1993, two years prior to the earliest claimed priority date of the '001 Patent. (Ex. E, page 109).

32. Paradiso and GEM thus both confirm that the Peach CMOS camera

was packaged and sold together with the ASIS 1011 electronics chip circuitry as a single unified product. Vellacott specifically describes the Peach CMOS camera (which included the ASIS 1011 electronics) as an integral part of the VVL imputer, and that the VVL imputer had been sold to the Applicant of the ‘001 Patent (“Donnelly Corporation,” Ex. C at page 4) as a vehicular vision system well before the ‘001 Patent’s priority date.

33. Most importantly, the ‘001 Patent itself specifically admits that the model “ASIS 1011” image sensor was the preferred embodiment for its disclosed “photosensor array 32” (Ex. B, col. 13, lines 30-37), which is the same element 32 utilized for both the rearward and forward embodiments. (Ex. B, col. 33, lines 9-15). Therefore, for the purposes of this discussion, I consider the terms “imputer,” “Peach camera,” and “ASIS 1011” to interchangeably refer to the same CMOS camera with an image processor and a logic and control circuit that were integral to the “VVL imputer” as described by Vellacott.

34. The only capability of the VVL imputer that I find to not be attributed to VVL by the ‘001 Patent is the VVL imputer’s additional “full library of machine-vision functions” that came pre-packaged with the imputer, as discussed by Vellacott, above. This considerable pre-packaged library of programming functions is very significant because Vellacott further explains how the VVL imputer was “completely programmable” with this full library. (Ex. C, page 3, cols. 2-3). Vellacott further discloses that the number of machine-vision applications which can be run on the imputer is limited only by the processing

power of the mothercard, which, at the time was an 8-bit Intel 8032 microcontroller in the main disclosed embodiment. (Ex. C, page 3, col. 1).

35. Vellacott further states, however, that the processing power of the imputer could be increased "3000-fold" using "optional plug-in coprocessors" (the Motorola 56002 DSP is provided as one example) if greater processing power was desired. As of 1994, such coprocessor of greater power were known and available, and it would have thus been an obvious matter of design choice for the POSITA to choose one or more of these more powerful coprocessors to run more complex algorithms, or more than one algorithm for the same vehicular vision system, dependent only on cost restrictions for the overall system. With a known, more powerful processor, the VVL imputer described by Vellacott would have easily been capable of running multiple complex processes and algorithms from its pre-packaged library of programs and control algorithms. No undue experimentation would have been required for the POSITA to choose from among the library of pre-packaged machine-vision functions.

36. Vellacott explicitly discloses that at least one of its pre-packaged library of machine-vision functions was dedicated to an automotive/vehicular vision system for headlight detection by a CMOS camera (with imputer) housed in the rearview mirror. Rearview mirror assemblies were well-known to the POSITA at the time of the invention, to be located at the upper portion of the windshield of the equipped vehicle for most passenger vehicles (large trucks being an exception). Such passenger vehicles were further commonly known to attach these mirror

assemblies directly to the windshield. Vellacott specifically states "The imputer was programmed to analyse this image to recognise when and where headlamps are present in the field of view." (Ex. C, page 4, col. 3). Although this specific mention of headlight detection is performed with the imputer facing rearwardly, the pre-packaged algorithm of the imputer would predictably function in exactly the same way when facing forward. That is, the algorithm used to detect and recognize the headlights would not change with the orientation of the camera.

37. Vellacott utilizes this pre-packaged headlight detection program to then send a control signal from the imputer to dim its rearview mirrors. Vellacott states "The dimming is controlled by an analogue voltage from the imputer, which directly sets the chrominance of the mirror." This option to control the mirror dimming, however, as opposed to any other system of the equipped vehicle (such as headlights, for example), would have been an obvious matter of design choice to the POSITA at the time of the claimed invention. Vellacott's imputer was clearly <u>capable</u> of sending an analogue control signal to any vehicle system wired directly to the imputer, or wired through vehicle communication bus connected to the imputer. No special skill in the art would have been required to send such a control signal to a different vehicle system. Fletcher (Ex. M) states that, for the VVL imputer specifically, "Binary ports are controllable from software," confirming that desired control signals from the imputer could have been purely a matter of programming, and not a change in the structure or operation of the device.

38. In its most general sense, a control signal is any type of signal that is used to control something. In the specific case of computer vision systems, the control signal would be a "true" or "false" signal that signifies whether an object of interest was detected in the field of view. The control signal does not necessarily mean that something will change, such as whether the state of the high beams, but it is anticipated that the signal will result in a change. In one example, an image is taken from the sensors and processed by a processor. The programming of the processor then "decides" whether or not an object is detected in the camera's field of view. If an object is detected (i.e. a headlight), then a control signal of "true" will be sent to a control signal receiving system, for example, one that controls the state of the high beams, dimming of a rear-view mirror, or any other vehicular system that can be controlled by a control signal, which is to say almost all, if not all, of such systems. The control signal receiver of the particular vehicular system then makes a decision on what to do based on the received control signal sent from the computer vision system.

39. It should be understood that such a "true" control signal would be sent over some communication network within the vehicle, for example, a bus communication system or by direct wiring. If it was desired to send the signal over the bus, no additional programming would be required to reroute the control signal of the detection/recognition program. Once the control signal is established by the program, the POSITA would need only to specify the address destination of the signal. In other words, the numerical variable of the control signal address would

simply need to be set to match the desired vehicle system, without changing any of the processing of the particular program.

40. Alternatively, a control signal from the imputer could be sent to a particular vehicle system (*e.g.*, headlights) by direct wiring, which would have been a very simple, but more cumbersome, solution that was well-known to the POSITA at the time of the claimed invention. If you have a control signal as an output of one system (*e.g*., Vellacott's imputer) that corresponds to the input of the receiver of another system (*e.g.*, rear-view mirror dimmer or headlights), it is obvious that you would connect the output of one system to the input of the other. Wiring electrical components together was an obvious capability of the POSITA requiring no special skill in the art or inventiveness.

41. Therefore, according to my complete review and understanding of the text of the '001 Patent, as well as the Vellacott reference (further explained by the GEM and Paradiso references analyzing the Vellacott imputer), it is my opinion that the entirety of the hardware structure of the claimed vehicular vision system of the '001 Patent is simply that of Vellacott's imputer, including both Vellacott's CMOS photosensor array and its image processor-plus-control, along with its considerable pre-packaged library of machine-vision functions. As discussed further below, all of the claims of the '001 Patent could easily be performed by the VVL imputer, utilizing one or more of the multitude of pre-packaged applications, or else by basic additional programming of similar algorithms that would have been well within the capability of the POSITA in 1994, who would have only had

to understand C-language computer programming for Windows. (Ex. C, page 3, col. 2).

42. The conclusion that the '001 Patent is simply utilizing the VVL imputer, as taught by Vellacott, is further confirmed by Vellacott's explicit statement, discussed above, that "One of VVL's customers is US automotive components manufacturer Donnelly Corp. Donnelly has used the imputer to develop electro-chromic rearview mirrors, which automatically reduce headlamp glare from behind." I see that "Donnelly Corporation" of Holland Michigan is the entity listed on the face of the '001 Patent as "Applicant." With respect to any potential development of electro-chromic mirrors in relation to Vellacott's imputer, it should be noted that none of the '001 Patent's claims require an electro-chromic mirror.

Kenue

43. Kenue (Ex. F) discloses a forward-facing vehicular vision system for viewing a roadway scene in front of a vehicle, utilizing a CCD camera, as well as "template matching techniques" and "Hough algorithms" to detect lane markers or other objects. (Ex F. at Abstract). Kenue's camera 10 is mounted "at the upper center of the windshield" (Ex. F at 2:31), and Kenue's system is further able to analyze captured image data and automatically send a control signal to one or more vehicle systems, for example, a warning system, vehicle guidance system (steering and braking), or headway control system. (Ex. F, at Abstract, 1:19-24, and 2:28-

39). Kenue's computer vision system is disposed "at the upper center of the windshield" (Ex. F at 2:31), very similar to Vellacott's express statement to house the imputer within a rearview mirror, which would be located at substantially the same location.

Yanagawa

44. Yanagawa (Ex. G) similarly describes a forward-facing vehicular vision system, or "traveling vehicle recognition device," which has the functional capability "of automatically controlling headlight beams to high and low beams according to the state of whether there is a vehicle ahead." (Ex. G, page 2, at upper right column). Yanagawa does not specify what type of imaging device is utilized to capture image data, other than the statement that the imaging device is a "color television camera (11)." Nevertheless, Yanagawa does state that the image data captured by its television camera is binarized, or digitized, and thereby converted into digital image data for image processing by the video signal processor 14. (Ex. G, page 2, col. 2, last two paragraphs).

45. Yanagawa further indicates that its video signal processor 14 includes "extracting," "recognizing," and "calculating" means (Ex. G, page 1, "Claim") that would render the video signal processor capable of the standard functionality of a conventional image processor available in 1994-1995. Similarly, Yanagawa's executing part 15, which "executes headlight control based on the recognition result" of the recognizing means of the image processor 14 is clearly a "control,"

as described by the '001 Patent disclosure. Again, although the logic and control circuitry within the written disclosure of the '001 Patent is described (for some embodiments) in differing levels of detail, the claims of the '001 Patent merely require a generic control having no more functionality than that described and shown by Yanagawa (and also Vellacott and Kenue, as discussed above).

46. It is significant to note that Yanagawa shows that it was well-known to utilize recognition results from the vehicular vision system's image processor to control the headlights of the equipped vehicle. (Ex. G, page 1, col. 2, first paragraph). The desired control signal, that is, which vehicle system (*e.g.*, headlights, mirror dimmer, etc.) is then just an obvious matter of design choice to the POSITA.

47. For a typical vehicular vision system at the time of the claimed invention, an image is taken from the sensors (for Yanagawa, by the camera 11) and then processed (*i.e.*, by the image processor 14). Within the typical image processor it is then decided whether or not an object is detected (Yanagawa's "recognizing means") in the field of view. If an object is detected (*i.e.* a headlight, as in both Yanagawa and Vellacott), then a control signal of "true" could be sent to a particular application run by the processor, such as the one that controls the state of the high beams, such as in Yanagawa. The particular application can thus make a "decision" on what to do – through the controller (executing means 14 in Yanagawa) based on the control signal that was sent from the processor. Yanagawa thus clearly demonstrates that it was well-known by the time of the

claimed invention to utilize the detection and recognition of headlights from a forward facing camera to control the equipped vehicle's own headlights. The selection of the particular control signal (headlight system or mirror dimmer) would have involved nothing more than an obvious design choice by the POSITA.

Venturello

48. Venturello (Ex. H) discloses yet another forward-facing vehicular vision system (2), which utilizes a CCD camera (8 and 10-12), image processor (13) and control (14) to detect and recognize objects for instrument-assisted vision in poor visibility, and control the equipped vehicle's headlamps (4) based on the processing of captured image data. (Ex. H, page 6, FIGS. 1, 2). Venturello describes how the detector of its CCD camera is capable of detecting illumination from a detected object (Ex. H, page 2, lines 16-17), or from the scattering of ambient light by the fog itself. (Ex. H, page 2, lines 10-12).

49. Venturello then utilizes its processor/control (13/14) to pulse the light from the headlamps (4) to address problems faced by the vehicular vision system when encountering the fog. (Ex. H, page 2, lines 54-59). This headlamp control method is significantly more complex than the high beam/low beam switching featured in the claims of the '001 Patent, but Venturello nevertheless makes clear that the more basic concepts of simply detecting fog, and then controlling the headlamps based on such recognition, were both well-known before the claimed priority date of the '001 Patent.

50. Of particular note is that Venturello's claims are all primarily drawn to its more complex and specific method of operating the headlights in fog (*e.g.*, Ex. H, page 5), and not merely to a system having the capability of fog detection, as more generally claimed by the '001 Patent.

Bottesch

51. Bottesch (Ex. I) discloses still another forward-facing vehicular vision system (Ex. I, Abstract, "passive optical system") utilizing a forward facing CCD camera (Ex. I at 3:10-11) and a vehicle computer (Ex. I at page 10, FIG. 16) that processes image data captured by the CCD sensor array (Ex. I at 5:59 through 6:56) to send a control signal to the equipped vehicle's cruise control system (Ex. I at 2:30-33), or collision avoidance system. (Ex. I at 11:30-31). Bottesch's sensor array may be a horizontal, single row array including an ambient light sensor, or a stack of linear arrays, such as with a typical CCD planar photosensor array. (Ex. I at 6:59-61; FIGS. 11-12). Bottesch acknowledges that such CCD sensors were, at the time of the claimed invention, "readily available on the market," and "not intended to be claimed per se as inventive." (Ex. I at 4:10-13).

52. Bottesch further teaches that the ambient light sensor has the same basic construction as the other photosensors in the array (Ex. I at FIGS. 8-9), and that the ambient light sensor 15c is merely one sensor at one end of the array of sensors 15a-15c. (Ex. I at FIGS. 4-5). Bottesch teaches that it was known at the time of the claimed invention to compare detected light information at the ambient

sensor and compare it with other sensors of the array (Ex. I at 4:66-68), and that the vehicle camera could include "low-lux sensor components," to indicate "a condition of reduced visibility, as at night time," which components "would be activated when the headlights of a vehicle are switched on." (Ex. I at 7:33-36).

53. Bottesch does not specify the exact processing steps to control the vehicle's headlights based on a daytime/nighttime condition detected by the ambient light sensor. Bottesch nevertheless describes a system that detects a nighttime condition from at least one or more sensors of its array, and compares the ambient light level with other sensor information to control another vehicle system based on the comparison. Bottesch does not explicitly state that the headlight switch is controlled as a result of such comparisons by the vehicle computer, but as discussed above with regard to Yanagawa, the choice of which vehicle system receives the particular control signal was an obvious matter of design choice to the POSITA, and a straightforward matter of programming well within the skill level of the POSITA.

54. In summary, all of the Kenue, Yanagawa, Venturello, and Bottesch references feature similar configurations of a basic vehicular vision system namely: a forward-facing camera; an image processor for detecting, recognizing, and processing image data from the camera, and; a control for controlling a vehicular system based on the results from the image processor. All of these references except Yanagawa expressly teach that the camera is a CCD photosensor array, and all four references otherwise only differ with regard to which particular

functional algorithms are programmed into and run by their respective processors, thereby which particular vehicular system is then controlled as a result of such processing. The basic ability of all four so-programmed respective vision systems though, is essentially the same.

55. The commonality of the structural configuration of these four vehicular vision systems is of particular relevance when compared with the VVL imputer taught by Vellacott, which was published after each of the four references discussed immediately above. Vellacott specifically states that one advantage of the VVL imputer is that it "replaces a camera, frame grabber, processing board and PC/workstation with a single integrated architecture." (Ex. C at page 4, col. 3). Based on this statement, in addition to the detailed description of the operation of the VVL imputer by Vellacott, a POSITA would have understood that the imputer would have had least all of the basic machine-vision capabilities of the earlier prior art vehicular vision systems, limited only by programming choices by the POSITA and processing power of the mothercard.

Schofield

56. Schofield (Ex. J) is different from the references above in that it does not directly relate to a vehicular vision system and the algorithmic control thereof, but instead focuses on well-known mounting methods and structures for attaching mirrors having a variety of electronic components at a windshield. Specifically, Schofield describes a mounting adaptor for removably securing an interior

rearview mirror assembly to a mounting support on the inner surface of a vehicle window such as a windshield. (Ex. J at Abstract). Schofield further describes that its mounting adaptor is intended to be universal for mounting a mirror to any style (old or new) of mirror mounting button (Ex. J at 1:29-36), which buttons were well-known at the time "for many years" to be adhered to the upper inside surface of the front windshield of the vehicle. (Ex. J at 1:16-20).

57. Schofield additionally states that its universal mirror mounting adaptor was intended for use at the upper windshield area for "an increasing amount of instrumentation and accessories" (Ex. J at 1:37-39), and particularly those electronic accessories housed in a rearview mirror assembly. Schofield specifically teaches that one such accessory housed within a rearview mirror assembly utilizing its universal mount is "a headlight dimming sensor 130." (Ex. J at 8:53-58). The headlight dimming sensor 130 is shown to face forward (Ex. J at FIG. 15), and except for the fact that the light sensor 140 is not a CMOS array, the dimming sensor 130 operates in a substantially similar matter to the other vehicular vision systems discussed above. That is, image information detected by the single sensor 140 is processed and used to control the headlights based on this simple detection/recognition circuitry. Adding a more complex CMOS array and processor to this configuration, as could be done with Vellacott's imputer, for example, would not change the basic operation, but instead, merely is sophistication.

58. Additionally, Schofield states it was well-known "to route electrical

cables between the vehicle interior roof headliner and the mirror assembly to provide appropriate electrical power" (Ex. J at 1:55-58), and that an "appropriate electrical circuit included on circuit board 144 … is connected to the vehicle electrical system via wiring 146." (1008 at 8:53-64). Therefore, according to Schofield, basic wiring and circuit connections for rearview mirror accessories were not novel at the time of the claimed invention, nor was the functional operation of such accessories affected by the choice of mounting or attachment structures at the vehicle windshield.

Denyer

59. Like Schofield, Denyer (Ex. K) also does not relate directly to the programming and operation of a vehicular vision system, but instead describes how it was well-known at the time of the claimed invention to add RGB color filters to existing solid-state photosensor camera arrays such as CCD and MOS devices. (Ex. K at page 10, lines 7-23). RGB filters would be considered, at a minimum, by a POSITA to be a "spectral filter." The addition of an RGB filter, such as that disclosed by Denyer, to a CMOS array (such as that described by Vellacott) would not change the operation of the CMOS device, but would instead enhance its ability to distinguish color information in addition to its inherent ability to distinguish light intensity and luminance. Denyer clearly teaches that its filter is applicable to all solid-state imaging devices such as CCD and CMOS (a subset of MOS devices).

60. In summary, both of Schofield and Denyer disclose nothing more than well-known structural design choices that were universally available to rearview mirror accessory systems and solid-state photosensor arrays, respectively. The use of such well-known structural features would not affect the basic operation of a vehicular vision system. Use of either structural option would have been an obvious design choice by the POSITA for the same reasons described by Schofield and Denyer, respectively, with the only limitations on such design choices being the desired cost of the vehicular vision system as a whole. Adding these structural options would increase the cost of the overall system, and such optional elements would not be necessary to perform the basic programming operations from the other vision systems discussed above.

F. <u>OBVIOUSNESS OF COMBINING THE PRIOR ART REFERENCES</u>

Vellacott in view of Kenue

61. Vellacott is the primary reference with respect to all of the claims of the '001 Patent. And except for certain minor details regarding the orientation of Vellacott's camera (and also spectral filter and attachment methods, both discussed further below), Vellacott clearly discloses all of the hardware – camera, image processor, controller, along with all related logic and control circuitry – required to meet the <u>structural</u> device requirements of all of the claims. As discussed above, the '001 Patent even admits to using the VVL imputer as its photosensor array 32 plus supporting circuitry (that is, the Peach CMOS camera plus ASIS 1011 electronics chip, which were known to be packaged and sold together as a unit in 1994). In the broadest sense, all of the claims of the '001 Patent appear to be simply claiming methods of orienting and operating/programming VVL's imputer device, without adding any inventive hardware or structure to the device.

62. Considering claim 1 of the '001 Patent as an exemplary claim, except only for the direction in which the CMOS photosensor array is pointed, I find no difference between the limitations of this claim and the specific automotive rearview mirror embodiment of the VVL imputer described by Vellacott. (Ex. C at page 4, col. 3). The imputer device itself would continue to function the same, irrespective of the direction in which it was aimed.

63. I note that the written description of the '001 Patent does not describe

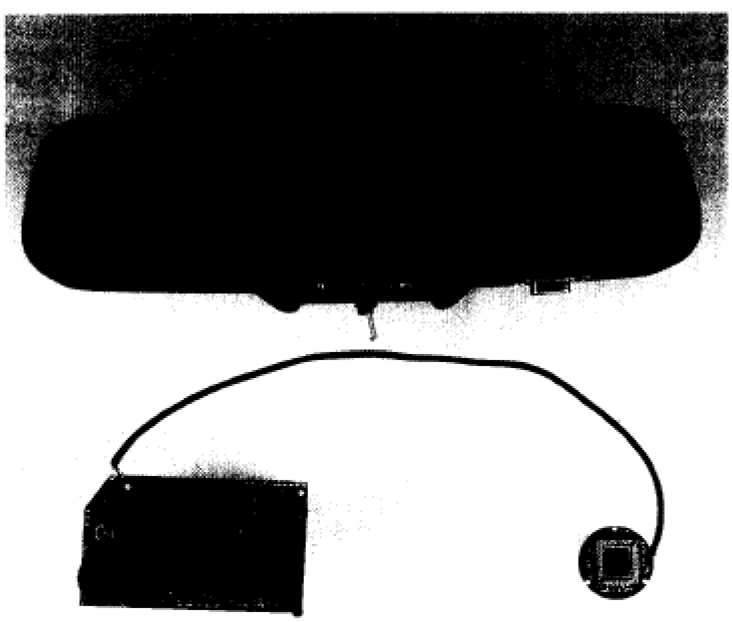
any change in structure, nor change in the basic operation of its light sensing and logic circuit 26 (including photosensor array 32 and logic and control circuit 34) from the rearward-facing embodiment (Ex. B at FIG. 6A) to the forward-facing embodiment. (Ex. B at FIG. 6B). The '001 Patent uses the same numeral (26) to refer to the circuit in both orientations, and admits that the forward-facing embodiment "may also be integrated with automatic rearview mirror system and vehicle interior monitoring system described herein" from the rearward-facing embodiment (FIG. 6A). (Ex. B at 33:9-12). According to the '001 Patent itself, therefore, there is no structural difference between the forward- and rearward-facing embodiments other than the orientation of the field of view of the array 32.

64. This lack of structural distinction between the forward- and rearward-facing embodiments in the '001 Patent is important because the rearward-facing embodiment featured in FIG. 6A is clearly the same as Vellacott's rearview mirror application of the VVL imputer. The rearward-facing embodiment of FIG. 6A of the '001 Patent deviates from Vellacott's vehicular vision system embodiment only with respect to its programming; the rearward-facing embodiment is programmed to determine an intrusion to the vehicle, whereas Vellacott's programming addresses headlight detection. The devices in both disclosures, however, are identical – including the orientation (rearward) of the two devices. Claim 1 of the '001 Patent though, requires no particular algorithms or method of operating the device.

65. Therefore, I find that claim 1 merely takes Vellacott's VVL imputer in

the rearview mirror embodiment (Ex. C at page 4, Figure 6), and simply directs the camera portion of the imputer forward, but without changing any other feature of the imputer. As an initial matter, the orientation of the camera should be nothing more than an obvious matter of design choice. It does not require any degree of skill in the art to understand that a camera should be pointed in the direction that is desired to be imaged.

66. Furthermore, reorienting the camera of the VVL imputer would not have involved any inventiveness, or even modification to the imputer itself. Figure 6 of Vellacott (Ex. C at page 4) illustrates the imputer and CMOS image sensor outside of the rearview mirror housing for comparison, clearly demonstrating that the single-chip camera portion of the imputer can be separated from the rest of the imputer, but still connected by wiring, as shown below:



6 Imputer application: a rear-view-mirror controller ASIC

67. According to this illustration in Figure 6 of Vellacott, it would therefore have been obvious to the POSITA to easily and separately move the CMOS camera into any desired position within, about, or adjacent the rearview mirror assembly housing, without having to change the location of the other imputer electronics that are separated from the camera. The camera/image sensor portion of Vellacott's imputer could be moved up to the windshield itself, with the only design considerations for such relocation being only accommodation for the wires to the camera portion, and other basic design choices for attachment methods.

68. To the extent that a specific written motivation is required to direct the POSITA to position a solid-state vehicular vision camera forward to view through the windshield at a location on or near the rearview mirror, Kenue (Ex. F) clearly provides such motivation. Kenue positions the CCD camera of its vehicular vision system facing forward, "at the upper center of the windshield" (Ex. F at 2:31), for "viewing a roadway scene in front of a vehicle." (Ex. F at Abstract). Facing Vellacott's imputer camera forward, therefore, would have predictably viewed the roadway scene in front of the equipped vehicle, exactly as described by Kenue. The obviousness of this particular design choice is further confirmed, for example, by Koshizawa (Ex. N), which clearly illustrates a vehicular vision system operating the same in both forward and rearward applications. (Ex. N at 1:10-15; 3:58-68).

69. It is important to note that Kenue describes two main algorithms executed by the image processor of the computer 14 – one using a Hough

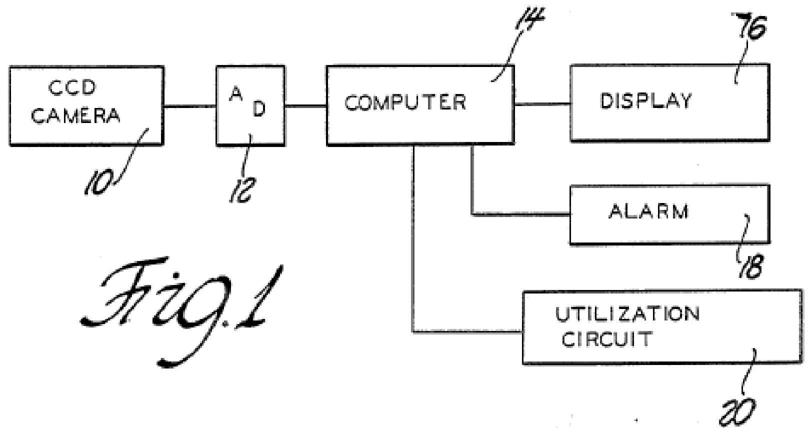
transform, and another using template matching – both of which compare one captured frame from the camera with a previous frame. (Ex. F at 2:40-51). These known algorithms are directly comparable with equivalent algorithmic functions that were pre-packaged in the library for the VVL imputer. Kenue's Hough transform, for example, would have very likely been included in Vellacott's library of "transforms" functions, or at least it would have been obvious to include with Vellacott's transforms an algorithm substantially similar to Kenue's Hough transform algorithm. Similarly, Kenue's template matching algorithm would have been an obvious form of Vellacott's library of "correlators" functions, since template matching is one method of correlation.

70. To the extent that a particular known algorithm may not have already been included within Vellacott's pre-packaged library of functions available to the "completely programmable" VVL imputer, Fletcher (Ex. M) further confirms that, in addition to the pre-packaged library, "More specialized functions can also be developed to order" from the manufacturer (VVL). Therefore, it would have been obvious for the POSITA to either himself/herself program known algorithms into Vellacott's completely programmable, Windows-based, C language imputer as desired, or simply have had the manufacturer specialize the desired functionality of the VVL imputer to order. This point is especially important because it would apply to any of the functional programming capabilities featured in many of the claims of the '001 Patent. The actual structural configuration of the VVL imputer would not have to be modified at all to accommodate such specialized

functionality. Only the programming of the imputer would change, if at all, to implement such customized functions. Fletcher confirms that such customization though, was known at the time of the claimed invention.

71. Looking at Vellacott and Kenue in reverse, it would also have been obvious to start with Kenue as the base reference for claim 1, and modify its forward facing vehicular vision system to replace its CCD video camera with a CMOS image sensor, as taught by Vellacott. Kenue satisfies all of the limitations of claim 1 of the '001 Patent, for example, except for the requirements of a CMOS photosensor array having exposure control at a plurality of exposure periods. Vellacott's CMOS photosensor array though, clearly includes such exposure capability, as discussed further below in more detail.

72. Kenue, for example, illustrates in Fig. 1 (shown below) the basic configuration of a vehicular vision system that was known in the art at the time of the claimed invention. (Ex. F at Fig. 1). According to Kenue, the vehicular vision system includes a camera 10 and a computer 14, where the computer 14 "is programmed with algorithms for processing the images sensed by the camera," and then outputs a control signal to one of several different vehicle systems 76, 18, or 20 (Ex. F at 2:40-51):



73. Accordingly, Kenue's forward-facing vehicular vision system would not require more than a replacement of a CMOS camera for Kenue's CCD camera 10, and the system would not change its basic operation merely by substituting one camera for the other. The motivation for the POSITA to replace Kenue's CCD camera with CMOS camera like Vellacott's is initially provided by Vellacott, which teaches that the CMOS is more versatile, lower-power, less-expensive alternative to CCD cameras (Ex. C at page 2), and specifically for vehicular vision systems. (Ex. C at page 4, col. 3). The POSITA would have obviously been motivated at the time of the claimed invention, to implement these stated CMOS advantages.

74. Substituting a CMOS camera with CCD camera-based image processors was not merely a theory at the time of the claimed invention; Paradiso (Ex. D) discloses that, as of 1994, the Peach camera (CMOS) was specifically implanted, in at least one example, with the Scion LG-3 frame grabber and image processor. (Ex. D at page 6, last paragraph). The Scion LG-3 processor was expressly known at the time to be "suitable for use with high end <u>CCD cameras</u>

and other imaging equipment." (Ex. E at page 110, col. 1). Paradiso therefore establishes that it was actually known at the time of the claimed invention to replace a CCD camera with a CMOS camera for the same applications and purposes, and that the actual substitution of one camera for the other was within the skill level of the POSITA.

75. The obviousness of combining the teachings of Vellacott with those from Kenue is therefore applicable to all of claims 1-24, 28, 32, 34-40, 42-69, 71, 73-109, and specifically to claims 1-5, 15-16, 23, 28, 35-40, 42-50, 52-53, and 55, which require no further programming functions or minor structural options than those disclosed by Vellacott and Kenue.

Vellacott and Kenue, in further view of Yanagawa

76. The proposed combination of the respective teachings of Vellacott and Kenue are directly relevant to all of the claims of the '001 Patent. Again, the '001 Patent claims really just require Vellacott's VVL imputer in the same location described by Vellacott (the rearview mirror assembly), with the CMOS camera portion pointed forward to view through the windshield, instead of toward the rear of the vehicle. Vellacott's pre-packaged library of functional programming would have likely included algorithms substantially the same as the algorithms used by Kenue's computer, or else the imputer was obvious to program to include such functions.

77. Other programmable functions for the VVL imputer of Vellacott

appear with respect to claims 6-10, 32, 34, 61-63, 69, 71, and 77 of the ‘001 Patent. All of these claims relate to control of the equipped vehicle’s headlights in response to the processing of image data captured by the CMOS camera. As discussed above with regard to Vellacott, the VVL imputer, housed within the rearview mirror assembly, was completely programmable to capture and process image data for the control of at least the mirror dimming system. (Ex. C at page 4, col. 3). Vellacott does not discuss control of another vehicle system with the VVL imputer.

78. Nevertheless, it was an obvious matter of design choice as to which particular vehicular system was controlled by VVL imputer. In the particular embodiment described by Vellacott (Ex. C at page 4), the VVL imputer already was programmed to detect and recognize headlights within the field of view of the CMOS sensor array. Vellacott does not mention that such headlight recognition could be used to control the vehicle’s own headlights. Such headlight control though, was known in the art at the time of the claimed invention.

79. Yanagawa (Ex. G), for example, clearly discloses a forward-facing vehicular vision system programmed to detect and recognize headlights (as well as taillights) in a camera’s field of vision, substantially similar to the operation of the vehicular vision system of Vellacott, except for the choice of controlling the equipped vehicle’s own headlights as a result of the recognition. Yanagawa, however, clearly teaches that it was known, at the time of the claimed invention, to control switching of the equipped vehicles own high beams and low beams as a

result of the recognition by the processor. (Ex. G at page 2, col. 1, "Operation). A POSITA would not have had to change any of the VVL imputer's hardware, or otherwise even reprogram the imputer to implement headlight control. Only a change of address to the control signal, or else a direct wiring input to the receiver of the headlight system, would be necessary.

80. In all of the claims of the '001 Patent relating to headlight control, I note that none of these claims actually describe additional device hardware, or even a specific method, to control the headlights. These claims instead merely require that the vehicular vision system be *capable* of controlling the headlights. As described above, Vellacott's VVL imputer was clearly capable of performing such control with nothing more than assigning an address to the control signal that corresponded to the vehicle headlight system.

Vellacott and Kenue, in further view of Venturello

81. Other programmable functions for the VVL imputer of Vellacott also appear with respect to claims 11-14, 64-65, 79-82, 84-86, 88-93, 95, and 98-99 of the '001 Patent. All of these claims relate to the capability of the vehicular vision system to detect fog, snow, or rain, and some of the claims then also require control of the equipped vehicle's headlights in response to such detection.

82. These claims therefore present a very similar issue to the one discussed immediately above with respect to the motivation to implement the programming functionality from Yanagawa or Kenue into the hardware of the

VVL imputer of Vellacott. The "completely programmable" VVL imputer of Vellacott would need only to have included programmed algorithms capable of detecting fog, snow, or rain. The option to control the vehicle's headlights would then be an obvious matter of design choice to the POSITA, for the same reasons discussed above.

83. Venturello (Ex. H) also specifically discloses that it was well known at the time of the claimed invention for a forward-facing vehicular vision system to detect the presence of fog from the scattering of ambient light around an object by the fog, or from the backscatter from the fog itself. (Ex. H, page 2, lines 10-17). Similar to the discussion above regarding the motivation to implement or program Kenue's and/or Yanagawa's algorithms into Vellacott's image processor, the implementation of Venturello's fog detection algorithms and functionality would have involved nothing more than programming, that is, a method of operating, Vellacott's VVL imputer, which already included all of the necessary hardware of the vehicular vision system of the '001 Patent, as admitted in the patent itself.

84. In all of the claims of the '001 Patent relating to fog detection, I similarly note that none of these claims describe additional device hardware, or even a specific method, to detect fog. These claims instead merely require that the vehicular vision system be *capable* of detecting the fog from backscatter or glare. As described above, Vellacott's "completely programmable" VVL imputer was clearly capable of being programmed with such fog detection algorithms as taught by Venturello. Such known algorithms would have likely been included in the

imputer's pre-packaged library of functional programming options, or else it would have been obvious to the POSITA to have algorithms similar to Venturello's customized by the manufacturer. (Ex. M).

Vellacott and Kenue, in further view of Bottesch

85. Yet another programmable function for a vehicular vision system is required by claims 17-22, 68, 86, and 101 of the '001 Patent. All of these claims relate to the capability of the vehicular vision system to determine a daytime or nighttime condition in response to a detected ambient light level, and some of these claims then also require the capability to control of the equipped vehicle's headlights or another vehicle accessory at the same time that the daytime/nighttime condition is determined.

86. These claims therefore also present a similar issue to the one discussed above with respect to the motivation to implement the programming functionality from Yanagawa, Kenue, or Venturello into the hardware of the VVL imputer of Vellacott. The "completely programmable" VVL imputer of Vellacott would need only to have included a sensor capable of detecting ambient light, together with a programmed algorithm capable of determining a daytime/nighttime condition from the ambient light level. The option to control the vehicle's headlights or another accessory would then be an obvious matter of design choice to the POSITA, for the same reasons discussed above.

87. These claims do not require a cause-and-effect between the

determination of a daytime/nighttime condition, but instead that the headlight control capability merely must be available "when" the daytime/nighttime determination occurs. This distinction is important, since the claims themselves require that the daytime/nighttime determination is "at least in part responsive to processing of captured image data by said image processor," which involves some cause and effect. The headlight/accessory control capability in these same claims, however, requires no such relationship to the processing of captured image data.

88. Bottesch (Ex. I) also specifically discloses that it was well known at the time of the claimed invention for a forward-facing vehicular vision system to detect ambient light from at least one photosensor of a solid-state array (Ex. I at 4:66-68), and determine a nighttime condition from detected low lux ambient light at the same time the headlights of the vehicle are switched on. (Ex. I at 7:33-36). Bottesch further discloses control of other vehicle accessories, like a cruise control system (Ex. I at 2:30-33), or collision avoidance system (Ex. I at 11:30-31), at the same time the ambient light sensor of the array is detecting lux levels.

89. Therefore, and again similar to the discussion above regarding the motivation to implement Kenue's, Yanagawa's, and/or Venturello's algorithms into Vellacott's VVL imputer image processor, the implementation of Bottesch's ambient light detection functionality would have involved nothing more than programming, that is, a method of operating, Vellacott's VVL imputer, which already included all of the necessary hardware of the vehicular vision system of the '001 Patent, as admitted in the patent itself. As shown by Bottesch, only one

photosensor (15c) at an end of the photosensor array need be monitored to detect ambient light. The choice of the particular photosensor to measure would then just have been an obvious matter of design choice by the POSITA, who would have only had to program the VVL imputer, for example, to utilize the measured value of the chosen photosensor to serve for the ambient light determination.

90. In all of the claims of the '001 Patent relating to daytime/nighttime determination, I similarly note that none of these claims describe additional device hardware, or even a specific method, to make the determination. These claims also instead merely require that the vehicular vision system be *capable* of making the determination based in part on the ambient light detection. As described above, Vellacott's "completely programmable" VVL imputer was clearly capable of being programmed to recognize values from a particular photosensor of the array as taught by Bottesch. Such known capabilities would have likely been included in the imputer's pre-packaged library of functional programming options, or else it would have been obvious to the POSITA to have had the manufacturer customize the imputer's functionality to realize this existing capability. (Ex. M).

Vellacott and Kenue, in further view of Schofield

91. Different from the purely programmable functionality of the claims discussed above, all of claims 24, 56-69, 71, 73-109 of the '001 Patent require an additional structural feature of having the CMOS imager being disposed in a "module," and this module must releasably mount to a mounting element

adhesively attached at the windshield. This structural requirement clearly refers to the embodiment shown in FIG. 1C of the '001 Patent (Ex. B), reproduced below:

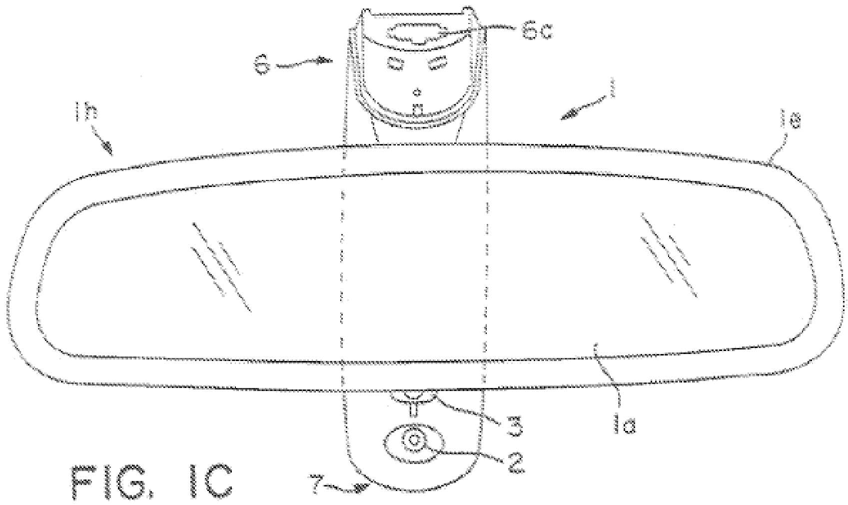


FIG. 1C

92. The only description of FIG. 1C of the'001 Patent states: "The mounting bracket 6 may also be releasably attached to a mounting button (not shown) that is attached to the windshield to provide generally improved ease of assembly and replacement, as well as safety." (Ex. B at 10:34-38). According to this disclosure in the '001 Patent, the "module" of these claims is clearly the rearview mirror "housing or **module** 7" (Ex. B at 10:27), and the mounting button is the "mounting element adhesively attached at the windshield." As disclosed by Schofield (Ex. J), such structures to attach rearview mirror assemblies were well-known at the time, and did not affect the functionality of the accessories included in or near such assemblies.

93. Adhesively attached mounting buttons and releasable mirror assemblies mounted thereto had been well-known at the time of the claimed

invention "for many years." (Ex. J at 1:16-20). Such mounting structures therefore represented nothing more than a known design convenience for the POSITA. The particular mounting structure of the rearview mirror assembly would not affect the operation of a vehicular vision system disposed in the mirror assembly, as confirmed by Figure 6 of Vellacott, shown above. (Ex. C at page 4). The POSITA need only position the CMOS camera array at a desired location in or on the mirror assembly housing such that the array would not be blocked by the mirror mount and mounting button in front of the assembly on the windshield. This level of camera positioning would not require any special skill in the art by the POSITA, and in actuality, the choice of position involves nothing more than an application of the old principle "do not block the camera view."

94. Therefore, adding the structural mounting capabilities of Schofield's mirror mount, or universal mirror mounting adaptor, to Vellacott's VVL imputer housed in the rearview mirror assembly, would not change the operation of the VVL imputer in any way, as long as the field of view of the CMOS camera was not blocked. This principle would have been particularly obvious to the POSITA given Vellacott's illustration (Ex. C at page 4, Figure 6) of the CMOS camera portion of the imputer being separate from most of the imputer's electronics, connected only by wiring. This structural configuration to the VVL imputer would have given the POSITA significant flexibility to move the very small camera portion of the imputer to almost any desired location without having to relocate the body of the imputer itself.

95. The functional operation of a the VVL imputer vehicular vision system simply would not have been affected by the choice of mounting or attachment structures at the vehicle windshield, and thus the particular mounting structure would have amounted to no more than an obvious design choice by the POSITA.

Vellacott and Kenue, in further view of Denyer

96. Claims 54, 78, 94, and 107of the ‘001 Patent require an additional structural feature of a spectral filter included with the CMOS imager. One well-known example of a spectral filter, at the time of the claimed invention, was an RGB filter for CCD and MOS solid-state photosensor arrays, as taught by Denyer. (Ex. K).

97. Similar to the discussion above regarding the obviousness of adding structural features of Schofield to the VVL imputer of Vellacott, the addition of Denyer’s RGB filter to Vellacott’s CMOS array would have also constituted no more than an obvious matter of design choice to the POSITA. Denyer discloses that it was well-known to add RGB filters to MOS arrays having at least the general structure of the Peach camera photosensor array, and these filters did not degrade such devices, but instead enhanced the range of visual discernment of such devices. To add a color filter to the Peach camera, or to simply substitute the VVL imputer camera with an equivalent CMOS camera having a color filter, would have increased the cost of the imputer, but would not have affected the operation.

98. The design choice to utilize a color CMOS camera instead of a monochrome CMOS camera is somewhat similar to the choice of including a color display for a computer instead of a monochrome display. As taught by Denyer (Ex. K at 3:17-32), color filtering for CCD and MOS devices was originally expensive and rare, but an obvious design choice of the POSITA at the time of the claimed invention for the same reasons discussed above with regard to Schofield.

99. Using a color CMOS camera with the VVL imputer, or adding an RGB filter to the base monochrome camera, would have increased the cost of the overall system, but such an optional element would not have affected the basic performance or programming operations of the vehicular vision system disclosed by Vellacott. Headlight recognition programming, for example, would not be significantly affected by the addition of an RGB filter, since the detection of headlights generally involves the detection of white light at the photosensor array. White light typically spans the entire spectrum of visible light, and thus would be measurable through each of the R, G, and B filters.

100. The inclusion of a spectral filter in combination with the other functional programming available to Vellacott's imputer would also not interfere with simple vision algorithms, and in fact, the ability to distinguish color would even enhance the ability of the imputer to perform some more complex vision functions where color, in addition to or as opposed to shape, can be a factor in distinguishing one object from another. Yanagawa (Ex. G) presents one such example. In addition to Yanagawa's functional capability to determine the

presence of headlights, Yanagawa is additionally capable of distinguishing red taillights from white headlights through similar RGB color filtering techniques. (Ex. G at page 2, col. 2).

G. ANALYSIS OF INVALIDITY OF THE '001 PATENT CLAIMS

101. The discussion below presents the exact language of each claim in italics as headings, which are followed by a discussion to show the presence of each element in the prior art together and a discussion of the rationale for combining references.

1. A vehicular vision system, said vehicular vision system comprising:

102. Both Vellacott and Kenue relate directly to vehicular vision systems capable of capturing an image by a CMOS camera (Vellacott) and a CMOS camera (Kenue).

an imager comprising a lens and a CMOS photosensor array;

103. Vellacott discloses a CMOS image sensor includes a CMOS photosensor array (Ex. C at page 1, Figure 1) "using chip mounted microlenses." (Ex. C, page 4 at col. 3).

wherein said photosensor array comprises a plurality of photosensor elements;

104. As an initial point of understanding, an "array" would generally mean, to the POSITA, a plurality of elements that make up the array. Therefore, "a CMOS photosensor array compris[ing] a plurality of photosensor elements" is a substantially redundant requirement. Nevertheless, this limitation simply describes a known construction of CMOS image sensors, as clearly shown by Figure 1 of

Vellacott, which illustrates a plurality of individual photosensor elements for the CMOS array's architecture.

> ***wherein said imager is disposed at an interior portion of a vehicle equipped with said vehicular vision system and wherein said imager views exterior of the equipped vehicle through a windshield of the equipped vehicle and forward of the equipped vehicle***;

105. This limitation is the only requirement of claim 1 that is not explicitly shown or described in Vellacott. Vellacott clearly shows in Figure 6 (Ex. C at page 4) that the imager is disposed in an interior portion of the vehicle, that is, within the rearview mirror housing, and also that the imager views exterior of the vehicle (*i.e.*, headlights of other vehicles). Vellacott does not, however, describe that the imager views forward of the vehicle.

106. Facing an imager/camera forward or backward is merely a matter of the functionality required of the application, not the functionality of the camera itself. Detecting headlights in the forward field of view would be accomplished using the very same algorithm as detecting headlights in the rearward field of view, with the obvious difference being the camera would merely be oriented in different directions, forward versus rearward. It should also be understood that algorithms for detecting headlights are similar to that for detecting taillights.

107. Turning the imager to face forward though, was simply not novel. Facing an existing camera forward is nothing more than an application of the mundane principle to "point the camera where you want it to view." (*See e.g.*, Koshizawa, Ex. N at 1:10-15; 3:58-68). The forward orientation of Vellacott's

imager, and more specifically, the CMOS camera portion of the VVL imputer, would have required no additional hardware or software to implement, and only trivial structural considerations to accommodate a forward facing camera without being blocked by any portion of the rearview mirror assembly. Kenue demonstrates that similar solid-state, forward-facing, vehicular vision system cameras were readily known to the POSITA and prevalent in the field.

108. The specification of the '001 Patent itself notably admits that forward-facing image sensors were well known in the art at the time of the claimed invention. (Ex. B at 1:65-67). Incorporating the discussion above regarding the rationale to orient Vellacott's camera in the known direction of vehicular vision system cameras taught by Kenue, the POSITA would have predictably found that such an orientation would have captured the field of view forward of the vehicle. This concept is really quite simple.

109. The combination of teachings from Vellacott and Kenue is also obvious to the POSITA in light of Vellacott's express teaching that its CMOS-based machine-vision system (the imputer) entirely replaces CCD-based vision systems (Ex. C at page 3, col. 1), thereby replacing Kenue's CCD-based system with the VVL imputer for the same vehicular vision applications. Vellacott's imputer would have been fully capable of performing Kenue's image processing algorithms and control functions for the reasons discussed above.

110. The combination of teachings from Vellacott and Kenue was also

obvious to the POSITA in light of the known practice, at the time of the invention, in light of the known practice (Ex. E) to utilize CMOS cameras with CCD-based image processors.

> ***wherein at least said imager is disposed in a module attached at the windshield of the equipped vehicle***;

111. Vellacott describes "The imputer, a complete standalone machine vision system," is "housed inside the rear-view mirror" (Ex. C, page 4, col. 3). The rearview mirror is clearly shown by the '001 Patent (Ex. B at FIG. 1C, reproduced above), to the "module attached at the windshield of the equipped vehicle." Again, Figure 6 of Vellacott (Ex. C at page 4) shows the imputer with its imager in relation to its housing within the rearview mirror module.

112. It is significant to note that Kenue similarly teaches a "CCD video camera 10 mounted in a vehicle … at the upper center of the windshield to capture the driver's view of the road ahead." (Ex. D at 2:28-32). Vellacott clearly shows, as discussed immediately above, that it was known to locate an imager in the rearview mirror assembly, and this additional description from Kenue is notable in that it emphasizes how it was well-known to the POSITA at the time to locate such cameras at the windshield of the vehicle, and orient such cameras to face forward.

> ***a control comprising an image processor, said image processor processing image data captured by said photosensor array***;

113. Vellacott describes (Ex. C at page 2, col. 3) elements of the image processor of the VVL imputer ("preprocessing and quantisation to form normalised binary image" and "post-correlation decision hardware," among several other logic

circuitry elements) that clearly performed the tasks associated with "processing image data captured by said photosensor array" as claimed. Furthermore, Vellacott also describes how the imputer performs control functions (dimming the mirrors) based on the processing of captured image data from the array. (Ex. C at page 4, col. 3). Controls and image processors were the standard features of known vehicular vision systems in the field at the time of the claimed invention.

wherein said image processor processes captured image data to detect an object viewed by said imager;

114. As discussed immediately above, the image processing elements of Vellacott's imputer performed, among other functions, "preprocessing and quantisation" of captured imaged data, and the "post-correlation decision hardware" would have been capable of determining that an object had been detected by the imager. Vellacott further explicitly states that the "imputer was programmed to analyse this image to recognise when and where headlamps are present in the field of view." (Ex. C at page 4, col. 3). Again, image processors were standard features of known vehicular vision systems in the field at the time of the claimed invention, and the processing of captured image data is the primary function of an image processor, by definition.

wherein said photosensor array is operable at a plurality of exposure periods; and

115. With respect to the general ability of a digital CMOS camera to utilize a plurality of exposure periods for a photosensor array, such functionality was a very common approach, at the time of the claimed invention, when detecting

objects in an image having different light intensities, for example. If there was a significant difference in the intensity of the object being detected, compared to other surrounding objects, the POSITA would have known to use a shorter exposure period, since the object would thus be more easily detectable.

116. This issue would be of particular importance when attempting to detect headlights at night, when the area surrounding the headlight is most likely at a significantly lower intensity than the headlight. In contrast, when such surrounding objects have more similar intensities to the headlight, a longer exposure period could be used to try to distinguish the more subtle intensity differences, as would be the situation when headlights are on during the day. The POSITA would understand that objects imaged during the day are more likely similar in intensity than objects imaged at night, and particularly objects generating their own luminance, such as headlights. Also, it was also known at the time of the claimed invention to detect objects having differing types of ambient light through use of different exposure periods, which could better distinguish the differing ambient intensities for the reasons described above.

117. Beyond these basic principles that were known to the POSITA, Vellacott specifically discloses that the VVL imputer was specifically configured such that "<u>Exposure control</u> is also implemented on-chip." (Ex. C at page 2, col. 1). "Exposure control" requires, by definition, that there must be more than one exposure. That is, if there was only one exposure period, then there would be no exposure to control. Vellacott further explains this exposure control, stating "The

length of exposure is controlled by varying the pixel reset time via the vertical shift register; this allows the exposure period to be set in multiples of the line readout time." (Ex. C at page 2, col. 1).

118. Although Vellacott clearly teaches operability of the photosensor array at a plurality of exposure periods, it is notable that GEM further confirms (Ex. E, page 109) "electronic exposure control" for the same CMOS Peach camera/ASIS 1011 system as Vellacott's imputer, which is also the same imager system admitted by the '001 Patent to be the hardware of the light sensing and logic circuit 26. (Ex. B at FIG. 6A-B). Paradiso describes and illustrates even further details relating to the known exposure control capabilities of the Peach camera utilized in the VVL imputer of Vellacott. FIG. 5 of Paradiso (Ex. D at page 6, reproduced below) shows a block diagram of the VVL's device, which clearly illustrates both "exposure control" and an "exposure control computer" (both surrounded by red boxes, for emphasis) were among the basic functional capabilities of the Peach camera hardware:

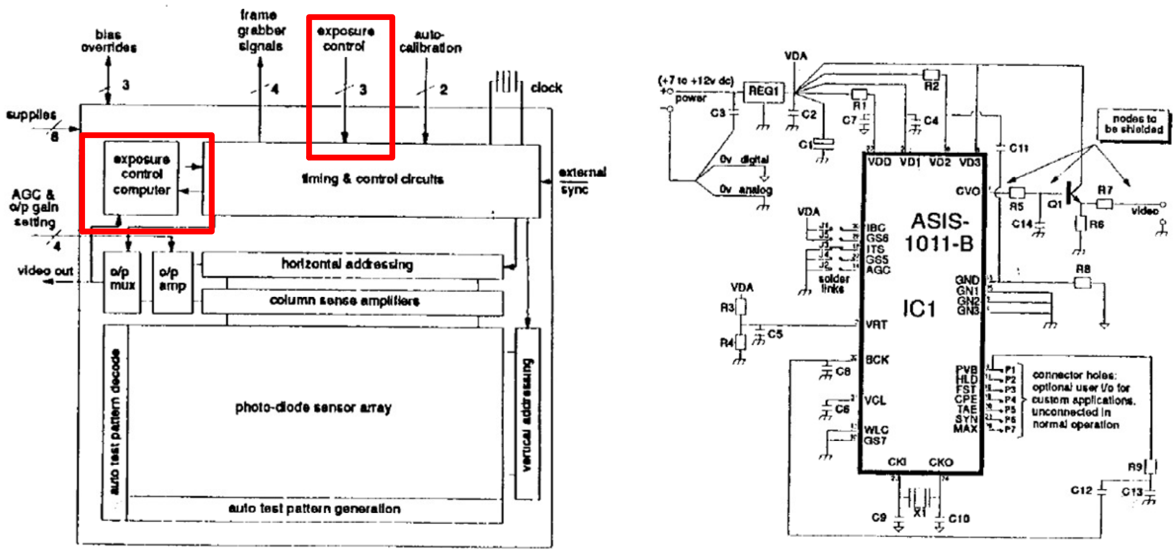


Figure 5: Block diagram of the VVL chip (left) and its recommended support electronics (right)

119. The exposure control requirements of claim 1, therefore, were simply not novel at the time of the invention. Such exposure control was a clearly known capability of the Peach camera, and therefore the VVL imputer as well, and the inclusion of such requirements to the forward-facing CMOS photosensor array, as required by the preceding language of the claim, would not have rendered such a device novel or nonobvious. CMOS photosensor array exposure control at a plurality of exposure periods was known to the POSITA at least by 1993.

> ***wherein said plurality of exposure periods comprises a first exposure period and a second exposure period, and wherein the time period of exposure of said first exposure period is longer than the time period of exposure of said second exposure period***.

120. Following the discussion immediately above, with variable exposure periods capability, it would be obvious to the POSITA that variable exposure periods would require at least two exposure periods, by definition, and that one

such exposure period would have to be longer than another, hence, the "variability."

121. Furthermore, with a longer exposure period, the POSITA at the time of the claimed invention would have understood that it would be possible to detect more subtle differences in the intensity of the pixels. Also, depending on the particular application desired, the POSITA would have understood that a longer exposure period may provide the camera with a better capability of detecting particular objects within the overall captured image regardless of whether there were significant differences between the intensity of surrounding pixels.

122. In summary, claim 1 of the '001 Patent appears to simply be claiming the imputer device (with a CMOS photosensor array operable at a plurality of exposure periods of differing lengths) already invented by VVL at least two years earlier than the '001 Patent's claimed priority, only pointed forward. Pointing a camera in a desired direction though, is not a novel invention warranting patentability. Claim 1 is thus clearly obvious in light of Vellacott, particularly when considered in combination with the teachings of Kenue.

***2. The vehicular vision system of claim 1, wherein said imager is disposed proximate the windshield of the equipped vehicle*.**

123. This subject matter from claim 2 is plainly disclosed by Vellacott's teaching to house the imputer and its camera within the rearview mirror assembly (Ex. C at page 4, col. 3; Figure 6), which would obviously be "proximate the windshield of the equipped vehicle," by definition. Claim 2 of the '001 Patent,

therefore, does not add any nonobvious features to claim 1, since it was well-known to the POSITA to mount the imager of a vehicular vision system proximate, that is, "near" the windshield. Vellacott's imager is part of the rearview mirror, which is at the windshield.

> ***3. The vehicular vision system of claim 1, wherein said photosensor array comprises an array of columns and rows of photosensor elements and wherein said array has more columns than rows*.**

124. With respect to the subject matter of claim 3 in general, the POSITA would have understood, at the time of the invention, that when an array is created, the number of columns and rows is used as input. In the example of a camera with sensing elements, the POSITA would have understood that there was no reason that the number of sensor elements in one direction could not have been greater than the number of sensor elements in another direction. In fact, it was known to the POSITA that is was possible that *each* row in an array could have a different number of sensor elements from each other, meaning that there did not have to be symmetry across rows and columns. Furthermore, it was known at the time that it was possible to program a vision system such that not all of the elements of the array need be processed. Such structural variations were thus known and obvious to the POSITA at the time as inherent functional design choice considerations that were built into photosensor arrays and related custom hardware.

125. More specifically, the subject matter of claim 3 is clearly disclosed by Figure 1 of Vellacott (Ex. C, page 1), which shows at least a 21x13 pixel array that is wider than tall). Although unnecessary for the present claim, it should be

understood that the other references describing known features of the Vellacott imputer device confirm that such photosensor array dimensions were known and obvious to the POSITA at the time.

126. GEM, for example, describes an "89,500 pixel resolution (312 x 287)" (Ex. E at page 9), and Paradiso, as another, but comparable, example, describes a CMOS array that "contains a 1/2" array of 312 x 287 photodiode pixels." (Ex. D at page 5). Claim 3 of the '001 Patent, therefore, does not add any nonobvious features to claim 1, since it was well-known to the POSITA at the time to utilize a CMOS photosensor array having more columns than rows. The selection of the size of the array would have been nothing more than an obvious design choice, limited by the particular application desired (such as a wider horizon to image), and the cost of the overall device, which would typically increase with an increase in the number of photosensors, or pixels, in the array.

***4. The vehicular vision system of claim 3, wherein said array comprises at least 40 rows*.**

127. Similar to the discussion immediately above, the subject matter of claim 4 is disclosed by the same portion of GEM (Ex. E, page 9) and Paradiso (Ex. D, page 5), which describe "312 x 287 photodiode pixels" of the CMOS image sensor, as they relate to Vellacott. Claim 4 of the '001 Patent, therefore, does not add any nonobvious features to claim 3, since many CMOS photosensor arrays known to the POSITA at the time included at least 40 rows.

5. The vehicular vision system of claim 1, wherein said image processor processes captured image data to detect at least one of (a)

a vehicle, (b) a headlight of a vehicle, (c) a taillight of a vehicle, and (d) a road sign.

128. This subject matter from claim 5 is disclosed by Vellacott (Ex. C, page 4 col. 3) where "The imputer was programmed to analyse this image to recognise when and where <u>headlamps are present in the field of view</u>. Vellacott (Ex. C, page 4 col. 3, emphasis added). Claim 5 only requires one the several objects listed to be detected, and the VVL imputer specifically sold to the Applicant of the '001 Patent already included the express capability of headlight detection.

129. Also, it is notable that Yanagawa taught that it was known at the time for the image processor of a vehicular vision system to detect headlights, stating "Specifically, the traveling vehicle recognition device of the present invention has an imaging apparatus such as a color television camera set up for imaging, for example, the forward direction of a traveling vehicle, extracts color features of <u>headlights</u> and taillights to form a feature extracted color image signal based on a color video signal imaged by this imaging apparatus, <u>recognizes the headlights</u> and taillights of a vehicle ahead, and controls the headlight beams based on this recognition result," (Ex. G at page 2, col. 2, emphasis added).

130. Claim 5 of the '001 Patent, therefore, does not add any nonobvious features to claim 1, since it was well-known to the POSITA at the time to utilize the image processor of a vehicular vision system to detect at least headlights. As with claim 1, claim 5 is simply claiming the known structure and capabilities of the

imputer already invented by VVL two years prior to the claimed priority date.

> ***6. The vehicular vision system of claim 1, wherein, at least in part responsive to processing of captured image data by said image processor, said vehicular vision system is operable to control an exterior light of the equipped vehicle to limit debilitation of a driver of another vehicle forward of the equipped vehicle*.**

131. Yanagawa discloses "executing headlight control based on the recognition result" of oncoming headlights or taillights by the video signal processor 14. (Ex. G at page 7, "Claim") Yanagawa states that "The image signal processor extracts the features of red, which is the color of taillights, and of white, which is the color of headlights, from the R,G,B color image signals, extracting, for example, a binary image signal, and causes the presence of taillights or headlights within the imaged video to be recognized based on this extracted image signal." (Ex. G at page 2, col. 2, last paragraph).

132. Claim 6 of the '001 Patent, therefore, does not add any nonobvious features to claim 1, since it was well-known to the POSITA at the time to control the equipped vehicle's own headlights in response to processing of capture image data, that is, recognitions of headlights (or taillights) as taught be Yanagawa. Again, implementing such recognition and control algorithms into Vellacott's "completely programmable" imputer would have involved no more than programming Vellacott's known hardware (or selecting from the imputer's pre-packaged library of functional algorithms) to operate as desired, without any modification to the structure of the imputer system.

7. The vehicular vision system of claim 6, wherein at least one of (a) control of the exterior light of the equipped vehicle involves adjustment of a light beam emitted by the exterior light of the equipped vehicle, (b) the exterior light of the equipped vehicle is operable to emit a plurality of light beams, and wherein said control adjusts between one light beam of said plurality of light beams and another light beam of said plurality of light beams, and (c) the exterior light of the equipped vehicle is operable to emit a plurality of light beams, and wherein said control adjusts between one light beam of said plurality of light beams and another light beam of said plurality of light beams, and wherein said plurality of light beams comprises at least one of a low beam, a mid beam and a high beam.

133. Yanagawa further discloses "The present invention … seeks to provide a traveling vehicle recognition device capable, for example, of automatically controlling headlight beams to high and low beams according to the state of whether there is a vehicle ahead," (Ex. G at page 2, col. 2), and that "with this type of high beam driving state, in the case that there is an oncoming vehicle or a vehicle travelling ahead is becoming close, the headlights must be switched to low beams so as to not obstruct the field of vision of the driver of the oncoming vehicle or the driver of the vehicle traveling ahead ." (Ex. G at page 2, col. 2).

134. A POSITA, at the time of the claimed invention, would have thus easily understood that "a plurality of light beams" would simply refer to the well-known high beams and low beams available on essentially every passenger vehicle on the market at the time. Claim 7 of the '001 Patent, therefore, does not add any nonobvious features to claim 6, since it was well-known to the POSITA at the time that control of a vehicle's headlights commonly involved the simple switching between high beams and low beams.

***8. The vehicular vision system of claim 6, wherein at least one of (a) said control is operable to control the exterior light of the equipped vehicle to emit a pattern of light appropriate to limit debilitation of the driver of the other vehicle forward of the equipped vehicle, (b) said control is operable to control the exterior light of the equipped vehicle to emit a pattern of light that illuminates a selected zone forward of the equipped vehicle, and (c) the exterior light of the equipped vehicle is operable to emit various patterns of light*.**

135. As discussed above with respect to claim 8, Yanagawa discloses "The present invention … seeks to provide a traveling vehicle recognition device capable, for example, of automatically controlling headlight beams to high and low beams according to the state of whether there is a vehicle ahead." (Ex. G). A POSITA, at the time of the invention, would have understood that switching from high beams to low beams would be a type of light pattern emission that would limit debilitation of another driver. Yanagawa states essentially the same purpose for switching from high beams on page 2, col. 1 of the description. (Ex. G). "Patterns of light" is really just a complicated way of saying "high beams and low beams," according to the '001 Patent.

136. Venturello also notably describes an "illumination means for sending a train of light pulses towards the object." (Ex. H, page 2 at line 42). A POSITA would have understood a "train of light pulses" from the headlamp (4) to mean "various patterns of light." In the case of Venturello, the more complex lamp pulsing is actually more than just switching between high and low beams.

137. Claim 8 of the '001 Patent, therefore, does not add any nonobvious features to claim 6, since it was well-known to the POSITA at the time that control

of a vehicle's headlights commonly involved the simple switching between high beams and low beams, and specifically to assist drivers of vehicles in front of the equipped vehicle.

> ***9. The vehicular vision system of claim 1, wherein, at least in part responsive to processing of captured image data by said image processor, said control at least in part controls at least one exterior light of the equipped vehicle, and wherein the at least one exterior light of the equipped vehicle comprises a headlight disposed at a front portion of the equipped vehicle and operable to illuminate with visible light a scene forward of and in a path of travel of the equipped vehicle***.

138. This claim is not substantively different from claim 6, except that for claim 9, the "exterior light" is now identified as a front headlight. The discussion of claim 6 though, above, already addresses how Yanagawa shows that it was known to control headlights. A headlight, by definition, is "operable to illuminate with visible light a scene forward of and in a path of travel of the equipped vehicle." This claim is simply stating what a headlight does, and does not add any additional nonobvious subject matter beyond, or different from, claim 6.

> ***10. The vehicular vision system of claim 9, wherein at least one of (a) said control, at least in part responsive to processing of captured image data by said image processor, controls a vehicular lighting switch, and wherein said vehicular lighting switch controls the at least one exterior light of the equipped vehicle, (b) a manual vehicle light switch is actuatable to override said control, and (c) a manual vehicle light switch is actuatable to override said control and wherein said control, at least in part responsive to processing of captured image data by said image processor, controls a vehicular lighting switch that controls the at least one exterior light of the equipped vehicle***.

139. As discussed above with respect to claims 6 and 9, Yanagawa discloses "Conditions that arise when the headlights must be switched from high beams to low beams are also detected based on this recognition result, and the headlight beams can be controlled automatically once detection conditions have been set," (Ex. G at page 2, upper left, emphasis added), and "headlights are controlled to switch the headlights to low beams," (Ex. G, page 4 at upper left). The POSITA, at the time of the invention, would have understood that Yanagawa is here describing the automatic control of the vehicular lighting switch to control the headlight of the vehicle (high beams and low beams). This section of Yanagawa clearly demonstrates that at least option (a) of the claims was obvious.

11. The vehicular vision system of claim 1, wherein, at least in part responsive to processing of captured image data by said image processor, said vehicular vision system determines a presence of at least one of fog, snow and rain present exterior and forward of the equipped vehicle.

140. Venturello clearly discloses that fog detection by an image processor of a vehicular vision system was well-known at the time of the invention. Venturello, in fact, teaches a much more complex system that goes well beyond the mere determination of the presence of fog. Venturello show a system for being able to distinguish objects in the fog from the fog itself.

141. For example, Venturello states, "The image intensifier 10 used in the device according to the invention is adapted for pulsed operation and thus also for performing the task of a shutter (as will be specified below) so as better to

discriminate between the backscattering from the obstacle to be displayed and that from the fog." (Ex H at 3:18-20) Venturello goes on to say "the ratio between the signal reflected back/scattered by the object and that scattered back by the fog in the space is at a maximum." (Ex. H at 3:44-45) To generate this ratio between the backscatter of the object and backscatter of the fog, Venturello would have had to first determine the backscatter of the fog itself, in order to determine the ratio.

142. Vellacott's imputer comes standard with a "full library of machine-vision functions … including morphological (shape) filters, transforms, correlators, convolvers, image segmentation, frequency filtering rotation, reflection and logical operators." (Ex. C, page 3, cols. 2-3). As one option, Vellacott's full library of functions may enable Vellacott's imputer to perform the algorithm as described by Vellacott. In the event that Venturello's known algorithms were not included in Vellacott's imputer library, it would have been a straightforward matter for the POSITA to add programming (in C language for windows). No creative step would have been involved to program the imputer, and with known functional algorithms as it was intended.

143. No additional hardware is required in Vellacott to perform the function of Venturello. The CMOS image sensor of the VVL imputer was fully capable of capturing the image data necessary to process according to Venturello.

> ***12. The vehicular vision system of claim 11, wherein said vehicular vision system determines the presence of at least one of fog, snow and rain by recognizing scattering of light output by a headlight of the equipped vehicle by at least one of fog, snow and rain present***

***exterior and forward of the equipped vehicle*.**

144. As discussed above for claim 11, Vellacott's imputer was capable of being programmed to with Venturello's known algorithms to detect fog. Venturello's algorithms specifically determine the presence of fog by the scattering and backscattering of light, as captured by the vehicle camera. The POSITA would have easily understood, at the time of the claimed invention, that measurement of light scattering was the preferred tool to determine the presence of fog. Venturello even states that fog is "a scattering medium." (Ex. H at 3:30).

***13. The vehicular vision system of claim 11, wherein said vehicular vision system, at least in part responsive to recognition of scattering of light output by a headlight of the equipped vehicle, controls the headlight of the equipped vehicle*.**

145. As discussed above for claim 11, Venturello clearly demonstrates algorithms for detecting fog by light scattering, determining the ratio between the scattering of light from the fog and that from the object, and controlling the vehicle's headlamps based on this determination. Vellacott's "completely programmable" imputer was therefore capable of being programmed to include such known algorithms from Venturello, if in fact the pre-packaged library of algorithms for the VVL imputer did not already include as much.

***14. The vehicular vision system of claim 1, wherein, at least in part responsive to processing of captured image data by said image processor, said control is operable to recognize veiling glare*.**

146. The '001 Patent does not describe what it means by the term "veiling glare." The only mention of "veiling glare" in the description is the statement "the

system may be used to recognize veiling glare caused by scattered light that maybe caused by fog." (Ex. B at 36:48-50). The '001 Patent here is simply stating that "veiling glare" can be recognized *as a result of* the detection of scattered light. This claim is essentially just a reworded version of claim 12, discussed above. The POSITA would have understood that the claim means that "veiling glare" will automatically be recognized as the presence of scattered light. By itself, insomuch as the phrase is briefly mentioned in the '001 Patent, "veiling glare does not have a separate meaning from scattered or backscattered light.

> ***15. The vehicular vision system of claim 1, wherein said image processor compares captured image data with stored data and outputs a vehicle equipment control signal based on the comparison*.**

147. This claim is essentially just utilizing what was, at the time of the claimed invention, a commonly known object detection method using a comparison or matching algorithm. A comparison or matching algorithm was one method for detecting objects in an image, specifically by comparing the detected object to a known object to see if there is a match. If they match, the conclusion is that the object has been detected in the image. This matching method was one of the basic well known methods, by 1993, of image processing with regards to detection of objects.

148. The imputer system of Vellacott includes both hardware and software for capturing and comparing image data with stored data to output a control signal.

Vellacott, for example, teaches "frame grabber" and "framestore" hardware, with a "full library of machine-vision functions is provided including morphological (shape) filters, transforms, correlators, convolvers, image segmentation, frequency filtering, rotation, reflection and logical operators," (Ex. C, page 3).

149. A frame grabber and a framestore are hardware elements used for capturing and storing images received at the imaging device. Machine-vision functions, like "correlators" are programmed software algorithms for comparing two images, for example, by generating an XY plot and correlation coefficients that indicate how well correlated two images are. A correlator can use the value from a given pixel in the first image as the x-coordinate and the value of the corresponding pixel in the second image as the y-coordinate. These values can be plotted to give a scatter plot representing the correlation between the two images. By this combination of hardware and software, it would have been clear to the POSITA that Vellacott's imputer was fully capable of comparing captured image data with stored data (captured from a previous frame) to output a control signal.

150. Kenue also teaches that it was well known at the time to compare captured image data from one frame with stored imaged data from a previous frame. Kenue states, for example, that "The template matching algorithm is widely used in image recognition and computer vision applications." (Ex. F at 3:22-23). Kenue's matching algorithm utilizes correlation functions of generate a correlation matrix, as discussed for Vellacott, above. That is, in Kenue's algorithm, "a template or window of desired intensity and shape is correlated with the image to

create a correlation matrix. The elements of this correlation matrix indicate the quality of the match between the template and the image at all locations." (Ex. F at 3:24-28). The POSITA would have understood at the time of the claimed invention that a "template" was one form of "pattern" that could be matched with a stored template or pattern by the correlator algorithm, and therefore "template matching" would have been one form of "pattern recognition" programmed into Kenue's image processing software.

151. Kenue also uses a convolver, as disclosed by Vellacott. Kenue teaches that "matching can also be done in the image-edge domain obtained by filtering the raw image with a Sobel filter." (Ex. F at 3:32-34). A Sobel filter is a computationally light operator which convolves an image with a small, separable, and integer valued filter in horizontal and vertical direction. The Sobel filter of Kenue is one example of a convolver function as taught by Vellacott and common in machine vision systems, for example, where edge detection is desired for purposes of matching a captured image from one frame with the stored image from a previous frame.

152. Once the images are compared, according to the similar algorithms in either Vellacott or Kenue, a control signal, such as a "true" signal would most likely be sent over a communication network within the vehicle, for example, a bus communication system or by direct wiring, both of which were well known at the time. All that would have been required to send this control signal was the selection of the bus address to which the control signal is to be sent, e.g., a

dimmable mirror (Vellacott), vehicle lights (Yanagawa, Schofield, and Bottesch), brakes (Kenue), a warning system (Kenue, Venturello), etc.

153. The effort to have the imputer programming send the desired control signal could have been as simple as entering the address destination into an address variable, for example, changing “ADDRESS1=000FF” to “ADDRESS1=000DD”. Readdressing requires no creative step or special skill by the operator. Only knowledge of the bus address, of the vehicle system to be controlled, would have been needed.

154. Upon receipt of the control signal, the receiving system then acts on the received control signal in a manner appropriate to that system. The specific communication method is a design choice and which is not related to the camera and processing of the image data. This design choice is an important distinction. The individual systems were connected together for a specific application (dimming a rear-view mirror or dimming headlights), and how these individual components function together was very well known.

155. If a bus communication was not utilized in the equipped vehicle, it was also well-known at the time to alternatively connect the control output to the destination system by wiring in a dedicated arrangement coming from the camera and processor to another subsystem. With a control signal as an output of one system (e.g., Vellacott’s imputer) that corresponds to the input of another system (rear-view mirror dimmer or headlights), the POSITA would have obviously

understood to connect the output of one system to the input of the other. No creative step was involved to wire two systems together.

> ***16. The vehicular vision system of claim 1, wherein said imager views through the windshield of the equipped vehicle at a windshield area that is swept by a windshield wiper of the equipped vehicle.***

156. As discussed above with respect to claim 1, Vellacott's imputer was housed in the rearview mirror at the vehicle windshield. It was obvious to the POSITA at the time of the invention, just as it is today, that the rearview mirror of a standard passenger vehicle is located at the vehicle windshield in an area swept by the windshield wipers.

157. It is also notable that Bottesch specifically states "The preferred location of the POS sensor tubes as input devices is high on the inner windshield surface in an area which is normally swept clean by the action of wiper blades." (Ex. I at 8:1-4). There was nothing creative about placing a camera at the windshield behind the area cleaned by wiper blades. It is simply a matter of common sense to place a camera in an area where it will not be obscured by dirt, or can at least be easily cleaned. This very same principle was confirmed by Koshizawa (Ex. N), as well, which not only teaches that the camera should view through the windshield at the area swept by the windshield wipers (Ex. N at FIG. 1), Koshizawa even provides algorithms to the controller 5/image processor 7 to remove the image of the wipers themselves from the captured image data of the road ahead (or behind). (Ex. N at 2:9-13; 4:1-16). By the time of the claimed invention, the POSITA had thus clearly moved well beyond the basic concept of

simply placing a camera behind the windshield wipers.

> ***17. The vehicular vision system of claim 1, wherein, at least in part responsive to processing of captured image data by said image processor, said control distinguishes between daytime and nighttime conditions.***

158. In the general sense, there are many ways to distinguish between and daytime and a nighttime conditions, and claim 16 does not explain how the system actually makes the distinction. Claim 16 merely requires the capability of making the determination. Many devices and methods available to the POSITA at the time of the claimed invention were capable of making this determination.

159. For example, one method of distinguishing between day and night conditions would be by using different exposure periods, to determine the amount of ambient light from imaged objects. This determination could have been easily done using, for example, pattern match, since the field of view could also include the sky in its viewing area. Taking the average intensities of a plurality of the pixels that are in the sky portion of an image would give you an accurate determination of whether it is day or night. Vellacott's imputer was plainly capable of performing this method, purely as a matter of programming its existing hardware. Similar to the discussion above, it is important to note that the '001 Patent does not describe, with respect to determining the day/night condition, additional hardware was added to the VVL imputer admittedly used by the Applicant.

160. Another way of determining day from night conditions would have been through use of a device that could have simply measured lux from a captured image, and then compare that measurement to known values for daylight and night to distinguish between the two. These examples are just two of the many possible methods available to the POSITA at the time for performing such operations.

161. Therefore, as purely a matter of programming, this claimed functionality was well within the capability of Vellacott's device, and would not require much, if any, programming on behalf of one skilled in the art. It was also likely that the pre-packaged library of the VVL imputer included an algorithm to execute this determination, since the library expressly includes correlator functions, which could be used to compare captured image data to that of known daytime or nighttime images or known lux values. This correlator function of the VVL imputer could have been fully utilized to distinguish between day and night conditions purely as a result of software programming, with no creative steps involved to utilize such well known functionality.

> ***18. The vehicular vision system of claim 1, wherein, at least in part responsive to processing of captured image data by said image processor, said control determines a nighttime condition exists at an ambient light level that is less than about 500 lux*.**

162. "Lux" is the measure of luminance, which is equal to one lumen per square meter. There are common ranges of lux that would have been known to a POSITA at the time of the claimed invention. Around 400 lux is considered to be the level at which sunset and sunrise are determined. Daylight is usually

considered to be a value over 1000 lux, and often as great as 10,000 lux for sunlight. Therefore, the determination that "a nighttime condition exists at an ambient light level that is less than about 500 lux" is merely a statement of commonly accepted terminology of measured light levels. Setting the threshold value for the imputer to be 500 lux would not have involved any creativity at all. "500 lux" is an arbitrary value, but essentially near what was commonly accepted to be a sunrise or sunset level (400 lux).

163. Bottesch (Ex. I), for example, specifically teaches a low-lux sensor for determining a nighttime condition. That is, Bottesch teaches a "using low-lux sensor components which would be activated when the headlights of a vehicle are switched on, indicating a condition of reduced visibility, as at night time." (Ex. I at 7:33-37, emphasis added). Furthermore, Vellacott's imputer is expressly stated to operate with a sensitivity as low as 0.5 lux (Ex. C at page 2, col. 3), and is therefore well within the range of operation to perform the functionality required by this claim.

164. In addition, Vellacott was completely capable of being programmed to determine lux, either at a single pixel, a subgroup of pixels, or as an average of all pixels within its CMOS array. Such capability was a standard feature of machine-vision systems by the time of the claimed invention. It is therefore reasonable, and in fact likely, that Vellacott's library of machine vision function included a function for determining lux such that a programmer was able to select a lux threshold value from a range of lux values. It was also known that certain lux

values are associated with certain types of lighted conditions; daytime, nighttime, sunrise, etc. Thus it would have been obvious to the POSITA to program Vellacott's device with the algorithms of Bottesch to determine a nighttime condition based on a lux determining machine vision function selected from Vellacott's library of functions.

> ***19. The vehicular vision system of claim 18, wherein said control is operable to control a headlight of the equipped vehicle when said control determines a nighttime condition***.

165. This claim does not actually require a cause and effect between the determination of the nighttime condition and the control of a headlight. The claim merely requires that the system was capable of both at the same time. Vellacott clearly had such capabilities, as shown in the discussion immediately above.

166. Furthermore, it was known since at least the 1970s to automatically control a headlight (on or off) based on a light signal received by a photosensor or photosensor array. Such functional ability was a standard feature on many passenger vehicles in the 1980s. Typically, the headlight ON/OFF or dimmer switch was automatically activated with the measured lux value fell above or below a predetermined threshold value, for example. Schofield (Ex. J) confirms such headlight dimming functionality utilizing a simple light sensor. (Ex. J at 1:61-68). No creativity would have been involved to simply assign the measured value of a particular sensor, or group of sensors, in the CMOS array of Vellacott's imputer to perform the same function as these earlier individual light sensors.

> ***20. The vehicular vision system of claim 1, wherein, when said***

control, at least in part responsive to processing of captured image data by said image processor, determines a daytime condition, said control is operable to control a vehicle accessory.

167. As discussed above with respect to claim 18, Vellacott's imputer was expressly capable of both controlling a vehicle accessory (mirror dimmer), and the imputer was also capable of determining a daytime condition in response to processing of captured image data. The claim does not require that the two capabilities be related, but the imputer was nevertheless capable of this additional functionality as well, namely, controlling a mirror dimmer upon determining a daytime (or nighttime) condition. Such functionality could have been had utilizing only the programming capability of the imputer, with no hardware additions or modifications.

21. The vehicular vision system of claim 1, wherein, at least in part responsive to processing of captured image data by said image processor, said control is operable to deactivate a light beam of a headlight of the equipped vehicle when said control determines a daytime condition.

168. The discussion above for claims 17-20 is equally applicable to claim 21 as it relates to the capability of Vellacott's imputer to both determine a daytime condition and also to control a vehicle accessory. One possible and well known accessory to be controlled by a vehicle vision system is a vehicle headlight. The selection of headlight control instead of, or in addition to, mirror dimming would have been an obvious matter of design choice to the POSITA, since no creative step would have been involved to merely address the control signal to the headlight system of the vehicle.

22. The vehicular vision system of claim 1, wherein said control, at least in part responsive to processing of captured image data by said image processor, determines an ambient light level present at the equipped vehicle.

169. Measurement of ambient light levels by image sensors was old and well known to the POSITA at the time of the claimed invention. Processing such measured ambient light information through the system image processor did not involve any creative step.

170. Specifically, Bottesch (Ex. I) discloses "The POS system also includes an ambient light sensor." (Ex. I at 4:44-49). Bottesch also states that "Use of camera like components (diaphragms, adjustable irises, etc.) are not excluded for this use." (Ex. I at 7:41-43). From these statements, the POSITA would have clearly understood that Bottesch's CCD photosensor array, which included an ambient light sensor in the array, was not limiting, but was instead intended to be expandable, and useful with more sophisticated cameras, such as the CMOS image sensor of Vellacott. Conversely, Vellacott's imputer likely included such ambient light determination functionality in its library, or else such functionality would have been easily programmable to the imputer by the POSITA.

23. The vehicular vision system of claim 1, wherein at least one of (a) an exposure period of said photosensor array is variable responsive to a light level detected by said vehicular vision system and (b) an exposure period of said photosensor array is variable responsive to an ambient light level detected by said vehicular vision.

171. As discussed above with respect to claim 1, Vellacott's CMOS imager

produces a video output waveform at the CMOS sensor's sense amplifiers' outputs. (Ex. C, page 2 at col. 1). Vellacott then states "Exposure control is also implemented on-chip, by monitoring the output waveform to determine the appropriate exposure setting. The length of exposure is controlled by varying the pixel reset time via the vertical shift register" (Ex. C, page 2 at col. 1, emphasis added).

172. From this description, the POSITA would have understood that the VVL imputer and its CMOS imager expressly included a variable exposure period. The POSITA would have further understood that the outputs from Vellacott's sense amplifiers would correspond to "a light level detected by said vehicular vision system" as claimed, and thus by controlling the variable exposure period ("length") according to the monitored output waveform, Vellacott's CMOS imager clearly included a variable exposure period responsive to the detected light level. Again, this claim appears to do no more than state a known capability of the imputer already invented by VVL two years earlier, and which the Applicant of the '001 was admittedly using.

> ***24. The vehicular vision system of claim 1, wherein said module releasably mounts to a mounting element adhesively attached at the windshield of the equipped vehicle.***

173. Schofield discloses "A mounting adaptor is disclosed for removably securing an interior rearview mirror assembly to a mounting support on the inner surface of a vehicle window such as a windshield." (Ex. J Abstract). Schofield goes on to say its device is "adapted to be adhere by a suitable adhesive such as

polyvinyl butyral (PVB) to the inside surface of a windshield." A POSITA would know that adapting of Schofield to Vellacott's system would not alter the functionality of Vellacott's imputer or CMOS imager. As discussed in more detail above, it would have been no more than an obvious matter of design choice by the POSITA to utilize such prevalent rearview mirror mounting devices, limited only by cost considerations.

174. The vehicular vision systems at the time of the claimed invention would have been capable of viewing the forward scene equally with a fixed mirror mount as with a releasable mount. Releasable mirror mounts were not known to take up more space than the fixed mounts, particularly when the attachment mechanism to the mirror mounting button was as simple as a small screw through a inset hole through the mirror mounting portion.

28. The vehicular vision system of claim 1, wherein image data processing by said image processor comprises pattern recognition.

175. Pattern recognition is one of the primary methods for detecting objects in an image using image processing. A person of ordinary skill in the art at the time would have known that one of the primary methods for object detection in image processing utilized pattern recognition. Pattern recognition did not require any special hardware to the vehicular vision system; the recognition could be performed by the image processor purely through programming.

176. As discussed above with respect to claim 15, Kenue demonstrates one such purely software-based pattern recognition algorithm, namely, pattern

matching. Such pattern recognition algorithms were likely included in the extensive algorithm library of Vellacott's imputer, and no creative step would have been involved by the POSITA to select one such algorithm, or else program the imputer with Kenue's known algorithms.

> ***32. The vehicular vision system of claim 1, wherein the equipped vehicle has at least one headlight, and wherein the at least one headlight is operable at least in a first beam mode and a second beam mode, and wherein, at least in part responsive to processing of captured image data by said image processor, said control controls operation of the at least one headlight, and wherein said control transitions the at least one headlight from said first beam mode to said second beam mode in response to detection of at least one of a headlight and a taillight viewed by said imager***.

177. As discussed above for claim 7, Yanagawa switches a vehicle headlight from a first beam mode to a second beam mode in response to captured and processed image data. Vellacott's imputer was expressly capable of detecting headlights and then sending a control signal as a result of such detection. Sending the control signal to the headlights, in addition to, or instead of the mirror dimmer was nothing more than an obvious matter of design choice for the POSITA, involving only an address selection in the software, which required no creative step to select.

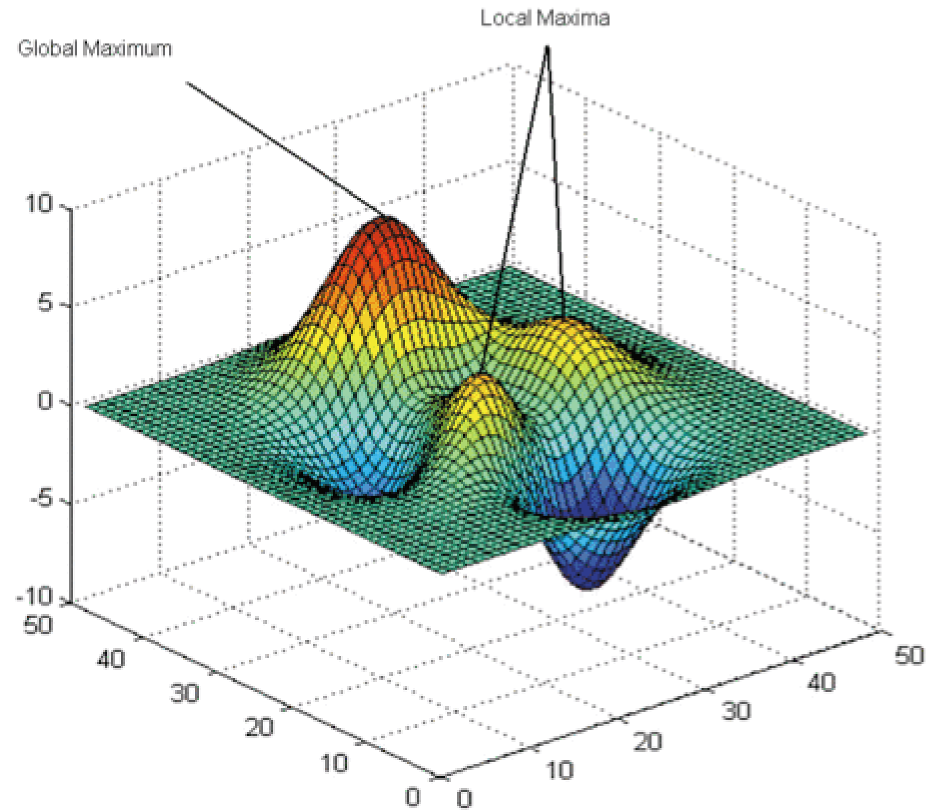
> ***34. The vehicular vision system of claim 32, wherein at least one of (a) said first beam mode comprises a high beam mode, (b) the at least one headlight is actuated at an ambient lighting level below a predetermined level, and (c) the at least one headlight is actuated at an ambient lighting level below approximately 500 lux***.

178. As also discussed above for claim 7, Yanagawa expressly states that

its headlight control system includes a high beam mode for the vehicle's headlights. There was no creativity involved, at the time of the claimed invention, for the POSITA to understand how to control the high beam of the headlights.

> ***35. The vehicular vision system of claim 1, wherein said control determines a peak light level of at least one sub-array of said photosensor array.***

179. Kenue teaches the "following criteria are used to select the correct lines: (a) the intensity of the selected pixels should have <u>local maxima</u>, … The selection algorithm is implemented by <u>identifying the maximum pixel intensity</u>." (Ex. F at 6:50-59). The POSITA would thus understand that a "maximum pixel intensity" means a "peak light level." This relevance of this portion of Kenue is better understood with reference to the illustration immediately below:



180. As shown immediately above, two types of maxima, or peaks, can he determined for a data set; a global maximum and a local maximum. A global maximum is essentially what it sounds to be: the "maximum" with the greatest value in the data set, *i.e.*, highest peak. A local maximum, on the other hand, is another type of maximum which has a value less than the global maximum, but greater that any point in its "local area." That is, a local maximum is the maximum value in a data set of *proximal* values that is a subset of the larger dataset, *i.e.*, a local peak as illustrated above.

181. The principles of the above illustration can therefore be directly applied to the quoted portion from Kenue, when the illustration is viewed as an intensity map of measured values from an array of pixels/photosensors. When so

viewed, the two "local maxima" would represent the "peak light levels of sub-arrays of a photosensor," as claimed. In other words, the image processor would simply view the "local areas" of the local maxima/peak values to correspond to sub-arrays of the photosensor that is, groups of proximal pixels corresponding to a region of the array smaller than the whole array.

182. Vellacott's imputer had the capability to specify "regions of interest" within the greater CMOS pixel/photosensor array to reduce the required processing time. (Ex. L at page 3, "Table 2"). Therefore, no creative step would have been involved to select regions of interest in the CMOS imager array of Vellacott as "sub-arrays," and then determine the local maxima/peak values of these local area sub-arrays, according to the known algorithm taught by Kenue.

> ***36. The vehicular vision system of claim 35, wherein said control determines peak light levels of a plurality of sub-arrays of said photosensor array*.**

183. The requirements of this claim are fully addressed above in the discussion of claim 35. Thus, Vellacott's imputer, programmed with Kenue's local maxima determination algorithm, would have been capable of determining the peak value of two-subarray regions of interest as easily as one sub-array.

> ***37. The vehicular vision system of claim 1, wherein said photosensor array resolves an area of interest in accordance with a predefined array*.**

184. The "predefined array" of claim 36 is vague, and the written description of the '001 Patent does not explain any meaning to this phrase.

Without such guidance, the following discussion explains the obviousness of the requirements of claim 37 under two different interpretations of the phrase that could have been understood by a POSITA at the time of claimed invention. A "predefined array" could mean: (1) one or more specific areas of adjacent pixels (that is, selecting in advance particular portions of the whole array), or (2) areas of interest resulting from edge detection type processing. *i.e.*, the edge of an object (that is, selecting portions of the image based on detected objects within the image).

185. With regard to the first interpretation, Kenue demonstrates how its photosensor array resolves an area of interest in accordance with a predefined array. For example, Kenue discloses the "broken line boxes 28 around the markers 24 define the area to be searched for detecting markers and is determined by the position of the lane boundaries in the previous image frame." (Ex. F at 3:3-7, emphasis added). Kenue's FIG. 2 is reproduced below, with the "broken line boxes" highlighted in yellow for emphasis. Boxes 28 "define the area to be search," i.e., the area of interest. The regions of interest of the array are selected in advance of the image processing, and therefore the "predefined array" corresponds to a particular group of pixels of the array.

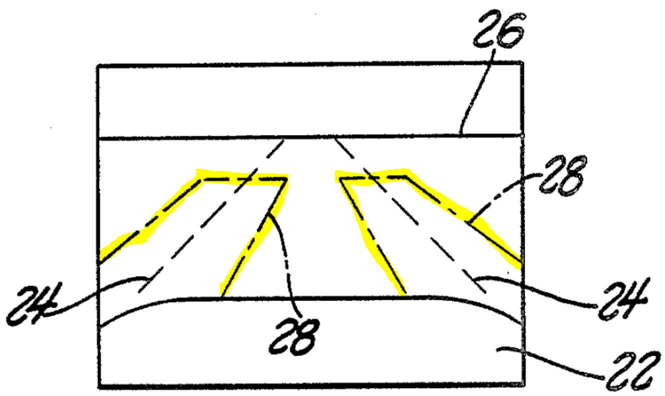


Fig. 2

186. As also discussed immediately above, Vellacott's imputer had a similar capability to specify such regions of interest reduce processing time, which would also render the "predefined array" of the first interpretation obvious to the POSITA. Moreover, Vellacott states that one of the pre-packaged algorithms of the imputer "samples a number of pixels around the centre of the imputer sensor to check whether the probe has crossed an edge." (Ex. C, page 4 at top.) In other words, Vellacott analyzes the elements around the center of the sensor more than the other elements outside of the center to determine the presence of the particular object. In this portion of the reference, Vellacott discloses that the manner of operating the control to analyze some sensors more than others is merely a matter of design choice of the particular algorithm by a programmer.

187. With regard to the second interpretation of "predefined array," Kenue also teaches the obviousness of defining the array according to processing of the

image utilizing a Hough Transform. A Hough Transform gives local maxima for where pixels change from one intensity to another, which is typically useful where there is a dividing line or object in an image, as with edge detection. Instead of focusing on a pre-selected group of pixels though, use of the Hough Transform on the entire image will then allow an algorithm to focus on specific areas that may be of greater interest without having to process all of the other points. In other words, the Hough transform allows the image processor to predefine the array of pixels for further analysis before *additional* processing. Kenue therefore utilizes algorithms to predefine the array according to either interpretation of the phrase. This second method of region selecting involve more processing power than the first, but it still requires less processing power than if the entire image was processed.

188. Both of these region selecting methods of Kenue required only programming to implement, and not any hardware additions or modifications. Since the Vellacott imputer was clearly capable of not only edge-detection, but also a wide array of other completely programmable machine-vision functions, no creative step by the POSITA was required at the time to implement these known algorithms from Kenue.

> ***38. The vehicular vision system of claim 37, wherein said image processor processes image data geometrically associated with a geometric arrangement of said predefined array, and wherein said control selects particular image information by analyzing particular groupings of said predefined array while ignoring other image information from other groupings of said predefined array so as to be responsive to image information chosen from at least one of presence, size, shape, contour and motion of an object viewed by said imager.***

189. Further to the discussion of claim 37, processing image data geometrically associated with a geometric arrangement need not involve more than the process of transforming the arrayed pixel data into a data set that can be computationally manipulated, processed, or analyzed. One very simple example of this known principle can be seen when transforming the pixel P', located at (x', y') into the set of equations, $x' = a_0x + a_1y + a_2$ and $y' = bx + b_1y + b_2$, which include scaling, rotation, and translation. These two equations can then be expressed as a matrix manipulation $\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} a_0 & a_1 & a_2 \\ b_0 & b_1 & b_2 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$. This matrix format of pixel P' may, for example, be stored in computer memory for processing, analyzing, and matching to other pixels in the array.

190. Such geometric processing of image data was known to the POSITA well before priority date of the '001 Patent. Kenue suggests such geometric processing where the reference states "The result of this procedure is a set of x,y coordinates specifying lane markers. Then a least-squares line fit is performed to generate the lane boundary." (Ex. F at 5:32-34). The POSITA, at the time of the claimed invention would have easily understood that Kenue's coordinate system was a form of geometric processing.

191. As also discussed above for claim 37, Kenue resolves areas of interest in an image, *i.e.*, a "predefined array," and then eliminates, that is "ignores," other image information that it considers less important. The POSITA would have known, at the time of the invention, that a computer does not actually "ignore" data, but instead devotes processing to only the data selected for further

processing. If a portion of data is to be "ignored," then that portion of data must be removed from the data set either by creating a new data set with that portion of data removed or by writing the analytic code to not extract data from those portions of the data set, which essentially has the same result.

192. According to this understanding of the term, Kenue thus teaches to "ignore" data where the reference states "When the obstacle 30 is more than 50 feet away the <u>image is processed but the obstacle is effectively erased</u> from the image by removing horizontal and vertical lines, thereby making the subsequent processing steps simpler." (Ex. F at 3:17-21, emphasis added). Therefore, the colloquial interpretation of "ignoring other image information," as the phrase would have been readily understood by the POSITA, would have been obvious in light of Kenue's algorithmic process of erasing data from an image.

193. Kenue also teaches that the selection of image data for processing is based on at least one of presence, size, shape, contour and motion of an object viewed by said imager. That is, Kenue discloses "To validate the estimated lane boundaries they are checked for consistency of angles and width." (Ex. F at 5:35-36). It would be understood by the POSITA at the time that angles and widths constitute "contours" of an image object, as claimed. As discussed above for claim 15, Kenue use of Sobel filters (Ex. F at 5:67) allows for edge detection of an object. The POSITA would have also understood that the edge of an object would also be an object "contour."

194. As with claim 37, all of this functional ability from Kenue was purely a matter of programing in Kenue's image processor. The POSITA would have understood that all of this programmed functionality could have been programmed into the Vellacott imputer without requiring any creative step, and the "completely programmable" imputer of Vellacott would have predictably implemented these known algorithms from Kenue to produce substantially identical results.

***39. The vehicular vision system of claim 1, wherein said imager comprises a single chip camera*.**

195. As with many of the claims in the '001 Patent, claim 39 additionally appears to be doing no more than stating a well-known feature of the VVL imputer, invented two years prior, and admittedly used in the '001 Patent as the hardware of the system. (Ex. B patent 13:35-37) Vellacott's imputer is expressly described as a "single-chip image sensor." (Ex. C at page 2, col. 2).

***40. The vehicular vision system of claim 39, wherein said single chip camera is disposed adjacent an interior rearview mirror assembly of the equipped vehicle*.**

196. This claim represents yet another example just a statement of a known feature of the VVL imputer. Vellacott expressly states that the imputer can be housed in the rearview mirror assembly of a vehicle. (Ex. C, page 4 col. 3; FIG. 6). Kenue similarly teaches a "CCD video camera 10 mounted in a vehicle … at the upper center of the windshield to capture the driver's view of the road ahead." (Ex. D at 2:28-32). Thus, combining Vellacott's plain teaching that it was known to locate an imager "in" the rearview mirror assembly, with this additional

description from Kenue that it was known to locate such cameras at the windshield of the vehicle, the different terminology of "adjacent" in claim 40 would not have been considered to have any new or distinctive meaning to the POSITA from "at" or "in" the mirror assembly. The exact location of the imager was an obvious matter of design choice, given Vellacott's illustration (FIG. 6, Ex. C at page 4) that the CMOS imager portion of the imputer could be positioned separately from the imputer, attached by wiring.

> ***42. The vehicular vision system of claim 1, wherein said lens is one of (i) bonded to said photosensor array and (ii) close to said photosensor array*.**

197. This claim is also just a statement of a known feature of the VVL imputer. Vellacott expressly teaches "a chip-mounted microlens (Fig. 6)." (Ex. C, page 4 at col. 3). This chip-mounted microlens is clearly shown in FIG. 6 (reproduced above) to be "close to said photosensor array." In addition, GEM (Ex. E, page 109) and Paradiso (Ex. D, page 5 last paragraph; page 6 at Figure. 4) also illustrate that the Peach camera of the Vellacott imputer included a lens close to the photosensor array.

> ***43. The vehicular vision system of claim 1, wherein said imager has a field of view forward of the equipped vehicle, and wherein said field of view comprises a horizontal span and a vertical span and wherein said horizontal span is greater than said vertical span*.**

198. Both GEM (Ex. E, page 109) and Paradiso (Ex. D, page 5) disclose that the shape of the particular CMOS photosensor array, namely, square vs. rectangular, was an obvious matter of design choice to the POSITA. The POSITA

would have understood that a rectangular photosensor array, where the longer dimension is arranged horizontally, would obviously have a field of view in the horizontal span greater than that of the vertical span. No creative step would have been involved to select a rectangular imager array over a square, nor would any creative step be involved in orienting the wider greater dimension horizontally instead of vertically.

> ***44. The vehicular vision system of claim 43, wherein said horizontal span of said field of view is no greater than approximately 100 degrees*.**

199. Initially, it is important to note that the '001 Patent does not actually state how it accomplishes a horizontal field of view "no greater than approximately 100 degrees." In a typical camera, the field of view is determined by the lens or other optics used by the camera. The claims of the '001 Patent, however, merely require that the imager *has* a lens, but nothing else about its structure or capability.

200. Fletcher (Ex. M) plainly states that the VVL imputer of Vellacott was capable of mounting different lenses and lens structures known at the time. Accordingly, it would have involved nothing more than an obvious matter of design choice for the POSITA to simply select from one of several available lenses for the Peach camera of Vellacott's imputer. It would have been predictable that the field of view of the CMOS imager would then be limited according to the particular lens utilized.

201. Alternatively, the field of view of the imager could be easily limited

simply by the shape of housing near or in front of the lens. The field of view could have been physically limited merely by the size and angle of the opening in the housing (most likely in the rearview mirror housing) through which the camera views. The shape of such a housing though, would have also been no more than an obvious matter of design choice to the POSITA.

202. The field of view of the imager could also be limited purely by programming of the imputer. One simple programming method for reducing the vertical field of view would have been through use of the "convolver" algorithms provided in Vellacott's imputer library. The POSITA would have understood that a convolver was used to create a "window function" that reduces the number of arrays processed. This additional choice to limit the field of view would not have required any additional hardware or hardware modifications (such as a change in lens or housing shape) to implement. The field of view limitation would have been purely a matter of programming the imputer by the POSITA.

203. Kenue similarly limits the field of view purely as a matter of programming. Kenue states "FIG. 2 is an example of a typical image as projected on the camera image plane and includes the vehicle hood 22 and broken or solid stripes or lane markers 24 painted on the road and terminating at the horizon 26. Since the image spaces above the horizon and below the hood line do not contain useful lane boundary information those regions are ignored by the image processing algorithms." Thus, Kenue demonstrate that it was obvious to the POSITA at the time to reduce the field of view (vertically, in this example) purely

by “ignoring” information in the undesired regions. FIG. 2 of Kenue is reproduced below, with “horizon 26” and ‘vehicle hood 22” both highlighted in yellow for emphasis:

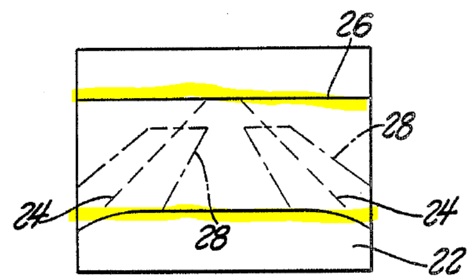


Fig. 2

45. The vehicular vision system of claim 44, wherein said vertical span of said field of view is no greater than approximately 30 degrees.

204. The requirements of claim 45 would have been obvious to the POSITA for the same reasons discussed above with respect to claim 44. As discussed immediately above, the span of the field of view was an obvious matter of design choice based on the selection of lens/optics, the shape of the opening through which the camera views, or straightforward software programming alone.

205. I note that the ‘001 Patent, however, does not actually describe a field of view limitation “no greater than” 30 degrees. The ‘001 Patent mentions a vertical field of view of “approximately 30 degrees” (Ex. B at 33:23), but the “no greater than” language appears only in the claim, with no explanation for the difference. A POSITA would understand “approximately 30 degrees” to also

mean "at least 30 degrees," which is different than "no greater than 30 degrees." Nevertheless, limiting the field of view to no greater than 30 degrees could have been easily accomplished by and of the methods stated above without involving any creative step by the POSITA.

> ***46. The vehicular vision system of claim 1, wherein said imager has a field of view forward of the equipped vehicle, and wherein said field of view comprises a vertical span and wherein said vertical span is asymmetric relative to a horizon*.**

206. As discussed above for claim 44, FIG. 2 of Kenue, reproduced above clearly illustrates its vertical field of view relative to the horizon (horizon 26) is asymmetric about the horizon. (Ex. F at FIG. 2). FIG. 2 of Kenue shows that the vertical span above the horizon 26 is substantially smaller than the vertical span below the horizon. The POSITA, at the time of the claimed invention, would have easily understood that this vertical difference above and below the horizon was "asymmetric" relative to the horizon.

207. Furthermore, Kenue teaches that the determination of horizon boundary, along with the decision to ignore the image space above the horizon 26 as not containing "useful lane boundary information," are solely a result of the image processing algorithms. (Ex. F at 2:56-59). It therefore would not have involved any creative step by the POSITA to program Vellacott's completely programmable imputer with such algorithms to perform the same determinations.

> ***47. The vehicular vision system of claim 46, wherein said vertical span comprises a first vertical span above the horizon and a second vertical span below the horizon, and wherein said first vertical span***

***has a different vertical dimension than said second vertical span*.**

208. The requirements of claim 47 would have been obvious to the POSITA for the same reasons discussed above with respect to claim 46. As discussed immediately above, FIG. 2 of Kenue clearly illustrates that the vertical span above the horizon 26 ("first vertical span") is smaller than the vertical span below the horizon ("second vertical span"). Again the determination of these two dimensions was purely a matter of programming the relevant algorithms into the image processor of the vehicular vision system. As discussed several times above, Vellacott's imputer was fully capable of being so programmed without any modifications to its hardware.

***48. The vehicular vision system of claim 1, wherein said control comprises logic and control circuitry*.**

209. This claim is yet another statement of a known basic feature of the VVL imputer. Vellacott clearly shows control logic and circuitry, for example, with its description of an "8-bit Intel 8032 microcontroller" (Ex. C, page 3 at col. 1), "a rear-view-mirror controller ASIC" (Ex. C at FIG. 6), "logical operators" (Ex. C, page 3 at col. 3), and also in all of FIGS. 1, 2, 3, 5, and 6, to name but a few.

210. In the general sense that would have been understood by the POSITA at the time of the invention, "logic and control circuitry" simply refers to a circuit responsible for sending the control signal to the system to be controlled. It would have been obvious to the POSITA that any application of a vehicular vision system for controlling another system requires logic and control circuitry, or there would

not be any functional ability to operate the vehicular vision system. In fact, it was a well-known *fundamental* principle in the field at the time of the claimed invention that, if a system is a computational system, that system requires logic and control circuitry.

***49. The vehicular vision system of claim 48, wherein said logic and control circuitry comprises said image processor*.**

211. This claim is still another statement of known basic features of the VVL imputer disclosed by Vellacott. As discussed immediately above, among the many different logic and control circuit elements disclosed by Vellacott were several circuits for processing image data captured by the CMOS photosensor array.

***50. The vehicular vision system of claim 49, wherein said module includes at least a portion of said logic and control circuitry*.**

212. As discussed above for claims 39 and 49, Vellacott teaches a single chip camera which supports both control circuitry and logic. FIG. 6 of Vellacott clearly illustrates that the imputer module itself housed all of the circuitry outside of the CMOS imager itself, and both the imputer module and the CMOS imager were housed within the rearview mirror assembly module. No creative step would have been required by the POSITA to understand that sensitive circuitry should be enclosed by a housing.

***51. The vehicular vision system of claim 50, wherein said module includes a heat sink for at least a portion of said logic and control circuitry*.**

213. Following the discussion of claim 50, it was also well-known to the POSITA at the time of the claimed invention that electronics, such as that used in the image processing systems of Vellacott and Kenue, create heat during their operation, and was both desirable and a standard practice to dissipate such heat. There are many ways of dissipating heat from an electronic circuit, but a very common and well known way available at the time was via a heat sink. A heat sink draws heat away from a processing unit such that the processing unit does not overheat, which can cause catastrophic failure of the processor.

214. While the addition of a heat sink to the imputer of Vellacott (on the off-chance that the imputer did not already include one as a standard feature of its electronics circuit) would have required some modification to the structure of the imputer, the mere addition of a heat sink to the structure would have been considered a very minor addition at the time of the claimed invention, and the ability of the POSITA to add a heat sink was well within the level of skill, requiring no creative step to make the modification.

> ***52. The vehicular vision system of claim 51, wherein said module includes a connector for electrically connecting to a power source of the equipped vehicle*.**

215. With respect to this limitation, Vellacott further discloses the imputer was housed inside the rear-view mirror (Ex. C at col. 4, FIG. 6), and that the automatic dimming of the rearview and wing mirrors is "controlled by an analogue voltage from the imputer, which directly sets the chrominance of the mirror." (*Id*).

For the imputer to be able to send an analog voltage to the side ("wing") mirror, which is a separate electrical system of the vehicle, the imputer would have had to have included a connector for electrically connecting to the side mirror dimmer system, which separate system would have had to connect to vehicle power simply just to operate. The claim does not require a direct connection, although such direct connection to mirror accessories were commonly known at the time. Schofield, for example, confirms this common knowledge of direct connections where the reference states "With such mirrors, there is a need to route electrical cables between the vehicle interior roof headliner and the mirror assembly to provide appropriate electrical power." (Ex. J at 1:55-60). This known principle, namely, the direct connection of electronic mirror accessories to vehicle power, is further illustrated in FIG. 15 of Schofield, reproduced below, which clearly shows wiring (146) from a mirror accessory routed up the windshield (W) toward the roof of the vehicle:

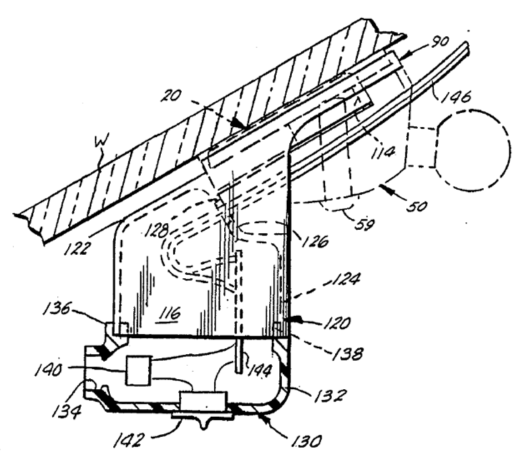


Fig. 15.

216. Schofield therefore confirms that it was obvious to the POSITA at the time of the claimed invention, at a minimum, to provide wiring at the rearview mirror assembly to directly connect electrical accessories to the vehicle power source. Vellacott alone does not expressly state the direct connection to vehicle power, but an indirect connection is clearly suggested by the reference's requirement to control a separate vehicle system by an analog signal. Whether the power connection was direct or indirect, the POSITA would have also easily understood that the imputer would have required no more than a compatible power input jack to connect the relevant power supply of the imputer to wiring provided at the same general vicinity of the rearview mirror assembly. The inclusion of a power input jack to the imputer would not have required any creative step.

> ***53. The vehicular vision system of claim 48, wherein said module includes a cover.***

217. As discussed above for claims 39 and 49-50, Vellacott clearly illustrates in FIG. 6 (Ex. C at page 4) that the imputer module housed – and therefore covered – the circuitry connected to the CMOS imager. Furthermore, and both the imputer module and the CMOS imager were housed within the rearview mirror assembly module, which would have also been clearly understood by the POSITA to function as a cover as well. This claim thus appears to do no more than state an obvious pre-existing feature of the VVL imputer.

> ***54. The vehicular vision system of claim 1, wherein said imager comprises a spectral filter.***

218. Denyer (Ex. K) describes that it would have been well-known at the

time of the claimed invention to add RGB color filters to existing solid-state photosensor camera arrays such as CCD and MOS devices. (Ex. K at page 10, lines 7-23). The POSITA at the time would have easily understood that an RGB color filter would have been considered to be one form of a "spectral filter."

219. The addition of an RGB filter, such as that disclosed by Denyer, to a CMOS array (such as that described by Vellacott) would not change the operation of the CMOS device, but would instead enhance its ability to distinguish color information in addition to its inherent ability to distinguish light intensity and luminance. Denyer clearly teaches that its filter is applicable to all solid-state imaging devices such as CCD and CMOS (a subset of MOS devices).

220. Alternatively, it was a well-known principle in the art at the time of the claimed invention that accessories located at the windshield of an automobile, as well as the automobile's dashboard, are often subjected to considerable exposure to ultraviolet (UV) light, which can damage the accessories over time after much UV exposure. Because of the risk of UV damage to sensitive electronic components, it was a common practice at the time, and known to the POSITA, to include a UV filter, or shield, on the windshield itself to block UV light radiation from entering the vehicle. Some automobile glass is designed with a UV filter, but a separate shield was also commonly laminated on the windshield glass to protect the interior of the vehicle and its occupants. Such a UV filter/shield would have been understood by the POSITA at the time to also constitute a "spectral filter."

221. The CMOS imager of the imputer itself could also have included such a UV filter over just the portion of the imager exposed to daylight through the windshield, without substantially affection the operation or ability of the imager or the imputer as a whole. No creative step would have been required by the POSITA to laminate an otherwise transparent UV filter/shield in front of an opening in the rearview mirror housing through which the imager views.

> ***55. The vehicular vision system of claim 1, wherein said image processor processes captured image data for at least one of (a) a headlight control system of the equipped vehicle, (b) a collision avoidance system of the equipped vehicle, and (c) an automatic vehicle system of the equipped vehicle*.**

222. This claim also appears to be just another statement of known basic features of the VVL imputer disclosed by Vellacott, at least with respect to option (c). The POSITA would have easily understood that the mirror dimmer of Vellacott was, at the time of the invention "an automatic vehicle system of the equipped vehicle."

223. Yanagawa and Venturello both disclose vehicular vision systems that automatically control the headlights of an equipped vehicle from the processed image data (option (a)), and Bottesch expressly discloses control of a collision avoidance system from the processed image data (option (b)). The POSITA at the time of the claimed invention would have easily understood that the basic purpose behind a vehicular vision system was to control one or more of the vehicle systems automatically from the processed image data.

56. A vehicular vision system, said vehicular vision system comprising:

an imager comprising a lens and a CMOS photosensor array;

wherein said photosensor array comprises a plurality of photosensor elements;

wherein said imager is disposed at an interior portion of a vehicle equipped with said vehicular vision system and wherein said imager views exterior of the equipped vehicle through a windshield of the equipped vehicle and forward of the equipped vehicle;

224. These limitations are present in claim 1. As such, I incorporate by reference herein the analysis I provide above with respect to these limitations in claim 1.

wherein said imager is disposed in a module that releasably mounts to a mounting element adhesively attached at the windshield of the equipped vehicle;

225. The limitation "imager is disposed in a module" is present in claim 1 and the limitation "module that releasably mounts to a mounting element adhesively attached at the windshield of the equipped vehicle" is present in claim 24. As such, I incorporate by reference herein the analysis I provide above with respect to these limitations in claims 1 and 24.

a control;

226. This limitation is present in claim 1. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 1.

wherein said control comprises logic and control circuitry;

227. This limitation is present in claim 48. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 48.

wherein said logic and control circuitry comprises an image processor, and wherein said image processor processes image data captured by said photosensor array to detect an object viewed by said imager; and

228. This limitation is present in claims 1 and 49. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 1 and 49.

wherein at least two of (a) said module includes a heat sink for at least a portion of said logic and control circuitry, (b) said module includes a connector for electrically connecting to a power source of the equipped vehicle, and (c) said module includes at least a portion of said logic and control circuitry.

229. This limitation is present in claims 50, 51, and 52. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 50, 51, and 52.

230. As such, Claim 56 of the '001 Patent does not claim anything inventive over the known forward facing vehicular vision systems taught by Vellacott, which can be properly modified to face forward as taught by Kenue, as known in the art.

231. As discussed above for claims 1, 24, 48, 50, 51, and 52, the subject matter of claim 56 was well known at the time.

***57. The vehicular vision system of claim 56, wherein said imager is disposed proximate the windshield of the equipped vehicle*.**

232. This limitation is present in claim 2. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 2.

233. As discussed above for claim 2, the subject matter of claim 57 was well known at the time.

***58. The vehicular vision system of claim 56, wherein said module includes a cover*.**

234. This limitation is present in claim 53. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 53.

235. As discussed above for claim 53, the subject matter of claim 58 was well known at the time.

***59. The vehicular vision system of claim 56, wherein said photosensor array comprises an array of columns and rows of photosensor elements and wherein at least one of (i) said array has more columns than rows and (ii) said array comprises at least 40 rows*.**

236. This limitation is present in claims 3 and 4. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in

claims 3 and 4.

237. As discussed above for claims 3 and 4, the subject matter of claim 59 was well known at the time.

> ***60. The vehicular vision system of claim 56, wherein said image processor processes captured image data to detect at least one of (a) a vehicle, (b) a headlight of a vehicle, (c) a taillight of a vehicle, and (d) a road sign*.**

238. This limitation is present in claim 5. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 5.

239. As discussed above for claim 5, the subject matter of claim 60 was well known at the time.

> ***61. The vehicular vision system of claim 56, wherein, at least in part responsive to processing of captured image data by said image processor, said vehicular vision system is operable to control an exterior light of the equipped vehicle to limit debilitation of a driver of another vehicle forward of the equipped vehicle, and wherein at least one of (a) control of the exterior light of the equipped vehicle involves adjustment of a light beam emitted by the exterior light of the equipped vehicle, (b) the exterior light of the equipped vehicle is operable to emit a plurality of light beams, and wherein said control adjusts between one light beam of said plurality of light beams and another light beam of said plurality of light beams, and (c) the exterior light of the equipped vehicle is operable to emit a plurality of light beams, and wherein said control adjusts between one light beam of said plurality of light beams and another light beam of said plurality of light beams, and wherein said plurality of light beams comprises at least one of a low beam, a mid beam and a high beam*.**

240. This limitation is present in claims 6 and 7. As such, I incorporate by

reference herein the analysis I provide above with respect to this limitation in claims 6 and 7.

241. As discussed above for claims 6 and 7, the subject matter of claim 61 was well known at the time.

> ***62. The vehicular vision system of claim 56, wherein, at least in part responsive to processing of captured image data by said image processor, at least one of (a) said control is operable to control the exterior light of the equipped vehicle to emit a pattern of light appropriate to limit debilitation of a driver of another vehicle forward of the equipped vehicle, (b) said control is operable to control the exterior light of the equipped vehicle to emit a pattern of light that illuminates a selected zone forward of the equipped vehicle, and (c) the exterior light of the equipped vehicle is operable to emit various patterns of light.***

242. This limitation is present in claims 6 and 8. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 6 and 8.

243. As discussed above for claims 6 and 8, the subject matter of claim 62 was well known at the time.

> ***63. The vehicular vision system of claim 56, wherein, at least in part responsive to processing of captured image data by said image processor, said control at least in part controls at least one exterior light of the equipped vehicle, and wherein the at least one exterior light of the equipped vehicle comprises a headlight disposed at a front portion of the equipped vehicle and operable to illuminate with visible light a scene forward of and in a path of travel of the equipped vehicle, and wherein at least one of (a) said control, at least in part responsive to processing of captured image data by said image processor, controls a vehicular lighting switch, and wherein***

***said vehicular lighting switch controls the at least one exterior light of the equipped vehicle, (b) a manual vehicle light switch is actuatable to override said control, and (c) a manual vehicle light switch is actuatable to override said control and wherein said control, at least in part responsive to processing of captured image data by said image processor, controls a vehicular lighting switch that controls the at least one exterior light of the equipped vehicle*.**

244. This limitation is present in claims 9 and 10. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 9 and 10.

245. As discussed above for claims 9 and 10, the subject matter of claim 63 was well known at the time.

***64. The vehicular vision system of claim 56, wherein, at least in part responsive to processing of captured image data by said image processor, said vehicular vision system determines a presence of at least one of fog, snow and rain present exterior and forward of the equipped vehicle*.**

246. This limitation is present in claim 11. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 11.

247. As discussed above for claim 11, the subject matter of claim 64 was well known at the time.

65. The vehicular vision system of claim 64, wherein said vehicular vision system determines the presence of at least one of fog, snow and rain by recognizing scattering of light output by a headlight of the equipped vehicle by at least one of fog, snow and rain present exterior and forward of the equipped vehicle, and wherein said vehicular vision system, at least in part responsive to recognition of

***scattering of light output by the headlight of the equipped vehicle, controls the headlight of the equipped vehicle*.**

248. This limitation is present in claims 12 and 13. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 12 and 13.

249. As discussed above for claims 12 and 13, the subject matter of claim 65 was well known at the time.

***66. The vehicular vision system of claim 56, wherein said image processor compares captured image data with stored data and outputs a vehicle equipment control signal based on the comparison*.**

250. This limitation is present in claim 15. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 15.

251. As discussed above for claim 15, the subject matter of claim 66 was well known at the time.

***67. The vehicular vision system of claim 56, wherein said imager views through the windshield of the equipped vehicle at a windshield area that is swept by a windshield wiper of the equipped vehicle*.**

252. This limitation is present in claim 16. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 16.

253. As discussed above for claim 16, the subject matter of claim 67 was well known at the time.

68. The vehicular vision system of claim 56, wherein said control, at least in part responsive to processing of captured image data by said image processor, at least one of (i) distinguishes between daytime and nighttime conditions, (ii) determines a nighttime condition exists at an ambient light level that is less than about 500 lux, (iii) is operable to control a headlight of the equipped vehicle when said control determines a nighttime condition, (iv) is operable to control a vehicle accessory when said control determines a daytime condition, (v) is operable to deactivate a light beam of a headlight of the equipped vehicle when said control determines a daytime condition, and (vi) determines an ambient light level present at the equipped vehicle.

254. This limitation is present in claims 17-22. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 17-22.

255. As discussed above for claims 17-22, the subject matter of claim 68 was well known at the time.

69. The vehicular vision system of claim 56, wherein the equipped vehicle has at least one headlight, and wherein the at least one headlight is operable at least in a first beam mode and a second beam mode, and wherein, at least in part responsive to processing of captured image data by said image processor, said control controls operation of the at least one headlight, and wherein said control transitions the at least one headlight from said first beam mode to said second beam mode in response to detection of at least one of a headlight and a taillight viewed by said imager.

256. This limitation is present in claim 32. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 32.

257. As discussed above for claim 32, the subject matter of claim 69 was well known at the time.

> ***71. The vehicular vision system of claim 69, wherein at least one of (a) said first beam mode comprises a high beam mode, (b) the at least one headlight is actuated at an ambient lighting level below a predetermined level, and (c) the at least one headlight is actuated at an ambient lighting level below approximately 500 lux.***

258. This limitation is present in claim 34. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 34.

259. As discussed above for claim 34, the subject matter of claim 71 was well known at the time.

> ***73. The vehicular vision system of claim 56, wherein said imager has a field of view forward of the equipped vehicle, and wherein said field of view comprises a horizontal span and a vertical span and wherein said horizontal span is greater than said vertical span, and wherein at least one of (i) said horizontal span of said field of view is no greater than approximately 100 degrees and (ii) said vertical span of said field of view is no greater than approximately 30 degrees.***

260. This limitation is present in claims 43, 44, and 45. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 43, 44, and 45.

261. As discussed above for claims 43, 44, and 45, the subject matter of claim 73 was well known at the time.

> ***74. The vehicular vision system of claim 56, wherein said imager***

has a field of view forward of the equipped vehicle, and wherein said field of view comprises a vertical span and wherein said vertical span is asymmetric relative to a horizon, and wherein said vertical span comprises a first vertical span above the horizon and a second vertical span below the horizon, and wherein said first vertical span has a different vertical dimension than said second vertical span.

262. This limitation is present in claims 46 and 47. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 46 and 47.

263. As discussed above for claims 46 and 47, the subject matter of claim 74 was well known at the time.

75. The vehicular vision system of claim 56, wherein said photosensor array is operable at a first exposure period and a second exposure period, and wherein the time period of exposure of said first exposure period is longer than the time period of exposure of said second exposure period.

264. This limitation is present in claim 1. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 1.

265. As discussed above for claim 1, the subject matter of claim 75 was well known at the time.

76. The vehicular vision system of claim 56, wherein image data processing by said image processor comprises pattern recognition.

266. This limitation is present in claim 28. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim

28.

267. As discussed above for claim 28, the subject matter of claim 76 was well known at the time.

> ***77. The vehicular vision system of claim 56, wherein said image processor processes captured image data for at least one of (a) a headlight control system of the equipped vehicle, (b) a collision avoidance system of the equipped vehicle, and (c) an automatic vehicle system of the equipped vehicle**.*

268. This limitation is present in claim 55. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 58.

269. As discussed above for claim 55, the subject matter of claim 77 was well known at the time.

> ***78. The vehicular vision system of claim 56, wherein said imager comprises a spectral filter**.*

270. This limitation is present in claim 54. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 54.

271. As discussed above for claim 54, the subject matter of claim 78 was well known at the time.

> ***79. A vehicular vision system, said vehicular vision system comprising:***
>
> ***an imager comprising a lens and a CMOS photosensor array;***

wherein said photosensor array comprises a plurality of photosensor elements;

wherein said imager is disposed at an interior portion of a vehicle equipped with said vehicular vision system and wherein said imager views exterior of the equipped vehicle through a windshield of the equipped vehicle and forward of the equipped vehicle;

wherein at least said imager is disposed in a module that releasably mounts to a mounting element adhesively attached at the windshield of the equipped vehicle;

a control comprising an image processor, said image processor processing image data captured by said photosensor array;

wherein said image processor processes captured image data to detect an object viewed by said imager; and

272. This limitation is present in claim 56. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 56.

wherein, at least in part responsive to processing of captured image data by said image processor, said vehicular vision system determines a presence of at least one of fog, snow and rain present exterior and forward of the equipped vehicle.

273. This limitation is present in claim 11. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 11.

274. As discussed above for claims 56 and 11, the subject matter of claim 79 was well known at the time.

80. The vehicular vision system of claim 79, wherein said imager is disposed proximate the windshield of the equipped vehicle, and

wherein said imager views through the windshield of the equipped vehicle at a windshield area that is swept by a windshield wiper of the equipped vehicle.

275. This limitation is present in claims 2 and 16. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 2 and 16.

276. As discussed above for claims 2 and 16, the subject matter of claim 80 was well known at the time.

81. The vehicular vision system of claim 79, wherein said photosensor array comprises an array of columns and rows of photosensor elements and wherein at least one of (i) said array has more columns than rows and (ii) said array comprises at least 40 rows.

277. This limitation is present in claims 3 and 4. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 3 and 4.

278. As discussed above for claims 3 and 4, the subject matter of claim 81 was well known at the time.

82. The vehicular vision system of claim 79, wherein said image processor processes captured image data to detect at least one of (a) a vehicle, (b) a headlight of a vehicle, (c) a taillight of a vehicle, and (d) a road sign.

279. This limitation is present in claim 5. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 5.

280. As discussed above for claim 5, the subject matter of claim 82 was well known at the time.

> ***83. The vehicular vision system of claim 79, wherein, at least in part responsive to processing of captured image data by said image processor, at least one of (a) said control is operable to control the exterior light of the equipped vehicle to emit a pattern of light appropriate to limit debilitation of the driver of another vehicle forward of the equipped vehicle, (b) said control is operable to control the exterior light of the equipped vehicle to emit a pattern of light that illuminates a selected zone forward of the equipped vehicle, and (c) the exterior light of the equipped vehicle is operable to emit various patterns of light*.**

281. This limitation is present in claims 6 and 8. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 6 and 8.

282. As discussed above for claims 6 and 8, the subject matter of claim 83 was well known at the time.

> ***84. The vehicular vision system of claim 79, wherein said vehicular vision system determines a presence of at least one of fog, snow and rain by recognizing scattering of light output by a headlight of the equipped vehicle by at least one of fog, snow and rain present exterior and forward of the equipped vehicle, and wherein said vehicular vision system, at least in part responsive to recognition of scattering of light output by the headlight of the equipped vehicle, controls the headlight of the equipped vehicle*.**

283. This limitation is present in claims 12 and 13. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 12 and 13.

284. As discussed above for claims 12 and 13, the subject matter of claim 84 was well known at the time.

***85. The vehicular vision system of claim 79, wherein at least one of (i) said image processor compares captured image data with stored data and outputs a vehicle equipment control signal based on the comparison, and (ii) said imager views through the windshield of the equipped vehicle at a windshield area that is swept by a windshield wiper of the equipped vehicle*.**

285. This limitation is present in claims 15 and 16. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 15 and 16.

286. As discussed above for claims 15 and 16, the subject matter of claim 85 was well known at the time.

***86. The vehicular vision system of claim 79, wherein said control, at least in part responsive to processing of captured image data by said image processor, at least one of (i) distinguishes between daytime and nighttime conditions, (ii) determines a nighttime condition exists at an ambient light level that is less than about 500 lux, (iii) is operable to control a headlight of the equipped vehicle when said control determines a nighttime condition, (iv) is operable to control a vehicle accessory when said control determines a daytime condition, (v) is operable to deactivate a light beam of a headlight of the equipped vehicle when said control determines a daytime condition, and (vi) determines an ambient light level present at the equipped vehicle*.**

287. This limitation is present in claims 17-22. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 17-22.

288. As discussed above for claims 17-22, the subject matter of claim 86 was well known at the time.

> ***87. The vehicular vision system of claim 79, wherein the equipped vehicle has at least one headlight, and wherein the at least one headlight is operable at least in a first beam mode and a second beam mode, and wherein, at least in part responsive to processing of captured image data by said image processor, said control controls operation of the at least one headlight, and wherein said control transitions the at least one headlight from said first beam mode to said second beam mode in response to detection of at least one of a headlight and a taillight viewed by said imager***.

289. This limitation is present in claim 32. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 32.

290. As discussed above for claim 32, the subject matter of claim 87 was well known at the time.

> ***88. The vehicular vision system of claim 79, wherein said imager has a field of view forward of the equipped vehicle, and wherein said field of view comprises a horizontal span and a vertical span and wherein said horizontal span is greater than said vertical span, and wherein at least one of (i) said horizontal span of said field of view is no greater than approximately 100 degrees and (ii) said vertical span of said field of view is no greater than approximately 30 degrees***.

291. This limitation is present in claims 43, 44, and 45. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 43, 44, and 45.

292. As discussed above for claims 43, 44, and 45, the subject matter of claim 88 was well known at the time.

> ***89. The vehicular vision system of claim 79, wherein said imager has a field of view forward of the equipped vehicle, and wherein said field of view comprises a vertical span and wherein said vertical span is asymmetric relative to a horizon, and wherein said vertical span comprises a first vertical span above the horizon and a second vertical span below the horizon, and wherein said first vertical span has a different vertical dimension than said second vertical span***.

293. This limitation is present in claims 46 and 47. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 46 and 47.

294. As discussed above for claims 46 and 47, the subject matter of claim 89 was well known at the time.

> ***90. The vehicular vision system of claim 79, wherein said photosensor array is operable at a first exposure period and a second exposure period, and wherein the time period of exposure of said first exposure period is longer than the time period of exposure of said second exposure period***.

295. This limitation is present in claim 75. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 75.

296. As discussed above for claim 75, the subject matter of claim 90 was well known at the time.

> ***91. The vehicular vision system of claim 79, wherein said module includes at least one of (i) logic and control circuitry, (ii) logic and***

control circuitry that comprises at least a portion of said control, (iii) logic and control circuitry that comprises said image processor, (iv) a heat sink for at least a portion of logic and control circuitry, (v) a connector for electrically connecting to a power source of the equipped vehicle, and (vi) a cover.

297. This limitation is present in claims 48-53. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 48-53.

298. As discussed above for claims 48-53, the subject matter of claim 91 was well known at the time.

92. The vehicular vision system of claim 79, wherein image data processing by said image processor comprises pattern recognition.

299. This limitation is present in claim 28. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 28.

300. As discussed above for claim 28, the subject matter of claim 92 was well known at the time.

93. The vehicular vision system of claim 79, wherein said image processor processes captured image data for at least one of (a) a headlight control system of the equipped vehicle, (b) a collision avoidance system of the equipped vehicle, and (c) an automatic vehicle system of the equipped vehicle.

301. This limitation is present in claim 55. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 55.

302. As discussed above for claim 55, the subject matter of claim 93 was well known at the time.

> ***94. The vehicular vision system of claim 79, wherein said imager comprises a spectral filter*.**

303. This limitation is present in claim 54. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 54.

304. As discussed above for claim 54, the subject matter of claim 94 was well known at the time.

> ***95. The vehicular vision system of claim 94, wherein said control comprises logic and control circuitry and wherein said logic and control circuitry comprises said image processor, and wherein at least two of (a) said module includes a heat sink for at least a portion of said logic and control circuitry, (b) said module includes a connector for electrically connecting to a power source of the equipped vehicle, (c) said module includes at least a portion of said logic and control circuitry, and (d) said module includes a cover*.**

305. This limitation is present in claims 49, 50, 51, 52, and 53. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 49, 50, 51, 52, and 53.

306. As discussed above for claims 49, 50, 51, 52, and 53, the subject matter of claim 95 was well known at the time.

> ***96. A vehicular vision system, said vehicular vision system comprising:***
>
> ***an imager comprising a lens and a CMOS photosensor array;***

wherein said photosensor array comprises a plurality of photosensor elements;

wherein said imager is disposed at an interior portion of a vehicle equipped with said vehicular vision system and wherein said imager views exterior of the equipped vehicle through a windshield of the equipped vehicle and forward of the equipped vehicle;

307. This limitation is present in claim 1. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 1.

wherein at least said imager is disposed in a module that releasably mounts to a mounting element adhesively attached at the windshield of the equipped vehicle;

308. This limitation is present in claim 24. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 24.

wherein said photosensor array comprises an array of columns and rows of photosensor elements and wherein said array has more columns than rows, and wherein said array comprises at least 40 rows;

309. This limitation is present in claims 3 and 4. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 3 and 4.

wherein said imager has a field of view forward of the equipped vehicle, and wherein said field of view comprises a horizontal span and a vertical span and wherein said horizontal span is greater than said vertical span;

310. This limitation is present in claim 43. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 43.

> ***a control comprising an image processor, said image processor processing image data captured by said photosensor array; and***
>
> ***wherein said image processor processes captured image data to detect an object viewed by said imager***.

311. This limitation is present in claim 1. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 1.

312. As discussed above for claims 1, 3, 4, 24, 43, the subject matter of claim 96 was well known at the time.

> ***97. The vehicular vision system of claim 96, wherein said image processor processes captured image data to detect at least one of (a) a vehicle, (b) a headlight of a vehicle, (c) a taillight of a vehicle, and (d) a road sign***.

313. This limitation is present in claim 5. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 5.

314. As discussed above for claim 5, the subject matter of claim 97 was well known at the time.

> ***98. The vehicular vision system of claim 96, wherein, at least in part responsive to processing of captured image data by said image processor, said vehicular vision system determines a presence of at***

least one of fog, snow and rain present exterior and forward of the equipped vehicle.

315. This limitation is present in claim 11. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 11.

316. As discussed above for claim 11, the subject matter of claim 98 was well known at the time.

99. The vehicular vision system of claim 98, wherein said vehicular vision system determines the presence of at least one of fog, snow and rain by recognizing scattering of light output by a headlight of the equipped vehicle by at least one of fog, snow and rain present exterior and forward of the equipped vehicle, and wherein said vehicular vision system, at least in part responsive to recognition of scattering of light output by the headlight of the equipped vehicle, controls the headlight of the equipped vehicle.

317. This limitation is present in claims 12 and 13. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 12 and 13.

318. As discussed above for claims 12 and 13, the subject matter of claim 99 was well known at the time.

100. The vehicular vision system of claim 96, wherein at least one of (i) said image processor compares captured image data with stored data and outputs a vehicle equipment control signal based on the comparison and (ii) said imager views through the windshield of the equipped vehicle at a windshield area that is swept by a windshield wiper of the equipped vehicle.

319. This limitation is present in claims 15 and 16. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 15 and 16.

320. As discussed above for claims 15 and 16, the subject matter of claim 100 was well known at the time.

> ***101. The vehicular vision system of claim 96, wherein said control, at least in part responsive to processing of captured image data by said image processor, at least one of (i) distinguishes between daytime and nighttime conditions, (ii) determines a nighttime condition exists at an ambient light level that is less than about 500 lux, (iii) is operable to control a headlight of the equipped vehicle when said control determines a nighttime condition, (iv) is operable to control a vehicle accessory when said control determines a daytime condition, (v) is operable to deactivate a light beam of a headlight of the equipped vehicle when said control determines a daytime condition, and (vi) determines an ambient light level present at the equipped vehicle***.

321. This limitation is present in claims 17-22. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 17-22.

322. As discussed above for claims 17-22, the subject matter of claim 101 was well known at the time.

> ***102. The vehicular vision system of claim 96, wherein said horizontal span of said field of view is no greater than approximately 100 degrees and said vertical span of said field of view is no greater than approximately 30 degrees.***

323. This limitation is present in claims 44 and 45. As such, I incorporate

by reference herein the analysis I provide above with respect to this limitation in claims 44 and 45.

324. As discussed above for claims 44 and 45, the subject matter of claim 102 was well known at the time.

> ***103. The vehicular vision system of claim 96, wherein said vertical span comprises a first vertical span above a horizon and a second vertical span below the horizon, and wherein said first vertical span has a different vertical dimension than said second vertical span***.

325. This limitation is present in claim 47. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 47.

326. As discussed above for claim 47, the subject matter of claim 103 was well known at the time.

> ***104. The vehicular vision system of claim 96, wherein said photosensor array is operable at a first exposure period and a second exposure period, and wherein the time period of exposure of said first exposure period is longer than the time period of exposure of said second exposure period***.

327. This limitation is present in claim 1. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 1.

328. As discussed above for claim 1, the subject matter of claim 104 was well known at the time.

105. The vehicular vision system of claim 96, wherein image data processing by said image processor comprises pattern recognition.

329. This limitation is present in claim 28. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 28.

330. As discussed above for claim 28, the subject matter of claim 105 was well known at the time.

106. The vehicular vision system of claim 96, wherein said image processor processes captured image data for at least one of (a) a headlight control system of the equipped vehicle, (b) a collision avoidance system of the equipped vehicle, and (c) an automatic vehicle system of the equipped vehicle.

331. This limitation is present in claim 55. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 55.

332. As discussed above for claim 55, the subject matter of claim 106 was well known at the time.

107. The vehicular vision system of claim 96, wherein said imager comprises a spectral filter.

333. This limitation is present in claim 54. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 54.

334. As discussed above for claim 54, the subject matter of claim 107 was

well known at the time.

> ***108. The vehicular vision system of claim 107, wherein said control comprises logic and control circuitry and wherein said logic and control circuitry comprises said image processor, and wherein at least two of (a) said module includes a heat sink for at least a portion of said logic and control circuitry, (b) said module includes a connector for electrically connecting to a power source of the equipped vehicle, (c) said module includes at least a portion of said logic and control circuitry, and (d) said module includes a cover*.**

335. This limitation is present in claim 48-53. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claim 48-53.

336. As discussed above for claims 48-53, the subject matter of claim 108 was well known at the time.

> ***109. The vehicular vision system of claim 96, wherein said imager is disposed proximate the windshield of the equipped vehicle, and wherein said imager views through the windshield of the equipped vehicle at a windshield area that is swept by a windshield wiper of the equipped vehicle*.**

337. This limitation is present in claims 2 and 16. As such, I incorporate by reference herein the analysis I provide above with respect to this limitation in claims 2 and 16.

338. As discussed above for claims 2 and 16, the subject matter of claim 109 was well known at the time.

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Personal Statement

Throughout my career, I have progressed through the technical ranks as a junior programmer, senior programmer, technical lead, chief architect, director of engineering, and founder and CEO of my own company that created wireless handheld point-of-sale systems for the restaurant industry. For five years while in graduate school, I taught undergraduate Computer Science courses at California State University, Los Angeles, earning the Professor of the Year award for the CS department in 2002. After receiving my Ph.D. in Computer Science in 2007 from the University of Southern California, I became an Assistant Professor in the Computer Systems Engineering program at the University of Alaska Anchorage (UAA) from August 2007-June 2011. I was promoted to Associate Professor and tenured at UAA beginning in the 2011/2012 academic year. From February 2011-November 2011, I was the Chair of the Bachelor of Science in Engineering department at UAA, which offered degrees in Computer, Electrical, and Mechanical Engineering with 13 tenure-track and 5 adjunct faculty. I am currently an Associate Professor of Engineering Practices in the Computer Science department at the University of Southern California.

While at UAA, I authored and achieved University approval for introductory programming, object-oriented programming, systems administration, digital circuits, computer networking, operating systems, FPGA, and VLSI classes for engineering students focused on applied applications in various engineering disciplines. I also was the Program Chair for the Computer Systems Engineering department in preparing ABET documents to ultimately achieve full accreditation in 2008, 2010, and again in 2012. In the 2012/2013 academic year, the Computer Science and Computer Systems Engineering programs were merged, and I have been involved in streamlining the curricula for both programs to reduce duplication and provide an improved education for students in both programs.

I have also been successful in securing over $930,000 as a PI or Co-PI in research funding since 2008 for projects concerning Intelligent Transportation Systems (ITS) networks and architectures. Single architectures are not always suitable for an application, so I focus on combining different network and system architectures to suit the needs of a specific application. In a mobile environment, combining centralized and distributed architectures into a single system allow wireless devices to behave as thin and thick clients. With ITS architectures, V2V (Vehicle-to-Vehicle), V2I (Vehicle-to-Infrastructure), and the hybrid V2V2I (Vehicle-to-Vehicle-to-Infrastructure) architectures provide a means for vehicles to transmit information to a central repository and other vehicles. One of the grants I have received focuses on installing tracking devices in 85 vehicles that communicate over the cellular network speed, location, and additional information available through a vehicle's on-board diagnostic (OBD) port. This data is combined with the data retrieved from other means, such as inductor loops, video cameras, driver reports, air tubes, and other vehicles equipped with GPS transmitters and receivers. From this data, a map of the roadways is provided showing the speed of select vehicles, average speed on arterial roadways, locations of congestion, fastest paths, and other information as requested by the stakeholders.

In addition, I organized and led the UAA School of Engineering K12 Summer Camps from 2010-2013. Starting with around 100 students in 2010, the camps grew to over 800 interested students in 2013. Initially funded by the School of Engineering through outreach activities, BP funded the summer camps in 2011, 2012, and 2013 at $80k each year. The IEEE Foundation also funded $20k in 2013. The camps were provided at no cost to the attendees, and topics included robotics, alternative energy, rapid prototyping, GPS tracking, FM radio setup, and structure destruction.

Within the IEEE, I have been quite active, being the General Chair for the IEEE 69th Vehicular Technology Conference in fall 2009 in Anchorage, the IEEE 15th Intelligent Transportation Systems Conference in fall 2012 in Anchorage, and the IEEE 77th Vehicular Technology Conference in fall 2013 in Las Vegas. I have also been a Program Co-Chair and Technical Program Chair for the IEEE 73rd Vehicular Technology Conference in fall 2011. I was on the IEEE Intelligent Transportation Systems Society Board of Governors for the term from January 2009-December 2011 and was elected as Vice President for Administrative Activities in the same society from January 2011-December 2012. I was also on the IEEE Vehicular Technology Society Board of Governors for the term from September 2011-December 2013. From October 2011-December 2013, I was the Editor-in-Chief of the IEEE ITS Magazine. Within the ITSS, I was an Associate Editor for the IEEE Transactions on Intelligent

Transportation Systems from 2010-2013. In 2010, I was the treasurer for the Alaska section of the IEEE and was the chair of the section from January 2011-December 2011. During my time as chair of the IEEE Alaska Section, the section won the 2011 Outstanding Section Award for the Region 6 Northwest Area. In addition to being a member of the Intelligent Transportation Society of Alaska, I was also the president from January 2010-December 2011. I have been involved in other conferences as well, being the program co-chair, publicity co-chair, local arrangements chair, volunteer coordinator chair, technical program committee member, session chair, special session organizer, and reviewer. Within ACM, I am a member and was the faculty advisor for the student chapter of the ACM at the University of Alaska Anchorage.

Research Statement

My research focuses on the software and network architectures and algorithms used in mobile and wireless communication. Single architectures are not always suitable for an application, so I also focus on combining architectures to suit the needs of a specific application. The application area I use in my research is Intelligent Transportation Systems (ITS). Pure Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) architectures have been proposed, and V2I communication is currently used by many ITS applications (such as automated toll booths, vehicle tracking, etc.). As more vehicles begin to use V2I communication for transmitting data to a central repository, different architectures or much creative utilization of bandwidth will be necessary. Hybrid architectures (such as the Vehicle-to-Vehicle-to-Infrastructure (V2V2I)) will be needed so that the data transmitted will not overwhelm the central systems.

In addition to the architecture, efficient algorithms are also necessary for analyzing the large amount of data that will be received. The data may be granular enough to determine the location of an accident or object in the roadway, the average speed on many different arterial roads for determining fastest paths, or for determining the impact of construction or a new building to the current traffic congestion, among many other potential applications. Making this data available in an efficient manner and performing real-time calculations on this data to produce usable results have been difficult challenges. The algorithms used need to be application-specific so they can be optimized for the utmost in efficiency.

One of the grants I have received is from the Alaska University Transportation Center, in conjunction with the Alaska Department of Transportation. The project has installed tracking devices in 65 vehicles in the city of Anchorage. The tracking devices are connected through the vehicle's on-board diagnostic (OBD) port, and the speed, location, and additional data from the vehicle's computer system are transmitted through the cellular network to a central server. This data is combined with the data retrieved from other means, such as inductor loops, video cameras, driver reports, air tubes, and other vehicles equipped with GPS transmitters and receivers. From this data, a map of the roadways is provided showing the speed of select vehicles, average speed on arterial roadways, locations of congestion, fastest paths, and other information as requested by the stakeholders. Some information, such as fastest paths or locations of congestion, are also returned to drivers as requested via text messages. With the devices strategically placed in 75 vehicles that traverse the main arterials of the city on a daily basis, the results have been quite promising. Probe vehicles are proving to be a very effective way of determining flow of traffic on main arterials, coupled with additional vehicle data from other means. The data is fed into a real-time simulator I created called FreeSim (http://www.freewaysimulator.com), which now utilizes Google Maps for its display. The data is also exposed over the Internet for other researchers to exploit and test their own algorithms given a live set of distributed data gathered via a V2I architecture at http://www.alaskatraffic.net.

Over the next few years, my research will continue to focus on architectures for large-scale systems and developing criteria by which different architectures can be evaluated. Various architectural methodologies will be employed to determine a priori advantages for a purely distributed versus a purely centralized versus a hybrid architecture. In addition, I expect to develop specialized algorithms that optimize the performance of each of these architectures, given the specific application. My approach to a posteriori analysis relies upon the development of simulation models that realize the underlying architecture and are calibrated by whatever actual data is available, as well as what data is required by the end-user applications. Typical questions I expect to address are bandwidth requirements, accuracy of the data representation, historical tracking of data, processing power required by each device, and reliability under failure modes, among other factors. Within Intelligent Transportation Systems, I will work on determining factors that are involved in a traffic incident (such as human, vehicular, and environmental factors) and assigning probabilities of an incident to different situations, attempting to predict not only traffic but the likelihood of an incident. Continuing to model traffic in real-time and answer questions posed by transportation engineers will also be an emphasis of my future research. Collaborating with faculty in other departments will prove useful in this field as well, such as determining vehicle slippage, location of potholes, and engine efficiency by installing additional sensors on vehicles. The potential number of applications is endless, and researchers from different departments will add invaluably to the project.

Teaching Statement

While working on my Ph.D. in Computer Science at the University of Southern California, I was teaching as an Adjunct Professor in the Computer Science department at California State University, Los Angeles. From 2002-2007, I taught many undergraduate Computer Science courses, including Introduction to Web Site Development (CS120), Introduction to SQL and Databases (CS122), Introduction to Programming (CS201), Introduction to Object-Oriented Programming (CS202), Programming with Data Structures (CS203), C Programming (CS242), Computer Ethics in the Information Age (CS301), Algorithm Design and Analysis (CS312), Web and Internet Programming (CS320), Introduction to Automata Theory (CS386), Java for C++ Programmers (CS454 – Special Topics), Enterprise Architecture (CS454 – Special Topics, now CS420), Compilers (CS488), and Undergraduate Computer Science Wrap-Up Course (CS490). I also led a team of students in a directed study (CS499) to create a project to be used as the basis for the undergraduate compiler course. In 2002, I was voted Professor of the Year by the students in the Computer Science department, which was the first time ever a part-time lecturer had received that award. While there, I also authored the CS420 course on enterprise architecture, covering distributed computing, RMI, CORBA, Web Services, and MVC architectures (including Spring and Struts).

After completing my Ph.D. in spring 2007, I accepted a position as an Assistant Professor in the Computer Systems Engineering department at the University of Alaska Anchorage, with a workload of teaching three classes a semester (60%-20%-20% teaching-research-service workload). As the department was only three years old, I was given the ability to author many courses, including Introduction to Computer Systems (CSE 102), Introduction to C Programming for Engineers (CSE 205/294A), Object-Oriented C++ Programming for Engineers (CSE 215/294B), Assembly Language Programming (CSE 225), Operating Systems Engineering (CSE 335), Digital Circuits Design (CSE 342), Computer Networking for Engineers (CSE 355), Engineering Systems Administration (CSE 394B), Engineering of Computer Systems – Capstone Course (CSE438), VLSI Circuit Design (CSE 442), and Network Security (CSE 465). I have taught all of the above courses during my time at UAA, as well as a circuits class entitled Elements of Electrical Engineering (ES 309). I have also been the advisor for independent study courses (CSE 497) our undergraduate senior design course (CSE 438), in which groups of students develop a project from conception through implementation that encompasses the knowledge they have gained during the course of their degree. I have also been actively involved in forming the curriculum based on ABET criteria, and in 2008, 2010, and 2012, I led the Computer Systems Engineering department through successful accreditation. I was promoted to Associate Professor with tenure in summer 2011.

As for my student evaluations for the past 11 years of teaching, on a scale of 1 to 5, with 1 being the best, my average score for teaching ability is 1.62 from 1215 students in 66 classes. While at Cal State LA, the scores from the student evaluations were the top in the Computer Science department. I like to mix traditional and non-traditional teaching methods to provide students with a unique educational experience. Powerpoint slides provide a basis for many of my lectures, but I incorporate much student participation, discussions on the whiteboard, programming with an overhead projector, and diverting from the lecture notes to emphasize the topics of interest to the students. I believe that the most exciting projects for students are the ones in which they have interest, so I allow students to provide input for the projects, and in most classes I have a final project that is decided by the students (with my approval). I have had much positive feedback from that approach, as the students have chosen projects based on their own interests.

I have also had experience creating course material and curricula for many traditional and online universities. The material has included Powerpoint presentations, lecture notes for instructors, assignments, exams, multimedia presentations, and interactive lab assignments. I have also taught online classes with the American Public University System since 2009, which included developing course material and facilitating the instruction in the class. Those classes revolve around discussion boards, assignments, exams, and email. Students have a textbook and presentations that they read on their own, and then they must post to a discussion board each week, complete an assignment, and take a quiz. A lot of interaction occurs among the students, and the feedback provided by me is instrumental to the success of the online education. Without the in-person interaction that takes place in traditional brick and mortar universities, online education needs to have an open line of communication between the student and the instructor, regardless of the medium. One improvement that I think should be added to many online courses is having recorded presentations from an instructor rather than merely requiring the students to read and learn on their own. This would make the course more similar to distance education rather than online education, especially if frequent interaction with the instructor was available.

I believe that education needs to occur inside and outside of the classroom. The interaction with students during office hours and discussions after class all lead to a rich understanding of material related to the class as well as unrelated material. Some of the best student interaction I have had occurred outside of the classroom, typically during office hours or in the lab. Just as technology needs to be adapted to changing conditions, I believe that the traditional teaching paradigm should be adjusted based on the class and effectiveness of different methods of information dissemination. The goal of teaching is for students to learn, and if that occurs without formal lectures using slides, I think an instructor is still successful. I post all of my notes, slides, assignments, and syllabi online, and you can see more about my courses taught at http://www.sigmacoding.com under Teaching.

Although I enjoy teaching a wide array of courses, I feel most comfortable in teaching courses involved in networking, algorithms, general programming, compilers, software systems and engineering, and databases. I feel I am the most knowledgeable in those areas because of my research focus being in those fields as well as my professional experience, though I have a genuine passion for teaching, and I enjoy the interaction with students regardless of the course (as can be seen by the wide array of courses I have taught). Although I enjoy the research I have done, I am very interested in teaching and passing along the knowledge I have gained to future generations of computer scientists and engineers.

Education

- **Ph.D. in Computer Science, May 2007**
  University of Southern California
    - Successfully defended dissertation on April 27, 2007, with topic "Algorithms and Data Structures for the Real-Time Processing of Traffic Data" under the advisement of Professor Ellis Horowitz, Professor Petros Ioannou, and Professor Ming-Deh Huang

- **Master of Science in Computer Science, December 2002**
  University of Southern California
    - Emphasis in Systems and Software Engineering

- **Bachelor of Science in Computer Engineering and Computer Science, May 2002**
  University of Southern California
    - Graduated cum laude

Professional Affiliations

- IEEE – member since 2002
- ACM – member since 2002
- Intelligent Transportation Society of Alaska – member June 2009-December 2013
- IEEE Communications Society – member 2002-2013
- IEEE Computer Society – member since 2002
- IEEE Intelligent Transportation Systems Society – member since 2006
- IEEE Vehicular Technology Society – member 2009-2013
- IEEE Intelligent Transportation Systems Society Board of Governors – January 2009-December 2012
- IEEE Intelligent Transportation Systems Society VP Admin Activities – January 2011-December 2012
- IEEE Intelligent Transportation Systems Society Best Ph.D. Dissertation Committee – 2011, 2012, 2013
- IEEE Vehicular Technology Society Board of Governors – September 2011-December 2013
- IEEE Vehicular Technology Society Conference Committee – January 2011-December 2013
- Intelligent Transportation Society of Alaska President – January 2010-December 2011
- IEEE Alaska Section Chair – January 2011-December 2011
- IEEE Alaska Section Treasurer – January 2010-December 2010
- IEEE Region 6 Northwest Area Awards Chair – January 2012-December 2013
- IEEE-USA's Career and Workforce Policy Committee – January 2011-December 2013
- IEEE-USA's Committee on Transportation and Aerospace Policy – April 2011-December 2013
- University of Alaska, Anchorage ACM Student Chapter Faculty Advisor – 2008-2011
- Municipality of Anchorage (MOA) Anchorage Metropolitan Area Transportation Solutions (AMATS) Freight Advisory Committee – 2010-2013
- Municipality of Anchorage (MOA) Anchorage Metropolitan Area Transportation Solutions (AMATS) Intelligent Transportation Systems Advisory Committee – January 2013-December 2013

Editor-in-Chief

- *IEEE Intelligent Transportation Systems Magazine, January 2012-December 2013*

Associate Editor

- *IEEE Transactions on Intelligent Transportation Systems, January 2010-December 2013*
- *IEEE Intelligent Transportation Systems Magazine Guest Editor – Traffic Simulators, fall 2010*
- *IEEE Intelligent Transportation Systems Magazine, January 2009-December 2011*

Editorial Board

- *IEEE Intelligent Transportation Systems Society Monthly Podcast, January 2013-present*

Grant Reviewer

- *NSF Panel*, 2011 (twice)

Ph.D. Dissertation Committee Member

- *Mohammad Hoque*, University of Alabama. Defended dissertation successfully on April 25, 2012.

Expert Witness Service

- *RIAA, MPAA et al vs Kazaa, Morpheus, Grokster,* fall 2003
  Representing: RIAA, MPAA et al (plaintiff)
  Role: I aided Prof. Ellis Horowitz in preparing as an expert witness. The case involved an examination of the source code of Kazaa, written in C/C++, and Morpheus, written in Java, in an attempt to determine the extent to which the software remained in contact with the distributor (i.e. Kazaa, Morpheus). The contention being that the connection was maintained and hence Kazaa and Morpheus were in a position to restrict the downloading of copyrighted material. Prof. Horowitz filed a declaration and was deposed.
  Status: The case was settled for Kazaa, et al, reaffirmed on appeal, but decided in favor of the RIAA et al by the Supreme Court in June 2005.
- *NAVCanada vs Adacel and CAE,* fall 2007
  Representing: NAVCanada (plaintiff)
  Role: I aided Prof. Ellis Horowitz in preparing as an expert witness. NAVCanada had developed an air traffic control system for flights across the North Atlantic. They accused Adacel and CAE of copyright infringement. Prof. Horowitz's task was to determine the extent to which the Adacel/CAE software was derivative from the NAVCanada software. The software was written using C++ and Pascal.
  Status: Prof. Horowitz filed a report in the case, and the case was settled.

Journal Publication Reviewer

- *IEEE Transactions on Intelligent Transportation Systems, 2013*
- *MDPI Algorithms Journal, 2013*
- *ACM Transactions on Interactive Intelligent Systems, 2012*
- *IEEE Transactions on Intelligent Transportation Systems, 2012*
- *IEEE Transactions on Vehicular Technology, 2012*
- *Elsevier Simulation Modeling Practice and Theory, 2012*
- *IEEE Vehicular Technology Magazine, 2011*
- *IEEE Intelligent Transportation Systems Magazine, 2011*
- *IEEE Transactions on Intelligent Transportation Systems, 2011*
- *IEEE Intelligent Transportation Systems Magazine, 2010*
- *IEEE Transactions on Intelligent Transportation Systems, 2010*
- *EURASIP Journal on Advances in Signal Processing, 2009*
- *IEEE Transactions on Intelligent Transportation Systems, 2009*
- *IEEE Communications Magazine, 2009*
- *IEEE Transactions on Intelligent Transportation Systems, 2008*
- *IEEE Communications Magazine, 2008*

- *IEEE Transactions on Intelligent Transportation Systems, 2007*
- *IEEE Communications Magazine, 2007*

Conference Proceedings Reviewer

- *IEEE 16th Intelligent Transportation Systems Conference*, the Hague, the Netherlands, October 2013.
- *IEEE 78th Vehicular Technology Conference*, Las Vegas, Nevada, USA, September 2013.
- *IEEE 9th Intelligent Vehicles Symposium*, Gold Coast, Australia, June 2013.
- *IEEE International Conference on Industrial Technology*, Cape Town, South Africa, February 2013.
- *IEEE 15th Intelligent Transportation Systems Conference*, Anchorage, Alaska, USA, September 2012.
- *IEEE 76th Vehicular Technology Conference*, Quebec City, Quebec, Canada, September 2012.
- *IEEE 8th Intelligent Vehicles Symposium*, Alcala de Henares, Spain, June 2012.
- *IEEE 8th International Conference on Information, Communications, and Signal Processing*, Shangri-La, Singapore, December 2011.
- *IEEE 2011 Systems, Man, and Cybernetics Conference*, Anchorage, Alaska, USA, October 2011.
- *IEEE 74th Vehicular Technology Conference*, San Francisco, California, USA, September 2011.
- *IFAC 18th World Congress*, Milano, Italy, August 2011.
- *IEEE 7th Intelligent Vehicles Symposium*, Baden-Baden, Germany, June 2011.
- *IEEE 1st Forum on Integrated and Sustainable Transportation Systems*, Vienna, Austria, June 2011.
- *IEEE 73rd Vehicular Technology Conference*, Budapest, Hungary, May 2011.
- *IEEE 13th Intelligent Transportation Systems Conference*, Madeira, Portugal, September 2010.
- *IEEE Workshop on Vehicular Networking and Applications*, co-located with *IEEE International Conference on Communication*, Cape Town, South Africa, May 2010.
- *IEEE 13th International Multitopic Conference*, Islamabad, Pakistan, December 2009.
- *IEEE 7th International Conference on Information, Communications, and Signal Processing*, Macau, China, December 2009.
- *IEEE 12th Intelligent Transportation Systems Conference*, St. Louis, Missouri, USA, October 2009.
- *IEEE 1st Vehicular Networking Conference*, Tokyo, Japan, October 2009.
- *IEEE 70th Vehicular Technology Conference*, Anchorage, Alaska, USA, September 2009.
- *IEEE 69th Vehicular Technology Conference*, Barcelona, Spain, April 2009.
- *IEEE 3rd Workshop on Automotive Networking and Applications*, co-located with *IEEE Global Communication Conference 2008*, New Orleans, Louisiana, USA, December 2008.
- *IEEE 11th Intelligent Transportation Systems Conference*, Beijing, China, October 2008.
- *3rd International Symposium of Transport Simulation*, Queensland, Australia, August 2008.
- *IEEE 4th Vehicle-to-Vehicle Communications Workshop*, in conjunction with *IEEE 4th Intelligent Vehicles Symposium*, Eindhoven, The Netherlands, June 2008.
- *IEEE 4th Intelligent Vehicles Symposium*, Eindhoven, The Netherlands, June 2008.
- *IEEE 10th Intelligent Transportation Systems Conference*, Seattle, Washington, USA, October 2007.
- *IEEE 3rd Vehicle-to-Vehicle Communications workshop*, in conjunction with *IEEE 3rd Intelligent Vehicles Symposium*, Istanbul, Turkey, June 2007.

Conference General Chair

- *IEEE 78th Vehicular Technology Conference*, Las Vegas, Nevada, USA, September 2013.
- *IEEE 15th Intelligent Transportation Systems Conference*, Anchorage, Alaska, USA, September 2012.
- *IEEE 70th Vehicular Technology Conference*, Anchorage, Alaska, USA, September 2009.

Conference Technical Program Chair

- *IEEE 74th Vehicular Technology Conference*, San Francisco, California, USA, September 2011.

Conference Technical Program Co-Chair

- *IEEE 7th Intelligent Vehicles Symposium*, Baden-Baden, Germany, June 2011.
- *IEEE 1st Forum on Integrated and Sustainable Transportation Systems*, Vienna, Austria, June 2011.

Conference Technical Program Committee Member

- *IEEE 16th Intelligent Transportation Systems Conference*, The Hague, The Netherlands, September 2013.

- *16th Portuguese Conference on Artificial Intelligence, Artificial Intelligence in Transportation Systems Track*, Azores, Portugal, September 2013.
- *IEEE 8th International Conference on Emerging Technologies*, Islamabad, Pakistan, October 2012.
- *IEEE 15th Intelligent Transportation Systems Conference*, Anchorage, Alaska, USA, September 2012.
- *IEEE 76th Vehicular Technology Conference*, Quebec City, Quebec, Canada, September 2012.
- *IEEE 14th Intelligent Transportation Systems Conference*, Washington DC, USA, October 2011.
- *IEEE 2nd Vehicular Networking Conference*, Jersey City, New Jersey, USA, December 2010.
- *IEEE International Conference on Communications, Vehicular Mobility Workshop*, Cape Town, South Africa, May 2010.
- *IEEE International Conference on Communications Vehicular Connectivity Workshop*, Cape Town, South Africa, May 2010.
- *IEEE 1st Vehicular Networking Conference*, Tokyo, Japan, October 2009.
- *IEEE 69th Vehicular Technology Conference*, Barcelona, Spain, April 2009.
- *IEEE 4th Intelligent Vehicles Symposium Vehicle-to-Vehicle Communications Workshop*, Eindhoven, The Netherlands, June 2008.

Conference Publicity Co-Chair

- *IEEE 13th Intelligent Transportation Systems Conference*, Madeira Island, Portugal, September 2010.

Conference Local Arrangements Chair

- *IEEE Systems, Man, and Cybernetics Conference 2011*, Anchorage, Alaska, USA, October 2011.
- *IEEE International Conference on Robotics and Automation*, Anchorage, Alaska, USA, May 2010.

Conference Awards Committee Member

- *IEEE 16th Intelligent Transportation Systems Conference Best Paper Committee Member*, The Hague, The Netherlands, September 2013.
- *IEEE 6th Intelligent Vehicles Symposium*, La Jolla, California, USA, June 2010.

Conference Session Chair

- *IEEE 16th Intelligent Transportation Systems Conference*, The Hague, The Netherlands, September 2013.
- *IEEE 9th Intelligent Vehicles Symposium*, Gold Coast, Australia, June 2013.
- *IEEE Systems, Man, and Cybernetics Conference 2011*, Anchorage, Alaska, USA, October 2011.
- *IEEE 14th Intelligent Transportation Systems Conference*, Washington DC, USA, October 2011.
- *IEEE 7th Intelligent Vehicles Symposium*, Baden-Baden, Germany, June 2011.
- *IEEE 2nd Vehicular Networking Conference*, Jersey City, New Jersey, USA, December 2010.
- *IEEE 12th Intelligent Transportation Systems Conference*, St. Louis, Missouri, USA, October 2009.
- *IFAC 12th Symposium on Control in Transportation Systems*, Redondo Beach, California, USA, September 2009.
- *IEEE 5th Intelligent Vehicles Symposium*, Xi'an, China, June 2009.
- *IEEE 11th Intelligent Transportation Systems Conference*, Beijing, China, October 2008.
- *IEEE 10th Intelligent Transportation Systems Conference*, Seattle, Washington, USA, October 2007.

Special Session Organizer

- "Intelligent Vehicular Applications, Simulations, and Implementations." *IEEE Systems, Man, and Cybernetics Conference 2011*, Anchorage, Alaska, USA, October 2011.

Workshop Organizer

- "Information Fusion for Intelligent Transportation Systems." *IEEE 15th Intelligent Transportation Systems Conference*, Anchorage, Alaska, USA, September 2012. (jointly organized with Javier Sanchez Medina of the University of Las Palmas de Gran Canaria, Spain)

Patents

- Timothy Menard, Jeffrey Miller, John Lund. "Real-Time Snow Plow Tracking." Provisional Patent Application 61/709,264, filed October 3, 2012.

Other Awards and Public Recognition

- "Carros estarao conectados a internet em 2025, dizem especialistas." November 5, 2013. *Brazil Epoca*. http://epoca.globo.com/vida/vida-util/tecnologia/noticia/2013/11/quando-seu-carro-estara-bconectado-internetb-em-2025-dizem-especialistas.html
- "The Future Mode of Intelligent Transportation." October 10, 2013. *iChina*.
- "Most new cars to be Internet-enabled by 2025." September 5, 2013. *The Denver Post.* http://www.denverpost.com/technology/ci_24021259/most-new-cars-be-internet-enabled-by-2025
- "60 percent of vehicles to be Internet-enabled by 2025." Ellyne Phneah, September 2, 2013. *ZDNet.* http://www.zdnet.com/60-percent-of-vehicles-to-be-internet-enabled-by-2025-7000020107/
- "IEEE: 60 Percent of Cars Will Be Internet-Enabled by 2025." Darryl K. Taft, August 29, 2013. *eWeek*. http://www.eweek.com/innovation/ieee-60-of-cars-will-be-internet-enabled-by-2025.html
- "The Need for High Speed: IEEE Experts Predict 60 Percent of the Vehicles on the Road Will Be Internet-Enabled by 2025." August 28, 2013. *PR News Wire article includes quotations from me.* http://www.prnewswire.com/news-releases/the-need-for-high-speed-ieee-experts-predict-60-percent-of-the-vehicles-on-the-road-will-be-internet-enabled-by-2025-221479981.html
- IEEE Vehicular Technology Society Conference Award for my leadership in the IEEE Vehicular Technology Conference-fall 2011 in San Francisco, California. September 3, 2013.
- "Vehicular Technology Conference Focuses on Wireless." July 8, 2013. IEEE The Institute article includes quotations from me. http://theinstitute.ieee.org/benefits/conferences/vehicular-technology-conference-focuses-on-wireless
- *IEEE Alaska Section 2013 Outstanding Leadership and Professional Service Award*, IEEE Alaska Section, 2013.
- "Major Road Blocks Linger, But Driverless Cars Are Here to Stay." July 5, 2013. *Fox Business article includes quotations from me.* http://www.foxbusiness.com/industries/2013/07/03/major-road-blocks-linger-but-driverless-cars-are-here-to-stay/
- Informania Interview on KRUA. May 16, 2013. Discussion about K12 summer camps and Intelligent Transportation Systems research. http://www.kruaradio.org/infomania-dr-miller-interview/
- "The Impact of Driverless Technology and Autonomous Cars." March 26, 2013. Written by Rebekah Coleman. Loans.org article includes quotations from me. http://loans.org/auto/articles/driverless-technology-autonomous-cars
- Nominated for "2013 White House Champions of Change – Transportation Technology Solutions for the 21st Century." March 26, 2013.
- "Intelligent Transportation Careers Speed Ahead." March 2013. Today's Engineer *Career Focus* article includes quotations from me. http://www.todaysengineer.org/2013/Mar/career-focus.asp
- Who Wants to Be a Millionaire? – A question on the show that aired on February 27, 2013 featured the IEEE from the articles below published about driverless cars by 2040. 4th Question – "With self-drviing cars expected to become the norm, the Institute of Electrical and Electronics Engineers predicts that by 2040, drivers will no longer need what?" Answer – Driver's licenses.
- NPR Southern California Radio Interview – "AirTalk with Larry Mantle." 89.3 KPCC, 89.1 KUOR, 90.3 KVLA. September 25, 2012. Discussion about Governor Larry Brown signing bill allowing self-driving cars in California. http://www.scpr.org/programs/airtalk/2012/09/26/28581/governor-brown-paves-the-road-for-hands-free-drivi/ Actual radio segment - http://www.scpr.org/programs/airtalk/2012/09/26/
- QR77 Radio Interview – "The Rob Breckinridge Show." September 21, 2012. Lead story for the show was on driverless vehicles.
- "You won't need a driver's license by 2040." September 18, 2012. CNN article includes quotations from me. http://www.cnn.com/2012/09/18/tech/innovation/ieee-2040-cars/index.html
- "You won't need a driver's license by 2040." September 17, 2012. Wired.com article includes quotations from me. http://www.wired.com/autopia/2012/09/ieee-autonomous-2040/
- "How Self-Driving Cars Will Change Transportation." September 10, 2012. MSN.com Autos article includes quotations from me. http://editorial.autos.msn.com/blogs/autosblogpost.aspx?post=fd1dd24a-7eea-4a00-8a97-dd7c3aab7a1c
- "Look Ma, No Hands! Expert Members of IEEE Identify Driverless Cars As Most Viable Form of Intelligent Transportation Dominating the Roadway by 2040 and Sparking Dramatic Changes in Vehicular Travel." September 5, 2012. PR Newswire article includes quotations from me. http://www.prnewswire.com/news-releases/look-ma-no-hands-168623236.html

- "Look Ma, No Hands!" September 2, 2012. IEEE News Release includes quotations from me. http://www.ieee.org/about/news/2012/5september_2_2012.html
- "Jeff Miller and ITS Help Anchorage Address a National Dilemma." *Transportation Communications Newsletter*, April 25, 2012, ISSN 1529-1057.
- *University of Alaska Anchorage Office of Undergraduate Research and Scholarship Faculty Mentor Award*, based on being the Faculty Mentor to a student who won an Undergraduate Research and Scholarship Award for Research, April 2012.
- *Alaska University Transportation Center Spotlight Column*, based on my research in Intelligent Transportation Systems in Alaska, March 2012.
- *IEEE Intelligent Transportation Systems Magazine Editor-in-Chief's Column*, announcing me as the incoming Editor-in-Chief of the ITS Magazine, winter 2011.
- *IEEE Region 6 Northwest Area Outstanding Section Award 2011*, IEEE Alaska Section while I was the chair of the section in 2011.
- *University of Alaska Anchorage School of Engineering Spring 2011 Engineering Competition Faculty Advisor*, based on being the Faculty Advisor to a student whose project won the Engineering Competition, April 2011.
- *University of Alaska Anchorage Office of Undergraduate Research and Scholarship Faculty Mentor Award*, based on being the Faculty Mentor to a student who won an Undergraduate Research and Scholarship Award for Research, April 2011.
- *Sustainable City Network Article by Randy Rodgers*, April 20, 2011. http://www.sustainablecitynetwork.com/topic_channels/transportation/article_ca00cf16-69db-11e0-9b0e-001a4bcf6878.html?mode=story
- *Anchorage Convention and Visitors Bureau Seymour Award Winner 2011*, based on being the Annual Meeting Champion from 2010.
- *University of Alaska Anchorage School of Engineering Fall 2010 Engineering Competition Faculty Advisor*, based on being the Faculty Advisor to a student whose project won the Engineering Competition, December 2010.
- *Anchorage Convention and Visitors Bureau Meeting Champion*, October 2010, based on the conferences I have aided in bringing to Anchorage having an economic impact of $3,157,341.94.
- Poster Honorable Mention (given to top 5 out of 250 posters), "Determining Time to Traverse Road Sections based on Mapping Discrete GPS Vehicle Data to Continuous Flows." *IEEE 6th Intelligent Vehicles Symposium*, La Jolla, California, USA, June 2010.
- *Professor of the Year of Computer Science* at California State University, Los Angeles in 2002 based on student votes. I was the first lecturer ever to be given this award.

Conferences Attended

- *IEEE 78th Vehicular Technology Conference*, Las Vegas, Nevada, USA, September 2013.
- *IEEE 9th Intelligent Vehicles Symposium*, Gold Coast, Queensland, Australia, June 2013.
- *IEEE 4th Vehicular Networking Conference*, Seoul, South Korea, November 2012.
- *ITS Alaska Annual Meeting*, Anchorage, Alaska USA, October 2012.
- *IEEE 15th Intelligent Transportation Systems Conference*, Anchorage, Alaska, USA, September 2012.
- *IEEE 8th Intelligent Vehicles Symposium*, Alcala de Hernares, Spain, June 2012.
- *IEEE 75th Vehicular Technology Conference*, Yokohama, Japan, May 2012.
- *IEEE Panel of Editors Meeting*, San Francisco, California, USA, April 2012.
- *IEEE 3rd Vehicular Networking Conference*, Amsterdam, The Netherlands, November 2011.
- *ITS Alaska Annual Meeting*, Anchorage, Alaska USA, October 2011.
- *IEEE Systems, Man, and Cybernetics Conference*, Anchorage, Alaska, USA, October 2011.
- *IEEE 14th Intelligent Transportation Systems Conference*, Washington DC, USA, October 2011.
- *IEEE 74th Vehicular Technology Conference*, San Francisco, California, USA, September 2011.
- *ITE Western District Annual Meeting*, Anchorage, Alaska, USA July 2011.
- *IEEE 73rd Vehicular Technology Conference*, Budapest, Hungary, May 2011.
- *American Planning Association's National Planning Conference*, Boston, Massachusetts, USA, April 2011.
- *IEEE 2nd Vehicular Networking Conference*, Jersey City, New Jersey, USA, December 2010.
- *ITS Alaska Annual Meeting*, Fairbanks, Alaska, USA, October 2010.

- *Alaska Community Transportation Transit Conference*, Fairbanks, Alaska, USA, October 2010.
- *IEEE 13th Intelligent Transportation Systems Conference*, Madeira Island, Portugal, September 2010.
- *IEEE 6th Intelligent Vehicles Symposium*, La Jolla, California, USA, June 2010.
- *IEEE International Conference on Robotics and Automation*, Anchorage, Alaska, USA, May 2010.
- *Maintenance Decision Support System Product Showcase*, Anchorage, Alaska, USA, April 2010.
- *Arctic Ice and Snow Roads 2010 Conference*, Anchorage, Alaska, USA, March 2010.
- *IEEE 12th Intelligent Transportation Systems Conference*, St. Louis, Missouri, USA, October 2009.
- *IEEE 70th Vehicular Technology Conference*, Anchorage, Alaska, USA, September 2009.
- *IFAC Symposium on Control Systems*, Redondo Beach, California, USA, September 2009.
- *IEEE 69th Vehicular Technology Conference*, Barcelona, Spain, April 2009.
- *IEEE 6th Consumer Communication and Networking Conference*, Las Vegas, Nevada, USA, January 2009.
- *IEEE 4th Intelligent Vehicles Symposium*, Eindhoven, The Netherlands, June 2008.
- *IEEE 10th Intelligent Transportation Systems Conference*, Seattle, Washington, USA, October 2007.
- *IEEE 3rd Intelligent Vehicles Symposium*, Istanbul, Turkey, June 2007.
- *IEEE 29th International Conference on Software Engineering*, Minneapolis, Minnesota, USA, May 2007.
- *IEEE 9th Intelligent Transportation Systems Conference*, Toronto, Ontario, Canada, September 2006.
- *ITS America Conference*, Phoenix, Arizona, USA, May 2005.
- *IEEE 1st Consumer Communication and Networking Conference*, Las Vegas, Nevada, USA, January 2004.

Awards Received by Students Advised

- Lowell Perry. *Office of Undergraduate Research and Scholarship (OURS)* for "ATV Remote Monitoring System," fall 2013. $2500
- Wolfram Donat. *Office of Undergraduate Research and Scholarship (OURS) Discovery Award* for "Computer Vision for Vehicular Robotics," spring 2013. $250
- Vex Robotics High School World Competition Participant, April 2013. As a regional winner, we were invited to participate in the world competition.
- Vex Robotics High School Region Competition Winner, March 2013. I advised a group of four high school students to participate in the competition.
- Jacob Wingerd. *Office of Undergraduate Research and Scholarship (OURS)* for "Digital Snow Plow Monitoring for User Navigation Purposes," fall 2012, $1900.
- Timothy Menard, 2nd Place, *IEEE 2012 Region 6 Paper Competition*, September 2012. $500
- Wolfram Donat. *Office of Undergraduate Research and Scholarship (OURS)* for "Computer Vision for Vehicular Robotics," spring 2012. $2000
- Timothy Menard. Admitted to University of Nevada, Las Vegas, Master's program in Electrical and Computer Engineering, fall 2012.
- Timothy Menard. Internship with Toyota InfoTechnology, Mountain View, California, summer 2012.
- Timothy Menard, *USUAA Leadership Award*, spring 2012. $1000
- Timothy Menard, BP 1st Place Award, *University of Alaska Anchorage School of Engineering Spring 2012 Design Competition*, spring 2012. $300
- Timothy Menard, Society of Women Engineers Community Engagement Award, *University of Alaska Anchorage School of Engineering Spring 2012 Design Competition*, spring 2012. $50
- Timothy Menard, 1st Place, *IEEE Spring 2012 Northwest Area Paper Competition*, April 2012. $750
- Timothy Menard. 1st Place, *IEEE UAA Student Branch Spring 2012 Paper Competition*. (moved onto IEEE Spring 2012 Northwest Area Paper Competition), March 2012.
- Timothy Menard. *UAA Leadership Honors*, spring 2012.
- Timothy Menard. *Society of American Military Engineers Scholarship – Anchorage Post*, 2011. $750
- Timothy Menard. *University of Alaska Anchorage School of Engineering Scholarship*, fall 2011. $500
- Timothy Menard. *UAA University Honors College Discovery Grant* to attend IEEE Intelligent Transportation Systems Conference, Washington DC, October 2011. $1000
- Timothy Menard. Internship with Toyota InfoTechnology, Mountain View, California, summer 2011.
- Timothy Menard. 1st Place, "FreeSim_Mobile: iPhone vs Android." *University of Alaska Anchorage School of Engineering Spring 2011 Design Competition.* $3000

- Timothy Menard. *USUAA Student Travel Grant* to attend IEEE Intelligent Vehicles Symposium in Baden-Baden, Germany, spring 2011. $850
- Timothy Menard. 2nd Place, *IEEE Spring 2011 Northwest Area Paper Competition*, April 2011. $500
- Timothy Menard. 1st Place, *IEEE UAA Student Branch Spring 2011 Paper Competition*. (moved onto IEEE Spring 2011 Northwest Area Paper Competition), March 2011.
- Timothy Menard. *USUAA Student Travel Grant* to attend IEEE Intelligent Vehicles Symposium in San Diego, California, spring 2010. $750
- Timothy Menard. 1st Place, "FreeSim_Mobile." *University of Alaska Anchorage School of Engineering Fall 2010 Design Competition.* $3000
- Timothy Menard. *Office of Undergraduate Research and Scholarship (OURS)* for FreeSim_Mobile, fall 2010. $1000

Presentations – NOTE: This list does not include presentations associated with publications at conferences. All of the papers published at conferences had associated presentations.

58. Miller, Jeffrey. "Are Computer Engineers and Computer Scientists Real Engineers?" *University of Alaska Anchorage Fall 2013 Preview Day*, Anchorage, Alaska, USA, November 15, 2013.

57. Miller, Jeffrey. "IEEE Intelligent Transportation Systems Society Magazine Editor-in-Chief Report." *IEEE Intelligent Transportation Systems Society Board of Governors and Executive Committee Meeting*, The Hague, The Netherlands, October 5-6, 2013.

56. Miller, Jeffrey. "ITS in Alaska and K12 STEM Robotics Competition." *ITE Alaska October 2013 Member Luncheon*, Anchorage, Alaska, USA, October 1, 2013.

55. Miller, Jeffrey. "IEEE 78th Vehicular Technology Conference" Welcome Address. *Presentation at IEEE 78th Vehicular Technology Conference*, Las Vegas, Nevada, USA, September 3, 2013.

54. Miller, Jeffrey. "IEEE Intelligent Transportation Systems Society Magazine Editor-in-Chief Report." *IEEE Intelligent Transportation Systems Society Board of Governors and Executive Committee Meeting*, Gold Coast, Queensland, Australia, June 23, 2013.

53. Miller, Jeffrey. "2013 Vex Robotics World Competition Recap." *IEEE Alaska Section May Member Luncheon*, May 15, 2013.

52. Miller, Jeffrey. "Intelligent Transportation System Projects in Alaska and Beyond." *IEEE Alaska Section March Member Luncheon*, March 20, 2013.

51. Miller, Jeffrey. "IEEE Intelligent Transportation Systems Society Magazine Editor-in-Chief Report." *IEEE Intelligent Transportation Systems Society Executive Committee Meeting*, New Orleans, Louisiana, USA, February 9, 2013.

50. Miller, Jeffrey (presented by Dave Butcher). "IEEE Northwest Area Awards Summary." *IEEE Region 6 Annual Meeting*, Las Vegas, Nevada, USA, February 2, 2013.

49. Miller, Jeffrey (presented by Joe Decuir). "IEEE Northwest Area Awards." *IEEE Fall 2012 Northwest Area Meeting*, Seattle, Washington, USA, October 20, 2012.

48. Miller, Jeffrey. "IEEE Intelligent Transportation Systems Society Magazine Editor-in-Chief Report." *IEEE Intelligent Transportation Systems Society Board of Governors and Executive Committee Meeting*, Anchorage, Alaska, USA, September 15, 2012.

47. Miller, Jeffrey. "IEEE Intelligent Transportation Systems Society VP Administrative Activities Report." *IEEE Intelligent Transportation Systems Society Board of Governors and Executive Committee Meeting*, Anchorage, Alaska, USA, September 15, 2012.

46. Miller, Jeffrey (presented by Alex Wyglinski). "IEEE 78th Vehicular Technology Conference." *Presentation at IEEE 76th Vehicular Technology Conference*, Quebec City, Quebec, Canada, September 5, 2012.

45. Miller, Jeffrey. "Intelligent Transportation System Projects in Heterogeneous Connectivity Environments." *Alaska Department of Transportation Quarterly Design Meeting*, July 31, 2012.

44. Miller, Jeffrey. "Vehicle-to-Infrastructure Design and Applications in Disconnected Environments." *Universitas Miguel Hernandez*, Elche, Spain, June 11, 2012.

43. Miller, Jeffrey. "IEEE Intelligent Transportation Systems Society Magazine Editor-in-Chief Report." *IEEE Intelligent Transportation Systems Society Board of Governors Executive Committee Meeting*, Alcala de Henares, Spain, June 7, 2012.

42. Miller, Jeffrey. "IEEE Intelligent Transportation Systems Society VP Administrative Activities Report." *IEEE Intelligent Transportation Systems Society Board of Governors and Executive Committee Meeting*, Alcala de Henares, Spain, June 7, 2012.

41. Miller, Jeffrey. "Design of Vehicular Ad-Hoc Networks (VANETs) and Applications in Disconnected Environments." *University of Alabama*, Tuscaloosa, Alabama, USA, April 27, 2012.

40. Miller, Jeffrey (presented by Joe Decuir). "IEEE Northwest Area Awards." *IEEE Spring 2012 Northwest Area Meeting*, Spokane, Washington, USA, April 14, 2012.

39. Miller, Jeffrey. "IEEE Intelligent Transportation Systems Society Magazine Editor-in-Chief Report." *IEEE Intelligent Transportation Systems Society Executive Committee Meeting*, Atlanta, Georgia, USA, February 11, 2012.

38. Miller, Jeffrey. "IEEE Intelligent Transportation Systems Society VP Administrative Activities Report." *IEEE Intelligent Transportation Systems Society Executive Committee Meeting*, Atlanta, Georgia, USA, February 11, 2012.

37. Miller, Jeffrey. "Intelligent Transportation Systems Projects in Alaska." *Municipality of Anchorage AMATS January 2012 Meeting*, Anchorage, Alaska, USA, January 12, 2012.

36. Miller, Jeffrey. "IEEE Alaska Report." *IEEE Fall 2011 Northwest Area Meeting*, Portland, Oregon, USA, October 15, 2011.

35. Miller, Jeffrey. *Introduction to Banquet Entertainment – IEEE Systems, Man, and Cybernetics Conference*, Anchorage, Alaska, USA, October 11, 2011.

34. Miller, Jeffrey. "IEEE Intelligent Transportation Systems Society VP Administrative Activities Report." *IEEE Intelligent Transportation Systems Society Board of Governors and Executive Committee Meeting*, Washington DC, USA. October 8, 2011.

33. Miller, Jeffrey. "IEEE 14th Intelligent Transportation Systems Conference." *Presentation at IEEE 13th Intelligent Transportation Systems Conference*, Washington DC, USA, October 6, 2011.

32. Miller, Jeffrey. *IEEE Alaska Section Award Banquet Master of Ceremony*, Anchorage, Alaska, September 17, 2011.

31. Miller, Jeffrey. "Academic Profession and Intelligent Transportation Systems Research." *Guest Lecture – Engineering Seminar (ENGR 192/292)*, University of Alaska Anchorage, September 13, 2011.

30. Miller, Jeffrey. "IEEE 74th Vehicular Technology Welcome Message." *IEEE 74th Vehicular Technology Conference*, San Francisco, California, September 6, 2011.

29. Miller, Jeffrey. "Using Vehicle Probes for Accurate Travel Time Estimation." *Institute of Transportation Engineers (ITE) Western District Annual Meeting*, Anchorage, Alaska, July 13, 2011.

28. Miller, Jeffrey. "IEEE 74th Vehicular Technology Conference." *Presentation at IEEE 73rd Vehicular Technology Conference*, Budapest, Hungary, May 16, 2011.

27. Miller, Jeffrey. *Engineering Graduation Luncheon*, Anchorage, Alaska, April 21, 2011.

26. Miller, Jeffrey. *Acceptance of Anchorage Convention and Visitors' Bureau Seymour Award (Meeting Champion of the Year, 2011)*, Anchorage, Alaska, April 15, 2011.

25. Miller, Jeffrey. "UAA Engineering Programs." *BP Explorers' Visit to UAA School of Engineering*, Anchorage, Alaska, April 12, 2011.

24. Miller, Jeffrey, Teresa Brewer. "Real-Time Freight Tracking using GPS and Cellular Transceivers for Transportation and Community Planning." *American Planning Association 2011 National Planning Conference*, Boston, Massachusetts, April 9, 2011.

23. Miller, Jeffrey. "IEEE Alaska Report." *IEEE Spring 2011 Northwest Area Meeting*, Richland, Washington, April 2, 2011.

22. Miller, Jeffrey. "Distributed Real-Time Vehicular Data Gathering through a Vehicle-to-Infrastructure Network in Anchorage." *University of Alaska Anchorage, Complex Systems Lecture*, Anchorage, Alaska, March 25, 2011.

21. Miller, Jeffrey. "IEEE Intelligent Transportation Systems Society VP Administrative Activities Report." *IEEE Intelligent Transportation Systems Executive Committee Meeting*, Orlando, Florida, February 5, 2011.

20. Miller, Jeffrey. "Fundamentals of Engineering Exam Review – Computers." *University of Alaska, Anchorage School of Engineering FE Refresher Series, Fall 2010*, University of Alaska, Anchorage, October 21, 2010.

19. Miller, Jeffrey. "Real-Time Data Collection through ITS Architectures in Anchorage." *Alaska Community Transportation Conference, ITS Alaska Annual Meeting*, Fairbanks, Alaska, October 6, 2010.

18. Miller, Jeffrey. "IEEE 14th Intelligent Transportation Systems Conference." *Presentation at IEEE 12th Intelligent Transportation Systems Conference*, Madeira Island, Portugal, September 22, 2010.

17. Miller, Jeffrey (presented by James Irvine). "IEEE 74th Vehicular Technology Conference." *Presentation at IEEE 72nd Vehicular Technology Conference*, Ottawa, Canada, September 7, 2010.

16. Miller, Jeffrey. "Anchorage Real-Time Traffic Gathering and Distribution." *Intelligent Transportation Society of Alaska Membership Meeting*, Anchorage, Alaska, July 13, 2010.

15. Miller, Jeffrey. "FreeSim Overview and Current Status." *Pangomedia Developer Meeting*, Anchorage, Alaska, May 14, 2010.

14. Miller, Jeffrey. "Determining Real-Time Flow of Traffic in Anchorage using Vehicle Probes." *Anchorage Freight Advisory Committee Meeting*, Municipality of Anchorage, Alaska, April 12, 2010.

13. Miller, Jeffrey. Welcome Speech for *Arctic Ice and Snow Roads 2010 Conference*, Anchorage, Alaska, March 30, 2010.

12. Miller, Jeffrey. "Fundamentals of Engineering Exam Review – Computers." *University of Alaska, Anchorage School of Engineering FE Refresher Series, Spring 2010*, University of Alaska Anchorage, March 25, 2010.

11. Miller, Jeffrey. "IEEE 70th Vehicular Technology Conference Welcome Message." *IEEE 70th Vehicular Technology Conference*, Anchorage, Alaska, September 21, 2009.

10. Miller, Jeffrey. "IEEE 70th Vehicular Technology Conference." *Presentation at IEEE 69th Vehicular Technology Conference*, Barcelona, Spain, April 28, 2009.

9. Miller, Jeffrey. "Dynamic Intelligent Transportation Systems." *Guest Lecture – American Indian Science and Engineering Society (AISES)*, University of Alaska Anchorage, April 3, 2009.

8. Miller, Jeffrey. "Fundamentals of Engineering Exam Review – Computers." *University of Alaska, Anchorage School of Engineering FE Refresher Series, Spring 2009*, University of Alaska Anchorage, March 31, 2009.

7. Miller, Jeffrey. "Fundamentals of Engineering Exam Review – Computers." *University of Alaska, Anchorage School of Engineering FE Refresher Series, Fall 2008*, University of Alaska Anchorage, October 23, 2008.

6. Miller, Jeffrey. "Jeffrey Miller's Current Research." *Bachelor of Science in Engineering Faculty Research Seminar*, University of Alaska Anchorage, October 14, 2008.

5. Miller, Jeffrey. "Career in Computer and Software Engineering." *Guest Lecture – Engineering Seminar (ENGR 192/292)*, University of Alaska Anchorage, September 30, 2008.

4. Miller, Jeffrey. "E-Week – Exciting Era of Engineering." *E-Week Presentation*, Bartlett High School, Anchorage, Alaska, February 13, 2008.

3. Miller, Jeffrey. "Intelligent Transportation Systems." *Guest Lecture – Transportation Engineering (CE 402)*, University of Alaska Anchorage, October 24, 2007.

2. Miller, Jeffrey. "A Future in Computer Science." *Guest Lecture for IEEE Student Chapter*, California State University, Los Angeles, November 14, 2002.

1. Miller, Jeffrey. "Web Services." *Directed Research Project (CS 590)*, University of Southern California, April 2002.

Professional Course Development

32. Rasmussen College, Computer Science Program Curriculum, September 2013.

31. Rasmussen College, Web Developer Program Curriculum, February 2013.

30. Rasmussen College, Software Application Developer Program Curriculum, February 2013.

29. Rasmussen College, Software Engineering Program Curriculum, January 2013.

28. Charter College, Project Management (PM4799), October 2012.

27. Everest College, CompTIA A+ (ITSS1004, ITSS2001, ITSS3001), October 2012.

26. ITT, Project Management for Information Technology (PM3440), October 2012.

25. ITT, Email and Web Services (NT2670), October 2012.

24. Strayer University, C++ Development (unknown course number), July 2012.
23. Columbia Southern University, Data Analytics (ITC12A), May 2012.
22. Education Affiliates, Windows Server Network Resources (CNS160), May 2012.
21. Education Affiliates, Windows Server Network Infrastructure (CNS150), May 2012.
20. Education Affiliates, Help Desk Support (CNS135), May 2012.
19. ITT, Managing Software Development Projects (PM4540), January 2012.
18. ITT, Project Management for Information Technology (PM3140), December 2011.
17. Everest Colleges, Institutes, and Universities, Basic Computing (ITSS2001), November 2011.
16. ITT, 3D Modeling Techniques (GC1330), September 2011.
15. ITT, Physical Networking (NT1310), September 2011.
14. ITT/ESI, Web Programming in VB.NET (WT1220), July 2011.
13. ITT/ESI, Systems Analysis (PM3140), May 2011.
12. International Education Corporation, System Architecture CompTIA A+ (CT2009-110), April 2010.
11. International Education Corporation, Windows Applied Computing CompTIA A+ (CT2009-120), April 2010.
10. Walden/Laureate University, Computer Forensics (CMIS 4104), August 2009.
9. Walden/Laureate University, Information Security Techniques II (CMIS 4103), May 2009.
8. Walden/Laureate University, Information Security and Privacy (CMIS 4101), March 2009.
7. International Education Corporation, Network Architecture (Module D in Computer Systems Technician Program), November 2008.
6. International Education Corporation, Client Operating Systems (Module E in Computer Systems Technician Program), November 2008.
5. Strayer University, System Modeling Theory (CIS212), September 2008.
4. Strayer University, Data Warehousing Systems (CIS522), September 2008.
3. Baker College, Internet and Web Security (ITS405), August 2008.
2. Strayer University, Java Programming II (CIS407), August 2007.
1. Westwood College, Compiler and Interpreter Design (SG400), July 2006.

Professional Training

1. State of Alaska, Department of Natural Resources, “AJAX for Java Developers”, March 2009.

Grants Received

Total funding as PI/Co-PI since spring 2008 - **$951,117.41**
Total funding as team member since spring 2008 - **$120,000**
Total funding pending - **$0**

37. IEEE Foundation Grant – “K12 STEM Outreach in Computer and Electrical Engineering.” July 1, 2013-August 31, 2013. $19,680, PI

36. Vex Robotics High School World Competition, funded by UAA’s School of Engineering, UAA’s Computer Science and Engineering department, Visit Anchorage, IEEE Alaska, and ITE Alaska. $7500, PI

35. BP – Robotics, Alternative Energy, and Structure Destruction Summer Camp Initiative for Pre-College Students. May 1, 2013-August 15, 2013. $80,000, PI

34. Municipality of Anchorage – “Freight Vehicle Tracking for Real-Time Freight Route Origin-Destination Data.” December 2012-December 2013. $5,000, PI

33. Vex Robotics – “RECF/VEX Robotics Competition Grant.” November 2012-February 2013. $1233.95, PI

32. University of Alaska Anchorage, Faculty Development Grant – “Test Bed for Robotic Driverless Transportation of Goods and Medical Supplies in Remote Areas.” January 2013-June 2013. $2147, PI

31. University of Alaska Anchorage Faculty Leadership in Expanding Undergraduate Research (FLEUR) – “Security in Mobile and Vehicular Ad Hoc Networks (MANET/VANET).” August 2014-December 2014. $4,913.89, PI

30. Personal Grant – Online Researching for Proprietary Project. July 15, 2012-December 31, 2013. $900, PI

29. University of Alaska, Research Travel Grant – IEEE Vehicular Technology Conference-fall 2012, Quebec City, Quebec, Canada. September 3-7, 2012. $580.20, PI

28. University of Alaska, Faculty Development Grant – “Disconnected Vehicular Ad Hoc Network Robotic Hardware Test Platform.” July 1, 2012-December 31, 2012. $2,853, PI

27. Visit Anchorage (formerly Anchorage Convention and Visitors’ Bureau) Funding for Student Internship. February 2012-October 2012. $3,750, PI

26. GCI – Cellular Data Plan for Vehicle Tracking at UAA. November 2011-?. $750/month, PI

25. BP – Robotics, GPS Tracking, and Rapid Prototyping Summer Camp Initiative for Middle and High School Students. May 1, 2012-August 15, 2012. $80,000, PI

24. BP – Robotics, GPS Tracking, and Rapid Prototyping Summer Camp Initiative for Middle and High School Students. May 1, 2011-August 15, 2011. $80,000, PI

23. Alaska University Transportation Center – “Information Gathering Infrastructure towards Intelligent Transportation.” August 1, 2011-December 31, 2012. $85,000, PI

22. University of Alaska, Anchorage – “Information Gathering Infrastructure towards Intelligent Transportation.” August 1, 2011-December 31, 2012. $85,000, PI

21. Alaska University Transportation Center – “Gathering of Vehicular Parameters in a Vehicle-to-Infrastructure Intelligent Transportation System.” August 1, 2010-December 31, 2011. $99,546, PI

20. University of Alaska, Anchorage – “Gathering of Vehicular Parameters in a Vehicle-to-Infrastructure Intelligent Transportation System.” August 1, 2010-December 31, 2011. $99,611, PI

19. University of Alaska, Faculty Development Grant – “Determining Time to Traverse and Origin-Destination Matrices using Probe Vehicles.” July 1, 2010-December 31, 2010. $4500, PI

18. Alaska University Transportation Center – “Assessment of Traffic Congestion in Anchorage Utilizing Vehicle-Tracking Devices and Intelligent Transportation System Technology.” August 1, 2009-July 30, 2011. $84,639, PI

17. University of Alaska, Anchorage – “Assessment of Traffic Congestion in Anchorage Utilizing Vehicle-Tracking Devices and Intelligent Transportation System Technology.” August 1, 2009-July 30, 2011. $72,252, PI

16. Alaska Natives in Science and Engineering Program (ANSEP) Grant – “Assessment of Traffic Congestion in Anchorage Utilizing Vehicle-Tracking Devices and Intelligent Transportation System Technology.” August 1, 2009-July 30, 2011. $12,394, PI

15. United States Department of Energy Grant – “A First Assessment of U.S. In-Stream Hydrokinetic Energy Resources since the 1986 NYU Study.” January 10, 2010-June 30, 2011. $120,000, Team Member

14. University of Alaska, Anchorage, Engineering K-12 Outreach, Bridging, and Summer Camps – “UAA School of Engineering Summer Robotics/Mechatronics Workshop and Competition.” May 1, 2010-May 31, 2010. $59,996, Co-PI

13. Alaska Natives in Science and Engineering Grant – “UAA School of Engineering Summer Robotics/Mechatronics Workshop and Competition.” May 1, 2010-May 31, 2010. $30,000, Co-PI

12. University of Alaska, Faculty Development Grant – “Distributed Vehicle Gathering for Intelligent Transportation System Applications”, July 1, 2009-December 31, 2009. $4500, PI

11. University of Alaska, Research Travel Grant – IFAC Symposium on Control of Transportation Systems, Redondo Beach, California, USA, September 2009. $400.38, PI

10. University of Alaska, Special United Academics Research Travel Grant – IEEE 69th Vehicular Technology Conference, Barcelona, Spain, April 26-29, 2009. $500, PI

9. Xilinx University Program Donation – 5 Digilent Inc. Spartan 3E FPGA Boards for Digital Circuits Design course (CSE342). April 2009. $745, Recipient

8. University of Alaska, Special United Academics Research Travel Grant – IEEE Intelligent Vehicles Symposium, Xi’an, China. June 3, 2009-June 6, 2009. $1000, PI

7. University of Alaska, Research Travel Grant – “Presentation of Alaska Intelligent Transportation Systems.” University of Southern California, Los Angeles, California, March 2009. $409.83, PI

6. Alaska Natives in Science and Engineering Program (ANSEP) Grant – “Acquisition and Analysis of Vehicular Tracking Technology in Anchorage.” January 1, 2009-December 31, 2009. $10,000, PI

5. University of Alaska, Faculty Development Grant – “Determination of Probabilities of Factors in Vehicle Crashes using Intelligent Transportation Systems.” July 1, 2008-December 31, 2008. $4500, PI

4. University of Alaska, Research Travel Grant – IEEE Intelligent Transportation Systems Conference 2008, Beijing, China. October 12, 2008-October 15, 2008. $316.16, PI

3. Alaska University Transportation Center – Additional support for IEEE 4th International Intelligent Vehicles Symposium, Eindhoven, The Netherlands. June 3, 2008-June 6, 2008. $2000, Recipient

2. University of Alaska, Faculty Development Grant – "Algorithms and Data Structures for the Application of a Super-Vehicle in a Hybrid Vehicle-to-Vehicle-to-Infrastructure (V2V2I) Mobile Ad-Hoc Network (MANET) Architecture." January 1, 2008-June 30, 2008. $4500, PI

1. University of Alaska, Special United Academics Research Travel Grant – IEEE Intelligent Vehicle Symposium 2008, Eindhoven, The Netherlands. June 3, 2008-June 6, 2008. $750, PI

Refereed Journal/Magazine Publications

3. *Under Review*. Miller, Jeffrey. "Determining Continuous Traffic Flow from Discrete Vehicle GPS Data." IEEE Transactions on Intelligent Transportation Systems, fall 2013.

2. *Under Review*. Miller, Jeffrey. "Overview and Analysis of Intelligent Transportation Systems Traveling Salesman Problem (ITS-TSP)." IEEE Transactions on Intelligent Transportation Systems, fall 2013.

1. Miller, Jeffrey. "Dynamically Computing Fastest Paths for Intelligent Transportation Systems." IEEE Intelligent Transportation Systems Magazine, Volume 1, Number 1, spring 2009.

Refereed Conference Publications – NOTE: All of the papers that were published in conference proceedings had associated presentations at the respective conference.

22. Smith, Kristian, Jeffrey Miller. "OBDII Data Logger Design for Large-Scale Deployments." *IEEE 16th Intelligent Transportation Systems Conference*, The Hague, The Netherlands, October 2013.

21. Menard, Timothy, John Lund, Jeffrey Miller, Todd Petersen. "907-Plow – Anchorage's Approach to Real-Time Snowplow Tracking." *IEEE 15th Intelligent Transportation Systems Conference*, Anchorage, Alaska, USA, September 2012.

20. Miller, Jeffrey, Wolfram Donat, John Harris. "Signal Timing for Fleeting Multiple Intersecting Roadways." *IEEE 15th Intelligent Transportation Systems Conference*, Anchorage, Alaska, USA, September 2012.

19. Enriquez, D.J., Alex Bautista, Paloma Field, Sun-il Kim, Sean Jensen, Muhammad Ali, Jeffrey Miller. "CANOPNR: CAN-OBD Programmable-Expandable Network-Enabled Reader for Real-Time Tracking of Slippery Road Conditions using Vehicular Parameters." *IEEE 15th Intelligent Transportation Systems Conference*, Anchorage, Alaska, USA, September 2012.

18. Menard, Timothy, Jeffrey Miller, Michael Nowak, David Norris. "Comparing the GPS Capabilities of the Samsung Galaxy S, Motorola Droid X, and the Apple iPhone for Vehicle Tracking using FreeSim_Mobile." *IEEE 14th Intelligent Transportation Systems Conference*, Washington DC, USA, October 2011.

17. Menard, Timothy, Jeffrey Miller. "Comparing the GPS Capabilities of the iPhone 4 and iPhone 3GS for Vehicle Tracking using FreeSim_Mobile." *IEEE 7th Intelligent Vehicles Symposium*, Baden Baden, Germany, June 2011.

16. Menard, Timothy, Jeffrey Miller. "FreeSim_Mobile: A Novel Approach to Real-Time Traffic Gathering using the Apple iPhone." *IEEE 2nd Vehicular Networking Conference*, Jersey City, New Jersey, December 2010.

15. Miller, Jeffrey, Sun-il Kim, Timothy Menard. "Intelligent Transportation Systems Traveling Salesman Problem (ITS-TSP) – A Specialized TSP with Dynamic Edge Weights and Intermediate Cities." *IEEE 13th Intelligent Transportation Systems Conference*, Madeira Island, Portugal, September 2010.

14. Miller, Jeffrey, Sun-il Kim, Muhammad Ali, Timothy Menard. "Determining Time to Traverse Road Sections based on Mapping Discrete GPS Vehicle Data to Continuous Flows." *IEEE 6th Intelligent Vehicles Symposium*, La Jolla, California, USA, June 2010.

13. Miller, Jeffrey. "Analysis of the Traveling Salesman Problem with a Subset of Intermediate Cities and Dynamic Edge Weights used with Intelligent Transportation Systems." Invited paper at *IEEE 7th International Conference on Information, Communications, and Signal Processing*, Fisherman's Wharf, Macau, China, December 2009.

12. Miller, Jeffrey, Muhammad Ali. "Dynamic Fastest Paths with Multiple Unique Destinations (DynFast-MUD) – A Specialized Traveling Salesman Problem with Intermediate Cities." *IEEE 12th Intelligent Transportation Systems Conference*, St. Louis, Missouri, USA, October 2009.

11. Miller, Jeffrey. "Analysis of Fastest and Shortest Paths in an Urban City Using Live Vehicle Data from a Vehicle-to-Infrastructure Architecture." *12th International Federation on Automatic Control (IFAC) Symposium on Control in Transportation Systems*, Redondo Beach, California, USA, September 2009.

10. Miller, Jeffrey. "Distributed Urban Data Gathering in a Vehicle-to-Infrastructure Architecture." 2009 *National Rural Intelligent Transportation Systems Conference*, Seaside, Oregon, USA, August 2009.

9. Miller, Jeffrey. "Fastest Path Analysis in a Vehicle-to-Infrastructure Intelligent Transportation System Architecture." *IEEE 5th Intelligent Vehicles Symposium*, Xi'an, Shaanxi, China, June 2009.

8. Miller, Jeffrey. "Analysis of Vehicle Lane Changes for Determining Fastest Paths in the V2V2I ITS Architecture." *IEEE 11th Intelligent Transportation Systems Conference*, Beijing, China, October 2008.

7. Miller, Jeffrey. "Aggregation Algorithms in a Vehicle-to-Vehicle-to-Infrastructure (V2V2I) Intelligent Transportation System Architecture." *3rd International Symposium of Transport Simulation*, Queensland, Australia, August 2008.

6. Miller, Jeffrey. "Fastest Path Determination at Lane Granularity using a Vehicle-to-Vehicle-to-Infrastructure (V2V2I) Intelligent Transportation System Architecture." *IEEE 4th International Workshop on Vehicle-to-Vehicle Communications* in conjunction with *IEEE 4th Intelligent Vehicles Symposium*, Eindhoven, The Netherlands, June 2008.

5. Miller, Jeffrey. "Vehicle-to-Vehicle-to-Infrastructure (V2V2I) Intelligent Transportation System Architecture." *IEEE 4th Intelligent Vehicles Symposium*, Eindhoven, The Netherlands, June 2008.

4. Miller, Jeffrey, Ellis Horowitz. "FreeSim – A Free Real-Time Freeway Traffic Simulator." *IEEE 10th Intelligent Transportation Systems Conference*, Seattle, Washington, USA, October 2007.

3. Miller, Jeffrey, Ellis Horowitz. "FreeSim – A V2V and V2R Freeway Traffic Simulator." *IEEE 3rd International Workshop on Vehicle-to-Vehicle Communications* in conjunction with *IEEE 3rd Intelligent Vehicles Symposium*, Istanbul, Turkey, June 2007.

2. Miller, Jeffrey, Ellis Horowitz. “Algorithms for the Real-Time Processing of Traffic Data.” *IEEE 9th Intelligent Transportation Systems Conference*, Toronto, Ontario, Canada, September 2006.

1. Miller, Jeffrey. “Characterization of Data on the Gnutella Peer-to-Peer Network.” *IEEE 1st Consumer Communication and Networking Conference*, Las Vegas, Nevada, USA, January 2004.

Other Refereed Publications

2. Miller, Jeffrey, John Harriss, Wolfram Donat, Vitaly Ivanov, Paul Kelly, Dustin Mendoza, Zakary Stone. “Vehicular Robotic Test Bed for ITS Applications.” Demonstration Abstract, *IEEE 4th Vehicular Networking Conference*, Seoul, Korea, November 2012.

1. Miller, Jeffrey. “FreeSim – A Free Real-Time V2V and V2I Freeway Traffic Simulator.” *IEEE Intelligent Transportation Systems Society Newsletter*, December 2007.

Supplement to Book

1. Miller, Jeffrey. Lab Manual to Accompany The Web Application Hacker’s Handbook: Discovering and Exploiting Security Flaws by Davydd Stuttard and Marcus Pinto, ISBN 978-0-470-17077-9, August 2008.

Other Publications

19. Miller, Jeffrey. “Expanding and Improving.” IEEE Intelligent Transportation Systems Magazine *Editor-in-Chief Column*, Volume 5, Number 3, fall 2013.

18. Miller, Jeffrey. “Timelines and Deadlines.” IEEE Intelligent Transportation Systems Magazine *Editor-in-Chief Column*, Volume 5, Number 2, summer 2013.

17. Miller, Jeffrey. “Motive, Motivate, Motivation.” IEEE Intelligent Transportation Systems Magazine *Editor-in-Chief Column*, Volume 5, Number 1, spring 2013.

16. Miller, Jeffrey. “September 2012 Executive Committee/Board of Governors Meeting Summary.” *IEEE Intelligent Transportation Systems Society Newsletter*, October 2012.

15. Miller, Jeffrey. “2012 IEEE Intelligent Transportation Systems Conference Summary.” *IEEE Intelligent Transportation Systems Society Newsletter*, October 2012.

14. Miller, Jeffrey. “Reflecting on First Year.” IEEE Intelligent Transportation Systems Magazine *Editor-in-Chief Column*, Volume 4, Number 4, winter 2012.

13. Miller, Jeffrey. “2012 IEEE Intelligent Transportation Systems Conference Summary.” IEEE Intelligent Transportation Systems Magazine *Conference Report*, Volume 4, Number 4, winter 2012.

12. Miller, Jeffrey. “IEEE Intelligent Transportation Systems Conference 2012 General Chair Message.” IEEE 15th Intelligent Transportation Systems Conference Program, September 2012.

11. Miller, Jeffrey. “June 2012 Executive Committee/Board of Governors Meeting Summary.” *IEEE Intelligent Transportation Systems Society Newsletter*, July 2012.

10. Miller, Jeffrey. “Back to School.” IEEE Intelligent Transportation Systems Magazine *Editor-in-Chief Column*, Volume 4, Number 3, fall 2012.

9. Miller, Jeffrey. “Time for the Magazine.” IEEE Intelligent Transportation Systems Magazine *Editor-in-Chief Column*, Volume 4, Number 2, summer 2012.

8. Miller, Jeffrey. “February 2012 Executive Committee Meeting Summary.” *IEEE Intelligent Transportation Systems Society Newsletter*, May 2012.

7. Miller, Jeffrey. “April 2012 Board of Governors Meeting Summary.” *IEEE Intelligent Transportation Systems Society Newsletter*, May 2012.

6. Miller, Jeffrey. “Continuing the Success.” IEEE Intelligent Transportation Systems Magazine *Editor-in-Chief Column*, Volume 4, Number 1, spring 2012.

5. Miller, Jeffrey. “October 2011 Executive Committee and Board of Governors Meeting Summary.” *IEEE Intelligent Transportation Systems Society Newsletter*, November 2011.

4. Miller, Jeffrey. “IEEE Vehicular Technology Conference Fall 2011 Technical Program Chair Message.” IEEE Vehicular Technology Conference Fall 2011 Program, September 2011.

3. Miller, Jeffrey. “February 2011 Executive Committee Meeting Summary.” *IEEE Intelligent Transportation Systems Society Newsletter*, April 2011.

2. Miller, Jeffrey. “IEEE Intelligent Transportation Systems Magazine Guest Editorial – Macroscopic and Microscopic Traffic Simulators.” IEEE Intelligent Transportation Systems Magazine, Volume 2, Number 4, fall 2010.

1. Miller, Jeffrey. “IEEE Vehicular Technology Conference Fall 2009 General Chair Message.” IEEE Vehicular Technology Conference Fall 2009 Program, September 2009.

Experience

Associate Professor of Engineering Practices, Computer Science
University of Southern California – Los Angeles, California, August 2014-present

- I will be teaching undergraduate and graduate courses in the Computer Science, Computer Engineering, and Electrical Engineering programs
- Research will continue in intelligent transportation systems
- Service to the department, school, university, professional societies, and community will continue in a manner similar to before

Associate Professor with tenure, Computer Science and Engineering, July 2011-December 2013
Assistant Professor, Computer Systems Engineering, August 2007-June 2011
Chair, Bachelor of Science in Engineering Department (Computer, Electrical, and Mechanical Engineering), February 2011-November 2011
University of Alaska Anchorage – Anchorage, Alaska, August 2007-present

- Courses Taught
  - Programming in Java (CS110)
  - Introduction to Computer Systems (CSE102)
  - Introduction to C Programming for Engineers (CSE294A/205) – online and traditional
  - Object-Oriented C++ Programming for Engineers (CSE 294B/215)
  - Engineering Systems Administration (CSE394B)
  - Digital Circuits Design (CSE342/394D)
  - Computer Networking for Engineers (CSE394F/355)
  - Design of Computer Systems Engineering (CSE438)
  - VLSI Circuit Design (CSE442)
  - Network Security (CSE465/CSCE465) – online and traditional
  - Independent Study (CSE497)
  - Elements of Electrical Engineering (ES309)
- Authored introduction to computer systems, introductory programming, object-oriented programming, systems administration, digital circuits, computer networking, operating systems, FPGA, and VLSI classes for engineering students focused on applied applications in various engineering disciplines
- Led Computer Systems Engineering department in preparing ABET documents for securing accreditation, which we received in fall 2008, fall 2010, and fall 2012
- IEEEXtreme Programming Competition Proctor for two UAA teams in 2012
- Started and facilitated Faculty Research Series where each faculty member in the engineering school presents his research to the rest of the faculty during the semester in 2009
- Hosted Prof. Javier Sanchez Medina from Canary Islands giving a talk on ITS technologies in September 2012.
- Hosted Prof. Mohan Trivedi from UC San Diego giving a talk on ITS technologies in August 2012.
- Hosted Alaska Department of Transportation 511 Training Event in March 2010
- Hosted Apple iPhone Development Training Event in April 2010
- Coordinated end-of-semester Engineering Competition for all School of Engineering students in December 2010
- University and School of Engineering Committees
  - School of Engineering Executive Committee, August 2011-November 2011
  - School of Engineering Facilities Committee Chair, August 2011-November 2011, responsible for being the point-man for the school on a new building and space usage in existing facilities
  - Chair of School of Engineering Web Site Steering Committee, 2009-present
  - Program Chair, Computer Systems Engineering ABET Visit, fall 2012
  - Program Chair, Computer Systems Engineering ABET Visit, fall 2010
  - Computer Systems Engineering Advising Committee, 2007-present
  - Computer Systems Engineering Equipment Committee, 2007-2011
  - School of Engineering Computer Committee, 2007-2011
  - Computer Systems Engineering/Electrical Engineering 2008 Faculty Search Committee
  - Computer Systems Engineering/Electrical Engineering 2009 Faculty Search Committee

    - United Academic Board Academic Computing Distance Learning and Instructional Technology Committee, 2008-2009
    - United Academic Board General Education Requirements Committee, 2008-2009
    - Institutional Learning Outcomes and Assessment Task Force, 2008-2009
    - Research, Scholarship, and Creative Activity Review and Evaluation Team, 2010
    - Chair of Computer Science and Engineering Promotion and Tenure Guidelines Committee, 2013
    - Computer Science and Engineering Outstanding Graduate Award Committee, 2013

Online Lecturer, Information Technology
American Public University System/American Military University System – December 2009-present

- Facilitated online education for APUS/AMUS (mostly active or retired military) students around the world
- Courses
    - Application Development (ENTD 411)
    - Systems Engineering (ENTD 412)
    - Enterprise Development using ASP.NET (ENTD 462)
    - Enterprise Development using C# (ENTD 463)
    - Enterprise Development using .NET (ENTD 464)
    - Enterprise Development using J2EE (ENTD 481)
    - Relational Database Concepts (INFO 221)
    - Local Area Network Technologies (ISSC 340)
    - Introduction to Networking (ISSC 341)

Senior Solutions Strategist
Pangomedia, Inc. – Anchorage, Alaska, May 2009-August 2010

- Architected high level solutions for clients, working with the development team to see the project from conception through completion
- Identified clients and projects, including ongoing software development projects, IT consulting placement, and fixed-cost projects
- Solicited business by being an active and participating member of the Alaska business community, performing build/buy analyses, and responding to requests for proposals (RFP)

Senior Programmer / Analyst
Resource Data, Inc. – Anchorage, Alaska, April 2008-October 2008

- Consulted at Chenega Federal Systems, working on the Joint Supply Management Module project for the US Department of Defense concerning fuel and ammunition inventory tracking
- Utilized Struts, Spring, Java, J2EE, JDBC, Hibernate, Ajax, and Web Services in the SCRUM software development methodology
- Re-architected the system as new requirements forced a redesign of the application
- Acted as a team lead for four developers and one database administrator

Computer Science Lecturer
California State University, Los Angeles – Los Angeles, California, February 2002-August 2007

- Courses
    - Introduction to Web Site Development (CS120)
    - Introduction to SQL and Databases (CS122)
    - Introduction to Programming (CS201)
    - Introduction to Object-Oriented Programming (CS202)
    - Programming with Data Structures (CS203)
    - C Programming (CS242)
    - Computer Ethics in the Information Age (CS301)
    - Algorithm Design and Analysis (CS312)
    - Web and Internet Programming (CS320)
    - Introduction to Automata Theory (CS386)
    - Java for C++ Programmers (CS454 – Special Topics)
    - Enterprise Architecture (CS454 – Special Topics, now CS420)

  - Compilers (CS488)
  - Undergraduate Computer Science Wrap-Up Course (CS490)
  - Directed Study (CS499)
- Led a team of undergraduate students in a directed research (CS499) in the design and implementation of a compiler project to be used for the programs in the compiler class (CS488)
- Aided in preparing course documents for ABET accreditation in 2006
- Voted 2002 Professor of the Year by the students in the Computer Science department – 1st lecturer ever to be given this award
- Authored CS420 class on enterprise web architecture, covering RMI, CORBA, Web Services, and different MVC architectures, including Spring and Struts

Independent Consultant, May 2005-present

- Performed small to mid-size programming tasks for different companies using predominantly Java, HTML, JavaScript, CMSs, and Flash
- Automated the drafting of legal documents for a law firm involved with estate planning, including creation of diagrams, flow charts, and Microsoft Word generation
- Migrated a Microsoft Access application to a multi-user web-based application
- Created a socket-based Flash chat application with multiple simultaneous users supporting multiple agents over a Java-based chat server

Founder / Chief Executive Officer

Imaginary Technology, LLC – Burbank, California, August 2005-April 2006

- Started a company that created handheld and standalone point of sale systems for the restaurant industry
- Worked with restaurant owners and potential clients to determine the requirements for the point of sale system
- Managed a team of 5 developers to implement the requirements and install the system
- Responsible for buying hardware, hiring personnel, obtaining investment money, selling the system, and working with owners to improve the system

Application Specialist – Technical Lead / Senior Architect

21st Century Insurance – Woodland Hills, California, February 2005-May 2005

- Worked as a lead and architect on a team responsible for all online payments of insurance policy premiums, including eCheck and direct-debit payments
- Coded in Java on a Websphere-based application using Struts
- Wrote a J2EE tool to allow customer service representatives to see all of the billing history of a customer and all activity that has ever occurred on a customer’s policy

Director of Engineering

inQ, Inc.– Agoura Hills, California, July 2004-February 2005

- Responsible for the personnel of the IT department and grew the development/QA team from 2 to 6 within the first 6 months
- Managed a team of 4 programmers and 2 QA engineers on a multi-threaded chat and outbound call application to up-sell online customers of client web sites
- Communicated with clients and partners on all technical issues related to interfacing our application with theirs
- Implemented a complete software development process for use by all departments of the company to interact with the IT department for any requests

Technical Consultant

SBC – Smartpages.com – Pasadena, California, July 2003-July 2004

- Managed a team of 12 programmers on an ongoing project to fix all issues with the production site and reported to the client weekly on the status of the issues
- Responsible for improving and implementing technical processes for the development team
- Created and initiated coding standards, then enforced the standards by performing code inspections on all modified code checked in to the version management software

- Involved in design of documentation templates and other process improvement strategies to aid in increasing the CMM level of the team to CMM Level 3 by 4th quarter of 2005
- Led team in initiating unit testing (using JUnit) and customized exception handling to reduce the number of bugs and the severity of bugs discovered by the quality assurance team

Graduate Research Assistant
Information Sciences Institute (ISI) – Marina Del Rey, California, May 2002-July 2003

- Used PHP4.0 running on Red Hat Linux 7.1 to create a tree structure for browsing the objects of a specified LDAP server
- Created a Service Data Browser using Java Swing to display the service data returned as a web service SOAP message from different providers in different formats, including raw XML, a tree structure, and a status bar
- Designed an interface to allow other programmers to create their own Visualizers to display the service data however they would like in the Service Data Browser
- Created a web-based interface using JSP and JavaBeans to browse specific service data through the use of web services and display the data in a user-friendly tree-based format

Principal Software Engineer
Corticon Technologies, Inc. – Culver City, California, June 2001-May 2002

- Worked as a technical lead on an 8-member project to design and develop an application to automate business rule generation
- Researched augmented decision tables to design efficient algorithms for optimization of business rules, such as expand, collapse (based on an algorithm designed by Dr. Richard N. Shiffman of Yale University), ambiguity checking, and completeness checking
- Helped to design a parser/compiler for creating Java files from business rule statements that could be used with any plug-in architecture
- Technologies included Weblogic, ILOG, JUnit, Ant, and XML (W3C and JDOM)

Programming Consultant
Dacor – Pasadena, California, January 2001-June 2001

- Developed B2B e-commerce site using JSPs, Servlets, JavaBeans, JDBC, and XML that allowed distributors and retailers to automate the ordering of their products –
- Created middleware application using Java to connect a SQL Server database to an existing Legacy system database
- Requested software and database applications to purchase that would best suit the company's growing needs

Systems Administrator / Programmer
Busybox.com – Century City, California, February 2000-January 2001

- Designed and maintained www.busybox.com (corporate site) and promo.busybox.com (promotions site), using HTML, JavaScript, JSP, Servlets, JDBC, and JavaBeans
- Installed necessary components for web applications, including servlet containers, video streaming software, and web servers on Windows NT Server 4.0
- Installed, configured, and developed with IBM Websphere Application Server and Allaire JRun Application Server, using IBM VisualAge for Java and Websphere Studio
- Completed IBM WebSphere Application Server 3.5 certification training and IBM Visual Age for Java certification training

Advanced Java Instructor / Teaching Assistant
Learning Tree University – Chatsworth, California, December 1999-March 2001

- Taught beginning and advanced Java concepts to classes of corporate students that consisted of programmers and managers
- Topics included: AWT, Swing, Networking, File I/O, Web Servers, Servlets, JSP, Reflection, Multi-threaded Applications, Design Patterns, JDBC, XML

US008599001B2

(12) **United States Patent**
Schofield et al.

(10) **Patent No.:** **US 8,599,001 B2**
(45) **Date of Patent:** **Dec. 3, 2013**

(54) **VEHICULAR VISION SYSTEM**

(71) Applicant: **Donnelly Corporation**, Holland, MI (US)

(72) Inventors: **Kenneth Schofield**, Holland, MI (US); **Mark L. Larson**, Grand Haven, MI (US)

(73) Assignee: **Magna Electronics Inc.**, Auburn Hills, MI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/680,534**

(22) Filed: **Nov. 19, 2012**

(65) **Prior Publication Data**

US 2013/0076241 A1 Mar. 28, 2013

Related U.S. Application Data

(63) Continuation of application No. 13/525,763, filed on Jun. 18, 2012, now Pat. No. 8,314,689, which is a continuation of application No. 13/351,098, filed on Jan. 16, 2012, now Pat. No. 8,203,440, which is a continuation of application No. 11/074,521, filed on Mar. 8, 2005, now Pat. No. 8,098,142, which is a continuation of application No. 10/940,700, filed on Sep. 14, 2004, now Pat. No. 6,953,253, which is a continuation of application No. 10/372,873, filed on Feb. 24, 2003, now Pat. No. 6,802,617, which is a continuation of application No. 09/975,232, filed on Oct. 11, 2001, now Pat. No. 6,523,964, which is a continuation of application No. 09/227,344, filed on Jan. 8, 1999, now Pat. No. 6,302,545, which is a continuation of application No. 08/478,093, filed on Jun. 7, 1995, now Pat. No. 5,877,897.

(51) **Int. Cl.**
B60Q 1/00 (2006.01)

(52) **U.S. Cl.**
USPC **340/425.5**; 340/438; 340/937; 348/148; 348/151

(58) **Field of Classification Search**
USPC 340/425.5, 438, 815.4, 426, 433, 937; 348/148, 151
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,598,420 A 5/1952 Onksen et al.
2,632,040 A 3/1953 Rabinow

(Continued)

FOREIGN PATENT DOCUMENTS

DE 1152627 8/1963
DE 1182971 12/1964

(Continued)

OTHER PUBLICATIONS

Bow, Sing T., "Pattern Recognition and Image Preprocessing (Signal Processing and Communications)", CRC Press, Jan. 15, 2002, pp. 557-559.

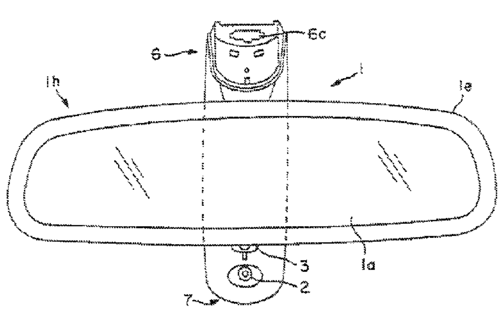
(Continued)

Primary Examiner — Toan N Pham
(74) *Attorney, Agent, or Firm* — Gardner, Linn, Burkhart & Flory, LLP

(57) **ABSTRACT**

A vehicular vision system includes a control and an imager having a lens and a CMOS photosensor array. The imager is disposed at an interior portion of a vehicle and views exterior of the vehicle through a windshield of the vehicle and forward of the vehicle. The control includes an image processor for processing image data captured by the photosensor array. The image processor processes captured image data to detect an object viewed by said imager. The photosensor array may be operable at a plurality of exposure periods that include a first exposure period and a second exposure period, with the time period of exposure of the first exposure period being longer than the time period of exposure of the second exposure period. The imager may be disposed in a module attached at the windshield of the vehicle.

109 Claims, 25 Drawing Sheets



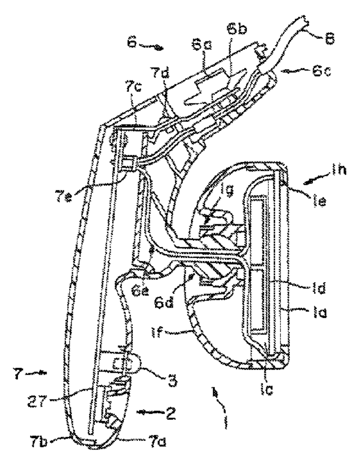


Exhibit B

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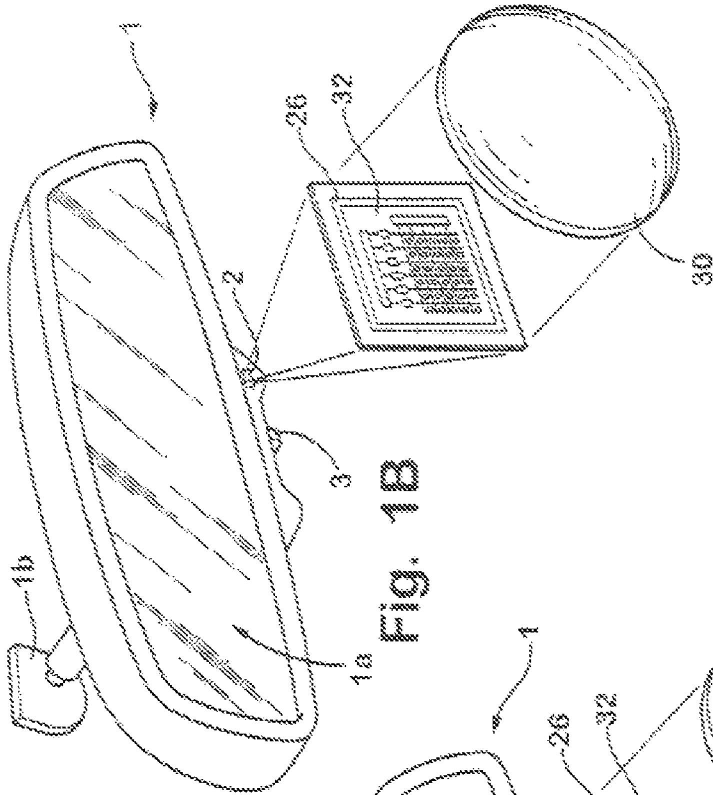


Fig. 1B

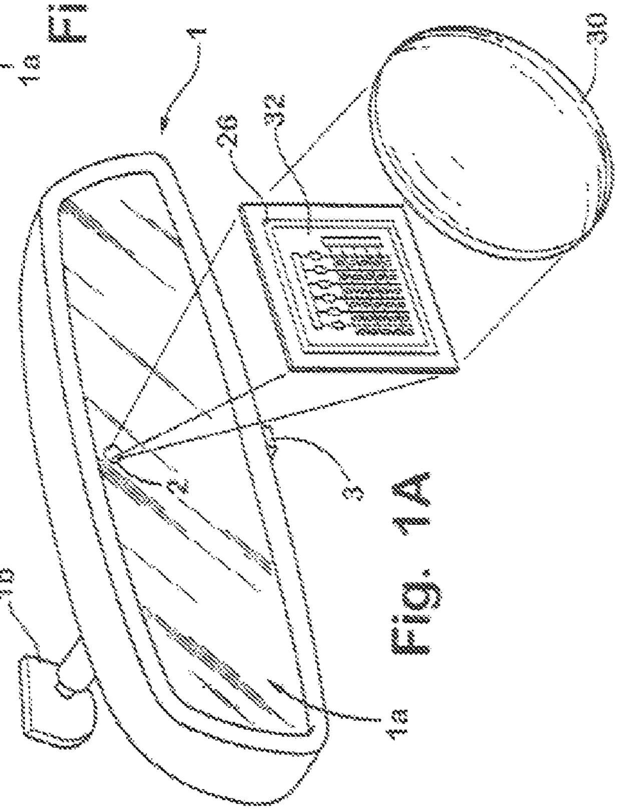


Fig. 1A

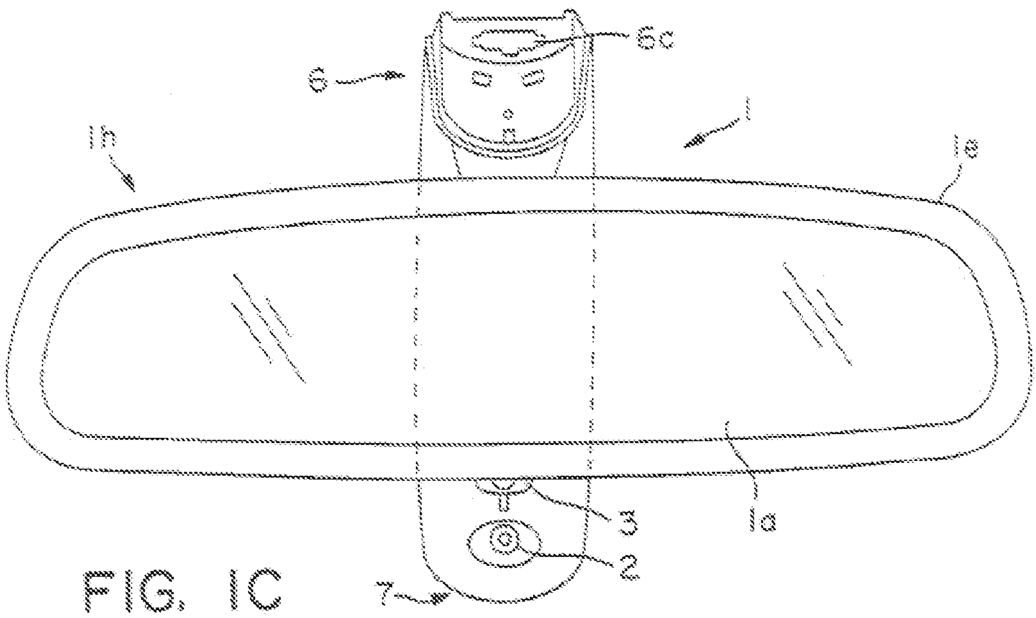

6c
6
1
1h
1e
3
1a
2
7

FIG. 1C

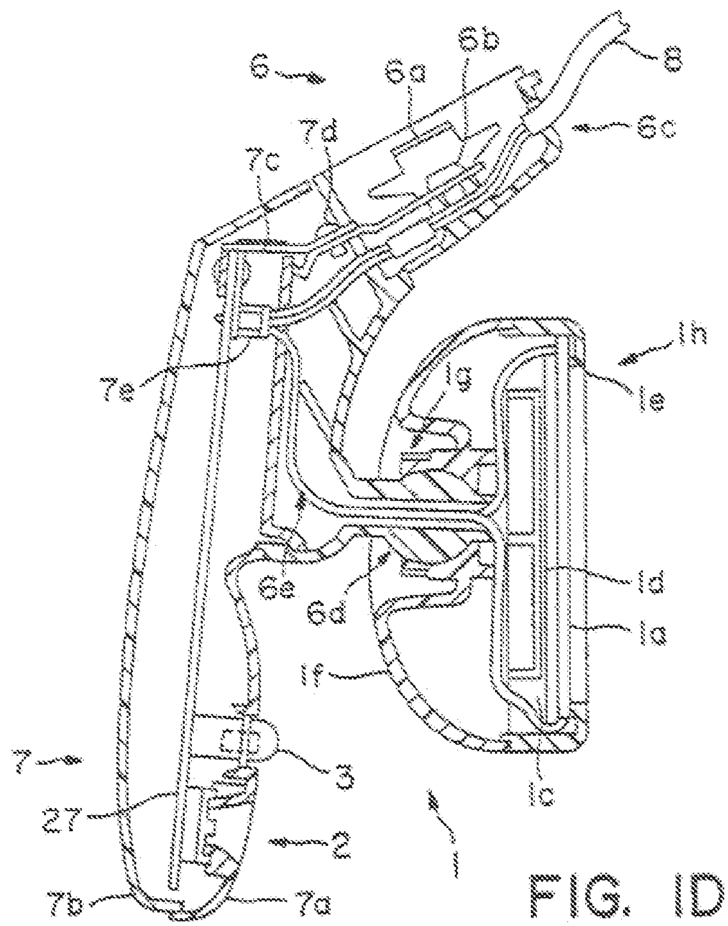

6
6a
6b
8
6c
7d
7c
1h
7e
1g
1e
6e
6d
1d
1a
1f
7
3
1c
27
2
1
7b
7a

FIG. 1D

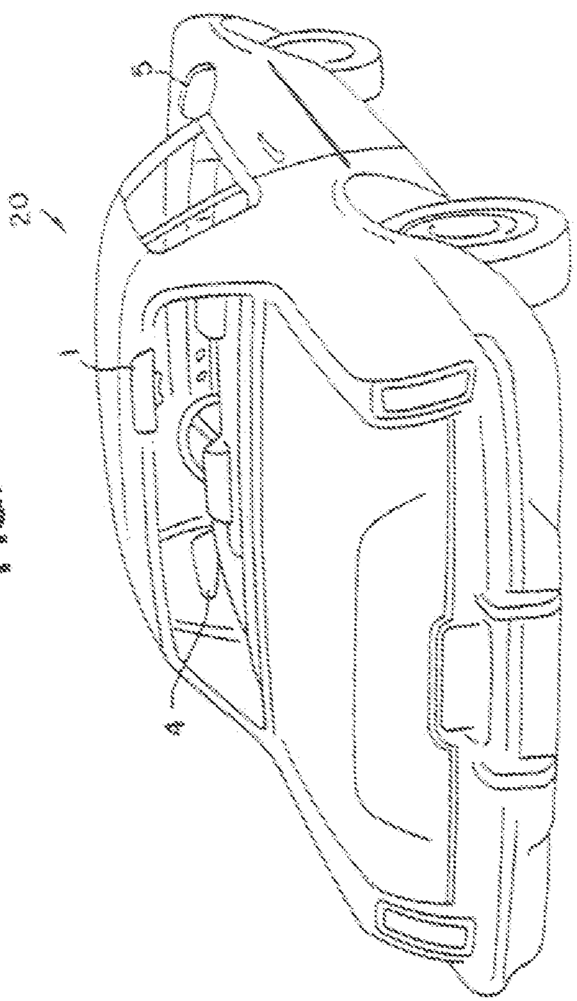


FIG. 2

FIG. 2A

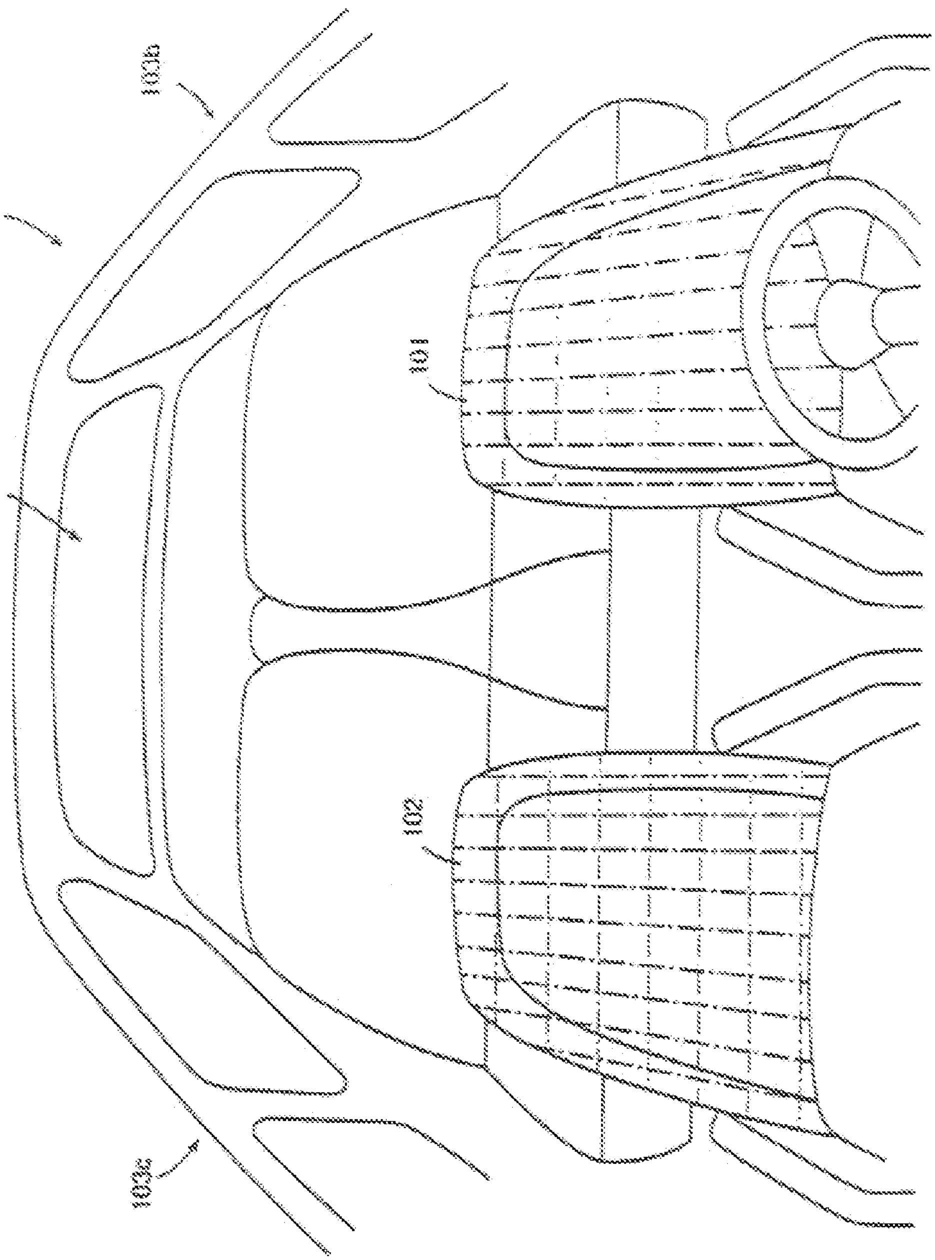


Fig. 3A

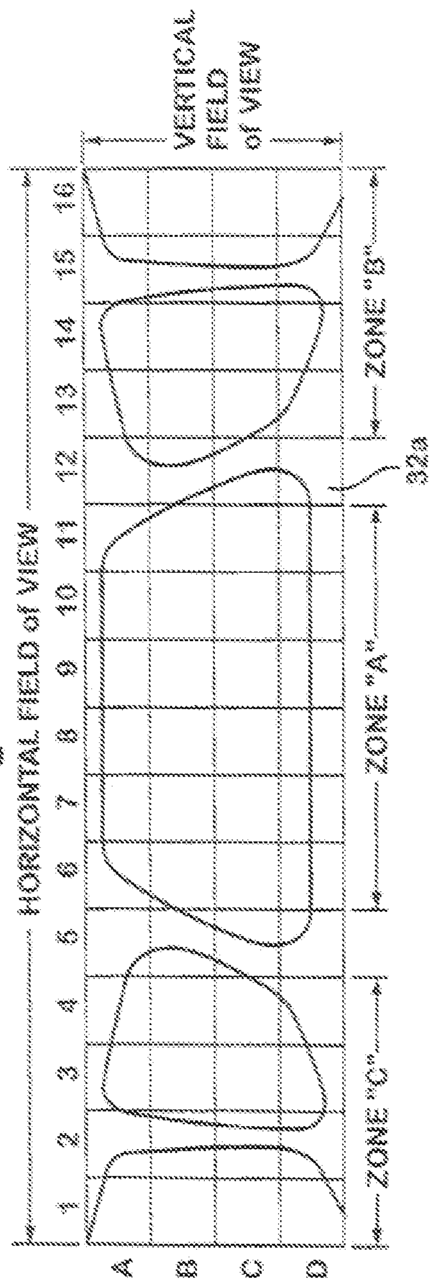

VERTICAL FIELD of VIEW
HORIZONTAL FIELD of VIEW
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
A
B
C
D
ZONE "C"
ZONE "A"
ZONE "B"
32a

Fig. 3B

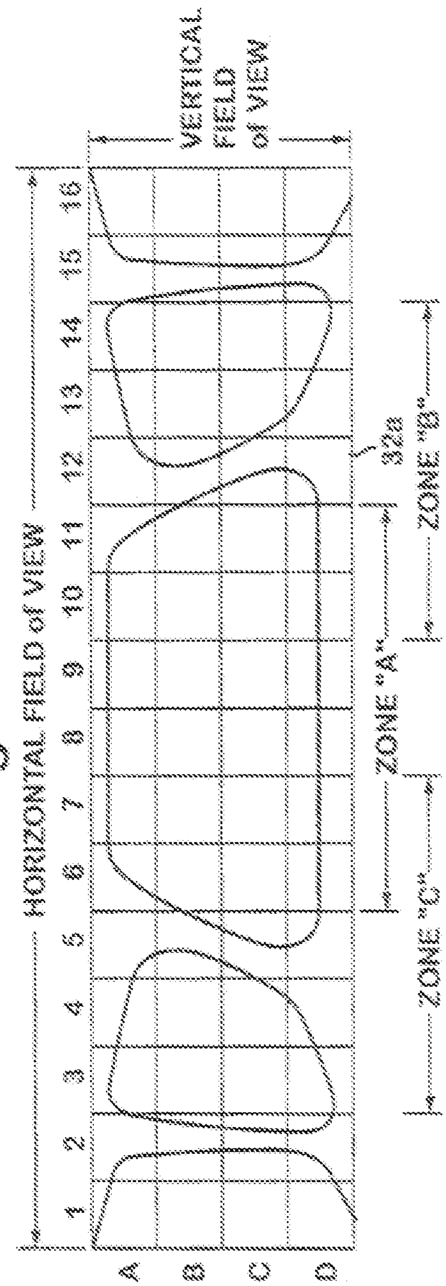
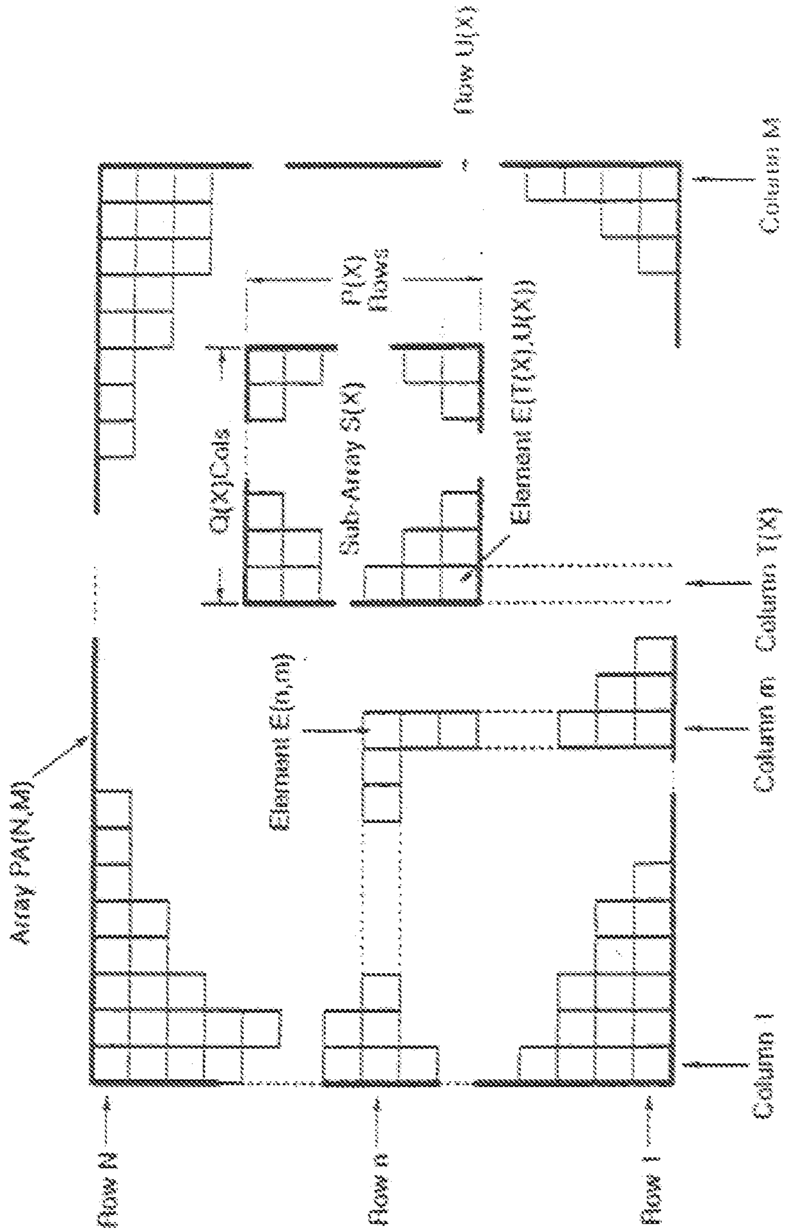

VERTICAL FIELD of VIEW
HORIZONTAL FIELD of VIEW
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
A
B
C
D
ZONE "C"
ZONE "A"
ZONE "B"
32a

FIG. 4A


Array PA(N,M)
Row N
Row n
Row 1
Column 1
Column m
Column T(X)
Column M
Row U(X)
Element E(n,m)
Q(X) Cols
P(X) Rows
Sub-Array S(X)
Element E(T(X),U(X))

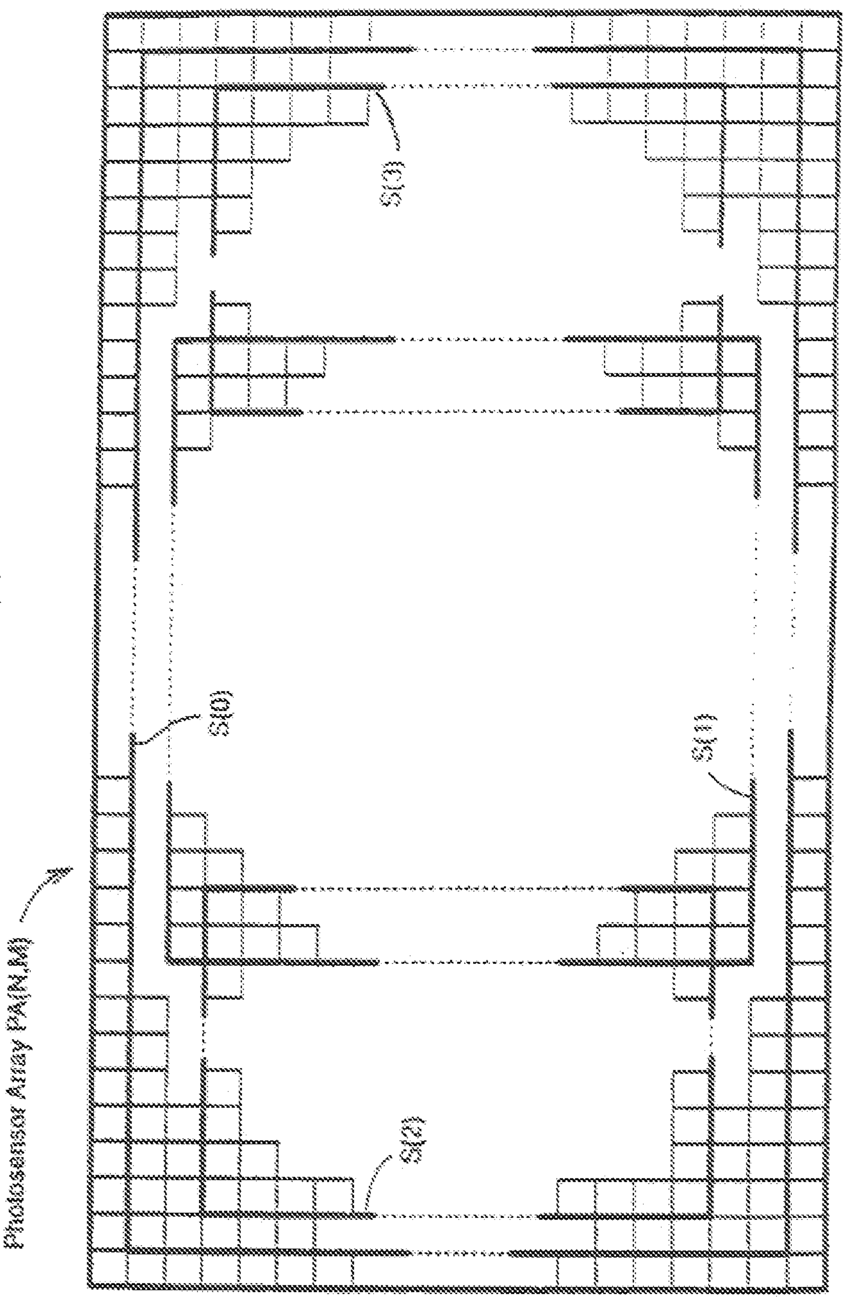


FIG. 4B

FIG. 5

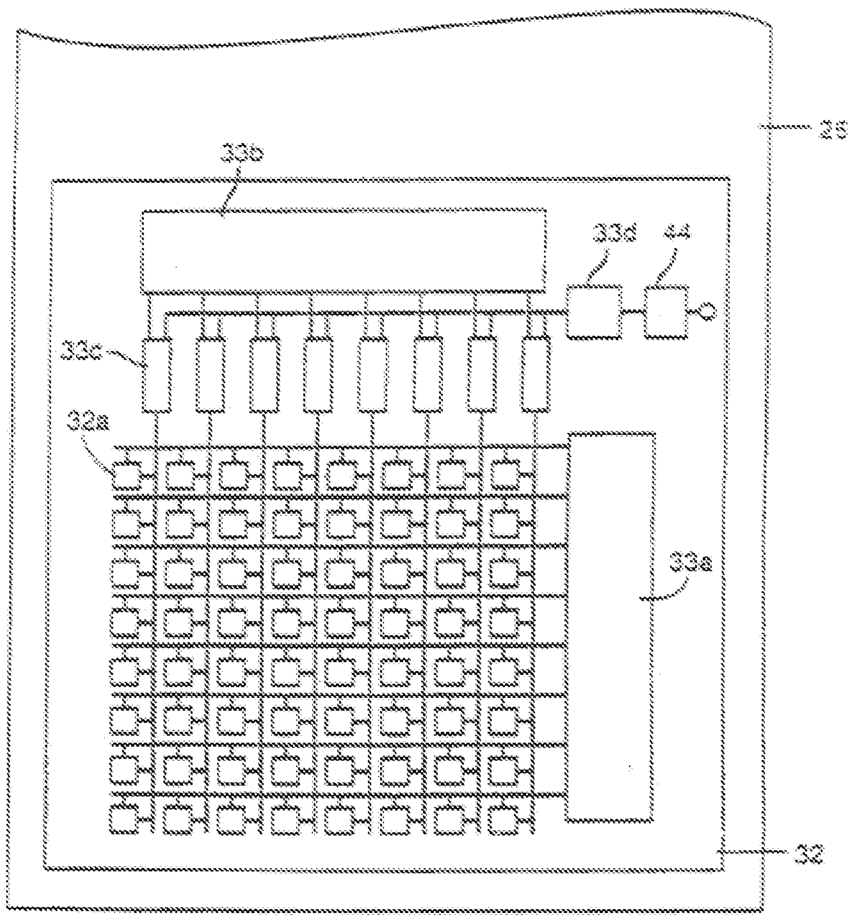


FIG. 6

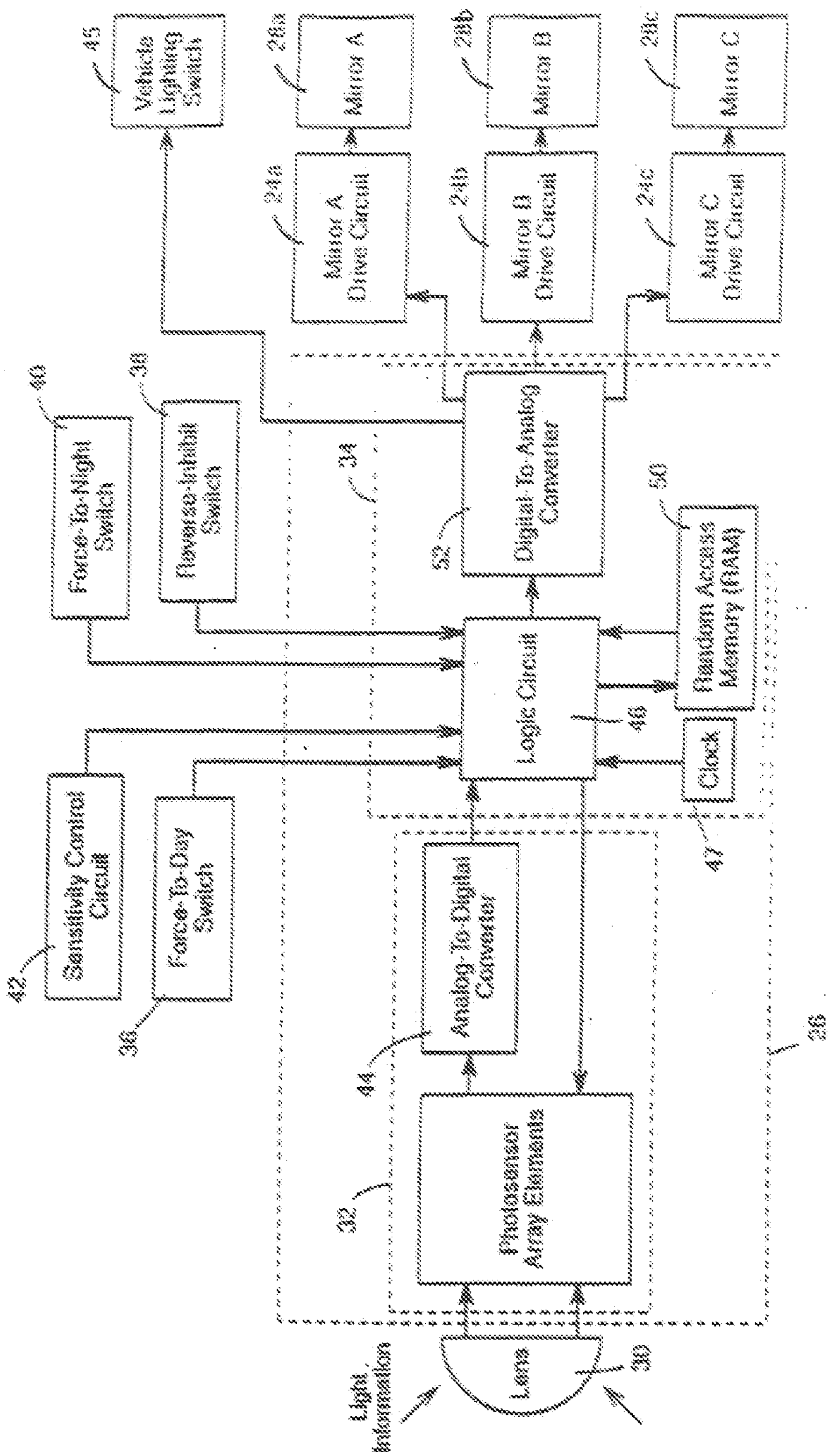
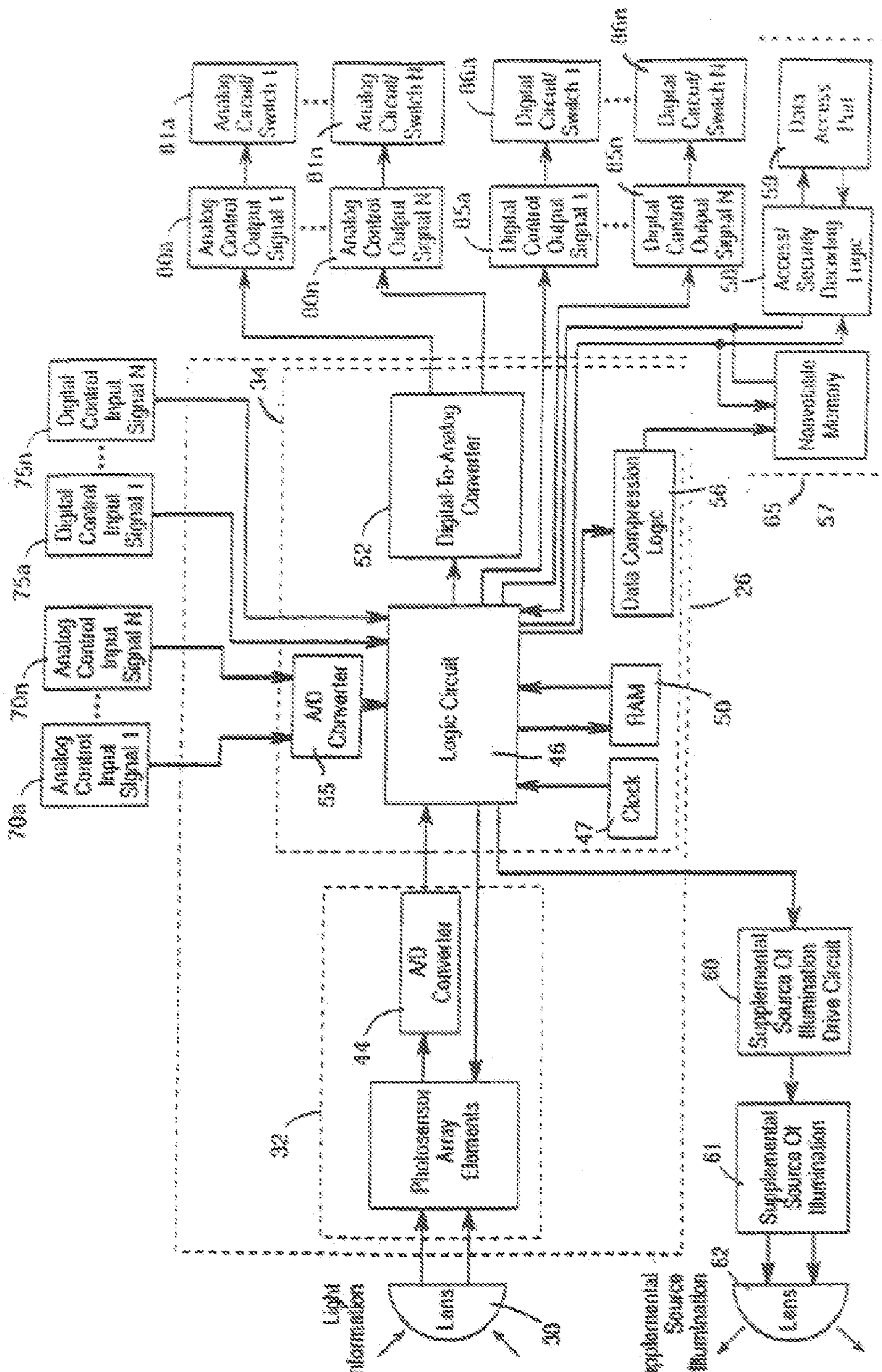
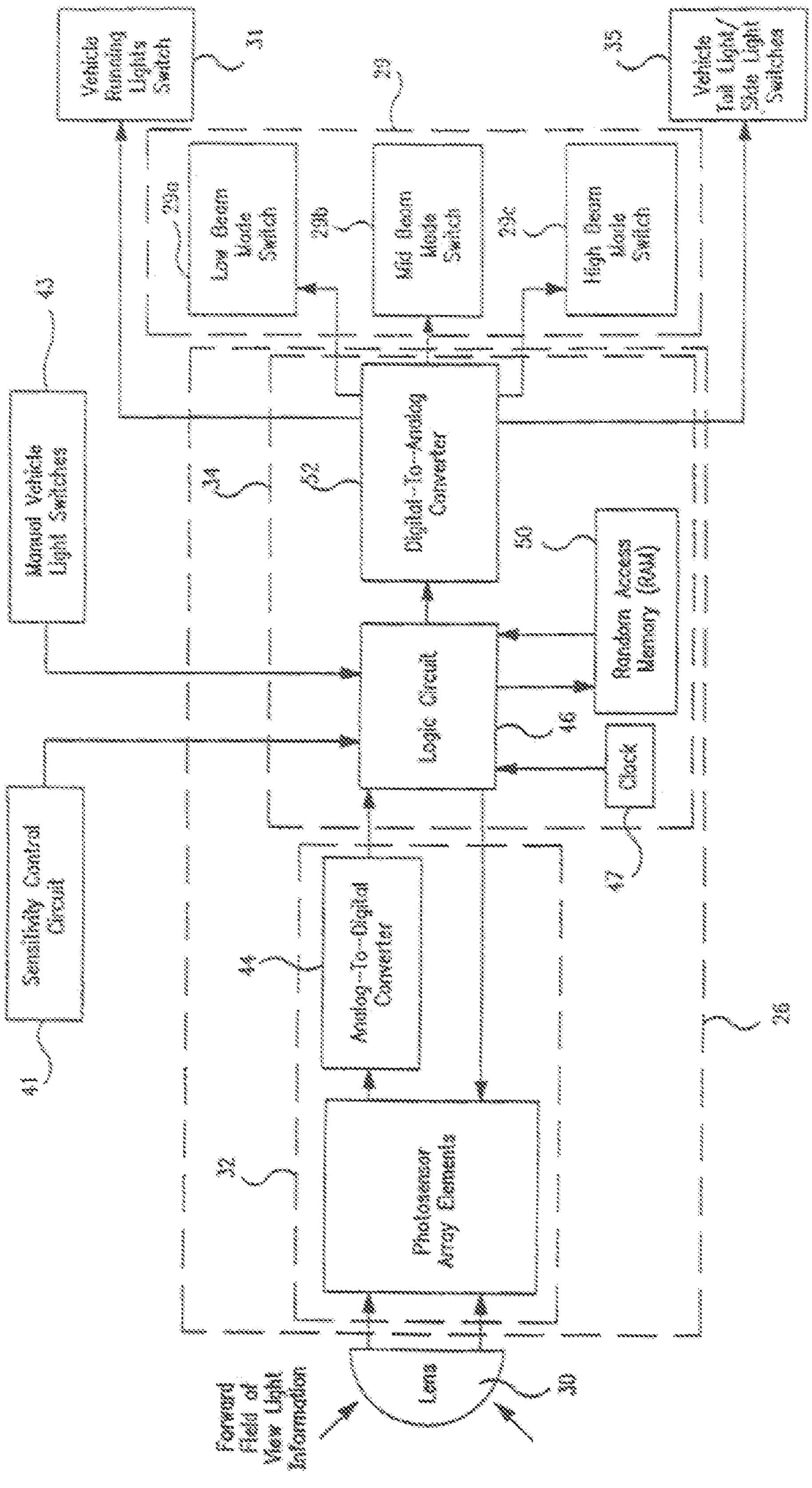

Vehicle Lighting Switch
45
Mirror A
28a
Mirror B
28b
Mirror C
28c
Mirror A Drive Circuit
24a
Mirror B Drive Circuit
24b
Mirror C Drive Circuit
24c
Force-To-Night Switch
40
Reverse-Inhibit Switch
38
34
Digital-To-Analog Converter
52
Random Access Memory (RAM)
50
Logic Circuit
46
Clock
47
Sensitivity Control Circuit
42
Force-To-Day Switch
36
Analog-To-Digital Converter
44
Photosensor Array Elements
32
26
Lens
30
Light Information

FIG. 6A



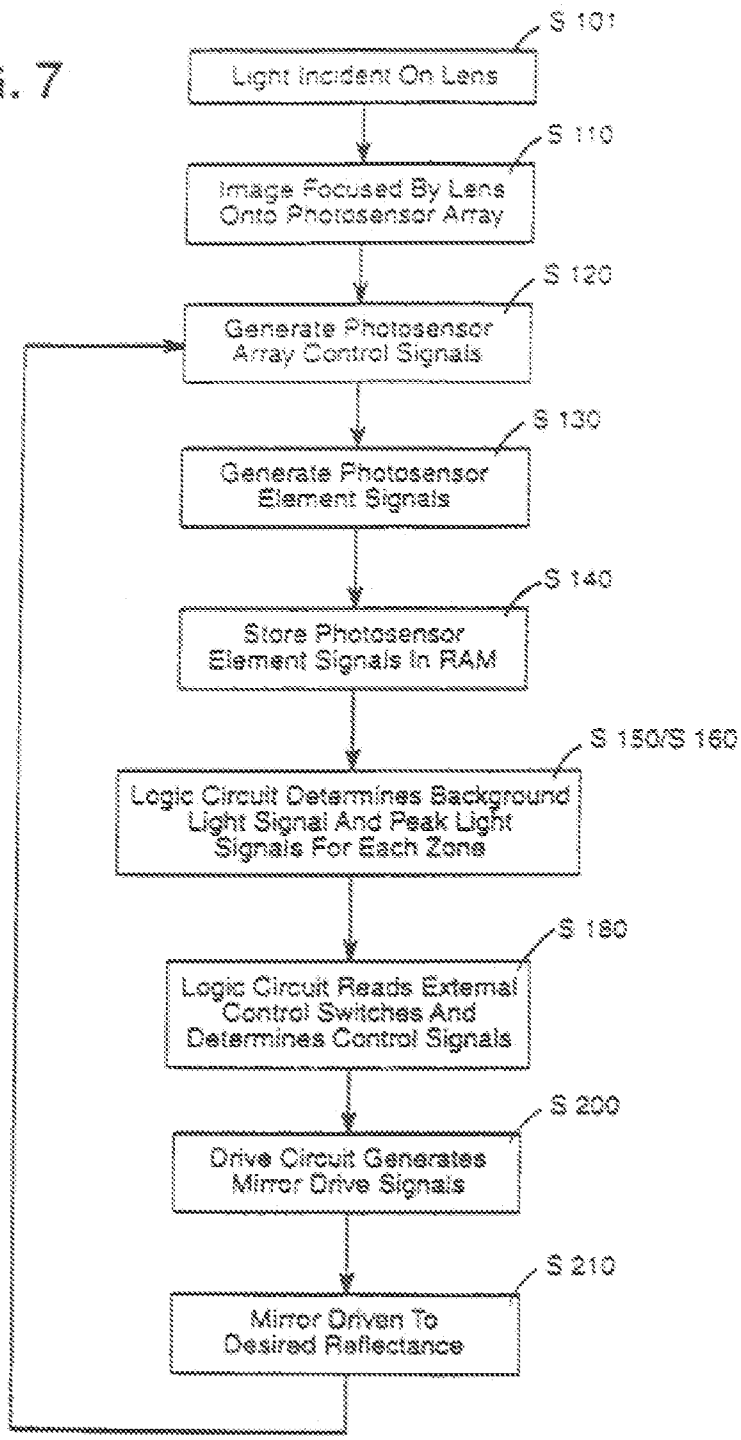
Analog Control Input Signal 1
Analog Control Input Signal N
Digital Control Input Signal 1
Digital Control Input Signal N
Analog Control Output Signal 1
Analog Control Output Signal N
Analog Circuit Switch 1
Analog Circuit Switch N
Digital Control Output Signal 1
Digital Control Output Signal N
Digital Circuit Switch 1
Digital Circuit Switch N
Digital-To-Analog Converter
A/D Converter
Logic Circuit
RAM
Clock
Data Compression Logic
Nonvolatile Memory
Access/Security Decoding Logic
Data Access Port
Photosensor Array Elements
Supplemental Source Of Illumination Drive Circuit
Supplemental Source Of Illumination
Lens
Light Information
Supplemental Source Illumination
70a
70n
75a
75n
80a
80n
81a
81n
85a
85n
86a
86n
59
58
57
56
65
55
52
50
47
46
44
34
32
30
26
61
62
60



Vehicle Running Lights Switch
31
29
35
Vehicle Tail Light/ Side Light Switches
29a
Low Beam Mode Switch
29b
Mid Beam Mode Switch
29c
High Beam Mode Switch
43
Manual Vehicle Light Switches
34
52
Digital-To-Analog Converter
50
Random Access Memory (RAM)
Logic Circuit
46
Clock
47
Sensitivity Control Circuit
41
44
Analog-To-Digital Converter
26
32
Photosensor Array Elements
Forward Field of View Light Information
Lens
30

FIG. 6B

FIG. 7


S 101
Light Incident On Lens
S 110
Image Focused By Lens Onto Photosensor Array
S 120
Generate Photosensor Array Control Signals
S 130
Generate Photosensor Element Signals
S 140
Store Photosensor Element Signals In RAM
S 150/S 160
Logic Circuit Determines Background Light Signal And Peak Light Signals For Each Zone
S 180
Logic Circuit Reads External Control Switches And Determines Control Signals
S 200
Drive Circuit Generates Mirror Drive Signals
S 210
Mirror Driven To Desired Reflectance

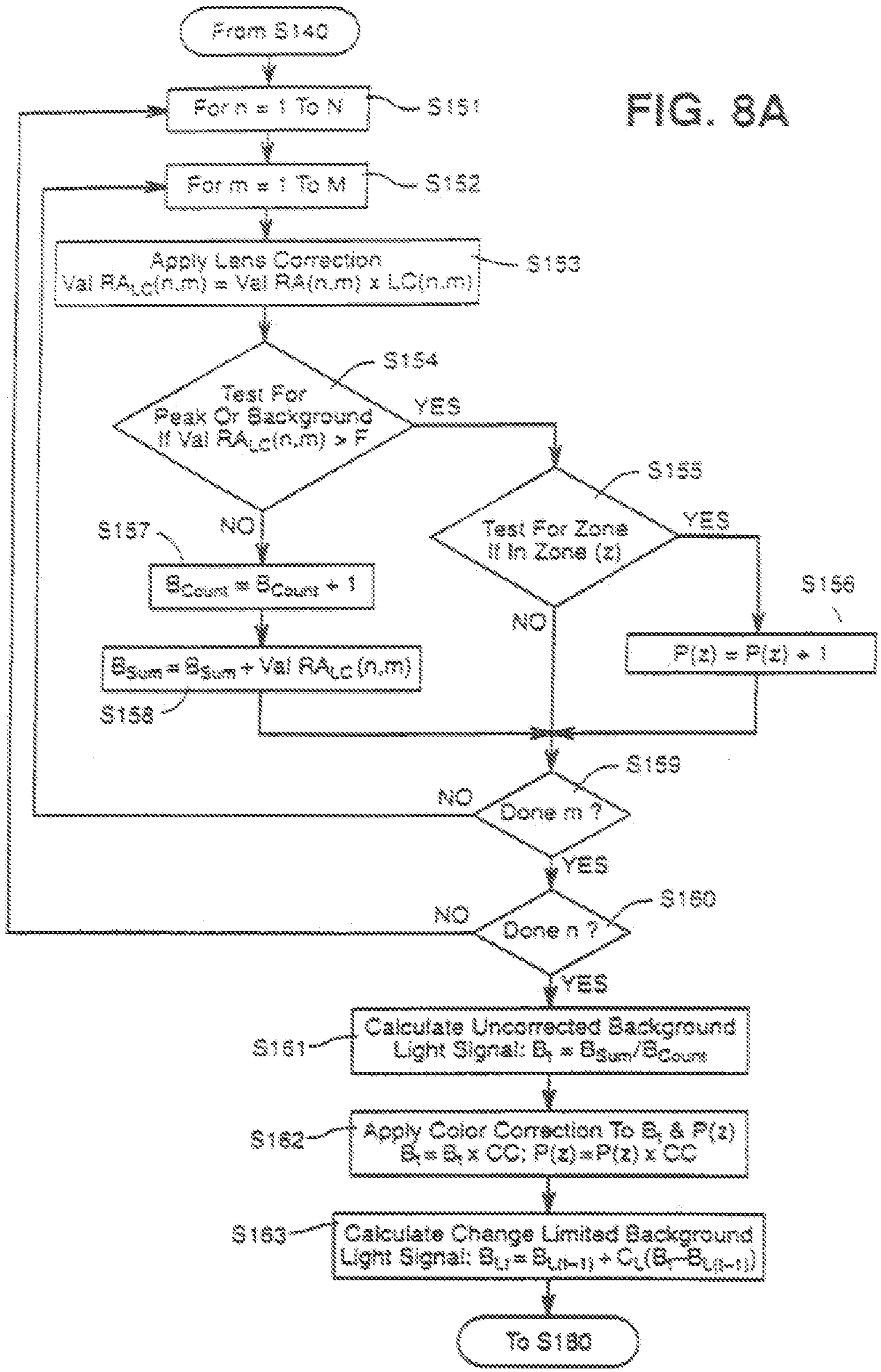
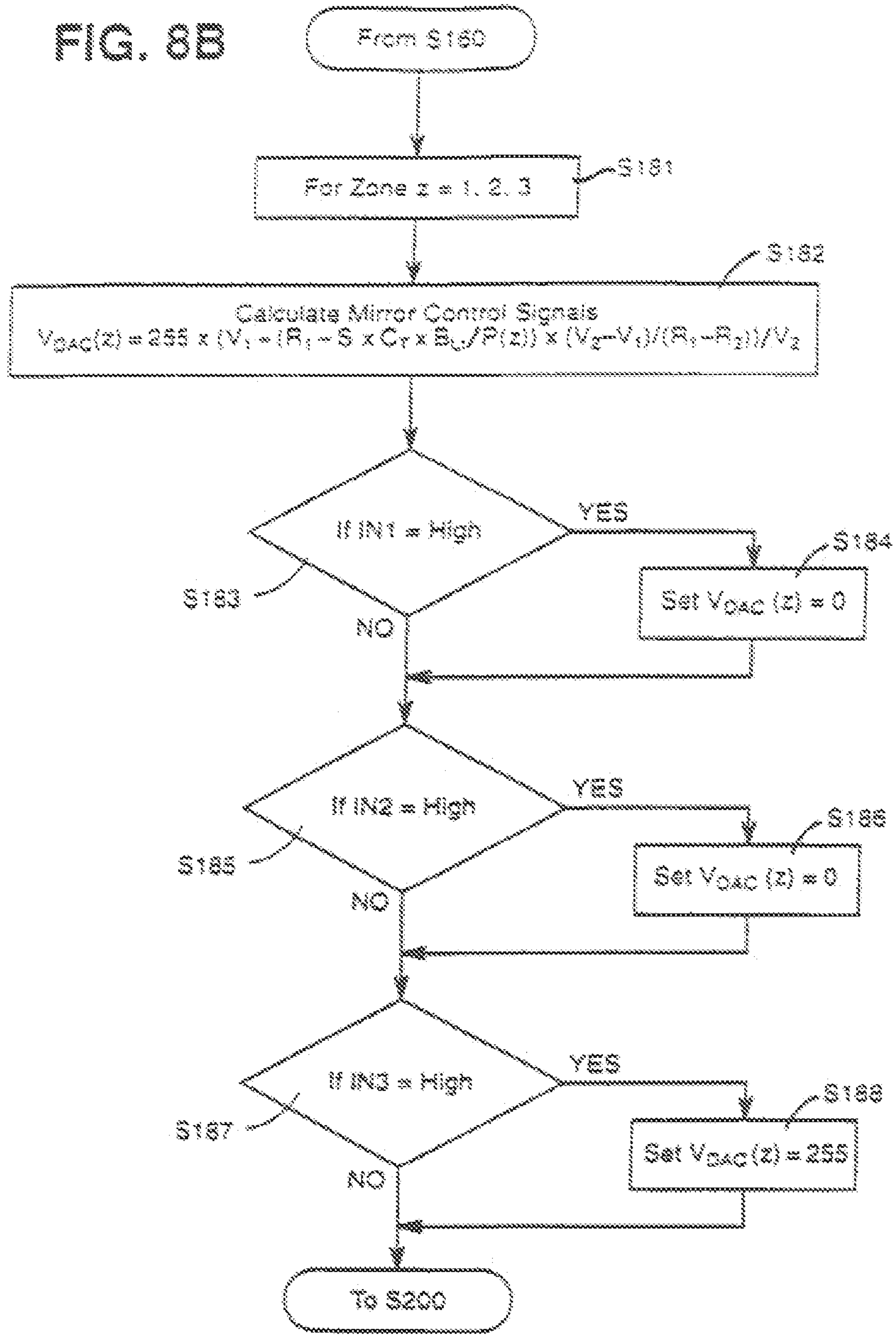

From S140
For n = 1 To N
S151
For m = 1 To M
S152
Apply Lens Correction
Val $RA_{LC}(n,m)$ = Val RA(n,m) x LC(n,m)
S153
Test For
Peak Or Background
If Val $RA_{LC}(n,m)$ > F
S154
YES
NO
S155
Test For Zone
If In Zone (z)
YES
NO
S156
P(z) = P(z) + 1
S157
$B_{Count} = B_{Count} + 1$
$B_{Sum} = B_{Sum}$ + Val $RA_{LC}(n,m)$
S158
S159
NO
Done m ?
YES
S160
NO
Done n ?
YES
S161
Calculate Uncorrected Background
Light Signal: $B_t = B_{Sum}/B_{Count}$
S162
Apply Color Correction To B_t & P(z)
$B_t = B_t$ x CC; P(z) = P(z) x CC
S163
Calculate Change Limited Background
Light Signal: $B_{Lt} = B_{L(t-1)} + C_L(B_t - B_{L(t-1)})$
To S180

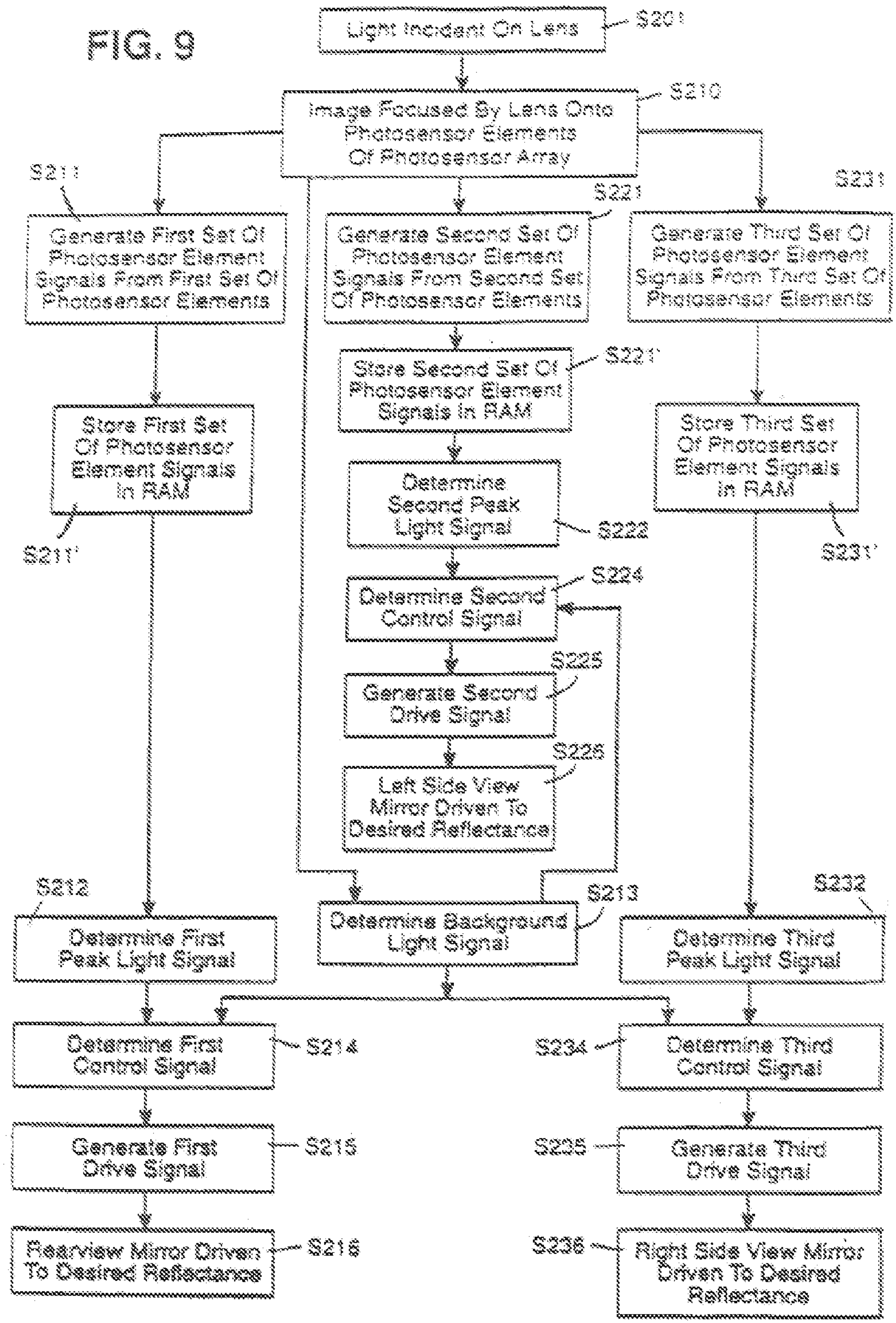
FIG. 8A

FIG. 8B

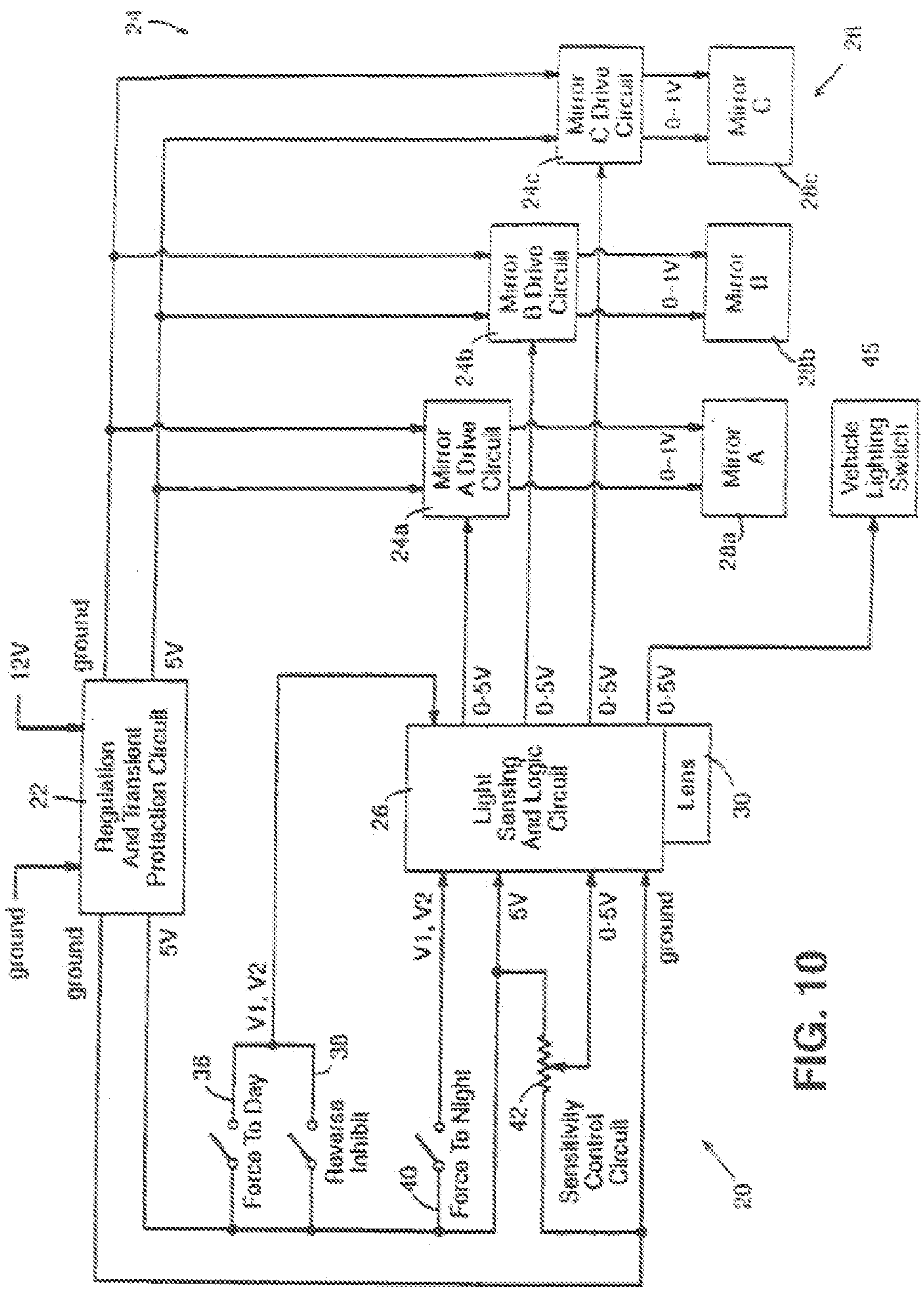


From S160
For Zone z = 1, 2, 3
S181
S182
Calculate Mirror Control Signals
$V_{DAC}(z) = 255 \times (V_1 - (R_1 - S \times C_T \times B_U/P(z)) \times (V_2-V_1)/(R_1-R_2))/V_2$
If IN1 = High
YES
S184
Set $V_{DAC}(z) = 0$
S183
NO
If IN2 = High
YES
S186
Set $V_{DAC}(z) = 0$
S185
NO
If IN3 = High
YES
S188
Set $V_{DAC}(z) = 255$
S187
NO
To S200

FIG. 9



Light Incident On Lens
S201
Image Focused By Lens Onto Photosensor Elements Of Photosensor Array
S210
S211
Generate First Set Of Photosensor Element Signals From First Set Of Photosensor Elements
S221
Generate Second Set Of Photosensor Element Signals From Second Set Of Photosensor Elements
S231
Generate Third Set Of Photosensor Element Signals From Third Set Of Photosensor Elements
Store First Set Of Photosensor Element Signals In RAM
S211'
Store Second Set Of Photosensor Element Signals In RAM
S221'
Store Third Set Of Photosensor Element Signals In RAM
S231'
Determine Second Peak Light Signal
S222
Determine Second Control Signal
S224
Generate Second Drive Signal
S225
Left Side View Mirror Driven To Desired Reflectance
S226
S212
Determine First Peak Light Signal
Determine Background Light Signal
S213
S232
Determine Third Peak Light Signal
Determine First Control Signal
S214
S234
Determine Third Control Signal
Generate First Drive Signal
S215
S235
Generate Third Drive Signal
Rearview Mirror Driven To Desired Reflectance
S216
S236
Right Side View Mirror Driven To Desired Reflectance



Regulation And Transient Protection Circuit
22
12V
ground
ground
ground
5V
5V
Light Sensing And Logic Circuit
26
Lens
30
0-5V
0-5V
0-5V
0-5V
V1, V2
V1, V2
5V
0-5V
ground
Force To Day
36
Reverse Inhibit
38
Force To Night
40
Sensitivity Control Circuit
42
20
Mirror A Drive Circuit
24a
Mirror B Drive Circuit
24b
Mirror C Drive Circuit
24c
24
0-1V
0-1V
0-1V
Mirror A
28a
Mirror B
28b
Mirror C
28c
28
Vehicle Lighting Switch
45

FIG. 10

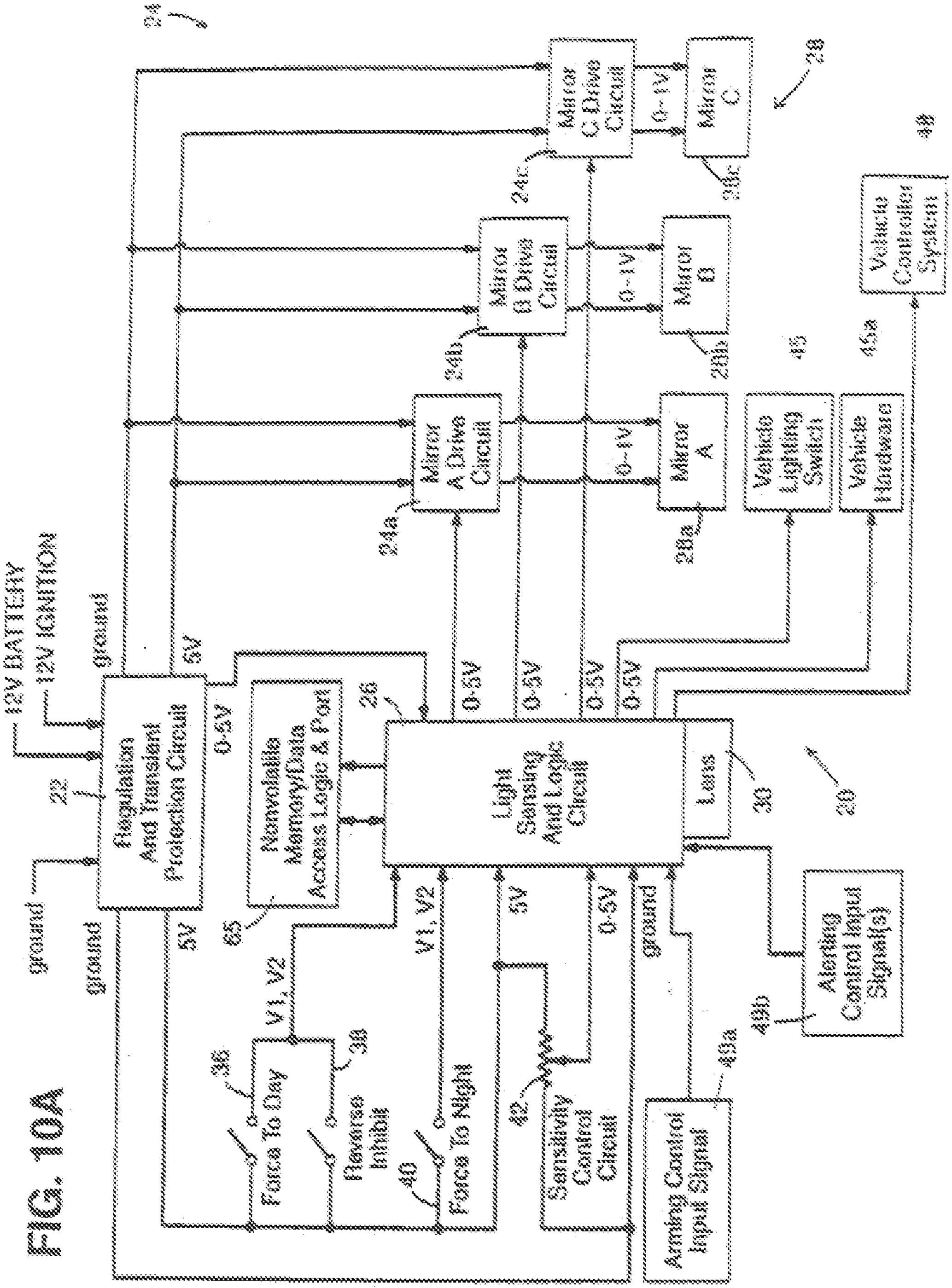

12V BATTERY
12V IGNITION
ground
Regulation And Transient Protection Circuit
22
5V
0-5V
Nonvolatile Memory/Data Access Logic & Port
65
26
Light Sensing And Logic Circuit
Lens
30
20
V1, V2
Force To Day
36
Reverse Inhibit
38
Force To Night
40
Sensitivity Control Circuit
42
Arming Control Input Signal
49a
Alerting Control Input Signal(s)
49b
Mirror A Drive Circuit
24a
Mirror B Drive Circuit
24b
Mirror C Drive Circuit
24c
24
0-1V
Mirror A
28a
Mirror B
28b
Mirror C
28c
28
Vehicle Lighting Switch
45
Vehicle Hardware
45a
Vehicle Controller System
48

FIG. 10A

FIG. 11A

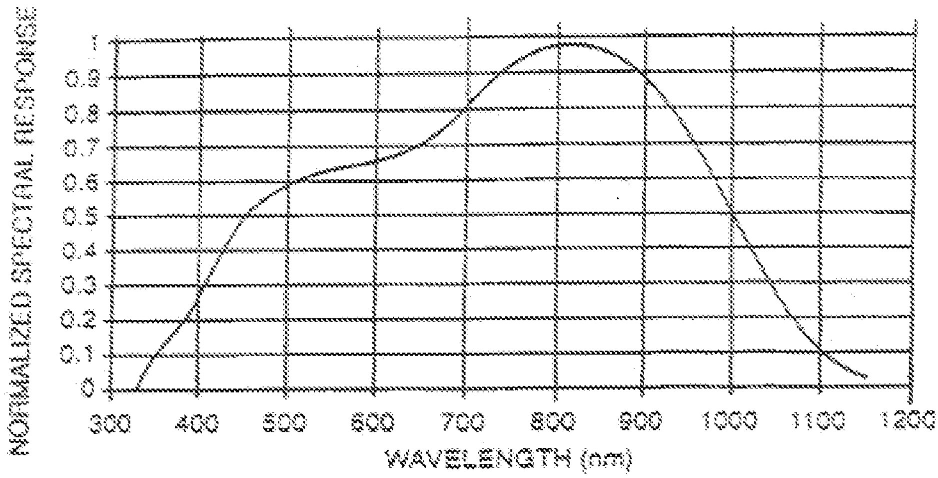


FIG. 11B

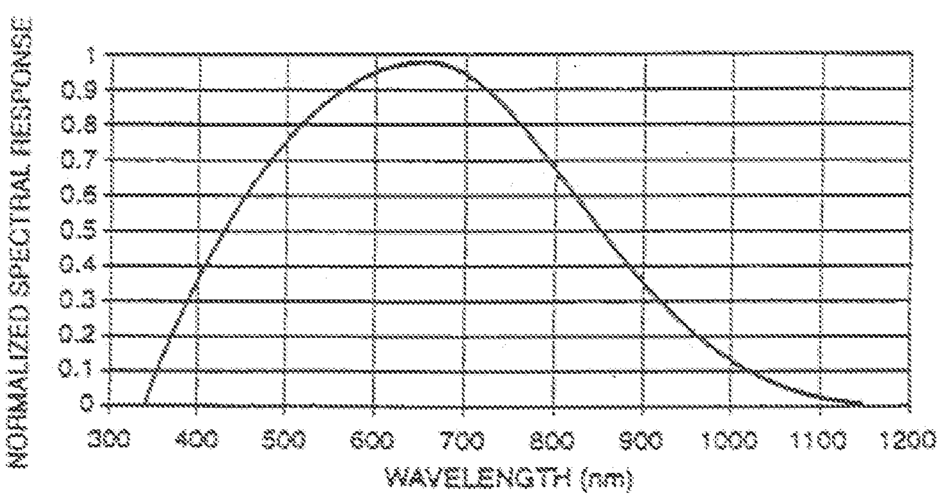


FIG. 12

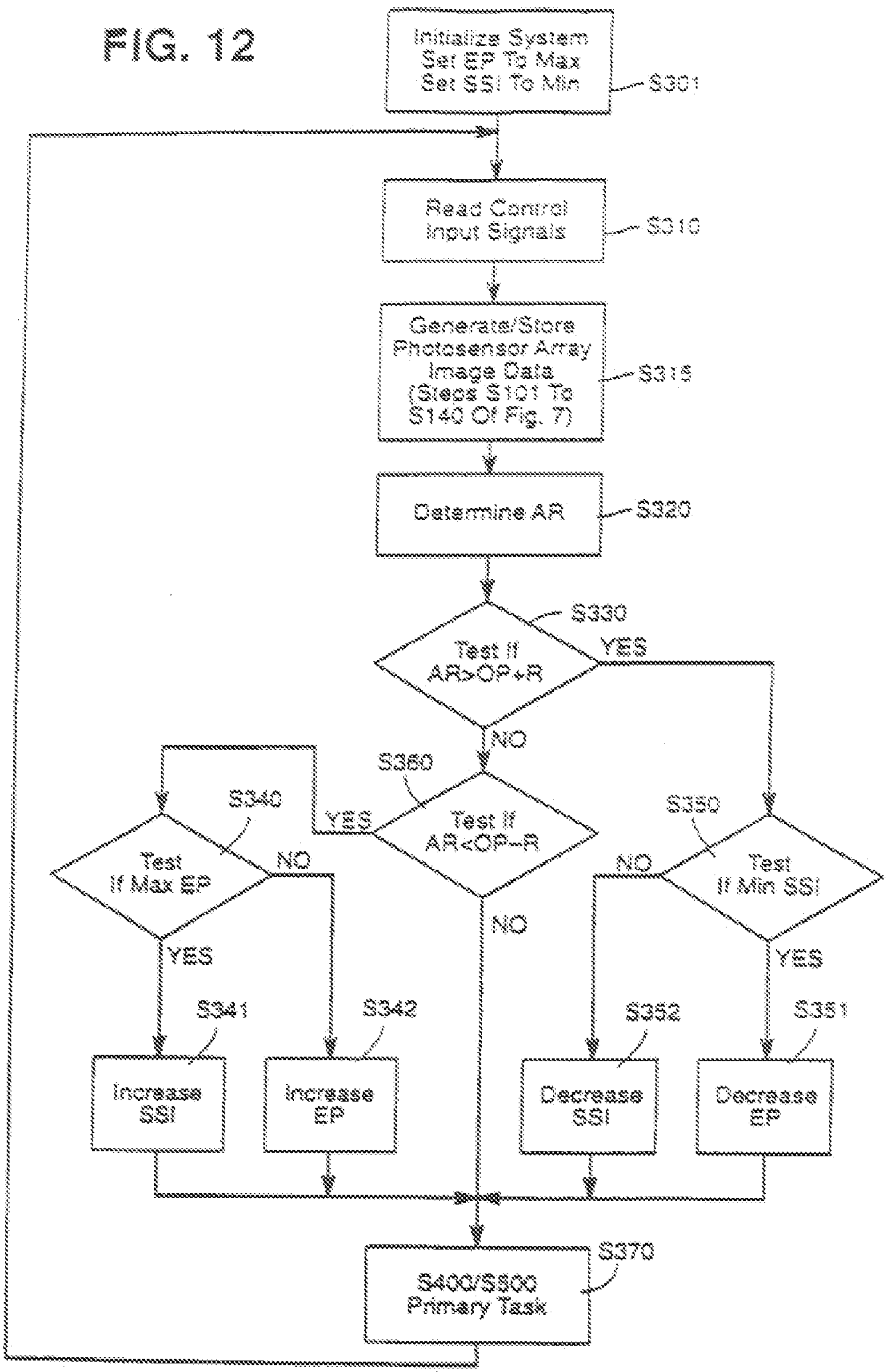

Initialize System
Set EP To Max
Set SSI To Min
S301
Read Control
Input Signals
S310
Generate/Store
Photosensor Array
Image Data
(Steps S101 To
S140 Of Fig. 7)
S315
Determine AR
S320
S330
Test If
AR>OP+R
YES
NO
S360
Test If
AR<OP−R
YES
NO
S340
Test
If Max EP
NO
YES
S350
Test
If Min SSI
NO
YES
S341
Increase
SSI
S342
Increase
EP
S352
Decrease
SSI
S351
Decrease
EP
S370
S400/S500
Primary Task

FIG. 12A

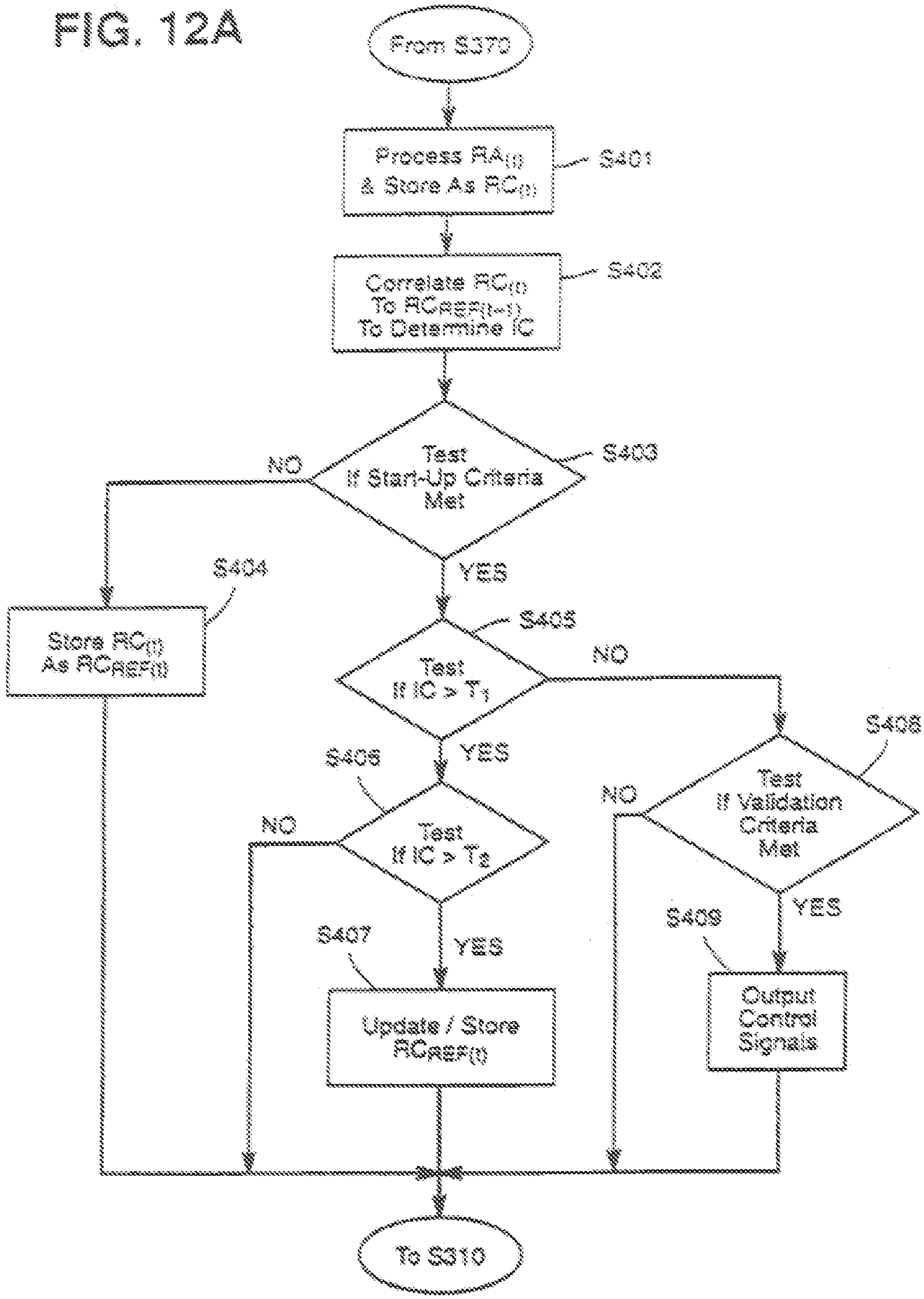
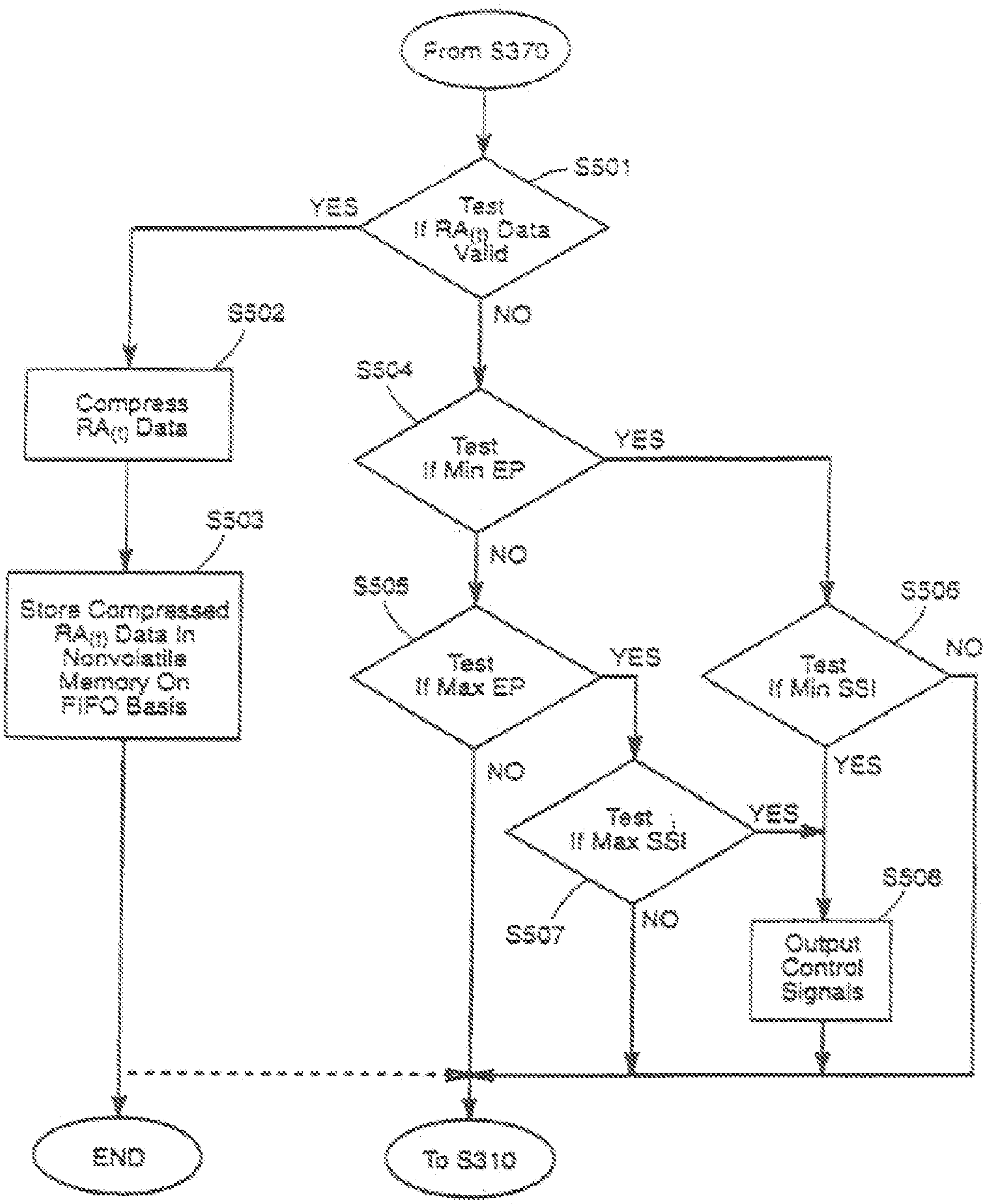

From S370
Process $RA_{(t)}$ & Store As $RC_{(t)}$
S401
Correlate $RC_{(t)}$ To $RC_{REF(t-1)}$ To Determine IC
S402
Test If Start-Up Criteria Met
S403
NO
YES
Store $RC_{(t)}$ As $RC_{REF(t)}$
S404
Test If IC > T_1
S405
NO
YES
Test If IC > T_2
S406
NO
YES
Update / Store $RC_{REF(t)}$
S407
Test If Validation Criteria Met
S408
NO
YES
Output Control Signals
S409
To S310

FIG. 12B


From S370
S501
Test
If $RA_{(t)}$ Data
Valid
YES
NO
S502
Compress
$RA_{(t)}$ Data
S503
Store Compressed
$RA_{(t)}$ Data In
Nonvolatile
Memory On
FIFO Basis
S504
Test
If Min EP
YES
NO
S505
Test
If Max EP
YES
NO
S506
Test
If Min SSI
NO
YES
Test
If Max SSI
YES
NO
S507
S508
Output
Control
Signals
END
To S310

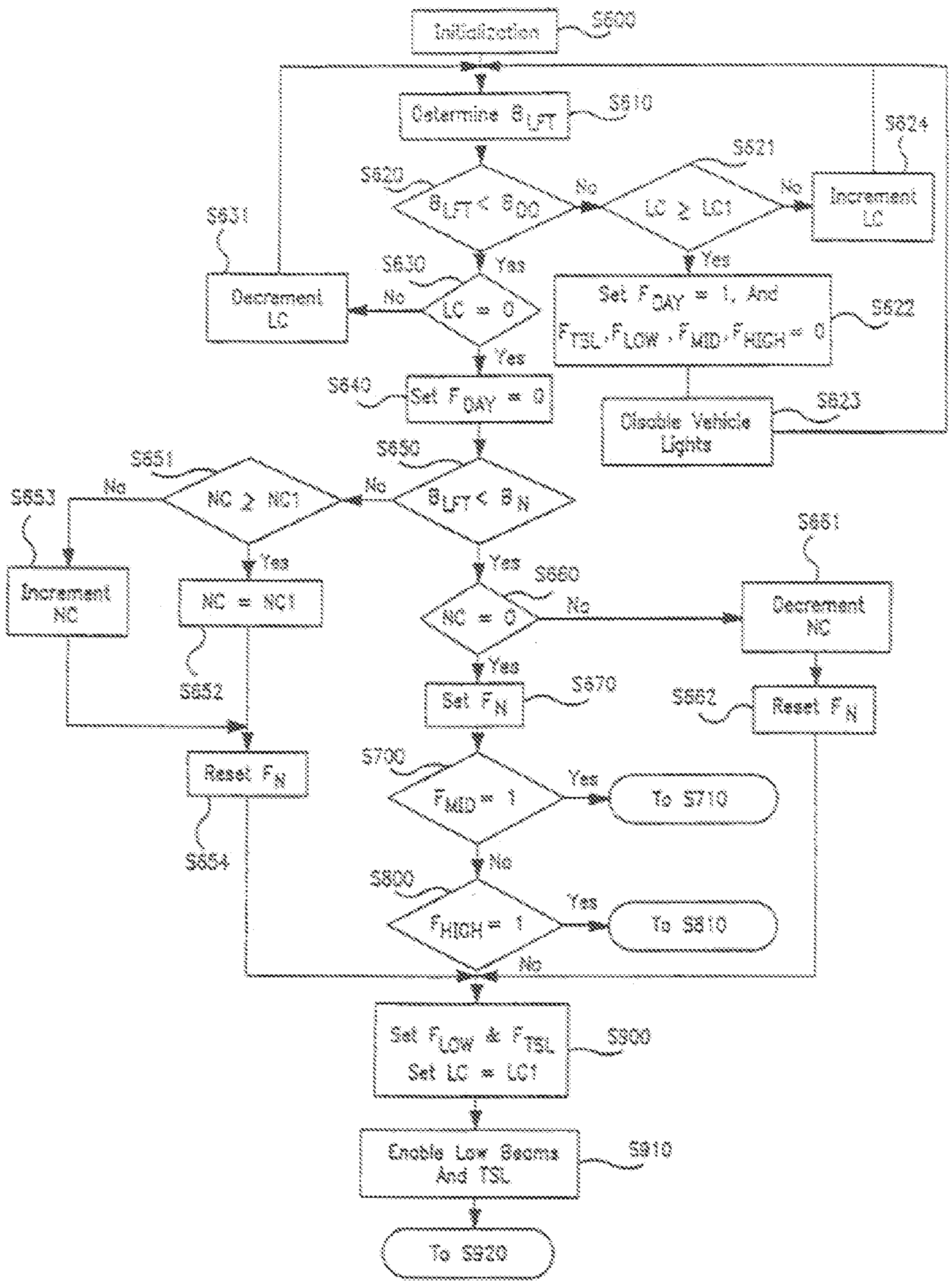

Initialization
S600
Determine B_{LFT}
S610
S624
S621
S620
$B_{LFT} < B_{DD}$
No
LC ≥ LC1
No
Increment LC
S631
S630
Yes
Yes
Decrement LC
No
LC = 0
Set F_{DAY} = 1, And
$F_{TSL}, F_{LOW}, F_{MID}, F_{HIGH}$ = 0
S622
Yes
S640
Set F_{DAY} = 0
Disable Vehicle Lights
S623
S651
S650
S653
No
NC ≥ NC1
No
$B_{LFT} < B_N$
S661
Yes
Yes
S660
Increment NC
NC = NC1
NC = 0
No
Decrement NC
S652
Yes
S670
Set F_N
S662
Reset F_N
Reset F_N
S700
Yes
F_{MID} = 1
To S710
S654
No
S800
Yes
F_{HIGH} = 1
To S810
No
Set F_{LOW} & F_{TSL}
Set LC = LC1
S900
Enable Low Beams And TSL
S910
To S920

FIG. 13A

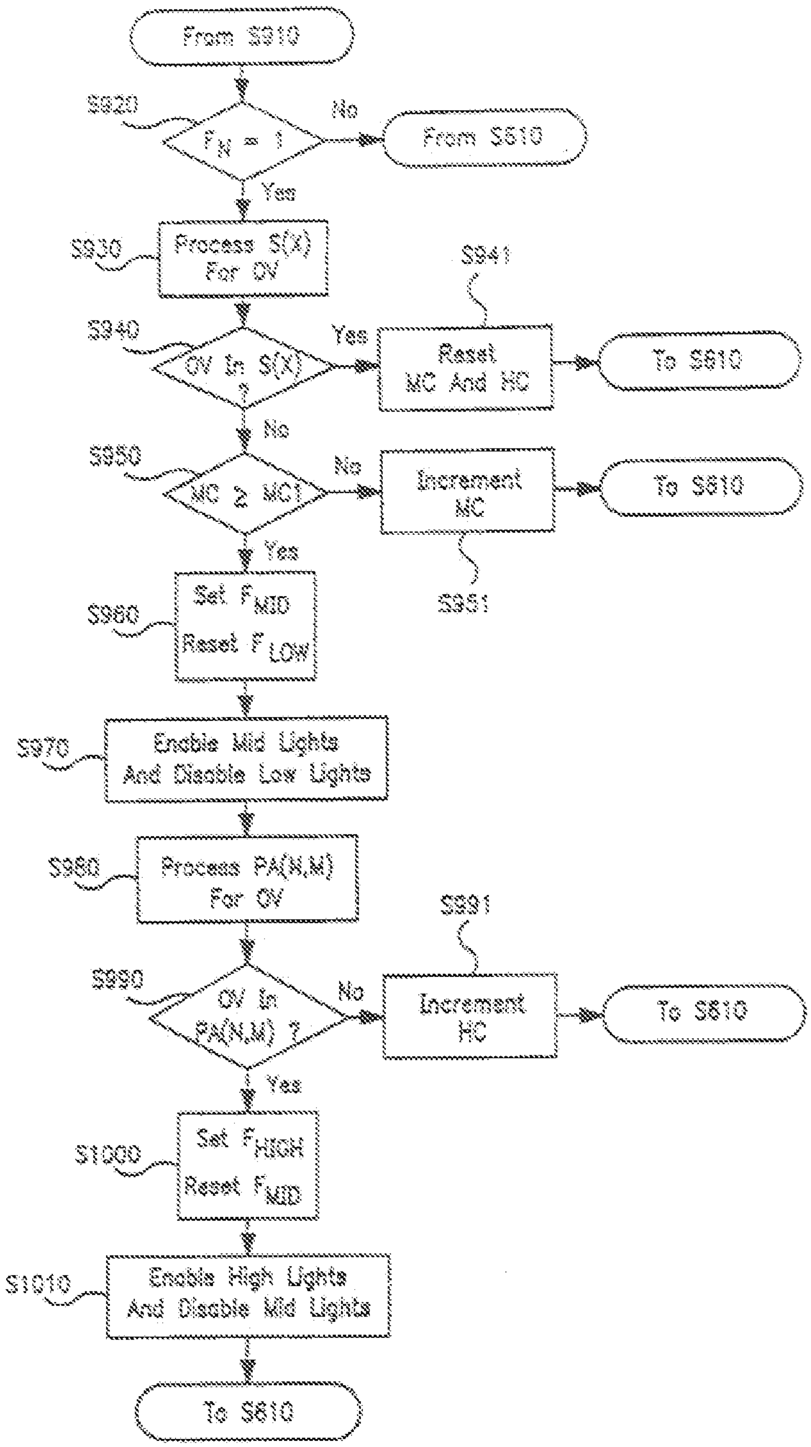

From S910
S920
F_N = 1
No
From S610
Yes
S930
Process S(X) For OV
S941
S940
OV In S(X) ?
Yes
Reset MC And HC
To S610
No
S950
MC ≥ MC1
No
Increment MC
To S610
Yes
S951
S960
Set F_MID
Reset F_LOW
S970
Enable Mid Lights And Disable Low Lights
S980
Process PA(N,M) For OV
S991
S990
OV In PA(N,M) ?
No
Increment HC
To S610
Yes
S1000
Set F_HIGH
Reset F_MID
S1010
Enable High Lights And Disable Mid Lights
To S610

FIG. 13B

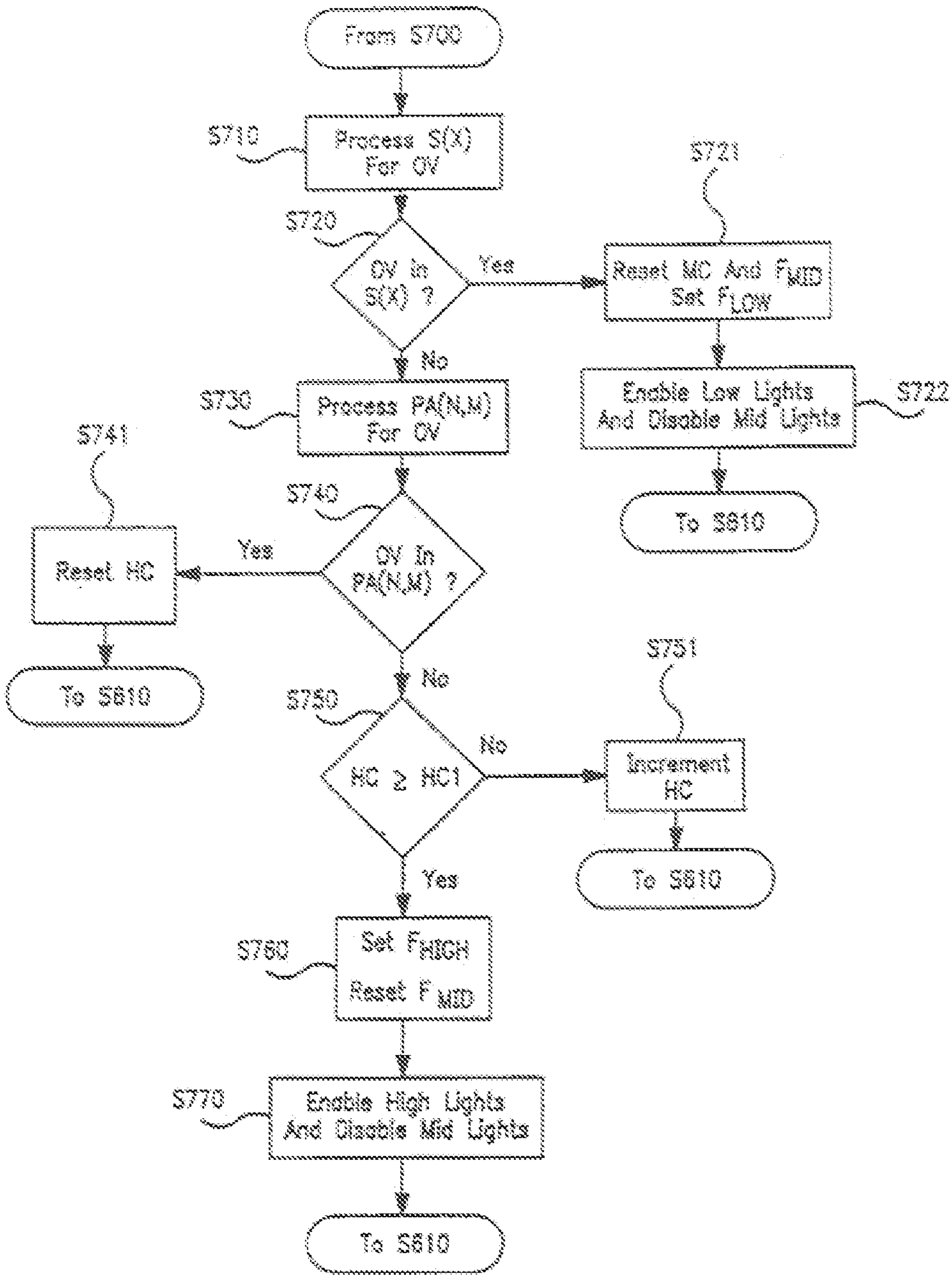
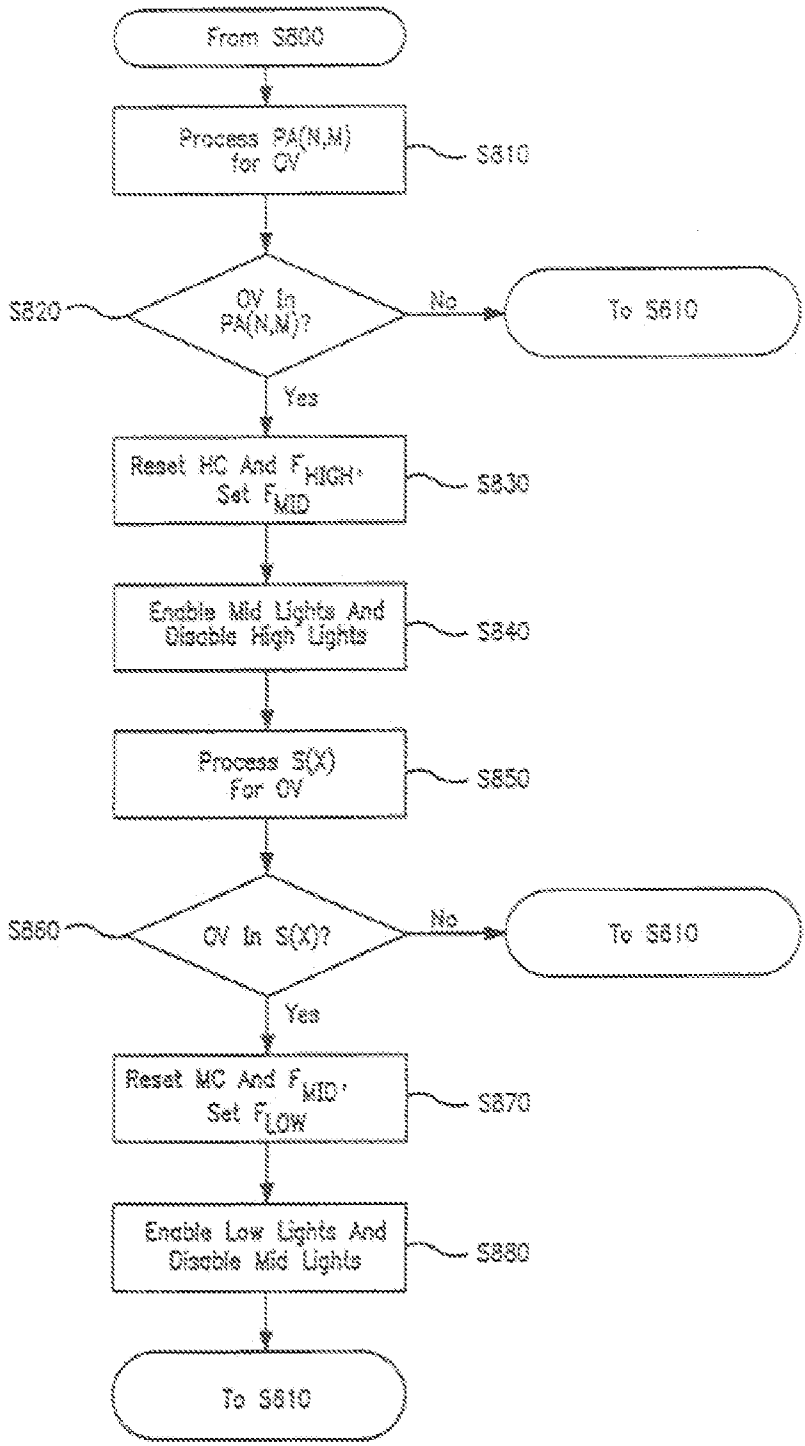

From S700
S710
Process S(X) For OV
S720
OV In S(X) ?
Yes
No
S721
Reset MC And F_{MID} Set F_{LOW}
Enable Low Lights And Disable Mid Lights
S722
To S610
S730
Process PA(N,M) For OV
S741
S740
OV In PA(N,M) ?
Yes
Reset HC
To S610
No
S750
S751
HC ≥ HC1
No
Increment HC
To S610
Yes
S760
Set F_{HIGH} Reset F_{MID}
S770
Enable High Lights And Disable Mid Lights
To S610

FIG. 13C



From S800
Process PA(N,M) for OV
S810
S820
OV In PA(N,M)?
No
To S810
Yes
Reset HC And F HIGH, Set F MID
S830
Enable Mid Lights And Disable High Lights
S840
Process S(X) For OV
S850
S860
OV In S(X)?
No
To S810
Yes
Reset MC And F MID, Set F LOW
S870
Enable Low Lights And Disable Mid Lights
S880
To S810

FIG. 13D

VEHICULAR VISION SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of prior application Ser. No. 13/525,763, filed Jun. 18, 2012, now U.S. Pat. No. 8,314, 689, which is a continuation of prior application Ser. No. 13/351,098, filed Jan. 16, 2012, now U.S. Pat. No. 8,203,440, which is a continuation of prior application Ser. No. 11/074, 521, filed Mar. 8, 2005, now U.S. Pat. No. 8,098,142, which is a continuation of application Ser. No. 10/940,700, filed Sep. 14, 2004, now U.S. Pat. No. 6,953,253, which is a continuation of application Ser. No. 10/372,873, filed Feb. 24, 2003, now U.S. Pat. No. 6,802,617, which is a continuation of application Ser. No. 09/975,232, filed Oct. 11, 2001, now U.S. Pat. No. 6,523,964, which is a continuation of application Ser. No. 09/227,344, filed Jan. 8, 1999, now U.S. Pat. No. 6,302,545, which is a continuation of application Ser. No. 08/478,093, filed on Jun. 7, 1995, now U.S. Pat. No. 5,877, 897.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an automatic rearview mirror system for automotive vehicles which automatically changes reflectance level in response to glare causing light, and more particularly relates to an improved automatic rearview mirror system using only a rearwardly facing sensor. This invention further relates to an automatic rearview mirror and vehicle interior monitoring system for automotive vehicles which also monitors a vehicle interior or compartment. This invention further relates to an automatic rearview mirror and vehicle interior monitoring system for automotive vehicles which may also be used as a vehicle intrusion detection system or as a compartment image data storage system. This invention further relates to an automatic rearview mirror and a vehicle lighting control system using an image sensor, such as a photosensor array.

2. Description of Related Art

Automatic rearview mirrors and mirror systems have been devised for varying the reflectance level of a variable reflectance rearview mirror by reducing the reflectance automatically in response to annoying glare light, as seen rearwardly of the rearview mirror or mirrors by a driver of the vehicle, and by increasing automatically the reflectance to a normal or maximum reflectance level when the annoying glare light subsides. These automatic mirrors have been changed over the years in an effort to improve their performance characteristics and associated level of glare protection.

Early automatic rearview mirrors used a rearwardly facing sensor and control circuit to change mirror reflectance. One example of such a "single-sensor" type mirror is described in U.S. Pat. No. 4,266,856. In these prior art single-sensor type mirrors, the rear glare light was incident on a rearwardly facing sensor or photocell, such as a photodiode, photoresistor or phototransistor. These mirrors suffered from various problems, however, including the problem that these mirrors would become increasingly sensitive and even "lock-up" in their minimum reflectance level or state as the driver encountered significantly higher light levels in town or city driving. This required the driver to repeatedly adjust the mirror's sensitivity control to prevent such problems.

To overcome the problems of single-sensor type mirrors, a non-rearwardly facing photocell for sensing "ambient" light was added. It was believed that the desired reflectance nec-

essary to relieve the driver from glare depended not only on glare light but also on ambient light. Accordingly, these "two-sensor" type mirrors used two separate photocells, one generally facing rearwardly and one generally facing forwardly (or other non-rearwardly facing direction) of the mirror or vehicle. The signals from these two photocells were then compared in some fashion, and when, for example, the glare light from the rear was comparatively high with respect to the "ambient" light, a control circuit would apply a control signal to reduce mirror reflectance. Some examples are described in German Laid-Open Patent No. 3,041,692; Japanese Laid-Open Patent No. 58-19941; and U.S. Pat. Nos. 3,601,614; 3,612,666; 3,680,951; 3,746,430; 4,443,057; 4,580,875; 4,690,508; and 4,917,477. In many of these prior art automatic rearview mirrors, light generally forward of the mirror or vehicle was incident on the second photocell.

These arrangements, however, also had problems. In some of these mirrors the forwardly facing or "ambient" light sensor was inaccurate because it did not correctly measure ambient light levels since it did not include light generally rearward of the mirror or vehicle. Some examples include the devices described in U.S. Pat. Nos. 4,443,057 and 4,917,477. Other prior art devices overcame these deficiencies by providing a control circuit which correctly measured ambient light as a combination of both the forward and rear light levels. Examples of this significantly different approach are described in U.S. Pat. Nos. 4,793,690 and 4,886,960.

The prior art two-sensor type systems generally provided improved performance over prior art single sensor type systems but were also more complex and costly. In part, this was because using separate forwardly and rearwardly facing photocells required that the performance characteristics of the two separate photocells, such as photoresistors, be matched appropriately to ensure consistent performance under various operating conditions. Matching photocells such as photoresistors, however, generally involves complex, expensive and time consuming operations and procedures.

Both the prior art single-sensor and two-sensor type mirrors presented additional problems when they were also used to control the exterior side view mirrors. This is because such prior art systems used a common control or drive signal to change the reflectance level of both the interior rearview mirror and the exterior left and/or right side view mirrors by substantially the same amount. In U.S. Pat. No. 4,669,826, for example, a single-sensor type mirror system used two rearwardly facing photodiodes to control both an interior rearview mirror and the left and/or right side view mirrors based on the direction of incident light from the rear. Another example includes the two-sensor type system described in U.S. Pat. No. 4,917,477.

In rearview mirror systems, however, each of the interior rearview and exterior side view mirrors may reflect different source light levels. More specifically, the inside rearview mirror, left side view mirror and right side view mirror each enable the driver to view a different portion or zone of the total rearward area. Of course, there may be some overlap of the image information contained in each of the three zones. The situation is further complicated with multi-lane traffic because each of the mirrors reflects different light levels caused by the headlights of the vehicles which are following passing or being passed. As a result, in the prior art systems, when the reflectance level of the interior rearview mirror was reduced to decrease the glare of headlights reflected therein, the reflectance level of the exterior left and right side view mirrors was also reduced by substantially the same amount, even though, for example, the side view mirrors might not be reflecting the same level of glare light, if any. Accordingly, rear vision in the exterior left and right side view mirrors could be improperly reduced.

Other prior art two-sensor type systems used a common ambient light sensor and several rearwardly facing sensors, one for each of the mirrors. An example is the alternate system also described in U.S. Pat. No. 4,917,477. This approach is not satisfactory, however, because it reduces system reliability and increases complexity and cost.

Finally, some prior anti-glare mirrors used several sensors to control the segments of a variable reflectance mirror. One example is disclosed in U.S. Pat. No. 4,632,509, which discloses a single-sensor type mirror using three rearwardly facing photocells to control three mirror segments depending on the direction of incident light from the rear. See also U.S. Pat. No. 4,697,883. These prior mirror systems generally have the same problems as the other single sensor type mirrors. Some other anti-glare mirrors are generally disclosed in U.S. Pat. Nos. 3,986,022; 4,614,415; and 4,672,457.

Consequently, there is a need for an automatic rearview mirror system for an automotive vehicle having improved reliability and low cost, which accurately determines or otherwise discriminates light levels that the driver will experience as glare without the need for a separate forwardly facing photocell. In addition, as noted above, there is also a need for an automatic rearview mirror system of high reliability and low cost, which accurately determines light levels that the driver will experience as glare, and which can control independently the reflectance of a plurality of mirrors according to the light levels actually reflected by each of the rearview and exterior side view mirrors without the need for additional and separate rearwardly facing photocells. There is also a need for an automatic rearview mirror-system that can independently control the segments of a variable reflectance mirror while accurately determining light levels that the driver will experience as glare in each segment of the mirror without the need for additional and separate forwardly and rearwardly facing photocells.

One concern with automatic rearview mirror systems, as well as other systems having sensing, control or logic circuits located in the rearview mirror, is that differences in vehicle design and mirror field of view requirements may result in rearview mirrors having a variety of appearances (or finishes), forms (or shapes) and sizes. These variations, generally require the redesign and re-tooling of a number of the components or sub-assemblies of the rearview mirror head assembly. However, it is generally desirable to reduce the number of components or sub-assemblies of the rearview mirror head assembly so as to reduce cost, product development lead time and manufacturing complexity. To achieve this in automatic rearview mirrors, as well as other systems having sensing, control or logic circuits located in the rearview mirror, it is desirable to locate the sensing, control or logic circuits and related components in a housing or module, which is attached, connected, made integral with or otherwise associated with the rearview mirror mounting bracket means or structure so that a common design of a mounting bracket sub-assembly for a rearview mirror may be used with a variety of rearview mirror head assemblies.

Vehicle lighting systems may include a variety of vehicle lights, including low intensity peripheral or side lights that allow other vehicle drivers to see the vehicle in lower light conditions, high intensity headlights that operate in a low beam mode or a high beam mode for general night driving, and fog lights that provide low ground lighting with less back scattering to improve the driver's views in adverse weather conditions, such as fog, rain and snow. Vehicle lighting systems may also include headlights having an intermediate or mid beam mode, as well as the low and high beam modes. Vehicle lighting systems may also include vehicle running lights, which are vehicle headlights that are operated at an appropriate intensity to improve the ability of other vehicle drivers to see the vehicle during the day. Vehicle running lights may also be used for lower lighting conditions, such as certain adverse weather conditions or other lower visibility conditions.

Thus, as the number of vehicle lighting options has increased, it has become more complex for the driver to determine the appropriate vehicle lighting configuration and to operate or control the vehicle lighting systems. Therefore, improved vehicle lighting control systems are required that may operate with other systems, such as automatic rearview mirror systems and vehicle interior monitoring systems, or as stand-alone systems.

Finally, unauthorized vehicle intrusion for the purpose of stealing the vehicle or its contents is a significant problem. Each year, automotive manufacturers are including vehicle anti-theft or intrusion detection systems on more vehicles to deter potential intruders and to prevent the theft of vehicles or their contents. Currently known vehicle anti-theft systems are generally designed to protect the vehicle or its contents from theft or vandalism. There are many versions of vehicle anti-theft systems using various sensor technologies that attempt to deter theft or vandalism using the horn, siren or flashing lights, or other alarm, mechanisms to bring attention to a vehicle. As is known, existing intrusion detection systems for vehicles use sensor technologies that have various limitations, including the problem of false triggering. For example, in many cases active vehicle alarms are simply ignored by people who assume that the alarm was falsely triggered. The proliferation of separate automatic rearview mirror systems and vehicle intrusion detection systems is also costly. Therefore, vehicle intrusion detection systems using an improved sensor technology are required that operate in combination with other vehicle systems (such as automatic rearview mirror systems) or that operate independently.

Even with such anti-theft systems, recovered stolen vehicles typically provide little or no evidence of the vehicle thief. Therefore, systems are required that provide an image of the vehicle thief that would be useful to law enforcement and the insurance industry as an aid in identifying the person(s) responsible for the vehicle theft, and that operate in combination with other vehicle systems (such as automotive rearview mirror systems) or that operate independently.

SUMMARY OF THE INVENTION

It is an object of the present invention to overcome the problems of the prior art.

It is another object of the present invention to provide an automatic rearview mirror system of improved reliability.

It is yet another object of the present invention to provide an automatic rearview mirror system that accurately determines light levels that the driver will experience as glare without the need for a separate forward facing sensor or other non-rearwardly facing photocells.

It is another object of the present invention to provide an automatic rearview mirror system of high reliability that accurately determines light levels that, the driver will experience as glare, and which can independently control a plurality of mirrors or mirror segments according to different fields of view without the need for additional and separate rearwardly facing photocells.

According to one aspect of the present invention, using a photosensor array and an appropriate control circuit allows the elimination of separate forwardly facing or other non-rearwardly facing photocells, thereby allowing for lower costs and increased reliability since it is not necessary to match two separate photocells such as photoresistors.

According to another aspect, the present invention which achieves one or more of these objectives relates to a control system for controlling a plurality of variable reflectance mirrors or mirror segments which change their reflectance in response to a signal from a drive circuit. The system comprises a plurality of variable reflectance mirrors, a photosensor array and a control circuit receiving signals from the photosensor array for controlling the mirrors. The photosensor array is mountable to view rearwardly of the mirror or vehicle. The photosensor array comprises a plurality of sets of photosensor elements corresponding to the plurality of variable reflectance mirrors. The photosensor elements in each set produce a plurality of photosensor element signals in response to light incident thereon. The control circuit determines control signals, indicative of a desired reflectance for each of the plurality of variable reflectance mirrors, in response to receiving photosensor element signals from the photosensor element set for each view or zone corresponding to the rearview mirror and exterior side view mirrors and also (or alternatively) the mirror segments. The control signals control the drive circuit to cause the plurality of variable reflectance mirrors or mirror segments to assume the desired reflectance.

According to another aspect, the present invention which achieves one or more of these objectives relates to an automatic rearview mirror system for an automotive vehicle comprising at least one variable reflectance rearview mirror, and an array of sensing elements to sense light levels in an area rearward of the at least one variable reflectance rearview mirror. Each of the sensing elements is adapted to sense light levels of light incident thereon and to output an electrical signal indicative of the sensed light levels. The system further comprises a signal processor, connected to the array of sensing elements, receiving and using the electrical signals indicative of the sensed light levels from the sensing elements to determine a first electrical signal indicative of a background light level in the area rearward of the at least one variable reflectance rearview mirror and to determine a second electrical signal indicative of at least one peak light level in the area rearward of the at least one variable reflectance rearview mirror. The signal processor determines at least one control signal indicative of the desired reflectance level of the at least one variable reflectance rearview mirror from the first electrical signal indicative of the background light level and the second electrical signal indicative of the at least one peak light level. The system further comprises at least one drive circuit connected to the signal processor and to the at least one variable reflectance rearview mirror for receiving the at least one control signal and generating and applying at least one drive signal to the at least one variable reflectance rearview mirror to drive the at least one variable reflectance mirror to the desired reflectance level.

According to another aspect, the present invention which achieves one or more of these objectives relates to a control system for controlling a plurality of variable reflectance mirrors, each of which change their reflectance level in response to a drive signal from an associated drive circuit, for an automotive vehicle. The system comprises a plurality of variable reflectance mirrors, and a photosensor array mountable to face substantially towards a rear area. The photosensor array comprises a plurality of photosensor element sets. Each set comprises a plurality of photosensor elements. Each of the photosensor elements generates a photosensor element signal indicative of a light level of light incident thereon, and each of the sets corresponds to one of the plurality of variable reflectance mirrors. The system further comprises a control circuit, connected to the photosensor array, for determining and applying a plurality of control signals. Each of the control signals is indicative of a desired reflectance level for each of the plurality of variable reflectance mirrors in response to receiving the photosensor element signals from each of the plurality of photosensor element sets. The system further comprises a plurality of drive circuits connected to the control circuit and to different ones of the plurality of variable reflectance mirrors associated therewith. Each of the control signals is output to the drive circuit associated therewith, to generate and apply a drive signal to each of the plurality of variable reflectance mirrors causing each of the mirrors to assume a desired reflectance level.

According to another aspect, the present invention which achieves one or more of these objectives relates to a control system for controlling at least one variable reflectance mirror for an automotive vehicle. The system comprises photosensor array means for sensing light levels in an area rearward of the at least one variable reflectance mirror and generating photosensor array signals, means for determining a background light signal from the photosensor array signals, means for determining a peak light signal from the photosensor array signals, and means for controlling a reflectance level of the at least one variable reflectance mirror using the background and peak light signals.

According to another aspect, the present invention which achieves one or more of these objectives relates to a method of controlling the reflectance of at least one variable reflectance mirror comprising the steps of sensing light levels in an area rearward of the at least one variable reflectance mirror with an array of sensing elements, determining a background light level from the sensed light levels, determining a peak light level from the sensed light levels, and controlling a reflectance level of the at least one variable reflectance mirror using the determined background and peak light levels.

By using a plurality of photosensor element sets or sub-arrays on a photosensor array to control a plurality of mirrors and also (or alternatively) mirror segments, the mirrors may be controlled independently to vary their reflectance in accordance with the view associated with each of the photosensor element sets or sub-arrays.

According to another aspect the present relates to an automatic rearview mirror system for an automotive vehicle comprising a variable reflectance rearview mirror, a photosensor array means for sensing light levels in an area rearward of said variable reflectance rearview mirror and for generating photosensor array signals, a signal processing means for receiving said photosensor array signals and for determining from said photosensor array signals a signal for controlling said variable reflectance rearview mirror, and a mounting bracket means for attaching said variable reflectance rearview mirror to said automotive vehicle, said mounting bracket means further comprising a housing means for housing said photosensor array means and said signal processing means.

According to another aspect the present relates to a vehicle lighting control system for controlling a vehicle lighting system in an automotive vehicle comprising a photosensor array means for sensing light levels in a forward field of view and generating a set of photosensor array signals, and a signal processing means coupled to said photosensor array means for receiving said set of photosensor array signals and determining from said set of photosensor array signals at least one control signal for controlling said vehicle lighting system.

According to another aspect, the present invention relates to a control system for monitoring a vehicle interior and for controlling at least one variable reflectance mirror for an automotive vehicle. The system comprises photosensor array means for sensing light levels in an area rearward of said photosensor array means and generating at least a first set of photosensor array signals, first determining means coupled to said photosensor array means for receiving said at least a first set of photosensor array signals and determining from at least a portion of said at least a first set of photosensor array signals a first signal for controlling said at least one variable reflectance mirror, second determining means coupled to said photosensor array means for receiving said at least a first set of photosensor array signals and determining at least a first set of values indicative of said at least a portion of said at least a first set of photosensor array signals, and memory means coupled to said second determining means for receiving and storing said at least a portion of said at least a first set of photosensor array signals.

According to another aspect, the present invention relates to a vehicle intrusion detection system for detecting movement within a vehicle interior for an automotive vehicle. The system comprises photosensor array means for sensing light levels in an area including at least a portion of a vehicle interior and generating at least a first set and a second set of photo sensor array signals, determining means coupled to said photosensor array means for receiving said at least a first set and a second set of photosensor array signals and determining at least a first set and a second set of values indicative of said at least a first set and a second set of photosensor array signals, and comparing means coupled to said determining means for receiving said at least a first set and a second set of values indicative of said at least a first set and a second set of photosensor array signals and comparing said at least a first set and a second set of values to generate at least one output control signal indicative of the correlation between said at least a first set and a second set of values.

According to another aspect, the present invention relates to a compartment image data storage system for an automotive vehicle. The system comprises photosensor array means for sensing light levels in at least a portion of a vehicle compartment and generating at least a first set of photosensor array signals, determining means coupled to said photosensor array means for receiving said at least a first set of photosensor array signals and determining at least a first set of values indicative of said at least a first set of photosensor array signals, and memory means coupled to said determining means for receiving and storing said at least a first set of values indicative of said at least a first set of photosensor array signals.

These and other objects, advantages and features of the present invention will be readily understood and appreciated with reference to the detailed description of preferred embodiments discussed below together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a drawing of an automatic rearview mirror of the present invention, including an expanded view of a rearwardly facing photosensor array located in the upper center area of the mirror surface;

FIG. **1**B is another drawing of an automatic rearview mirror of the present invention, including an expanded view of the rearwardly facing photosensor array alternatively located in a bezel or chin of the mirror;

FIG. **1**C is a diagram of an automatic rearview mirror of the present invention, in which the photosensor array and logic and control circuit are located in a housing or module that is attached, connected, made integral or otherwise associated with the rearview mirror mounting bracket structure;

FIG. **1**D is a side sectional view of the automatic rearview mirror of FIG. **1**C;

FIG. **2** is a drawing of an automotive vehicle with the automatic rearview mirror system of the present invention;

FIG. **2**A is an illustrative diagram of a rearward area of a vehicle interior as viewed by the photosensor elements of the photosensor array for monitoring the vehicle interior;

FIGS. **3**A and **3**B are illustrative diagrams of a rearward area as viewed by the photosensor elements of the photosensor array;

FIG. **4**A is a generalized diagram of a photosensor array PA(N,M) having a sub-array S(X);

FIG. **4**B is a generalized diagram of the photosensor array PA(N,M) and sub-arrays S(**0**), S(**1**), S(**2**) and S(**3**);

FIG. **5** is another schematic diagram of the photosensor array commonly located on a light sensing and logic circuit;

FIG. **6** is a schematic block diagram of the automatic rearview mirror system;

FIG. **6**A is a schematic block diagram of the automatic rearview mirror and vehicle interior monitoring system;

FIG. **6**B is a schematic block diagram of a vehicle lighting control system having a photosensor array that has a forward field of view;

FIG. **7** is a flow chart illustrating the method of the present invention for controlling the reflectance of a rearview mirror or mirrors;

FIGS. **8**A and **8**B are detailed flow charts for steps S**150**, S**160** and S**180** of FIG. **7**;

FIG. **9** is a flow chart of the general logic flow of FIGS. **7**, **8**A and **8**B for controlling the reflectance of three mirrors;

FIG. **10** is another schematic block diagram of the automatic rearview mirror system of the present invention;

FIG. **10**A is a schematic block diagram of the automatic rearview mirror and/or vehicle interior monitoring system of the present invention;

FIG. **11**A illustrates the normalized spectral response of the photosensor array made using a non-epitaxial silicon process;

FIG. **11**B illustrates the normalized spectral response of the photosensor array made using an epitaxial silicon process;

FIG. **12** is a flow chart illustrating the method of the present invention of the vehicle interior monitoring system;

FIG. **12**A is a flow chart illustrating the method of the present invention for a vehicle intrusion detection system configuration of the vehicle interior monitoring system of FIG. **12**;

FIG. **12**B is a flow chart illustrating the method of the present invention for the compartment image data storage system configuration of the vehicle interior monitoring system of FIG. **12**; and

FIGS. **13**A, **13**B, **13**C and **13**D are flow charts illustrating the method of the present invention for controlling a vehicle lighting system.

DESCRIPTION OF PREFERRED EMBODIMENTS

I. The Automatic Rearview Mirror System

FIG. **1**A illustrates an automatic rearview mirror **1** comprising a variable reflectance mirror element **1***a* and a single rearwardly facing photosensor **2**. The photosensor **2** is mounted facing rearwardly of the rearview mirror **1** so that its field of view encompasses an area comprising a rear window area and at least a portion of either or both side window areas. Also shown is a switch **3** to allow a driver to manually control several possible mirror functions, such as an on-off control switch, a sensitivity adjustment and a force-to-day or a force-to-night switch (i.e., forced maximum or minimum reflectance levels, respectively). An expanded view of the photosensor **2**, which is preferably located in an upper center area of the variable reflectance mirror element **1***a* as shown, shows a light sensing and logic circuit **26** comprising a photosensor array **32** and a logic and control circuit **34** (which is not shown in FIG. **1**A but is shown in FIG. **6** as discussed below). A photosensitive surface of each of the photosensor elements **32***a* (shown in FIG. **5**) of the photosensor array **32** senses light levels or image information in a predetermined field of view encompassing an area located rearwardly of the rearview mirror **1**. A lens **30** images or otherwise focuses the light information from the predetermined field of view onto the photosensor array **32**.

The rearview mirror **1** further comprises a channel mount **1***b* or other mounting means used to fixedly attach the mirror **1** to the windshield or headliner area of the vehicle. The rearview mirror **1** is generally adjustable with respect to the channel mount **1***b* to allow a driver to position the mirror for correct viewing of the rearward area or scene so that the driver's sightline through the rearview mirror **1** is aligned approximately with the vehicle's centerline.

Preferably, the photosensor **2** is fixedly mounted on the adjustable portion of the rearview mirror **1** as shown in both FIGS. **1**A and **1**B so that the viewing axis of the photosensor **2** is generally aligned with the viewing axis of the mirror **1** which is perpendicular to the glass surface of the mirror **1**. This approach is preferable both because of packaging concerns and because it provides a guaranteed sightline. It is, however, within the scope of the present invention to mount the photosensor array **32** so that it is movable with respect to the variable reflectance mirror element **1***a* of the rearview mirror **1**.

More preferably, as shown in FIG. **1**A, the photosensor **2** is located in the upper center area of the variable reflectance mirror element **1***a*. This may be required, for example, if it is necessary to reduce the bezel size of the rearview mirror **1**. If the photosensor **2** is located behind a glass surface of the variable reflectance mirror element **1***a*, an appropriately sized hole is provided in the protective and reflective materials of the variable reflectance mirror element **1***a*. Additionally, a corresponding area within an active layer of the variable reflectance mirror element **1***a* may be removed or otherwise rendered inactive to enable the photosensor **2** to view directly the rearward scene. Alternatively, for manufacturing reasons, the photosensor **2** may view the rearward scene through the active layer of the variable reflectance mirror element **1***a*, in which case it is preferable to compensate for or otherwise negate the effects of reducing reflectance and correspondingly the transmittance of the variable reflectance mirror element **1***a* so that the photosensor **2** effectively views the rearward scene directly as will be described later.

Most preferably, a reflective surface is maintained within the hole to both preserve the cosmetic appearance of the assembly as viewed by the driver and to maximize the reflective surface. This can be achieved by providing a very thin metal reflective layer (100 A thickness or lower) of aluminum, stainless steel, chromium, or silver, etc., so as to be sufficiently transmitting for incident light to enable proper operation of the photosensor array **32** but also sufficiently reflective to appear mirror-like in the area of the hole. Alternatively, a reflective tape, which is both sufficiently transmitting and reflective to achieve the objectives described herein, may be adhered at the hole region using suitable means such as an optical adhesive and the photosensor array **32** may then be mounted behind the optical adhesive. Additionally, thin film stacks such as a solid state tri-layer of wave TiO_2, ¼ wave SiO_2 and ¼ wave TiO_2 or some other single thin film of a high index material may be mounted behind or coated upon the area of the hole. Finally, since the preferred photosensor array **32** is responsive to both visible light and near infrared, it is preferable to select a material which reflects a significant proportion of visible light while being essentially transparent to infrared.

As shown in FIG. **1**B, the photosensor **2** may also be located in the bezel or chin of the rearview mirror **1** to view the rearward area directly without any compensation. In another preferred embodiment, the photosensor **2** may also be located on or near the channel mount or mounting bracket **1***b* so that the axis of the photosensor **2**, which is perpendicular to the plane of the photosensor array **32**, is in fixed alignment with the vehicle's centerline regardless of the adjusted position of the rearview mirror **1**.

In particular, as shown in FIGS. **1**C and **1**D, a sensing and logic circuit assembly **27**, which comprises a sensing and logic circuit **26** and the photosensor **2** and switch **3** on a printed circuit board, is located in a housing or module **7** that is attached, connected, made integral or otherwise associated with the rearview mirror **1**. In the embodiment shown in FIGS. **1**C and **1**D, a mounting bracket **6** is fixed relative to the headliner area of the vehicle body in a header mount arrangement; and a rearview mirror head assembly **1***h* is adjusted by a spherical pivot **6***d* at the interface of the mounting bracket **6** and the rearview mirror head assembly **1***h*. The mounting bracket **6** may also be releasably attached to a mounting button (not shown) that is attached to the windshield to provide generally improved ease of assembly and replacement, as well as safety. Alternatively, the mounting bracket **6** may be attached to the windshield or headliner area of the vehicle by any of the various means well known to those skilled in the art.

In particular, the mounting bracket **6** comprises a retaining spring **6***a*, a retaining screw **6***b*, a wire harness opening **6***c* for receiving a wire harness assembly **8**, and a spherical pivot **6***d* having an opening for wires **6***e* that are used to control the variable reflectance mirror element **1***a*. The housing or module **7** comprises a retaining housing or module **7***a* for partially mounting the sensing and logic circuit assembly **27**, a rear housing or module cover **7***b*, a heat sink **7***c* for the sensing and logic circuit assembly **27**, a screw **7***d* for securing the heat sink **7***c* to the mirror bracket **6**, and a wire connector **7***e* for connecting the harness assembly **8** and wires **6***e* to the sensing and control circuit assembly **27**. The harness assembly **8** is used, in part, to supply power to the sensing and logic circuit assembly **27**.

Also, as shown in FIGS. **1**C and **1**D, the automatic rearview mirror **1** comprises the variable reflectance mirror element **1***a*, a mirror cushion support **1***c*, an impact absorber layer **1***d*, a bezel **1***e*, a mirror case **1***f* and clamp springs **1***g* for receiving and securing the spherical pivot **6***d* of the mounting bracket **6**.

For other vehicles, such as trucks, the photosensor **2** may also be located with each of the external side view mirrors as will be described later.

The lens **30** is preferably a single molded plastic lens approximately 2 millimeters in diameter and is preferably bonded to or in close contact with the photosensor array **32**. The lens **30** may, however, include any appropriate image focusing means such as conventional single component optics, holographic lens type optics, binary optics or a microlens. The lens **30** preferably is also designed to focus an image of the rearward scene within a field of view defined by a cone. The cone's centerline is perpendicular to the plane of the photosensor array **32** and the cone preferably has an included angle of approximately 100 degrees. Thus, the image is focused onto a circular area of the plane of the photosensor array **32**.

Of course, the photosensor array **32** could be positioned in other than a rearwardly facing direction so long as appropriate lenses or other optics are used to direct the light or image information from the rearward area onto the photosensitive surface of the photosensor array **32**.

The pre-positioning of the photosensor array **32** in the rearview mirror **1** depends on whether the automatic rearview mirror system **20** is being used in a left hand or a right hand drive vehicle. In either case, the photosensor array **32** is preferably pre-positioned within the circular area of the focused image so that for either a left or right hand drive vehicle and with only driver adjustment of the rearview mirror **1**, the rearward scene imaged onto the photosensitive surface of the photosensor array **32** includes the rear window area and at least a portion of the left and right side window areas of the vehicle.

If a sufficiently large photosensor array **32** is used, then the pre-positioning of the photosensor array **32** is not vehicle specific as described above, and a system **20** using a larger photosensor array **32** may be used for both left and right hand drive vehicles. The larger photosensor array **32** is positioned symmetrically within the circular area of the focused image described above. Using the larger photosensor array **32** involves using a pattern recognition means to determine the approximate vehicle centerline so that the appropriate portion of the larger photosensor array **32** may be selected depending on whether the automatic rearview mirror system **20** is installed in a left or right hand drive vehicle.

FIG. **2** illustrates an automatic rearview mirror system **20** for an automotive vehicle, comprising the rearview mirror **1**, a left side view mirror **4** and a right side view mirror **5**. As will be discussed below, either or both of the side view mirrors **4** and **5** may be connected to a control circuit of the rearview mirror **1**. The mirrors **1**, **4** and **5** may be constructed according to any of the methods known to those skilled in the art and are generally constructed according to the styling preferences and specifications of the automotive vehicle manufacturers. The means for mounting the rearview mirror **1**, such as the channel mount **1***b*, and the electrical connectors used to connect the mirrors **4** and **5** to the control circuit of the rearview mirror **1** and the vehicle's electrical system may include anyone of the many configurations known to those having ordinary skill in the art. The variable reflectance mirror element **1***a* of the mirrors **1**, **4** and **5** may be any device having more than one reflectance level corresponding to a specific control or drive signal. Preferably, however, the variable reflectance mirror element **1***a* is an electrochromic mirror.

As discussed, the photosensor **2** is mounted facing rearwardly of the rearview mirror **1** so that its field of view encompasses an area comprising the rear window area and at least a portion of both the left side window area and the right side window area. The horizontal and vertical fields of view of the rearward area as seen by the photosensor **2**, and more particularly by the photosensor array **32**, are illustratively shown in FIGS. **3**A and **3**B.

As shown in FIG. **3**A, the photosensor array **32** senses a field of view divided into three separate zones: a center zone a, a left zone b (generally corresponding to the left side window area) and a right zone c (generally corresponding to the right side window area). Each zone is sensed by a separate set or sub-array S(X) of photosensor elements **32***a* (described with respect to FIGS. **4**A and **4**B) within the photosensor array **32**. The center zone, zone a, generally receives light from the rear window area of the vehicle. This rear window area is depicted by a trapezoidally shaped rear window figure superimposed on a first set or sub-array S(**1**) of photosensor elements **32***a* used to sense light levels in zone a. Zone b includes light from at least a portion of a left side window area. This is depicted by a trapezoidally shaped left rear side window figure and a partially shown left front side window figure superimposed on a second set or sub-array S(**2**) of photosensor elements **32***a* used to sense light levels in zone b. Similarly, zone c includes light from at least a portion of a right side window area. This is depicted by a trapezoidally shaped right rear side window figure and a partially shown right front side window figure superimposed on a third set or sub-array S(**3**) of photosensor elements **32***a* used to sense light levels in zone c. Additionally, all three zones include light reflected from whatever fixed body work and interior trim, head rests, vehicle occupants or other objects that are within the zones a, b and c.

Also as illustratively shown in FIG. **3**A, the photosensor elements **32***a* in columns 1 to 4 comprise the third photosensor element set in zone c, the photosensor elements **32***a* in columns 6-11 comprise the first photosensor element set in zone a and the photosensor elements **32***a* in columns 13 to 16 comprise the second photosensor element set in zone b. Null zones are provided between the zones a and b and between the zones a and c to allow for driver adjustment of the rearview mirror **1**. These null zones also ensure that the center zone a does not include light or other image information from the side window areas of zones b and c.

As will be discussed in more detail below, the logic and control circuit **34** selects photosensor element signals from the first photosensor element set or sub-array S(**1**) (shown in FIG. **4**B) corresponding to zone a to control the reflectance level of the rearview mirror **1**. Similarly, the control circuit **34** selects photosensor element signals from the second photosensor element set or sub-array S(**2**) (shown in FIG. **4**B) corresponding to zone b to control the reflectance level of the left side view mirror **4**, and further selects photosensor element signals from the third photosensor element set or sub-array S(**3**) (shown in FIG. **4**B) corresponding to zone c to control the reflectance level of the right side view mirror **5**. Additionally, for a variable reflectance mirror element **1***a* having segments, such as a center, left and right segment, appropriately defined zones a, b and c, i.e., sub-arrays S(**1**), S(**2**) and S(**3**), corresponding to the mirror segments may be used by the logic and control circuit **34** to control independently the individual mirror segments.

FIG. **3**B illustratively shows the preferred embodiment for the zones of the photosensor array **32**. In this embodiment, the logic and control circuit **34** selects photosensor element signals from three overlapping sets or sub-arrays S(**1**), S(**2**) and S(**3**) of photosensor elements **32***a* corresponding to the three overlapping zones a, b and c to control, respectively, the reflectance level of the mirrors **1**, **4** and **5**. More specifically, the control circuit **34** selects photosensor element signals from the photosensor elements **32***a* in columns 6 to 11 (zone a) to control the reflectance level of the rearview mirror **1**. The control circuit **34** also selects photosensor element signals from photosensor elements **32***a* in columns 10 to 14 (zone b) to control the reflectance level of the left side view mirror **4**, and further selects photosensor element signals from photosensor elements **32***a* in columns 3 to 7 (zone c) to control the reflectance level of the right side view mirror **5**.

Additionally, in the FIG. **3**B embodiment, the lens **30** focuses or images light information from: (1) the rear window area onto zone a; (2) at least a portion of the rear window and left side window areas onto zone b; and (3) at least a portion of the rear window and right side window areas onto zone c. Contrastingly, in the FIG. **3**A embodiment, the lens **30** focuses light from: (1) the rear window area onto zone a; (2) the left side window area onto zone b; and (3) the right side window area onto zone c. The overlapping zones in the FIG. **3**B embodiment are advantageous because each set of overlapping photosensor elements **32***a* in zones a and b and each set of overlapping photosensor elements **32***a* in zones a and c, as well as the logic and control circuit **34**, is able to "preview" the light information that may, for example, first appear in the rear window area (and correspondingly in the rearview mirror **1**), but which may appear shortly thereafter in the left or right side view mirrors **4** and **5**. By examining at least a portion of the rear window area, the automatic rearview mirror system **20** is able to more quickly respond to annoying glare light from approaching vehicles or other sources. Overlapping zones are also generally preferred because a glare light source located in a common or overlapping area of the rearview mirror **1** and one of the side view mirrors **4** or **5** can influence both mirrors.

II. The Light Sensing Device

The light sensing device of the light sensing and logic circuit **26** is preferably the photosensor array **32** shown in FIG. **5**. The photosensor array **32** has sufficient resolution to view the real image of a scene but may also use a spatial distribution of light intensities as an approximation of the imaged scene. An example of such a photosensor array **32** is the VLSI Vision Limited (VVL) Single Chip Video Camera Model #ASIS 1011.

Since a photosensor array **32** of the type described, namely the VVL Single Chip Video Camera, is capable of providing image information having sufficient resolution for displaying an actual image or for some other purpose, it will be readily understood that additional features or functions may be incorporated by adding circuitry to provide video output from the photosensor array **32** in addition to the primary control functions described herein. For example, the video output may be output to a CRT, flat LC panel display or other appropriate display device, located within the vehicle, to provide a display of the imaged scene for viewing by the driver.

The photosensor array **32** may be located in any of the mirrors **28** or in any other appropriate location, whether local or remote, such as on the vehicle's rear bumper, thereby extending significantly the effective field of view normally available to the driver either directly or through the vehicle's mirrors **28**.

Additionally, the photosensor array **32** may even replace one or more of the side view mirrors **4** and **5** of the automatic rearview mirror system **20**, thereby reducing the aerodynamic drag on the vehicle while providing sufficient information to the driver comparable to that available through the side view mirrors **4** and **5**.

A video signal from the photosensor array **32** may also be used by the logic and control circuit **34** to determine the presence of a vehicle or other object within the field of view of the photosensor array **32** to provide a visual signal warning such as through a display panel, or even an audible warning, based on certain parameters, such as distance and speed of the object. Additionally, if the photosensor array **32** is located in the rearview mirror **1**, the video signal may be used to monitor the vehicle's interior to detect unauthorized intrusion into the vehicle. This may be achieved by providing electrical power to the mirror's logic and control circuit **34** from a vehicle power supply and by activating a vehicle intrusion monitoring mode when a signal indicates that the vehicle's door and trunk locks have been activated. The logic and control circuit **34** may be used to continuously monitor the image from the vehicle's interior thereby allowing detection of objects or persons moving within the vehicle, and if movement is detected, another signal from the logic and control circuit **34** may then activate an intrusion alarm.

Thus, the photosensor array **32** may be used to monitor the vehicle interior or compartment in a vehicle interior monitoring system. This monitoring capability may be used in a vehicle intrusion detection system or in a compartment image data storage system, either in combination with the automatic rearview mirror system or as an independent system. Using the photosensor array **32** to monitor the vehicle interior to detect potential intruders provides an effective vehicle intrusion detection system. In an automatic rearview mirror and vehicle intrusion detection system, the photosensor array **32** in the rearview mirror **1** provides a good location for monitoring the vehicle interior because the rearview mirror **1** is: (1) centrally located along the vehicle axis; (2) forward of the front seat; and (3) relatively high in the vehicle interior. This location is sufficiently high and far forward so as to provide a very good view of the vehicle interior, including the front and rear seat areas, front and rear door areas and hatchback or rear cargo door areas. The photosensor array **32** may also be positioned in other locations, including the headliner and headliner console areas, for example, or any other appropriate location depending on the particular application.

As is discussed later, when the vehicle interior monitoring system is used as a vehicle intrusion detection system, the logic and control circuit **34** processes image data to detect motion or movement in the vehicle interior, establishes an intrusion condition if such motion is detected and outputs one or more control signals to vehicle hardware or to a vehicle controller system. Vehicles today are often equipped with such controller systems. These vehicle controller systems may be used to control the exterior lights, interior lights, horn (or siren), ignition or other such vehicle hardware. The logic and control circuit **34** therefore outputs one or more control signals to various vehicle hardware or to the vehicle controller system to activate the interior and exterior lights, horn or siren or to disable the ignition to deter intruders from stealing the vehicle or its contents. Other control output signals may activate RF beacon devices or similar devices within the vehicle so that the vehicle may be tracked, as will be further described later.

It is, however, within the scope of the present invention for the light sensing device to comprise any similarly appropriate image or array sensor. When the light sensing and logic circuit **26** is formed as a very-large-scale-integrated (VLSI) complementary-metal-oxide-semiconductor (CMOS) device, as is known to those skilled in the art, the light sensing device will share a common semiconductor substrate with the logic and control circuit **34**.

Preferably, for the described three mirror system, the photosensor array **32** comprises a plurality of photosensor elements **32***a* arranged in 160 columns and 40 rows (a 160×40 array) providing a horizontal field of view of approximately 100 degrees and a vertical field of view of approximately 30 degrees. As discussed, FIGS. **3**A and **3**B illustratively show a 16×4 photosensor array **32**. The photosensor array **32** may, however, comprise any appropriately sized array having an appropriate field of view. For example, the field of view may be narrower when controlling the segments of only one mirror. Each photosensor element **32***a* is preferably about 10 microns square.

As shown in FIG. **4**A, the photosensor array **32** generally comprises a plurality of photosensor elements **32***a* arranged in a photosensor array PA(N, M) having N rows of M columns. When viewing the photosensitive surface of the photosensor array PA(N,M) in a vertical plane, the lower row is row 1, the top row is row N, the left hand column is column 1, and the right hand column is column M. A specific photosensor element is identified as E(n, m) and the signal indicative of a light level incident thereon is L(n, m). Also, the sub-array S(X), where X=0, 1, 2, . . . , Z, is a rectangular array having P(X) rows of Q(X) columns of photosensor elements **32***a* and is located such that its lower left hand element is photosensor element E(T(X),U(X)).

As shown in FIG. **4**B, a background sub-array S(X) designated S(**0**) is used to determine a general background light level B. Signals from the photosensor elements **32***a* of each peak sub-array S(X), designated S(**1**), S(**2**), . . . , S(Z), are used to determine a peak light level P(z) incident on each peak sub-array S(**1**), S(**2**), . . . , S(Z). The general background light level B for background sub-array S(**0**) and the peak light level P(z) for each peak sub-array S(X) are then used to determine a mirror control signal $V_C(z)$ for controlling at least one mirror or mirror segments associated with each zone.

FIG. **5** generally illustrates a logic layout of the photosensor array **32**. The logic and control circuit **34** generates array control signals to control the photosensor array **32**. As is well known in the art, the photosensor array **32** is typically accessed in scan-line format, with the array **32** being read as consecutive rows, and within each row as consecutive columns or pixels. Each photosensor element **32***a* is connected to a common word-line **33***e*. To access the photosensor array **32**, a vertical shift register **33***a* generates word-line signals for each word-line **33***e* to enable each row of photosensor elements **32***a*. Each column of photosensor elements **32***a* is connected to a bit-line **33***f* which is connected to a charge-to-voltage amplifier **33***c*. As each word-line **33***e* is accessed, a horizontal shift register **33***b* uses a line **33***g* to output the bit-line signals on consecutive bit-lines **33***f* to an output line **33***h* connected to the logic and control circuit **34**. Also shown is a voltage amplifier **33***d* used to amplify the resulting analog photosensor element signals. The analog photosensor element signals are then output on line **33***h* to the analog-to-digital converter **44** and converted to digital photosensor element signals.

As discussed above, the photosensor array **32** is responsive to or senses both visible light and near infrared illumination. FIGS. **11**A and **11**B illustrate the normalized spectral response for two versions of the preferred photosensor array **32**. In FIGS. **11**A and **11**B, visible light generally covers the wavelengths from about 400 nm to about 750 nm, while near infrared illumination or light generally covers the wavelengths from about 750 nm to about 3000 nm (not shown). More particularly, FIG. **11**A illustrates the normalized spectral response of the preferred photosensor array **32** made using a non-epitaxial silicon process, where the peak spectral response occurs at about 800 nm. FIG. **11**B shows the normalized spectral response of the preferred photosensor array **32** made using an epitaxial silicon process, where the peak spectral response occurs at about 650 nm. As shown, the non-epitaxial silicon photosensor array is more sensitive to near infrared illumination having wavelengths on the order of about 800 nm. The photosensor array **32** made using the non-epitaxial silicon process and having the normalized spectral response of FIG. **11**A is most preferred in both the particular automatic rearview mirror and vehicle interior monitoring systems described herein. For automatic rearview mirror systems as described herein, this is because vehicle headlights generally provide significant levels of near infrared illumination. For vehicle interior monitoring systems as described herein, either natural sources (such as sunlight) or supplemental sources of near infrared illumination may be used to enhance the image information available to and the performance of such systems, as will be further discussed below.

The field of view and resolution of the photosensor array **32** depends on the number and physical dimensions of the photosensor elements **32***a* and on the design or geometry of the lens **30**. For the lens type illustrated in FIG. **1**A, the lens **30** may, for example, be designed to have an included angle on the order of up to about 140°. For the automatic rearview mirror system previously described, the effective field of view of approximately 100° horizontal and approximately 30° vertical is preferred. For the automatic rearview mirror and vehicle interior monitoring system described herein, an effective field of view of approximately 100° horizontal and approximately 75° vertical is preferred. Also as discussed for the automatic rearview mirror system, the lens **30** preferably focuses an image within a field of view defined by a cone having an included angle of approximately 100 degrees. Accordingly, when the lens **30** focuses the image onto the focal plane of the 160×40 photosensor array **32**, the photosensor array **32** only falls within a segment of the focused image area.

FIG. **2**A generally illustrates a view of a vehicle interior **100** (which includes the window areas of FIGS. **3**A and **3**B) as focused by the lens **30** and as viewed by a 160×120 photosensor array **32**. Also shown are a driver or left seat **101**, a front passenger or right seat **102**, a rear window area **103***a*, a right side window area **103***b* and a left side window area **103***c*. The 160×40 photosensor array **32**, however, only sees a portion or segment of the vehicle interior **100**, as is shown in FIGS. **3**A and **3**B. In a dedicated automatic rearview mirror system, the 160×40 sized array is generally preferred since it provides sufficient image information for providing effective automatic rearview mirror control and because it reduces the cost of the photosensor array **32**. If the photosensor array **32** is also used to monitor the vehicle interior **100** (or for other applications) as is described herein, then the larger 160×120 array size may be used to view the vehicle interior **100** as is generally illustrated in FIG. **2**A.

Finally, it should be understood that the spatial resolution of the photosensor array **32** may also be increased. This may be done by making the photosensor elements **32***a* smaller so as to increase the number of photosensor elements **32***a* in a photosensor array **32** having the same physical dimensions. Additionally, spatial resolution may be increased by varying the lens **30** to decrease the included angle of the image cone so that the photosensor array **32** views a smaller portion of an image on the vehicle interior **100**.

In summary, the array size of the photosensor array **32** and the number and physical dimensions of the size of the photosensor elements **32***a* and the lens design or geometry of lens **30** may all be varied to optimize the effective field of view of the photosensor array **32** depending on the application.

As is discussed later, an exposure time or exposure period EP of the photosensor array **32** may be varied over some range depending on the light level. Thus, the value of EP is increased for decreasing light levels and approaches a maximum for low light levels, and it is decreased for increasing light levels and approaches a minimum for high light levels.

For a given value EP_V of the exposure period, there is a light level LL_{MIN} that is sufficiently distinct from low signal noise in the photosensor element signal L(n, m) of each photosensor element E(n, m) so that it may be accurately sensed, and there is also a light level LL_{MAX} for which the photosensor element signal L(n, m) of each photosensor element E(n, m) is a maximum. The ratio of LL_{MAX}/LL_{MIN} at EP_V may be used to represent a dynamic range of DR(n, m) in decibel (dB) units of each photosensor element E(n, m), where DR(dB)=10 LOG (LL_{MAX}/LL_{MIN}). The image data is preferably optimized such that it is approximately centered within the dynamic range DR(N,M) of the photosensor array **32**. This may be done by determining an array response AR of RA(N, M), which is described later, where the minimum and maximum digital values of AR correspond to the minimum and maximum digital values possible for Val RA(n, m) (e.g., 0 and 255 for 8-bit data resolution). The exposure period is varied or adjusted until AR approaches the center or mid-point of the possible data value range (e.g., 127 for 8-bit data resolution).

Since there is a minimum photosensor element signal that may be accurately measured, a supplemental source of illumination may be desirable or necessary to enhance the effective sensing capabilities of the photosensor array **32** by providing supplemental source illumination SSI. Although the photosensor array **32** is able to monitor the vehicle interior **100** over a range 5 of background lighting levels from about 0.1 lux (a dark garage) to about 30-60K lux (a bright, sunny day), using either visible or near infrared SSI to illuminate the vehicle interior **100** generally (or specific areas therein) significantly enhances the effectiveness or performance of the photosensor array **32** in various applications. Also, SSI is preferably provided only during the exposure period EP of the photosensor array **32** rather than continuously. Pulsed SSI reduces power consumption, extends the life of the supplemental source of illumination and provides generally higher instantaneous illumination than may be provided by continuous illumination. Also, pulsed infrared SSI is generally more difficult to detect by infrared illumination sensing apparatus that may be used by potential intruders.

For the specific vehicle interior monitoring system applications described herein, near infrared illumination between about 700 and 1200 nm is preferred because: (1) it is visible to the photosensor array **32** but not to the human eye (see FIGS. **11**A and **11**B); and (2) it does not affect adaption of the human eye. There are a number of readily available near infrared illumination sources, including solid-state sources such as light emitting diodes (LEDs) and lasers, flash lamps such as xenon or krypton lamps, incandescent lamps such as tungsten lamps, as well as many others. Preferred, however, are gallium arsenide (GaAs) or gallium aluminum arsenide (GaAlAs) LEDs because they provide a relatively narrow band (about 750 to 950 nm) of near infrared illumination (see FIGS. **11**A and **11**B). Such illumination sources are also typically packaged with a lens to distribute the illumination. Depending on the particular application, the illumination distribution characteristics of readily available lens/source packages may range from narrow so as to provide spot or collimated illumination to very diffuse so as to cover about 160°. In the vehicle interior monitoring system described herein, the lens/source package preferably provides illumination coverage on the order of about 100°.

Other illumination sources providing broad-band illumination (ultraviolet through infrared) may also be used, but it may be desirable or necessary to filter such broad-band illumination using absorption or interference type filters, or any other appropriate filter. In particular, an interference filter known as a long-wave pass filter or cold mirror reflects visible light, transmits infrared illumination and looks like the normal silvered mirrors typically used in the rearview mirror **1**. Unlike cold mirrors, however, silvered mirrors reflect near infrared illumination. Since the cold mirror resembles the silvered mirror in the rearview mirror **1**, it may be used to replace a section or even all of the silvered mirror. In particular, the supplemental source of illumination may be located behind the cold mirror element and adjacent to the photosensor array **32** with an opaque barrier separating the two to prevent supplemental illumination reflections within the rearview mirror **1** from directly affecting the photosensor array **32**.

Alternatively, a long-wave pass absorption filter may be used with a supplemental source of broad-band infrared illumination. Long-wave pass absorption filters may be fabricated using a wide variety of polymers having appropriate optical transmission characteristics such as epoxies, acrylics, polycarbonates, as well as a variety of glasses. The acrylic and polycarbonate polymers are preferred because they are environmentally stable, cost effective and because they may be used to injection mold parts having various geometric shapes or polished or textured surfaces. Using absorption filter materials, the photosensor array **32** and supplemental source of illumination may be integrated into the rearview mirror **1** or elsewhere within or on the vehicle so that they are not readily apparent to vehicle occupants, passers by or potential intruders.

III. The Logic and Control Circuit

FIG. **6** shows the light sensing and logic circuit **26** comprising, the photosensor array **32** and the logic and control circuit **34**. The logic and control circuit **34** comprises a logic circuit **46**, a clock **47**, a random-access-memory (RAM) **50**, or other appropriate memory, and a digital-to-analog converter **52**. The logic circuit **46** is preferably a dedicated configuration of digital logic elements constructed on the same semiconductor substrate as the photosensor array **32**. Alternatively, the logic circuit **46** may also be a microprocessor comprising a central processing unit (CPU) and a read-only-memory (ROM). The logic circuit **46** may also be implemented using gate array technology or any other appropriate hardwired logic circuit technology.

The logic circuit **46** interfaces with the clock **47**, provides array control signals to the photosensor array **32**, manages data flow to and from the RAM **50** and converters **44** and **52**, and performs all computations for determining a digital mirror control signal $V_{DAC}(Z)$ for causing the variable reflectance mirror element **1***a* to assume a desired reflectance level. As discussed, the analog-to-digital converter **44** converts the analog photosensor element signals to the digital photosensor element signals processed by the logic circuit **46**. It has been found that an eight-bit analog-to-digital converter **44** provides adequate data resolution for controlling the mirrors **1**, **4** and **5**. Preferably, the analog-to-digital converter **44** is constructed on the same semiconductor substrate as the photosensor array **32** as shown in FIG. **5**.

The digital photosensor element signals output to the logic and control circuit **34** are generally stored in the RAM **50** for processing. The values of the digital photosensor element signals for the photosensor array PA(N,M) are correspondingly stored in an array in the RAM **50** designated RA(N,M). The logic circuit **46** processes the values of each of the digital photosensor element signals, which are designated Val RA(n, m), to determine an instantaneous or substantially real-time background light signal B_t for a time period t and at least one peak light signal P(z). The logic circuit **46** uses these signals, which may also be temporarily stored in the RAM **50**, to determine a digital control signal $V_{DAC}(z)$ to cause at least one mirror or mirror segment to assume a desired reflectance level. The digital mirror control signal $V_{DAC}(z)$ then output to the digital-to-analog converter **52**, which outputs a corresponding analog mirror control signal V_C to a mirror drive circuit **24**. Alternatively, the digital to-analog converter **52** need not be used if the logic circuit **46** generates a pulse-width-modulated (PWM) mirror control signal to control the mirror drive circuit **24**.

The mirror drive circuit **24** comprises mirror drive circuits **24***a*, **24***b* and **24***c*. The drive circuit **24** drives mirrors **28**, which comprises a rearview mirror **28***a* (mirror A), a left side view mirror **28***b* (mirror B) and a right side view mirror **28***c* (mirror C). Mirrors A, B and C correspond, respectively, to the rearview mirror **1**, the left side view mirror **4** and the right side view mirror **5** shown in FIG. **2**. It is, of course, within the scope of the present invention for the mirror A to be a mirror other than the rearview mirror **1**. It is similarly within the scope of the present invention for the mirror B to be a mirror other than the left side view mirror **4**, and for the mirror C to be a mirror other than the right side view mirror **5**. It is also within the scope of the invention for the mirrors A, B and C to be mirror segments or zones of the variable reflectance mirror element **1***a* where the peak sub-array S(X) for each zone corresponds to a segment of the variable reflectance mirror element **1***a*. Thus, for example, S(**1**) may correspond to a center mirror segment, S(**2**) may correspond to a left mirror segment and S(**3**) may correspond to a right mirror segment. Any other appropriate mirror segmentation scheme may also be used.

A sensitivity control circuit **42** is used to input a sensitivity signal S to the logic and control circuit **34**, In addition, signals from a force-to-day (maximum reflectance) switch **36**, a reverse-inhibit (maximum reflectance) switch **38** and a force-to-night (minimum reflectance) switch **40** may also be input to, the logic and control circuit **34**. The switch **3** of FIGS. **1**A and **1**B may include the sensitivity control circuit **42**, as well as the force-to-day switch **36** and the force-tonight switch **40**.

The switches **36**, **38** and **40** each generate a signal causing the logic circuit **46** to override its normal operation, as will be described with respect to FIGS. **7**, **8**A and **8**B, and to output mirror control signals $V_C(z)$ to the mirror drive circuit **24** causing the variable reflectance mirror **28** to assume a maximum or minimum reflectance level in accordance with the appropriate signals from the switches **36**, **38** or **40**.

Finally, the logic and control circuit **34** may also be used to control a vehicle lighting switch **45** to automatically turn on and off a vehicle's headlights and sidelights. This feature will be further described later.

FIG. **6**A shows the block schematic diagram of the automatic rearview mirror and vehicle interior monitoring system. The previous description of FIG. **6** applies here except as follows. First, the logic and control circuit **34** includes an analog-to-digital converter **55** for converting one or more analog control input signals **70** (1, 2, . . . , N; blocks **70***a* to **70***n*) to digital signals that are input to the logic circuit **46**.

With respect to the automatic rearview mirror system, the analog control input signals **70** may include any analog control input signal used therein, including, for example, analog versions of the control input signals provided by the force-to-day-switch **36**, reverse-inhibit-switch **38**, force-to-night-switch **40** or sensitivity control circuit **42** of FIG. **6**. Of course, digital versions of these same control input signals may also be input to the logic circuit **46** as digital control input signals **75** (1, 2, . . . , N; blocks **75***a* to **75***n*). The analog control output signals **80** (1, 2, . . . , N; blocks **80***a* to **80***n*) may include any analog control output signal used in the automatic rearview mirror system, including the analog mirror control signals $V_C(z)$. The analog circuits/switches **81** (1, 2, . . . , N; blocks **81***a* to **81***n*) may include the drive mirror circuits **24** that are used to drive the variable reflectance mirrors **28**. As discussed with respect to FIG. **6**, the analog mirror control signal $V_C(z)$ is output to the mirror drive circuit **24** causing the variable reflectance mirror **28** to change reflectance levels. Of course, digital control output signals **85** (1, 2, . . . , N; blocks **85***a* to **85***n*) may also be output to digital circuits/switches **86** (1, 2, . . . , N; blocks **86***a* to **86***n*) to the extent that the control output signals are digital and not analog.

With respect to the vehicle interior monitoring system configured as a vehicle intrusion detection system, analog control input signals **70** and digital control input signals **75** may include, respectively, analog and digital versions of control input signals used to "arm" or "alert the vehicle intrusion detection system, as will be further described later. The analog control output signals **80** may include any analog control signals output to analog circuits/switches **81** that are used in the above system, including analog circuits or switches used to actuate various vehicle hardware, such as the vehicle horn (or siren), exterior and interior lights or ignition control devices. Of course, digital control output signals **85** (1, 2, . . . , N; blocks **85***a* to **85***n*) may also be output to digital circuits/switches **86** (1, 2, . . . , N; blocks **86***a* to **86***n*) to the extent that the control output signals are digital and not analog. In particular, the digital control output signal **85** may include a digital word provided to a digital circuit/switch **86** that is a vehicle controller system that interfaces with such vehicle hardware.

When the vehicle interior monitoring system is configured as a compartment image data storage system, a nonvolatile memory **57**, as shown in FIG. **6**A, is included. The nonvolatile memory **57** interfaces with the logic circuit **46**. The nonvolatile memory **57** is used to store image data, as will be further described later. The nonvolatile memory **57** may be an EEPROM or other appropriate nonvolatile memory. An access/security decoding logic circuit **58** interfaces with a data access port **59** and the logic circuit **46**. The access/security decoding logic circuit **58** and data access port **59** are used to access the image data stored in the nonvolatile memory **57**, as will be further described later. Optionally, this system may include a data compression logic circuit **56** for compressing image data received from the logic circuit **46** before it is stored in the nonvolatile memory **57**. The data compression logic circuit **56** may be integral with the logic circuit **46**.

Finally, whether configured as a vehicle intrusion detection system or as a compartment image data storage system, the vehicle interior monitoring system preferably includes a supplemental source of illumination **61** having a lens **62** as shown in FIG. **6**A. A supplemental source of illumination drive circuit **60** is connected to the supplemental source of illumination **61**. The drive circuit **60** also interfaces with and receives control signals from the logic circuit **46** to drive the supplemental source of illumination **61**.

IV. Operation of the Invention

FIG. **7** shows an overview of the logic flow chart and method for controlling the reflectance levels of any one or all of the mirrors or mirror segments **28***a*, **28***b* or **28***c*. It should be understood that the reflectance level of each of the mirrors **28***a*, **28***b* and **28***c* in the automatic rearview mirror system of the present invention may be commonly or independently controlled. FIGS. **8**A, **8**B and **9** provide more detail on the logic and method of FIG. **7**.

In step S**101** of FIG. **7**, light information seen rearwardly of the rearview mirror **1** is incident on the lens **30**. In step S**110**, light passing through the lens **30** is refracted such that the light information is imaged or focused onto the photosensitive surface of the photosensor array **32**. In step S**120**, the logic circuit **46** generates and outputs the array control signals to the photosensor array **32**. In step S**130**, photosensor element signals indicative of the light levels incident on each of the photosensor elements **32***a* are generated. In step S**140**, these photosensor element signals are temporarily stored in RAM or any other appropriate memory. In steps S**150** and S**160**, the logic circuit **46** determines values for the background light signal and the peak light signal for each zone corresponding to each of the mirrors **28**. In step S**180**, the logic circuit **46** uses the background and peak light signals of step S**150** to determine the control signals required to cause each of the mirrors **28** to achieve a desired reflectance level. Also, the logic and control circuit **34** in step S**180** reads and processes the states of the optional sensitivity control circuit **42**, force-to-day switch **36**, force-to-night switch **40** and reverse-inhibit switch **38**. In step S**200**, the mirror drive circuits **24** use the control signals determined in step S**180** to generate drive signals to cause the mirrors **28** to assume the desired reflectance levels in step S**210**.

In one embodiment of the invention, the logic circuit **46** determines the background light signal B_t in steps S**150** and S**160** by calculating the average value of the photosensor element signals, previously stored in RAM in step S**140**, for the photosensor elements **32***a* in a lowest row or rows of the photosensor array **32** corresponding to an area below the rear window. With respect to FIGS. **3**A and **3**B, this means that the background light signal B_t is determined from photosensor element signals generated by the photosensor elements **32***a* located in row D of the photosensor matrix array **32**. The logic circuit **46** may then output B_t to the RAM **50** for later processing. The logic circuit **46** may also determine by calculating an average value of all of the photosensor element signals in the entire photosensor array **32**. More generally, the background light signal B_t for the rearward scene may be determined by calculating the average value of X percent of the lowest photosensor element signal values in the RAM array RA(N,M), where X is preferably 75, but typically may be in the range of 5 to 100.

Alternatively, an exposure period EP, as is described herein, may be used to determine the background light signal B_t. An array response AR may be determined using an array average method, as is also described herein, for the photosensor element signal values corresponding to a sub-array S(X) of the photosensor elements **32***a* of the photosensor array **32** that correspond to an area below the rear window. The exposure period EP may be varied within an operating point range OP±R, where OP is 10 and R is 5 (8-bit data), but where OP may be from 5 to 175 and R may be from 2 to 15. The exposure period is varied to maintain AR within OP±R. The background light signal B_t may therefore be determined where B_t varies inversely with EP.

Additionally, the background light signal B_t is preferably change-limited to determine a limited background light signal B_{Lt}. The signal may be change-limited, for example, by limiting changes in the background light signal B_t to 2% per time frame. A time frame may be, for example, 250 milliseconds or any other time relating to the rate at which the logic circuit **46** samples the photosensor element signals from the photosensor array **32**. The logic circuit **46** determines the change-limited value B_{Lt} used to determine the digital mirror control signal $V_{DAC}(z)$ as follows: $B_{Lt}=B_{L(t-1)}+C_L\times(B_t-B_{L(t-1)})$, where B_{Lt}=the change-limited background light signal for a current time frame t, B_t=the actual or substantially real-time background light signal for the current time frame t, $B_{L(t-1)}$=the change-limited background light signal for a previous time frame (t−1) and C_L=the change-limit value. Additionally, the background light signal B_t from step S**150** may be processed by the logic circuit **46** to determine whether the change limited background light signal B_{Lt} is less than or greater than $B_{L(t-1)}$. If B_{Lt} is greater than $B_{L(t-1)}$, then the logic circuit **46** may use a higher change-limit value C_{LH} to determine B_{Lt}. If the background light signal B_{Lt} is less than or equal to $B_{L(t-1)}$, then the logic circuit **46** may use a lower change limit value C_{LL} to determine B_{Lt}. The values C_{LH} and C_{LL} are in the range of 0.01 to 2, but are preferably on the order of about 0.02 or 2%.

The logic circuit **46** in step S**150** also determines the peak light signal P(z) for each zone or sub-array S(X) of the photosensor matrix array **32**. The peak light signal P(z) used to determine the appropriate mirror control signal $V_C(z)$ for the mirror **28** may be determined by counting or summing the number of occurrences where the digital value for a photosensor element signal is greater than a peak threshold value F for each zone or sub-array S(X). For the preferred analog-to-digital converter having eight-bit data resolution, the logic circuit **46** generates digital values indicative of light levels of light incident on each photosensor element **32***a* in the range of 0 to 255 ($2^8-1=255$), with headlights resulting in values in the range of about 200 to 255, so that the peak threshold value F is selected to be in the range of about 200 to 255 but is preferably 245. The resulting count or sum P(z) provides a measure of the peak light level for the following reasons.

One design objective of the lens **30** and the photosensor array **32** combination is to be able to measure background light levels in the approximate range of 0.01 to 0.1 lux when driving on sufficiently dark roads. This is achieved by ensuring that the lens **30**, photosensor elements **32***a* and charge-to-voltage amplifiers **33***c* are able to measure such light levels and by providing a maximum exposure time. The maximum exposure time determines the operating frequency or sampling rate of the system **20**. In the case of the described system, 1.5 MHz has been found to be appropriate.

By varying the exposure time relative to a general background light level B and using a substantially constant sampling rate, a wide range of background light levels in the range of 0.01 to 1000 lux can be measured. Thus, when the background light level is low, the exposure time is relatively long such that headlights within the rearward area cause the affected photosensor elements **32***a* to saturate. Correspondingly, for higher background light levels the exposure time is reduced. Saturation occurs when the incident light charges the photosensor element **32***a* to capacity so that any excess charge will leak or transfer to adjacent photosensor elements **32***a*. This charge leakage effect is commonly referred to as "blooming." It has been found that a count of the number of photosensor elements **32***a* at or near saturation, i.e., those having digital values greater than the peak threshold value F, provides an excellent approximation of the peak light levels and is further described in FIG. **8**A. The above described method effectively extends the range of measurable light levels for the photosensor array **32**.

As discussed, photosensor element signals are indicative of the incident light level or intensity and the time period for which they are exposed to such light. By operating the photosensor array **32** for a known exposure time or exposure period EP, the incident light intensity may be determined from the photosensor element signal generated by each photosensor element **32**a. After the exposure period, the logic and control circuit **34** processes all of the photosensor element signals for each photosensor element **32**a of the photosensor array **32**. This signal processing at least includes the process of storing the digital value of each photosensor element signal to obtain RA(N,M), but normally includes all other processing for each image data set RA(N,M) up to and including the generation of output control signals, such as the mirror control signal $V_C(z)$. The time from the beginning of the exposure period EP through the processing of each image data set RA(N,M) and the generation of the appropriate output control signals is referred to as the operating or sampling period, and the frequency thereof is referred to as the operating frequency or sampling rate. The frequency at which the process is repeated may also be referred to as the frame rate or the image sampling frequency. The rate of each sub-process (e.g., exposure period) within the sampling period is controlled by the system clock **47**. Thus, the frame rate or image sampling frequency is essentially fixed for a particular system clock frequency. The total period corresponds to a maximum exposure period EP and the total processing time relating to an image data set RA(N,M). The system clock frequency may be adjusted to scale the image sampling frequency, thereby adjusting EP. In summary, the maximum exposure period, the operating or sampling period, the signal processing time and the frequency of the system clock **47** should be considered in each application.

Alternatively, if an anti-blooming device is incorporated in the photosensor array **32**, such as is well known to those skilled in the art, then the peak light signal P(z) may be determined by calculating an average value of Y percent of the highest photosensor element signal values for each zone, where Y is preferably 10, but may be in the range of 1 to 25. When using this approach for determining P(z), it is also preferable to include logic to adjust the sampling rate or operating frequency of the logic circuit **46** to an appropriate value depending on B_{Lt}.

The general background light signal B, whether B_t or B_{Lt}, and the peak light signal P(z) for each zone of the photosensor array **32**, as determined in steps S**150** and S**160**, are then used by the logic circuit **46** to determine a mirror control signal $V_C(z)$ as a function of the ratio of B^n (n preferably has a value of one but may typically range from 0.8 to 1.3) to P(z), i.e., $V_C(z)=f(B^n/P(z))$. The control signal $V_C(z)$ is then output to the mirror drive circuits **24** in step S**180** to drive the mirrors **28** or segments thereof to their desired reflectance level in the steps S**200** and S**210**.

FIG. **12** shows the logic flow chart and method for the vehicle interior monitoring system or mode.

In step S**301**, the logic circuit **46** initializes the system, sets EP to its maximum and if used, SSI to a predetermined minimum, such as zero. Next in step S**310**, the logic circuit **46** reads any analog control input signals **70** (**70**a to **70**n of FIG. **6**A) and/or digital control input signals **75** (**75**a to **75**n of FIG. **6**A) that may be used in the vehicle interior monitoring mode.

In step S**315**, the photosensor element signals are generated, processed and stored in RAM **50** by the logic circuit **46** (see steps S**101** to S**140** of FIG. **7**). The logic circuit **46** also applies the lens correction factor LC(n,m) to each digital value Val RA(n,m) indicative of the photosensor element signal L(n,m) of each photosensor element **32**a in the RAM array RA(N,M) to correct for the effect of lens **30**. This results in RA(N, M) containing the lens corrected digital value Val $RA_{LC}(n,m)$ indicative of the photosensor element signal of each photosensor element **32**a.

Next, in step S**320**, the logic circuit **46** determines the array response AR, which is indicative of either RA(N,M) (an entire image data frame or set $RA_{(t)}$ at time t) or of a selected sub-array or sub-set thereof RS (N_S,M_S) (a partial image data frame or set $RS_{(t)}$ at time t), where N_S and M_S are the row and column dimensions corresponding to a selected sub-array S(X) of the photosensor array **32**. The logic circuit **46** processes the image data frame $RA_{(t)}$ using one of the methods described below to determine the array response AR. An appropriate operating point range OP±R is associated with each AR calculation method.

The preferred method for determining AR is the array average method, in which the logic circuit **46** determines AR by averaging all of the data values Val $RA_{LC}(n,m)$ in the image data frame $RA_{(t)}$ (or selected sub-array $RS_{(t)}$ where:

$$AR = \frac{1}{N-M}\sum_{n}\sum_{m} ValRA_{LC}(n, m),$$

for n=1 to N, m=1 to M. Using the array average method, it has been found that appropriate OP and R values are 127 and 20 (8-bit data resolution), respectively; however, the operating point range may be non-symmetrical for some tasks by using non-symmetrical R values, such as +20 and −10.

An alternative method is the "no saturation" method, in which, EP is set to its highest level at which there is no saturation or blooming in any photosensor element **32**a. In this case, the logic circuit **46** reduces EP until the peak value of $RA_{(t)}$ or $RS_{(t)}$ is within the operating point range OP±R. It has been found that appropriate OP and R values are 249 and 5, respectively. Still another method involves maximizing the useful image area, in which the logic circuit **46** determines AR by determining the difference between the number of photosensor elements **32**a having digital values of 0 and the number having digital values of 255 (8-bit data resolution). In this case, appropriate OP and R values are 0 and 5% of the number of photosensor elements **32**a corresponding to the image data set $RA_{(t)}$ or sub-array $RS_{(t)}$. It should be understood that the specific values, such as 127 and 255, are based on 8-bit data resolution and would be appropriately scaled for other data resolutions.

In step S**330** and S**360**, it is determined whether AR is in the operating point range OP±R. If AR is outside the range, then the image data frame is either too bright (AR>OP+R) or too dim (AR<OP−R) and EP and SSI are incrementally increased or decreased according to steps S**340**, S**341**, S**342** or S**350**, S**351**, S**352**. This is repeated for every image data frame $RA_{(t)}$. The system thus optimizes EP and SSI for the particular circumstances at system startup, and thereafter continues to adjust EP and SSI to maintain AR within the operating point range OP±R as lighting conditions change.

If AR is within the operating point range OP±R, then the vehicle interior monitoring system/mode enters a primary task routine or mode in step S**370**, such as the vehicle intrusion detection system/mode (S**400**) of FIG. **12**A or the compartment image data storage system/mode (S**500**) of FIG. **12**B. After completing the primary task routine, the program returns to the vehicle interior monitoring mode to generate and store another image data frame $RA_{(t)}$.

V. The Preferred Embodiments

The general lighting conditions of the rearward scene can be defined as follows: the background light level of the viewed rearward scene is B and the peak light level for each zone or sub-array S(X) is P(z). A contrast ratio C(z) may be defined as the ratio of the peak light level P(z) for each zone to the general background light level B; thus, C(z)=P(z)/B. Given the background light level B, the human eye can tolerate varying peak light levels in the viewed rearward scene up to a particular contrast ratio tolerance C_T. Contrast ratios greater than C_T initially cause discomfort and are generally known as glare. As the eye adjusts its light sensitivity to protect itself from the discomforting peak or glare light levels, vision is reduced and the glare may become disabling. Thus, the maximum tolerable peak light level P_T of the viewed rearward scene is equal to the product of the contrast ratio tolerance C_T and the background light level B, i.e., $P_T=C_T \times B$.

The desired reflectance $R_d(z)$ of a variable reflectance mirror for each zone is that reflectance level which reduces a peak light level P(z) to a value equal to the maximum tolerable peak light level P_T, i.e., $P_T=R_d(z)\times P(z)$ or $R_d(z)=P_T/P(z)$, and substituting the expression for P_T, $R_d(Z)=(C_T\times B)/P(z)$. However, the maximum tolerable contrast ratio C_T varies across the population due to aging and other factors; accordingly, a sensitivity factor S may be used to account for this variation in contrast tolerance sensitivity so that $R_d(z)=(S\times C_T\times B)/P(z)$. Selecting the desired reflectance $R_d(z)$ for each zone provides maximum information from the rearward scene viewed in each mirror or mirror segment while reducing discomforting or disabling peak light levels to tolerable levels.

The mirror control signal $V_C(z)$ required to obtain the desired reflectance $R_d(z)$ depends on the particular variable reflectance mirror element that is used. For electrochromic mirrors, a voltage-reflectance relationship can be approximated and generally defined. In general, an electrochromic mirror has a reflectance level R having a maximum value of R_1 with an applied voltage V_{app} of 0 volts. As the applied voltage V_{app} is increased, the reflectance level R perceptually remains on the order of R_1 until V_{app} reaches a value of approximately V_1. As V_{app} is further increased, the reflectance level R decreases approximately linearly until a minimum reflectance of approximately R_2 is reached at a voltage V_2 Thus, the applied voltage V_{app} can be approximately defined as:

$$V_{app}=V_1+(R_1-R)\times(V_2-V_1)/(R_1-R_2)$$

Substituting desired reflectance $R_d(z)$ for the reflectance R results in the mirror control signal, the voltage of which is determined as follows:

$$V_C(Z)=V_1+(R_1-S\times C_T\times B/P(z))\times(V_2-V_1)/(R_1-R_2).$$

To obtain a digital value $V_{DAC}(z)$, $V_C(z)$ is scaled by a factor that is the ratio of the maximum digital value to the value V_2; thus, for eight-bit data resolution $V_{DAC}(z)=255\,V_C(z)/V_2$, and substituting for $V_C(z)$:

$$V_{DAC}(z)=255(V_1+(R_1-S\times C_T\times B/P(z))\times(V_2-V_1)/(R_1-R_2))/V_2.$$

FIG. **8**A provides further detail on the steps S**150** and S**160** where the logic circuit **46** determines the background and peak light signals. More particularly, steps S**151**, S**152**, S**159** and S**160** provide two processing loops for sequentially determining the digital values indicative of the photosensor element signals, Val RA(n,m), in the RAM array RA(N,M) for each of the photosensor elements **32***a* of the photosensor array PA(N,M).

In step S**153**, a lens correction factor LC(n,m) is applied to each digital value indicative of the photosensor element signal, Val RA(n,m), to correct for the effects of lens **30**, which results in a lens corrected digital value of the photosensor element signal Val RA_{LC}(n,m). These effects are typically referred to as cosine effects or Lambert's Law effects. The lens correction factor LC(n,m) depends on the radial distance of the photosensor element **32***a* from a central axis of the lens **30**, and is typically in the range of 1 to 15 but will depend on the geometry of the lens and the selected photosensor array. The lens correction factor LC(n,m) applied to each Val RA(n, m) may be calculated according to Lambert's Law each time Val RA(n,m) is processed. More preferably, the logic circuit **46** initially stores an array of values LC(n,m) in the RAM **50** for each photosensor element **32***a* of the photosensor array PA(n,m) during an initialization routine. Alternatively, the size of the photosensor elements **32***a* of the photosensor array **32** may be adjusted to correct for the lens effects at each photosensor element **32***a*.

As discussed, it has been found that light levels for headlights generally result in an eight-bit digital value greater than a peak threshold value F having a value of about 245. Correspondingly, during non-daylight operation of the automatic rearview mirror system **20**, background light levels generally result in eight-bit digital values indicative of the light levels incident on the photosensor elements **32***a* that are less than or equal to the peak threshold value F.

Accordingly, the lens corrected value Val RA_{LC}(n,m) is compared in step S**154** to the peak threshold value F. If Val RA_{LC}(n,m) is less than or equal to F it is used to increment a counter B_{count}, in the logic circuit **46**, by 1 in step S**157** (thereby indicating that a value less than or equal to F has been identified) and by increasing a value B_{sum} by the value of Val RA_{LC}(n,m) in step S**158**, where B_{Sum} is the sum of all the values of Val RA_{LC}(n,m) which are less than or equal to F. The background light signal B_t is then determined in step S**161** as follows: $B_t=B_{Sum}/B_{Count}$. If Val RA_{LC}(n,m) is greater than F in step S**154**, then the logic circuit **46** uses a counter P(z) indicative of the peak light levels for each of the zones or sub-arrays S(X) of the photosensor array PA(N,M), which is incremented by 1 as previously described. More particularly, Val RA_{LC}(n,m) is tested in step S**155** to determine whether it originates from a particular zone or sub-array S(X), where X=1 to Z. If Val RA_{LC}(n,m) does not fall within a defined zone or sub-array S(X), then P(z) is not incremented; otherwise, P(z) is incremented in step S**156** for the appropriate zone.

If the photosensor array **32** is arranged to view the rearward area through the active layer of the variable reflectance element **1***a*, then a color correction factor CC is applied in step S**162** to B_t, and P(z) to compensate for any reduction in transmittance when the reflectance level (and transmittance) of the rearview mirror **1** is reduced. The value of CC is determined from the last calculated value indicative of the digital mirror control signal $V_{DAC}(z)$ applied to the rearview mirror **1**. In step S**163**, a change-limited background light signal B_{Lt} is determined as has been described previously.

FIG. **8**B provides further detail on step S**180** where the logic circuit **46** determines the appropriate digital mirror control signal $V_{DAC}(z)$ for each zone or sub-array S(X) and corresponding mirror **28**. In steps S**181** and S**182**, $V_{DAC}(z)$ is calculated for each mirror **28**. In step S**183**, the logic circuit **46** reads a state IN**1** of the reverse-inhibit switch **38** and if the vehicle is in reverse gear so that IN**1** is high, then all digital mirror control signals $V_{DAC}(z)$ are set to 0 in step S**184** forcing the mirror **28** to its maximum reflectance level. In step S**185**, a state IN**2** of the force-to-day switch **36** is read and if IN**2** is high, then all digital mirror control signals $V_{DAC}(z)$ are set to 0 in step **186** forcing the mirror **28** to its maximum reflectance level. Finally, in step S**187**, a state IN**3** of the force-tonight switch **40** is read and if IN**3** is high, then all digital mirror control signals $V_{DAC}(z)$ are set to 255 (the maximum digital value for eight-bit data resolution) in step S**188** forcing the mirror **28** to its minimum reflectance level.

FIG. **9** shows another view of the logic flow whereby the rearview mirror, the left side view mirror and the right side view mirror (or alternatively three mirror segments) are independently driven to their desired reflectance levels by the independent and separate control and drive signals using photosensor element signals from three photosensor element sets (i.e., the sub-arrays S(**1**), S(**2**) and S(**3**) of photosensor elements **32***a* in the photosensor array PA(n,m)). The specific subroutines shown in FIGS. **8**A and **8**B corresponding to the general steps shown in FIG. **7** are also used with the general steps shown in FIG. **9**.

In step S**201**, light incident on the lens **30** is focused in step S**210** onto the photosensor array **32** comprising the first, second and third sets of photosensor elements **32***a* in zones a, b and c, respectively. Next, in step S**211**, the light incident on the first photosensor element set in zone a generates a first set of photosensor element signals, which, in step S**211'**, are then stored in RAM and later used by the logic circuit **46** to determine a first peak light signal in step S**212**.

In step S**221**, the light incident on the second photosensor element set in zone b generates a second set of photosensor element signals, while in step S**231**, the light incident on the third photosensor element set in zone c generates a third set of photosensor element signals. The second set of photosensor element signals, generated in step S**221** are also stored in step **221'** in RAM and then used by the logic circuit **46** to determine a second peak light signal in step S**222**. Similarly, the third set of photosensor element signals, generated in step S**231**, is next stored in step S**231'** in RAM and then used by the logic circuit **46** to determine a third peak light signal in step S**232**.

In step S**213**, photosensor element signals generated from selected photosensor elements on which light is incident in step S**210** are used to determine the background light signal.

In step S**214**, the logic circuit **46** uses the background light signal determined in step S**213** and the first peak light signal determined in step S**212** to determine a first control signal. Similarly, the logic circuit **46** uses the background light signal of step S**213** and the second peak light signal determined in step S**222** to determine a second control signal in step S**224**. In the same manner, the background light signal of step S**213** and the third peak light signal of step S**232** are used by the logic circuit **46** to determine a third control signal in step S**234**.

The first control signal determined in step S**214** is used by the drive circuit **24***a* to generate a first drive signal in step S**215**. This first drive signal drives the rearview mirror **28***a* to a desired reflectance level in step S**216**. Likewise, the second control signal determined by the logic circuit **46** in step S**224** is used by the drive circuit **24***b* to generate a second drive signal in step S**225**, which is then used to drive the left side view mirror **28***b* to a desired reflectance level in step S**226**. Finally, the third control signal determined by the logic circuit **46** in step S**234** is used by the drive circuit **24***c* to generate a third drive signal to drive the right side view mirror **28***c* to a desired reflectance level in step S**236**. Of course, the first, second and third control signals may also be used to control the segments of a mirror **28**.

Finally, as previously discussed, one advantage of the present invention is that it is able to use a single photosensor array **32** to determine both a background light level and a peak light level for controlling the reflectance level of a mirror. This is especially advantageous where the sensor must be placed outside the interior of the vehicle to view the rearward scene. This may be required, for example, in certain truck type vehicles where only exterior side view mirrors may be used and automatic operation is desired. Accordingly, the photosensor array **32** may be located with each side view mirror. The other electronics for the automatic rearview mirror system **20**, described previously, may be located either with the photosensor array **32** in each side view mirror, inside the vehicle cab or elsewhere in or on the vehicle. A desired reflectance level for each exterior side view mirror may then be accurately determined using both the determined background light level and peak light level using only a single photosensor array **32** for each mirror.

FIGS. **12** and **12**A show the logic flow charts of the vehicle interior monitoring system configured as a vehicle intrusion detection system (primary task S**400**). In step S**401**, the current image data frame $RA_{(t)}$ is processed to enhance its contrast characteristics so that it is largely unaffected by changing light levels or shadows, etc. Preferably, the logic circuit **46** selects an appropriate sub-array $RS_{(t)}$ corresponding to the sub-array S(X) (or other appropriate set) of photosensor elements **32***a* of the photosensor array **32** containing the relevant image information.

As discussed, the particular area of interest or significance in the photosensor array **32** may be a sub-array S(X) of photosensor elements **32***a* of the photosensor array **32** (or other appropriate set not necessarily rectangular in shape, such as a trapezoid). The ability to select image data corresponding to S(X) is important because some sets of photosensor elements **32***a* may provide image information that is redundant, irrelevant or even damaging to a particular application and should therefore be ignored by the logic circuit **46**. A significant advantage of the photosensor array **32** over other sensing technologies is its ability to provide selected image information so that the logic circuit **46** need only process $RS_{(t)}$ when, for example, the relevant sub-array S(X) and corresponding sub-array $RS_{(t)}$ contain all the image information necessary to a particular application. For example, in the automatic rearview mirror and vehicle intrusion detection system described herein, a selected sub-array S(X) of photosensor elements **32***a* may provide image information as shown in FIGS. **3**A and **3**B, which may be used by logic circuit **46** to provide information regarding the location and intensity of the headlights of following vehicles. To the extent that other areas of the photosensor array **32** do not provide such image information, they may be ignored. Likewise, since the same photosensor array **32** may be used for vehicle intrusion detection, the logic circuit **46** need only process the image information of FIG. **2**A that excludes the image information of FIGS. **3**A and **3**B. Without this ability to select particular sets or sub-arrays, at least more intensive processing may be required to distinguish between unauthorized activity within the vehicle and irrelevant activity outside the vehicle.

After selecting the appropriate set of image data, the logic circuit **46** processes the values in $RA_{(t)}$ to enhance the contrast or robustness of that image data frame. Excluding photosensor elements **32***a* in the outside rows and columns of the photosensor array **32**, every photosensor element E(n,m) has eight (8) adjacent photosensor elements **32***a* or neighbors: E(n−1,m); E(n,m1); E(n−1,m−1); E(n+1,m); E(n,m+1); E(n+1,m−1); E(n−1,m+1); and E(n+1,m+1). Therefore, a contour value CV(n,m) for each photosensor element E(n,m) may be calculated by determining the average of the differences between the value Val RA_{LC}(n,m) of the photosensor element E(n,m) and the value of each neighbor. If the photosensor element value is an n-bit value, then CV(n,m) is also an n-bit value. Thus, using 8-bit data resolution, for example, if E(n,m) has a 0 value and each neighbor has a value of 255, then

CV(n,m) is 255. If E(n,m) has a value of 255 and each neighbor has a 0 value, then CV(n,m) is 255. Both examples indicate a high degree of local contrast or discontinuity. On the other hand, if E(n,m) and each neighbor has a value of 127, then CV(n,m) is 0, which indicates a low degree of local contrast. Thus, the logic circuit **46** uses the above method, to determine the contrast value CV(n,m) for each value Val RA_{LC}(n,m) of $RA_{(t)}$ to obtain a contour enhanced image data frame $RC_{(t)}$ in which the "harder" image contours or discontinuities are emphasized or enhanced, while "softer" image contours are reduced in significance.

Next, in step S**402**, the logic circuit **46** correlates the current image data frame $RC_{(t)}$ and a reference image data frame $RC_{REF(t-1)}$ by comparing them to determine an image correlation factor IC. This factor is indicative of the correlation or degree of similarity (or difference) between the two image data frames independent of the particular image or photosensor array size. An IC value of 0 indicates no image similarity and an IC value of 1 indicates a perfect match. In particular, the image correlation factor IC is indicative of the number of corresponding photosensor elements **32***a* within the photosensor array **32** (or sub-array S(X)) having the same value Val RA_{LC}(n,m) within some tolerance value T for the current and reference image data frames or sets. The tolerance value T accounts for mirror image variations, such as may be caused by system vibration or other system "noise". Thus, the value from the current image data frame $RC_{(t)}$ corresponding to photosensor element E(1,1) is compared with the value from the reference image data frame $RC_{REF(t-1)}$ corresponding to photosensor element E(1,1), and if:

$$Val\ RC_{(t)}(1,1)=Val\ RC_{REF(t-1)}(1,1)\pm T,$$

then the $RC_{(t)}$ and $RC_{REF(t-1)}$ values of photosensor element E(1,1) correlate. This is done for all photosensor elements **32***a* within the photosensor array **32** or selected sub-set thereof, and the logic circuit **46** stores and sums each correlation occurrence for each element E(n,m). The logic circuit **46** then divides the resulting sum of correlation occurrences by the number of elements E(n,m) considered in determining the image correlation factor IC.

Next, in step S**403**, the logic circuit **46** determines whether certain system start-up criteria are met. This is done to ensure that a stable image data frame $RC_{(t)}$ is stored as $RC_{REF(t)}$. Importantly, $RC_{REF(t)}$ must correspond to an optimized and stable image data frame $RC_{(t)}$. When power is initially supplied to light sensing and logic circuit **26**, electrical and thermal transients occur as is typical for silicon integrated circuits. For the system described herein, satisfactory start-up criteria include: (1) a minimum number of image data frames that must be processed to allow electrical stabilization and the completion of the majority of EP and SSI optimization, where the minimum number of data frames is preferably 25 but may be in the range of 15 to 40; and (2) a stable reference image $RC_{REF(t)}$, where $RC_{REF(t)}$ is sufficiently stable when AR is within the operating point range OP±R and IC exceeds 0.95 for at least 2 to 10 image data frames, but preferably 4 image data frames.

If the start-up criteria are not met in step S**403**, then, in step S**404**, the logic circuit **46** stores $RC_{(t)}$ in RAM **50** as a reference image data frame $RC_{REF(t)}$ (which is $RC_{REF(t)}$ where the current image data frame is $RC_{(t)}$ on the next system cycle) and the program returns to step S**310**. If the start-up criteria in step S**403** are met, then the program goes to step S**405**.

In steps S**405** and S**406**, threshold values T_1 and T_2 are used to determine the degree to which the current and reference image data frames match or mismatch. The values T_1 and T_2 depend on the particular application and the degree of confidence or reliability required in the match/mismatch conditions of steps S**405** and S**406**. For the vehicle intrusion detection system, it has been found that appropriate threshold values may range from 0.0 to 0.6 for T_1 and from 0.95 to 1.0 for T_2, but are preferably 0.6 and 0.95 for T_1 and T_2, respectively. Due to image or system variations, perfect image correlation does not normally occur; therefore, compared image data frames having an IC value greater than 0.95 are considered a match, those having an IC value less than 0.6 are considered a mismatch and those having an IC between T_1 and T_2 are neither a definite match nor a definite mismatch.

More particularly, if IC exceeds T_1 in step S**405**, then the logic circuit **46** determines whether IC exceeds T_2 in step S**406**. If IC does not exceed T_2, then the program returns to step S**310** since there is neither a match nor a mismatch condition. If IC does exceed T_2, then there is a match and the logic circuit **46** updates the reference image data frame $RC_{REF(t)}$. It should be understood that $RC_{REF(t)}$ may be the same as $RC_{(t)}$ or may represent any appropriate combination of two or more image data frames. For example, $RC_{REF(t)}$ may be determined using a digital lag filter:

$$RC_{REF(t)}=RC_{REF(t-1)}+K\times(RC_{(t)}-RC_{REF(t-1)}),$$

where K may be a constant. After the logic circuit **46** updates $RC_{REF(t)}$ and stores it in the RAM **50**, the program again returns to step S**310**.

If IC does not exceed $T_{(1)}$ in step S**405**, then the image data frames are considered a mismatch. Even though $T_{(1)}$ is selected so that only significant differences between $RC_{(t)}$ and $RC_{REF(t-1)}$ provide a mismatch condition, the logic circuit **46** determines in step S**408** whether the mismatch condition is a valid intrusion condition. This is because there are conditions that result in the logic circuit **46** erroneously determining a mismatch condition. For example, automotive electrical system noise may affect the ability of the photosensor array **32** to provide accurate photosensor element signals, although this normally occurs only for short periods given the nature of such noise. While not all system applications may require the same level of confidence for a correct mismatch condition, it has been found that requiring a number of successive mismatch conditions represents a good validation test for step S**408**. In particular, it has been found that this validation test better ensures that the mismatch condition is valid by requiring from 2 to 300 successive mismatch conditions. Alternatively, the validation test may require from 2 to 300 initial mismatch conditions and allow a number of match conditions in step S**405**, where the number of match conditions may be from 1 to 15 depending on the required number of mismatch conditions.

If the logic circuit **46** determines that the mismatch condition is not valid in steps S**408**, then the program will go to step S**310**. If the mismatch condition is valid, then the logic circuit **46** outputs one or more control signals in step S**409**. The control output signals are generally of two types: (1) signals that may be used to control directly certain vehicle hardware (lights, horn, etc.); and (2) signals that may be used as inputs to other vehicle controller systems that directly interface with such hardware. The logic circuit **46** may output any combination of these control output signals depending on the desired level of integration between the system of the present invention and other vehicle systems. Digital control signals, such as bi stable signals or digitally coded words interpreted by other vehicle systems, are typical for most applications. If the logic circuit **46** outputs bi-stable control signals directly to vehicle hardware, then the control output signal lines may be latched in a high or low state to control the vehicle hardware. If the logic circuit **46** outputs control signals to a vehicle controller system, then a higher protocol level, (such as digitally coded words) may have to be output from the logic circuit **46**.

FIG. **12**B shows the logic flow chart of the compartment image data storage system configuration (primary task routine **5500**) of the vehicle interior monitoring systems of FIG. **12**.

In step S**501**, the image data frame $RA_{(t)}$ (although this may be $RC_{(t)}$ is tested to determine whether it is valid. To determine whether $RA_{(t)}$ is valid in step S**501**, the logic circuit **46** may determine whether the array response AR is within the operating point range OP±R. More stringent validity tests may include vehicle feature recognition, in which the system attempts to identify reference vehicle features, such as the seats or window pillars, and if the logic circuit **46** cannot identify these reference features in $RA_{(t)}$, then it determines that $RA_{(t)}$ is invalid. If $RA_{(t)}$ is valid, then $RA_{(t)}$ may be optionally compressed in step S**502** using any appropriate digital compression method to reduce the amount of image data. Next, in step S**503**, the logic circuit **46** stores the image data in the nonvolatile memory **57** on a first-in-first-out (FIFO) basis. As will be described further below, the program may end or return to step S**310** to obtain and process additional image data frames depending on the particular application. If $RA_{(t)}$ is not valid, then in steps S**504**, S**505**, S**506** and S**507**, the logic circuit **46** determines whether the photosensor **2** has been intentionally defeated so that an accurate image data frame of the vehicle interior or compartment cannot be generated and stored in the nonvolatile memory **57**.

More particularly, in steps S**504** and S**506**, if it is determined that both EP and SSI are minimums, then the photosensor **2** is probably being defeated by an intruder or vehicle thief who is blinding the photosensor **2** by directing a light source, such as a bright flashlight, directly at the photosensor **2**. This action saturates the photosensor array **32** so that the image data frame appears "white". Since the photosensor array **32** normally does not saturate when both EP and SSI are at their minimums, a "white" image data frame would not normally occur. In steps S**505** and S**507**, if it is determined that both EP and SSI are maximums, then the photosensor **2** is probably being defeated by an intruder who is blinding the photosensor by placing a piece of tape or other opaque material over the lens **30** (or window) which the photosensor array **32** uses for seeing the vehicle interior **100**. This action results in a "black" image data frame. Since SSI is maximized to allow the photosensor array **32** to generate images even if there is insufficient natural light, a "black" image data frame would also not normally occur.

If steps S**504**, S**505** and S**507** result in a "black" image condition or steps S**504** and S**505** result in a "white" image condition, then the logic circuit **46** outputs a control signal in step S**508** to the vehicle controller to disable the ignition control device and/or to the vehicle controller system to activate the horn and lights. Otherwise, EP and SSI have not reached their adjustment limits, and the system attempts to optimize them and generates another image data frame which is then again tested to determine its validity in step S**501**.

VI. Integrated Headlight Control System

It is generally important for driver safety reasons that the headlights and sidelights of operating vehicles are turned on as night approaches or when background lighting levels fall below approximately 500 lux. More particularly, it is desirable to have the vehicle's headlights and sidelights automatically turn on when background lighting levels fall to a sufficiently low level and automatically turn off when background lighting levels rise sufficiently.

While there are other automatic headlight control systems, such systems require that the photocells, which are used to control the headlights, be located and positioned so that they generally face upward either to avoid the effects of oncoming headlights for generally forward facing photocells or to avoid the effects of following headlights for generally rearward facing photocells.

An advantage of the automatic rearview mirror system **20** is that the background light signal B_{Lt} may be used to automatically turn on and off a vehicle's headlights and sidelights by controlling the vehicle lighting switch **45**. Importantly, since B_{Lt} is determined regardless of the presence of peak light sources, such as oncoming or following headlights, the directional constraints on how and where the sensor is located or positioned are avoided. Accordingly, using the photosensor array **32** of the present invention to provide additional vehicle lighting control functions results in lower costs and improved reliability over other headlight control systems.

The limited background light signal B_{Lt} has been described for the purpose of controlling the reflectance levels of an automatic rearview mirror system **20**. Additionally, the logic circuit **46** may use B_{Lt} to generate a vehicle lighting control signal to control the vehicle lighting switch **45** to turn on and off automatically the vehicle's headlights and sidelights. The ability to use B_{Lt} is important because the vehicle lighting switch **45** should not be responsive to rapid or small fluctuations in background light levels in the region of the desired point at which the vehicle lighting switch is turned on or off, i.e., the switch point. Such fluctuations can be caused by the shadowing effect of overhanging trees or structures or the lighting differences between the eastern and western skylines at dawn and dusk which may be encountered when turning the vehicle.

Additionally, hysteresis is also provided between the switch-on and switch-off conditions of the vehicle lighting switch **45** to further stabilize operation of the switch **45** in such fluctuating light conditions. More specifically, if the required switch point for falling light. The levels is SP, then the switch point for rising light levels is SP×(1+H), where H is a hysteresis factor typically in the range of about 0.005 to 0.5, but is preferably 0.2. Thus, if B_{Lt} is less than SP, then the vehicle lighting control signal to the vehicle lighting switch **45** is set high to turn on the vehicle's headlights and sidelights. If B_u is greater than SP×(1+H), then the vehicle lighting control signal to the vehicle lighting switch **45** is set low to turn off the vehicle's headlights and sidelights.

Additionally, if the photosensor array **32** and logic circuit **46** are both powered directly by the vehicle's electrical system through the ignition switch, then a time delay t_d may be provided 'such that if the ignition switch is turned off when the headlight control signal is set high, the vehicle lighting control signal will remain high for a time t_d and thereafter fall to a low value to turn off the vehicle's headlights and sidelights. A manual control may also be provided to allow the driver to adjust the time delay t_d.

The vehicle lighting control signal and, more specifically, the lighting control switch **45** may also be used to inhibit automatic control of the automatic rearview mirror system **20**. For example, if the vehicle lighting control signal indicates that the vehicle lighting should be turned off, then the logic and control circuit **34** may be used to enable sensitivity switch **42** or some other switch allowing the driver to manually adjust the reflectance level of the mirrors **28**. Thus, the driver may manually select a lower reflectance level during daylight conditions to provide protection against peak light sources, such as a bright setting sun. As background light levels fall or during non-daylight conditions, the vehicle lighting control signal would indicate non-daylight conditions and the logic and control circuit **34** may then be used to disable manual control and return the automatic rearview mirror system **20** to full automatic control.

FIG. **6**B shows another embodiment of a stand-alone vehicle lighting control system, which has a number of the components identified with respect to FIG. **6**. The vehicle lighting control system of FIG. **6**B may also be integrated with automatic rearview mirror system and vehicle interior monitoring system described herein. In FIG. **6**B, however, the photosensor array **32** is directed generally forward of the vehicle so that it may sense a field of view forward of the rearview mirror **1**. The forward field of view is through the vehicle's front windshield and generally in line with the primary vehicle direction. In the embodiment of the vehicle lighting control system as described herein, the photosensor array **32** comprises a plurality of photosensor elements **32***a* arranged in 160 columns and 120 rows (a 160×120 array) and has a forward field of view of approximately 50 degrees centered at the vehicle center line and a vertical field of view of approximately 30 degrees, where the vertical field of view is approximately 10 degrees above and 20 degrees below the horizon in the forward field of view. It should be understood that the forward field of view may also be provided to the photosensor array **32** by using any appropriate image directing optics or other appropriate means for directing a forward field of view onto the photosensor array **32** regardless of its orientation.

The logic and control circuit **34** processes the photosensor array signals corresponding to the forward field of view to determine an appropriate vehicle lighting configuration depending on the light information in the forward field of view. The methods used by the logic and control circuit **34** to determine the appropriate vehicle lighting configuration are described below. After determining the appropriate vehicle lighting configuration, the logic and control circuit **34** generates and applies control signals to headlight switches **29**, which comprise a low beam mode switch **29***a*, a mid beam mode switch **29***b* and a high beam mode switch **29***c*, and to a vehicle running lights switch **31** and tail lights and side lights switches **35**. Also shown in FIG. **6**B is a sensitivity control circuit **41**, which may be used to control the level of hysteresis in the vehicle lighting control system, and manual vehicle light switches **43** for manually controlling the vehicle lights.

The photosensor array **32** is preferably located within the vehicle interior since this provides protection against the outside elements, including dirt, moisture, rain and snow, as well as reduced exposure to ultraviolet light, and generally provides a relatively controlled environment, including temperature environment. It should be understood, however, that the photosensor array **32** may also be located in one or both of the external sideview mirrors **4** and **5**, or in any other appropriate location on the vehicle.

The methods defined for determining the change-limited background light signal B_{Lt} may also be used to determine a change-limited background forward light signal B_{LFt} that may be used to control the vehicle lighting system. Also, the methods previously described for determining and identifying peak light levels may generally be used to determine and identify whether there are other headlights and taillights in the driver's forward field of view. The logic and control circuit **34** uses this information to control automatically the vehicle headlights (low beam, mid beam and high beam modes) so as to limit the annoyance or debilitation of other vehicle drivers forward of the vehicle. The method for processing the forward field of view image is the same as that shown through step S**140** in the flow chart of FIG. **7**A, and is generally the same as to steps S**150** and S**160** as detailed in the flow chart FIG. **8**A, except that steps S**155**, S**156** and S**162** are excluded. FIGS. **13**A, **13**B, **13**C and **13**D are the flow charts that show the methods used by the logic and control circuit **34** to determine the appropriate vehicle lighting configuration and to control the vehicle lighting system. The methods detailed in FIGS. **13**A, **13**B, **13**C and **13**D may generally be described as follows:

After the logic and control circuit **34** determines B_{LFt}, it determines whether B_{LFt} exceeds a threshold B_{DD}, which corresponds to the light level at dawn, dusk or a comparable lighting condition. If B_{LFt} exceeds B_{DD}, then a flag F_{DAY} corresponding to a daytime condition, which indicates that the vehicle running lights, if any, may be turned on but that vehicle headlights and taillights should otherwise be off, and resets to zero flags F_{LOW}, F_{MID} and F_{HIGH} which respectively correspond to the low, mid and high beam modes for the vehicle headlights. If B_{LFt} is less than B_{DD} and exceeds a threshold B_N, which corresponds to a light level at night below which the mid or high beam modes may be operated, then the logic and control circuit **34** sets F_{LOW} to 1 and resets F_{LAY}, F_{MID} and F_{HIGH}.

If B_{LFt} is less than B_N, then the logic and control circuit **34** processes a mid zone, which corresponds to a sub-array S(X) within the array PA(N,M) of the photosensor array **32**. This mid zone or zone of interest represents an appropriate area of the forward field of view image, in which the vehicle headlights may be set to their mid beam mode if there are no other vehicles as indicated by other vehicle light sources (headlights or taillights) within the mid zone. If there are no other vehicle light sources, then the logic and control circuit **34** sets F_{MID} to 1 and resets F_{LOW}. Otherwise, F_{LOW} remains set, and the logic and control circuit **34** determines and processes the next set of photosensor element signals.

If, however, F_{MID} is set to 1, then the logic and control circuit **34** processes a high zone corresponding to the Array PA(N,M). The high zone represents an appropriate area of the forward field of view image, in which the vehicle headlights may be set to their high beam mode if there are no other vehicle light sources within the high zone. If there are no other vehicle light sources, then the logic and control circuit **34** sets F_{HIGH} to 1 and resets F_{MID}. Otherwise, F_{MID} remains set, and the system determines and processes the next set of photosensor element signals.

More complex vehicle lighting configurations may be controlled by determining an appropriate zone of interest for each available vehicle lighting mode or pattern.

Also, as discussed above with respect to the first embodiment of a vehicle lighting control system, hysteresis is used to moderate the frequency of transitions between the various beam modes and is reflected in FIGS. **13**A, **13**B, **13**C and **13**D by low beam counter LC, mid beam counter MC, high beam counter HC and night counter NC, each having corresponding hysteresis values LC**1**, MC**1**, HC**1** and NC**1**, respectively. The hysteresis values may correspond to about 1 to 30 forward field of view image frames, and therefore correspond to a certain period of time since each image frame takes on the order of about 0.1 seconds to process. It should also be understood that in the described embodiment, hysteresis has only been provided for transitions from low to mid or mid to high transitions, while transitions from high to mid or mid to low occur after the processing of only one image frame. Of course, hysteresis may also be used for transitions from high to mid or mid to low. Also, transitions to the initial low beam mode may be delayed on the order of 15 seconds to five minutes, rather than occurring within one image frame as described herein. Further, in addition to or alternatively to hysteresis, specific time delays of from about 1 to 15 seconds, or any other appropriate delay be used for transitions between beam modes.

Also, the vehicle driver may use the sensitivity control circuit **41** to adjust the level of hysteresis. The vehicle driver may also use the manual vehicle light switches **43** to override the vehicle lighting control system.

As discussed, FIG. **13**A shows the initialization of the system and the initial low beam mode determination, FIG. **13**B shows the initial mid and high beam mode determinations, FIG. **13**C shows subsequent transitions from the mid beam mode to either the low or high beam modes, and FIG. **13**D shows subsequent transitions from the high beam mode to the mid and low beam modes.

As to FIG. **13**A, in the initialization step S**600**, the logic and control circuit **34** sets flag F_{DAY} to 1, sets flags F_{LOW}, F_{MID}, F_{HIGH} and F_N to 0, and sets counters LC, MC, HC and NC to 0.

Next, in step S**610**, the logic and control circuit **34** determines B_{LFt} as previously described. In step S**620**, if B_{LFt} is not less than B_{DD}, then the logic and control circuit **34** determines whether LC equals or exceeds LC**1** in step S**621**. If LC is less than LC**1**, then LC is incremented in step S**624** and the processing is returned to step **610**. If LC equals or exceeds LC**1**, then the logic and control circuit **34** in step S**622** sets F_{LAY} to 1, resets flags F_{LOW}, F_{MID} and F_{HIGH} to 0 and also resets a flag F_{TSL}, which corresponds to the status of the vehicle tail lights and side lights. Next, in step S**623**, the logic and control circuit outputs control signals to disable all vehicle night lights, including the headlights, side lights and tail lights.

If in step S**620**, B_{LFt} is less than B_{DD}, then the system goes to step S**630**. In step S**630**, if LC exceeds 0, then LC is decremented in step S**631** and the system returns to step S**610**. If LC equals 0 in step S**630**, then the logic and control circuit **34** sets F_{LAY} to 0 in step S**640**, and then goes to step S**650**. In step S**650**, if B_{LFt} is not less than B_N, then the logic and control circuit **34** determines whether NC equals or exceeds NC**1** in step S**651**. If not, then NC is incremented in step S**653**. If yes, then NC is set to NC**1** in step S**652**. In either case, F_N is then reset and the system goes to step S**900**. If B_{LFt} is less than B_N, the system goes to step S**660**. If NC exceeds 0 in step S**660**, then NC is decremented in step S**661** and F_N is reset in step S**662**, after which the system goes to step S**900**. If NC equals 0 in step S**660**, then F_N is set to 1 in step S**670**. Next, in steps S**700** and S**800**, if F_{MID} and F_{HIGH} are not 1, then the system also goes to step S**900**. In step S**900**, F_{LOW} and F_{TSL} are set and LC is set to LC**1**. Next, in step S**910**, the logic and control circuit **34** enables the tail and side lights (TSL) and low beam mode, and proceeds to step S**920**.

Next, FIG. **13**B shows the logic for making an initial transition from the low beam mode to the mid beam mode and for making an initial transition from the initial mid beam mode to the initial high beam mode. Thus, in step S**920**, if F_N equals 1, then the system returns to step S**610**. Otherwise, the logic and control circuit **34** processes the Sub-Array S(X) in step S**930** to determine whether there are any other vehicles (OV) in S(X) in the forward field of view, as previously described. In step S**940**, if OV is in S(X), then MC and HC are reset in step S**941** and the system returns to step S**610**. If not, then the system goes to step S**950**. If MC does not equal or exceed MC**1**, then MC is incremented in step S**951** and processing returns to step S**610**. Otherwise, F_{MID} is set and F_{LOW} is reset in step S**960**, and the logic and control circuit **34** outputs control signals to enable the mid beam mode and disable the low beam mode in step S**970**. Next, in step S**980**, the logic and control circuit **34** processes PA(N,M) to determine if there are any other vehicles (OV) in PA(N,M). In step S**990**, if OV is not in PA(N,M), then HC is incremented and the system returns to step S**610**. Otherwise, F_{HIGH} is set and F_{MID} is reset in step S**1000**, after which the logic and control circuit **34** outputs control signals to enable the high beam mode and disable the mid beam mode in step S**1010**, and the system returns to step S**610**.

As discussed, FIG. **13**C shows the logic for making transitions from the mid beam mode to either low or high beam modes. Thus, if F_{MID} equals 1 in step S**700** of FIG. **13**A, then the logic and control circuit **34** processes S(X) for OV in step S**710**. If OV is in S(X) in step S**720**, F_{LOW} is set and F_{MID} and MC are reset in step S**721**, after which the logic and control circuit **34** outputs control signals to enable the low beam mode and disable the mid beam mode in step S**722** and the system returns to step S**610**. If OV is not in S(X) in step S**720**, then the logic and control circuit **34** processes PA(N,M) for OV in step S**730**. In step S**740**, if OV is in PN(N,M), then HC is reset in step S**741** and the system returns to step S**610**. Otherwise, in step S**750**, if HC does not equal or exceed HC**1**, then HC is incremented in step S**751** and processing returns to step S**610**. If HC equals or exceeds HC**1** in step S**750**, then F_{HIGH} is set and F_{MID} is reset, after which the logic and control circuit **34** outputs control signals to enable the high beam mode and disable the mid beam mode in step S**770** and then returns to step S**610**.

Finally, FIG. **13**D shows transitions from the high beam mode to the mid beam and low beam modes. Thus, if F_{HIGH} equals 1 in step S**800** of FIG. **13**A, then the system goes to step S**810**, in which the logic and control circuit **34** processes PA(N,M) for OV. In step S**820**, if OV is not in PA(N,M), the system returns to step S**610**. Otherwise, F_{MID} is set and F_{HIGH} and HC are reset in step S**830**, after which the logic and control circuit **34** outputs control signals to enable the mid beam mode and disable the high beam mode in step S**840**. Next, in step S**850**, the logic and control circuit processes S(X) for OV. In step S**860**, if OV is not in S(X), then the system returns to step S**610**. Otherwise, F_{LOW} is set and F_{MID} and MC are reset in step S**870**, after which the logic and control circuit **34** outputs control signals to enable the low beam mode and disable the high beam mode in step S**880** and then returns to step S**610**.

Additionally, the above system may also be used to determine an appropriate vehicle lighting configuration and then controlling the vehicle lighting systems so as to improve the driver's forward field of view. For example, by providing the photosensor array **32** with a forward field of view, the system may be used to recognize veiling glare caused by scattered light that maybe caused by fog, snow, rain or other adverse conditions. In particular, the logic and control circuit **34** may be used to determine a contrast factor representing the level of contrast within the forward field of view. This information may then be used to select the appropriate vehicle lighting configuration so as to reduce the level of veiling glare.

The system may also be used to monitor varying windshield surface conditions caused by condensation, dirt, rain or snow. In particular, the system may be used to identify these conditions by analyzing the forward field of view image frames for distortion, or degradation. This capability may be enhanced by using infra-red supplemental source illumination (SSI) having wavelengths within the responsive range of the photosensor array **32**.

More particularly, since the photosensor array **32** may have a forward field of view that includes at least the windshield area, which is swept by the windshield wipers, the logic and control circuit **34** may be used to generate control signals to operate the vehicle's windshield wiper system, windshield washer system, defogger system or windshield de-icing system so as to improve forward viewing conditions.

Also, for a forward field of view, the photosensor array **32** may be used to generate image frame data that controls or supplements the control of vehicle collision avoidance systems or other automatic vehicle systems using forward field of view information. Additionally, since the photosensor array **32** responds to a portion of the non-visible electromagnetic spectrum as previously described, it may be used to receive non-visible, spatially or time varying data from objects in the forward field of view, such as vehicles or road signs having an infra-red source emitter and to provide vehicle-to-vehicle or road-to-vehicle communications, which may be used to support intelligent vehicle and highway systems (IVHS), which are designed to improve road travel safety and efficiency.

VII. The Automatic Rearview Mirror and Vehicle Interior Monitoring System

FIG. **10** also shows the automatic rearview mirror system **20** of the present invention. The system **20** is powered by the vehicle's electrical system (not shown) to which the system **20** is connected. A voltage regulation and transient protection circuit **22** regulates power and protects the system **20** from voltage transients as is well known in the art. The circuit **22** is connected to the vehicle's electrical system and to ground, and outputs a voltage of up to about 5 volts to power the mirror drive circuits **24** and the light sensing and logic circuit **26**. The circuit **22** also has a ground line connected to the light sensing and logic circuit **26**.

The 5 volt line is also connected to the force-to-day switch **36** and the reverse-inhibit switch **38** (connected in parallel to the light sensing and logic circuit **26**) which are used to force the mirrors **28** to their maximum reflectance level. More particularly, when either of these switches is closed, they generate a high level signal V_H such as a 3 volt signal, which is input to the light sensing and logic circuit **26**. This high level signal overrides the normal operation of the light sensing and logic circuit **26** causing it to output a control signal to the drive circuits **24** to drive the mirrors **28** to their maximum reflectance level. Conversely, when these switches are open, they each generate a low level signal V_L such as a signal of less than 3 volts, thereby permitting normal operation of the light sensing and logic circuit **26**, as has been discussed with respect to FIGS. **7**, **8**A and **8**B. The force-to-day switch **36** and the reverse-inhibit switch **38** may be alternatively configured to generate a low level signal when closed and a high level signal when open. The force-to-day switch **36** is a manually operated switch and is preferably placed on the rearview mirror **28***a* and may be switch **3**. The reverse-inhibit switch **38** is connected to a reverse inhibit line in the vehicle's electrical system (not shown) so that the reverse-inhibit switch **38** is actuated automatically whenever the vehicle is in reverse gear.

The force-to-night switch **40**, used to force the mirrors **28** to their minimum reflectance level, generates a high level signal V_H when closed and a low level signal V_L when opened. The signal V_H or V_L is then input to the light sensing and logic circuit **26**. The high level signal may, for example, be between 3 to 5 volts and the low level signal may be below 3 volts. The high level signal overrides the normal operation of the light sensing and logic circuit **26**, as discussed with respect to FIGS. **7**, **8**A and **8**B, causing the circuit **26** to output a control signal to the drive circuits **24** to drive the mirrors **28** to their minimum reflectance level. The low level signal, on the other hand, permits normal operation of the light sensing and logic circuit **26**. Alternatively, the force-to-night switch **40** may be configured to generate a low level signal when closed and a high level signal when open. The force-to-night switch **40** is also a manually operable switch, preferably located on the rearview mirror **28***a*, and may also be switch **3**.

The light sensing and logic circuit **26** is also connected to the sensitivity control circuit **42**. The circuit **42** enables the operator to manually adjust the sensitivity of the mirrors **28** using the switch **3** (shown in FIGS. **1**A and **1**B). The sensitivity control circuit **42** (switch **3**) may comprise a potentiometer whose voltage may be varied from zero to five volts. Alternatively, a single resistor may be used to provide a single preset sensitivity setting that cannot be changed by the driver.

As previously discussed with respect to FIGS. **5** and **6**, the light sensing and logic circuit **26** comprises the photosensor array **32** (or other light sensing device) and the logic and control circuit **34**. These two devices may be either separate or commonly located on a single semiconductor substrate. The light sensing and logic circuit **26** is preferably a single VLSI CMOS circuit.

Also shown in FIG. **10**, the light sensing and logic circuit **26** outputs analog mirror control signals having voltages varying from zero to approximately 5 volts to the mirror drive circuits **24** and a vehicle lighting control signal of 0 to 5 volts to the vehicle lighting switch **45**. Alternatively, as previously discussed the light sensing and logic circuit **26** may output a 5 volt pulse-width-modulated (PWM) signal to the mirror drive circuits **24**. The mirror drive circuits **24** then generate and apply drive voltages varying from a low voltage on the order of 0 volts to a high voltage on the order of 1 volt to drive the mirrors **28**. The actual driving voltage (or current) may, of course, be significantly lower or higher depending on the variable reflectance mirror element **1***a* used.

Each of the mirrors **28** preferably comprises a reflective electrochromic (EC) cell whose reflectance level may be varied from a maximum of anywhere from approximately 50 to 90 percent to a minimum of approximately 4 to 15 percent, and having a maximum driving voltage on the order of about 1 to 2 volts. As is well known in the art, electrochromic devices change their reflectance level when a voltage or, other appropriate drive signal is applied to the electrochromic device. The mirrors **28** alternatively may comprise any other suitable variable reflectance mirror.

As previously discussed, it is also within the scope of the present invention for the light sensing and logic circuit **26** to be located remotely from the mirrors **28** of the system **20**. However, depending on vehicle design and styling requirements, it may be preferred that the light sensing and logic circuit **26** be integral with the rearview mirror **28***a* such that: (1) the center line of the field of view of the photosensor array **32** is substantially perpendicular to the reflective surface of the rearview mirror **28***a*; and (2) the horizontal field of view of the photosensor array **32** is aligned with the horizontal axis of the rearview mirror **28***a*. As a result, the photosensor array **32** receives the light that will be incident on the rearview mirror **28***a* as shown in FIG. **6**.

As has been discussed, the automatic rearview mirror system containing the photosensor array **32** may be extended to include a vehicle interior monitoring system configured as a vehicle intrusion detection system by vertically extending the effective field of view of the photosensor array **32** and by providing vehicle intrusion detection logic in the logic circuit **26**. Importantly, the automotive rearview mirror and vehicle interior monitoring systems do not have to function simultaneously in both the vehicle intrusion detection mode and automatic rearview mirror mode. Therefore, the operation of the vehicle intrusion detection mode may be described independently of the operation of the automatic rearview mirror mode. As is described further below, a switch is used to input a mode select signal to the logic circuit **46** to select the desired operating mode.

In the vehicle intrusion detection mode, those photosensor elements **32***a* corresponding to the image segment below the lower edge of the vehicle window areas (i.e., the image information of FIG. **2**A excluding the image information FIGS. **3**A and **3**B) are considered, significant. Each photosensor element **32***a* is associated with a small and unique portion of the imaged scene. In particular, each photosensor element **32***a* senses light within its own image cone. For the preferred photosensor array **32**, each photosensor element **32***a* is responsive to an area approximately one (1) inch square at 100 inches, which is about the maximum distance from the photosensor array **32** mounted in the rearview mirror **1** to most vehicle cabin interior surfaces within the area of interest. For the photosensor array **32** described above, one set of about 6,400 (160×40 sub-array) photosensor elements **32***a* are used in the automatic rearview mirror mode and another set of about 12,800 (160×80 sub-array) photosensor elements **32***a* are used in the vehicle intrusion detection mode. The ability of the photosensor array **32***a* to resolve the area of interest into a number of data values and to select particular image information, while ignoring other image information, is significant and distinguishes this vehicle intrusion detection system from other vehicle intrusion detection systems and technologies.

The automatic rearview mirror and vehicle interior monitoring system as shown in the schematic block diagram of FIG. **10**A is identical to the automatic rearview mirror system shown in the schematic block diagram of FIG. **10** except as follows. First, as explained above, the array size required for an independent automatic rearview mirror system must be expanded from 160×40 to 160×120 to provide a larger effective field of view that includes most of the vehicle interior **100**. Second, additional logic or control circuitry is incorporated in logic circuit **46** to process the vehicle intrusion detection logic of FIGS. **12** and **12**A. The light sensing and logic circuit **26** includes additional control input lines for the "arming" and "alerting" control input signals and control output lines to interface with vehicle hardware or vehicle controller systems. Finally, the regulation and transient protection circuit **22** also has an additional vehicle power supply line (12V BATTERY), and a switch or other logic for providing a mode select signal that is input to the light sensing and logic circuit **26**.

Normally, power is provided to vehicle hardware through the ignition switch controlled power supply circuits to avoid battery drain. Since the automatic rearview mirror system operates when the vehicle is being driven, it is normally connected to an ignition switch controlled power supply circuit as shown in FIG. **10**. Since the vehicle intrusion detection system operates when the ignition switch is off, the regulation and transient protection **22** includes the additional vehicle battery power supply line for supplying power directly from the vehicle battery. The regulation and transient protection circuit **22** also includes a switch or other logic circuit (not shown) to output a mode select signal to the light sensing and logic circuit **26**. The mode select signal is low (0 volts) when power is not available through the ignition switch controlled power supply circuit and high (5 volts) when it is.

The light sensing and logic circuit **26** includes an input line to receive an "arming" input signal **49***a* to actively arm the vehicle intrusion detection system.

Although not shown in FIG. **10**A, other vehicle systems are typically used to supply an "arming" input signal. Such systems may be actuated by using conventional infrared or RF type remote control or by the activation of central door locking systems using the door key or entry combination keypad.

The light sensing and logic circuit **26** also includes input lines to receive an "alert" input signal(s) **49***b* to increase the sampling rate, such as when a trunk lid opening has been detected and increased monitoring may be required. The light sensing and logic circuit **26** also includes one or more output signal lines to the vehicle hardware **45***a* and/or to the vehicle controller system **48**, for activating the horn and lights or disabling the ignition control device. The control output signal is normally low (0 volts) and goes high (5 volts) when there is an intrusion condition, but may also be a data word providing more detailed information, (such as the location of the intrusion) to the vehicle controller system.

When power is supplied to the automatic rearview mirror system through the ignition switch controlled power supply circuit, the regulation and transient protection circuit **22** outputs a high (5 volts) mode select signal to the logic circuit **46**. This causes it to select the automatic rearview mirror mode and the system functions as an automatic rearview mirror system as previously described.

When the ignition switch is turned off, the mode select signal goes low (0 volts) and the logic circuit **46** sets the system to a low power mode, in which the logic circuit **46** only monitors the status of the mode select and "arming" control input signals. In this state, the vehicle intrusion detection mode is available, but the system is not "armed" and it is not monitoring the vehicle cabin. When in this state and when the "arming" control input signal is active, then the logic circuit **46** enters the vehicle intrusion detection mode described with respect to FIGS. **12** and **12**A.

As previously described, in step S**301**, the logic circuit **46** initializes the system (e.g., resets the counters, etc., used in the automatic rearview mirror mode) and sets EP to its maximum value and SSI to its minimum level. Since the lighting levels are not known and may be at any level within the full operating range of the system at the time of arming, the system must determine the optimum combination of EP and SSI by maximizing the number of photosensor elements **32***a* providing useful image data. To minimize system power consumption, the method is biased to minimize SSI and maximize EP. In step S**310**, the status of the mode select, "arming" and "alerting" signals is monitored to confirm the appropriate operating mode. For example, if the "arming" signal goes inactive, then the system returns to a disarmed, low power mode and only monitors the mode select and "arming" signals. If there is no status change, then the system generates and stores $RA_{(t)}$(using steps S**101** to S**140** of FIG. **7**). The logic circuit **46** ignores RAM array data corresponding to the 160×40 array of photosensor elements **32***a* generally associated with the window areas as shown in FIGS. **3**A and **3**B, and processes the RAM array data corresponding to the 160×80 array of photosensor elements **32***a* generally associated with the vehicle cabin interior generally excluding the window areas of FIGS. **3**A and **3**B. It should be understood that a trapezoidal sub-set of RAM array data, corresponding to the same sub-set of photosensor elements **32***a*, may be selected so as to better correspond to the vehicle cabin interior excluding the window areas.

In step S**320**, the logic circuit **46** determines AR by calculating the average value of all the values in the selected sub-set of RAM array data. In the system described, AR may be in they range 0 to 255 (8-bit data resolution), but it is preferably at the operating point OP of 127 (mid-point of the range);

however, for system stability purposes the range factor R results in an operating point OP range of 127±20. In step S**330** and S**360**, it is determined whether AR is in the range OP±R. If AR is outside the range, then EP and SSI are incrementally increased or decreased according to steps S**341**, S**342** or S**351**, S**352**. This is repeated for every image data frame. The system thus optimizes EP and SSI for the particular circumstances at system startup, and thereafter continues to adjust EP and SSI to maintain AR within the range OP±R as lighting conditions change. If AR is within the range, then the program enters the primary task S**400** in block S**370**.

The vehicle intrusion detection system is designed to be responsive or sensitive to movement or motion within the vehicle interior **100** and insensitive to changes in general lighting conditions, moving shadows, etc. The system does this by reducing every image data frame to its robust and unique characteristics, largely unaffected by random light sources or changes in general lighting conditions. After sufficient image data frames have been processed to allow electrical stabilization and optimization of EP and SSI, the contour enhanced image data frame $RC_{(t)}$ is stored as the reference image data frame. Every image data frame is processed in the same way as the reference image and is then compared to the reference image. Decisions are reached after several images have been compared producing the same result. Three conclusions are possible after comparing images in the manner described. Images, may be essentially the same, significantly different or neither similar enough nor different enough to make a decision. If this first condition exists for long enough, changes to the reference image are considered. Confirmation of the differences over several images result in a concluded intrusion.

More particularly, in step S**401**, the logic circuit **46** converts $RA_{(t)}$ to its contour enhanced form $RC_{(t)}$ by calculating the average difference between the value of $RA_{(t)}$ for each element E(n,m) and each of its eight (8) neighbors. As discussed, at system start-up, the system must electrically stabilize and must also adjust EP and SSI to optimize the image data frame stored as $R_{REF(t)}$. This is done by cycling at least several times from step S**310** through steps S**403** and S**404** and then returning to step S**310**. In step S**404**, the image data frame $RC_{(t)}$ is stored in RAM **50** as $RC_{REF(t)}$ so that $RC_{(t)}$ and $RC_{REF(t-1)}$ are available in step S**402** in RAM **50** for comparison. In step S**402**, the correlation factor IC for $RC_{(t)}$ and $RC_{REF(t-1)}$ is determined. During this start-up period, EP and SSI become stable.

In step S**403**, the start-up criteria are tested, as previously described, and if the count is greater than 25 and the images $RC_{(t)}$ and $RC_{REF(t-1)}$ correlate (IC exceeds 0.95), then the system continues through step S**405**. Otherwise, it continues through step S**404** until the image is stable. In the normal monitoring mode, IC is tested against T_1 in step S**405**, where T_1 is 0.6 (T_1 may be less than 0.6). If the degree of correlation or correspondence between the current and reference image data frames is poor (IC is less than 0.6), then the image data frames are judged to be sufficiently different to suggest that vehicle intrusion has occurred. Vehicle intrusion detection systems are evaluated on their ability to detect intrusion conditions and to avoid false intrusion conditions. To avoid false intrusion conditions, in step S**408**, the number of successive mismatch conditions is counted and compared to a preset value of 20 (which may be in the range 2 to 300), and a valid intrusion detection condition is established in step S**408** after 20 successive mismatch conditions. In step S**409**, the logic circuit **46** outputs control signals to vehicle hardware **45***a* or to the vehicle controller system **48** for further processing, which may result in an alarm sounding, vehicle immobilization or other appropriate action. The system continues to monitor the vehicle interior or compartment by returning to step S**310**. If the number of successive mismatch conditions falls below 20 in step S**408**, then the system returns to step S**310**.

In step S**405**, if IC is greater than 0.6, then the images are not sufficiently different to confirm an intrusion condition. It is desirable to update the reference image data frame $RC_{REF(t)}$ if changes occur due to mirror and slowly changing conditions outside the vehicle, such as changing light levels or slowly moving shadows due to the sun tracking across the sky. Accordingly, in step S**406**, IC is compared to T_2 (where T_2 is 0.95 but may be in the range 0.95 to 1), and if IC exceeds T_2 then the logic circuit **46** updates and stores the reference image data frame $RC_{REF(t)}$ in step S**407**. The logic circuit **46** may replace $RC_{REF(t-1)}$ with $RC_{(t)}$ or modify $RC_{REF(t-1)}$ as previously described. The system continues to monitor the vehicle interior by returning to step S**310** until the "arming" control input signal goes inactive.

It should be understood that the larger field of view provided by the 160×120 array of the vehicle intrusion detection system enables further analysis of the rearward scene. Specifically, the background light signal B_t may be determined using a larger set of photosensor array elements **32***a*.

The combination of the automatic rearview mirror detection system and vehicle intrusion detection system additionally provides an opportunity for using SSI to illuminate the vehicle interior under dark conditions for the purpose of precise identification of specific vehicle features such as those indicated in FIG. **2**A.

Vehicle feature identification is useful in the automatic rearview mirror system because it allows the logic circuit **46** to select each of the sub-arrays S(X) of photosensor elements **32***a* corresponding to zones a, b and c indicated in FIGS. **3**A and **3**B. This is useful when the photosensor array **32** is positioned in the rearview mirror **1**. Active adjustment allows the logic circuit **46** to select sets or sub-arrays S(X) of photo sensor elements **32***a* such that zones a, band care indicative of identical vehicle regions independently of driver rearview mirror **1** adjustment.

Finally, to minimize battery power drain, the system described may be operated in a low power mode by reducing the sampling rate at which images are obtained and processed, such as one image data frame per second.

However, if the logic circuit **46** receives an "alerting" control input signal such as may be received from a vibration, motion, trunk lid or door opening sensor, then the system described herein may return to its normal sampling rate. Alternatively, this may also be achieved by having the system use the lower sampling rate until the logic circuit **46** establishes a poor image correlation (i.e., IC<0.6) in step S**406** and selects the higher sampling rate.

The vehicle interior monitoring system may also be configured as a compartment image data storage system to store any compartment image, such as the driver image, in the nonvolatile memory **57**. The automatic rearview mirror and vehicle interior monitoring system configured as a compartment image data storage system is shown in the schematic block diagram of FIG. **10**A and the previous description of FIGS. **10** and **10**A applies except as follows. First, in the specific embodiment described herein, the light sensing and logic circuit **26** does not use control input lines for receiving the "arming" control input signal **49***a* and the "alerting" control input signal(s) **49***b* as in the vehicle intrusion detection system. Second, the additional vehicle power supply line (12V BATTERY) and mode select signal line are also not used in the specific embodiment described herein. This is because the compartment image data storage system may be limited to operating when the vehicle has been started since both authorized and unauthorized drivers actuate the ignition switch to start the vehicle (the vehicle thief may, of course, break the steering column ignition lock system to do this). Thus, power is always supplied through the ignition switch controlled power supply (12V IGNITION) when the vehicle is started. Finally, the light sensing and logic circuit **26** includes input/output lines to interface with the nonvolatile memory/data access logic and port **65**, which comprises the nonvolatile memory **57**, access/security decoding logic **58** circuit and data access part **59** of FIG. **6**A. To reduce data storage requirements, the image data frame may be compressed using any appropriate digital image compression technique as discussed with respect to FIG. **6**A. The image data frame is then stored in the nonvolatile memory **57**, such as an EEPROM or any other appropriate nonvolatile memory, which has sufficient storage to store a predetermined number of image data frames.

The compartment image data storage system may be configured to store a single image data frame in the nonvolatile memory **57** for each ignition cycle. When power is supplied to the automatic rearview mirror system through the ignition switch controlled power circuit, the regulation and transient protection circuit **22** supplies 5 volts to the light sensing and logic circuit **26**, which begins system initialization for a set period of between zero (0) seconds and two (2) minutes, but preferably 30 seconds. This delay condition or wait state reduces the opportunity for vehicle thieves to detect SSI which may be emitted during the image optimization process of FIG. **12**. After the wait state has ended, the compartment image data storage system operates as has already been described with respect to FIGS. **12**A and **12**B. The nonvolatile memory **57** should be sufficiently large to store a number N of valid image data frames $RA_{(t)}$ to document N sequential ignition cycles where N is in the range of 2 to 10, but is preferably 5. The image data frames are addressed via pointers that select a general memory location which are used to store each valid image data frame $RA_{(t)}$. The pointer addressing scheme is cycled on a first-in-first-out (FIFO) basis so that the most recent valid image data frames replace the "oldest" image data frames in the nonvolatile memory **57**. After storing a valid image data frame $RA_{(t)}$, the system ends cycling and enters a dormant state waiting for the next ignition cycle.

Alternatively, multiple valid image data frames may be stored for a single ignition cycle. This second version of the compartment image data storage system performs exactly as the first description except as follows. After storage of the initial image data frame, the system returns to step S**310** and the logic circuit **46** generates a random wait state ranging from 8 to 15 minutes during which the system stops generating image data frames.

After the wait state has ended, the system proceeds to attempt generate another valid image data frame. This cycle of randomly waiting and then attempting to generate valid image data frames is continued as long as the ignition supplies power to the system. This approach is more difficult for thieves to defeat. This system may also be configured as a real time image data storage system (e.g., 30 frames per second). Of course, since at least several hundred image data frames may need to be processed, compressed and stored in the nonvolatile memory **57**, the processing and nonvolatile memory storage requirements are significantly greater than for the other image data storage systems described above. An initiation sensor, such as accelerometers, motion sensors, vibration sensors or any other sensor capable of detecting vehicle motion, inputs an initiation signal, and after receiving the initiation signal, the light sensing and logic circuit **26** generates and stores in real-time the image data frames for a predetermined period, such as 10 seconds.

The nonvolatile memory **57** is preferably housed in a separate module in a physically difficult to access location within the vehicle, such as high on the fire wall behind the instrument cluster. The module is preferably a durable metal housing or other housing sufficiently durable so that it will protect the nonvolatile memory **57** from extreme shock or heat, such as might occur in a vehicle accident. To better ensure that the image data frames in the nonvolatile memory **57** are not accessed by unauthorized personnel, access may be limited by the security access/decoding logic **58**. The security access codes necessary to access the image data frames may, for example, be distributed only to authorized persons. When the proper security access code is entered, the image data frames may be accessed through the access port **59**; typically, the access port **59** is a multi-pin connector to which a data retrieval system may be connected.

It should be understood that the vehicle interior monitoring system described above, including the vehicle intrusion detection system and the compartment image data storage system configurations, may be implemented as an independent or stand-alone system in a module (without the automatic rearview mirror system), and that it may be mounted independently within the vehicle, such as in the headliner, headliner console or other appropriate areas.

The performance of the vehicle interior monitoring systems described herein may be enhanced by providing enhanced infrared reflectance characteristics in certain areas within the vehicle interior **100**. For example, some fibers (such as cotton and silk) tend to reflect near infrared illumination better than other fibers (such as nylon and rayon) which tend to absorb near infrared illumination. Therefore, a pattern may be established in the vehicle interior **100** such as on the driver seat **101** or passenger seat **102** or front or rear seats or on the vehicle's interior door panels, etc., by using different fibers or other materials to establish a pattern, such as a grid or any other appropriate pattern. Near infrared illumination of the pattern provides a higher contrast image to the photosensor array **32**. This better ensures that the logic circuit **46** accurately determines, for example, the presence of an intruder, an occupant or other object (such as a child restraint system in the front passenger seat).

Using fibers or materials having better infrared reflectance characteristics as described above is useful both during the day and at night. During the day, any near infrared reflective pattern in the vehicle will generally provide a higher contrast pattern to the photosensor array **32** because of natural sources (sunlight) or supplemental sources of near infrared of illumination. In particular, if light levels fall below some predetermined level (typically in the range of about 0.1 lux to 5 lux), then near infrared SSI may be used to provide a higher contrast image pattern, to the photosensor array **32**.

The vehicle interior monitoring system may also be used to monitor the vehicle interior **100** to determine whether there is an adult occupant, a child restraint system or no occupant in the front or rear passenger seat areas. Various mechanical and electrical sensors have been considered or used for detecting or sensing the size and presence of vehicle occupants, particularly those in the front passenger seat. These sensors include pressure sensors (mechanical and solid-state), accelerometers, ultrasonic sensors and mechanical or electrical switch mechanisms for indicating seat belt use. As air bags are becoming more prevalent, vehicle owners, insurance companies and automotive companies have a strong interest in having air bags deploy properly at all times, since replacing deployed airbags is costly. Additionally, there has been some discussion as to whether air bags should deploy when there is a child restraint system that is positioned rearwardly facing in the front passenger seat. Since performance requirements are stringent for safety related components, it is problematic to make appropriate airbag deployment decisions using currently known sensor technologies. The vehicle interior monitoring system may be configured as a vehicle occupant detection system that may be used to aid in the intelligent deployment of air bags depending, for example, on the status of the vehicle occupant. Image information, such as size, shape, contour and motion may be processed by the logic circuit **46** to determine whether to output a control signal to the air bag deployment system to prevent an air bag from deploying (such as a passenger air bag when there is no front seat passenger) or for controlling the rate at which the airbag deploys.

The individual components represented by the blocks shown in the schematic block diagrams of FIGS. **6**, **6**A, **6**B, **10** and **10**A are well known in the art relating to automatic rearview mirrors, vehicle lighting systems and vehicle intrusion detection systems, and their specific construction and operation is not critical to the invention or the best mode for carrying out the present invention. Moreover, the logic flow charts discussed in the specification and shown in FIGS. **7**, **8**A, **8**B, **12**, **12**A, **12**B, **13**A, **13**B, **13**C and **13**D may be implemented in digital hardwired logic or programmed into well-known signal processors, such as microprocessors, by persons having ordinary skill in the art. Since such digital circuit construction or programming per se is not part of the invention, no further description thereof is deemed necessary.

While the present invention has been described in connection with what are the most practical and preferred embodiments as currently contemplated, it should be understood that the present invention is not limited to the disclosed embodiments. Accordingly, the present invention is intended to cover various modifications and equivalent arrangements, methods and structures that are within the spirit and scope of the claims.

What is claimed is:

1. A vehicular vision system, said vehicular vision system comprising:

- an imager comprising a lens and a CMOS photosensor array;
- wherein said photosensor array comprises a plurality of photosensor elements;
- wherein said imager is disposed at an interior portion of a vehicle equipped with said vehicular vision system and wherein said imager views exterior of the equipped vehicle through a windshield of the equipped vehicle and forward of the equipped vehicle;
- wherein at least said imager is disposed in a module attached at the windshield of the equipped vehicle;
- a control comprising an image processor, said image processor processing image data captured by said photosensor array;
- wherein said image processor processes captured image data to detect an object viewed by said imager;
- wherein said photosensor array is operable at a plurality of exposure periods; and
- wherein said plurality of exposure periods comprises a first exposure period and a second exposure period, and wherein the time period of exposure of said first exposure period is longer than the time period of exposure of said second exposure period.

2. The vehicular vision system of claim **1**, wherein said imager is disposed proximate the windshield of the equipped vehicle.

3. The vehicular vision system of claim **1**, wherein said photosensor array comprises an array of columns and rows of photosensor elements and wherein said array has more columns than rows.

4. The vehicular vision system of claim **3**, wherein said array comprises at least 40 rows.

5. The vehicular vision system of claim **1**, wherein said image processor processes captured image data to detect at least one of (a) a vehicle, (b) a headlight of a vehicle, (c) a taillight of a vehicle, and (d) a road sign.

6. The vehicular vision system of claim **1**, wherein, at least in part responsive to processing of captured image data by said image processor, said vehicular vision system is operable to control an exterior light of the equipped vehicle to limit debilitation of a driver of another vehicle forward of the equipped vehicle.

7. The vehicular vision system of claim **6**, wherein at least one of (a) control of the exterior light of the equipped vehicle involves adjustment of a light beam emitted by the exterior light of the equipped vehicle, (b) the exterior light of the equipped vehicle is operable to emit a plurality of light beams, and wherein said control adjusts between one light beam of said plurality of light beams and another light beam of said plurality of light beams, and (c) the exterior light of the equipped vehicle is operable to emit a plurality of light beams, and wherein said control adjusts between one light beam of said plurality of light beams and another light beam of said plurality of light beams, and wherein said plurality of light beams comprises at least one of a low beam, a mid beam and a high beam.

8. The vehicular vision system of claim **6**, wherein at least one of (a) said control is operable to control the exterior light of the equipped vehicle to emit a pattern of light appropriate to limit debilitation of the driver of the other vehicle forward of the equipped vehicle, (b) said control is operable to control the exterior light of the equipped vehicle to emit a pattern of light that illuminates a selected zone forward of the equipped vehicle, and (c) the exterior light of the equipped vehicle is operable to emit various patterns of light.

9. The vehicular vision system of claim **1**, wherein, at least in part responsive to processing of captured image data by said image processor, said control at least in part controls at least one exterior light of the equipped vehicle, and wherein the at least one exterior light of the equipped vehicle comprises a headlight disposed at a front portion of the equipped vehicle and operable to illuminate with visible light a scene forward of and in a path of travel of the equipped vehicle.

10. The vehicular vision system of claim **9**, wherein at least one of (a) said control, at least in part responsive to processing of captured image data by said image processor, controls a vehicular lighting switch, and wherein said vehicular lighting switch controls the at least one exterior light of the equipped vehicle, (b) a manual vehicle light switch is actuatable to override said control, and (c) a manual vehicle light switch is actuatable to override said control and wherein said control, at least in part responsive to processing of captured image data by said image processor, controls a vehicular lighting switch that controls the at least one exterior light of the equipped vehicle.

11. The vehicular vision system of claim **1**, wherein, at least in part responsive to processing of captured image data by said image processor, said vehicular vision system determines a presence of at least one of fog, snow and rain present exterior and forward of the equipped vehicle.

12. The vehicular vision system of claim 11, wherein said vehicular vision system determines the presence of at least one of fog, snow and rain by recognizing scattering of light output by a headlight of the equipped vehicle by at least one of fog, snow and rain present exterior and forward of the equipped vehicle.

13. The vehicular vision system of claim 11, wherein said vehicular vision system, at least in part responsive to recognition of scattering of light output by a headlight of the equipped vehicle, controls the headlight of the equipped vehicle.

14. The vehicular vision system of claim 1, wherein, at least in part responsive to processing of captured image data by said image processor, said control is operable to recognize veiling glare.

15. The vehicular vision system of claim 1, wherein said image processor compares captured image data with stored data and outputs a vehicle equipment control signal based on the comparison.

16. The vehicular vision system of claim 1, wherein said imager views through the windshield of the equipped vehicle at a windshield area that is swept by a windshield wiper of the equipped vehicle.

17. The vehicular vision system of claim 1, wherein, at least in part responsive to processing of captured image data by said image processor, said control distinguishes between daytime and nighttime conditions.

18. The vehicular vision system of claim 1, wherein, at least in part responsive to processing of captured image data by said image processor, said control determines a nighttime condition exists at an ambient light level that is less than about 500 lux.

19. The vehicular vision system of claim 18, wherein said control is operable to control a headlight of the equipped vehicle when said control determines a nighttime condition.

20. The vehicular vision system of claim 1, wherein, when said control, at least in part responsive to processing of captured image data by said image processor, determines a daytime condition, said control is operable to control a vehicle accessory.

21. The vehicular vision system of claim 1, wherein, at least in part responsive to processing of captured image data by said image processor, said control is operable to deactivate a light beam of a headlight of the equipped vehicle when said control determines a daytime condition.

22. The vehicular vision system of claim 1, wherein said control, at least in part responsive to processing of captured image data by said image processor, determines an ambient light level present at the equipped vehicle.

23. The vehicular vision system of claim 1, wherein at least one of (a) an exposure period of said photosensor array is variable responsive to a light level detected by said vehicular vision system and (b) an exposure period of said photosensor array is variable responsive to an ambient light level detected by said vehicular vision system.

24. The vehicular vision system of claim 1, wherein said module releasably mounts to a mounting element adhesively attached at the windshield of the equipped vehicle.

25. The vehicular vision system of claim 24, wherein said mounting element comprises a rearview mirror mounting button.

26. The vehicular vision system of claim 25, wherein said module comprises a rearview mirror mounting bracket.

27. The vehicular vision system of claim 26, wherein said rearview mirror mounting bracket comprises part of an interior electrochromic rearview mirror assembly.

28. The vehicular vision system of claim 1, wherein image data processing by said image processor comprises pattern recognition.

29. The vehicular vision system of claim 1, wherein said imager monitors a surface condition of the windshield of the equipped vehicle.

30. The vehicular vision system of claim 29, wherein at least one of (a) the equipped vehicle's windshield wiper system is operable in response to a signal generated by said control responsive to image processing of image data captured by said photosensor array, (b) said surface condition is caused by rain, (c) said surface condition is caused by condensation, and (d) said surface condition is caused by snow.

31. The vehicular vision system of claim 1, including supplemental source illumination having wavelengths within a responsive range of said photosensor array, and wherein at least one (a) said supplemental source illumination comprises infra-red supplemental source illumination, (b) said supplemental source illumination comprises a near infrared illumination source having a peak spectral output greater than about 750 nm, (c) said supplemental source illumination illuminates an illuminated target area that is at least partially viewed by said imager, (d) said supplemental source illumination has a peak spectral output between about 750 nm and 1200 nm, (e) said supplemental source illumination is chosen from at least one of a light-emitting diode and a laser, (f) said supplemental source illumination comprises a light-emitting diode, (g) said supplemental source illumination comprises a light-emitting diode chosen from the group consisting of a gallium arsenide light-emitting diode and a gallium aluminum arsenide light-emitting diode, (h) said vehicular vision system includes a lens to distribute illumination of said supplemental source illumination, (i) said vehicular vision system includes a lens that provides illumination in a cone of at least about 100 degrees, (j) said vehicular vision system includes a lens that provides illumination in a cone in the range from about 100 degrees to about 160 degrees, (k) said vehicular vision system includes an optical filter for said supplemental source illumination, (l) said vehicular vision system includes an optical filter for said supplemental source illumination and wherein said optical filter is chosen from one of an absorption filter and an interference filter, (m) said vehicular vision system includes an optical filter for said supplemental source illumination and wherein said optical filter comprises a long-wave pass absorption filter, (n) said supplemental source illumination is adjacent said photosensor array, (o) said supplemental source illumination is adjacent said photosensor array and an opaque barrier is between said supplemental source illumination and said photosensor array, and (p) said supplemental source illumination provides illumination only during an exposure period of said photosensor array.

32. The vehicular vision system of claim 1, wherein the equipped vehicle has at least one headlight, and wherein the at least one headlight is operable at least in a first beam mode and a second beam mode, and wherein, at least in part responsive to processing of captured image data by said image processor, said control controls operation of the at least one headlight, and wherein said control transitions the at least one headlight from said first beam mode to said second beam mode in response to detection of at least one of a headlight and a taillight viewed by said imager.

33. The vehicular vision system of claim 32, wherein said control transitions the at least one headlight over a first time interval from said first beam mode to said second beam mode in response to detection of at least one of a headlight and a taillight viewed by said imager, and wherein said control transitions the at least one headlight over a second time inter-

val from said second beam mode to said first beam mode upon cessation of said detection of the at least one of a headlight and a taillight viewed by said imager, and wherein said first time interval for said transitioning from said first beam mode to said second beam mode is shorter than said second time interval for said transitioning from said second beam mode to said first beam mode.

34. The vehicular vision system of claim **32**, wherein at least one of (a) said first beam mode comprises a high beam mode, (b) the at least one headlight is actuated at an ambient lighting level below a predetermined level, and (c) the at least one headlight is actuated at an ambient lighting level below approximately 500 lux.

35. The vehicular vision system of claim **1**, wherein said control determines a peak light level of at least one sub-array of said photosensor array.

36. The vehicular vision system of claim **35**, wherein said control determines peak light levels of a plurality of sub-arrays of said photosensor array.

37. The vehicular vision system of claim **1**, wherein said photosensor array resolves an area of interest in accordance with a predefined array.

38. The vehicular vision system of claim **37**, wherein said image processor processes image data geometrically associated with a geometric arrangement of said predefined array, and wherein said control selects particular image information by analyzing particular groupings of said predefined array while ignoring other image information from other groupings of said predefined array so as to be responsive to image information chosen from at least one of presence, size, shape, contour and motion of an object viewed by said imager.

39. The vehicular vision system of claim **1**, wherein said imager comprises a single chip camera.

40. The vehicular vision system of claim **39**, wherein said single chip camera is disposed adjacent an interior rearview mirror assembly of the equipped vehicle.

41. The vehicular vision system of claim **1**, wherein at least one optic element of said lens comprises a plastic optic element.

42. The vehicular vision system of claim **1**, wherein said lens is one of (i) bonded to said photosensor array and (ii) close to said photosensor array.

43. The vehicular vision system of claim **1**, wherein said imager has a field of view forward of the equipped vehicle, and wherein said field of view comprises a horizontal span and a vertical span and wherein said horizontal span is greater than said vertical span.

44. The vehicular vision system of claim **43**, wherein said horizontal span of said field of view is no greater than approximately 100 degrees.

45. The vehicular vision system of claim **44**, wherein said vertical span of said field of view is no greater than approximately 30 degrees.

46. The vehicular vision system of claim **1**, wherein said imager has a field of view forward of the equipped vehicle, and wherein said field of view comprises a vertical span and wherein said vertical span is asymmetric relative to a horizon.

47. The vehicular vision system of claim **46**, wherein said vertical span comprises a first vertical span above the horizon and a second vertical span below the horizon, and wherein said first vertical span has a different vertical dimension than said second vertical span.

48. The vehicular vision system of claim **1**, wherein said control comprises logic and control circuitry.

49. The vehicular vision system of claim **48**, wherein said logic and control circuitry comprises said image processor.

50. The vehicular vision system of claim **49**, wherein said module includes at least a portion of said logic and control circuitry.

51. The vehicular vision system of claim **50**, wherein said module includes a heat sink for at least a portion of said logic and control circuitry.

52. The vehicular vision system of claim **51**, wherein said module includes a connector for electrically connecting to a power source of the equipped vehicle.

53. The vehicular vision system of claim **48**, wherein said module includes a cover.

54. The vehicular vision system of claim **1**, wherein said imager comprises a spectral filter.

55. The vehicular vision system of claim **1**, wherein said image processor processes captured image data for at least one of (a) a headlight control system of the equipped vehicle, (b) a collision avoidance system of the equipped vehicle, and (c) an automatic vehicle system of the equipped vehicle.

56. A vehicular vision system, said vehicular vision system comprising:

- an imager comprising a lens and a CMOS photosensor array;
- wherein said photosensor array comprises a plurality of photosensor elements;
- wherein said imager is disposed at an interior portion of a vehicle equipped with said vehicular vision system and wherein said imager views exterior of the equipped vehicle through a windshield of the equipped vehicle and forward of the equipped vehicle;
- wherein said imager is disposed in a module that releasably mounts to a mounting element adhesively attached at the windshield of the equipped vehicle;
- a control;
- wherein said control comprises logic and control circuitry;
- wherein said logic and control circuitry comprises an image processor, and wherein said image processor processes image data captured by said photosensor array to detect an object viewed by said imager; and
- wherein at least two of (a) said module includes a heat sink for at least a portion of said logic and control circuitry, (b) said module includes a connector for electrically connecting to a power source of the equipped vehicle, and (c) said module includes at least a portion of said logic and control circuitry.

57. The vehicular vision system of claim **56**, wherein said imager is disposed proximate the windshield of the equipped vehicle.

58. The vehicular vision system of claim **56**, wherein said module includes a cover.

59. The vehicular vision system of claim **56**, wherein said photosensor array comprises an array of columns and rows of photosensor elements and wherein at least one of (i) said array has more columns than rows and (ii) said array comprises at least 40 rows.

60. The vehicular vision system of claim **56**, wherein said image processor processes captured image data to detect at least one of (a) a vehicle, (b) a headlight of a vehicle, (c) a taillight of a vehicle, and (d) a road sign.

61. The vehicular vision system of claim **56**, wherein, at least in part responsive to processing of captured image data by said image processor, said vehicular vision system is operable to control an exterior light of the equipped vehicle to limit debilitation of a driver of another vehicle forward of the equipped vehicle, and wherein at least one of (a) control of the exterior light of the equipped vehicle involves adjustment of a light beam emitted by the exterior light of the equipped vehicle, (b) the exterior light of the equipped vehicle is operable to emit a plurality of light beams, and wherein said control adjusts between one light beam of said plurality of light beams and another light beam of said plurality of light beams, and (c) the exterior light of the equipped vehicle is operable to emit a plurality of light beams, and wherein said control adjusts between one light beam of said plurality of light beams and another light beam of said plurality of light beams, and wherein said plurality of light beams comprises at least one of a low beam, a mid beam and a high beam.

62. The vehicular vision system of claim **56**, wherein, at least in part responsive to processing of captured image data by said image processor, at least one of (a) said control is operable to control the exterior light of the equipped vehicle to emit a pattern of light appropriate to limit debilitation of a driver of another vehicle forward of the equipped vehicle, (b) said control is operable to control the exterior light of the equipped vehicle to emit a pattern of light that illuminates a selected zone forward of the equipped vehicle, and (c) the exterior light of the equipped vehicle is operable to emit various patterns of light.

63. The vehicular vision system of claim **56**, wherein, at least in part responsive to processing of captured image data by said image processor, said control at least in part controls at least one exterior light of the equipped vehicle, and wherein the at least one exterior light of the equipped vehicle comprises a headlight disposed at a front portion of the equipped vehicle and operable to illuminate with visible light a scene forward of and in a path of travel of the equipped vehicle, and wherein at least one of (a) said control, at least in part responsive to processing of captured image data by said image processor, controls a vehicular lighting switch, and wherein said vehicular lighting switch controls the at least one exterior light of the equipped vehicle, (b) a manual vehicle light switch is actuatable to override said control, and (c) a manual vehicle light switch is actuatable to override said control and wherein said control, at least in part responsive to processing of captured image data by said image processor, controls a vehicular lighting switch that controls the at least one exterior light of the equipped vehicle.

64. The vehicular vision system of claim **56**, wherein, at least in part responsive to processing of captured image data by said image processor, said vehicular vision system determines a presence of at least one of fog, snow and rain present exterior and forward of the equipped vehicle.

65. The vehicular vision system of claim **64**, wherein said vehicular vision system determines the presence of at least one of fog, snow and rain by recognizing scattering of light output by a headlight of the equipped vehicle by at least one of fog, snow and rain present exterior and forward of the equipped vehicle, and wherein said vehicular vision system, at least in part responsive to recognition of scattering of light output by the headlight of the equipped vehicle, controls the headlight of the equipped vehicle.

66. The vehicular vision system of claim **56**, wherein said image processor compares captured image data with stored data and outputs a vehicle equipment control signal based on the comparison.

67. The vehicular vision system of claim **56**, wherein said imager views through the windshield of the equipped vehicle at a windshield area that is swept by a windshield wiper of the equipped vehicle.

68. The vehicular vision system of claim **56**, wherein said control, at least in part responsive to processing of captured image data by said image processor, at least one of (i) distinguishes between daytime and nighttime conditions, (ii) determines a nighttime condition exists at an ambient light level that is less than about 500 lux, (iii) is operable to control a headlight of the equipped vehicle when said control determines a nighttime condition, (iv) is operable to control a vehicle accessory when said control determines a daytime condition, (v) is operable to deactivate a light beam of a headlight of the equipped vehicle when said control determines a daytime condition, and (vi) determines an ambient light level present at the equipped vehicle.

69. The vehicular vision system of claim **56**, wherein the equipped vehicle has at least one headlight, and wherein the at least one headlight is operable at least in a first beam mode and a second beam mode, and wherein, at least in part responsive to processing of captured image data by said image processor, said control controls operation of the at least one headlight, and wherein said control transitions the at least one headlight from said first beam mode to said second beam mode in response to detection of at least one of a headlight and a taillight viewed by said imager.

70. The vehicular vision system of claim **69**, wherein said control transitions the at least one headlight over a first time interval from said first beam mode to said second beam mode in response to detection of at least one of a headlight and a taillight viewed by said imager, and wherein said control transitions the at least one headlight over a second time interval from said second beam mode to said first beam mode upon cessation of said detection of the at least one of a headlight and a taillight viewed by said imager, and wherein said first time interval for said transitioning from said first beam mode to said second beam mode is shorter than said second time interval for said transitioning from said second beam mode to said first beam mode.

71. The vehicular vision system of claim **69**, wherein at least one of (a) said first beam mode comprises a high beam mode, (b) the at least one headlight is actuated at an ambient lighting level below a predetermined level, and (c) the at least one headlight is actuated at an ambient lighting level below approximately 500 lux.

72. The vehicular vision system of claim **56**, wherein said lens comprises at least one plastic optic element, and wherein said lens is one of (i) bonded to said photosensor array and (ii) close to said photosensor array.

73. The vehicular vision system of claim **56**, wherein said imager has a field of view forward of the equipped vehicle, and wherein said field of view comprises a horizontal span and a vertical span and wherein said horizontal span is greater than said vertical span, and wherein at least one of (i) said horizontal span of said field of view is no greater than approximately 100 degrees and (ii) said vertical span of said field of view is no greater than approximately 30 degrees.

74. The vehicular vision system of claim **56**, wherein said imager has a field of view forward of the equipped vehicle, and wherein said field of view comprises a vertical span and wherein said vertical span is asymmetric relative to a horizon, and wherein said vertical span comprises a first vertical span above the horizon and a second vertical span below the horizon, and wherein said first vertical span has a different vertical dimension than said second vertical span.

75. The vehicular vision system of claim **56**, wherein said photosensor array is operable at a first exposure period and a second exposure period, and wherein the time period of exposure of said first exposure period is longer than the time period of exposure of said second exposure period.

76. The vehicular vision system of claim **56**, wherein image data processing by said image processor comprises pattern recognition.

77. The vehicular vision system of claim **56**, wherein said image processor processes captured image data for at least one of (a) a headlight control system of the equipped vehicle,

(b) a collision avoidance system of the equipped vehicle, and (c) an automatic vehicle system of the equipped vehicle.

78. The vehicular vision system of claim **56**, wherein said imager comprises a spectral filter.

79. A vehicular vision system, said vehicular vision system comprising:

an imager comprising a lens and a CMOS photosensor array;

wherein said photosensor array comprises a plurality of photosensor elements;

wherein said imager is disposed at an interior portion of a vehicle equipped with said vehicular vision system and wherein said imager views exterior of the equipped vehicle through a windshield of the equipped vehicle and forward of the equipped vehicle;

wherein at least said imager is disposed in a module that releasably mounts to a mounting element adhesively attached at the windshield of the equipped vehicle;

a control comprising an image processor, said image processor processing image data captured by said photosensor array;

wherein said image processor processes captured image data to detect an object viewed by said imager; and

wherein, at least in part responsive to processing of captured image data by said image processor, said vehicular vision system determines a presence of at least one of fog, snow and rain present exterior and forward of the equipped vehicle.

80. The vehicular vision system of claim **79**, wherein said imager is disposed proximate the windshield of the equipped vehicle, and wherein said imager views through the windshield of the equipped vehicle at a windshield area that is swept by a windshield wiper of the equipped vehicle.

81. The vehicular vision system of claim **79**, wherein said photosensor array comprises an array of columns and rows of photosensor elements and wherein at least one of (i) said array has more columns than rows and (ii) said array comprises at least 40 rows.

82. The vehicular vision system of claim **79**, wherein said image processor processes captured image data to detect at least one of (a) a vehicle, (b) a headlight of a vehicle, (c) a taillight of a vehicle, and (d) a road sign.

83. The vehicular vision system of claim **79**, wherein, at least in part responsive to processing of captured image data by said image processor, at least one of (a) said control is operable to control the exterior light of the equipped vehicle to emit a pattern of light appropriate to limit debilitation of the driver of another vehicle forward of the equipped vehicle, (b) said control is operable to control the exterior light of the equipped vehicle to emit a pattern of light that illuminates a selected zone forward of the equipped vehicle, and (c) the exterior light of the equipped vehicle is operable to emit various patterns of light.

84. The vehicular vision system of claim **79**, wherein said vehicular vision system determines a presence of at least one of fog, snow and rain by recognizing scattering of light output by a headlight of the equipped vehicle by at least one of fog, snow and rain present exterior and forward of the equipped vehicle, and wherein said vehicular vision system, at least in part responsive to recognition of scattering of light output by the headlight of the equipped vehicle, controls the headlight of the equipped vehicle.

85. The vehicular vision system of claim **79**, wherein at least one of (i) said image processor compares captured image data with stored data and outputs a vehicle equipment control signal based on the comparison, and (ii) said imager views through the windshield of the equipped vehicle at a windshield area that is swept by a windshield wiper of the equipped vehicle.

86. The vehicular vision system of claim **79**, wherein said control, at least in part responsive to processing of captured image data by said image processor, at least one of (i) distinguishes between daytime and nighttime conditions, (ii) determines a nighttime condition exists at an ambient light level that is less than about 500 lux, (iii) is operable to control a headlight of the equipped vehicle when said control determines a nighttime condition, (iv) is operable to control a vehicle accessory when said control determines a daytime condition, (v) is operable to deactivate a light beam of a headlight of the equipped vehicle when said control determines a daytime condition, and (vi) determines an ambient light level present at the equipped vehicle.

87. The vehicular vision system of claim **79**, wherein the equipped vehicle has at least one headlight, and wherein the at least one headlight is operable at least in a first beam mode and a second beam mode, and wherein, at least in part responsive to processing of captured image data by said image processor, said control controls operation of the at least one headlight, and wherein said control transitions the at least one headlight from said first beam mode to said second beam mode in response to detection of at least one of a headlight and a taillight viewed by said imager.

88. The vehicular vision system of claim **79**, wherein said imager has a field of view forward of the equipped vehicle, and wherein said field of view comprises a horizontal span and a vertical span and wherein said horizontal span is greater than said vertical span, and wherein at least one of (i) said horizontal span of said field of view is no greater than approximately 100 degrees and (ii) said vertical span of said field of view is no greater than approximately 30 degrees.

89. The vehicular vision system of claim **79**, wherein said imager has a field of view forward of the equipped vehicle, and wherein said field of view comprises a vertical span and wherein said vertical span is asymmetric relative to a horizon, and wherein said vertical span comprises a first vertical span above the horizon and a second vertical span below the horizon, and wherein said first vertical span has a different vertical dimension than said second vertical span.

90. The vehicular vision system of claim **79**, wherein said photosensor array is operable at a first exposure period and a second exposure period, and wherein the time period of exposure of said first exposure period is longer than the time period of exposure of said second exposure period.

91. The vehicular vision system of claim **79**, wherein said module includes at least one of (i) logic and control circuitry, (ii) logic and control circuitry that comprises at least a portion of said control, (iii) logic and control circuitry that comprises said image processor, (iv) a heat sink for at least a portion of logic and control circuitry, (v) a connector for electrically connecting to a power source of the equipped vehicle, and (vi) a cover.

92. The vehicular vision system of claim **79**, wherein image data processing by said image processor comprises pattern recognition.

93. The vehicular vision system of claim **79**, wherein said image processor processes captured image data for at least one of (a) a headlight control system of the equipped vehicle, (b) a collision avoidance system of the equipped vehicle, and (c) an automatic vehicle system of the equipped vehicle.

94. The vehicular vision system of claim **79**, wherein said imager comprises a spectral filter.

95. The vehicular vision system of claim **94**, wherein said control comprises logic and control circuitry and wherein said logic and control circuitry comprises said image processor, and wherein at least two of (a) said module includes a heat sink for at least a portion of said logic and control circuitry, (b) said module includes a connector for electrically connecting to a power source of the equipped vehicle, (c) said module includes at least a portion of said logic and control circuitry, and (d) said module includes a cover.

96. A vehicular vision system, said vehicular vision system comprising:

an imager comprising a lens and a CMOS photosensor array;

wherein said photosensor array comprises a plurality of photosensor elements;

wherein said imager is disposed at an interior portion of a vehicle equipped with said vehicular vision system and wherein said imager views exterior of the equipped vehicle through a windshield of the equipped vehicle and forward of the equipped vehicle;

wherein at least said imager is disposed in a module that releasably mounts to a mounting element adhesively attached at the windshield of the equipped vehicle;

wherein said photosensor array comprises an array of columns and rows of photosensor elements and wherein said array has more columns than rows, and wherein said array comprises at least 40 rows;

wherein said imager has a field of view forward of the equipped vehicle, and wherein said field of view comprises a horizontal span and a vertical span and wherein said horizontal span is greater than said vertical span;

a control comprising an image processor, said image processor processing image data captured by said photosensor array; and

wherein said image processor processes captured image data to detect an object viewed by said imager.

97. The vehicular vision system of claim **96**, wherein said image processor processes captured image data to detect at least one of (a) a vehicle, (b) a headlight of a vehicle, (c) a taillight of a vehicle, and (d) a road sign.

98. The vehicular vision system of claim **96**, wherein, at least in part responsive to processing of captured image data by said image processor, said vehicular vision system determines a presence of at least one of fog, snow and rain present exterior and forward of the equipped vehicle.

99. The vehicular vision system of claim **98**, wherein said vehicular vision system determines the presence of at least one of fog, snow and rain by recognizing scattering of light output by a headlight of the equipped vehicle by at least one of fog, snow and rain present exterior and forward of the equipped vehicle, and wherein said vehicular vision system, at least in part responsive to recognition of scattering of light output by the headlight of the equipped vehicle, controls the headlight of the equipped vehicle.

100. The vehicular vision system of claim **96**, wherein at least one of (i) said image processor compares captured image data with stored data and outputs a vehicle equipment control signal based on the comparison and (ii) said imager views through the windshield of the equipped vehicle at a windshield area that is swept by a windshield wiper of the equipped vehicle.

101. The vehicular vision system of claim **96**, wherein said control, at least in part responsive to processing of captured image data by said image processor, at least one of (i) distinguishes between daytime and nighttime conditions, (ii) determines a nighttime condition exists at an ambient light level that is less than about 500 lux, (iii) is operable to control a headlight of the equipped vehicle when said control determines a nighttime condition, (iv) is operable to control a vehicle accessory when said control determines a daytime condition, (v) is operable to deactivate a light beam of a headlight of the equipped vehicle when said control determines a daytime condition, and (vi) determines an ambient light level present at the equipped vehicle.

102. The vehicular vision system of claim **96**, wherein said horizontal span of said field of view is no greater than approximately 100 degrees and said vertical span of said field of view is no greater than approximately 30 degrees.

103. The vehicular vision system of claim **96**, wherein said vertical span comprises a first vertical span above a horizon and a second vertical span below the horizon, and wherein said first vertical span has a different vertical dimension than said second vertical span.

104. The vehicular vision system of claim **96**, wherein said photosensor array is operable at a first exposure period and a second exposure period, and wherein the time period of exposure of said first exposure period is longer than the time period of exposure of said second exposure period.

105. The vehicular vision system of claim **96**, wherein image data processing by said image processor comprises pattern recognition.

106. The vehicular vision system of claim **96**, wherein said image processor processes captured image data for at least one of (a) a headlight control system of the equipped vehicle, (b) a collision avoidance system of the equipped vehicle, and (c) an automatic vehicle system of the equipped vehicle.

107. The vehicular vision system of claim **96**, wherein said imager comprises a spectral filter.

108. The vehicular vision system of claim **107**, wherein said control comprises logic and control circuitry and wherein said logic and control circuitry comprises said image processor, and wherein at least two of (a) said module includes a heat sink for at least a portion of said logic and control circuitry, (b) said module includes a connector for electrically connecting to a power source of the equipped vehicle, (c) said module includes at least a portion of said logic and control circuitry, and (d) said module includes a cover.

109. The vehicular vision system of claim **96**, wherein said imager is disposed proximate the windshield of the equipped vehicle, and wherein said imager views through the windshield of the equipped vehicle at a windshield area that is swept by a windshield wiper of the equipped vehicle.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 8,599,001 B2
APPLICATION NO. : 13/680534
DATED : December 3, 2013
INVENTOR(S) : Kenneth Schofield et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

Column 29
Line 25, “mirror” should be --minor--

Column 31
Line 6, “5500)” should be --S500)--

Column 35
Line 27, “F_{LAY}” should be --F_{DAY}--
Line 37, “F_{LAY}” should be --F_{DAY}--

Signed and Sealed this
Twelfth Day of August, 2014

Michelle K. Lee
Deputy Director of the United States Patent and Trademark Office

CMOS in camera

Oliver Vellacott
explains how a device small enough to fit inside a car's rear-view mirror can be programmed to see

In 1988, a team of researchers at Edinburgh University developed a fingerprint matching system. This compared a fingerprint captured by a charge-coupled device (CCD) image sensor with a description held on a smart card and gave a pass/fail result within a second. The matching of the live fingerprint with the reference was performed with a highly parallel application-specific integrated circuit, performing some 3 billion operations per second.

Despite the technical success of the project, in concluding the work, team leader Prof. Denyer noted that by far the most expensive component of the system was the CCD image sensor. In the light of this, the team turned its attention to making image-sensing technology cheaper.

Instead of fabricating sensors using the MOS-varient process found in CCD sensors, the team tried to realise an image sensor using a commercial CMOS process. When the results were presented at CICC in 1990, they met with near incredulity; several research groups had tried the same thing and concluded that it was not technically feasible. Since then, Denyer has formed VLSI Vision Ltd in Edinburgh to exploit the technology; this company has grown to some 40 people.

Over the previous 20 years, CCD technology had been highly refined to allow quality image capture. Some CCD sensor manufacturers use a variant of single-channel MOS technology, in which only doping levels are altered to optimise optical performance measures such as anti-blooming (preventing the charge from optically saturated pixels from spilling over to their neighbours).

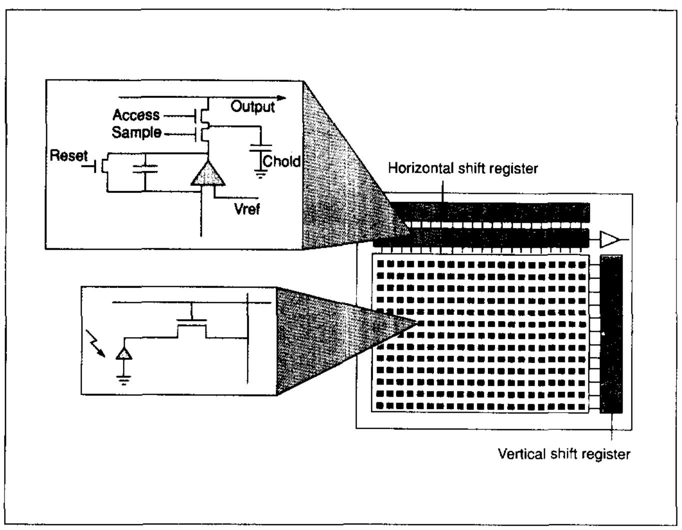
Because of the specialised process needed to implement the sensor array, digital functions cannot be implemented on the same chip. This means that (for instance) timing signals for controlling exposure and readout of the sensor array must be generated by a separate CMOS chip.

VVL's approach has been to combine image sensing with control functions on a single CMOS chip. As in previous attempts to realise CMOS sensors, each pixel is formed by extending and exposing the source region of a standard MOS transistor to make a photodiode (Fig. 1). This can be reset and then isolated within the array under the control of a MOS transistor gate. All pixels in a row are reset together.

Once reset, the reverse-biased photodiode converts incident light to a small current, which gradually discharges the gate capacitance. The pixel is then read by opening the gate, thus connecting the photodiode to the MOS transistor drain. In each column of the array, the transistor drains are connected in common and thus only one row of pixels is read at a time.

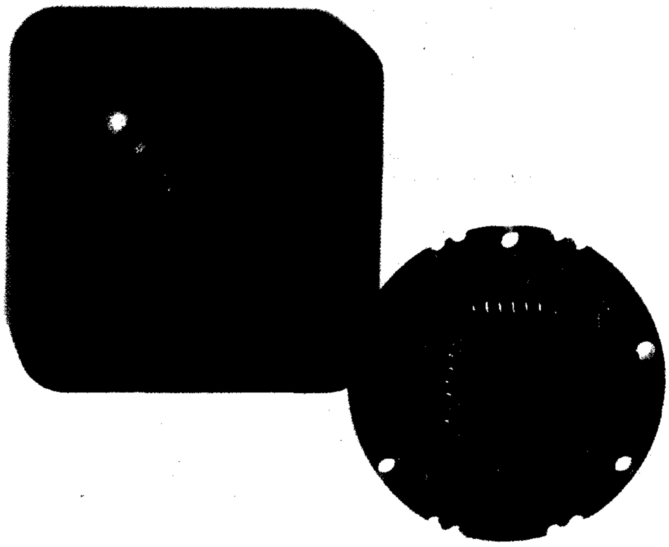
This structure had been used in previous designs, but without success. This was because all pixel outputs were gated through a single charge-sense amplifier, placing huge demands on its operation: this sense amplifier had to give a wide dynamic range from pixel charge packets as low as 1 fC, yet operating at a 6 MHz read frequency.

The Edinburgh approach gets around this problem by using a separate charge-sense amplifier at the head of each column of pixels. This means that the amplifiers operate at line rate rather than at pixel rate.



1 VVL's CMOS image-sensor architecture

Exhibit C



2 **The VVL Peach camera: 12 V in, video out**

Outputs from the sense amplifiers are sampled and stored on a row of capacitors, then multiplexed out through an on-chip charge integrator, including a sample-and-hold stage. By using an analogue multiplexer to switch in blanking and synchronisation levels at the appropriate times, it is then relatively easy to produce the 1 V peak-to-peak composite video waveform required by the CCIR (International Consultative Committee for Radio) and EIA (Electronic Industries Association) standards.

The readout of the sensor array is controlled by vertical and horizontal digital shift registers placed along the edges of the array. The vertical register activates each row, while the horizontal register reads out the pixels within each row. Unlike CCDs, the performance of the array is insensitive to these control signals, which is a significant advantage.

Exposure control is also implemented on-chip, by monitoring the output waveform to determine the appropriate exposure setting. The length of exposure is controlled by varying the pixel reset time via the vertical shift register; this allows the exposure period to be set in multiples of the line readout time.

By gating this readout signal with a pulse that is a multiple of the pixel readout time, it is possible to decrease the exposure even further, down to 500 ns. This gives a total exposure range of 40 000:1, since the maximum exposure time is 20 ms – the time to read out a field at the CCIR speed of 50 Hz.

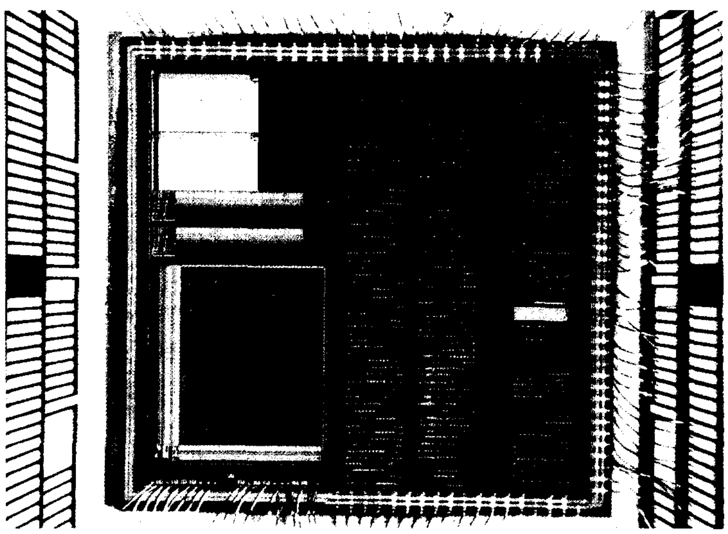
The result is the single-chip image sensor, which, because of the low power consumption of CMOS, consumes just 200 mW, compared with the 1 W typical of CCDs. VVL's first CMOS cameras could not match the performance of CCDs in terms of noise and sensitivity, mainly because of fixed-pattern noise effects arising from process variations inherent in unmodified (digital) CMOS processes.

To overcome this, VVL has devised several novel techniques that actively compensate for these effects. These cancel out the process variations and thus allow sensitivity down to 0·5 lux, matching CCDs. According to VVL, there is no intrinsic reason why CMOS sensors should not be able to perform just as well as CCD sensors.

If this is an achievable aim, single-chip CMOS sensors could eventually displace the multi-chip CCDs that are the current standard. This would result in smaller, cheaper, less power-hungry cameras. VVL's Peach camera, which is comparable with low-end CCDs in performance, measures only 35 mm across and is quite literally '12 V in, video out' (Fig. 2).

The full potential of this technology becomes more apparent when we turn to the fingerprint system and similar machine-vision tasks. Having developed a cheap image sensor, Denyer and his team immediately applied the technology to their fingerprint system by combining everything on one chip (Fig. 3), integrating all the functions needed:

- 258 × 258 × 8-bit pixel array
- ADC to digitise analogue pixel outputs
- preprocessing and quantisation to form normalised binary image
- 64-cell correlator array performing 3 billion operations per second



3 **Single-chip CMOS fingerprint acquisition and matching system**

- post-correlation decision hardware
- 16 kbyte RAM cache
- 16 kbyte ROM look-up table

This approach could allow single-chip implementations of smart cameras at low cost, which is not possible using CCD technology.

The imputer

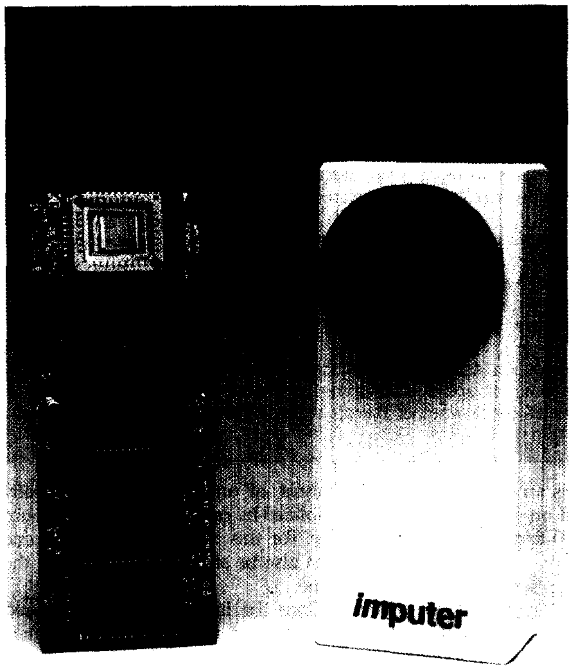
This was all very gratifying for the cause of UK research, but the technology remained inaccessible to applications developers because of the high engineering costs involved in tooling an ASIC. Accordingly, VVL then set out to produce a completely programmable machine-vision system. The result was the 'imputer', launched a year ago (Fig. 4)

Similar in concept to the configuration of PCs, the imputer contains a mothercard, into which expansion cards can be plugged as needed (Fig.5). The mothercard contains all the necessary components for most machine-vision applications: image sensor, frame grabber, microprocessor, framestore and external I/O. This is implemented on a board little larger than a credit card – 100 × 50 mm – and smaller than many CCD cameras alone, even though it forms a complete machine-vision system.

One of the limitations of the device is its processing power, which consists of an 8-bit Intel 8032 microcontroller. However, many machine-vision applications consist of very simple techniques such as line gauges.

Line gauge techniques treat lines of pixels as if they were physical gauges on the object being measured, and take readings accordingly; the imputer mothercard has enough processing power for these applications. For example, to measure the height of mercury in a thermometer, the imputer would measure at which pixel the line moves over a greyscale threshold and correlate this to a temperature.

Another apparent limitation of the imputer is the sensor resolution, which is restricted to 256 × 256 pixels. However, if one doubles the resolution in each dimension, to 512 × 512 pixels, the amount of image processing is quadrupled; this creates a strong incentive to solve applications using the lower resolution. To meet those applications that really cannot be solved at lower resolution, VVL is now working on a 512 × 512 pixel imputer.



4 The imputer, a complete standalone machine-vision system

The processor is programmed in C using IDS, the imputer development system, a Windows software package. A full library of machine-vision functions is provided, including morphological (shape) filters, transforms, correlators, convolvers, image segmentation, frequency filtering, rotation, reflection and logical operators. For high process-

5 More cards may be added as needed for more complex applications

Component inspection by imputer

Renishaw plc is a leading supplier of inspection probes for co-ordinate measuring machines (CMMs) and machine tools. Touch-trigger tools remain the standard inspection technique in these markets. However, for applications where it is necessary to probe deformable or two-dimensional components, non-contact measurement is preferable.

Renishaw has used the imputer to develop a probe for contactless inspection on a CMM.[1] Unusually, when the probe detects an edge, it sends a trigger signal to the CMM just like a conventional touch-trigger probe. This means that it can be fitted easily into existing CMM installations.

The edge-detection algorithm developed by Renishaw samples a number of pixels around the centre of the imputer sensor to check whether the probe has crossed an edge; if so, it outputs a trigger signal to the CMM. By sampling a collection of pixels, contributions from stray and background light are minimised.

Performance of the edge-detection probe is limited by the frame-update rate of the video sensor (50 Hz) and the pixel resolution (50 μm). For example, at a probing speed of 10 mm/s and a 50 mm field of view, the theoretical error would be 200 μm. A similar performance can be obtained using a CCD camera, framestore card and PC with image-processing software; however, the imputer offers a much smaller, simpler and cheaper way to achieve the same performance.

1 Guy, S., Skinner, C., and Wilson, W.: 'The investigation of an imputer-based probe for component inspection on a co-ordinate measuring machine', 1994 UK IT Forum: 'Wealth creation from information technology', DTI/JFIT/SERC

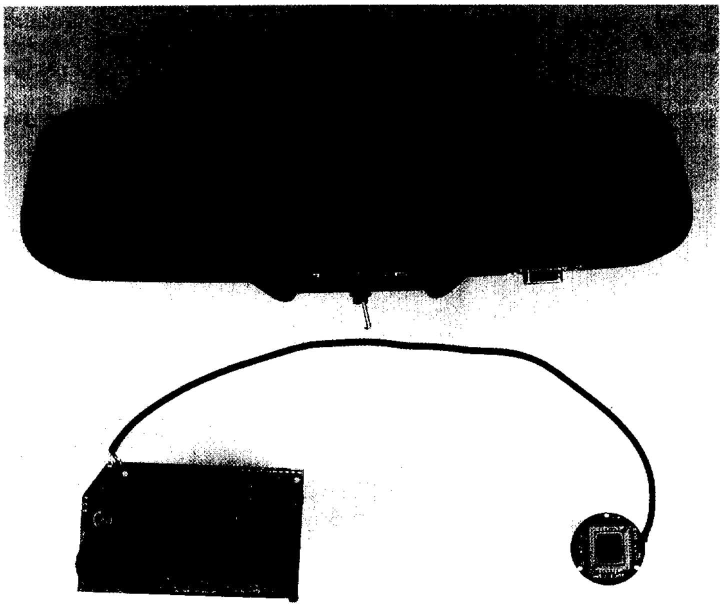
ing power, there is an optional plug-in coprocessor (based on a Motorola 56002 DSP), giving a 3000-fold speed improvement.

The CMOS image sensor generates its own pixel clock, making pixel digitisation accurate and allowing an exact correlation between the physical photosensitive silicon area and its digital value in memory. This is important for accuracy in measurement applications.

The sensor can be reset to the start of the frame by an external source, so that it can be synchronised to fast-moving objects – a common requirement in production-line inspection, where the analysis of an image can be greatly simplified by catching it at the optimum time. For this to be effective, the scene must also be strobed at the start of the frame.

Once the image has been captured and analysed, the imputer can interact with its environment using an RS232 interface and eight binary I/Os. A binary I/O might be used, for instance, as a pass/fail signal for the item under inspection.

The PC is only needed during application development; thereafter, the imputer units are left to work unsupervised and will communicate directly with other machinery to provide the required levels of verification. This is a break from the tradition of machine vision tied to PC or workstation platforms. An imputer replaces a camera, frame grabber, processing board and PC/workstation with a single integrated architecture, optimised for machine vision.



6 Imputer application: a rear-view-mirror controller ASIC

Field trials

One of VVL's customers is US automotive components manufacturer Donnelly Corp. Donnelly has used the imputer to develop electro-chromic rear-view mirrors, which automatically reduce headlamp glare from behind. The imputer was housed inside the rear-view mirror and positioned to look out the rear and sides of the car in a 90° arc, using a chip-mounted microlens (Fig. 6).

The imputer was programmed to analyse this image to recognise when and where headlamps are present in the field of view. Based on this information, the imputer then dims the rear-view and wing mirrors automatically to reduce glare to the driver. The dimming is controlled by an analogue voltage from the imputer, which directly sets the chrominance of the mirror.

Donnelly's system is now undergoing field trials with car manufacturers. Following this, it can be migrated to a single ASIC costing less than $10. Because of the engineering costs involved in tooling an ASIC, this is obviously only viable for volume applications. However, it does open up a large market that would remain nascent without CMOS imaging technology.

Acknowledgment
Research and development of the imputer was supported by the DTI and SERC.

WIDE-RANGE PRECISION ALIGNMENT FOR THE GEM MUON SYSTEM

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1. GEM MUON ALIGNMENT

The GEM muon system [l] is designed to achieve high momentum resolution by precisely measuring muon trajectories at three equidistant superlayers separated by a long lever arm in a large magnetized volume. In order to retain the desired precision at high momentum (i.e. $\Delta p_t/p_t$ = 5% for the barrel detector at p_t = 500 GeV/c), the muon system must determine the net 3-point sagitta of a muon track to σ = 55 μm in the bending plane. Chamber accuracies, fiducialization placement, alignment transfers, and alignment measurement error are included in this allotment. A set of realizable requirements on these quantities that combine to maintain this 55 μm tolerance are specified in Table 4-l of Ref. [1], where it has been determined that the false sagitta (i.e. error in the measurement of the bending-plane misalignment of the three superlayers) must be limited to σ = 25 μm.

Rather than place the drift chamber superlayers with such extreme precision (and require a similar degree of stability from the support structure), the relative positions of the superlayers are actively monitored and the reconstructed spacepoints are correspondingly compensated. A projective alignment scheme that relaxes the chamber positioning requirements in all coordinates has been proposed [2] and simulated [2,3]. Under this scheme, a set of six 3-point straightness monitors are used to measure the superlayer misalignment orthogonal to straight lines that extend along the muon path. Three straightness monitors run from the inner to outer superlayers at opposite edges of a muon alignment "tower" (as depicted in Fig. 2 of Ref. [4]), providing alignment measurements that determine a linear/quadratic interpolation function able to correct alignment-induced false sagitta errors for a projective muon track at arbitrary incidence. This alignment scheme is discussed in more detail elsewhere in these proceedings [4]; its immediate consequence is that the muon super-layers may be placed in the GEM detector relatively coarsely; the current requirements (i.e. Table 1 of Ref. [4]) dictate a placement of ±l to ±3 mm and ±l to ±5 milliradians (depending on the superlayer and coordinate), which should be realizable with standard survey techniques (for several practical reasons, it is desirable to avoid highly exacting positioning/stability requirements for structures approaching the size of the GEM muon system, which is 5000 m^3 in volume). Current efforts indicate that it should be possible to extend this range even further by employing an optimal estimator to incorporate other information, such as muon data and sagitta-orthogonal alignment measurements, and improving the θ-coordinate track resolution; the false sagitta then could be appropriately compensated with superlayer misalignments reaching the order of a centimeter.

In conclusion, the GEM muon alignment system requires a precision straightness monitor to be developed that exhibits a resolution better than σ = 25 μm across a dynamic measurement range approaching a centimeter. This system must perform at this specification in a magnetic field of order 1T and function with an optical path reaching beyond 9 meters (the maximum projective distance between inner and outer superlayers). Since many of these devices are required (i.e. the extreme all-projective alignment system baselined in Ref. [1] requires over 3000 straightness monitors), they must be inexpensive, easy to calibrate/install, and function reliably in the anticipated detector environment.

2. THE VIDEO STRAIGHTNESS MONITOR (VSM) ARCHITECTURE

Three-point optical straightness monitors were first developed [5] for the L3 muon detector at LEP, where they were deployed as the RASNIK [6] system. These are simple devices composed of a light source, lens, and position-sensitive photodetector, as shown in Fig. 1. An image of a smooth-aperture, collimated source (i.e. LED) is projected onto a planar

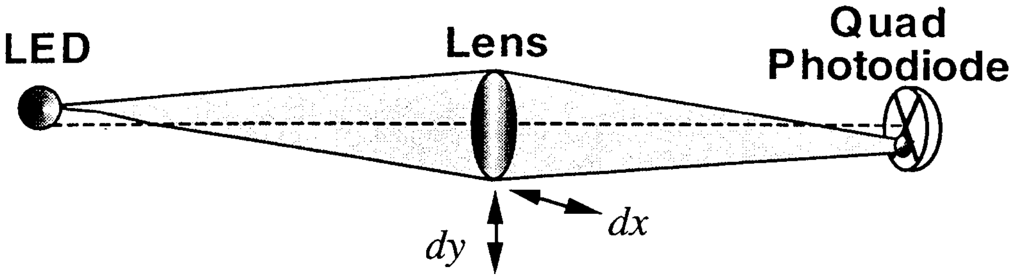

Fig. 1: Standard 3-point straightness monitor as applied in the L3 muon detector

detector (i.e. quadrant photodiode) through a focusing lens. Displacements of the lens from the line between source and detector are measured as a shift in the illumination centroid at the photodiode. With the lens at the midpoint, these devices have an implicit gain of two in the sagitta measurement; the offset read at the detector is twice the 3-point sagitta error. The measured displacement is insensitive to rotations of the lens and LED (provided it exhibits a symmetric illumination profile) about their optical axes. The LED is modulated by a low-frequency carrier, and synchronously detected to minimize the effects of any ambient light background. One straightness monitor component is fixed to each super-layer package such that it precisely references the cathode (sensing) plane of one composite CSC (Cathode Strip Chamber) layer; incident charged tracks (and/or X-rays from a calibration table) will rapidly determine the displacement of the mounted layer (hence the alignment element) with respect to the superlayer mean to better than $\sigma = 10$ μm.

Although simple LED/Lens/Quad-cell systems such as depicted in Fig. 1 are proven to provide high accuracy in deployed detector systems (below 5 μm [6,7]) at minimal cost, their useful measurement range doesn't generally extend beyond 1-2 mm [8]. The range of these alignment systems may be increased by replacing the quad-cell with a continuous lateral-effect photodiode [8] or by employing a wide-area diffuser over the LED and using a larger quadrant diode [9]. These techniques, however, can appreciably increase the hardware complication and expense, plus potentially degrade the alignment resolution beyond the 25 μm limit.

Recent advances in imaging technology and related microelectronics have dramatically reduced the cost and size of solid-state video cameras and image processing hardware. Highly integrated monochrome cameras are now available [10,11] on circuit cards that measure under 45 x 45 mm. They are self-contained, in that they typically require only 12 V of power and will output composite RS-170 video onto a 75 Ω cable. These units are quite inexpensive, costing well below $100 in large quantities. Such cameras typically employ inductive DC/DC converters, however, which prevent operation at high magnetic fields. These converters may be readily bypassed; one of the cameras under investigation [11] has already been so modified for application in the high-field region of a Magnetic Resonance Imager. This technology has an exploding future in many emerging commercial media applications, thus will be aggressively developed, leading to further reductions in price and improved performance.

An early effort [12] in aligning muon chambers focused a single narrow light spot onto a 256-pixel CCD line array, and determined the offset of this feature relative to the sensor by taking the illumination centroid. Because only one feature is detected and a 1D sensor is used, this technique possesses certain drawbacks; the available range is restricted to the active detector area, the measured position can be sensitive to ambient light (thus skewing the centroid), and only one axis of displacement is measured. Now that more powerful 2D video cameras, frame acquisition systems, and processors are available, alignment systems can employ image processing techniques to analyze more complicated, multi-feature images, enabling a robust precision measurement over a much wider range [13].

This concept is illustrated in Fig. 2, where a large precision mask is illuminated and projected through a lens onto a smaller area focal plane array. Misalignment is detected by correlating the captured video image to the mask template. Provided that the portion of the image viewed by the camera is unambiguous, the camera position can be precisely located anywhere across the projected mask, yielding a very wide measurement range.

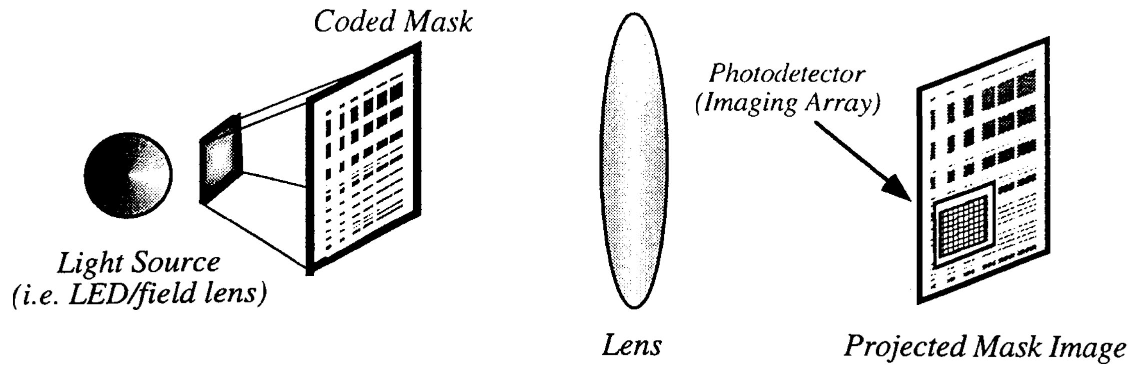

Fig. 2: Video straightness monitor (VSM) scheme

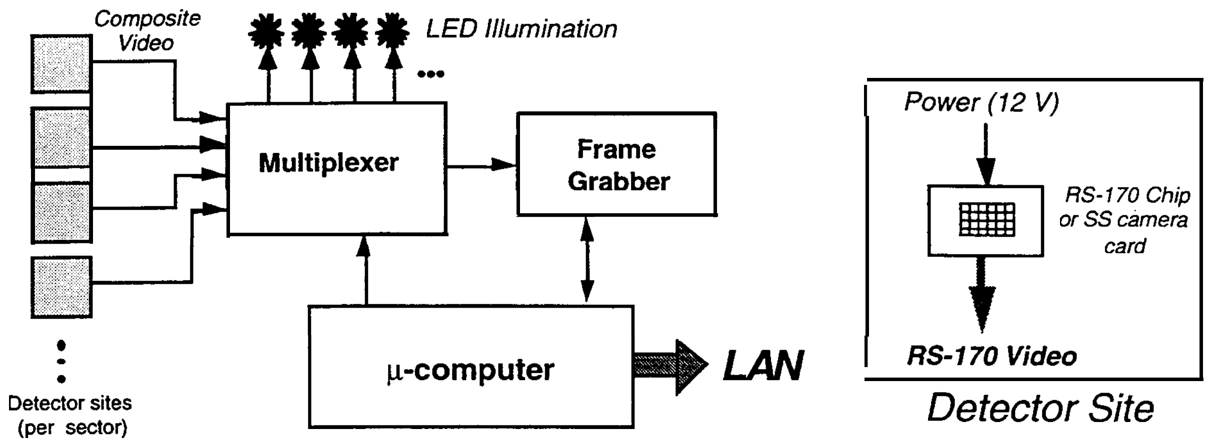

Fig. 3: Data acquisition for multiple-VSM system

Fig. 3 shows the implementation of such a system in the GEM muon detector. This layout entails very little electronics at each monitor site (only an LED illuminator and the camera card), and minimal cabling; a unipolar power supply and video line for the camera (which can both be combined into a single pair), plus a gate for every LED illuminator. Proper shielding will avoid crosstalk into the chamber signal electronics. All video sources for each GEM muon sector (currently estimated to cover $^1/_{12}$ of 2π, which includes 136 video channels in the ah-projective case [1] are multiplexed and input to a standard frame-grabber, which is managed by a simple processor that analyzes the captured images as described below and fits to the mask template. Successive frames are summed at a 1 Hz rate for at least 15 seconds in order to average out the effects of atmospheric turbulence. Under these assumptions, the entire muon system can thus be scanned in well under a half hour. The processors will communicate via a Local Area Network, exchanging alignment results, parameters, programs, and diagnostic data. This system is very easy to diagnose and verify; intelligent “watchdog” processing of the video frames provides a wealth of information, and if needed, the real-time video can be visually analyzed.

3. BARCODE DESIGN AND ANALYSIS

The most direct implementation of the VSM technique would be to image a mask of complicated (i.e. pseudorandom) features, and derive the alignment measurement by cross-correlating the captured image to the mask template. This process can be computationally demanding, however, especially if the lens magnification is not precisely known, or there is no coarse *a priori* knowledge of the mask offset. A 2-dimensional barcode has been developed in

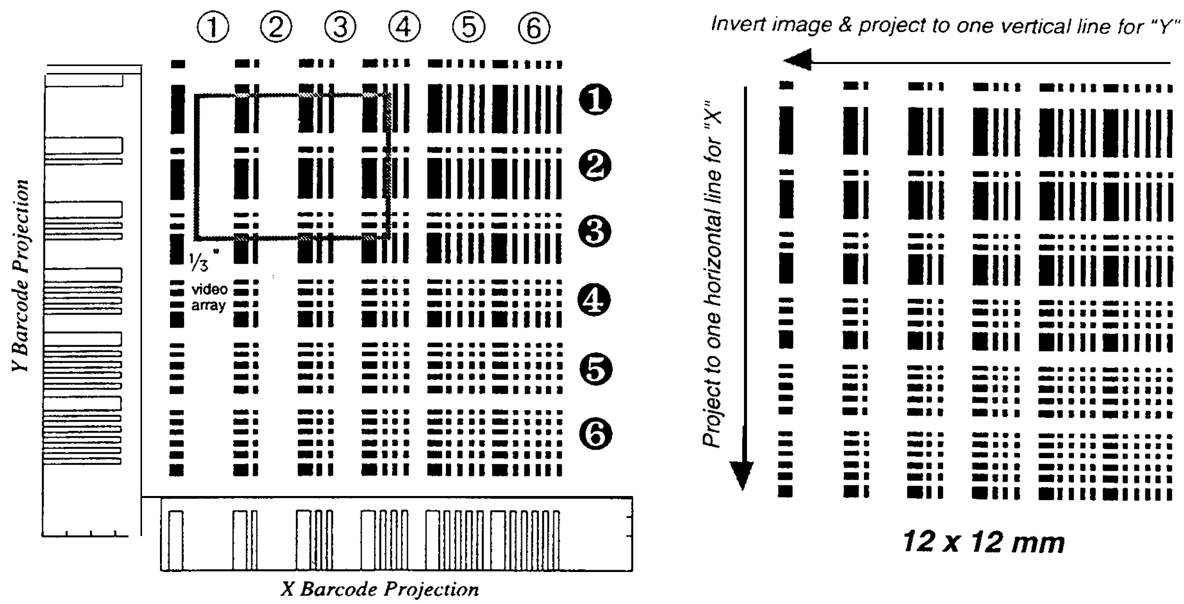

Fig. 4: Principle behind 2-dimensional barcode pattern

order to greatly simplify the needed processing; the two-dimensional pattern matching problem is now decoupled into two essentially independent 1-dimensional problems.

Fig. 4 shows such a barcode and indicates how it is read. The barcode superimposes both x and y information by making one code the negative image of the other. In Fig. 4, we see the horizontal code (x) as being a positive image (black lines), where the vertical code (y) is a negative image (horizontal lines). As indicated at right in Fig. 4, the two barcodes are separated in a captured 2D frame by summing (i.e. "projecting") all pixels horizontally (then reversing their amplitude) for the "y", and summing all pixels vertically for the "x". This yields two 1-dimensional barcodes, as plotted at left in Fig. 4. The barcode digits can be read by simply thresholding this data and counting bars, coarsely positioning the imager relative to the mask (in this simple coding scheme, a thick bar denotes the beginning of a digit; the digit's value is derived by counting the number of narrow bars that follow). Provided that the frame width can accommodate at least two full digits, at least one digit can be completely read at any position, thus the camera offset can be unambiguously determined anywhere in the pattern (every digit in this coding scheme is unique). This is also illustrated at left in Fig. 4, where we see the footprint of a typical ⅓" solid-state imager (such as has been used in tests) superimposed over the barcode pattern. The centroids of the projected bars may then be fit to the code template to produce a precise position reference, as detailed below.

The monotonic barcode of Fig. 4 is extremely simple, and was used in early tests [1]. It was composed manually in a Macintosh drawing package, and the feature locations were extracted into a CAD database. A new barcode has been programmed entirely in PostScript, thus the features are absolutely accurate to the resolution of the output device. This code is shown at left in Fig. 5, and incorporates several additional innovations. The digits are now binary-encoded (i.e. the width of a digit and presence/absence of a bar determines its value), plus the digit sequence is scrambled to insure a more-or-less uniform feature density across the pattern. The thick bars still denote the begin/end of encoded digits. An 8-bar "comb" pattern has been appended to the edges of the main barcode to provide good resolution reaching beyond the edges of the basic code. Because the coding scheme is much more compact, this image is twice as large than that of Fig. 3; the dynamic range is now increased to over 24 mm.

A captured frame (averaged over 15 4-bit grabs) from this barcode is displayed at right in Fig. 5, using the test setup described below. As can be noted, the image is hardly perfect; there are several visible defects due to smudges, etc. on the imager surface and barcode transparency. Because the entire frame is used in analyzing the data, this alignment scheme is tolerant of these defects, and they do not appreciably affect the accuracy. The feature resolution

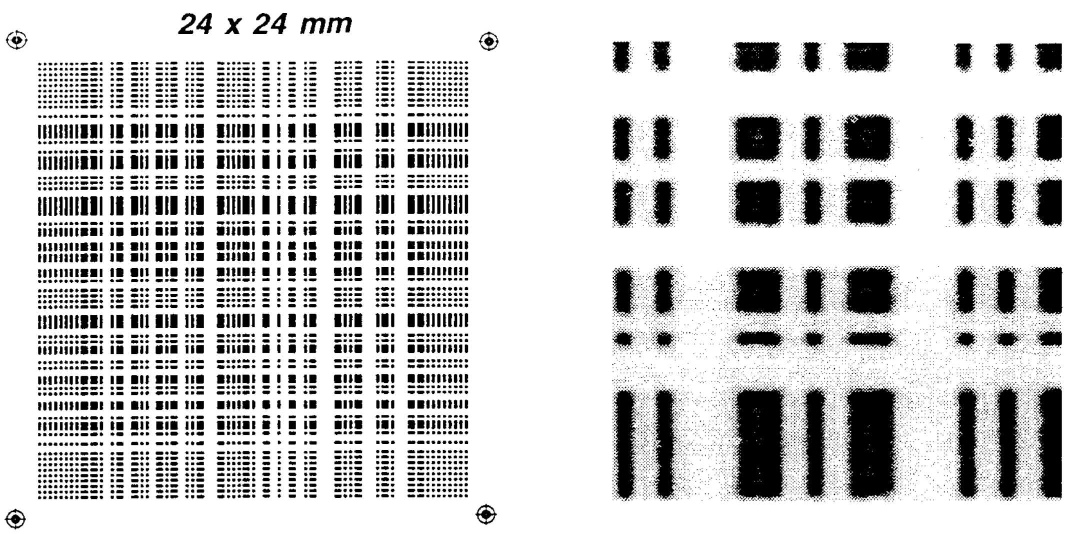

Fig. 5: PostScript barcode (left) and frame captured by test setup (right)

(hence number of possible features, thus length of code and dynamic range) is dictated by the diffraction limit of the lens; in these tests (over an 8 meter path with a 42 mm diameter lens), the narrow-bar features measure $\approx 120\,\mu m$. With the 8 meter baseline, the barcode features are seen to be adequately resolved with a lens aperture down to 25 mm, or defocus of $\approx \pm 25$ mm (otherwise, the image should be appropriately filtered, etc. before it is analyzed).

An analysis program has been written to process the X\Y projections of frame data; Fig. 6 shows an illustrative plot for a typical projection. First, the data is slightly low-pass filtered (using a phase-invariant Butterworth filter) to remove noise. It is then filtered much more heavily to produce a floating threshold curve, clipped to stay above and below an upper/lower noise floor. The data is discriminated by this threshold to recover the barcode, plotted at the top of the figure. This code is then parsed (i.e. the digits are read and located on the master template), and quadratics are fit to each corresponding peak and narrow valley in order to determine the feature centroids (only data down to half of the peak height is used, to prevent asymmetric tails from skewing the fits; in addition, "valley" data is only used between identical peaks; i.e. between two thick bars or two narrow bars). A linear least-squares fit is then applied to determine the offset and scale factor relating the barcode template reference to the captured frame, as determined by the centroids of the features extracted from the code segments that could be actually read (i.e. those completely in the frame; these are denoted by a "+" in Fig. 6). The remaining features that were detected are then checked to see if they are consistent to within a fiducial tolerance of this fit; if so, the fit is repeated with these points included (the added peaks are tagged "x" and added valleys are tagged "o" in Fig. 6) for greater precision.

The fit performed above relates the imager coordinates (in pixels) from the captured frame to the coordinate system that was used to generate the barcode; i.e. solve for α and β in the relation: $y_{barcode} = \alpha\, x_{pixels} + \beta$, where x_{pixels} is a vector of detected feature centroids (in pixels) and $y_{barcode}$ is a vector of the corresponding feature positions in the barcode template (in mm). The current formulation expresses β as the offset of the lower-left corner of the imaging array from the lower left-corner of the barcode; α is the scale factor between the detected and generated barcode. Although the relevant alignment parameter is given by β, fits are performed with both α and β free, which compensates for effects of image magnification and small rotations. If the scale factor a has been calibrated and is stable, it may be held fixed, and only β determined. This produced significant improvement in earlier results [1] with the old manually-generated barcode (Fig. 4), but yields much less benefit with the PostScript barcode of Fig. 5, which has more precise features.

In addition to the above fit technique, another approach was examined, where the barcode template was fit to the entire frame projection (the code was not actually read and no features were extracted) by maximizing the correlation integral and minimizing chi-square.

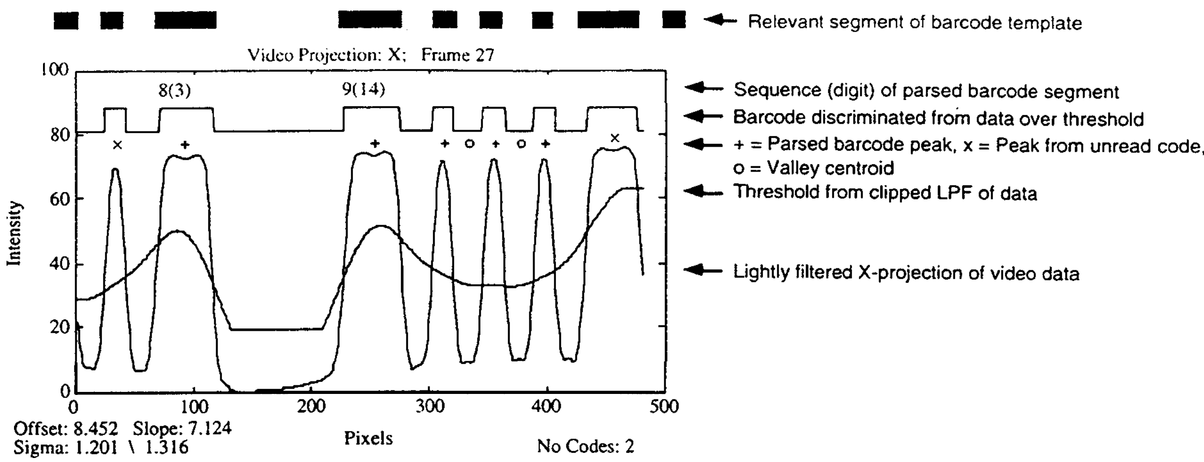

Fig. 6: Analysis of X-projection from captured frame

Because of offset shifts, tails, etc. created by the optical point-spread function, this method produced less accurate results, although the performance may improve after appropriate data filtering. By selecting particular features, such background effects are reduced.

Because of the large amount of data available in the full frame, many effects may be detected and compensated. Rotations of the mask relative to the camera can be determined by performing the feature fit on several band projections across the image (e.g. upper, middle, and lower thirds) or by applying the Hough transform [14] to the 2-dimensional frame data. Small rotational effects in the captured frame may be compensated by translating the calculated β value to the frame center, using the measured scale α.

4. TEST RESULTS

A series of tests was performed on a prototype VSM system. An 8-meter optical baseline (barcode\camera distance) was set up on a 5x12 foot optical table. A 2-meter focal length, 42 mm diameter lens was used at the midpoint to image the barcode at 1:1 magnification. A Chinon CX-102 mini-camera [10] was used, featuring a switched MOS photodiode matrix of 324 **x** 246 pixels across a ⅓" diagonal area. Video data was acquired and averaged via a Data Translation DT2861 frame grabber in an IBM PC, and transported to a Macintosh II for analysis, where the above procedure was coded in the MATLAB [15] interpreter. Future efforts [4] will incorporate real-time analysis and will be based entirely around a Macintosh using a SCION LG-3 frame grabber, which can drive a multiplexer and enable up to 64 VSM channels to be addressed.

The PostScript barcode of Fig. 5 was used in these tests. It was printed across a full page using a Linotronic 200 printer with 1200 DPI resolution, and photographically reduced by a factor of 8 (down to 24 x 24 mm) onto a conventional high-contrast negative, which was back-illuminated using a standard IR LED and field lens (which collimates the light like a flashlight beam), as shown in Fig. 2. Future tests [4] will use chrome-on-glass masks made directly from the barcode template, with features accurate to 0.1 μm [16]; the possibility of front-illuminating an opaque mask, which could be lithographed directly onto the cathode plane of a chamber layer, will also be investigated.

In these tests, the lens was translated, and its position computer-monitored by a precision digital linear gauge. The lens displacements are thus quoted in the plots; because of the geometry, the displacement of the source and detector are a factor of two larger.

Results from two scans across the barcode are plotted in Fig. 7. The left column shows the results of a scan across the vertical (Y) axis, and the right column shows the results of a scan across the horizontal (X) axis, as referenced to the barcode drawing in Fig. 5. The top

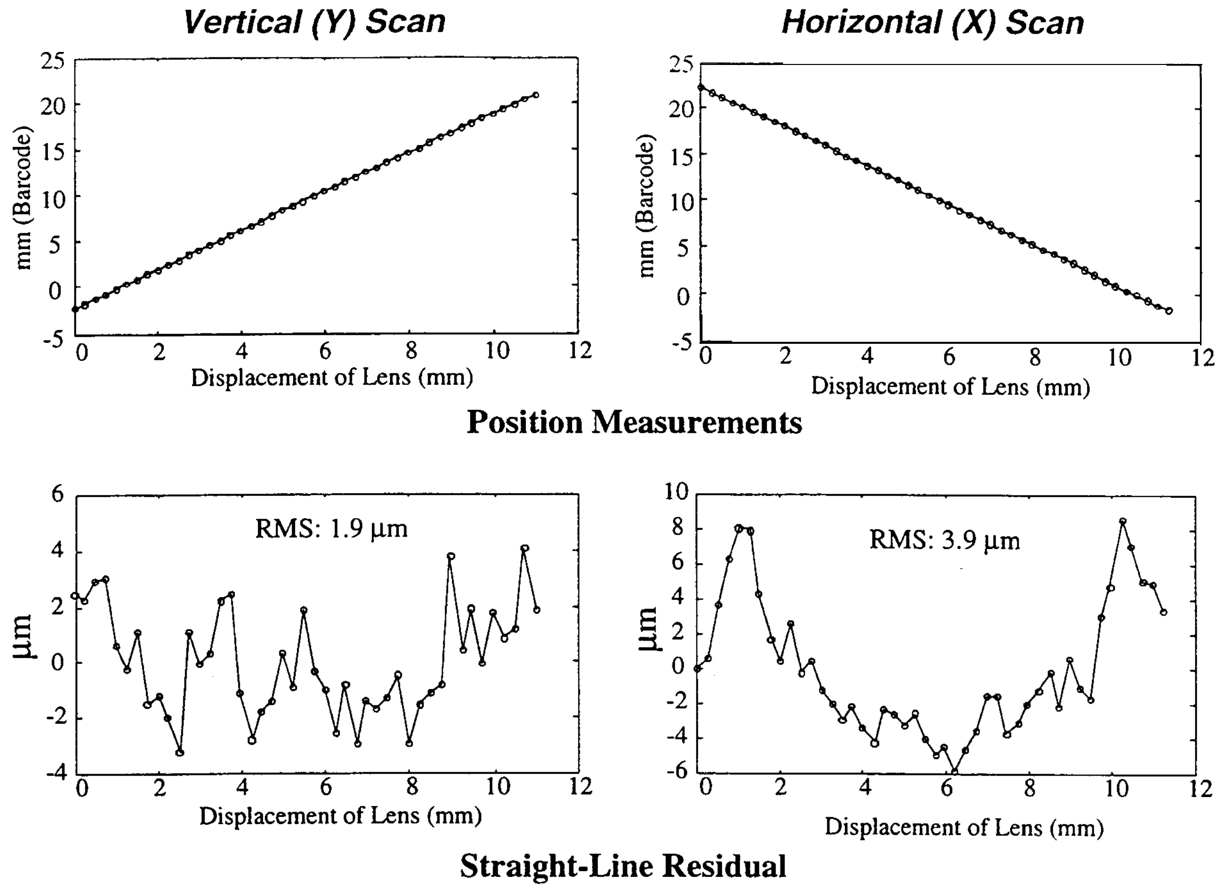

Fig. 7: Transfer characteristic and linearity extracted from VSM scans

plots show the transfer characteristic; i.e. lens position, measured in mm, vs. the barcode offset (β) as calculated from the fitting procedure described above (both α and β were free in the fits). The factor of two between lens and detector displacement is obvious from these plots. Because the photographic reduction of the barcode mask was not accurately controlled (thus the template scale is not precisely determined), these plots are essentially calibrations, i.e. they relate the coordinates produced by the barcode fit to the physical displacement of alignment elements (the straight-line sagitta error). The curves are very linear, and span nearly 12 mm of lens displacement (24 mm across the barcode), demonstrating the wide dynamic range.

The lower two plots show the deviation in linearity across these scans. In both cases, the worst-case departures remain below 10 ym. The errors for the vertical scans seem to be mainly due to thermal variations across the 8 meter optical path, and exhibit a σ = 1.9 μm. The horizontal scans show more of a structured nonlinearity (still with RMS under 4 μm), with peaks near either edge of the barcode pattern; nonetheless, these excursions remain within the GEM resolution requirements. In addition, the scan-orthogonal coordinate was resolved for this data (the X coordinate during a Y scan, and vice-versa), to examine the steady-state performance of the system during the test interval (which ran roughly 30 minutes). In both cases, the orthogonal coordinate was stable to within σ < 2 μm, at which level thermal effects dominate over the 8 meter optical path.

The source of the structured errors seen in the X scan of Fig. 7 is under investigation; possibilities include aberration effects (i.e. narrow-angle illumination during the vertical scan introducing errors when the lens is far off axis) and defects or curl on the mask negative. Another possibility arises from errors generated by wide features - the thick bars yield projections that are not quadratic (see Fig. 6), producing some uncertainty in the resulting centroid fit (due to the rectangular imager aspect, the X scan has a wider scale than the Y scan).

5. CONCLUSIONS AND FUTURE WORK

The video straightness monitors have been demonstrated to resolve sagitta errors to well within 10 μm over long optical path lengths and exhibit over a centimeter of dynamic range in sagitta, as will be required for the GEM muon system. Future efforts will explore effects of image distortion (e.g. recovering from significant turbulence, defocus, etc.), more efficient correlation analysis, extraction of rotational and other information from the 2D data, and establishing efficient fiducialization/calibration procedures [1]. Alternate coding schemes will also be investigated, including multi-digit codes (reading at least two digits at once) for increased range and uni-digit codes (e.g. rather than code several digits separated by thick bars, encode one long digit entirely with narrow bars, in which each captured frame will be uniquely identified); radically different masks have also been suggested [13]. Experience with a multi-channel VSM implementation will be provided by the proposed Alignment Test Stand [4], which will explore the operation of these systems in a realistic environment. The solid-state cameras that will be chosen for GEM must be able to tolerate the anticipated radiation environment. If difficulty is encountered with the candidate devices [10,11], radiation-tolerant imagers using Charge Injection Devices (CIDs) can be employed; if this proves unfeasible, a multiple LED backup option [1] has also been developed.

ACKNOWLEDGMENTS

The authors acknowledge Harry van der Graaf, of NIKHEF, Amsterdam for many discussions that were invaluable to launching this effort, and for several fruitful Internet exchanges since. The optical advice of Jacques Govignon from Draper Laboratory was also appreciated, as were suggestions offered by the GEM muon group, particularly Gena Mitselmakher, Andrey Ostapchuk, Craig Wuest, Frank Taylor, Mike Marx, and Scott Whitaker.

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GEM TN-93-433

GEM Muon Review Meeting - SSCL

June 30, 1993

Abstract:

Agenda, attendees, and presentations of the GEM Muon Review Meeting held at the SSC Laboratory on June 30, 1993.

Exhibit E

June 30, 1993
GEM muon group meeting
AGENDA

- Gena Mitselmakher - Chamber development plan
- Coleman Johnson - Chamber engineering at the SSCL
- Otto Steger - Strip board measurements
- Vinnie Polychronakos - BNL chamber / electronics progress
- Curt Belser - LLNL chamber activities
- Scott Whitaker - BU chamber / electronics activities
- Igor Golutvin - Dubna progress with large prototype
- Yinzhi Huang - Progress in IHEP
- Dan Marlow - Plans of muon electronics development
- Craig Wuest - Alignment Test Rig plans and chamber / alignment interface prototyping
- Joe Paradiso - Alignment monitor prototyping and simulations
- Alignment discussion - contributions from Gershtein and Korytov (presented by Mitselmakher)
- Joe Antebi - Monolith support structure
- Frank Nimblett - Support structure
- Mike Marx - Compare TDR and SGH support structures
- Discussion

GEM Muon Group Meeting

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COLEMAN Johnson	SSCL	(214) 708-1188	JohncoLE@SSC
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Draft-3

GEM Post TDR Muon R&D Program for FY93

May 7, 1993

Abstract

The objectives of the Post-TDR FY93 R&D and Engineering Program for the GEM Muon System are to carry the chamber design, alignment, and support structure into fully integrated, and engineered system. In contrast, the Pre-TDR program concentrated on the conceptual design of the muon system and on extexsive investigations of various chamber technologies. This effort lead to our choosing Cathode Strip Chambers for both the triggering and tracking functions of the muon system. In the Post-TDR program certain aspects of the Cathode Strip Chamber design will be developed and tested by means of small prototype chambers where the parameters of interest will be varied. Such issues as the resolution of the chamber for different anode-cathode gaps will be investigated. In addition, the full engineering details and "industrialization" of the chamber design will be conducted with the intent of setting up a pilot factory and producing first production chambers in FY94. The design of the chamber support and alignment systems will be developed in sufficient detail to allow for the fabrication of a sector prototype in late FY94. The construction of an alignment test-stand will be an important objective for this phase of the R&D program. The test stand will enable the concept of the "false-sagitta" measaurement and interpolation to be validated.

Table of Contents

Compiled by:

Gena Mitselmakher - SSCL [SSCVX1::MITSELMAKHER]
Frank Taylor - MIT [MITNLS::FET]

In order to manage the activities of the groups contributing to the chamber design a Chamber Commitee will be created with the primary function to overlook all activities and coordinate chamber design. The chairman of the Commitee is the Task Coordinator.

The proposed work is broken down into the following subtasks:

Deliverables:

(2.1.0) Purchase common parts (raw materials) for chamber construction.

(2.1.1) Fix the baseline chamber design for barrel and endcap chambers. Document all mechanical tolerances and dimensions. Compile a set of drawings. Integrate with electronics, alignment, gas and services.

(2.1.2) Investigate and validate with reduced size prototype measurements of different aspects of chamber design:
a) resolution performance vs. gap and strip segmentation;
b) investigation of different possibilities of calibration: with wire induced signal, electronically and using data from real particles.
c) consider the possibility of molded chamber frame production.

(2.1.3) Construction of full size prototypes:
a) "-1 generation" prototype of a barrel middle layer chamber: 3m by 1.1m - six 4mm gaps;
b) "0 generation" prototype of a barrel outer layer chamber: 3.5m by 1.4m - six 5mm gaps;
c) "0 generation" prototype of an end cap middle layer trapezoidal chamber: 2.2m by 0.9/0.61m - six 4mm gaps.

Task Coordinator: Gena Mitselmakher - SSCL

Chamber Commitee: Carl Bromberg. Igor Golutvin, Ya-nan Guo, Coleman Johnson, Yuri Kiryushin, Kwong Lau, Louis Osborne, Vinnie Polychronakos, Alexei Vorobyov, Craig Wuest, Scott Whitaker.

Task Contributors:

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IHEP-Beijing
Y. Chen, Y. Guo, Y. Xie, physicists and engineers
ITEP
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SSCL

- Prototypes

a) Small "performance optimization" prototypes.
(Cell geometry optimization, performance in magnetic field - barrel, endcap, wire - strip angle effect on resolution, etc...)
committed: SSCL (laser test stand), ITEP, PNPI, BNL, Dubna

b) Engineering prototypes - parts of chambers (panels, frames from new materials etc.)
committed - SSCL, BNL, LLNL ...need more

c) Large prototypes
(-1) generation barrel chamber 3m by 1.1m , six 4mm gaps - Dubna
(with SSCL participation - components, BNL, BU , PNPI - electronics)
August 1993

(0) generation barrel outer layer chamber 3.5m by 1.4m - six 5mm gaps
producer TBD (SSCL, LLNL, Dubna ???)
design by November 1993
construction by January 1994

(0) generation endcap chamber
design by December 1993
construction be February 1994
producer TBD (MIT, PNPI ???)

- Electronics for prototypes.

a) Cathode electronics - 2000 channels - Amplex based - BNL
b) Anode electronics - 500 channels - BU,PNPI(hybrids)

- Prototypes of "real electronics" - first samples in 1994 -
first production for prototypes for Sector test and Fermilab tests 1995
(discussed with Marlow)

(4.0) Schedules and Milestones

4.1 Chamber Design, Prototyping and Studies. Tasks 1 and 2.

Item (Task)	M (1993)	J	J	A	S	O	N	D	J (1994)	F
1. Barrel Chamber design (2.1.1a)		xxx	xxx	xxx	xxx	xxx ^Design Parameters Fixed	xxx	xxx	xxx	
2. End Cap Chamber Design (2.1.1b)			xxx	xxx	xxx	xxx	xxx ^Design Parameters Fixed	xxx	xxx	xxx
3. Barrel type (-1) generation prototype (2.1.3a)	Construction xxx	Construction xxx	Construction xxx	Tests xxx	Tests xxx	Tests xxx				
4. Barrel type (0) generation prototype (2.1.3b)				Design xxx	Design xxx	Design xxx / Construction xxx	Design xxx / Construction xxx	Construction xxx	Construction xxx	Construction xxx
5. Endcap type (0) generation prototype (2.1.3c)					Design xxx	Design xxx	Design xxx / Construction xxx	Design xxx / Construction xxx	Design xxx / Construction xxx	Construction xxx
6. Tests of small chambers (2.2.2, 2.2.3, 2.2.4)	Construction xxx	Construction xxx	Construction xxx / Tests xxx	Tests xxx	Tests xxx	Tests xxx				
7. Construction of engineering prototypes (large panels, molded frames) (2.1.2)	Construction xxx	Construction xxx	Construction xxx / Tests xxx	Tests xxx	Tests xxx	Tests xxx				

CHAMBER WEIGHTS

Different "baselines" considered

- BNL cast edges: nominal 3.5 x 1.19 m chamber
  epoxy edges, G-10 frames, no electronics, etc
  baseline chamber weight = 134 kg
  cast polymer frame weight = 103 kg, i.e. 77%
- SSC minimization design: nominal 2.55 x 1.08 m chamber
  epoxy edges, G-10 frames, no electronics, etc
  baseline chamber weight = 93.6 kg
  minimization design weight = 69.5 kg, i.e. 74%
- Both designs baselines use epoxy in HC close-outs
  consider lower density material, ie from 1.23 to 0.5 gm/cc
  could lower SSC design to 59.4 kg, ie 63.5 %
- TDR weights based on incorrect densities
  realistic chamber weights 3/4 of TDR
  However, cables, tubes not included

cvjxxxxx-4
6/28/93

DESIGN

Current efforts:

- Reduce materials in "edges"
- Wire fixation concepts
- High voltage distribution details
- Gas distribution system details
- "Spacer" details
- Alignment transfer details

14

Questions to be answered soon

- Flatness requirements
- edge material concept
- Solder vrs epoxy for wire fixation
- Anode plane relative alignment requirements

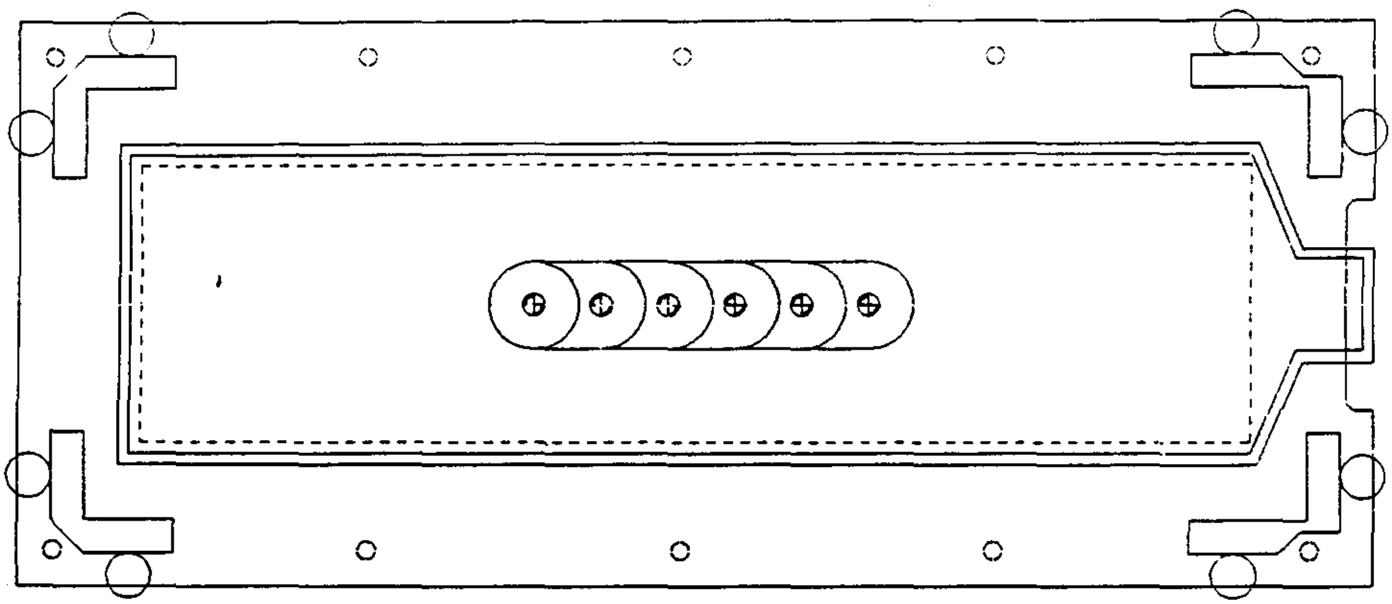
Plans:

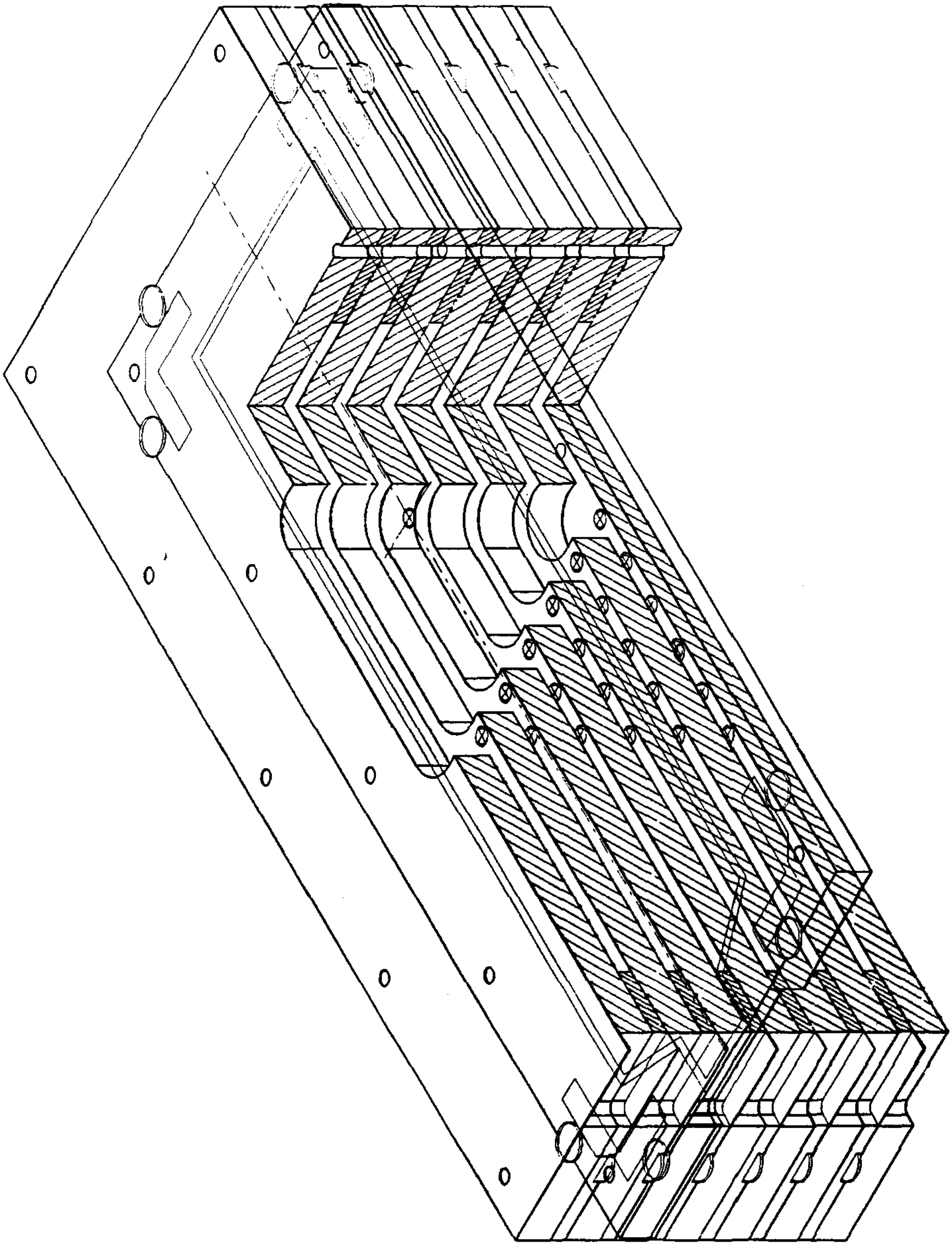
Full sized, mid layer prototype:

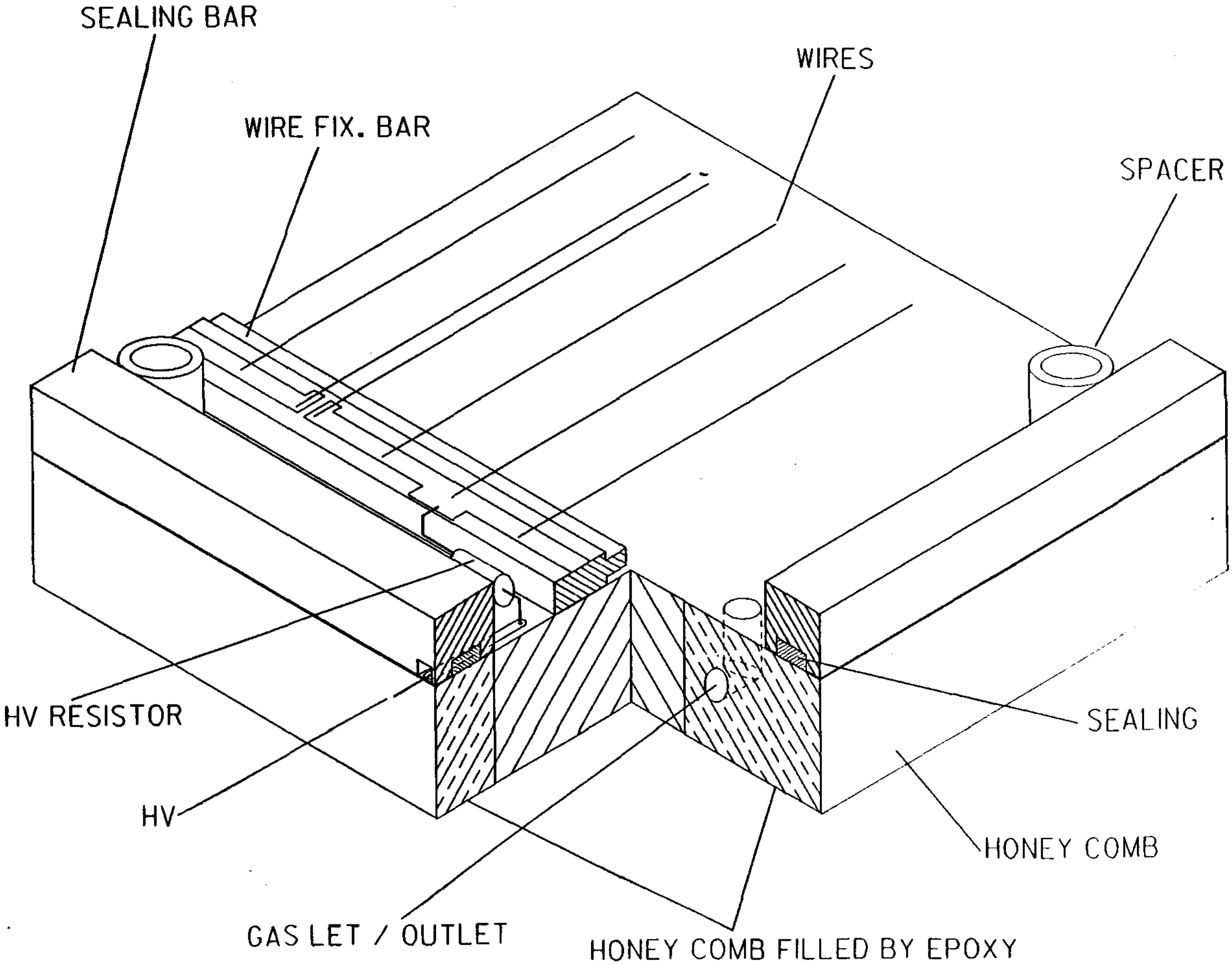
- ship parts
- build six gap chamber, starting mid July
- test in TTR, results by Sept?

Full sized, largest barrel prototype:

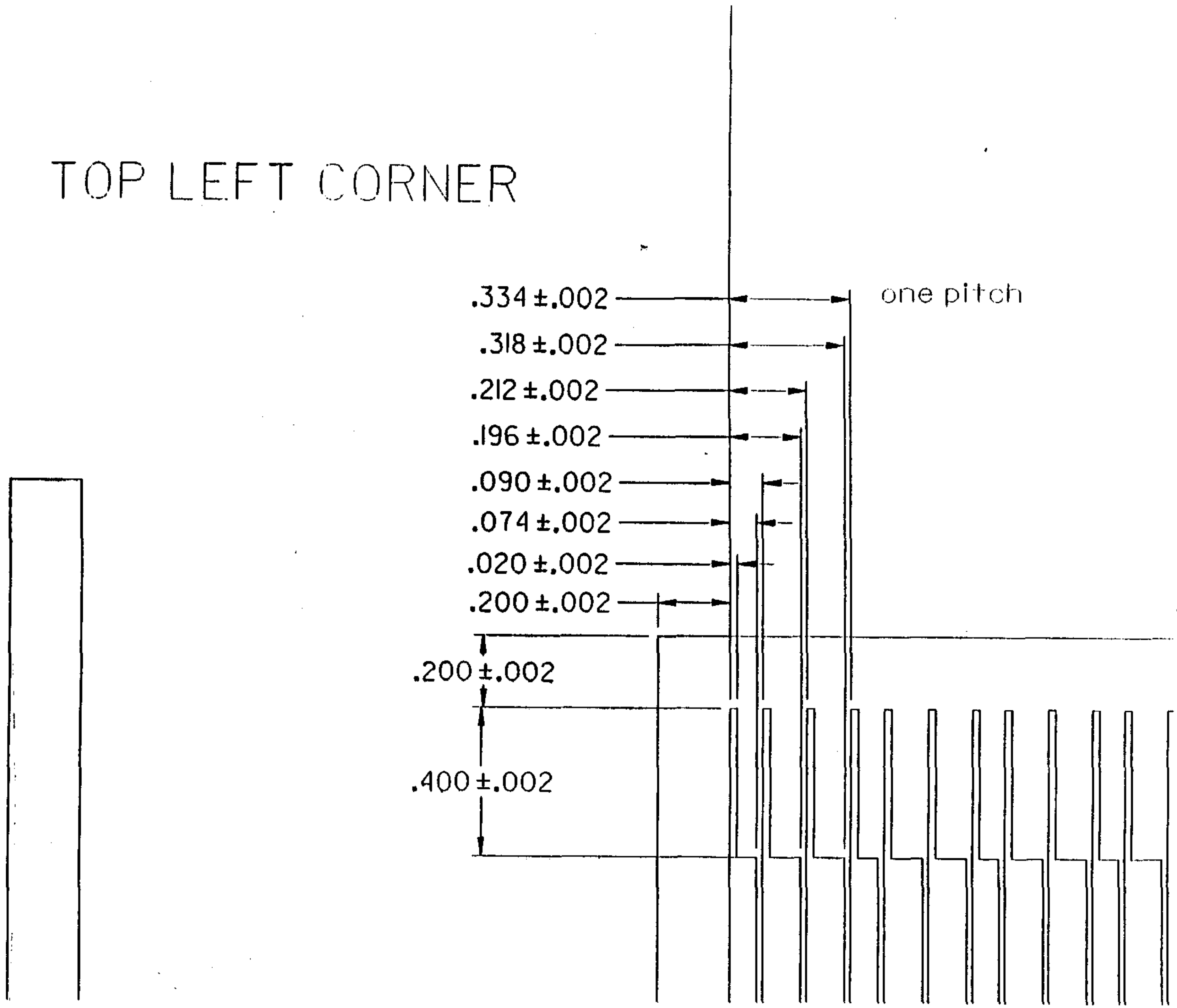
- Results of summer design effort
- Choose representative design features
- Complete design drawing package by Nov
- Manufacture components by anticipated mass prod
- First cut at "final" chamber building techniques
- Available for test by Feb, 94??

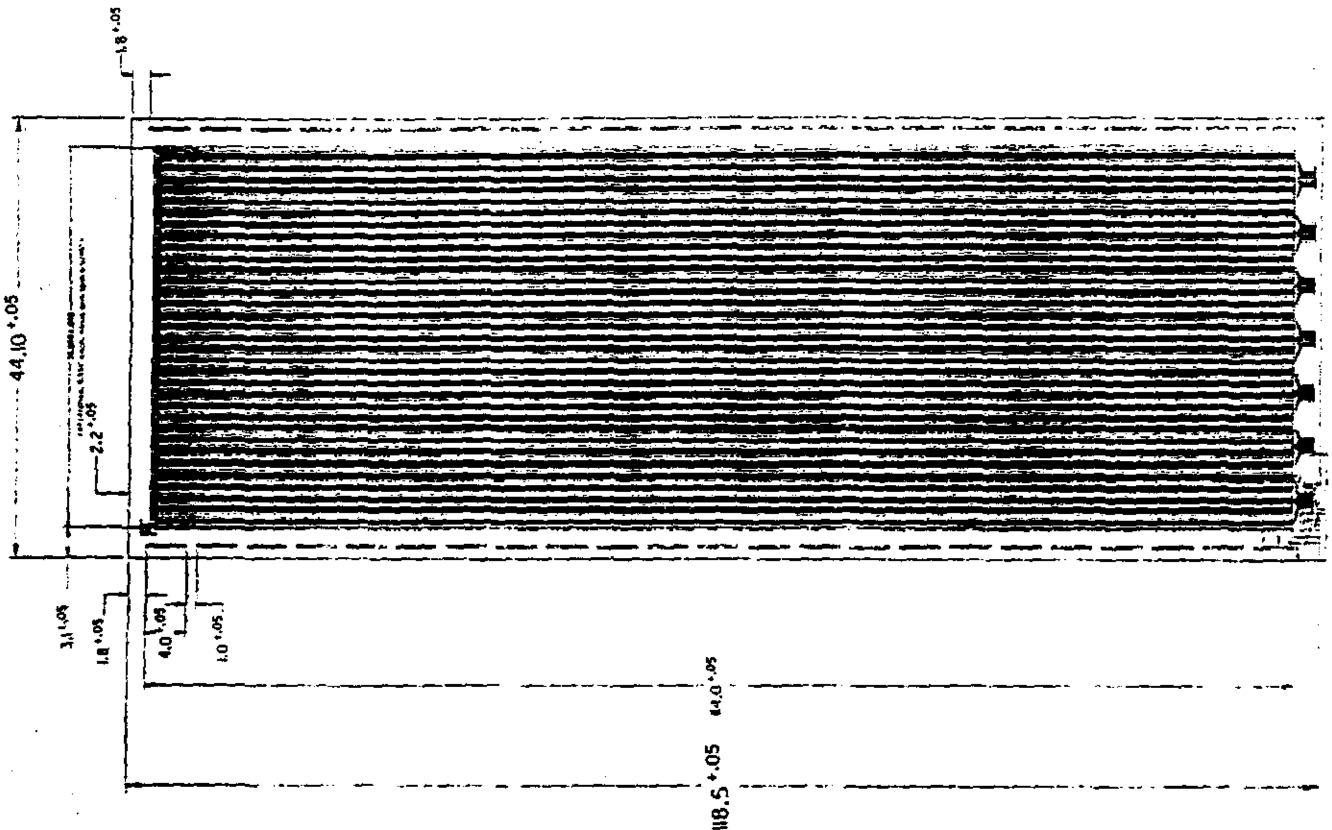





SEALING BAR
WIRES
WIRE FIX. BAR
SPACER
HV RESISTOR
SEALING
HV
HONEY COMB
GAS LET / OUTLET
HONEY COMB FILLED BY EPOXY

TOP LEFT CORNER





1.8 ±.05
44.10 ±.05
2.2 ±.05
3.1 ±.05
1.8 ±.05
4.0 ±.05
1.0 ±.05
44.0 ±.05
118.5 ±.05

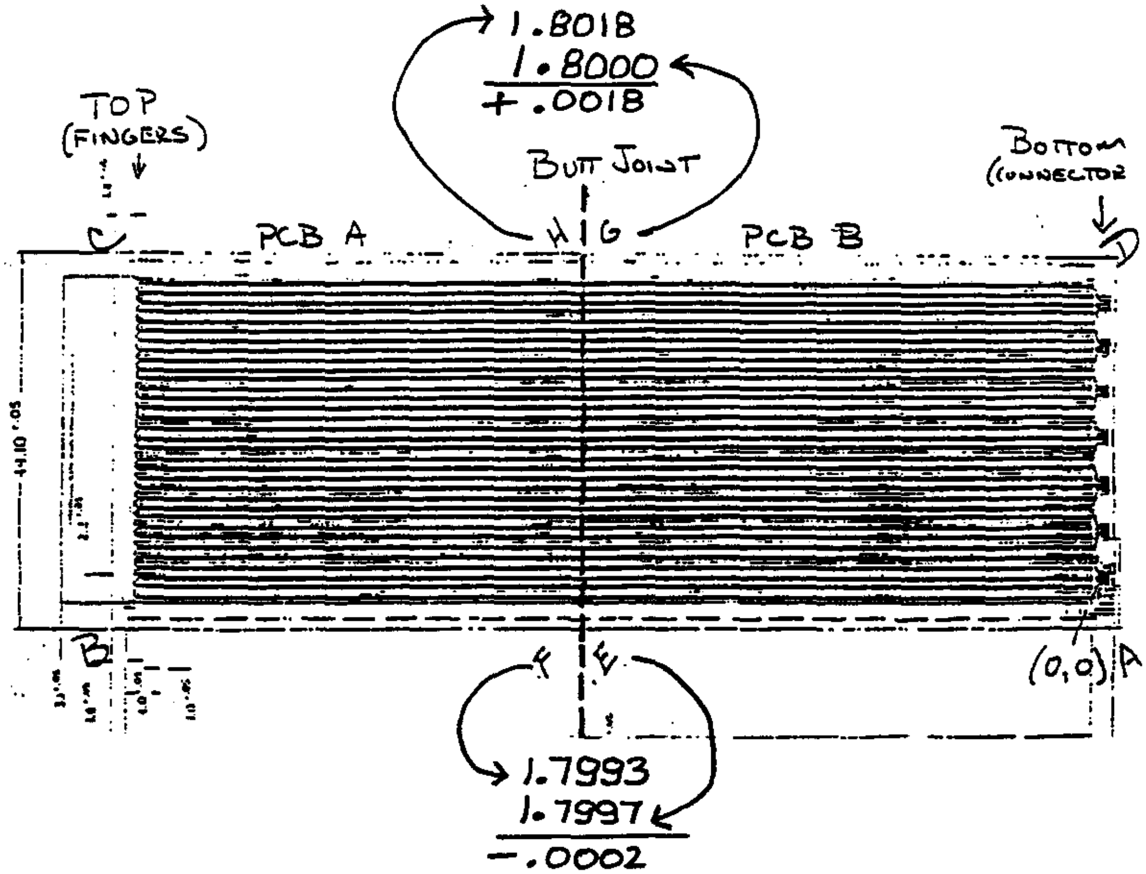
PROTOTYPES

PROGRESS:

- Full sized, mid layer prototype
  3 x 1.1 m
  cathode strip boards manufactured, being measured
  other parts packaged for shipping
- Reduced material edge design prototypes
  BNL cast edge concept
  SSC minimization design
- Error transfer prototype
  LLNL design, test

21

CCT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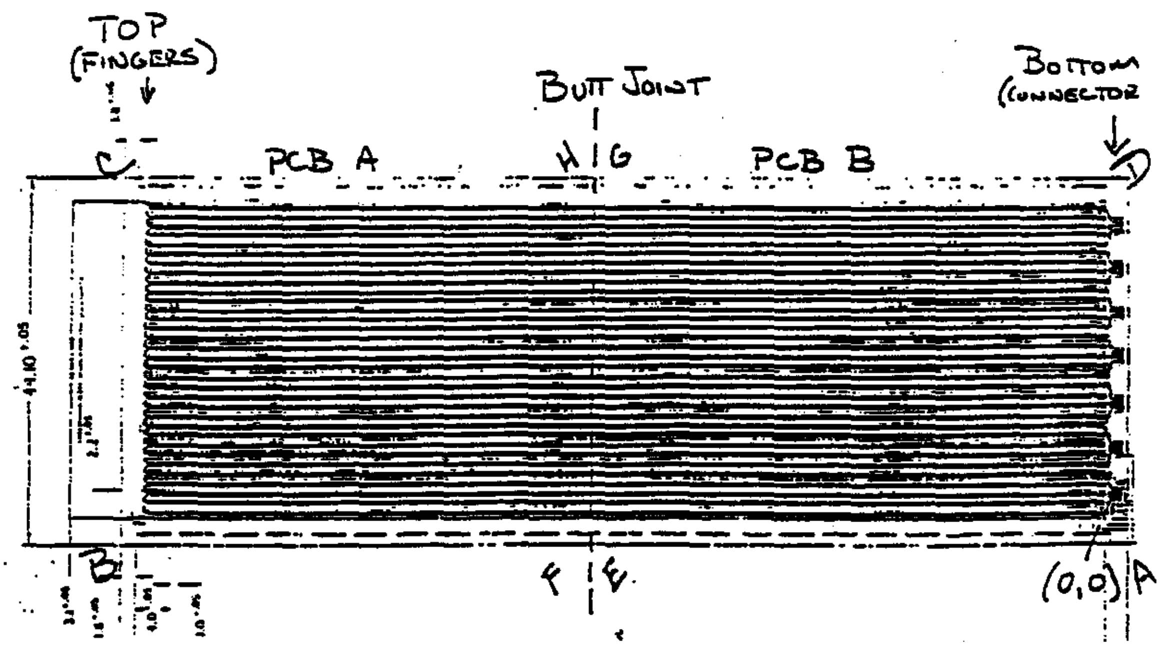
MIT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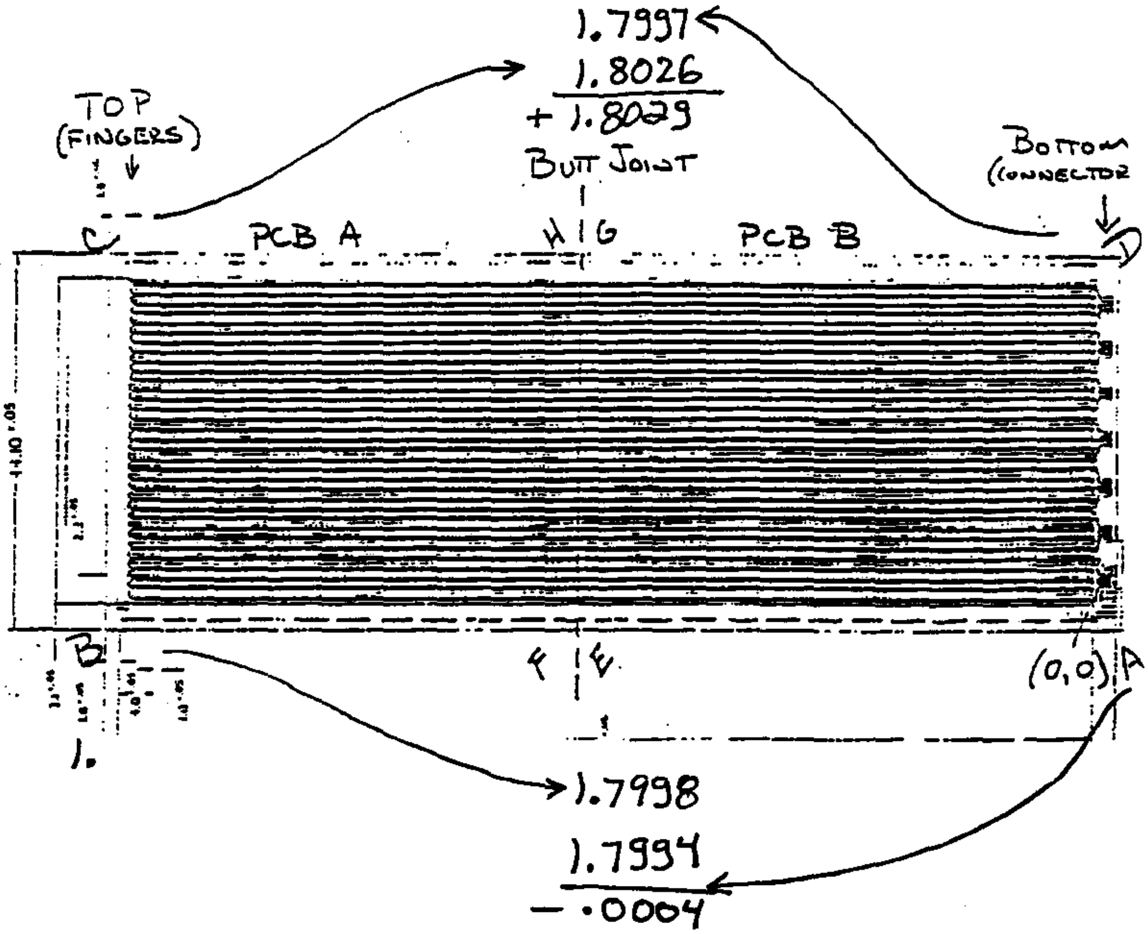
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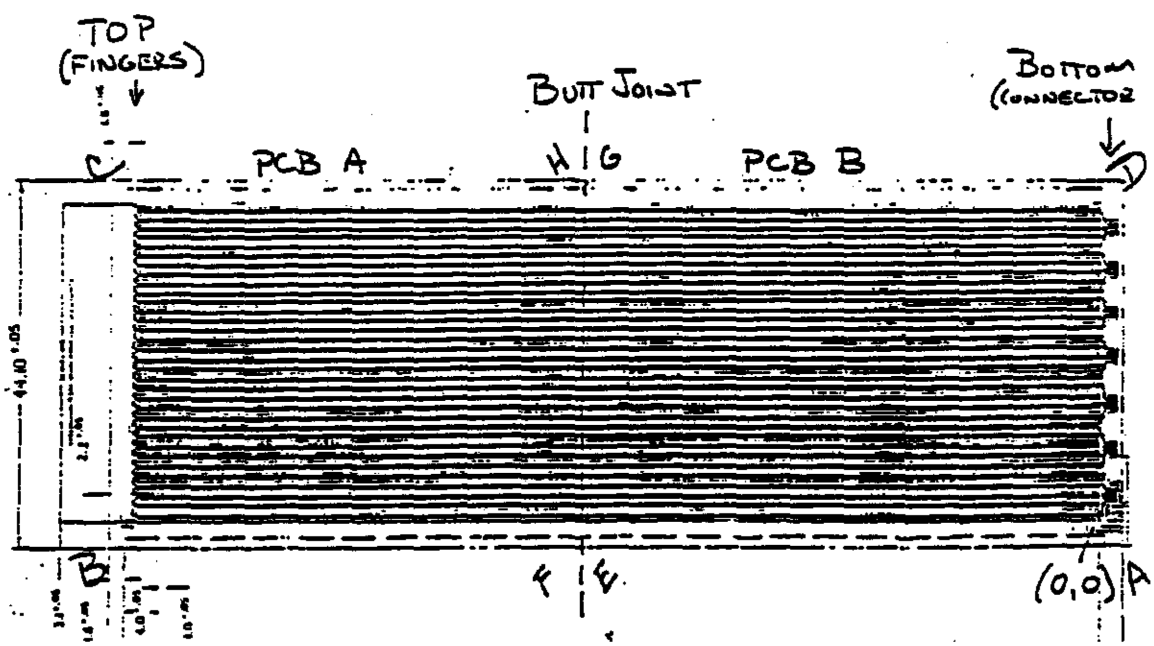
MIT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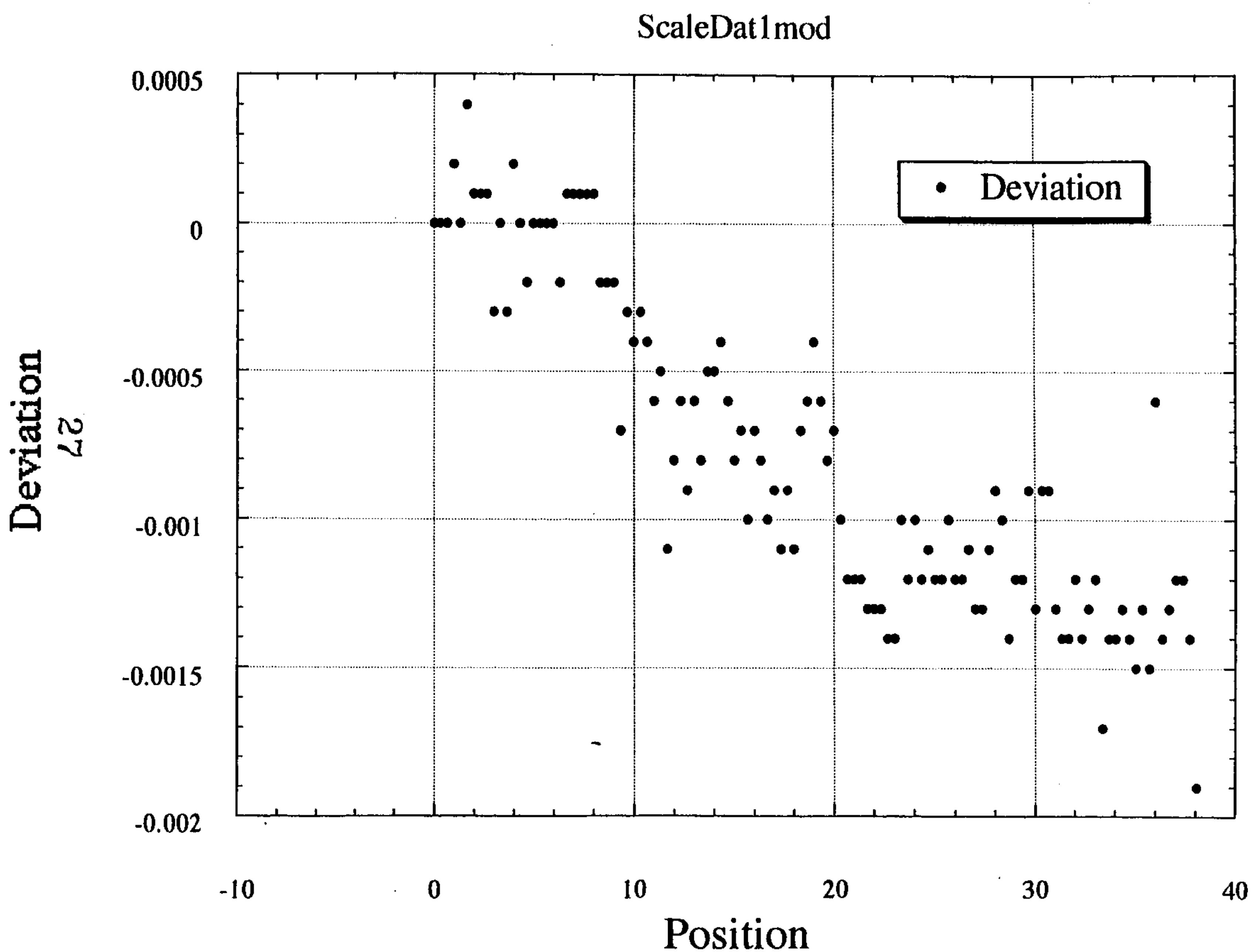
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-0.0005
-0.001
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-10
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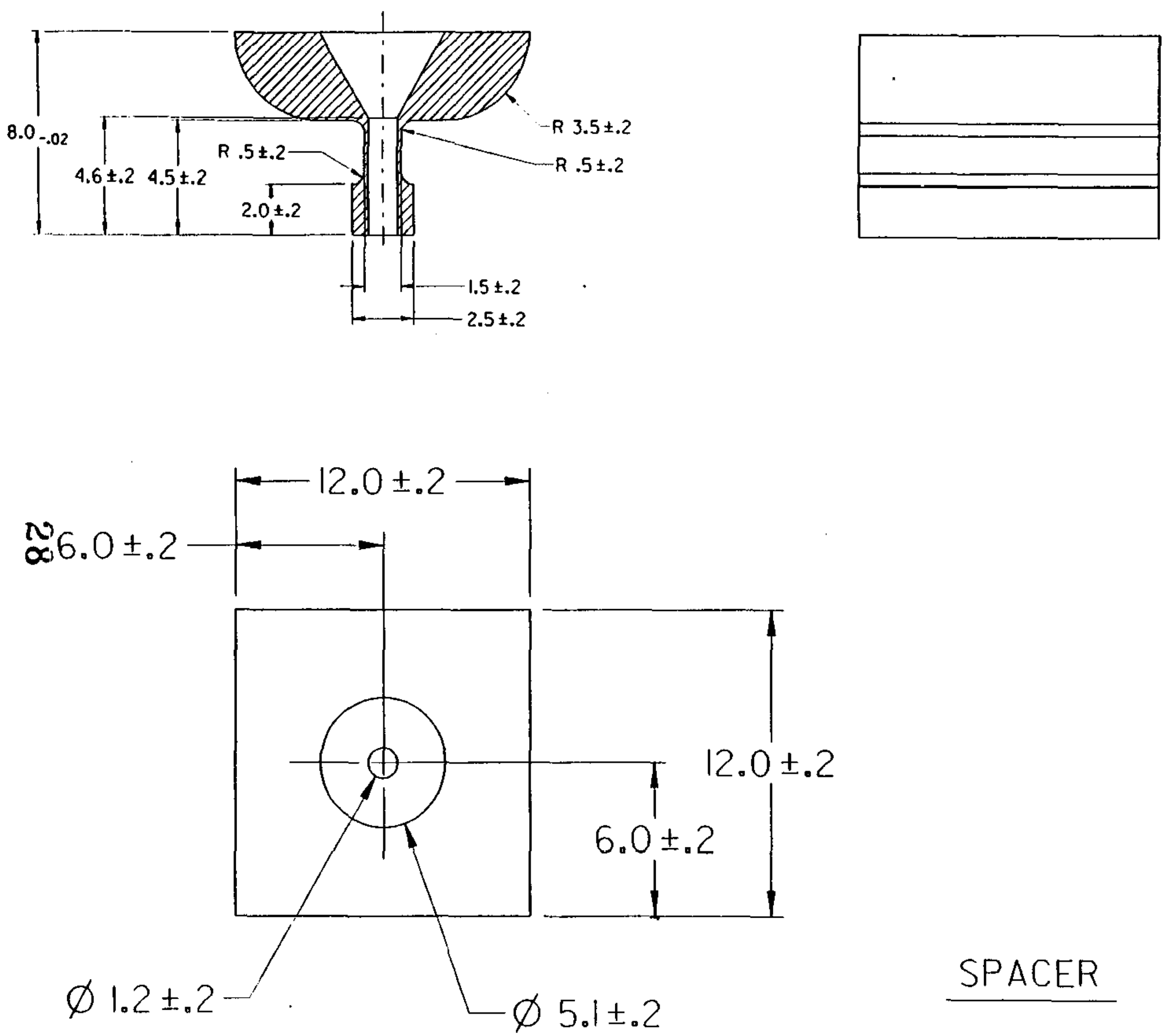
10
20
30
40
Position
Deviation

REC 6/21/93
Amoroso



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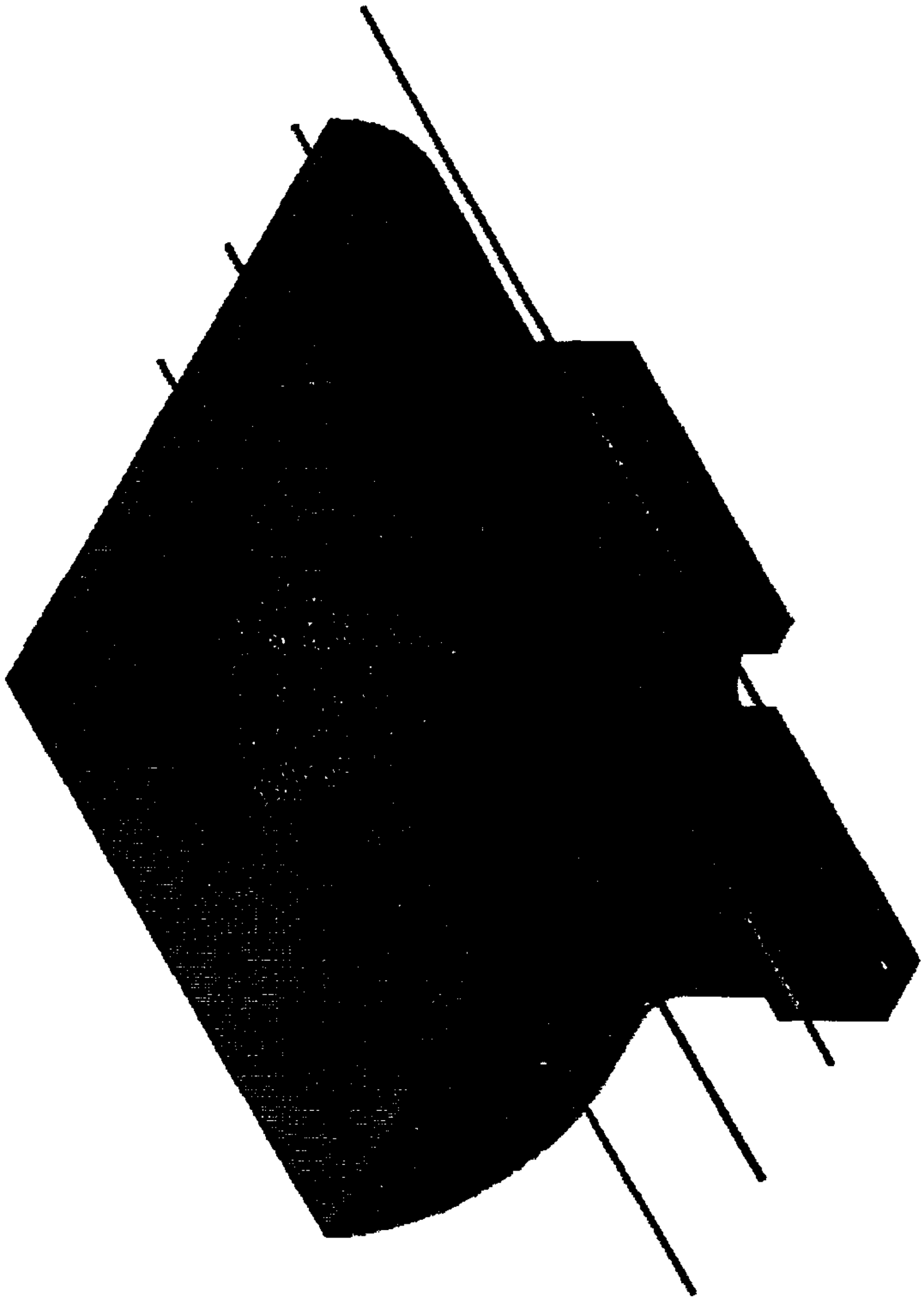
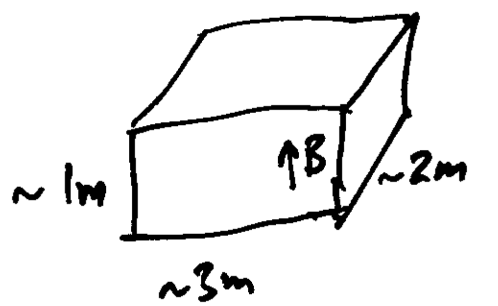


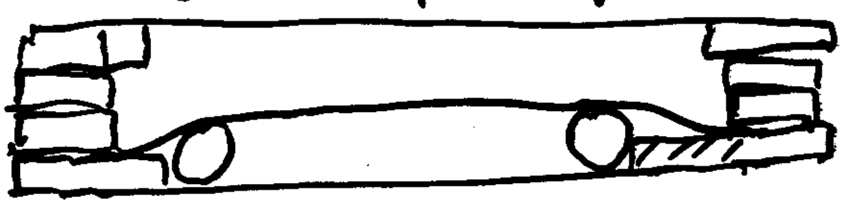
BNL Activities with Ø money

1. Measure Lorentz effect in an Endcap configuration using the BNL MPS magnet and cosmic rays



10 kG
3MW

2. Use small chambers to kludge 3d Superlayer geometry.



3 Repeat x-ray measurements now that we understand electronics better and have 10-bit FADC.

Polymer Concrete (PC)

Works just like concrete with Portland Cement. Properties are analogous to concrete, i.e. good compressive strength, poor tensile strength (unreinforced).

- Many different polymer resins
- Many aggregates

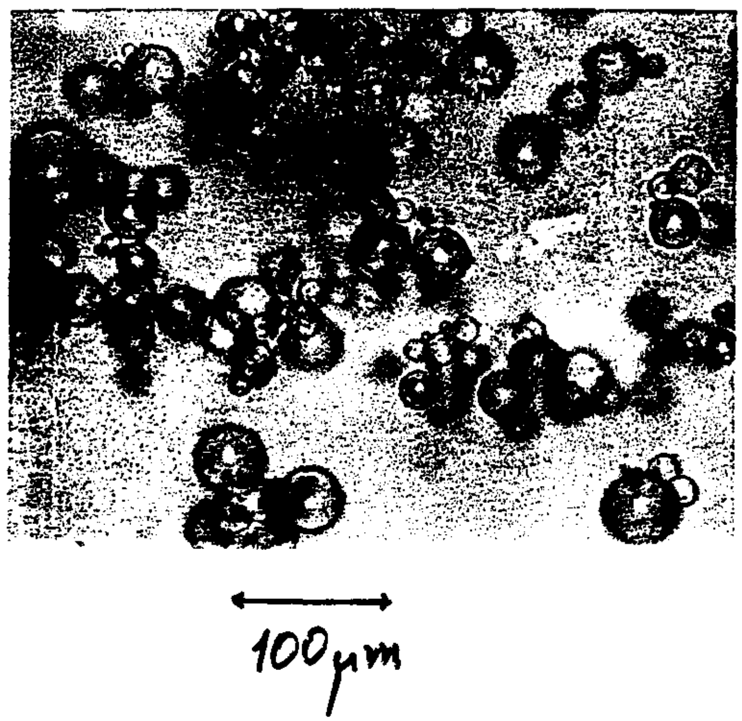
Selection depends on desired properties.

Usage of interest: PC for machine tool bases.
PC for machine tool bases used instead of cast iron.

- High stiffness to weight ratio
- Dimensional stability
- High vibration damping coefficient
- Low thermal conductivity
- Low production cost
- Minimum machining required after casting

In our case:

- Use hollow glass microspheres as a filler
- Density of 0.4 g/cm^3

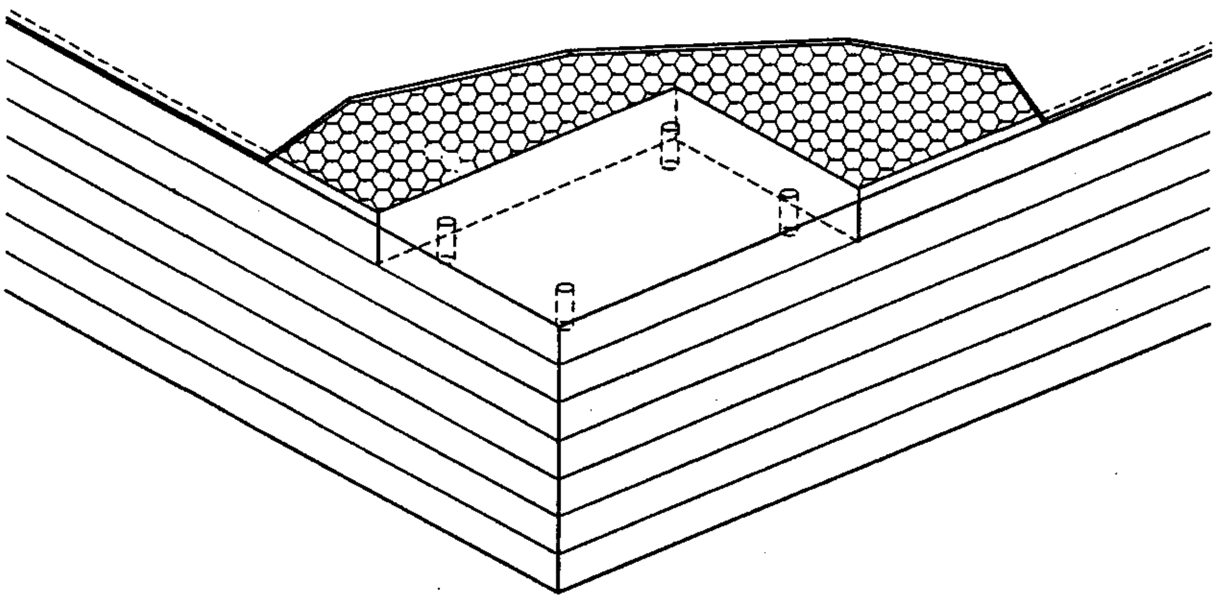

100μm

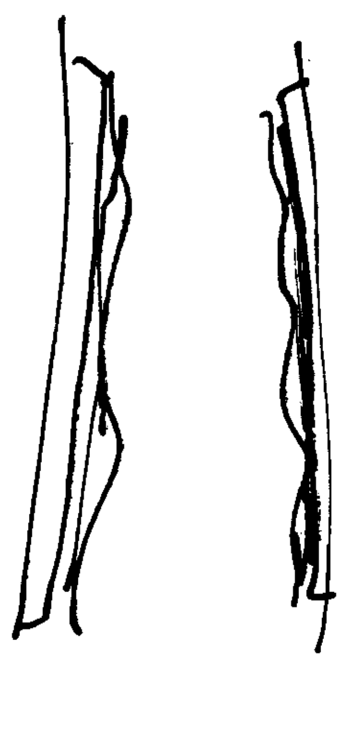
LIGHTWEIGHT PC TARGET FRAME SYSTEMS

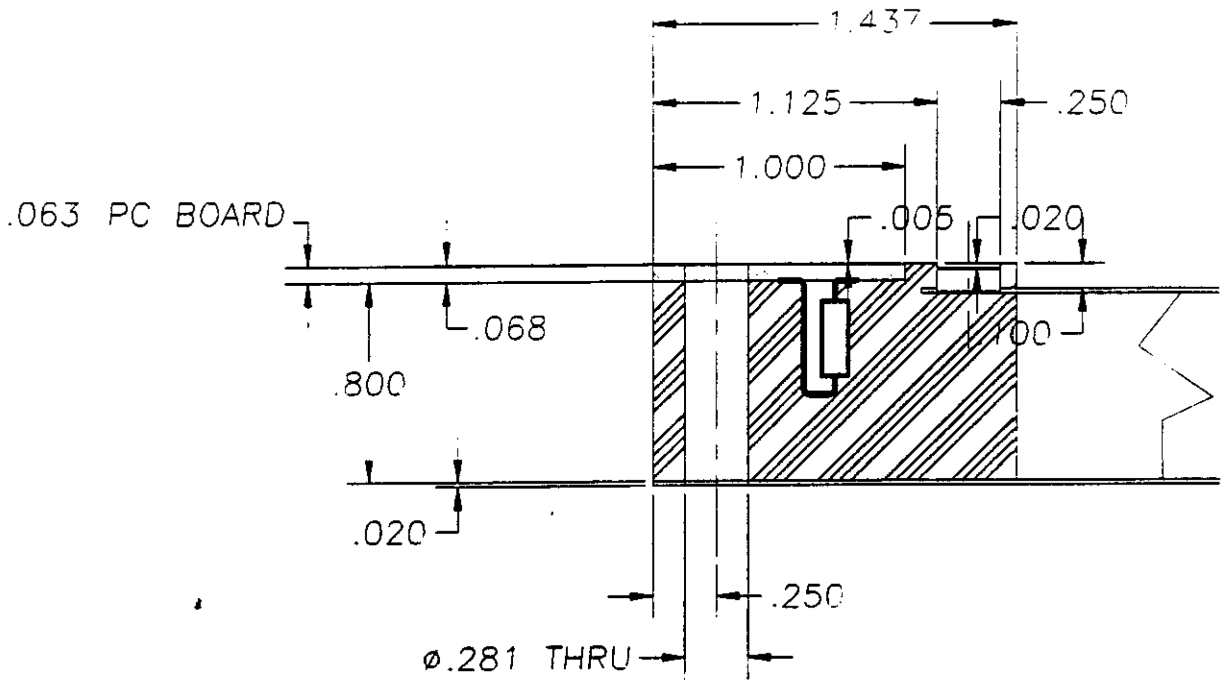
PROPERTY	SYSTEM	
	1	2
System Formulation, wt%:		
Resin	53	64
Hardener	9	10
Black	1	2
Glass spheres	37	24
Flexure Strength, psi	1225	--
Flexual Modulus of Elasticity, psi	139,500	--
Compressive Strength, psi	1755	3925
Young's Modulus, psi	98,395	142,700
Density, lb/cu ft	26.2 (0.42)	34.6 (0.55)

Desired Properties

1. Low Density ($< 0.5 gr/cm^3$)
2. Dimensional Stability
   - Low casting shrinkage ($< 0.05\%$)
   - Low creep
   - TAC 1–3 $10^{-5} in/in/C^\circ$
3. No outgassing
4. Resistant to water vapor absorption
5. Good adhesion to G10, Al, Cu
6. Low viscosity (possible to cast features ≈2.0mm)
7. Modulus of elasticity (¿5,000,000 psi)
8. Dielectric constant (<4)
9. Dielectric strngth
10. Vibration damping factor (¿0.003)



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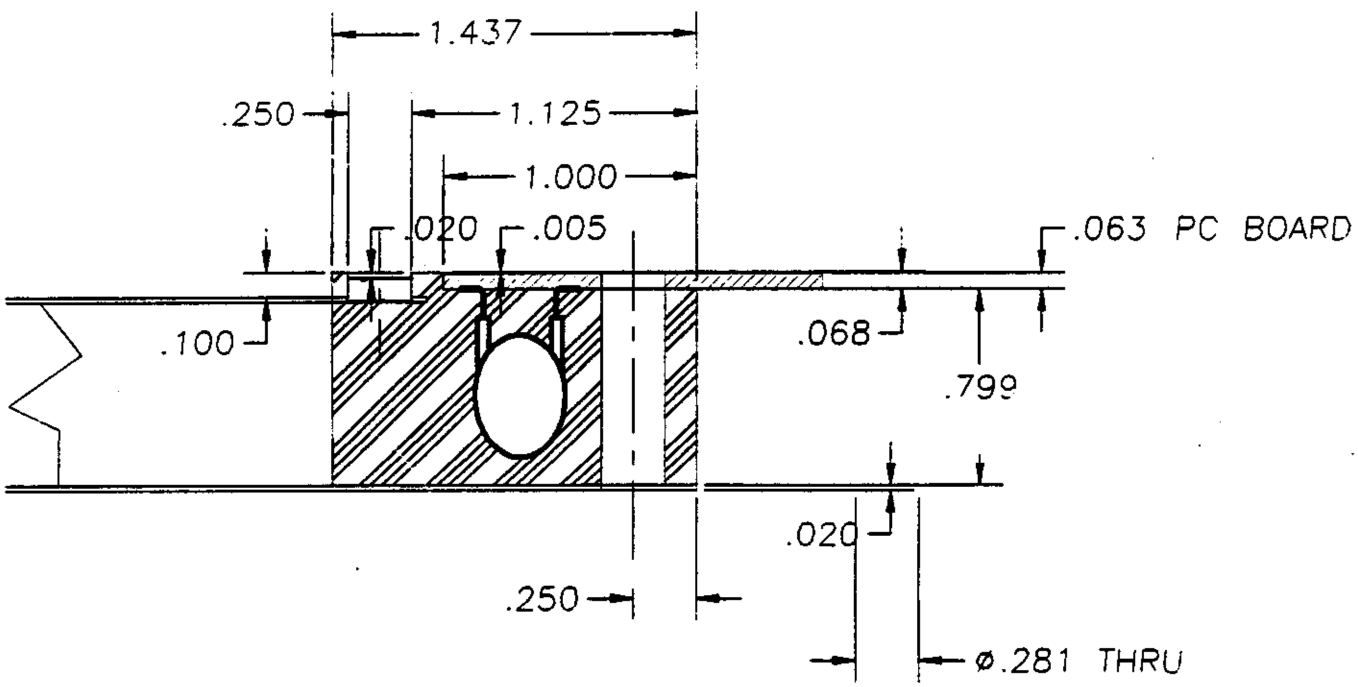
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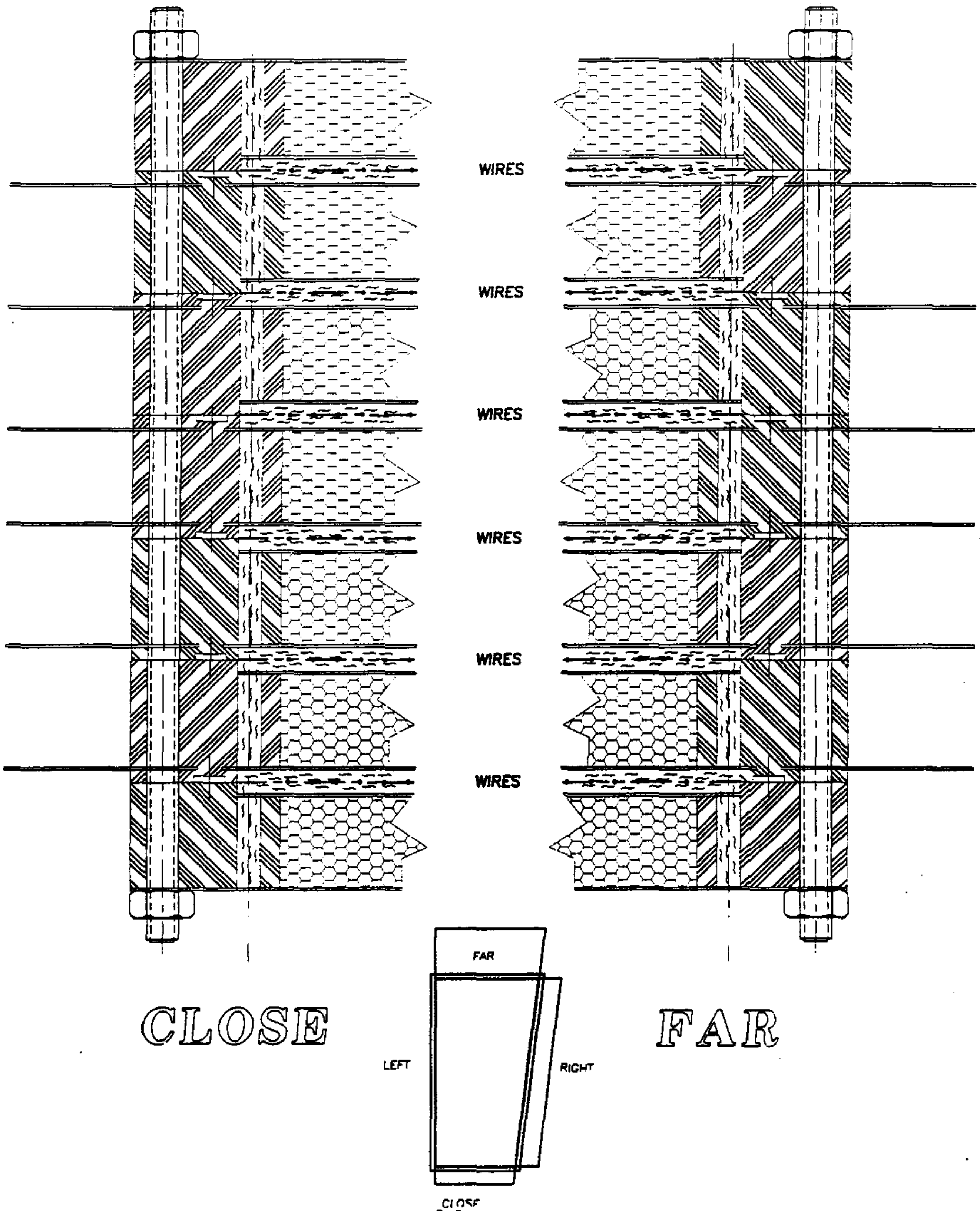
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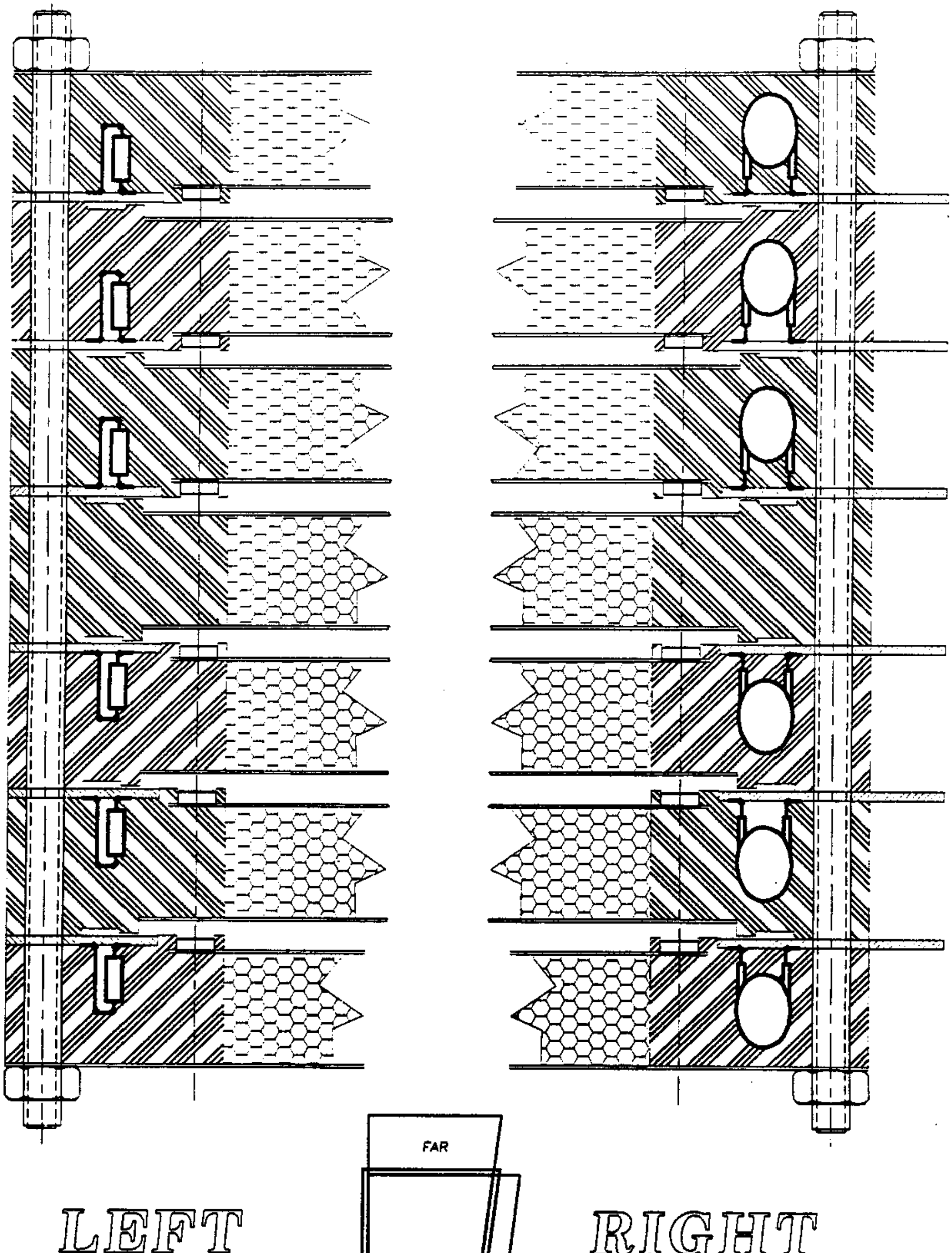
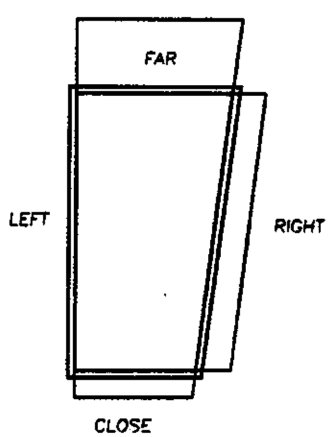
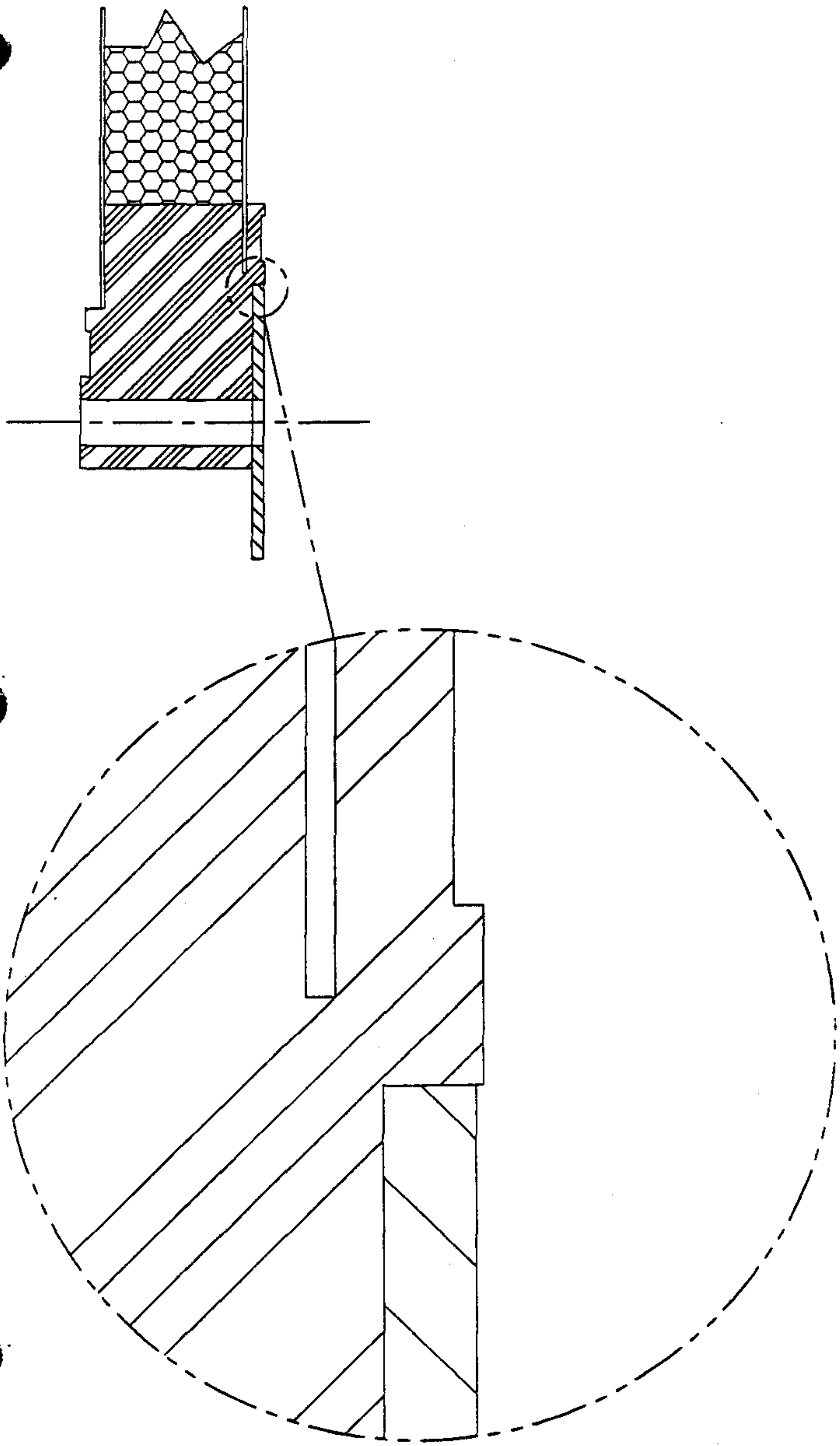

LEFT
RIGHT

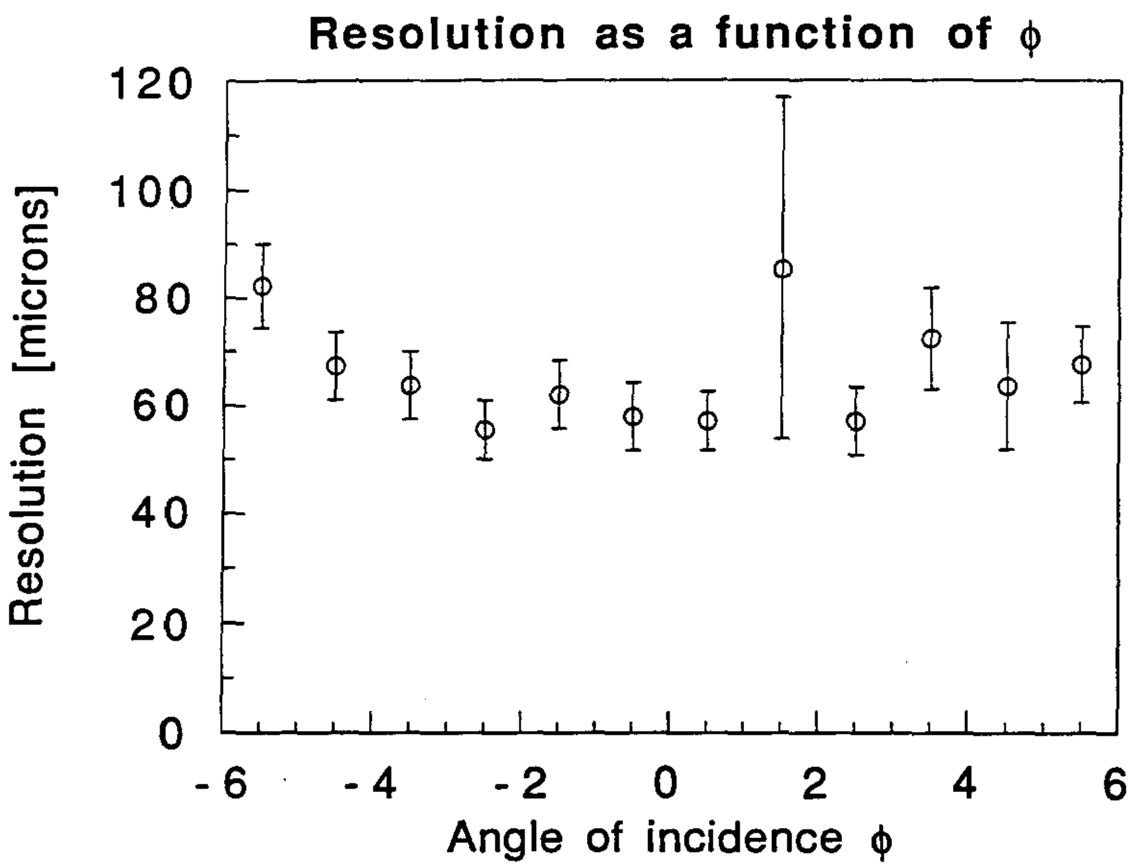

FAR
LEFT
RIGHT
CLOSE



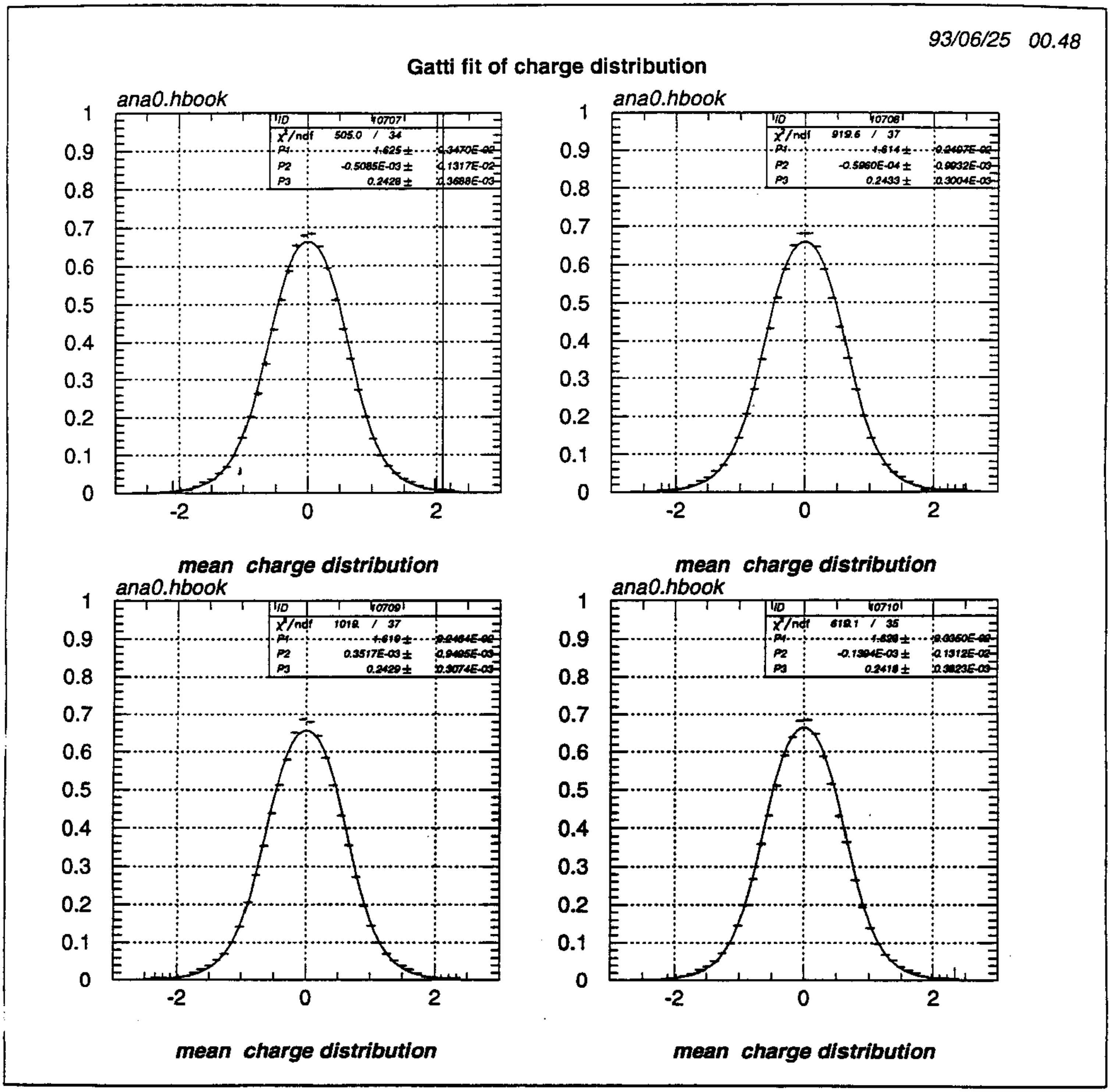
	SL1	SL2	SL3
Module Length L		257	
Module Width W		114	
Skin thickness G10		0.05	
Copper thickness		0.0017	
Frame thickness h		0.4	
Frame Width		6.5	
Panel thickness (epoxy)		2	
Width of epoxy		1.5	
Cross Section of Polymer		9.4072	
G10 boards for wire attachement xsection		0.4064	
Density of G10		1.7	
Density of copper		8.96	
Density of epoxy		1.3	
Density of Nomex Honeycomb		0.029	
Density of Polymer		0.4	

		Total weight	
		Current Design	Polymer Frames
Weight of Frame		29517	
Weight of Epoxy Border		20257	
Weight of Skins (G10)		34865	34865
Weight of Skins (Copper)		6248	6248
Weight of Honeycomb		11895	11895
Weight of G10 wire attachment boards			2131
Weight of Polymer Frame			19544
	Total	102781	~~53607~~ 74683
Frame weight reduced by	~~2.55~~ 0.43		
Total weight reduced by	~~1.94~~ 0.73		

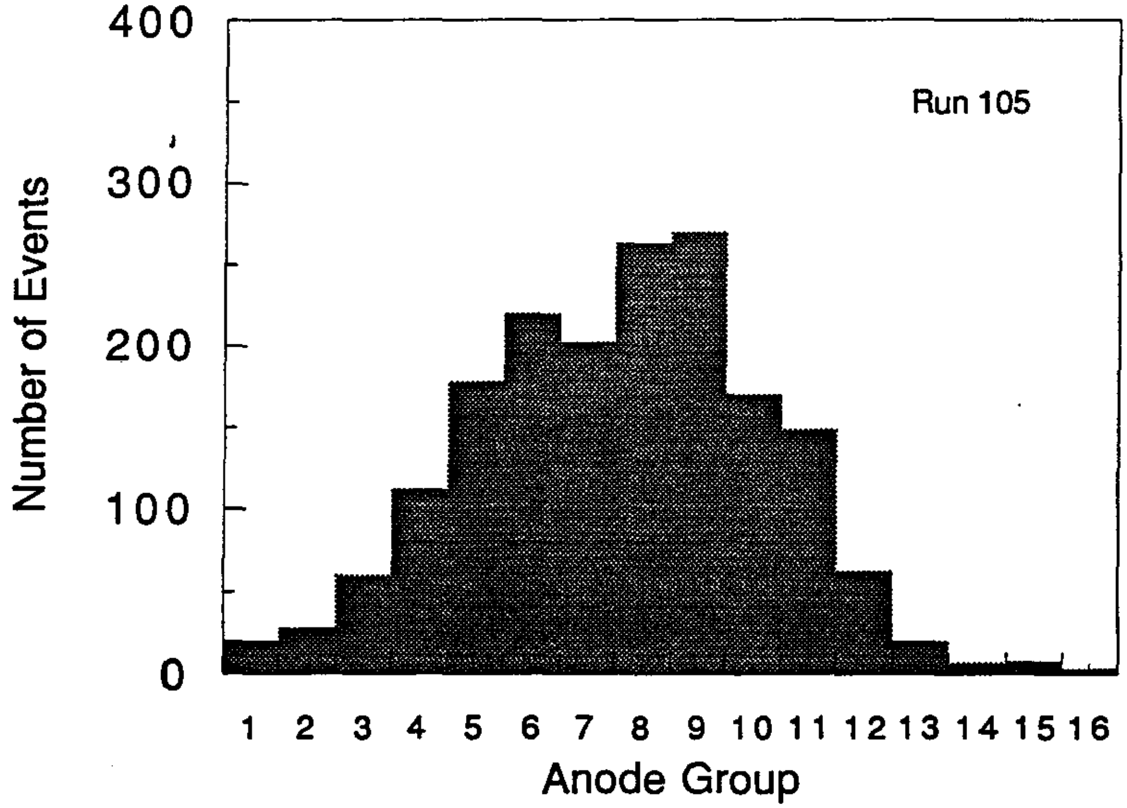
Note: The weight of the the frame assumes that 25% of the volume is machined out



Resolution as a function of φ
120
100
80
60
40
20
0
Resolution [microns]
-6
-4
-2
0
2
4
6
Angle of incidence φ



93/06/25 00.48
Gatti fit of charge distribution
ana0.hbook
ID 10707
χ²/ndf 505.0 / 34
P2 -0.5085E-03 ±
P3 0.2428 ±
ana0.hbook
ID 10708
χ²/ndf 919.6 / 37
P2 -0.5960E-04 ±
P3 0.2433 ± 0.3004E-03
mean charge distribution
ana0.hbook
ID 10709
χ²/ndf 1019. / 37
P2 0.3517E-03 ±
P3 0.2429 ±
mean charge distribution
ana0.hbook
ID 10710
χ²/ndf 619.1 / 35
P3 0.2418 ±
mean charge distribution
mean charge distribution


400
300
200
100
0
Number of Events
Run 105
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Anode Group

What is the next step(s)

1. Continue experimenting with different polymer to filler mixing ratios to achieve stiffest possible PC while maintaining the low density.
2. Produce a $2 \times 4 ft^2$ panel to study potential problems in the casting process and study the mechanical properties of the panel.
3. If [2] successful then proceed to make panels to be used for the construction of a prototype module with real dimensions (e.g. inner endcap)

LLNL Engineering Activities to the End of FY93

Optimize Chamber/Support Structure Interface

- Kinematic mounts
- Quarter point chamber supports vs. end supports
- Endcap chamber support (radial merging or alternatives)
- Resolve alignment requirements w.r.t. minimized actuator deployment

Alignment Test Stand

- Obtain "go ahead" to proceed with project and finalize schedule
  - Basic preparations for facility are complete at LLNL
  - Identify interface requirements and plans for eventual move to SSCL

- Preliminary Design Review to be scheduled in July
  - Design and drafting are proceeding
  - Procurement and fabrication need approval from GEM management

"Wire Positioning Machine" Proposal to be circulated in July

LLNL Engineering Activities (cont.)

Participation in Muon Chamber Workshop

- Verify intra-chamber alignment scheme
  - Fiducial transfer "steps" from cathode strips to chamber assembly
  - Fiducial transfer from chamber assembly to projective alignment components
  - Develop statistics for accuracies obtained during each transfer
  - Investigate alternate transfer techniques as warranted
- Prepare "CSC Structural Design Bible" draft for circulation (early July)
- Resolve chamber over-pressure design issues (specification)
- Provide general engineering and analysis support during workshop
- Fabricate models of concepts as necessary
- Develop "CSC Process Bible" during workshop
  - Refine process steps, assembly techniques, testing, and QA/QC requirements
  - Follow-up with "CSC Prototype Factory Proposal"

CSC Structural Design Bible

OBJECTIVE: A design guide for optimizing the CSC structure

- Summary of the "major players" in the CSC structural assembly and relative importance of each component in the overall structural design (stiffness and other mechanical properties)
- Detailed analysis and parameter studies are included in appendices
- Trade-offs of geometry and material selection vs. effect on chamber sag
- "Rule of thumb" equations describing relations between chamber sag, stress, etc. vs. various geometry, environment, or material property parameters (where possible)

CSC Structural Design Bible (cont.)

Contents

- CSC Structural Components and Effects on Chamber Mechanical Properties

  a) Honeycomb panel (geometry and materials)
  - Skin (G-10 composite with Cu cathode strips)
  - Core
  - Edge fillers/inserts
  - Adhesives and assembly/bonding techniques
  - Composite assembly

  b) Gap frame (geometry and materials)

  c) Chamber Assembly
  - "Shear link" between panels
  - Bolted or glued interfaces between panels
  - Chamber support attachment points

  d) General considerations
  - Designing with composites
  - Designing for creep
  - Stability of materials
  - "Shear" lag

CSC Structural Design Bible (cont.)

- Manufacturing and other practical considerations

  a) Cathode strip panel faces (G-10 "skins")

  b) ...

- Baseline Design description
  - List of the assumptions used in the analyses (geometry and material properties)
  - To be updated with the new baseline design at the end of the workshop

- Appendices
  - Detailed analyses
  - Parameter studies

Additional analyses are being prepared

- Optimum bolt pattern and sizing around perimeter of chamber
- Alternate methods of stiffening chamber (external)
- Chamber support attachment points
- "Shear lag" effects on modeling assumptions

Prepare "Mechanical Properties Test Plan" to verify analyses

An Integrated 3D Muon System Model is Needed

A self-consistent, 3D CAD model of the Muon Subsystem must be used as the basis for configuration control and physics performance optimization.

- Includes support structure, chambers, chamber interface, alignment system components and lines-of-site, and eventually utilities and services.
- Manufacturing drawings and other 2D representations are "extracted" from the 3D model and linked to the model database. This allows automatic updating of 2D drawings when the model changes.
- Used as an aid to laying out utilities and services and can reduce the use of expensive mockups.
- Analysis models are dependent on data from the 3D CAD model.
- Multiple, "un-linked" software packages result in multiple versions of the same design - *poor configuration control leads to confusion!*
    - Built in inertia against design changes (even if driven by physics)
    - Less efficient; slow turn around for a design evaluation means fewer complete evaluations and uncertainty if design is optimum
    - Slow evaluation of "radical" ideas (brainstorming discouraged)
    - Fiscal pressures encourage premature defense of a design

Integrated 3D Muon System Model (cont.)

Integrated modeling of the Muon Subsystem must be used as the basis for physics performance optimization.

- GEANT geometry should include support structure, chambers, chamber interface, alignment system components and lines-of-site, and eventually utilities and services.

  – “extracted” from the 3D model and linked to the GEANT model.

57

- In its recent review of the GEM TDR, the Program Advisory Committee emphasized the importance of establishing strong links between hardware design and physics performance studies.

- Close linkage can be achieved through the interaction of the Muon Group physics team, in close communication with the broader physics group, with the muon design and engineering effort.

- Close coupling between hardware engineering and physics modeling provides rapid feedback on the physics impact of design modifications and is essential to producing an optimized detector design.

Status Report on Muon System Activities at Boston University

Scott Whitaker

SSCL
29 June 1993

I. Electronics

- Anode readout electronics for next prototypes
- HV monitoring / current measuring

II. Temperature and humidity effects on FR4/hexcell laminations

III. Angled-wire test chamber with variable wire/strip angle

- Being designed

IV. RD5 activities

- Results from last summer's tests
- Plans for September run

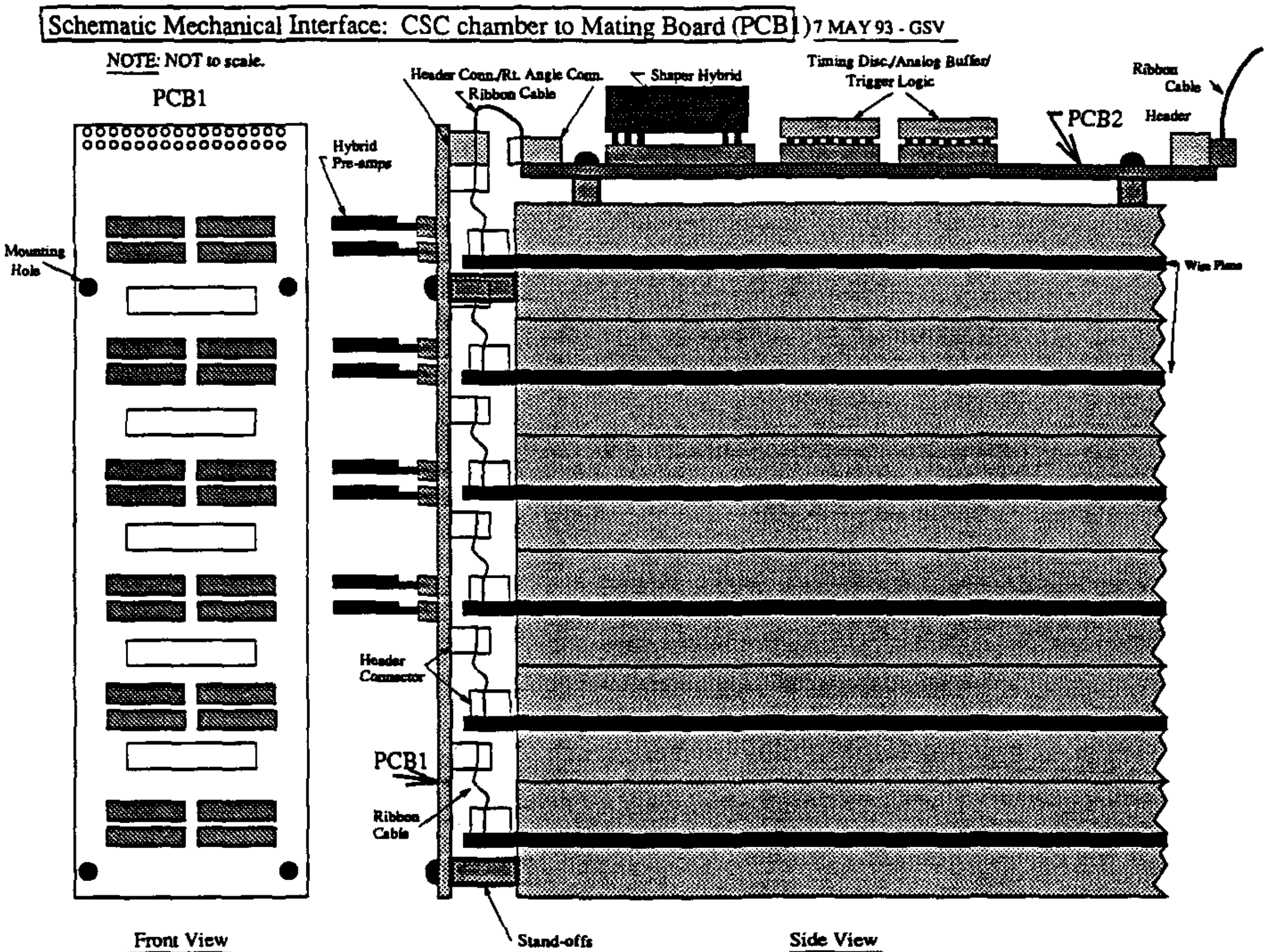


Figure 2: Mechanical Interface Diagram. Side view shows explicitly the flexible interconnection of the ribbon cable between CSC anode tongues and the pre-amp/interface board (PCB1). For specific dimensions of PCB1 and PCB2, see figures 4 and 5.

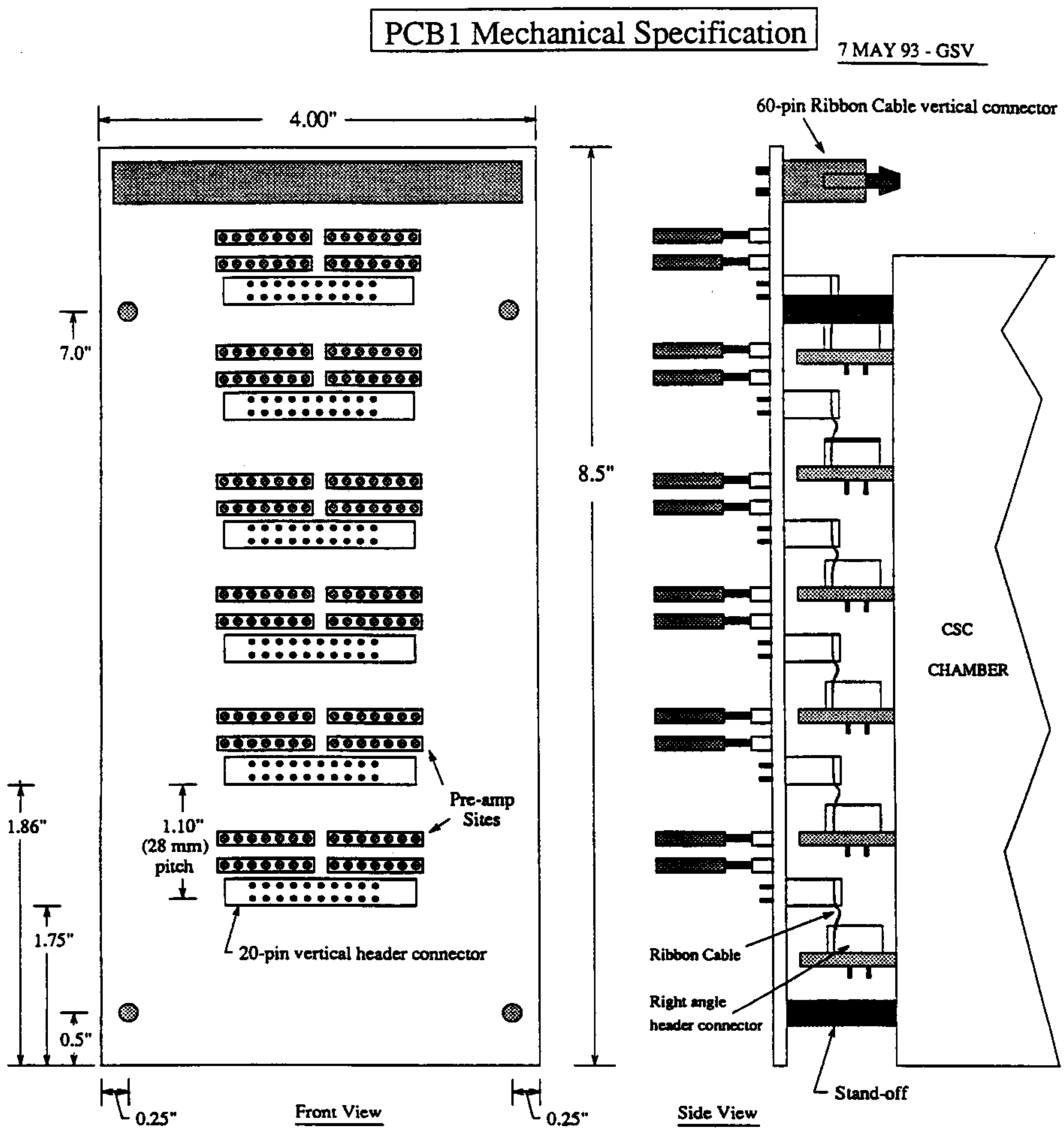


Figure 4: Mechanical dimensions and preliminary component placement for PCB1. Note that filter and bypass capacitors are supressed for clarity,

Anode Electronics Delivery Schedule

as of 1 June 93

Item	Allocated Time	Completion Date
PCB1 Design Review	1 day	1 JUN
PCB1 Layout	1.5 weeks	16 JUN
PCB2 Design Finalization	2 weeks	21 JUN
PCB2 Prototype Layout	2 weeks	2 JUL
PCB1 and PCB2 Delivery	4/1 weeks	12 JUL
PCB1 and PCB2 Testing	1 week	19 JUL
Update schematics/layout	1 week	26 JUL
Receive Production Boards	2 weeks	9 AUG
Prod. Proto. and Test	1 week	16 AUG
Prod. Assembly and Test *	3 weeks	3 SEP

* This assumes in-house assembly. Faster (1 or 2 weeks) with outside assembly.

NOTE: This schedule assumes 3 weeks dedicated technician/engr layout time. Individual items represent "good" guesses at their completion time, the cumulative date represents the cumulative error in the estimates.

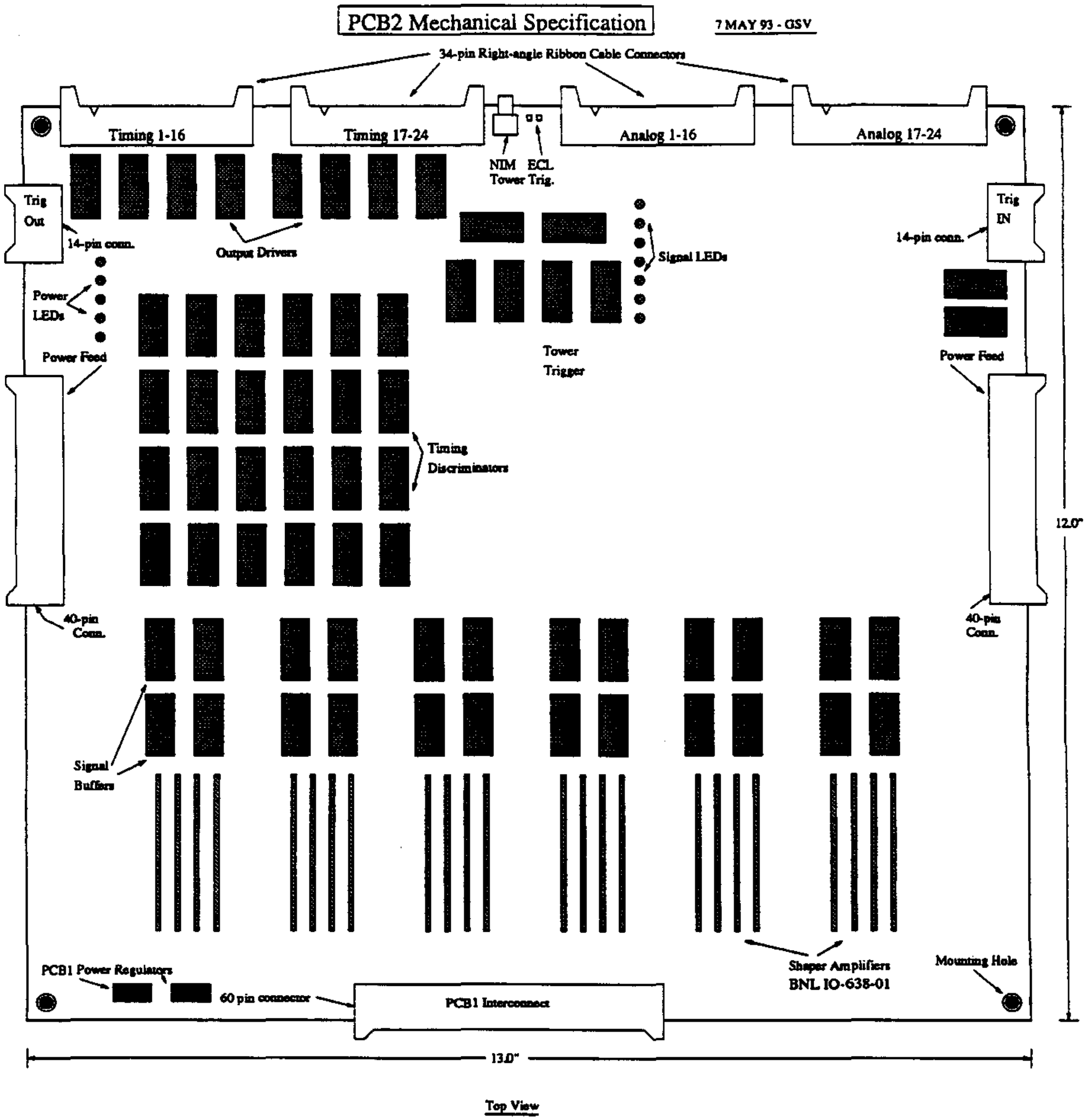
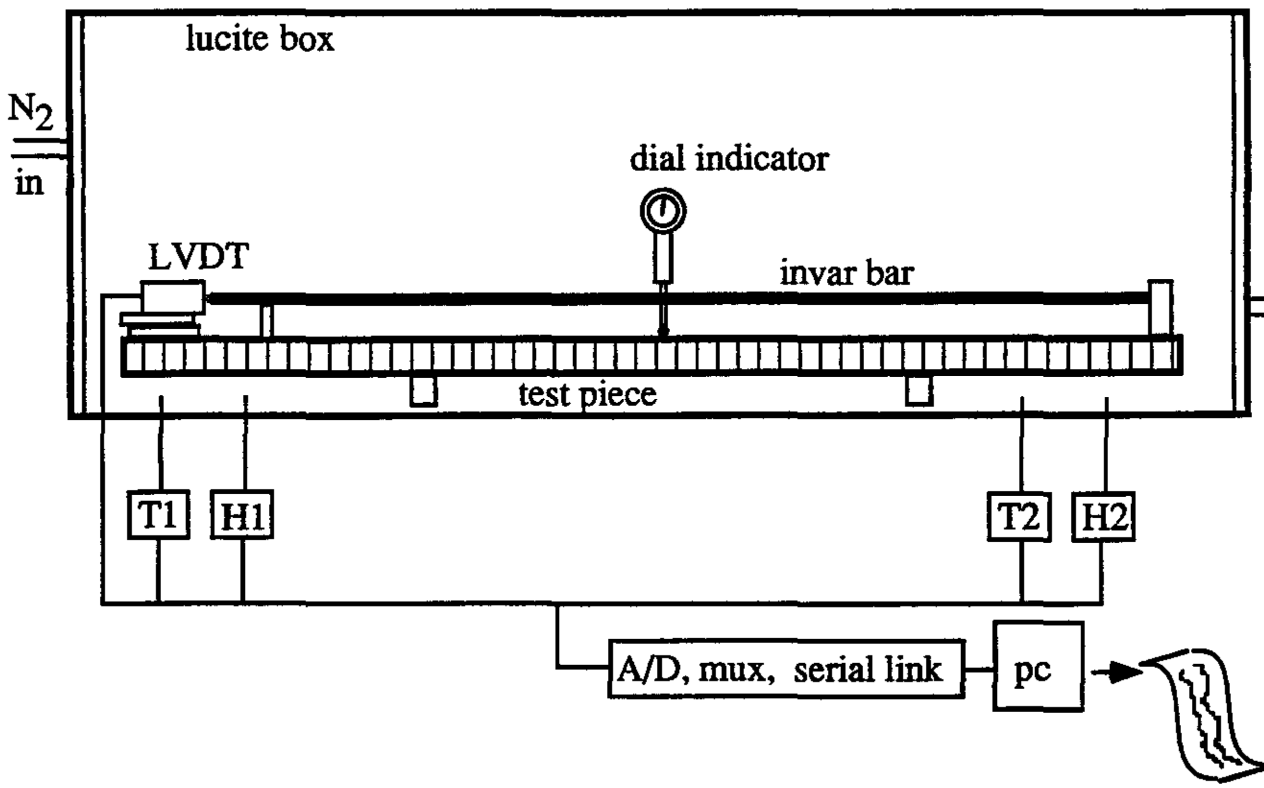


Figure 5: Mechanical dimensions and preliminary component placement for PCB2. Note that bypass caps, filter caps, resistors, and heatsinks are supressed for clarity.

Environmental Test Chamber

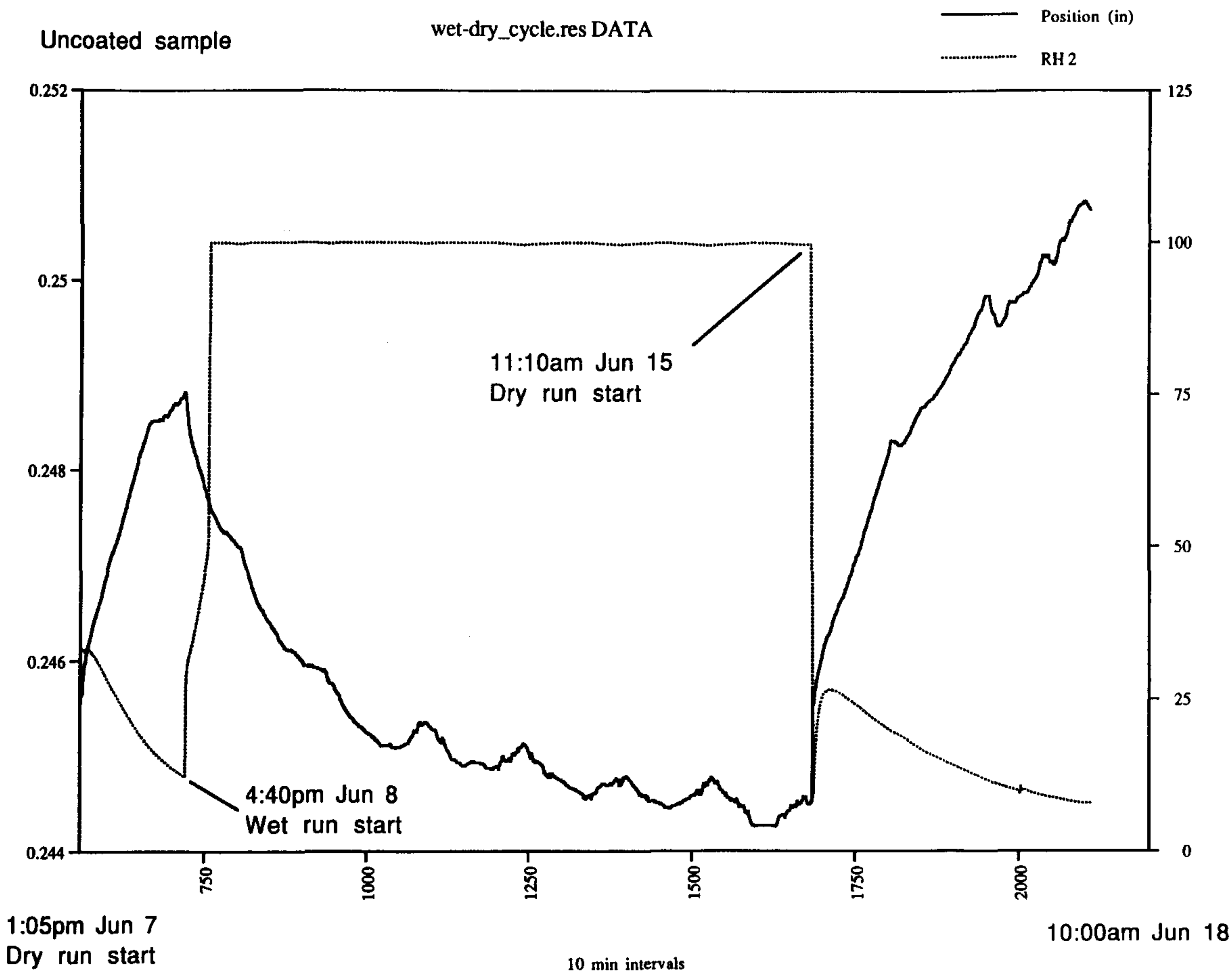


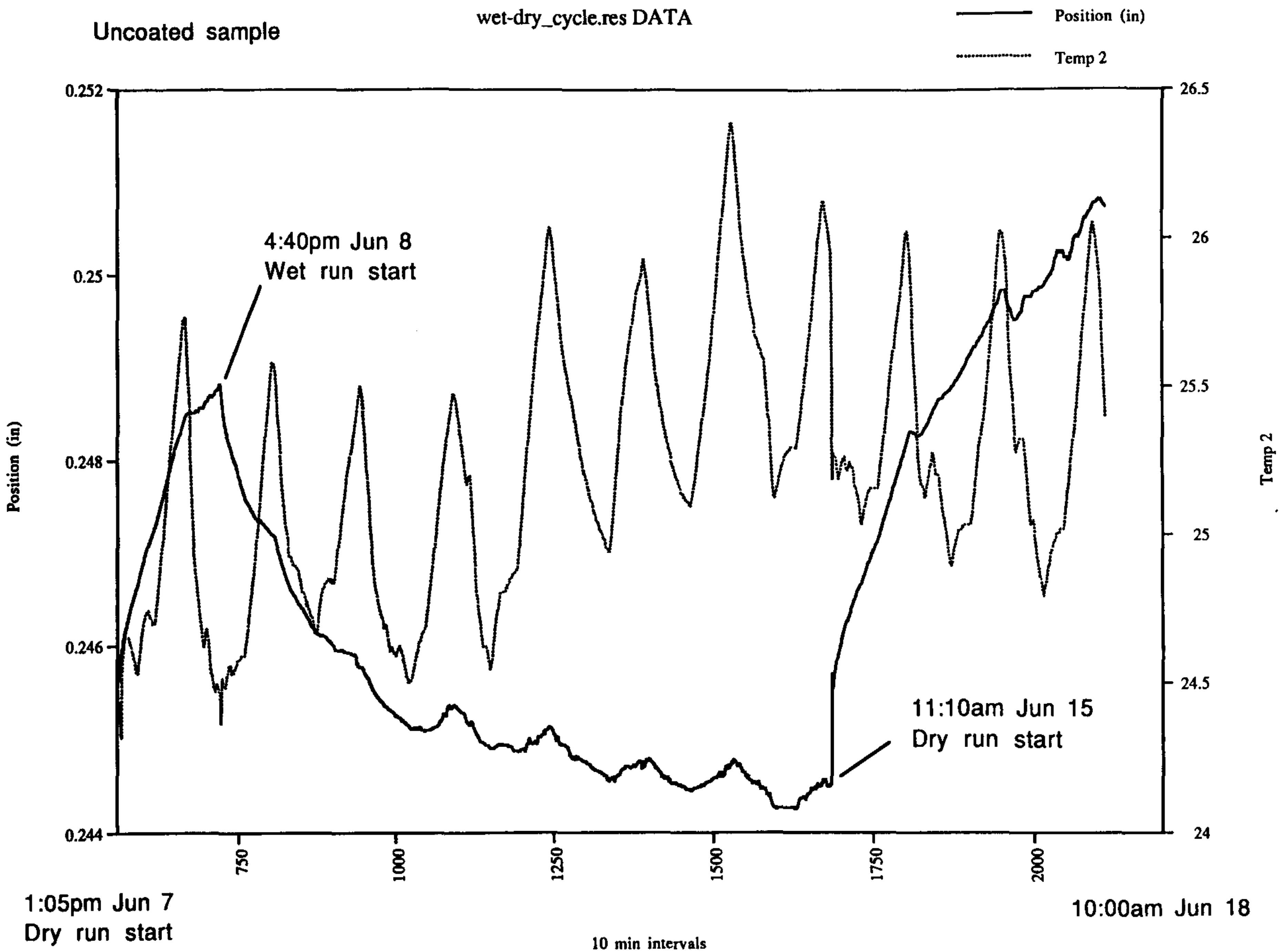
Monitoring length of a mock CSC versus temperature, humidity:

humidity control: dry = purge box with dry N2
wet = seal box with dish of water inside

humidity measurement: Phys-Chem Scientific PRCR-11
temperature measurement: AD590JH
length measurement: Schaevitz Eng. (via CSDL) Model 100HR LVDT,
on a 2D micrometer stage for calibration

test piece: 36" x 7.5" x 1"
2 x 0.031" FR4 solid copper-clad, 0.5 oz/ft^2, both sides of each piece
0.908" hexcell CIBA Geigy HMX20, 1/4" cell, 4 lb/ft^3
glued with Ecobond epoxy


Uncoated sample
wet-dry_cycle.res DATA
Position (in)
RH 2
0.252
0.25
0.248
0.246
0.244
125
100
75
50
25
0
750
1000
1250
1500
1750
2000
11:10am Jun 15
Dry run start
4:40pm Jun 8
Wet run start
1:05pm Jun 7
Dry run start
10:00am Jun 18
10 min intervals



Uncoated sample
wet-dry_cycle.res DATA
Position (in)
Temp 2
4:40pm Jun 8
Wet run start
11:10am Jun 15
Dry run start
1:05pm Jun 7
Dry run start
10:00am Jun 18
10 min intervals
Position (in)
0.252
0.25
0.248
0.246
0.244
26.5
26
25.5
25
24.5
24
750
1000
1250
1500
1750
2000

RD5 -- Results and Plans

Results from last summer written up in J. Shank et. al, GEM TN-93-402

- gas gain limited to ~$1x10^4$ due to low tension in some (hand-strung) wires
- position resolution 79 µm rms
- measurements with Ruthenium source on 4th layer at beam spot =>
  position resolution independent of rate at least up to ~5 KHz per strip

Plans for upcoming run:

- use small BNL prototype ~ .5m x .5m
- study resolution vs
  - gas mixtures, gas gain
  - rate dependence
  - muon momentum
- possibly measure performance in a barrel-geometry magnetic field
- Installation of detectors starts ~August 15
- data-taking ~August 31--September 14

Tentative Results for properties of laminations

Thermal expansion coefficient $1.6 \times 10^{-5} /°C$ at 11.5% RH

Humidity effects are evident:

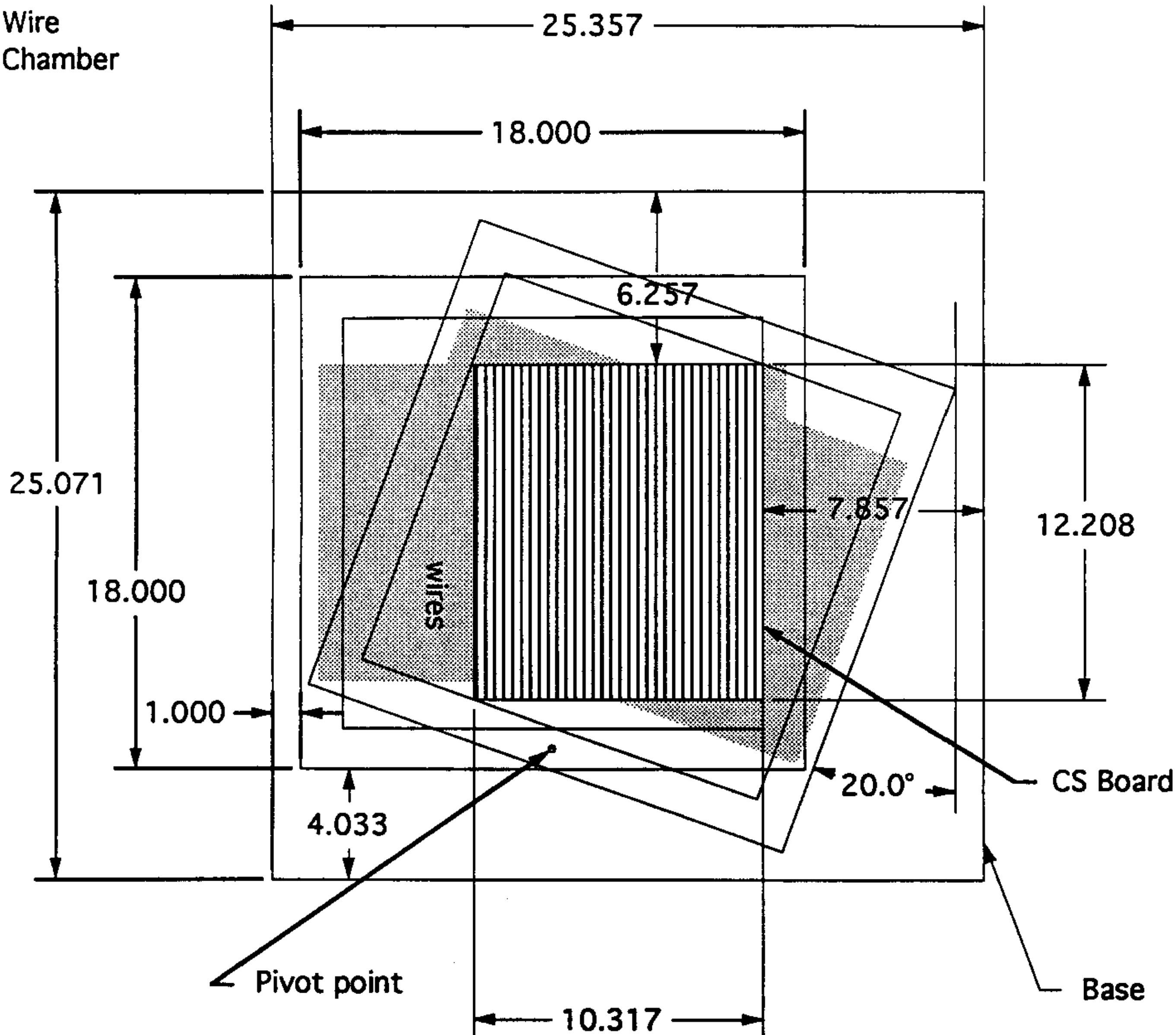
- apparent length decreases with increased humidity!
- response is slow -- several (3--7) days to reach ~ asymptotic reading

But may have several sources:

- still studying contributions from edges
- application of flexible epoxy water sealant to Cu surfaces reduced but did not eliminate humidity response
- need a dummy run to observe response of electronics only
- bowing is eliminated as a significant source of apparent shrinkage

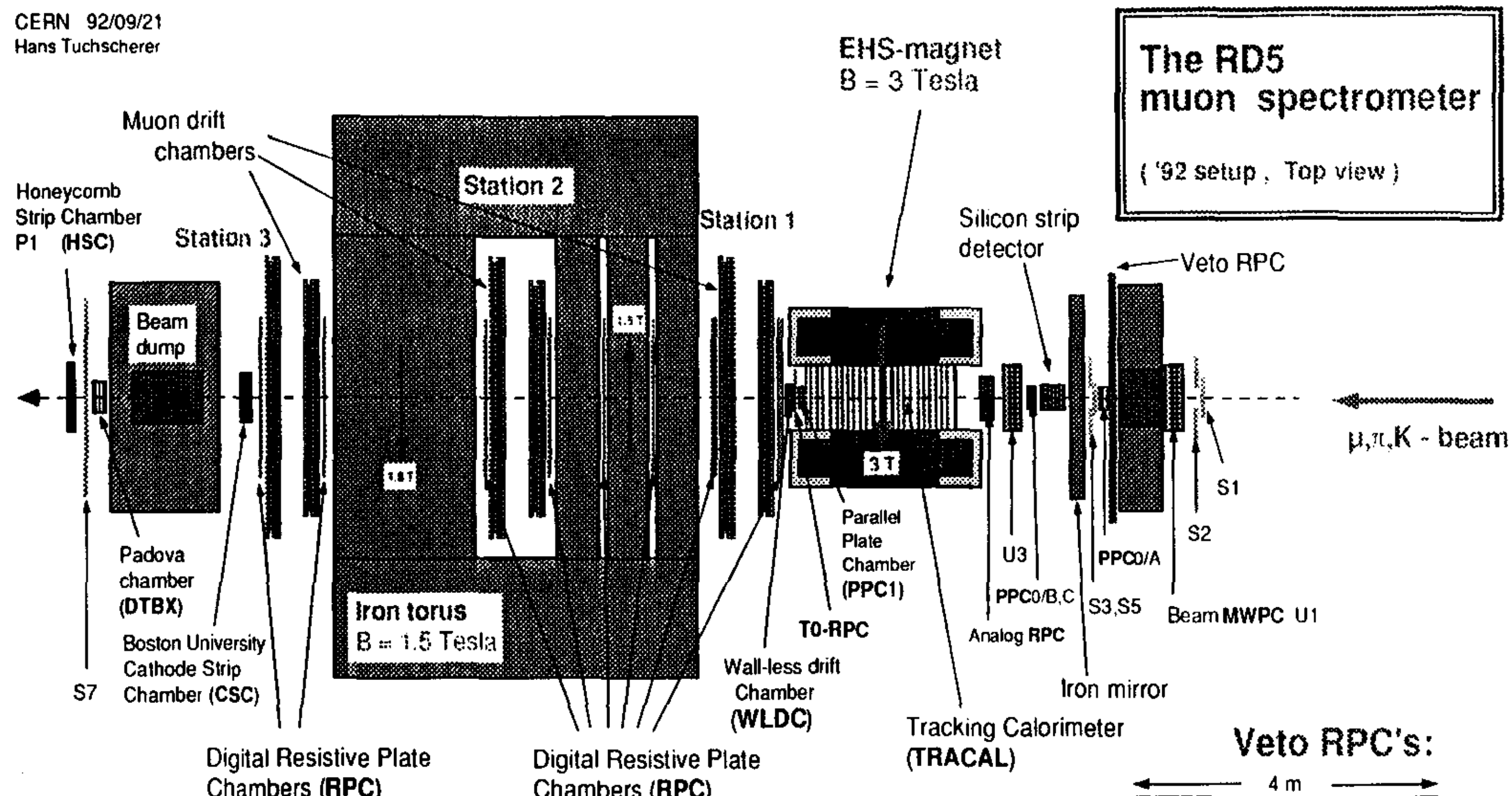
IF the observed decrease in length measurement is due to shrinkage of the lamination: -6.6x10^{-3}" over 33.5" for relative humidity 10% -> 10% then the coefficient for fractional change in length is $\frac{\Delta l}{l} \approx -2 \times 10^{-6} / \%RH$

Moveable
Wire
Chamber



Notes:
- 115 wires per wireframe
- 3/8" thick jig plate for base
- 30 micron wire
- 4 wireframes
- 5 hexcell sandwiches
- 1/2" thick plexiglass enclosure

All units in inches



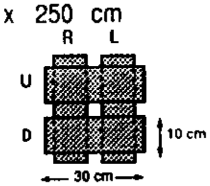
Trigger:

	μ	π		
		min.bias.	>10 λ	>20 λ
S1 x S5	•	•	•	•
VETO	•	•	•	•
PPC0	•	•	•	•
Station 1	•		•	•
Station 2	•			•
TRACAL		•	•	•

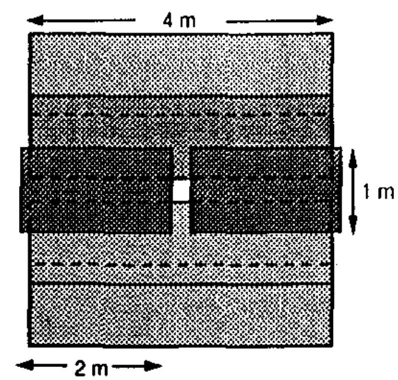
Scintillation counters:

S1: 10 cm x 15 cm
S5: 15 cm x 15 cm
S7: 100 cm x 250 cm

S2, S3 counters:



Veto RPC's:



STATUS OF MUON R&D AT DUBNA

I. GOLUTVIN

29/06/93

CONTENT:

- 0.3m × 3.0m 4 LAYER PROTOTYPE

- 1.1m × 3.0m 6 LAYER PROTOTYPE
  - LAYOUT
  - FACILITY
  - SCHEDULE

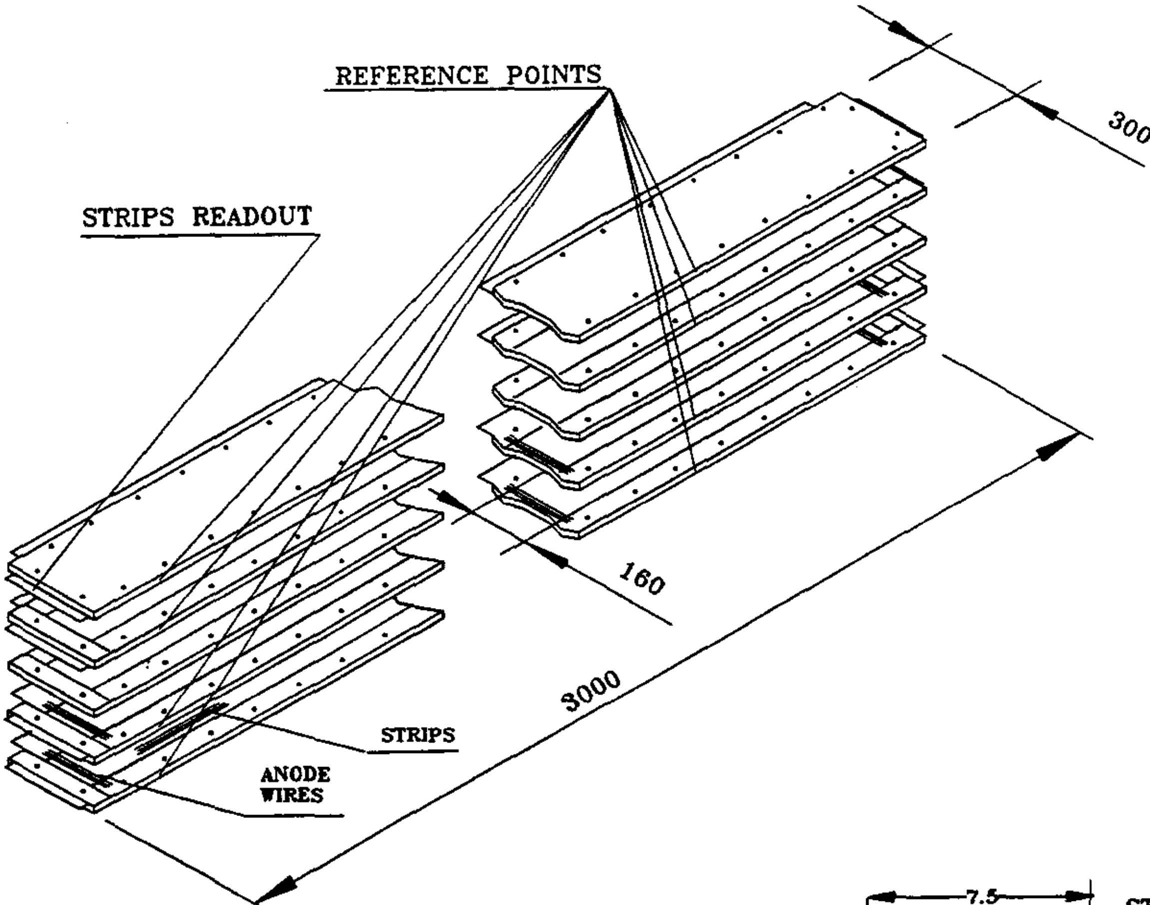
- MASS-PRODUCTION FACILITY DESIGN
  - TOOLS
  - AREA & CLEAN ROOMS

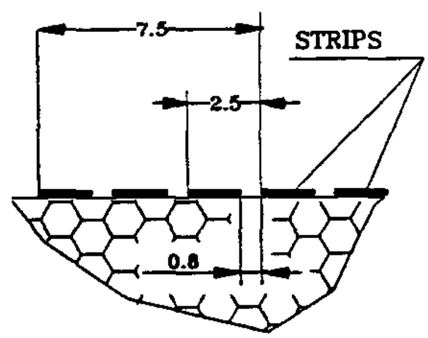
GOAL

⇓

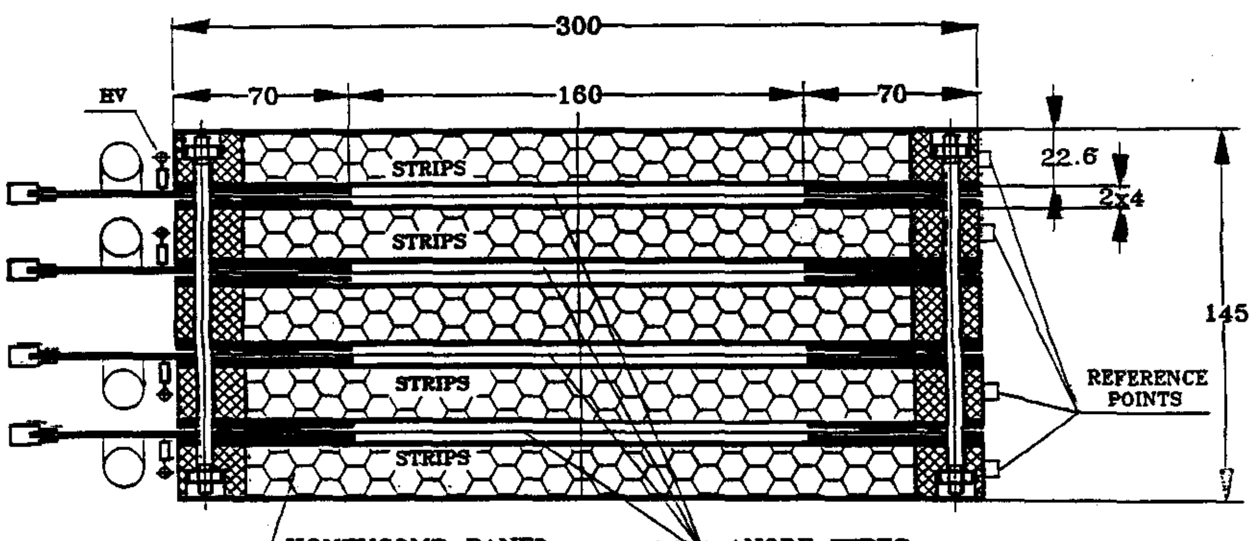
TO DESIGN THE TECHNOLOGY

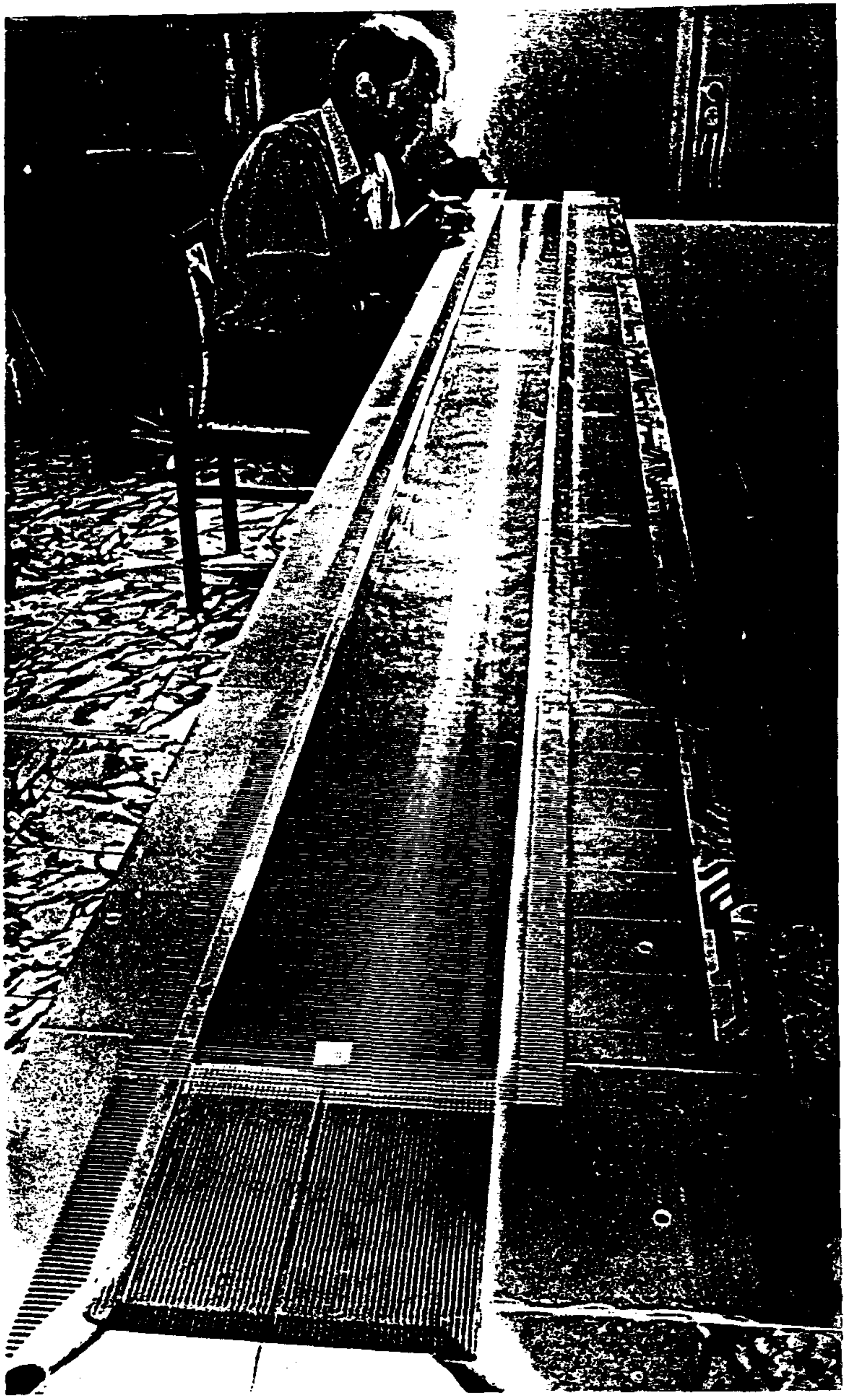
CSC 3m x 0.3m

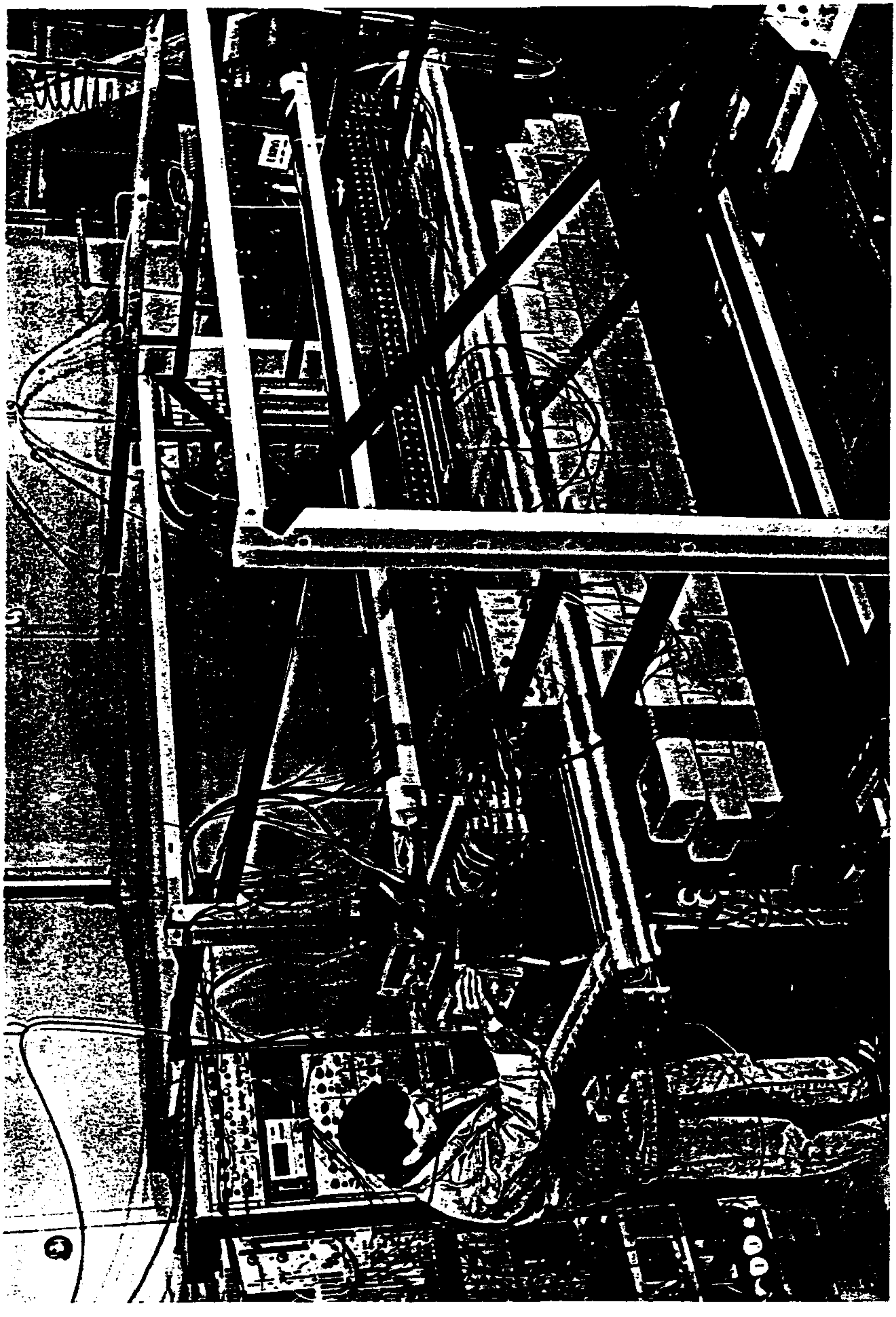


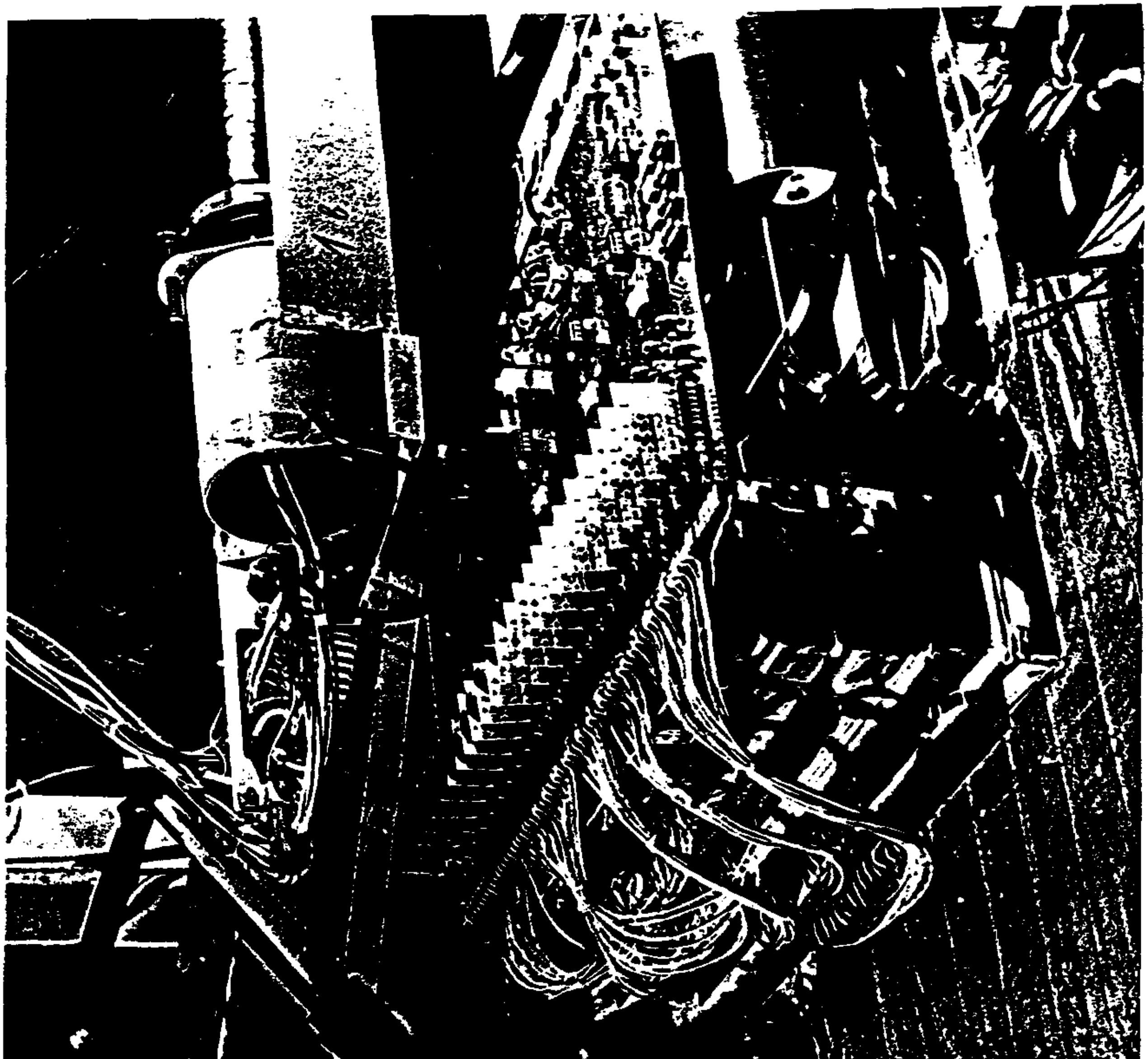


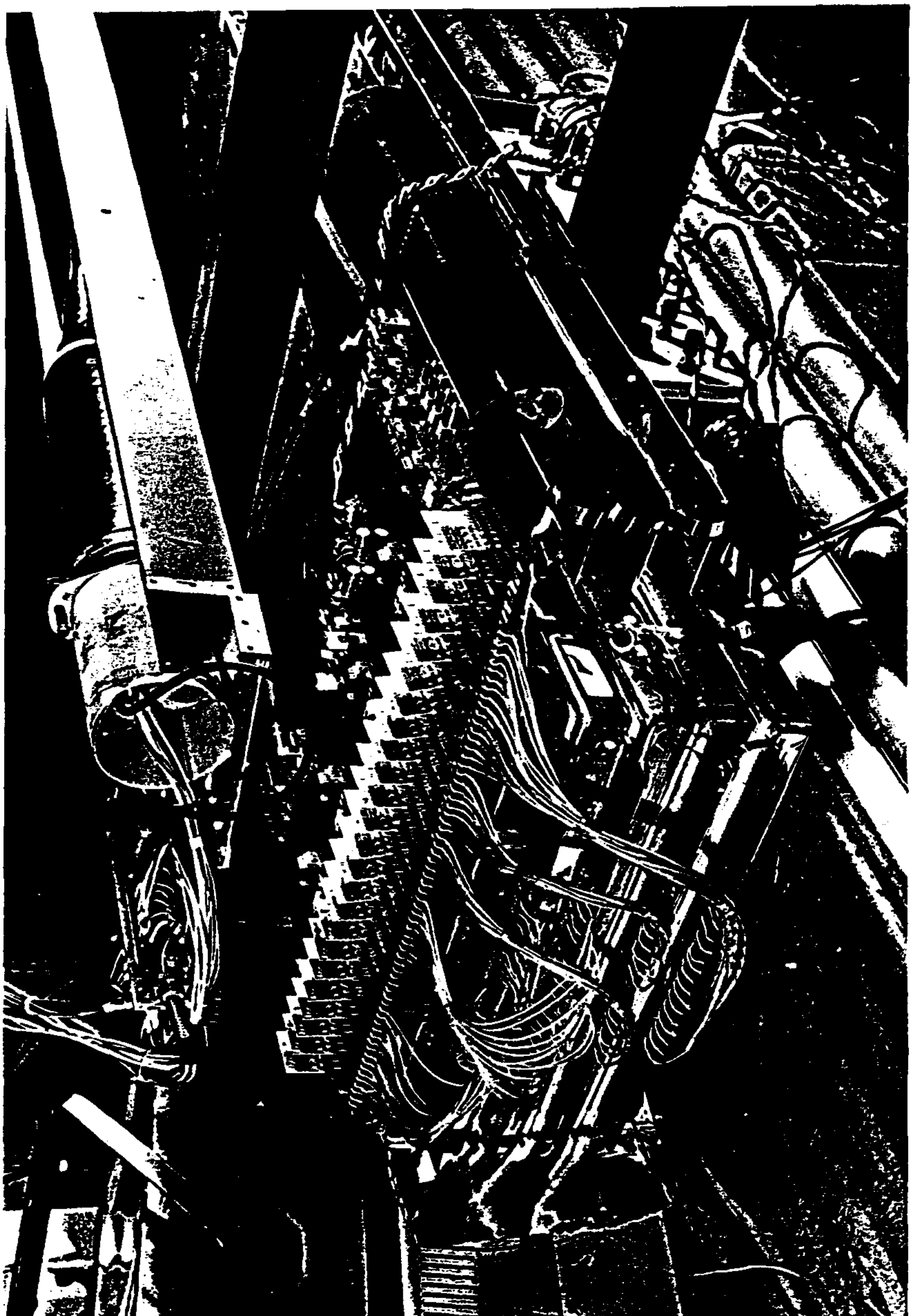
CROSS SECTION
ALONG THE WIRE








C1-65



THE MAIN CONCLUSION:

TO ASSEMBLE 1.1m x 3m PROTOTYPE WE NEED BETTER CLEAN ROOM

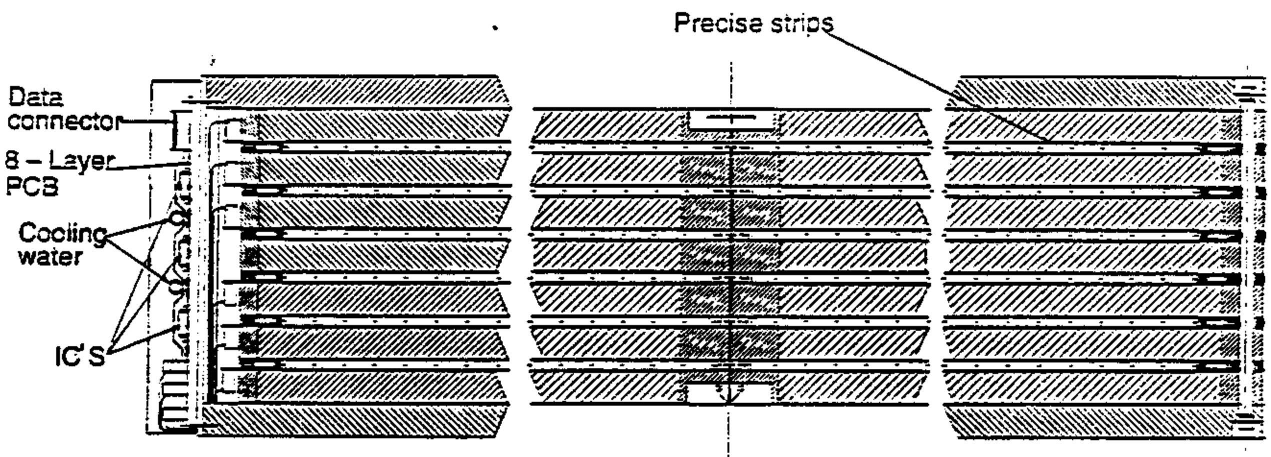
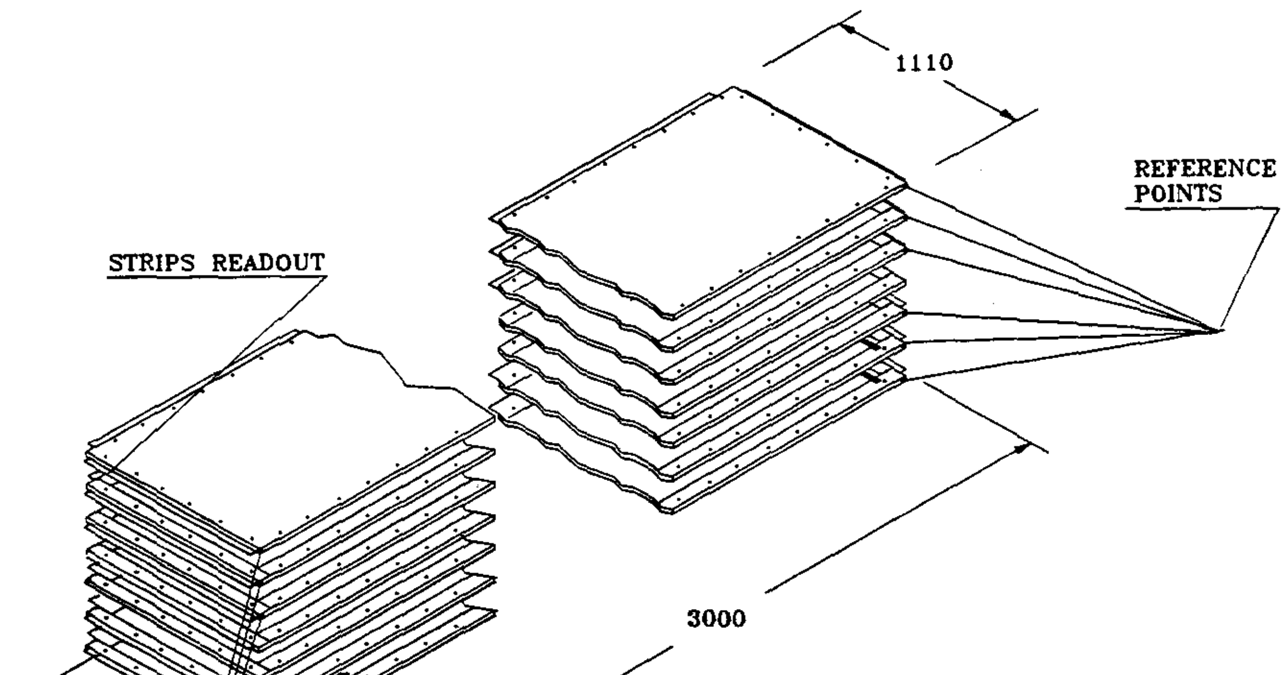
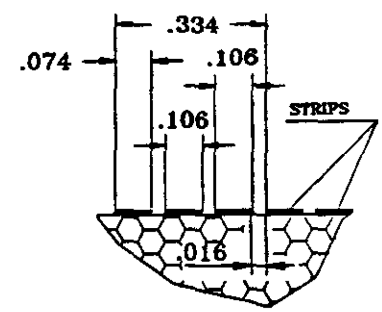


fig4_49

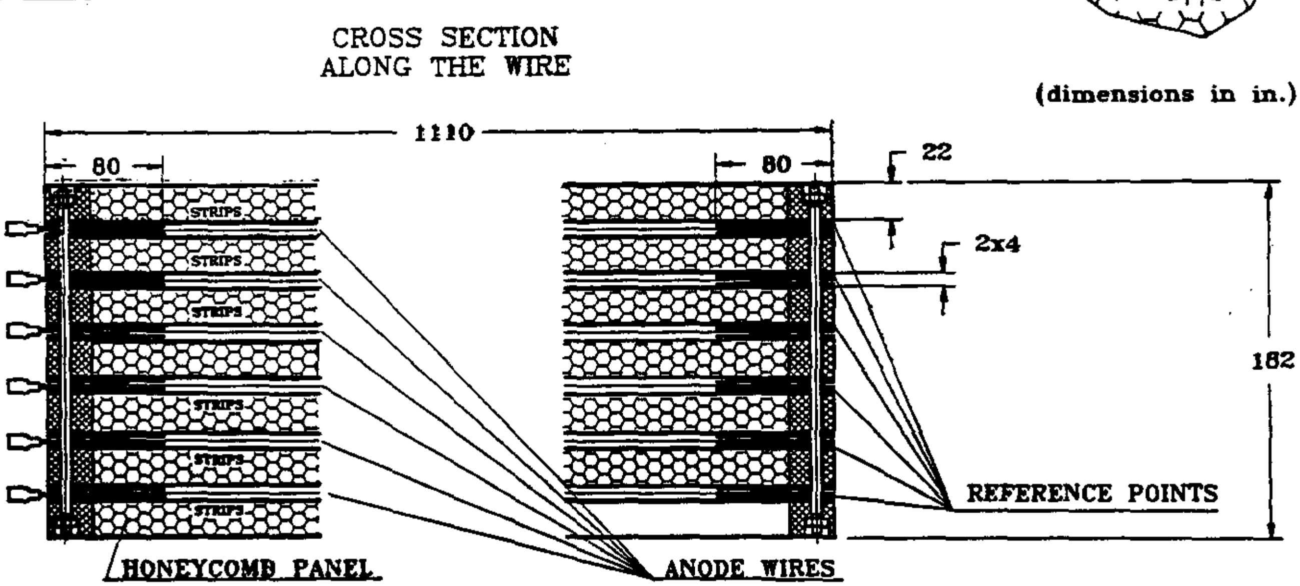
PRECISE STRIP READOUT

CSC 3m x 1.1m



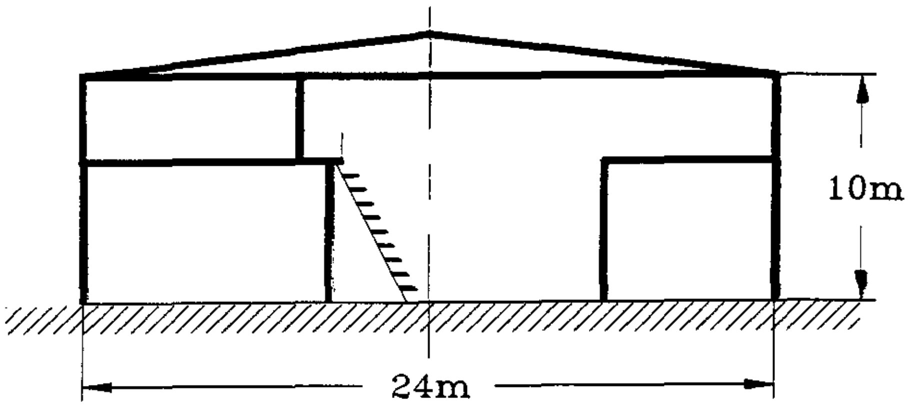


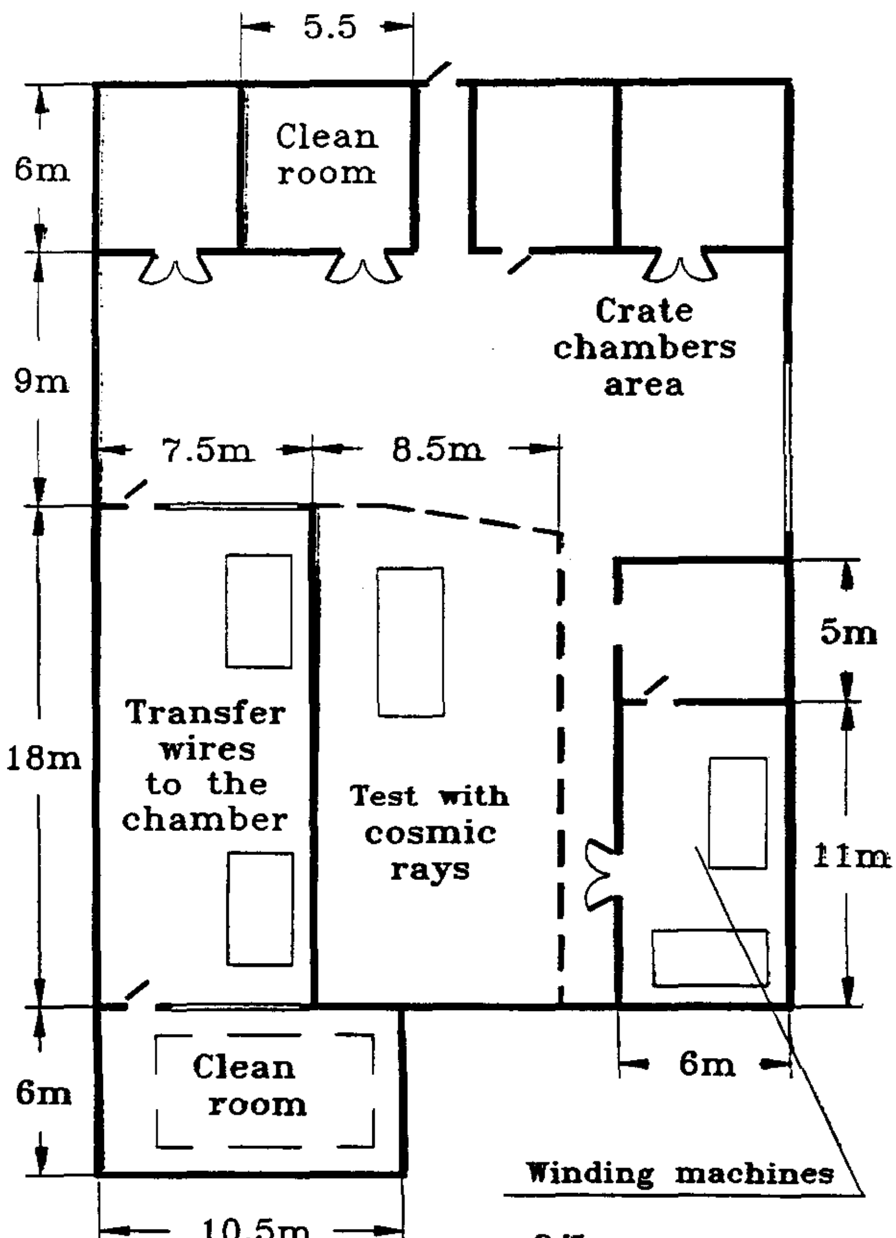
(dimensions in in.)



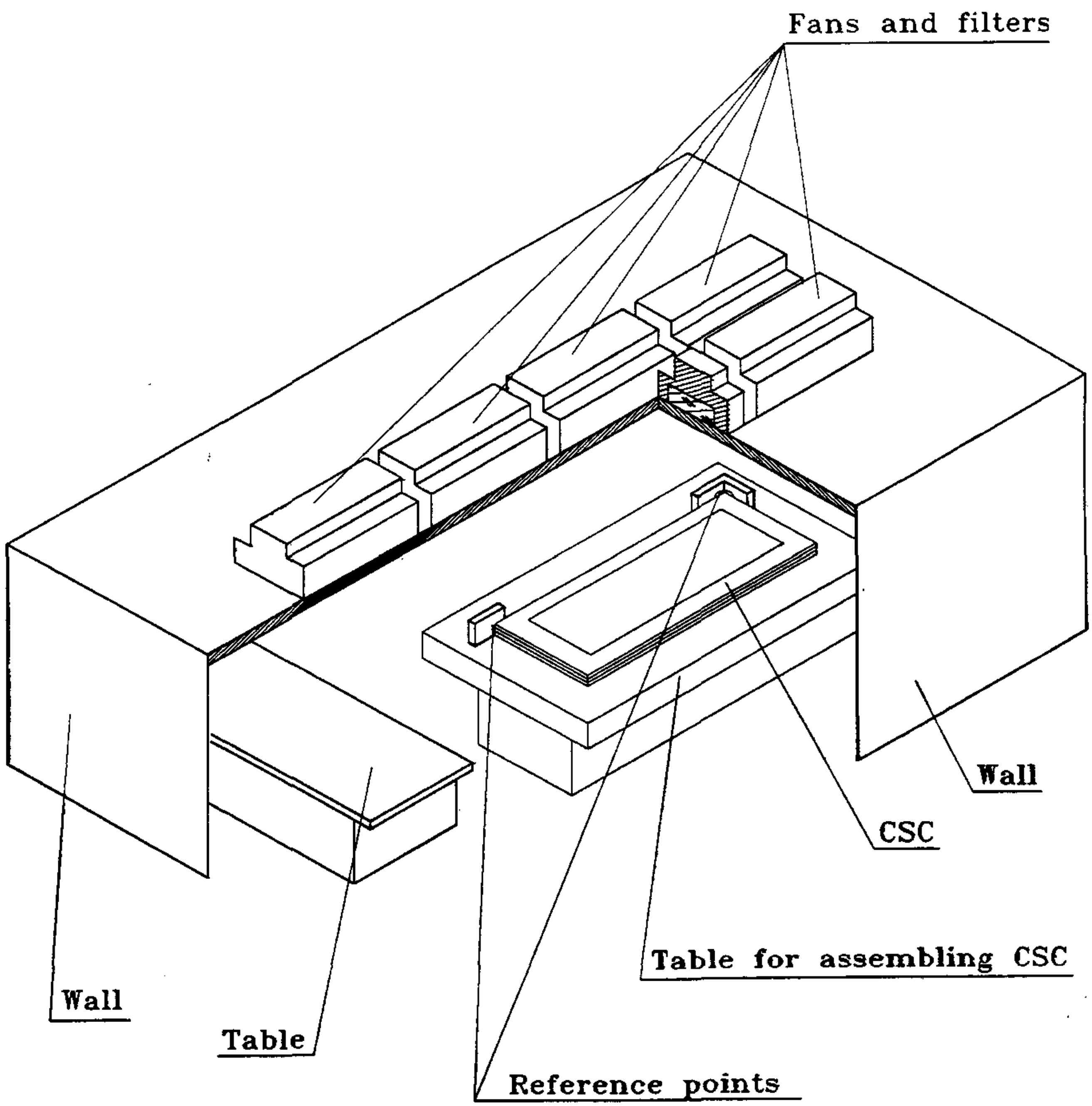
(dimensions in mm)

CSC PROTOTYPES PRODUCTION FACILITY





CLEAN ROOM



T = 20 C
HUMIDITY = 60%
AIR RATE CLEAN =10 000 dust part./cu.ft

CSC PROTOTYPE MILESTONES

*	1. Panels preprocessing	**June 1993**
*	2. Materials from SSCL received	**June 1993**
	3. Panels processing, precise gauges mounting, stripped boards gluing	2 August 1993
	4. Getting bars ready for gluing	13 August 1993
	5. Glue bars to panels	15 August 1993
	6. Drill holes	16 August 1993
*	7. Test assembly of the panels	**17 August 1993**
	8. Assemble spacers and gas outlets	24 August 1993
	9. Cover strips with resistive mater.	25 August 1993
	10. Install anode wires	1 September 1993
	11. Mount Capacitors, resistors, connectors	2 September 1993
*	12. Assembled planes acceptance check	**3 September 1993**
	13. Get planes ready to assemble, clean	4 September 1993
*	14. Assemble chamber	**5 September 1993**
	15. Mount exterior parts	8 September 1993
*	16. Final test	**9-13 September 1993**
*	17. Packing	**14 September 1993**

Steps 4-6, 8-9, 10-13 go in parallel for all planes.
Key operations are shown in bold.

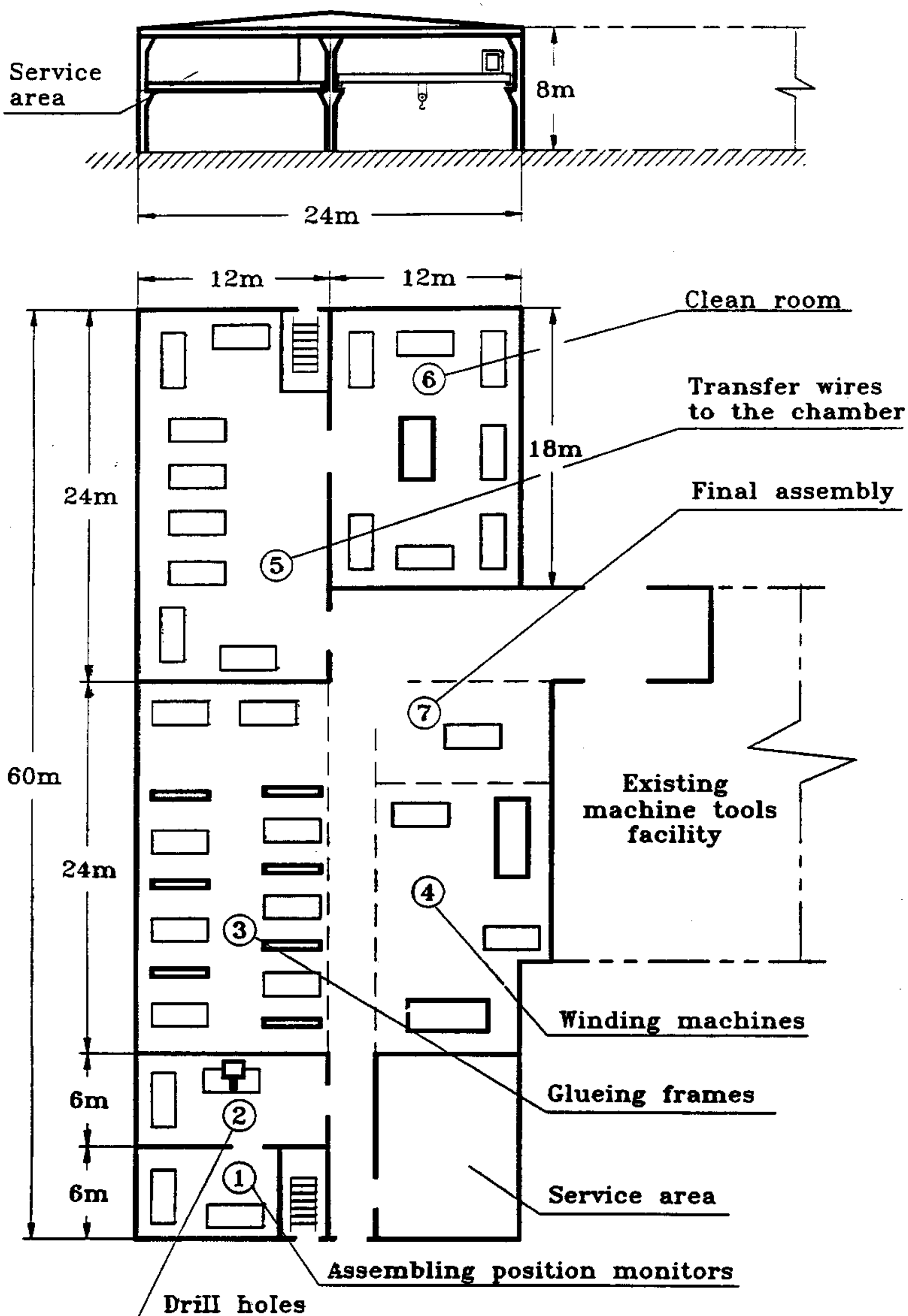
WHAT IS STILL NEEDED TO COMPLETE THE TASK?

- PARTS SHIPMENT EXPENSES
  SSC → DUBNA
- PROTOTYPE SHIPMENT EXPENSES
  DUBNA → SSC
- TRAVEL EXPENSES (CRUCIAL)

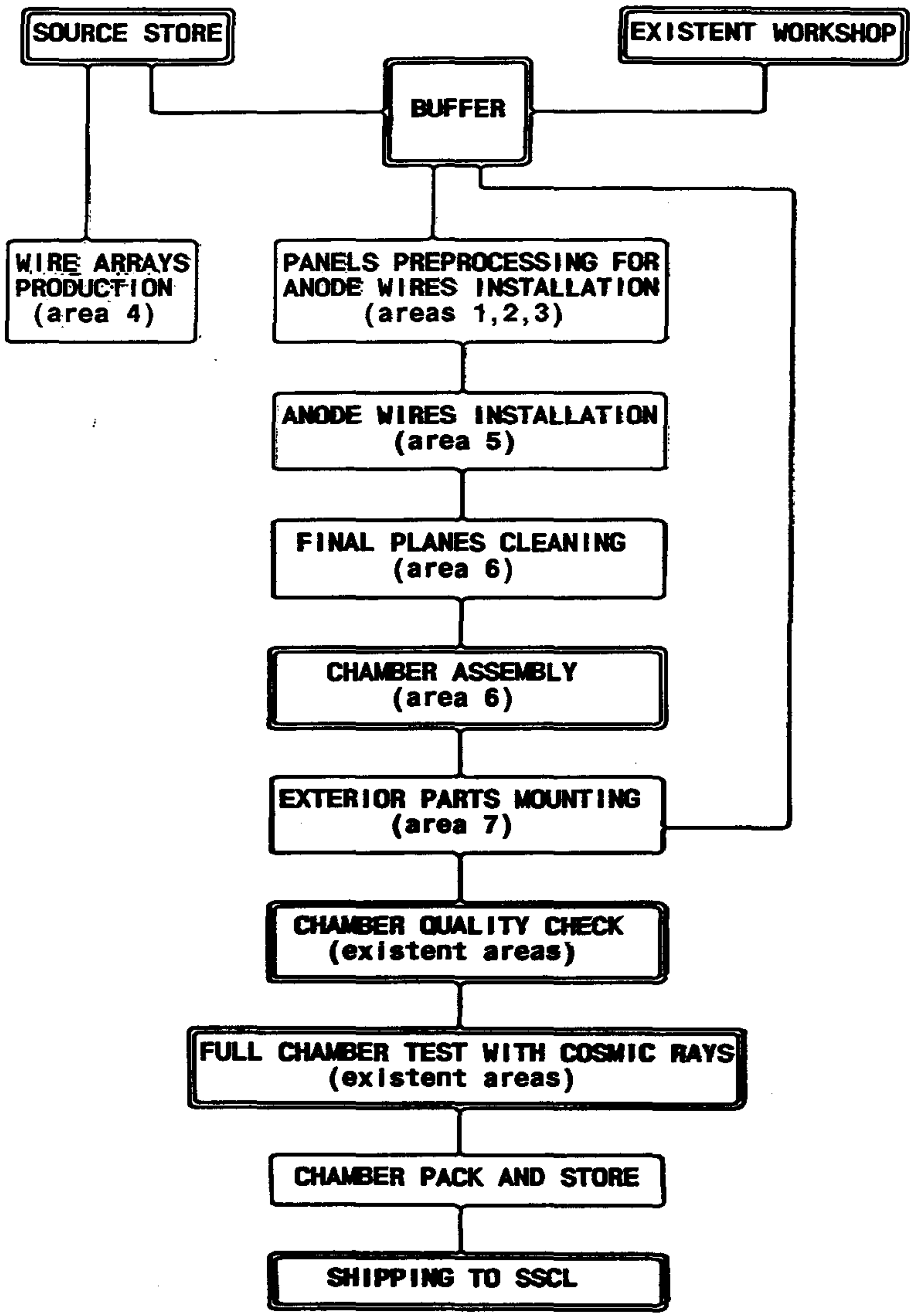
★ ELECTRONICS !!!

CSC MASS PRODUCTION FACILITY

(PROJECT)



CSC MASS PRODUCTION TECHNOLOGICAL CHAIN AT CSC FACTORY (project)



(continue)

Procedures in Bld. 6

Items	Area (m^2)
1. Solder resistors	10 (5*2)
2. Clean cathodes and chamber frames	10 (5*2)
3. Wind wires and wire tension control	30 (6*5)
4. Solder wires	20 (5*4)
5. Wire tension, location & connection check	20 (5*4)
6. Assemble chamber	20 (5*4)
7. Connectors	16 (6.5*2.5)
8. Gas leak test & HV training	22 (5.5*4)
9. Gas supply & final test	45 (5*9)
10. Package	35 (7*5)

The Objects of GEM in IHEP

and

Advance in GEM Muon Detector in IHEP

Yinzhi Huang

29

June ~~18~~, 1993

Status and Objects

•Muon system:

1. R and D of CSC Prototypes: Baby, Mini, Full-size
2. Mass-Production of Muon Chambers:
   40-50 % of Barrel Part
3. Electronics and Trigger for Muon System
4. MC Simulation for Muon System
5. Coordinator for Some Materials:
   Sandwich Panels from MRI (BIAM)
   Strip Boards from CPEIAI
6. Take Part in the Beam Test for Muon Chamber

•Calorimeter:

1. Coordinator and Quality Control
2. MC Simulation
3. Take part in the Beam Test for Calorimeter

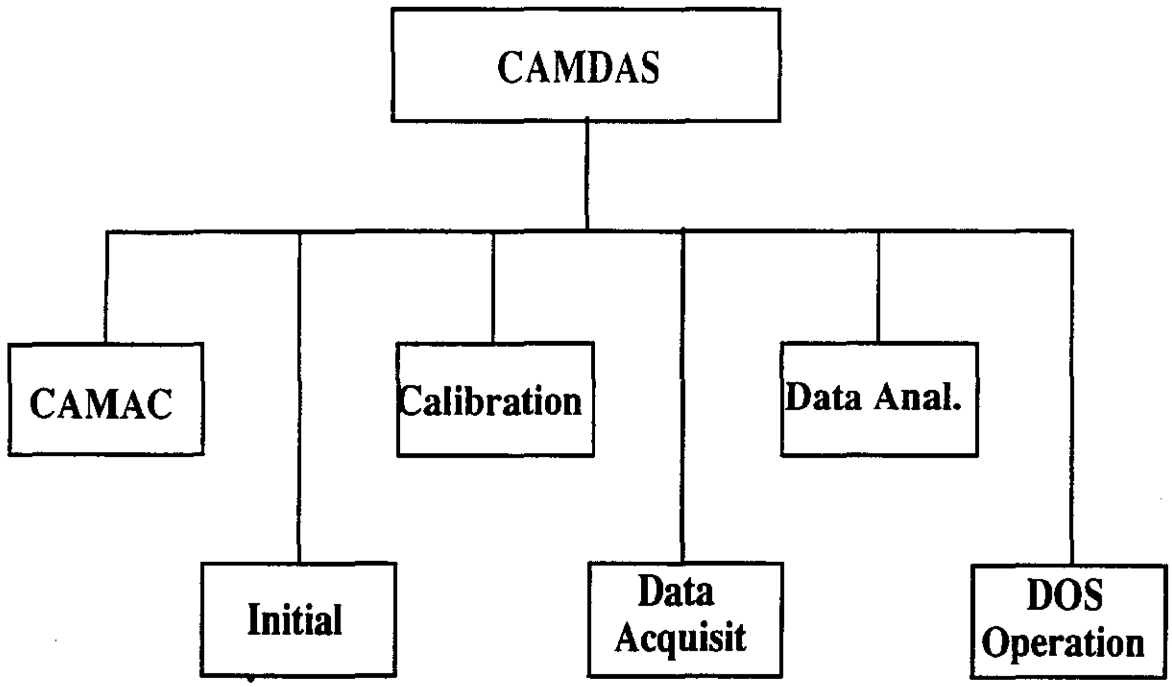
Advance in Muon Camber of GEM in IHEP

•Baby Prototype: 18*25 cm^2

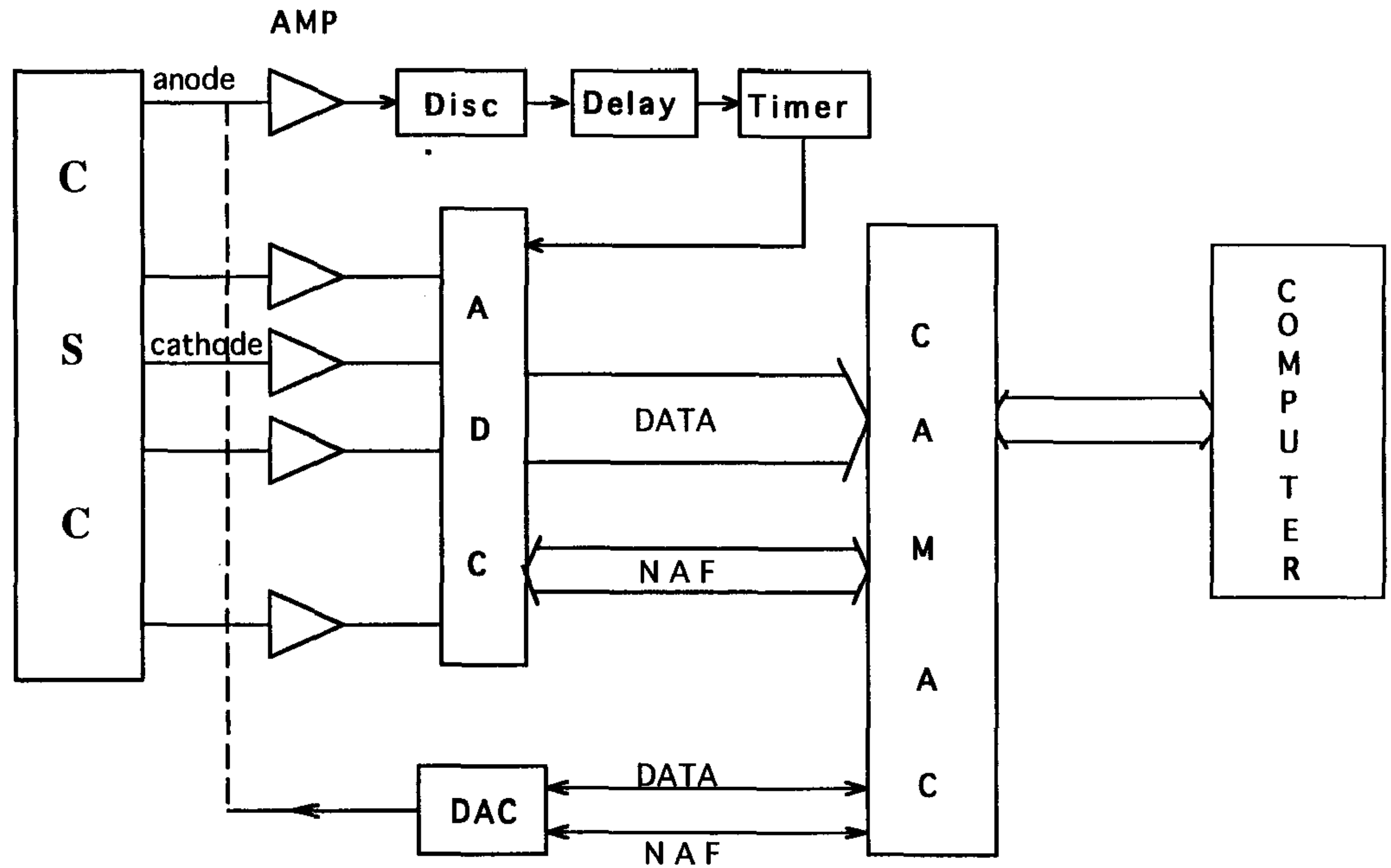
1. The chamber prototype and test facilities have been built.
2. The signals from both cathodes and anodes have been gotten (after preamplifier and shaping amplifier).
3. CAMAC data acquisition system has been developed (can be used for both Baby and Mini). We call it CAMDAS.
4. The CAMDAS working with Baby is good, and the Baby has good centroid distribution.

•Mini Prototype: 50*50 cm^2, 2 or 4 gaps

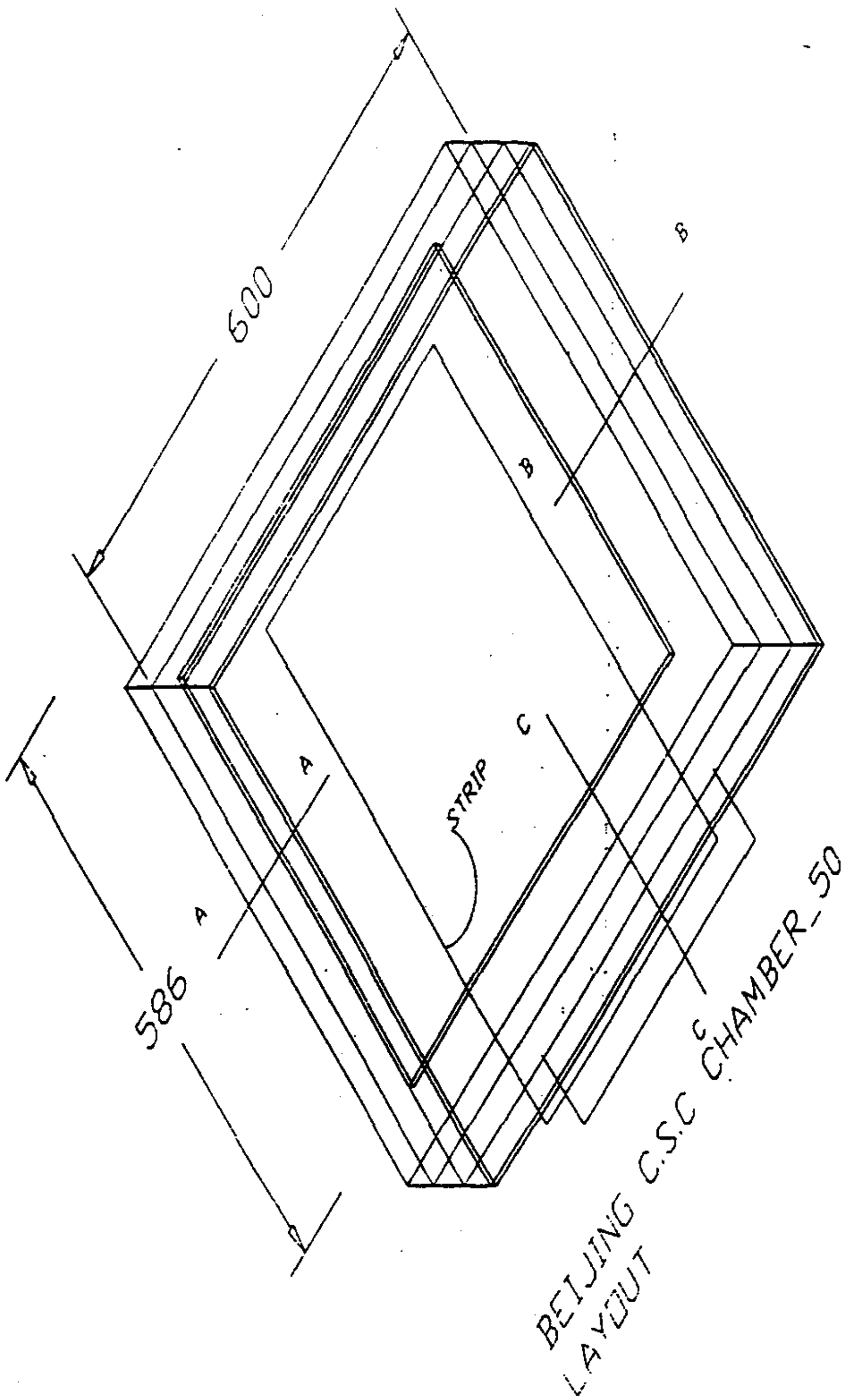
1. The design and drawings for manufacture have been completed , using partly US and partly Chinese components. It is ready for machining.
2. Depending on the budget problem (US$30k have not been received yet), we are considering some substitute materials (much cheaper than exist one). The mainly consideration is concentrating on the characteristics influencing the quality, feasibility and economy.

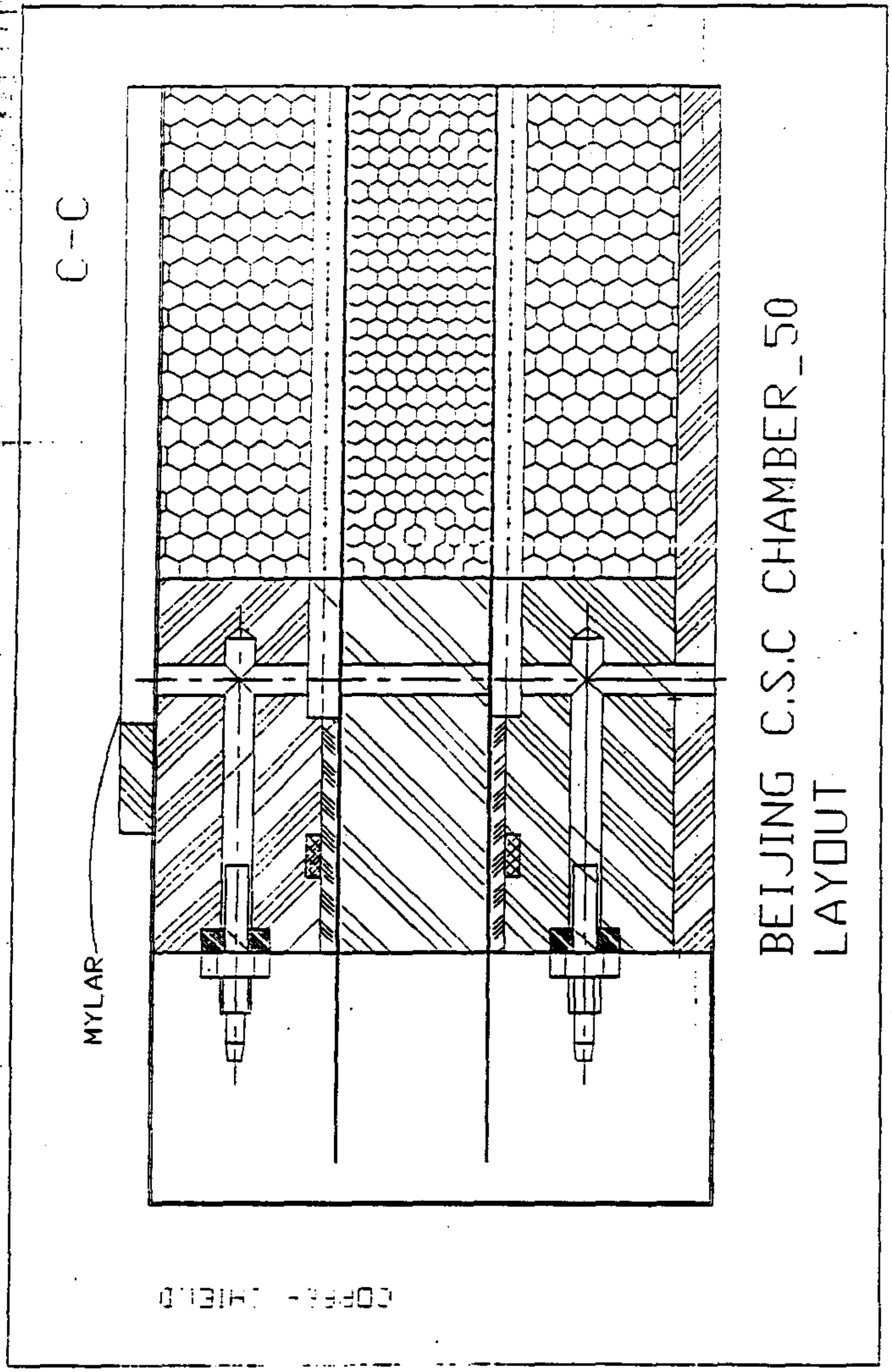


Data Acquisition Software
Block Diagram



Data Acquisition System Hardware


600
586
A
A
B
B
C
C
STRIP
BEIJING C.S.C CHAMBER_50
LAYOUT


C–C
MYLAR
BEIJING C.S.C CHAMBER_50
LAYOUT

•Coordinator for Some Materials

As a coordinator of other two Chinese institutes intending to produce CSC components, i.e. cathode strip boards (China Precision Engineering Institute for Aircraft Industry) and hexcel panels (Material Research Institute or call Beijing Institute of Aeronautical Materials), we keep contacts and have many discussions with them. The status's are:

1. The strip boards made by CPEIAI have been used in our Baby CSC and are working good. Now, we are working together in making the boards for our Mini prototype.
2. The hexcel panels made by MRI (BIAM) have been shown to GEM Muon delegation and we are working together with MRI in making hexcel panels for our Mini prototype.

•Full Size Prototype:

1. The working table (+- 10 μm) and other facilities for both full size CSC and mass production are being prepared.
2. The stretching wire machine for Full size prototype has been designed.
3. The gas system and 32 channels HV power supply are ready to use now.
4. Data acquisition system has been prepared for both Full size prototype and mass production. These are:

   Super 386 computer,

   CAMAC crate and modules,

   NIM crate and modules,

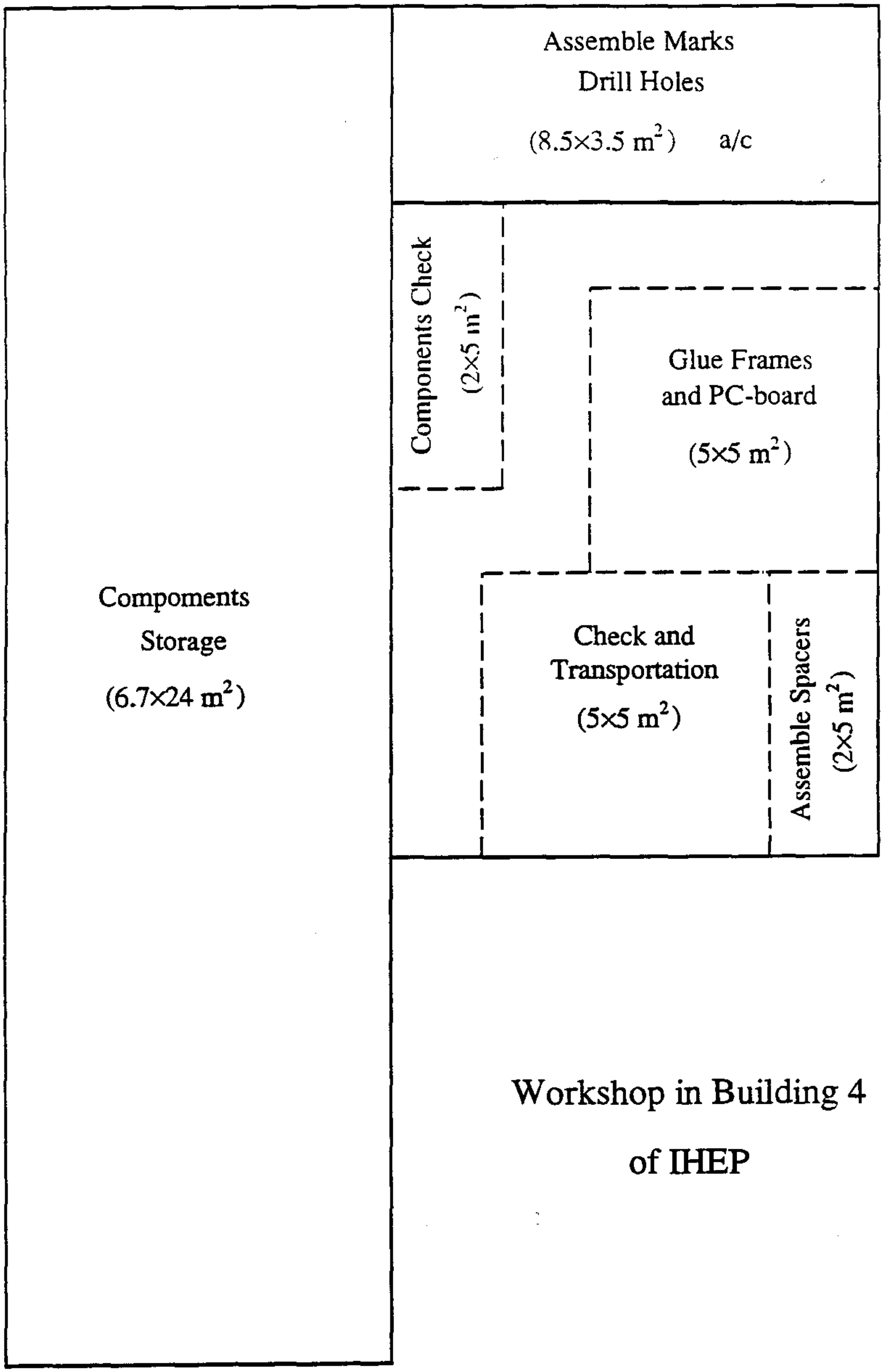
   Scintillators.

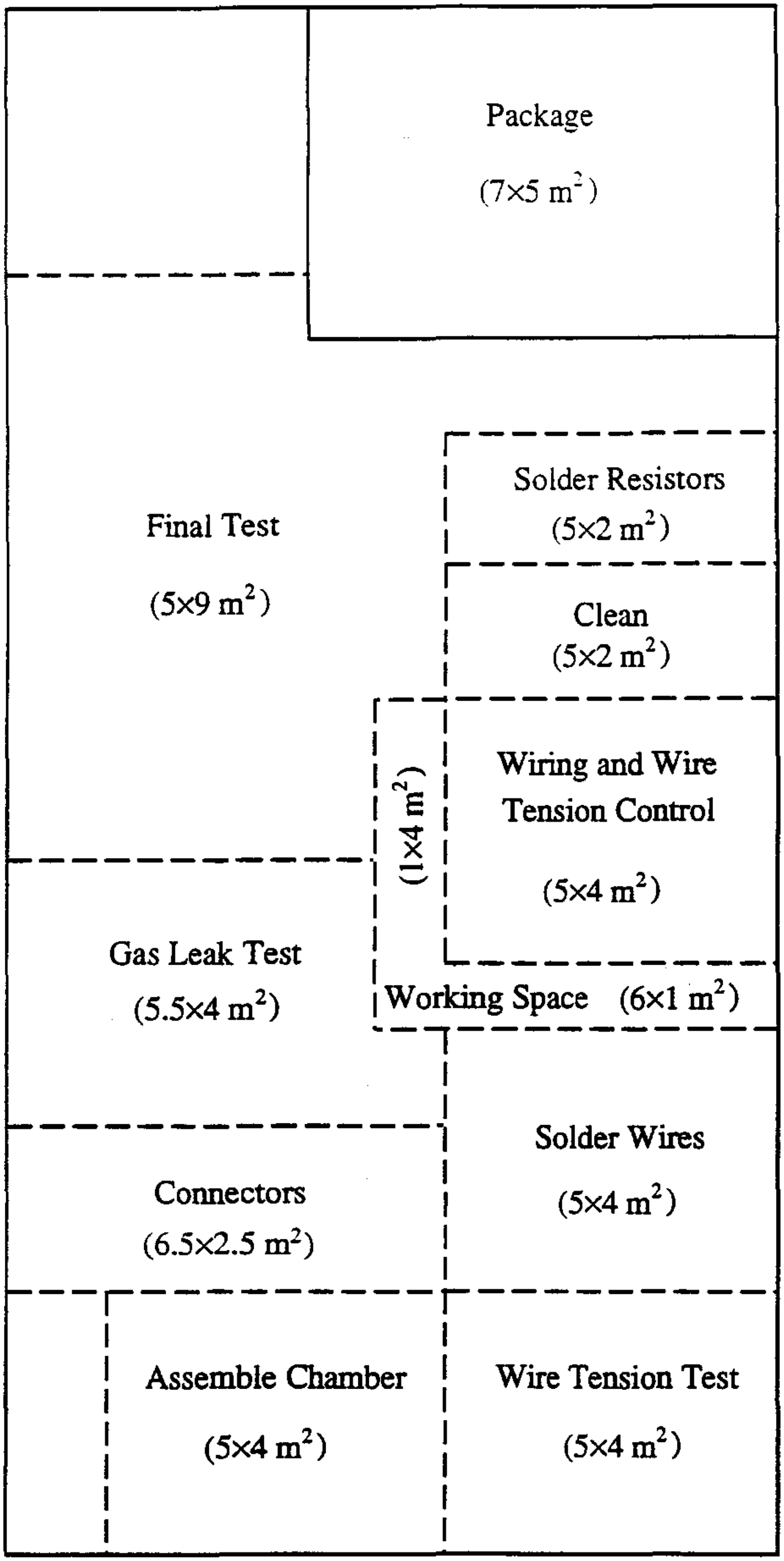
•Preparations for Mass Production

1. The data acquisition system, HV power supply and gas mixture system for Full size CSC prototype can be used for mass production.
2. Wire tension test system and precision measurement system are ready to be used.
3. 550 m^2 workshop space has been vacated for chamber assembly, test and storage:

Procedures in Bld. 4

Items	area (m^2)
1. Components storage	160 (6.7*2.4)
2. Components acceptance, check	10 (2*5)
3. Assemble fiducial marks and drill holes	30 (8.5*3.5) (Air conditioning)
4. Glue chamber frames and PC-boards	25 (5*5)
5. Assemble spacers	10 (2*5)
6. Check and transportation	25 (5*5)


Assemble Marks
Drill Holes
(8.5×3.5 m²) a/c
Components Check
(2×5 m²)
Glue Frames
and PC-board
(5×5 m²)
Compoments
Storage
(6.7×24 m²)
Check and
Transportation
(5×5 m²)
Assemble Spacers
(2×5 m²)
Workshop in Building 4
of IHEP



Workshop in Building 6 of IHEP

CSC Front End Readout

- Status of SCA Development

- 2nd Generation Prototype Schedule

109

GEM Muon Meeting
SSC Laboratory
June 29, 1993

Daniel Marlow
Princeton University

SCA Prototype Tests

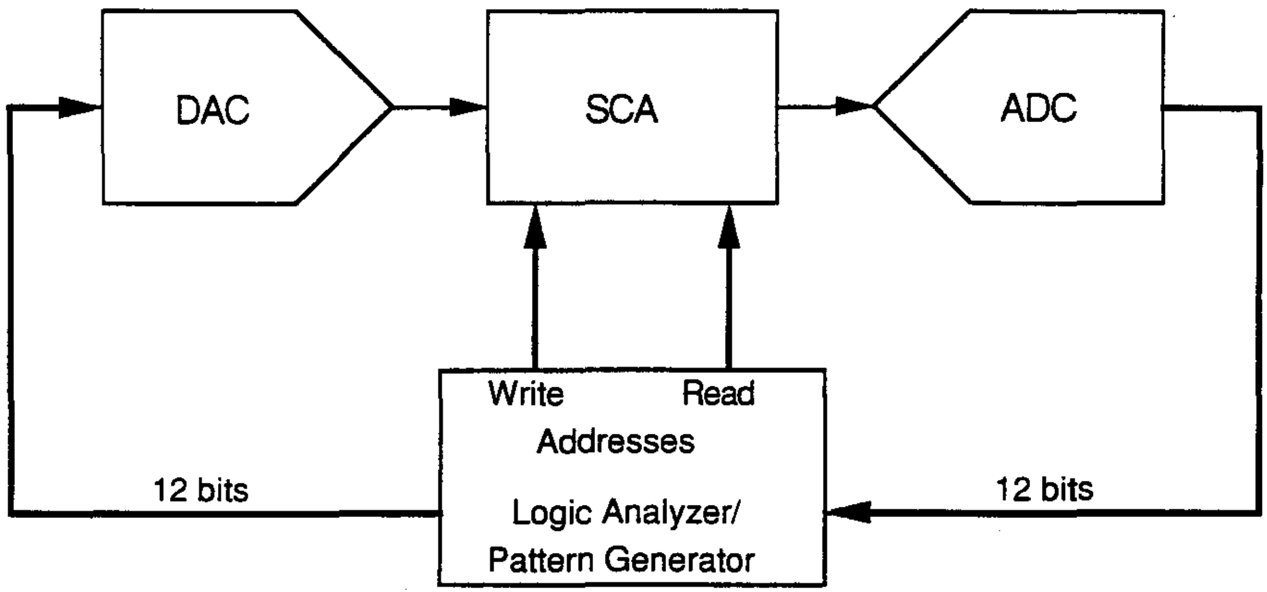
-Work of Bob Wixted & Stan Chidzik

-Prototype is 3-channels, each having 28 storage cells.

-CSC Requirement is 10 bits with 100 ns sampling.

-Test setup uses 12-bit DAC and 12-bit ADC (Analog Devices HAS 1201)

-Write address and read address generated using HP pattern generator. Test using FPGA List Processor'' will commence soon. The latter will allow simultaneous read/write operati(



SCA Test Fixture

Conclusions

-Initial tests look promising

- 10-11 bit SCA operation on first iteration.

- Cell "gains" the same from cell to cell.

- Cell-dependent pedestals at 9 bit level..

-Work to be done

- Complete testing of SCA#1: amplifier settling time, capacitor decay time, additional channels.

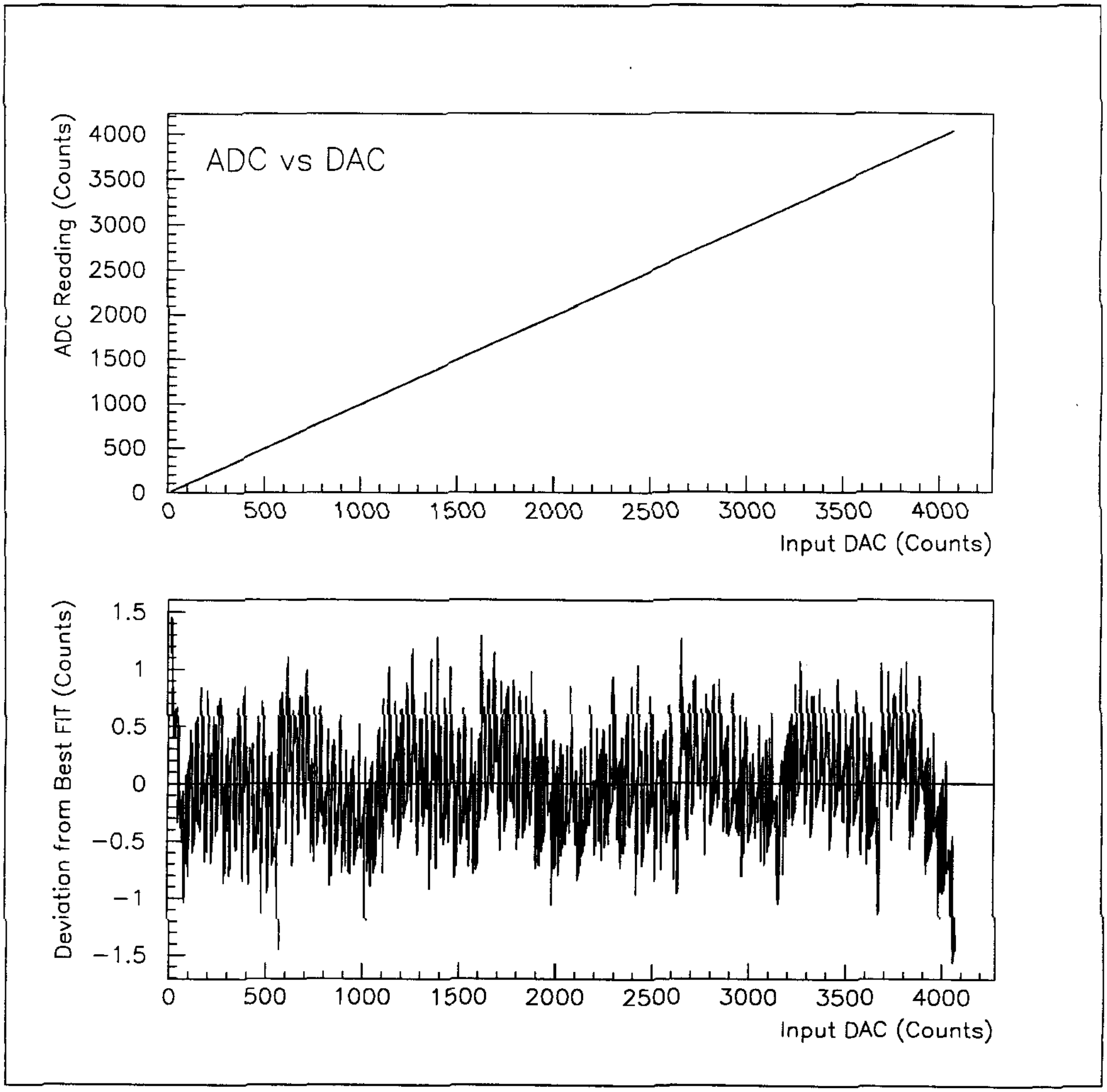
- Improved test setup: 16-bit ADC plus other odds & ends.

- Submit next iteration with on-chip buffer

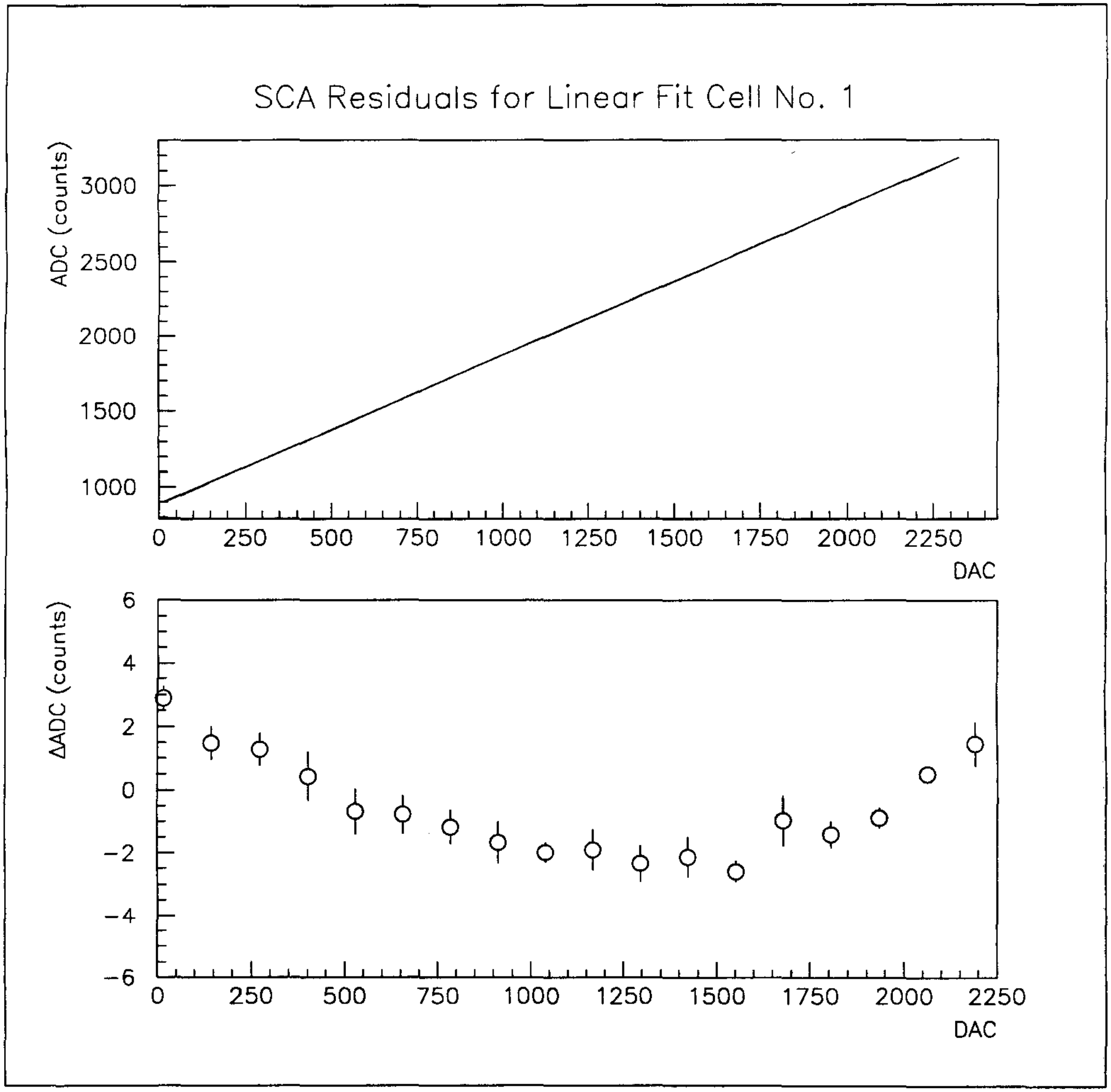
- Understand and reduce cell-dependent pedestals.

- Test and characterize integrated Turko & Smith CFD

-



ADC vs DAC
ADC Reading (Counts)
4000
3500
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
3000
3500
4000
Input DAC (Counts)
Deviation from Best FIT (Counts)
1.5
1
0.5
0
−0.5
−1
−1.5
0
500
1000
1500
2000
2500
3000
3500
4000
Input DAC (Counts)


SCA Residuals for Linear Fit Cell No. 1
ADC (counts)
3000
2500
2000
1500
1000
0
250
500
750
1000
1250
1500
1750
2000
2250
DAC
ΔADC (counts)
6
4
2
0
−2
−4
−6
0
250
500
750
1000
1250
1500
1750
2000
2250
DAC

SCA Based CSC Readout Electronics Schedule

```
            1993                          |                 1994
        Jun  Jul  Aug  Sep  Oct  Dec  Jan  Feb  Mar  Apr  May  Jun  Jul

                  test
Prot  SCA#1       ------->

                   design           fabricate    test
Prot  SCA#2        ---------->--------->----->

                        design             fabricate     test
Prod SCA#1              ---------------->---------->----->

                                                  design   fabricate    test
Prod  SCA#2                                       ----->--------->---->

Prot  P/A#1       --->---------->---------->

                            design       fabricate      test
Prod P/A#1                  --------->----------->------->

                                                design        fabricate      test
Prod P/A#2                                     - -------->--------->----->

                  study  heatflow,  packaging,  &  EMI  issues
PCB R&D                 ------------------------------->

                              design          fab      test
Prod  PCB#1                   ------------->---->------>

                                                    design          fab     test
Prod  PCB#2                                      ----------------->---->----->
```

Alignment System R&D Program

The Alignment System R&D Program will study a number of different alignment concepts and straightness monitor technologies including:

Alignment Concepts:

- 3-point Projective Alignment.
- Hybrid Axial/Projective.
- All-optical Axial/Projective.
- X rays.

Straightness Monitors:

- Multiple LED/Lens/quad-cell.
- Video Straightness Monitor (VSM).
- Stretched Wire Alignment (Capacitive Pick-up and Inductive Pad).

A dedicated facility, the Alignment Test Stand will be constructed at SSCL to test these and other options as our R&D program evolves.

be checked against a precise external alignment system for a realistic path lenght with realistic chambers.

In summary the Alignment R&D program will cover the following:

- Assess technology options and develop them for GEM application (LED-LENS, or CCD, etc).
- Set up test bench to evaluate technologies in a standard way.
- Integrate alignment technology with chamber design and support structure.
- Set up Alignment Test Rig (ATR) to evaluate alignment technology with chamber mock-ups.
- Design complete system - specifying the type, number, and deployment of monitors.
- Simulate operation of complete system and validate the design and its error budget.
- Evaluate X-ray alignment scheme. Develop mass production techniques for aligning layers within a chamber module.

A revised WBS with task and sub-task leaders follows for the Muon System Alignment Task.

2.4.1 Define and develop alignment technology (LLNL, SSCL, Draper; Joe Paradiso - Task Leader)

2.4.1.1 Review alignment systems on other HEP experiments. (C. Wuest, J. Paradiso)
2.4.1.2 Review Draper R&D results. (J. Paradiso)
2.4.1.3 Review LLNL R&D results. (C. Wuest)
2.4.1.4 Review Tsinghua University R&D results. (C. Wuest)
2.4.1.5 Review PNPI x-ray alignment results. (A. Vorobyov, C. Wuest)
2.4.1.6 Review MIT stretched wire/inductive pad results. (A. Korytov)
2.4.1.7 Review six-point interpolation technique. (J. Paradiso, Yu. Gerstein)
2.4.1.8 Define alignment technology (or technologies) for GEM. (J. Paradiso, C. Wuest, G. Mitselmakher)

2.4.2 X-ray alignment methods – inter-layer alignment. (PNPI, SSCL, LLNL; A. Vorobyov, Task Leader)

2.4.2.1 Construction of a movable table (CMM) at PNPI, modification of existing CMM at LLNL. (A. Smirnov, O. Prokofiev, C. Wuest)
2.4.2.2 Computer controlled motion system and metrology development. (A. Smirnov, O. Prokofiev, C. Wuest)

R&D of Alignment Technology
Second Half FY 1993 Detailed Breakdown and Budget

Craig R. Wuest, Joseph A. Paradiso

Lawrence Livermore National Laboratory
Charles Stark Draper Laboratory

June 9, 1993

(2.4) Task 4: Alignment Technology

The detailed design of the chamber precision alignment system will be developed and analyzed. Emphasis will be placed on the evaluation of sensors, integration of alignment systems with the chosen technologies, and testing of the alignment system. Cost and schedule estimates for the alignment system will be formulated. The design will be documented in terms of drawings and specifications so that a prototype of the alignment system can be built.

One of the improvements of the TDR design worth considering is to increase the solid angle coverage. Several strategies are under consideration depending on the the location of the non-coveraged. For example, small chambers can be inserted in some regions near the CDS. These chambers will have to be aligned by some means. Another area is the gaps in the barrel region where an axial alignment scheme has been discussed. All of these improvements will be evaluated.

The alignment of the individual layers of cathode boards in a chamber is an important engineering issue and key to acheiving the desired performance of the chamber modules. For this task it has been proposed by the PNPI contingent in collaboration with LLNL to employ penetrating X-rays to orient the individual layers together.

To validate the concept of the sagitta correction function determined by projective alignment of the chambers, the basis of all proposed GEM alignment schemes, a prototype alignment system will be constructed, called the "Alignment Test Rig" (ATR). Some specific engineering approaches will be tested as well. The ATR will consist of three dummy chambers representing the three superlayers of the barrel (endcap). Each of the dummy chambers will be instruemented with positioning actuators used to place the chambers within the few millimeters dynamic range of the alignment system, and alignment fixtures. A series of tests will be conducted whereby the alignment system will

Task Consultants:
Andrei Korytov, Gena Mitselmakher, Frank Nimblett, Yuri Gerstein, Fred Holdener

Task Collaboration:

Draper Lab.
Howard Baker, Frank Nimblett, Joe Paradiso, mechanical engineer, optics engineer
ITEP
V. Balagura, I. Korolko, V. Gavrilov, A. Ostapchuk
LLNL
Elden Ables, Curt Belser, Fred Holder, Craig Wuest, Martin Roeben
MIT
Andrei Korytov, Louis Osborne
MSU
Carl Bromberg, R. Miller, R. Richards, B. Tigner
PNPI
A. Vorobyov, et al.
SSCL
G. Crutcher, M. Jons, G. Mitselmakher, Yu. Gerstein, D. Weal
Tsinghua University-Beijing
Ni Weidou, Rencheng Shang, Keren Shi, Li Dachen

Appendices:

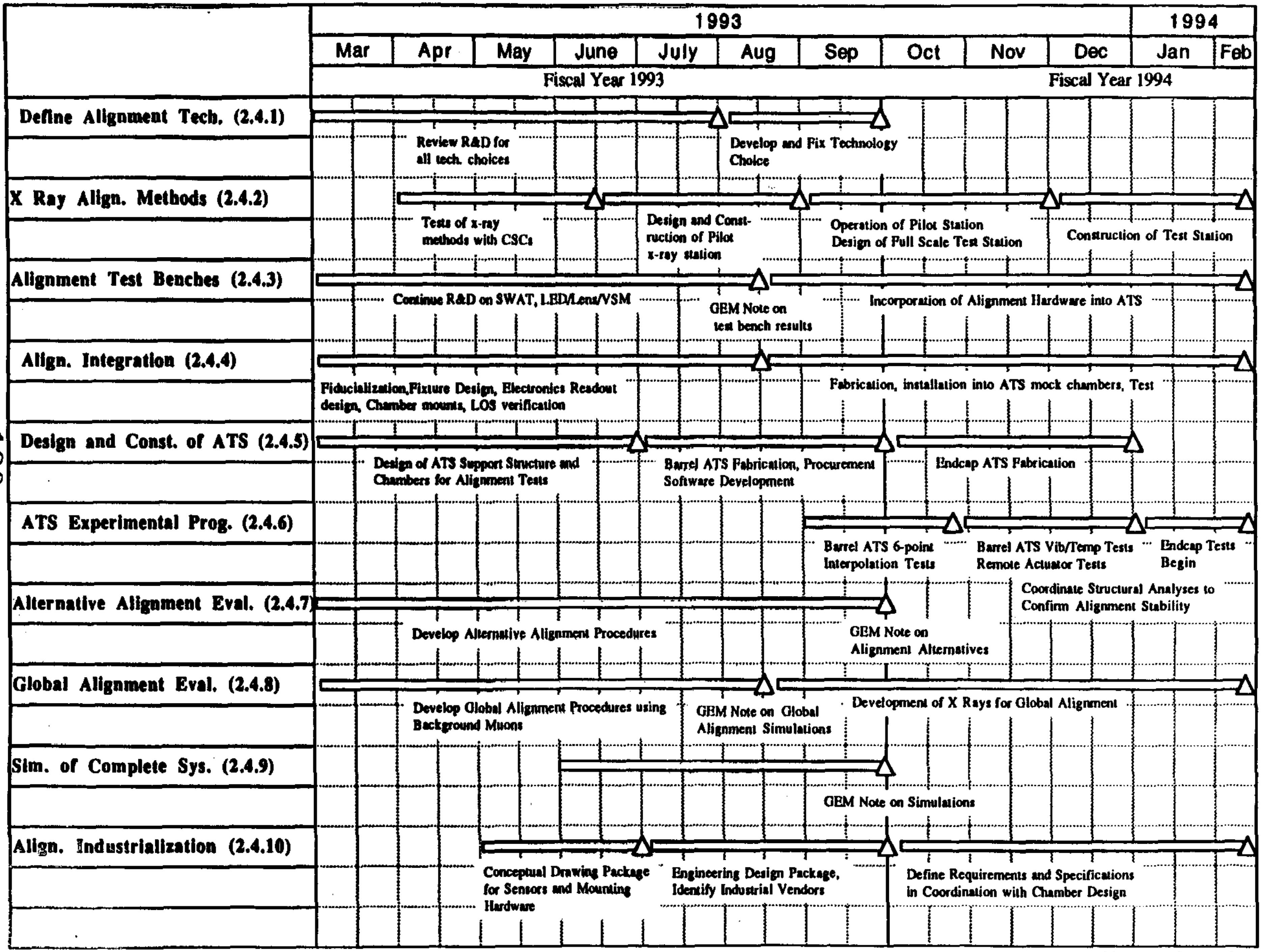
1. Fred R. Holdener and F. Curtis Belser, "Alignment Test Stand and Experimental Test Program Project Plan for SSC GEM Detector Muon Subsystem," May 21, 1993.

2. Li Dachen, "R&D (1993) of Alignment at Tsinghua University," April 30, 1993.

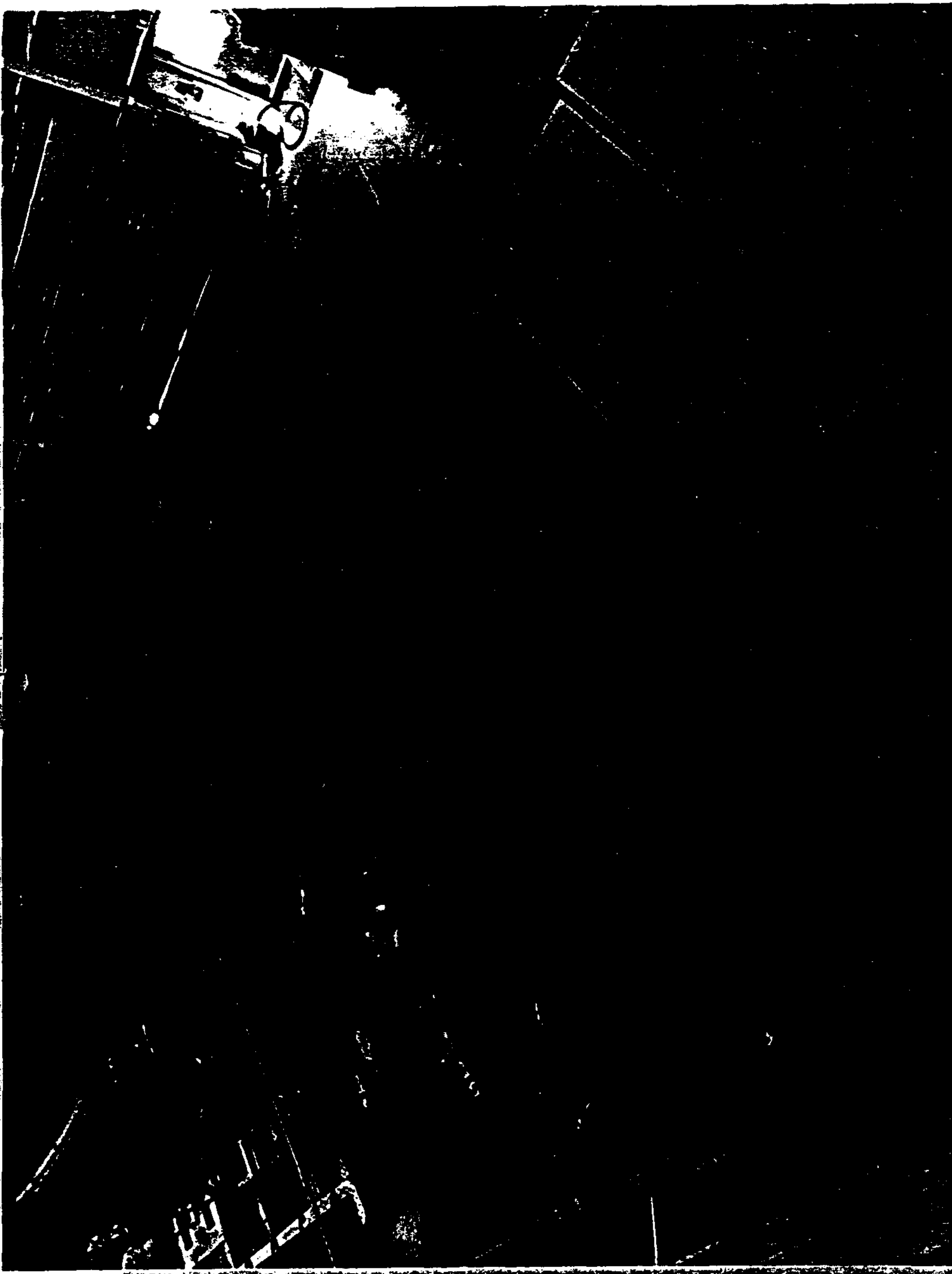
3. A. Vorobyov, et al., "X-ray Test Station for Cathode Strip Muon Chambers at SSCL, Technical Proposal," March 31, 1993.

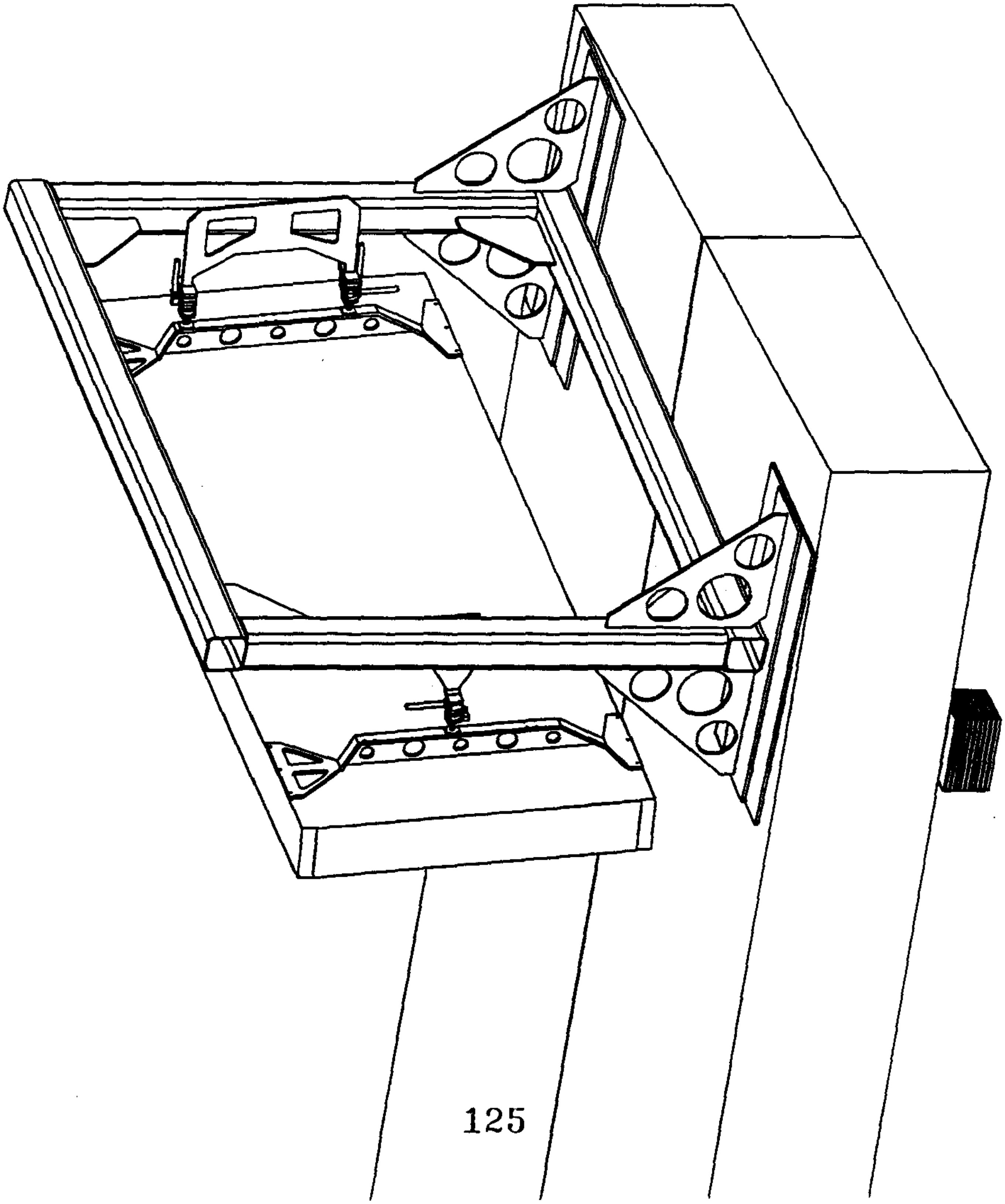
4. O. Prokofiev, et al., "Plans for R&D on GEM End Cap Muon Chambers for the Second Half of FY93," April 20, 1993.

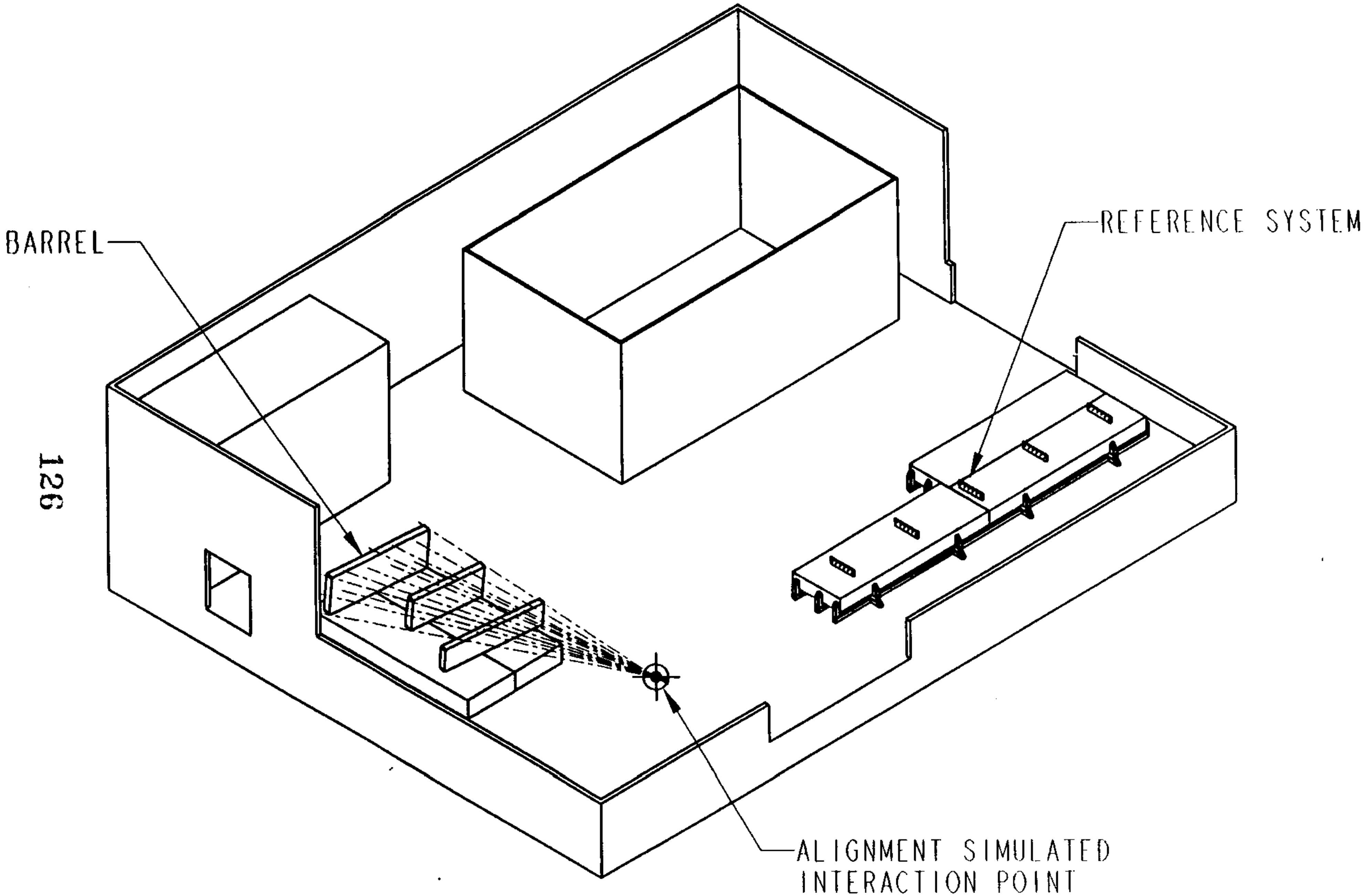
5. A. Vorobyov, et al., "GEM Global Alignment Test with X-ray Beams, Technical Proposal," April 3, 1993.

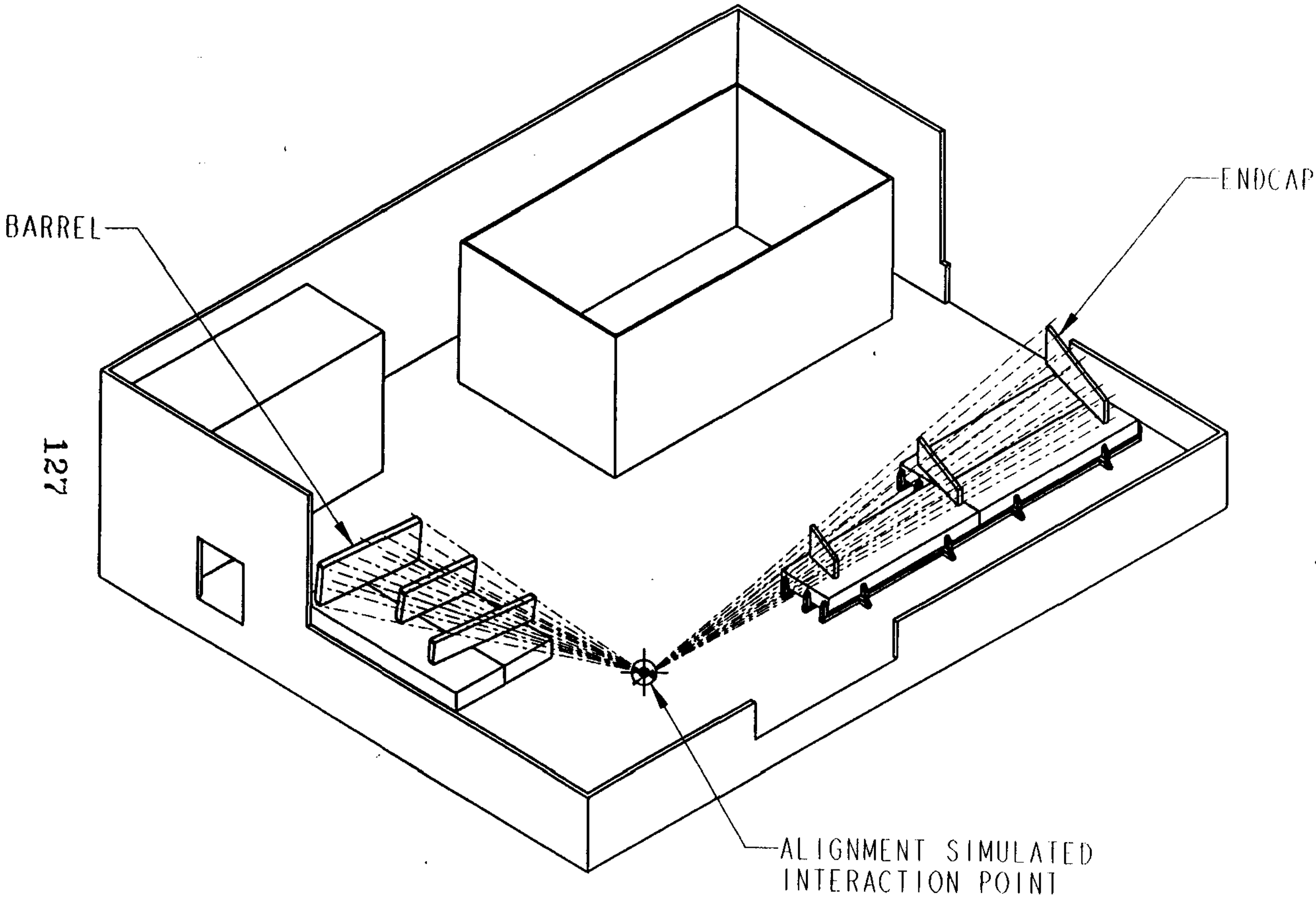


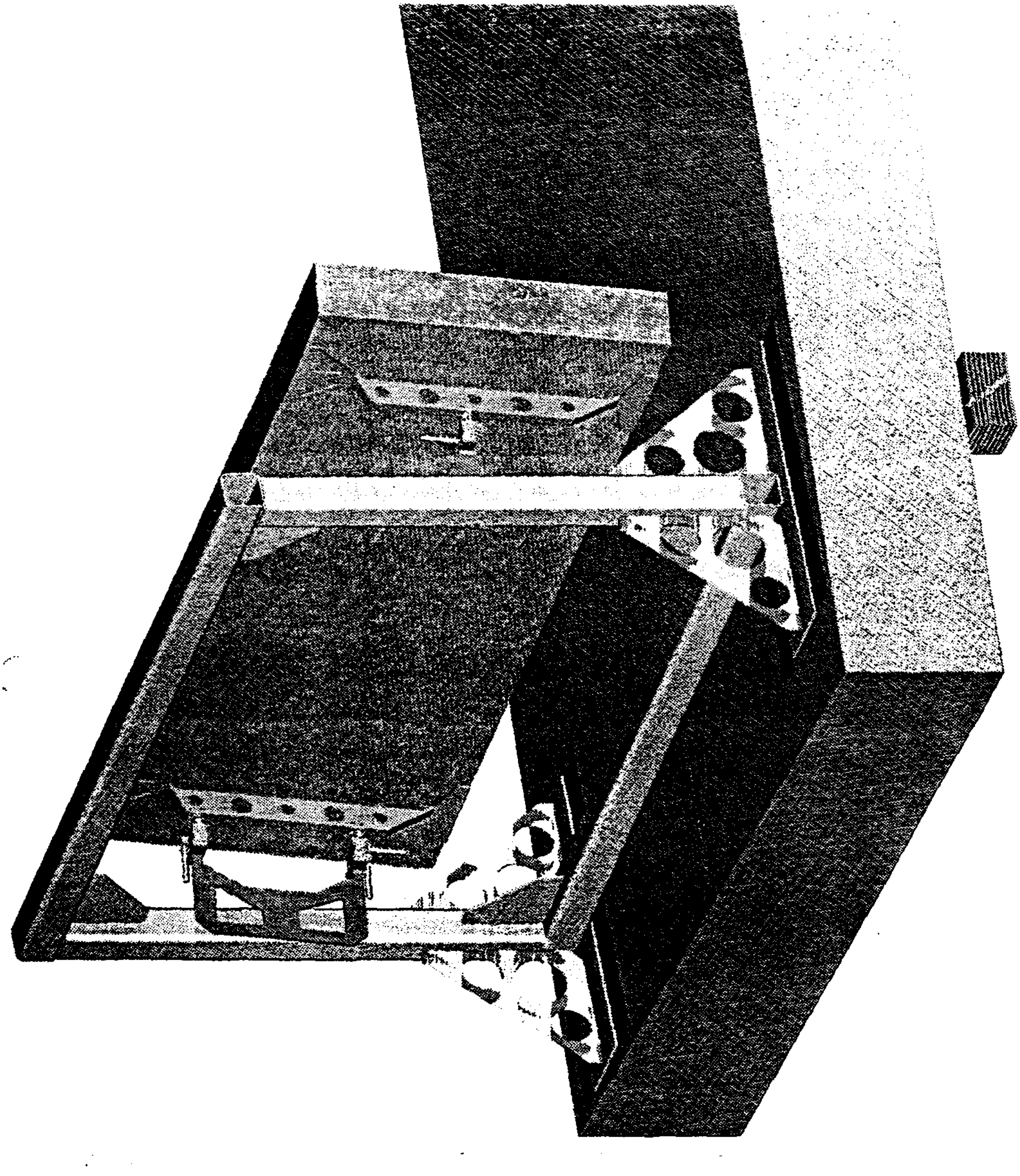
Wednesday, June 9, 1993






BARREL
REFERENCE SYSTEM
ALIGNMENT SIMULATED
INTERACTION POINT


BARREL
ENDCAP
ALIGNMENT SIMULATED
INTERACTION POINT



Alignment System R&D Program

ATS Experimental Plan

- Measure stability of alignment hardware for 3-point projective alignment scheme.
- Measure sensitivity of alignment hardware to temperature and atmospheric variations.
- Study procedures for installation of CSC mock chambers and chamber/structure interface hardware concepts.
- Study quadratic interpolation method by intentionally distorting chambers in controlled ways.
- Evaluation of remote actuator system, operation of remote position actuators and encoders, and development of alignment procedures.
- Vibration sensitivity measurement.
- Hardware optimization, including chamber interface hardware.
- Repeat tests for all straightness monitor technologies.

More Muon Alignment

24 x 24 mm

New Barcode

12 x 12 mm

Old Barcode

133

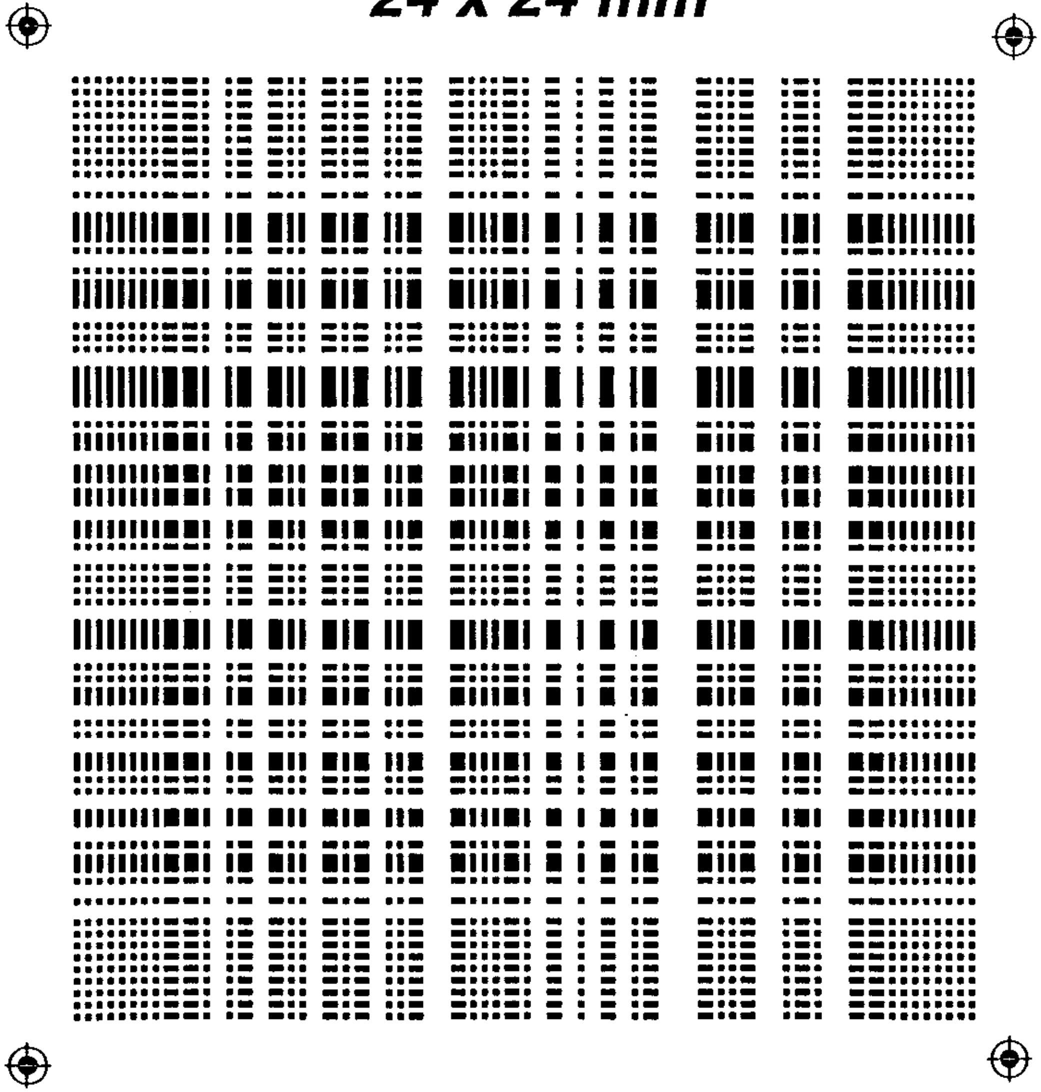
- New VSM Test Results
- New Gear for ATS DAQ
- More Implementation Analysis
  - Refined axial simulation

GEM

- J. Paradiso, SSCL, 6/30/93

PostScript Barcode Mask

24 x 24 mm



New Barcode

- Programmed in PostScript
  - Accurate to full printer resolution
- Binary-encoded digits
  - Width of number field and absence/presence of bar encodes digit
- Digits scrambled for uniform feature density

Precision Digital Gauge now used to automatically read scan position in Lab

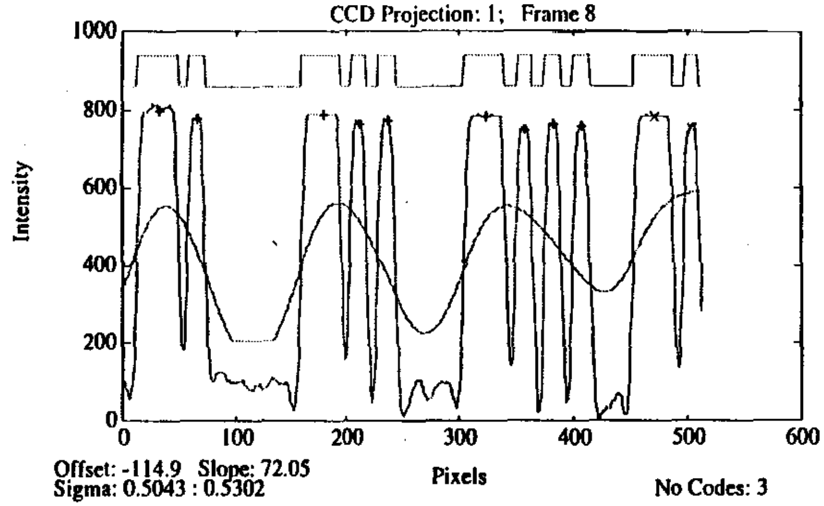
Lens position monitored

GEM

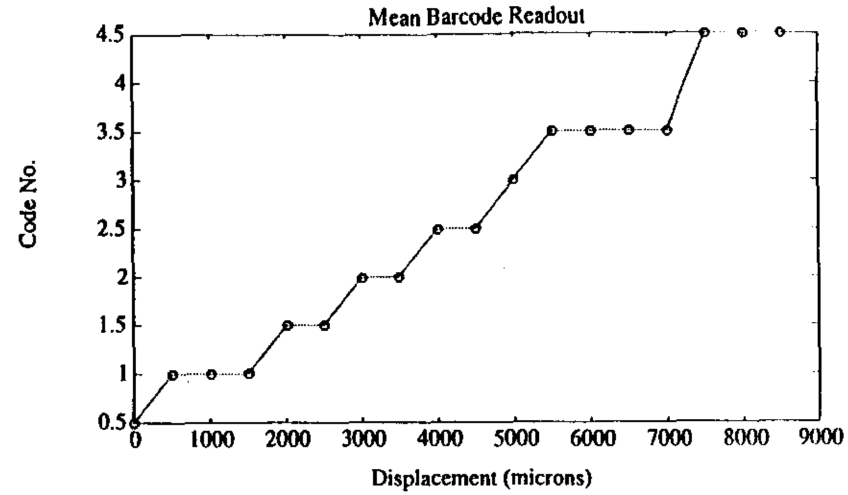
2

CCD Alignment System Performance; 1 cm scan, 500 μm intervals

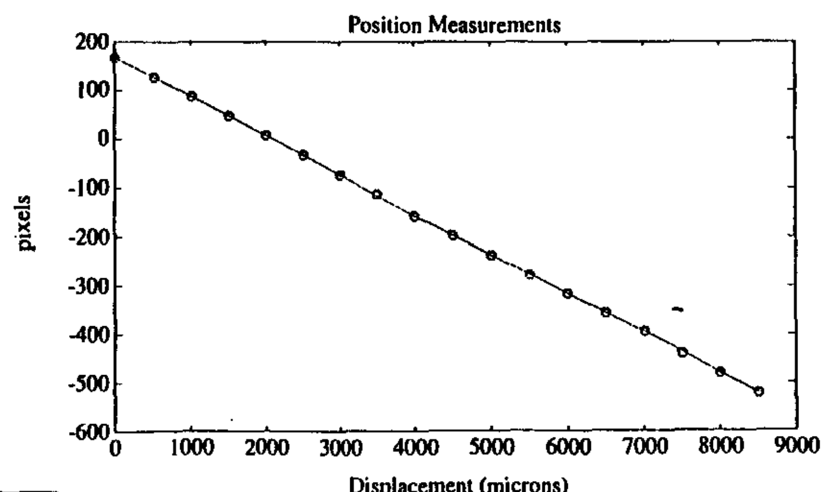
9 meter optical baseline; 15 frames averaged at 1 Hz; simple monotonic barcode



Sample data frame; X Projection



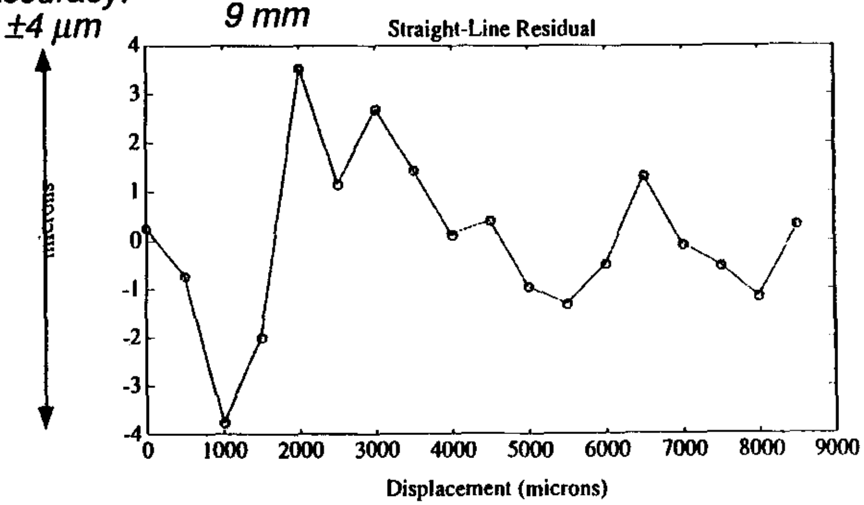
Average Barcode Digits



Measurement vs. Micrometer Position

Accuracy: ±4 μm

Range: 9 mm

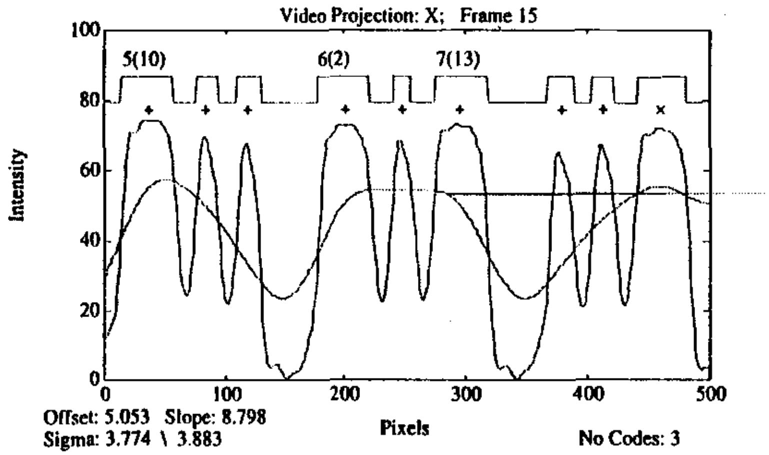


Deviation from Linearity

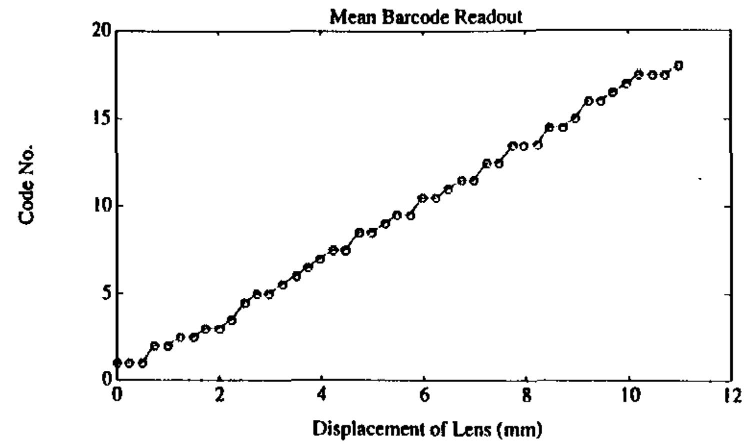
GEM

VSM Performance; 1.2 cm X-Coordinate lens scan, Chinon mini-çamera

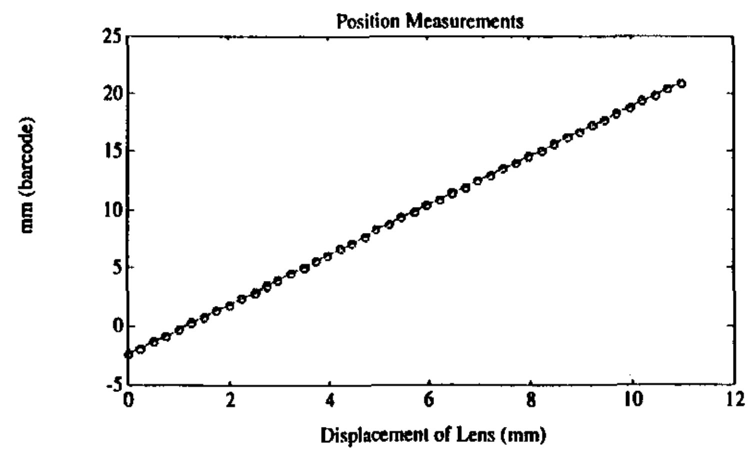
9 meter optical baseline; 15 frames averaged at 1 Hz; PostScript barcode



Sample data frame; X Projection

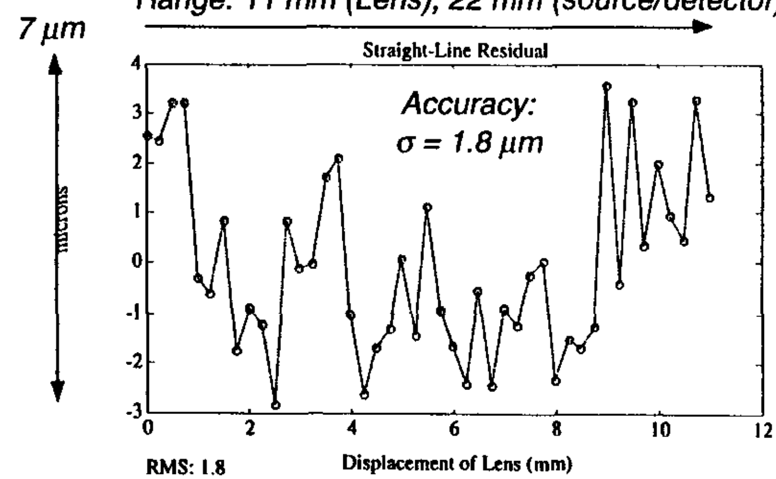


Average Barcode Digits



Measurement vs. Micrometer Position

Range: 11 mm (Lens), 22 mm (source/detector)



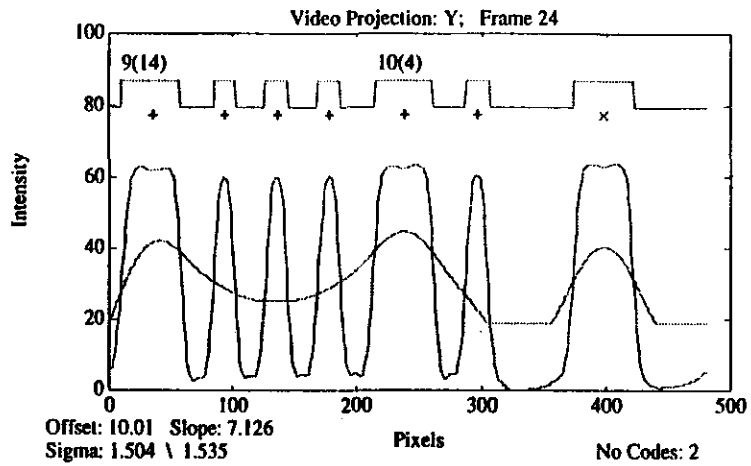
Deviation from Linearity

GEM

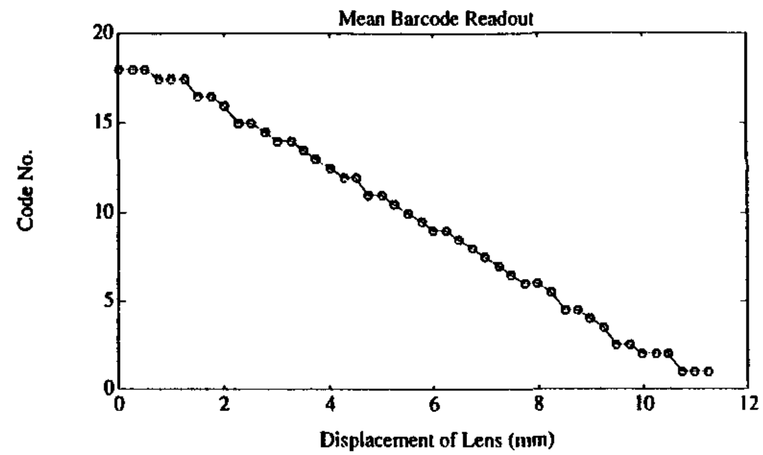
Note: Scale and Offset both determined in frame coordinate fits

VSM Performance; 1.2 cm Y-Coordinate lens scan, Chinon mini-camera

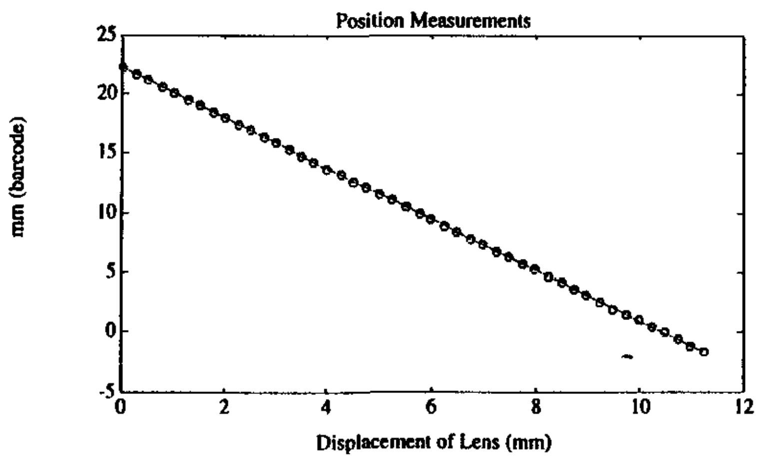
9 meter optical baseline; 15 frames averaged at 1 Hz; PostScript barcode



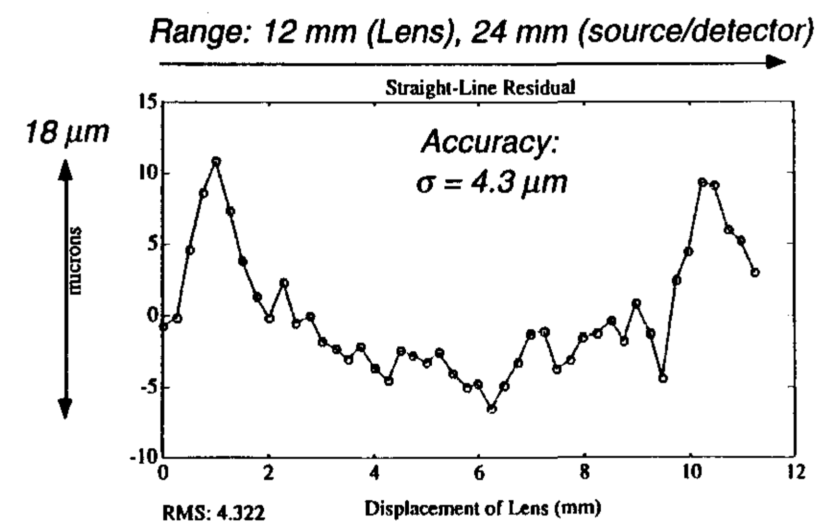
Sample data frame; Y Projection



Average Barcode Digits



Measurement vs. Micrometer Position



Deviation from Linearity

GEM

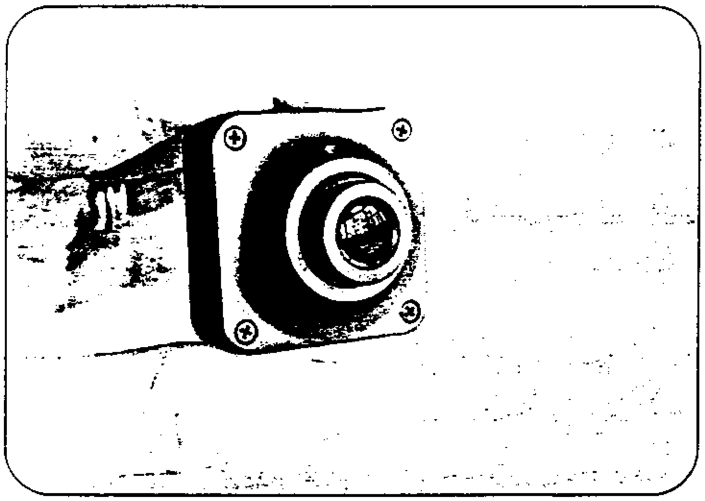
Note: Scale and Offset both determined in frame coordinate fits

>200 units: Chip = £ 29.-
PCB = £ 9.-
Full Camera = £ 55.-

VVL

→ Can be made to work in B
→ Low-Noise Design

Meet the *Peach* video camera...



Peach is a different kind of 35mm camera; its external profile is 35mm square! This tiny technological miracle runs off a single DC supply, outputting a CCIR-compatible (625-line) monochrome video signal.

Peach features include:

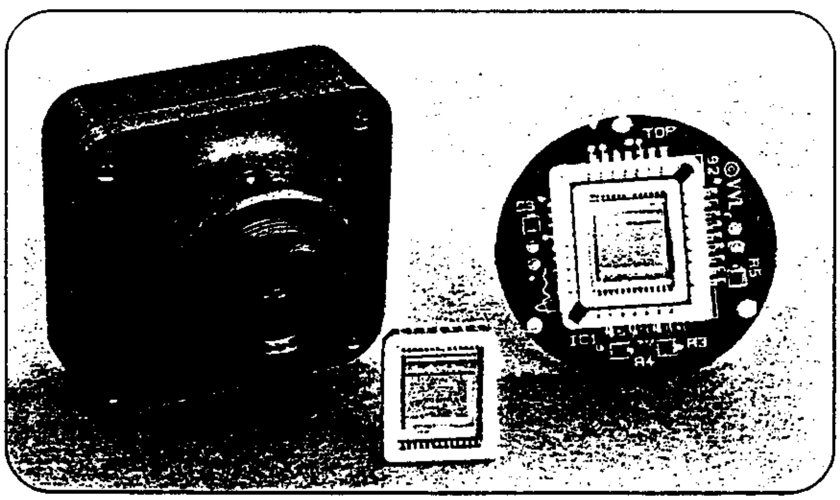
- 89,500 pixel resolution (312 x 287)
- electronic exposure and gain control
- operation down to 5 lux
- 78° field of view
- 40mA nominal supply current
- totally self-calibrating
- control in/out for digital video

Unprecedented integration of electronic vision function on a single CMOS silicon chip – ***VVL's*** ASIS-1011-B – means that ***Peach*** is completely self-calibrating, and capable of over 15 hours continuous operation from an alkaline PP3 battery. Along with a 1/2" format image sensor array, ASIS-1011-B includes the circuits which control and read the array, plus a comprehensive control input and output set for digital video applications.

Such versatility combined with amazingly low cost, size and power consumption makes ***Peach*** a juicy proposition indeed....

...and the ~~pip~~ chip inside!

Now OEMs can enjoy the cream of chip technology on which ***Peach*** is built. The ASIS-1011-B video camera chip is available by itself or mounted on an evaluation PCB. Developers of low-cost, low size and low-power vision applications, such as robot eyes, computer input devices or CCTV, need look no further than ASIS-1011-B for robust and flexible image sensing function.



Contact: VLSI Vision Ltd.
Aviation House
31 Pinkhill
Edinburgh EH12 8BD

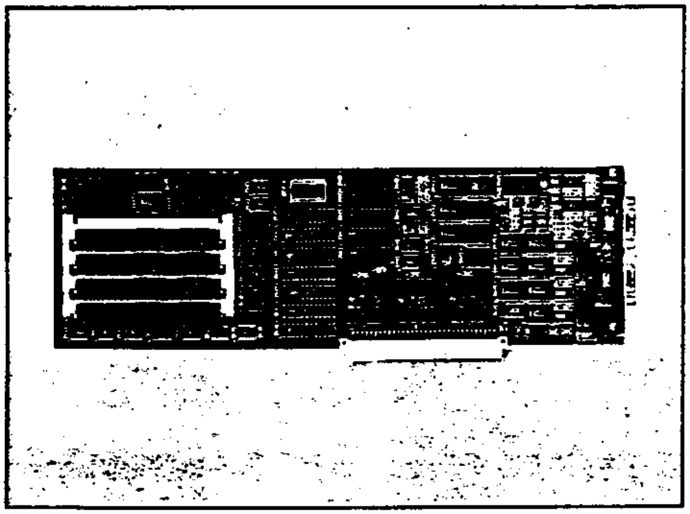
Telephone 031-539 7111
Facsimile 031-539 7140

Scion Corporation

$815.-
+$75. (cable kit)

1 unit does entire ATS!

LG-3



Features

- Low-noise 8 bit grayscale image digitizer
- Captures 640 x 480 frames in 1/30 of a second
- Expandable frame buffer — 1 MByte to 64 MBytes
- Captures complete frames or single fields
- Software control of range of digitization
- Up to 4 input sources — select sync from any source
- Analog and digital I/O capabilities
- Compatible with all Macintosh II or Quadra computers
- Supported by many popular image analysis packages
- Full 30 day money back guarantee of satisfaction

The LG-3 is a scientific quality frame grabber suitable for use with high end CCD cameras and other imaging equipment. Images are captured in 8 bit depth at a speed of 1/30 of a second. Image resolution is 640 x 480 pixels.

Images are captured to the LG-3's expandable on-board frame buffer. This buffer, expandable from 1 to 64 MBytes, is composed of standard Macintosh SIMM's for easy field upgrades. SIMM's 100 ns or faster may be used.

The LG-3 provides features which make it particularly suited for use by developers of custom configurations. Four TTL input lines and four TTL output lines are available for monitoring and controlling external events. Also provided are two analog outputs which may be varied from 0 to 5 Volts in 256 steps.

The LG-3 allows software control of gain and offset through control of the range of digitization. The digitized data may be modified using one of eight input look-up tables. Images are captured from one of four input sources, and the sync information may be selected from any of the input sources.

Full capturing flexibility is provided. Frames may be captured with either the even or the odd field first. Single fields may also be captured, with either the even or odd field specified. The LG-3 allows software to detect video information such as field status and vertical sync.

The LG-3 ships with a cable and a copy of the "Image" software package developed at the National Institutes of Health. In addition the LG-3 is supported by a variety of other third party image analysis packages.

Specifications

Digitizing Speed: 1/30 second
Pixel Depth: 8 bits
Image Resolution: 640 x 480 pixels
Pixel Aspect Ratio: 1 to 1

Capture Mode: field or frame
Initial Field: even or odd

Frame Buffer: 1 to 64 MBytes
Input Look-up Tables: 8
Input Sources: 4, AC coupled

Digital Inputs: 4 TTL level
Digital Outputs: 4 TTL level
Digitizing Range, Bottom: 0 to 2 Volts
Digitizing Range, Top: 0 to 2 Volts
Analog Outputs: 2, 0 to 5 Volts

Video Input Level: 1 Volt peak to peak
Video Signal Type: RS-170 or similar

Installation: 1 NuBus slot
Video Connector: 9 pin D shell
Utility Connector: 15 pin HD D shell

Operating Conditions : 0 to 70° C
Power: 12.5 Watts maximum

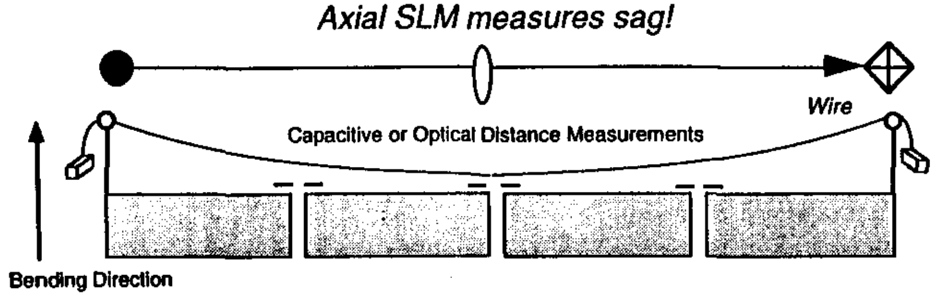
System Requirements and Support

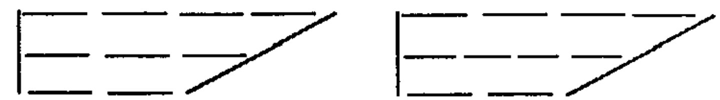
The LG-3 is compatible with all Macintosh II and Quadra family computers and may be used with grayscale video sources having RS-170 timing characteristics. It is designed for use with high-quality CCD imaging equipment, and as such incorporates no time base correction.

The LG-3 comes with a complete 30 day money back guarantee. The LG-3 is warranted against defects in materials and workmanship for a period of one year. An extended warrantee is available.

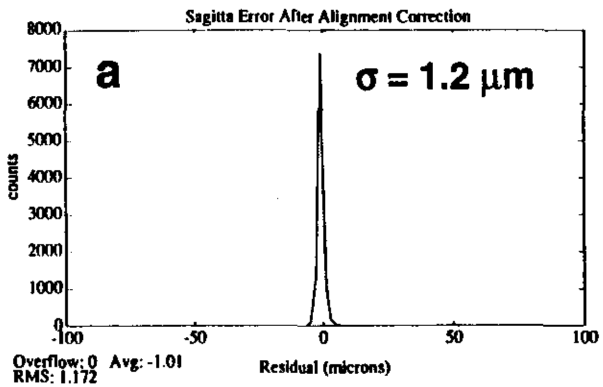
Scion Corporation
152 West Patrick Street Frederick, Maryland 2170?
Tel: (301) 695-7870 Fax: (301) 695-0035 AppleLink: D1337

Hybrid Wire Monitors Revisited

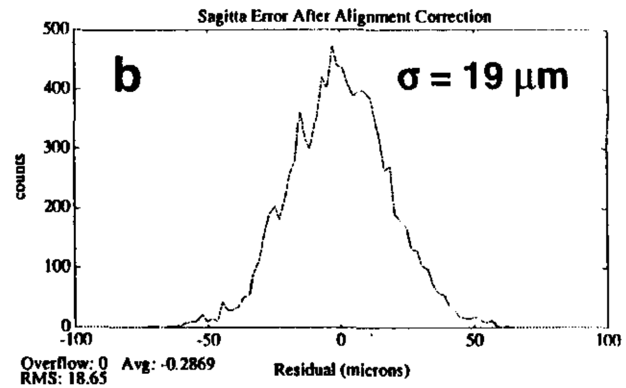




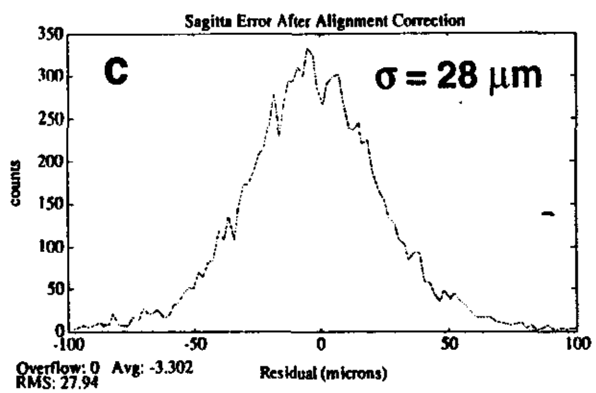
Note: BL1 Used **Not TDR**



Ideal; no SLM, Projectivity errors

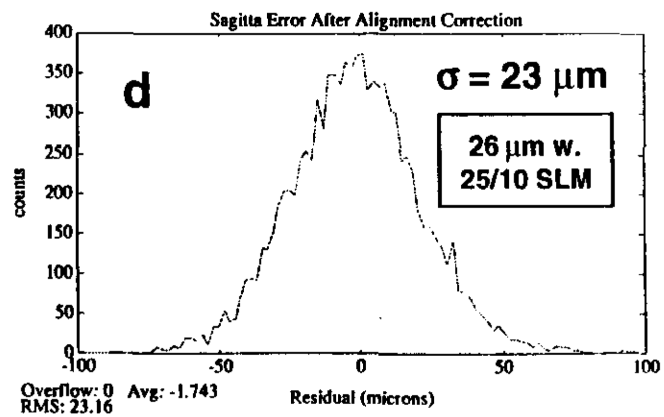


25/10 μm SLM, 15/10 μm wire, 10 μm handoff



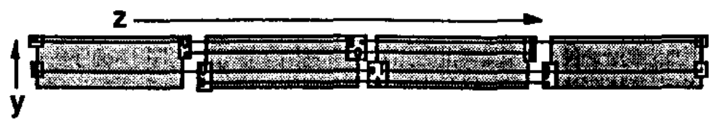
Projectivity, Bunch smear, 60% ϕ spacing

**Note:
300 μm Δy resolution produces little difference after other errors!**



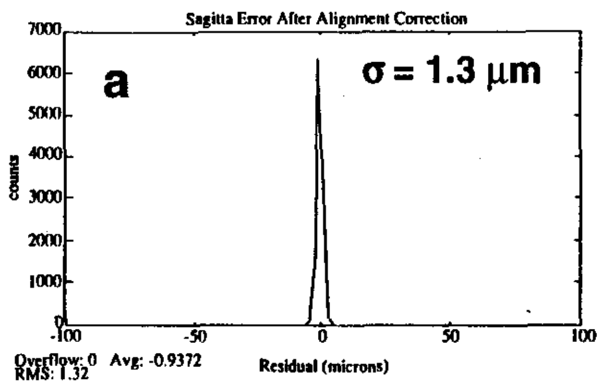
12/10 μm SLM, 10/5 μm wire

Hybrid Nested Optical Monitors Revisited

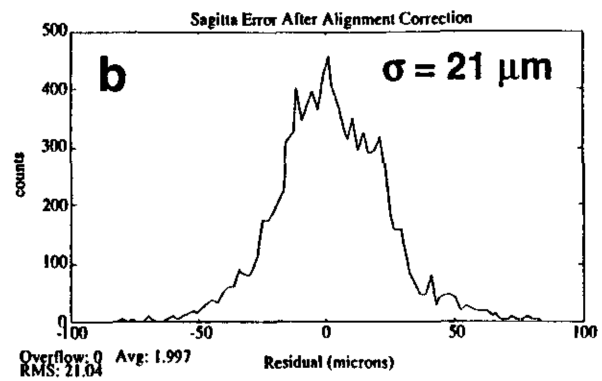


Again, BL1 not TDR!

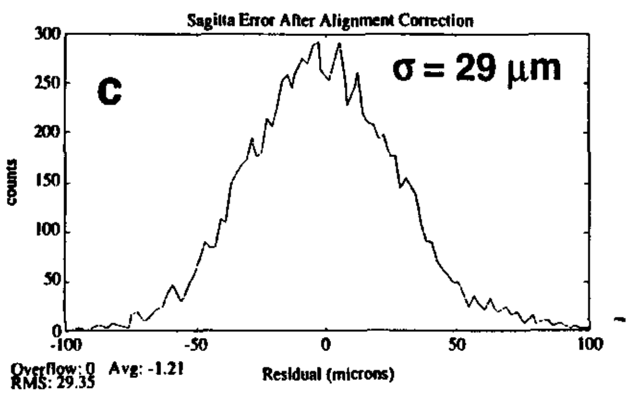
2 Sets of nested straight ness monitors for opposite corners



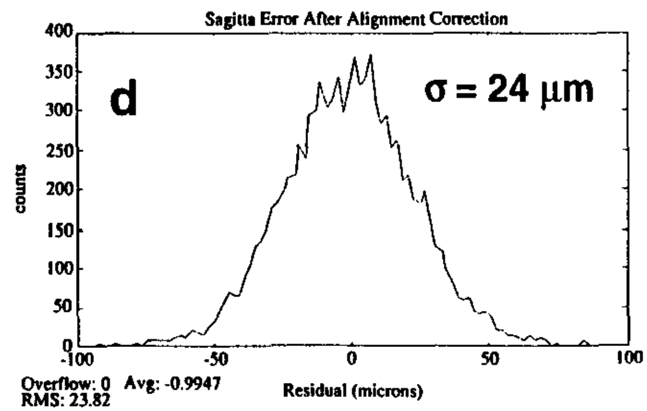
Ideal; no SLM, Projectivity errors



25/10 μm SLM 10 μm handoff



Projectivity, Bunch smear, 60% ϕ spacing



12/10 μm SLM

Endcap chambers alignment

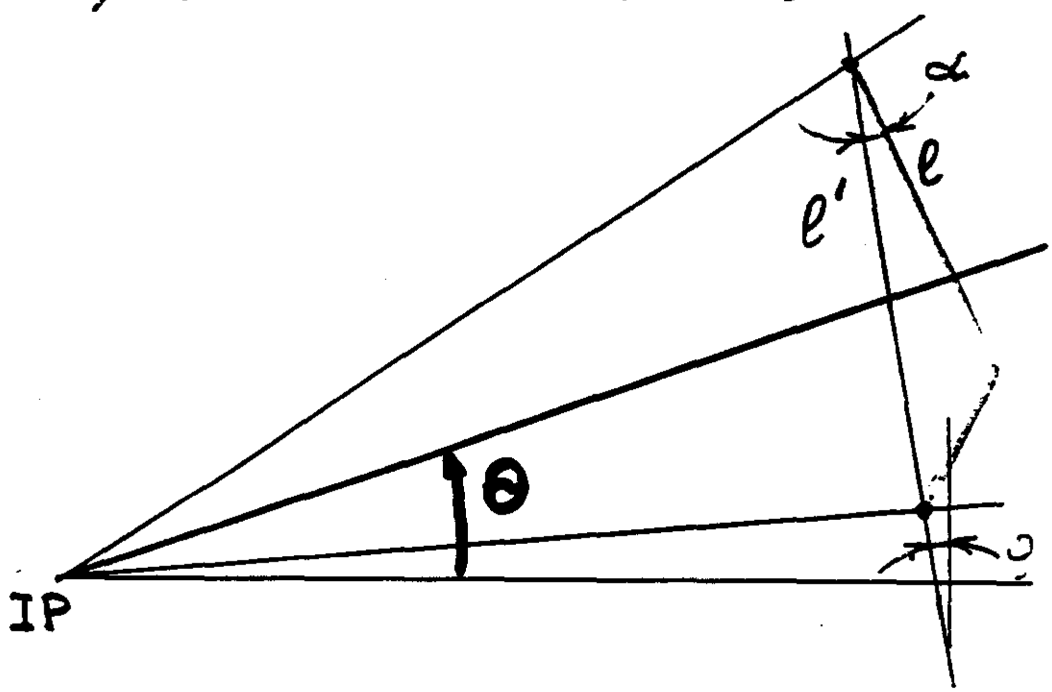
Differencies from BARREL:

- 5-point option
- Two chambers per SL

  Angle between the chambers is measured by planar monitors

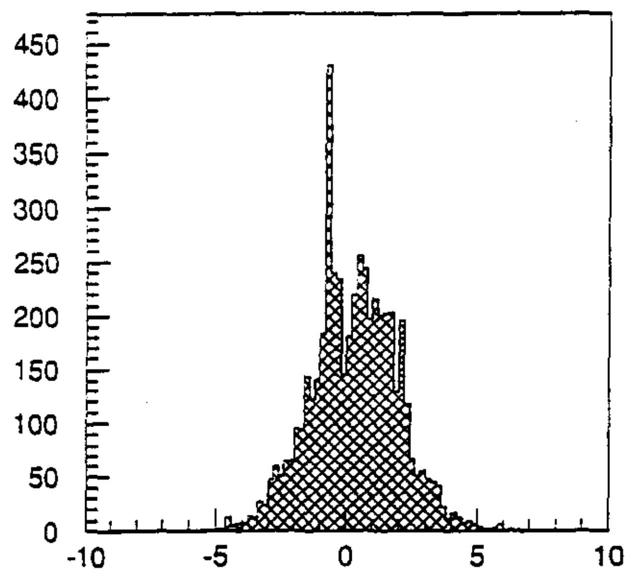
The false sagitta method assumes that chambers are flat ⇒

⇒ introduce "PSEUDO-CHAMBER FRAME"



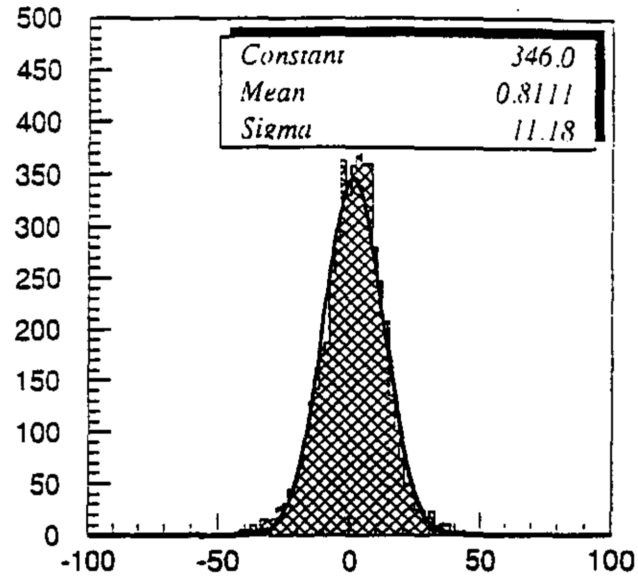
$$\ell' = \ell \cdot (1 + tg(\theta + \varphi) \cdot \alpha)$$

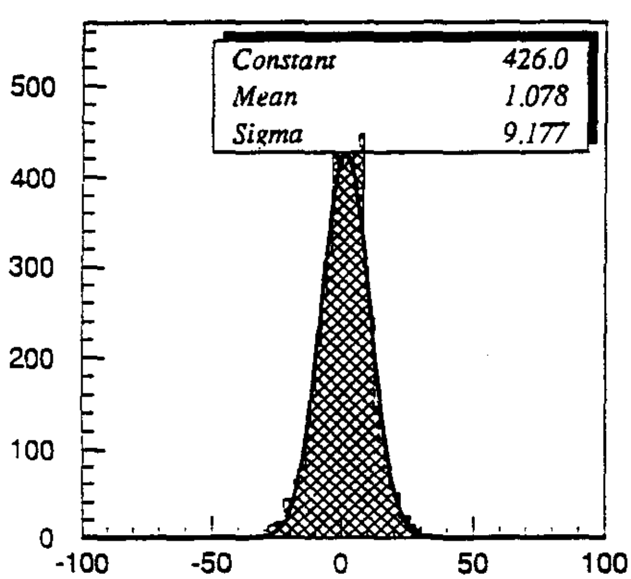
False sagitta



corrected saggita

5-point option

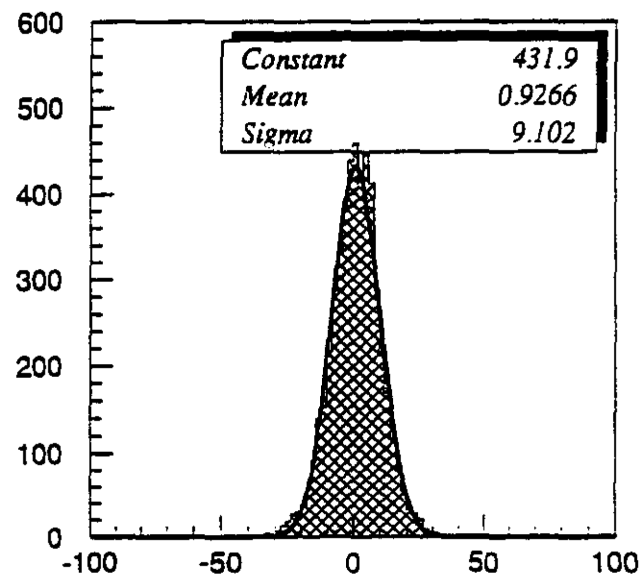




corrected saggita

5-point option with

planar correction

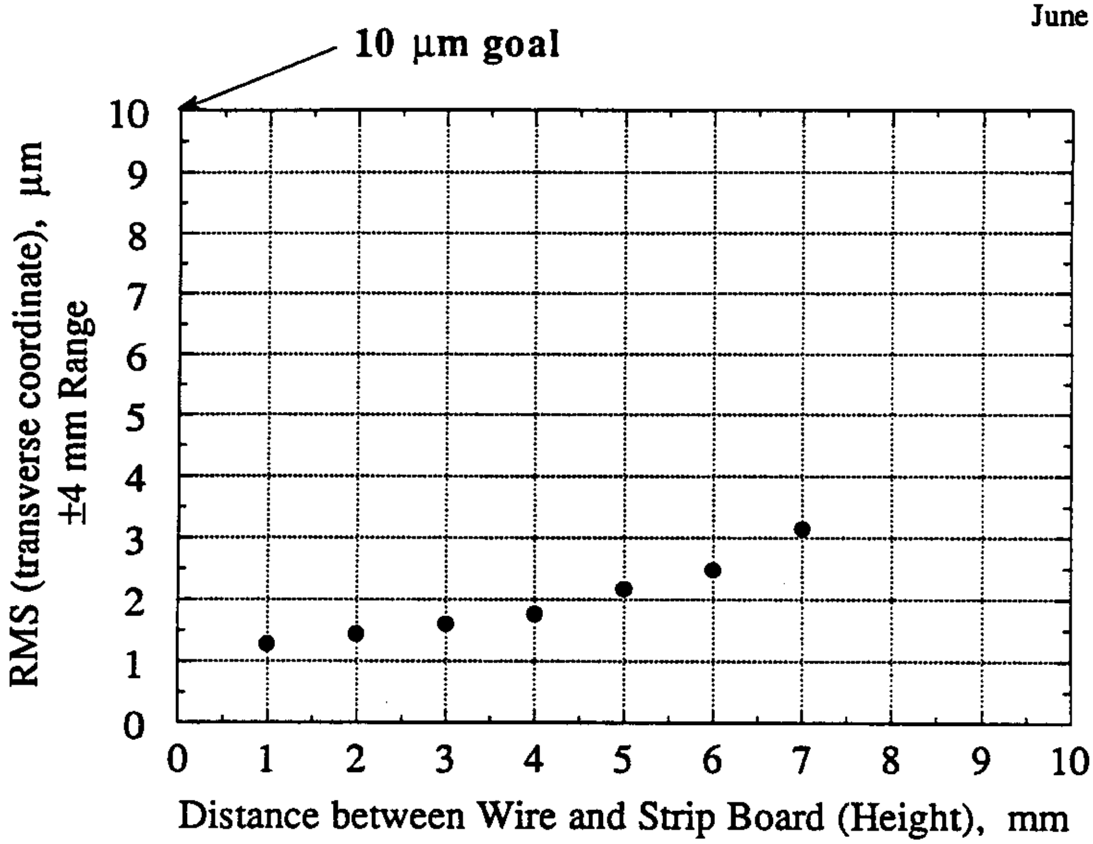


corrected saggita

only shifts and rotations

RESULTS OBTAINED WITH 11 (1 mm wide) STRIPS

June 24, 1993



A. Korytov

Modular Barrel vs Integrated Monolith

- Structure assembly (barrel)
- Chamber Insertion (barrel)
- Chamber Insertion (endcap)
- Monolith Assembly (barrel/endcap)
- Installation
- Commissioning
- Coverage
- Structure Performance

Structure assembly (barrel)

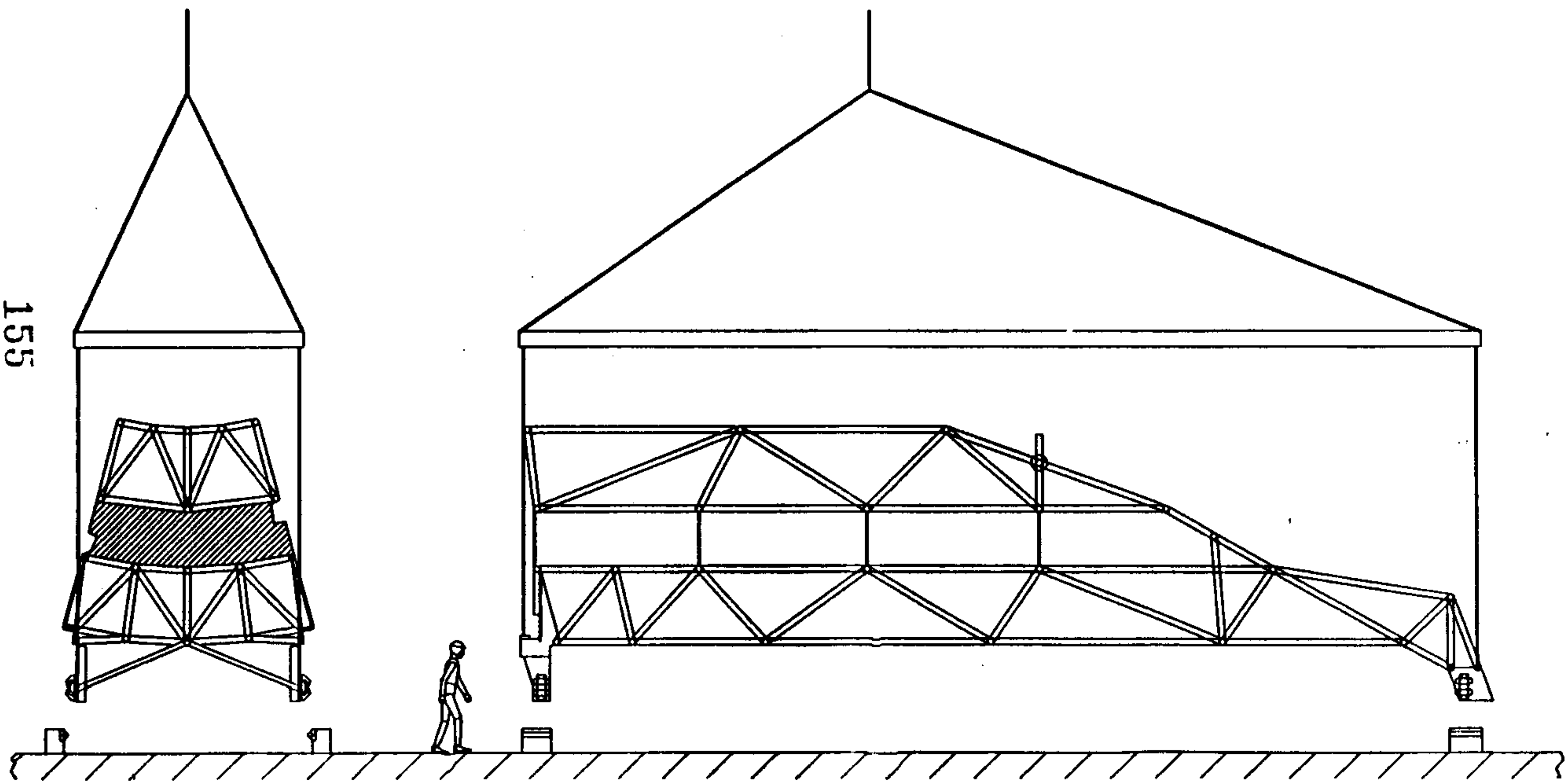
gem γeμ

MODULAR

- Module concept permits the complete assy of structure associated with a three-layer measurement unit
- Module structure can be fully evaluated before insertion of chambers.

INTEGRATED MONOLITHIC

- Integrated monolith has elements of reticulated shells and diaphragms as the subassemblies which are then merged into full shells and diaphrams,(still no complete structure!)
- Optimized structure creates assembly differences in the various subassemblies whose effects will not be evaluated until completion of the major assemblies.



ASSEMBLED BARREL MODULE STRUCTURE

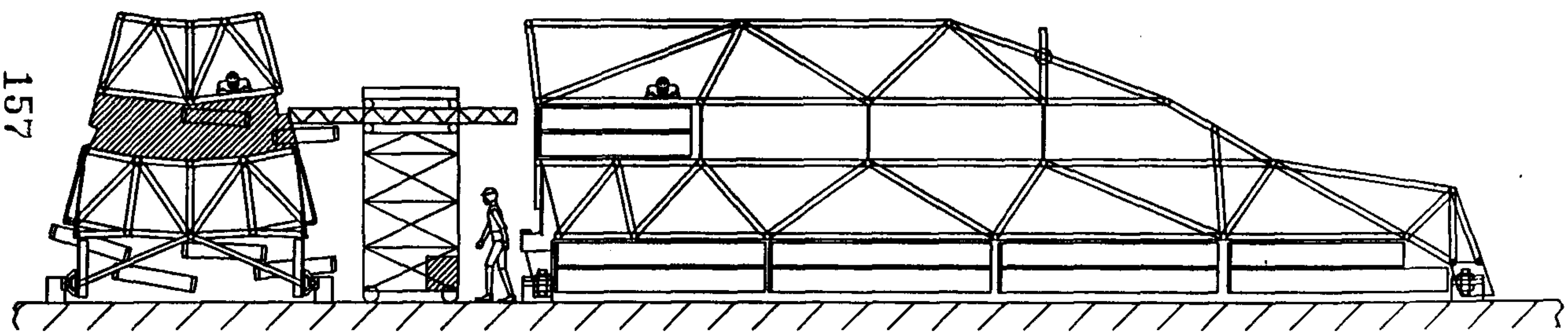
Chamber Insertion (barrel)

MODULAR

- Modular design permits easy access for all three layers to insert chambers into fully assembled modular structure
  - All three layers that make up a measurement unit can be inserted with simple fixtures at relatively low elevations. (repeatable, easily measured and verified).
  - Requires several size chambers to be available to complete module assembly.
  - Barrel module is complete and commissionable!!

INTEGRATED MONOLITH

- Chambers are installed in layers a process where the structures are rotated about a large shaft to permit repeatable and simple installation process.
- Process requires that chambers for specific layers be available in adequate numbers to complete major assemblies.



ASSEMBLY OF CHAMBERS
INTO
SUPPPORT STRUCTURE

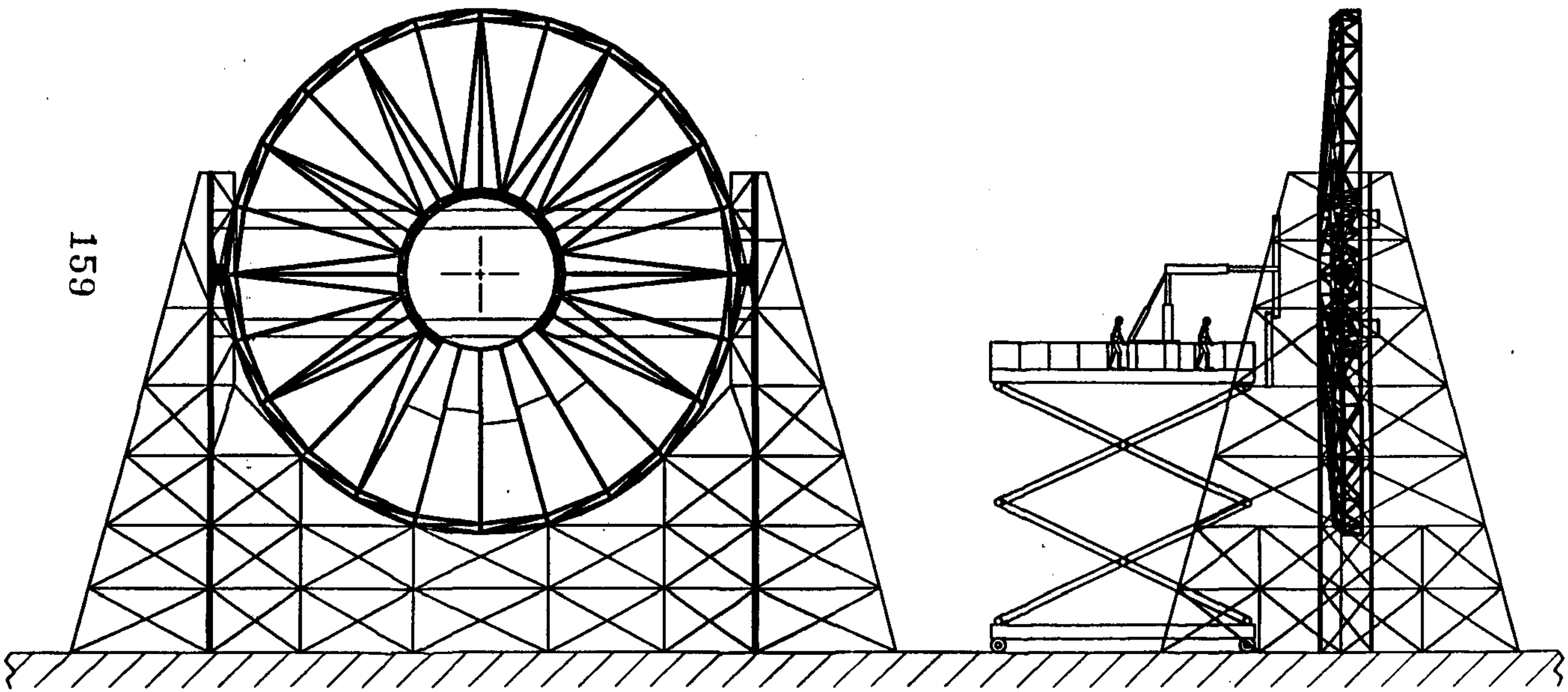
Chamber Insertion (endcap)

Modular endcap (three wheel assemblies)

- Support Structure is assembled before insertion of chambers
- Three wheel assemblies allow simple insertion of chambers on both sides of wheel structure
- Wheel assemblies do require fixturing for stabilization during the insertion process
- Services can be attached by the layer rather than the three-layer grouping. Same as Integrated Monolith.
- Chamber insertion done in NAB.
- Installation "Staged" should be much faster than IM

Integrated Monolith

- Chambers are either inserted in the middle of the assembly of integrated structure or in a slightly more difficult procedure relative to the Modular Endcap.
- Option exists for install chambers through the structure in the underground hall.
- Option requires separate chambers radially (BETTER CHAMBER STRUC TURE)



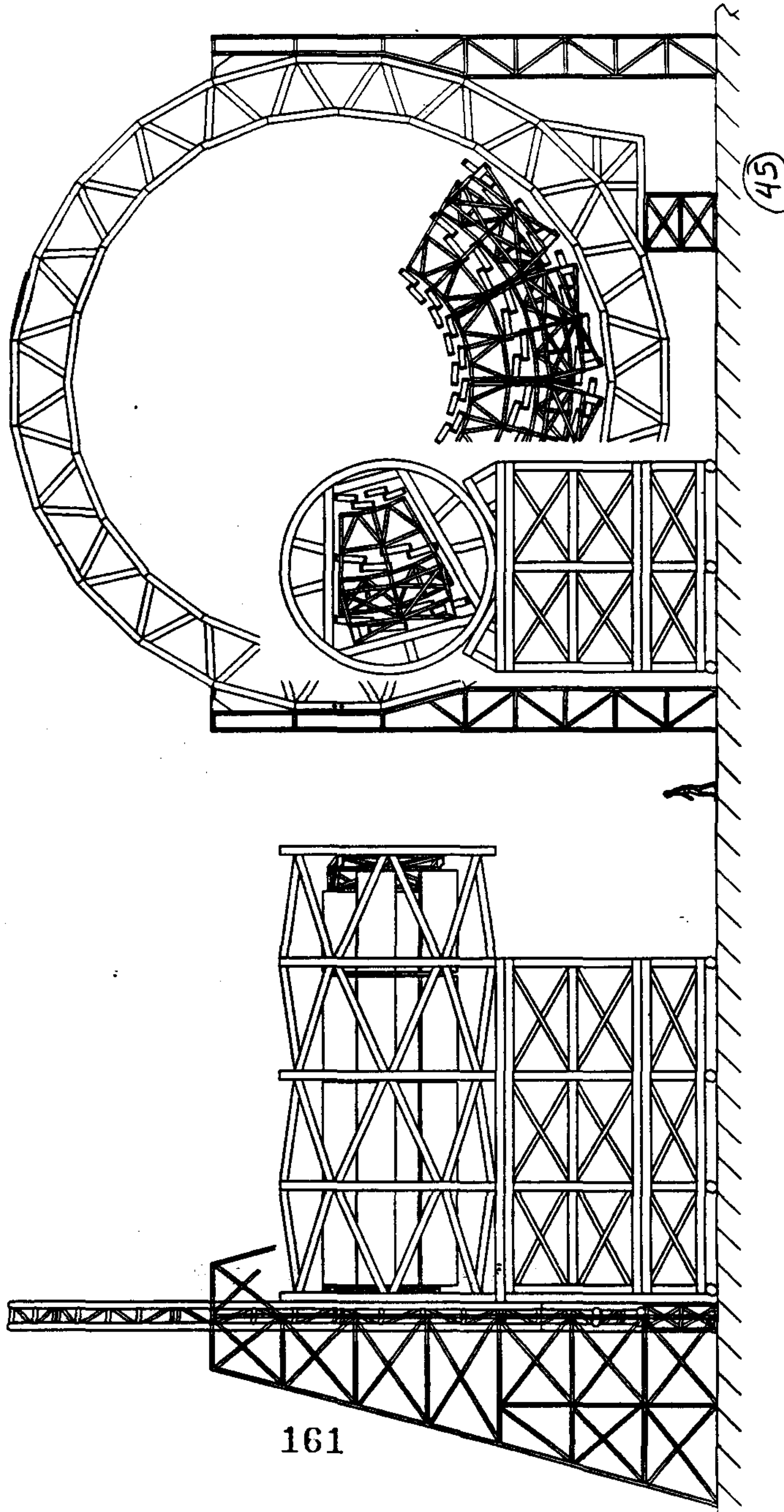
ASSEMBLY OF CHAMBERS
INTO
OUTER SUPERLAYER

Monolith Assembly (barrel/endcap)

160

MODULAR

- Barrel Monolith requires two end support rings and fixturing to complete assembly of the twelve modules into an monolithic barrel structure.
- Local alignment,IF MAINTAINED IN ASSY.,offer significant advantage (R&D on prototype should resolve issue).
- Assembly merges prealigned modules with two preassembled and braced end ring support structures.
- Individual modules can still be adjusted as an assembly after all 12 modules per monolith assembly have been inserted and the support rings are deformed in their final configuration.
- Endcap monolith is assembled in NAB, installation is planned using the FFS as a transport tool to insert endcap into barrel, transfer load and connect with barrel to merge structures.


45

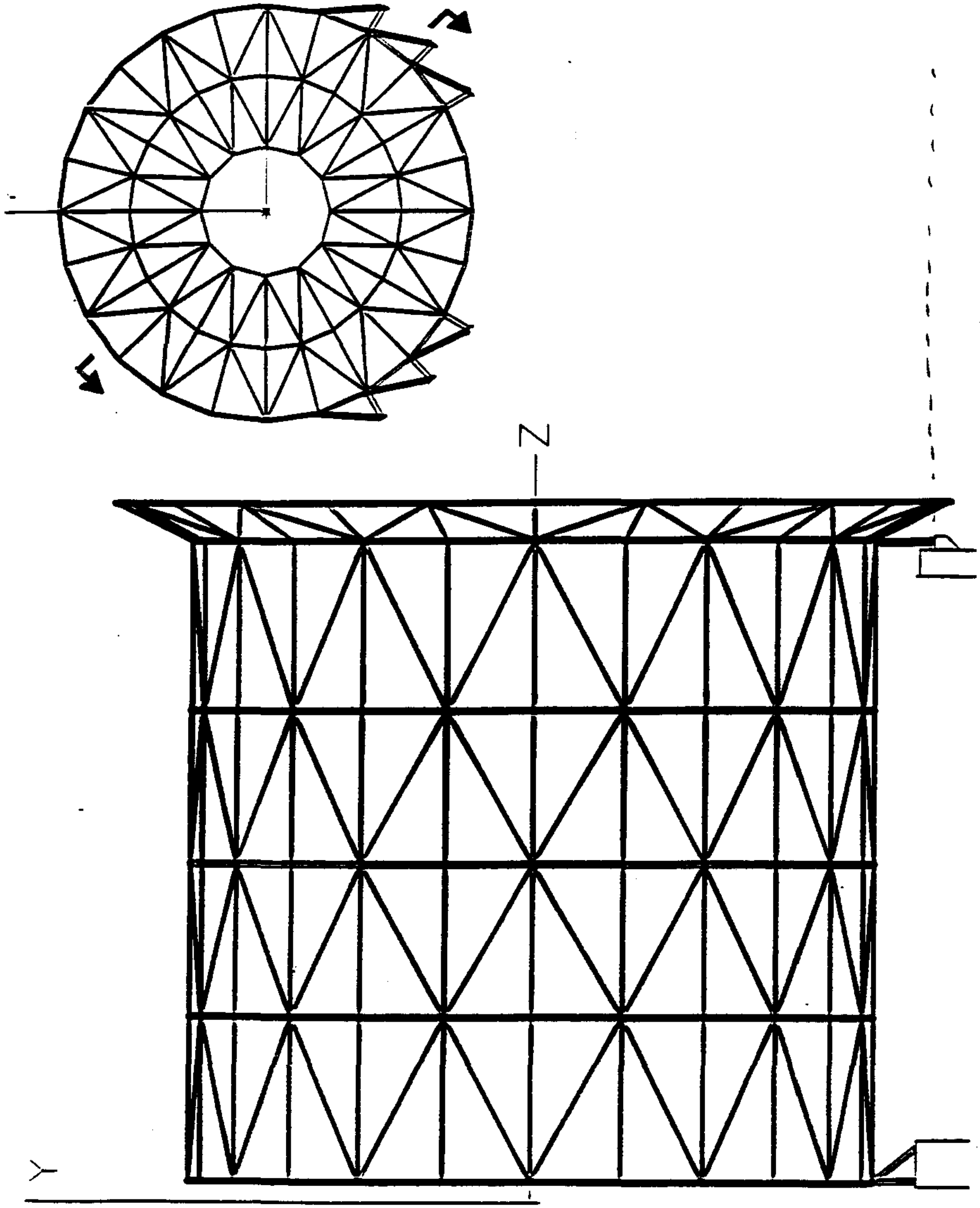
Installation

MODULAR

- Options exist to install either a barrel monolith followed by a completed endcap later or as a complete assy.
- FFS Ring requires no additional structure for installation (Unified Monolith appears to need extensions for installation)
- Z-restraint does not sacrifice coverage for this function as in the the case of the IM concept.
- Z-Restraint used by "IM" could be partially used at the same loss of chamber coverage as for the "IM" concept.
- EITHER Z-RESTRAINT WILL PROBABLY WORK WITH EITHER STRUCTURE!!

INTEGRATED MONOLITH

- Essentially the same concept of installation.
- Z-restraint chops off 6-12 chambers on the CDS end
- Unclear how installation actually can be done with the present rail concept (APPEARS TO NEED HARDWARE TO PROVIDE TEMPORARY ATTACHMENTS ON FFS END OUT BEYOND THE STRUCTURE THAT HOLDS SL3 ENCAP CHAMBERS IN ORDER TO GET TO A RAIL WHICH WOULD CLEAR THIS STRUCTURE DURING INSERTION!)



Supports for Muon Subsystem Structure

Commisssioning

MODULAR

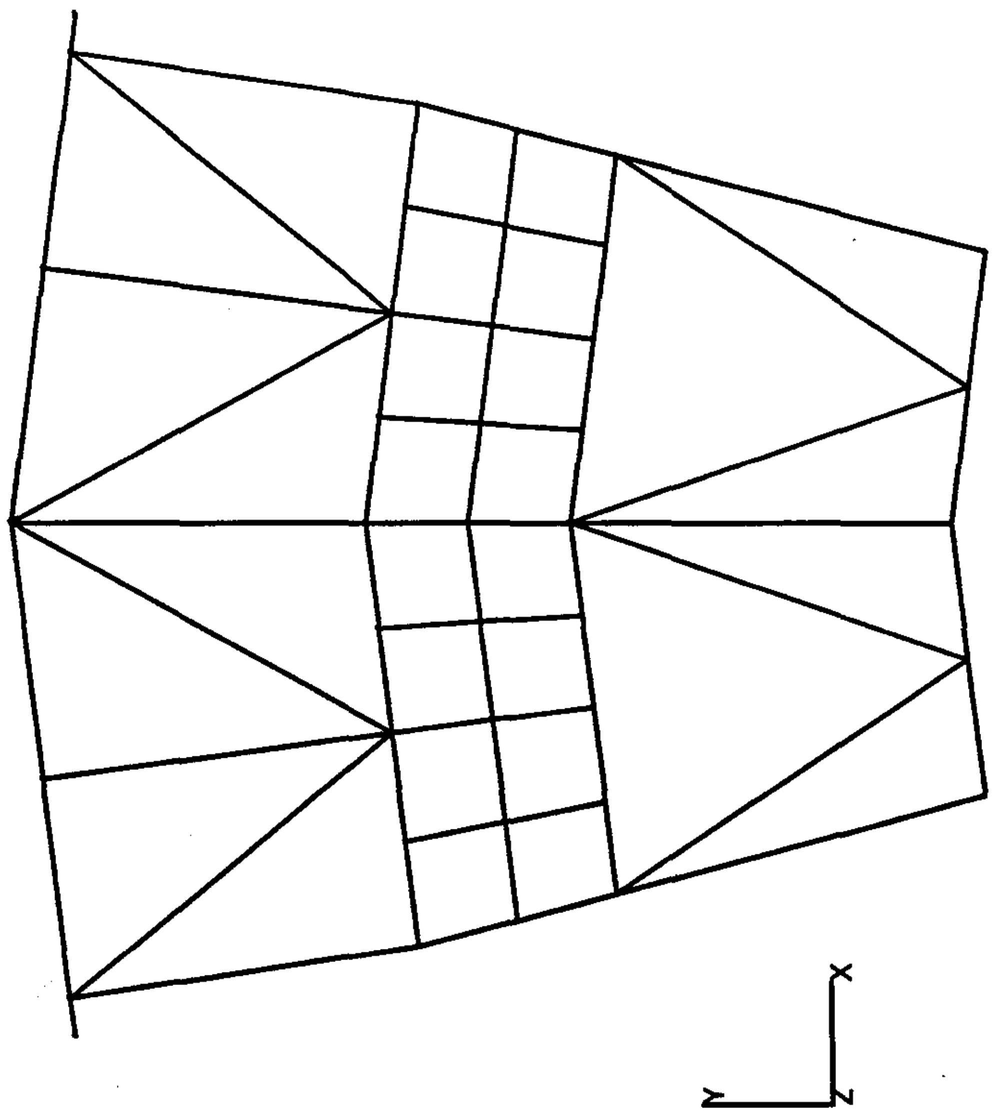
- Modules are essentially commissioned at the module level along with addtional checkout time during the Monolith Assembly phase. These are complete system checkouts up to the final manifold and junction boxes.
- Final commissioning should be limited to the final connections of cables to the magnet mounted service junction boxes.

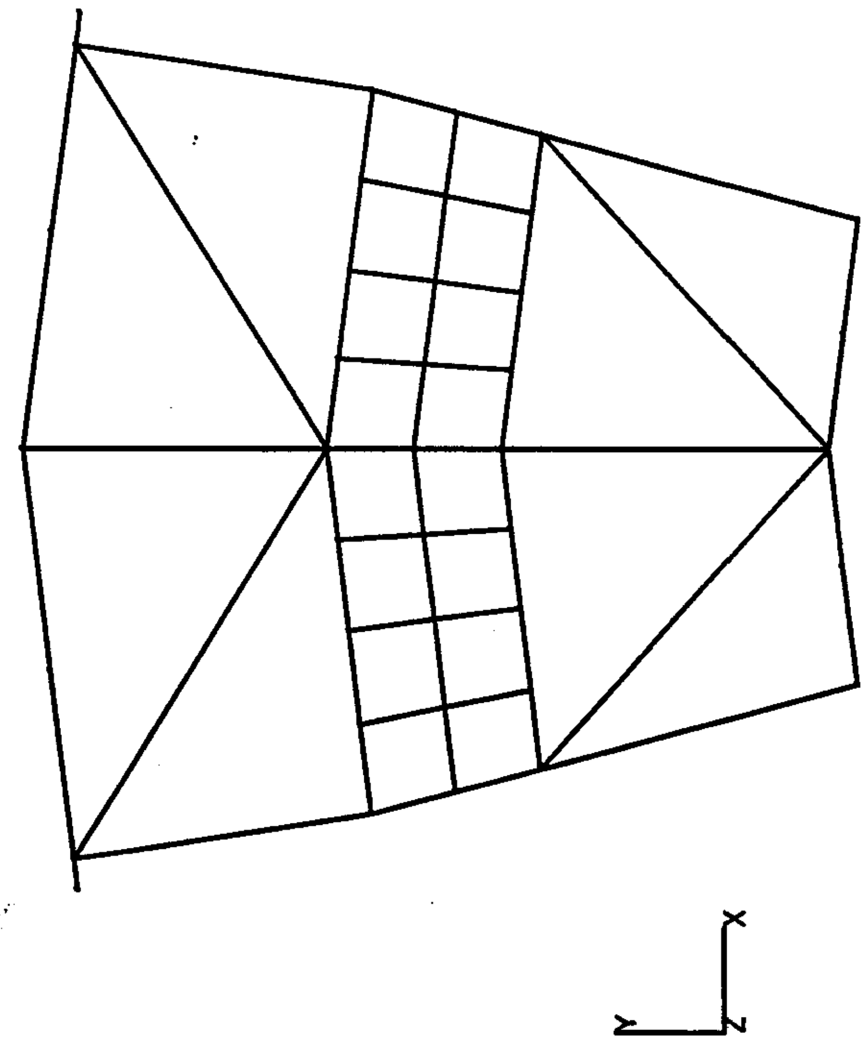
INTEGRATED MONOLITH

- Commissioning can perhaps be initated as the chambers are attached to the various superlayers(similar to the situation of the endcap monolith in the modular concept)
- Evaluation of entire three-layer measurement units cannot start until the unified monolith is completely assembled.

ACCESS

- EITHER THE IM OPTION OR A AN OPTIMIZED MODULAR WILL PROVIDE VERY SIMILAR SPACE FOR ACCESS. REAL ACCESS PROBLEM IS PLACEMENT OF SERVICABLE ITEMS ON CHAMBERS SO THAT THEY CAN BE REACHED FROM THE VARIOUS STRUCTURE SITES.


X
Y
Z


X
Y
Z

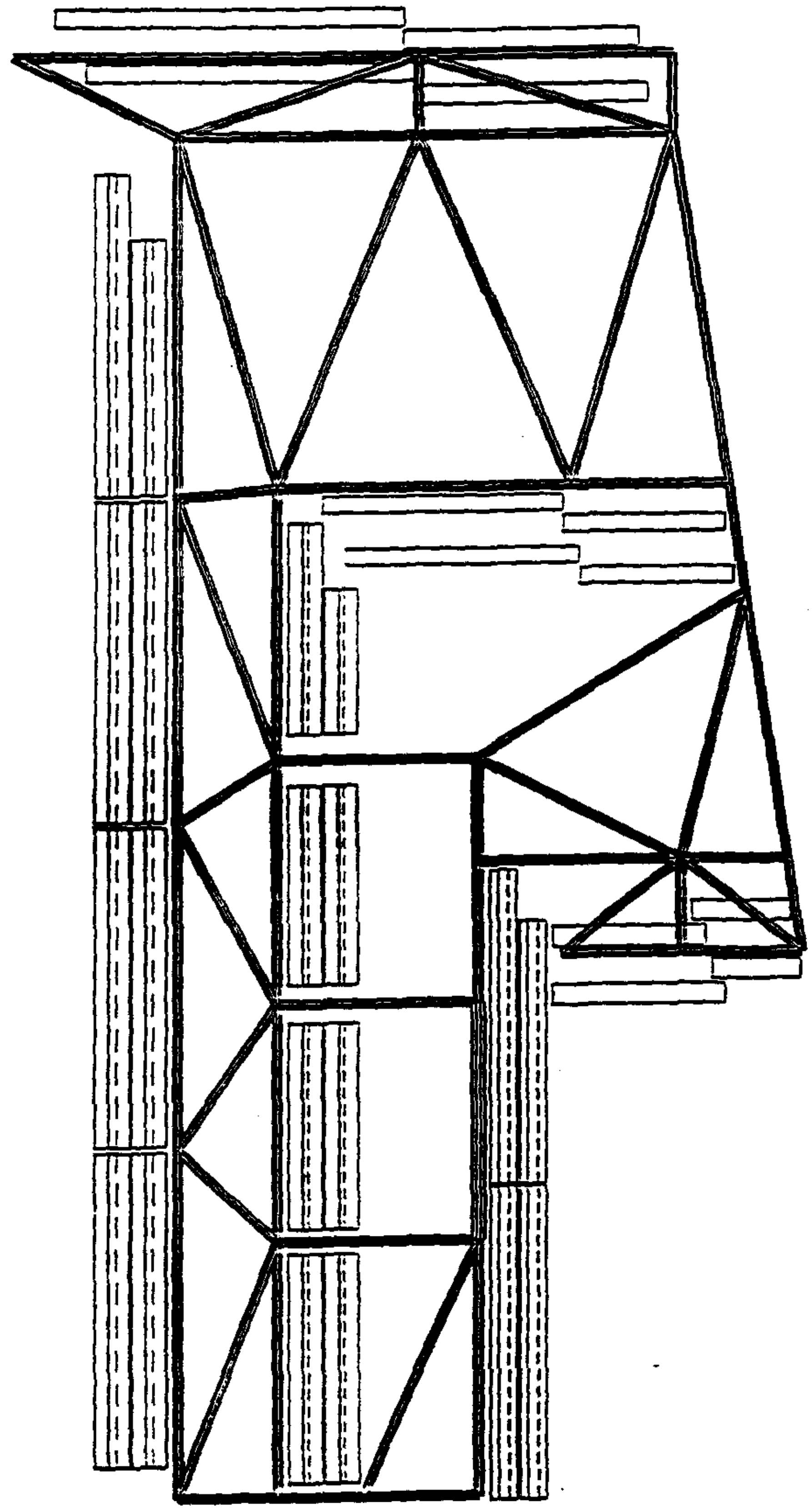
Coverage

MODULAR

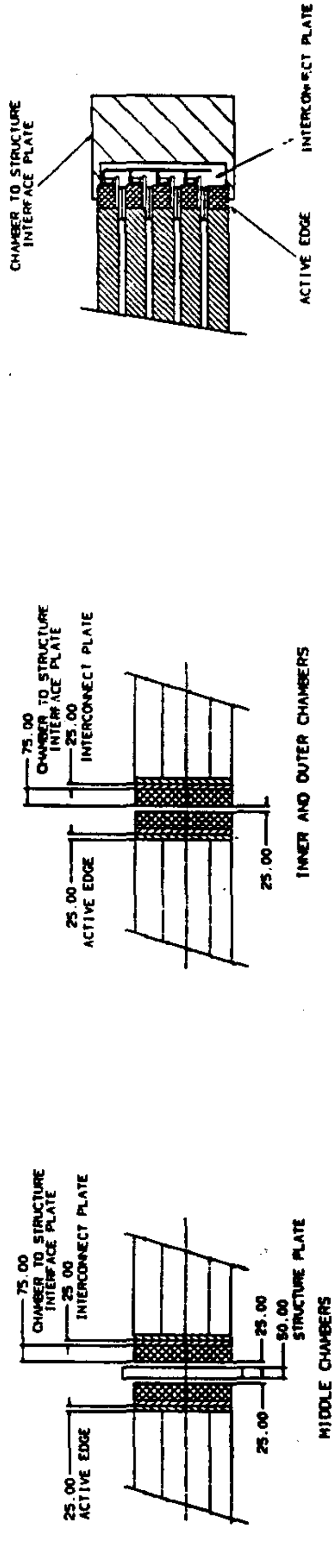
- Gap at 30° must allow for at least the structure in the barrel plus two alignment lines of sight (best is 1.4°) ← Middle Layer of chambers
- Gaps in barrel must allow for passage of plate structure between chamber ends (50mm total 25 mm structure plus 25mm per side for clearance)

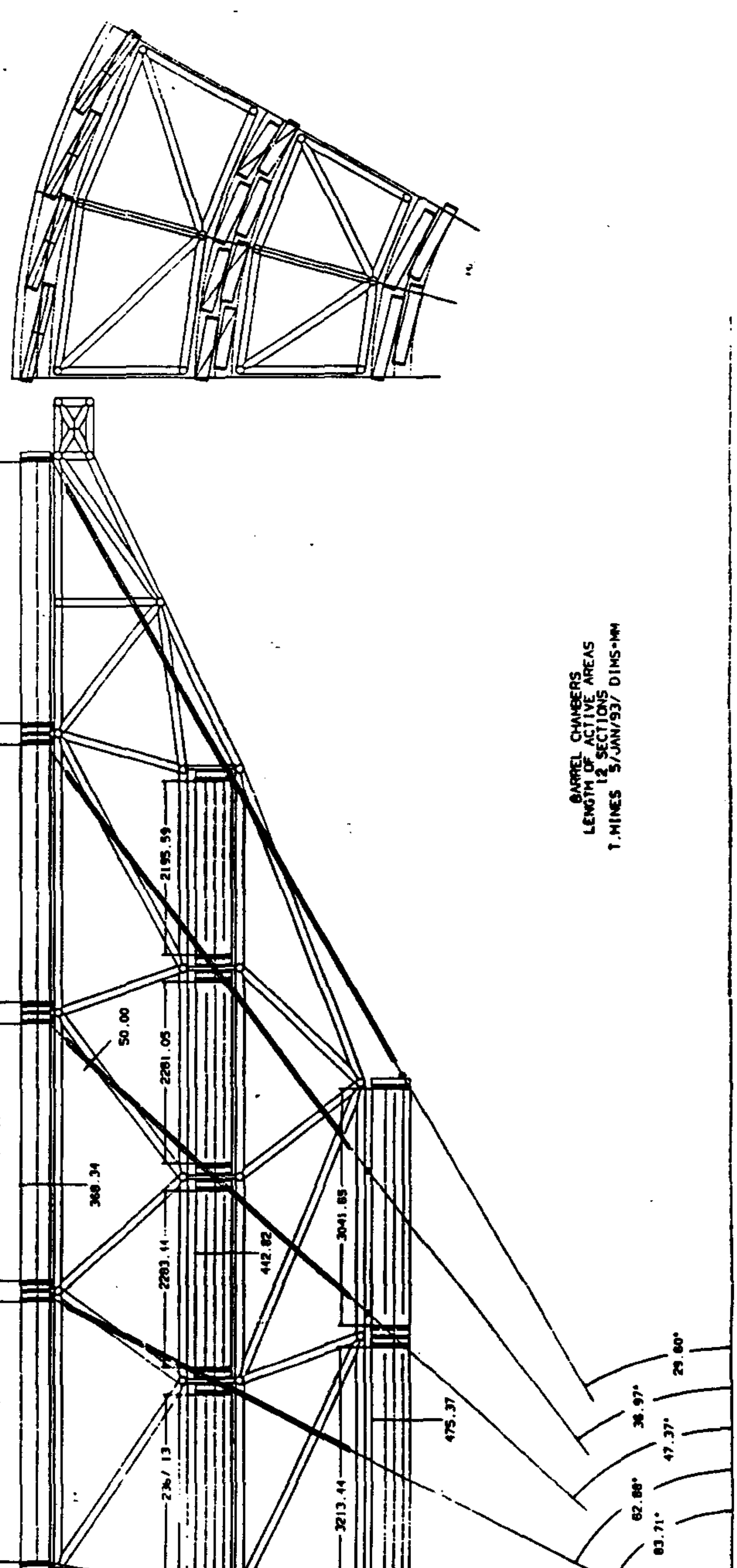
INTEGRATED MONOLITH

- Gap at 30° can be as small as 0.5° ← ?
- Similar restriction to Modular in barrel for MIC1 concept
- Barrel gaps in MIC2 concepts can be reduced by another 25 mm from the Modular concept.



Quadrant Elevation View of MICI Muon Subsystem Structure


CHAMBER TO STRUCTURE INTERFACE PLATE
INTERCONNECT PLATE
ACTIVE EDGE
75.00
CHAMBER TO STRUCTURE INTERFACE PLATE
25.00
INTERCONNECT PLATE
25.00
ACTIVE EDGE
25.00
INNER AND OUTER CHAMBERS
75.00
CHAMBER TO STRUCTURE INTERFACE PLATE
25.00
INTERCONNECT PLATE
25.00
50.00
STRUCTURE PLATE
25.00
ACTIVE EDGE
25.00
MIDDLE CHAMBERS


3273.77
3271.13
3274.35
3308.68
2195.59
2281.05
2283.14
2361.13
50.00
368.34
442.82
3041.65
3213.44
475.37
29.60°
36.97°
47.37°
62.88°
83.71°
BARREL CHAMBERS
LENGTH OF ACTIVE AREAS
12 SECTIONS
T.MINES 5/JAN/93/ DIMS-MM

Structural Performance

- **Material in the detector**

  Modular Structure (TDR) in detector (65300 Kg.)

  Expected Structure Mass Full Optimized (49000 Kg.)

  Integrated Monolith Structure mass (37000 Kg., MIC1)

  Uniformity of Mass with Phi (good with Modular)

  Uniformity of Mass for Unified Monolith is limited by optimization of support structure.

- **Random vibration performance**

  Presentation of integrated Monolith utilized lower PSD input than was used to evaluate the TDR muon support structure.

  When TDR structure is excited with same base motion PSD as used for Integrated Monolith, TDR response is smaller than that of IM even comparing the MIC1 structure.

- **Is performance still going to be the "TOP DOG" of evaluation criteria?**

- **WHAT ARE THE IMPORTANT CRITERIA? WHAT ARE THE RELATIVE RATINGS??**

Complete Muon Chamber Support Structure

- Vibration Performance
  - Natural Frequency
  - Random Vibration

	First Nat'l Freq.	# Modes under 20 Hz	Random Vib Response (Barrel Monolith) • 1 milli g RMS	Random Vib Response (Barrel Monolith) • Magnet Supports
TDR Design	2.36 Hz	68	2.4 µm	25.0 µm
SGH Design	5.0 Hz	-	12.4 µm	
TDR Design w/8 Z constraints used by SGH	3.92 Hz	50	1.9 µm	23.4 µm

Muon System Weights

Barrel Mass Summary

- Barrel Module Structure — 4274 Kg.
- FFS Support Ring — 14700 Kg.
- CDS Support Ring — 5455 Kg.
- Barrel Module (w/chamb) — 11000 Kg.
- *Barrel Structure (modules TDR, half) — 51300 Kg.*
- *Barrel Structure (modules Opt,half) — 38500 Kg.*
- Barrel Structure (half) — 73400 Kg.
- Barrel Region (w/chamb, half) — 152200 Kg.
- *Barrel Structure (SGH Mono) — 37000-42000Kg.*

Endcap Mass Summary (half)

- Structure Mass (half) — 14000Kg.
- Total Mass (w/chamb, half) — 40300 Kg.
- Outer Wheel (struct/total) — 4000 / 18350 Kg.
- Middle Wheel (struct/total) — 2100 / 9900 Kg.
- Inner Wheel (struct/total) — 1100 / 5200 Kg.
- Outer/Middle Structure — 4650 Kg.
- Middle/ Inner Stucture — 1650 Kg

Total Struct. Mass in detector (MOD/TDR) 65300 Kg.
(Optimized MOD barrel, same endcap) 52500 Kg.
(Optimized MOD barrel and endcap) 49000 Kg.
SGH IM Min. 37000 Kg.
(25% less than Optimized MOD version)

M. MA...
6/29/93

COMPARISON OF TDR Structure with SGH Monolith

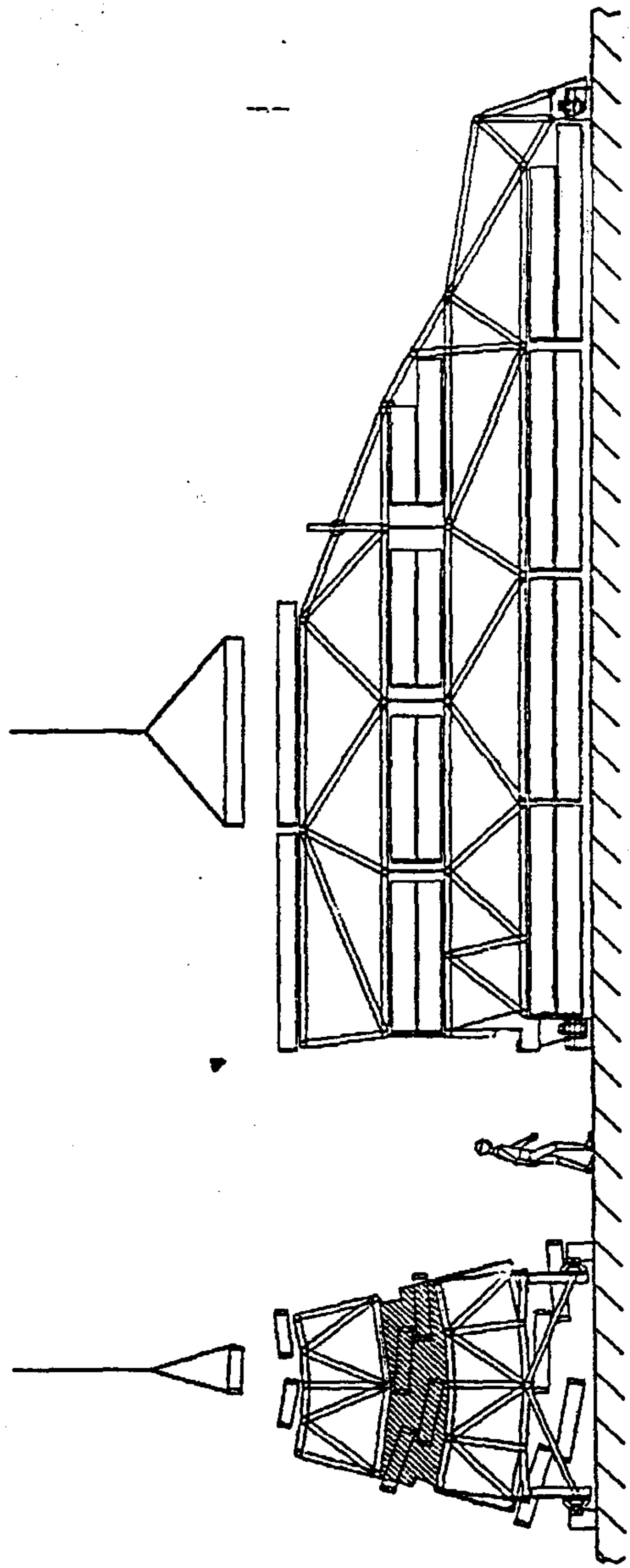
TDR	SGH
Separate End / Barrel	Integrated End / Barrel Structure
Built of Modules / Wheels	Monolith
Joined as Little as Required	Joined as Completely as Possible
Chambers Installed / Commissioned in Module	Chambers Installed into Monolith
Stage by Installing Complete End	Stage by Installing Chambers
Chamber Support at Nodes	Support Between Nodes

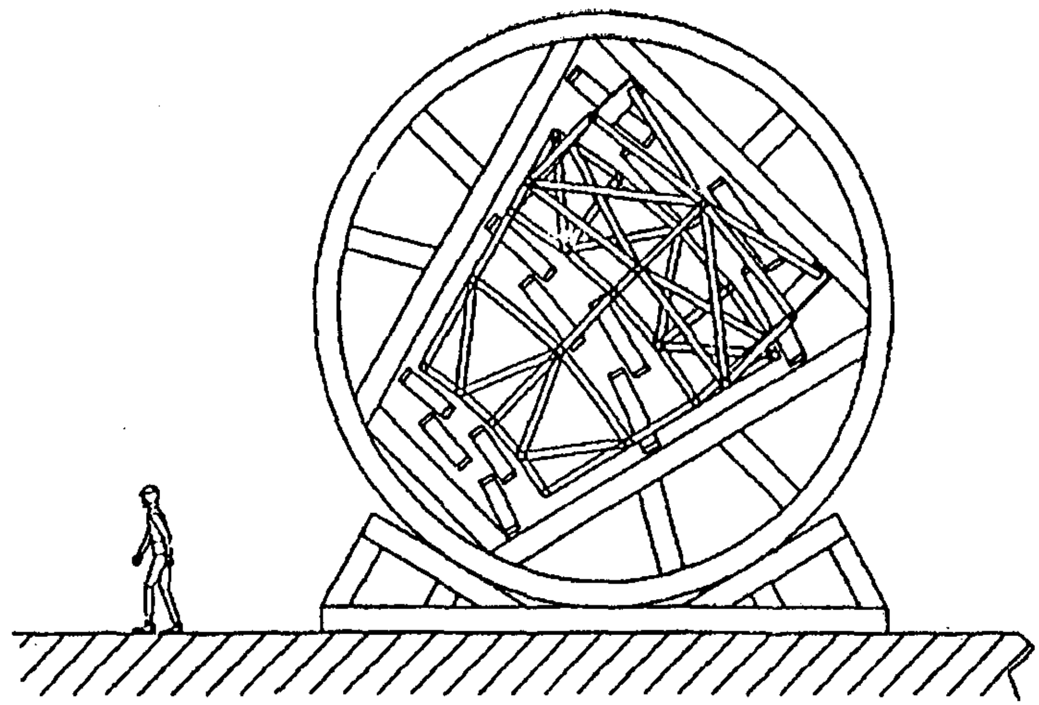
TDR Structure

+	−
Access to chambers during install	End/Barrel Gap
Modules commissioned	End Support
Prototypability	More Material Tight Access

SGH Structure

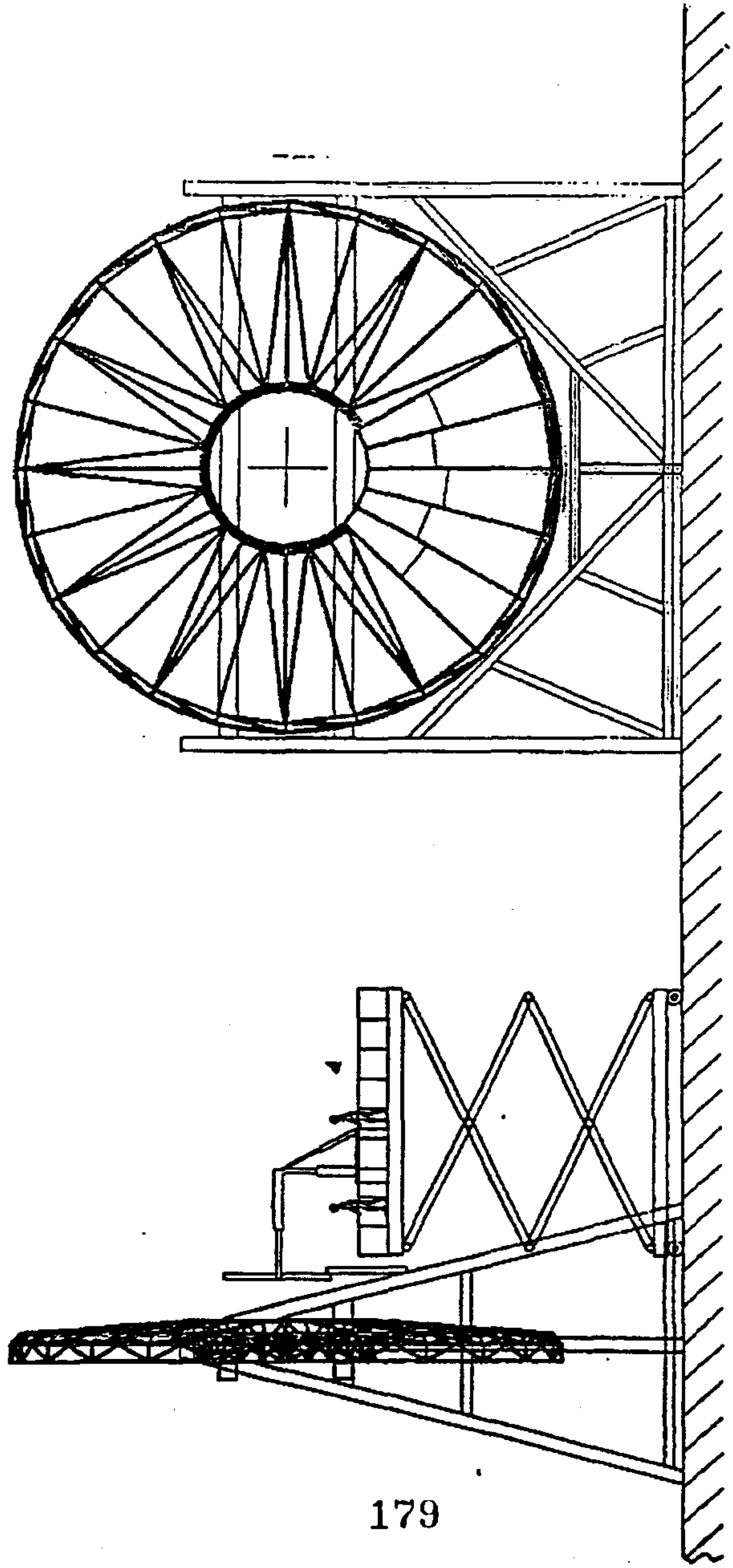
+	−
Smaller 30° Gap	No prototype
Lighter Structure	More awkward chamber handling
Stability	Commissioning.
Easier Access	

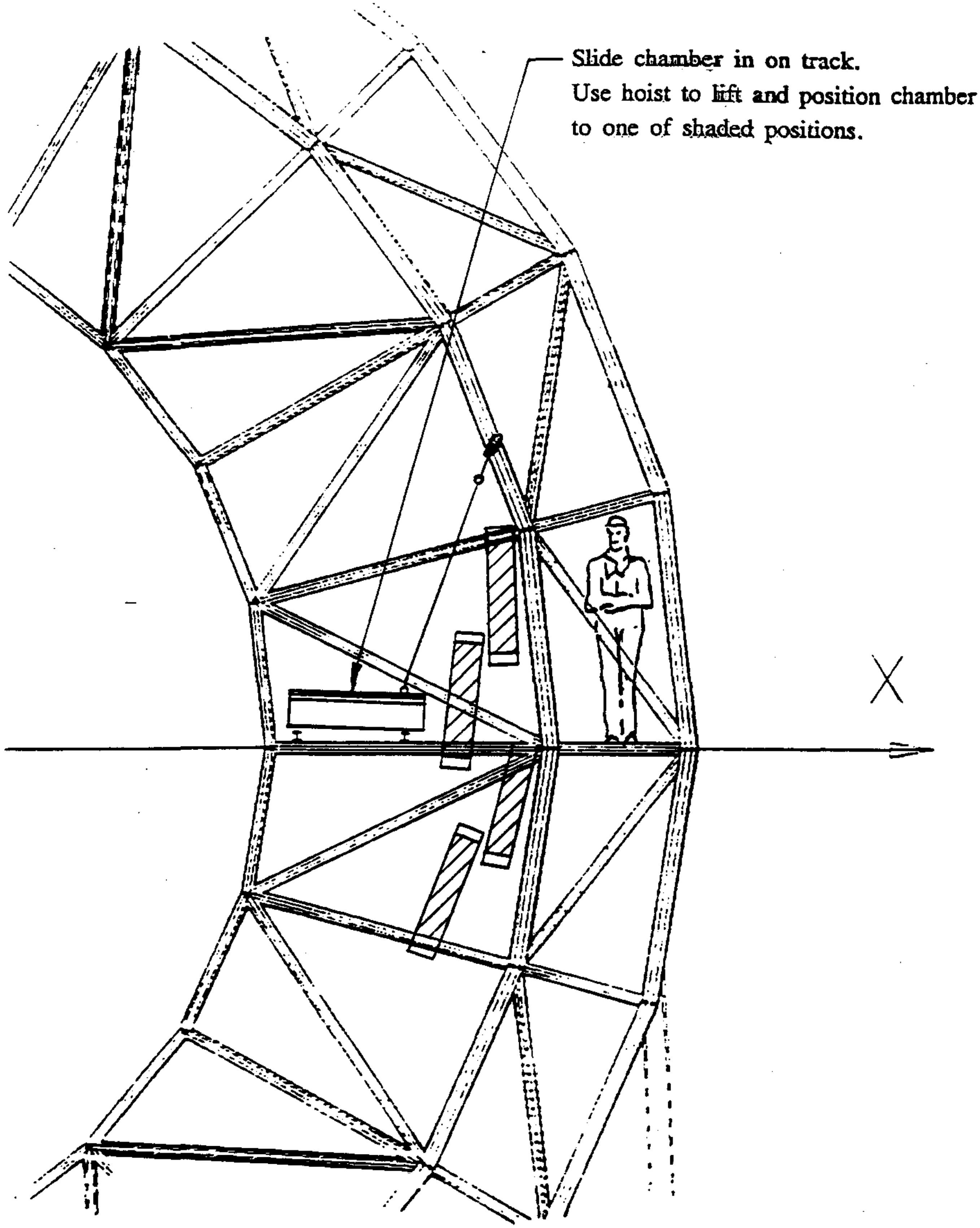




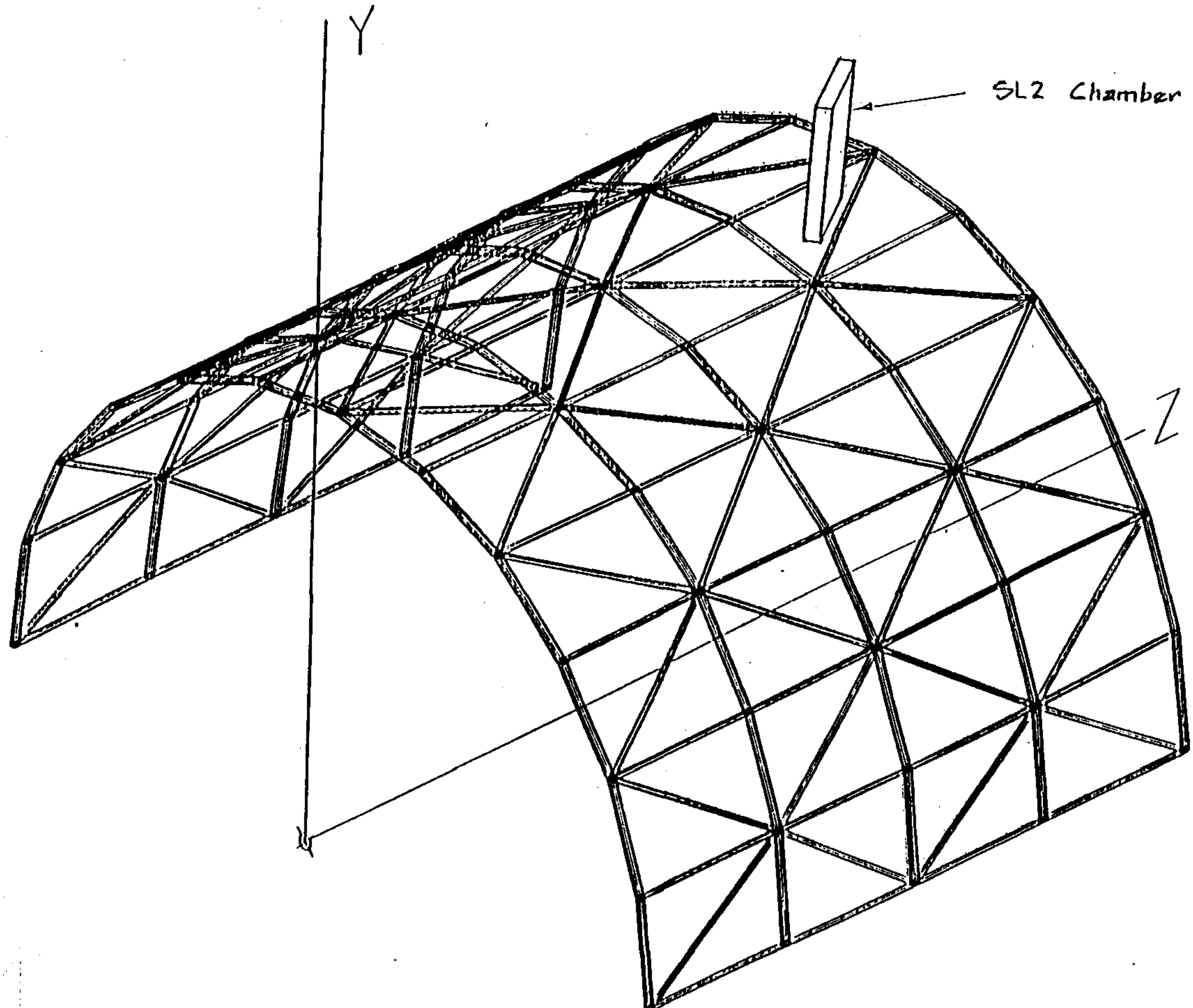
ORIENTED FOR ALIGNMENT

308519





Insertion of SL2 Barrel Chambers – MIC1



Installation — SL2 C

Many SGH Improvements should be included in final structure:

- Shells, diaphragms
- Lateral Restraint
- Chamber Support away from nodes
- Simplify Chamber Support + Adjustment
- Approach to Global Alignment
- Optimization Approach

United States Patent [19]

Kenue

[11] **Patent Number:** **4,970,653**

[45] **Date of Patent:** **Nov. 13, 1990**

[54] **VISION METHOD OF DETECTING LANE BOUNDARIES AND OBSTACLES**

[75] Inventor: **Surender K. Kenue**, Southfield, Mich.

[73] Assignee: **General Motors Corporation**, Detroit, Mich.

[21] Appl. No.: **334,033**

[22] Filed: **Apr. 6, 1989**

[51] **Int. Cl.**5 .... **G06F 15/50**

[52] **U.S. Cl.** **364/461**; 364/424.02; 358/103

[58] **Field of Search** 364/424.02, 461, 424.02; 180/167, 168, 169; 318/587, 103

[56] **References Cited**

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4,819,169	4/1989	Saitoh et al.	364/424.02
4,847,774	7/1989	Tomikawa et al.	364/424.02
4,862,047	8/1989	Suzuki et al.	318/587
4,868,752	9/1989	Fujii et al.	364/424.02

OTHER PUBLICATIONS

Dickmanns, E. D. and Zapp, A., "A Curvature-Based Scheme for Improving Road Vehicle Guidance by Computer Vision," Proc. SPIE on Mobile Robots, vol. 727, Oct. 1986, pp. 161–168.

Primary Examiner—Gary Chin
Attorney, Agent, or Firm—Howard N. Conkey

[57] **ABSTRACT**

An image processing method operates on an image from a ccd camera viewing a roadway scene in front of a vehicle to detect lane markers and determine the relationship of the vehicle to the lane. Obstacles in the lane near the vehicle are detected and a warning is given to the driver. The method uses template matching techniques or a Hough algorithm to detect the lane markers or road edges.

10 Claims, 7 Drawing Sheets

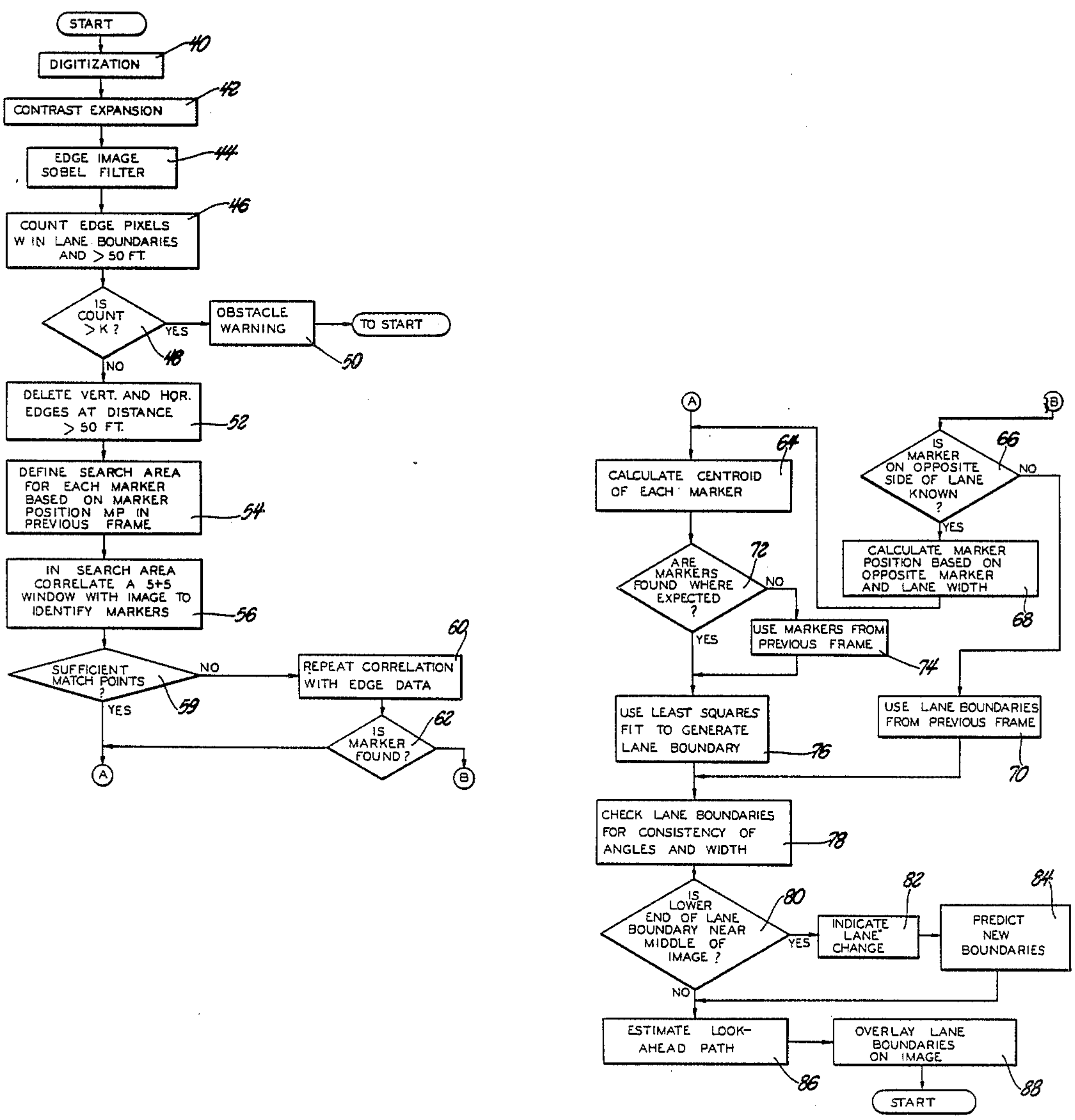

Exhibit F

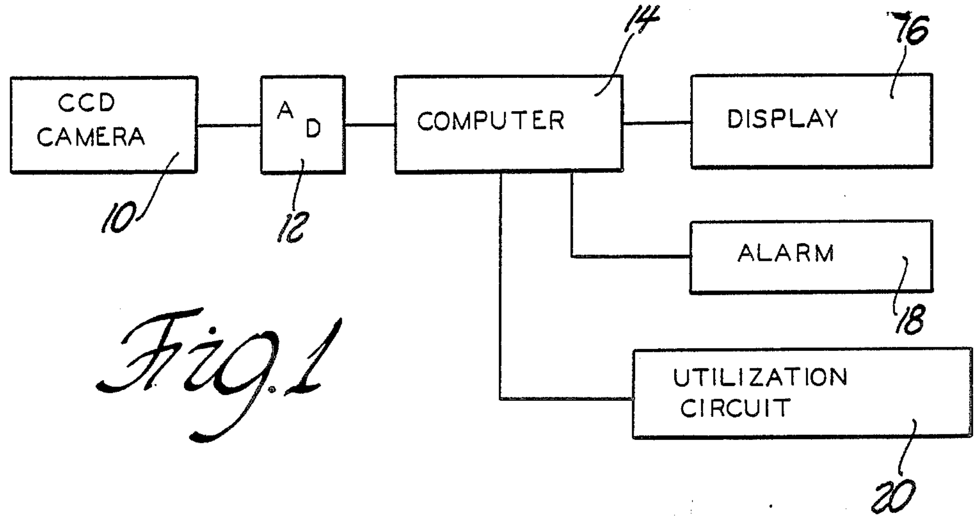

Fig. 1

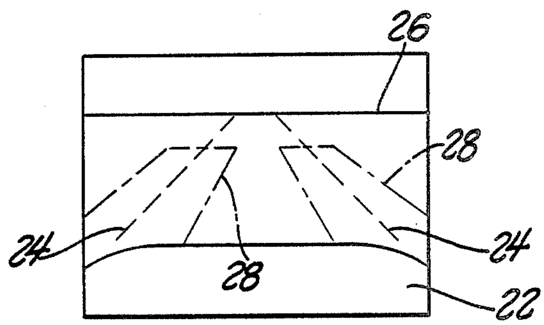

Fig. 2

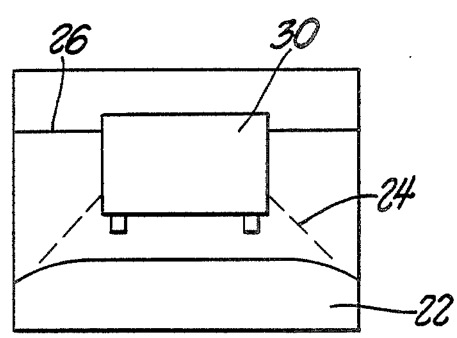

Fig 3

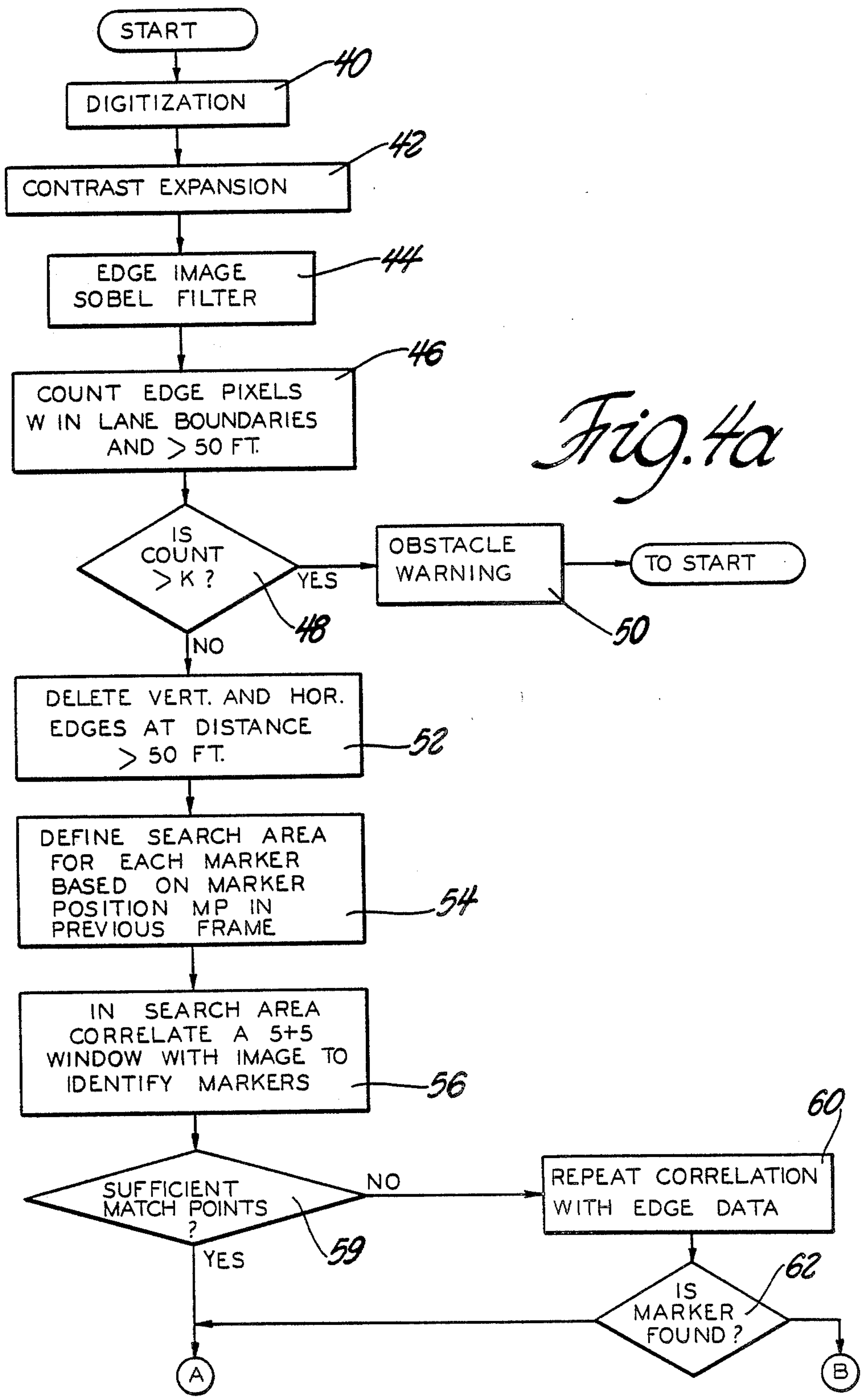
START
DIGITIZATION
40
CONTRAST EXPANSION
42
EDGE IMAGE
SOBEL FILTER
44
COUNT EDGE PIXELS
W IN LANE BOUNDARIES
AND > 50 FT.
46
IS
COUNT
> K ?
48
YES
NO
OBSTACLE
WARNING
50
TO START
DELETE VERT. AND HOR.
EDGES AT DISTANCE
> 50 FT.
52
DEFINE SEARCH AREA
FOR EACH MARKER
BASED ON MARKER
POSITION MP IN
PREVIOUS FRAME
54
IN SEARCH AREA
CORRELATE A 5+5
WINDOW WITH IMAGE TO
IDENTIFY MARKERS
56
SUFFICIENT
MATCH POINTS
?
59
NO
YES
REPEAT CORRELATION
WITH EDGE DATA
60
IS
MARKER
FOUND ?
62
A
B

Fig. 4a

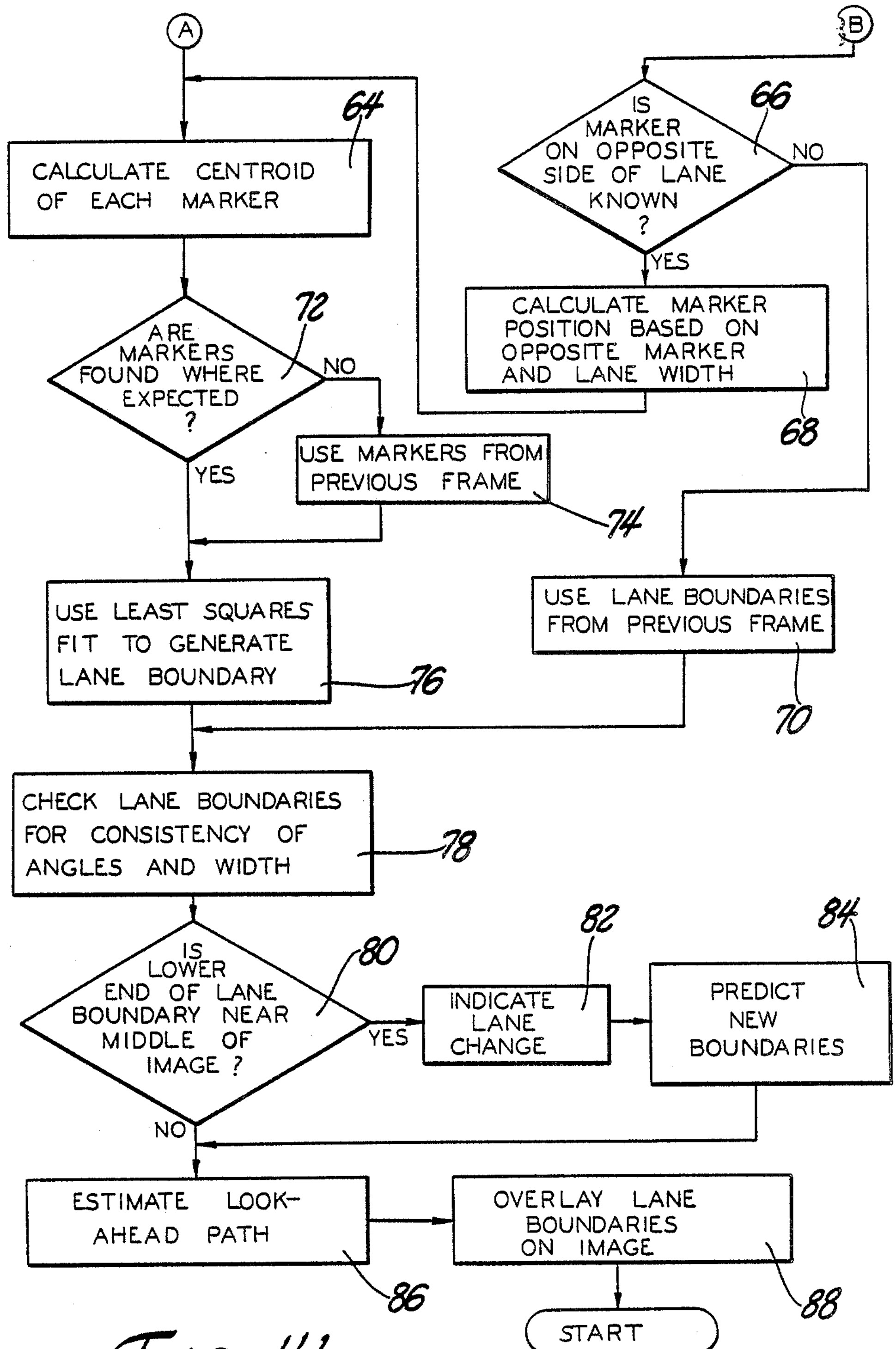
A
B
CALCULATE CENTROID OF EACH MARKER
64
IS MARKER ON OPPOSITE SIDE OF LANE KNOWN ?
66
NO
YES
CALCULATE MARKER POSITION BASED ON OPPOSITE MARKER AND LANE WIDTH
68
ARE MARKERS FOUND WHERE EXPECTED ?
72
NO
YES
USE MARKERS FROM PREVIOUS FRAME
74
USE LEAST SQUARES FIT TO GENERATE LANE BOUNDARY
76
USE LANE BOUNDARIES FROM PREVIOUS FRAME
70
CHECK LANE BOUNDARIES FOR CONSISTENCY OF ANGLES AND WIDTH
78
IS LOWER END OF LANE BOUNDARY NEAR MIDDLE OF IMAGE ?
80
YES
NO
INDICATE LANE CHANGE
82
PREDICT NEW BOUNDARIES
84
ESTIMATE LOOK-AHEAD PATH
86
OVERLAY LANE BOUNDARIES ON IMAGE
88
START

Fig. 4b

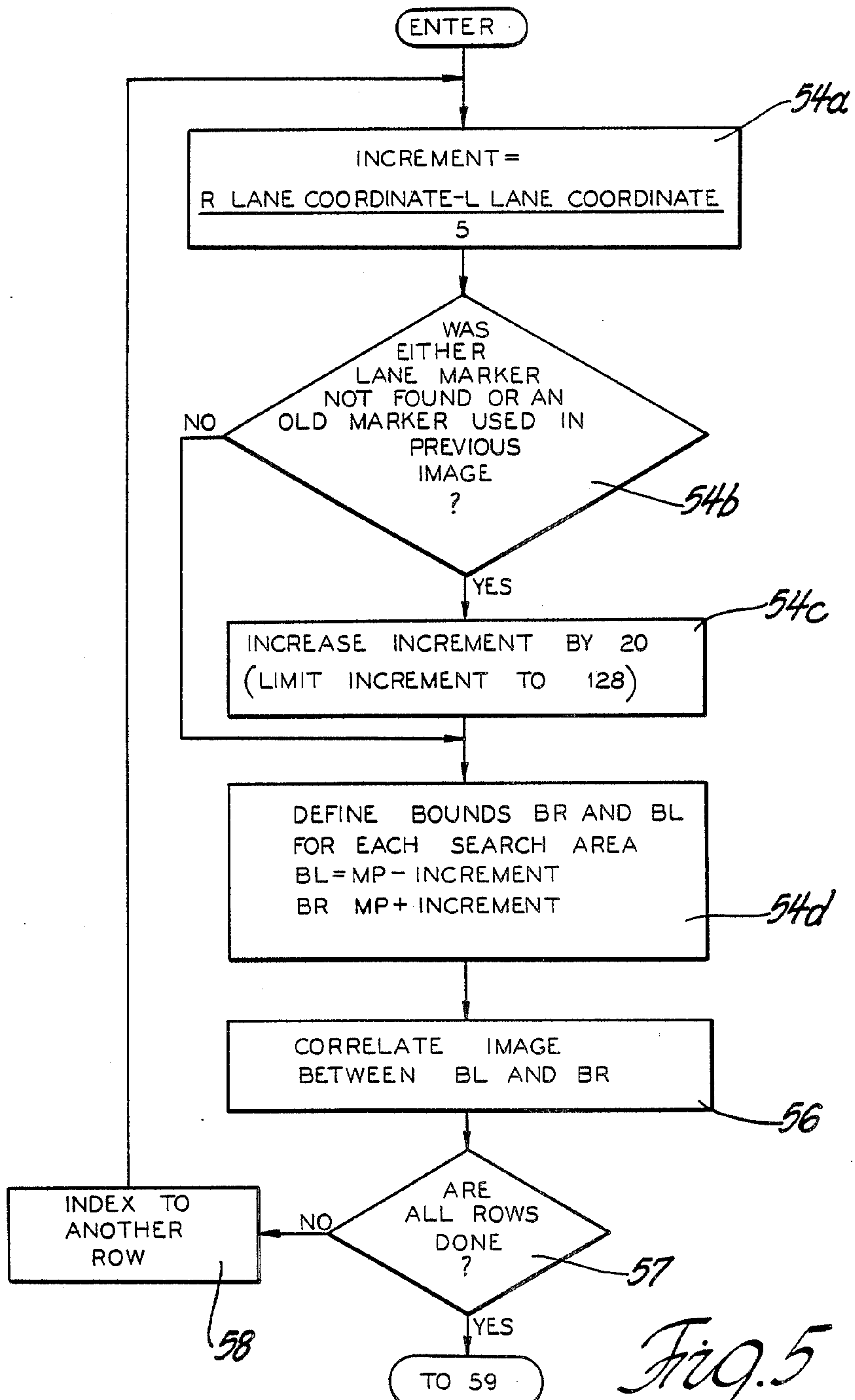
ENTER
54a
INCREMENT =
R LANE COORDINATE-L LANE COORDINATE
5
WAS EITHER LANE MARKER NOT FOUND OR AN OLD MARKER USED IN PREVIOUS IMAGE ?
NO
54b
YES
54c
INCREASE INCREMENT BY 20 (LIMIT INCREMENT TO 128)
DEFINE BOUNDS BR AND BL FOR EACH SEARCH AREA
BL=MP− INCREMENT
BR MP+ INCREMENT
54d
CORRELATE IMAGE BETWEEN BL AND BR
56
ARE ALL ROWS DONE ?
NO
INDEX TO ANOTHER ROW
57
58
YES
TO 59

Fig.5

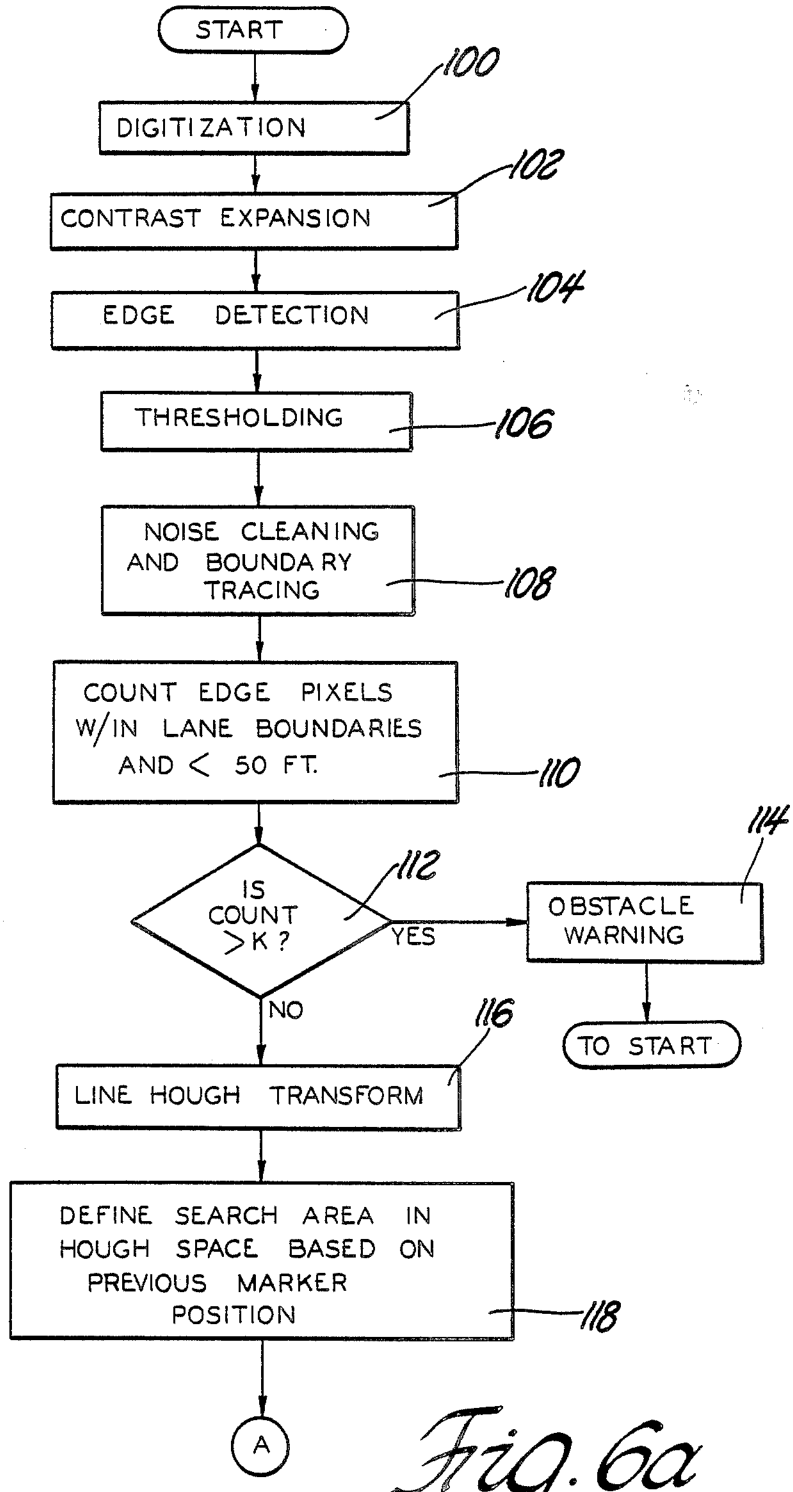
START
DIGITIZATION
100
CONTRAST EXPANSION
102
EDGE DETECTION
104
THRESHOLDING
106
NOISE CLEANING AND BOUNDARY TRACING
108
COUNT EDGE PIXELS W/IN LANE BOUNDARIES AND < 50 FT.
110
IS COUNT > K ?
112
YES
OBSTACLE WARNING
114
TO START
NO
LINE HOUGH TRANSFORM
116
DEFINE SEARCH AREA IN HOUGH SPACE BASED ON PREVIOUS MARKER POSITION
118
A

Fig. 6a

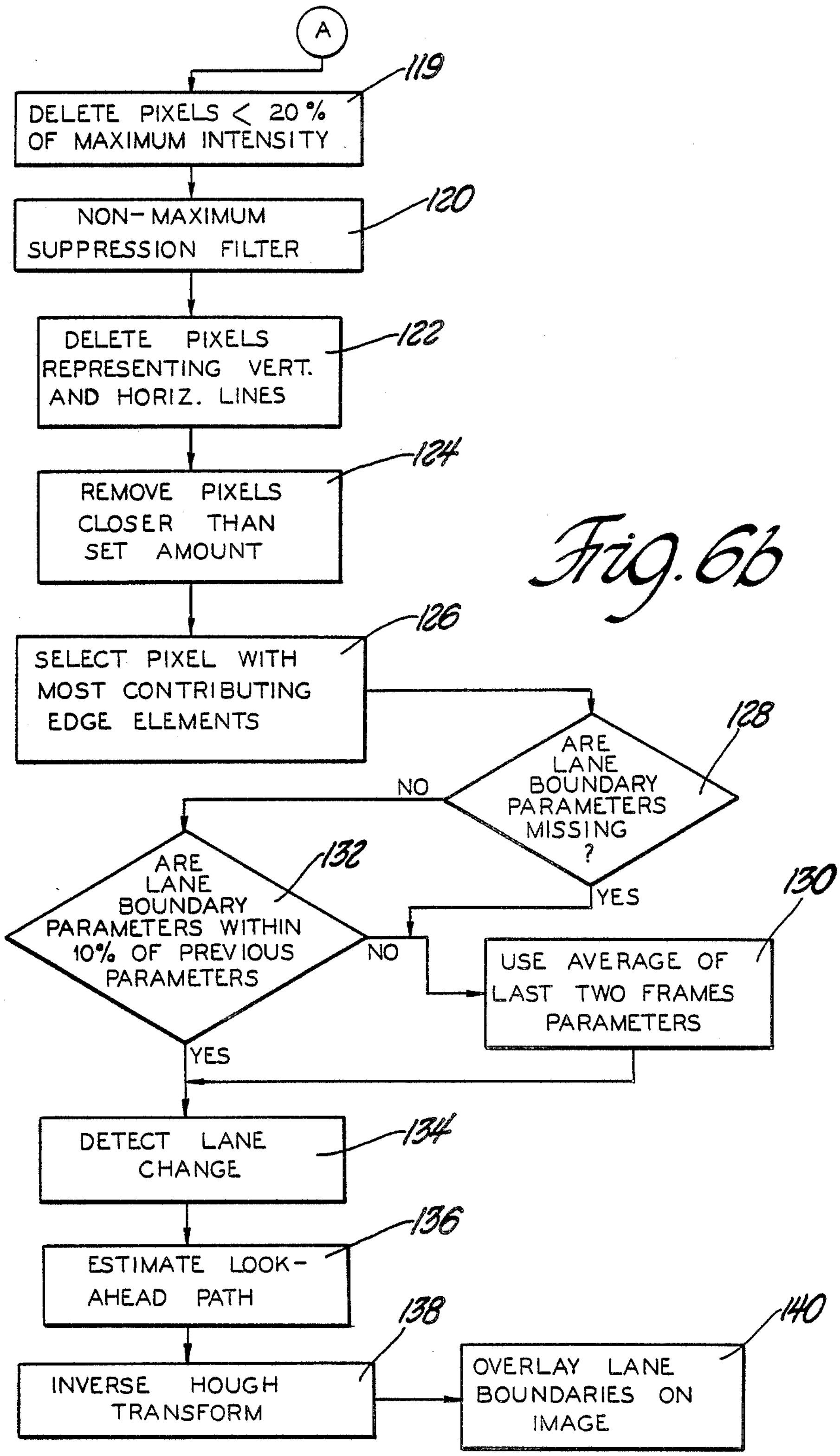
A
119
DELETE PIXELS < 20 % OF MAXIMUM INTENSITY
120
NON-MAXIMUM SUPPRESSION FILTER
122
DELETE PIXELS REPRESENTING VERT. AND HORIZ. LINES
124
REMOVE PIXELS CLOSER THAN SET AMOUNT
126
SELECT PIXEL WITH MOST CONTRIBUTING EDGE ELEMENTS
128
ARE LANE BOUNDARY PARAMETERS MISSING ?
NO
YES
132
ARE LANE BOUNDARY PARAMETERS WITHIN 10% OF PREVIOUS PARAMETERS
NO
YES
130
USE AVERAGE OF LAST TWO FRAMES PARAMETERS
134
DETECT LANE CHANGE
136
ESTIMATE LOOK-AHEAD PATH
138
INVERSE HOUGH TRANSFORM
140
OVERLAY LANE BOUNDARIES ON IMAGE

Fig. 6b

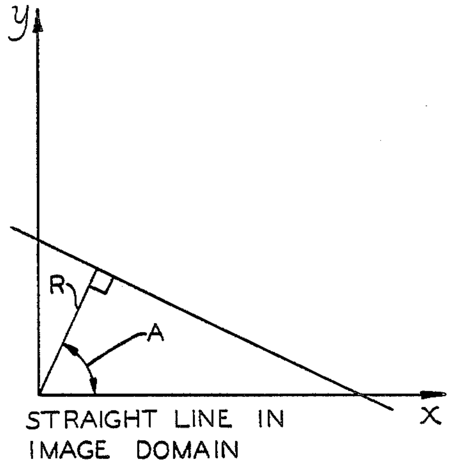
y
R
A
X
STRAIGHT LINE IN
IMAGE DOMAIN

Fig. 7a

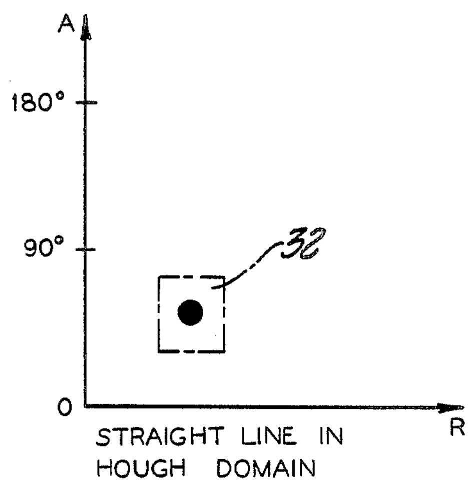
A
180°
90°
32
0
R
STRAIGHT LINE IN
HOUGH DOMAIN

Fig. 7b

VISION METHOD OF DETECTING LANE BOUNDARIES AND OBSTACLES

FIELD OF THE INVENTION

This invention relates to a vision method of detecting lane boundaries and obstacles close to a vehicle within the lane boundaries, and particularly to such a method employing image processing techniques and which is operative for moderately marked roads.

BACKGROUND OF THE INVENTION

The use of an on-board video camera and image processing of the roadway scenes allows useful information to be gathered for vehicle control. Detecting lane boundaries is a core capability for advanced automotive functions such as collision warning, collision avoidance and automatic vehicle guidance. If the lane boundaries and thus the road path can be detected several other functions can be implemented. Lane control uses the boundary information and vehicle dynamics knowledge to derive steering and braking commands for keeping the vehicle in the lane. Headway control uses a laser or radar system to track the vehicle ahead and keeps a safe driving distance. The lane boundary information can be used to prevent the detection of a vehicle in an adjacent lane on a curved road. Then the sensor beam can be directed to points within the lane. To monitor driving performance, the behavior of the driver is tracked and evaluated using the estimated position of the vehicle with respect to the lane boundaries.

Lane boundary detection for guiding vehicles along roadways has been reported in the paper by Dickmanns, E. D. and Zapp, A , "A Curvature-based Scheme for Improving Road Vehicle Guidance by Computer Vision," Proc. SPIE on Mobile Robots, Vol. 727, October 1986, which is incorporated herein by reference. Contour correlation and high order world models are the basic elements of that method, realized on a special multi-processor computer system. Perspective projection and dynamical models (Kalman filter) are used in an integrated approach for the design of the visual feedback control system. That system requires good lane markings and thus is limited to only those roads having good lane markings. It is of course desirable to extend the benefits of the computer vision system to roads with less good markings and to incorporate other features such as obstacle detection.

SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide a computer vision method of lane boundary detection operable on roads having moderate markings and even with some markers missing. It is a further object to provide such a method with obstacle detection capability.

The invention is carried out in an automotive vehicle having a computer vision system and an associated camera for viewing the scene ahead of the vehicle, by a method of detecting lane markers on a roadway comprising the steps of: obtaining an image of the scene and digitizing the image, normalizing the image, defining a search area in the image, searching for lane markers in the search area of the image, estimating the position of any missing lane marker, and defining lane boundaries from the position of the lane markers.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other advantages of the invention will become more apparent from the following description taken in conjunction with the accompanying drawings wherein like references refer to like parts and wherein:

FIG. **1** is a block diagram of a computer vision system for carrying out the method of the invention,

FIG. **2** is an illustration of a roadway scene in a camera image plane,

FIG. **3** is an illustration of a roadway scene in a camera image plane, the scene having an obstacle in the roadway,

FIGS. **4a** and **4b** together comprise a flow chart of an embodiment of the method of the invention employing template matching,

FIG. **5** is a flow chart of the dynamic search area definition method used in the FIG. **4** method.

FIGS. **6a** and **6b** together comprise a flow chart of another embodiment of the method of the invention employing a Hough transform, and

FIGS. **7a** and **7b** are an image plane view of a line and a Hough space representation of the same line, respectively.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As shown in FIG. **1**, the hardware used to implement the method of the invention comprises a black and white CCD video camera **10** mounted in a vehicle, say at the upper center of the windshield to capture the driver's view of the road ahead, an analog-to-digital converter **12** for coupling the camera output to a computer **14**, and output devices driven by the computer including a display **16**, an obstacle warning alarm **18** and a utilization circuit **20** which may be any device using the lane boundary information for vehicle guidance, performance monitoring or headway control, for example.

The computer is programmed with algorithms for processing the images sensed by the camera. Two main algorithms for processing the image are disclosed herein. One uses a Hough transform and the other uses template matching. Both algorithms, however, dynamically define the search area for lane markers based on the lane boundaries of the previous frame, and provide estimates of the position of missing markers on the basis of current frame and previous frame information.Also in both cases preprocessing procedures detect obstacles in the lane within about 50 feet of the vehicle and give a warning via the alarm **18**.

FIG. **2** is an example of a typical image as projected on the camera image plane and includes the vehicle hood **22** and broken or solid stripes or lane markers **24** painted on the road and terminating at the horizon **26**. Since the image spaces above the horizon and below the hood line do not contain useful lane boundary information those regions are ignored by the image processing algorithms. A special calibration procedure enables range estimation, based on known characteristics of the road and the camera. It assumes flat roads with parallel markers at known look-ahead distances. The calibration determines the relationships between the positions of the actual markers and the images of these markers. This process defines a set of "reference markers" which are used as an initial set of lane boundaries seen by the vehicle when it is in the middle of the lane.The reference markers are also used when consistency of width is violated or when the two estimated lane boundaries cross each other.

The broken line boxes **28** around the markers **24** define the area to be searched for detecting markers and is determined by the position of the lane boundaries in the previous image frame. In reality many other objects are in the image such as trees, other vehicles, overpasses and signs. The defined search area helps eliminate much of them from the processed image as well as to minimize the processing time. FIG. **3** illustrates the presence of a vehicle **30** or other obstacle in the roadway of FIG. **2**. If the other vehicle is close, say, within 50 feet of the trailing vehicle, it tends to obscure the lane markers **24** to such an extent that there is insufficient information to determine the boundaries. In that case an obstacle warning is given and no further image processing is done on that frame. When the obstacle **30** is more than 50 feet away the image is processed but the obstacle is effectively erased from the image by removing horizontal and vertical lines, thereby making the subsequent processing steps simpler.

The template matching algorithm is widely used in image recognition and computer vision applications. In this algorithm, a template or window of desired intensity and shape is correlated with the image to create a correlation matrix. The elements of this correlation matrix indicate the quality of the match between the template and the image at all locations, according to some metric. Here, the absolute difference metric is used as the correlation measure. Other types of measures such as normalized correlation can also be used. The matching can also be done in the image-edge domain obtained by filtering the raw image with a Sobel filter. The advantage of edge matching is its insensitivity to light variations; however, with this method, potholes, streaks, road texture and shadows may generate false objects. The template matching algorithm described below uses both image data and edge data.

FIGS. **4***a* and **4***c* comprise a flow chart of an image processing method which uses a template matching algorithm. The figures are joined at nodes A and B. Numerals in the text marked by angle brackets <> refer to reference numerals on the flow chart boxes. The raw image is digitized <**40**> into a $512\times512\times8$ image. The processing area is reduced in the vertical and horizontal directions. In the vertical direction, it is limited by the horizon line **26** and by the hood **22**. These limits are obtained from the camera geometry and the calibration image. Then the gray level distribution of the processing area is contrast expanded or normalized <**42**> to have standard statistics (e.g., a gray level distribution with mean=100 and standard deviation=20; the gray level range is 0 to 255 with 0 being full black and 255 being full white). Next, a 3×3 Sobel filter is used <**44**> to generate edge data 124×512 pixels in size.

An obstacle in the lane ahead will give rise to strong edges in addition to those presented by the roadway. The presence of obstacles is detected by counting the number of strong edge points within the area defined by the lane boundaries of the previous frame <**46**> and comparing to a threshold <**48**> for a given look-ahead distance. For example, the number of pixels within 50 feet of the vehicle having a gray level greater than 150 are counted and compared to a threshold. If an obstacle is detected within 50 feet, then a warning to the driver is given <**50**> and the control returns back to the first step for a new frame. The location of lane boundaries is not updated since the presence of the obstacle obscures them. The obstacle distance is determined by the ground level obstacle image since the image plane calibration does not take into account the vertical height of an object. As seen in FIG. **3**, the top of the vehicle **30** appears to be beyond the horizon as seen in the image plane although the vehicle **30** is actually close as is realistically shown near ground level. Thus for obstacle detection, only the bottom of the vehicle **30** image is scanned since it is in the near portion of the image plane.

Obstacles detected at distances greater than 50 feet (in the far field portion of the image) are effectively deleted from both the image and the edge data <**52**> to facilitate the execution of the following steps. For this purpose it is assumed that the obstacle has a high content of vertical and horizontal lines whereas the lane markers to be detected comprise diagonal lines. The obstacles are deleted from the image using the following criteria: lines to be deleted must be either vertical or horizontal, their length must exceed **40** pixels, and their intensity must exceed 150.

After the obstacle deletion step the search area is defined dynamically <**54**>. Given the previous lane boundaries, a truncated triangular search region is defined for each marker location such that the search region for the two sides of the lane do not overlap.- Moreover, the search area changes with marker position MP, and increases in size if the marker was not found in the search of the previous frame. This limits the search space in which the markers can move from one frame to another and shortens the processing time.

The dynamic search method is shown separately in FIG. **5**. The search is conducted one row at a time and the search field is selected for each row. It begins by defining an increment for a given row as one fifth of the distance between the right and left lane coordinates for that row <**54***a*>. It is then decided <**54***b*> whether either a lane marker was not found or an old marker was used in the previous image. If so, the increment is increased by 20 pixels to enlarge the search area <**54***c*>. Then the right bound BR and the left bound BL (for each search area) is found <**54***d*> by adding and subtracting the increment from the marker position MP for that line. Next a correlation procedure <**56**> is followed for the defined search field in the current line and if all the rows have not been processed <**57**> the search continues in another row <**58**> and the search field is redefined for that row.

When the search area is defined a template matching operation begins <**56**>. For the defined search area, a window of size 5×5 pixels with constant gray level of 240 is correlated with the image. The correlation measure is based on the absolute difference of the window's gray level and the image's gray level. The window is moved horizontally across the image pixel by pixel to obtain a correlation measure at every point in the traverse and is then indexed vertically to make another horizontal traverse. To reduce computations, the window may be indexed vertically by more than one line so that strips of the search area are sampled rather then the complete search area. Using the absolute difference metric, a perfect match will yield a zero element in the correlation matrix. The correlation matrix is therefore searched for its minimum values. Elements with values under some threshold are selected to represent the marker positions.

This correlation procedure will not yield any match for yellow or faded white lane markers. If such markers are present or markers are missing altogether, there will be only a few match points. The match points are counted <59> and if there are too few, say, 6 points out of a possible 100, the correlation is repeated with the edge data <60>. Then if the marker is found <62> or there were sufficient match points <59>, the centroid of each marker is calculated <64>. If the marker is not found <62> and the marker position on the opposite side of the lane is known <66>, the missing marker position is calculated based on the opposite marker position and the lane width <68> and its centroid is calculated <64>. When the marker position on the opposite side of the lane is not known <66> the lane boundary from the previous frame is used <70>. After the centroid of each marker is calculated <64>, if the markers are not found where expected <72> based on the previously detected lane geometry, the marker locations from the previous frame are used <74>.

The determination of expected marker position <72> involves comparing the position of each marker centroid with that of the previous frame. If the change is more than nine pixels a flag is set. Then a check is made for the presence of a second marker in each search area as may occur, for example, when an exit lane is sensed. The distance between two such markers is computed and if it is above a threshold for some distance (15 rows of the image) the outside marker (i.e., the rightmost marker in the right search area) is rejected and a flag is set. Then for each row, if a marker is not found the previous marker is used, provided no flag has been set. If a flag is set, only new marker locations are used. The result of this procedure is a set of x,y coordinates specifying lane markers. Then a least-squares line fit is performed to generate the lane boundary <76>.

To validate the estimated lane boundaries they are checked for consistency of angles and width <78>. If the angle between the present lane boundary and the previous lane boundary is greater than 35°, then the present lane boundary is rejected. It is then estimated from the other lane boundary based on lane width. Similarly, the width of the lane is checked at two different look-ahead distances for upper and lower bounds.

The algorithm also checks for lane changes by determining if the lower end of a lane boundary is near the middle of the image <80>. If it is a lane change, warning is given <82> and depending on the lane change direction (left or right), the markers are exchanged, i.e., for a left lane change, the left boundary is redefined as the right boundary and a new left boundary is predicted based on the road/camera geometry.

The estimated lane boundaries are used to compute the vanishing point (where the left and right boundaries intersect) and the intersection of the right marker at a fixed distance. These points and the vehicle dynamics information are then used by a Kalman filter for estimating the road curvature, the lateral shift from the center of the lane, and the heading error as disclosed in the Dickmanns et al paper, supra. These estimates determine a coordinate transformation which determines the look-ahead path required for autonomous vehicle control <86>. For display purposes the lane boundaries are overlaid on the image <88>.

FIGS. 6*a* and 6*b* comprise a flow chart showing an image processing algorithm using a Hough transform. The two figures are joined at node A. The process starts by digitization of the camera signals <100>, contrast expansion <102> and edge detection by a Sobel filter <104> as described for the previous method. The image area between the vehicle hood and the horizon is the only area operated upon. A thresholding operation <106> generates a binary image by setting all gray levels above 150 to one and the rest to zero. Noise cleaning and boundary tracing <108> removes isolated, single pixels and traces the boundaries of the lane and road markers. The boundary tracing algorithm saves connected or adjacent pixels and follows the contour of a lane marker or a road edge in all directions. This is done by dividing the image into three equal segments representing the left, center and right portions of the image. For each segment, the left and right edges of the lane or road markers are searched for at least two adjacent edge pixels. After marking the edge pixels, the boundaries of the lane markers are traced until either the top of the image is reached or until no edge pixels are found. The resulting boundary traced image has clean lane markers and road edges. Then obstacle detection is performed by counting edge pixels within the lane boundaries and within 50 feet of the vehicle <110> and comparing the count to a threshold <112>. If the count is greater than the threshold an obstacle is detected and an obstacle warning is given to the driver <114> and the program returns to START. If no obstacle is detected a line Hough transform is performed <116>.

The Hough algorithm uses the boundary traced lane markers to estimate the location of the lane boundaries. The Hough transform has been used extensively for image processing applications. By knowing the desired shape a priori, the transform maps complex shapes, whether lines or curves, into simple ones in the Hough domain. The simplest transform in terms of computational burden is a line transform.Accordingly the lane boundaries are approximated by several straight lines. FIGS. 7*a* and 7*b* show a line in the image plane and the Hough transform of the same line. The normal parameterization of a straight line is given by R x cosA + y sinA where R is the shortest distance from the origin to the line, and A is the angle between the normal to the line and the x axis. Each pixel in the Hough domain represents a potential line in the image space. After a line Hough transform is performed on the boundary traced image <116> a search area is defined around the previous boundary position <118> in Hough space as indicated by the box 32 in FIG. 7*b*.

The intensity of each pixel in the Hough domain corresponds to the strength of a line in the image space or the number of edge elements contributing to that line. To select the n strongest lines in the image, one needs to identify the n pixels with the highest intensity in the Hough domain. The following criteria are used to select the correct lines: (a) the intensity of the selected pixels should have local maxima, (b) the separation of the selected pixels should exceed a certain threshold, and (c) the intensity of the selected pixels should exceed 20% of the maximum intensity. The selection algorithm is implemented by identifying the maximum pixel intensity and deleting those that are less than 20% of that maximum intensity <119>. Then the Hough domain is filtered with an 11×11 non-maximum suppression filter <120>, i.e., for a given pixel, if the other 120 pixels around it were higher in intensity, then the intensity of the subject pixel is set to zero. After filtering, only one local maximum pixel for each 11×11 neighborhood could survive in the Hough domain but some points can still be close together. The number of Hough pixels is further reduced by deleting pixels which would generate near horizontal or vertical lines (A=0°, A=90°, A=180°) <**122**>. Additional pixels are removed if the distance between two pixels is less than **34** <**124**>. Finally the pixels are sorted based on intensity or the number of contributing edge elements and the top four pixels are chosen <**126**>.

In a typical application, the roadway may include discernible lane markers defining two lanes, and road edges may also be visible even if not painted. In this case four edges will be searched for to define the road and the vehicle relationship to the road. When the Hough transform is performed about **300** points may be present in Hough space which represent minor edges, major edges including the ones of interest, and noise. Each operation reduces the number of remaining edges. For example, the deletion of those less than 20% of maximum intensity may eliminate all but 50 points. The non-maximum filter may leave 10 points, and the deletion of pairs that are close together and of those representing horizontal and vertical lines may remove a few more points. Finally the strongest four pixels of the remainder are selected as the lane markers and road edges.

These pixels represent the lane boundaries. The pixels are checked to determine if any lane boundary parameters are missing <**128**>. If they are, the average of the last two frames parameters are used

If the parameters are not missing they are validated by comparison with parameters of previous frames <**132**> and if they are within 10% they are considered to be valid. If not, the average parameters of the last two frames is used <**130**>. Then lane change is detected <**134**> and the look-ahead path is estimated <**136**> using the Kalman filter as described for the previous method, and an inverse Hough transform generates lane boundaries <**138**> in the image space which are overlaid on the image for display purposes <**140**>.

The Hough domain is quantized to a 256×256 space for this implementation. Since pixels are selected based on a distance of **34**, it is evident that the quantized space can easily be reduced to 128×256 for decreasing the processing time. For real time applications, systolic array chips could be used for fast calculations of the Hough transform. The image could be divided into several sub-images with several systolic chips working in parallel, mapping the results into several Hough domains. Since the Hough transform operation is linear for the continuous case, the final transform can be obtained by summing the partial Hough results. Another advantage of the transform is that a priori knowledge about lane and road boundaries can easily be embedded in the algorithm.

The method of the invention performed by either algorithm, template matching or Hough transform, has several advantages:

(a) The method works well with missing and discontinuous markers, both yellow and white.

(b) The search area in both algorithms is defined dynamically and adapts to the location of the lane markers, which saves processing time.

(c) This method estimates road boundaries with low radius of curvature (e.g., entrance and exit highway ramps).

(d) This method detects lane changes and warns the driver when lanes are crossed.

(e) This method can detect certain obstacles in the lane.

The description of a preferred embodiment of the invention for the purpose of illustrating the invention is not to be considered as limiting the invention since many modifications may be made by the exercise of skill in the art without departing from the scope of the invention.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In an automotive vehicle having a computer vision system and an associated camera for viewing a scene ahead of the vehicle, a method of detecting lane markers on a roadway comprising the steps of:

obtaining an image of the scene and digitizing the image,

normalizing the image,

defining a search area in the image,

searching for lane markers in the search area of the image to locate lane marker positions,

estimating the position of any missing lane marker from said located lane marker positions, and

defining lane boundaries from the said located lane marker positions and the estimated position of the missing lane marker.

2. The invention as defined in claim **1** wherein the step of estimating the position of missing lane markers comprises averaging the corresponding marker positions from previous images.

3. In an automotive vehicle having a computer vision system and an associated camera for viewing a scene ahead of the vehicle and obtaining a series of images of the scene, a method of locating lane boundaries on a roadway comprising for each image the steps of:

digitizing the image and normalizing the image,

dynamically defining a search area in the image based on the lane boundaries located in a previous image,

searching for lane markers in the search area of the image to locate lane marker positions,

estimating the position of any missing lane marker based on information selected from the current image and previous images, and

defining lane boundaries from the said located lane marker positions and the estimated position of the missing lane marker.

4. The invention as defined in claim **3** wherein the step of estimating the position of missing lane markers comprises the steps of:

determining the lane width from said previous image, and

calculating the estimated position of a missing lane marker from the position of a marker on the opposite side of the lane and the lane width.

5. The invention as defined in claim **2** including the steps of:

checking the validity of a current lane boundary position by comparing a current lane boundary angle and lane width with that of the previous image wherein a discrepancy of said current lane boundary angle or said current lane width greater than threshold values reveals an invalid boundary, and

when said current lane boundary position is invalid, substituting a preceding boundary position.

6. The invention as defined in claim **2** wherein the step of searching for lane markers comprises the steps of:

generating edge data from the image,

correlating a template with the image in the search area, and

if insufficient match points are found to define a marker then correlating said template with the edge data in the search area.

7. The invention as defined in claim **2** wherein the steps of defining a search area and searching for lane markers comprise the steps of:

generating edge data from the image,

performing a boundary tracing operation on the edge data to generate a boundary traced image,

performing a line Hough transform on the boundary traced image to yield pixels in Hough space,

defining a search area in Hough space based on lane boundaries defined in a previous frame, and

searching for lane markers in Hough space to locate said lane marker positions.

8. The invention as defined in claim **7** wherein the step of search for lane markers in Hough space comprises the steps of:

reducing the number of said pixels in Hough space by filtering said pixels in Hough space with a non-maximum suppression filter,

deleting pixels in Hough space representing vertical and horizontal lines,

removing pixels in Hough space closer than a set amount, and

selecting pixels in Hough space with the most contributing edge elements as said lane markers.

9. In an automotive vehicle having a computer vision system and an associated camera for viewing a scene ahead of the vehicle and obtaining a series of images of the scene, a method of locating lane boundaries and close obstacles on a roadway comprising for each image the steps of:

digitizing the image and normalizing the image,

generating edge data from the image,

determining an edge pixel count by counting edge pixels between lane boundaries defined in the previous image ad in the image portion representing space close to the vehicle,

comparing the edge pixel count to a threshold value and issuing an obstacle warning when the count is above the threshold value,

when the edge pixel count is below the threshold value, dynamically defining a search area in the image based on the lane boundaries located in said previous image,

searching for lane markers in the search area of the image to locate lane marker positions,

estimating the position of any missing lane marker based on information selected from the current image and previous images, and

defining lane boundaries from the said located lane marker positions and the estimated position of the missing lane marker.

10. The invention as defined in claim **9** including the step of:

before searching for said lane markers, effectively deleting obstacles from far field portions of the image by removing vertical and horizontal lines within the said search area in the image.

* * * * *

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(54) Title of the Invention: Traveling Vehicle Recognition Device

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(22) Application Date: December 5, 1985

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Specification

1. Title of the Invention

Traveling Vehicle Recognition Device

2. Claim

A traveling vehicle recognition device characterized in comprising:

color imaging means for imaging the forward direction of a traveling vehicle;

means for forming color image signals corresponding to each color based on a video signal imaged by the imaging means;

features extraction means for extracting an image signal of colors corresponding to taillights and headlights based on the color image signals obtained by said means;

means for recognizing the presence of taillights or headlights according to the image signal extracted by the features extraction means;

calculating means for computing the distance between vehicles and the speed relative to a vehicle ahead based on said recognized taillight image; and

executing means for executing headlight control based on the recognition result of said recognition means;

and controlling to switch the vehicle headlights to low beams at least when a state in which there is an oncoming vehicle in the forward direction has been recognized by said recognition of headlights.

3. Detailed description of the invention

<Industrial field of use>

The present invention relates to a recognition device for a traveling vehicle which recognizes the presence of taillights of a vehicle traveling ahead and headlights of an oncoming vehicle, especially at night, calculates and displays the interrelationship with the vehicle ahead, and is capable of controlling the device vehicle's headlights automatically.

<Prior art>

When driving an automobile at night, the headlights are lit while travelling, and in particular, the headlights are set to high beams when driving in an area with few other traveling automobiles.

However, with this type of high beam driving state, in the case that there is an oncoming vehicle or a vehicle traveling ahead is becoming close, the headlights must be switched to low beams so as not to obstruct the field of vision of the driver of the oncoming vehicle or the driver of the vehicle traveling ahead. This type of beam control of the headlights is troublesome for the driver, however, and further complicates the driving operation, especially when driving on a road with many curves. Moreover, in the case that there is a vehicle traveling ahead, the driver must accurately perceive the distance from the vehicle ahead and the speed relative to the vehicle ahead, and must control the lights in this way and accurately know the relative relationship with the vehicle ahead in order to drive safely.

<Problems that the invention is to solve>

The present invention was devised in consideration of such points, and seeks to provide a traveling vehicle recognition device capable, for example, of automatically controlling headlight beams to high and low beams according to the state of whether there is a vehicle ahead, especially when driving at night, and of issuing warnings to the driver according to the interrelationship with a vehicle traveling ahead.

<Means of solving the problems>

Specifically, the traveling vehicle recognition device of the present invention has an imaging apparatus such as a color television camera set up for imaging, for example, the forward direction of a traveling vehicle, extracts color features of headlights and taillights to form a feature extracted color image signal based on a color video signal imaged by this imaging apparatus, recognizes the headlights and taillights of a vehicle ahead, and controls the headlight beams based on this recognition result. The traveling vehicle recognition device also computes the distance from and the speed relative a vehicle traveling ahead based on the image signal of a recognized taillight.

<Operation>

With the traveling vehicle recognition device configured as above, the headlights and taillights of a vehicle ahead can be recognized from color features, and the driver can be notified that there is an oncoming vehicle and there is a vehicle traveling ahead based on this recognition., Conditions that arise when the headlights must be switched from high beams to low beams are also detected based on this recognition result, and the headlight beams can be controlled automatically once detection conditions have been set. The distance from and the speed relative to a vehicle traveling ahead can also be calculated based on taillight recognition, and a warning can therefore be issued to the driver in states such as when there is risk of a rear-end collision.

<Working examples of the invention>

A working example of the present invention will be described hereinafter with reference to the appended drawings. Fig. 1 shows the configuration of this working example, which is provided with a color television camera 11. The television camera 11 is mounted and set up in the front of a vehicle 12 as shown in Fig. 2, for example, and is set so as to be able to image the forward direction of the vehicle 12, especially a vehicle 121 traveling ahead and a vehicle 122 traveling in the oncoming lane. By setting up in this way, the red taillights of the vehicle 121 and the white headlights of the vehicle 122 may be imaged accurately, especially at night.

A video signal of images imaged by the television camera 11 is supplied to a decoder 13. The decoder 13 forms R (red), G (green) and B (blue) color image signals based on the video signal, and supplies the R, B and B color image signals to an image signal processor 14.

The image signal processor 14 extracts the features of red, which is the color of taillights, and of white, which is the color of headlights, from the R, G, B color image signals, extracting, for example, a binary image signal, and causes the presence of taillights or headlights within the

the imaged video to be recognized based on this extracted image signal. The recognition results are then sent to an executing part 15.

The executing part 15 is also supplied a detection signal corresponding to the vehicle speed from a vehicle speed sensor 16 and a signal from a headlight switch 17 indicating the state of whether the headlights are set to a high or low beam . The executing part 15 then executes tasks for controlling the headlight beams or issuing a warning to the driver based on the recognition information, vehicle speed information and headlight information.

Fig. 3 shows the flow of operating states of the device described above, which starts when the ignition switch of the vehicle is turned on. In step 101, whether it is nighttime is determined according to whether the headlights are lit, and in the case that it is determined to be nighttime, the operation advances to step 102. Settings are initialized instep 122 [Translator's note: error for 102]. In this initializing step 102, the scanning area of the screen to be imaged is set and feature extraction conditions for recognizing taillights and headlights are set.

Once the settings have been initialized in this way, the operation advances to step 103, in which the color image signal from the decoder 13 formed based on the video signal from the color television camera 11 is captured and inputted to the image signal processor 14. The operation then advances to a 104. In step 104 features are extracted by the image signal processor 14 from the color image signal, and the luminescent colors of white and red are emphasized.

This image signal processor 14 is configured as shown in Fig. 4, for example, and is provided with a features extraction unit 141. The R, G and B color image signals from the decoder 13 are supplied to the features extraction unit 141. "Extracting features by the features extraction unit 141" means that the inputted image signals are binarized to capture only information relating to headlights and taillights, which are to be recognized. In this example, color image signals corresponding to the luminescent colors of headlights and taillights are extracted. Conditional expressions for the features extraction are then set, and the image signals are extracted in accordance with the conditional expressions.

For example, with white luminescence such as when a headlight is lit, the R, G and B values are large and there is little difference between the values. The conditional expressions for white luminescence are as follows.

$| R - G | < \varepsilon / 10$

$| G - B | < \varepsilon / 10$

$| B - R | < \varepsilon / 10$

$4\varepsilon / 5 < R, G, B$ ... ... (1)

The potential values that R, G and B may assume range from 0 to ε.

With red luminescence when a taillight is lit, the value of R (red) is at least twice that of G (green) and B (blue). Therefore, the extraction conditional expression for the red luminescence of taillights is as follows.

$R > 2 B$, and $R > 2 G$ ... ... (2)

The image data of features extracted in step 104 in this way are stored in a memory 142 in step 105. Image data are stored every 0.05 second, for example. Next, In step 106, the image data stored in the memory 142 are sent to a recognition unit 143, which determines whether the image from which features have been extracted is a taillight.

As determination criteria, the determination is made according to whether there are two red images 52 and 53 at the same height within a setting range 51 on a screen corresponding to the range of the traffic lane in which the device vehicle is traveling, as shown in Fig. 5(A). In the case that taillights are recognized in step 106, the operation advances to step 107, in which whether the headlights are in a high beam state is determined from the state of a headlight high/low-beam switch. In the case that the headlights are in a high beam state in this step 107, in the next step 108, the headlights are controlled to switch the headlights to low beams, and the operation advances to step 109. In this case, that the headlights have been switched from high to low beams is stored in a memory. This storage is erased in the case that the headlights are returned to high beams or the ignition switch is disengaged, but is retained in the meantime. Alternatively, in the case that the headlights are determined to be low beams in step 107, the operation advances directly to step 109.

In step 109, the image data stored every 0.05 second in the memory 142 are inputted to a computation unit 144, and in the next step 110, the distance Z from a vehicle traveling ahead and the speed relative to the vehicle traveling ahead are calculated.

This distance Z from a vehicle traveling ahead is calculated based, for example, on a distance r1 between the recognized taillights 52 and 53 Specifically, the distance r1 is obtained by a calculation such as the following:

If the focal length of the television camera 11 is f, the distance from the lens of the camera 11 to the vehicle is Z, and the magnification of the camera 11 is β, the following equation holds true.

$$\beta = f / Z \quad \text{......} \quad (3)$$

If the distance between taillights is R when β is "1", the following equation then holds true.

$$\beta = r / R \quad \text{......} \quad (4)$$

From equations (3) and (4), the distance Z between vehicles is obtained by the following equation.

$$Z = f R / r \quad \text{......} \quad (5)$$

The distance between vehicles is calculated in this way every 0.05 second as the image data are stored, and the speed of the device vehicle relative to a vehicle traveling ahead is calculated from the distance between vehicles obtained every 0.05 second. Specifically, 0.05 second after a taillight image such as shown in Fig. 5(A) has been obtained, the same taillight image is as shown in Fig. 5(B), and the distance between taillights 52 and 53 changes from r1 to r2. If Z1 is the distance between vehicles calculated using the distance r2, the speed V relative to the vehicle ahead can be obtained by the following equation.

$$V = (Z - Z1) / 0.05 \quad \text{......} \quad (6)$$

The distance Z from and the speed V relative to a vehicle ahead are obtained by such a calculation in step 110, and the results of this calculation are displayed in step 111.

A numerical display on a panel meter of the vehicle, for example, may be used as a display means in the step 111.

In the case that a taillight was not recognized in step 106, the operation advances to step 112. In this step 112, headlights are recognized by determining whether there are two white luminescent colors 62 and 63 at the same height in a setting range 61 corresponding to an oncoming traffic lane on a screen as shown in Fig. 6, and recognizing the headlights of an oncoming vehicle according to whether there are these two white luminescent colors 62 and 63.

In the case that headlights have been recognized in this step 112, the operation advances to step 113, and the state of the headlights of the device vehicle is determined in the same manner as in step 107, and in the case that they are high beams, the headlights are switched to low beams in step 114.

In the case that headlights were not recognized in step 112, it is determined that there is neither a car traveling ahead nor an oncoming car, in which case, the operation advances to step 115. In step 115, the past headlight setting status is determined from the contents stored in memory, and in the case that a state of high beams has been stored in memory, the operation advances to step 116 to switch the headlights to high beams. For example, in the case that the headlights have been switched to low beams in step 108 or 114 from a state of traveling with high beams on and the previous high beam state has been stored in memory, the headlights are switched to high beams in step 116after passing the vehicle ahead or being passed by the oncoming vehicle.

In other words, with the device, in the case that there is a vehicle ahead or an oncoming vehicle while traveling at night and the headlights are in the high beam state, for example, the headlights are automatically switched to low beams, thus automating road traffic safety. The distance from and the speed relative to a vehicle ahead at night can also be known accurately, and can be used effectively as a means for preventing rear-end collisions. Because the distance between vehicles and relative speed have been calculated in this case, these data can be used to predict a potential rear-end collision, and an audible or other type of warning can be issued to a driver based on this prediction. In other words, the device may also be used as a means for preventing drowsy driving.

The television camera for imaging in the forward direction may be mounted at any location from which the forward direction of the vehicle can be imaged. The television camera may also be configured such that the mounting angle of the camera can be varied, such that, for example, the angle is automatically controlled in response to the angle of steering maneuvers. When configured in this way, the camera always faces the steered direction of the vehicle so as to effectively monitor vehicles ahead. The device can also be used effectively as a safe driving warning system by setting a safe distance between vehicles according to the absolute speed of the device vehicle, and warning the driver by voice or a buzzer if the distance between vehicles has become less than the set distance between vehicles. A delay timer processing may also be used in the working example described earlier when controlling to switch from low beams to high beams.

<Effects of the invention>

As described above, the traveling vehicle recognition device of the present invention recognizes whether there is a vehicle traveling ahead or an oncoming vehicle, especially at night, and automatically controls the headlights according to the recognition result. Therefore, the invention can achieve a significant effect in terms of safe driving by executing a basic safety operation of nighttime driving automatically. In connection with this, the invention can also issue various warning actions for safe driving, thereby effectively expanding the range of applications for safe driving.

4. Brief explanation of the drawings

Fig. 1 is a block diagram illustrating the recognition device according to a working example of the present invention; Fig. 2 is a diagram illustrating the setting state of a television camera in this working example; Fig. 3 is a flowchart illustrating the operation states of this working example; Fig. 4 is a diagram showing an example of a configuration of the image signal processor of this working example; Fig. 5 is a diagram illustrating images of taillight recognition, and Fig. 6 is a diagram illustrating an image of headlight recognition.

11 ... Color television camera, 12 ... Vehicle, 13 ... Decoder, 14 ... Video signal processor, 15 ... Executing part, 16 ... Vehicle speed sensor, 17 ... Headlight switch

Takehiko Suzue, Patent Attorney

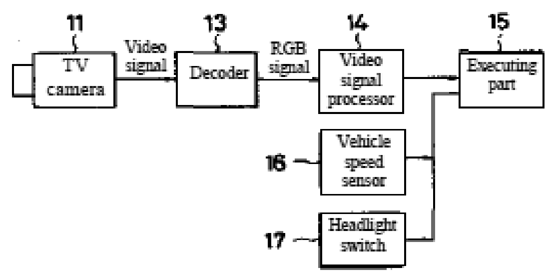

Fig. 1

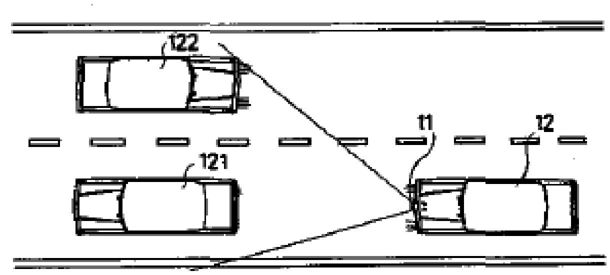

Fig. 2

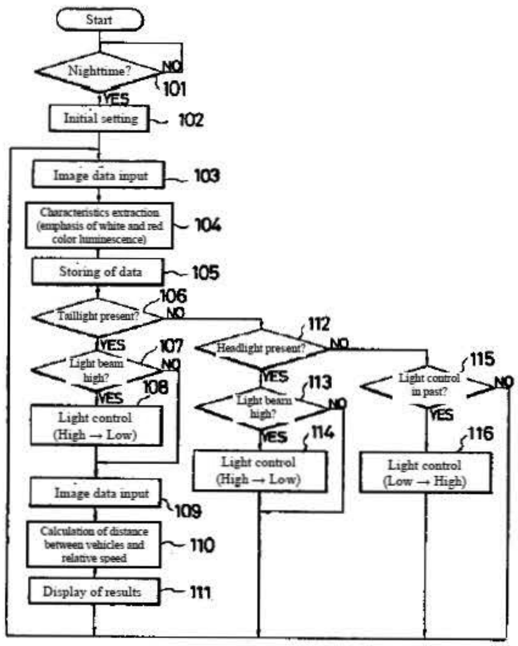

Fig. 3

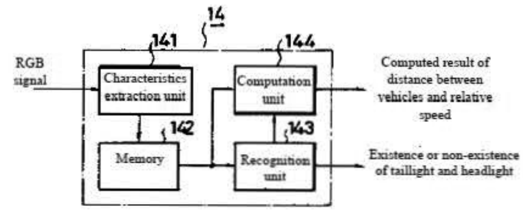

Fig. 4

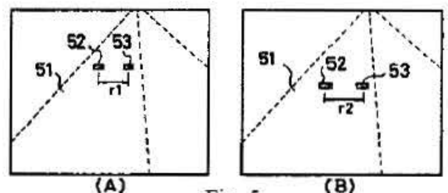

Fig. 5

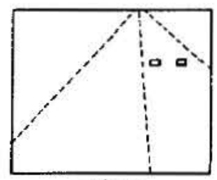

Fig. 6

PARK
IP TRANSLATIONS

June 24, 2013

Certification

Park IP Translations

This is to certify that the attached translation is, to the best of my knowledge and belief, a true and accurate translation from Japanese into English of: Japanese patent S62-131837.

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⑭発明の名称　走行車両の認識装置

㉑特　願　昭60-272478
㉒出　願　昭60(1985)12月5日

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明　細　書

1．発明の名称

走行車両の認識装置

2．特許請求の範囲

走行する車両の前方を撮影するカラー撮像手段と、

この撮像手段で撮影された映像信号に基づき、各色にそれぞれ対応するカラー画像信号を形成する手段と、

上記手段によって得られたカラー画像信号に基づき、テールランプおよびヘッドライトにそれぞれ相当する色彩の画像信号を抽出する特徴抽出手段と、

この特徴抽出手段によって抽出された画像信号によって、テールランプあるいはヘッドライトの存在を認識する手段と、

上記認識されたテールランプの画像に基づいて、前方車両との間の車間距離並びに相対速度を算出する計算手段と、

上記認識手段の認識結果に基づき、ヘッドライトコントロールを実行させる実行手段とを具備し、

少なくとも上記ヘッドライトの認識によって前方に対向車の存在する状態が認識されたときに、車両のヘッドライトをロービームに切換え制御するようにしたことを特徴とする走行車両の認識装置。

3．発明の詳細な説明

［産業上の利用分野］

この発明は、特に夜間において前方を走行する車両のテールランプの存在、さらに対向車のヘッドライトの存在を認識し、前方車両との相対関係を計算表示すると共に、自車ヘッドライトを自動的にコントロールできるようにする走行車両の認識装置に関する。

［背景技術］

自動車を夜間運転する場合、ヘッドライトを点

灯して走行しているものであり、特に走行している車両の少ない場所等を運転する際には、ヘッドライトをハイビームに設定して運転している。

しかし、このようなハイビームの運転状態にあっては、対向車が存在する場合、あるいは前方を走行する車両が近接した状態では、ヘッドライトをロービームに切換え、対向車の運転者あるいは前方を走行する車両の運転者の視界を妨げないようにする必要がある。しかし、このようなヘッドライトのビームコントロールは運転者にとって煩わしいものであり、特にカーブの多い道路を運転している場合には、運転操作をより複雑なものとしている。また、前方を走行している車両が存在する場合には、この前方車両との車間距離、さらに前方車両との相対速度を運転者が正確に認知する必要のあるものであり、安全運転のためには、このようなライトコントロールと共に、前方車両との相対関係を正確に知る必要のあるものである。

［発明が解決しようとする問題点］

この発明は上記のような点に鑑みなされたもので、特に夜間に運転する場合において、前方に存在する車両の状態に対応して例えばヘッドライトのビームをハイビームおよびロービームに自動的に制御できるようにするものであり、また前方を走行する車両との相対関係に対応して運転者に警告を発することができるようにした走行車両の認識装置を提供しようとするものである。

［問題点を解決するための手段］

すなわち、この発明に係る走行車両の認識装置は、走行する車両に対してこの車両の前方を撮影する例えばカラーテレビジョンカメラのような撮像装置を設定し、この撮像装置で撮影したカラー映像信号に基づいて、ヘッドライト並びにテールランプの色彩の特徴を抽出することによって特徴抽出カラー画像信号を形成し、前方車両のヘッドライト、並びにテールランプを認識するものであり、この認識結果に基づいてヘッドライトのビーム制御を実行させるようにするものである。また、認識されたテールランプの画像信号に基づいて前方を走行する車両との車間距離並びに相対速度を算出するようにしている。

［作用］

上記のように構成される走行車両の認識装置にあっては、色彩の特徴から前方の車両のヘッドライトおよびテールランプを認識できるものであり、この認識によって対向車の存在、さらには前方を走行する車両の存在を運転者に知らせることができるようになる。また、この認識結果に基づいてヘッドライトをハイビームからロービームに切換える必要が生じたときの条件が検出されるものであり、この検出条件が設定されたときにヘッドライトのビームコントロールを自動的に実行させることができるようになる。また、テールランプの認識から、前方車両との車間距離並びに相対速度が計算できるものであり、したがって例えば追突の危険性があるような状態で、運転者に対して警告が発せられるようになるものである。

［発明の実施例］

以下、図面を参照してこの発明の一実施例を説明する。第１図はその構成を示すもので、カラーテレビジョンカメラ11を備える。このテレビジョンカメラ11は、例えば第２図で示すように自動車等の車両12の前方に取り付け設定されているもので、この車両12の前方を撮影し、特に前方を走行する車両121 と共に、対向車線を走行する車両122 までも撮影できるように設定されている。この場合、特に夜間において車両121 の赤色のテールランプおよび車両122 の白色のヘッドライトが確実に撮影されるようにしてある。

このテレビジョンカメラ11で撮影された映像のビデオ信号は、デコーダ13に供給されるもので、このデコーダ13にあっては、上記ビデオ信号に基づいてＲ（赤）、Ｇ（緑）、Ｂ（青）のカラー画像信号を形成し、このＲ、Ｇ、Ｂのカラー画像信号は画像信号処理部14に供給する。

この画像信号処理部14にあっては、上記Ｒ、Ｇ、

Bのカラー画像信号から、テールランプの色彩である赤色、さらにヘッドライトの色彩である白色の特徴を抽出し、例えば2値の画像信号を抽出するものであり、この抽出画像信号に基づいて撮影された映像の中にテールランプあるいはヘッドライトの存在を認識させるようにするものである。そして、この認識結果は実行部15に送られる。

また、この実行部15には、車速センサ16からの車両速度に対応して検出信号、およびヘッドライト切換えスイッチ17からの、ヘッドライトのハイビームあるいはロービームの設定状態を示す信号が供給されている。そして、この実行部15で上記認識情報、車速情報、並びにヘッドライト情報に基づいて、ヘッドライトのビーム制御あるいは運転者に対する警報報知の作業が実行されるようにしているものである。

第３図は上記のような装置の動作状態の流れを示しているものであり、車両のイグニッションスイッチが投入されることによってスタートされるようになる。そして、ステップ101でヘッドライトの点灯の有無から夜間であるか否かを判断するもので、夜間であることが判断されたならばステップ102に進む。そして、このステップ122で初期設定する。この初期設定ステップ102においては、撮影する画面の走査部分の設定や、テールランプおよびヘッドライトを認識するための特徴抽出条件を設定するものである。

このように初期設定されたならば次のステップ103に進み、カラーテレビジョンカメラ11からのビデオ信号に基づいて形成されたデコーダ13からのカラー画像信号を取り込み、画像信号処理部14に入力させる。そして、次のステップ104に進む。このステップ104は上記カラー画像信号から画像信号処理部14での特徴抽出を実行させるもので、発光色の白および赤を強調するものである。

この画像信号処理部14は、例えば第４図で示すように構成されるもので、特徴抽出部141を備え、この特徴抽出部141に上記デコーダ13からのR、G、Bのカラー画像信号が供給される。この特徴抽出部141で実行する特徴抽出とは、入力画像信号を２値化して、認識する対象であるヘッドライトおよびテールランプに関連する情報のみを取り出すものであり、ここではヘッドライトおよびテールランプそれぞれの発光色彩に対応したカラー画像信号を抽出するものである。そして、この特徴抽出のための条件式が設定されるものであり、この条件式に対応した画像信号を抽出するものである。

例えばヘッドライトの点灯時のような白の発光色は、R、G、Bのそれぞれの値が大きく、且つこの各値の相互の間の差が小さい状態となる。そして、この白の発光色を抽出する条件式は、次のようになる。

$$|R-G|<\varepsilon/10$$
$$|G-B|<\varepsilon/10$$
$$|B-R|<\varepsilon/10$$
$$4\varepsilon/5<R.\ G.\ B \cdots\cdots\cdots\cdots (1)$$

但し、R、G、Bの取り得る値の範囲は０～εとする。

また、テールランプの点灯時の赤の発光色は、R（赤）の値が他のG（緑）、B（青）の２倍以上となるものであるため、このテールランプの赤の発光色の抽出条件式は次のようになる。

$$R>2B、および R>2G \cdots\cdots (2)$$

このようにしてステップ104で特徴抽出された画像データは、ステップ105でメモリ142にストアされる。この画像データのストアは、例えば０．０５秒毎に実行される。そして、このメモリ142にストアされた画像データは、ステップ106で認識部143に送られて、この特徴抽出された画像がテールランプであるか否か判断される。

この判断の基準としては、第５図（A）に示すように自分の車両の走行する走行車線の範囲に対応する画面上の設定範囲51内に、同じ高さで２つの赤い色の像52、53があるか否かによって判断する。このステップ106でテールランプが認識されたならば、ステップ107に進んで、ヘッドライトの遠近切換えスイッチの状態から、ヘッドライトの状態がハイビームであるか否か判断する。このステップ107でヘッドライトがハイビームの状

態であったならば、次のステップ108でヘッドライトをロービームに切換えるライトコントロールを実行し、ステップ109に進む。この場合、ヘッドライトをハイビームからロービームへの切換えを実行したことは、メモリに対して記憶しておく。この記憶は、ヘッドライトビームが再びハイビームとなった場合、あるいはイグニッションスイッチが開放された場合に消去されるもので、それまでは保持されている。また、ステップ107でヘッドライトがロービームであると判断されたならば、そのままステップ109に進む。

このステップ109では、０．０５秒毎に上記メモリ142にストアさせれた画像データを計算部144に対して入力させるものであり、次のステップ110で前方を走行する車両との車間距離Ｚ、さらに前方を走行する車両との相対速度を計算させる。

ここで、前方を走行する車両との車間距離Ｚは、例えば上記認識されたテールランプ52および53の間の距離ｒ１に基づき計算するもので、具体的には次のような計算により上記距離ｒ１を求める。

すなわち、テレビジョンカメラ11の焦点距離をｆ、このカメラ11のレンズから車両までの距離をＺ、カメラ11の倍率をβとすると、

$\beta = f / Z$ ……………………（３）

の式が成り立つ。そして、上記倍率βが「１」の場合のテールランプ間の距離をＲとすると、次の式が成り立つ。

$\beta = r / R$ ……………………（４）

上記（３）および（４）式から、車間距離Ｚは次式で求められる。

$Z = fR / r$ ……………………（５）

このような車間距離の演算は上記画像データのストアされる０．０５秒毎に実行されるものであり、この０．０５秒毎に得られる車間距離から自己の車両と前方を走行する車両との相対速度が計算される。すなわち、第５図（Ａ）で示すようなテールランプの画像が得られてから０．０５秒後の同じテールランプの画像は第５図の（Ｂ）に示すようになるものであり、テールランプ52と53との間の距離はｒ１からｒ２に変化するようになる。

そして、この距離ｒ２によって計算した車間距離をＺ１とすると、前方車両との相対速度Ｖは次の式で求められる。

$V = (Z - Z1) / 0.05$ ……（６）

このような計算によってステップ110で前方車両との車間距離Ｚおよび相対速度Ｖが求められるもので、この計算結果はステップ111で表示されるようになる。

このステップ111における表示の手段としては、例えば車両のメータパネルに数字によって表示するようにすればよい。

上記ステップ106でテールランプが認識されなかった場合はステップ112に進む。このステップ112ではヘッドライトの認識を行なうもので、第６図に示すように画面上の対向車線に相当する設定範囲61に、同じ高さで２つの白い発光色62、63が存在するか否かによって判断するもので、この２つの白い発光色62、63の存在によって対向車のヘッドライトを認識する。

このステップ112でヘッドライトが認識されたならばステップ113に進み、自己の車両のヘッドライトの状態をステップ107と同様に判断し、ハイビームであった場合にはステップ114でロービームに切換える。

上記ステップ112でヘッドライトが認識されなかった場合には、前方を走行する車両および対向車が存在しないことが判断されるもので、この場合にはステップ115に進む。このステップ115では、メモリの記憶内容から過去のヘッドライトの設定状態を判断し、メモリにハイビームであったことが記憶されていたならば、ステップ116に進んでヘッドライトをハイビームに切換える。例えば、ハイビームで走行している状態でステップ108あるいは114でロービームに切換えられ、その前のハイビームの状態がメモリに記憶されていたならば、前方車両を追い越し、あるいは対向車とすれ違った後にステップ116でヘッドライトがハイビームに切換えられるものである。

すなわち、上記の装置にあっては夜間走行中において、前方に車両が存在する場合、あるいは対

向車が存在する場合には、例えばヘッドライトがハイビーム状態である場合に、これを自動的にロービームに切換えるものであり、道路の安全運転が自動的に実行されるものである。また、夜間にあって特に前方車両との車間距離および相対速度が、正確な状態で知ることができるものであり、追突防止手段としても効果的に利用できる。この場合、車間距離および相対速度が計算されているものであるから、これらのデータから追突予測もできるものであり、この予測から運転者に音響等によって警告を発することもできる。すなわち、居眠り運転の防止手段としても使用できるようになる。

尚、前方を撮影するテレビジョンカメラの取り付け位置は、車両の前方を撮影することのできる位置であればどの位置であってもよい。また、カメラの取り付け角度を変化できるように構成し、例えばステアリングの操作角度に対応して自動的に角度制御できるようにしてもよい。このようにすれば、カメラは常に車両の操舵方向に向くようになり、前方車両の監視が効果的に実行されるようになる。また、自己の車両の絶対車速によって安全車間距離を設定し、車間距離がその設定車間距離以下の状態となったときに、音声またはブザーによって運転者に報知できるようにしておけば、安全運転警告システムとして効果的に利用できるものである。さらに、上記実施例でロービームからハイビームに切換え制御する場合に、遅延タイマ処理を施すようにしてもよい。

［発明の効果］

以上のようにこの発明に係る走行車両の認識装置によれば、特に夜間において前方を走行する車両、さらに対向車の存在を確実に認識し、この認識結果によってヘッドライトコントロールが自動的に実行されるようになる。したがって、夜間運転の基本的な安全操作が自動的に実行されるものであり、安全運転上で大きな効果を発揮することができる。また、これに附随して各種の安全運転上の警告動作も実行できるようになるものであり、その安全運転のための応用範囲も効果的に拡大されるものである。

４．図面の簡単な説明

第１図はこの発明の一実施例に係る認識装置を説明する構成図、第２図は上記実施例におけるテレビジョンカメラの設定状態を説明する図、第３図は上記実施例の動作状態を説明するフローチャート、第４図は上記実施例の画像信号処理部の構成例を示す図、第５図はテールランプを認識する画像状態を説明する図、第６図は同じくヘッドライトを認識する画像状態を説明する図である。

11…カラーテレビジョンカメラ、12…車両、13…デコーダ、14…画像信号処理部、15…実行部、16…車速センサ、17…ヘッドライト切換えスイッチ。

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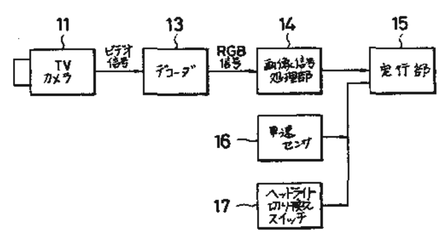
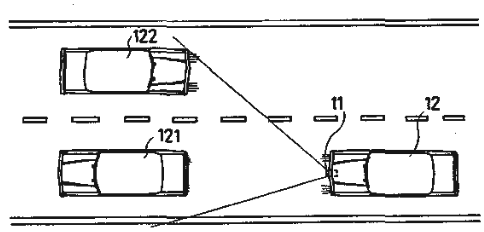
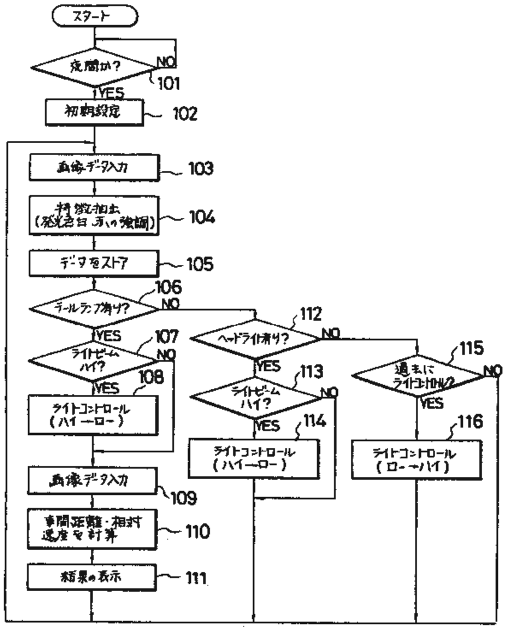


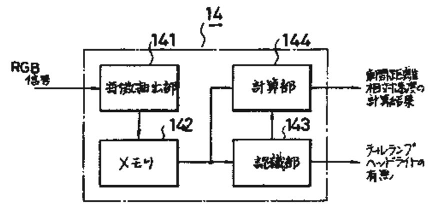
第１図



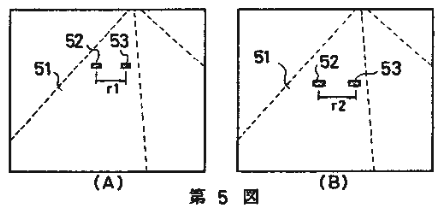
第２図



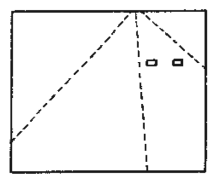
第 3 図



第 4 図



第 5 図



第 6 図

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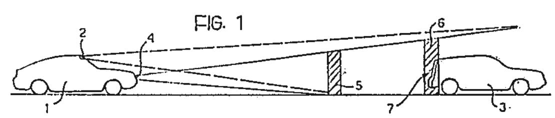
The title of the invention has been amended (Guidelines for Examination in the EPO, A-III, 7.3).

(54) **Method and device for instrument-assisted vision in poor visibility, particularly for driving in fog.**

(57) The method comprises the steps of:
- illuminating a portion of space situated in the region through which the vehicle is about to travel (1) by means of a plurality of pulses (5, 6) emitted at predetermined time intervals;
- monitoring the scene in front of the vehicle (1), including the light which is reflected back by the obstacle (3) in respective time windows;
- reconstructing the image graphically, and
- displaying the reconstructed and processed image on the windscreen.

FIG. 1



EP 0 353 200 A2

Exhibit H

Description

A method and device for instrumental vision in conditions of poor visibility, particularly for driving in fog

The present invention relates in general to the display of scenes in conditions of low visibility.

In particular, the present invention has been developed with a view to its possible use for facilitating the driving of motor vehicles in conditions of poor visibility, for example in fog.

Devices which use equipment with radar systems have already been proposed for identifying objects in fog. Whilst they enable objects to be located in conditions of poor visibility, these devices are not without disadvantages for use in motor vehicles since the instrumental information they supply is not readily understood by the average driver.

In general, the problem with vision in fog, both during the day and at night, results from the low level of illumination of the detector by the object to be detected compared with the level generated by the scattering of the ambient light by the fog itself.

In fact, the scattering by the fog obviously affects all of the illuminated space and the signal detected by the receiver is dependent on the space itself and on the laws by which the light is attenuated/propagated in the receiving geometry in question.

The presence of an object to be detected in order to describe the scene, however, is connected only with reflection/scattering by the surface of the object which faces the receiver.

As a result, the signal/noise ratio is largely dependent on the density of the scattering medium in the space between the observer and the object.

Moreover, regardless of the method used for detecting the image of the scene, there are two basic aproaches to the problem of using the information obtained:

a) the reproduction of a processed scene which still contains the shape and appearance of what the observer would see if the visibility were better (interpretation and decision on the part of the observer);

b) the reproduction of summarised information concerning the contents of the scene without the "photographic" reconstruction thereof (interpretation -and decision - on the part of the automatic system).

Case a) includes television systems for detection in the visible and near-infrared; case b) includes microwave radar systems and passive thermographic systems, whilst far-infrared (10 micron) systems with active illumination belong to an intermediate category.

Essentially, the object of the present invention is to provide means for seeing in conditions of poor visibility, which are suitable for application in the automotive field, particularly with regard to driving in fog, and at the same time ensure reliable monitoring, even in critical conditions, and the ability to reconstitute for the driver visual information which is immediately recongisable as an image of the scene at which he is looking.

According to the invention, this object is achieved by virtue of a method for detecting images of an object in conditions of poor visibility, characterised in that it comprises the steps of:

- sending a train of light pulses towards the object,
- observing the object illuminated by the pulses in respective time windows,
- reconstructing images of the object from the observation in the respect time windows, and
- displaying the image thus reconstructed.

A further object of the present invention is a device for detecting images of an object in conditions of poor visibility, particularly by the method specified above, characterised in that it comprises:

- illumination means for sending a train of light pulses towards the object,
- televisual means for observing the object illuminated by the pulses and for generating corresponding television signals, the televisual means including a shutter which is operable selectively to make the televisual means sensitive only in respective time windows,
- processor means for reconstructing images of the object from the television signals obtained, and
- display means for presenting the reconstructed images.

For a better understanding of the invention, a description of an embodiment of the invention will now be given, purely by way of non-limiting example, with reference to the appended drawings, in which:

- Figure 1 shows schematically a possible situation of use of an instrumental vision device according to the invention, and
- Figure 2 shows the structure of part of the device of Figure 1 in greater detail, in the form of a block diagram.

With reference to Figure 1, a car, indicated 1, is provided with a device 2, 4 for detecting, in accordance with the invention, the preence of a moving car 3 which is not visible to the driver of the vehicle because of fog between the two vehicles 1 and 3. A lamp, indicated 4, preferably with monochromatic emission (for example, operating at a wavelength λ of the order of 900 nm), is mounted on the front part of the car 1 and can emit light pulses of a duration τ (e.g. 10^{-8} seconds) with a frequency of repetition $f = 1/T$ equal to an average of 3 KHz, where T represents the interval between the pulses.

Each pulse emitted by the lamp 4 is propagated in the space in front of the car 1 and illuminates a respective "window" or "slice" with a depth C τ (where C is the speed of light in the medium) equal, for example, to approximately3 metres (not to scale in the drawings). This window moves forwards towards the car 3 as shown schematically in Figure 1 where 5 and 6 represent the successive positions reached by the window corresponding to a given light pulse or, alternatively, the positions reached at the same time by two pulses emitted in succession.

In the case of the window 5, which illuminates a space without obstacles, it is clear that no image will be returned to the vehicle 1, except that due to the backscattering caused by the fog.

In the case of the window 6, however, both the fog and the obstacle (the vehicle 3) will contribute to the signal since, in this case, the useful back-scattering region 7, that is, the rear part of the car 3 is included in the space illuminated by the pulse.

The reference numeral 2 indicates a processing system which is also mounted on the front part of the car 1 and is constituted by a lens 8 adapted to focus the reflected image of the obstacle 3 (whose intensity is very low) onto an image intensifier 10. In this way, a completely reconstructed image of the vehicle 3 is provided by the subsequent processing of the intensified signal by a televisual sensor 11 (for example, of the CCD type), by the respective management unit (television camera) 12, and by a processing and control system 13 and 14.

The image reconstructed by the processing and control system 13, 14 (which also controls the operation of the lamp 4) can then be presented on the windscreen by means of a head-up display unit 15, according to criteria widely known in the aeronautical field. The driver can thus see the obstacle 3 with the exact dimensions and at the exact distance at which it is situated, under just the same conditions as those governing vision under conditions of normal visibility.

The image intensifier 10 used in the device according to the invention is adapted for pulsed operation and thus also for performing the task of a shutter (as will be specified below) so as better to discriminate between the backscattering from the obstacle to be displayed and that from the fog.

According to a variant of the invention, the rapid obturation of the television camera 11, 12 carried out by the intensifier device 10 may alternatively be achieved by control of the grid voltage of any vacuum tube (e.g. a vidicon) which replaces the CCD televisual sensor 11, or at any rate other sensors for carrying out these functions.

In order better to understand the criteria governing the pulsed operation of the intensifier shutter 10 (or a member equivalent thereto) which is controlled by the system 14 through a piloting line 16, it should be noted that any object lying in a space illuminated by the pulses from the lamp 4 reflects back/scatters the incident light. The sources of the light "echo" are located in the space and are active continuously or in pulses at the moment when the illuminating wave front 5, 6 strikes them.

If a scattering medium (fog) is present, in addition to the attenuation of all the light signals passing through it, there is also an emission (continuous or pulsed) of backscattered radiation constituting a background which can rapidly mask the other signal sources.

However, if only pulsed illumination is considered, there is, at any moment, a layer (whose shape depends on the illuminating lens) with a thickness $c\,\tau$ (c = the speed of light, τ = pulse duration). If a receiving time window of a duration τ is opened (by means of the actuator 10) with a delay $n\,\tau$ (n = 1, 2, 3...) relative to the illuminating pulse, an image of a "slice" of the space of a thickness $c\,\tau$ at a distance

$$\frac{n\,\tau \cdot c}{2}$$

is obtained.

If there is an object in this slice, the ratio between the signal reflected back/scattered by the object and that scattered back by the fog in the space is at a maximum.

This signal is propagated towards the receiver 2 and is attenuated due to the characteristics of the propagation medium, but the original signal/background ratio remains unaltered.

This is because the receiving time selected by the shutter 10 excludes all the signal contributions outside the selected "slice".

Since the positions of various objects in the scene are not known beforehand, it is necessary to carry out a scanning sweep through the entire space up to the greatest distance of interest in order to achieve complete monitoring.

Quantitatively, and as a first approximation, the improvement in the signal/background (S/N) ratio resulting from the use of a pulsed illumination-detection system can be evaluated by considering that:

1) with continuous illumination, this ratio (S/N) is proportional to Ro/Rv where Ro is the signal reflected back/scattered by the object to be displayed (vehicle 3) and Rv is the signal scattered back by the volume of fog concerned between the object 3 and the receiver 2;

2) with pulsed illumination (of repetition N), the (S/N) ratio is proportional to

$$\frac{N\,\tau \cdot Ro}{N\,\tau \cdot Rv} \cdot \frac{D}{\tau\,c}$$

where D is the maximum distance monitored.

The convenience of having illumination pulses (lamp 4) and receiving windows (shutter 10) of equal and short duration (10 ns) is obvious. If a standard television camer (11, 12) is used as the sensor and it is proposed to take a "slice" for every frame (1/25 sec, 1/30 sec) with a maximum S/N ratio, pulses of 10 ns would be required.

A reasonable number Nq of frames for the reconstruction of a scene would be approximately 50, thus covering a maximum monitored distance

$D = Nq \cdot \tau \cdot c = 50 \cdot 10^{-8} \cdot 3 \cdot 10^{-8} = 150$ m is 1.5 s.

Information on the distance would thus be associated with each frame, enabling an immediate three-dimensional reconstruction of the scene.

However, it is clearly necessary to increase the acquisition rate by one order of magnitude to achieve detection rates more appropriate for monitoring the road (0.1 s). This can also be achieved but, combined with the above requirement, involves rather complex management of the television camera.

In order to simplify this management, it is possible to integrate the contributions of the Nq light pulses necessary to cover with slices the whole space concerned up to the distance D in the television camera, in a standard time frame (1/25s - 1/30s).

This can be done by summing Nq light pulses of a duration τ with Nq openings of a duration τ with increasing delays until the maximum distance concerned is covered for each television frame; in this case, the total exposure (E) of the television camera for each television frame will be

$E = N\tau\ (= 5 \cdot 10^{-7}$ s).

Alternatively, with even simpler management, receiving windows with a duration $T = \frac{2D}{c}$ may be opened for each light pulse emitted.

Thus, the total exposure (E) of the television camera for each frame is

$$E = Nq\,\frac{2D}{c} = Nq\,\frac{2\,\tau\,cNq}{c} \quad (5 = 5.10^{-5}s)$$

It is considered that, apart from the contribution of any light sources other than the active one, this second hypothesis provides a signal/background ratio which is worse by a factor less than or equal to 2 than the previous one since the time for which the scattering space is illuminated is equal in both cases ($Nq.\tau$) and the accumulation of signals due to backscattering by the fog is $Nq\,\tau$ in one case and $2Nq^2\,\tau$ in the other, whilst the contribution of the objects present in the scene remains constant but is summed only once in the first case and Nq times in the second (the factor is less than or equal to 2 because the additional integration relates to the space between D and 2D). Therefore, in the two cases:

Case 1 - Background = E = $Nq\,\tau$

Signal = 1

S/N = 1/Nq

Case - Background = $Nq \cdot \frac{2D}{c} = 2\,Nq^2\,\tau$

Signal = $Nq\,\tau$

S/N = 1/2 Nq.

In each case, however, it is possible to cancel out the contribution from the backscattering in the space in the immediate vicinity of the receiver where it is most intense (blind space).

The attenuation of signals due to propagation in the scattering medium (which may possibly be compensated for by an increase in the power emitted by the light source 4 so as to retain visibility by virtue of the better signal/interference ratio) will not be considered herein, but that resulting from the pulsed-light method will be considered.

It is clear that the pulsed method provides a signal which is inferior by a factor $1/N\,\tau$ to that with continuous light.

With reference to the typical values indicated above, the order of magnitude of this reduction is approximately $6 \cdot 10^4$.

The signal recovery can take place with the use of intensifying television cameras in which the intensifier 10 acts both as such and as a rapid shutter.

Television cameras of this type are currently available commercially. For example, known antiblooming CID television cameras which are produced by General Electric and intensify with an optical gain of 5000 are capable of pulsed operation with rise times of the order of 5ns.

In order to minimise the interference generated by the environment, such as daylight or street lighting, it is possible to carry out optical filtering at the wavelength of the monochromatic light used for the active emission associated with a limited opening time of the television camera (e.g. 5.10^{-5} s of exposure per frame) or even to increase the power emitted by the lamp 4.

As regards interference caused by passing vehicles, if they are provided with the same device 2, 4 operating at the same wavelength, frequency of repetition, and duration of acquisition time-windows, the law of casual coincidence between non-synchronised devices applies. The number of coincidences, that is, the direct illumination of the sensor unit 2 in one vehicle by the lamp 4 of another vehicle, is $2NT = 2 \cdot 1.5 \cdot 10^3 \cdot 10^6 =$

3.10^{-3} for each vehicle passed.

This coincidence poses problems only of signal dynamics (which are easily resolved since they relate to pulses) whilst the probability of the passing vehicle being detected is increased and the performance of the system is therefore slightly improved.

Claims

1. A method for detecting images of an object (3) in conditions of poor visibility, characterised in that it comprises the steps of:
- sending (4) a train of light pulses (5, 6) towards the object (3);
- observing (2) the object (3) illuminated by the pulses (5, 6) in respective time windows (10);
- reconstructing (12 to 14) images of the object (3) from the observations in the respective time windows (5, 6) and
- displaying (15) the images thus reconstructed.

2. A method according to Claim 1, characterised in that the pulses (5, 6) are monochromatic light pulses (4), preferably with a wavelength λ substantially equal to 900 nm.

3. A method according to Claim 1 or Claim 2, characterised in that the object (3) is observed in substantially monochromatic conditions.

4. A method according to Claim 2 and Claim 3, characterised in that the object (3) is observed by means of filtering at a wavelength which corresponds substantially to the wavelength of the monochromatic light (14) of the pulses (5, 6).

5. A method according to any one of Claims 1 to 4 characterised in that the duration of each observation time window is of the same order of magnitude as the duration of each light pulse (5, 6).

6. A method according to any one of Claims 1 to 4, characterised in that each observation time window has a duration equal to a plurality (Nq) of light pulses (5, 6).

7. A method according to Claim 1 or Claim 6, characterised in that each observation time window has a duration T with

$T = \frac{2D}{c}$

where c is the speed of light in the observation medium and D is the maximum permitted distance of the object.

8. A device for detecting images of an object (3) in conditions of poor visibility, particularly by the method according to Claim 1, characterised in that it comprises:
- illumination means (14) for sending a train of light pulses (5, 6) towards the object (3);
- televisual means (10 to 12) for observing the object (3) illuminated by the pulses and for generating corresponding television signals, the televisual means including a shutter (10) which is operable selectively (14, 16) so as to make the televisual means sensitive only in respective time windows,
- processor means (13) for reconstructing images of the object (3) from the television signals obtained, and
- display means (15) for presenting the reconstructed images.

9. A device according to Claim 8, characterised in that the illumination means (4) generate monochromatic light, preferably with a wavelength λ substantially equal to 900 nm.

10. A device according to Claim 8 or Claim 9, characterised in that the televisual means (10 to 12) have a substantially monochromatic sensitivity due to optical filtering.

11. A device according to Claim 9 and Claims 10, characterised in that the televisual means (10 to 12) have a monochromatic sensitivity which substantially corresponds to the monochromatic light generated by the illumination means (4).

12. A device according to any one of Claims 8 to 10, characterised in that the televisual means (10 to 12) include an image-intensifier element (10).

13. A device according to Claim 11, characterised in that the image-intensifier element (10) can be activated selectively so that the intensifier element (10) also acts as a shutter (10) for defining the observation time windows.

14. A device according to any one of Claims 8 to 13, characterised in that the display means comprise a head-up display unit (15).

15. A motor vehicle (1) provided with a device (2, 4) according to any one of Claims 8 to 14, for driving in conditions of poor visibility.

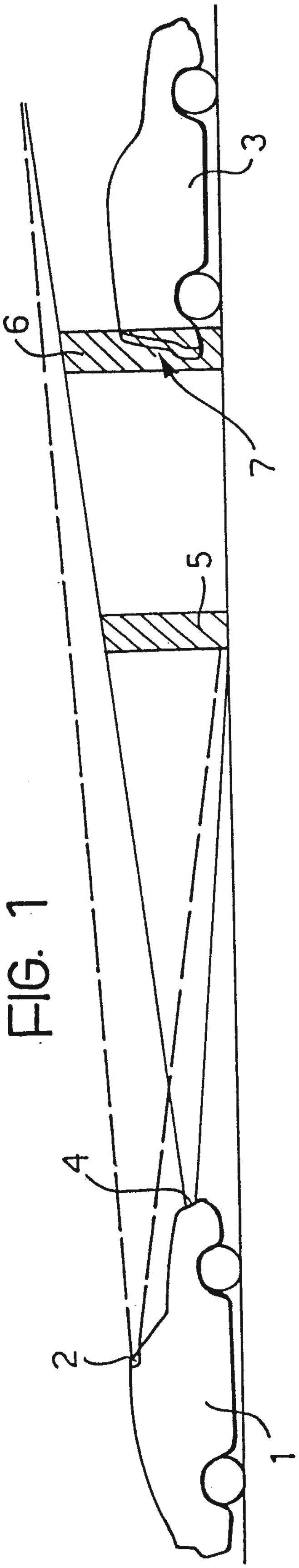


FIG. 1

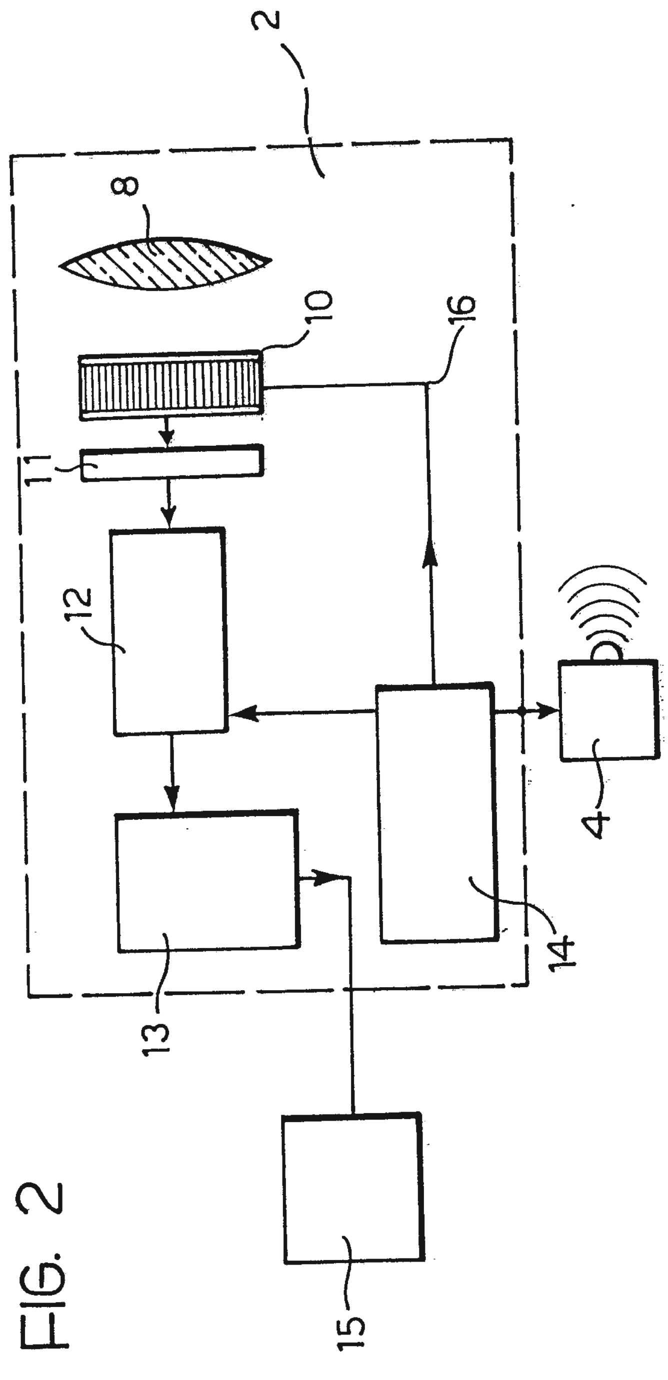


FIG. 2

US005166681A

United States Patent [19]

Bottesch et al.

[11] **Patent Number: 5,166,681**

[45] **Date of Patent: Nov. 24, 1992**

[54] **PASSIVE VEHICLE PRESENCE DETECTION SYSTEM**

[76] Inventors: **H. Werner Bottesch**, R.D. #6, Box 374, Danville, Pa. 17821; **David A. Freas**, P.O. Box 324, Mifflinville, Pa. 18631

[21] Appl. No.: **560,052**

[22] Filed: **Jul. 30, 1990**

[51] **Int. Cl.**[5] **G08G 1/04**

[52] **U.S. Cl.** **340/933;** 340/942; 340/901; 340/903; 340/436; 340/555; 180/167; 250/336.1

[58] **Field of Search** 340/933, 942, 901, 903, 340/904, 436, 555, 556; 455/600, 603, 604; 342/27, 29, 41, 53; 180/167; 250/336.1

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Primary Examiner—Donnie L. Crosland
Attorney, Agent, or Firm—Bernard A. Chiama

[57] **ABSTRACT**

A passive optical system (POS) is disclosed for detecting the presence of an object, such as a vehicle, in one or more areas of surveillance. The system includes one or more sensor tubes, each having one or more photosensitive devices arranged interiorly at one end and an opening in a wall at the other end, capable of focusing light rays emanating from a specific area of surveillance. Variations in the light rays caused by an object moving into or out of the area of surveillance cause corresponding fluctuations of the light rays impinging on the photosensitive devices, which, in turn, produce variation in a signal. The signal may be utilized to inform the driver of the host vehicle of a nearby vehicle or, when the POS is connected into a cruise control system, to manipulate the host vehicle, accordingly.

17 Claims, 13 Drawing Sheets

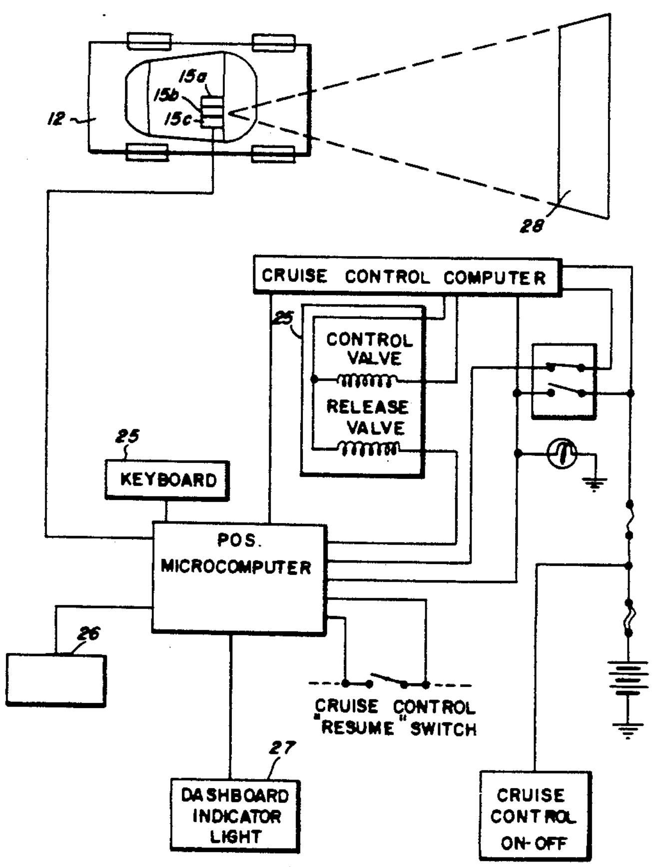


Exhibit I

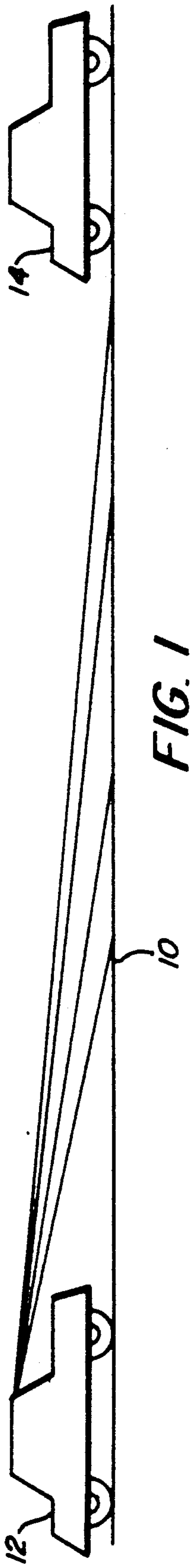


FIG. 1

FIG. 2

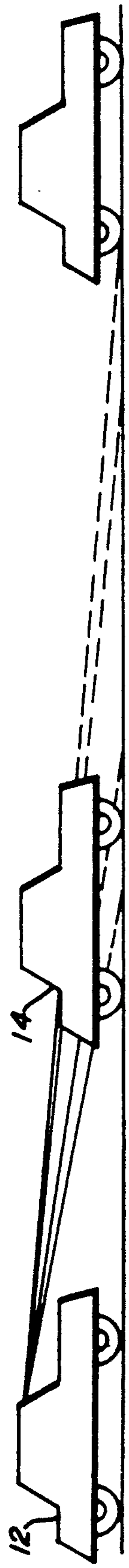


FIG. 3

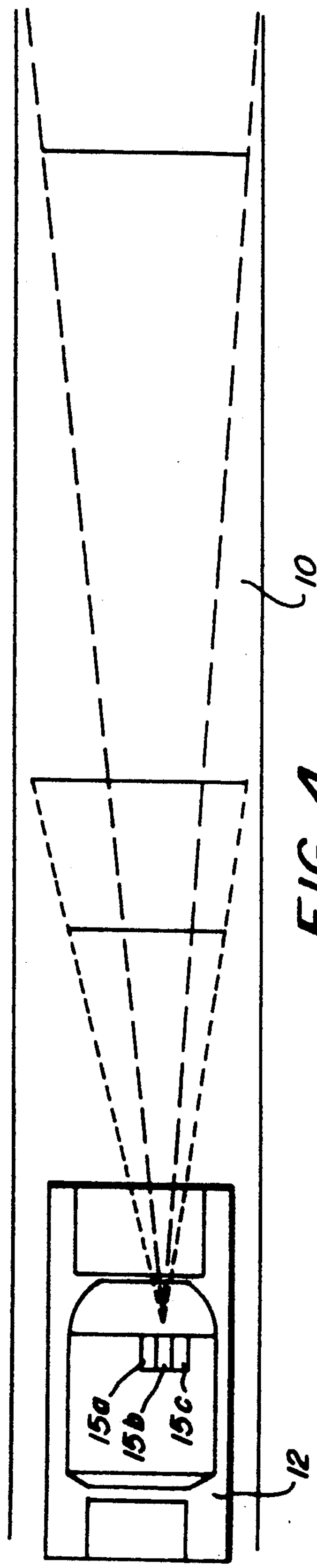


FIG. 4

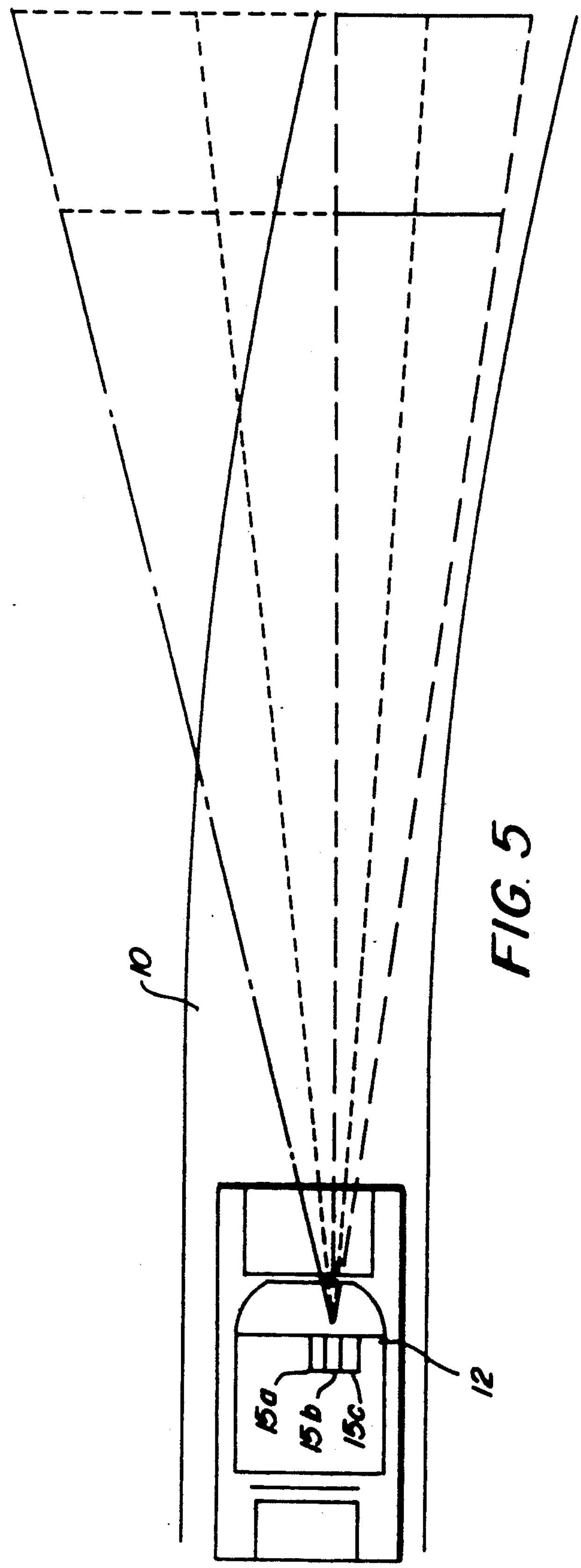


FIG. 5

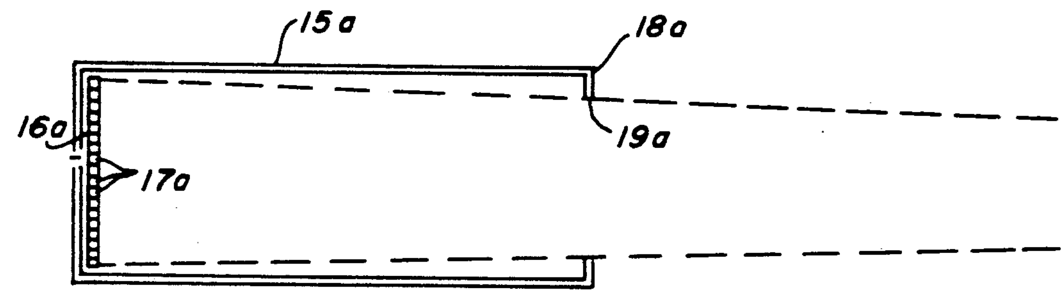


FIG. 6a

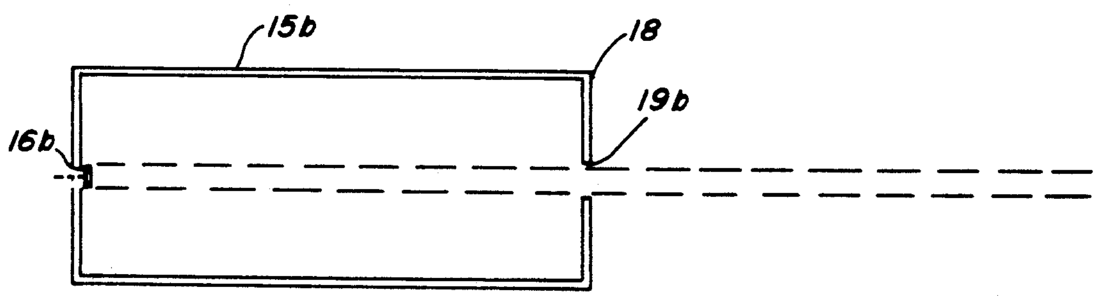


FIG. 6b

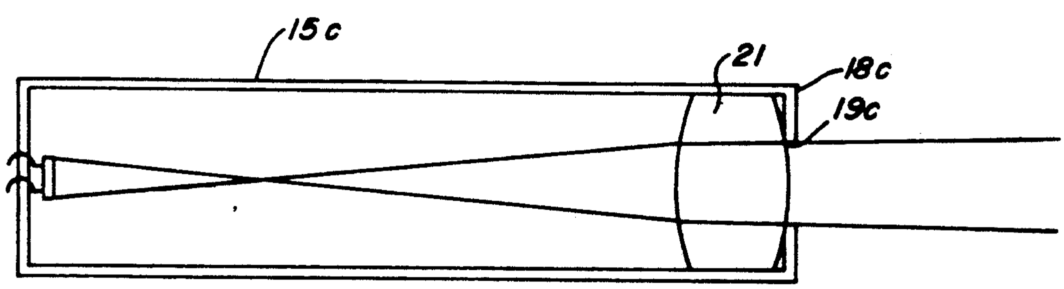


FIG. 9

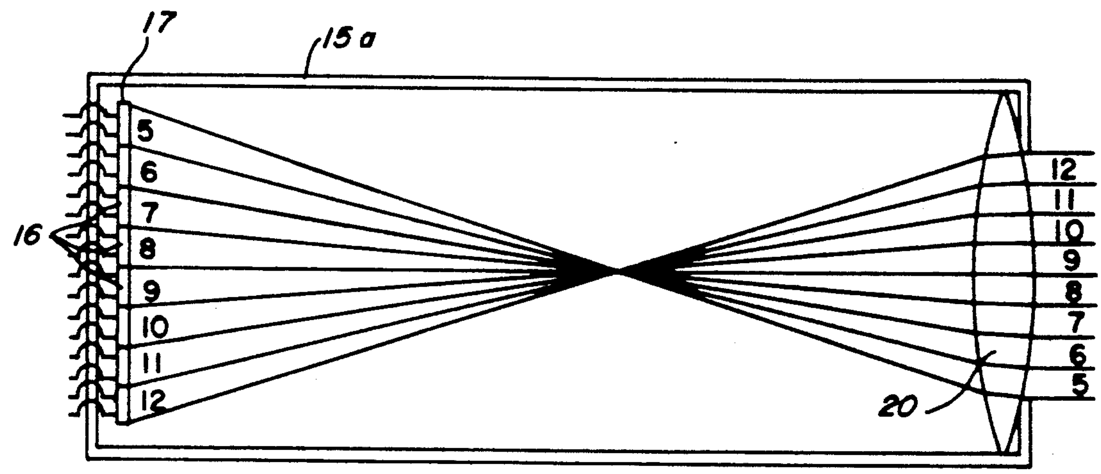


FIG. 8

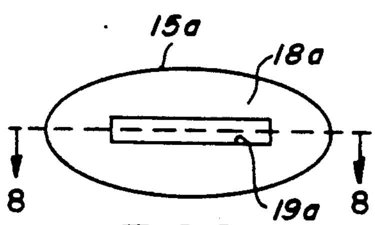


FIG. 7a

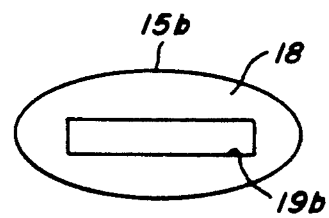


FIG. 7b

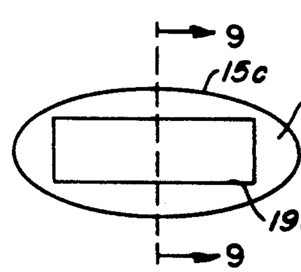


FIG. 7c

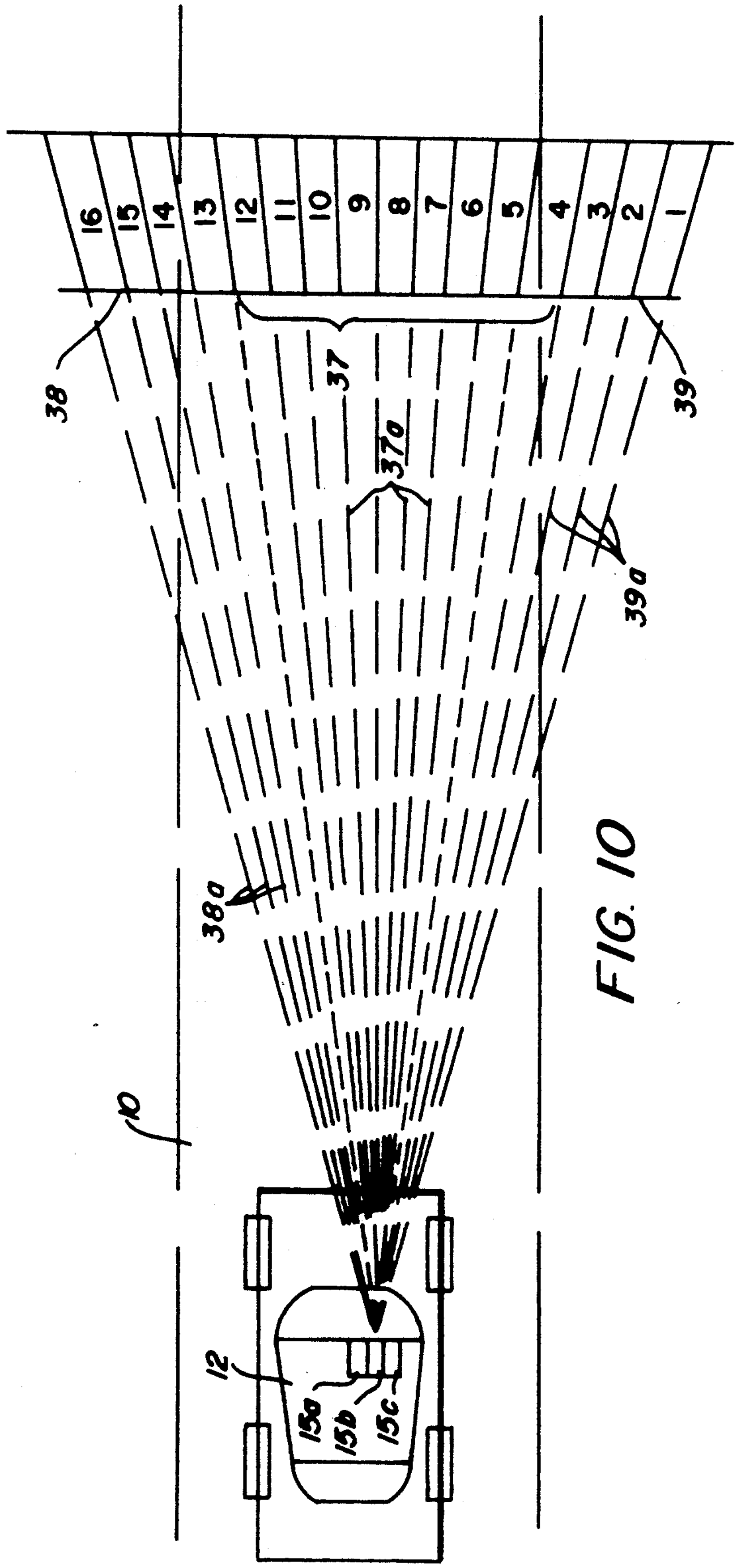

16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
37
37a
38
38a
39
39a
10
12
15a
15b
15c

FIG. 10

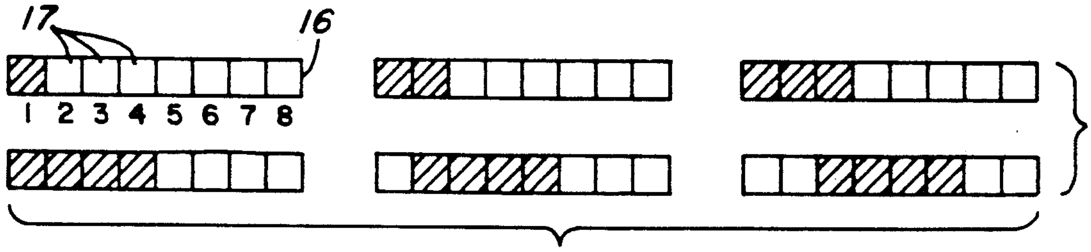


FIG. 11

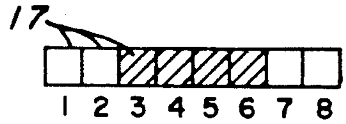


FIG. 11a

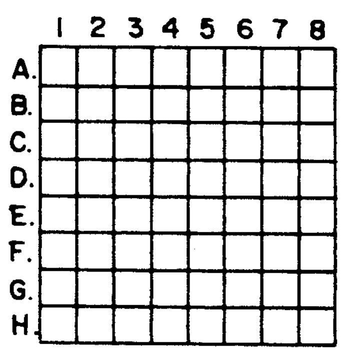


FIG. 12a

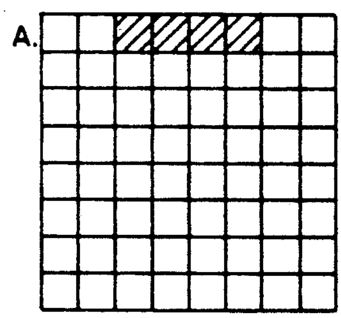


FIG. 12b

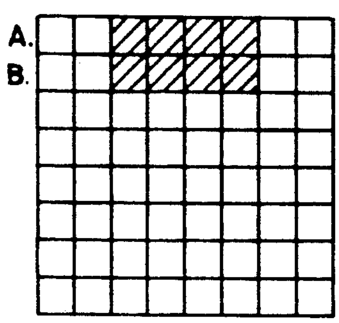


FIG. 12c

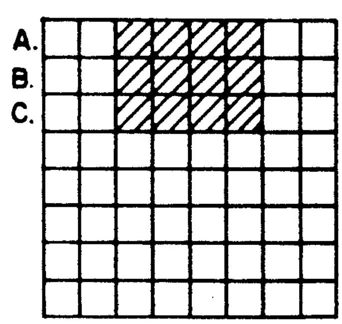


FIG. 12d

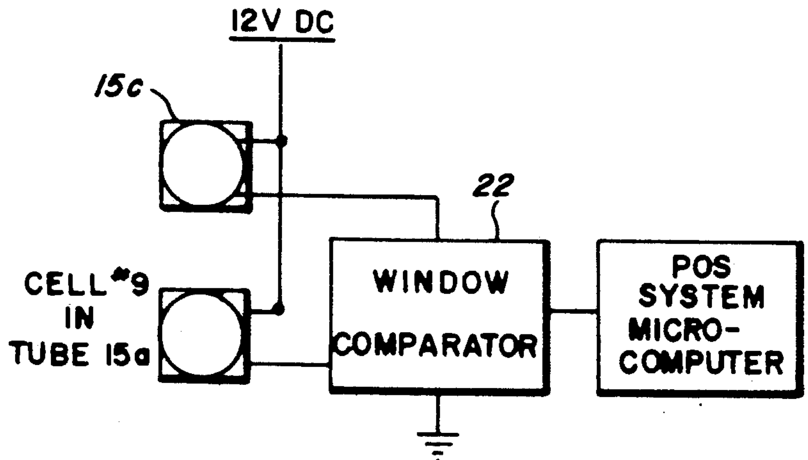

12V DC
15c
22
CELL #9
IN
TUBE 15a
WINDOW
COMPARATOR
POS
SYSTEM
MICRO-
COMPUTER

FIG. 13

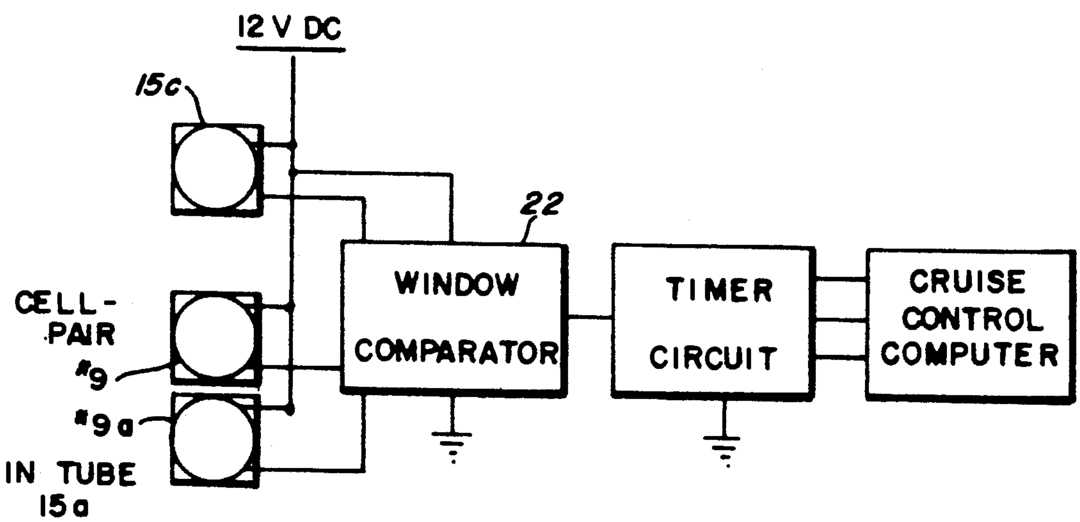

12 V DC
15c
22
CELL-
PAIR
#9
#9a
IN TUBE
15a
WINDOW
COMPARATOR
TIMER
CIRCUIT
CRUISE
CONTROL
COMPUTER

FIG. 14

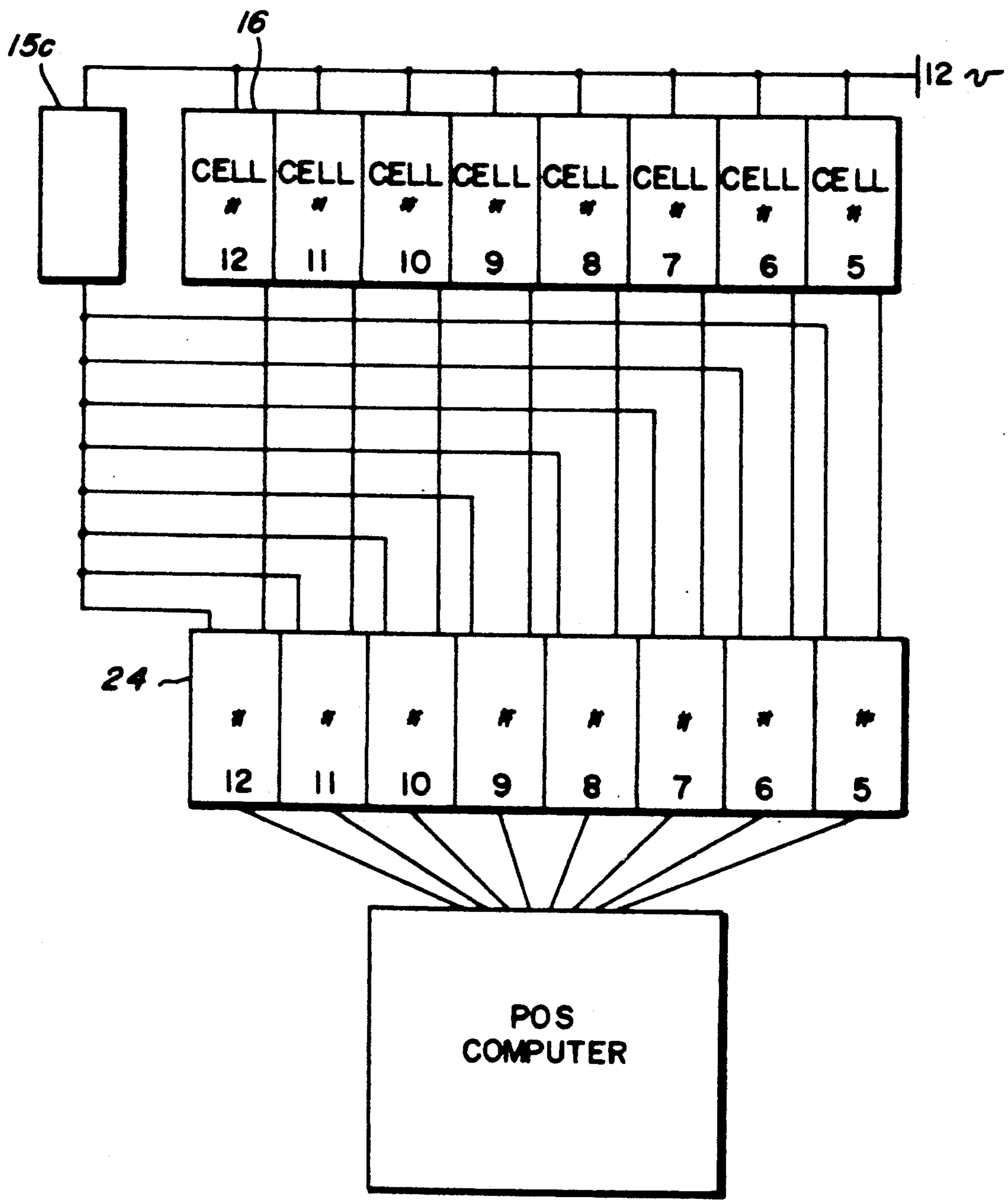

15c
16
12 v
CELL # 12
CELL # 11
CELL # 10
CELL # 9
CELL # 8
CELL # 7
CELL # 6
CELL # 5
24
12
11
10
9
8
7
6
5
POS COMPUTER

FIG. 15

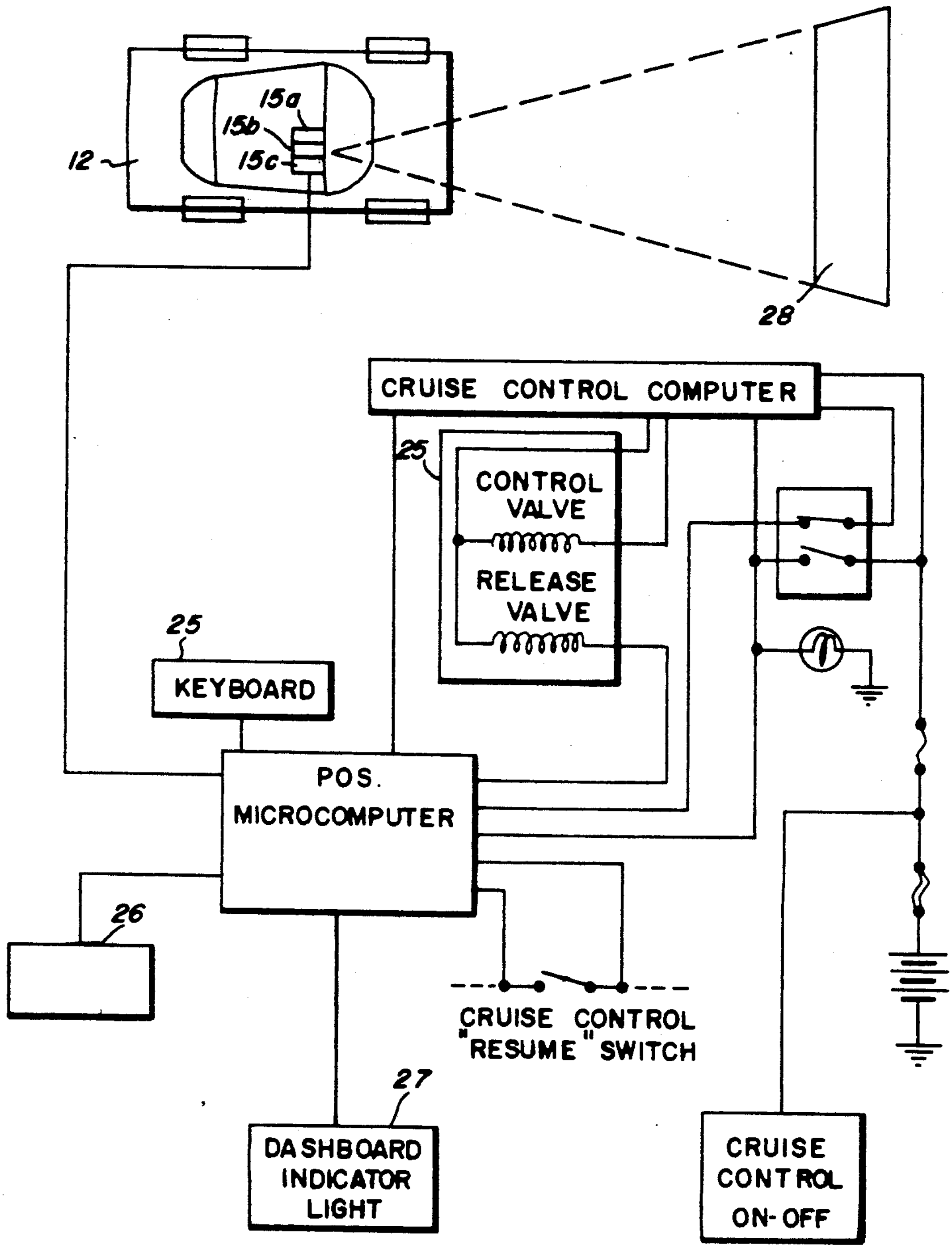

15a
15b
15c
12
28
CRUISE CONTROL COMPUTER
25
CONTROL VALVE
RELEASE VALVE
25
KEYBOARD
POS. MICROCOMPUTER
26
CRUISE CONTROL "RESUME" SWITCH
27
DASHBOARD INDICATOR LIGHT
CRUISE CONTROL ON-OFF

FIG. 16

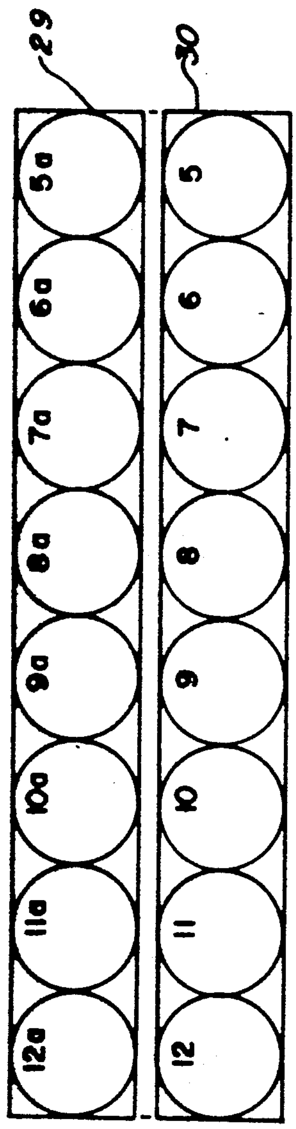

29
30
5a
6a
7a
8a
9a
10a
11a
12a
5
6
7
8
9
10
11
12

FIG. 17

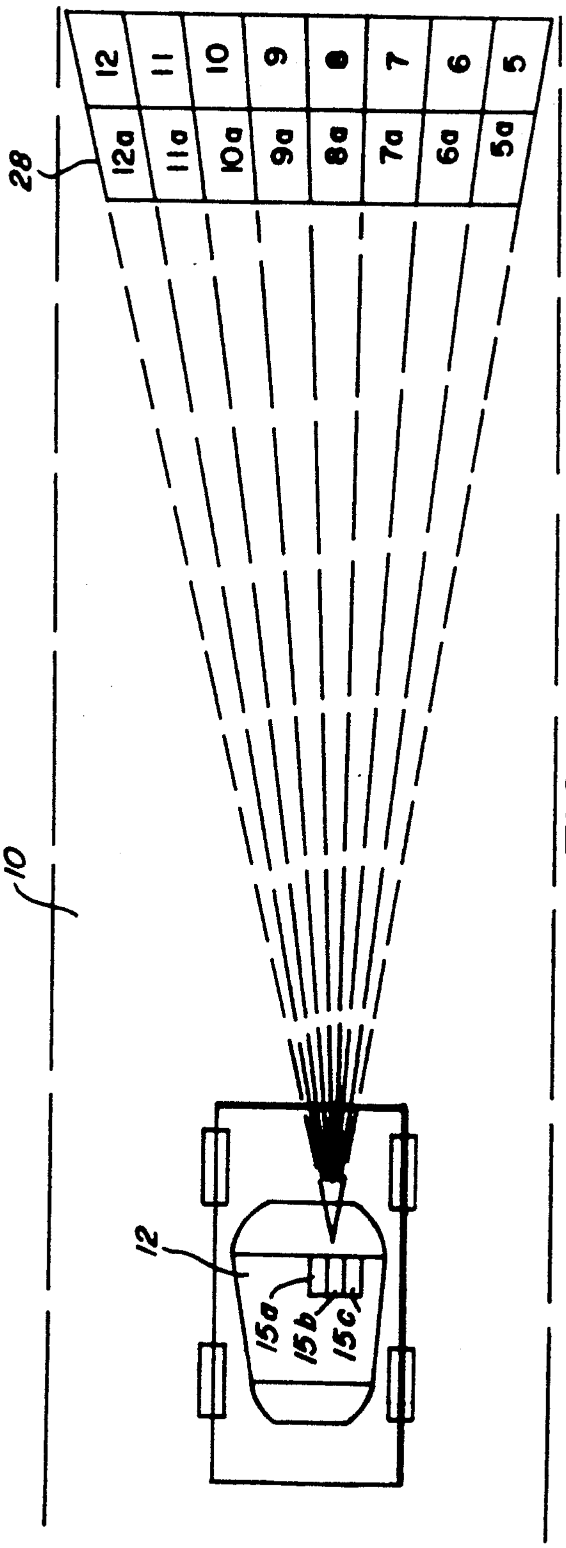
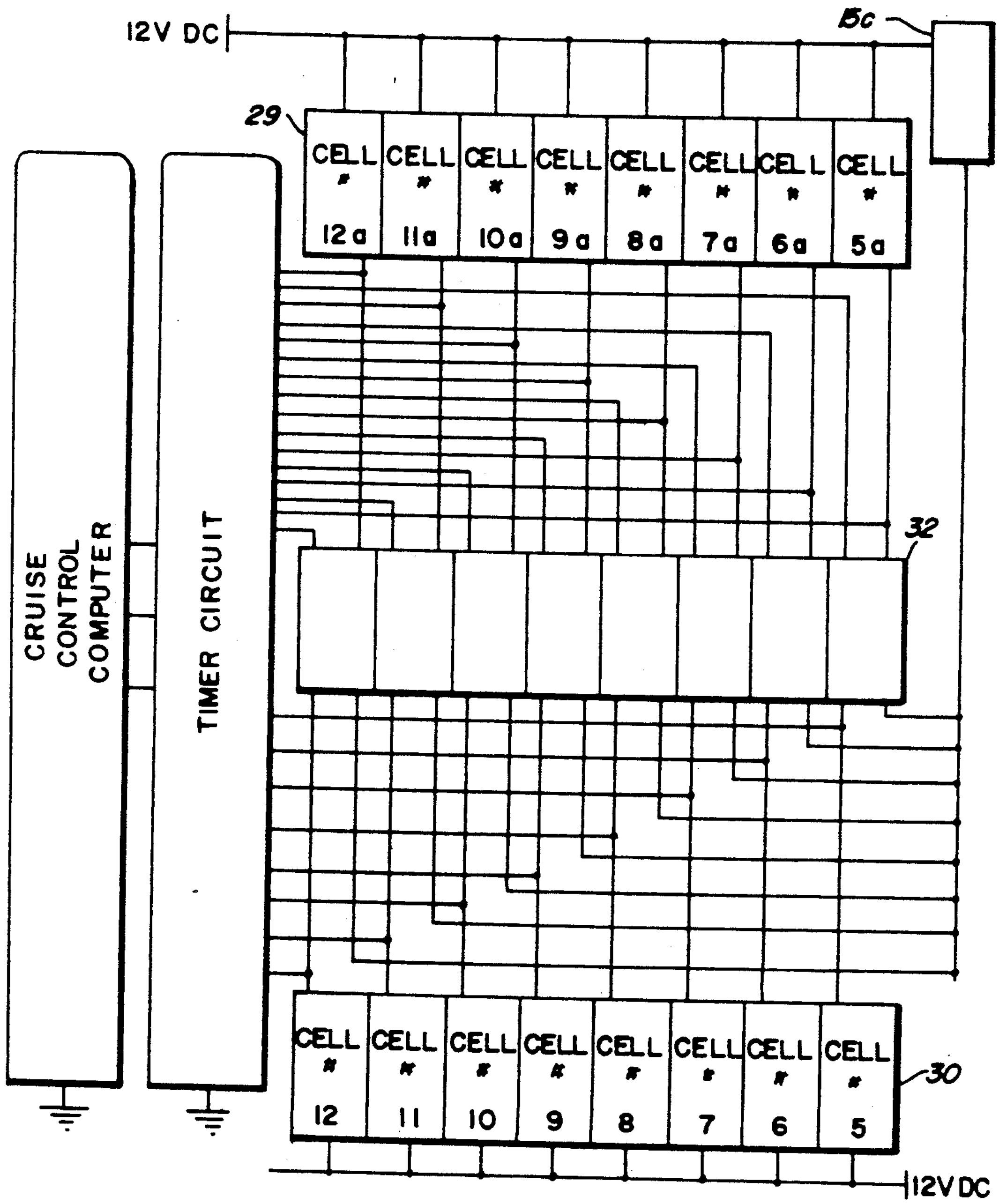
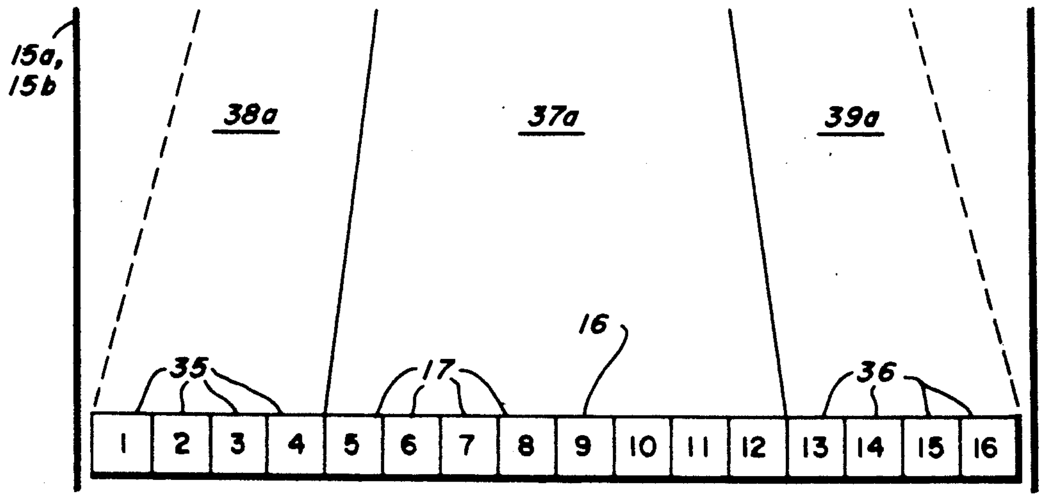

28
12
11
10
9
8
7
6
5
12a
11a
10a
9a
8a
7a
6a
5a
10
12
15a
15b
15c

FIG. 18



12V DC
15c
29
CELL # 12a
CELL # 11a
CELL # 10a
CELL # 9a
CELL # 8a
CELL # 7a
CELL # 6a
CELL # 5a
CRUISE CONTROL COMPUTER
TIMER CIRCUIT
32
CELL # 12
CELL # 11
CELL # 10
CELL # 9
CELL # 8
CELL # 7
CELL # 6
CELL # 5
30
12V DC

FIG. 19


15a,
15b
38a
37a
39a
16
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16

FIG. 20

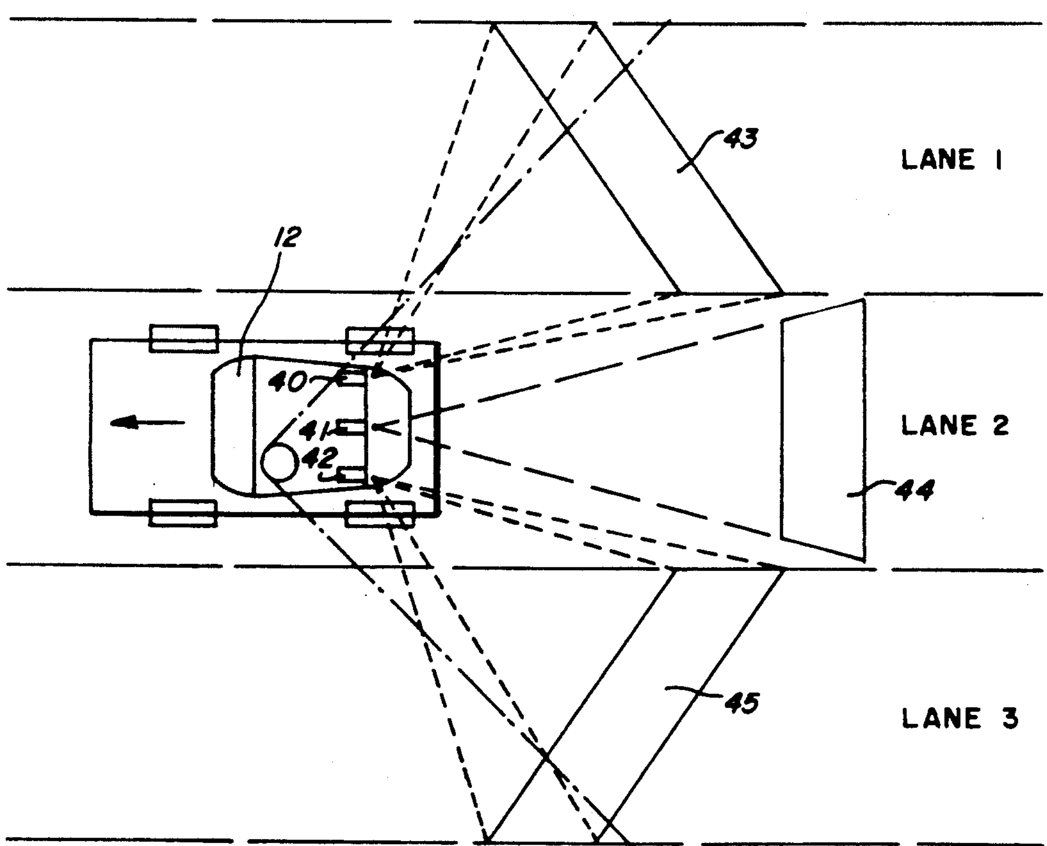
43
LANE 1
12
40
41
42
LANE 2
44
45
LANE 3

FIG. 21

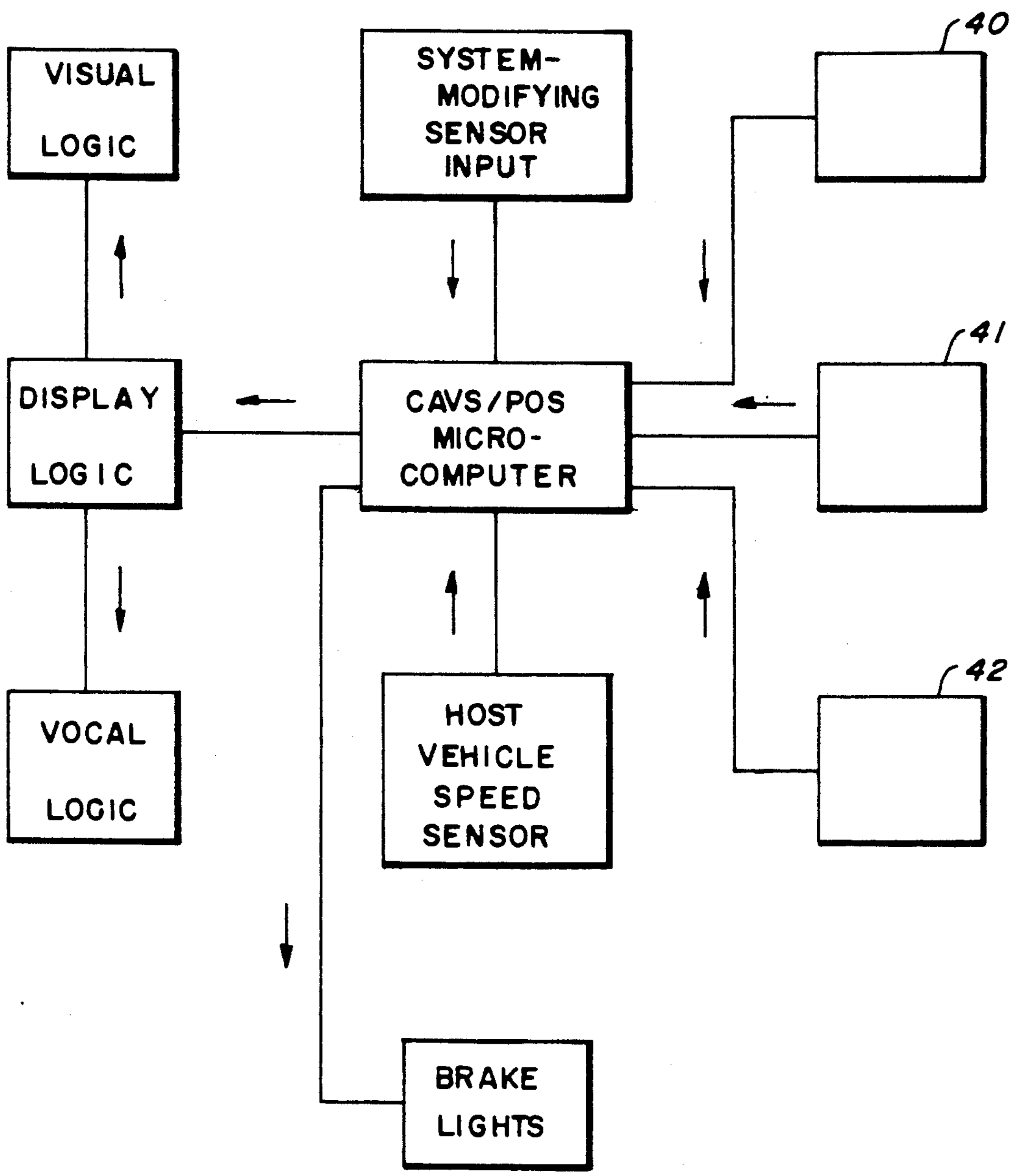
VISUAL LOGIC
SYSTEM-MODIFYING SENSOR INPUT
40
41
DISPLAY LOGIC
CAVS/POS MICRO-COMPUTER
VOCAL LOGIC
HOST VEHICLE SPEED SENSOR
42
BRAKE LIGHTS

FIG. 22

PASSIVE VEHICLE PRESENCE DETECTION SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates to vehicle presence detection systems and, more particularly, to a detection system wherein presence signals are passively detected. In its broadest sense, the invention relates to detecting the presence of any object capable of varying light rays emanating therefrom in contrast to the ambient light conditions.

The prior art for vehicle presence systems generally utilize reflected signals, such as in radar systems, for detecting the presence of a vehicle and also the distance relative to the monitoring vehicle. These systems usually require a signal generator in the host vehicle which transmits and directs a suitable scanning signal along one or more lanes of a roadway, and a receiver for picking up the reflected signal from a nearby vehicle struck by the beam of the transmitted signal. These systems are very complicated and require complex electronic circuits, components and microprocessors.

In U.S. Pat. No. 4,258,351, a passive system is disclosed for detecting the presence of vehicles utilizing the change in brightness when a vehicle moves across a designated targeted area on a roadway. While this system may be efficient in use upon the roof of a building, it depends upon the accurate angularity and distance of a detecting device from the target area. The standard-ized device would not be suitable for use in a moving host vehicle whereby targets to-be-sensed are in continuous motion and at variable distances and angles relative to a target vehicle. The specific sensing device utilized in the patented system is devised to be insensitive to orientation of a target vehicle as to distance and to the relative angularity between the host vehicle and the roadway, or of positioning of one or more target vehicles.

In U.S. Pat. No. 4,433,325, a similar system is disclosed wherein a camera is mounted for surveillance upon a measured pole and has photocells therein angularly related to target points on a roadway.

The space monitoring system disclosed in U.S. Pat. No. 3,972,021 requires detecting devices to be mounted on a plurality of traffic light posts and therefore use in a moving vehicle is not feasible. Furthermore, the patented system is very complex with respect to the details incorporated in the detecting devices. The system relies on the analysis of measurements of a signal phase and amplitude and their variations with respect to the presence and/or motion of objects within a field of detection. A passive electro-optical device is disclosed for use in a rangefinding system in U.S. Pat. No. 4,009,960.

The present invention has many advantages over the art, most notably the POS system uses inexpensive commercially available components and the small size of the POS tube(s) requires a minimum of space for installation, and may permit a variety of mounting locations which would otherwise be impractical for larger units used in the other systems. The POS system is a single unit relying on passively reflected light in order to function while other systems require both a transmitter and receiver of some kind. Active systems such as radar, infrared, ultrasonic, etc. require transmitters and receivers which are relatively expensive to manufacture and are complex in construction. They also require careful calibration to function properly and may require periodic recalibration due to loss of accuracy from road vibrations, etc.

Other advantages will become apparent since the other systems previously mentioned have limited applications while the POS system is adaptable to a wide variety of uses. Other, active systems require electrical energy to power a transmitter and receiver whereas the POS system requires a minimal amount of electrical energy to perform its functions and may act more like a switching device. Wide-spread use of ground level radar or microwave transmissions may pose possible and unforeseen long-term health hazards for the public. The POS system offers simplified installation since complex wiring is not required, and the small physical size of the POS system contributes to ease of installation. The POS system has no moving parts to wear out and affect accuracy. It does not need complex electronic components thereby reducing the possibility of component related malfunctions. Finally, the POS system does not cause interference with police radar, citizen's radar detectors, remote control garage door openers or other devices utilizing microwaves for operation.

Therefore, it is the principal object of the invention to detect the presence or absence of moving objects, such as vehicles, on a roadway in a manner which is efficient, simple and provides highly credible information for the operator of the vehicle.

It is another object of the invention to utilize a passive object detection system in a vehicle cruise control system, thereby effecting credible control of the vehicle under conditions of functional visibility.

In accomplishing the object of the present invention, a Passive Optical Sensor, herinafter referred to as "POS", is devised to react to a change in the intensity of light passively reflected from its field of surveillance in response to the sudden presence or absence of an object within its field of surveillance.

Monitoring the field of surveillance is accomplished using a single photosensitive device or an array of such devices within tube structures arranged to be directed at one or more areas of surveillance. The devices may be arranged in a single linear array or multiple arrays and be monitored individually or in cell-pairs for voltage or current flucturations. These fluctuations are interpreted as indicating the presence of an object such as a vehicle, the relative motion of the vehicle and its direction of movement for use either to alert the driver or to automatically control his own vehicle accordingly. The photosensitive devices may include photoresistive photocells, such as the silicon dioxide or gallium arsenide types, or any PV cells made by stacking different PV materials, as known in the art, or phototransistors, because of their faster response times or any other light sensitive device.

These and other objects of the invention will become apparent after reviewing the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**, **2** and **3** are schematic views of a typical roadway with vehicles thereon, one of which incorporates the invention;

FIGS. **4** and **5** are plan views of the roadway in FIG. **1** showing areas of surveillance being scanned by the invention;

FIGS. *6a*, and *6b* are cross-sectional views, each being 90° oriented relative to the other of a scanning sensor tube used in the invention;

FIGS. *7a*, *7b* and *7c* are end views of the sensor tubes showing light admitting slits;

FIG. **8** is a cross-sectional view of one of the sensor tubes taken along the line **8—8** in FIG. *7a;*

FIG. **9** is a cross-sectional view of the ambient light sensor tube taken along the line **9—9** in FIG. *7c;*

FIG. **10** is a plan view of a roadway showing an area of surveillance in greater detail;

FIG. **11** is a group of schematic illustrations of an array of photosensitive cells showing the progressive effects thereon as a vehicle moves laterally relative to the direction of movement of the scanning vehicle;

FIG. **11***a* is a schematic illustration of an array of showing the effects of a host vehicle coming upon another vehicle in the same lane;

FIGS. **12***a*, **12***b*, **12***c* and **12***d* are schematic vie plurality of arrays showing the progressive effect of light rays thereon during one condition of operation such as the host vehicle's approach to a target vehicle;

FIG. **13** is a schematic illustration of a control arrangement of a single cell;

FIG. **14** is a schematic illustration of a control arrangement for the cruise control system of a host vehicle;

FIG. **15** is a schematic illustration of the control arrangement for a single array;

FIG. **16** is a schematic illustration of a cruise control system in detail;

FIG. **17** is a schematic view of dual photocell arrays which may function as cell-pairs;

FIG. **18** is a plan view of a roadway showing the area of surveillance in greater detail;

FIG. **19** is a schematic illustration of a cruise control arrangement in conjunction with the arrays in FIG. **17** wherein the timer circuit incorporates functions of the POS computer interactions in the cruise control system of FIG. **16**

FIG. **20** is a schematic illustration of an embodiment of sensor arrays taken in conjunction with FIG. **10** for use in lateral tracking of vehicles;

FIG. **21** is a plan view of a roadway showing the scanning capability of a collision avoidance system; and

FIG. **22** is a schematic illustration of the control system for the collision avoidance system.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the vehicle presence detecting system of the present invention, a roadway **10**, as shown in FIGS. **1-3**, immediately before a host vehicle **12** endowed with the system is continuously scanned for the presence of one or more target vehicles. This scanning activity of the system is maintained regardless of the orientation of the roadway, that is, for straightaway roads, as shown in FIG. **4**, for upward or downward inclines or for curves in either direction, as shown in FIG. **5**. As shown in FIGS. **1-3**, the vehicle **12**, which is provided with the POS system, is shown on a roadway a few car lengths behind another vehicle **14** on the same roadway or in the same lane of traffic if the roadway is of the multiple lane type. The POS system, as will be described below, is arranged on vehicle **12** as an illustrative example only to scan the one or more lanes of the roadway **10**.

The POS system comprises a set of two small hollow tubes **15***a*, **15***b*, having oval cross-sections, each being interiorly lined with a non-reflective coating or material to absorb extraneous light which is directed into the tubes. The rear interior end of each of the tubes supports a photosensitive device **16**, **16***a* which, for illustrative purposes, comprises a plurality of identical and independently functioning photo-cells **17**, **17***a*, preferably eight in number, arranged in an array having a height of one cell. Each cell may utilize gallium arsenide, cadmium sulfide or other suitable light sensitive material. Any other photo sensitive device may also be used, such as CCD's. Such cells are readily available in the market and are not intended to be claimed per se as inventive herein.

The other end of each tubes is provided with walls **18***a*, **18***b*, formed with slits **19***a*, **19***b*, respectively, which may be left open or capped with a compatible solid material having an opening of predetermined slit shape, width, height and orientation based on application. Photochromic or similar glass, which responds to increasing light intensity by darkening, may be utilized as a filter in front of or immediately behind a slit to reduce the chance of light of very high intensity from causing damage to the photosensitive devices. The longitudinal axes of the slits **19***a*, **19***b* are arranged parallel to the axes of the corresponding arrays **16**, **16***a* which are coincident with the long axes of the oval cross-section. The sensor tubes may be filled with nitrogen gas to prevent condensation, or may be evacuated to enhance light transmission and to prevent condensation.

Each of the tubes **15***a*, **15***b* of the POS system is aimed at a specific area of the roadway **10**. For example, the sensor tube **15***a* with slit **19***a* is aimed at a section of the road approximately seven car lengths in front of the host vehicle and is limited laterally to viewing the area approximately within the confines of the traffic lane in which the host vehicle is being driven, as shown in FIG. **1**. This scanning is accomplished by varying the dimensions of the slit opening **19***a*.

The sensor tube **15***b* is aimed at a section of the roadway two or three car lengths in front of the host vehicle and is limited laterally to viewing the area within the confines of the traffic lane in which the host vehicle is being driven, as shown in FIG. **1**.

The POS system also includes an ambient light sensor tube **15***c* internally coated with non-reflective material. This tube is aimed forward on a generally horizontal plane, parallel to the center line of the host vehicle and arranged to monitor the ambient light levels from the general direction of the area of surveillance. As shown in FIGS. *7c* and **9**, use may be made of a light gathering lens **21** at the forward end of this tube for achieving a more accurate measurement of ambient light levels and a forward wall **18***c* having a slit **19***c* formed thereon. Still another arrangement would involve the elimination of the horizontal slit and end cap, leaving the entire area of the tube open for light gathering.

In the detailed cross-sectional view of the sensor tube **15***a* in FIG. **8**, the array **16** is shown with the eight individually functioning cells **17**, numbered from **#5** to **#12** as receiving focusing light rays from corresponding inverted segments of light from an area of surveillance through a converging lens **20**. These segments are also numbered **#5** to **#12** in accordance with the focused light rays on the respective cell. The sensor tube **15***b* is similarly constructed except for the height of the respective light admitting slot. Each of the sensor tubes **15***a*, **15***b* functions in conjunction with the ambient light sensor **15***c* and a window comparator with the resultant output being monitored by the system microcomputer. Each of the cells **17** is connected to the window comparator, as shown in FIG. **13**, only one of which is shown: cell #**9** of tube **15***a*, which would also be the arrangement if only one cell comprised the photosensitive device. In the event that cell-pairs are utilized, when two arrays **17** are utilized, one above the other, a cell-pair would be connected as shown in FIG. **14**. Cell-pairs arrangements for linear arrays are utilized when more accurate and closer monitoring of vehicle position and movement are desirable. Such arrangements produce a refinement in the production of detecting and/or control signals from the system microcomputer.

The foregoing described sensor tubes may focus entering light rays by virtue of adjusting or varying their widths and lengths by utilizing an optical lens, or combination of both. Light admitted through the slits is focused onto the light sensitive material such as gallium arsenide in a sensing cell or onto a photosensitive cell or a lateral or linear array of such cells.

In one embodiment of the invention, when only a single gallium arsenide cell or other suitable cell is employed in the sensor tubes **15***a*, **15***b*, the data, in the form of a fluctuation of light intensity converted into fluctuating voltage, will be monitored by the POS system microcomputer and constantly compared with the ambient light reading taken by the ambient light monitoring sensing tube **15***c*.

The variation in the reading from sensor tubes **15***a*, **15***b*, will usually be gradual, however, when an object such as a vehicle enters the field of vision or area of surveillance of sensor **15***a*, as in FIG. **2**, there will be registered an abrupt change in the voltage which the microcomputer will interpret as the presence of an object. Since the distance between the area of surveillnace and the host vehicle can be mechanically adjusted by varying the angle of one or more of the sensor tubes to the road surface, as depicted in FIGS. **1** and **3**, a precise distance between the host vehicle and target vehicle can be easily obtained. This distance may be adjusted at the factory level to conform to government or industry mandated safety parameters.

In another embodiment, when a linear array of gallium arsenide or other suitable photosensitive cells is employed, as depicted in FIGS. **6***a*, **6***b*, object detection can then be broken down into a number of individual components as the microcomputer of the system controller monitors the light intensity related voltage fluctuations of each of the photocells separately. Light from the slit of the sensor tube is focused on the array, enabling each photovoltaic cell of the array to monitor a specific segment of the road area under the surveillance of the surveillance in such manner as to make detection of a number of different traffic scenarios possible and easily recognizable by a relatively simple computer program.

In operation, with a sensor tube mounted in the vehicle **12**, as shown in FIG. **10**, light enters the same from the area of surveillance **23** which the target vehicle **14** has obscured. The area segments numbered **5** to **12** correspond to the individual segments of light from the area. The inverted focused light impinging the arrays **16** in the sensor tube **15***a*, for example, will produce an inverted image which is focused segmentally on the corresponding like-numbered photocells. That arrangement allows each photocell of the array to monitor its assigned segment of the area of surveillance within that segment.

These changes in light intensity effect a change in the output of the individual photocells when an object, such as a vehicle, sequentially enters the individual segment of the area of surveillance. The resulting fluctuations in voltage are then compared with the reference voltage from the ambient light sensor **15***c* through a circuit including the window comparator **22** and the output is monitored and interpreted by the POS system microcomputer, as shown in FIG. **13**, for a single cell of the array **16**, illustrated as cell #**9**, and in FIG. **15** for the entire array **16**, illustrated as cell #**9**, and in FIG. **15** for the entire array **16** having individual window comparators in a group **24**.

In this embodiment, if a vehicle is being monitored at distant range by sensor tube **15***a*, and a third vehicle cuts between the target vehicle and host vehicle from the left lane, the linear array will be activated from right to left (if the image is inverted), or left to right, in increments, as illustrated in the flowing sequences of FIG. **11**. Darkened areas represent changes in voltage of each of the individual photosensitive cells as the third vehicle moves into their field of view. If the third vehicle cuts in from the right to left, the opposite response would occur.

If the host vehicle encroaches on a distant, but slower, moving vehicle, as in FIG. **2**, the photosensitive cells in the middle of the array will show voltage fluctuations in unison, as in FIGS. **11***a* or **12***b*, while those at either end of the array will remain more or less constant. In the event the target vehicle encounters a rise in elevation while in the area of surveillance, which, for example, is at approximately seven car lengths in front of the host vehicle, and proceeds to climb out of the field of surveillance of the POS sensor tubes as the angle of the road increases, the four middle sensor cells, as shown in FIG. **11***a*, experience a sudden and uniform change since no light rays impinge thereon. The POS computer is programmed to interpret this change as temporary andto instruct the cruise control computer to maintain its present speed for a short duration of time, that automatic acceleration to a former speed should not be implemented.

As the target vehicle continues to climb, the host vehicle encounters the same rise in elevation, whereupon the target vehicle is again in position to be scanned by the POS sensor tubes causing a return of sensor fluctuations of the middle cells of the array **16**, as shown in FIG. **11***a*. It will be understood that the same scanning activity occurs in the event the road takes a drop in elevation. Both activities can be distinguished from other traffic related events such as shown and described above in relation to FIG. **11** and to the event when the host vehicle changes from a center lane to the left lane in preparation for passing the target vehicle.

While a horizontal, single row array is used for illustration purposes, any other arrangement of sensors, either in a single row or in multiple rows or any other discernible arrangement, is to be considered within the scope and intent of this invention.

It is also acknowledged that by stacking several linear arrays on top of each other, a rate of closure reading may be obtained by sampling response times between arrays indicated as A, B and C as the voltage changes occur, as indicated in FIGS. **12***a*–**12***d*. Shaded photosensitive cells in **12***b*, **12***c* and **12***d*, indicate a change in voltage as an object progressively obscures the area of surveillance. Unshaded cells indicate approximately constant voltage associated with the unobscured portion of the area of surveillance. Light entering the slit in the sensor tube opening can be readily focused on several linear arrays as easily as it can be focused on one array in accordance with the laws governing optics. The multiple array arrangement of the POS system enables the microcomputer to recognize the presence of an object without the need to make qualitative identification of that object in relation to size or distance.

If more than one forward facing sensor tube is employed, the closest vehicle in front of the host vehicle will obscure the areas of surveillance of the other sensors, as shown in FIG. 3. The voltage fluctuation of the sensor tube **15***b*, or the combined readings of sensor tubes **15***a* and **15***b*, will indicate the intrusion and presence of a vehicle at the closer range. Both sensor tubes will show voltage fluctuations if a taller vehicle is present at the closer range, and sensor **15***b*, alone, will show voltage changes if a small, low-to-the-ground vehicle is at close range. Distantly aimed sensor tube **15***a*, alone, will show voltage changes when a vehicle enters its area of surveillance.

The size of the sensor tubes can be enlarged or miniaturized to accommodate the type of photovoltaic or photo-sensitive cells used. The use of fiber optics can allow the main portion of the device (the photo cells and microcomputer) to be remotely located anywhere within the vehicle while sensor input remains in the upper windshield. This would prevent the driver's view through the windshield from being obscured if larger components are used.

A parallel system may also be installed using low-lux sensor components which would be activated when the headlights of a vehicle are switched on, indicating a condition of reduced visibility, as at night time. Photochromic, or similar glass that responds to the intensity of sunlight by darkening, could be used to reduce possible damage to the low-lux components caused by exposure to direct or very intense sunlight. Use of camera-like components (diaphragms, adjustable irises, etc.) are not excluded for this use.

It is also acknowledged that the same effect of aiming the sensor tubes can be accomplished by optical means such as by splitting of images from a single tube, etc., thus having combined the functions of several individual tubes and that any optical variation on the main theme be included within the scope and intent of the invention.

The use of trapezoidal openings **19***a*, **19***b*, replacing the rectangular opening in FIGS. 7*a*, 7*b*, with the wider area at the bottom and narrower area at the top, may be used to eliminate the trapezoidal coverage area on the road, as shown in FIGS. **4**, **5** and **10**, thereby enhancing coverage of the lane in which the host vehicle is traveling and eliminating the possibility of missing narrow vehicles such as motorcycles traveling near either edge of the scanned lane.

The use of photochromic glass, or any other type of glass which darkens as light intensity increases, may reduce the effect of sensors being overpowered by too much light. An optical monitor to detect dirt, debris or precipitation on the external window glass may be used to ensure optimal performance of the POS system in circumstances where transmission of light may be reduced or compromised by contamination of the external window glass.

The preferred location of the POS sensor tubes as input devices is high on the inner windshield surface in an area which is normally swept clean by the action of wiper blades. The oval shape cross-sectional sections of the tubes **15***a*, **15***b*, **15***c* enable these tubes to be mounted within a vehicle. However, it is acknowledged that other suitable locations may be discerned and that such variations in location be included within the scope and intent of the invention. The POS system is interfaced with the windshield directly or by using any suitable clear material having the same refractive index as the windshield glass, thereby preventing the sensor tubes from becoming inactivated by dust or other contaminants within the vehicle.

The POS system can be used to automate cruise control functions in several ways, two of which are described below for illustrative purposes.

In one arrangement, utilizing a stack of lateral photocell arrays as shown in FIGS. **12***a*–**12***d*, the POS system will detect the presence of a target vehicle in the manner previously described. The POS system microcomputer, schematically shown in FIGS. **15** and **16**, is arranged to signal or effect a break in the circuit to the cruise actuator release valve, for the cruise control system thereby simulating actuation of the brake pedal, or "DECEL" switch by the driver of the vehicle. A rate of closure is derived as previously described with respect to a multiple array, and an automatic braking device **26** is engaged to hasten deceleration if the rate of closure is unacceptably high. As the speed of the host vehicle decreases, the target vehicle will retreat from the area of surveillance array 'C', FIG. **12***d*, to the area of surveillance array 'B', FIG. **12***c*. With this occurrence, the POS system microcomputer signals or effects the closing of the cruise control's 'RESUME' circuit, simulating actuation of the 'RESUME' switch by the driver of the vehicle.

The driver may opt either to remain behind the target vehicle, allowing the interplay between the cruise control and POS microcomputer to continue, or to change lanes to pass the target vehicle, thereby breaking sensor contact and automatically resuming the former speed.

In another arrangement, utilizing a stack of lateral photocell arrays, as shown in the sequence of events in FIGS. **12***a*–**12***d*, the POS system will detect the presence of a target vehicle in the manner previously described. As the host vehicle approaches the target vehicle, arrays A, B and C fluctuate sequentially, and a rate of closure is calculated. The POS microcomputer, which is interfaced with the cruise control computer as shown in FIGS. **14** and **16**, will then direct the cruise control computer to reduce the speed of the vehicle until array C in FIG. **12***d* is no longer fluctuating. When only arrays A and B are fluctuating, FIG. **12***c*, the POS microcomputer will direct the cruise control computer to maintain the speed at which array C stopped fluctuating. Again, an automatic braking device may be engaged to hasten deceleration if the rate of closure is unacceptably high.

If the target vehicle accelerates, array B will cease fluctuating and the POS microcomputer will signal the cruise control computer to accelerate until array B is again fluctuating. At this point, the POS microcomputer will direct the cruise control computer to maintain speed at that level. Actuation of the brake pedal, or "RESUME" switch, by the driver will cancel the acceleration phase of this aspect of the programming in the event that the driver does not wish to accelerate automatically. As the host vehicle changes lanes to pass the target vehicle, sensor contact is broken, and the POS microcomputer recalibrates the cruise control computer to resume the speed at thich the host vehicle was traveling before initial sensor contact was made.

Such a cruise control regulating system, as described above, could be utilized effectively as a traffic control system, especially if all vehicles are so equipped. This would greatly lessen the 'accordion' effect which dense traffic is subject to and would improve the overall flow of traffic by maintaining a higher minimum speed. Large quantities of otherwise wasted fuel could be conserved by reducing traffic jams as well as through automatic throttle control.

As an added enhancement, the POS microcomputer will also effect a two to four second flashing of the brake lights for the host vehicle whenever a deceleration action is initiated by the POS microcomputer. A dashboard deceleration indicator **27**, audio and/or visual in nature, is included in the POS system to alert the driver that deceleration has been initiated by the POS microcomputer.

In another embodiment, a further enhancement to the POS system may be achieved by adding one or more additional lateral arrays to the existing array, as shown in FIG. **17**, and focusing the incoming light from the POS surveillance areas onto both arrays. This will serve to further divide the area of surveillance **28**, as illustrated in FIG. **18**, nd thereby enable this POS system variation to be used in the cruise control regulating application which will provide finer control of the host vehicle. Light from segments **#5–#12** and **#5*a*–#12*a*** of the surveillance area **28** in FIG. **18** is focused onto the like-numbered cell-pair groups **29**, **30** of photocells shown in FIG. **17** in the same manner as previously described in the above description. It will be appreciated that the number of POS arrays can be varied as can the number and size of component photo-cells per array. The POS wiring for the cruise control application is illustrated in FIGS. **14**, **16**, and **19** utilizing cell-pairs to both detect the presence of a leading or target vehicle, as well as to adjust the speed of the trailing or host vehicle to approximately match that of the leading or target vehicle.

The following is a description of the operation of the arrangement in FIG. **19**. One or more ambient light sensors **15*c*** provide reference voltage to the window comparators **32** when the cruise control is turned on. The lower and upper POS arrays **29**, **30** are tilted or separated slightly to give adequate response time between the arrays, and the POS tube **15*a*** is aimed approximately seven car lengths in front of the host vehicle, see FIG. **1**, as previously described. The window comparators **32** monitor the difference between the voltage passed by the sensor **15*c*** and that passed by each cell of the individual cell-pairs, as shown in FIG. **17**. When the host vehicle overtakes the target vehicle, this causes voltage fluctuations in cells **#7–#10**, for example. During these fluctuations, the timer circuit(s) monitors the time lapse between voltage fluctuations of cells **#7–#10** and **#7*a*–#10*a***. Voltage fluctuations in cells **#7–#10** causes the timer circuit(s) to be turned 'on', while voltage fluctuations in cells **#7*a*–#10*a*** cause the timer circuit(s) to be turned 'off'. The timer program is arranged to calculate the rate of closure of the host vehicle to the target vehicle and compares that calculated value to a signal from the cruise control in the host vehicle computer which indicates the speed of the host vehicle. The window comparators also interact with the timer circuit(s) to confirm the response of the sensor tubes.

As the host vehicle approaches the target vehicle, the latter enters the POS system area of surveillance, causing a change in status of cells **#7–#10**, for example. The cells **#7–#10** respond to the change in light from the surveillance area and send their respective signals to the appropriate window comparator and timer circuit(s). The window comparators compare voltages from the sensor **15*c*** and the individual cells **#7–#10** and send signals to the timer circuit(s) indicating a change in status of the cells **#7–#10**. The change status of the cells starts the timer circuitry.

The host vehicle continues to approach the target vehicle causing a change in the status of the cells **#7*a*–#10*a*** of the upper array. The cells **#7*a*–#10*a*** now respond in the same manner as the cells **#7–#10**, sending their signals to the window comparators and timer circuit(s). The window comparators compare the voltages from the sensor **30** and the individual cells **#7*a*–#10*a*** and send signals to the timer circuit(s) indicating a change in the status of the cells. This change in status of the cells stops the timer circuitry.

The timer circuit(s) compares the time of the onset of voltage change of cells **#7–#10** with those of cells **#7*a*–#10*a***. Then it compares that value with the speed signal from the cruise control computer in the host vehicle. The timer circuit(s) is programmed to calculate the difference in speed between the target and host vehicles, and in accordance therewith, sends a signal to the cruise control in the host vehicle to adjust the speed to match that of the target vehicle.

Lateral tracking capabilities can be accomplished by adding a group of photovoltaic or other light sensitive devices **35**, **36**, one at each end of linear array **16**, as shown in FIG. **20**, which is an enlarged cross-sectional view of the sensing end of either of the sensor tubes **15*a*** or **15*b***. The photocells **17** of the array **16** actively monitor the area of surveillance **37**, as in FIG. **10**, by way of the light rays **37*a***. The groups of photocells **35**, **36** monitor the areas of surveillance **38**, **39** by way of the light rays **38*a***, **39*a***. It is to be noted that there may be overlapping of light rays upon the photocells **#4** and **#13**. Such overlapping may be eliminated with the use of trapezoidal shaped slits for the slits **19*a***, **19*b*** and **19*c***.

This arrangement functions in combination with a steering wheel sensor or other motion and/or direction sensing device in the following manner:

The area of sensor surveillance is expanded laterally to the left and right of the straight ahead area of surveillance **37**. However, the light from the laterally expanded area **38** and **39** is focused on photocells **35** and **36**, respectively, which remain inactive at the computer level while the vehicle is traveling in a straight line. When the steering wheel arc sensor is engaged as the vehicle begins execution of a turn, as shown in FIG. **5**, the active photocells **17** in the array **16** are progressively and sequentially inactivated with regard to the computer, while the inactive photocells **35**, **36** to the right or left are progressively and sequentially activated at the computer level. Either group portion **35** or **36** of the array in FIG. **20** will become active while cells **#5–#8**, or cells **#9–#12**, of the array **16** will become inactive, depending on whether the vehicle, is turning to the right or left. Assuming image inversion is employed, if the vehicle is entering a right handed curve as in FIG. **5**, passive photocells **#1**, **2**, **3** and **4** of the group

35 will become actively monitored in sequence: #4, 3, 2 and 1, while the active photocells 17 will become deactivated or unminitored in sequence: #12, 11, 10, 9. The pattern of surveillance area shifts to the right as in FIG. 5. The result is a limited object tracking capability as the vehicle enters a turn. This effect may also be enhanced by arranging the array in a concave or convex pattern facing the incoming light, to increase border coverage area. This system may be used with a singular array or in combination with multiple arrays which are stacked as previously mentioned.

The steering wheel arc sensor will sense the gradual turning of the steering wheel and, in increments, will signal a progressive sequential deactivation and activation of the photocells as previously discussed.

It is also acknowledged that the POS array itself may be mechanically moved with regard to windage and elevation in response to a steering wheel or other sensor to accomplish object tracking capability in turns or curves, inclines and declines.

As shown in FIG. 13, another feature which may be added to the system is a small keypad type device 25 with display integrated with the cruise control system in such a manner as to permit the vehicle operator to enter, via the keypad, the exact speed at which he/she wishes to travel, which will be shown on the display. This keypad type device could be used in place of the current arrangement of switches used to activate and set current cruise controls.

The present invention is also adapted to be utilized in a collision avoidance system. Sensor tubes 40, 41, 42 devised in accordance with sensor tubes 15*a*, 15*b*, 15*c* are mounted high on the interior side or rear window, as shown in FIG. 21, and should be angled down and rearward on both sides of the host vehicle 12 to detect adjacent objects in monitored areas of potential contact. The collision avoidance system, referred to hereinafter as CAVS, is regulated through signals received from suitable sensors connected to the host accelerator, steering mechanism and/or turn signal system of the host vehicle so that it will operate in an alternate mode when the host vehicle passes another vehicle.

When an object is present in an area under surveillance, the CAVS operates to alert the driver with an audio and/or visual signal. The system can be 'on' continuously, giving a visual signal when an object is present and then going to an additional audio alert signal if the operator attempts to change lanes. The CAVS may be turned 'off' or 'on' at the driver's discretion.

The POS tubes at positions 40, 41, 42 are aimed rearward and down toward the road surface and are adjusted to scan the areas of surveillance 43, 44, 45, respectively, forward or rearward from their positions, as illustrated, within the confines of lanes 1, 2 and 3, respectively, and to any pre-determined optimal distance required for appropriate signal initiation. Thus, the same areas of surveillance 43, 45 are positioned to monitor the so-called blind spots of a vehicle located diagonally to the rear of both sides of that vehicle and can be adjusted for each unique blind spot location. For added safety, the areas of surveillance are adjusted to slightly overlap the driver's limits of vision when his head is turned left or right, as illustrated in FIG. 21.

The POS tube 41 is employed for surveillance of the area 44, lane 2, similar to sensors 15*a* and 15*c* but pointing directly to the rear and downward to the road surface. The function of the POS sensor 41 is to detect the presence of a "tailgating" vehicle and to initiate the actuation of the brake lights in the host vehicle, the third brake light, or the rear mounted message display panel as a warning to the tailgating driver that safety parameters with regard to safe following distances have been violated. The driver of the host vehicle will be alerted to the presence of the trailing vehicle by an audio and/or visual signal.

Although the POS system has been described for brake light actuation, etc., it is understood that any sensor capable of detecting the presence of an object may be suitably employed for this purpose and that such usage is to be included within the scope and intent of the invention.

Several POS tubes may be employed, each with an area of surveillance at its own predetermined distance from the rear of the host vehicle, within the confines of lane 2. This will enable the CAVS computer, as shown in FIG. 22, to correlate the host vehicle speed with recommended safe following distances and initiate brake lights, etc., actuation when appropriate. The CAVS computer functions the same as the POS computer previously described, in relation to data from the POS sensor or sensors, and directs initiation of the appropriate alert signals when the respective areas of surveillance become obscured by the presence of a vehicle.

In addition, tracking capabilities, as previously described, can be employed in these side and rear-facing sensors, although the sensing sequences will be reversed to accommodate reversed road curvature as seen from sensor tubes 40, 41 and 42 posterior view of the road.

In addition, as previously described, the areas of surveillance may be illuminated by on-board light sources having visible or non-visible spectra, for times of low visibility and for night time use. Activation of light sources may be linked to the headlight switch for the host vehicle.

The POS system described above also has particular application in aviation as a visual monitor when aimed at desired sectors of the airspace surrounding an aircraft. It may be useful as an adjunct to the pilot's visual review of the surrounding sky and may be linked to aircraft detection and collision avoidance systems, functioning as an additional backup system or as a free-standing device producing an audio and/or visual alert signal or warning.

The POS sensor tubes can be utilized as sensors for an airspace intrusion detector and/or collision avoidance system and would function in object detection identically to its previously mentioned application with respect to automobiles. However, the POS system would activate an audio and/or visual alarm to alert the pilot to potential danger.

The sensor tubes may be distance regulated using an optical lens or lenses which will bring objects which are at an optically pre-determined distance into focus. An array of sensors, each with a lens or lenses pre-focused to a specific distance, can be used to monitor an area for target aircraft at the distances determined by the lens or lenses used. The pertinent distances will be determined by safe aviation practices. In military aircraft applications, the POS system could be used as a detector of approaching hostile aircraft either in conjunction with existing systems or as a free-standing unit.

A spherical arrangement of sensors may be employed in such a manner as to provide coverage of all airspace surrounding the aircraft. Sensor field can be arranged to overlap and to provide complete coverage. Another possible configuration consists of a group of sensors aimed at one area and mounted in such a manner that they can be continuously rotated by means of a small motor, thereby providing complete sensor field coverage. Other configurations and locations may be discerned and are to be considered within the scope and intent of this invention.

The present invention has many advantages over the art. Most notably, the POS system uses inexpensive commercially available components, and the small size of the POS tube(s) requires a minimum of space for installation and may permit a variety of mounting locations which would be otherwise impractical for larger units used in the other systems. The POS system is a single unit relying on passively reflected light in order to function while other systems require both a transmitter and receiver of some kind.

While this invention has been described in connection with different embodiments thereof, it will be understood that it is capable of further modification, and this application is intended to cover any variations, uses, or adaptations of the invention following, in general, the principles of the invention and including such departures from the present disclosure as come within known or customary practice in the art to which the invention pertains, and as may be applied to the essential features hereinbefore set forth and fall within the scope of the invention or the limits of the appended claims.

What is claimed is:

1. In a passive optical system for use in a host vehicle for detecting the presence of one or more target vehicles in an area of surveillance, comprising

at least one tubular sensor member mounted on the host vehicle and arranged with its longitudinal axis directed to the area of surveillance in which the target vehicle may intrude, said tubular sensor member having a light sensitive device including at least one light sensitive cell mounted interiorly thereof at one end and being adapted for sensing the light variations of light rays entering and projecting through said member in response to one or more target vehicles intruding into the area of surveillance, said cell being adapted for producing a signal in accordance with variations thereof and therefore the presence of one or more target vehicles, said member also being formed with means for directing and focusing light rays emanating from the area of surveillance, through said member and upon said at least one light sensitive cell.

2. The system as defined in claim **1** wherein said means for directing and focusing light rays includes a wall closing off the other end of said tube and having an opening formed therein through which the light rays project.

3. The system as defined in claim **1** wherein said light sensitive device includes a linear array of a plurality of cells, said cells being oriented in a line arranged to scan the target vehicle moving from outside the area of surveillance on one side thereof to the area of surveillance whereby light rays indicative of the moving vehicle strike the end cell of said array and sequentially move therealong.

4. The system as defined in claim **1** wherein said light sensitive device includes a linear array of a plurality of cells arranged along a line and said means for directing and focusing light rays including a light admitting member having a slit formed thereon with its axis arranged parallel to said line.

5. The system as defined in claim **1** including a second sensor tube mounted on the host vehicle arranged for sensing a second area of surveillance

6. The system as defined in claim **5**, including a sensor tube aranged for sensing the ambient light conditions adjacent the areas of surveillance.

7. The system as defined in claim **1** including a sensor tube arranged for sensing the ambient light conditions adjacent the area of surveillance

8. The system as defined in claim **1** wherein said light sensitive device includes a stack of a plurality of cells, said cells being oriented in a line arranged to sequentially monitor the target vehicle in either direction as the host vehicle approaches or recedes from the target vehicle, respectively, within the area of surveillance whereby light rays indicative of the distance between the vehicles strike either end cell of said stack and sequentially move therealong.

9. The system as defined in claim **8** wherein the host vehicle includes a cruise control system and said light sensitive device is operatively associated with said system for controlling the speed of the host vehicle in accordance with relative movement between the vehicles.

10. The system as defined in claim **1** wherein said light sensitive device includes a linear array of cells and the passive optical system includes a control system operatively connected to said cells, said control system being arranged to deactivate the cells at one end of said array and activate the cells at the other end thereof when the host vehicle is turning along a curve along a roadway.

11. In a passive optical system for use in detecting the presence of one or more objects in an area of surveillance, comprising

a tubular sensing member arranged with its longitudinal axis directed to the area of surveillance in which the object may intrude, said sensor member having a light sensitive device including at least one light sensitive cell mounted interiorly thereof at one end and being adapted for sensing the light variations of light rays entering and projecting through said member in response to light variations produced between light rays emanating from one or more target vehicles intruding into the area of surveillance and the light rays emanating from the ambient light conditions adjacent or within the area of surveillance, said member being adapted to produce a signal in accordance with variations thereof, said member also being formed with means for directing and focusing light rays emanating from the area of surveillance through said tubular member and upon said at least one light sensitive cell, and a second sensor member arranged for sensing the ambient light conditions within the area of surveillance.

12. The system as defined in claim **11** wherein said means for directing and focusing light rays includes a wall closing off the other end of said tube and having an opening formed therein through which the light rays project.

13. A passive optical system for use in a host vehicle for detecting the presence of a target vehicle approaching the host vehicle and to avoid collision therewith, comprising

a plurality of tubular sensor members mounted on the host vehicle and arranged with one of said members having its longitudinal axis directed to the area of surveillance rearwardly of the host vehicle and two others of sàid members having their longitudinal axes for sensing directed to the areas of surveillance outwardly form the sides of the host vehicle, respectively, in which the target vehicle may intrude, each of said sensor members having a light sensitive device including at least one light sensitive cell mounted interiorly thereof at one end and being adapted for sensing light variations of light rays entering and projecting through said member in response to light variations produced between light rays emanating from one or more target vehicles intruding into the area of surveillance and the light rays emanating from the ambient light conditions adjacent and within the area of surveillance, each of said members being adapted to produce a signal in accordance with said light variations thereat, each of said members also being formed with means for directing and focusing light rays emanating from their respective areas of surveillance, through said tubular member and upon said light sensitive cell associated therewith.

14. The system as defined in claim **13** wherein said light sensitive device includes a linear array of a plurality of cells arranged along a line and said means for directing and focusing light rays including a light admitting member having a slit formed thereon with its axis arranged parallel to said line.

15. A passive optical system for use in a host aircraft for detecting the presence of one or more aircraft in airspace under surveillance, comprising

a plurality of sensing tubes, each being arranged with its longitudinal axis directed to a predetermined portion of the air-space under surveillance in which an aircraft may intrude, each of said sensor tubes having a light sensitive device including at least one light sensitive cell mounted interiorly thereof at one end and being adapted for sensing light variations of light rays entering and projecting through said tube in response to light variations produced between light rays emanating from one or more target aircraft intruding into the airspace under surveillance and the light rays emanating from the ambient light conditions within the airspace under surveillance, said tubes being adapted to produce a signal in accordance with said light variations thereon, each of said tubes also being formed with means for directing and focusing light rays emanating from their respective portions of the airspace under surveillance upon said at least one light sensitive cell, said means for directing and focusing including a lens device prefocused to a predetermined distance into its respective portion of the airspace.

16. The system as defined in claim **15** wherein said plurality of sensor tubes are arranged in the host aircraft for scanning spherically thereabout.

17. In a passive optical system for use in a host vehicle for detecting the presence of one or more target vehicles in an area of surveillance, comprising

at least one cylindrical sensor member mounted on the host vehicle and arranged with its longitudinal axis directed to the area of surveillance in which the target vehicle may intrude, said sensor member having a light sensitive device including at least one light sensitive cell mounted interiorly thereof at one end and being adapted for sensing the light variations of light rays entering said member in response to one or more target vehicles intruding into the area of surveillance, said cell being adapted for producing a signal in accordance with variations thereof and therefore the presence of one or more target vehicles, said member also being formed with means for directing and focusing light rays emanating from the area of surveillance upon said at least one light sensitive cell, said light sensitive including a linear array of cells and the passive optical system including a control system operatively connected to said cells, said control system being arranged to deactivate the cells at one end of sid array and activate the cells at the other end thereof when the host vehicle is turning along a curve of a roadway.

* * * * *

United States Patent [19]

Schofield et al.

[11] **Patent Number: 4,930,742**

[45] **Date of Patent: Jun. 5, 1990**

[54] **REARVIEW MIRROR AND ACCESSORY MOUNT FOR VEHICLES**

[75] Inventors: **Kenneth Schofield; William W. Gallmeyer; Theodore C. Zwiep,** all of Holland, Mich.

[73] Assignee: **Donnelly Corporation,** Holland, Mich.

[21] Appl. No.: **173,307**

[22] Filed: **Mar. 25, 1988**

[51] **Int. Cl.**[5] **A47F 7/14**

[52] **U.S. Cl.** **248/475.1;** 248/225.1; 248/558; 350/631; 403/408.1

[58] **Field of Search** 248/467, 475.1, 225.1, 248/222.1, 224.4, 558; 350/631; 403/388, 408.1

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Exhibit A–Photographs of General Motors wire cover Part No. 16507661–it is believed this part has been on sale for more than one year in the United States.

(List continued on next page.)

Primary Examiner—David L. Talbott

Attorney, Agent, or Firm—Price, Heneveld, Cooper, DeWitt & Litton

[57] **ABSTRACT**

A mounting adaptor is disclosed for removably securing an interior rearview mirror assembly to a mounting support on the inner surface of a vehicle window such as a windshield. The adaptor preferably has a recessed channel on one side for receiving a window mounting button and a projection on the opposite surface simulating a window mounting button for removably mounting a rearview mirror assembly. The projection may be shaped to receive the same or a different mirror assembly channel mount as compared to the support on the window to allow conversion from one assembly to another without changing the window support. The adaptor may also include a support for a vehicular accessory such as a microphone, compass, headlight dimmer, light, moisture sensor, radar detector or the like. Such accessory is thus supported for convenient use by the driver or other vehicle occupant and in a highly advantageous operating position without interference with the rearview mirror, its replacement, interchangeability or adjustability. A wire cover may also be included on the adaptor.

An assembly combining a microphone and a support for mounting a rearview mirror adjacent a driver within a vehicle is also disclosed.

20 Claims, 5 Drawing Sheets

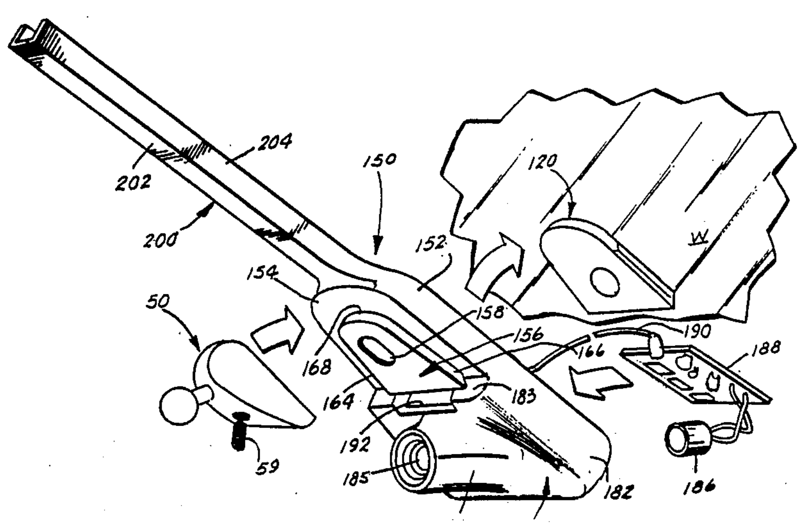

Exhibit J

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Exhibit B–Photographs of Gentex wire clip–it is believed that this clip has been on sale in the United States for more than one year.

Exhibit C–Photographs of a prototype wire cover structure developed by Donnelly Corporation, Holland, Michigan and disclosed to General Motors/Chevrolet Truck on Mar. 13, 1986.

Exhibit D–Drawings from co-pending patent application Serial No. 07/021,636, filed Mar. 4, 1987 assigned to the common assignee, Donnelly Corporation, and illustrating various forms of a wire cover device adapted to extend from a rearview mirror mount to a vehicle interior headliner.

Exhibit I–photographs and sample of a mirror mounting attachment sold by General Motors Corporation and believed to be first released by General Motors Service Parts Division on Jul. 9, 1987.

Exhibit II–photographs and sample of a mirror mounting attachment manufactured and sold by Wink Corporation at least one year prior to the filing date of the present application, namely, Mar. 25, 1988.

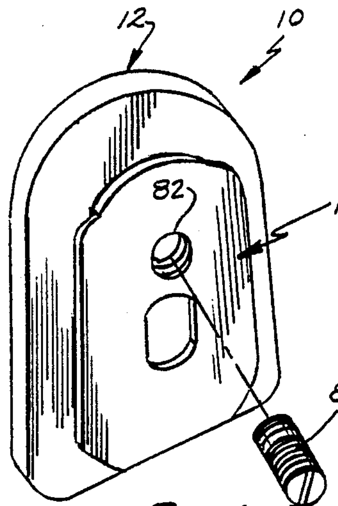


Fig. 1.

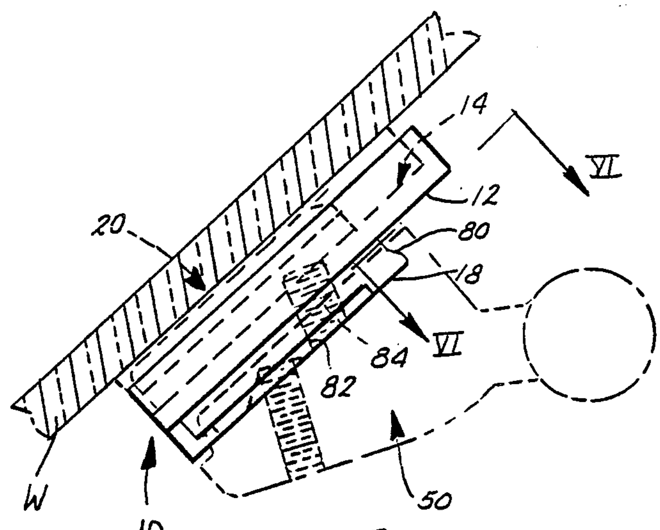


Fig. 2.

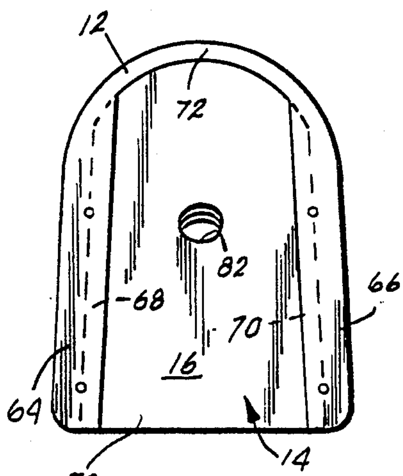
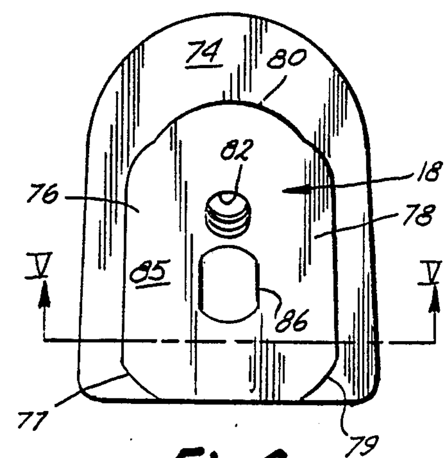


Fig. 3.



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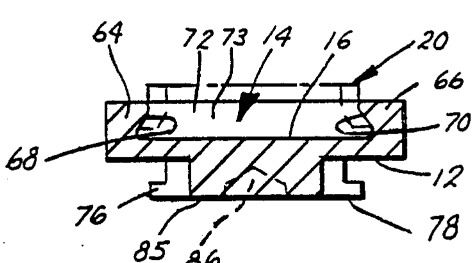

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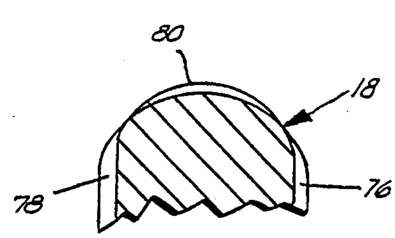

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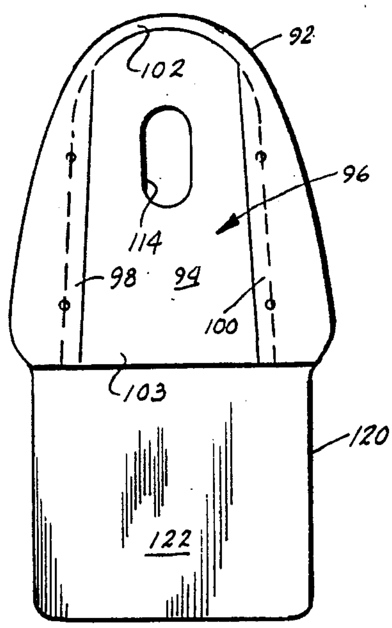


Fig. 14.

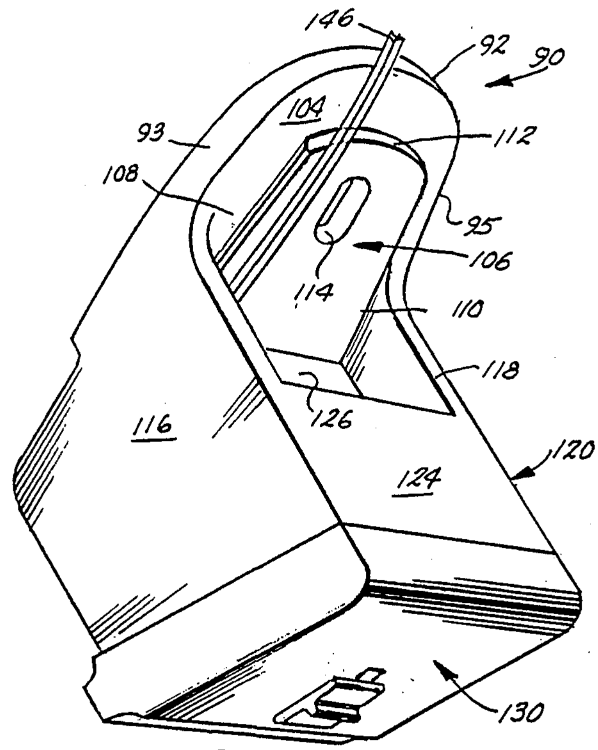


Fig. 13.

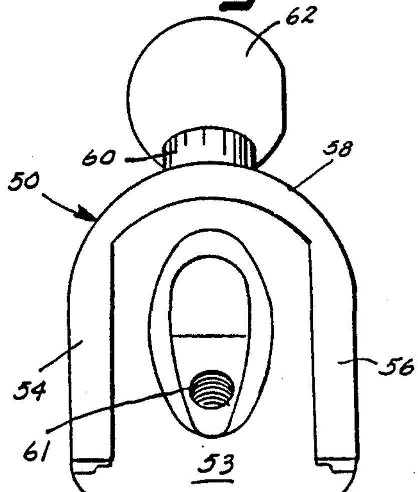


Fig. 12.

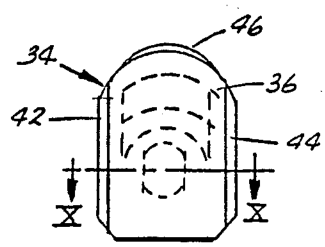


Fig. 9.

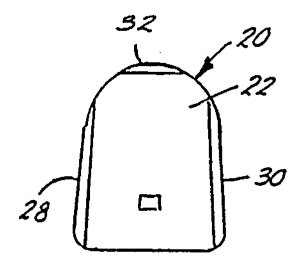


Fig. 7.

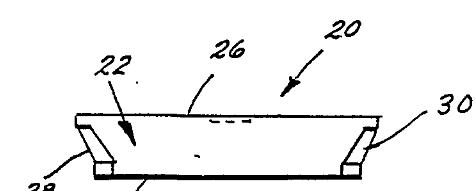


Fig. 8.

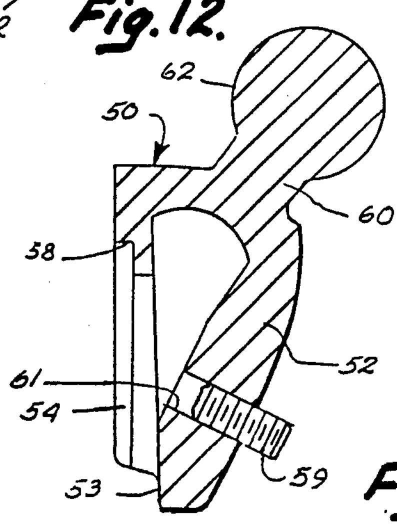


Fig. 11.

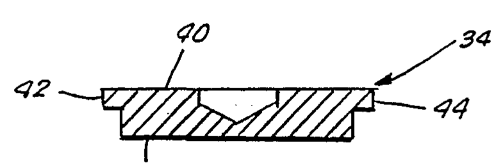


Fig. 10

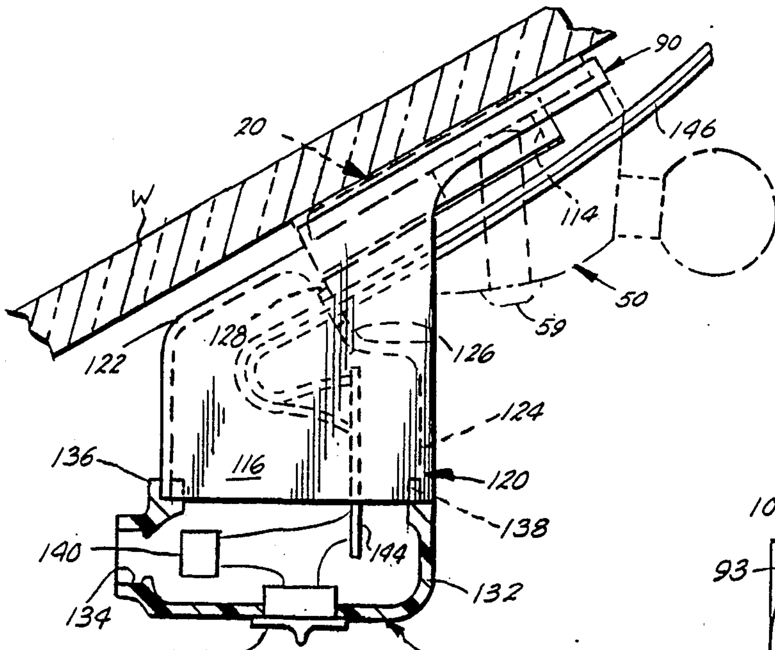


Fig.15.

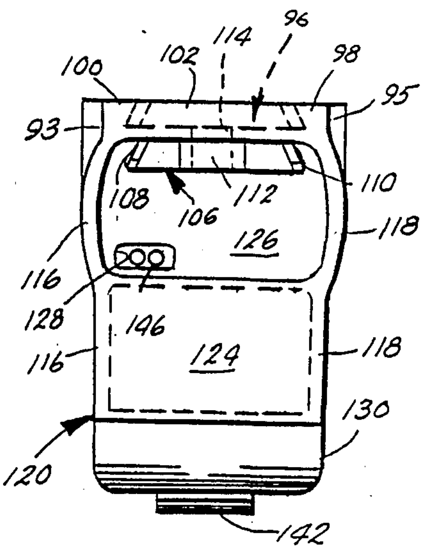


Fig.16

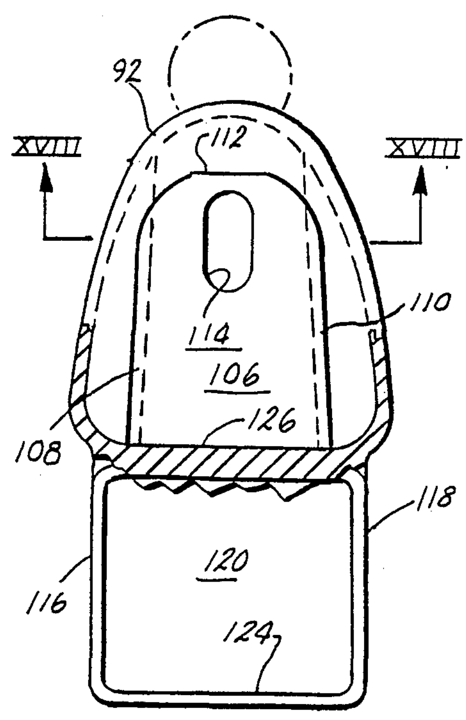


Fig.17.

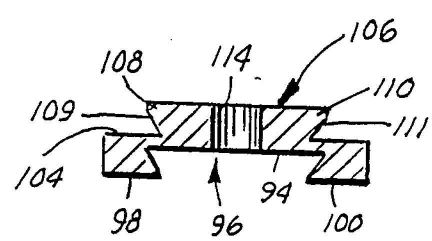
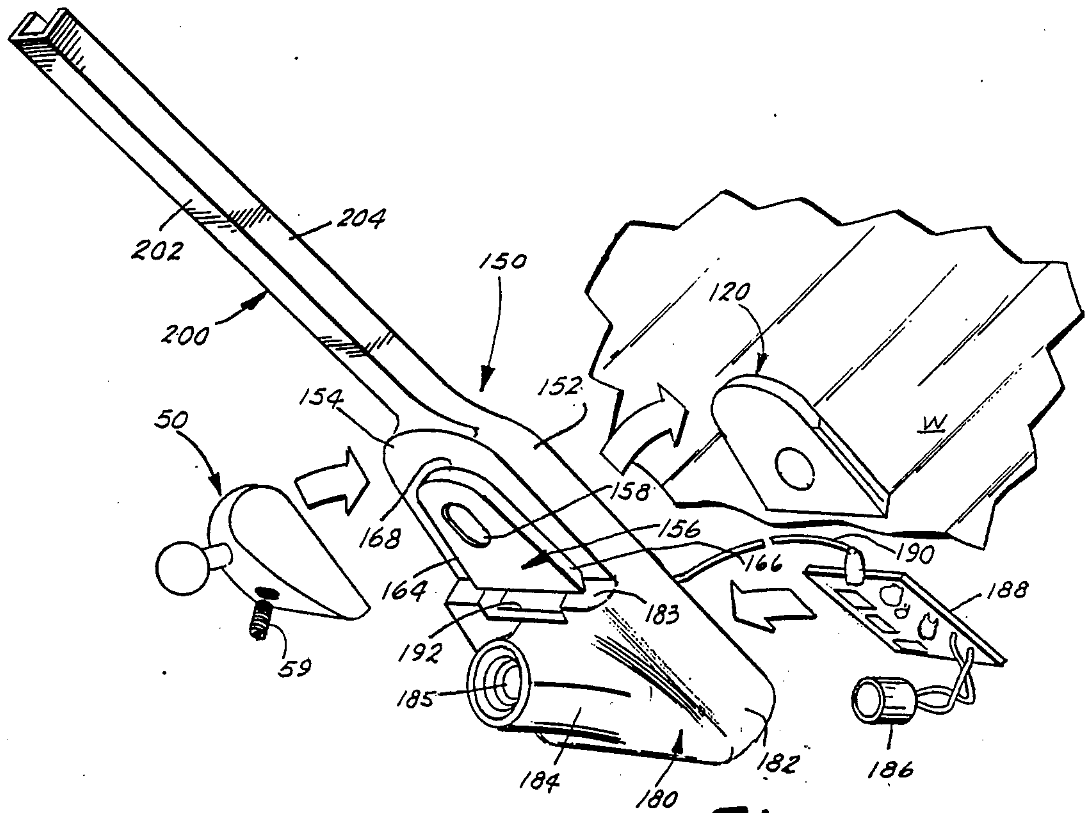


Fig.18.



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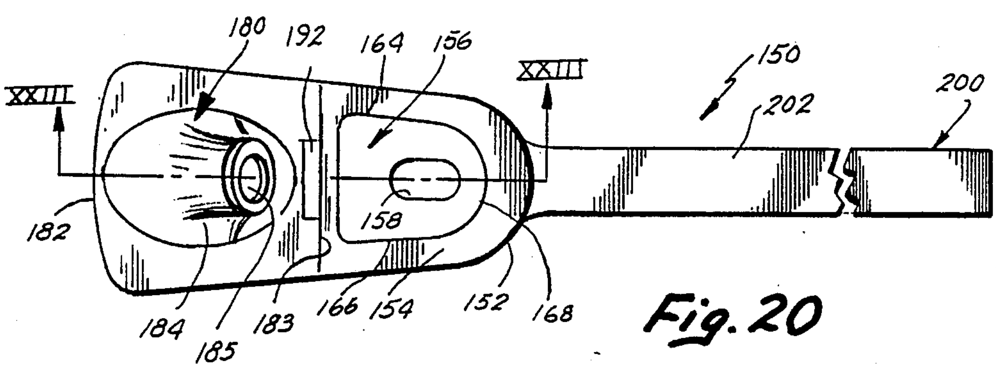

Fig. 20

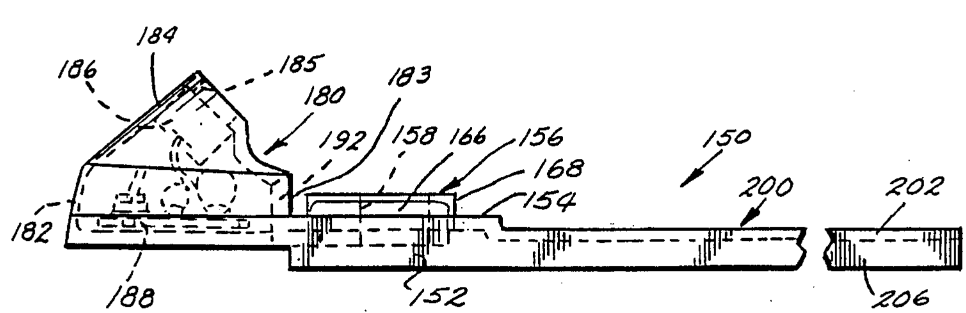

Fig. 21.

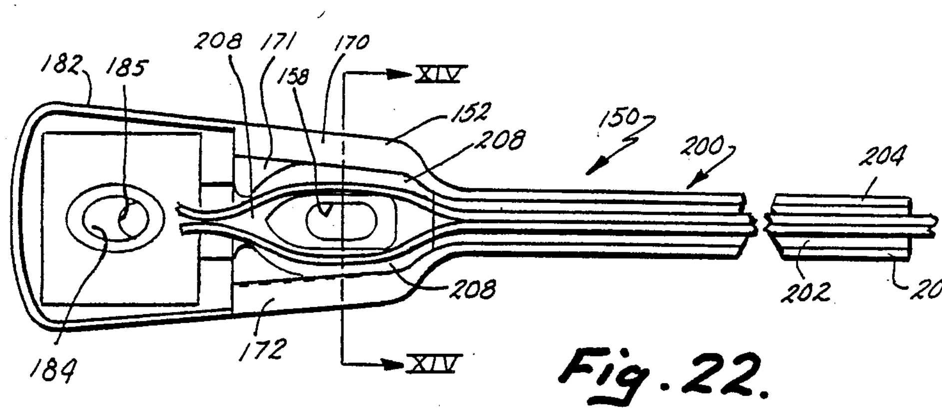

Fig. 22.

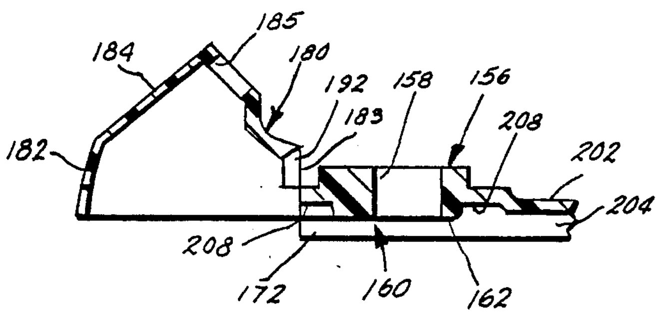

Fig. 23.

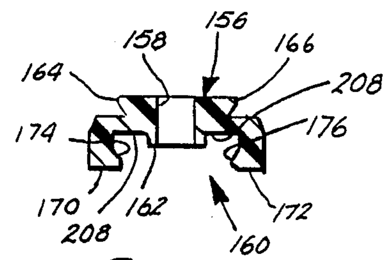

Fig. 24.

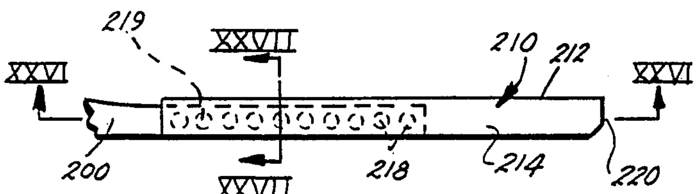

Fig. 25.

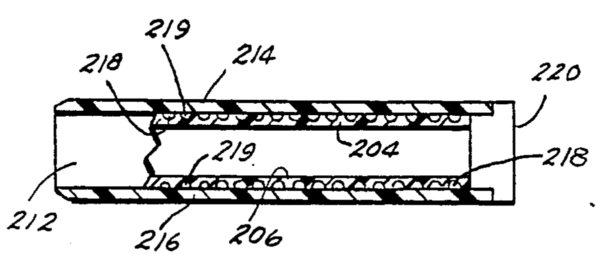

Fig. 26.

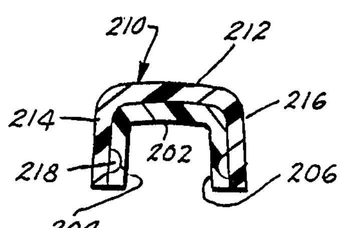

Fig. 27.

REARVIEW MIRROR AND ACCESSORY MOUNT FOR VEHICLES

BACKGROUND OF THE INVENTION

This invention relates to mounting structures for inside rearview mirror assemblies in vehicles and, more particularly, to a mounting adaptor adapted to mate with a support secured to the inside surface of a window such as a windshield to allow support of various types of mirror assemblies as well as various vehicle accessories adjacent to the mirror assembly. The invention also relates to supports for a microphone adjacent and in the vicinity of a rearview mirror for use by the driver and other passengers in the vehicle.

For many years, rearview mirror assemblies have been supported within vehicles by securing them to mounting supports, known as "buttons", adhered to the upper inside surface of the front windshield of the vehicle. The rearview mirror assembly typically includes a swivel joint ending with a mounting member known as a channel mount having a recessed channel slot for slidably receiving the windshield button or support therein through a bottom opening. While the shape and size of windshield mounting buttons have long been standardized throughout the vehicle industry, at least in the United States, various proposals for modified shapes and sizes of windshield buttons have recently been proposed. This creates a problem for rearview mirror manufacturers who would be required to stock both new and old assemblies having channel mounts adapted to fit the new and old style windshield mounting buttons. Likewise, in the aftermarket for vehicle accessories, both new and old style rearview mirror assemblies would have to be offered having channel mounts adapted to both new and old windshield buttons.

Automobiles and trucks in recent years have also included an increasing amount of instrumentation and accessories. It is desired to mount various of these accessories and instruments in places conveniently accessible to the driver or other vehicle passengers, or in locations where operation and function of such accessories is most advantageous. For instance, the upper front windshield area is one of a very few locations in a conventional vehicle which allows satisfactory operation of a magnetic compass. Also, with the increasing use of mobile/cellular telephones in vehicles, the inclusion of microphones for use by various persons within the vehicle has been desired.

Further, many rearview mirror assemblies are now adapted to perform functions other than merely holding a reflective mirror element in correct position. Items such as map, courtesy or reading lamps, information displays, clocks, compasses and the like have been built into the mirror assemblies. With such mirrors, there is a need to route electrical cables between the vehicle interior roof headliner and the mirror assembly to provide appropriate electrical power and to allow ease and convenience in the removal and replacement of the mirror unit.

In the past, it has been known to support certain vehicle accessories such as a headlight dimming sensor on the channel mount for the inside rearview mirror assembly when secured to a windshield mounting button. In several vehicles in the past few years, a spring clip has been attached to the bottom of a conventional rearview mirror channel mount for the attachment of a headlight dimming sensor. The electrical connection and cable running from that sensor pass behind the channel mount and are at least partially shielded as they extend toward the vehicle headliner by a rectilinear, channel-shaped wire cover secured between the channel mount and windshield support button by fitting a tab on the wire cover over the inner end of the channel mount set screw. However, this structure included a ball member integral with the channel mount to which a swivel joint and rearview mirror assembly was permanently attached. Thus, to replace the rearview mirror assembly or accommodate a different shaped windshield mounting button, it is necessary to provide a complete new assembly including the channel mount on the rearview mirror assembly. Also, the prior known wire cover was inadequately supported at the channel mount and was difficult to retain in place, especially over relatively stiff wires.

Accordingly, the prior mirror support structures failed to provide for convenient substitution of different mirror assemblies, failed to accommodate the support of different types of vehicle accessories, failed to suggest any support for microphones, and failed to properly integrate wire covers for electrical cables and wiring from the accessories in a secure manner.

SUMMARY OF THE INVENTION

Accordingly, the present invention provides a mounting adaptor for use with interior rearview mirror assemblies which allows substitution or change of the rearview mirror assembly to accommodate different types of windshield mounted supports easily and conveniently. The adaptor can also provide a support for different vehicle accessories adjacent the rearview mirror without interfering with the mounting of the rearview mirror assembly, or its replacement, interchangeability or adjustability. Support of the accessories on the adaptor places the accessories or information therefrom in an appropriate position for vehicle operator sighting and use, allows the addition of desirable options without the need to modify existing vehicle components, and positions the accessories for their most advantageous functional operation. In addition, the adaptor may provide an appropriate wire cover for shielding and concealing electrical wires leading from either the mirror assembly or the accessory mounted on the adaptor to the vehicle headliner area.

Also, the invention contemplates an appropriate mounting for a microphone within the vehicle interior adjacent the rearview mirror assembly in a convenient location for use by the driver and other vehicle passengers.

In one aspect, the invention is a mounting adaptor for securing an interior rearview mirror assembly to a mounting support when the support is affixed on the inner surface of a vehicle window such as the windshield. The adaptor includes an adaptor body, mounting means on one surface of the adaptor body for securing the mounting support when fixed on the window, and securing means on a second surface of the adaptor body for removably mounting a rearview mirror assembly to the adaptor body. Accordingly, the adaptor body spaces the rearview mirror assembly outwardly of the window and the mounting support.

In preferred forms of this invention, where the rearview mirror includes a channel-like mounting member, the mounting means is a recessed channel on the windshield facing surface of the adaptor while the securing means is a projection on the interior facing surface of the adaptor for receiving a channel-like mounting member thereover. The recessed channel may have a different sectional shape from the projection to allow attachment of a rearview mirror assembly having one channel mount shape to a windshield support member of different shape.

The adaptor body may also include an aperture extending therethrough and communicating with the recessed channel for receiving a fastener for engaging the mounting support to secure the adaptor in place. In one form, the fastener may extend from the channel-like mounting member of the rearview mirror assembly such that the rearview mirror assembly and the adaptor are simultaneously locked in place. Alternately, the adaptor may include a separate fastener for securement to the windshield mounted support while the channel-like mounting member from the rearview mirror assembly is separately fastened to the adaptor with its own fastener.

In another aspect of the invention, a mounting adaptor is provided for securing an accessory adjacent an interior rearview mirror in a vehicle. Such adaptor includes an adaptor body, first mounting means on a first surface of said adaptor body for securing a mounting support when the support member is secured to the inner surface of a vehicle window such as a windshield, and securing means on a second surface of the adaptor body for removably mounting a rearview mirror assembly on the adaptor. The adaptor body also includes support means for supporting a vehicle accessory such that the accessory may be mounted adjacent the interior rearview mirror for convenient use by the vehicle driver or other occupant without interfering with the support of the rearview mirror or its replacement, interchangeability or adjustability. Various types of accessories may be accommodated such as microphones, compass sensors, moisture sensors, radar detectors, information displays, garage door openers, keyless entry systems, vehicle identification apparatus, headlight dimmers or navigation system receivers and others.

A specific form of the invention for supporting a microphone such as that for a cellular phone is contemplated including a housing having a receptacle for the microphone and adapted to open toward the interior of the vehicle when the adaptor is mounted on the mounting support member on a window. The housing also includes an interior space for enclosing wiring and/or circuitry for the microphone. The adaptor incorporating such housing may also include a wire cover extending toward the vehicle headliner to shield and conceal electrical wiring from the microphone.

In a further aspect of the invention, a combined rearview mirror and microphone mounting assembly is provided for use in vehicles including a support for mounting a rearview mirror assembly adjacent a driver within a vehicle and means on the support for mounting a microphone adjacent the position of the rearview mirror assembly. Such assembly allows use of the mirror assembly by the vehicle driver and use of the microphone by persons within the vehicle passenger compartment, including the driver.

Accordingly, the present invention provides a convenient, easy to use adaptor for supporting rearview mirror assemblies, supporting various types of vehicle accessories near the rearview mirror assembly, and provides structure for shielding and concealing electrical wiring from either the rearview mirror assembly or the supported accessory. In addition, the invention provides support for a microphone within a vehicle for use with cellular telephones and the like.

These and other objects, advantages, purposes and features of the invention will become more apparent from a study of the following description taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a first embodiment of the rearview mirror mounting adaptor of the present invention;

FIG. **2** is a side elevation of the adaptor of FIG. **1** shown secured to a windshield support member and having a conventional rearview mirror assembly channel mount secured to it;

FIG. **3** is a rear elevation of the mounting adaptor of FIGS. **1** and **2**;

FIG. **4** is a front elevation of the mounting adaptor of FIGS. **1-3**;

FIG. **5** is a sectional view of the mounting adaptor taken along plane V—V of FIG. **4**;

FIG. **6** is a fragmentary rear elevation of a conventional windshield support member or mounting button;

FIG. **7** is a rear elevation of a conventional, double wedge-shaped windshield mounted support member or button;

FIG. **8** is a top plan view of the windshield support member of FIG. **7**;

FIG. **9** is a rear elevation of an alternate type of conventional windshield mounted support member;

FIG. **10** is a section of the support member taken along plane X—X of FIG. **9**;

FIG. **11** is a sectional, side elevation of a channel mount member as used on conventional interior rearview mirror assemblies;

FIG. **12** is a rear elevation of the conventional channel mount member of FIG. **11**;

FIG. **13** is a perspective view of a second embodiment of the rearview mirror mounting adaptor including a receptacle support for attachment of a vehicle accessory;

FIG. **14** is a rear elevation of the mounting adaptor of FIG. **13**;

FIG. **15** is a side elevation of the mounting adaptor of FIGS. **13** and **14** with a headlight dimming sensor shown in section secured in the support receptacle and the adaptor mounted on the inside surface of a windshield;

FIG. **16** is a top plan view of the mounting adaptor of FIGS. **13-15**;

FIG. **17** is a front elevation of the mounting adaptor of FIGS. **13-16** shown partially in section;

FIG. **18** is a sectional view of the mounting adaptor of FIGS. **13-17** taken along plane XVIII—XVIII of FIG. **17**;

FIG. **19** is an exploded, perspective view of a third embodiment of the mounting adaptor of the present invention including a housing for supporting a microphone and a wire cover;

FIG. **20** is a broken, front elevation of the mounting adaptor of FIG. **19**;

FIG. **21** is a broken, side elevation of the mounting adaptor of FIGS. **19** and **20**;

FIG. **22** is a broken, rear elevation of the mounting adaptor of FIGS. **19-21**;

FIG. 23 is a fragmentary, sectional, side elevation of the mounting adaptor taken along plane XXIII—XXIII of FIG. 20;

FIG. 24 is a sectional view of the mounting adaptor taken along plane XXIV—XXIV of FIG. 22;

FIG. 25 is a fragmentary side elevation of a modified wire cover extension for use with a mounting adaptor such as that shown in FIGS. 19–24;

FIG. 26 is a sectional rear elevation of the wire cover extension taken along plane XXVI—XXVI of FIG. 25; and

FIG. 27 is a sectional end view of the wire cover extension taken along plane XXVII—XXVII of FIG. 25.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings in greater detail, FIGS. 1–6 illustrate a first embodiment **10** of the interior rearview mirror mounting adaptor for vehicles. Adaptor **10** includes a body **12** having an open ended, recessed channel **14** on its windshield facing, back or rear surface **16** (FIGS. 3 and 5) and a front projection **18** extending toward the interior of the vehicle for receiving the channel-like mounting member or "channel mount" **50** (as it is known in the U.S. vehicle industry) from a rearview mirror assembly as shown in FIGS. 2, 11 and 12. Projection **18** thus forms a securing structure for removably attaching or mounting a rearview mirror assembly to the adaptor. Likewise, recessed channel **14** forms a mount for removably securing the entire adaptor to a window or windshield mounted support.

As shown in FIG. 2, adaptor **10** is preferably adapted to be slidably fitted over a conventional windshield support member or windshield "button" such as that shown at **20** in FIGS. 2, 5, 7 and 8 or that shown at **34** in FIGS. 9 and 10. Windshield support member **20** includes an elongated support body **22** having a planar rear surface **24** (which faces the front of the vehicle when installed) adapted to be adhered by a suitable adhesive such as polyvinyl butyral (PVB) to the inside surface of a windshield as shown in FIG. 2. Front surface **26** of body **22** is also generally planar and faces inwardly of the vehicle interior when mounted on the windshield. On either lateral side edge of the body **22** are tapered side edges or flanges **28**, **30** which taper inwardly toward the narrower rear surface **24**. Also, side edges **28**, **30** are nonparallel with and extend toward one another at the top end of the body **22** as seen in FIG. 6. This provides the support member with its overall double wedge shape for receiving a channel mount such as that at **50** in FIGS. 11 and 12. The top end of body **22** is rounded and may also be tapered inwardly toward rear surface **24** as at **32**.

Alternately, another conventional windshield support member **34** may be used as shown in FIGS. 8 and 9. Support **34** has a body **36** including planar rear and front surfaces **38**, **40** and rectilinear side edges or flanges **42**, **44** which extend perpendicularly outwardly from the sides of body **36**. Flanges **42**, **44** are generally parallel with one another and provide an L-shaped shoulder area on either lateral side for retaining a channel mount such as that shown at **50** in FIGS. 11 and 12. Thus, support **34** has a different sectional shape than support **20** for matching a different sectional shape in a modified channel mount. The top end **46** of support member **34** is rounded and may be tapered inwardly toward rear surface **38** as in support member **20**.

With reference to FIGS. 2, 11 and 12, a conventional channel-like mounting member or "channel mount" **50** is shown. Such mounting members have been used for many years in the U.S. vehicle industry to support rearview mirror assemblies on windshield mounted support members as illustrated. Channel mount **50** typically includes a body **52** cast from zinc or molded from a strong resinous plastic and has a recessed channel on its rear surface defined by longitudinal flanges **54**, **56** which extend out and over the rear surface **53** of body **52** and a closed, rounded top end **58**. Projecting outwardly from body **52** and formed integrally therewith is a neck **60** and ball member **62** which are adapted to mate with a corresponding socket member to form a swivel joint for supporting a rearview mirror assembly in the conventionally known manner. Depending on the precise shape of flanges **54**, **56**, channel mount **50** is adapted to slide over mounting support member **20** or **34** with support member **20** or **34** received through the bottom opening between flanges **54** and **56**. Support member **20** or **34** slides into the channel until top end **32** or **46** abuts end **58** while flanges **54**, **56** engage side edges **28**, **30** or flanges **42**, **44** for retention purposes.

As shown in FIG. 2, mounting adaptor **10** is also slidably fitted over the top end of a conventional windshield mounted support member such as that at **20** or **34** in a manner similar to channel mount **50**. Support member **20** or **34** has previously been secured or adhered to the inside surface of windshield W. After adaptor **10** is fitted, a channel member **50** is then slidably mounted over projection **18** such that ball member **62** projects substantially horizontally into the vehicle interior and properly positions the rearview mirror assembly for use by the driver of the vehicle.

As is best seen in FIGS. 3 and 5, the channel recess **14** at the rear of adaptor **10** is formed by flanges **64**, **66** which extend along the sides of body **12** on rear surface **16** and have inwardly extending surfaces **68**, **70**. Surfaces **68**, **70** extend at an angle to one another to form a double taper or double wedge in the channel recess. A rounded top wall **72** (FIG. 3) closes the top end of recess **14** between flanges **64**, **66**. At the bottom end of adaptor **10** is an opening **73** between flanges **64**, **66** through which the support member **20** may be inserted and slid upwardly until top end **32** abuts top wall **72** as shown in FIG. 2. As will be seen in FIG. 5, inwardly extending surfaces **68**, **70** are adapted to engage and mate with side edges **28**, **30** on windshield support member **20** to firmly support the adaptor on the windshield mounting button without play or vibration. Since the thickness of support **20** or **34** is greater than the depth of channel **14**, adaptor **10** is spaced outwardly of windshield W. This allows the adaptor to be easily installed and prevents noise from contact between the adaptor and windshield.

As shown in FIGS. 2, 4 and 5, projection **18** on the front surface **74**, of adaptor **10** is elongated in the direction of adaptor **10** and includes laterally extending retaining flanges **76**, **78** which extend along the lateral sides of projection **18**. Flanges **76**, **78** extend parallel to surface **74** and form an L shape on each side of projection **18** to provide a shoulder for retaining channel mount **50**. The lower edges **77**, **79** of flanges **76**, **78** are rounded inwardly to avoid sharpness to reduce the chance of injury to occupants of the vehicle. The upper end **80** of projection **18** is likewise rounded and may be tapered inwardly as shown in FIGS. 2 and 6 for engagement with the top wall **58** in a channel mount such as that at 50. Projection 18 is also slightly thicker than the depth of the channel included in channel mount 50. This spaces the channel mount slightly away from surface 74 as shown in FIG. 2 to allow ease of insertion and to prevent contact between the mount and surface 74.

As shown in FIGS. 1-4, an aperture 82 is provided through projection 18 and body 12 of adaptor 10 such that it opens into the recessed channel 14 behind the adaptor and opens toward the front or interior of the vehicle as well. Aperture 82 is preferably threaded, extends at an upward angle toward the top of body 12, and receives a set screw 84 which may be tightened against the front surface 26 or 40 of one of the windshield mounted support members 20 or 34. The set screw draws surfaces 68, 70 against surfaces 28, 30 or flanges 42, 44 to tightly retain the adaptor 10 on the support member 20 or 34 without vibration, play or release. When a channel mount such as that at 50 is slidably received over projection 18, aperture 82 and set screw 84 are concealed from view. Front surface 85 of projection 18 ma also include a conical recess 86 for receiving the end of a set screw from a channel mount 50 as shown in FIG. 2 and explained more fully below.

When received over projection 18, through the opening between flanges 54, 56 in the channel mount, flanges 76, 78 engage flanges 54, 56 while end 80 engages top wall 58 in the channel mount. Although flanges 54, 56 securely retain the channel mount on the projection while gravity holds end 80 against top wall 58, additional protection against vibration or sliding movement of the channel mount on projection 18 is provided by a set screw 59 received in aperture 61 in body 52 of the channel mount. When tightened, set screw 59 is received in recess 86 to draw flanges 54, 56 tightly against the inside surfaces of flanges 76, 78 for more secure retention.

Alternately, as will be explained below, aperture 82 may be enlarged and left unthreaded such that an elongated fastener on a channel mount may be received entirely through the adaptor 10 for direct engagement with the front surface 26 or 40 of support member 20 or 34. Thus, such an elongated fastener in the channel mount would simultaneously secure both the channel mount 50 to adaptor 10 and adaptor 10 to support member 20 or 34 without the need for a second fastener (see FIG. 15).

As will also be understood, the precise sectional shape of channel recess 14 on the rear surface of adaptor 10 may have the double tapered, wedge shape of support member 20 or the rectilinear L flange shape of support member 34. Likewise, projection 18 may have the same shape as channel recess 14 or a different shape as is shown in FIG. 5 such that adaptor 10 will allow support of a rearview mirror assembly having a channel mount with a different sectional shape than that of the support member already secured to the windshield surface.

Preferably, adaptor 10 is formed from sintered metal or is die cast from zinc or another casting metal. Alternately, the adaptor may be molded from high strength resinous plastic material such as glass filled acetal. In any event, it is preferred that the material from which adaptor 10 is made be sufficiently rigid and strong to properly support the rearview mirror assembly on the windshield mounted support member.

Referring now to FIGS. 13-18, a second embodiment 90 of the mounting adaptor is illustrated. Adaptor 90 includes an adaptor body 92 which is similar in its upper portions to adaptor 10 but extends downwardly to form a mounting receptacle for a vehicle accessory such as the headlight dimmer sensor 130 shown in FIGS. 13, 15 and 16. The rear surface 94 of adaptor 90 (FIGS. 14-16) includes a recessed channel 96 similar in all respects to recessed channel 14 in adaptor 10. Channel recess 96 is adapted to receive a double tapered or wedge-shaped windshield mounted support member such as that shown at 20 in FIGS. 7 and 8 in the same manner as does recessed channel 14 as described above. Channel 96 includes inwardly tapered flanges 98, 100 which are nonparallel and extend toward one another at the top end of the adaptor which is closed by top wall 102. A bottom opening 103 is included between the lower ends of flanges 98, 100.

On the front surface 104 of adaptor body 92 is an elongated projection 106 similar to but of different sectional shape from projection 18 on adaptor 10. Projection 106 has a sectional shape which is substantially identical to that of channel recess 96. Hence, adaptor 90 may be fitted between a windshield mounted support member 20 and a channel mount 50 which would otherwise be received on support member 20 such that adaptor 90 spaces the channel mount outwardly from the support member 20 but otherwise secures it in the same manner. As explained below, adaptor 90 also provides support structure for a vehicle accessory adjacent the rearview mirror assembly such that the accessory is conveniently located for driver use or operation adjacent the mirror assembly. Yet, adaptor 90 allows removable attachment of rearview mirror assemblies without disturbing the accessory Likewise, the accessory does not interfere with use of the rearview mirror assembly.

With reference to FIGS. 13 and 15-17, the accessory support structure on adaptor 90 includes a pair of parallel, generally planar sidewalls 116, 118 which are inteqral with and extend downwardly from the side edges 93, 95 of adaptor body 92 beginning at an area approximately even with the midpoint of projection 106. Sidewalls 116, 118 form the lateral sides of a rectangular receptacle 120 which also includes an angled rear wall 122 which extends downwardly from the lower end of adaptor body 92 as well as a forward wall 124 which faces the interior of the vehicle when the adaptor is mounted on the windshield support member 20. Intermediate sidewalls 116, 118 is a top wall 126 which defines the bottom of a depressed well partially enclosing projection 106. Wall 126 also includes a wiring aperture 128 through which electrical wiring for operating the accessory supported in receptacle 120 extends as shown in FIGS. 13 and 15.

As will now be understood from FIGS. 13, 15 and 16, a vehicle accessory such as a headlight dimming sensor 130, including a housing 132 having a light receiving opening 134 and mounting flanges 136, 138, is received in the opening to receptacle 120 by engagement with walls 116, 18, 122 and 124. Dimming sensor 130 includes an appropriate light sensing/electrical signaling device 140 connected to a slide switch 142 controlling the operation of the dimmer and an appropriate electrical circuit included on circuit board 144 which is connected to the vehicle electrical system via wiring 146 passing through aperture 128 in top wall 126. When positioned on the windshield mounted support member 20, which is slanted at the rearwardly inclined angle of the windshield, adaptor 90 supports receptacle 120 such that it opens vertically downwardly and holds the housing 132 of headlight dimming sensor 130 substantially horizontally such that opening 134 is aligned toward the front of the vehicle. Headlights impinging on the vehicle from the opposite direction are received through opening 134 on sensor 140 when switch 142 is on.

As shown in FIG. 15, a rearview mirror assembly supported by channel mount 50 may be supported on projection 106 simultaneously without affecting sensor 130. When so mounted, the channel mount 50 extends partially into the well partially enclosing projection 106 and is secured directly to the front surface 26 of support member 20 by fastener 59 passing through aperture 114. This simultaneously retains adaptor 90 in position on the support member 20 and eliminates the need for a second fastener as used in embodiment 10.

If desired a wire cover having a snap-on, clamp-type mount of the type disclosed in co-pending, commonly assigned United States patent application Ser. No. 021,636, filed Mar. 4, 1987, the disclosure of which is hereby incorporated by reference, may be attached to channel mount 50 to shield and conceal wires 146 as they extend from adaptor 90 along the inside surface of windshield W to the headliner area of the vehicle.

As with adaptor 10, adaptor 90 may be formed from sintered metal, cast from zinc or other metal, or molded from a suitably rigid resinous plastic material such as glass filled acetal. Of course, support 120 may be used or modified to support other vehicle accessories such as a compass sensor, radar detector, information display, garage door opener, keyless entry system, vehicle security identification, rain sensor or navigation system receiver. Also, the support may be included above as well as below the adaptor body with shapes designed for and fitted to the particular accessory being supported. Further, supports both above and below the adaptor body may be used. For example, a compass sensor could be supported below the adaptor body and mirror assembly with an information readout for the compass supported above the adaptor body and mirror assembly for viewing by the vehicle occupants and driver.

Referring now to FIGS. 19–27, a third embodiment 150 of the mounting adaptor is illustrated. Adaptor 150 is a hybrid form of the invention including an adaptor body 152, a housing 180 integral with and positioned below the adaptor body for a microphone for a cellular phone, dictation system or the like and its controlling circuitry and wiring, and a wire cover 200 also integral with the adaptor body and extending from the adaptor body in an opposite direction from the microphone housing. As is seen in FIGS. 19 and 20, adaptor body 152 includes a front surface 154 on which is located a double tapered, wedge-type projection 156 substantially similar to projection 106 on adaptor embodiment 90. A fastener aperture 158 extends through projection 156 and communicates with a recessed channel 160 (FIGS. 23 and 24) on rear surface 162. Projection 156 includes inwardly tapered side edges 164, 166 adapted to mate with flanges 54, 56 on a channel mount such as that shown at 50 in FIGS. 11 and 12 for retention purposes. A rounded top end 168 joins flanges 164, 166. Projection 156 has a thickness slightly greater than the depth of the recessed channel of channel mount 50 to prevent contact between mount 50 and surface 154.

Recessed channel 160 on the rear surface of body 152 is formed by outwardly extending lateral flanges 170, 172 having inwardly flared retaining surfaces 174, 176. Flanges 170, 172 are nonparallel and extend toward one another toward the top of body 152 and provide recessed channel 160 with a double tapered, wedge shape adapted to receive a windshield mounted support member 20 through opening 173 between the flanges as shown in FIGS. 7, 8 and 19. The depth of recessed channel 160 is slightly less than the thickness of support member 20 to prevent contact between adaptor body 152 and the inside windshield surface. Accordingly, when positioned on a windshield mounted support member 20, projection 156 will face inwardly toward the interior of the vehicle for receipt of a channel mount 50 which, in turn, supports a rearview mirror assembly. Microphone housing 180 is supported below the adaptor body 152 while wire cover 200 extends upwardly toward the vehicle headliner above the adaptor body. Although microphone housing 180 and wire cover 200 are adjacent the rearview mirror assembly, neither interferes with the operation, removability, or adjustability of the mirror assembly or vice-versa.

Microphone housing 180 includes a slightly trapezoidal housing 182 when viewed from the front which is integral with, extends continuously from, and is generally parallel to adaptor body 152. An integrally formed generally cylindrical microphone cylinder 184 extends at an angle to the general extent of housing 182. Housing 182 is formed by four walls with a generally hollow interior as seen in FIGS. 22 and 23. That hollow interior may receive a microphone sensor such as that shown at 186 and an appropriate microphone circuit board 188 and wiring 190. The forward facing wall of housing 182 merges outwardly into microphone cylinder 184 which includes opening 185 through which sound waves may pass to microphone sensor 186. A rectangular aperture 192 at the top wall of housing 182 is included for insertion of an appropriate mold part to allow formation of the bottom wall of projection 156. Aperture 192 also provides access to the interior of the housing to allow insertion of wires leading from any lights or electrical accessories in the adjacent rearview mirror assembly so they may be concealed behind wire cover 200 as they extend toward the vehicle headliner with wires 190. Top wall 183 of the housing is substantially planar and is adapted to lie adjacent to or abut the bottom of a channel mount such as that shown at 50 when received over projection 156. Thus, the general exterior shape of housing 182 merges into the general shape of the channel mount 50. Likewise, the side surfaces of adaptor body 152 generally lie flush with the side edges of channel mount 50 when mounted on projection 156.

At the upper end of body 152 wire cover 200 extends rectilinearly upwardly away from adaptor body 152. Wire cover 200 is a channel member including a front wall 202 and rearwardly extending sidewalls 204, 206 which define a rear opening to the channel. Front wall 202 merges into the top wall of adaptor body 152 while sidewalls 204, 206 merge into the sidewalls of adaptor body 152. The internal space within channel member 200 communicates with the recessed channel 160 at the rear of adaptor body 152 which, in turn, communicates with the internal space within housing 182 and microphone cylinder 184 as is shown in FIGS. 21–23. In order to allow access space for wiring 190 to microphone circuit 188 and sensor 186 from the headliner area of the vehicle, through the interior space in channel 200, a bifurcated, recessed channel 208 is formed in the rear surface 162 of adaptor body 152. Channel 208 includes left and right branches which merge adjacent the top and bottom of aperture 158 into a single channel. At the top of body **152** channel **208** merges into the interior space of channel member **200**. Adjacent the bottom end of aperture **158** channel **208** merges into the interior space of housing **182** and also communicates with aperture **192**. Since channel **208** is deep enough to receive wiring **190** below the level of rear surface **162**, channel recess **160** may still receive windshield mounted support member **20** therein without causing obstruction or wear on wiring **190**. When inserted, wiring **190** continues unimpeded from the interior of housing **152** through channel **208** adjacent support member **20** when it is received in channel recess **160** and on into the interior of channel member **200** to the headliner area of the vehicle.

Since the distance between the support member **20** on the windshield's inner surface and the vehicle headliner is different for each type of vehicle, mounting adaptor **150** may be provided with an extension for wire cover **200** as shown in FIGS. **25–27**. Such extension is provided by a second rectilinear channel member **210** which slidably telescopes over channel **200** and includes a front wall **212** which is slightly wider than the entire width of channel **200** and a pair of parallel, rearwardly extending sidewalls **214**, **216** which extend along the exterior surface of sidewalls **204**, **206** as shown in FIGS. **25–27**.

In order to position channel extension **210** with respect to channel member **200**, a series of semi-spherical depressions **218** are formed in the outer surfaces of sidewalls **204**, **206** of channel **200** near the upper end thereof. A pair of inwardly extending semi-spherical projections **219** are formed on the inner surface of sidewalls **214**, **216** of channel extension **210** adjacent its lower end for receipt in an opposing pair of semi-spherical recesses **218**. Accordingly, when the distance between the support member **20** and the headliner is known, the channel extension **210** may be positioned to cover the extra distance between the upper end of channel **200** and the headliner and snapped into place with semi-spherical projections **220** received in one pair of the semi-spherical recesses **218** to hold the extension in place. Sidewalls **214**, **216** may be flexed outwardly sufficiently to allow insertion of the projections **219** into recesses **218**. Also, upper end **220** of channel extension **210** may include a flange as disclosed in co-pending application Ser. No. 21,636 referred to above for receipt under the vehicle headliner to help retain it in place.

As with mounting adaptors **10** and **90**, adaptor **150** may be formed from sintered metal, or, more preferably, molded from a sufficiently rigid resinous plastic material in one piece. Channel extension **210** may be separately molded from resinous plastic for the telescoping fit with channel **200**. When mounted on support member **20** via opening **173** to channel recess **160**, a microphone sensor **186** for a cellular phone, recording-/dictation system or the like may be received in microphone cylinder **184** and is connected via wiring **190** to the vehicle electrical system. When a rearview mirror assembly including a channel mount such as that shown at **50** is received over projection **156** and secured through aperture **158** with fastener **59** on the channel mount to support member **20**, the mirror assembly is positioned in front of and immediately adjacent and above the microphone housing **180**. Wiring **190** and any wiring leading from the mirror assembly is concealed from view in the passenger compartment by wire cover **200** and channel extension **210** as it extends to the headliner of the vehicle. Both the mirror assembly and the microphone are thus conveniently positioned for access adjacent the driver while the microphone is in a position above the dashboard of the vehicle where voices from others in the passenger compartment of the vehicle can be properly received. Of course, as with adaptors **10** and **90**, projection **156** may have a sectional shape different from that of recessed channel **160** so that the adaptor will effectively convert from one type channel mount or rearview mirror assembly to another.

While several forms of the invention have been shown and described, other forms will now be apparent to those skilled in the art. Therefore, it will be understood that the embodiments shown in the drawings and described above are merely for illustrative purposes, and are not intended to limit the scope of the invention which is defined by the claims which follow.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A mounting adaptor for securing an accessory adjacent an interior rearview mirror in a vehicle, said adaptor comprising:

an adaptor body;

first mounting means on a first surface of said adaptor body for securing said adaptor body to a mounting support member when the support member is secured to the inner surface of a vehicle window such as a windshield;

securing means on a second surface of said adaptor body for removably mounting a rearview mirror assembly on said adaptor body;

said adaptor body also including support means for supporting a vehicular accessory; said support means including means for positioning the vehicle accessory for exposure to and visibility from the interior of the vehicle and/or for exposure to the vehicle exterior through the vehicle window on which the adaptor body is mounted;

whereby the accessory may be mounted adjacent the interior rearview mirror for proper operation of the accessory and/or convenient use by the vehicle driver or other occupant without interfering with the support of the rearview mirror, or its replacement, interchangeability or adjustability.

2. The mounting adaptor of claim **1** wherein said support means include a support for attaching a vehicle accessory including at least one of a headlight dimmer, moisture sensor, compass sensor, radar detector, information display, garage door opener, keyless entry system, vehicle identification apparatus, or navigation system receiver and means for securing said support to said body.

3. The mounting adaptor of claim **1** wherein said support means include a receptacle for receiving at least a portion of an accessory.

4. The mounting adaptor of claim **1** wherein said support means includes an aperture therethrough for passing an electrical wire to or from an accessory when mounted on said support.

5. The mounting adaptor of claim **1** wherein said support means include means for mounting a microphone on said adaptor body.

6. The mounting adaptor of claim **5** wherein said means for mounting a microphone include a housing including a receptacle for a microphone adapted to open toward the interior of the vehicle when said adaptor is mounted on the mounting support member on a window, said housing also including an interior space for enclosing wiring and/or circuitry for the microphone.

7. The mounting adaptor of claim 6 wherein said receptacle for the microphone is on a lower end of said adaptor body; said body including a wire cover extending therefrom opposite said lower end toward the interior roof area of the vehicle for shielding electrical wiring extending from the roof area to the microphone.

8. The mounting adaptor of claim 7 wherein said wire cover is an elongated, hollow channel member opening toward said first surface of said adaptor body and the window when said adaptor is mounted on the support member on a window, said body including channel means in said first surface communicating with said channel member for routing wiring from said interior space of said housing to said channel member.

9. The mounting apparatus of claim 8 wherein said channel member includes a telescoping extension member slidably mounted thereon for adjusting the length of said channel member wire cover.

10. The mounting apparatus of claim 8 wherein said adaptor body includes an aperture extending through said body and communicating with said first mounting means at said first surface for receiving a fastener for engaging the mounting support.

11. The mounting adaptor of claim 1 including a wire cover extending from said adaptor body for concealing any electrical wiring leading to or from said adaptor from or to another portion of the vehicle when said adaptor is installed in a vehicle.

12. The mounting adaptor of claim 11 wherein said wire cover is an elongated, hollow channel member opening toward said first surface of said adaptor body and the window when said adaptor is mounted on the support member on a window.

13. The mounting adaptor of claim 1 including an aperture extending through said body and communicating with said first mounting means for receiving a fastener for engaging the mounting support.

14. The mounting adaptor of claim 1 wherein said first mounting means include a recessed channel for receiving the mounting support member; said securing means including projecting means extending outwardly from said second surface for receiving a channel-like mounting member from the rearview mirror assembly.

15. The mounting adaptor of claim 14 including an aperture extending through said body and communicating with said recessed channel for receiving a fastener for engaging the mounting support; said aperture in said body extending through said projecting means such that a fastener on the channel-like mounting member may pass therethrough to engage the mounting support.

16. The mounting adaptor of claim 14 wherein said aperture includes a fastener for securing said adaptor to the mounting support.

17. The mounting adaptor of claim 16 wherein said first mounting means also include a pair of spaced, inwardly inclined side flanges, an end wall joining said inclined side flange to form a closed end, and an open end opposite said closed end, said recessed channel adapted to slidably receive the mounting support therein through said open end; said aperture and fastener being located in said projection means and inclined from said projection means toward said closed end wall.

18. The mounting adaptor of claim 1 wherein said first mounting means include first flanges extending along either lateral side edge of said body on said one surface and defining a recessed channel, an end wall defining a closed end at one end of said recessed channel, and an open end opposite said closed end, said recessed channel being adapted to slidably receive the mounting support member therein for retention by said flanges; said securing means including an elongated projection and second flanges extending along either lateral side edge of said projection for cooperation with a channel-like mounting member from a rearview mirror assembly for retention thereof, said projection adapted to be received in the recessed channel of the channel-like mounting member to support the mounting member thereon.

19. The mounting adaptor of claim 18 wherein said first flanges are tapered inwardly toward one another as they extend away from said one surface; said second flanges extending laterally out from said projection generally parallel to but spaced from said one surface wherein said projection will receive a channel-like mounting member having a recessed channel with a different cross-sectional shape than said recessed channel on said one surface.

20. The mounting adaptor of claim 18 wherein said recessed channel is wedge-shaped with said first flanges being nonparallel to one another and extending toward one another at said closed end, said open end being wider than said closed end.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,930,742

DATED : June 5, 1990

INVENTOR(S) : Schofield, et al

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 7, line 21

"ma" should be -- may --

Column 8, line 58

"18" should be -- 118 --

Signed and Sealed this

Tenth Day of December, 1991

Attest:

HARRY F. MANBECK, JR.

Attesting Officer *Commissioner of Patents and Trademarks*

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

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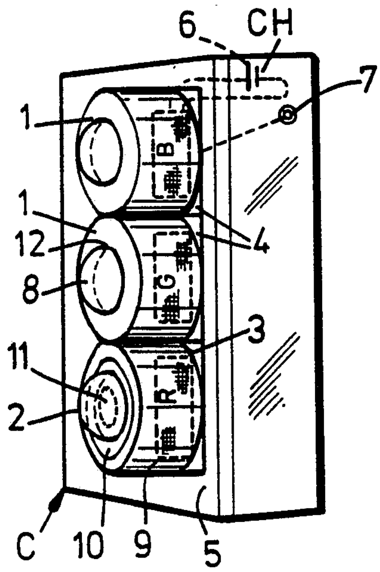

(57) Abstract

The present invention relates to an image capture system suitable for use in an electronic camera system *C* and comprising a solid state image capture device (1) comprising an integrated circuit (5) having at least two sensor arrays (4), each said array having an image sensing surface (3) and a respective lens system (8) associated therewith.

Exhibit K

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SOLID STATE SENSOR ARRANGEMENT FOR VIDEO CAMERA

The present invention relates to electronic cameras including electronic colour cameras.

It is well known that colour sensors can be produced by discriminating three images of the primary colours (blue, green, red) of the scene. All colours can be analysed and synthesised via these primaries (or other complementary triples like cyan, magenta, yellow). Conventional electronic cameras classically use one of two approaches for forming the separate colour images. 3-tube cameras use a single lens followed by a prism which forms three separate r.g.b images. Three sensors are used simultaneously to detect these three images. If the sensors are accurately aligned the resulting picture is of very high quality. However the sensors are separated in space and orientation and their assembly and alignment with the prism and lens is difficult for a volume manufacturing process. This technique is therefore used exclusively for expensive broadcast-quality equipment. Colour-Mosaic Cameras use a single lens and sensor, but the sensor surface is covered with a high-resolution mosaic or grid of colour filters, with the pattern dimension equal to the pixel-pitch for a semiconductor CCD or MOS sensor array. Pixels of different colours are demultiplexed at the sensor output and interpolated to form synchronous parallel colour signals. This is well-suited to volume production as the surface colour mosaic can be fabricated as an extension of the semiconductor wafer fabrication process. The techniques for mosaic fabrication are restricted to relatively few companies worldwide who supply the colour sensor market and thus they are not commonly available. Furthermore, associated with this technique there are technical problems concerned with resolution and aliasing. Much work has been done to correct these effects, but usually at some cost in image-processing hardware.

It is an object of the present invention to avoid or minimise one or more of the above disadvantages.

In one of its broadest aspects, the present invention provides an image capture system comprising a solid state image capture device which device comprises an integrated circuit having at least two sensor arrays, each said array having an image sensing surface and a respective lens system associated therewith.

Thus in effect the present invention provides two or more cameras on one chip each with its own lens system and sensor array. With such an arrangement the problem of alignment is greatly reduced by the fabrication of the various sensors required one one chip. This ensures that the sensors all lie in the same plane and have the same rotational orientation, and this is an important advantage. Assuming lenses can be accurately assembled in a parallel plane (see below), the only alignment errors which are likely to occur are simple orthogonal translations in the form of vertical and horizontal errors in the centres of the optical axes. It is relatively easy though to calibrate these cameras after assembly and electronically to correct for these translations. Whilst the inevitable lateral off-set between the cameras at even the closest dispositions of the cameras on the chip, will of course give rise to a degree of parallax error, it has now been found that with a preferred system of the present invention with generally adjacent sensor arrays, the degree of error in producing a single composite image (i.e. a single image produced by the more or less accurately aligned super imposition of two or more corresponding images e.g. at different wavelengths, of the same scene) can be acceptably small for small camera geometries for low to medium resolution applications. Thus in said one preferred aspect the present invention provides a composite image camera of particularly simple and economic construction.

The present invention also provides in another aspect a stereoscopic image capture system where larger sensor spacings are used to provide a greater parallax differential for producing different images with a more or less accurately defined parallax differential for use in producing stereoscopic image pairs. Again the use of two or more cameras mounted on a single chip helps substantially to minimise alignment problems in producing an accurate stereoscopic view.

Advantageously the lens systems are mounted substantially directly on the image sensing surfaces. Preferably there is used a lens system in accordance with our earlier British Patent Application No. 9103846.3 dated 23rd February 1991 (published in International Publication No. WO92/15036) which lens comprises a lens and a spacer in substantially direct contact with each other, said spacer preferably having a refractive index not less than that of said lens, said lens and spacer having refractive indices and being dimensioned so as to form an image in a plane at or in direct proximity to a rear face of said spacer element remote from said lens element, from an object, whereby in use of the lens system with said lens system mounted substantially directly on the image sensing surface of the image capture device an optical image may be captured thereby.

These lens systems have the advantage of physical dimensions which can be made similar to those of the sensor array itself, so that sensors and lenses may be immediately adjacent to each other. Camera separations as low as 2 to 3mm are easily achieved and this helps to minimise the parallax error. The flat surfaces of the cylindrical lens spacer also help to maintain accurate planarity for groups of lenses attached to the same chip substrate.

It is also possible though to use more conventional, albeit similarly small, lens systems which are mounted on a suitable support so as to be spaced from the sensor surface with an air gap therebetween. One advantage of such systems is that they allow the use of more conventional and cheaper lens materials without the need for special materials having particular refractive indices.

In general at least one of the individual cameras constituted by respective lens system and sensor arrays, is provided with a filter means for passing a desired wavelength (or wavelength range) of the electromagnetic radiation spectrum, whereby there may be captured a composite image comprised of two or more (depending on the number of individual cameras used) images of the same object differing substantially only in the wavelength thereof.

In one preferred form of the invention the integrated circuit has three sensor arrays provided with respective lens systems and filters for three different wavelengths e.g. red, green, and blue, or cyan, magenta, and yellow for providing a desired composite image e.g. a full-colour image.

Where three or more individual cameras are used, it will be appreciated that various different layouts of the sensor arrays relative to each other may be employed including e.g. linear arrangements or generally "circular" or other close-packed arrangements.

In cameras using the 3 primary colours, green is dominant in providing image acuity since it generally dominates the derived luminance. In all cases therefore, the green camera is desirably made as central as possible, and the red and blue cameras are referenced to it. The parallax errors will therefore show up on red and blue only.

With reference to lens systems of our earlier application No. 9103846.3, the expression "substantially direct contact" is used to mean that there should not be any significant interspace containing low refractive index material such as air i.e. no interspace having a thickness resulting in a significant optical effect. In the case of an air gap this should normally be not more than 500 um, preferably not more than 100 um, thick, In the case where resin or like material is used between the components adhesively to secure them together and has a refractive index comparable to that of the lens or spacer, it may be considered as an extension of the lens or spacer and thus need not be so restricted in thickness though preferably the thickness thereof should not be excessive and should be more or less similarly restricted.

Advantageously there is used a plano-convex (or possibly plano-concave - see below) lens with a substantially plane spacer for manufacturing convenience and economy but other combinations e.g. a bi-convex lens and a plano-concave spacer, may also be used.

Preferably the lens system is secured to said image sensing surface by an optical grade adhesive i.e. a substantially transparent optically uniform adhesive. Desirably there is used between the lens and spacer an adhesive having the same refractive index as the lens (or if preferred, as the spacer) and between the spacer and the sensing surface, an adhesive having the same refractive index as the spacer.

Preferably the spacer has a higher, most preferably a substantially higher, refractive index than the lens. Where the same refractive index is acceptable for both then it will be appreciated that the spacer could be formed integrally with the lens.

It will be appreciated that the radius (or radii) of curvature of the lens element and its refractive index may be varied through a wide range of values depending on the required performance in terms of depth of field, image size, freedom from aberrations etc. In general there will desirably be used solid state image capture devices in the form of photoelectric sensor arrays (wherein photons are used to generate electric current and/or voltage or change electrical properties such as resistance etc.) which have relatively small size image sensing surfaces e.g. in the range from 0.1 to 5 cms across. Thus the lens system should in such cases desirably be formed and arranged to provide a similarly small-sized image. Where a wide angle field of view is also required (e.g. in surveillance applications), then a lens of relatively short focal length should be used e.g. for a field of view angle of 80 degrees the (maximum) focal length will not normally exceed 1.19 times the image height and for 60 degrees will not normally exceed 1.73 times the (maximum) image height, the (maximum) image height corresponding to half the sensing surface diameter. The use of a high refractive index spacer and the exclusion of any low refractive index material from the optical path significantly decreases aberration due to Petzval Curvature (otherwise known a curvature of field aberration) and limits spherical aberration. The lens system is therefore particularly advantageous in wide field and/or large aperture applications required for low light conditions. In general there is desirably used, for such wide angle applications, a lens element having a refractive index a_{nd} in the range from 1.45 to 1.65, and a spacer element with a higher, refractive index a_{nd} in the range from 1.45 to 1.85.

Various optical grade materials having suitable refractive indices are widely available. Low-dispersion glass such as type BK7 (available from various sources e.g. Schott Glaswerke) is particularly suitable for the lens element. The spacer element may be made of LaK10 glass also readily available. Other materials that may be used for the lens and/or spacer elements comprise plastics materials, although these are generally less preferred in view of their lower resistance to scratching and other damage and the lower refractive indices available. Nevertheless they may be acceptable for certain applications requiring low cost such as consumer door-entry and security cameras.

Suitable adhesive materials for use between the spacer and lens elements and between the spacer element and the solid state image capture device include optical grade epoxy resins.

In a preferred image capture system of the present invention the solid state image capture device comprises an integrated circuit image array sensor such as that disclosed in our earlier International patent application No. PCT/GB90/01452 (publication No. WO91/04633 the contents of which are hereby incorporated herein by reference thereto) which has on-board signal processing means formed and arranged for directly providing a video signal output. Naturally though other image capture devices such as CCD, MOS and CCD sensors may also be used. Also the image capture device may comprise simply a sensor chip on which are only provided the sensor arrays with all the electronic circuitry required to detect the response of individual sensor cells to incident radiation and further processing of the detected response provided externally of the sensor chip, and of course other arrangements with a greater or lesser part of this electronic circuitry provided on the chip bearing the sensor arrays, are also possible. Accordingly references to "cameras" herein includes references to apparatus in which substantially the whole of the electronic circuitry required to produce a video output signal is provided on the same chip as the sensor arrays, as well as apparatus in which a greater or lesser part is provided separately. Thus references to camera alignment relate only to alignment of the lenses and sensor arrays (and not to any other components that may be required to produce a video signal output.

Thus using miniature, chip-mounted lenses, it is possible to fabricate multiple independent cameras on single VLSI chips. These cameras accurately lie in the same plane and are rotationally in substantially perfect alignment. Any remaining alignment errors are primarily translational and can be easily corrected by retiming the readout control sequences.

Further preferred features and advantages of the present invention will appear from the following detailed description by way of example of a preferred embodiment illustrated with reference to the accompanying drawings in which:

Fig. 1 is a schematic perspective view of a composite image colour video camera of the invention with three individual camera units;

Figs 2(a) to (d) are schematic views showing 4 different 2-D arrangements of the three camera elements relative to each other;

Fig. 3 is a schematic illustration of the optical performance of a camera of the invention;

Fig. 4 is a block circuit diagram of one possible electronic architecture for a camera of the invention;

Fig. 5 is a sectional elevation of another camera of the invention; and

Fig. 6 is a schematic perspective view of a spacer support element suitable for use in the camera of Fig. 5.

Fig.1 shows a miniature colour video camera system C having three cameras 1 each comprising a lens system 2 mounted directly onto the image sensing surface 3 of a respective solid state image capture device in the form of an integrated circuit image array sensor 4. The sensors 4 are formed as separate sections of a single monolithic VLSI microchip 5 mounted in a suitable housing CH containing a power supply 6 and provided with a video signal output interface 7.

In more detail the lens system 2 comprises a generally hemispherical lens 8 having a radius of curvature of the order of 0.85 mm, and a cylindrical spacer element 9 of substantially larger diameter (ca. 1.7mm) and a length of 1.59 mm, with an aperture stop 10 therebetween. The aperture stop 10 is of metal e.g. steel alloy with a thickness of 0.15 mm and an iris diameter of 0.8 mm providing an effective lens aperture of f2.0. The aperture opening is filled with clear epoxy resin 11 which has a refractive index substantially similar to that of the lens 8 and secures the lens 8 and spacer 9 to each other and to the aperture stop 10. Alternatively an aperture stop of metal or other material could simply be printed onto the spacer or lens e.g. using a photolithographic technique. The R, G, B (red, green and blue) filters 12 for the three respective lenses 8 can also be disposed between the lenses 8 and spacers 9.

The lens 8 is of low dispersion glass (Bk7) having a refractive index n_d of 1.568 and the spacer is of LaK10 glass which has a higher refractive index n_d of 1.7200. This combination produces low image blur and large image size (ca. 1.4mm image height from central axis). The spacer 9 has a length of around 1.59mm. This lens system has an effective depth of field of from 2cms to ∞ with a field of view angle of 90° and has an rms blur of around 5um which is within the unit sensor pixel dimensions thereby providing a reasonably good video signal image output from the video signal output connection 7.

It will be appreciated that various modifications may be made to the above described embodiment without departing from the scope of the present invention. Thus for example the spacer element could be a composite element made up of a plurality of plane components. The lens element could also be composite though this would normally be less preferred due to the significantly increased complexity. The various surfaces of the lens system could moreover be provided with diverse coatings for e.g. reducing undesirable reflections and selective filtration of the incident light rays in generally known manner. Also the R, G, B filters could be mounted on a suitable support in front of the lenses 8 as further described hereinbelow.

Fig. 2 shows some possible alternative layouts for the individual cameras on the single chip. In layout (a) the absolute red-green and blue-green distances are minimised. All of the parallax error is vertical. This may not be optimum for TV applications, as in this case the colour signal is greatly averaged horizontally, but not at all vertically. Layout (b) forces all of the parallax error into the horizontal dimension to take advantage of this. Layout (c) has slightly worse red-green and blue-green parallax than (a), but the red-blue distance is greatly less. Intuitively, this configuration minimises the total parallax error. Layout (3) is as for (c), but pushes most of the r-g, b-g errors into the horizontal axis.

Apart from its substantial simplicity, the colour camera system of the present invention provides two further potential technical advantages over the alternative known approaches. Axial colour aberration causes the focal plane for blue to be slightly closer to the lens, and for red slightly further from the lens, than green. This aberration may actually be an advantage if we design the lens for green light and the blue and red images become slightly defocussed, thereby also blurring the effect of parallax errors. For ordinary glasses, the blue and green images are blurred by around 1 pixel at the geometries used above. If we wish, the 3-lens approach could be adapted to accommodate this aberration by fine-tuning the focal length of each lens. This is impossible with either of the existing single-lens approaches. Transversal colour aberration is a change in magnification factors at different wavelengths. Again it may be possible to correct for this by modifying slightly the red and blue lens geometries.

Fig. 3 shows how the parallax errors between closely adjacent identical cameras can be maintained at or below one pixel for cameras with useful resolutions of several hundred pixels. If the cameras are calibrated to provide image alignment for objects at infinity, then an object at distance O (on the optical axis of one camera for simplicity) is imaged at an offset of e pixels in the second camera. It is obvious that the parallax error is greatest for objects which are closest to the cameras. To help in generalising the result, suppose we wish to image objects at minimum range Omm with a field of view of 2ø degrees and sensor resolution of P pixels. Then by trigonometry, the parallax error e, in pixels, is:-

$$e = P.s \ / \ 0.2 \tan (\varnothing) \text{ pixels} \qquad (1)$$

where s is the camera separation. This important result is independent of the focal length of the lens and shows that the error is reduced by lowering s, lengthening O or increasing ø.

Actually, e in equation (1) is the parallax error for a close object with reference to objects at infinity. Advantageously we might calibrate the cameras to provide alignment for objects at some mid range and achieve a balance of errors between close and far objects. It is easy to show that if we calibrate on objects at range 2xO then the worst case parallax error for near and far objects is:-

$$e' = P.s \ / \ 0.4 \tan (\varnothing) \text{ pixels} \qquad (2)$$

Thus in the case of a colour camera for computer vision using a typical standard resolution of e.g. 240 x 320 pixels, then if we require a lens with 52° angle-of-view (ø = 26°), horizontal resolution, P, of 320 pixels, minimum range O, of 50cm and we achieve a separation, s, of 3mm, e′ will be slightly less than one pixel. In the case of a low resolution colour camera for video telephones using the QCIF standard (144 x 178 pixels), this device must work at close range, say down to 25cm. Say we use the same angle of view, 52°, and achieve a lens separation of 1.5mm (allowing for the smaller array), then the error in this case will be approximately 0.5 pixels. In both cases, the parallax error is less than one pixel and therefore of the same order as aliasing and interpolation errors in single-chip colour mosaic cameras and accordingly reasonably acceptable.

Conversely it will be appreciated that where it is desired to capture stereo images the parallax error and should be greater than 1. It may be seen from the above equations that parallax error increases for small object ranges or distances O and for larger camera separations s. With a sensor size P of 240 pixels, camera pitch separation s of 3.1.mm, and field of view of 45° (2ø), stereo image capture is feasible at ranges up to 1.8 metres. This range can be increased simply by corresponding increases in the camera separation s.

The electronic architecture of the camera is substantially independent of the optical and sensor arrangement described above. Nevertheless, the availability of synchronous, continuous RGB colour signals minimises the required image processing. This results in a simpler and lower-cost electronic implementation than for colour-mosaic cameras. Furthermore, the electronic requirements may be implemented feasibly on the same chip as the sensors where CMOS sensor technology such as that described in our earlier Patent Publication No. WO91/04498, is used.

Figure 4 gives an overview of one possible electronic architecture. Three colour arrays are driven in similar style to a monochrome array, except that the timing of vertical and horizontal control on the red and blue arrays is altered by offset values loaded into the controller from an off-chip PROM (Programmable Read Only Memory) Chip which has been programmed with the offset calibration data.

Automatic Exposure Control (AEC) is provided as for monochrome arrays. The same exposure value is used for all three arrays. Exposure is monitored via the green output alone, or possibly by deriving luminance from a combination of RGB signals.

Automatic Gain Control (AGC) is also provided as for monochrome arrays, but in this case, independent gains can be set for each colour. AGC provides three functions:-

(i) automatic peak level calibration using a saturated reference line in the Green array. In normal exposure circumstances, the gain of the green channel is fixed at this value and this forms a nominal gain for the red and blue channels also.

(ii) dynamic colour balancing to correct for variations in the colour of ambient light by adjusting the blue and red gains according to colour analysis of the three channels.

(iii) automatic gain of weak images in low light conditions when AEC has reached maximum exposure. At first dynamic colour balancing can continue, but at the lowest light levels (maximum gain), flexibility may be lost. This is characteristic of many colour cameras.

The resulting balanced colour signals are passed through a colour correction matrix, which performs weighted mixing of the three colours (see e.g. D'Luna and Parulski, IEEE JSSC Vol. 26, No. 5, pp. 727-737) followed by gamma correction on each colour. Both these functions are standard requirements for colour cameras intended for TV displays as they correct for known colour and amplitude nonlinearities in the display tubes.

The matrix may be implemented in analogue CMOS, either by using switched capacitors or switched current-sources. Either of these can accommodate alterable coefficients in digital form, or they could be fixed in layout. In the former case the coefficients may be stored in the PROM already provided for offset calibration and this may afford a useful degree of flexibility.

The gamma corrected RGB signals are then passed to an appropriate encoder for whatever standard is required. Suitable encoders for e.g. NTS/PAL are readily available.

In Figs. 5 and 6 like parts corresponding to those in Fig. 1 are indicated by like reference numerals. The Figs. 5 and 6 illustrate an alternative embodiment in which is used a lens system 20 supported at its edges 21 on spacer elements 22 with a substantial free air space 23 between the three lenses 8 of the lens system and the respective sensors 4. In more detail, the lens system 20 is a one-piece moulding from a suitable optical grade plastics material and incorporating an array of three lens portions 8 joined edge-to-edge. It will be appreciated that this affords a particularly economic and convenient form of production whilst at the same time simplyfying assembly of the camera insofar as the three lenses for the R, G, B components of the image, are automatically aligned with each other. Nevertheless it will be understood that, if desired, the lenses 8 could be manufactured from other materials e.g. glass or any other suitable optical material and/or as discrete individual components. Moreover each lens could comprise more than one element e.g. a doublet. The lenses 8 may conveniently be aspheric or spherical or planar at either surface thereof.

As in the first embodiment, the sensors 4 are formed as separate sections of a single monolithic VLSI microchip 5, mounted in a housing CH (only part shown). An optical support sub-housing 24 has various shoulder portions 25-28, for respectively securing the monolithic chip 5 to the housing CH, supporting the lens system 20 on the spacer elements 22 above the chip 5, supporting R, G and B filters 29-31 above the lenses 8, and supporting a protective outer Infra Red filter 32 (conveniently of doped glass e.g. Schott KG3 or BG39). Additional support to the lens system 21 and the filters 29-31 is conveniently provided by spacer walls 33, 34 which have the further advantage of acting as light baffles between the three, R, G, B, cameras 1 to prevent cross-imaging between each lens 8 and the other sensors 4. As shown in Fig. 6 the lower spacer walls 33 may conveniently be formed integrally with the support sub-housing 24.

It will be understood that various modifications may readily be made to the above described embodiment. Thus, for example, the order of the filters 29-31 and 32 may be changed.

CLAIMS

1. An image capture system comprising a solid state image capture device which device comprises an integrated circuit having at least two sensor arrays, each said array having an image sensing surface and a respective lens system associated therewith.

2. A system according to claim 1 in which system at least one of the lens systems is mounted spaced apart from the sensor means with a fluid medium between the lens and the sensor.

3. A system according to claim 1 in which system at least one of the lens systems, comprises a lens in substantially direct contact with a transparent spacer in substantially direct contact with the sensor and extending between said lens and sensor, said lens and spacer having refractive indices and being dimensioned so as to form an image in a plane at or in direct proximity to a rear face of said spacer element remote from said lens element, from an object, whereby in use of the lens system with said lens system mounted substantially directly on the image sensing surface of the image capture device an optical image may be captured thereby.

4. A system according to claim 3 wherein said spacer has a refractive index not less than that of said lens.

5. A system according to any one of claims 1 to 4 wherein at least two said lens systems are formed integrally with each other.

6. A system according to any one of claims 1 to 5 wherein said sensor arrays are photoelectric.

7. A system according to claim 6 wherein each sensor array has a diameter of from 1 to 10mm.

8. A system according to any one of claims 1 to 7 which has a pair of sensor arrays spaced apart so as to provide a stereo image capture system for objects within a predetermined range from the camera.

9. A system according to any one of claims 1 to 7 which has at least three sensor arrays and wherein at least one of the respective lens systems is provided with a wavelength selective filter means, so as to provide a composite image capture system.

10. A system according to claim 9 wherein are provided three sensor arrays and in which the respective lens systems are provided with red, green, and blue filters, whereby substantially full colour composite image capture may be effected.

11. A system according to claim 9 wherein are provided three sensor arrays and in which the respective lens systems are provided with cyan, magenta and yellow filters, whereby substantially full colour composite image capture may be effected.

12. A system according to any one of claims 9 to 11 wherein said sensor arrays are arranged in a linear array.

13. A system according to any one of claims 9 to 11 wherein said sensor arrays are arranged in a close-packed non-linear array.

14. A system according to any one of claims 9 to 13 wherein said sensor arrays are disposed at a pitch spacing of not more than 5mm.

15. A system according to any one of claims 1 to 14 wherein are used wide angle lens systems having a field of view of at least 60°.

16. A video camera having an image capture system according to claim 8 or any of claims 7 to 15 when dependant on claim 6.

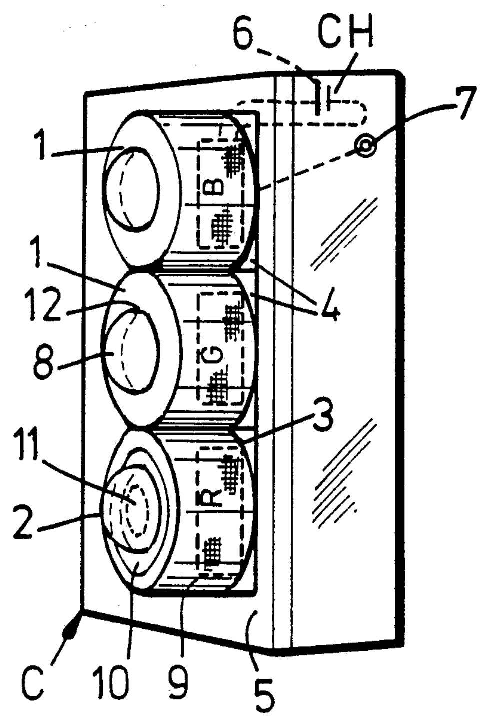


FIG. 1

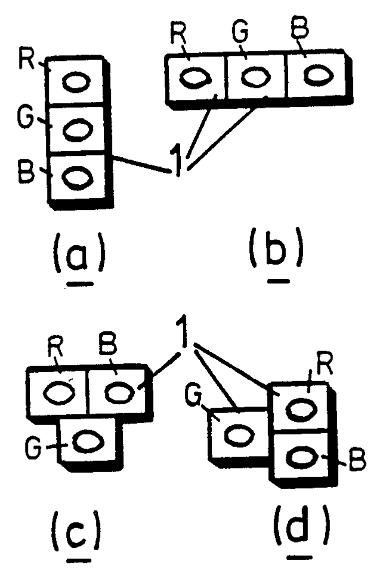


FIG. 2

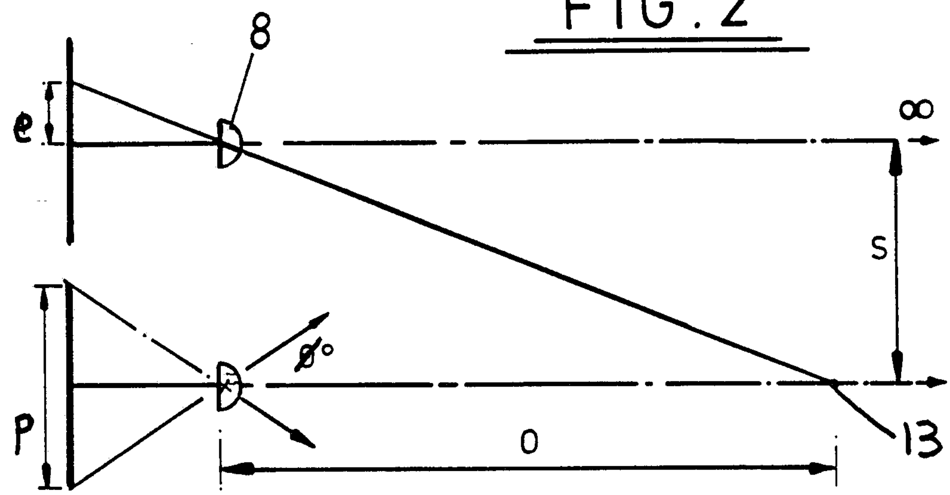


FIG. 3

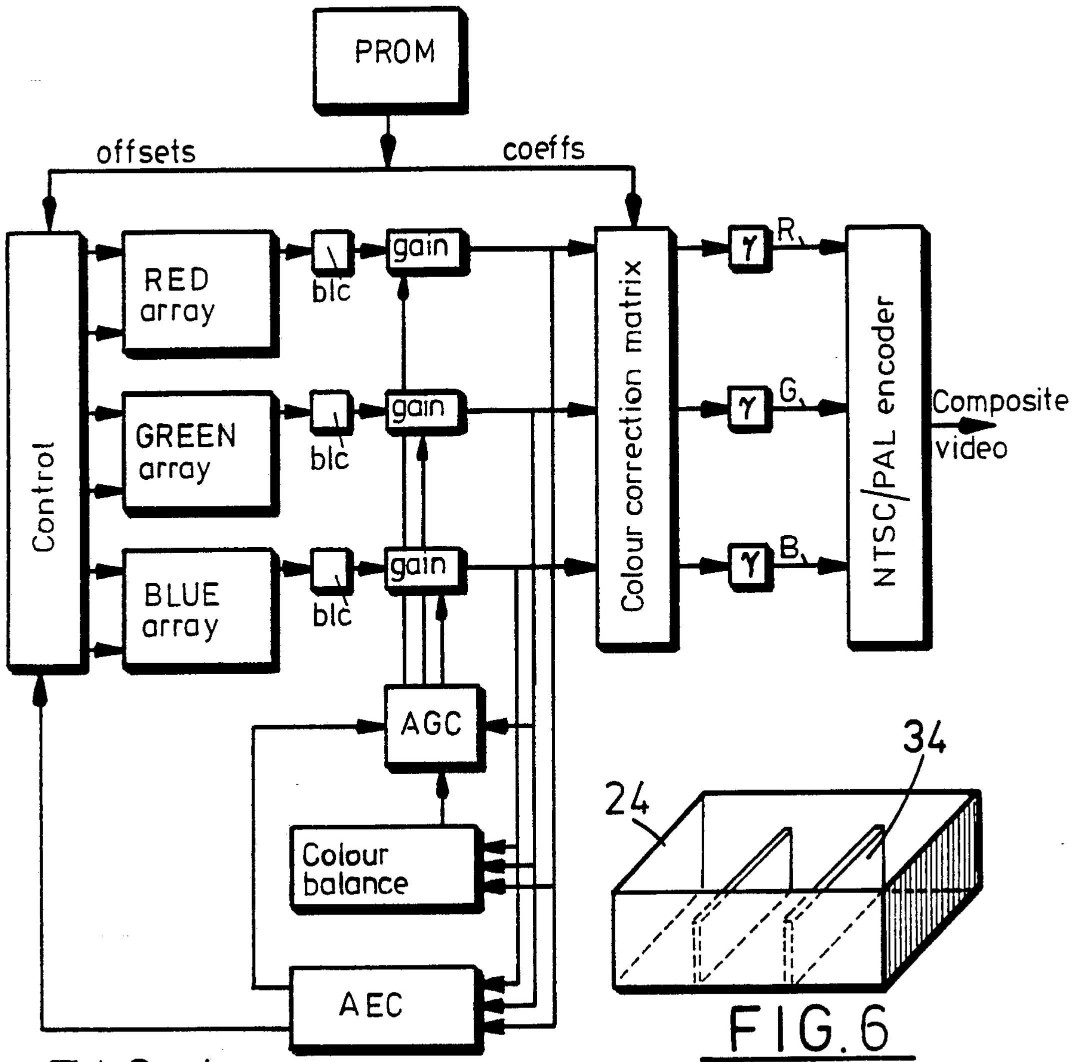


FIG.4

FIG.6

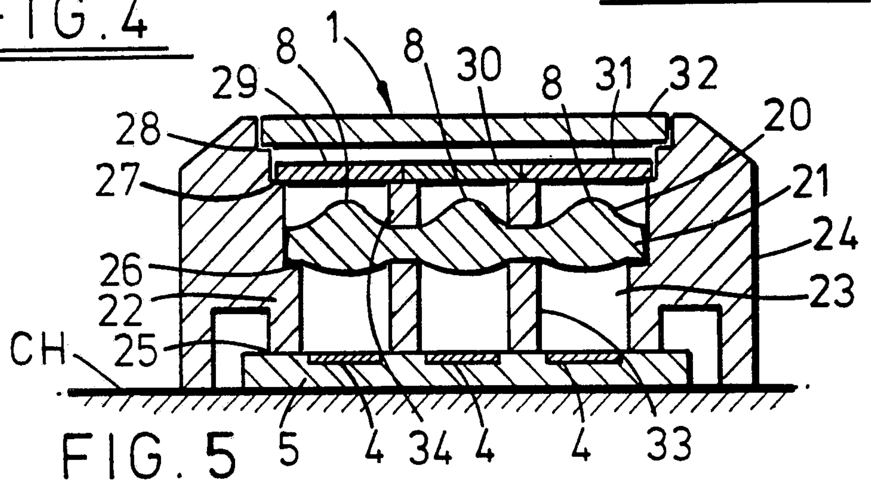


FIG.5

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 92/02260

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 H04N5/335; H04N9/097; H04N5/225

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	H04N

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
Y	GB,A,2 240 444 (PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED) 31 July 1991 see page 3, line 12 - line 26 see page 7, line 10 - line 19 see page 8, line 30 - page 9, line 7 see page 9, line 26 - line 30 see page 14, line 11 - line 25 ---	1,2,3,5, 6
Y	EP,A,0 248 687 (SOCIETE NATIONALE INDUSTRIELLE AEROSPATIALE) 9 December 1987 see column 1, line 46 - line 57 see column 2, line 22 - line 34 ---	1,2,3,5, 6
	-/--	

° Special categories of cited documents : [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

1

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
24 MARCH 1993	01. 04. 93
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	BEQUET T.P.

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category°	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 6, no. 259 (E-149)(1137) 17 December 1982 & JP,A,57 157 683 (CANON K.K) 29 September 1982 see abstract	1
A	PATENT ABSTRACTS OF JAPAN vol. 9, no. 178 (E-330)23 July 1985 & JP,A,60 047 560 (RICOH K.K) 14 March 1985 see abstract	9,10,12, 16
A	EP,A,0 043 721 (XEROX CORPORATION) 13 January 1982 see abstract; figures 1,3	9,10,12, 16
A	PATENT ABSTRACTS OF JAPAN vol. 12, no. 351 (E-660)(3198) 20 September 1988 & JP,A,63 107 389 (TOSCHIBA CORP) 12 May 1988 see abstract	8,14,16
A	PATENT ABSTRACTS OF JAPAN vol. 10, no. 356 (E-459)(2412) 29 November 1986 & JP,A,61 154 390 (TOSHIBA CORP) 14 July 1986 see abstract	16
P,A	WO,A,9 215 036 (VLSI VISION LIMITED) 3 September 1992 cited in the application see page 2, line 11 - page 3, line 16; figure 1	1,2

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

GB 9202260
SA 67353

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 24/03/93
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB-A-2240444	31-07-91	US-A- 5109158	28-04-92
EP-A-0248687	09-12-87	FR-A- 2598273	06-11-87
		CA-A- 1266523	06-03-90
		JP-A- 62263778	16-11-87
		US-A- 4760451	26-07-88
EP-A-0043721	13-01-82	CA-A- 1175360	02-10-84
		JP-A- 57041071	06-03-82
WO-A-9215036	03-09-92	None	

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

DEVELOPMENTS IN CMOS CAMERA TECHNOLOGY

Ian T Muirhead

Abstract.

This paper gives an overview of developments in CMOS camera technology and sensor related products at VLSI Vision Ltd.

Introduction.

It has been previously reported [1,2] that quality images may be obtained by carefully designed sensors implemented in standard ASIC CMOS processes. This leads to several advantages;

- greatly reduced size through a high level of integration.
- greatly reduced power consumption, and operation from a single 5v rail.
- lower cost than comparable systems constructed with discrete camera technologies.

These advantages are relevant to many applications in vision systems. With this in mind Prof. Denyer of the University of Edinburgh formed VLSI Vision Technology (VVL) in 1990 to exploit the technology. Since that time the company have developed a range of CMOS sensors and imaging products built around them.

Sensor Architecture.[3]

In CMOS sensors each pixel is formed by extending and exposing the source region of a standard MOS transistor to make a photodiode. This can be reset and then isolated within the array under the control of a MOS transistor gate. All pixels in a row are reset together. Once reset, the reverse-biased photodiode converts incident light to a small current, which gradually discharges the gate capacitance. The pixel is then read by opening the gate, thus connecting the photodiode to the MOS transistor drain. In each column of the array, the transistor drains are connected in common and thus only one row of pixels is read at a time. A separate charge-sensing amplifier is used at the head of each column of pixels. This means that the amplifiers operate at the line rate rather than at pixel rate. Outputs from the sense amplifiers are sampled and stored on a row of capacitors, then multiplexed out through an on-chip charge integrator, including a sample-and-hold stage. By using an analogue multiplexer to switch in blanking and synchronisation levels at the appropriate times, it is them relatively easy, for a single-chip CMOS camera to produce the 1V peak-to-peak composite video waveform required by the CCIR standards.

Product and System Development.

An important aspect of the technology is the ability to design image sensors and image processing modules to specific applications. However many imaging problems can be satisfied by a range of standard products. To this end VVL have developed:

- Camera Products. A range of low, medium and high resolution monochrome CMOS image sensors which are available in chip or complete video camera module form. Applications include surveillance, robotic vision, process control, vision toys and video conferencing.

Printed and published by the IEE, Savoy Place, London WC2R 0BL, UK.

Exhibit L

Part No.	Pixels	Output
1070	160 x 160	Digital
1043	320 x 240	EIA/CCIR
1060	756 x 574	EIA/CCIR & Progressive

Table 1. CMOS sensor range.

• *i*mputer. This programmable intelligent camera is designed for machine vision. Potential applications include smart surveillance systems; inspection and process control; automotive and aerospace and telecommunications.

• PC Card Camera. This is the first sub-miniature video camera which can be completely integrated into mobile computers. Stills and real-time motion video clips can be captured instantly into any PC equipped with a PCMCIA 2.1 Type II slot. Applications are wide ranging and include photographic databases, remote conferencing, interactive presentations, document imaging, meter reading, inventory control and many more.

CMOS cameras.

From a user perspective there are essentially four levels of sensor resolution which are of interest. In the 8k to 40k pixel range, a sensor provides a low resolution image at a very low cost. Such a device can find application in vision toys or low tolerance image detection. A reasonable picture can be obtained with pixels in the 40k to 200k range. This would be used when a slightly higher image resolution is required but applications are still cost sensitive, such as budget security and video door entry phones. Professional video applications requires a pixel count in the 200k to 500k range. Beyond this level are primarily a high resolution custom application e.g. scientific, replacement of photographic film.

With CCD technology it is possible to produce a colour image system by coating each pixel with a primary colour dye, red green, or blue. The signal from the chip is decoded and sorted into the three primary colours. A similar process is possible with CMOS image sensors with the added advantage that the algorithm circuitry can placed on the silicon adjacent to the sensor.

The imputer.[3]

The imputer is a completely programmable machine vision system which replaces a camera, frame grabber, processing board and PC/workstation. It is configured as a mother-board into which expansion cards can be plugged as needed. The mother-board contains all the necessary components for most machine-vision applications; image sensor, frame grabber, microprocessor, framestore and external I/O. This is implemented on a board a little larger than a credit card - 100 x 50 mm. A PC is only needed during application development, thereafter the imputer units are programmed and left unsupervised. Even though the imputer forms a complete machine-vision system it is smaller than many CCD cameras alone.

One of the limitations of the device is processing power, which consists of an 8-bit 8032 microcontroller. However, many machine vision applications consist of very simple techniques such as line gauges. Line gauge techniques treat lines of pixels as if they were physical gauges on the object being measured, and take readings accordingly; the imputer motherboard has enough processing power for these applications.

Another apparent limitation of the imputer is the sensor resolution, which is restricted to 256 x 256 pixels. However, if the resolution is doubled in each dimension to 512 x 512 pixels, the amount of image processing is quadrupled. This creates a strong incentive to solve applications using the lower resolution. Higher resolution versions of the imputer are under development. For processing power, there is an optional plug-in coprocessor (based on a Motorola 56002 DSP), giving a 3000 fold speed improvement.

The processor is programmed in C using IDS, the imputer development system, a Windows software package. A full library of machine vision functions is provided, including morphological (shape) filters, transforms, correlators, convolvers, image segmentation, frequency filtering, rotation, reflection and logical operators.

Catagory	Function	Time (mS)
Arithmetic	absolute difference	35
Convolvers	3 x 3 filter	124
Logical	Binary OR	4.2
Threshold	Threshold	24

Table 2. Example of Coprocessor Function Library for full 256 x 256 pixel image. (region of interest can be specified to reduce times)

The CMOS image sensor generates its own pixel clock, making pixel digitisation accurate and allowing an exact correlation between the physical photosensitive silicon area and its digital value in memory. This is important for accuracy in measurement applications. The sensor can be reset to the start of the frame by an external source, so that it can be synchronised to fast-moving objects. Once the image has been captured and analysed, the imputer can interact with its environment using an RS232 interface and eight binary I/Os.

PC Card Camera.

As mentioned previously CMOS cameras are small in size and low in power consumption. This has allowed them to be used in areas which were not previously feasible or were economically unrealistic. On such development is the PC Card Camera. This is a small, palm size, video camera which integrates into mobile computers, where power consumption is a key feature. The camera uses a $^1/_4$" format 320 x 240 pixels x 256 grayscales sensor. The power consumption is 150mA @ V_{cc}5V, 30mA @ V_{pp}12V (active), and 0mA when inactive.

Summary.

CMOS camera technology has moved from a laboratory curiosity to integration in volume consumer products within the space of a few years. Fundamental developments in the basic sensor devices continue to advance the technology. CMOS technology is ideally suited to the integration of imaging sensors and processing leading to powerful and compact integrated machine vision systems among many applications.

Acknowledgement.

Research and development of the *i*mputer was supported by the DTI and SERC. The development of the PC Card Camera was supported by LEEL.

1 Renshaw D., Denyer P.B., Wang G., and Lu M., "ASIC Vision", CICC 90

2 Renshaw D., Denyer P.B., Wang G., and Lu M., "CMOS Image Sensors for Multimedia Applications", Proceedings of the IEEE 1993 Custom Integrated Circuits Conference, San Diego, California, May 9-12, 1993.

3 Vellacott O., "CMOS in camera", IEE Review May 1994.

Title: CMOS light-sensor process makes possible low-cost smart machine-vision systems

Author(s): Peter Fletcher

Source: Electronic Design. 41.12 (June 10, 1993): p29.

Document Type: Article

Full Text:

Using the combination of innovative circuit design and chip layout, a light-sensor technology can now be built with standard CMOS processes. As a result, additional circuit elements can be integrated onto the same chip as the sensing element, creating a more intelligent, low-cost, machine-vision sensor than is possible with other processes. All of the elements needed for "smart electronic vision"--analog light-sensor array, image-processing circuits and memory--can be put on the small-sized chip.

VLSI Vision Ltd. (VVL), Edinburgh, Scotland, claims that the new light sensors are comparable in sensitivity with conventional charge-coupled-device (CCD) image arrays, yet outperform CCDs in terms of noise, dark current, and ease of integration. These characteristics make them suitable for applications ranging from fingerprint recognition to bar-code reading. They can also be used for image-capture circuits in electronic still or movie photography, where integration with algorithm processors can cut chip costs to $5.00.

The VVL programmable smart sensor is based on a 256-by-256-pixel array. Each pixel is represented by a single photodiode made by extending and exposing the source region of a standard MOS transistor. This can be reset and then isolated within the array for reading under the transistor's-gate control.

All of the gates in each row of the array are driven in common. Once reset, the reverse-biased photodiode converts incident light to a small current that gradually discharges the gate capacitance. Reading is achieved by opening the gate and connecting the photodiode to the MOS transistor drain. In the array, the transistor drains are connected in common.

VLSI Vision's product manager Oliver Vellacott explains that while this structure is not uncommon and other researchers have used similar designs, they all have failed to achieve results that match CCD performance. "The problem is that they commonly gate column-lines through an analog multiplexer to a single external charge-sense amplifier," he says. Multiplexing analog charge-sense signals through a single sense amplifier means that the design of the final amplifier is critical. It must work at very high speed and have a very wide dynamic range achieved from a single charge packet in the pixel.

By contrast, the VVL design uses a separate charge-sense amplifier for each column. Using charge-sense amplifiers at the head of each column means their design rules can be relaxed. Individual column-sense amplifiers need not work so quickly, because their activation frequency is equal to the line rate rather than the pixel rate. Furthermore, they're located on the chip, as close as possible to the pixel array.

The design of these amplifiers is constrained only by the need for a wide dynamic range and that they must be no wider than the pitch of the pixel columns. The latter constraint depends on the CMOS process used. Currently, with 1.5-||micro~meter~ CMOS processes, a pixel size of 16 ||micro~meter~ by 16 ||micro~meter~ and column and row pitches of between 10 and 20 ||micro~meter~ are readily achievable, with good yields and performance equal to CCD arrays. Moving to finer-resolution processes opens the door to producing either bigger arrays--VVL is targeting a 512-by-512 array in the next few months--or physically smaller chip sizes. The smaller size would allow a number of arrays to be built onto a common substrate to provide multiple images for color or other processing.

The theoretical dynamic range of the vision sensor circuit, a single-ended charge integrator, is better than 70 dB. The circuit provides a low-impedance 1-V analog representation of the pixel charge and a read time of about 500 ns.

The sense-amplifier output is sampled and stored on a row of capacitors. This information is multiplexed through an on-chip integrator that includes a sample-and-hold stage. By using an analog multiplexer to switch in blanking and synchronization levels at the appropriate times, the chip can provide a 1-V pk-pk composite-video waveform that conforms with International Consultative Committee for Radio (CCIR) and the Electronic Industries Association (EIA) standards.

The array can be scanned serially by adding vertical and horizontal digital shift registers along two edges of the sensor array. These are designed to match the physical row and column pitch of the pixel array. The vertical register successively activates row lines, while the horizontal register controls sequential pixel readout within each line.

Compared with CCD arrays, the array's performance is insensitive to these control waveforms and amplitudes. Digital output is in the form of an 8-bit/pixel data stream with a rate of 50 frames/s, or around 3.3 Mbits/s.

Compensation circuits overcome the early problems of fixed pattern noise derived from threshold variations in the MOS pixel-access transistors (which caused speckles), and mismatches between column sense amplifiers (which caused vertical stripes). Speckles were eliminated by reducing the applied pixel reset voltage to make the actual reset value independent of gate potential and threshold. Implementing an offset compensation phase in the common-sense amplifiers during idle periods, and during frame and line synchronization periods, eliminated the striping effects.

The result is an array that has wide tolerance to temperature and supply-voltage variations. Light sensitivity covers the visible spectrum and extends into the near-infrared region. When powered from 5 V, the array features a light sensitivity of 0.5 lx minimum, saturation of 20 lx, a signal-to-noise ratio of 51 dB, and power consumption of 200 mW. Integration time range is 40,000:1 and dark current, expressed as a fraction of saturation at room temperature and with a 20-ms integration time, is 0.0004.

Adjusting the integration period allows the array's sensitivity to be altered, thus creating a high degree of automatic exposure control. The adjustment is achieved by controlling the duration of reset pulse cycles entered at the top of the vertical shift register. This changes the integration time in steps equal to the line period.

If this signal is also gated with a short-duration pulse, the exposure time can be reduced in steps, equal to the pixel read time, to a minimum of around 500 ns. The result is potential exposure compensation over a 40,000:1 range. This can be automated by monitoring the video output signal, and eliminates the need for mechanical iris control of lenses. In turn, surface-mounted lenses bonded directly to the chip's surface can be used.

VVL integrated a 156-by-100-pixel array light sensor with a bonded-glass lens on one 1.5-||micro~meter~ CMOS chip measuring 5.8 by 4 mm. The result is a complete intruder alarm camera with a 90 |degrees~ field of view on a 40-by-30-mm hybrid circuit. The array was integrated together with timing, control, and driver circuits that could automatically trigger a lamp or flash. The camera is installed with a passive infrared detector. When triggered by an alarm event, it transmits a short video sequence of what it sees to a remote observer.

A second demonstration device uses a 258-by-258-pixel array integrated with image processing and quantization circuits to form a normalized binary image. It also has a 64-cell correlator array that can perform 2 billion operations/s, post-correlation decision hardware, 16 kbits of cache RAM, and 16 kbits of lookup-table ROM. Together with 64 kbits of external RAM and an Intel 8085 microcontroller, the device performed--within one second--all of the image sensing and processing functions necessary to capture and verify a fingerprint against a stored reference print.

In addition, VVL launched a smart image-processor system, called the Imputer, so that users can develop specialized application algorithms as quickly as possible. Measuring 107 by 53 by 24 mm, the Imputer can be incorporated as a unit in a robot-vision or other imaging system, or be used as a development tool. For development, the company came up with a software package that incorporates a compiler for the C programming language. The software runs on an IBM or compatible PC under the Microsoft Windows 3.x operating environment.

The Imputer includes an Intel 8032 processor, 128 kbytes of frame-store RAM, 128 kbytes of flash memory, and a 256-by-256-pixel light sensor array integrated with image-processing logic on a chip measuring 0.5 in. by 0.5 in. Memory can be expanded to 1 Mbyte. There are provisions to install coprocessors such as static-RAM FPGA accelerators. The Imputer can also work with a video generator to produce real-time CCIR/EIA standard video at 50 frames/s using data stored in RAM.

Coprocessor functions available in the C library include interframe difference or sum, edge extraction, morphological filters, thresholding, correlation, convolution, image segmentation, frequency filtering, rotation, reflection, and other logical operations. More specialized functions can also be developed to order.

Communication with either a PC used for development or with external control systems is via an RS-232 serial port. Image-analysis data is made available through two binary inputs requiring 0- and 3-V signals, and six binary outputs each providing signal levels of 0 and 5 V. Binary ports are controllable from software. The hardware supports standard C or CS lens mountings.

The Imputer is available now for |pounds~500 (about $765) each, reducing to |pounds~180 (about $275) for quantities of 1000 or more. Development kits that include the Imputer, development software, a tripod, lenses, and cables cost |pounds~2000 (approximately $3000).

Contact VLSI Vision Ltd., Aviation House, 31 Pinkhill, Edinburgh, EH12 8BD Scotland. Telephone +44(0)31 539 7111.

Abstract:

An inexpensive smart machine-vision system is now possible through light sensor technology that uses a CMOS design based on an innovative merging of circuit design with chip layout. The minute chip contains all the elements that constitutes smart devices such as analog light-sensor array, image manipulation circuits and memory. The light sensors outperform charge-coupled-device image arrays in the aspects of noise, dark current and facility of integration. Scotland-based VLSI Vision Ltd uses the new light sensors in their smart image processing system called the Imputer. The device incorporates an Intel 8032 processor, 128Kbytes of frame-store memory, 128Kbytes of flash memory and a light sensor array coupled with image-processing logic on a 0.5 sq-in chip. It sells for 500 pounds sterling.

US005177606A

United States Patent [19]

Koshizawa

[11] Patent Number: 5,177,606

[45] Date of Patent: Jan. 5, 1993

[54] IMAGE DETECTION SYSTEM FOR A CAR WITH ADJUSTMENT FOR WIPER IMAGE

[75] Inventor: **Toshifumi Koshizawa**, Ebina, Japan

[73] Assignee: **Isuzu Motors Limited**, Tokyo, Japan

[21] Appl. No.: **766,068**

[22] Filed: **Sep. 27, 1991**

[30] **Foreign Application Priority Data**

Sep. 28, 1990 [JP] Japan 2-262661
Sep. 28, 1990 [JP] Japan 2-262662
Sep. 28, 1990 [JP] Japan 2-262663

[51] **Int. Cl.**[5] **H04N 7/18**
[52] **U.S. Cl.** **358/103**; 358/93
[58] **Field of Search** 358/103, 108, 229, 93

[56] **References Cited**

U.S. PATENT DOCUMENTS

5,111,289 5/1992 Lucas et al. 358/103

Primary Examiner—Victor R. Kostak
Attorney, Agent, or Firm—Staas & Halsey

[57] **ABSTRACT**

An image detection system for a car arranged such that only when the drive angle of a wiper of the car resides within a predetermined image pickup angle range or a predetermined image pickup angle range corrected according to the pan angle of a TV camera unit, a change-over switch is controlled to change over to the side of an image storage from which static image data are provided as outputs. Alternatively, it can be arranged such that a masking range the wiper crosses in all of the scanning lines, of an image in front of the wiper, perpendicular to the moving direction of the wiper is determined from a drive angle of the wiper and only the image of the scanning lines for the wiper is masked and substituted by blank data or static update data.

10 Claims, 11 Drawing Sheets

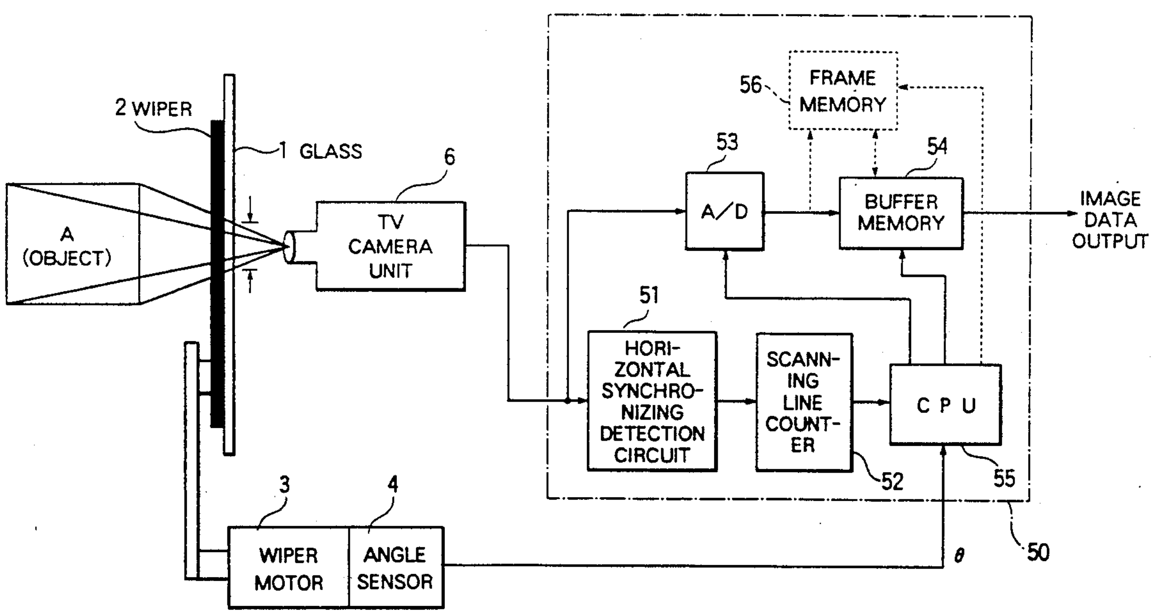


Exhibit N

FIG. 1

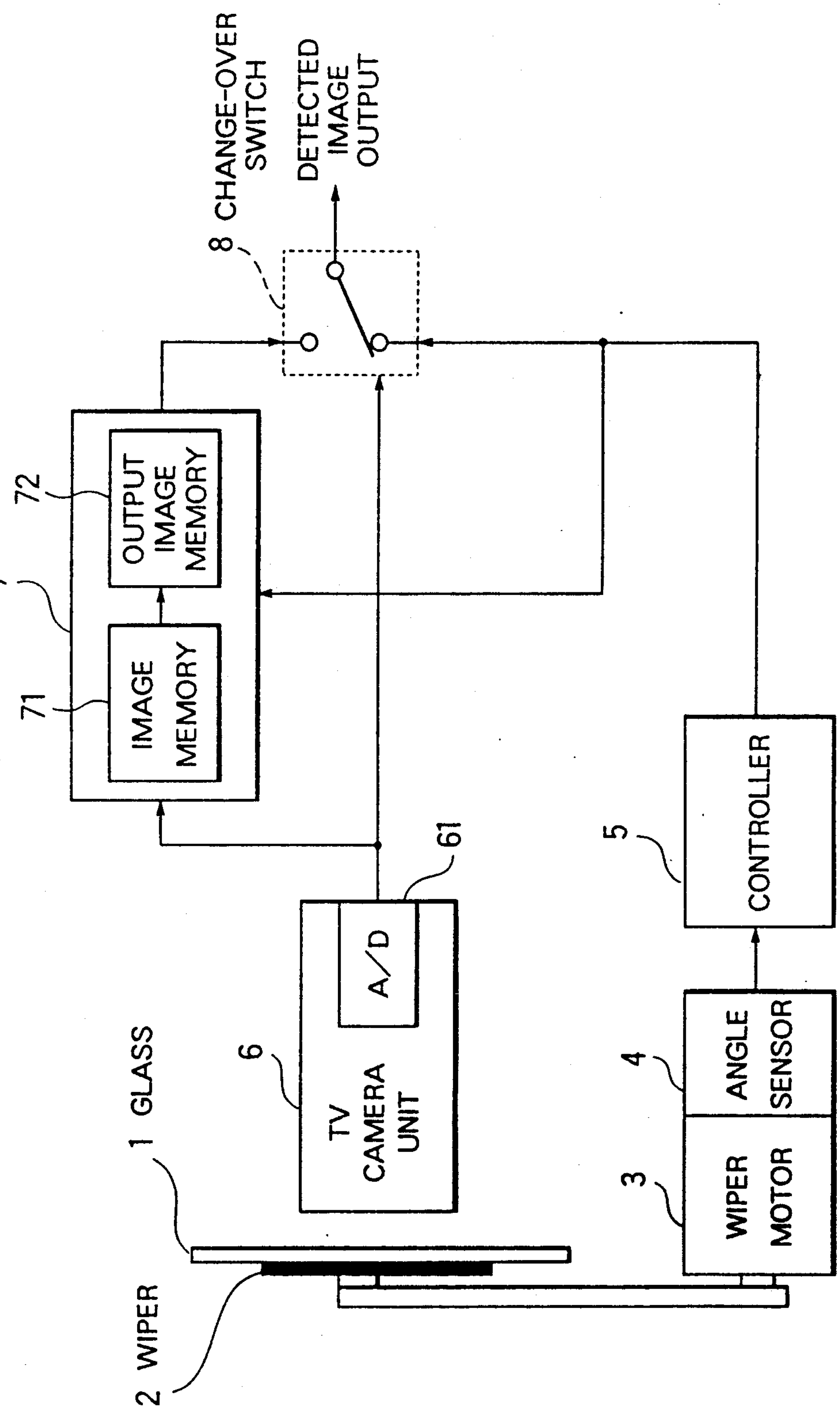
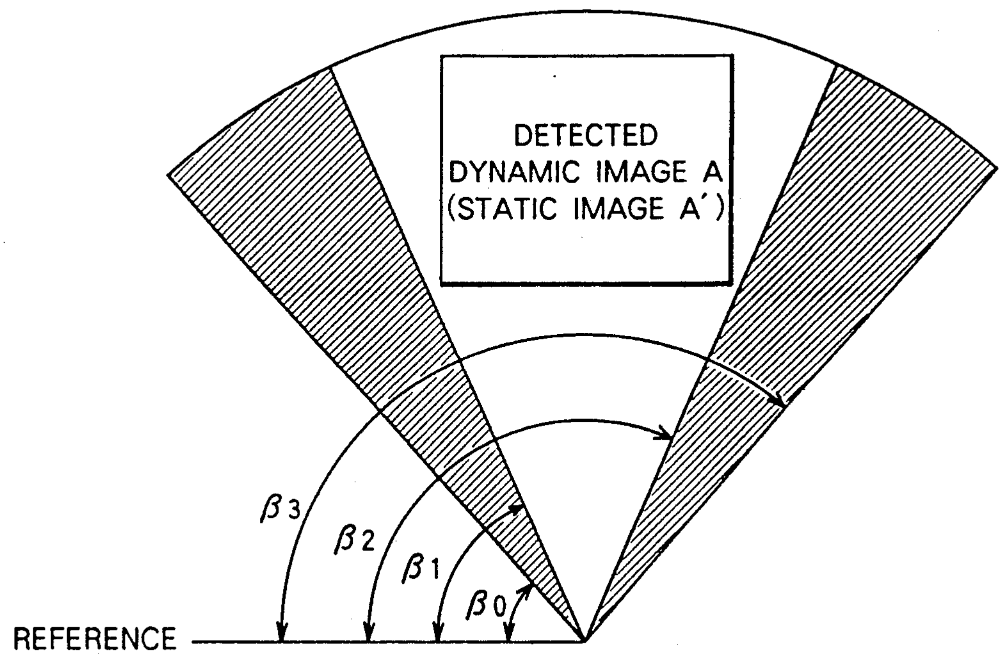

8 CHANGE-OVER SWITCH
DETECTED IMAGE OUTPUT
7
72
OUTPUT IMAGE MEMORY
71
IMAGE MEMORY
61
A/D
6
TV CAMERA UNIT
1 GLASS
2 WIPER
5
CONTROLLER
4
ANGLE SENSOR
3
WIPER MOTOR

FIG. 2



$\beta 0 \sim \beta 3$: WIPER OPERATING ANGLE RANGE

$\beta 1 \sim \beta 2$: ANGLE RANGE INCLUDING A WIPER

FIG. 3

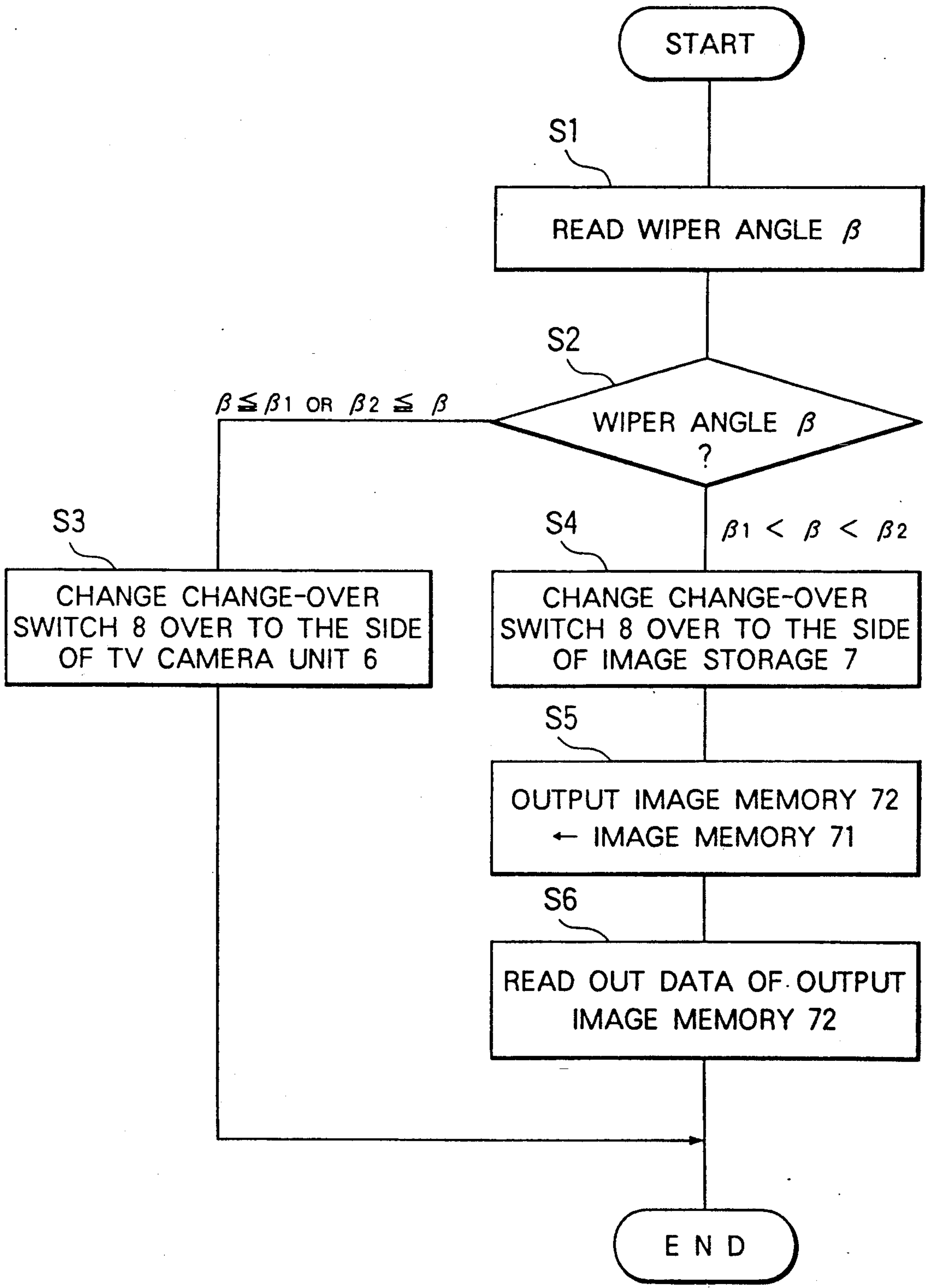
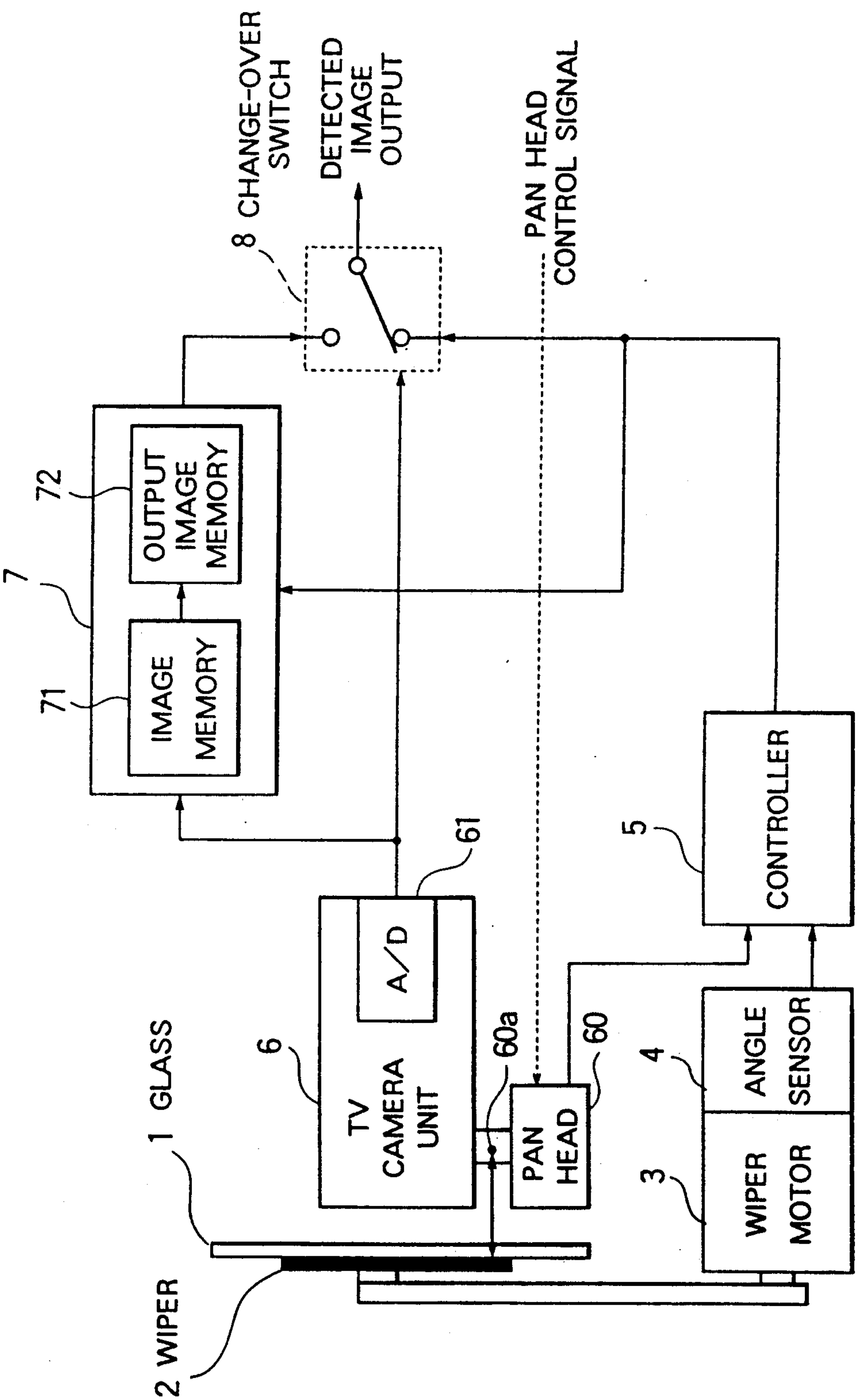

START
S1
READ WIPER ANGLE β
S2
WIPER ANGLE β
?
β≦β1 OR β2 ≦ β
β1 < β < β2
S3
CHANGE CHANGE-OVER SWITCH 8 OVER TO THE SIDE OF TV CAMERA UNIT 6
S4
CHANGE CHANGE-OVER SWITCH 8 OVER TO THE SIDE OF IMAGE STORAGE 7
S5
OUTPUT IMAGE MEMORY 72 ← IMAGE MEMORY 71
S6
READ OUT DATA OF OUTPUT IMAGE MEMORY 72
END

FIG. 4



1 GLASS
2 WIPER
3
WIPER MOTOR
4
ANGLE SENSOR
5
CONTROLLER
6
TV CAMERA UNIT
A/D
61
60a
60
PAN HEAD
PAN HEAD CONTROL SIGNAL
7
71
IMAGE MEMORY
72
OUTPUT IMAGE MEMORY
8 CHANGE-OVER SWITCH
DETECTED IMAGE OUTPUT

FIG. 5

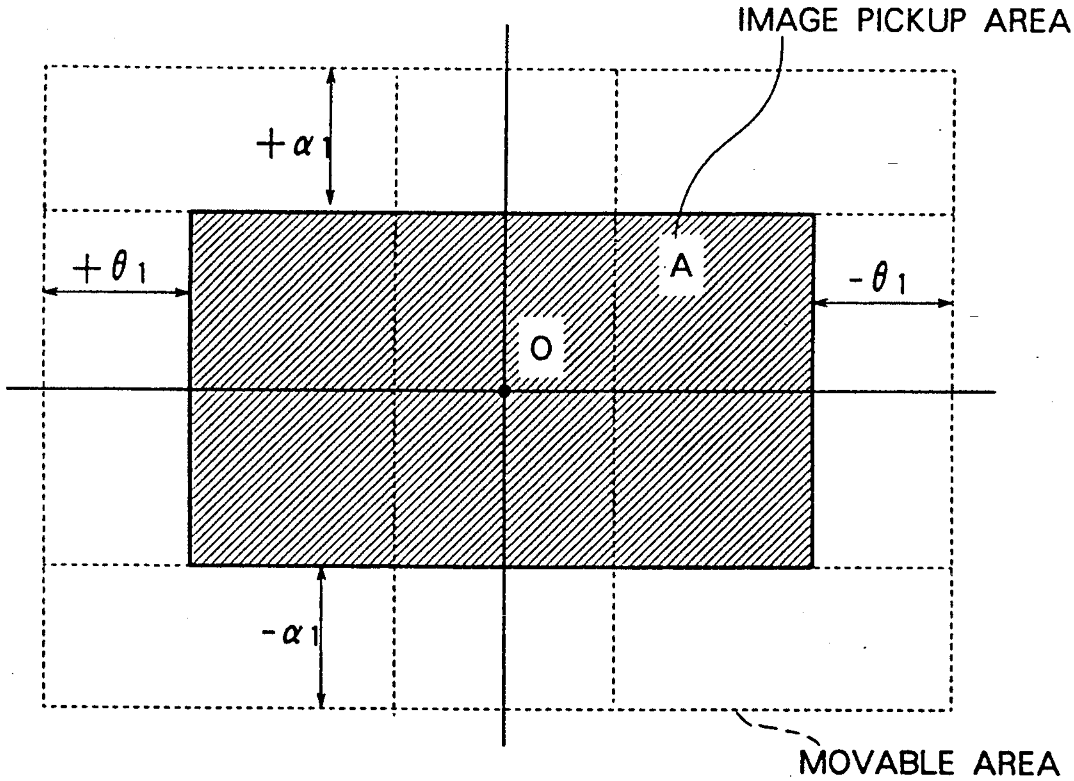


IMAGE PICKUP AREA
$+\alpha_1$
$+\theta_1$
A
$-\theta_1$
O
$-\alpha_1$
MOVABLE AREA

FIG. 6

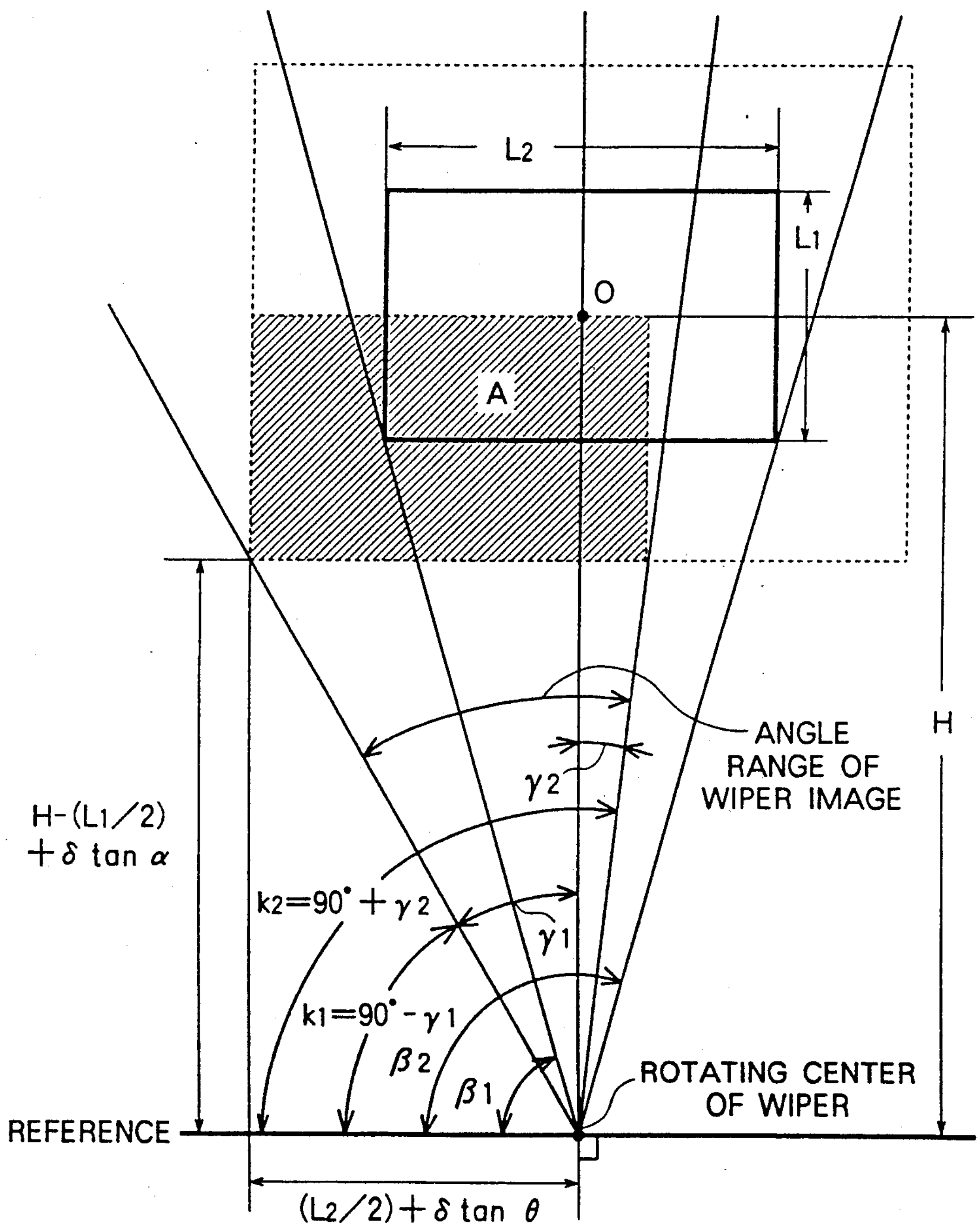

L2
L1
O
A
ANGLE
RANGE OF
WIPER IMAGE
H
γ2
H-(L1/2)
+δ tan α
k2=90°+γ2
γ1
k1=90°-γ1
β2
β1
ROTATING CENTER
OF WIPER
REFERENCE
(L2/2)+δ tan θ

FIG. 7

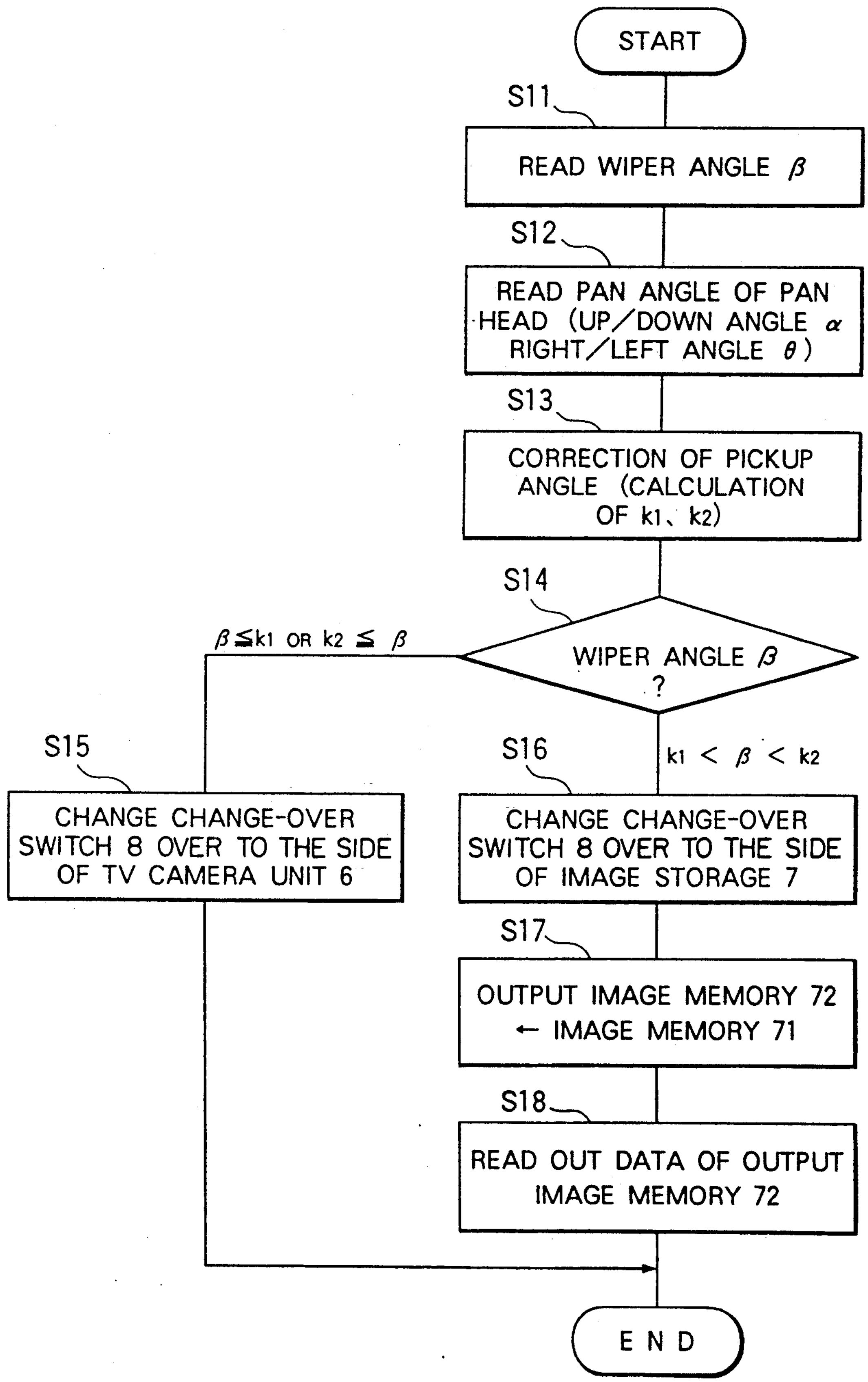

START
S11
READ WIPER ANGLE β
S12
READ PAN ANGLE OF PAN HEAD (UP/DOWN ANGLE α RIGHT/LEFT ANGLE θ)
S13
CORRECTION OF PICKUP ANGLE (CALCULATION OF k1、k2)
S14
WIPER ANGLE β ?
β≦k1 OR k2 ≦ β
k1 < β < k2
S15
CHANGE CHANGE-OVER SWITCH 8 OVER TO THE SIDE OF TV CAMERA UNIT 6
S16
CHANGE CHANGE-OVER SWITCH 8 OVER TO THE SIDE OF IMAGE STORAGE 7
S17
OUTPUT IMAGE MEMORY 72 ← IMAGE MEMORY 71
S18
READ OUT DATA OF OUTPUT IMAGE MEMORY 72
END

FIG. 8

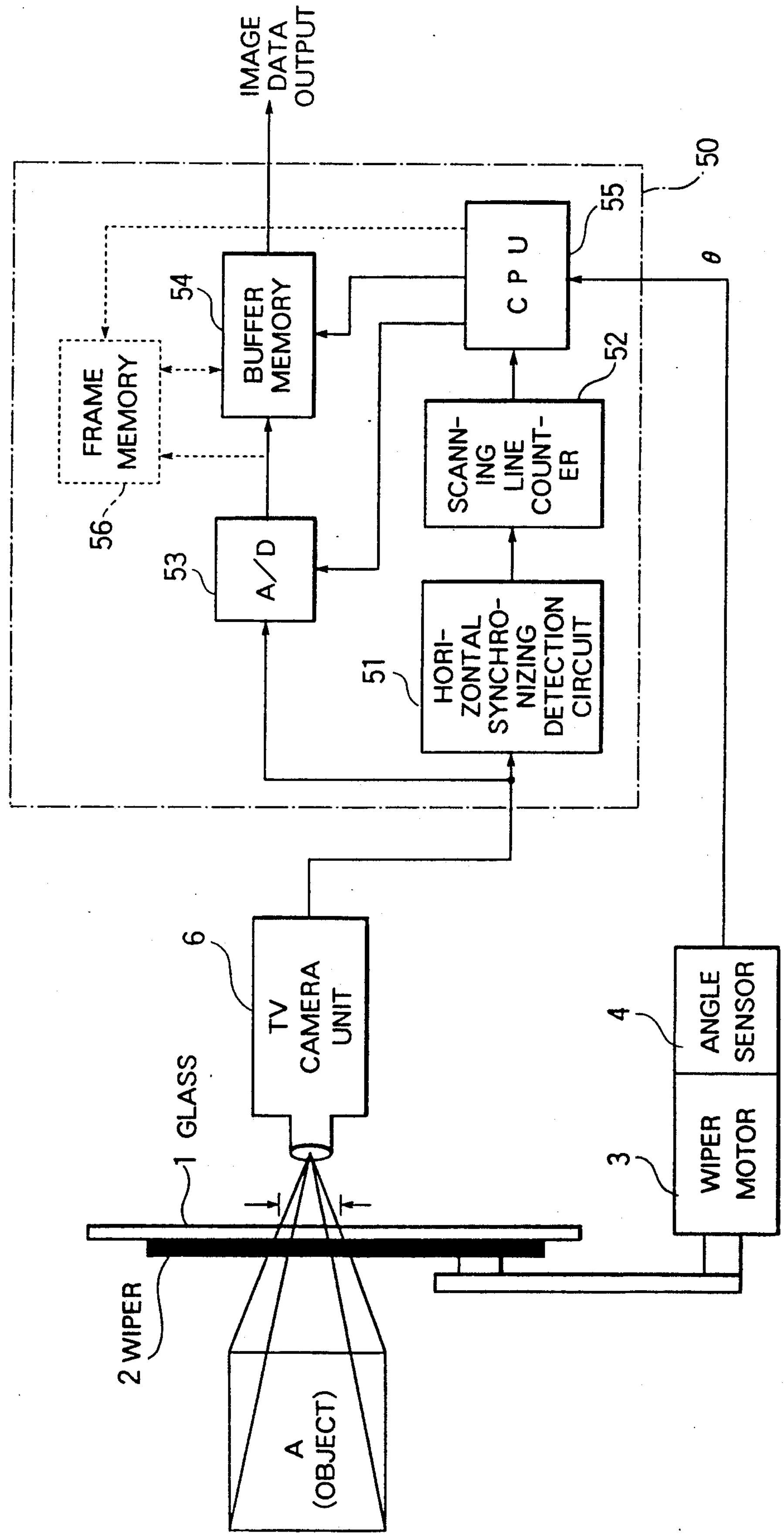


IMAGE DATA OUTPUT
50
55
C P U
θ
54
BUFFER MEMORY
FRAME MEMORY
56
52
SCANN-ING LINE COUNT-ER
53
A/D
51
HORI-ZONTAL SYNCHRO-NIZING DETECTION CIRCUIT
6
TV CAMERA UNIT
1 GLASS
4
ANGLE SENSOR
3
WIPER MOTOR
2 WIPER
A (OBJECT)

FIG. 9

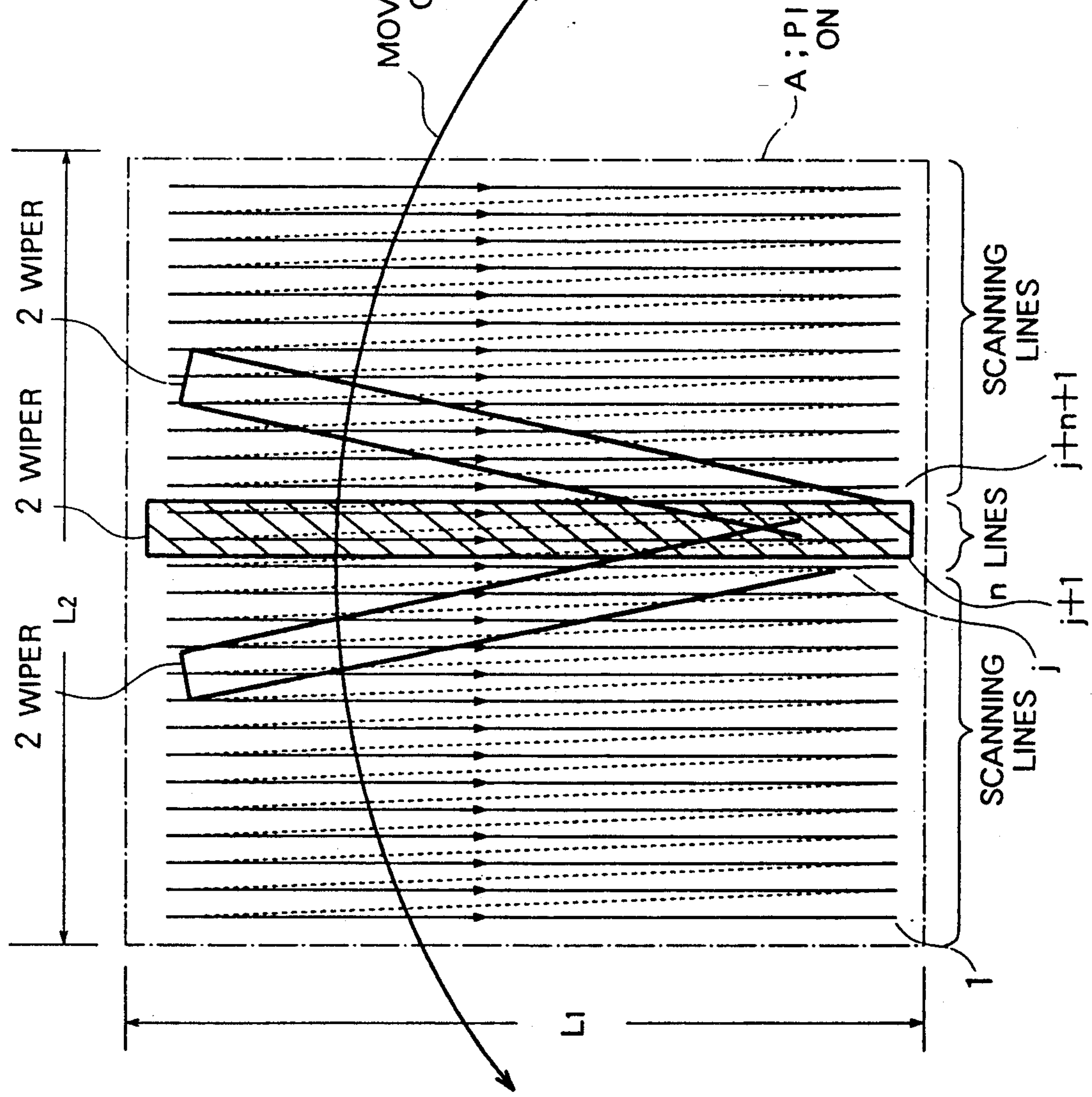

MOVING DIRECTION OF WIPER 2
A ; PICKUP AREA ON GLASS 1
2 WIPER
2 WIPER
2 WIPER
2 WIPER
L2
L1
SCANNING LINES
n LINES
SCANNING LINES
j+n+1
j+1
j
1

FIG. 10

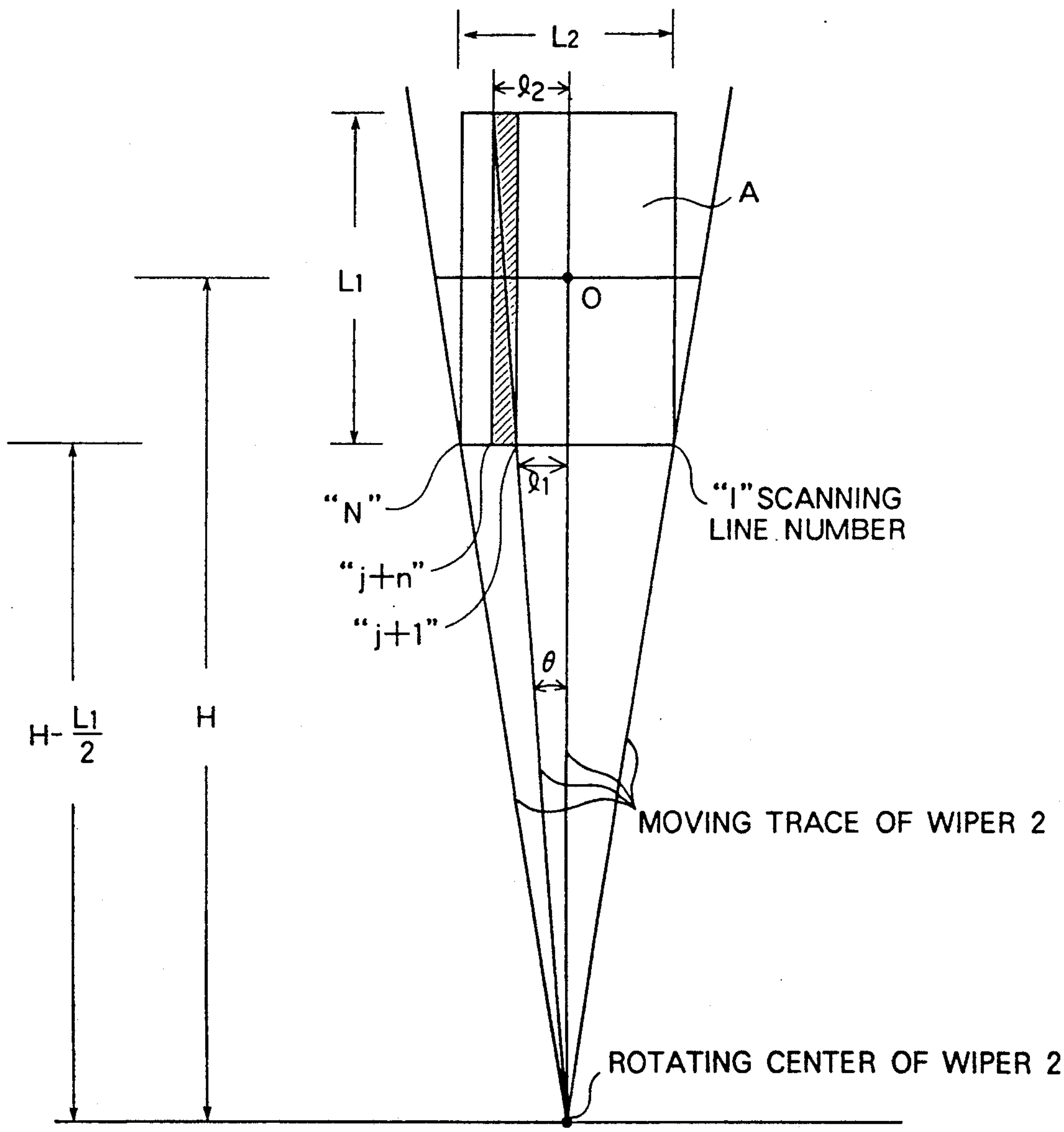

L2
ℓ2
A
L1
O
H
H- L1/2
"N"
ℓ1
"1"SCANNING LINE NUMBER
"j+n"
"j+1"
θ
MOVING TRACE OF WIPER 2
ROTATING CENTER OF WIPER 2

FIG. 11

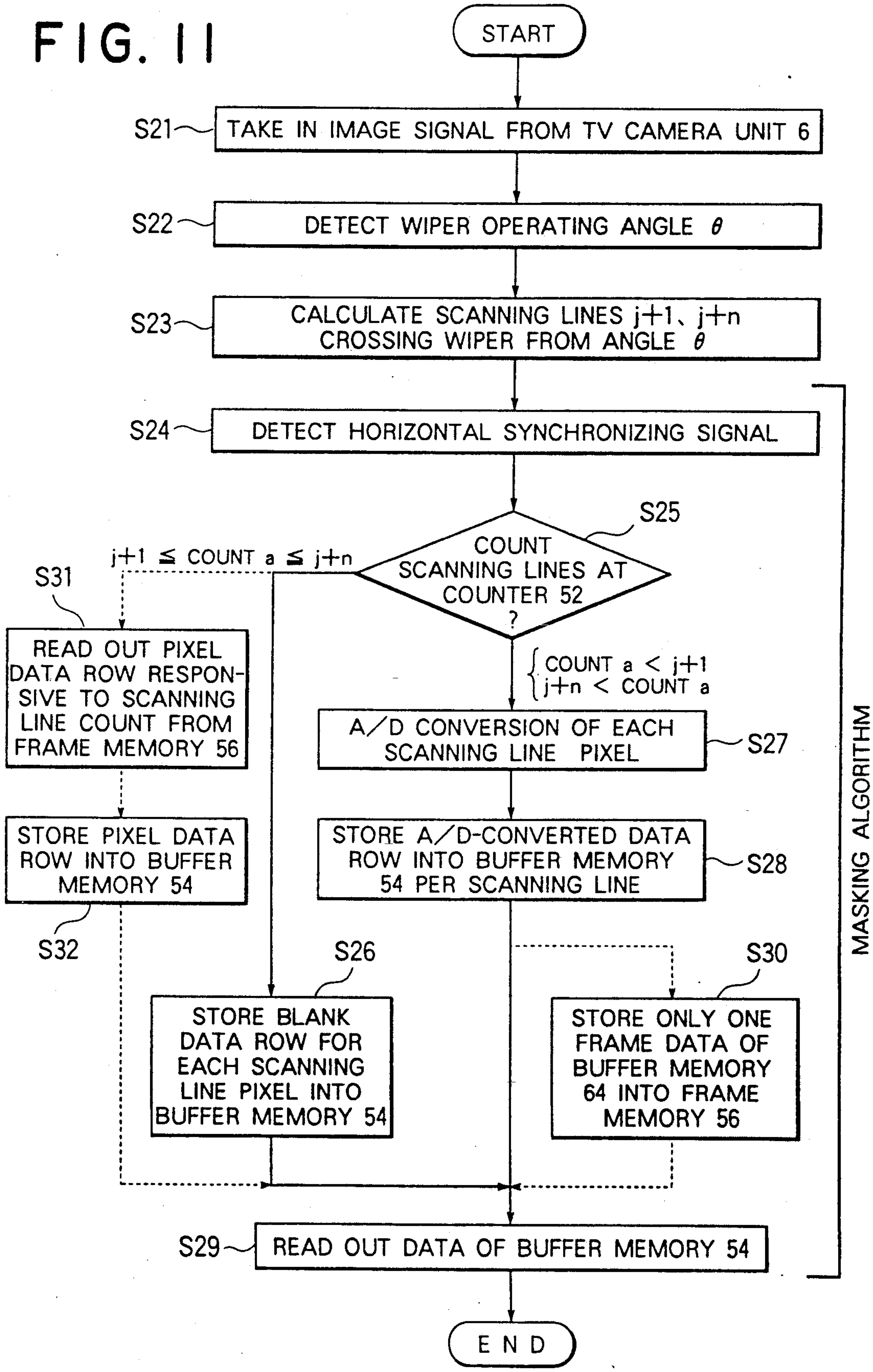

START
S21
TAKE IN IMAGE SIGNAL FROM TV CAMERA UNIT 6
S22
DETECT WIPER OPERATING ANGLE θ
S23
CALCULATE SCANNING LINES j+1、j+n CROSSING WIPER FROM ANGLE θ
S24
DETECT HORIZONTAL SYNCHRONIZING SIGNAL
S25
COUNT SCANNING LINES AT COUNTER 52 ?
j+1 ≦ COUNT a ≦ j+n
COUNT a < j+1
j+n < COUNT a
S31
READ OUT PIXEL DATA ROW RESPONSIVE TO SCANNING LINE COUNT FROM FRAME MEMORY 56
STORE PIXEL DATA ROW INTO BUFFER MEMORY 54
S32
S27
A/D CONVERSION OF EACH SCANNING LINE PIXEL
S28
STORE A/D-CONVERTED DATA ROW INTO BUFFER MEMORY 54 PER SCANNING LINE
S26
STORE BLANK DATA ROW FOR EACH SCANNING LINE PIXEL INTO BUFFER MEMORY 54
S30
STORE ONLY ONE FRAME DATA OF BUFFER MEMORY 64 INTO FRAME MEMORY 56
S29
READ OUT DATA OF BUFFER MEMORY 54
MASKING ALGORITHM
END

IMAGE DETECTION SYSTEM FOR A CAR WITH ADJUSTMENT FOR WIPER IMAGE

BACKGROUND OF THE INVENTION

The present invention relates to an image detection system for a car, and in particular to a system for detecting and processing an image of a TV camera mounted on a car.

Heretofore, a system has been researched and developed in which a TV camera is mounted on a car as image detection means in order to find out obstacles on the road forward or backward of the car wherein an alarm is given to a driver, or a brake or a steering gear is automatically operated.

In this system, the TV camera can be mounted outside a car on one hand or inside a car on the other hand.

In the former case, it is disadvantageous in that raindrops in case of rain etc. or dust adhere to the surface of the lens of the TV camera, thereby disturbing a clear image.

A system for removing raindrops or dust which thus adheres to the surface of the lens of the TV camera is disclosed in Japanese Utility Model Application Laid-open No. 59-25528. However, this system is disadvantageous in that the lens of the TV camera should be rotated every time one desires to clean up raindrops or dust on the lens, which consumes time and disables an image taken meanwhile to be used.

Moreover, in the latter case where the TV camera is mounted outside a car, the TV camera per se is exposed to raindrops or dust so that the function thereof is easily deteriorated, resulting in a short life.

Therefore, the TV camera mounted inside a car is preferably to the one mounted outside a car.

However, it is also disadvantageous in that the image of a wiper for removing raindrops or dust intrudes into images detected by the TV camera. Therefore, if image processing is carried out as it is, a screen including the wiper image has no context with the adjacent screens so that the wiper image is to be detected as the nearest obstacle.

Thus, useless image processing with such an unavailable image, is carried out so as to cause the car erroneously to run in an automatic chase for an object.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide an image detection system for a car, with a TV camera mounted inside a car, which always makes clear images available with no influence of a wiper image.

According to the present invention, image detecting means continuously detects an image in front of a wiper and provides it for image storing-updating means and a change-over means in the form of data.

While the wiper is driven by driving means, when the drive angle of the driving means is detected by drive angle detecting means and provided for controlling means, the controlling means determines whether or not the detected drive angle of the wiper resides within a predetermined image pickup angle of the image detecting means and controls the change-over means to the side of the image storing-updating means. At the same time, the controlling means makes the storing-updating means provide the image as data output.

Thus, as shown in FIG. 2, when the wiper resides outside the predetermined image pickup angle $\beta_1 \sim \beta_2$, the dynamic image A detected by the image detecting means is directly provided as an output without change while when the wiper resides within the predetermined image pickup angle $\beta_1 \sim \beta_2$, the dynamic image is unavailable so that an update image A' having been updated and stored in the image storing-updating means from the image detecting means so far is provided as an static image output.

Accordingly, a clear image is detected with no influence of the wiper image even in rainy weather etc. and useless processing time can be removed in image processing and recognition etc. which are carried out for the provided image data.

According to another aspect of the present invention normally, for the purpose of more accurate recognition (object chase) of visual information around the car with reference to the region of the detected image A as shown in FIG. 2, the image detecting means is panned in the up, down, right and left directions within a certain fixed range by panning means to obtain a desired image.

Since the image detecting means is thus panned up, down, right and left by the panning means, the detected dynamic image A in FIG. 2 is relatively moved according to the panning of the image detecting means even though the moving range of the wiper is fixed.

Therefore, if the panning range of the detected dynamic image A is such as shown by dotted lines in FIG. 5, and in a case where the detected dynamic image A is panned up, down, right and left by the panning means to e.g. the moved lower left position shown by oblique line in FIG. 6, it is found necessary that the wiper angle $\beta_2 - \beta_1$ of invalid image before panning is corrected for the processing to an angle $\gamma_1 + \gamma_2$.

Thereupon, the controlling means takes into account not only the drive angle of the driving means but also the pan angle from the panning means in which comparison and determination are made between the predetermined image pickup angle range corrected from the above noted predetermined image pickup angle range $\beta_1 \sim \beta_2$ according to the pan angle and the drive angle of the driving means, thereby changing the dynamic image over to the dynamic image A'.

Thus, even if the image detecting means is panned up, down, left and right anyhow, a clear image is obtained with no influence of the wiper image and whatever panning position the image detecting means is controlled to chase an object.

According to a further aspect of the present invention, the scanning lines of an image detected by the image detecting means is preset in the direction substantially perpendicular to the moving (cleaning) direction of the wiper as shown in FIG. 9.

Hereupon, since the wiper has a certain width as shown by oblique lines in FIG. 9, image processing means which has taken in the detected image form the image detection means determines the scanning lies in the masking range for the wiper on the basis of the drive angle of the driving means, in a range which crosses the detected image of the wiper in scanning lines forming the detected image.

Then, the image processing means masks only the scanning lines in the masking range and provides them as blank data output and provides as an output the detected image with respect to other scanning lines as it is.

Hereby, when the wiper image intrudes into the image processing means in the form of the detected image, the portion of the scanning lines not crossing the image of the wiper is provided as an output while only the portion of the scanning lines crossing the same is masked and then provided as an output.

Also, according to the present invention, the image processing means, instead of the above masking operation, may substitute update static detected image in a valid portion of scanning lines not including the wiper image for the image of the scanning lines the range to be masked. Therefore, only the image of the scanning lines in the masked range is transplanted with static image data for the corresponding scanning lines among an update detected image not including the wiper image.

Thus, the deterioration of the quality of the image data due to the wiper image in rainy weather etc. is kept to an extremely limited, minimum area in which the wiper can exist on the detected image.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be more apparent to those skilled in the art from the attached drawings in which:

FIG. 1 is a block diagram showing a system arrangement of one embodiment of an image detection system for a car according to the present invention;

FIG. 2 is a principle graph for illustration of the relationship between an operating angle of a wiper and a detected image in the present invention;

FIG. 3 is a flow chart showing the processing algorithm of a controller used in FIG. 1;

FIG. 4 is a block diagram of a system arrangement of another embodiment of an image detection system for a car according to the present invention;

FIG. 5 is a graph for the illustration of a movable area of an image pickup area of a TV camera unit at the time of panning in the embodiment in FIG. 4;

FIG. 6 is a principle graph showing the relationship between an operating angle of a wiper and a movable image pickup area when the TV camera unit is panned in the embodiment in FIG. 4;

FIG. 7 is a flow chart showing the processing algorithm of a controller used in the embodiment in FIG. 4;

FIG. 8 is a block diagram showing a system arrangement of a further embodiment of an image detection system for a car according to the present invention;

FIG. 9 is a graph for the illustration of the relationship between the image of a wiper and scanning lines of a TV camera unit in the embodiment in FIG. 8;

FIG. 10 is a principle graph for the illustration of a method for determining a scanning line range to be masked in the embodiment in FIG. 8; and,

FIG. 11 is a flow chart showing the masking algorithm of the embodiment in FIG. 8.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a block diagram illustrating the arrangement of one embodiment of a distance measuring equipment according to the present invention, in which a non-reflecting protective glass 1 forms a front window (or a rear window under some circumstances) of a car (not shown), a wiper 2 is provided outside the protective glass 1 to clean up raindrops or dust which adheres to the protective glass 1, a wiper motor 3 is connected to the wiper 2 and serves as means for driving the wiper 2, and an angle sensor 4 is provided for detecting a drive angle of the wiper motor 3.

A controller 5 is connected to the angle sensor 4 and serves as change-over controlling means to generate a control signal on the basis of the output signal of the angle sensor 4. A TV camera unit 6 is provided to detect an image in front of the wiper 2 and includes an A/D (Analog/Digital) converter which converts the detected image into digital data. An image storage 7 which includes an image memory 71 and an output image memory 72 is connected to the TV camera unit 6 and serves as means for updating and storing (hereinafter abbreviated as storing-updating) the output data of the TV camera unit 6. A change-over switch 8 is connected to the TV camera unit 6 and the image storage 7, and changes the image storage 7 over to the TV camera unit 6. The image storage 7 and the change-over switch 8 are under control of the controller 5.

Next, the operation of the above embodiment will be described with reference to FIG. 2 and FIG. 3 showing the processing algorithm of the controller 5.

The TV camera unit 6 detect an image A (FIG. 2) in front of the wiper 2, converts it into digital data at the A/D converter 61 included therein, and continuously delivers the data to the image memory 71 of the image storage 7 as well as the change-over switch 8. At this time, storing the image data from the TV camera unit 6, the image memory 71 is updated by the latest image data.

In this state, the data of the image memory 71 has not yet been transferred to the output image memory 72.

In the meantime, the wiper 2 is being driven by the wiper motor 3 the drive angle β of which is detected by the angle sensor 4 and is read to the controller 5, as shown at Step S1 in FIG. 3.

The controller 5 then determines whether or not the drive angle β resides within a predetermined image pickup angle range $\beta_1 \sim \beta_2$ shown in FIG. 2 of the TV camera unit 6, as shown at Step S2.

As a result of this determination, if it is found that the drive angle β of the wiper 2 resides in the angle range ($\beta_0<\beta\leqq\beta_1$ or $\beta_2<\beta\leqq\beta_3$) shown by oblique lines in FIG. 2, which means that the detected image A is not disturbed by the wiper 2, the controller 5 makes the change-over switch 8 change over to the side of the TV camera unit 6 to provide as an output the detected image data, as shown at Step S3.

If it is found that the drive angle β of the wiper 2 resides in the angle range ($\beta_1<\beta<\beta_2$) other than the oblique line portion in FIG. 2, the detected image A is disturbed by the wiper 2 so that it can not be used as it is. It should be noted that the angle range $\beta_1 \sim \beta_2$ can be preset in the controller 5 so as to correspond with the detected image A as a reference.

Therefore, the controller 5 makes the change-over switch 8 change over to the side of the image storage 7, as shown at Step S4.

Then the controller 5 makes the update image data which is always updated and stored at the image memory 71 of the image storage 7 transfer to the output image memory 72 as shown at Step S5, and makes the data of the output image memory 72 provide as an output through the change-over switch 8 as shown at Step S6.

Thus, when the wiper 2 resides outside the angle range $\beta_1 \sim \beta_2$, the detected image A from the TV camera unit 6 is directly provided as dynamic image data output without change, and when the wiper 2 resides inside the pickup angle range $\beta_1 \sim \beta_2$, the update image A' which has been stored while updated at the image memory **71** is sequentially transferred as a static image to the output image memory **72** for a time interval the wiper **2** takes to pass through the angle range $\beta_1 \sim \beta_2$. Then, the static image data of the output image memory **72** is read out and provided as an output through the change-over switch **8**.

FIG. **4** is a block diagram illustrating the arrangement of another embodiment of an image detection system according to the present invention for the purpose of chasing an object in front of the car by using an image taken by the TV camera unit **6**.

For this purpose, the TV camera unit **6** is mounted on a pan head **60** which serves as panning means for panning the TV camera unit **6** in the up/down and right/left directions and provides as an output an angle signal in the respective directions at the time of panning. So, the controller **5** serving as change-over controlling means generates a control signal for the image storage **7** and the change-over switch **8** by comparing a predetermined image pickup angle range as shown in FIG. **2** of the TV camera unit **6** corrected with the pan angle provided from the pan head **60** with the angle of the wiper **2** detected by the angle sensor **4**. It is to be noted that a control signal shown by dotted line in FIG. **4** is provided for the pan head **60** when a control unit (not shown) finds it necessary to pan the TV camera unit **6** as a result of processing image data from the change-over switch **8**, and that other elements correspond wit the elements shown by the same reference numerals in FIG. **1**.

Next, the operation of the above embodiment in FIG. **4** will be described with reference to FIG. **2** and FIGS. **5** to **7**.

It is now assumed that the TV camera unit **6** supported by the pan head **60** can pan to the maximum angle $\pm\alpha_1$ in the up/down pickup directions and the maximum angle $\pm\theta_1$ in the right/left pickup directions with reference to the origin **0** as shown in FIG. **5**. Namely, a pickup image A, shown by oblique lines, corresponding to the detected dynamic image A in FIG. **2** can move within an area shown by dotted lines.

At this time, the pan head **60** always provides as an output for the controller **5**, by means of a potentiometer or a rotary encoder included therein, the angles of α ($\alpha \leqq \alpha_1$) and θ ($\theta \leqq \theta_1$) respectively in the up/down and right/left directions at the time of panning. It is to be noted that such an angle detection may be carried out by various known techniques.

The TV camera unit **6** on the pan head **60** takes an image A (see FIG. **2**) in front of the wiper **2**, converts it into digital data at the A/D converter **61**, and continuously delivers the data to the image memory **71** of the image storage **7** and the change-over switch **8**.

At this time, storing the image data from the TV camera unit **6**, the image storage **71** is continuously updated by the latest image data. In this state, the data of the image memory **71** has not yet been transferred to the output image memory **72**.

In the meantime, the wiper **2** is being driven by the wiper motor **3** the drive angle β of which is detected by the angle sensor **4** and is provided for the controller **5**, shown at Step **S11** in the flow chart of the controller **5** in FIG. **7**.

Also, the controller **5** is provided with an up/down angle α and a right/left angle θ which are the pan angles of the TV camera unit **6**, as shown at Step **S12**

From these angles, the controller **5** recognizes the pickup direction of the TV camera unit **6** and correspondingly converts the predetermined angle range $\beta_1 \sim \beta_2$ of the detected dynamic image A shown by oblique lines in FIG. **5** into an angle γ_1 commencing the interference with the wiper **2** and an angle γ_2, terminating the interference of the pickup area A as shown in FIG. **6**, as follows at Step **S13**:

At first, assuming that a distance from the panning axis **60***a* of the pan head **60** to the cleaning face of the wiper is δ, the size of he pickup area A is L_1 long by L_2 wide, and a distance between the rotating axis of the wiper **2** and the origin **0** of the pickup area A is H, the angles γ_1, γ_2 are given by the following equation:

$$\gamma_1 = \tan^{-1}\frac{(L_2/2) + \delta\tan\theta}{H - (L_1/2) + \delta\tan\alpha}$$

$$\gamma_2 = \tan^{-1}\frac{(L_2/2) - \delta\tan\theta}{H - (L_1/2) + \delta\tan\alpha}$$

Therefore, according to the up/down angle α and the right/left angle θ of the pan angle, pickup angles k_1, k_2 are corrected from the reference angle range $\beta_1 \sim \beta_2$ (see FIG. **2**) as follows:

$$k_1 = 90° - \gamma_1$$

$$k_2 = 90° + \gamma_2$$

Namely, in the angle range $k_1 \sim k_2$, the wiper image gets into the pickup area.

It is to be noted that the size L_1, L_2 of the pickup area A can be predetermined by the aforementioned distance δ and the pickup angle of the TV camera unit **6**.

The controller **5** which has thus calculated the corrected angle range $k_1 \sim k_2$ determines whether or not the drive angle β from the angle sensor **4** resides within the corrected angle range $k_1 \sim k_2$ of the TV camera unit **6**, as shown at Step **S14**.

As a result of this determination, if the drive angle β of the wiper **2** resides in the angle range ($\beta \leqq k_1$ or $k_2 \leqq \beta$) shown by oblique lines in FIG. **6**, which means that the detected dynamic image A is not disturbed by the wiper **2**, the controller **5** makes the change-over switch **8** change over tot he side of the TV camera unit **6** to provide as an output the detected image data without changes, as shown at Step **S15**.

On the other hand, if the driven angle β of the wiper **2** resides in the angle range ($k_1 < \beta < k_2$) within the oblique line portion in FIG. **6**, the detected image A is disturbed by the wiper **2** so that it can not be used as it is.

Therefore, the controller **5** makes the change-over switch **8** change over to the side of the image storage **7**, as shown at Step **S16**.

Then, the controller **5** makes the update image data which is always updated and stored at the image memory **71** of the image storage **7** transfer to the output image memory **72**, as shown at Step **S17**, and makes the data of the static image A' of the output image memory **72** provide as an output through the change-over switch **8**, as shown at Step **S18**.

Thus, when the wiper **2** resides outside the predetermined image pickup angle range $k_1 \sim k_2$ corrected according to the pan angle of the TV camera unit **6**, the detected dynamic image A is directly provided as a dynamic image data output without changes, However, when the wiper **2** resides within the pickup angle range $k_1 \sim k_2$, the update static image A' which has been stored while updated at the image memory **71** is sequentially transferred as static image data to the output image memory **72** for a time interval the wiper **2** takes to pass through the pickup angle $k_1 \sim k_2$. Then, the data of the output image memory **72** are read out therefrom and provided as outputs through the change-over switch **8**.

FIG. **8** is a block diagram illustrating the arrangement of a further embodiment of an image detection system according to the present invention for the purpose of substituting predetermined data for the image of the wiper during moving.

For this purpose, an image processing circuit **50** is connected to the TV camera unit **6** and the angle sensor **4** and serves as image processing means which determines the range of scanning lines to be masked with an angle signal from the angle sensor **4** and masks the portion of scanning line in the masked range with respect to an image signal obtained form the TV camera unit **6**.

The image processing circuit **50** is formed of a horizontal synchronizing detection circuit **51** for detecting a horizontal synchronizing signal in the image signal from the TV camera unit **6**, a scanning line counter **52** for counting the scanning line number of the detected image signal based on the horizontal synchronizing signal detected at the horizontal synchronizing detection circuit **51**, an A/D converter **53** for converting pixel signals into the corresponding digital signals between adjacent scanning lines, a buffer memory **54** for storing the output data from the A/D converter **53**, and CPU **55** responsive to the scanning line number from the counter **52** and the wiper angle θ from the angle sensor **4** to control the A/D converter **53** and the buffer memory **54**. It is to be noted that other elements correspond with the elements shown by the same reference numerals in FIGS. **1** and **4**.

Next, the operation of the above embodiment in FIG. **8** will be described with reference to FIGS. **9-11**.

The TV camera unit **6** detects an image A of an object (see FIG. **8**) in front of the wiper **2** and continuously delivers the image signal to the image processing circuit **50**, as shown at Step **S21** in the flow chart of the image processing circuit **50** in FIG. **11**.

On the other hand, the wiper **2** is being electrically driven by the wiper motor **3**, and a signal indicating a drive angle θ of the wiper motor **3** is detected by the angle sensor **4** interlocked with the wiper motor **3** and is then provided for the image processing circuit **50**, as shown at Step **S22**.

It is to be noted that the position of the camera is preset such that the direction of scanning lines of the TV camera unit **6** is perpendicular to the direction of the moving (cleaning) of the wiper **2**, as shown by oblique lines in FIG. **9**.

Then, the image of the wiper **2** during the cleaning operation is detected by the TV camera unit **6**. If the wiper image is positioned at such a position as shown by oblique lines in FIG. **9** and it is assumed that the number of invalid scanning lines which the image of the wiper crosses and forms an image signal is n, the CPU **65** of the image processing circuit **50** calculates scanning line numbers j+1 and j+n in the scanning line range on the basis of the drive angle θ of the wiper **2** detected by the angle sensor **4**, as shown at Step **S23**. It is to be noted that the drive angle at the time when the wiper **2** passes through the image pickup area A shown by a dot-dash line in FIG. **9** is predetermined from the mutual positional relationship of the wiper **2** and the TV camera unit **6** so that the position in the image taken by the TV camera unit **6** where the image of the wiper **2** intrudes, is found from the driven angle θ from the angle sensor **4**.

Hereinafter, the method of calculating the above-noted scanning line number j+1 and j+n form the drive angle of the wiper **2** will be described with reference to FIG. **10**.

In FIG. **10**, assuming that the size of the pickup area is L_1 long and L_2 wide and the distance between the rotational center of the wiper **2** and the origin O of the pickup area A is H, and the horizontal distances l_1, l_2 from the origin O in the range of the scanning lines j+1~j+n (shown by oblique lines which are thought to be crossing the wiper **2**, are given by the respective equations:

$$l_1=\{H-(L_1/2)\}\tan\theta$$

$$l_2=\{H+(L_1/2)\}\tan\theta$$

Namely, if the wide distance L_2 of the pickup area is formed by scanning lines, the position of the scanning lines of the image of the wiper **2** resides between the distances l_1 and l_2.

Accordingly, the scanning line members j+1 and j+n corresponding to the distance range $l_1 \sim l_2$ are given by the following equations because L_2 corresponds to N, l_1 corresponds to j+1, and l_2 corresponds to j+n, respectively:

$$j+1=N\{(\tfrac{1}{2})-(l_1/L_2)\}$$

$$j+n=N\{(\tfrac{1}{2})-(\mathrm{i}l_2/L_2)\}$$

It is to be noted that in practice a margin may be given tot he above j+1 and j+n, taking into account that the wiper **2** has an arm or blade which can be unintentionally moved due to its transformation.

Then, the following masking operation will be carried out with respect to the $j+1_{st}$ scanning line $\sim j+n_{th}$ scanning line to be masked as noted-above among all of the scanning lines forming the image signal provided as an output form the TV camera unit **6**:

First of all, the horizontal synchronizing detection circuit **51** of the image processing circuit **50** detects a horizontal synchronizing signal from the detected image signal of the TV camera unit **6**, as shown at Step **S24**.

Then, the scanning line counter **62** counts the scanning lines from the number of 1 to the maximum N included in the horizontal synchronizing signal as detected and the count is provided for the CPU **65**, which carries out the following processing in the respective cases of the count a being such that $j+1 \leqq a \leqq j+n$, $a<j+1$, or $j+n<a$, as shown at Step **S25**.

At first, in the case where the count a is such that $j+1 \leqq a \leqq j+n$, a row of blank data corresponding to the pixels of the scanning line is stored at the buffer memory **64**, as shown at Step **S26**. It is to be noted that the blank data may be "1" if "0" data are detected for actual wiper images. Other various blank data may also be used if predetermined.

In the case where the count a is such that $a<j+1$ or $j+n<a$, the CPU **65** makes the A/D converter **63** convert the pixel signals into the corresponding digital data in the scanning lines, as shown at Step **S27** and stores the data row into the buffer memory **64** in correspondence with the scanning lines, as shown at Step **S28**.

The CPU **65** sequentially reads the data row for each scanning line out of the buffer memory **64**, as shown at Step **S29**, and provides as image data output for one screen after the masking operation, while the wiper portion gives no rise to processing error because of the blank data disregarded for the following data processing.

It is to be noted that the scanning lines forming the image shown in FIG. **9** are formed of 525 scanning lines (=N scanning lines) according to the NTSC system. In this case, the range of the scanning lines $1\sim j+1$ and $j+n\sim$**525** is provided as valid image region where no image of the wiper **2** is included.

Next, the method of the present invention wherein instead of the scanning line portion as masked in the above masking operation, being given blank data, this portion is substituted by data before masking will be described. It is to be noted that the flow of the processing of this alternative is shown by dotted lines.

The CPU **65** caused each pixel data row for each of the scanning lines after the A/D conversion which have been stored as data in the buffer memory **64**, to be stored in the frame memory **66** for one frame of the screen in the case where the count a is such that $a<j+1$ or $j+n<a$, as shown at Step **S30**. Namely, the pixel data for each of the scanning lines stored in the frame memory **66**, is updated non-masked data.

Therefore, the CPU **65** reads the pixel data row of the scanning lines corresponding to the count of the scanning line counter **62** out of the frame memory **66** in the case where the count a is such that $j+1\leqq a\leqq j+n$, as shown at Step **S31**.

Then, the pixel data row as read out is again stored in the buffer memory **64**, as shown at Step **S32**.

Thereafter, the data of the buffer memory **64** are provided as outputs as aforementioned, as shown at Step **S29**, thereby transplanting the data just before masking into the scanning line portion to be masked.

Thus, the image of the wiper **2** intruding into the detected image is masked and blank-displayed, or substituted by image data from just before the masking operation, whereby a portion displaying no wiper, i.e. non-masked portion is provided as output data out of the buffer memory **64** because it is valid.

While a number of alternatives and modifications have been discussed above, it will be appreciated that the invention encompasses all forms and variations within the scope of the appended claims.

What is claimed is:

1. An image detection system for a car comprising:

means for driving a wiper;

means for detecting a drive angle of said driving means;

means for detecting an image in front of said wiper from the inside of the car and providing it as data output;

means for storing-updating the image data output from said image detecting means;

means for changing the output of said image detecting means over to the output of said storing-updating means;

means for controlling said change-over means to the side of said image storing-updating means only when said drive angle resides in a predetermined image pickup angle range of said image detecting means and for providing, as an output, static image data from said storing-updating means.

2. An image detection system for a car as claimed in claim **1**, wherein said storing-updating means includes an image memory continuously updated by the data output of said imaged detecting means and an output image memory connected to one side of said change-over means and storing and providing as outputs the update image data of said image memory when said change-over means is changed over to the side of said image storage.

3. An image detection system for a car as claimed in claim **1**, wherein said controlling means controls said change-over means to the side of sad image detecting means when said drive angle resides outside the predetermined image pickup angle range and for providing, as an output, dynamic image data from said image detecting means.

4. An image detection system for a car comprising

means for driving a wiper;

means for detecting a drive angle of said driving means;

means for detecting an image in front of said wiper from the inside of the car and providing it as data output;

means for panning said image detecting means up, down, right and left within a predetermined range and for providing, as an output, the pan angle;

means for storing-updating the image data output from said image detecting means;

means for changing the output of said image detection means over to the output of said storing-updating means; and

means for controlling said change-over means tot he side of said image storing-updating means only when said drive angle resides in a predetermined image pickup angle range of said image detecting means which is corrected in response to said drive angle and for providing as an output status image data from said storing-updating means.

5. An image detection system for a car as claimed in claim **4**, wherein said storing-updating means includes an image memory continuously updated by the data output of said image detecting means and an output image memory connected to one side of said change-over means and storing and providing as outputs the update image data of said image memory when said change-over means is changed over to the side of said image storage.

6. An image detection system for a car as claimed in claim **4**, wherein said controlling means controls said change-over means to the side of said image detecting means when said drive angle resides outside the predetermined image pickup angle range and for providing, as an output, dynamic image data from said image detection means.

7. An image detection system for a car comprising:

means for driving a wiper;

means for detecting a drive angle of said driving means;

means for detecting an image in front of said wiper, which is formed of scanning lines perpendicular to the moving direction of said wiper, from the inside of the car; and,

image processing means for calculating, from said drive angle, a masking range said wiper crosses in all of the scanning lines of the image detected by said image detecting means and for masking only the image of the scanning lines in the masking range and providing, as outputs, blank data.

8. An image detection system for a car as claimed in claim 7, wherein said image processing means includes a buffer memory continuously updated by the output of said image detecting means for providing as outputs the updated data, and a frame memory continuously storing the update image data of said buffer memory and transferring the data therein corresponding to the masking range into said buffer memory only when said wiper crosses the masking range.

9. An image detection system for a car comprising:

means for driving a wiper;

means for detecting a drive angle of said driving means;

means for detecting an image in front of said wiper, which is formed of scanning lines perpendicular to the moving direction of said wiper, from the inside of the car; and,

image processing means for calculating, from said drive angle, a masking range said wiper crosses in all of the scanning lines of the image detected by said image detecting means and for masking only the image of the scanning lines in the masking range and providing, as outputs, static image data just before masking.

10. An image detection system for a car as claimed in claim 9, wherein said image processing means includes a buffer memory continuously updated by the output of said image detecting means for providing as outputs the updated data, and a frame memory continuously storing the update image data of said buffer memory and transferring the data therein corresponding to the masking range into said buffer memory only when said wiper crosses the masking range.

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 5,177,606

DATED : JANUARY 5, 1993

INVENTOR(S) : TOSHIFUMI KOSHIZAWA

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Col. 2, line 57, "form" should be --from--;
line 58, "lies" should --lines--.

Col. 5, line 28, "wit" should be --with--.

Col. 6, line 9, "he" should be --the--;
line 44, "tot he" should be --to the--.

Col. 8, line 6, "form" should be --from--;
line 6, "number" should be --numbers--;
line 14, "lines" should be --lines)--;
line 33, "$(il_2/$" should be --$(l_2/$--;
line 36, "tot he"should be --to the--;
line 43, "form" should be --from--.

Col. 10, line 32, "tot he" should be --to the--;
line 37, "providing" should be --providing,--;
line 37, "output" should be --output,--.

Signed and Sealed this

Twenty-eighth Day of December, 1993

Attest:

BRUCE LEHMAN

Attesting Officer — *Commissioner of Patents and Trademarks*