UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

HP INC.

Petitioner,

v.

LARGAN PRECISION CO., LTD.,

Patent Owner.

U.S. Patent No. 8,988,796

Filing Date: December 13, 2013
Issue Date: March 24, 2015

Title: Image Capturing Lens System, Imaging Device and Mobile Terminal

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DECLARATION OF WILLIAM T. PLUMMER, Ph.D.

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EXHIBIT LIST

Exhibit 1001	U.S. Patent No. 8,988,796 ("'796 patent")
Exhibit 1002	File history of the '796 patent
Exhibit 1003	U.S. Patent No. 9,097,860 ("Yu")
Exhibit 1004	File history of Yu
Exhibit 1005	Certified translation of Taiwan Application No. 102131525
Exhibit 1006	U.S. Patent Application Publication No. 2004/0012861 ("Yamaguchi")
Exhibit 1007	Declaration of William T. Plummer, Ph.D.
Exhibit 1008	Code V Introductory User's Guide, Code V 9.7 (October 2006)
Exhibit 1009	OSLO Optics Reference, Version 6.1 (2001)
Exhibit 1010	ZEMAX Optical Design Program User's Guide (August 1, 2006)
Exhibit 1011	U.S. Patent Application Publication No. 2012/0147249 ("Okano")
Exhibit 1012	WO 2013/125248 A1 ("Sugiyama")
Exhibit 1013	Certified translation of WO 2013/125248 A1 ("Sugiyama")
Exhibit 1014	Arthur Cox, A System of Optical Design (1964)
Exhibit 1015	Warren J. Smith, Modern Optical Engineering (3d ed. 2000)
Exhibit 1016	Warren J. Smith, Modern Lens Design (2d ed. 2005)
Exhibit 1017	Warren J. Smith, Modern Optical Engineering (2d ed. 1990)

I. INTRODUCTION

1. I, William T. Plummer, Ph.D. make this declaration on behalf of HP Inc. (“HP”) in connection with HP’s petition for *inter partes* review of U.S. Patent No. 8,988,796 (“’796 patent”) assigned to Largan Precision Co. Ltd.

2. I make this declaration based on my personal knowledge. I am over the age of twenty-one and competent to make this declaration. The statements in this declaration include my opinions, and the bases for those opinions, regarding the ’796 patent.

3. I have been asked by HP to provide my opinion as to whether certain claims of the ’796 patent were disclosed in certain prior art patents that predate the ’796 patent. This declaration contains my opinions and explains how I arrived at those opinions.

4. I am being compensated for my work on this matter at my standard hourly rate of $520 ($260 for travel). My compensation is in no way dependent on the outcome of this *inter partes* review. The opinions expressed in this declaration are my own.

II. QUALIFICATIONS

5. I have been the President of WTP Optics since 2002. WTP Optics provides consulting services relating to the design, engineering, and manufacture of camera optical systems.

6. As set forth below, I have worked in, and taught college-level classes relating to, the field of optics and optical systems including camera optical systems for more than 40 years. A copy of my curriculum vitae, detailing my educational background, professional and teaching experience, patents, and publications is attached hereto as Appendix A.

7. I received my B.A. degree in Physics and Mathematics from the Johns Hopkins University in 1960, and my Ph.D. in Physics from the Johns Hopkins University in 1965. From 1991 to the present, I have been appointed as Senior Lecturer in the Mechanical Engineering Department of the Massachusetts Institute of Technology, and have been a member of various Ph.D. dissertation committees at MIT from 2004 to the present.

8. From 1984 to 1988, I served as Visiting Industry Professor, Electro-Optics Technology Center, Electrical Engineering Department at Tufts University (Medford, Massachusetts), and in 1991-1992, I personally supervised a Ph.D. dissertation on lens design for a Tufts University student.

9. From 1967 to 1969, I served as Assistant Professor, Physics and Astronomy, at the University of Massachusetts (Amherst). At the University of Massachusetts, I taught a course in astronomical optics, including lens design and geometrical and physical optics for graduate students. During that time, I cleaned and overhauled the mechanical and optical systems of the 18" diameter refractive telescope at Amherst College and the 20" diameter reflective telescope at the University of Massachusetts.

10. From 1960 to 1964, I taught an optics laboratory course for graduate students at the Johns Hopkins University concerning light, lenses, lens aberrations, and testing lenses.

11. From 1969 to 2001, I worked at Polaroid Corporation (Cambridge, Massachusetts) on lens design, mechanics, electronics, and engineering. My work included optical design of Polaroid's SX-70 Single Lens Reflex folding camera, OneStep and Sun camera series, Spectra camera, Captiva camera and other Polaroid camera products, and the design and development of the associated manufacturing instrumentation and tooling required for these products.

12. While working at Polaroid, I was appointed Director of Optical Engineering in 1978 and Senior Director / Divisional Vice President in 1997. I directly collaborated with and supervised the work of several lens designers and other professionals. The lens designers included internationally known designers David S. Grey, James G. Baker, and Ellis Betensky, each working for me as a consultant.

13. In 2000, I was elected to the Polaroid Technology Hall of Fame. I am a named inventor on 102 U.S. patents, mostly relating to the design and manufacture of optical components and systems. Many of my patents relate to digital and film cameras. These include U.S. Patent No. 3,836,931, Eye Lens in a Single Lens Reflex Camera Viewfinder for Providing Field Tilt Compensation; U.S. Patent No. 3,902,792, Landscape Lens; U.S. Patent No. 3,904,294, Automatic Lens Testing Apparatus; U.S. Patent No. 4,102,581, Unicell Photoelectric Photometer; U.S. Patent No. 4,105,308, Aspheric Plastic Triplet; U.S. Patent No. 4,157,216, Adaptor for Optically Coupling a Photographic Camera with a Viewing Device; U.S. Patent No. 4,443,067, Zone Focusing Optical System; U.S. Patent No. 4,498,748, Camera for Photographing Scale Models; U.S. Patent No. 4,650,292, Analytic Function Optical Component; U.S. Patent No. 5,260,828, Methods and Means for Reducing Temperature-Induced Variation in Lenses and Lens Devices; U.S. Patent No. 5,327,291, Compact Objective Lens; U.S. Patent No. 6,643,390, Compact Fingerprint Identification System; U.S. Patent No. 7,426,020, System for Print Imaging with Prism Illumination Optics.

14. I have published more than forty articles in professional publications, including Applied Optics and Optics & Photonic News. I have presented more than fifty illustrated optical technical talks before university, scientific, industrial,

government, and commercial groups in several countries. A listing of these patents, publications, and presentations is included in my attached curriculum vitae.

15. I am a Fellow of the Optical Society of America and of the Society of Photo-Optical Instrumentation Engineers, now abbreviated as SPIE. In 1999, I was elected to membership in the National Academy of Engineering in recognition of my contributions to optical science and engineering, and for leadership in high-volume manufacturing of precision optics.

16. I have received numerous awards from the Optical Society of America and other organizations in the optics industry. In 1980, I was awarded the David Richardson Medal for applied optics from the Optical Society of America for my optical and mechanical contributions to the design team, led by Dr. Edwin H. Land, which designed the Polaroid SX-70 Land Camera. In 1997, I was awarded the Robert M. Burley Prize for optical engineering, and the Joseph Fraunhofer Award for optical engineering, for my accomplishments in photographic product design and development, both from the Optical Society of America. In 2006, I received the Steve Benton Memorial Award from the New England Section, O.S.A.

17. After leaving Polaroid in 2001, I was almost immediately contacted by SMaL Camera Technologies for help with a problem obtaining their needed production of a new digital camera lens. I asked whether the problem was with the design or with the manufacture, and learned that both were issues. I introduced SMaL to my

colleagues still at Polaroid and arranged to have a new lens design calculated for their need. The new design comprised four plastic elements of size and complexity similar to those of the ’796 patent. The third and fourth lens elements were strongly aspheric to limit the angle by which light rays hit the digital sensor. By September 2004, the new lens was in production by Asia Optical, in DongGuan, China. But there were minor quality and testing problems. At SMaL’s request, I measured the optical properties of some sample lenses. I then visited Asia Optical, reviewed the design, the manufacturing, and the test procedures with them, and suggested new ways to improve their costs and the quality yield. These suggestions included a method to reduce the design sensitivity to imperfect centering of the two sides of the third lens element, a way to mold the lenses more consistently, and an improvement to the test procedure. Asia Optical thanked me for this help. The SMaL camera was sold commercially under various names, including the Radio Shack Flatfoto, the same size as a credit card, with a collapsed thickness of 7.5 mm.

18. As a result of my experience, I am familiar with the design, operation, and functionality of components of camera optical and mechanical systems.

19. Further details regarding my employment and academic history are included in my curriculum vitae, attached as Appendix A.

III. LEGAL STANDARDS

20. I have been asked to provide my opinion as to whether certain claims of the ’796 patent are anticipated or would have been obvious to a person of ordinary skill in the art at the time of the invention in view of the prior art.

21. I am an engineer by training and profession. The opinions I am expressing in this report involve the application of my knowledge and experience to the evaluation of certain prior art with respect to the ’796 patent. My formal knowledge of patent law is no different than that of any lay person. Therefore, I have requested the attorneys from Maynard Cooper, who represent HP, to provide me with guidance as to the applicable law in this matter. The paragraphs below express my understanding of how I must apply current principles related to patent validity to my analysis.

22. It is my understanding that in determining whether a patent claim is anticipated or obvious in view of the prior art, the Patent Office must apply the *Phillips* standard to construe the claim by giving the claim its ordinary and customary meaning, consistent with the specification and prosecution history.

23. It is my understanding that a claim is anticipated under 35 U.S.C. § 102 if each and every element and limitation of the claim is found either expressly or inherently in a single prior art reference.

24. It is my understanding that a claim is unpatentable under 35 U.S.C. § 103 if the claimed subject matter as a whole would have been obvious to a person of

ordinary skill in the art at the time of the invention. I also understand that an obviousness analysis takes into account the scope and content of the prior art, the differences between the claimed subject matter and the prior art, and the level of ordinary skill in the art at the time of the invention.

25. In determining the scope and content of the prior art, it is my understanding that a reference is considered analogous prior art if it falls within the field of the inventor's endeavor. In addition, a reference is analogous prior art if it is reasonably pertinent to the particular problem with which the inventor was involved. A reference is reasonably pertinent if it logically would have commended itself to an inventor's attention in considering his problem. If a reference relates to the same problem as the claimed invention, that supports use of the reference as prior art in an obviousness analysis.

26. To assess the differences between prior art and the claimed subject matter, it is my understanding that 35 U.S.C. § 103 requires the claimed invention to be considered as a whole. This "as a whole" assessment requires showing that one of ordinary skill in the art at the time of invention, confronted by the same problems as the inventor and with no knowledge of the claimed invention, would have selected the elements from the prior art and combined them in the claimed manner.

27. It is my further understanding that the Supreme Court has recognized several rationales for combining references or modifying a reference to show obviousness of

claimed subject matter. Some of these rationales include: combining prior art elements according to known methods to yield predictable results; simple substitution of one known element for another to obtain predictable results; a predictable use of prior art elements according to their established functions; applying a known technique to a known device (method or product) ready for improvement to yield predictable results; choosing from a finite number of identified, predictable solutions, with a reasonable expectation of success; and some teaching, suggestion, or motivation in the prior art that would have led one of ordinary skill in the art to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed invention.

IV. BASES OF OPINIONS AND MATERIALS CONSIDERED

28. My opinions are based on my review of the ’796 patent (Ex. 1001), the file history of the ’796 patent (Ex. 1002), U.S. Patent No. 9,097,860 (“Yu”) (Ex. 1003), the file history of Yu (Ex. 1004), the certified translation of Taiwan Application No. 102131525 (Ex. 1005), U.S. Patent Application Publication No. 2004/0012861 (“Yamaguchi”) (Ex. 1006), Code V Introductory User’s Guide (Ex. 1008), OSLO Optics Reference (Ex. 1009), ZEMAX Optical Design Program User’s Guide (Ex. 1010), U.S. Patent Application Publication No. 2012/0147249 (“Okano”) (Ex. 1011), the certified translation of WO 2013/125248 A1 (“Sugiyama”) (Ex. 1013), A System of Optical Design by Arthur Cox (Ex. 1014), Modern Optical Engineering

(3d ed. 2000) by Warren J. Smith (Ex. 1015), Modern Lens Design (2d ed. 2005) by Warren J. Smith (Ex. 1016), Modern Optical Engineering (2d ed. 1990) by Warren J. Smith (Ex. 1017), and the documents referenced within the body of this declaration.

V. SUMMARY OF MY OPINIONS

29. In my opinion Yu renders claims 1-11, and 15-25 of the '796 patent obvious.

30. In my opinion Yamaguchi in view of Yu renders claims 1-11, 15-16, and 19-24 of the '796 patent obvious.

VI. U.S. PATENT NO. 8,988,796

A. Overview

31. U.S. Patent No. 8,988,796 ("'796 patent") is titled "Image Capturing Lens System, Imaging Device and Mobile Terminal." Ex. 1001, [54].

32. The '796 patent "relates to a compact image capturing lens system applicable to a mobile terminal." Ex. 1001, 1:14-16. The '796 patent recites that demand driven by "the popularity of mobile terminals having camera functionalities" and reductions in "the pixel size of sensors" has increased demand for smaller optical systems. Ex. 1001, 1:18-25. The '796 patent asserts that it discloses a lens system that in an improvement over "conventional compact optical systems provid[ing] a four-element lens structure." Ex. 1001, 1:34-41.

33. The ’796 patent’s lens system comprises four lens elements. Ex. 1001, 1:45-48. The lens system is described with reference to the object-side (to the left of the lens system) and image-side (to the right of the lens system). In order from the object side to the image side, the lens system comprises the first, second, third, and fourth lens elements. Ex. 1001, 1:45-48. The first lens element 110, second lens element 120, third lens element 130, and fourth lens element 140 are shown in the Fig. 1A’s illustration of a first embodiment. Ex. 1001, 7:10-11, 7:17-23.

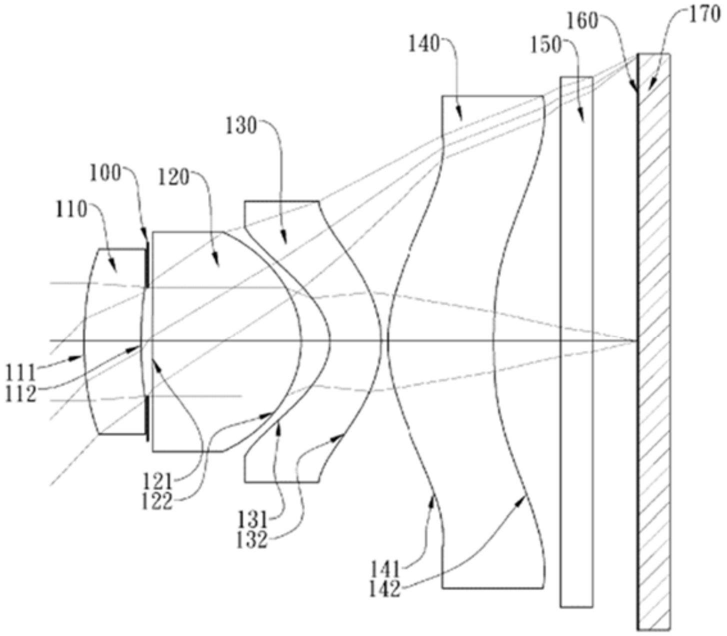


Fig. 1A

34. One property of lenses is their refractive power. Lenses can have positive or negative refractive power. A lens with positive refractive power causes light entering the lens to converge upon its central axis and is thicker near its central axis. A lens with negative refractive power causes light entering the lens to spread

through a wider angle and is thinner near its central axis. One way the ’796 patent describes its lens system is based on the refractive power of the individual lens elements. The ’796 patent discloses that “[t]he first lens element has refractive power”; it is positive in eight embodiments (1st, 2nd, 3rd, 6th, 7th, 8th, 9th, 10th) and negative in two embodiments (4th, 5th). Ex. 1001, 1:48-49, 7:24-28, 10:65-11:2, 14:4-8, 16:23-27, 18:36-40, 20:38-42, 22:38-42, 24:38-42, 26:38-42, 28:37-41. The ’796 patent discloses that the second lens element has positive refractive power, and the third lens element has negative refractive power. Ex. 1001, 1:49-54. The ’796 patent discloses that the fourth lens element has refractive power, which is positive in all ten embodiments. Ex. 1001, 1:54-59, 7:39-43, 11:13-12:3, 14:21-25, 16:39-43, 18:52-56, 20:53-57, 22:53-57, 24:53-57, 26:53-57, 28:52-56.

35. Another property of lenses is the shape of their surfaces. A lens has two surfaces, an object-side surface (on the left) and an image-side surface (on the right). A lens surface can be convex or concave. A convex surface protrudes outward, and a concave surface protrudes inward. By convention, this property is defined by the shape of the lens surface near its central axis, i.e., “in the paraxial region” in the language of the ’796 patent. The ’796 patent discloses that certain lens surfaces have a particular shape in all of its embodiments, i.e., the second lens element “has a convex image-side surface,” the third lens element “has a concave object-side surface” and “a convex image-side surface,” and the fourth lens element “has a

concave image-side surface." Ex. 1001, 1:48-59. In the '796 patent's Fig. 1A, it is easy to see the concave object-side surface (131) and the convex image-side surface (132) of the third lens element (130).

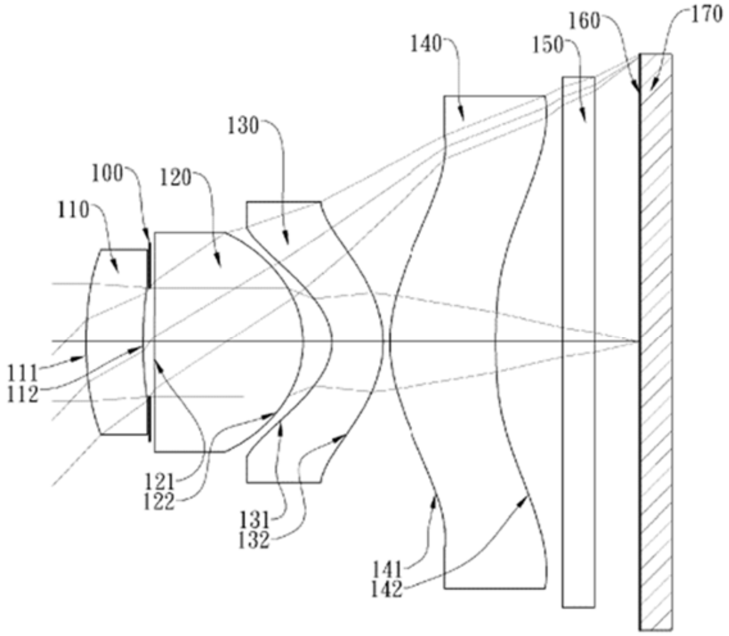


Fig. 1A

36. The concave or convex shape of a lens surface can be identified from other information disclosed in the '796 patent. For each embodiment, the '796 patent provides a table of "detailed optical data." *E.g.*, Ex. 1001, 9:5-6. Table 1 for the first embodiment is reproduced below. The first column in this table identifies the surface number. As indicated by the associated labels, some surfaces are lenses, while others indicate the object (Surface No. 0), aperture stop (Surface No. 3), IR-cut filter (Surface No. 10), or image (Surface No. 12). The numbering scheme begins with the object (Surface No. 0) and increases from left to right (object-side to

image-side), ending with the image (Surface No. 12). In the second column, the curvature radius of a surface is listed. For the non-lens surfaces (0, 3, 10-12), “Plano” denotes a flat surface. Each lens surface (1-2, 4-9) has an associated curvature radius defined in millimeters.

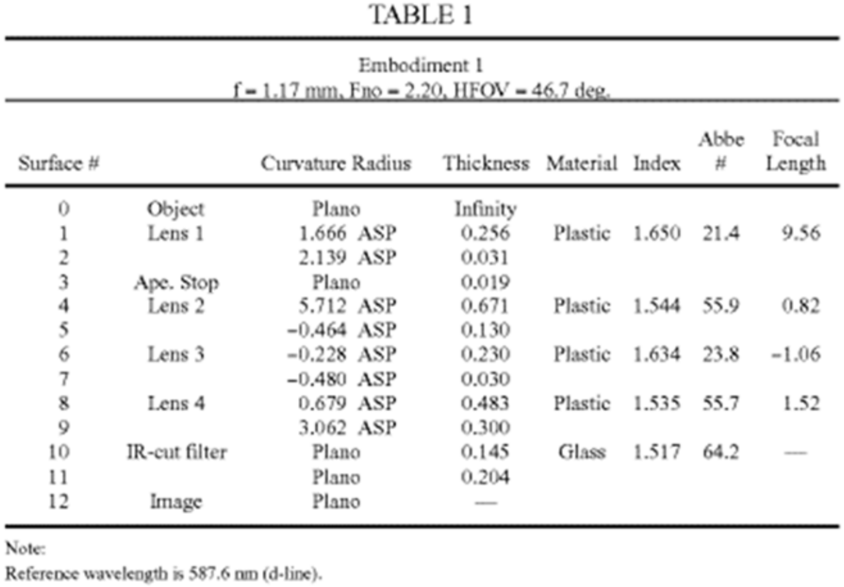


TABLE 1

Embodiment 1
f = 1.17 mm, Fno = 2.20, HFOV = 46.7 deg.

Surface #		Curvature Radius	Thickness	Material	Index	Abbe #	Focal Length
0	Object	Plano	Infinity				
1	Lens 1	1.666 ASP	0.256	Plastic	1.650	21.4	9.56
2		2.139 ASP	0.031				
3	Ape. Stop	Plano	0.019				
4	Lens 2	5.712 ASP	0.671	Plastic	1.544	55.9	0.82
5		−0.464 ASP	0.130				
6	Lens 3	−0.228 ASP	0.230	Plastic	1.634	23.8	−1.06
7		−0.480 ASP	0.030				
8	Lens 4	0.679 ASP	0.483	Plastic	1.535	55.7	1.52
9		3.062 ASP	0.300				
10	IR-cut filter	Plano	0.145	Glass	1.517	64.2	—
11		Plano	0.204				
12	Image	Plano	—				

Note:
Reference wavelength is 587.6 nm (d-line).

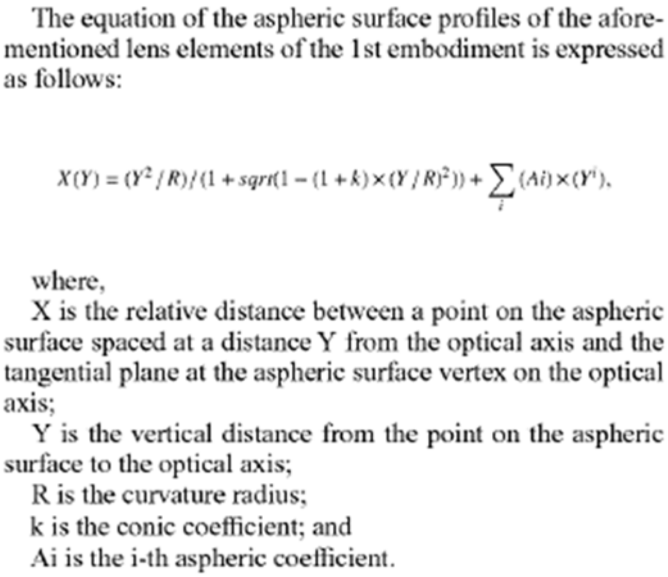
37. A radius is positive if its center is to the right of the surface, and it is negative if its center is to the left of the surface. For an object-side (left) surface of a lens, this means that a positive radius denotes a convex surface that protrudes outward to the left, and it means that a negative radius denotes a concave surface that protrudes inward to the right. For an image-side (right) surface of a lens, this means that a positive radius denotes a concave surface that protrudes inward to the left, and it means that a negative radius denotes a convex surface protrudes outward to the right.

38. As discussed above, the ’796 patent discloses that the third lens element 130 has a concave object-side surface 131 and a convex image-side surface 132. Ex. 1001, 1:51-54. In Table 1, the radius of curvature for both of these surfaces is negative. The radius of the object-side surface 131 (Surface No. 6) is -0.228 mm, and the radius of the image-side surface 132 (Surface No. 7) is -0.480 mm. Ex. 1001, Table 1. Table 1 confirms the text of the ’796 specification because, as explained above, a negative radius denotes a concave object-side surface and a convex image-side surface.

39. Other values specified in the optical-data tables for the ’796 patent’s embodiments include thickness, material, Abbe number, and focal length. *E.g.*, Ex. 1001, Table 1. The thickness for a lens surface specifies either the thickness of the lens at its center from the object-side to the image-side if specified for the object-side surface, or the distance from the image-side surface of a lens to the next surface. For example, the third lens in Table 1 comprises object-side surface 6 and image-side surface 7. Ex. 1001, Table 1. The thickness of 0.230 mm for surface 6 means the third lens is 0.230 mm thick at the center, and the thickness of 0.030 mm for surface 7 means that there is a space of 0.030 mm from the center of the image-side surface of the third lens to the object-side surface of the fourth lens (Surface No. 8). Ex. 1001, Table 1. The 0.019 mm thickness of the aperture stop (Surface No. 3) in Table 1 denotes the space between the aperture stop and the object-side surface of

the second lens (Surface No. 4). Ex. 1001, Table 1. The material column indicates if a lens is made of glass or plastic; the index column provides the refractive index for a lens, which describes how fast light travels through the material; the Abbe number is a measure of how the material's refractive index changes with the wavelength of light; and the focal length is a measure of how strongly the lens converges (positive focal length) or diverges (negative focal length) light.

40. The '796 patent also describes certain lenses as being aspheric. A spherical lens has a surface that has the shape of the surface of a sphere; an aspherical lens is non-spherical, having a surface with a more general shape with its height and curvature changing with distance from the optical axis. Such a surface gives a lens designer more options for producing a sharp image. The '796 patent includes the following "equation of the aspheric surface profiles" and includes a table for each embodiment showing "the aspheric surface data," which, along with the curvature radius defines the shape of the lens surface:



The equation of the aspheric surface profiles of the aforementioned lens elements of the 1st embodiment is expressed as follows:

$$X(Y) = (Y^2/R)/(1 + sqrt(1 - (1 + k) \times (Y/R)^2)) + \sum_i (Ai) \times (Y^i),$$

where,

X is the relative distance between a point on the aspheric surface spaced at a distance Y from the optical axis and the tangential plane at the aspheric surface vertex on the optical axis;

Y is the vertical distance from the point on the aspheric surface to the optical axis;

R is the curvature radius;

k is the conic coefficient; and

Ai is the i-th aspheric coefficient.

Ex. 1001, 7:52-8:2, Tables 2, 4, 6, 8, 10, 12, 14, 16, 18, 20.

B. File History

41. U.S. Patent Application No. 14/105,811, which issued as the ’796 patent, was filed on December 13, 2013. Ex. 1001, [21], [22]; Ex. 1002, 1. The ’796 patent asserts a claim of priority to Taiwan Application No. 102139029 filed in Taiwan on October 29, 2013. Ex. 1001, 1:6-8; Ex. 1002, 4.

42. The twenty-six claims in U.S. Patent Application No. 14/105,811 where allowed in the initial office action dated January 27, 2015. Ex. 1002, 210-14. The Examiner provided little explanation of the reasons for allowance. The Examiner stated: “Regarding claims 1, 15 and 21, the prior art fails to satisfy the conditions as claimed.” Ex. 1002, 213. The Examiner also stated: “The prior art taken either singly or in combination fails to anticipate or fairly suggest the limitations of the

independent claims, in such a manner that a rejection under 35 USC 102 or 103 would be improper." Ex. 1002, 103.

VII. TECHNOLOGY BACKGROUND & THE STATE OF THE ART

43. The earliest claimed priority date of the '796 patent is October 29, 2013. By that time, the art of lens design and manufacture was well advanced. The first kind of lens that comes to mind is the popular magnifying glass, usually with a handle attached. A magnifying glass has positive refractive power. This means that light incident on it is caused to converge and may make some kind of image. On a sunny day, that image can be hot enough to burn a leaf or paper. When a ray of light enters the glass (or clear plastic) of a lens, it changes direction according to a well-known relation known as Snel's Law of refraction, dating from the 17th century. The change in direction can be calculated easily because the ratio of the sines of the ray angle entering the glass and the angle continuing through it is determined by the refractive index of the glass, usually named N. This refractive index changes with wavelength, or color of the light, in a way that depends on the kind of glass (or plastic). The amount of change is specified by the Abbe number, commonly called V. Because of the law of refraction, the passage of light through a lens can be calculated accurately from its geometry.

44. A magnifying glass has "positive" refractive power, and is usually made with both of its surfaces convex, so that the lens is thicker at its center. But other shapes

are possible, such as one side being convex, and the other side flat or even slightly concave. A lens designer uses these alternate shapes in perfecting the design for some purposes, and would call the use of these other shapes “bending.” The figure below from Jenkins & White, Fundamentals of Optics (attached as Appendix B), illustrates bending.

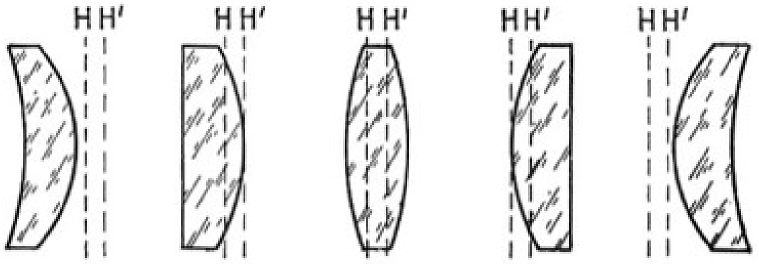


FIG. 5B. Illustrating the variation of the positions of the primary and secondary principal planes, as a thick lens of a given focal length is subject to “bending.”

45. A lens of negative refractive power is thinnest at its center. It may be concave on both sides, or concave on one side but flat on the other, or may have one concave side and one weaker convex side. Again, this range is called “bending.” When viewed through a lens with negative refractive power, distant objects will appear shrunken.

46. As well as making printed material look larger, a magnifying glass can be used to make an image of a distant subject, such as a window or a lamp, onto a piece of paper, just as a photographic camera would make an image on film. That image would be recognizable, but would have poor quality because of various kinds of

aberration, or blurring. The art of the lens designer is to make a lens that can produce a clear image on the paper, or on photographic film, or on an electronic sensor. Such a lens is more complicated than the magnifying glass. The designer normally makes that improvement by assembling two or more individual lens elements of different materials and shapes.

47. Lens designers recognize five fundamental monochromatic "Seidel" aberrations and two fundamental chromatic aberrations. The monochromatic aberrations are Spherical Aberration, Coma, Astigmatism, Curvature of Field, and Distortion. The chromatic aberrations are Axial and Lateral. Spherical Aberration is the result when different annular zones on a lens focus at different distances. Coma occurs when different annular zones on a lens have different effective focal lengths. Astigmatism is a result of a lens having different focal lengths across different axes on its surface. Curvature of Field is a problem when the distance to the focus changes with angles away from the optical axis, forming a concave or convex best image surface. Distortion is simply a difference of magnification for different field angles, rendering the image of a square with stretched or compressed corners. Axial chromatic aberration is a difference of focus distance with color. Lateral chromatic aberration is a difference of magnification by color.

48. These aberrations interplay in a variety of ways. Distortion can be changed in a multi-lens system by introducing spherical aberration in one place and cancelling it

in another at some distance away. Coma can be modified by an overall concave or convex "bending" of a lens element, and astigmatism can be modified by introducing coma in one place and cancelling it at some distance away. Lateral chromatic aberration can be modified by introducing axial chromatic aberration at one place and cancelling it in another. These interactions can be complex in a real optical system, so they are handled algebraically, or by precise raytracing in a computer.

49. There is a lens form called a Cooke Triplet, well-known since 1893. This three-element design, with positive, negative, and positive elements arranged along an axis, is the simplest lens form that can make a good reduction in all of the Seidel aberrations. There are three lens powers, three thicknesses, two separations, and three glass types. It has been manufactured for use in cameras for many years, but is not ideal. The negative middle element is sensitive to tilting or decentering, so the triplet may be expensive to manufacture. Also, even the triplet's "good" state of correction is not perfect, but leaves some level of "residual" aberrations not fully eliminated. The triplet has therefore been displaced with a variety of four-element lens designs that can provide better optical correction and are even easier manufacture. If additional requirements are imposed along with the reduction of all the Seidel aberrations, such as a need for telephoto power or for partial telecentricity

(perpendicular incidence) of the illumination onto a digital sensor, more than three elements may be essential.

50. Through the 1940s, lens designers were limited to using mechanical desktop calculators, made by companies like Marchant (1911) and Friden (1934), with trigonometry tables for tracing light rays through a design. But early digital computers were quickly used to speed up the design process. By the 1960s and 1970s, many commercial lens design software packages became available, such as Accos V (1970) and Code V (1975), capable of tracing rays through and optimizing the shapes of complicated lens forms. Before 2013, there were many more commercial optical software options, such as OSLO (1976) and ZEMAX (1990) that could effectively run on laptop computers. In the design process, the computer does not only trace light rays through a complicated design, it also improves the design step by step with several kinds of optimization software. The goal is to reach such a good state of performance that any further change, of any of the dozens or scores of numbers that characterize the design, will detract from its quality.

51. Digital photography began at Bell Labs with experiments in 1969. Kodak experimented with a prototype in 1975. SONY showed their first MAVICA digital camera in 1981. Canon sold their RC-701 in 1984. Nikon sold their F3 in 1991. Canon continued with the Powershot 600 in 1996 and the D30 SLR in 2000. The first sensors were CCD (charge coupled devices), originally with pixels measuring 4

to 6 microns (0.004 to 0.006 mm). The CCD sensors were gradually replaced by the lower current and cheaper CMOS (complementary metal-oxide semiconductor) technology, with CMOS dominating after about 2004. The CMOS sensor has an electrode structure above the light sensitive surface that can cause some shadowing if the light hits it obliquely, so lens designs have favored some "telecentricity," where light around the edges of the image falls more directly onto the sensor. More recently, a trend toward BSI (back side illuminated) CMOS sensors has helped with the shadowing problem. Also during this history, the pixel size on the sensor has been getting smaller. The Fujifilm FinePix F30 used 2.5 micron (0.0025 mm) CCD pixels in 2006. By 2011, the Fujifilm X10 used 2.2 micron (0.0022 mm) CMOS pixels, and the Canon Powershot S100 used 1.9 micron (0.0019 mm) CMOS BSI pixels. Before 2013, this steady reduction in pixel size had already enabled the use of smaller sensors for increasingly compact cameras, and the use of more pixels on each sensor has put additional demands on lens quality.

52. A lens designer of ordinary skill knows that dividing the image task among four lens elements, rather than the minimal three in the old Cooke Triplet, can improve the image quality at some extra cost. Four lens elements provide the computer with four thicknesses, three spacings, four refractive indexes, four Abbe V numbers, and eight surfaces. All of these variables can be adjusted by the computer in its quest for the best possible result.

53. If each of the four lens elements must have either positive or negative refractive power, there appear to be 2x2x2x2=16 ways to allocate those powers. But one of ordinary skill at the time of the ’796 patent would have known that such a lens design can be kept shorter if the first lens element has positive refractive power, and that at least one of the other lens elements inherently must have negative refractive power in a glass or plastic of lower Abbe V number, for more change in refractive index with wavelength, in order to correct the two chromatic aberrations. The designer of ordinary skill will then be expected to investigate just these six options for a four-element assembly: [+ + + -], [+ + - +], [+ - + +], [+ + - -], [+ - + -], [+ - - +]. There are no other ways to distribute the required refractive powers among these four elements.

54. A photographic lens design request usually begins with specifications for size, image quality, Fno, angular scene coverage, any CMOS telecentricity needs, manufacturing cost, and sometimes weight. A designer will first consider classic lens design forms found in textbooks or the patent literature. There are also several online resources, including the LensVIEW Optical Design Database, available at https://www.photonicsonline.com/doc/lensview-optical-design-database-0001. LensVIEW was founded in the 1980s and provided classic lens designs on CD-ROM before providing them on the Internet. By 1997, the LensVIEW database included more than 11,000 lens systems. (See

https://www.laserfocusworld.com/optics/article/16551051/design-database.) Even before LensVIEW, the details regarding hundreds of patented designs found at the back of Arthur Cox's 1964 book, A System of Optical Design, were an important source for classic lens designs. *E.g.*, Ex. 1014, 558-59, 661.

55. A candidate design is tested by tracing rays through it by computer and comparing the result with the specification. If the design is not quite good enough, all of its design data (surface radii, thicknesses, spacing, and materials) can be adjusted to balance its performance against the specification. If the result is still not good enough, the designer will consider splitting one or more of the lens elements into two parts to improve the performance, or may allow one or more surfaces to become aspheric. Possibly, an aspheric surface will be changed to allow more defining coefficients, so that its shape may be more complex. If a design performs well but the lens just has the wrong focal length, all of the dimensions can simply be scaled to correct it. If necessary, a different classic starting design can be selected.

56. Sometimes a design can be made simpler or smaller by examining the original specification and removing any unnecessary requirements. For example, the unusually simple and effective photographic lens described in my own U.S. Patent No. 5,327,291 was achieved after I realized that one of the classic lens aberrations, axial chromatic error, was not important when used with color film. This lens was introduced in 1992 in the Polaroid Captiva camera, and made excellent images with

only two plastic elements, despite a large difference in focus of 3.25 mm between red and blue light. This invention was possible because the human eye is insensitive to blur in the blue-light part of a color image, so it does not require the complexity even of a Cooke Triplet. (We may think of it as a two-element triplet with just enough correction for its purpose.)

57. A lens designer can evaluate a design quite accurately by tracing rays of light geometrically through it with a computer to see how well the light is brought together in an image, and whether other properties such as distortion are acceptable. For digital image use, a CMOS sensor may require that light incident on it should be somewhat perpendicular to its surface to avoid shadowing by local electrode structures. Design requirements may include size, weight, expense of materials, heat resistance, wavelength range, and others. The designer will use the computer to adjust all the design data for the best result, or may add more familiar design features when necessary, such as by splitting one lens element into two, or making another surface aspheric.

58. A number of concepts discussed in the ’796 patent would have been known to a person of ordinary skill in the art at the time of the ’796 patent. A brief overview of some of those concepts that I have not already discussed above will help set the foundation for my analysis later in this declaration. The ’796 patent discusses the shape of the surfaces of lens elements. For example, the ’796 patent discusses

surfaces that are convex and surfaces that are concave. By convention, a lens design is usually drawn with light going through it from left to right. An object distance is called positive when measured from the left of a lens, and an image distance is called positive if it is to the right of the lens. Any spherical lens surface has a positive radius if its center is to the right of the surface, and has a negative radius if the center is to the left of the surface. A convex lens surface protrudes outward from its edge, and a concave surface is recessed inward from its edge. With this sign convention, any single lens element has a convex first (object-side) surface if that radius is positive and a concave first (object-side) surface if that radius is negative, and it has a convex second (image-side) surface if that radius is negative and a concave second (image-side surface) if that radius is positive.

59. The ’796 patent also discusses aspheric surfaces. A lens surface with a traditional spherical shape is literally part of a sphere. Eyeglasses were made with spherical shapes as early as the 13th century. Spherical shapes are easy to generate and polish because a spherical lens surface and a matching tool get better when ground together with a random motion. High spots just wear off. But non-spherical (aspheric shapes) can be made on a machine like a high quality lathe, and give a lens designer more options to form a good image. The first aspheric lenses were made in the 17th century, but did not appear in cameras until the 20th century, first in a 16 mm movie camera, then in a few 35 mm camera lenses with unusually low Fno, the

ratio of focal length to entrance pupil diameter. The first high-volume aspheric camera lens was introduced in 1976 in the Polaroid OneStep! camera, described in my own patent, U.S. Patent No. 3,902,792. Although based on the historic Landscape Lens design from the early 19th century, application of the aspheric shape greatly improved both its spherical aberration and its field curvature. With aspheric lens surfaces, the convention is to describe the lens as convex or concave, and define the radius of curvature, based on the region near the optical axis.

60. Another concept appearing throughout the ’796 patent is the focal length of a lens element. The focal length “f” of a photographic imaging lens defines the size of the image it will produce on the film or digital sensor plane for a given size and position of an object. When light enters the lens at a particular angle from the optical axis, and comes to a focus on the film or sensor plane, that image will appear at a distance from the center given by the focal length multiplied by the tangent of that angle.

61. The ’796 patent also refers to the Abbe number for certain lens elements. The Abbe number for a glass or plastic optical material, usually written as ν (Greek nu) or commonly v or V, is a measure of how fast that material’s refractive index N changes with wavelength, or color of light. It is calculated as v = (Nd -1)/(NF-NC), where Nd is the index for yellow helium light at 0.5876 nm wavelength, NF is the index for blue hydrogen light at 0.4861 nm wavelength, and NC is the index for red

hydrogen light at 0.6563 nm wavelength. The number is reciprocal, so that a material with a larger number changes index more slowly with a change in wavelength. Ex. 1015, 93-94.

VIII. PERSON OF ORDINARY SKILL IN THE ART

62. It is my understanding that when interpreting the claims of the ’796 patent, I must do so based on the perspective of one of ordinary skill in the art as of the relevant priority date. My understanding is that the earliest claimed priority date of the ’796 patent is October 29, 2013.

63. Based on my review of the ’796 patent and my background and experience in the field of camera optical systems, it is my opinion that a person of ordinary skill in the art of the ’796 patent would have a bachelor’s degree in optical engineering, mechanical engineering, electrical engineering, optics, or physics with at least three years of experience working in optical engineering; a master’s degree in one of the above disciplines with at least two years of experience working in optical engineering; a Ph.D. in one of the above disciplines focusing on optical engineering; or other equivalent experience.

64. As described above, my own training and experience exceeds that of a person of ordinary skill in the art.

IX. CLAIM CONSTRUCTION

65. It is my understanding that in determining whether a patent claim is anticipated or obvious in view of the prior art, the Patent Office must apply the *Phillips* standard to construe the claim by giving the claim its ordinary and customary meaning, consistent with the specification and prosecution history. In my analysis below, this is how I have interpreted the claims of the ’796 patent. At this time, I do not propose any terms for construction. However, I do not waive, and expressly reserve, the right to respond to any constructions proposed by Largan or the Board.

X. OVERVIEW OF U.S. PATENT NO. 9,097,860 (“YU”)

66. U.S. Patent No. 9,097,860 (“Yu”), titled “Lens Assembly,” was filed on December 27, 2013, and issued on August 4, 2015. Ex. 1003, [22], [45], [54]. Yu claims priority to Taiwan Application No. 102131525, which was filed on September 2, 2013. Ex. 1003, [30]. A certified copy of Taiwan Application No. 102131525 is included in Yu’s file history. Ex. 1004, 58-85.

67. Yu relates to “a compact wide-angle four-piece imaging lens assembly.” Ex. 1003, 1:12-14. Specifically, Yu discloses “a four-piece imaging lens assembly which has compact and thin dimensions and which has a wider angle of view for improving resolving power thereof.” Ex. 1003, 1:41-44. Yu’s lens assembly “comprises a lens set and a non-adjustable diaphragm.” Ex. 1003, 1:45-46. “The

lens set includes a first lens, a second lens, a third lens and a fourth lens arranged in sequence from an object side to an image side along an optical axis of the lens assembly." Ex. 1003, 1:46-49.

68. Yu discloses that the first lens has "a positive optical power adjacent to the optical axis" and "a convex object-side surface." Ex. 1003, 1:49-52, 2:58-61. Yu's second lens has "a positive optical power adjacent to the optical axis" and "a convex image-side surface." Ex. 1003, 1:54-57, 2:63-66. Yu's third lens has "a negative optical power adjacent to the optical axis," "a concave object-side surface," and "a convex image-side surface." Ex. 1003, 1:59-62, 3:1-5. Yu's fourth lens has "a positive optical power adjacent to the optical axis," a concave image-side surface, and "[e]ach of the object-side surface and the image-side surface … is an aspherical surface." Ex. 1003, 1:64-2:4, 3:7-18. "At least one of the object-side surface and the image-side surface of the fourth lens has an inflection point located between the optical axis and the peripheral surface." Ex. 1003, 2:4-7.

69. Fig. 1, Fig. 4, and Fig. 7 show first, second, and third preferred embodiments of Yu's lens assembly. Ex. 1003, 2:24-26, 2:37-39, 2:40-42. The lens assembly "comprises a lens set 1, a non-adjustable diaphragm 2, and a filter lens 2." Ex. 1003, 2:52-54. "The lens set 1 includes a first lens 11, a second lens 12, a third lens 13 and a fourth lens 14 arranged in sequence from an object side to an image side along an

optical axis L of the lens assembly." Ex. 1003, 2:55-58. This labeling is the same in Fig. 1, Fig. 4, and Fig. 7.

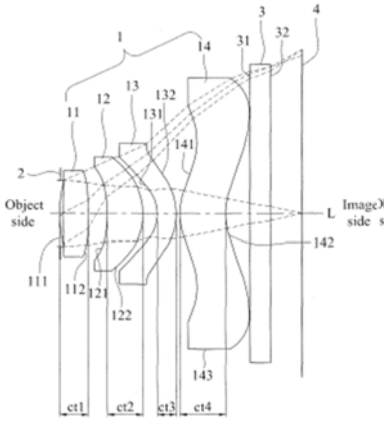


FIG.1

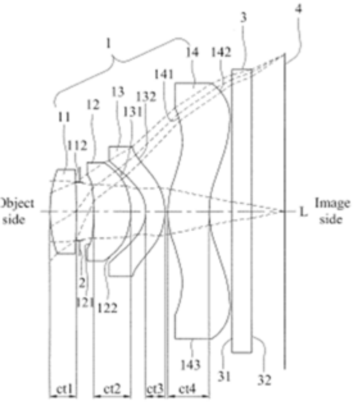


FIG.4

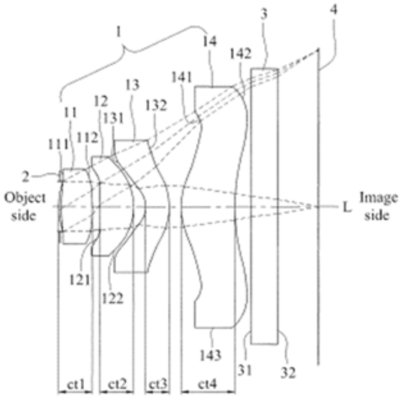


FIG.7

70. For each of Yu's three preferred embodiments, Yu provides a table (Tables 1, 3, 5) listing the "component/surface," "radius of curvature," "thickness/interspace," "refractive index," "Abbe number," and "focal length." Ex. 1003, 4:39-43, 4:54-5:20, 5:52-57, 6:58-7:24, 8:36-41, 8:48-9:14. Yu also provides a table for each embodiment (Tables 2, 4, and 6) providing the aspheric coefficients. Ex. 1003, 5:21-49, 7:25-8:32, 9:16-43.

A. Taiwan Application No. 102131525

71. As indicated above, Yu claims priority to Taiwan Application No. 102131525 ("'525 Application"). Ex. 1003, [30]. I have reviewed the certified translation of the '525 Application (Ex. 1005). Based on my review of Yu and the '525

Application, it is my opinion that all of the subject matter described in Yu is described in the ’525 Application.

72. Yu and the ’525 Application share nearly identical titles, abstracts, and figures. The ’525 Application is titled “thin wide-angle four-piece imaging lens assembly,” while Yu’s title was shortened to just “Lens Assembly.” Both abstracts disclose a lens assembly with four lens elements, wherein the refractive power of the four lens elements are positive, positive, negative, positive, respectively. Both abstracts disclose an inflection point on the fourth lens element. Both abstracts state that the lens assembly satisfies the following equation: $15 < HFOV/f < 50$. The abstract of the ’525 Application provides even more information than the abstract of Yu. For example, the ’525 Application’s abstract also discloses the concavity of each lens. Further, the ’525 Application and Yu include the same Fig. 1 shown below. Fig. 2 through Fig. 9 of the ’525 Application are identical to Fig. 2 through Fig. 9 of Yu as well.

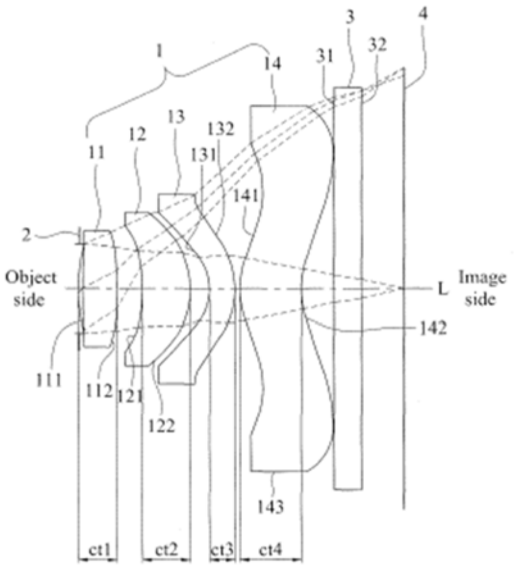


FIG.1

Yu Fig. 1

(Ex. 1003)

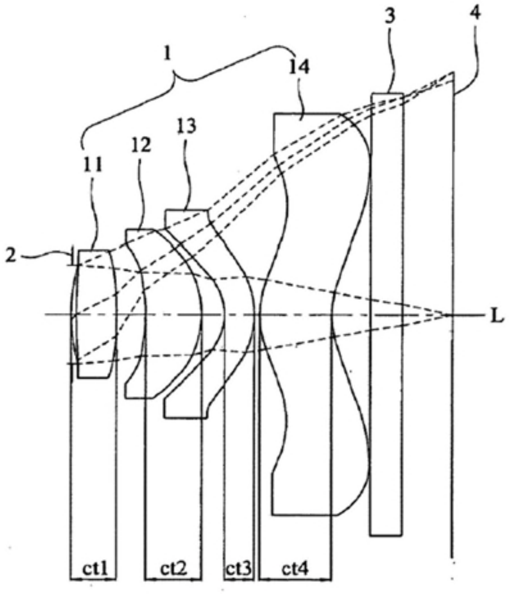


Fig. 1

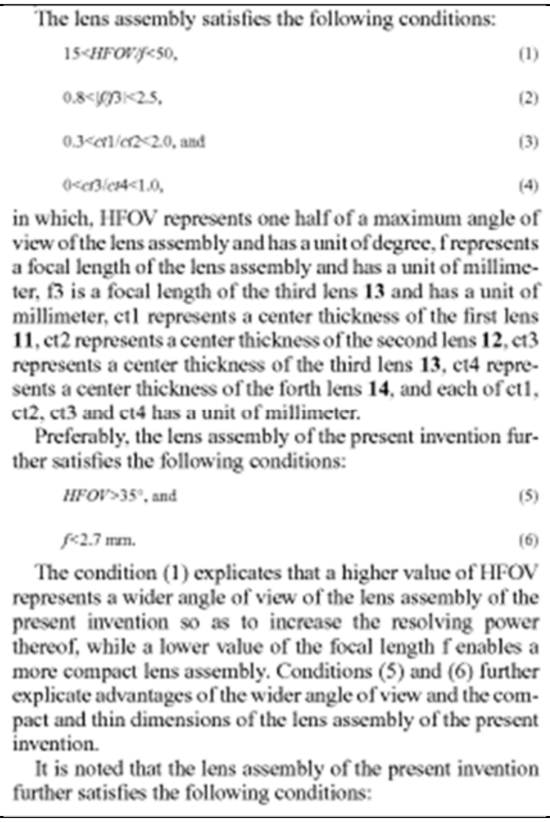
’525 Application Fig. 1

(Ex. 1005)

73. The specifications of the ’525 Application and Yu are substantively identical and describe the same lens assembly. The ’525 Application and Yu share a similar structure and breakdown of the specification. Both specifications include the following sections: field of invention, prior art, summary of the invention, description of figures, and embodiments. These sections are substantively identical in the ’525 Application and Yu.

74. First, the field of the invention and prior art sections of the ’525 Application are substantively identical to the corresponding sections of Yu. *Compare* Ex. 1003, 1:9-37 *with* Ex. 1005 ¶¶ 0001-0004. There are minor verbiage changes, i.e.

"Accordingly" instead of "Therefore," which are likely due to translations. *E.g.*, Ex. 1003, 1:33; Ex. 1005 ¶ 0004. Further, the summary of the invention sections of the '525 Application and Yu are substantively identical. *Compare* Ex. 1003, 1:39-2:16 *with* Ex. 1005 ¶¶ 0005-0008. There are minor typographical differences between the '525 Application and Yu that have no effect on the structure disclosed. For example, the '525 Application describes the diaphragm as "fixed," while Yu describes the diaphragm as "non-adjustable." *E.g.*, Ex. 1003, 1:45-46; Ex. 1005 ¶ 0006. The '525 Application includes 10 conditions regarding the refractive indices, focal lengths, and coefficient of dispersions. Ex. 1005 ¶¶ 0006-0028. As shown below, the same 10 conditions are described in Yu. Ex. 1003, 3:21-4:18.



The lens assembly satisfies the following conditions:

$$15<HFOV/f<50, \quad (1)$$

$$0.8<|f/f3|<2.5, \quad (2)$$

$$0.3<ct1/ct2<2.0, \text{ and} \quad (3)$$

$$0<ct3/ct4<1.0, \quad (4)$$

in which, HFOV represents one half of a maximum angle of view of the lens assembly and has a unit of degree, f represents a focal length of the lens assembly and has a unit of millimeter, f3 is a focal length of the third lens **13** and has a unit of millimeter, ct1 represents a center thickness of the first lens **11**, ct2 represents a center thickness of the second lens **12**, ct3 represents a center thickness of the third lens **13**, ct4 represents a center thickness of the forth lens **14**, and each of ct1, ct2, ct3 and ct4 has a unit of millimeter.

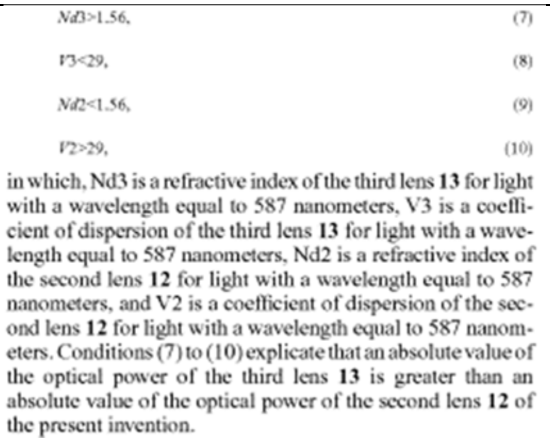
Preferably, the lens assembly of the present invention further satisfies the following conditions:

$$HFOV>35°, \text{ and} \quad (5)$$

$$f<2.7 \text{ mm}. \quad (6)$$

The condition (1) explicates that a higher value of HFOV represents a wider angle of view of the lens assembly of the present invention so as to increase the resolving power thereof, while a lower value of the focal length f enables a more compact lens assembly. Conditions (5) and (6) further explicate advantages of the wider angle of view and the compact and thin dimensions of the lens assembly of the present invention.

It is noted that the lens assembly of the present invention further satisfies the following conditions:



$$Nd3>1.56, \quad (7)$$

$$V3<29, \quad (8)$$

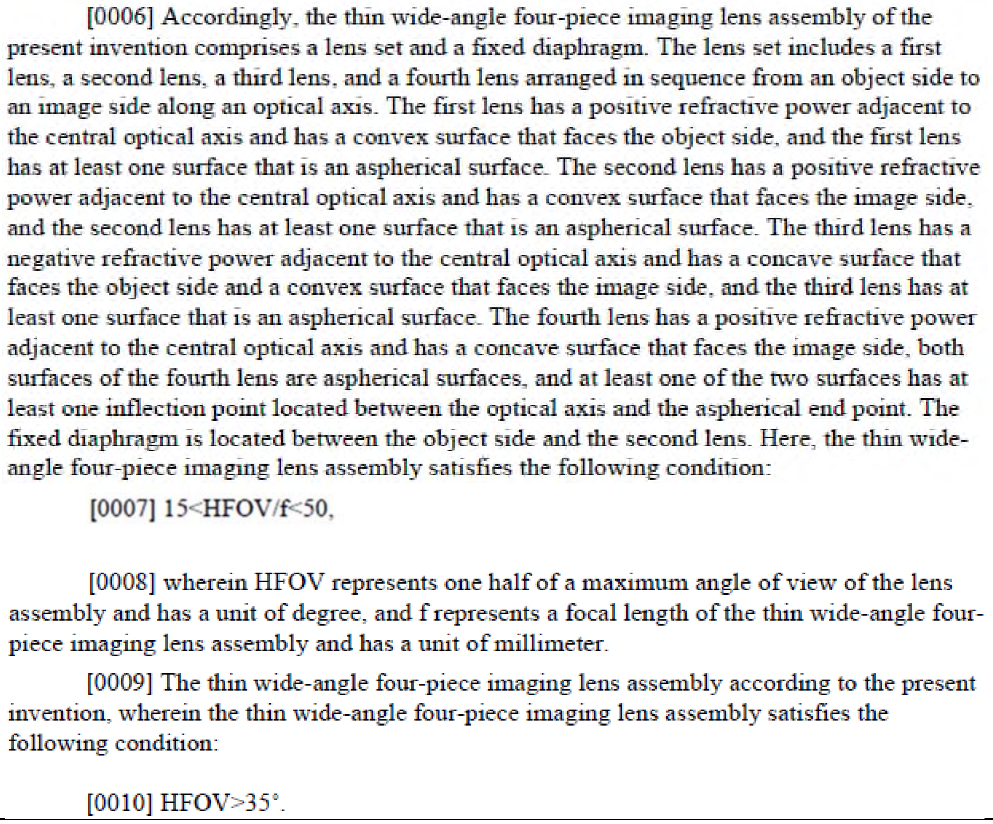
$$Nd2<1.56, \quad (9)$$

$$V2>29, \quad (10)$$

in which, Nd3 is a refractive index of the third lens **13** for light with a wavelength equal to 587 nanometers, V3 is a coefficient of dispersion of the third lens **13** for light with a wavelength equal to 587 nanometers, Nd2 is a refractive index of the second lens **12** for light with a wavelength equal to 587 nanometers, and V2 is a coefficient of dispersion of the second lens **12** for light with a wavelength equal to 587 nanometers. Conditions (7) to (10) explicate that an absolute value of the optical power of the third lens **13** is greater than an absolute value of the optical power of the second lens **12** of the present invention.

Ex. 1003, 3:21-4:18.

(Yu)



[0006] Accordingly, the thin wide-angle four-piece imaging lens assembly of the present invention comprises a lens set and a fixed diaphragm. The lens set includes a first lens, a second lens, a third lens, and a fourth lens arranged in sequence from an object side to an image side along an optical axis. The first lens has a positive refractive power adjacent to the central optical axis and has a convex surface that faces the object side, and the first lens has at least one surface that is an aspherical surface. The second lens has a positive refractive power adjacent to the central optical axis and has a convex surface that faces the image side, and the second lens has at least one surface that is an aspherical surface. The third lens has a negative refractive power adjacent to the central optical axis and has a concave surface that faces the object side and a convex surface that faces the image side, and the third lens has at least one surface that is an aspherical surface. The fourth lens has a positive refractive power adjacent to the central optical axis and has a concave surface that faces the image side, both surfaces of the fourth lens are aspherical surfaces, and at least one of the two surfaces has at least one inflection point located between the optical axis and the aspherical end point. The fixed diaphragm is located between the object side and the second lens. Here, the thin wide-angle four-piece imaging lens assembly satisfies the following condition:

[0007] $15<HFOV/f<50$,

[0008] wherein HFOV represents one half of a maximum angle of view of the lens assembly and has a unit of degree, and f represents a focal length of the thin wide-angle four-piece imaging lens assembly and has a unit of millimeter.

[0009] The thin wide-angle four-piece imaging lens assembly according to the present invention, wherein the thin wide-angle four-piece imaging lens assembly satisfies the following condition:

[0010] $HFOV>35°$.

[0011] The thin wide-angle four-piece imaging lens assembly according to the present invention, wherein the thin wide-angle four-piece imaging lens assembly satisfies the following condition:

[0012] $f<2.7$ mm.

[0013] The thin wide-angle four-piece imaging lens assembly according to the present invention, wherein the thin wide-angle four-piece imaging lens assembly satisfies the following conditions:

[0014] $Nd3>1.56$, and

[0015] $V3<29$,

[0016] wherein Nd3 is a refractive index of the third lens, and V3 is a dispersion coefficient of the third lens.

[0017] The thin wide-angle four-piece imaging lens assembly according to the present invention, wherein the thin wide-angle four-piece imaging lens assembly satisfies the following conditions:

[0018] $Nd2<1.56$, and

[0019] $V2>29$,

[0020] wherein Nd2 is a refractive index of the second lens, and V2 is a dispersion coefficient of the second lens.

[0021] The thin wide-angle four-piece imaging lens assembly according to the present invention, wherein the thin wide-angle four-piece imaging lens assembly satisfies the following condition:

[0022] $0.8<|f/f3|<2.5$,

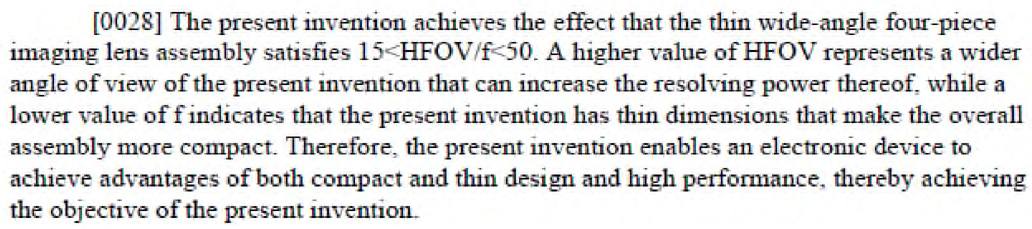
[0023] wherein f3 represents a focal length of the third lens and has a unit of millimeter.

[0024] The thin wide-angle four-piece imaging lens assembly according to the present invention, wherein the thin wide-angle four-piece imaging lens assembly satisfies the following conditions:

[0025] $0.3<ct1/ct2<2.0$, and

[0026] $0<ct3/ct4<1.0$,

[0027] wherein ct1 is a center thickness of the first lens, ct2 is a center thickness of the second lens, ct3 is a center thickness of the third lens, and ct4 is a center thickness of the fourth lens, all of which have a unit of millimeter.

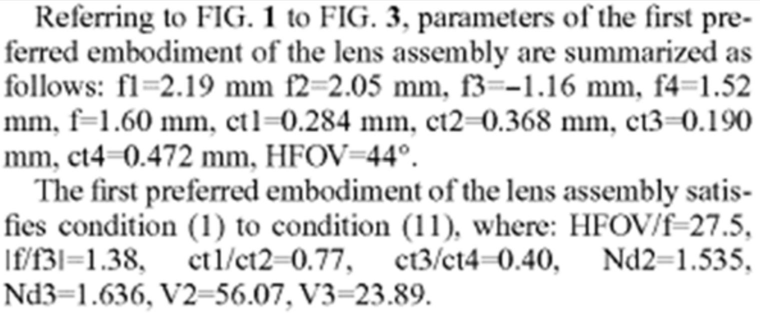


[0028] The present invention achieves the effect that the thin wide-angle four-piece imaging lens assembly satisfies 15<HFOV/f<50. A higher value of HFOV represents a wider angle of view of the present invention that can increase the resolving power thereof, while a lower value of f indicates that the present invention has thin dimensions that make the overall assembly more compact. Therefore, the present invention enables an electronic device to achieve advantages of both compact and thin design and high performance, thereby achieving the objective of the present invention.

Ex. 1005 ¶¶ 0006-0028.

('525 Application)

75. The '525 Application and Yu include three identical embodiments of the shared invention. The first embodiment of the '525 Application is substantively identical to the first embodiment of Yu. The description of the '525 Application's first embodiment is substantively identical to the description of Yu's first embodiment. *Compare* Ex. 1003, 4:39-5:49 *with* Ex. 1005 ¶¶ 0051-0057. The shared Fig. 1 depicts the first embodiment of both the '525 Application and Yu. Both the '525 Application and Yu include the same lens shape parameters as shown below. Ex. 1003, 4:39-47; Ex. 1005 ¶¶ 0052-0053.

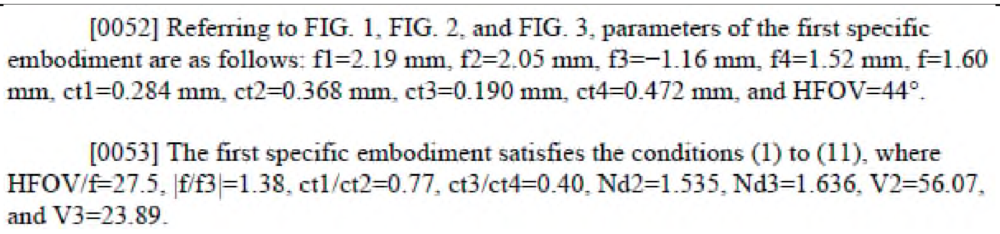


Referring to FIG. 1 to FIG. 3, parameters of the first preferred embodiment of the lens assembly are summarized as follows: f1=2.19 mm f2=2.05 mm, f3=–1.16 mm, f4=1.52 mm, f=1.60 mm, ct1=0.284 mm, ct2=0.368 mm, ct3=0.190 mm, ct4=0.472 mm, HFOV=44°.

The first preferred embodiment of the lens assembly satisfies condition (1) to condition (11), where: HFOV/f=27.5, |f/f3|=1.38, ct1/ct2=0.77, ct3/ct4=0.40, Nd2=1.535, Nd3=1.636, V2=56.07, V3=23.89.

Ex. 1003, 4:39-47.

(Yu)



[0052] Referring to FIG. 1, FIG. 2, and FIG. 3, parameters of the first specific embodiment are as follows: f1=2.19 mm, f2=2.05 mm, f3=−1.16 mm, f4=1.52 mm, f=1.60 mm, ct1=0.284 mm, ct2=0.368 mm, ct3=0.190 mm, ct4=0.472 mm, and HFOV=44°.

[0053] The first specific embodiment satisfies the conditions (1) to (11), where HFOV/f=27.5, |f/f3|=1.38, ct1/ct2=0.77, ct3/ct4=0.40, Nd2=1.535, Nd3=1.636, V2=56.07, and V3=23.89.

Ex. 1005 ¶¶ 0052-0053.

(’525 Application)

76. Further, the ’525 Application and Yu both include a first table that describes the radius of curvature, thickness, refractive index, Abbe number, and focal length of each lens element. Ex. 1003, Table 1; Ex. 1005 ¶ 0055. The tables contain identical values and therefore describe identical lens assemblies as shown below. Both the ’525 Application and Yu also include a second table that describes the “aspherical parameters”/“coefficients for the aspherical surfaces,” and these tables include identical values. Ex. 1003, Table 2; Ex. 1005 ¶ 0056.

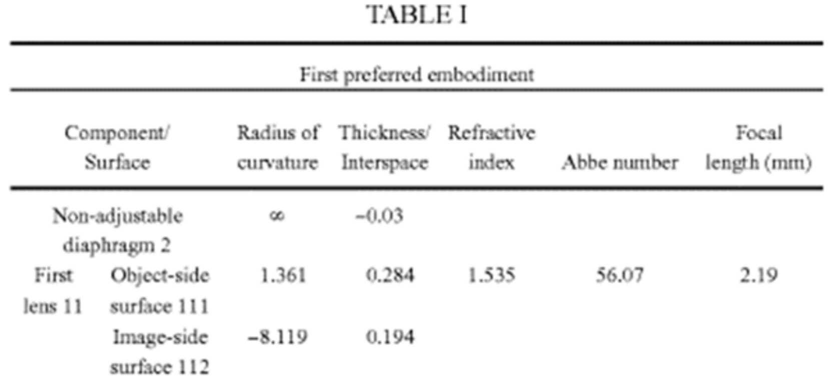


TABLE I

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Non-adjustable diaphragm 2		∞	−0.03			
First lens 11	Object-side surface 111	1.361	0.284	1.535	56.07	2.19
	Image-side surface 112	−8.119	0.194			

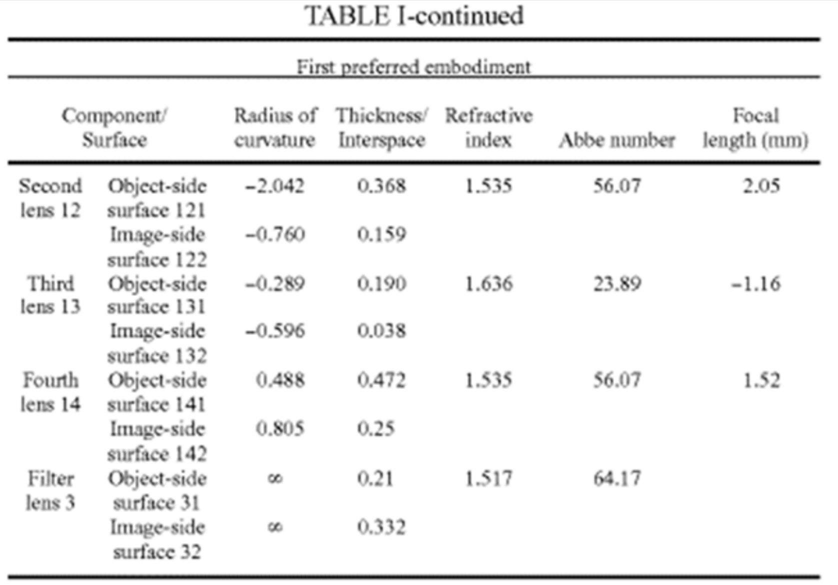


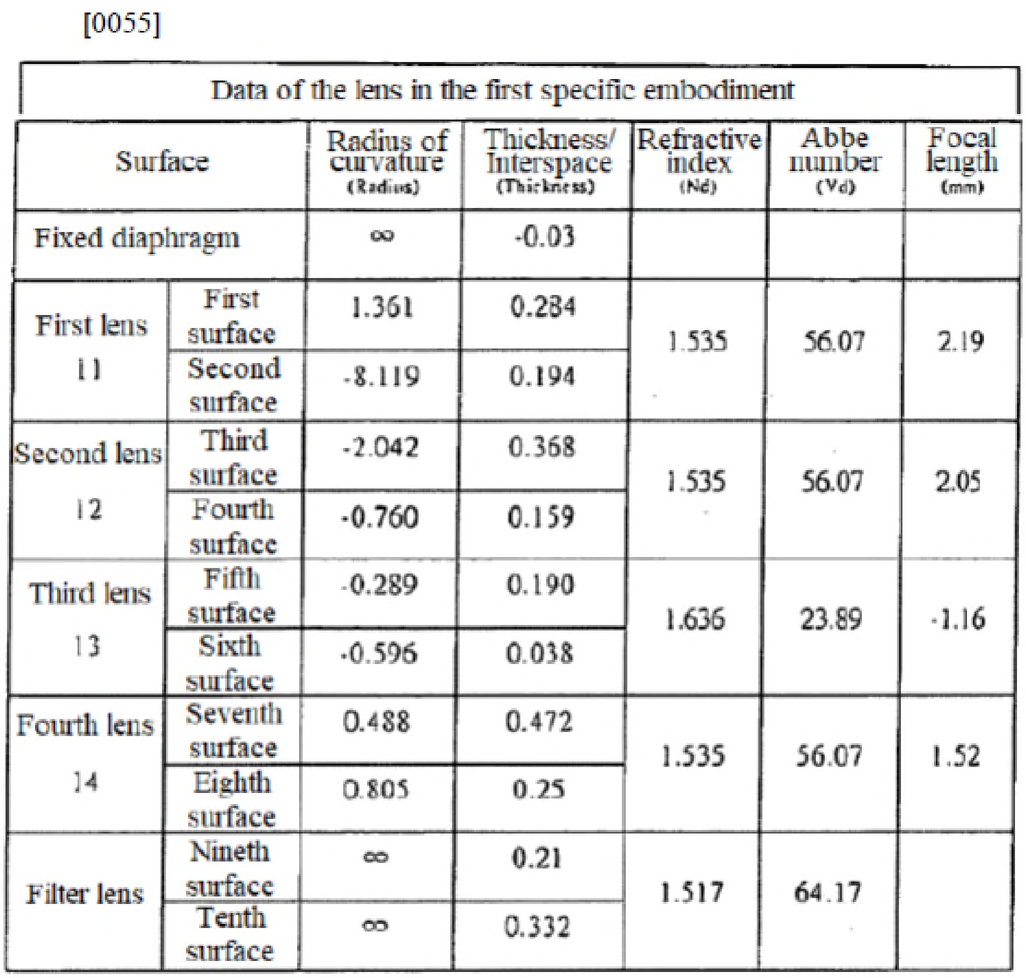
TABLE I-continued

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Second lens 12	Object-side surface 121	−2.042	0.368	1.535	56.07	2.05
	Image-side surface 122	−0.760	0.159			
Third lens 13	Object-side surface 131	−0.289	0.190	1.636	23.89	−1.16
	Image-side surface 132	−0.596	0.038			
Fourth lens 14	Object-side surface 141	0.488	0.472	1.535	56.07	1.52
	Image-side surface 142	0.805	0.25			
Filter lens 3	Object-side surface 31	∞	0.21	1.517	64.17	
	Image-side surface 32	∞	0.332			

Ex. 1003, Table 1.

(Yu)



[0055]

Data of the lens in the first specific embodiment						
Surface		Radius of curvature (Radius)	Thickness/ Interspace (Thickness)	Refractive index (Nd)	Abbe number (Vd)	Focal length (mm)
Fixed diaphragm		∞	-0.03			
First lens 11	First surface	1.361	0.284	1.535	56.07	2.19
	Second surface	-8.119	0.194			
Second lens 12	Third surface	-2.042	0.368	1.535	56.07	2.05
	Fourth surface	-0.760	0.159			
Third lens 13	Fifth surface	-0.289	0.190	1.636	23.89	-1.16
	Sixth surface	-0.596	0.038			
Fourth lens 14	Seventh surface	0.488	0.472	1.535	56.07	1.52
	Eighth surface	0.805	0.25			
Filter lens	Nineth surface	∞	0.21	1.517	64.17	
	Tenth surface	∞	0.332			

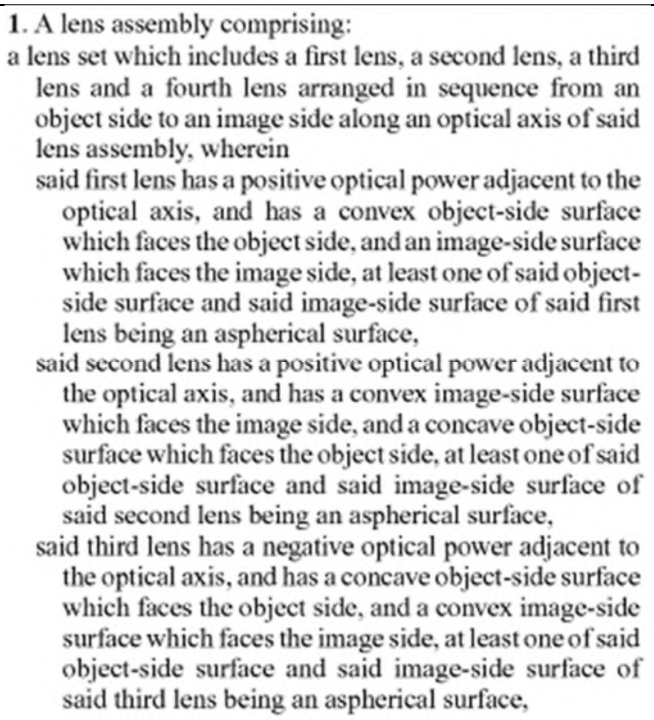
Ex. 1005 ¶ 0055.

(’525 Application)

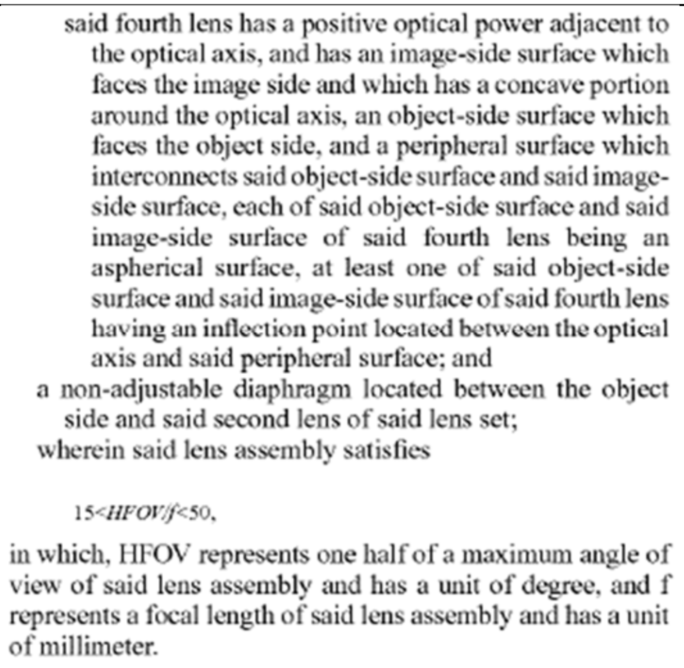
77. The second and third embodiments of the ’525 Application and Yu are substantively identical as well. For the second embodiments, *compare* Ex. 1003, 5:50-8:32 *with* Ex. 1005 ¶¶ 0058-0064. For the third embodiments, *compare* Ex. 1003, 8:34-9:43 *with* Ex. 1005 ¶¶ 0065-0071. The specifications of both the ’525 Application and Yu conclude with a nearly identical summary of “the effects

[achieved by/of] the present invention." *Compare* Ex. 1003, 9:44-67 *with* Ex. 1003 ¶¶ 0072-0077.

78. Finally, the '525 Application and Yu include substantively identical claims. Both include one independent claim and six dependent claims. Independent claim 1 of the '525 Application is substantively identical to independent claim 1 of Yu as shown below. Dependent claims 2-7 of the '525 Application are substantively identical to dependent claims 2-7 of Yu as well.



1. A lens assembly comprising:
a lens set which includes a first lens, a second lens, a third lens and a fourth lens arranged in sequence from an object side to an image side along an optical axis of said lens assembly, wherein
  said first lens has a positive optical power adjacent to the optical axis, and has a convex object-side surface which faces the object side, and an image-side surface which faces the image side, at least one of said object-side surface and said image-side surface of said first lens being an aspherical surface,
  said second lens has a positive optical power adjacent to the optical axis, and has a convex image-side surface which faces the image side, and a concave object-side surface which faces the object side, at least one of said object-side surface and said image-side surface of said second lens being an aspherical surface,
  said third lens has a negative optical power adjacent to the optical axis, and has a concave object-side surface which faces the object side, and a convex image-side surface which faces the image side, at least one of said object-side surface and said image-side surface of said third lens being an aspherical surface,



said fourth lens has a positive optical power adjacent to the optical axis, and has an image-side surface which faces the image side and which has a concave portion around the optical axis, an object-side surface which faces the object side, and a peripheral surface which interconnects said object-side surface and said image-side surface, each of said object-side surface and said image-side surface of said fourth lens being an aspherical surface, at least one of said object-side surface and said image-side surface of said fourth lens having an inflection point located between the optical axis and said peripheral surface; and

a non-adjustable diaphragm located between the object side and said second lens of said lens set;

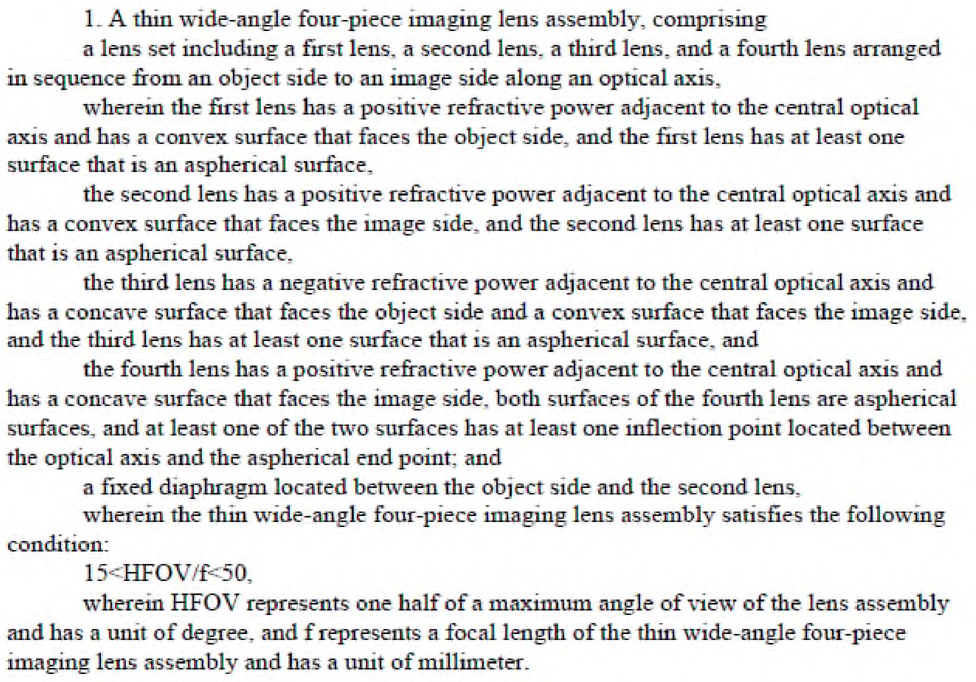
wherein said lens assembly satisfies

$$15<HFOV/f<50,$$

in which, HFOV represents one half of a maximum angle of view of said lens assembly and has a unit of degree, and f represents a focal length of said lens assembly and has a unit of millimeter.

Ex. 1003, claim 1.

(Yu)



1. A thin wide-angle four-piece imaging lens assembly, comprising

a lens set including a first lens, a second lens, a third lens, and a fourth lens arranged in sequence from an object side to an image side along an optical axis,

wherein the first lens has a positive refractive power adjacent to the central optical axis and has a convex surface that faces the object side, and the first lens has at least one surface that is an aspherical surface,

the second lens has a positive refractive power adjacent to the central optical axis and has a convex surface that faces the image side, and the second lens has at least one surface that is an aspherical surface,

the third lens has a negative refractive power adjacent to the central optical axis and has a concave surface that faces the object side and a convex surface that faces the image side, and the third lens has at least one surface that is an aspherical surface, and

the fourth lens has a positive refractive power adjacent to the central optical axis and has a concave surface that faces the image side, both surfaces of the fourth lens are aspherical surfaces, and at least one of the two surfaces has at least one inflection point located between the optical axis and the aspherical end point; and

a fixed diaphragm located between the object side and the second lens,

wherein the thin wide-angle four-piece imaging lens assembly satisfies the following condition:

$15<HFOV/f<50$,

wherein HFOV represents one half of a maximum angle of view of the lens assembly and has a unit of degree, and f represents a focal length of the thin wide-angle four-piece imaging lens assembly and has a unit of millimeter.

Ex. 1005, claim 1. ('525 Application)

79. Based on the analysis above, it is my opinion that the '525 Application discloses the same subject matter as Yu.

XI. OVERVIEW OF U.S. PATENT APPLICATION PUBLICATION NO. 2004/0012861 ("YAMAGUCHI")

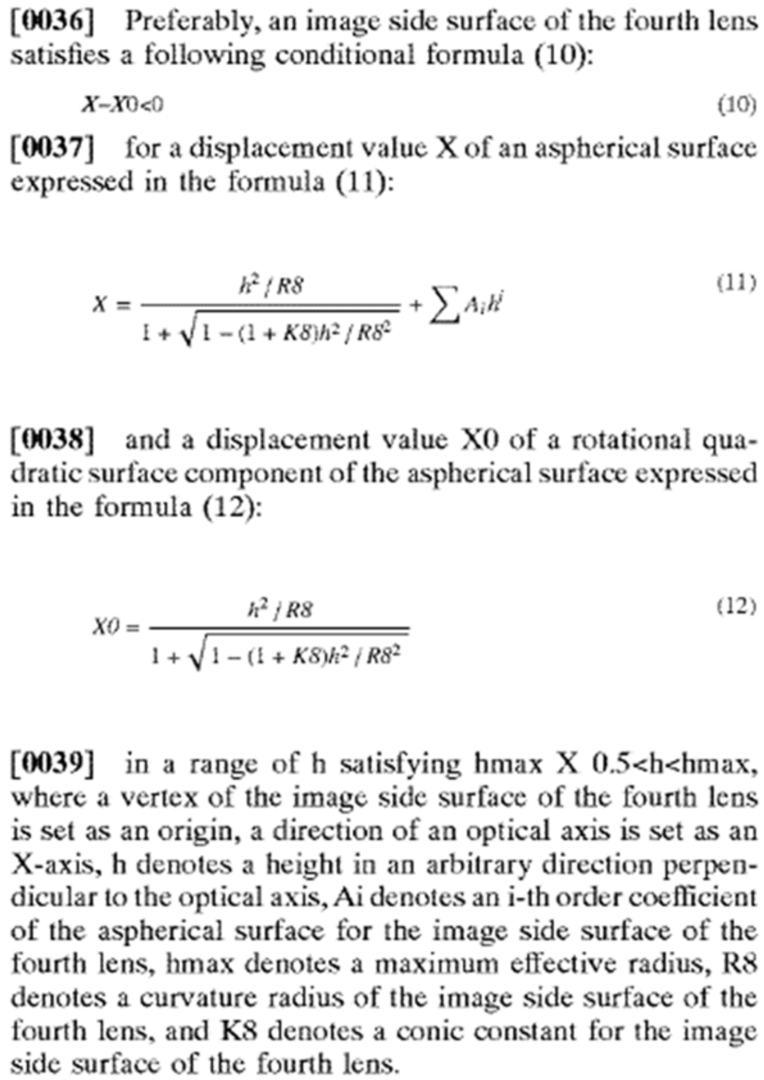
80. U.S. Patent Application No. 2004/0012861 ("Yamaguchi"), titled "Image Pickup Lens, Image Pickup Unit and Portable Terminal," was filed on July 7, 2003, published on January 22, 2004. Ex. 1006, [22], [43], [54].

81. Yamaguchi relates to "an image pickup lens preferable as an optical system of a solid state pickup element such as a CCD type image sensor or a CMOS type image sensor." Ex. 1006 ¶ 0002. Yamaguchi teaches that the "heightened performance and the miniaturization of an image pickup device," along with "the miniaturization and the dense arrangement of pixels," necessitated "the further miniaturization of an image pickup lens mounted on the image pickup device." Ex. 1006 ¶¶ 0004-0005. To address this need, Yamaguchi discloses "an image pickup lens which is composed of a plurality of lenses and is miniaturized." Ex. 1006 ¶ 0008.

82. Yamaguchi's image pickup lens comprises "four lenses arranged in an order of a first lens, a second lens, a third lens, and a fourth lens from an object side." Ex.

1006 ¶ 0009. Yamaguchi discloses that “the first lens has positive refractive power and has a convex surface facing toward the object side.” Ex. 1006 ¶ 0010. “[T]he second lens has … positive refractive power ….” Ex. 1006 ¶ 0010. “[T]he third lens has negative refractive power and has a concave surface facing toward the object side to be formed in a meniscus shape, and the fourth lens has … positive or negative refractive power and has a convex surface facing toward the object side to be formed in the meniscus shape.” Ex. 1006 ¶ 0010.

83. Yamaguchi discloses that “the image side surface of the fourth lens and nearest to the image side among the surfaces of the lenses is formed in the aspherical surface shape satisfying the formulas (10), (11), and (12),” which are reproduced below:



[0036] Preferably, an image side surface of the fourth lens satisfies a following conditional formula (10):

$$X-X0<0 \tag{10}$$

[0037] for a displacement value X of an aspherical surface expressed in the formula (11):

$$X = \frac{h^2/R8}{1+\sqrt{1-(1+K8)h^2/R8^2}} + \sum A_i h^i \tag{11}$$

[0038] and a displacement value X0 of a rotational quadratic surface component of the aspherical surface expressed in the formula (12):

$$X0 = \frac{h^2/R8}{1+\sqrt{1-(1+K8)h^2/R8^2}} \tag{12}$$

[0039] in a range of h satisfying hmax X 0.5<h<hmax, where a vertex of the image side surface of the fourth lens is set as an origin, a direction of an optical axis is set as an X-axis, h denotes a height in an arbitrary direction perpendicular to the optical axis, Ai denotes an i-th order coefficient of the aspherical surface for the image side surface of the fourth lens, hmax denotes a maximum effective radius, R8 denotes a curvature radius of the image side surface of the fourth lens, and K8 denotes a conic constant for the image side surface of the fourth lens.

Ex. 1006 ¶¶ 0036-0039, 0041; *see also* Ex. 1006 ¶¶ 0054-57, 0062.

84. Fig. 5 (Examples 1 and 2), Fig. 8 (Example 3), and Fig. 10 (Example 4) shows representative sectional views of four Examples of Yamaguchi's pickup lens. Ex. 1006 ¶¶ 0112, 0115, 0117.

FIG.5

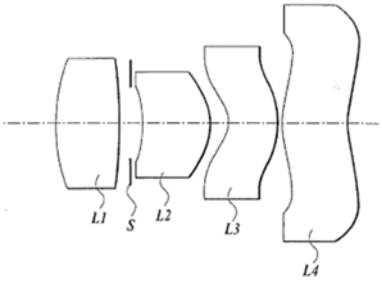


FIG.8

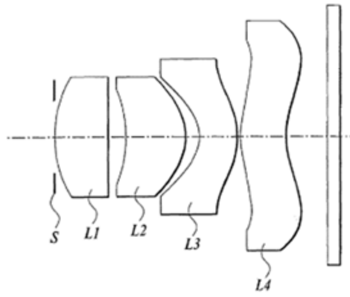
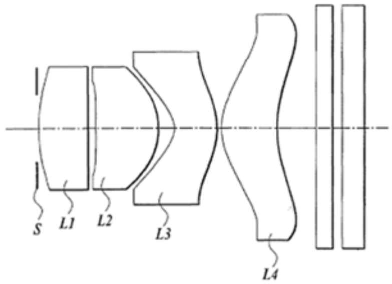
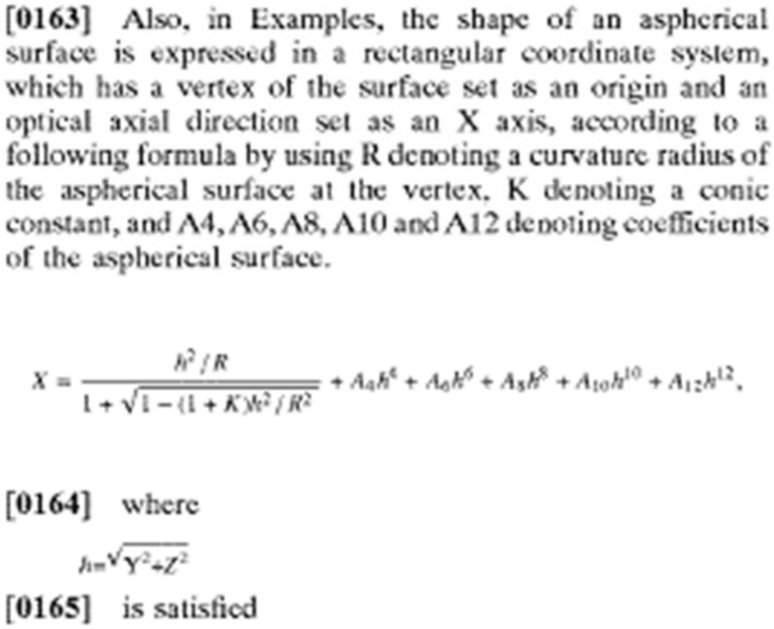


FIG.10



85. For each of Yamaguchi's four examples, Yamaguchi provides four tables listing various lens data (Tables 1-4 for Example 1, Tables 5-8 for Example 2, Tables 9-12 for Example 3, and Tables 13-16 for Example 4.), which include "f: focal length of the whole image pickup lens," "F: F number," "2Y: length of diagonal line on effective image screen," "R: curvature radius of refractive surface," "D: interval between refractive surfaces on axis," and "vd: Abbe number of lens material." Ex. 1006 ¶¶ 0154-0162, 0167-0169, 0172-0175, 0178-0181, 0185-0188, 0192. In Examples 1-4, "the shape of an aspherical surface is expressed in a rectangular coordinate system," as indicated below:



[0163] Also, in Examples, the shape of an aspherical surface is expressed in a rectangular coordinate system, which has a vertex of the surface set as an origin and an optical axial direction set as an X axis, according to a following formula by using R denoting a curvature radius of the aspherical surface at the vertex, K denoting a conic constant, and A4, A6, A8, A10 and A12 denoting coefficients of the aspherical surface.

$$X = \frac{h^2/R}{1+\sqrt{1-(1+K)h^2/R^2}} + A_4h^4 + A_6h^6 + A_8h^8 + A_{10}h^{10} + A_{12}h^{12},$$

[0164] where

$$h=\sqrt{Y^2+Z^2}$$

[0165] is satisfied

Ex. 1006 ¶ 0163-0165.

XII. GROUND 1: YU RENDERS CLAIMS 1-11, AND 15-25 OBVIOUS.

A. Claim 1

1. Preamble: "An image capturing lens system comprising, in order from an object side to an image side:"

86. The preamble of claim 1 recites: "An image capturing lens system comprising, in order from an object side to an image side." Ex. 1001, 30:48-49.

87. Yu discloses "a compact wide-angle four-piece imaging lens assembly." Ex. 1003, 1:12-14. Yu's "lens assembly … comprises a lens set and a non-adjustable diaphragm." Ex. 1003, 1:45-46. "The lens set includes a first lens, a second lens, a third lens and a fourth lens arranged in sequence from an object side to an image side along an optical axis of the lens assembly." Ex. 1003, 1:46-49.

88. Yu's Fig. 1 shows "a first preferred embodiment of a lens assembly." Ex. 1003, 2:52-54. I analyze this first embodiment for all of the claims discussed in this section with the exception of claim 10.

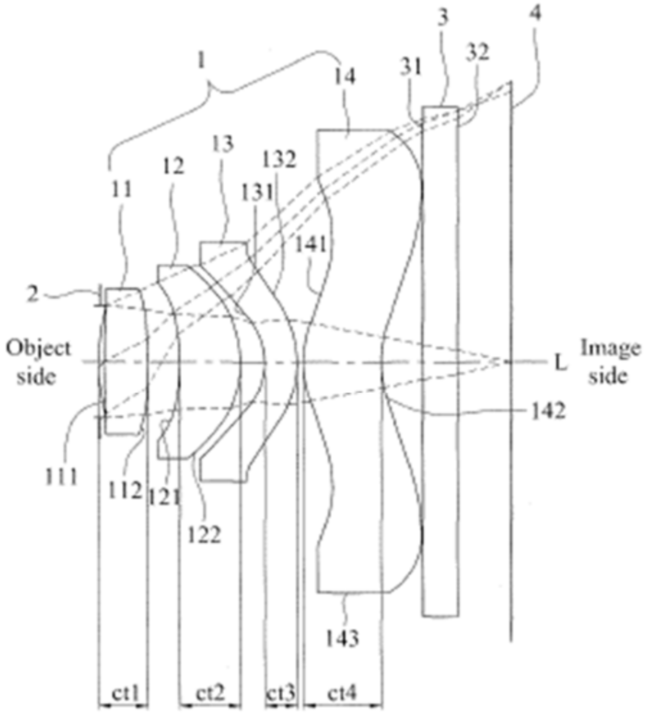


FIG.1

89. Yu's Fig. 7 "is a schematic diagram illustrating a third preferred embodiment of a lens assembly." Ex. 1003, 2:40-42. I analyze this third embodiment for claims 1, 8, and 10.

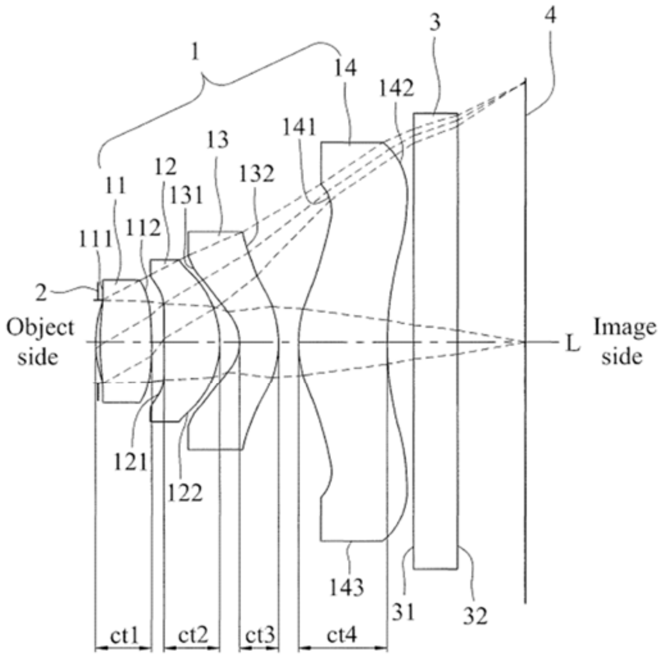


FIG.7

90. To the extent the preamble is limiting, Yu's lens assembly is "[a]n image capturing lens system."

2. Element 1a: "a first lens element having refractive power;"

91. Element 1a recites: "a first lens element having refractive power." Ex. 1001, 30:50.

92. In order from the object side to the image side, Yu's lens assembly comprises first "a first lens 11." Ex. 1003, 2:55-58. I have highlighted the first lens 11 in the annotated versions of Yu's Fig. 1 (first embodiment) and Fig. 7 (third embodiment) below. "The first lens 11 has a positive optical power adjacent to the optical axis L …." Ex. 1003, 2:58-61. One of ordinary skill would understand that "optical

power” in this use means the same as “refractive power.” A lens element expresses “power” only through refraction. Yu’s first lens 11 is a “first lens element having refractive power.”

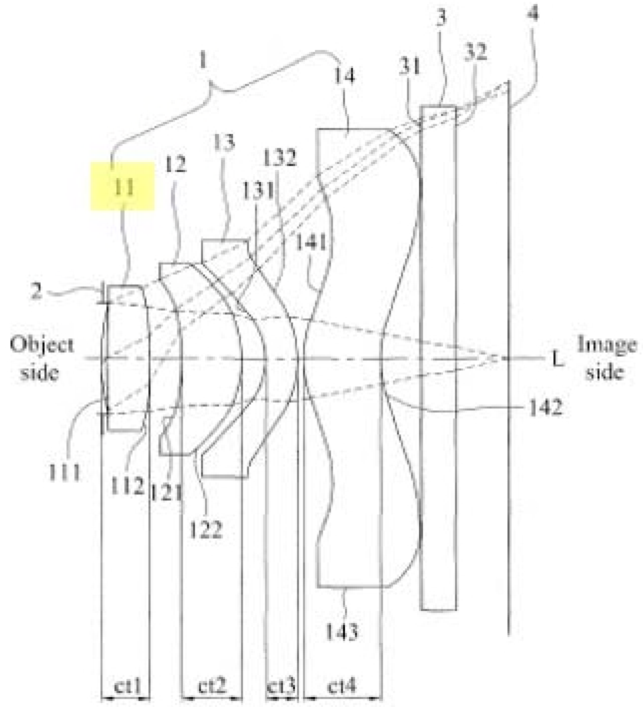


FIG.1

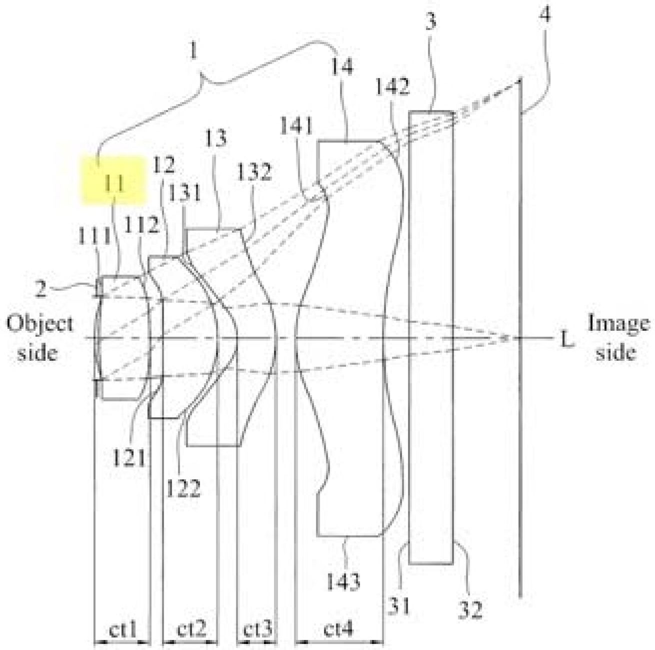


FIG.7

3. Element 1b: “a second lens element with positive refractive power having a convex image-side surface in a paraxial region thereof;”

93. Element 1b recites: “a second lens element with positive refractive power having a convex image-side surface in a paraxial region thereof.” Ex. 1001, 30:51-53.

94. After the first lens 11, from the object side to image side in Yu’s lens assembly, is “a second lens 12.” Ex. 1003, 2:55-58. I have highlighted the second lens 12 in the annotated versions of Yu’s Fig. 1 (first embodiment) and Fig. 7 (third embodiment) below. “The second lens 12 has a positive optical power adjacent to the optical axis L, and has a convex image-side surface [122] which faces the image

side ….” Ex. 1003, 2:63-66. In the preceding sentence taken from Yu’s specification, the image-side surface of Yu’s second lens 12 is labeled “121,” and the object-side surface is labeled “122,” but it is apparent that the labels 121 and 122 are transposed in this sentence. This would be easily recognized by a person of ordinary skill in the art when they look at Fig. 1 and Fig. 7, which have these surfaces labeled correctly. Also, in the next sentence, these two surfaces are labeled correctly. Ex. 1003, 2:66-3:1. I have also highlighted the labels in the annotated versions of Fig. 1 and Fig. 7 below.

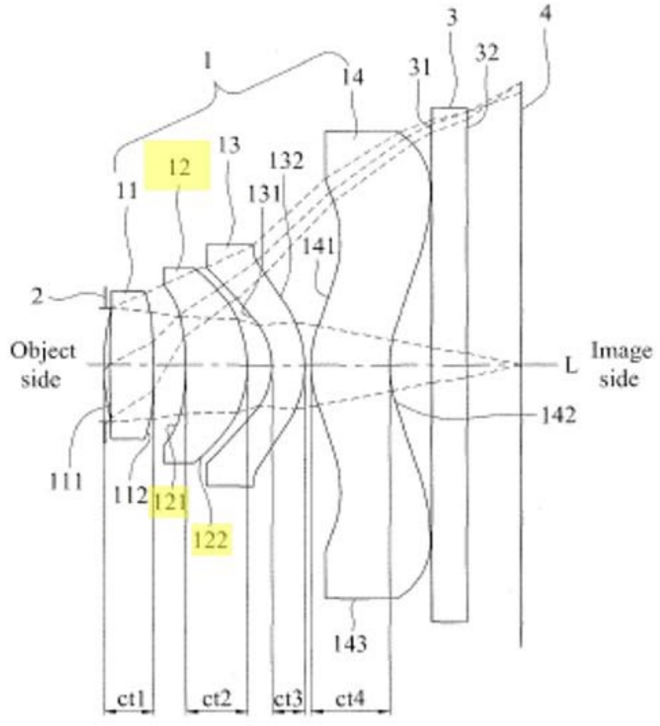


FIG.1

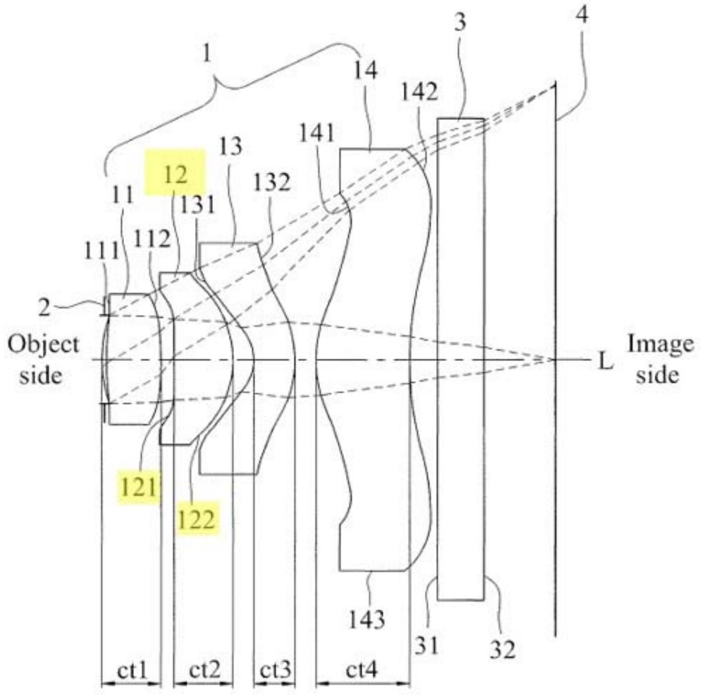


FIG.7

95. One of ordinary skill would understand that “positive optical power” as used in Yu means the same as “positive refractive power.” A lens element expresses “power” only through refraction.

96. With an aspheric surface, like those in Yu’s Fig. 1 and Fig. 7, there may be some question about whether either side is convex or concave. By convention one of ordinary skill in the art bases an identification of surface as convex or concave by considering just the central region, near the optical axis. The convexity or concavity of the shape there is given by the spherical radius data for the surface, and that central curvature is not changed by any of the additional aspheric data.

97. The shape of the second lens 12 in Fig. 1 (first embodiment) and Fig. 7 (third embodiment) above confirms that it has positive refractive power, because the lens is thicker in the paraxial region. As I explained above, a lens with positive refractive power is thicker at its center. The convex image-side surface in a paraxial region of the second lens 12 can also be seen in these figures.

98. Table 1 (first embodiment) and Table 5 (third embodiment) confirm that the second lens 12 has a convex image-side surface 122 in the paraxial region, because the radius of curvature for this surface is negative in both embodiments (-0.760 mm in the first embodiment and -0.528 mm in the third embodiment). Ex. 1003, 5:9-10, 8:62-63. I have highlighted the radius of curvature of the image-side surface 122 of the second lens 12 in the annotated versions of Table 1 (first embodiment) and Table 5 (third embodiment) below. As I explained above, a negative radius of curvature denotes a convex image-side surface. Yu’s second lens 12 is a “second lens element with positive refractive power having a convex image-side surface in a paraxial region thereof.”

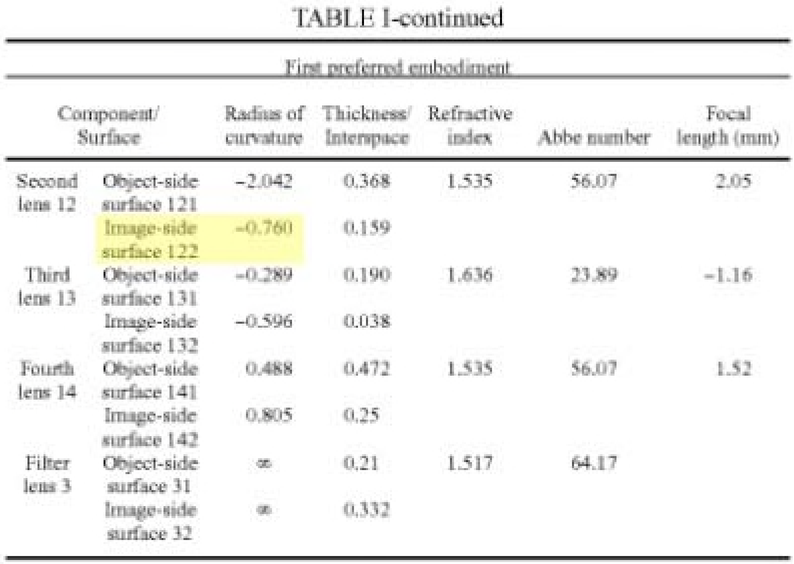


TABLE I-continued

First preferred embodiment						
Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Second lens 12	Object-side surface 121	−2.042	0.368	1.535	56.07	2.05
	Image-side surface 122	−0.760	0.159			
Third lens 13	Object-side surface 131	−0.289	0.190	1.636	23.89	−1.16
	Image-side surface 132	−0.596	0.038			
Fourth lens 14	Object-side surface 141	0.488	0.472	1.535	56.07	1.52
	Image-side surface 142	0.805	0.25			
Filter lens 3	Object-side surface 31	∞	0.21	1.517	64.17	
	Image-side surface 32	∞	0.332			

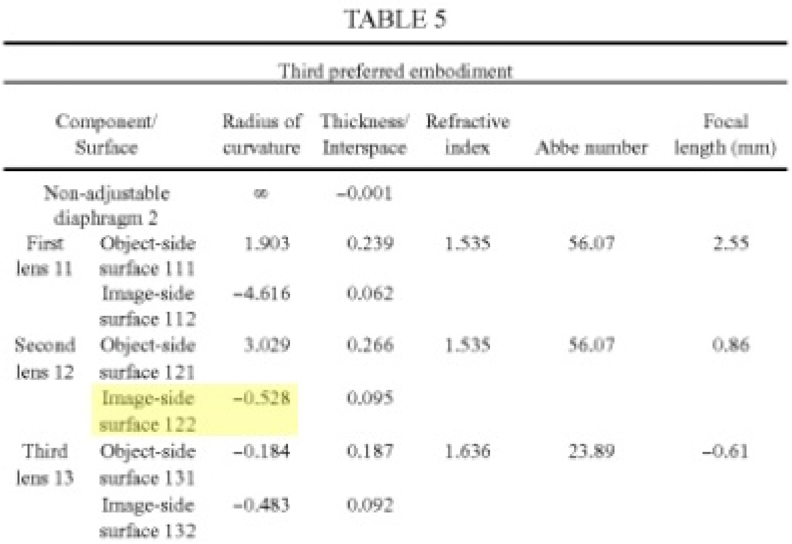


TABLE 5

Third preferred embodiment						
Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Non-adjustable diaphragm 2		∞	−0.001			
First lens 11	Object-side surface 111	1.903	0.239	1.535	56.07	2.55
	Image-side surface 112	−4.616	0.062			
Second lens 12	Object-side surface 121	3.029	0.266	1.535	56.07	0.86
	Image-side surface 122	−0.528	0.095			
Third lens 13	Object-side surface 131	−0.184	0.187	1.636	23.89	−0.61
	Image-side surface 132	−0.483	0.092			

4. Element 1c: "a third lens element with negative refractive power having a concave object-side surface in a paraxial region thereof and a convex image-side surface in a paraxial region thereof; and"

99. Element 1c recites: "a third lens element with negative refractive power having a concave object-side surface in a paraxial region thereof and a convex image-side surface in a paraxial region thereof." Ex. 1001, 30:54-57.

100. After the second lens 12, from the object side to image side in Yu's lens assembly, is "a third lens 13." Ex. 1003, 2:55-58. I have highlighted the third lens 13 in the annotated versions of Yu's Fig. 1 (first embodiment) and Fig. 7 (third embodiment) below. "The third lens 13 has a negative optical power adjacent to the optical axis L, and has a concave object-side surface 131 which faces the object side, and a convex image-side surface 132 which faces the image side." Ex. 1003, 3:1-5. One of ordinary skill would understand that "negative optical power" in this use means the same as "negative refractive power." A lens element expresses "power" only through refraction. By convention one of ordinary skill in the art bases an identification of a surface as convex or concave by considering just the central region, near the optical axis. The convexity or concavity of the shape there is given by the spherical radius data for the surface, and that central curvature is not changed by any of the additional aspheric data.

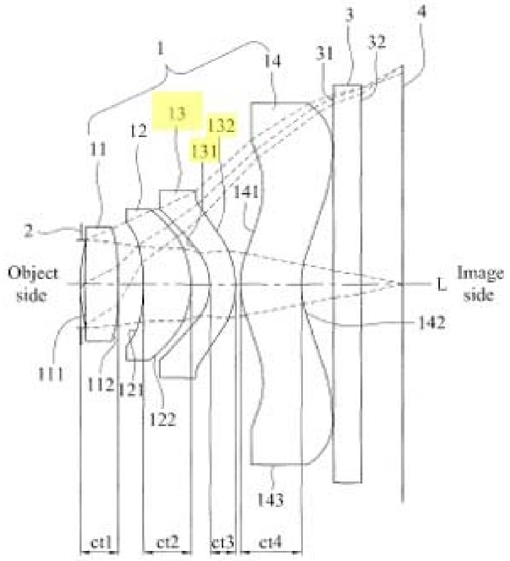


FIG.1

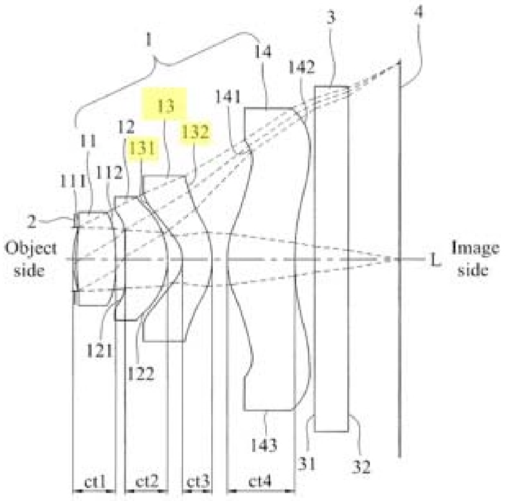


FIG.7

101. The shape of the third lens 13 in Fig. 1 (first embodiment) and Fig. 7 (third embodiment) above confirms that it has negative refractive power, because the lens is thinner in the paraxial region. As I explained above, a lens with negative refractive power is thinner at its center. The concave object-side surface in a

paraxial region and convex image-side surface in a paraxial region of the third lens 13 can also be seen in these figures.

102. Table 1 (first embodiment) and Table 5 (third embodiment) confirm that the third lens 13 has a concave object-side surface 131 in the paraxial region and a convex image-side surface 132 in a paraxial region, because the radius of curvature for the object-side surface 131 is negative in both embodiments (-0.289 mm in the first embodiment and -0.184 in the third embodiment) and the image-side surface 132 is negative in both embodiments (-0.596 in the first embodiment and -0.483 in the third embodiment). Ex. 1003, 5:11-14, 8:64-67. I have highlighted the radius of curvature of the object-side surface 131 and image-side surface 132 of the third lens 13 in the annotated versions of Table 1 (first embodiment) and Table 5 (third embodiment) below. As I explained above, a negative radius of curvature denotes a concave object-side surface and a convex image-side surface. Yu's third lens 13 is "a third lens element with negative refractive power having a concave object-side surface in a paraxial region thereof and a convex image-side surface in a paraxial region thereof."

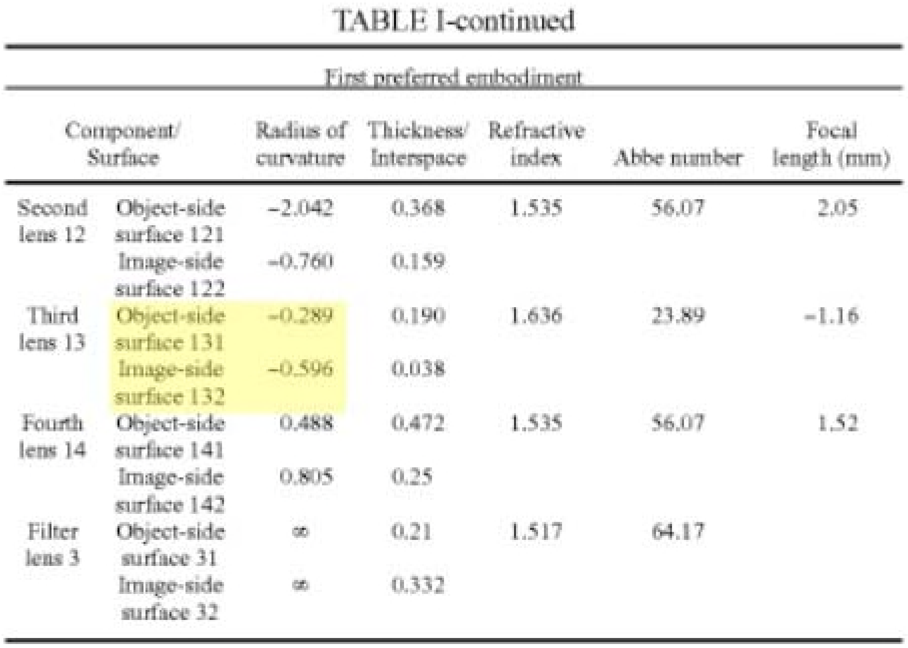


TABLE I-continued

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Second lens 12	Object-side surface 121	−2.042	0.368	1.535	56.07	2.05
	Image-side surface 122	−0.760	0.159			
Third lens 13	Object-side surface 131	−0.289	0.190	1.636	23.89	−1.16
	Image-side surface 132	−0.596	0.038			
Fourth lens 14	Object-side surface 141	0.488	0.472	1.535	56.07	1.52
	Image-side surface 142	0.805	0.25			
Filter lens 3	Object-side surface 31	∞	0.21	1.517	64.17	
	Image-side surface 32	∞	0.332			

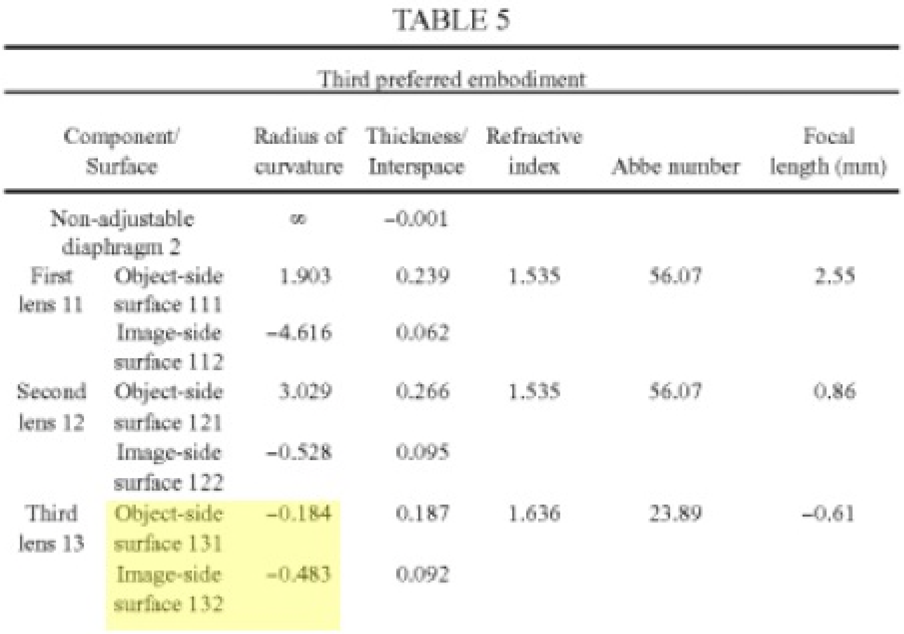


TABLE 5

Third preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Non-adjustable diaphragm 2		∞	−0.001			
First lens 11	Object-side surface 111	1.903	0.239	1.535	56.07	2.55
	Image-side surface 112	−4.616	0.062			
Second lens 12	Object-side surface 121	3.029	0.266	1.535	56.07	0.86
	Image-side surface 122	−0.528	0.095			
Third lens 13	Object-side surface 131	−0.184	0.187	1.636	23.89	−0.61
	Image-side surface 132	−0.483	0.092			

5. Element 1d: "a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof, wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric, and the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof;"

103. Element 1d recites: "a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof, wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric, and the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof." Ex. 1001, 30:58-63.

104. After the third lens 13, from the object side to image side in Yu's lens assembly, is "a fourth lens 14." Ex. 1003, 2:55-58. I have highlighted the fourth lens 14 in the annotated versions of Yu's Fig. 1 (first embodiment) and Fig. 7 (third embodiment) below. "The fourth lens 14 has a positive optical power adjacent to the optical axis L, and has an image-side surface [142] which faces the image side and which has a concave portion around the optical axis L …." Ex. 1003, 3:7-13. In the quoted portion of the preceding sentence taken from Yu's specification, the image-side surface of Yu's fourth lens 14 is labeled "141," and the object-side surface is labeled "142," but it is apparent that the labels 141 and 142 are transposed in this portion of the sentence. This would be easily recognized by a person of ordinary skill in the art when they look at Fig. 1 and Fig. 7, which have these

surfaces labeled correctly. Also, later in the same sentence, and in the next two sentences, these two surfaces are labeled correctly. Ex. 1003, 3:12-18. I have also highlighted the labels in the annotated versions of Fig. 1 and Fig. 7 below.

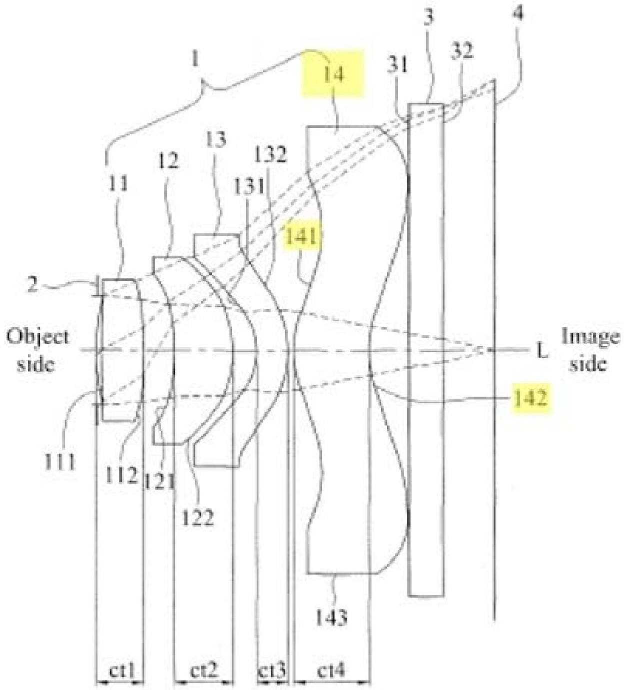


FIG.1

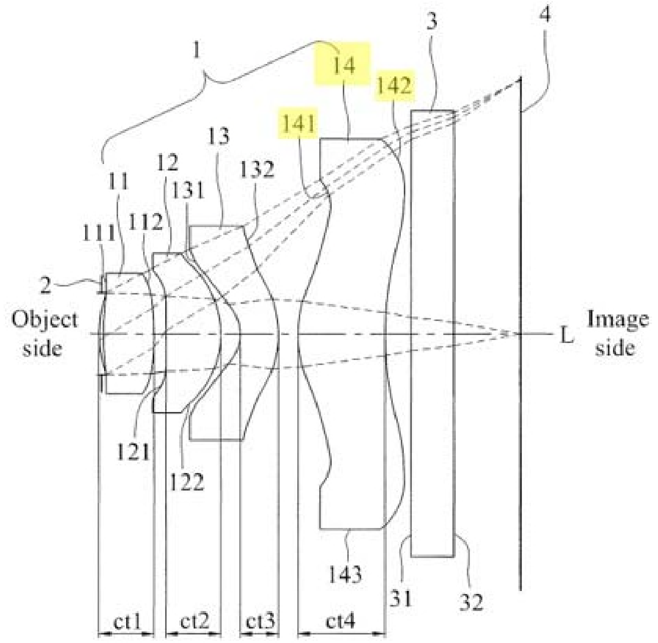


FIG.7

105. One of ordinary skill would understand that "optical power" as used in Yu means the same as "refractive power." A lens element expresses "power" only through refraction. By convention one of ordinary skill in the art bases an identification of a surface as convex or concave by considering just the central region, near the optical axis, often referred to as "the paraxial region." The convexity or concavity of the shape there is given by the spherical radius data for the surface, and that central curvature is not changed by any of the additional aspheric data.

106. The shape of the fourth lens 14 in Fig. 1 and Fig. 7 above confirms that it has positive refractive power, because the lens is thicker in the paraxial region. As I

explained above, a lens with positive refractive power is thicker at its center. The concave image-side surface in a paraxial region of the fourth lens 14 can also be seen in these figures.

107. Table 1 (first embodiment) and Table 5 (third embodiment) confirm that the fourth lens 14 has a concave image-side surface 142 in a paraxial region, because the radius of curvature for this surface is positive in both embodiments (0.805 mm in the first embodiment and 1.549 mm in the third embodiment). Ex. 1003, 5:17-18, 9:7-8. I have highlighted the radius of curvature of image-side surface 142 of the fourth lens 14 in the annotated versions of Table 1 (first embodiment) and Table 5 (third embodiment) below. As I explained above, a positive radius of curvature denotes a concave image-side surface. Yu's fourth lens 14 is "a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof."

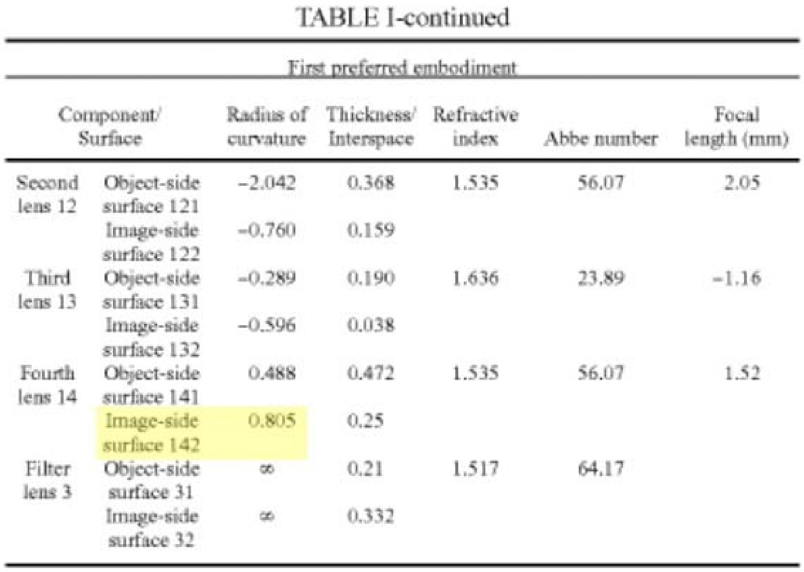


TABLE I-continued

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Second lens 12	Object-side surface 121	−2.042	0.368	1.535	56.07	2.05
	Image-side surface 122	−0.760	0.159			
Third lens 13	Object-side surface 131	−0.289	0.190	1.636	23.89	−1.16
	Image-side surface 132	−0.596	0.038			
Fourth lens 14	Object-side surface 141	0.488	0.472	1.535	56.07	1.52
	Image-side surface 142	0.805	0.25			
Filter lens 3	Object-side surface 31	∞	0.21	1.517	64.17	
	Image-side surface 32	∞	0.332			

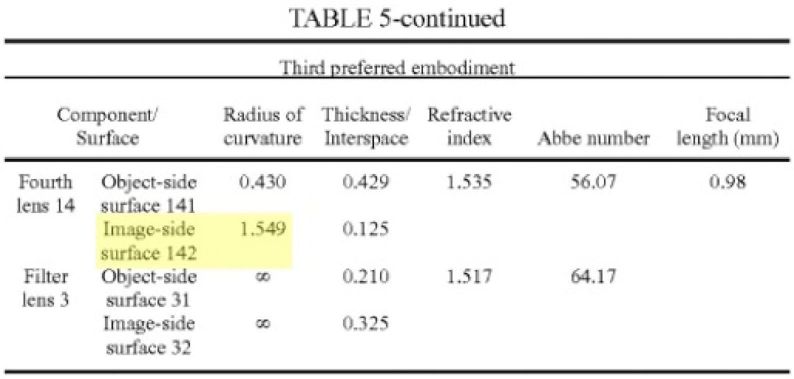


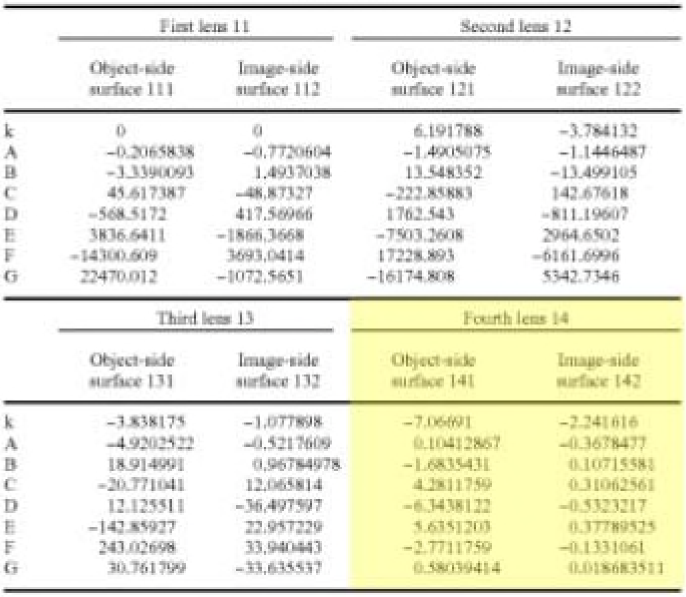
TABLE 5-continued

Third preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Fourth lens 14	Object-side surface 141	0.430	0.429	1.535	56.07	0.98
	Image-side surface 142	1.549	0.125			
Filter lens 3	Object-side surface 31	∞	0.210	1.517	64.17	
	Image-side surface 32	∞	0.325			

108. Yu discloses that "[e]ach of the object-side surface 141 and the image-side surface 142 of the fourth lens 14 is an aspherical surface." Ex. 1003, 3:13-15. This is visible in Fig. 1 (first embodiment) and Fig. 7 (third embodiment) above. Yu also provides aspherical coefficients for the object-side surface 141 and image-side surface 142 of the fourth lens 14 in Table 2 (first embodiment) and Table 6 (third embodiment.) Ex. 1003, Table 2, Table 6. I have highlighted these coefficients in the annotated versions of Table 2 (first embodiment) and Table 6 (third embodiment) below. Thus, Yu's fourth lens 14 is "a fourth lens element … wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric."

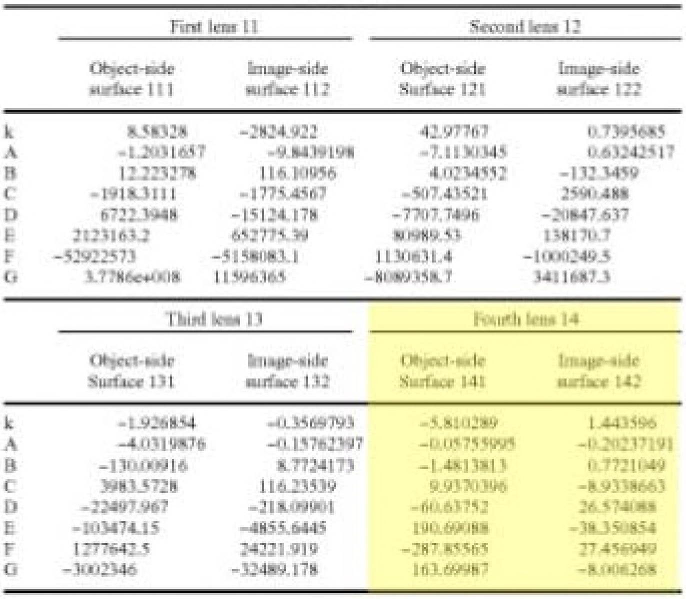
TABLE 2



	First lens 11		Second lens 12	
	Object-side surface 111	Image-side surface 112	Object-side surface 121	Image-side surface 122
k	0	0	6.191788	−3.784132
A	−0.2065838	−0.7720604	−1.4905075	−1.1446487
B	−3.3390093	1.4937038	13.548352	−13.499105
C	45.617387	−48.87327	−222.85883	142.67618
D	−568.5172	417.56966	1762.543	−811.19607
E	3836.6411	−1866.3668	−7503.2608	2964.6502
F	−14300.609	3693.0414	17228.893	−6161.6996
G	22470.012	−1072.5651	−16174.808	5342.7346

	Third lens 13		Fourth lens 14	
	Object-side surface 131	Image-side surface 132	Object-side surface 141	Image-side surface 142
k	−3.838175	−1.077898	−7.06691	−2.241616
A	−4.9202522	−0.5217609	0.10412867	−0.3678477
B	18.914991	0.96784978	−1.6835431	0.10715581
C	−20.771041	12.065814	4.2811759	0.31062561
D	12.125511	−36.497597	−6.3438122	−0.5323217
E	−142.85927	22.957229	5.6351203	0.37789525
F	243.02698	33.940443	−2.7711759	−0.1331061
G	30.761799	−33.635537	0.58039414	0.018683511

TABLE 6



	First lens 11		Second lens 12	
	Object-side surface 111	Image-side surface 112	Object-side Surface 121	Image-side surface 122
k	8.58328	−2824.922	42.97767	0.7395685
A	−1.2031657	−9.8439198	−7.1130345	0.63242517
B	12.223278	116.10956	4.0234552	−132.3459
C	−1918.3111	−1775.4567	−507.43521	2590.488
D	6722.3948	−15124.178	−7707.7496	−20847.637
E	2123163.2	652775.39	80989.53	138170.7
F	−52922573	−5158083.1	1130631.4	−1000249.5
G	3.7786e+008	11596365	−8089358.7	3411687.3

	Third lens 13		Fourth lens 14	
	Object-side Surface 131	Image-side surface 132	Object-side Surface 141	Image-side surface 142
k	−1.926854	−0.3569793	−5.810289	1.443596
A	−4.0319876	−0.15762397	−0.05755995	−0.20237191
B	−130.00916	8.7724173	−1.4813813	0.7721049
C	3983.5728	116.23539	9.9370396	−8.9338663
D	−22497.967	−218.09901	−60.63752	26.574088
E	−103474.15	−4855.6445	190.69088	−38.350854
F	1277642.5	24221.919	−287.85565	27.456949
G	−3002346	−32489.178	163.69987	−8.006268

109. Yu discloses that "[a]t least one of the object-side surface 141 and the image-side surface 142 of the fourth lens 14 has an inflection point located between the optical axis L and the peripheral surface 143." Ex. 1003, 3:15-18. The image-side surface 142 of the fourth lens 14 is concave in a paraxial region, as explained above,

and the existence of "an inflection point located between the optical axis L and peripheral surface 143" means that Yu's fourth lens 14 is convex in its off-axis region on the image-side surface as shown in Fig. 1 and Fig. 7. Ex. 1003, 3:7-18. I have highlighted this convex, off-axis region in the annotated versions of Fig. 1 (first embodiment) and Fig. 7 (third embodiment) below. If you think of the shape of surface 142 as the map of a road, and imagine driving along it, you will curve to the right and to the left by turning your steering wheel. The inflection points are the places where the steering wheel passes across the center. The road is actually straight for a short distance there, just where the curvature is reversing its direction. Thus, Yu's fourth lens 14 is "a fourth lens element … wherein … the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof."

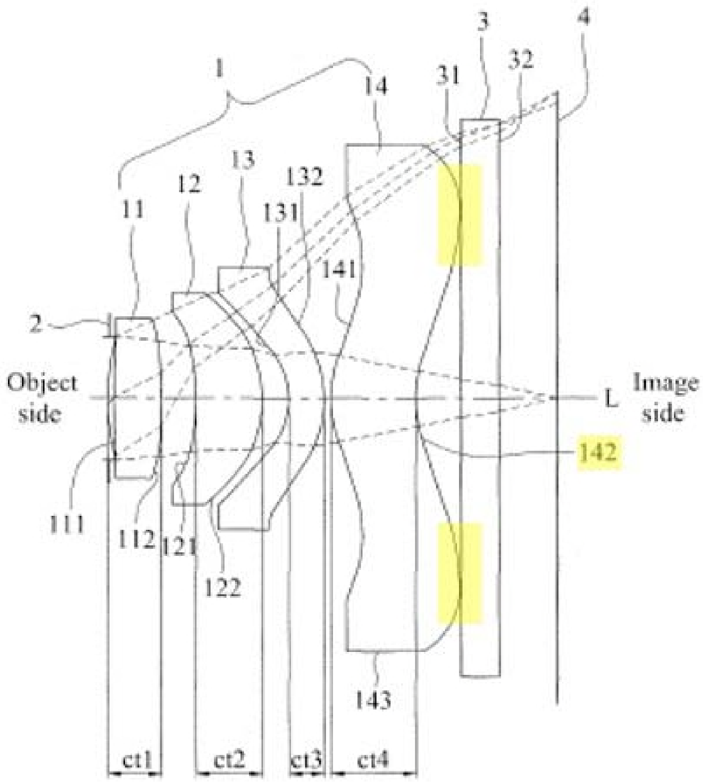

1
3
4
32
31
14
13
12
132
11
131
141
2
Object side
Image side
L
142
111
112
121
122
143
ct1
ct2
ct3
ct4

FIG.1

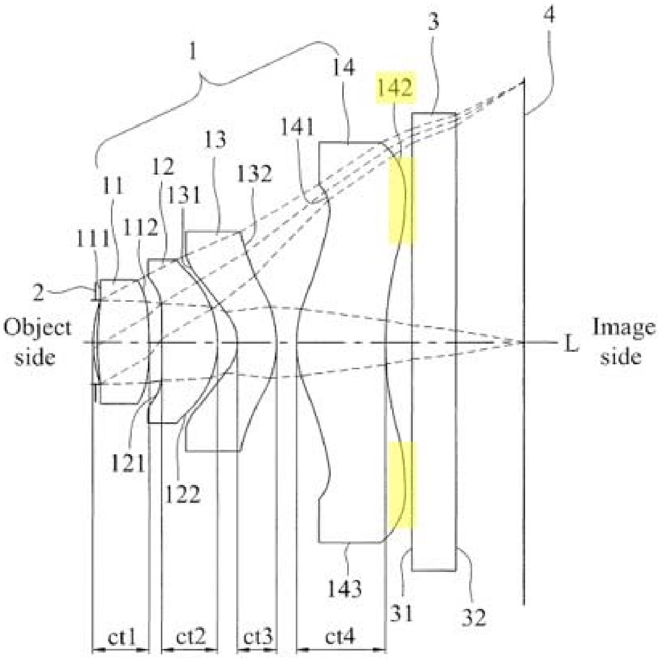


FIG.7

110. Accordingly, Yu's fourth lens 14 is "a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof, wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric, and the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof."

6. Element 1e: "wherein the image capturing lens system has a total of four lens elements with refractive power,"

111. Element 1e recites: "wherein the image capturing lens system has a total of four lens elements with refractive power." Ex. 1001, 30:64-65.

112. Yu discloses that its lens assembly “has a total of four lens elements with refractive power,” i.e., the first lens 11, second lens 12, third lens 13, and fourth lens 14 discussed above. Ex. 1003, 2:55-3:18. As shown in Fig. 1 (first embodiment) and Fig. 7 (third embodiment), Yu’s lens assembly comprises these four lenses and two non-lens components that do not have refractive power, i.e., “a non-adjustable diaphragm 2” and “a filter lens 3.” Ex. 1003, 2:52-58, Fig. 1, Fig. 7. Surface 4 is the receiving surface of the image sensor. Ex. 1005 ¶ 0030. Accordingly, Yu discloses that “the image capturing lens system has a total of four lens elements with refractive power.”

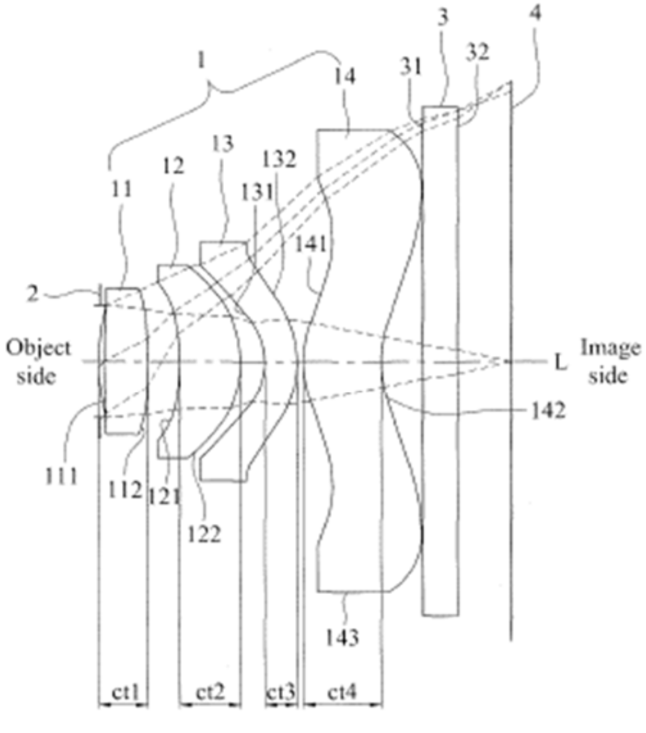


FIG.1

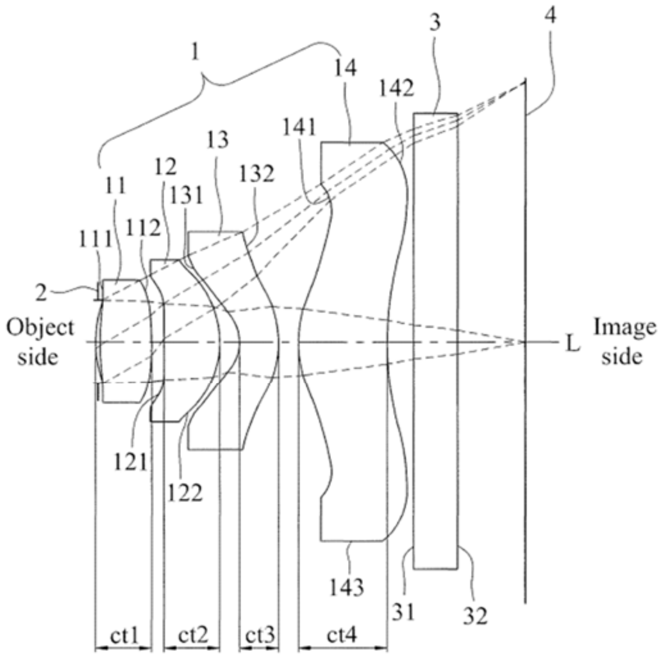


FIG.7

7. Element 1f: "an axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, half of a maximal field of view of the image capturing lens system is HFOV, a focal length of the image capturing lens system is f, a focal length of the fourth lens element is f4, a focal length of the second lens element is f2, a focal length of the third lens element is f3, and the following conditions are satisfied: 0.5 mm<Td<3.2 mm; 1.0 mm<Td/tan(HFOV)<3.75 mm; |f/f4|<1.20; and f2/f3<-0.65."

113. Element 1f recites:

- "an axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element is Td";
- "half of a maximal field of view of the image capturing lens system is HFOV";

- "a focal length of the image capturing lens system is f, a focal length of the fourth lens element is f4, a focal length of the second lens element is f2, a focal length of the third lens element is f3"; and
- "the following conditions are satisfied:

  0.5 mm<Td<3.2 mm;

  1.0 mm<Td/tan(HFOV)<3.75 mm;

  |f/f4|<1.20; and

  f2/f3<-0.65."

Ex. 1001, 30:65-31:15.

114. Yu's Table 1 "shows the parameters of components of the first preferred embodiment." Ex. 1003, 4:39-43, 4:51-5:20. The third column in Table 1 lists the center thickness of Yu's lenses and the interspace distance. Ex. 1003, 4:39-43, 4:51-5:20. To determine the "axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element … Td," one sums the following values: the center thickness of first lens 11 (0.284 mm), the interspace distance from the first lens 11 to the second lens 12 (0.194 mm), the center thickness of the second lens 12 (0.368 mm), the interspace distance from the second lens 12 to the third lens 13 (0.159 mm), the center thickness of the third lens 13 (0.190 mm), the interspace distance between the third lens 13 and the fourth lens 14 (0.038 mm), and the center thickness of the fourth lens 14 (0.472 mm). Ex. 1003, 4:51-5:20. In

Yu's first embodiment, Td equals 1.705 mm, which satisfies the condition "0.5 mm<Td<3.2 mm."

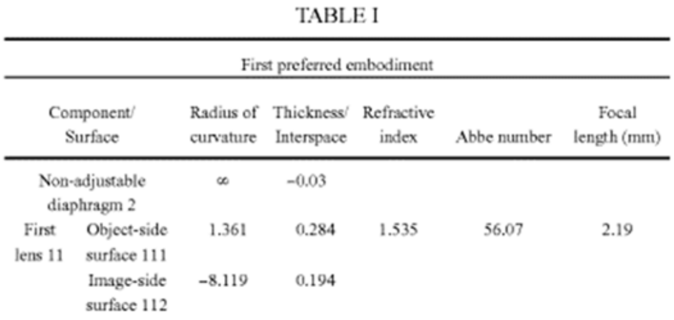


TABLE I

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Non-adjustable diaphragm 2		∞	−0.03			
First lens 11	Object-side surface 111	1.361	0.284	1.535	56.07	2.19
	Image-side surface 112	−8.119	0.194			

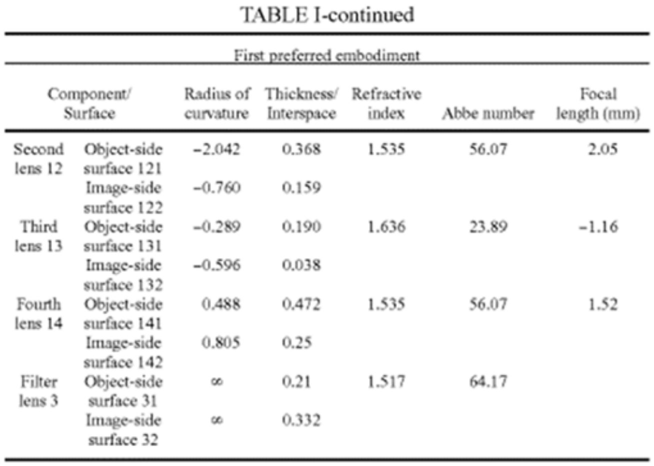


TABLE I-continued

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Second lens 12	Object-side surface 121	−2.042	0.368	1.535	56.07	2.05
	Image-side surface 122	−0.760	0.159			
Third lens 13	Object-side surface 131	−0.289	0.190	1.636	23.89	−1.16
	Image-side surface 132	−0.596	0.038			
Fourth lens 14	Object-side surface 141	0.488	0.472	1.535	56.07	1.52
	Image-side surface 142	0.805	0.25			
Filter lens 3	Object-side surface 31	∞	0.21	1.517	64.17	
	Image-side surface 32	∞	0.332			

115. Yu also discloses that "HFOV=44°," "f=1.60 mm," "f4=1.52 mm," "f2=2.05 mm," and "f3=-1.16 mm" in the first embodiment. Ex. 1003, 4:39-43. With these numbers:

- Td/tan(HFOV) equals 1.76558 mm, which satisfies the condition "1.0 mm<Td/tan(HFOV)<3.75 mm";
- The absolute value of f/f4 (i.e., |f/f4|) equals 1.05263, which satisfies the condition "|f/f4|<1.20"; and

- The value of f2/f3 is -1.76724, which satisfies the condition "f2/f3<-0.65."

116. Yu's Table 5 shows the "parameters of a third preferred embodiment of the lens assembly." Ex. 1003, 8:36-41, 8:48-9:14. The third column in Table 5 lists the center thickness of Yu's lenses and the interspace distance. Ex. 1003, 8:36-41, 8:48-9:14. To determine the "axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element … Td," one sums the following values: the center thickness of first lens 11 (0.239 mm), the interspace distance from the first lens 11 to the second lens 12 (0.062 mm), the center thickness of the second lens 12 (0.266 mm), the interspace distance from the second lens 12 to the third lens 13 (0.095 mm), the center thickness of the third lens 13 (0.187 mm), the interspace distance between the third lens 13 and the fourth lens 14 (0.092 mm), and the center thickness of the fourth lens 14 (0.429 mm). Ex. 1003, 8:48-9:14. In Yu's third embodiment, Td equals 1.37 mm, which satisfies the condition "0.5 mm<Td<3.2 mm."

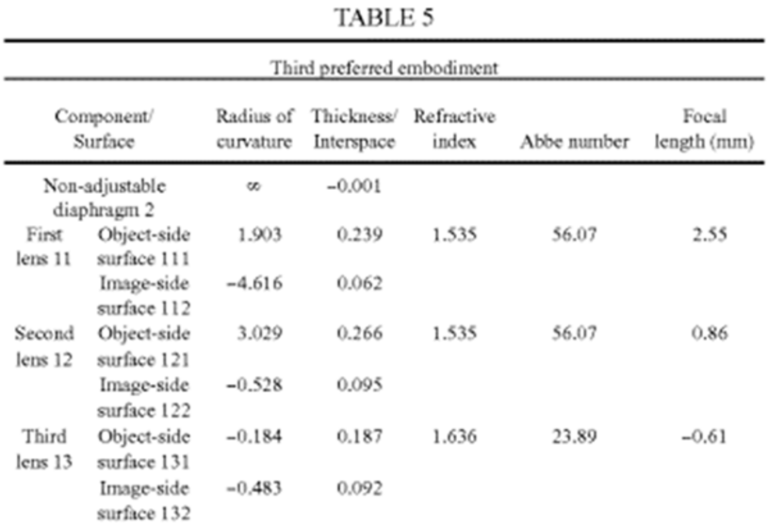


TABLE 5

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Third preferred embodiment						
Non-adjustable diaphragm 2		∞	−0.001			
First lens 11	Object-side surface 111	1.903	0.239	1.535	56.07	2.55
	Image-side surface 112	−4.616	0.062			
Second lens 12	Object-side surface 121	3.029	0.266	1.535	56.07	0.86
	Image-side surface 122	−0.528	0.095			
Third lens 13	Object-side surface 131	−0.184	0.187	1.636	23.89	−0.61
	Image-side surface 132	−0.483	0.092			

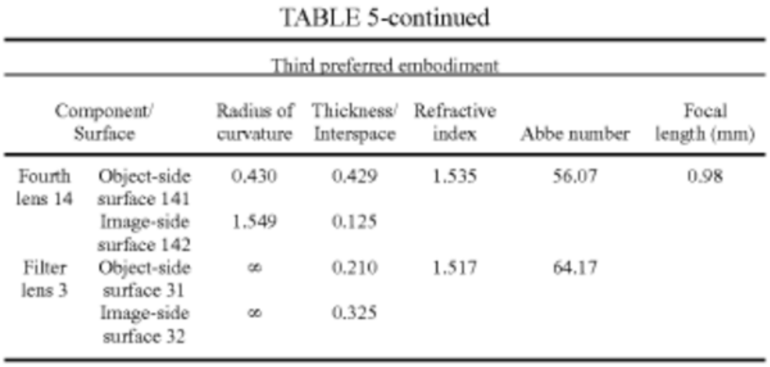


TABLE 5-continued

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Third preferred embodiment						
Fourth lens 14	Object-side surface 141	0.430	0.429	1.535	56.07	0.98
	Image-side surface 142	1.549	0.125			
Filter lens 3	Object-side surface 31	∞	0.210	1.517	64.17	
	Image-side surface 32	∞	0.325			

117. Yu also discloses that "HFOV=44°," "f=1.13 mm," "f4=0.98 mm," "f2=0.86 mm," and "f3=-0.61 mm" in the third embodiment. Ex. 1003, 8:36-41. With these numbers:

- Td/tan(HFOV) equals 1.41868 mm, which satisfies the condition "1.0 mm<Td/tan(HFOV)<3.75 mm";
- The absolute value of f/f4 (i.e., |f/f4|) equals 1.15306, which satisfies the condition "|f/f4|<1.20"; and
- The value of f2/f3 is -1.40984, which satisfies the condition "f2/f3<-0.65."

118. Accordingly, Yu discloses "an axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, half of a maximal field of view of the image capturing lens system is HFOV, a focal length of the image capturing lens system is f, a focal length of the fourth lens element is f4, a focal length of the second lens element is f2, a focal length of the third lens element is f3, and the following conditions are satisfied: 0.5 mm<Td<3.2 mm; 1.0 mm<Td/tan(HFOV)<3.75 mm; |f/f4|<1.20; and f2/f3<-0.65."

8. Conclusion for Claim 1

119. As I have explained above in this section, Yu discloses all elements of claim 1. Accordingly, Yu renders claim 1 obvious.

B. Claim 2: "The image capturing lens system of claim 1, wherein the fourth lens element has the object-side surface being convex in a paraxial region thereof."

120. Claim 2 depends from claim 1 and recites: "The image capturing lens system of claim 1, wherein the fourth lens element has the object-side surface being convex in a paraxial region thereof." Ex. 1001, 31:16-18.

121. As discussed above, I analyze Yu's first embodiment for claim 2. Yu discloses that "[t]he fourth lens 14 has … an object-side surface [141] which faces the object side." Ex. 1003, 3:7-13, Fig. 1. As I explained in Section XII.A.5, the object-side surface of Yu's fourth lens 14 should have been labeled 141 in this sentence, but the specification has a typo. Yu's Table 1 (first embodiment) lists the

radius of curvature of the object-side surface 141 of the fourth lens 14 as 0.488 mm. Ex. 1003, 5:12-13. I have highlighted the radius of curvature of the object-side surface 141 of the fourth lens 14 in the annotated version of Table 1 (first embodiment) below. As I explained above, this positive radius denotes a convex object-side surface in the paraxial region of the fourth lens 14.

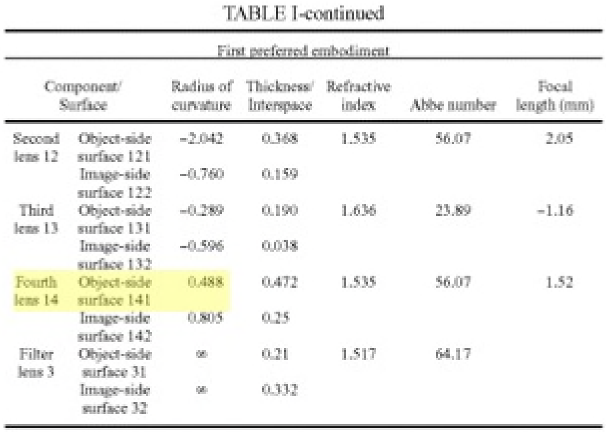


TABLE I-continued

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Second lens 12	Object-side surface 121	−2.042	0.368	1.535	56.07	2.05
	Image-side surface 122	−0.760	0.159			
Third lens 13	Object-side surface 131	−0.289	0.190	1.636	23.89	−1.16
	Image-side surface 132	−0.596	0.038			
Fourth lens 14	Object-side surface 141	0.488	0.472	1.535	56.07	1.52
	Image-side surface 142	0.805	0.25			
Filter lens 3	Object-side surface 31	∞	0.21	1.517	64.17	
	Image-side surface 32	∞	0.332			

122. I have highlighted the convex object-side surface 141 of the fourth lens 14 in the annotated version of Fig. 1 (first embodiment) below. Accordingly, Yu discloses that “the fourth lens element has the object-side surface being convex in a paraxial region thereof.”

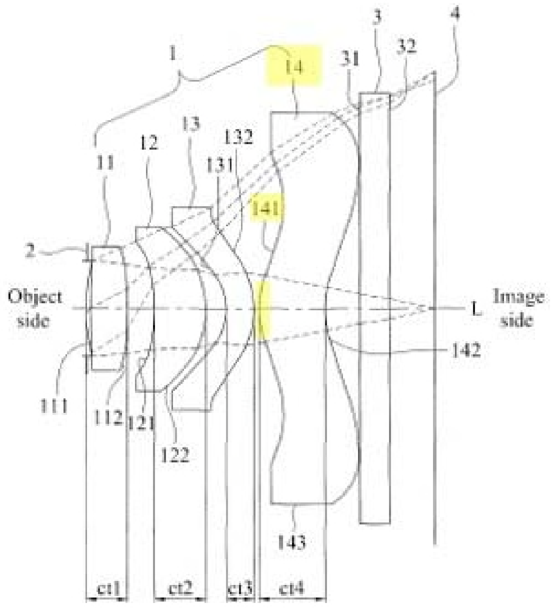


FIG.1

1. Conclusion for Claim 2

123. As I explained in Section XII.A, Yu renders claim 1 obvious. As I explained in this section, Yu discloses the additional element of claim 2. Accordingly, Yu renders claim 2 obvious.

C. Claim 3: "The image capturing lens system of claim 2, wherein the focal length of the image capturing lens system is f, a focal length of the first lens element is f1, and the following condition is satisfied: -0.25<f/f1<0.75."

124. Claim 3 depends from claim 2 and recites: "The image capturing lens system of claim 2, wherein the focal length of the image capturing lens system is f, a focal length of the first lens element is f1, and the following condition is satisfied: -0.25<f/f1<0.75." Ex. 1001, 31:19-24.

125. As discussed above, I analyze Yu's first embodiment for claim 3. In Yu's first embodiment, "f=1.60 mm" and "f1=2.19 mm." Ex. 1003, 4:39-43. Thus, f/f1 equals 0.73059, which satisfies the condition "-0.25<f/f1<0.75." Thus, Yu discloses that "the focal length of the image capturing lens system is f, a focal length of the first lens element is f1, and the following condition is satisfied: -0.25<f/f1<0.75."

1. Conclusion for Claim 3

126. As I explained in Section XII.B, Yu renders claim 2 obvious. As I explained in this section, Yu discloses the additional element of claim 3. Accordingly, Yu renders claim 3 obvious.

D. Claim 4: "The image capturing lens system of claim 2, wherein the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.8 mm<Td<2.5 mm."

127. Claim 4 depends from claim 2 and recites: "The image capturing lens system of claim 2, wherein the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.8 mm<Td<2.5 mm." Ex. 1001, 31:25-30.

128. As discussed above, I analyze Yu's first embodiment for claim 4. I calculated Td for Yu's first embodiment in Section XII.A.7, and it equals 1.705 mm. This satisfies the condition "0.8 mm<Td<2.5 mm." Thus, Yu discloses that "the axial distance between the object-side surface of the first lens element and the image-side

surface of the fourth lens element is Td, and the following condition is satisfied: 0.8 mm<Td<2.5 mm."

1. Conclusion for Claim 4

129. As I explained in Section XII.B, Yu renders claim 2 obvious. As I explained in this section, Yu discloses the additional element of claim 4. Accordingly, Yu renders claim 4 obvious.

E. Claim 6: "The image capturing lens system of claim 2, wherein a curvature radius of the object-side surface of the second lens element is R3, a curvature radius of the image-side surface of the second lens element is R4, and the following condition is satisfied: 0.5<(R3+R4)/(R3-R4)<2.5."

130. Claim 6 depends from claim 2 and recites: "The image capturing lens system of claim 2, wherein a curvature radius of the object-side surface of the second lens element is R3, a curvature radius of the image-side surface of the second lens element is R4, and the following condition is satisfied: 0.5<(R3+R4)/(R3-R4)<2.5." Ex. 1001, 31:36-43.

131. As discussed above, I analyze Yu's first embodiment for claim 6. Yu's Table 1 (first embodiment) lists the radius of curvature for the object-side surface 121 of the second lens 12 ("R3") as -2.042 mm and the radius of curvature of the image-side surface 122 of the second lens 12 ("R4") as -0.760 mm. Ex. 1003, 5:4-7. I have highlighted the radius of curvature of object-side surface 121 and image-side surface 122 of the second lens 12 in the annotated version of Table 1 (first

embodiment) below. Thus, (R3+R4)/(R3-R4) equals 2.18565, which satisfies the condition "0.5<(R3+R4)/(R3-R4)<2.5." Yu discloses that "a curvature radius of the object-side surface of the second lens element is R3, a curvature radius of the image-side surface of the second lens element is R4, and the following condition is satisfied: 0.5<(R3+R4)/(R3-R4)<2.5."

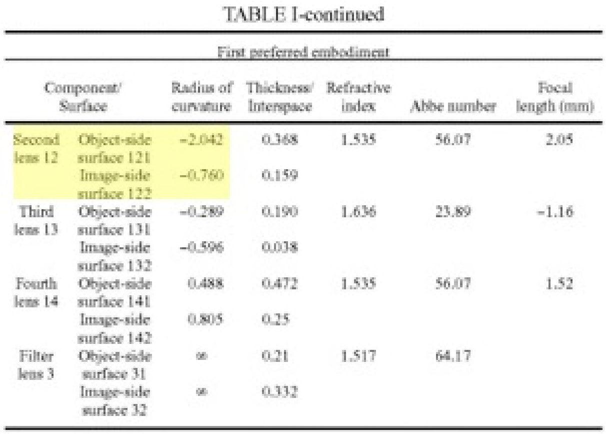


TABLE I-continued

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Second lens 12	Object-side surface 121	−2.042	0.368	1.535	56.07	2.05
	Image-side surface 122	−0.760	0.159			
Third lens 13	Object-side surface 131	−0.289	0.190	1.636	23.89	−1.16
	Image-side surface 132	−0.596	0.038			
Fourth lens 14	Object-side surface 141	0.488	0.472	1.535	56.07	1.52
	Image-side surface 142	0.805	0.25			
Filter lens 3	Object-side surface 31	∞	0.21	1.517	64.17	
	Image-side surface 32	∞	0.332			

1. Conclusion for Claim 6

132. As I explained in Section XII.B, Yu renders claim 2 obvious. As I explained in this section, Yu discloses the additional element of claim 6. Accordingly, Yu renders claim 6 obvious.

F. Claim 7: "The image capturing lens system of claim 2, wherein the focal length of the image capturing lens system is f, and the following condition is satisfied: 0.5 mm<f<2.0 mm."

133. Claim 7 depends from claim 2 and recites: "The image capturing lens system of claim 2, wherein the focal length of the image capturing lens system is f, and the following condition is satisfied: 0.5 mm<f<2.0 mm." Ex. 1001, 31:44-48.

134. As discussed above, I analyze Yu's first embodiment for claim 7. In Yu's first embodiment, "f=1.60 mm," which satisfies the condition "0.5 mm<f<2.0 mm." Ex. 1003, 4:39-44. Yu discloses that "the focal length of the image capturing lens system is f, and the following condition is satisfied: 0.5 mm<f<2.0 mm."

1. Conclusion for Claim 7

135. As I explained in Section XII.B, Yu renders claim 2 obvious. As I explained in this section, Yu discloses the additional element of claim 7. Accordingly, Yu renders claim 7 obvious.

G. Claim 8: "The image capturing lens system of claim 1, wherein the first lens element has a convex object-side surface in a paraxial region thereof."

136. Claim 8 depends from claim 1 and recites: "The image capturing lens system of claim 1, wherein the first lens element has a convex object-side surface in a paraxial region thereof." Ex. 1001, 31:49-51.

137. As discussed above, I analyze Yu's first and third embodiments for claim 8. Yu discloses that "[t]he first lens 11 … has a convex object-side surface 111 which faces the object side." Ex. 1003, 2:58-61, Fig. 1, Fig. 7. By convention one of ordinary skill in the art bases an identification of a surface as convex or concave by considering just the central region, near the optical axis, often referred to as "the paraxial region."

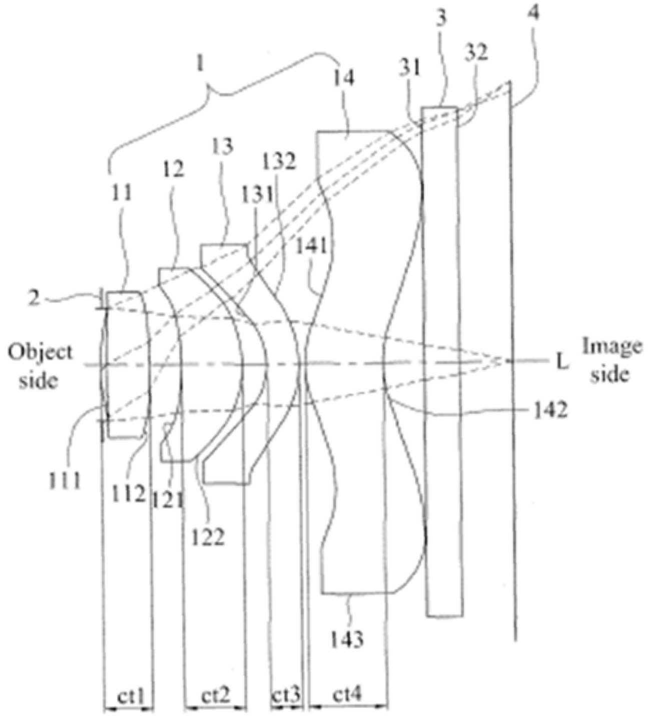
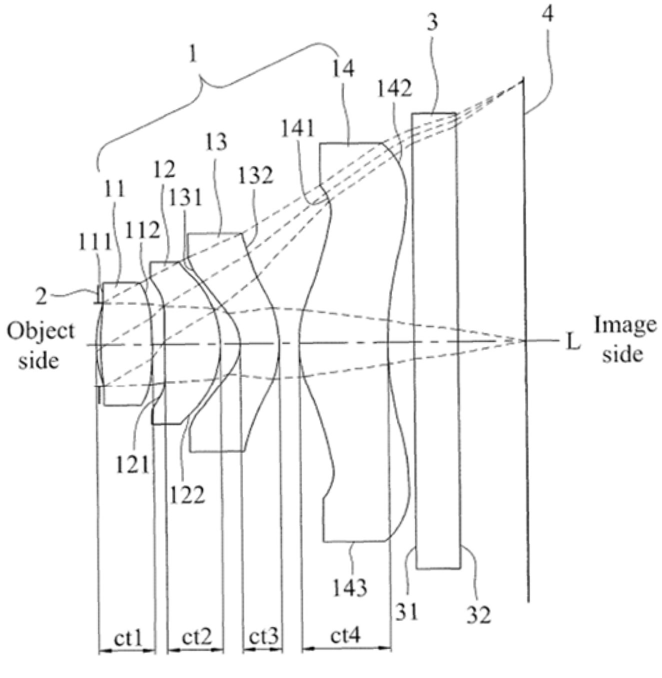

1
14
31
3
32
4
11
12
13
132
131
141
2
Object side
L
Image side
142
111
112
121
122
143
ct1
ct2
ct3
ct4

FIG.1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Object side
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ct1
ct2
ct3
ct4

FIG.7

138. Table 1 (first embodiment) and Table 5 (third embodiment) confirm that the first lens 11 has a convex object-side surface 111 in the paraxial region, because the radius of curvature for this surface is positive in both embodiments (1.361 mm in the first embodiment and 1.903 mm in the third embodiment). Ex. 1003, 4:64-65, 8:56-57. I have highlighted the radius of curvature of the object-side surface 111 of the first lens 11 in the annotated versions of Table 1 (first embodiment) and Table 5 (third embodiment) below. As I explained above, a positive radius of curvature denotes a convex object-side surface. Thus, Yu discloses that "the first lens element has a convex object-side surface in a paraxial region thereof."

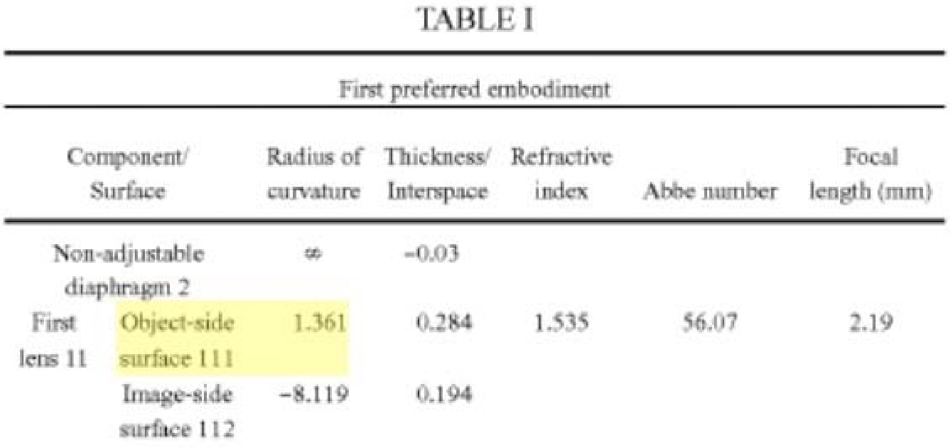


TABLE I

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Non-adjustable diaphragm 2		∞	−0.03			
First lens 11	Object-side surface 111	1.361	0.284	1.535	56.07	2.19
	Image-side surface 112	−8.119	0.194			

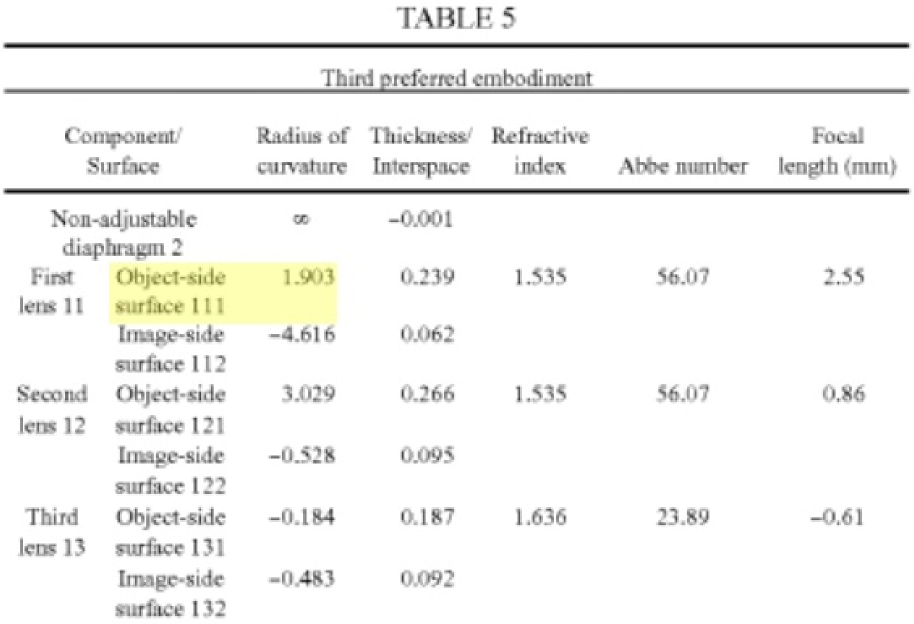


TABLE 5

Third preferred embodiment						
Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Non-adjustable diaphragm 2		∞	−0.001			
First lens 11	Object-side surface 111	1.903	0.239	1.535	56.07	2.55
	Image-side surface 112	−4.616	0.062			
Second lens 12	Object-side surface 121	3.029	0.266	1.535	56.07	0.86
	Image-side surface 122	−0.528	0.095			
Third lens 13	Object-side surface 131	−0.184	0.187	1.636	23.89	−0.61
	Image-side surface 132	−0.483	0.092			

1. Conclusion for Claim 8

139. As I explained in Section XII.A, Yu renders claim 1 obvious. As I explained in this section, Yu discloses the additional element of claim 8. Accordingly, Yu renders claim 8 obvious.

H. Claim 9: "The image capturing lens system of claim 8, wherein the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, half of the maximal field of view of the image capturing lens system is HFOV, and the following condition is satisfied: 1.2 mm<Td/tan(HFOV)<2.75 mm."

140. Claim 9 depends from claim 8 and recites: "The image capturing lens system of claim 8, wherein the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, half of the maximal field of view of the image capturing lens system is HFOV, and the

following condition is satisfied: 1.2 mm<Td/tan(HFOV)<2.75 mm." Ex. 1001, 31:52-58.

141. As discussed above, I analyze Yu's first embodiment for claim 9. I calculated Td/tan(HFOV) for Yu's first embodiment in Section XII.A.7, and it equals 1.76558 mm. This satisfies the condition "1.2 mm<Td/tan(HFOV)<2.75 mm." Thus, Yu discloses that "the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, half of the maximal field of view of the image capturing lens system is HFOV, and the following condition is satisfied: 1.2 mm<Td/tan(HFOV)<2.75 mm."

1. Conclusion for Claim 9

142. As I explained in Section XII.G, Yu renders claim 8 obvious. As I explained in this section, Yu discloses the additional element of claim 9. Accordingly, Yu renders claim 9 obvious.

I. Claim 10: "The image capturing lens system of claim 8, wherein a sum of the central thicknesses of the first lens element, the second lens element, the third lens element, and the fourth lens element is ∑CT, the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.80<∑CT/Td<0.95."

143. Claim 10 depends from claim 8 and recites: "The image capturing lens system of claim 8, wherein a sum of the central thicknesses of the first lens element, the second lens element, the third lens element, and the fourth lens element is ∑CT, the

axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.80<∑CT/Td<0.95." Ex. 1001, 31:59-67.

144. As discussed above, I analyze Yu's third embodiment for claim 10. Yu's Table 5 shows the "parameters of a third preferred embodiment of the lens assembly." Ex. 1003, 8:36-41, 8:48-9:14. The third column in Table 5 lists the center thickness of Yu's lenses and the interspace distance in the third embodiment. Ex. 1003, 8:36-41, 8:48-9:14. In the third embodiment, the center thickness of the first lens 11 is 0.239 mm, the center thickness of the second lens 12 is 0.266 mm, the center thickness of the third lens 13 is 0.187 mm, and the center thickness of the fourth lens 14 is 0.429 mm. Ex. 1003, 8:36-41, 8:48-9:14. Thus, ∑CT equals 1.121 mm.

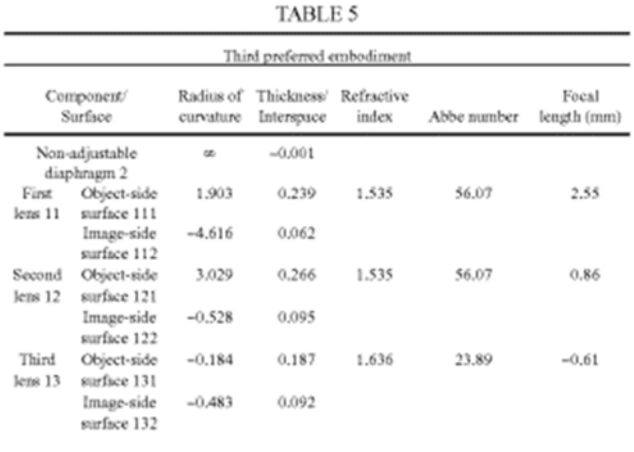


TABLE 5

Third preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Non-adjustable diaphragm 2		∞	−0.001			
First lens 11	Object-side surface 111	1.903	0.239	1.535	56.07	2.55
	Image-side surface 112	−4.616	0.062			
Second lens 12	Object-side surface 121	3.029	0.266	1.535	56.07	0.86
	Image-side surface 122	−0.528	0.095			
Third lens 13	Object-side surface 131	−0.184	0.187	1.636	23.89	−0.61
	Image-side surface 132	−0.483	0.092			

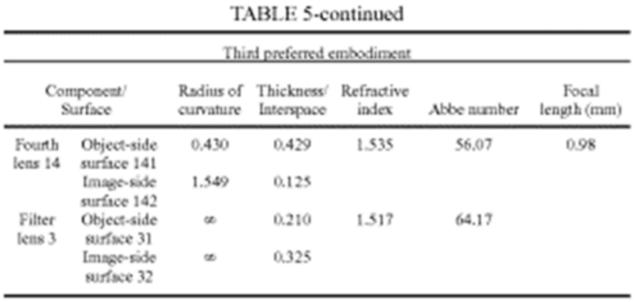


TABLE 5-continued

Third preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Fourth lens 14	Object-side surface 141	0.430	0.429	1.535	56.07	0.98
	Image-side surface 142	1.549	0.125			
Filter lens 3	Object-side surface 31	∞	0.210	1.517	64.17	
	Image-side surface 32	∞	0.325			

145. I explained in Section XII.A.7 that Td equals 1.37 mm for Yu's third embodiment. Thus, in Yu's third embodiment, ∑CT/Td equals 0.81825, which satisfies the condition "0.80<∑CT/Td<0.95." Yu discloses that "a sum of the central thicknesses of the first lens element, the second lens element, the third lens element, and the fourth lens element is ∑CT, the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.80<∑CT/Td<0.95."

1. Conclusion for Claim 10

146. As I explained in Section XII.G, Yu renders claim 8 obvious. As I explained in this section, Yu discloses the additional element of claim 10. Accordingly, Yu renders claim 10 obvious.

J. Claim 11: "The image capturing lens system of claim 8, wherein an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1."

147. Claim 11 depends from claim 8 and recites: "The image capturing lens system of claim 8, wherein an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1." Ex. 1001, 32:1-5.

148. As discussed above, I analyze Yu's first embodiment for claim 11. The Abbe number of the first lens 11 in Yu's first embodiment is 56.07. Ex. 1003, 4:60. Thus, Yu discloses that "an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1."

1. Conclusion for Claim 11

149. As I explained in Section XII.G, Yu renders claim 8 obvious. As I explained in this section, Yu discloses the additional element of claim 11. Accordingly, Yu renders claim 11 obvious.

K. Claim 15

1. Preamble: "An image capturing lens system comprising, in order from an object side to an image side:"

150. The preamble of claim 15 recites: "An image capturing lens system comprising, in order from an object side to an image side." Ex. 1001, 32:19-20. As discussed above, I analyze Yu's first embodiment for claim 15. This is identical to the preamble of claim 1. *Compare* Ex. 1001, 32:19-20 *with* Ex. 1001, 30:48-49. Because the preambles are identical, my analysis for the preamble of claim 1 in Section XII.A.1 applies equally to the preamble of claim 15. To the extent the preamble is limiting, Yu discloses the preamble of claim 15.

2. Element 15a: "a first lens element having refractive power;"

151. Element 15a recites: "a first lens element having refractive power." Ex. 1001, 32:21. This is identical to Element 1a. *Compare* Ex. 1001, 32:21 *with* Ex. 1001, 30:50. Because Element 1a and Element 15a are identical, my analysis for Element 1a in Section XII.A.2 applies equally to Element 15a. Yu discloses Element 15a.

3. Element 15b: "a second lens element with positive refractive power having a convex image-side surface in a paraxial region thereof;"

152. Element 15b recites: "a second lens element with positive refractive power having a convex image-side surface in a paraxial region thereof." Ex. 1001, 32:22-24. This is identical to Element 1b. *Compare* Ex. 1001, 32:22-24 *with* Ex. 1001, 30:51-53. Because Element 1b and Element 15b are identical, my analysis for Element 1b in Section XII.A.3 applies equally to Element 15b. Yu discloses Element 15b.

4. Element 15c: "a third lens element with negative refractive power having a concave object-side surface in a paraxial region thereof and a convex image-side surface in a paraxial region thereof; and"

153. Element 15c recites: "a third lens element with negative refractive power having a concave object-side surface in a paraxial region thereof and a convex image-side surface in a paraxial region thereof." Ex. 1001, 32:25-28. This is identical to Element 1c. *Compare* Ex. 1001, 32:25-28 *with* Ex. 1001, 30:54-57.

Because Element 1c and Element 15c are identical, my analysis for Element 1c in Section XII.A.4 applies equally to Element 15c. Yu discloses Element 15c.

5. Element 15d: "a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof, wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric, and the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof;"

154. Element 15d recites: "a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof, wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric, and the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof." Ex. 1001, 32:29-34. This is identical to Element 1d. *Compare* Ex. 1001, 32:29-34 *with* Ex. 1001, 30:58-63. Because Element 1d and Element 15d are identical, my analysis for Element 1d in Section XII.A.5 applies equally to Element 15d. Yu discloses Element 15d.

6. Element 15e: "wherein the image capturing lens system has a total of four lens elements with refractive power,"

155. Element 15e recites: "wherein the image capturing lens system has a total of four lens elements with refractive power." Ex. 1001, 32:35-36. This is identical to Element 1e. *Compare* Ex. 1001, 32:35-36 *with* Ex. 1001, 30:64-65. Because Element 1e and Element 15e are identical, my analysis for Element 1e in Section XII.A.6 applies equally to Element 15e. Yu discloses Element 15e.

7. Element 15f: “an axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, half of a maximal field of view of the image capturing lens system is HFOV, a focal length of the image capturing lens system is f, a focal length of the fourth lens element is f4, a focal length of the third lens element is f3, and the following conditions are satisfied: 0.5 mm<Td<3.2 mm; 1.0 mm<Td/tan(HFOV)<3.75 mm; |f/f4|<1.20; and -2.0<f/f3<-0.95.”

156. Element 15f recites:

- “an axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element is Td”;
- “half of a maximal field of view of the image capturing lens system is HFOV”;
- “a focal length of the image capturing lens system is f, a focal length of the fourth lens element is f4, a focal length of the third lens element is f3”; and
- “the following conditions are satisfied:

  0.5 mm<Td<3.2 mm;

  1.0 mm<Td/tan(HFOV)<3.75 mm;

  |f/f4|<1.20; and

  -2.0<f/f3<-0.95.”

Ex. 1001, 32:36-51.

157. In Section XII.A.7, I explained that Td equals 1.705 mm, f equals 1.60 mm, f4 equals 1.52 mm, f3 equals -1.16 mm, Td/tan(HFOV) equals 1.76558 mm, and

|f/f4| equals 1.05263 in Yu's first embodiment. Using these numbers, f/f3 equals -1.37931. These values of Td, Td/tan(HFOV), |f/f4|, and f/f3 for Yu's first embodiment satisfy each of the conditions in Element 15f: "0.5 mm<Td<3.2 mm; 1.0 mm<Td/tan(HFOV)<3.75 mm; |f/f4|<1.20; and -2.0<f/f3<-0.95."

8. Conclusion for Claim 15

158. As I have explained above in this section, Yu discloses all elements of claim 15. Accordingly, Yu renders claim 15 obvious.

L. Claim 16: "The image capturing lens system of claim 15, wherein an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1."

159. Claim 16 depends from claim 15 and recites: "The image capturing lens system of claim 15, wherein an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1." Ex. 1001, 32:52-56.

160. As discussed above, I analyze Yu's first embodiment for claim 16. I explained in Section XII.J that Yu discloses that "an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1" because the Abbe number of the first lens 11 in Yu's first embodiment is 56.07. Ex. 1003, 4:60.

1. Conclusion for Claim 16

161. As I explained in Section XII.K, Yu renders claim 15 obvious. As I explained in this section, Yu discloses the additional element of claim 16. Accordingly, Yu renders claim 16 obvious.

M. Claim 17: "The image capturing lens system of claim 15, wherein the focal length of the image capturing lens system is f, a focal length of the first lens element is f1, and the following condition is satisfied: -0.25<f/f1<0.75."

162. Claim 17 depends from claim 15 and recites: "The image capturing lens system of claim 15, wherein the focal length of the image capturing lens system is f, a focal length of the first lens element is f1, and the following condition is satisfied: -0.25<f/f1<0.75." Ex. 1001, 32:57-62.

163. As discussed above, I analyze Yu's first embodiment for claim 17. I explained in Section XII.C that Yu discloses that "the focal length of the image capturing lens system is f, a focal length of the first lens element is f1, and the following condition is satisfied: -0.25<f/f1<0.75" because f/f1 equals 0.73059 in Yu's first embodiment. Ex. 1003, 4:39-43.

1. Conclusion for Claim 17

164. As I explained in Section XII.K, Yu renders claim 15 obvious. As I explained in this section, Yu discloses the additional element of claim 17. Accordingly, Yu renders claim 17 obvious.

N. Claim 18: "The image capturing lens system of claim 15, wherein a maximal field of view of the image capturing lens system is FOV, and the following condition is satisfied: 80 degrees<FOV<110 degrees."

165. Claim 18 depends from claim 15 and recites: "The image capturing lens system of claim 15, wherein a maximal field of view of the image capturing lens

system is FOV, and the following condition is satisfied: 80 degrees<FOV<110 degrees." Ex. 1001, 32:63-67.

166. As discussed above, I analyze Yu's first embodiment for claim 18. In Yu's first embodiment, "HFOV=44°." Ex. 1003, 4:39-43. "HFOV represents one half of a maximum angle of view of the lens assembly …." Ex. 1003, 2:13-14. Thus, the "maximal field of view" of Yu's first embodiment equals 2 times 44°, which equals 88 degrees and satisfies the condition "80 degrees<FOV<110 degrees."

1. Conclusion for Claim 18

167. As I explained in Section XII.K, Yu renders claim 15 obvious. As I explained in this section, Yu discloses the additional element of claim 18. Accordingly, Yu renders claim 18 obvious.

O. Claim 19: "The image capturing lens system of claim 15, wherein the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.8 mm<Td<2.5 mm."

168. Claim 19 depends from claim 15 and recites: "The image capturing lens system of claim 15, wherein the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.8 mm<Td<2.5 mm." Ex. 1001, 33:1-6.

169. As discussed above, I analyze Yu's first embodiment for claim 19. I explained in Section XII.D that Yu discloses that "the axial distance between the

object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.8 mm<Td<2.5 mm" because Td equals 1.705 mm in Yu's first embodiment.

1. Conclusion for Claim 19

170. As I explained in Section XII.K, Yu renders claim 15 obvious. As I explained in this section, Yu discloses the additional element of claim 19. Accordingly, Yu renders claim 19 obvious.

P. Claim 20: "The image capturing lens system of claim 15, wherein a focal length of the second lens element is f2, the focal length of the third lens element is f3, and the following condition is satisfied: f2/f3<-0.75."

171. Claim 20 depends from claim 15 and recites: "The image capturing lens system of claim 15, wherein a focal length of the second lens element is f2, the focal length of the third lens element is f3, and the following condition is satisfied: f2/f3<-0.75." Ex. 1001, 33:7-12.

172. As discussed above, I analyze Yu's first embodiment for claim 20. I explained in Section XII.A.7 that f2/f3 equals -1.76724 in Yu's first embodiment. This satisfies the condition " f2/f3<-0.75."

1. Conclusion for Claim 20

173. As I explained in Section XII.K, Yu renders claim 15 obvious. As I explained in this section, Yu discloses the additional element of claim 20. Accordingly, Yu renders claim 20 obvious.

Q. Claim 5: "The image capturing lens system of claim 2, wherein an f-number of the image capturing lens system is Fno, and the following condition is satisfied: 1.40<Fno≤2.25."

174. Claim 5 depends from claim 2 and recites: "The image capturing lens system of claim 2, wherein an f-number of the image capturing lens system is Fno, and the following condition is satisfied: 1.40<Fno≤2.25." Ex. 1001, 31:31-35.

175. The f-number (Fno) of a lens system equals the focal length of the lens system divided by the diameter of the entrance pupil. The entrance pupil of a lens system is the view of the aperture stop as seen through all of the lenses of the lens system, if any, that are on the object side (to the left) of the aperture stop.

176. As discussed above, I analyze Yu's first embodiment for claim 5. Yu discloses that a "non-adjustable diaphragm is located between the object side and the second lens of the lens set." Ex. 1003, 2:7-9, 3:19-20. Yu's non-adjustable diaphragm is an aperture stop. It is a constricted opening that limits the size of the beam of light passing through the lens system. As shown in Yu's Fig. 1, the non-adjustable diaphragm 2 is to the left of the first lens 11 in the first embodiment. Ex.

1003, 2:52-54, Fig. 1. I have highlighted the non-adjustable diaphragm 2 in Yu's Fig. 1 below.

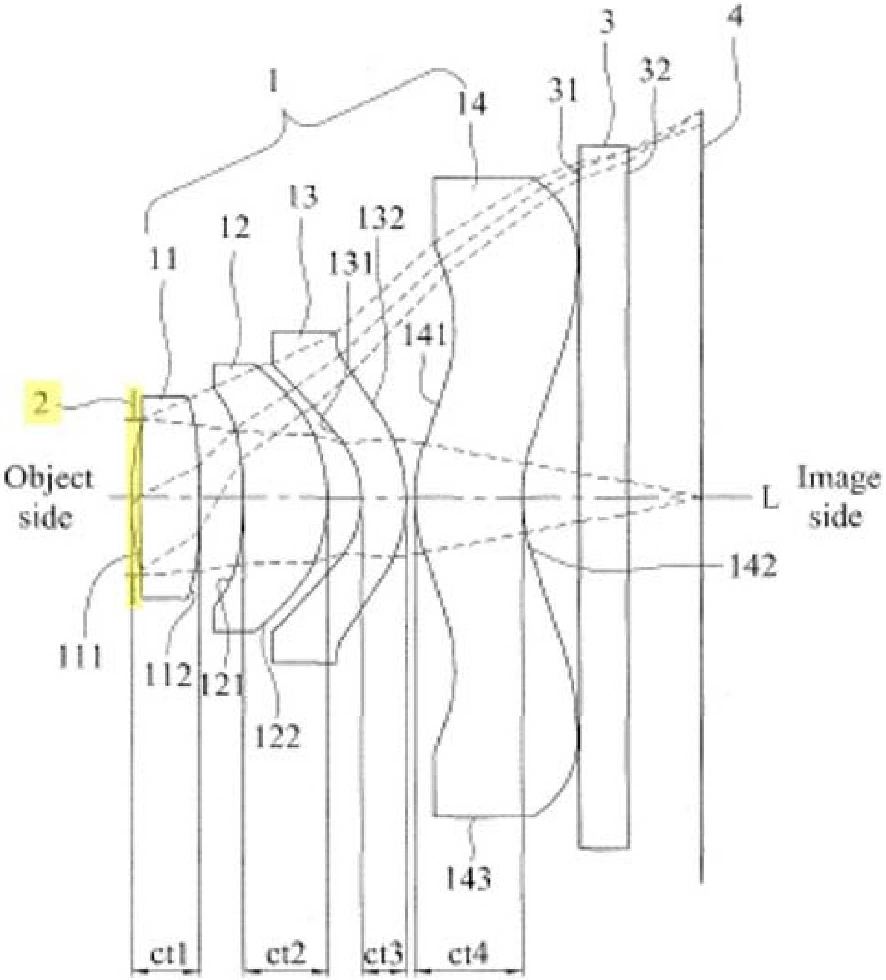


FIG.1

177. Yu's Table 1 discloses that the center of the non-adjustable diaphragm 2 is 0.03 mm to the right of the center vertex of the object-side surface 111 of the first lens 11 in Yu's first embodiment, because the interspace distance is listed as -0.03 mm for the non-adjustable diaphragm 2. Ex. 1003, 4:62-63. The object-side surface

111 of the first lens 11 protrudes slightly through the opening in the non-adjustable diaphragm 2, so it actually crosses the axis to the left of the center of the hole in the non-adjustable diaphragm 2. I have highlighted this value in Yu's Table 1 below.

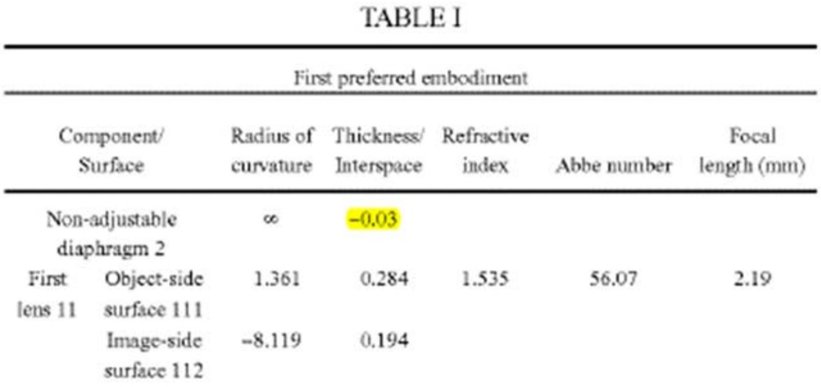


TABLE I

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Non-adjustable diaphragm 2		∞	−0.03			
First lens 11	Object-side surface 111	1.361	0.284	1.535	56.07	2.19
	Image-side surface 112	−8.119	0.194			

178. Because the non-adjustable diaphragm 2 is physically to the left of the first lens 11 in Yu's first embodiment, however, the diameter of its opening is the entrance pupil of the lens system.

179. At the time of the '796 patent (and still today), the lens-design process begins with classic lens designs, as I discussed above in Section VII. At the time of the '796 patent, one such design would have been Yu's first embodiment. It would have been obvious to a person of ordinary skill in the art to use Yu's first embodiment as the starting point for a new design.

180. As I mentioned in Section VII, a lens design request usually begins with certain specifications, which include the f-number (Fno). The f-number (Fno) specified for a particular lens system design may vary depending on the end-use of the lens system. Selecting an f-number (Fno) always involves a tradeoff between

the light-gathering ability of the lens system on the one hand (which increases with a smaller f-number (Fno)) and the sharpness of the image produced by the lens system on the other hand. In certain applications, such as photographing a fast moving athletic event, improving the ability of the lens system to gather light and freeze motion is more important than maintaining the fullest sharpness of the image. Or, as disclosed in U.S. Patent Application Publication No. 2012/0147249 ("Okano"), which was published on June 14, 2012, and is prior art to the '796 patent, a lens assembly with a low f-number may be desired "in order to prevent deterioration of image quality due to noise in photographing in dark places." Ex. 1011 ¶ 0005.

181. The tradeoff between light-gathering ability and sharpness in this context is analogous to the tradeoff made by photographers using cameras that allow the size of the aperture to be adjusted manually. Whenever a photographer using one of these classic cameras sets up to take a picture, he or she must decide what is more important, more light or a sharper image. The balancing between these two considerations has been known since such cameras were first introduced, and took place every time a photographer read a light meter and selected an Fno and shutter speed combination to take a picture.

182. If the lens designer starting a new design, after selecting Yu's first embodiment as a good starting point, needs to increase the light-gathering ability of the design of that embodiment with a lower f-number (Fno), increasing the size of

the entrance pupil would be a standard and obvious first step to take in the design process. A lens designer always considers the size of the entrance pupil because it determines how sensitive the system will be for low-light operation. In Yu's first embodiment, since the non-adjustable diaphragm 2 is located to the left of the object-side side surface 111 of the first lens 11, a person of ordinary skill in the art would know that increasing the size of the diameter of the non-adjustable diaphragm 2 increases the size of the entrance pupil, which it defines.

183. A lens designer considering enlargement of the diameter of the opening in Yu's non-adjustable diaphragm 2 to increase the light-gathering ability of Yu's first embodiment would logically consider how Fno would be affected by opening it up to match the size of Yu's first lens 11, which would be the maximum increase to the diameter that does not require changing any of the dimensions of the lens elements.

184. Yu does not expressly disclose the diameter of the first lens 11, but a person of ordinary skill in the art could determine its diameter for the purposes of deciding how much the non-adjustable diaphragm 2 could be opened up to increase the light-gathering ability of Yu's first embodiment by using the information in Table 1 and Fig. 1's illustration of the first embodiment. For example, using a paper printout of Yu's Fig. 1, I measured the axial distance between the object-side surface 111 of the first lens 11 and the image-side surface 142 of the fourth lens 14 to be 56.0 mm. Yu's Table 1 "shows the parameters of components of the first preferred

embodiment." Ex. 1003, 4:39-43, 4:51-5:20. The third column in Table 1 lists the center thickness of Yu's lenses and the interspace distances. Ex. 1003, 4:39-43, 4:51-5:20. As I explained in Section XII.A.7, I can use this information to calculate the axial distance between the object-side surface 111 of the first lens 11 and the image-side surface 142 of the fourth lens 14. In Yu's first embodiment, this equals 1.705 mm, as I explained in Section XII.A.7. I have highlighted the values in Table 1 that are summed together to give this value. Ex. 1003, Table 1.

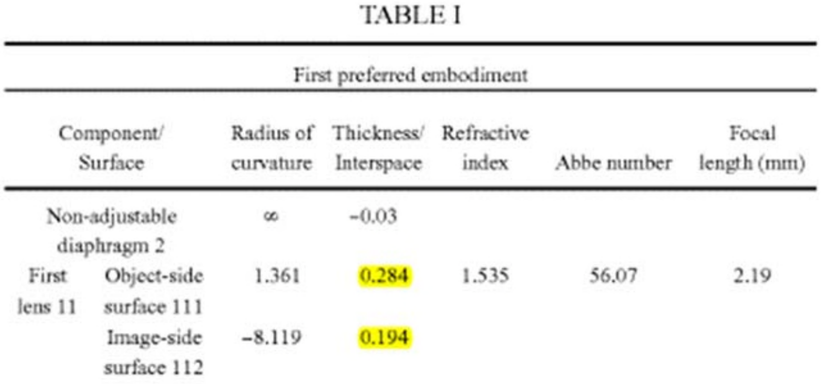


TABLE I

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Non-adjustable diaphragm 2		∞	−0.03			
First lens 11	Object-side surface 111	1.361	0.284	1.535	56.07	2.19
	Image-side surface 112	−8.119	0.194			

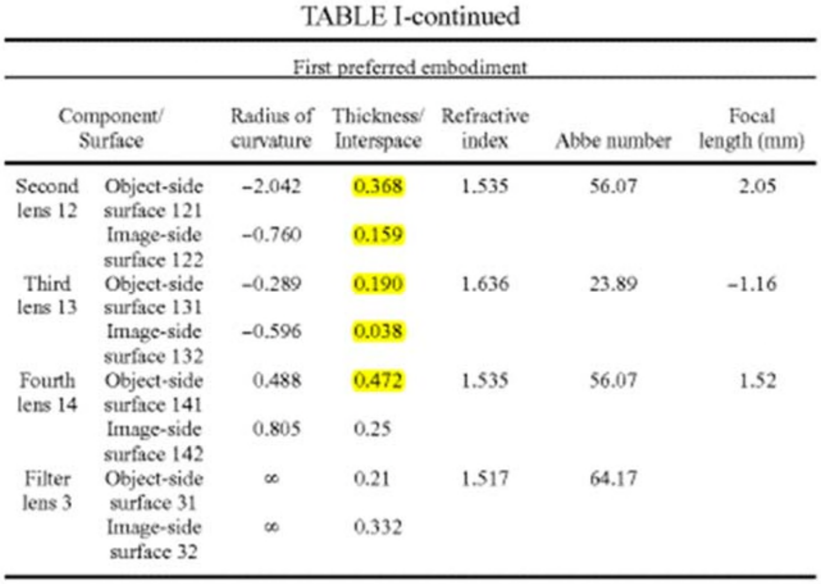


TABLE I-continued

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Second lens 12	Object-side surface 121	−2.042	0.368	1.535	56.07	2.05
	Image-side surface 122	−0.760	0.159			
Third lens 13	Object-side surface 131	−0.289	0.190	1.636	23.89	−1.16
	Image-side surface 132	−0.596	0.038			
Fourth lens 14	Object-side surface 141	0.488	0.472	1.535	56.07	1.52
	Image-side surface 142	0.805	0.25			
Filter lens 3	Object-side surface 31	∞	0.21	1.517	64.17	
	Image-side surface 32	∞	0.332			

185. Since I measured the axial distance between the object-side surface 111 of the first lens 11 and the image-side surface 142 of the fourth lens 14 to be 56.0 mm, on the paper printout of Fig. 1, and I know from Table 1 that this distance is 1.705 mm in Yu's first embodiment, the scale of the printed Fig. 1 is such that every 1 mm in Yu's first embodiment as disclosed in Table 1 equals approximately 32.8446 mm (56.0 mm/1.705 mm) in the printed Fig. 1 representation of that embodiment.

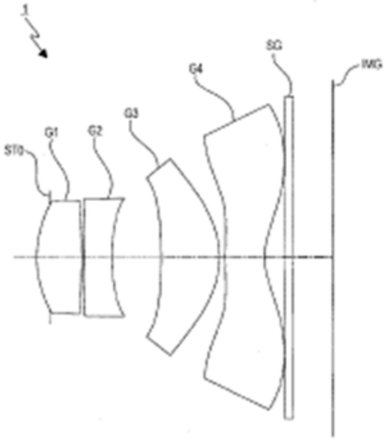
186. I measured the diameter of the first lens 11 in the printed Fig. 1 as 29.1 mm. Using the scale above, this translates to a diameter of 0.886 mm (29.1 mm/32.8446) for the first lens 11 in Yu's first embodiment. A person of ordinary skill in the art would find it obvious and convenient to increase the diameter of the opening in the non-adjustable diaphragm 2 in Yu's first embodiment up to the 0.886 mm diameter of the first lens 11 to increase the light-gathering ability of the lens system. The focal length of Yu's first embodiment is 1.60 mm. Ex. 1003, 2:9-16, 4:39-43. If the diameter of the opening in the non-adjustable diaphragm 2 in Yu's first embodiment is increased to 0.886 mm, then the f-number (Fno) equals 1.806, (1.60 mm / 0.886 mm), which is well within the range of $1.40<\text{Fno}\leq 2.25$ recited in claim 5. It would have been obvious to a person of ordinary skill in the art to increase the diameter of the opening in the non-adjustable diaphragm 2 in Yu's first embodiment to this or a lesser amount to increase the light-gathering ability of the lens system.

187. Because it would have been obvious to increase the diameter of the opening in the non-adjustable diaphragm 2 in Yu's first embodiment up to the diameter of the first lens 11, it would also have been obvious to increase the diameter of the opening in the non-adjustable diaphragm 2 to a lesser extent as well, depending on the particular requirements for light-gathering ability and sharpness of the new lens system design. For example, it would have been obvious to a person of ordinary skill in the art to increase the diameter of the non-adjustable diaphragm 2 to a value greater than 0.711 mm but less than or equal to 0.886 mm. At the lower end of this obvious range of diameters, the f-number (Fno) of Yu's first embodiment would equal 2.25 (1.60 mm/0.711 mm). The range of diameters from 0.711 mm to 0.886 would all have been obvious, and all would satisfy the recited relation "$1.40<\text{Fno}\leq 2.25$." The ultimate choice depends on the precise requirements for the new lens system. Of course, the first lens 11 can also be enlarged if even more light-gathering ability is needed.

188. Lens assemblies having f-numbers in the recited range were known before the '796 patent. For example, Okano discloses "an imaging lens which is suitable for a small sized apparatus such as a digital still camera or mobile phone" that comprises first, second, third, and fourth lenses with positive, negative, positive, and negative refractive power, respectively Ex. 1011 ¶¶ 0001, 0013. A first embodiment of "[t]he imaging lens 1[, which] includes an aperture stop STO, a first lens G1 …, a

second lens G2 …, a third lens G3 …, and a fourth lens G4 …, which are sequentially disposed from the side of an object to the image side" is shown in Okano's Fig. 1. Ex. 1011 ¶ 0106, Fig. 1. One of ordinary skill in the art would understand that the amount of light accepted by Okano's imaging lens is directly proportional to the area of the aperture stop STO, and therefore is inherently proportional to $1/(Fno)^2$. This first embodiment has an f-number of 2.2, as shown below Table 1. Ex. 1011 ¶ 0112. Okano discloses embodiments with f-numbers ranging from 2.1 to 2.6 "to realize a bright optical system." Ex. 1011 ¶¶ 0005, 0077-0078, 0228, 0256-0257, Table 23.

FIG.1



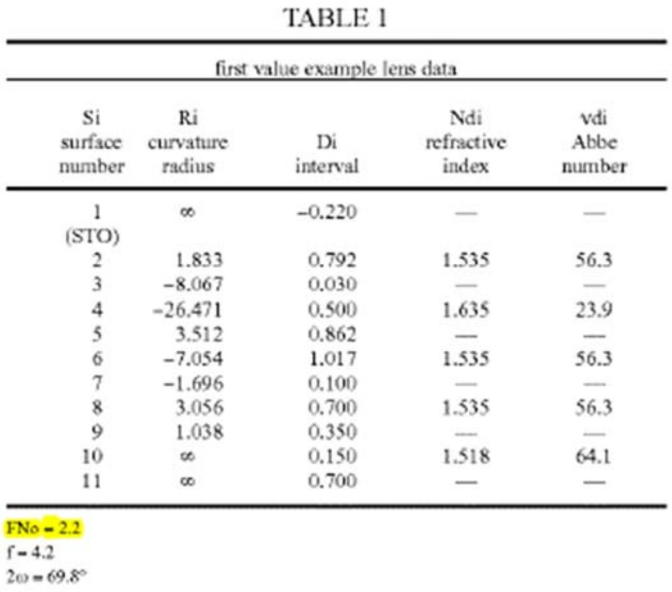


TABLE 1

first value example lens data

Si surface number	Ri curvature radius	Di interval	Ndi refractive index	νdi Abbe number
1 (STO)	∞	−0.220	—	—
2	1.833	0.792	1.535	56.3
3	−8.067	0.030	—	—
4	−26.471	0.500	1.635	23.9
5	3.512	0.862	—	—
6	−7.054	1.017	1.535	56.3
7	−1.696	0.100	—	—
8	3.056	0.700	1.535	56.3
9	1.038	0.350	—	—
10	∞	0.150	1.518	64.1
11	∞	0.700	—	—

FNo = 2.2
f = 4.2
2ω = 69.8°

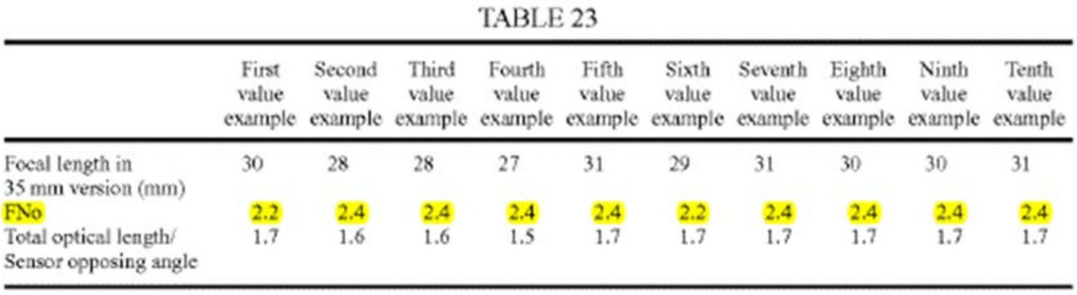


TABLE 23

	First value example	Second value example	Third value example	Fourth value example	Fifth value example	Sixth value example	Seventh value example	Eighth value example	Ninth value example	Tenth value example
Focal length in 35 mm version (mm)	30	28	28	27	31	29	31	30	30	31
FNo	2.2	2.4	2.4	2.4	2.4	2.2	2.4	2.4	2.4	2.4
Total optical length/ Sensor opposing angle	1.7	1.6	1.6	1.5	1.7	1.7	1.7	1.7	1.7	1.7

189. As another example, WO 2013/125248 ("Sugiyama"), which was published on August 29, 2013, and is prior art to the '796 patent, discloses "a compact, high resolution, wide-angle lens composed of four to six lenses" for a camera. Ex. 1013 ¶¶ 0001-0002. Sugiyama discloses multiple embodiments having an f-number of 2, 2.2, or 2.4. *E.g.*, Ex. 1013 ¶¶ 0021, 0065, 0080. Sugiyama's lens assemblies are described as having "a bright configuration." Ex. 1013 ¶¶ 0036, 0048, 0061, 0076, 0091.

190. As the diameter of the non-adjustable diaphragm 2 is enlarged, there may be some degradation of the sharpness of the image. As I discussed above, there are end-use applications in which such degradation is an acceptable tradeoff for improved light-gathering ability. While a lens designer might consider further refinements to the design of Yu's first embodiment at a later stage in the design process to reduce this degradation, the design at this stage—i.e., after the size of the diameter of the non-adjustable diaphragm is increased to improve the light-gathering ability of the lens system—renders claim 5 obvious. Neither claim 5, nor claims 1 and 2 from which it depends, recites any limitations regarding the quality of the resulting image of the lens system. The limitations of these claims are all disclosed by Yu's first embodiment, as explained above, and adjusting the diameter of the opening in the non-adjustable diaphragm 2 does not change that fact. The individual lenses will still have the same refractive power, surface shapes, and focal length, and the axial distances between elements and the HFOV of the lens system will not change.

191. Changing the diameter of the opening in the non-adjustable diaphragm 2 in Yu's first embodiment, as explained in this section, would have been obvious to a person of ordinary skill in the art because it amounts to the simple substitution of one known element for another to obtain predictable results, a predictable use of prior art elements according to their established functions, and applying a known

technique to a known device to yield predicable results with a reasonable expectation of success.

1. Conclusion for Claim 5

192. As I explained in Section XII.B, Yu renders claim 2 obvious. As I explained in this section, Yu renders the additional element of claim 5 obvious. Accordingly, Yu renders claim 5 obvious.

R. Claim 21

1. Preamble: "An image capturing lens system comprising, in order from an object side to an image side:"

193. The preamble of claim 21 recites: "An image capturing lens system comprising, in order from an object side to an image side." Ex. 1001, 33:13-14. As discussed above, I analyze Yu's first embodiment for claim 21. This is identical to the preamble of claim 1. *Compare* Ex. 1001, 33:13-14 *with* Ex. 1001, 30:48-49. Because the preambles are identical, my analysis for the preamble of claim 1 in Section XII.A.1 applies equally to the preamble of claim 21. To the extent the preamble is limiting, Yu discloses the preamble of claim 21.

2. Element 21a: "a first lens element having refractive power;"

194. Element 21a recites: "a first lens element having refractive power." Ex. 1001, 33:15. This is identical to Element 1a. *Compare* Ex. 1001, 33:15 *with* Ex. 1001,

30:50. Because Element 1a and Element 21a are identical, my analysis for Element 1a in Section XII.A.2 applies equally to Element 21a. Yu discloses Element 21a.

3. Element 21b: "a second lens element with positive refractive power having a convex image-side surface in a paraxial region thereof;"

195. Element 21b recites: "a second lens element with positive refractive power having a convex image-side surface in a paraxial region thereof." Ex. 1001, 33:16-18. This is identical to Element 1b. *Compare* Ex. 1001, 33:16-18 *with* Ex. 1001, 30:51-53. Because Element 1b and Element 21b are identical, my analysis for Element 1b in Section XII.A.3 applies equally to Element 21b. Yu discloses Element 21b.

4. Element 21c: "a third lens element with negative refractive power having a concave object-side surface in a paraxial region thereof and a convex image-side surface in a paraxial region thereof; and"

196. Element 21c recites: "a third lens element with negative refractive power having a concave object-side surface in a paraxial region thereof and a convex image-side surface in a paraxial region thereof." Ex. 1001, 33:19-22. This is identical to Element 1c. *Compare* Ex. 1001, 33:19-22 *with* Ex. 1001, 30:54-57. Because Element 1c and Element 21c are identical, my analysis for Element 1c in Section XII.A.4 applies equally to Element 21c. Yu discloses Element 21c.

5. Element 21d: “a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof, wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric, and the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof;”

197. Element 21d recites: “a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof, wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric, and the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof.” Ex. 1001, 33:23-28. This is identical to Element 1d. *Compare* Ex. 1001, 33:23-28 *with* Ex. 1001, 30:58-63. Because Element 1d and Element 21d are identical, my analysis for Element 1d in Section XII.A.5 applies equally to Element 21d. Yu discloses Element 21d.

6. Element 21e: “wherein the image capturing lens system has a total of four lens elements with refractive power,”

198. Element 21e recites: “wherein the image capturing lens system has a total of four lens elements with refractive power.” Ex. 1001, 33:29-30. This is identical to Element 1e. *Compare* Ex. 1001, 33:29-30 *with* Ex. 1001, 30:64-65. Because Element 1e and Element 21e are identical, my analysis for Element 1e in Section XII.A.6 applies equally to Element 21e. Yu discloses Element 21e.

7. Element 21f: "an axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, half of a maximal field of view of the image capturing lens system is HFOV, a focal length of the image capturing lens system is f, a focal length of the fourth lens element is f4, an f-number of the image capturing lens system is Fno, and the following conditions are satisfied: 0.5 mm<Td<3.2 mm; 1.0 mm<Td/tan(HFOV)<3.75 mm; |f/f4|<1.20; and 1.40<Fno≤2.25."

199. Element 21f recites:

- "an axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td";
- "half of a maximal field of view of the image capturing lens system is HFOV";
- "a focal length of the image capturing lens system is f, a focal length of the fourth lens element is f4, an f-number of the image capturing lens system is Fno"; and
- "the following conditions are satisfied:

  0.5 mm<Td<3.2 mm;

  1.0 mm<Td/tan(HFOV)<3.75 mm;

  |f/f4|<1.20; and

  1.40<Fno≤2.25."

Ex. 1001, 33:30-34:7.

200. In Section XII.A.7, I explained that Td equals 1.705 mm, f equals 1.60 mm, f4 equals 1.52 mm, Td/tan(HFOV) equals 1.76558 mm, and |f/f4| equals 1.05263 in Yu's first embodiment. These values of Td, Td/tan(HFOV), and |f/f4| for Yu's first embodiment satisfy the first three conditions of Element 21f: "0.5 mm<Td<3.2 mm; 1.0 mm<Td/tan(HFOV)<3.75 mm; |f/f4|<1.20."

201. In Section XII.Q, I explained that it would be obvious to a person of ordinary skill in the art to adjust the size of the entrance pupil in Yu's first embodiment, which results in the f-number (Fno) satisfying the condition "1.40<Fno≤2.25." Accordingly, Yu renders Element 21f obvious.

8. Conclusion for Claim 21

202. As I have explained above in this section, Yu discloses or renders obvious all elements of claim 21. Accordingly, Yu renders claim 21 obvious.

S. Claim 22: "The image capturing lens system of claim 21, wherein a focal length of the second lens element is f2, a focal length of the third lens element is f3, and the following condition is satisfied: f2/f3<-0.65."

203. Claim 22 depends from claim 21 and recites: "The image capturing lens system of claim 21, wherein a focal length of the second lens element is f2, a focal length of the third lens element is f3, and the following condition is satisfied: f2/f3<-0.65." Ex. 1001, 34:8-13.

204. As discussed above, I analyze Yu's first embodiment for claim 22. I explained in Section XII.A.7 that the value of f2/f3 is -1.76724 in Yu's first embodiment. Accordingly, Yu discloses that "a focal length of the second lens element is f2, a focal length of the third lens element is f3, and the following condition is satisfied: f2/f3<-0.65."

1. Conclusion for Claim 22

205. As I explained in Section XII.R, Yu renders claim 21 obvious. As I explained in this section, Yu discloses the additional element of claim 22. Accordingly, Yu renders claim 22 obvious.

T. Claim 23: "The image capturing lens system of claim 21, wherein an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1."

206. Claim 23 depends from claim 21 and recites: "The image capturing lens system of claim 21, wherein an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1." Ex. 1001, 34:14-17.

207. As discussed above, I analyze Yu's first embodiment for claim 23. I explained in Section XII.J that Yu discloses that "an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1" because the Abbe number of the first lens 11 in Yu's first embodiment is 56.07. Ex. 1003, 4:60.

1. Conclusion for Claim 23

208. As I explained in Section XII.R, Yu renders claim 21 obvious. As I explained in this section, Yu discloses the additional element of claim 23. Accordingly, Yu renders claim 23 obvious.

U. Claim 24: "The image capturing lens system of claim 21, wherein the first lens element has positive refractive power, the focal length of the image capturing lens system is f, a focal length of the first lens element is f1, and the following condition is satisfied: 0.25<f/f1<0.75."

209. Claim 24 depends from claim 21 and recites: "The image capturing lens system of claim 21, wherein the first lens element has positive refractive power, the focal length of the image capturing lens system is f, a focal length of the first lens element is f1, and the following condition is satisfied: 0.25<f/f1<0.75." Ex. 1001, 34:18-24.

210. As discussed above, I analyze Yu's first embodiment for claim 24. Yu discloses that "[t]he first lens 11 has a positive optical power adjacent to the optical axis L." Ex. 1003, 2:58-61. One of ordinary skill would understand that "positive optical power" in this use means the same as "positive refractive power." A lens element expresses "power" only through refraction. The shape of the first lens 11 in Fig. 1 (first embodiment) below confirms that it has positive refractive power, because the lens is thicker in the paraxial region. As I explained above, a lens with positive refractive power is thicker at its center.

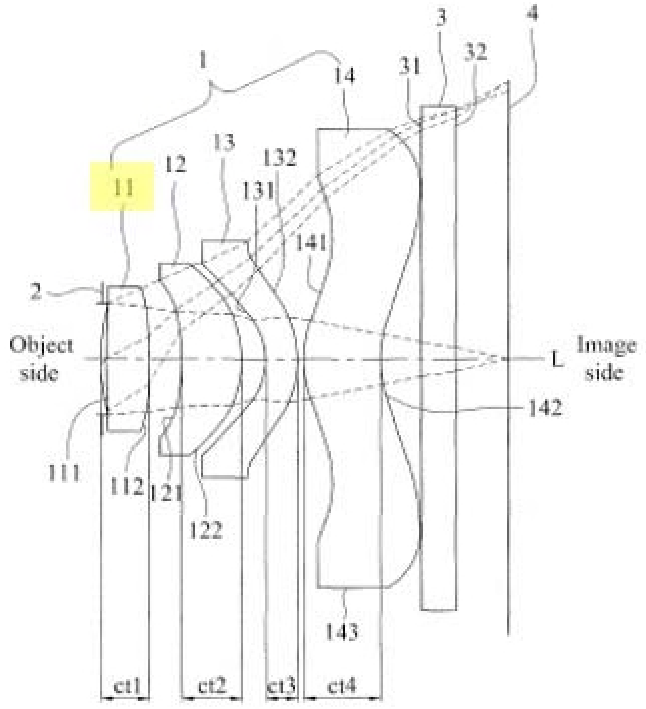


FIG.1

211. I explained in Section XII.C that f/f1 equals 0.73059 in Yu's first embodiment. This satisfies the condition "0.25<f/f1<0.75." Thus, Yu discloses that "the first lens element has positive refractive power, the focal length of the image capturing lens system is f, a focal length of the first lens element is f1, and the following condition is satisfied: 0.25<f/f1<0.75."

1. Conclusion for Claim 24

212. As I explained in Section XII.R, Yu renders claim 21 obvious. As I explained in this section, Yu discloses the additional elements of claim 24. Accordingly, Yu renders claim 24 obvious.

V. Claim 25: "The image capturing lens system of claim 21, wherein a maximal field of view of the image capturing lens system is FOV, and the following condition is satisfied: 80 degrees<FOV<110 degrees."

213. Claim 25 depends from claim 21 and recites: "The image capturing lens system of claim 21, wherein a maximal field of view of the image capturing lens system is FOV, and the following condition is satisfied: 80 degrees<FOV<110 degrees." Ex. 1001, 34:25-29.

214. As discussed above, I analyze Yu's first embodiment for claim 25. I explained in Section XII.N that Yu discloses that "a maximal field of view of the image capturing lens system is FOV, and the following condition is satisfied: 80 degrees<FOV<110 degrees" because the "maximal field of view" of Yu's first embodiment is 88 degrees. Ex. 1003, 2:13-14, 4:39-43.

1. Conclusion for Claim 25

215. As I explained in Section XII.R, Yu renders claim 21 obvious. As I explained in this section, Yu discloses the additional element of claim 25. Accordingly, Yu renders claim 25 obvious.

XIII. GROUND 2: YAMAGUCHI IN VIEW OF YU RENDERS CLAIMS 1-11, 15-16, AND 19-24 OBVIOUS.

A. Obvious Design Changes

1. Scaling the dimensions of Yamaguchi's pickup lens would have been obvious.

216. Yamaguchi discloses a lens assembly having an axial distance between the object-side surface of the first lens and the image-side surface of the fourth lens that is greater than recited in the '796 patent's claims. However, a person of ordinary skill in the art would have known that a lens assembly may be scaled up or down in size, while maintaining the same properties, by adjusting all of its dimensions by the same numerical ratio. Yu discloses a lens assembly supporting a smaller sensor that has an axial distance within the range of the '796 patent's claims. In view of Yu, it would have been obvious to a person of ordinary skill in the art to scale down Yamaguchi's lens assembly to support a smaller sensor.

217. At the time of the '796 patent (and still today), the lens-design process begins with classic lens designs, as I discussed above in Section VII. If a design performs well but the lens just has the wrong focal length, all of the dimensions can simply be scaled to correct it. If necessary, a different classic starting design can be selected.

218. At the time of the '796 patent, one such design would have been the image pickup lens disclosed in Yamaguchi, specifically Yamaguchi's Example 3 and Example 4. Yamaguchi discloses "an image pickup lens preferable as an optical

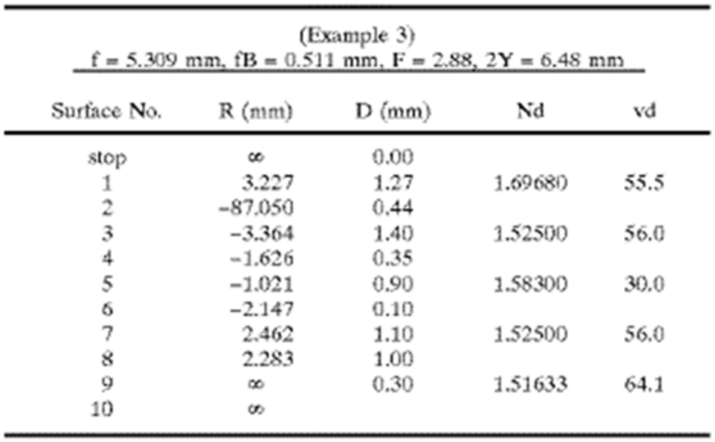
system of a solid state pickup element such as a CCD type image sensor or a CMOS type image sensor." Ex. 1006 ¶ 0002. And Yamaguchi recognized that the "heightened performance and the miniaturization of an image pickup device," along with "the miniaturization and the dense arrangement of pixels," necessitated "the further miniaturization of an image pickup lens mounted on the image pickup device." Ex. 1006 ¶¶ 0004-0005. Thus, Yamaguchi discloses "an image pickup lens which is composed of a plurality of lenses and is miniaturized." Ex. 1006 ¶ 0008.

219. Yamaguchi's pickup lens comprises four lenses. Ex. 1006 ¶ 0009. The refractive power of the four lenses, from the object side to the image side of the pickup lens is positive (first lens), positive (second lens), negative (third lens), and positive or negative (fourth lens). Ex. 1006 ¶ 0010.

220. Yamaguchi discloses standard lens data for Example 3 and Example 4. Table 9 (Example 3) and Table 13 (Example 4) list, for each surface number of the pickup lens, "R (mm)," which is the "curvature radius of refractive surface"; "D (mm)," which is the "interval between refractive surfaces on axis"; "Nd," which is the "refractive index of lens material at d-line"; and "νd," which is the "Abbe number of lens material." Ex. 1006 ¶¶ 0159-0162, 0179, 0186. In addition, Table 9 (Example 3) and Table 13 (Example 4) disclose "f," which is the "focal length of the whole image pickup lens"; "fB," which is the "back focal length"; "F," which is the "F

number”; and “2Y,” which is the “length of a diagonal line on effective image screen (length of diagonal line of rectangular shaped light receiving plan of solid-state image pickup element).” Ex. 1006 ¶¶ 0155-0158, 0179, 0186.

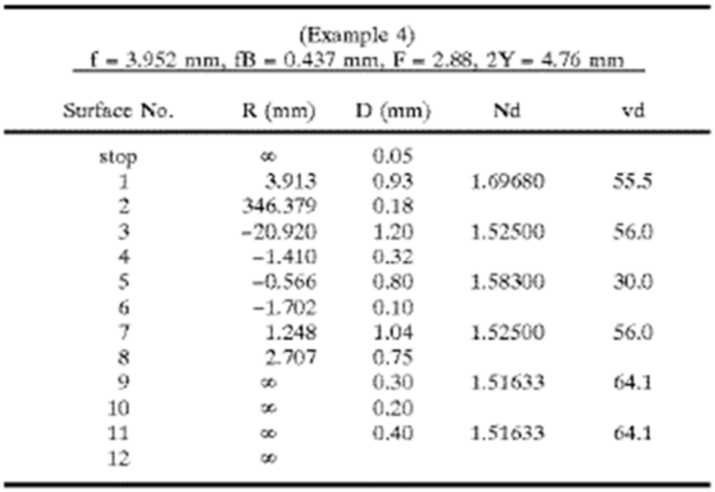
TABLE 9



(Example 3)
f = 5.309 mm, fB = 0.511 mm, F = 2.88, 2Y = 6.48 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.00		
1	3.227	1.27	1.69680	55.5
2	-87.050	0.44		
3	-3.364	1.40	1.52500	56.0
4	-1.626	0.35		
5	-1.021	0.90	1.58300	30.0
6	-2.147	0.10		
7	2.462	1.10	1.52500	56.0
8	2.283	1.00		
9	∞	0.30	1.51633	64.1
10	∞			

TABLE 13



(Example 4)
f = 3.952 mm, fB = 0.437 mm, F = 2.88, 2Y = 4.76 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.05		
1	3.913	0.93	1.69680	55.5
2	346.379	0.18		
3	-20.920	1.20	1.52500	56.0
4	-1.410	0.32		
5	-0.566	0.80	1.58300	30.0
6	-1.702	0.10		
7	1.248	1.04	1.52500	56.0
8	2.707	0.75		
9	∞	0.30	1.51633	64.1
10	∞	0.20		
11	∞	0.40	1.51633	64.1
12	∞			

221. Yamaguchi also discloses that, in its examples:

> the shape of an aspherical surface is expressed in a rectangular coordinate system, which has a vertex of the surface set as an origin and an optical axial direction set as an X axis, according to a following

> formula by using R denoting a curvature radius of the aspherical surface at the vertex, K denoting a conic constant, and A4, A6, A8, A10 and A12 denoting coefficients of the aspherical surface,
>
> $$X = \frac{h^2/R}{1 + \sqrt{1 - (1 + K)h^2/R^2}} + A_4h^4 + A_6h^6 + A_8h^8 + A_{10}h^{10} + A_{12}h^{12},$$
>
> where
>
> $$h = \sqrt{Y^2 + Z^2}$$
>
> is satisfied.

Ex. 1006 ¶¶ 0163-0164. Yamaguchi also includes Table 10 (Example 3) and Table 14 (Example 4), which list the coefficients of the aspherical surfaces. Ex. 1006 ¶¶ 0180, 0187.

TABLE 10

Coefficients of aspherical surface

Third surface

$K = -3.69470$
$A4 = -2.00408 \times 10^{-2}$
$A6 = 5.93561 \times 10^{-3}$
$A8 = 5.22016 \times 10^{-4}$
$A10 = -2.38137 \times 10^{-4}$

Fourth surface

$K = -8.46375 \times 10^{-1}$
$A4 = -2.02564 \times 10^{-2}$
$A6 = 1.62756 \times 10^{-2}$
$A8 = -4.14965 \times 10^{-3}$
$A10 = 6.66591 \times 10^{-4}$

Fifth surface

$K = -8.10560 \times 10^{-1}$
$A4 = 6.31710 \times 10^{-2}$
$A6 = 4.14530 \times 10^{-4}$
$A8 = 4.30470 \times 10^{-3}$
$A10 = -2.38210 \times 10^{-3}$
$A12 = 3.81300 \times 10^{-4}$

Sixth surface

$K = -4.69690 \times 10^{-1}$
$A4 = 1.50160 \times 10^{-2}$
$A6 = 9.94400 \times 10^{-3}$
$A8 = -2.33050 \times 10^{-3}$
$A10 = 3.92580 \times 10^{-4}$
$A12 = -2.86340 \times 10^{-5}$

Seventh surface

$K = -8.06986$
$A4 = -1.22203 \times 10^{-2}$
$A6 = -1.10253 \times 10^{-3}$
$A8 = 2.97022 \times 10^{-4}$
$A10 = -1.61617 \times 10^{-5}$
$A12 = -1.33104 \times 10^{-6}$

Eight surface

$K = -4.95420$
$A4 = -1.49047 \times 10^{-2}$
$A6 = 7.29589 \times 10^{-4}$
$A8 = -2.84963 \times 10^{-4}$
$A10 = 4.02284 \times 10^{-5}$
$A12 = -2.14994 \times 10^{-6}$

TABLE 14

Coefficients of aspherical surface

Third surface

$K = -1.34157 \times 10^{-3}$
$A4 = -1.15552 \times 10^{-2}$
$A6 = -9.72356 \times 10^{-2}$
$A8 = 1.64161 \times 10^{-1}$

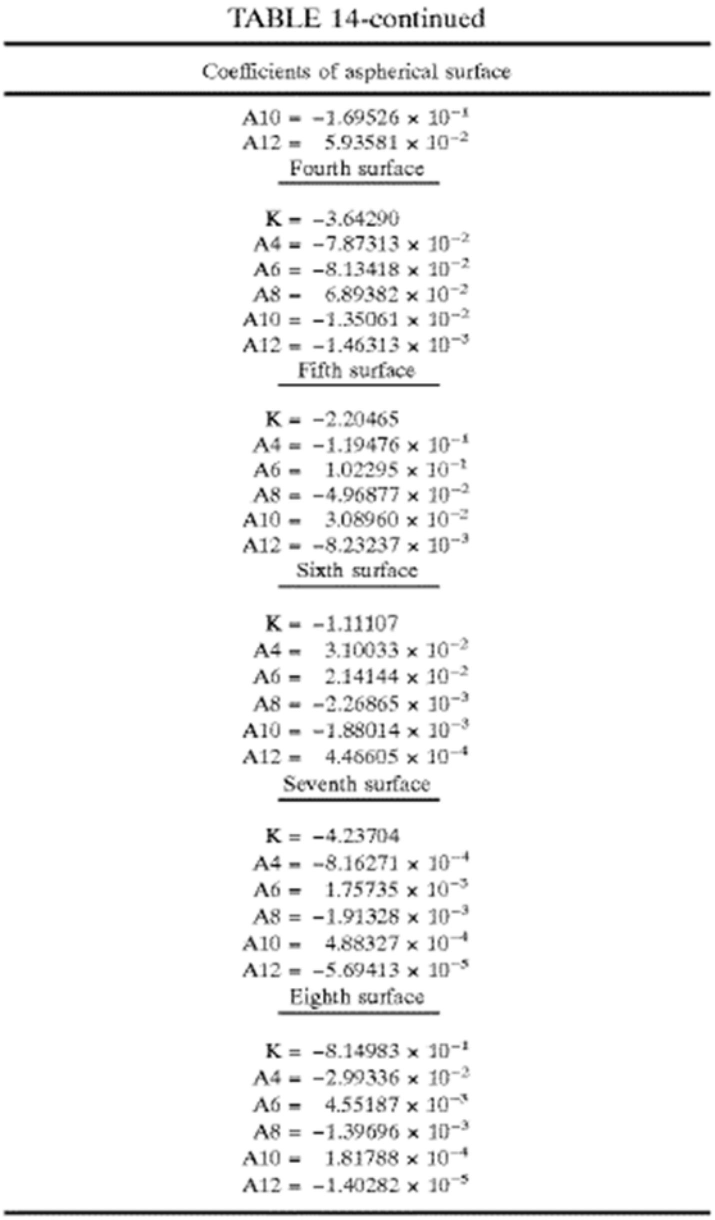


TABLE 14-continued

Coefficients of aspherical surface

A10 = -1.69526×10^{-1}
A12 = 5.93581×10^{-2}

Fourth surface

K = -3.64290
A4 = -7.87313×10^{-2}
A6 = -8.13418×10^{-2}
A8 = 6.89382×10^{-2}
A10 = -1.35061×10^{-2}
A12 = -1.46313×10^{-3}

Fifth surface

K = -2.20465
A4 = -1.19476×10^{-1}
A6 = 1.02295×10^{-1}
A8 = -4.96877×10^{-2}
A10 = 3.08960×10^{-2}
A12 = -8.23237×10^{-3}

Sixth surface

K = -1.11107
A4 = 3.10033×10^{-2}
A6 = 2.14144×10^{-2}
A8 = -2.26865×10^{-3}
A10 = -1.88014×10^{-3}
A12 = 4.46605×10^{-4}

Seventh surface

K = -4.23704
A4 = -8.16271×10^{-4}
A6 = 1.75735×10^{-5}
A8 = -1.91328×10^{-3}
A10 = 4.88327×10^{-4}
A12 = -5.69413×10^{-5}

Eighth surface

K = -8.14983×10^{-1}
A4 = -2.99336×10^{-2}
A6 = 4.55187×10^{-3}
A8 = -1.39696×10^{-3}
A10 = 1.81788×10^{-4}
A12 = -1.40282×10^{-5}

222. With this and the other information disclosed in Yamaguchi, a person of ordinary skill in the art could use Yamaguchi's Example 3 and Example 4 as the starting point for a new design.

223. Another design that would have been available at the time of the '796 patent is Yu's first embodiment. Yu discloses "a compact wide-angle four-piece imaging

lens assembly." Ex. 1003, 1:12-14. Specifically, Yu discloses "a four-piece imaging lens assembly which has compact and thin dimensions and which has a wider angle of view for improving resolving power thereof." Ex. 1003, 1:41-44.

224. Yu's lens assembly "includes a first lens, a second lens, a third lens and a fourth lens arranged in sequence from an object side to an image side along an optical axis of the lens assembly." Ex. 1003, 1:46-49. The refractive power of the four lenses, from the object side to the image side of the lens assembly, is positive (first lens), positive (second lens), negative (third lens), and positive (fourth lens). Ex. 1003, 1:49-52, 1:54-57, 1:59-62, 1:64-2:4, 2:58-61, 2:63-66, 3:1-5, 3:7-18.

225. Yu discloses standard lens data for its first embodiment in Table 1. For each component or surface of the lens assembly, Table 1 lists its radius of curvature, thickness or interspace distance, refractive index, Abbe number, and focal length. Ex. 1003, Table 1.

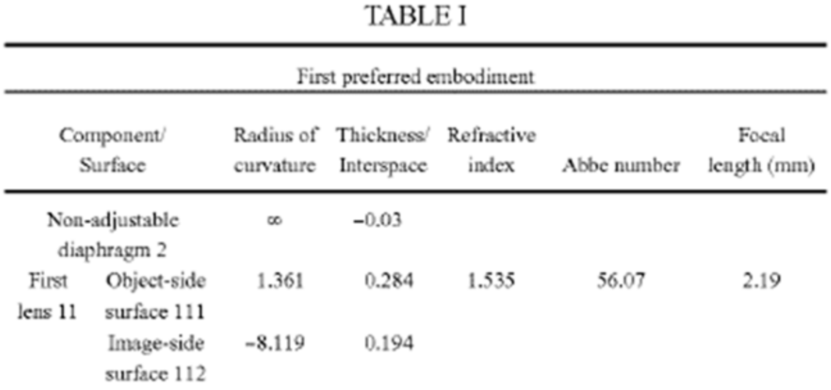


TABLE I

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Non-adjustable diaphragm 2		∞	−0.03			
First lens 11	Object-side surface 111	1.361	0.284	1.535	56.07	2.19
	Image-side surface 112	−8.119	0.194			

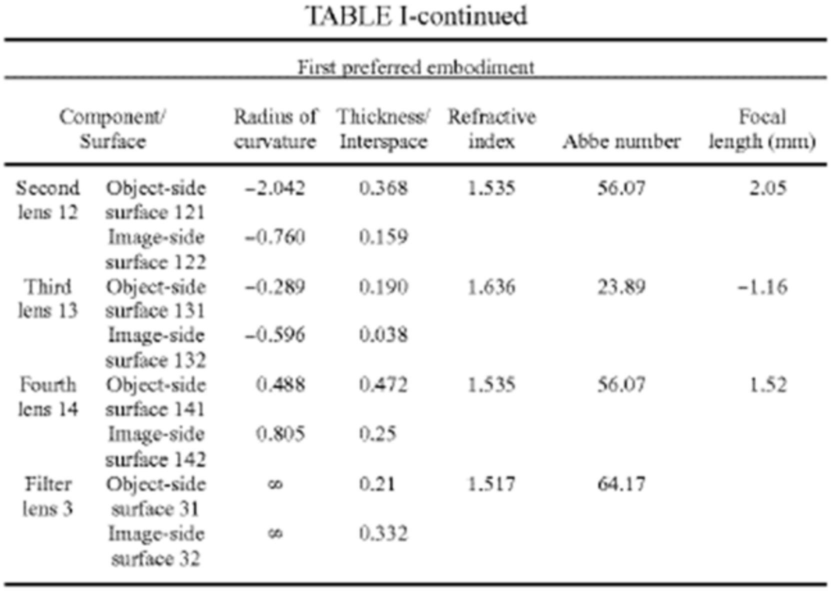


TABLE I-continued

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Second lens 12	Object-side surface 121	−2.042	0.368	1.535	56.07	2.05
	Image-side surface 122	−0.760	0.159			
Third lens 13	Object-side surface 131	−0.289	0.190	1.636	23.89	−1.16
	Image-side surface 132	−0.596	0.038			
Fourth lens 14	Object-side surface 141	0.488	0.472	1.535	56.07	1.52
	Image-side surface 142	0.805	0.25			
Filter lens 3	Object-side surface 31	∞	0.21	1.517	64.17	
	Image-side surface 32	∞	0.332			

226. Yu also discloses that the following equation describing the lens assembly's aspheric surfaces:

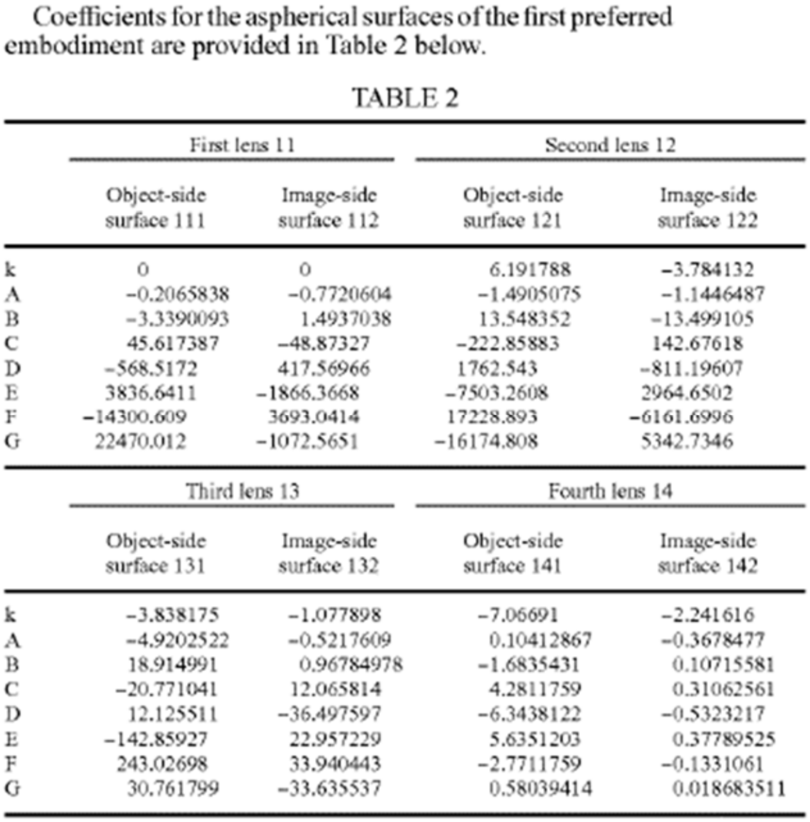
$$z = \frac{ch^2}{1 + [1 - (k+1)c^2h^2]^{0.5}} + Ah^4 + Bh^6 + Ch^8 + Dh^{10} + Eh^{12} + Fh^{14} + Gh^{16} + Hh^{18} + Jh^{20} + \ldots$$

Ex. 1003, 4:21-27. In this equation:

> z is a displacement, along the optical axis L, of the aspherical surface from a vertex of the aspherical surface at a distance h from the optical axis L, c is a reciprocal of the radius of curvature, k is the conic constant, and A, B, C, D, E, F, G, H, J and so forth are aspheric coefficients.

Ex. 1003, 4:28-32.

227. Yu also includes Table 2, which provides the "[c]oefficients for the aspherical surfaces of the first preferred embodiment." Ex. 1003, Table 2.



Coefficients for the aspherical surfaces of the first preferred embodiment are provided in Table 2 below.

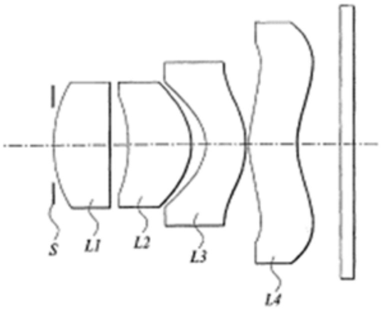
TABLE 2

	First lens 11		Second lens 12	
	Object-side surface 111	Image-side surface 112	Object-side surface 121	Image-side surface 122
k	0	0	6.191788	−3.784132
A	−0.2065838	−0.7720604	−1.4905075	−1.1446487
B	−3.3390093	1.4937038	13.548352	−13.499105
C	45.617387	−48.87327	−222.85883	142.67618
D	−568.5172	417.56966	1762.543	−811.19607
E	3836.6411	−1866.3668	−7503.2608	2964.6502
F	−14300.609	3693.0414	17228.893	−6161.6996
G	22470.012	−1072.5651	−16174.808	5342.7346

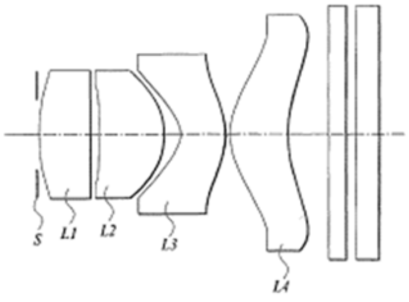
	Third lens 13		Fourth lens 14	
	Object-side surface 131	Image-side surface 132	Object-side surface 141	Image-side surface 142
k	−3.838175	−1.077898	−7.06691	−2.241616
A	−4.9202522	−0.5217609	0.10412867	−0.3678477
B	18.914991	0.96784978	−1.6835431	0.10715581
C	−20.771041	12.065814	4.2811759	0.31062561
D	12.125511	−36.497597	−6.3438122	−0.5323217
E	−142.85927	22.957229	5.6351203	0.37789525
F	243.02698	33.940443	−2.7711759	−0.1331061
G	30.761799	−33.635537	0.58039414	0.018683511

228. The lens assemblies disclosed in Yamaguchi and Yu are very similar. Both disclose four-lens designs. Ex. 1003, 1:46-49; Ex. 1006 ¶ 0009. Yamaguchi discloses that the refractive power of the lenses from first to fourth is positive, positive, negative, and then positive or negative. Ex. 1006 ¶ 0010. The refractive powers of these lenses in Yu are positive, positive, negative, positive. Ex. 1003, 1:49-2:3. Both lens assemblies are intended for use in small electronic products, such as mobile phones. Ex. 1003, 1:16-19, Ex. 1006 ¶¶ 0002, 0004-0005, 0008, 0105-0106, 0149, 0227. Below, Yamaguchi's Examples 3 and 4 and Yu's first

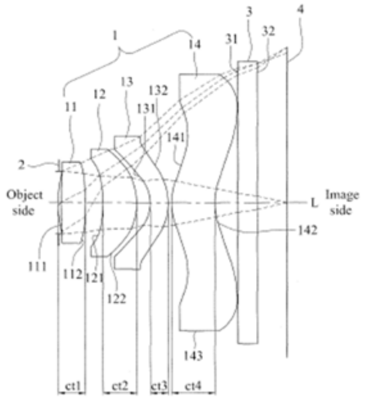
embodiment are shown side-by-side, which makes it easy to see the similarities between the lens assembly designs.



Yamaguchi Fig. 8
(Example 3)



Yamaguchi Fig. 10
(Example 4)



Yin Fig. 1
(first embodiment)

229. Yamaguchi teaches that "with the miniaturization and the dense arrangement of pixels … the further miniaturization of an image pickup lens mounted on the image pickup device is strongly required." Ex. 1006 ¶ 0005. Thus, an object of Yamaguchi's invention "is to provide an image pickup lens which is composed of a plurality of lenses and is miniaturized." Ex. 1006 ¶ 0008. One measure of the length of the pickup lens is the axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element. This distance can be calculated by summing the values of D in Table 9 (Example 3) or Table 13 (Example 4) for surface numbers 1-7. In Yamaguchi's Example 3 this equals 5.56 mm, and in Example 4 it equals 4.57 mm. I have highlighted the

relevant values in Yamaguchi's Table 9 (Example 3) and Table 13 (Example 4) below.

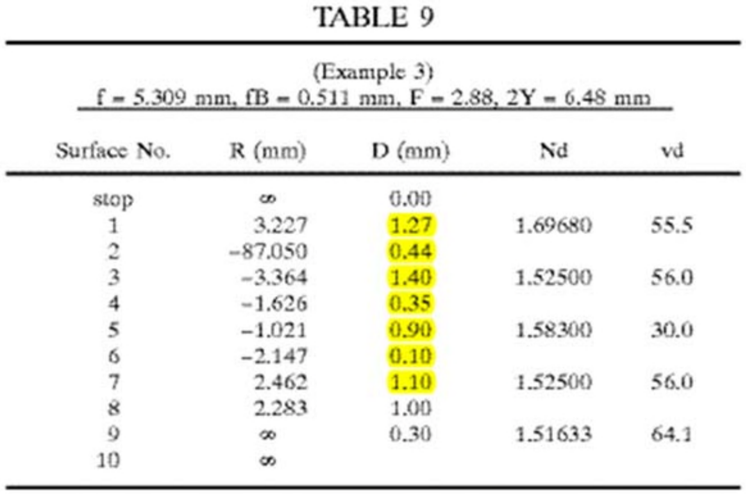


TABLE 9

(Example 3)
f = 5.309 mm, fB = 0.511 mm, F = 2.88, 2Y = 6.48 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.00		
1	3.227	1.27	1.69680	55.5
2	-87.050	0.44		
3	-3.364	1.40	1.52500	56.0
4	-1.626	0.35		
5	-1.021	0.90	1.58300	30.0
6	-2.147	0.10		
7	2.462	1.10	1.52500	56.0
8	2.283	1.00		
9	∞	0.30	1.51633	64.1
10	∞			

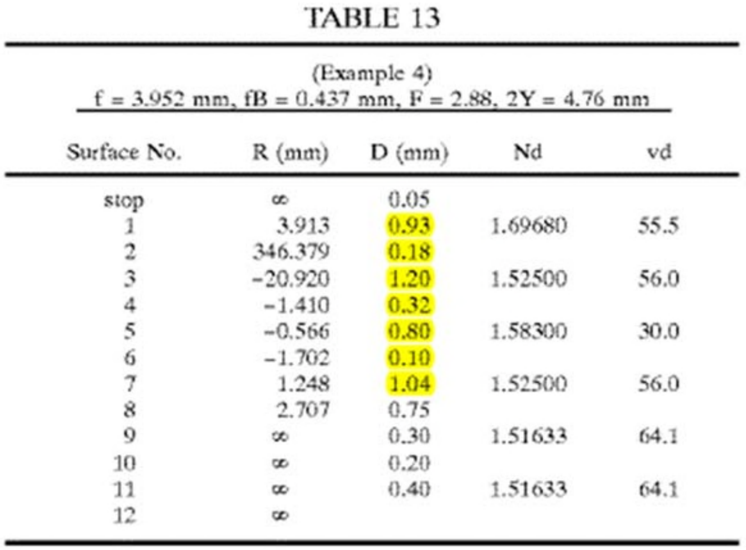


TABLE 13

(Example 4)
f = 3.952 mm, fB = 0.437 mm, F = 2.88, 2Y = 4.76 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.05		
1	3.913	0.93	1.69680	55.5
2	346.379	0.18		
3	-20.920	1.20	1.52500	56.0
4	-1.410	0.32		
5	-0.566	0.80	1.58300	30.0
6	-1.702	0.10		
7	1.248	1.04	1.52500	56.0
8	2.707	0.75		
9	∞	0.30	1.51633	64.1
10	∞	0.20		
11	∞	0.40	1.51633	64.1
12	∞			

230. Similar to Yamaguchi, Yu discloses that "[w]ith the continuous improvement of electronic products, a tendency toward compact design while maintaining high performance of the electronic product is desired." Ex. 1003, 1:19-22. "Accordingly, an imaging lens assembly is also developed toward a trend of being compact and

having thin dimensions." Ex. 1003, 1:22-24. With the information in Yu's Table 1, the same axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element can be determined for Yu's first embodiment by summing the thickness/interspace distance values for the object-side surface 111 of the first lens 11 through the object-side surface 141 of the fourth lens 14. This distance equals 1.705 mm in Yu's first embodiment. I have highlighted the relevant values in Yu's Table 1 below.

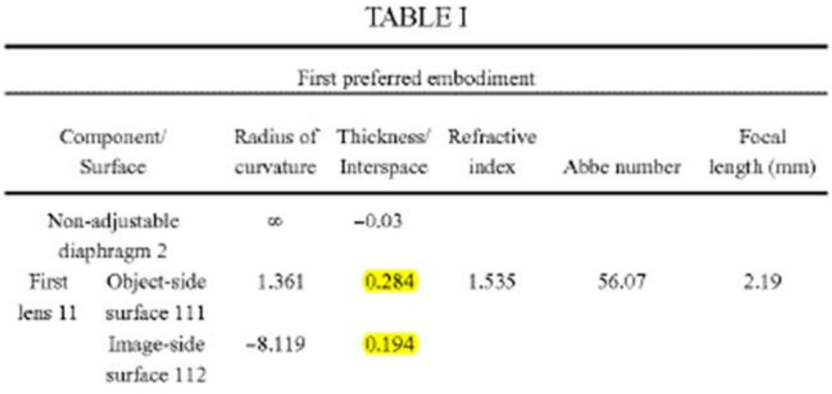


TABLE I

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Non-adjustable diaphragm 2		∞	−0.03			
First lens 11	Object-side surface 111	1.361	0.284	1.535	56.07	2.19
	Image-side surface 112	−8.119	0.194			

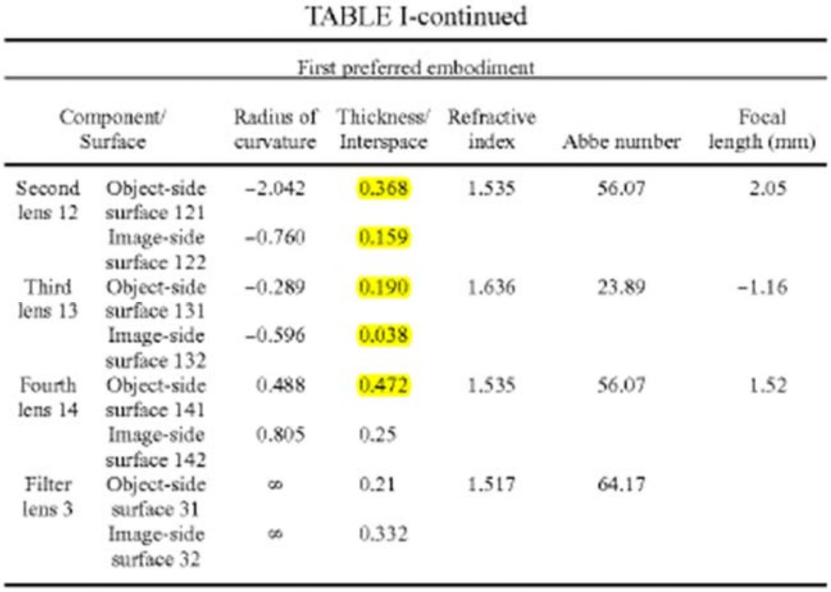


TABLE I-continued

First preferred embodiment

Component/ Surface		Radius of curvature	Thickness/ Interspace	Refractive index	Abbe number	Focal length (mm)
Second lens 12	Object-side surface 121	−2.042	0.368	1.535	56.07	2.05
	Image-side surface 122	−0.760	0.159			
Third lens 13	Object-side surface 131	−0.289	0.190	1.636	23.89	−1.16
	Image-side surface 132	−0.596	0.038			
Fourth lens 14	Object-side surface 141	0.488	0.472	1.535	56.07	1.52
	Image-side surface 142	0.805	0.25			
Filter lens 3	Object-side surface 31	∞	0.21	1.517	64.17	
	Image-side surface 32	∞	0.332			

231. The axial distance calculated above in Yu's first embodiment (1.705 mm) is 30.67% of the same distance in Yamaguchi's Example 3 (5.56 mm) and 37.31% of the same distance in Yamaguchi's Example 4 (4.57 mm). The reduced dimensions of Yu's first embodiment mean that it focuses the image on a smaller sensor. If Yu's first embodiment were used with Yamaguchi's larger electronic sensor without being rescaled for the purpose, the pixels far from the optical axis would be dark, and only the central part of the sensor would receive a good image.

232. Throughout the history of photography and videography, first film and then digital sensors and their pixels have reduced in size over time. The history of film photography progressed in stages from the large glass sensitive plates used by Matthew Brady in the 1860s, through the 4" by 5" cut film used in the well-known Speed Graphic cameras used by press photographers after 1912, to the sizes 120 and 620 roll film popular in the 1940s, to the 35 mm film cameras popular in the 1960s, to the Kodak Instamatic cameras and the Pocket Instamatic 110 format cameras of the 1970s, to the even smaller 8x10 mm Disk Camera format that came in 1982. This progression of film size was accompanied by similar reductions in lens size. By about 2004, when I was involved with digital lens design and manufacture, the common pixel size had been reduced to about 2.5 microns, or 0.0025 mm.

233. Smaller sensors require smaller lens assemblies, as recognized in the prior art. Ex. 1003, 1:19-24; Ex. 1006 ¶ 0005. At the time of the '796 patent, sensors of

various sizes would have been known to a person of ordinary skill in the art, as demonstrated by the range of sensor sizes supported by the prior art lens assembly designs of Yamaguchi's Examples 3 and 4 and Yu' first embodiment. As one textbook put it, "A lens prescription can be scaled to any desired focal length simply by multiplying all of its dimensions by the same constant. All of the linear aberration measures will then be scaled by the same factor." Ex. 1016, 96. More than 10 years elapsed between the filing dates of Yamaguchi and Yu, and in light of the trend of smaller sensors and smaller lens assemblies, the smaller size of Yu's lens assembly is to be expected. When Yamaguchi was first filed in 2002, digital sensor pixels still had dimensions of 3 microns (0.003 mm) or smaller. By 2006, the pixel size was down to 2.5 microns or smaller, and by 2011, sensors were sold with 1.9 micron dimensions.

234. It would have been obvious to a person of ordinary skill in the art at the time of the '796 patent to start with Yamaguchi's Example 3 or Example 4 and then adjust the design to support a smaller electronic sensor. A person of ordinary skill in the art would recognize that a geometric lens design may be scaled easily and as necessary to make the design useful for a larger or smaller electronic sensor. To obtain an equivalent scaled lens design, all of the dimensions of the design (e.g., surface radii, lens element thicknesses, diameters, and spacings) are scaled by the same numerical ratio, and aspheric coefficients are scaled by that ratio raised to the

appropriate power. Such scaling is so common and important that it can be performed with the use of a function built into software, although it can also be performed through manual calculations. Code V from Optical Research Associates, OSLO (Optics Software for Layout and Optimization) from Lambda Research Corporation, and ZEMAX from ZEMAX Development Corporation are three separate optical design software programs. Each allows a lens designer to scale a lens design using few menu selections. As shown in the Introductory User's Guide for Code V 9.7 (October 2006), a lens design can be scaled and plotted in seven steps. Ex. 1008, 29-31. The OSLO Optics Reference Manual Version 6.1 (2001) explains how a lens originally designed for a film camera can be scaled to have a smaller focal length more suited for digital cameras by opening the lens, opening the surface data spreadsheet, opening the edit menu, and changing the focal length. Ex. 1009, 247. A ZEMAX User's Guide from August 1, 2006, describes a "Scale Lens" function that "will scale the entire lens by the specified factor." Ex. 1010, 227-28. It explains that "[t]his is useful for scaling an existing design to an new focal length, for example." Ex. 1010, 227. Based on my personal experience, I know that ZEMAX Version 12 allows a lens designer to scale a lens design using the following sequence of menu items: "Tools" > "Modify" > "Scale Lens" > "Scale by Factor." ZEMAX Version 9 had the same capability in 1999-2001, but with slightly different commands: "Tools" > "Scale Lens" > "Scale by Factor."

235. Since Yu's first embodiment discloses a lens assembly with an axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element that is 30.67% of the same distance in Yamaguchi's Example 3 and 37.31% of the same distance in Yamaguchi's Example 4, it would have been obvious to a person of ordinary skill in the art at the time of the '796 patent to scale down the dimensions of Yamaguchi's Examples 3 and 4 by that or a lesser amount. For example, it would have been obvious to scale the dimensions of Yamaguchi's Example 3 to 40% of their original size and to scale Example 4 to 49% of their original size. When scaled by these factors, the axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element in Yamaguchi's Example 3 would be 2.224 mm (5.56 mm x 0.40) and in Yamaguchi's Example 4 would be 2.2393 mm (4.57 mm x 0.49). When these examples are scaled, the refractive index and Abbe number of the individual lenses, the angles at which light rays are refracted at each lens, the f-number, and the HFOV remain unchanged. The lens focal lengths will be scaled by the same factor, but the optical aberrations will remain optically corrected.

236. Scaling the dimensions of Yamaguchi's Example 3 and Example 4 to support a smaller electronic sensor in this manner amounts to the application of a known technique to a known device ready for improvement to yield predictable results and would have been obvious to try with a reasonable expectation of success. Further

both Yamaguchi and Yu include teachings that would have led a person of ordinary skill in the art to scale Yamaguchi's Examples 3 and 4 in this way. Both references disclose that smaller sensors require smaller lens assemblies. Ex. 1003, 1:19-24; Ex. 1006 ¶ 0005.

2. Adjusting the size of Yamaguchi's entrance pupil would have been obvious.

237. Claim 5 of the '796 patent recites: "The image capturing lens system of claim 2, wherein an f-number of the image capturing lens system is Fno, and the following condition is satisfied: $1.40<Fno\leq 2.25$." Ex. 1001, 31:31-35. Element 21f of claim 21 of the '796 patent includes a similar limitation. Ex. 1001, 33:30-34:7.

238. As I discussed in Section XII.Q, the f-number (Fno) of a lens system equals the focal length of the lens system divided by the diameter of the entrance pupil, and the entrance pupil of a lens system is the view of the aperture stop as seen through all of the lenses of the lens system, if any, that are on the object side (to the left) of the aperture stop.

239. I analyze Yamaguchi's Example 4 for claims 5 and 21 below. Yamaguchi discloses its pickup lens includes "a stop S," which "has a function for determining an F number of the whole image pickup lens." Ex. 1006 ¶¶ 0127, 0129. In Yamaguchi's Example 4, Fig. 10 and Table 13 disclose that the stop S is located to the left of the object-side surface of the first lens L1. Specifically, Table 13

discloses that the stop S is 0.05 mm to the left of the first lens L1 in Yamaguchi's Example 4 because the value of D for the stop is 0.05 mm. Ex. 1006 ¶ 0186. I have highlighted the stop S in Fig. 10 and Table 13 below.

FIG.10

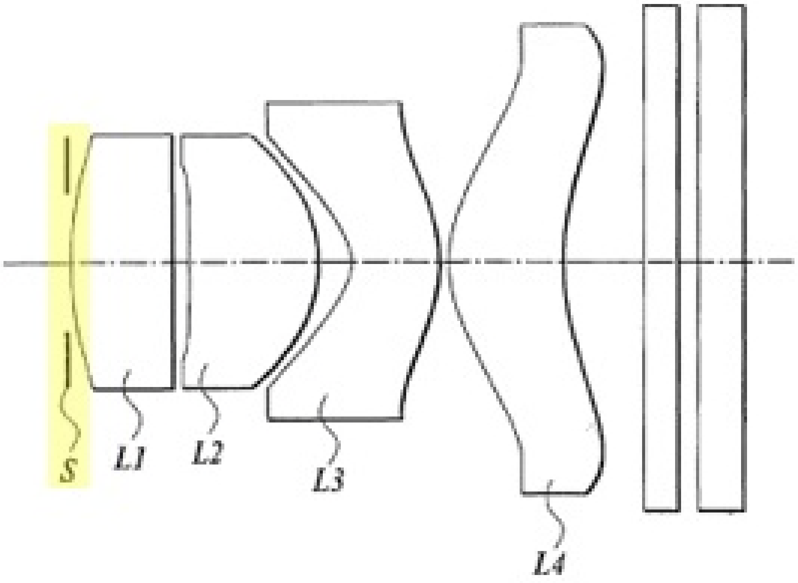


TABLE 13

(Example 4)

f = 3.952 mm, fB = 0.437 mm, F = 2.88, 2Y = 4.76 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.05		
1	3.913	0.93	1.69680	55.5
2	346.379	0.18		
3	−20.920	1.20	1.52500	56.0
4	−1.410	0.32		
5	−0.566	0.80	1.58300	30.0
6	−1.702	0.10		
7	1.248	1.04	1.52500	56.0
8	2.707	0.75		
9	∞	0.30	1.51633	64.1
10	∞	0.20		
11	∞	0.40	1.51633	64.1
12	∞			

240. Because the stop S is to the left of the first lens L1 in Yamaguchi's Example 4, the diameter of its opening is the entrance pupil of the lens system. Yamaguchi discloses that the f-number (Fno) of Example 4 equals 2.88. Ex. 1006 ¶¶ 0157, 0186. I have highlighted where the f-number (Fno) is identified in Yamaguchi's Table 13 below.

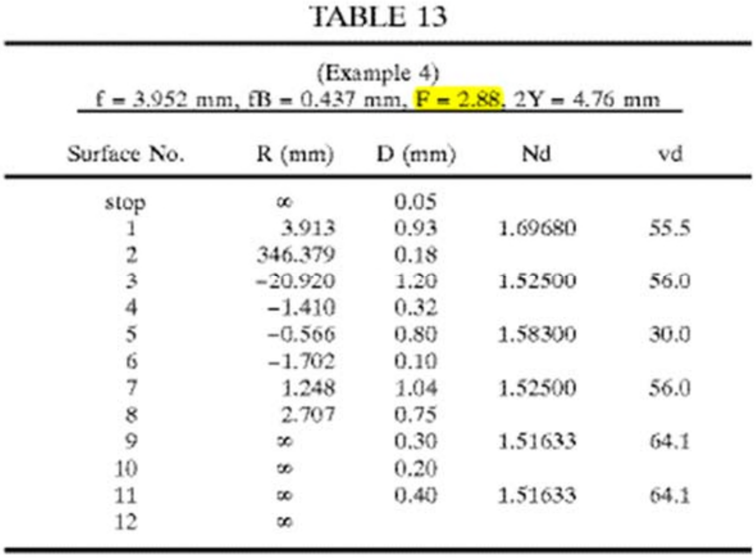


TABLE 13

(Example 4)
f = 3.952 mm, fB = 0.437 mm, F = 2.88, 2Y = 4.76 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.05		
1	3.913	0.93	1.69680	55.5
2	346.379	0.18		
3	−20.920	1.20	1.52500	56.0
4	−1.410	0.32		
5	−0.566	0.80	1.58300	30.0
6	−1.702	0.10		
7	1.248	1.04	1.52500	56.0
8	2.707	0.75		
9	∞	0.30	1.51633	64.1
10	∞	0.20		
11	∞	0.40	1.51633	64.1
12	∞			

241. The f-number (Fno) of Yamaguchi's Example 4 is larger than the range (1.40<Fno≤2.25) recited in claim 5 and Element 21f, but it would have been obvious to a person of ordinary skill in the art at the time of the '796 patent to increase the size of the diameter of the opening in the stop S in Yamaguchi's Example 4 and, in doing so, arrive at a lens system with an f-number (Fno) within the recited range.

242. As I have mentioned before, at the time of the '796 patent, the lens-design process begins with classic lens designs, and minor adjustments to those designs are made to satisfy present design specifications. A lens design request usually begins

with specifications that include the f-number (Fno). The f-number (Fno) specified for a particular lens system design may vary depending on the end-use of the lens system. Selecting an f-number (Fno) always involves a tradeoff between the light-gathering ability of the lens system on the one hand (which increases with a smaller f-number (Fno)) and the sharpness of the image produced by the lens system on the other hand. In certain applications, such as photographing a fast moving athletic event, improving the ability of the lens system to gather light and freeze motion is more important than maintaining the fullest sharpness of the image. Or, as disclosed in the prior art Okano publication, a lens assembly with a low f-number may be desired "in order to prevent deterioration of image quality due to noise in photographing in dark places." Ex. 1011 ¶ 0005.

243. The tradeoff between light-gathering ability and sharpness in this context is analogous to the tradeoff made by photographers using cameras that allow the size of the aperture to be adjusted manually. Whenever a photographer using one of these classic cameras sets up to take a picture, he or she must decide what is more important, more light or a sharper image. The balancing between these two considerations has been known since such cameras were first introduced, and took place every time a photographer read a light meter and selected an Fno and shutter speed combination to take a picture.

244. If the lens designer starting a new design, after selecting Yamaguchi's Example 4 as a starting point, needs to increase the light-gathering ability of the lens assembly with a lower f-number (Fno), increasing the size of the entrance pupil would be a standard and obvious first step to take in the design process. A lens designer always considers the size of the entrance pupil because it determines how sensitive the system will be for low-light operation. As Yamaguchi discloses, "the stop S has a function for determining an F number of the whole image pickup lens." Ex. 1006 ¶ 0129. Because the stop S is to the left of the object-side surface of the first lens L1 in Yamaguchi's Example 4, increasing the diameter of its opening directly increases the size of the entrance pupil, which it defines.

245. Yamaguchi discloses that the focal length of the pickup lens in Example 4 is 3.952 mm. Ex. 1006 ¶¶ 0155, 0186. I have highlighted where this is shown in Table 13 below.

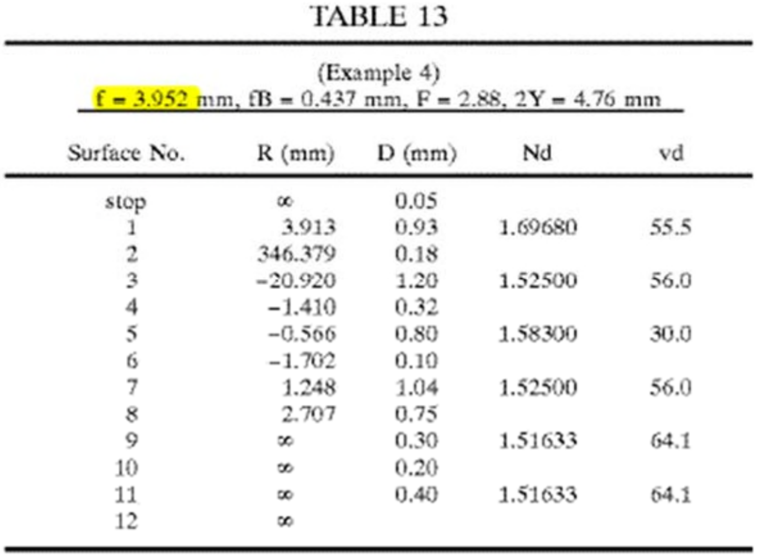


TABLE 13

(Example 4)
f = 3.952 mm, fB = 0.437 mm, F = 2.88, 2Y = 4.76 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.05		
1	3.913	0.93	1.69680	55.5
2	346.379	0.18		
3	−20.920	1.20	1.52500	56.0
4	−1.410	0.32		
5	−0.566	0.80	1.58300	30.0
6	−1.702	0.10		
7	1.248	1.04	1.52500	56.0
8	2.707	0.75		
9	∞	0.30	1.51633	64.1
10	∞	0.20		
11	∞	0.40	1.51633	64.1
12	∞			

246. Because Yamaguchi discloses both the f-number (Fno) and focal length of the pickup lens of Example 4, the diameter of the entrance pupil, in this case the diameter of the opening in the stop S, can be calculated. It equals the focal length (3.952 mm) divided by the f-number Fno (2.88), which equals 1.372 mm. This diameter would only need to be increased to 1.76 mm to fall within the range ($1.40<Fno\leq2.25$) recited in claim 5 and Element 21f. With a diameter of 1.76 mm, the Fno for Yamaguchi's Example 4 equals 2.245 (3.952 mm/1.76 mm), which satisfies the relation $1.40<Fno\leq2.25$. This is only a 28.3% increase to the size of the diameter of opening in the stop S in Yamaguchi's Example 4, and it would have been obvious to a person of ordinary skill in the art to use a stop with a diameter of this size. Such slight modifications to the size of the diameter of the opening in an

aperture stop would have been obvious and typical in the design process at the time of the ’796 patent.

247. Lens assemblies having f-numbers in the recited range were known before the ’796 patent. As I explained in Section XII.Q, Okano is an example of a prior art reference that discloses “an imaging lens which is suitable for a small sized apparatus such as a digital still camera or mobile phone” having f-numbers that range from 2.1 to 2.6 “to realize a bright optical system.” Ex. 1011 ¶¶ 0005, 0013, 0077-0078, 0106, 0112, 0228, 0256-0257, Table 23, Fig. 1. And the prior art publication Sugiyama is another example that discloses “a compact, high resolution, wide-angle lens composed of four to six lenses” for a camera having an f-number of 2, 2.2, or 2.4 and having “a bright configuration.” Ex. 1013 ¶¶ 0001-0002, 0021, 0036, 0048, 0061, 0065, 0076, 0080, 0091.

248. When the dimensions of Yamaguchi’s Example 4 are scaled down to support a smaller sensor, as I discussed in Section XIII.A.2, the f-number (Fno) remains the same, because the focal length of the lens system and the diameter of the entrance pupil scale by the same factor.

249. As the diameter of the opening in the stop S is enlarged, there may be some degradation of the sharpness of the image toward the edges of the electronic sensor. As I discussed above, there are end-use applications in which such degradation is an acceptable tradeoff for improved light-gathering ability. While a lens designer

might consider further refinements to the design of Yamaguchi's Example 4 at a later stage in the design process to reduce this degradation, the claims of the '796 patent do not recite any limitations regarding the quality of the resulting image of the lens system.

250. Changing the diameter of the opening in the stop S in Yamaguchi's Example 4, as explained in this section, would have been obvious to a person of ordinary skill in the art because it amounts to the simple substitution of one known element for another to obtain predictable results, a predictable use of prior art elements according to their established functions, and applying a known technique to a known device to yield predictable results.

B. Claim 1

1. Preamble: "An image capturing lens system comprising, in order from an object side to an image side:"

251. The preamble of claim 1 recites: "An image capturing lens system comprising, in order from an object side to an image side." Ex. 1001, 30:48-49.

252. Yamaguchi discloses "an image pickup lens comprising four lenses arranged in an order of a first lens, a second lens, a third lens, and a fourth lens from an object side." Ex. 1006 ¶ 0009; *see also* Ex. 1006 ¶¶ 0002, 0008, 0011, 0051, 0059. Yamaguchi's Fig. 5 (Examples 1 and 2), Fig. 8 (Example 3), and Fig. 10 (Example 4) show section views of four examples of "a small-sized image pickup lens." Ex.

1006 ¶¶ 0112, 0115, 0117. I analyze Yamaguchi's Example 4 for claims 1-11 and 21-24, and I analyze Yamaguchi's Example 3 for claims 1, 15-16, and 19-20. To the extent the preamble is limiting, Yamaguchi's pickup lens is "[a]n image capturing lens system."

FIG.5

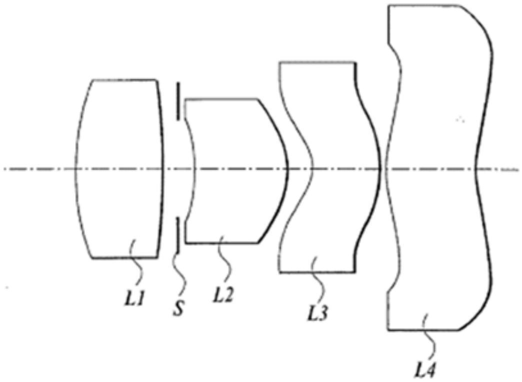


FIG.8

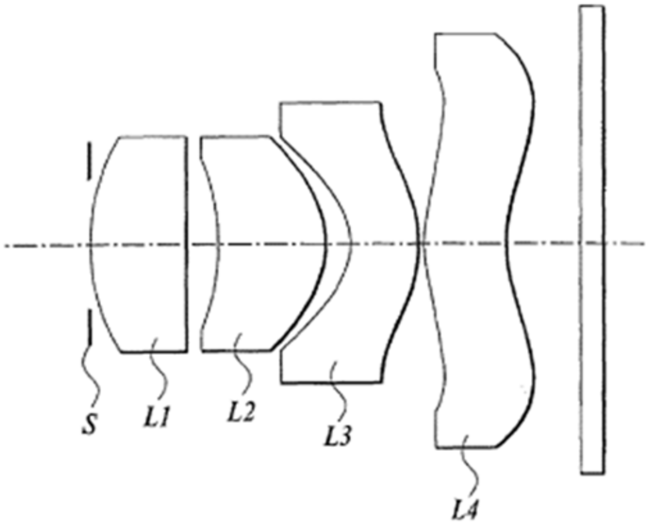
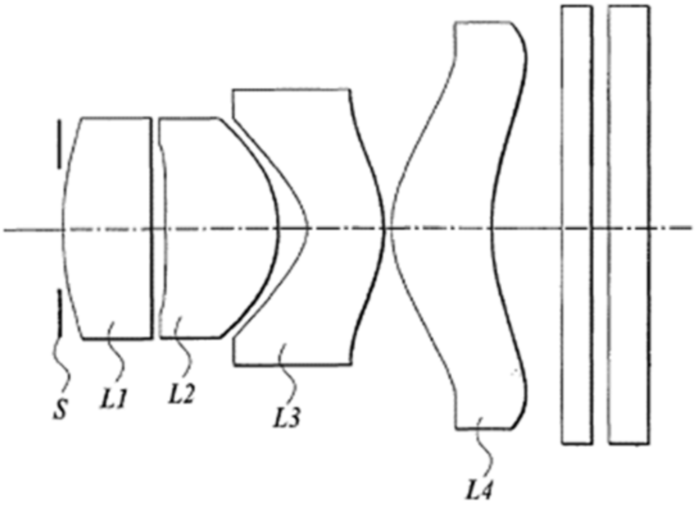


FIG.10



2. Element 1a: "a first lens element having refractive power;"

253. Element 1a recites: "a first lens element having refractive power." Ex. 1001, 30:50.

254. In order from the object side to the image side, Yamaguchi's pickup lens comprises first a "first lens L1." Ex. 1006 ¶ 0191. I have highlighted the first lens L1 in the annotated versions of Yamaguchi's Fig. 8 (Example 3) and Fig. 10 (Example 4) below. Yamaguchi discloses that "the first lens has positive refractive power." Ex. 1006 ¶¶ 0010, 0052. Yamaguchi's first lens L1 is a "first lens element having refractive power."

FIG.8

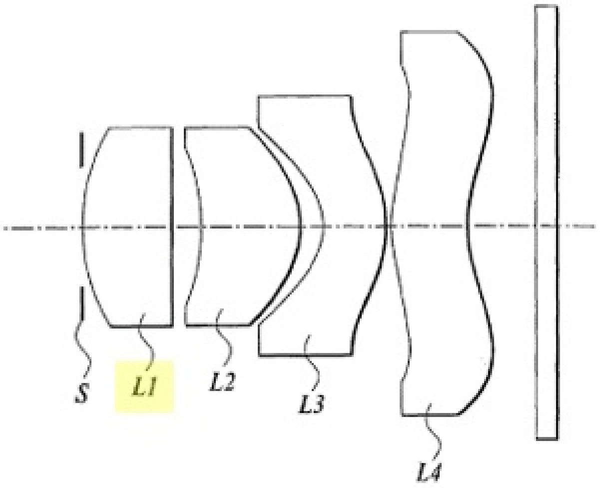
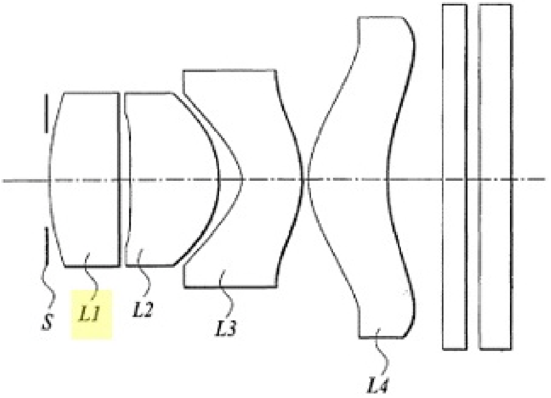


FIG.10



3. Element 1b: "a second lens element with positive refractive power having a convex image-side surface in a paraxial region thereof;"

255. Element 1b recites: "a second lens element with positive refractive power having a convex image-side surface in a paraxial region thereof." Ex. 1001, 30:51-53.

256. After the first lens L1, from the object side to image side in Yamaguchi's pickup lens is a "second lens L2." Ex. 1006 ¶ 0191. I have highlighted the second lens L2 in the annotated versions of Yamaguchi's Fig. 8 (Example 3) and Fig. 10 below (Example 4). Yamaguchi discloses that "the second lens has … positive refractive power." Ex. 1006 ¶ 0010. The shape of the second lens L2 in Fig. 8 (Example 3) and Fig. 10 (Example 4) confirms that it has positive refractive power, because the lens is thicker in the paraxial region. As I explained above, a lens with positive refractive power is thicker at its center.

FIG.8

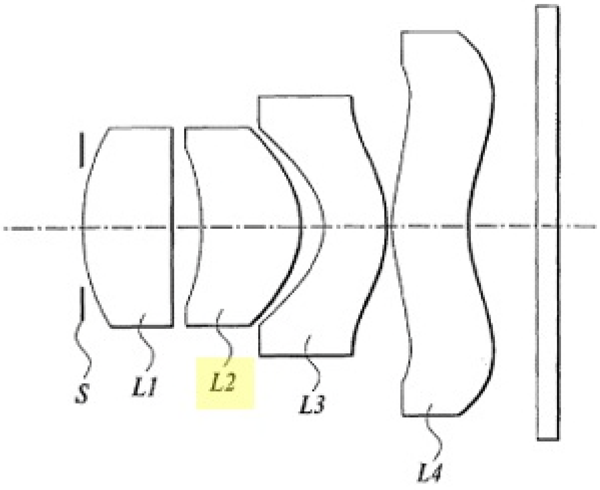
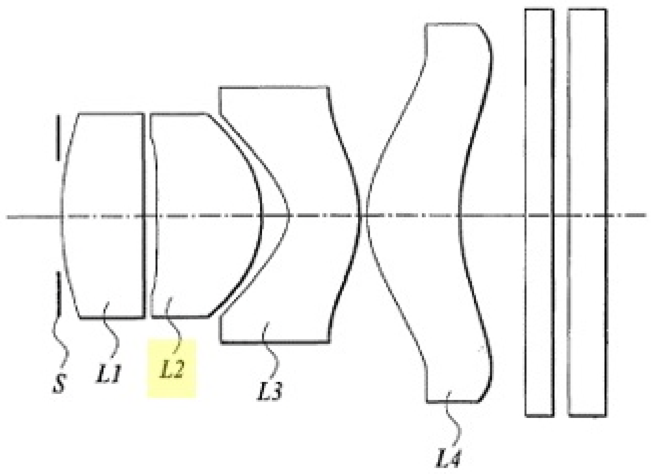


FIG.10



257. Yamaguchi's Table 9 and Table 13 list the radius of curvature (R) for the lens surfaces of Example 3 and Example 4, respectively. Ex. 1006 ¶¶ 0154, 0159, 0179, 0186. The radius of curvature of the image-side surface of the second lens L2 (Surface No. 4) is -1.626 mm in Example 3 and -1.410 mm in Example 4. Ex. 1006 ¶¶ 0179, 0186. As I explained above, a negative radius of curvature denotes a convex image-side surface. In order to avoid ambiguity, by convention a lens surface is judged concave or convex by reference to its paraxial region, i.e., the central area. I have highlighted the radius of curvature for Surface No. 4 in the annotated versions of Table 9 (Example 3) and Table 13 (Example 4) below. Fig. 8 (Example 3) and Fig. 10 (Example 4) above also confirm that Yamaguchi's second lens L2 has a convex image-side surface in a paraxial region. Yamaguchi's second lens L2 is a "second lens element with positive refractive power having a convex image-side surface in a paraxial region thereof."

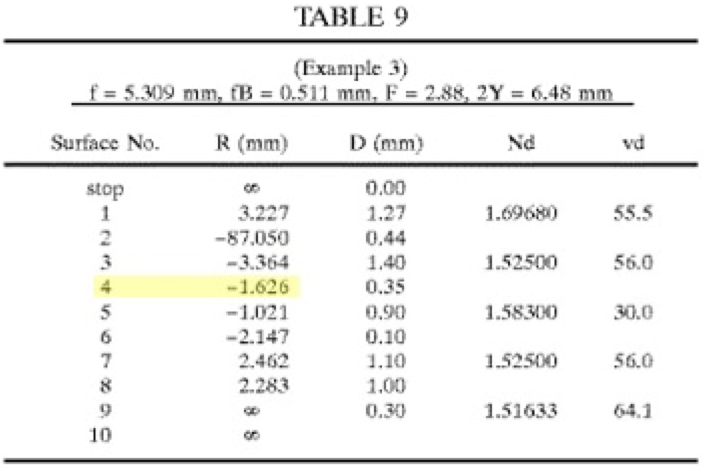


TABLE 9

(Example 3)
f = 5.309 mm, fB = 0.511 mm, F = 2.88, 2Y = 6.48 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.00		
1	3.227	1.27	1.69680	55.5
2	−87.050	0.44		
3	−3.364	1.40	1.52500	56.0
4	−1.626	0.35		
5	−1.021	0.90	1.58300	30.0
6	−2.147	0.10		
7	2.462	1.10	1.52500	56.0
8	2.283	1.00		
9	∞	0.30	1.51633	64.1
10	∞			

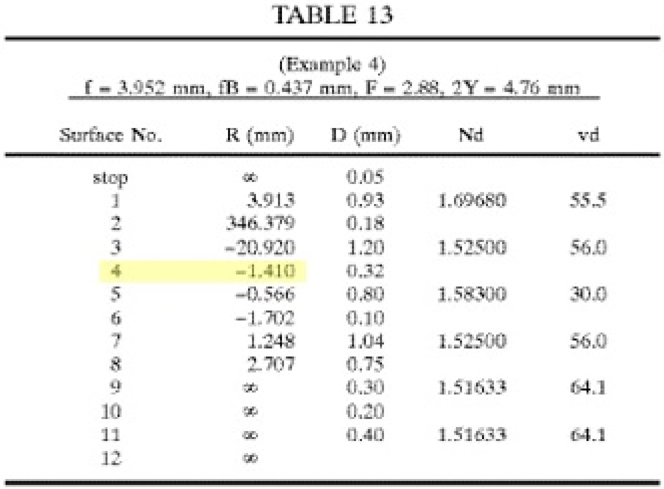


TABLE 13

(Example 4)
f = 3.952 mm, fB = 0.437 mm, F = 2.88, 2Y = 4.76 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.05		
1	3.913	0.93	1.69680	55.5
2	346.379	0.18		
3	−20.920	1.20	1.52500	56.0
4	−1.410	0.32		
5	−0.566	0.80	1.58300	30.0
6	−1.702	0.10		
7	1.248	1.04	1.52500	56.0
8	2.707	0.75		
9	∞	0.30	1.51633	64.1
10	∞	0.20		
11	∞	0.40	1.51633	64.1
12	∞			

4. Element 1c: "a third lens element with negative refractive power having a concave object-side surface in a paraxial region thereof and a convex image-side surface in a paraxial region thereof; and"

258. Element 1c recites: "a third lens element with negative refractive power having a concave object-side surface in a paraxial region thereof and a convex image-side surface in a paraxial region thereof." Ex. 1001, 30:54-57.

259. After the second lens L2, from the object side to image side in Yamaguchi's pickup lens is a "third lens L3." Ex. 1006 ¶ 0191. I have highlighted the third lens

L3 in the annotated versions of Yamaguchi's Fig. 8 (Example 3) and Fig. 10 (Example 4) below. Yamaguchi discloses that "the third lens has negative refractive power and has a concave surface facing toward the object side to be formed in a meniscus shape." Ex. 1006 ¶ 0010. A meniscus-shaped lens has a convex surface on one side and a concave surface on the opposite side, so the image-side surface of the third lens L3 is convex. In order to avoid ambiguity, by convention a lens surface is judged concave or convex by reference to its paraxial region, i.e., the central area. The shape of the third lens L3 in Fig. 8 (Example 3) and Fig. 10 (Example 4) below confirms that it has negative refractive power, because the lens is thinner in the paraxial region. As I explained above, a lens with negative refractive power is thinner at its center. The concave object-side surface in a paraxial region and convex image-side surface in a paraxial region of the third lens L3 can also be seen in these figures.

FIG.8

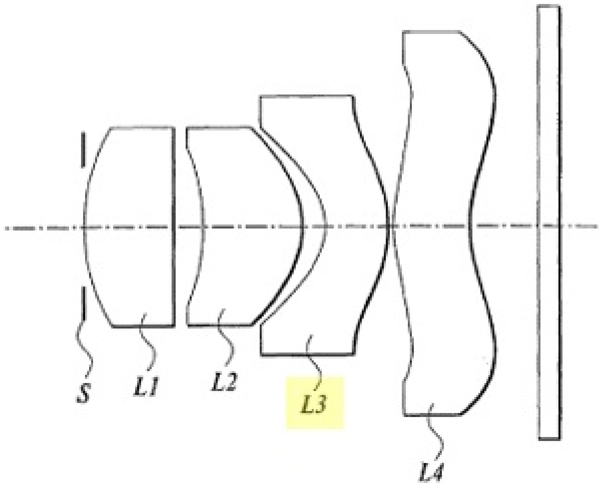
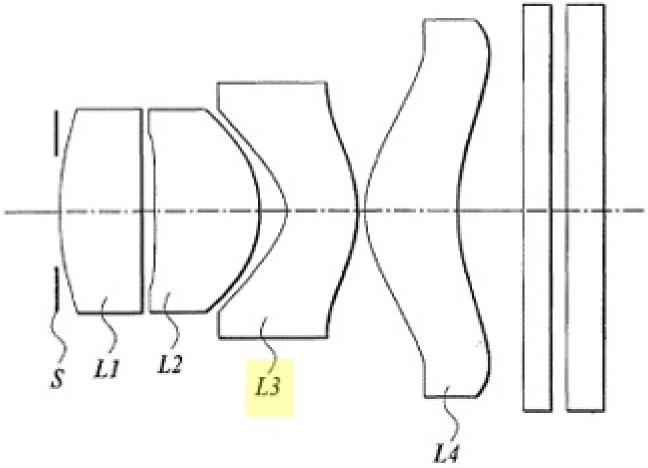


FIG.10



260. Table 9 (Example 3) and Table 13 (Example 4) confirm that the third lens L3 has a concave object-side surface in the paraxial region and a convex image-side surface in the paraxial region, because the radius of curvature for the object-side surface (Surface No. 5) is negative in both embodiments (-1.021 mm in Example 3 and -0.566 mm in Example 4) and the radius of curvature for the image-side surface

(Surface No. 6) is negative in both embodiments (-2.147 mm in Example 3 and -1.702 mm in Example 4). Ex. 1006 ¶¶ 0179, 0186. As I explained above, a negative radius of curvature denotes a concave object-side surface and a convex image-side surface. I have highlighted the radius of curvature for Surface No. 5 and Surface No. 6 in the annotated versions of Table 9 (Example 3) and Table 13 (Example 4) below. Yamaguchi's third lens L3 is "a third lens element with negative refractive power having a concave object-side surface in a paraxial region thereof and a convex image-side surface in a paraxial region thereof."

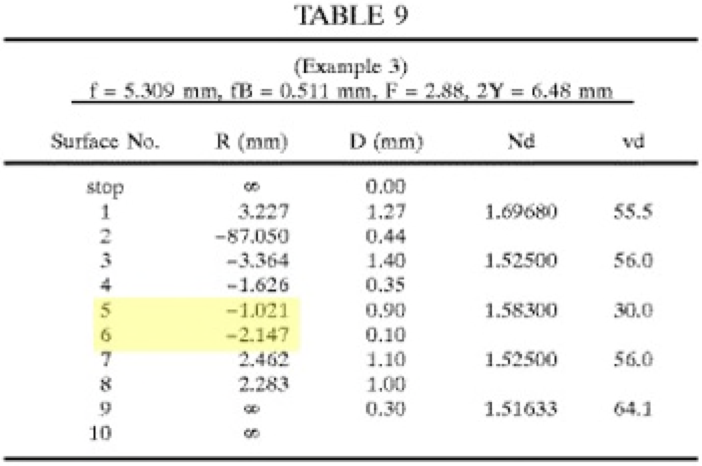


TABLE 9

(Example 3)
f = 5.309 mm, fB = 0.511 mm, F = 2.88, 2Y = 6.48 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.00		
1	3.227	1.27	1.69680	55.5
2	−87.050	0.44		
3	−3.364	1.40	1.52500	56.0
4	−1.626	0.35		
5	−1.021	0.90	1.58300	30.0
6	−2.147	0.10		
7	2.462	1.10	1.52500	56.0
8	2.283	1.00		
9	∞	0.30	1.51633	64.1
10	∞			

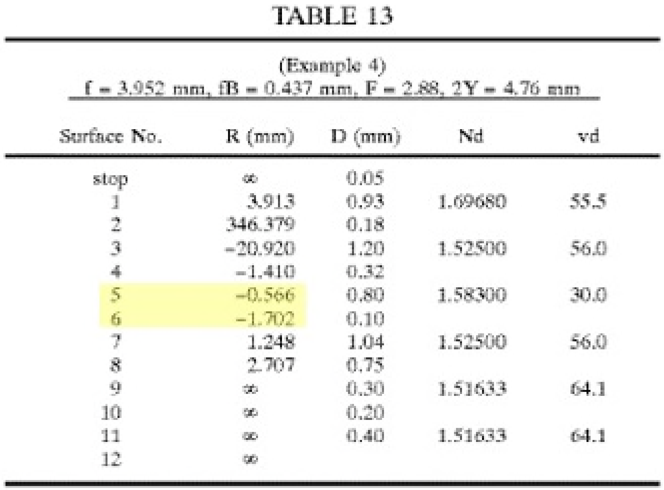


TABLE 13

(Example 4)
f = 3.952 mm, fB = 0.437 mm, F = 2.88, 2Y = 4.76 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.05		
1	3.913	0.93	1.69680	55.5
2	346.379	0.18		
3	−20.920	1.20	1.52500	56.0
4	−1.410	0.32		
5	−0.566	0.80	1.58300	30.0
6	−1.702	0.10		
7	1.248	1.04	1.52500	56.0
8	2.707	0.75		
9	∞	0.30	1.51633	64.1
10	∞	0.20		
11	∞	0.40	1.51633	64.1
12	∞			

5. Element 1d: “a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof, wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric, and the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof;”

261. Element 1d recites: “a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof, wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric, and the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof.” Ex. 1001, 30:58-63.

262. After the third lens L3, from the object side to image side in Yamaguchi’s pickup lens is a “fourth lens L4.” Ex. 1006 ¶ 0191. I have highlighted the fourth lens L4 in the annotated versions of Yamaguchi’s Fig. 8 (Example 3) and Fig. 10 (Example 4) below. Yamaguchi discloses that “the fourth lens has … positive or negative refractive power and has a convex surface facing toward the object side to

be formed in the meniscus shape." Ex. 1006 ¶ 0010. A meniscus-shaped lens has a convex surface on one side and a concave surface on the opposite side, so the image-side surface of the fourth lens L4 is concave. In order to avoid ambiguity, by convention a lens surface is judged concave or convex by reference to its paraxial region, i.e., the central area. The concave image-side surface in a paraxial region of the fourth lens L4 can be seen in the figures below.

FIG.8

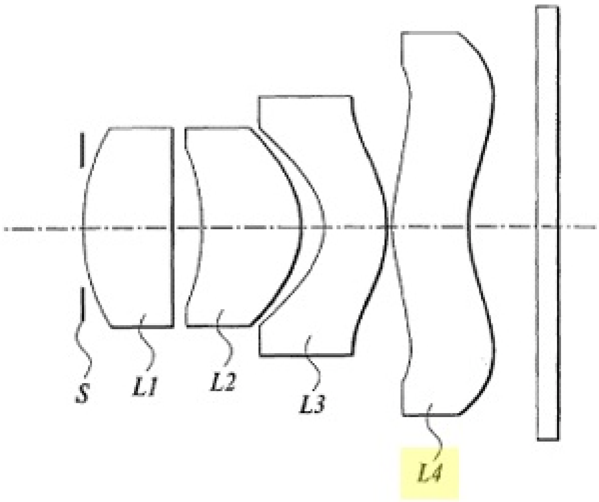
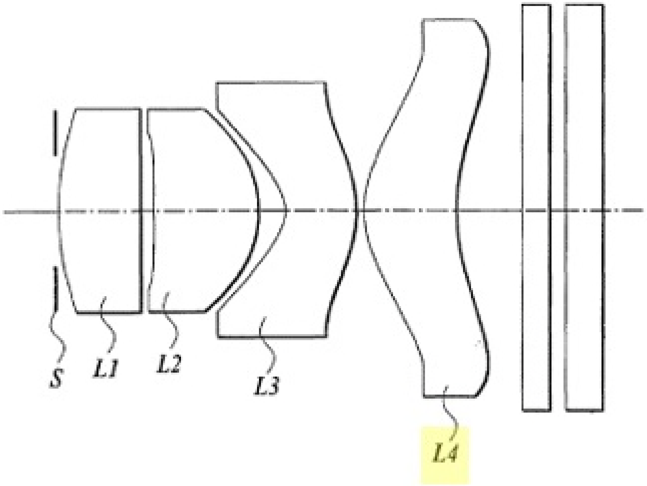


FIG.10



263. Table 9 (Example 3) and Table 13 (Example 4) confirm that the fourth lens L4 has a concave image-side surface (Surface No. 8) in a paraxial region, because the radius of curvature for this surface is positive in both embodiments (2.283 mm in Example 3 and 2.707 in Example 4). Ex. 1006 ¶¶ 0179, 0186. As I explained above, a positive radius of curvature denotes a concave image-side surface. I have highlighted the radius of curvature for Surface No. 8 in the annotated versions of Table 9 (Example 3) and Table 13 (Example 4) below. Yamaguchi's fourth lens L4 is "a fourth lens element with refractive power having a concave image-side surface in a paraxial region."

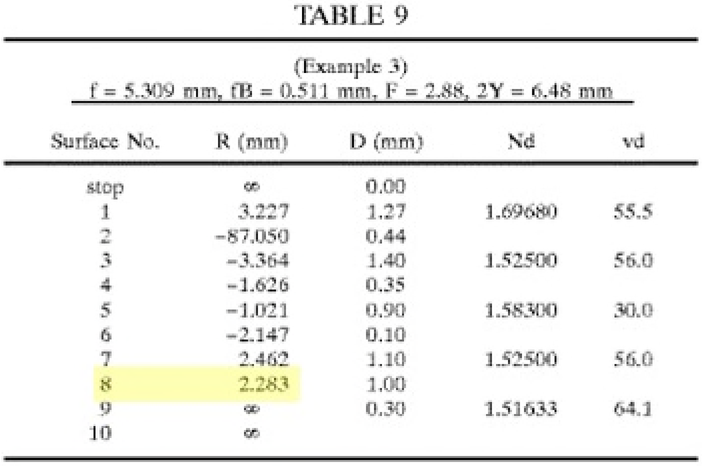


TABLE 9

(Example 3)
f = 5.309 mm, fB = 0.511 mm, F = 2.88, 2Y = 6.48 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.00		
1	3.227	1.27	1.69680	55.5
2	−87.050	0.44		
3	−3.364	1.40	1.52500	56.0
4	−1.626	0.35		
5	−1.021	0.90	1.58300	30.0
6	−2.147	0.10		
7	2.462	1.10	1.52500	56.0
8	2.283	1.00		
9	∞	0.30	1.51633	64.1
10	∞			

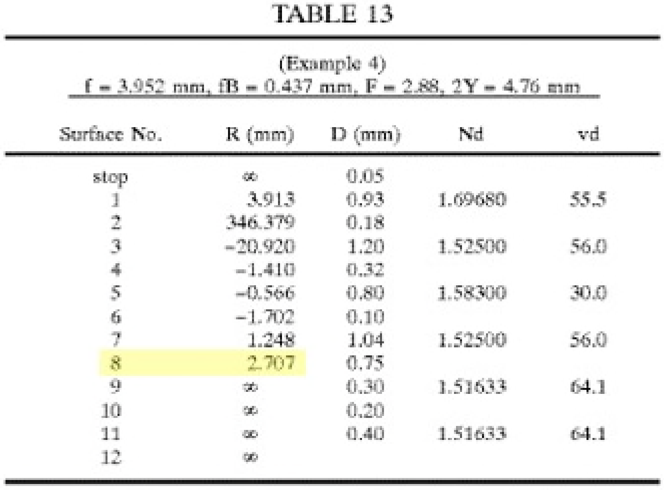


TABLE 13

(Example 4)
f = 3.952 mm, fB = 0.437 mm, F = 2.88, 2Y = 4.76 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.05		
1	3.913	0.93	1.69680	55.5
2	346.379	0.18		
3	−20.920	1.20	1.52500	56.0
4	−1.410	0.32		
5	−0.566	0.80	1.58300	30.0
6	−1.702	0.10		
7	1.248	1.04	1.52500	56.0
8	2.707	0.75		
9	∞	0.30	1.51633	64.1
10	∞	0.20		
11	∞	0.40	1.51633	64.1
12	∞			

264. Yamaguchi discloses that "the image side surface of the fourth lens is formed in the aspherical surface shape satisfying the formulas (14), (15) and (16)." Ex. 1006 ¶¶ 0054-0056, 0062. This is visible in Fig. 8 (Example 3) and Fig. 10 (Example 4) above. For Example 3 and Example 4, Yamaguchi discloses a version of this formula using "a rectangular coordinate system" and lists the aspheric coefficients in Table 10 (Example 3) and Table 14 (Example 4). Ex. 1006 ¶¶ 0163-0165, 0180, 0187. Table 10 (Example 3) and Table 14 (Example 4) show that the

object- (Surface No. 7) and image-side (Surface No. 8) surfaces of the fourth lens L4 are aspheric in Example 3 and Example 4 because they provide aspheric coefficients for those surfaces. Ex. 1006 ¶¶ 0180, 0187. I have highlighted these coefficients in the annotated versions of Table 10 (Example 3) and Table 14 (Example 4) below. Thus, Yamaguchi's fourth lens L4 is "a fourth lens element … wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric."

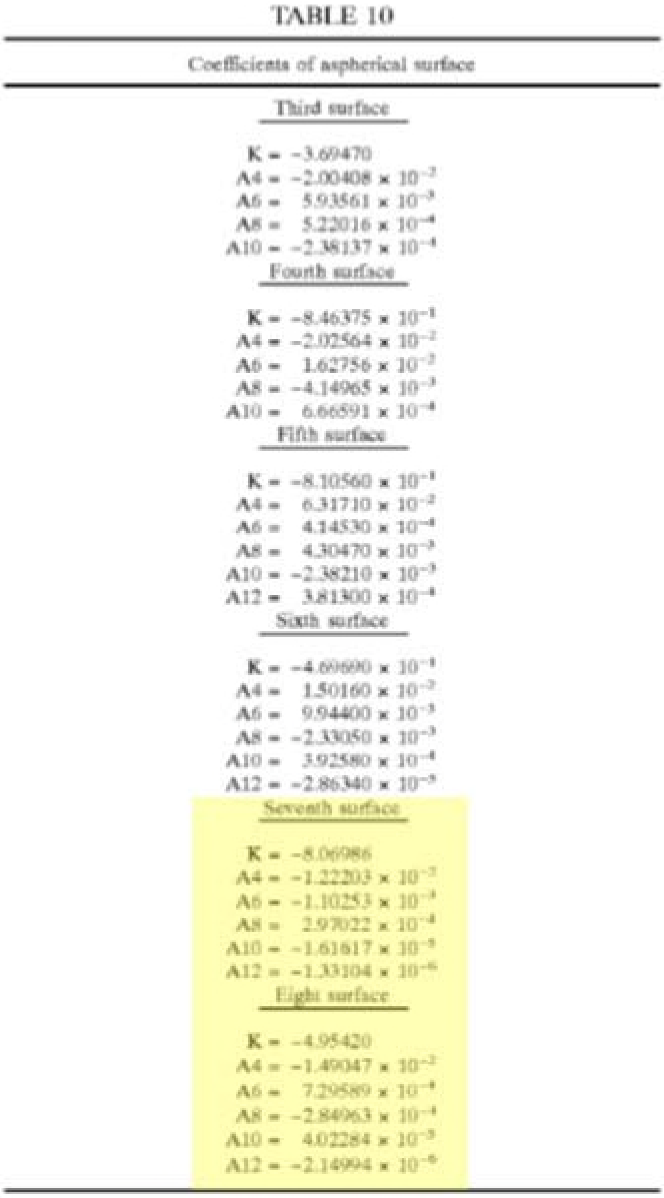


TABLE 10

Coefficients of aspherical surface

Third surface

$K = -3.69470$

$A4 = -2.00408 \times 10^{-2}$

$A6 = 5.93561 \times 10^{-3}$

$A8 = 5.22016 \times 10^{-4}$

$A10 = -2.38137 \times 10^{-4}$

Fourth surface

$K = -8.46375 \times 10^{-1}$

$A4 = -2.02564 \times 10^{-2}$

$A6 = 1.62756 \times 10^{-2}$

$A8 = -4.14965 \times 10^{-3}$

$A10 = 6.66591 \times 10^{-4}$

Fifth surface

$K = -8.10560 \times 10^{-1}$

$A4 = 6.31710 \times 10^{-2}$

$A6 = 4.14530 \times 10^{-4}$

$A8 = 4.30470 \times 10^{-3}$

$A10 = -2.38210 \times 10^{-3}$

$A12 = 3.81300 \times 10^{-4}$

Sixth surface

$K = -4.69690 \times 10^{-1}$

$A4 = 1.50160 \times 10^{-2}$

$A6 = 9.94400 \times 10^{-3}$

$A8 = -2.33050 \times 10^{-3}$

$A10 = 3.92580 \times 10^{-4}$

$A12 = -2.86340 \times 10^{-5}$

Seventh surface

$K = -8.06986$

$A4 = -1.22203 \times 10^{-2}$

$A6 = -1.10253 \times 10^{-3}$

$A8 = 2.97022 \times 10^{-4}$

$A10 = -1.61617 \times 10^{-5}$

$A12 = -1.33104 \times 10^{-6}$

Eight surface

$K = -4.95420$

$A4 = -1.49047 \times 10^{-2}$

$A6 = 7.29589 \times 10^{-4}$

$A8 = -2.84963 \times 10^{-4}$

$A10 = 4.02284 \times 10^{-5}$

$A12 = -2.14994 \times 10^{-6}$

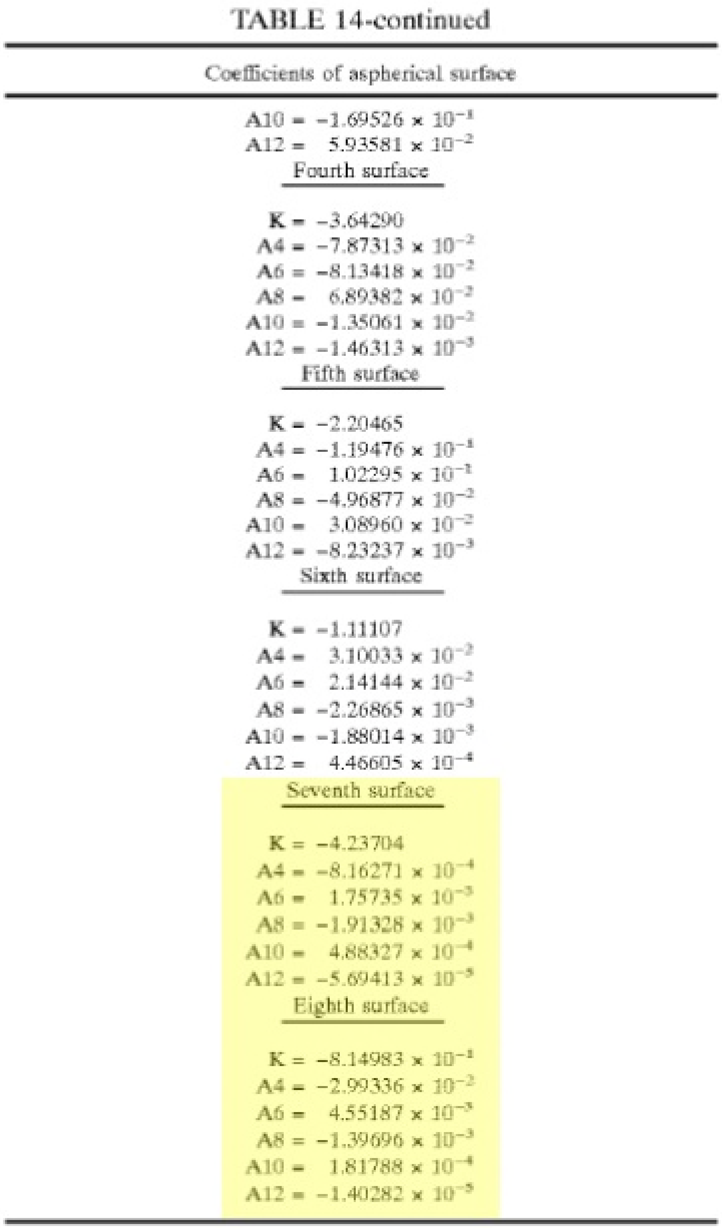


TABLE 14-continued

Coefficients of aspherical surface

$A10 = -1.69526 \times 10^{-1}$
$A12 = 5.93581 \times 10^{-2}$

Fourth surface

$K = -3.64290$
$A4 = -7.87313 \times 10^{-2}$
$A6 = -8.13418 \times 10^{-2}$
$A8 = 6.89382 \times 10^{-2}$
$A10 = -1.35061 \times 10^{-2}$
$A12 = -1.46313 \times 10^{-3}$

Fifth surface

$K = -2.20465$
$A4 = -1.19476 \times 10^{-1}$
$A6 = 1.02295 \times 10^{-1}$
$A8 = -4.96877 \times 10^{-2}$
$A10 = 3.08960 \times 10^{-2}$
$A12 = -8.23237 \times 10^{-3}$

Sixth surface

$K = -1.11107$
$A4 = 3.10033 \times 10^{-2}$
$A6 = 2.14144 \times 10^{-2}$
$A8 = -2.26865 \times 10^{-3}$
$A10 = -1.88014 \times 10^{-3}$
$A12 = 4.46605 \times 10^{-4}$

Seventh surface

$K = -4.23704$
$A4 = -8.16271 \times 10^{-4}$
$A6 = 1.75735 \times 10^{-3}$
$A8 = -1.91328 \times 10^{-3}$
$A10 = 4.88327 \times 10^{-4}$
$A12 = -5.69413 \times 10^{-5}$

Eighth surface

$K = -8.14983 \times 10^{-1}$
$A4 = -2.99336 \times 10^{-2}$
$A6 = 4.55187 \times 10^{-3}$
$A8 = -1.39696 \times 10^{-3}$
$A10 = 1.81788 \times 10^{-4}$
$A12 = -1.40282 \times 10^{-5}$

265. Fig. 8 and Fig. 10 show the shape of the fourth lens L4 in Yamaguchi's Example 3 and Example 4, respectively. Ex. 1006 ¶¶ 0182, 0184, 0189, 0191. Fig. 8 (Example 3) and Fig. 10 (Example 4) show that the image-side surface of the fourth lens L4 has "has at least one convex shape in an off-axis region." I have highlighted this convex, off-axis region in the annotated versions of Fig. 8 (Example

3) and Fig. 10 (Example 4) below. Thus, Yamaguchi's fourth lens L4 is "a fourth lens element … wherein the image-side surface of the fourth lens element has at least one convex shape in an off-axis region."

FIG.8

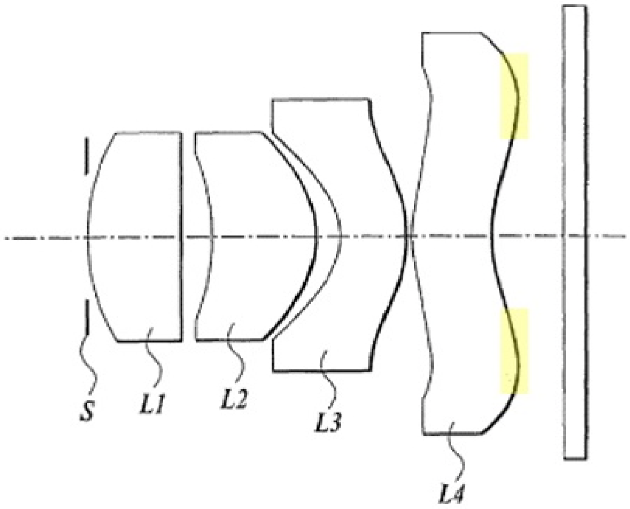
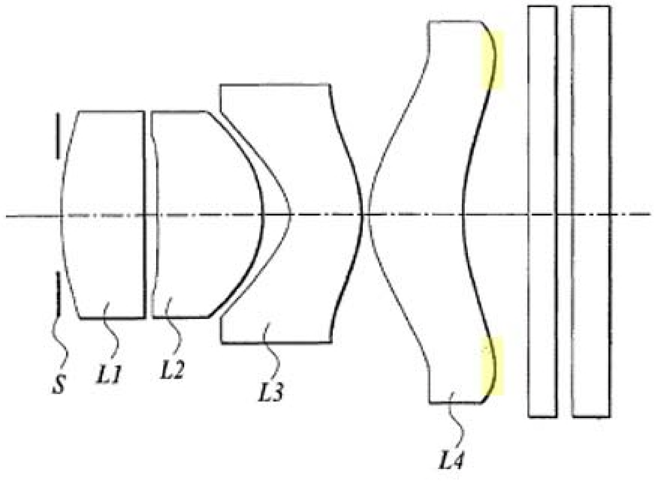


FIG.10



266. Accordingly, Yamaguchi's fourth lens L4 is "a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof,

wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric, and the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof."

6. Element 1e: "wherein the image capturing lens system has a total of four lens elements with refractive power,"

267. Element 1e recites: "wherein the image capturing lens system has a total of four lens elements with refractive power." Ex. 1001, 30:64-65.

268. Yamaguchi discloses that its pickup lens "has a total of four lens elements with refractive power," i.e., the first lens L1, second lens L2, third lens L3, and fourth lens L4 discussed above. *E.g.*, Ex. 1006 ¶¶ 0009-0010, Fig. 8, Fig. 10. There are no additional lens elements with refractive power. Accordingly, Yamaguchi discloses that "the image capturing lens system has a total of four lens elements with refractive power."

FIG.8

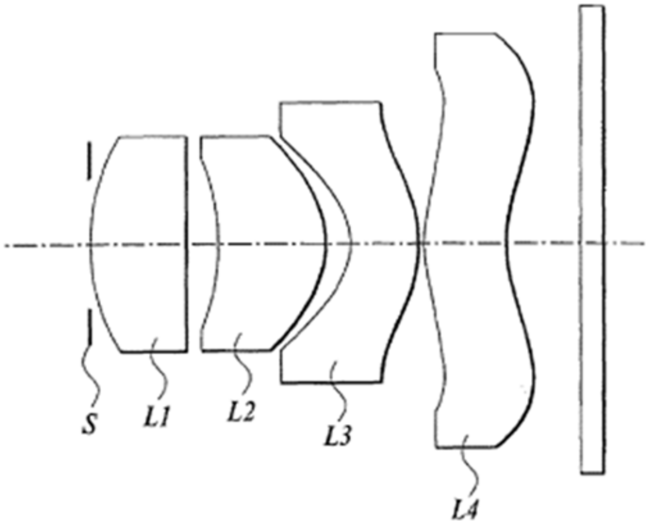
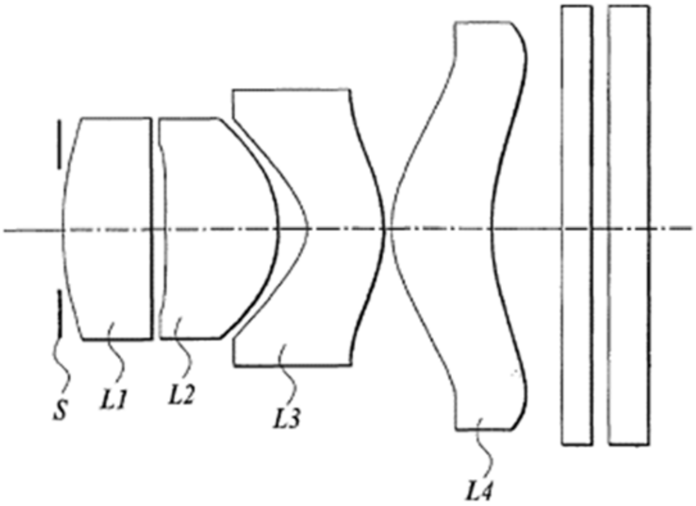


FIG.10



7. Element 1f: "an axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, half of a maximal field of view of the image capturing lens system is HFOV, a focal length of the image capturing lens system is f, a focal length of the fourth lens element is f4, a focal length of the second lens element is f2, a focal length of the third lens element is f3, and the following conditions are satisfied: 0.5 mm<Td<3.2 mm; 1.0 mm<Td/tan(HFOV)<3.75 mm; |f/f4|<1.20; and f2/f3<-0.65."

269. Element 1f recites:

- "an axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element is Td";
- "half of a maximal field of view of the image capturing lens system is HFOV";

- "a focal length of the image capturing lens system is f, a focal length of the fourth lens element is f4, a focal length of the second lens element is f2, a focal length of the third lens element is f3"; and
- "the following conditions are satisfied:

  $0.5\text{ mm} < Td < 3.2\text{ mm}$;

  $1.0\text{ mm} < Td/\tan(HFOV) < 3.75\text{ mm}$;

  $|f/f4| < 1.20$; and

  $f2/f3 < -0.65$."

Ex. 1001, 30:65-31:15.

270. Yamaguchi's Tables 9 (Example 3) and 13 (Example 4) list the "interval between refractive surfaces" (D). Ex. 1006 ¶¶ 0154, 0160, 0179, 0186. To determine the "axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element … Td," one sums the D values for Surfaces Nos. 1-7 as indicated in the table below. Ex. 1006 ¶¶ 0179, 0186.

Surface No.	Example 3 (mm)	Example 4 (mm)
1	1.27	0.93
2	0.44	0.18
3	1.40	1.20
4	0.35	0.32

5	0.90	0.80
6	0.10	0.10
7	1.10	1.04
Td	5.56	4.57

271. As indicated in the table above, Td equals 5.56 mm for Example 3 and 4.57 mm for Example 4. As I explained in Section XIII.A.1, it would have been obvious to a person of ordinary skill in the art at the time of the ’796 patent to scale the dimensions of Yamaguchi’s pickup lens. As I explained in that section, Yamaguchi’s Example 3 can be scaled to 40% of its original size, such that Td equals 2.224 mm (5.56 mm x 0.40), and Yamaguchi’s Example 4 can be scaled to 49% of its original size, such that Td equals 2.2393 mm (4.57 mm x 0.49). Both of these Td values satisfy the condition “0.5 mm<Td<3.2 mm.”

272. Yamaguchi discloses the value 2Y, which “denotes the length of a diagonal line on an effective image screen” for each of its embodiments. Ex. 1006 ¶¶ 0015, 0022, 0073, 0158. In Yamaguchi’s Example 3, “2Y = 6.48 mm.” Ex. 1006 ¶ 0179. Thus, Y is 3.24 mm. The dimension Y is simply the distance from the center of a digital sensor surface to its most distant corner. The whole diagonal of the sensor surface is then 2Y. For Example 3, Yamaguchi discloses that “f = 5.309 mm,” where f is the “focal length of the whole image pickup lens.” Ex. 1006 ¶¶ 0154-

0155, 0179. One can calculate the half of a maximal field of view (HFOV) for Example 3 because Y/f = tan(HFOV). When light enters an imaging lens from its extreme acceptance angle, the HFOV, it will form its image at the extreme corner of the sensor array. The lengths Y and f can be thought of as two sides of a right triangle, their ratio being the tangent of the HFOV angle. Light going through a compound imaging lens does not really travel along the hypotenuse of that triangle, but that would describe its path in a simple pinhole camera with the same dimensions.

273. Using this equation, and solving for HFOV, HFOV equals atan(Y/f). In the case of Example 3, HFOV equals atan(3.24 mm/5.309 mm), which equals 31.396 degrees. The value of HFOV remains the same when the dimensions of the pickup lens are scaled. The HFOV is an angle in a triangle, and all sides of that triangle scale by the same factor. Accordingly, Td/tan(HFOV) when Example 3 is scaled to 40% of its original size equals 2.224 mm/tan(31.396°), which equals 3.644 mm and satisfies the condition "1.0 mm<Td/tan(HFOV)<3.75 mm."

274. In Yamaguchi's Example 4, "2Y = 4.76 mm." Ex. 1006 ¶ 0186. Thus, Y is 2.38 mm. For Example 4, "f = 3.952 mm." Ex. 1006 ¶ 0186. Performing the same calculations discussed above, HFOV for Example 4 equals atan(2.38 mm/3.952 mm), which equals 31.057 degrees. Again, HFOV remains unchanged when the dimensions of the pickup lens are scaled. Accordingly, Td/tan(HFOV) when

Example 4 is scaled to 49% of its original size equals 2.2393 mm/tan(31.057°), which equals 3.7184 mm and satisfies the condition "1.0 mm<Td/tan(HFOV)<3.75 mm."

275. The focal length f of a "thick lens," such as the lens elements in Yamaguchi's Example 3 and Example 4, can be calculated with a standard formula, where N is the refractive index, R1 and R2 are the two surface radii, and t is the thickness of the lens: 1/f = (N-1)[1/R1-1/R2+t(N-1)/R1R2N]. Ex. 1017, 38. The focal length can also be conveniently calculated on line at: https://tinyurl.com/THICKLENS.

276. Yamaguchi discloses that "f = 5.309 mm" in Example 3. Ex. 1006 ¶ 0179. Using the information in Table 9 (Example 3), and the formula above, I can calculate that f2 equals 4.6932 mm, f3 equals -4.7323 mm, and f4 equals 53.6144 mm in Yamaguchi's Example 3.

277. Yamaguchi discloses that "f = 3.952 mm" in Example 4. Ex. 1006 ¶ 0186. Using the information in Table 13 (Example 4), and the formula above, I can calculate that f2 equals 2.8201 mm, f3 equals -1.9639 mm, and f4 equals 3.5414 mm in Yamaguchi's Example 4.

278. Using the values of f and f4 above, the absolute value of f/f4 (i.e., |f/f4|) equals 0.099 in Example 3 and 1.116 in Example 4, which both satisfy the condition "|f/f4|<1.20." Using the values of f2 and f3 above, f2/f3 equals -0.9917 in Example 3 and -1.436 in Example 4, which both satisfy the condition "f2/f3<-0.65." These

ratios are unaffected when the dimensions of the pickup lens are scaled because both the numerator and the denominator are scaled by the same factor.

279. Accordingly, Yamaguchi in view of Yu discloses “an axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, half of a maximal field of view of the image capturing lens system is HFOV, a focal length of the image capturing lens system is f, a focal length of the fourth lens element is f4, a focal length of the second lens element is f2, a focal length of the third lens element is f3, and the following conditions are satisfied: 0.5 mm<Td<3.2 mm; 1.0 mm<Td/tan(HFOV)<3.75 mm; |f/f4|<1.20; and f2/f3<-0.65.”

8. Conclusion for Claim 1

280. As I have explained above in this section, Yamaguchi in view of Yu discloses all elements of claim 1. Accordingly, Yamaguchi in view of Yu renders claim 1 obvious.

C. Claim 2: “The image capturing lens system of claim 1, wherein the fourth lens element has the object-side surface being convex in a paraxial region thereof.”

281. Claim 2 depends from claim 1 and recites: “The image capturing lens system of claim 1, wherein the fourth lens element has the object-side surface being convex in a paraxial region thereof.” Ex. 1001, 31:16-18.

282. As discussed above, I analyze Yamaguchi's Example 4 for claim 2. Yamaguchi discloses that "the fourth lens … has a convex surface facing toward the object side." Ex. 1006 ¶ 0010. I have highlighted the convex object-side surface of the fourth lens L4 in the annotated version of Yamaguchi's Fig. 10 (Example 4) below. Yamaguchi's Table 13 (Example 4) lists the radius of curvature of the object-side surface of the fourth lens L4 (Surface No. 7) as 1.248 mm. Ex. 1006 ¶ 0186. I have highlighted this radius of curvature in the annotated version of Table 13 (Example 4) below. As I explained above, this positive radius denotes a convex object-side surface in a paraxial region of the fourth lens L4. All of the aspheric terms in the mathematical formula for an aspheric surface have high powers of the distance from the axis, and shrink to very small contributions in the paraxial (central) region, leaving just the curvature of the spherical term. Then there is no possible ambiguity related to the shape of the outer parts of the aspheric surface. The convex shape of this surface is unaffected when the dimensions of the pickup lens are scaled. The center of a convex surface protrudes above its surrounding area. When the dimensions of the lens are scaled the center still protrudes, but by a different amount due to the scaling. Thus, Yamaguchi discloses that "the fourth lens element has the object-side surface being convex in a paraxial region."

FIG.10

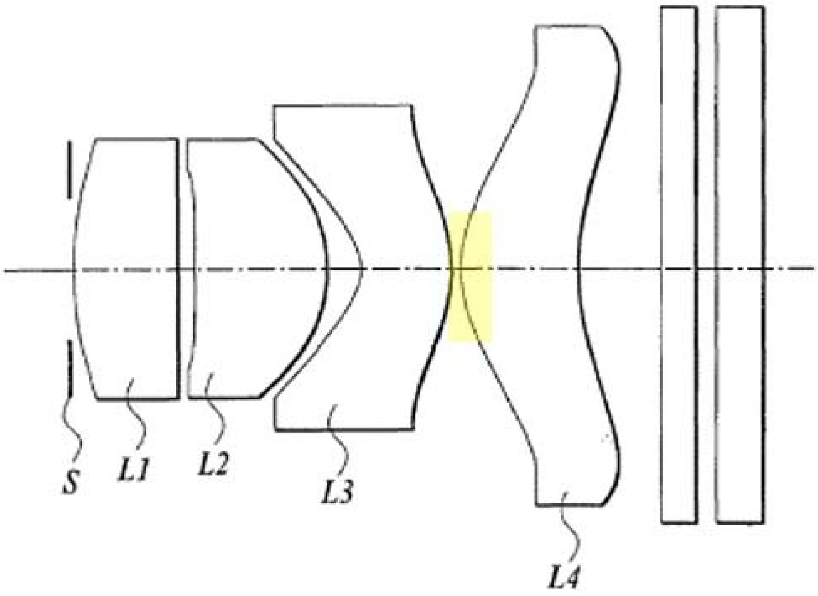
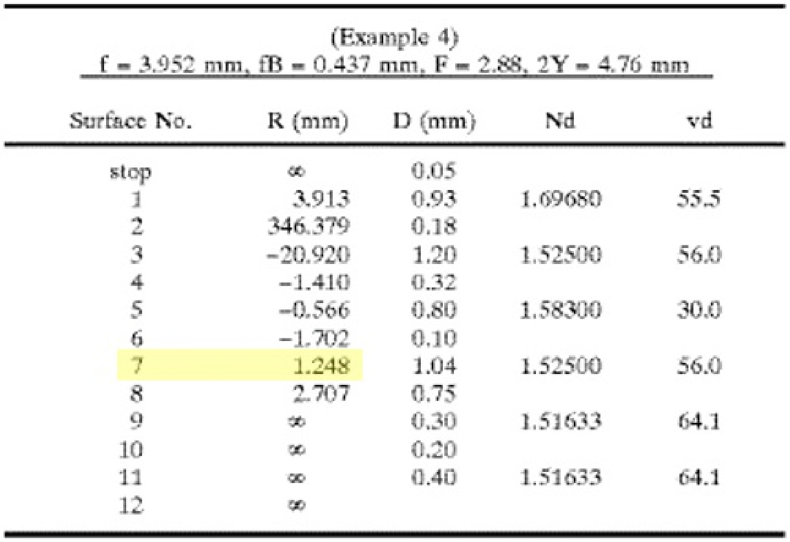


TABLE 13



(Example 4)
f = 3.952 mm, fB = 0.437 mm, F = 2.88, 2Y = 4.76 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.05		
1	3.913	0.93	1.69680	55.5
2	346.379	0.18		
3	−20.920	1.20	1.52500	56.0
4	−1.410	0.32		
5	−0.566	0.80	1.58300	30.0
6	−1.702	0.10		
7	1.248	1.04	1.52500	56.0
8	2.707	0.75		
9	∞	0.30	1.51633	64.1
10	∞	0.20		
11	∞	0.40	1.51633	64.1
12	∞			

1. Conclusion for Claim 2

283. As I explained in Section XIII.B, Yamaguchi in view of Yu renders claim 1 obvious. As I explained in this section, Yamaguchi discloses the additional element of claim 2. Accordingly, Yamaguchi in view of Yu renders claim 2 obvious.

D. Claim 3: “The image capturing lens system of claim 2, wherein the focal length of the image capturing lens system is f, a focal length of the first lens element is f1, and the following condition is satisfied: -0.25<f/f1<0.75.”

284. Claim 3 depends from claim 2 and recites: “The image capturing lens system of claim 2, wherein the focal length of the image capturing lens system is f, a focal length of the first lens element is f1, and the following condition is satisfied: -0.25<f/f1<0.75.” Ex. 1001, 31:19-24.

285. As I discussed in Section XIII.B.7, the focal length f of a “thick lens” can be calculated with a standard formula, where N is the refractive index, R1 and R2 are the two surface radii, and t is the thickness of the lens: $1/f = (N-1)[1/R1-1/R2+t(N-1)/R1R2N]$. The focal length can also be conveniently calculated on line at: https://tinyurl.com/THICKLENS.

286. As discussed above, I analyze Yamaguchi’s Example 4 for claim 3. Yamaguchi discloses that “f=3.952 mm” in Example 4. Ex. 1006 ¶ 0186. Using the information in Yamaguchi’s Table 13 (Example 4), and the formula above, I can calculate that f1 equals 5.6984 mm in Yamaguchi’s Example 4. Using these values, f/f1 equals 0.6935, which satisfies the condition “-0.25<f/f1<0.75.” This ratio is unaffected when the dimensions of the pickup lens are scaled because both the numerator and the denominator are scaled by the same factor. Accordingly, Yamaguchi discloses that “the focal length of the image capturing lens system is f, a

focal length of the first lens element is f1, and the following condition is satisfied: -0.25<f/f1<0.75."

1. Conclusion for Claim 3

287. As I explained in Section XIII.C, Yamaguchi in view of Yu renders claim 2 obvious. As I explained in this section, Yamaguchi discloses the additional element of claim 3. Accordingly, Yamaguchi in view of Yu renders claim 3 obvious.

E. Claim 4: "The image capturing lens system of claim 2, wherein the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.8 mm<Td<2.5 mm."

288. Claim 4 depends from claim 2 and recites: "The image capturing lens system of claim 2, wherein the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.8 mm<Td<2.5 mm." Ex. 1001, 31:25-30.

289. As discussed above, I analyze Yamaguchi's Example 4 for claim 4. I calculated Td for Yamaguchi's Example 4 scaled to 49% of its original size in Section XIII.B.7, and it equals 2.2393 mm. This satisfies the condition "0.8 mm<Td<2.5 mm." Thus, Yamaguchi in view of Yu discloses that "the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.8 mm<Td<2.5 mm."

1. Conclusion for Claim 4

290. As I explained in Section XIII.C, Yamaguchi in view of Yu renders claim 2 obvious. As I explained in this section, Yamaguchi in view of Yu discloses the additional element of claim 4. Accordingly, Yamaguchi in view of Yu renders claim 4 obvious.

F. Claim 5: "The image capturing lens system of claim 2, wherein an f-number of the image capturing lens system is Fno, and the following condition is satisfied: 1.40<Fno≤2.25."

291. Claim 5 depends from claim 2 and recites: "The image capturing lens system of claim 2, wherein an f-number of the image capturing lens system is Fno, and the following condition is satisfied: 1.40<Fno≤2.25." Ex. 1001, 31:31-35.

292. As discussed above, I analyze Yamaguchi's Example 4 for claim 5. As I explained in Section XIII.A.2, it would have been obvious to a POSITA to enlarge the size of the opening in the stop in Yamaguchi's pickup lens at the time of the '796 patent. As I explained in that section, enlarging the opening in the stop by 28.3% results in an f-number (Fno) that equals 2.245 for Yamaguchi's Example 4, which satisfies the condition "1.40<Fno≤2.25."

1. Conclusion for Claim 5

293. As I explained in Section XIII.C, Yamaguchi in view of Yu renders claim 2 obvious. As I explained in this section, Yamaguchi renders the additional element

of claim 5 obvious. Accordingly, Yamaguchi in view of Yu renders claim 5 obvious.

G. Claim 6: "The image capturing lens system of claim 2, wherein a curvature radius of the object-side surface of the second lens element is R3, a curvature radius of the image-side surface of the second lens element is R4, and the following condition is satisfied: 0.5<(R3+R4)/(R3-R4)<2.5."

294. Claim 6 depends from claim 2 and recites: "The image capturing lens system of claim 2, wherein a curvature radius of the object-side surface of the second lens element is R3, a curvature radius of the image-side surface of the second lens element is R4, and the following condition is satisfied: 0.5<(R3+R4)/(R3-R4)<2.5." Ex. 1001, 31:36-43.

295. As discussed above, I analyze Yamaguchi's Example 4 for claim 6. Yamaguchi's Table 13 (Example 4) lists the radius of curvature for the object-side surface (Surface No. 3) of the second lens L2 ("R3") as -20.920 mm and the radius of curvature of the image-side surface (Surface No. 4) of the second lens L2 ("R4") as -1.410 mm. Ex. 1006 ¶ 0186. I have highlighted these values in the annotated version of Yamaguchi's Table 13 (Example 4) below. With these numbers, (R3+R4)/(R3-R4) equals 1.1445, which satisfies the condition "0.5<(R3+R4)/(R3-R4)<2.5." This ratio is unaffected when the dimensions of the pickup lens are scaled because both the numerator and the denominator are scaled by the same factor. Thus, Yamaguchi discloses that "a curvature radius of the object-side surface

of the second lens element is R3, a curvature radius of the image-side surface of the second lens element is R4, and the following condition is satisfied: 0.5<(R3+R4)/(R3-R4)<2.5."

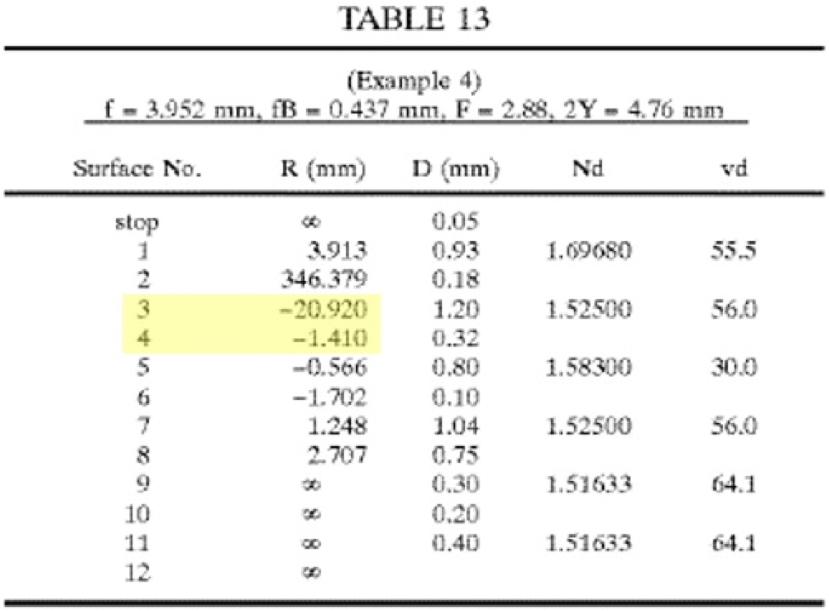


TABLE 13

(Example 4)

f = 3.952 mm, fB = 0.437 mm, F = 2.88, 2Y = 4.76 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.05		
1	3.913	0.93	1.69680	55.5
2	346.379	0.18		
3	−20.920	1.20	1.52500	56.0
4	−1.410	0.32		
5	−0.566	0.80	1.58300	30.0
6	−1.702	0.10		
7	1.248	1.04	1.52500	56.0
8	2.707	0.75		
9	∞	0.30	1.51633	64.1
10	∞	0.20		
11	∞	0.40	1.51633	64.1
12	∞			

1. Conclusion for Claim 6

296. As I explained in Section XIII.C, Yamaguchi in view of Yu renders claim 2 obvious. As I explained in this section, Yamaguchi discloses the additional element of claim 6. Accordingly, Yamaguchi in view of Yu renders claim 6 obvious.

H. Claim 7: "The image capturing lens system of claim 2, wherein the focal length of the image capturing lens system is f, and the following condition is satisfied: 0.5 mm<f<2.0 mm."

297. Claim 7 depends from claim 2 and recites: "The image capturing lens system of claim 2, wherein the focal length of the image capturing lens system is f, and the following condition is satisfied: 0.5 mm<f<2.0 mm." Ex. 1001, 31:44-48.

298. As discussed above, I analyze Yamaguchi's Example 4 for claim 7. In Yamaguchi's Example 4, "f = 3.952 mm." Ex. 1006 ¶ 0186. This focal length scales proportionally to the other dimensions of Yamaguchi's Example 4. In a scaled lens design, all of the linear dimensions such a radii, spacings and diameters are changed by the same factor, so angles of incidence and refraction where light passes through lens surfaces are all kept the same, with the result that all of the traced light rays behave just the same, but in miniature. The rays that come together to form an image just form that image in a scaled location, defined by the focal length. Thus, when Yamaguchi's Example 4 is scaled to 49% of its original size, as discussed in Sections XIII.A.1 and XIII.B.7, f also scales to 49% of its original value, so that it equals 1.9365 mm, which satisfies the condition "0.5 mm<f<2.0 mm." Thus, Yamaguchi in view of Yu discloses that "the focal length of the image capturing lens system is f, and the following condition is satisfied: 0.5 mm<f<2.0 mm."

1. Conclusion for Claim 7

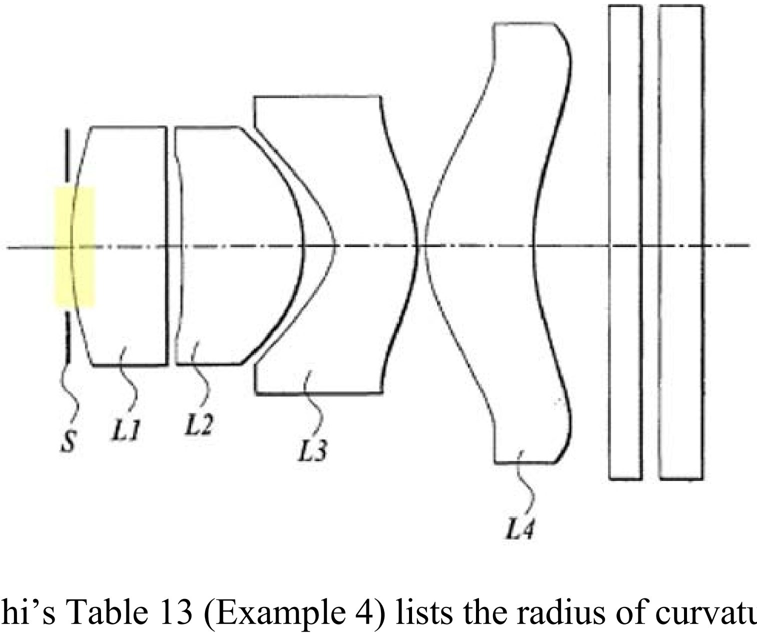
299. As I explained in Section XIII.C, Yamaguchi in view of Yu renders claim 2 obvious. As I explained in this section, Yamaguchi in view of Yu renders the additional element of claim 7 obvious. Accordingly, Yamaguchi in view of Yu renders claim 7 obvious.

I. Claim 8: "The image capturing lens system of claim 1, wherein the first lens element has a convex object-side surface in a paraxial region thereof."

300. Claim 8 depends from claim 1 and recites: "The image capturing lens system of claim 1, wherein the first lens element has a convex object-side surface in a paraxial region thereof." Ex. 1001, 31:49-51.

301. As discussed above, I analyze Yamaguchi's Example 4 for claim 8. Yamaguchi discloses that "the first lens … has a convex surface facing toward the object side." Ex. 1006 ¶ 0010. I have highlighted the convex object-side surface of the first lens L1 in the annotated version of Yamaguchi's Fig. 10 (Example 4) below.

FIG.10



302. Yamaguchi's Table 13 (Example 4) lists the radius of curvature of the object-side surface of the first lens L1 (Surface No. 1) as 3.913 mm. Ex. 1006 ¶ 0186. I

have highlighted this radius of curvature in the annotated version of Table 13 (Example 4) below. As I explained above, this positive radius denotes a convex object-side surface in a paraxial region of the first lens L1. By convention one of ordinary skill in the art bases an identification of a surface as convex or concave by considering just the central region, near the optical axis, often referred to as "the paraxial region." The convexity or concavity of the shape there is given by the spherical radius data for the surface, and that central curvature is not changed by any of the additional aspheric data.

303. The convex shape of this surface is unaffected when the dimensions of the pickup lens are scaled. The center of a convex surface protrudes above its surrounding area. When the dimensions of the lens are scaled the center still protrudes, but by a different amount due to the scaling. Thus, Yamaguchi discloses that "the first lens element has a convex object-side surface in a paraxial region thereof."

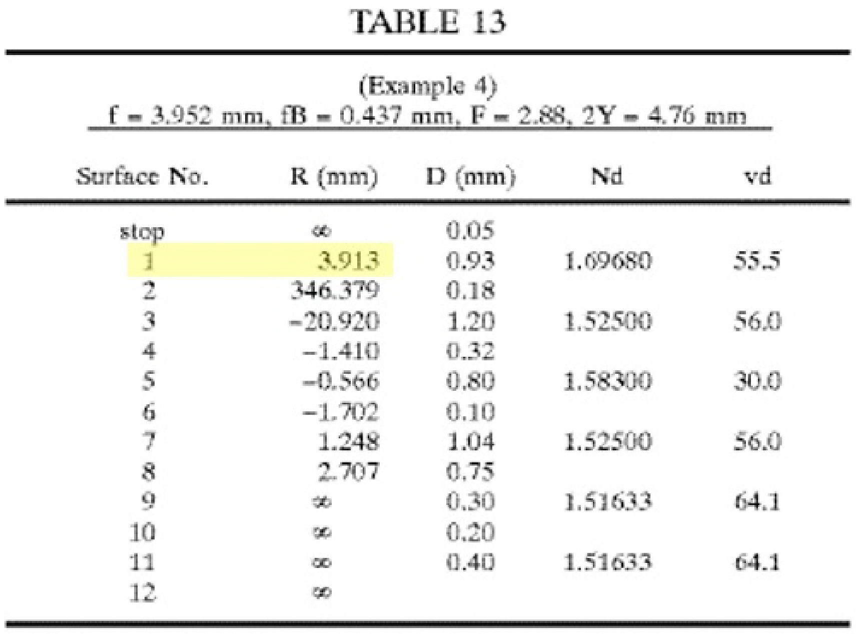


TABLE 13

(Example 4)
f = 3.952 mm, fB = 0.437 mm, F = 2.88, 2Y = 4.76 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.05		
1	3.913	0.93	1.69680	55.5
2	346.379	0.18		
3	−20.920	1.20	1.52500	56.0
4	−1.410	0.32		
5	−0.566	0.80	1.58300	30.0
6	−1.702	0.10		
7	1.248	1.04	1.52500	56.0
8	2.707	0.75		
9	∞	0.30	1.51633	64.1
10	∞	0.20		
11	∞	0.40	1.51633	64.1
12	∞			

1. Conclusion for Claim 8

304. As I explained in Section XIII.B, Yamaguchi in view of Yu renders claim 1 obvious. As I explained in this section, Yamaguchi discloses the additional element of claim 8. Accordingly, Yamaguchi in view of Yu renders claim 8 obvious.

J. Claim 9: "The image capturing lens system of claim 8, wherein the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, half of the maximal field of view of the image capturing lens system is HFOV, and the following condition is satisfied: 1.2 mm<Td/tan(HFOV)<2.75 mm."

305. Claim 9 depends from claim 8 and recites: "The image capturing lens system of claim 8, wherein the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, half of the maximal field of view of the image capturing lens system is HFOV, and the

following condition is satisfied: 1.2 mm<Td/tan(HFOV)<2.75 mm.” Ex. 1001, 31:52-58.

306. As discussed above, I analyze Yamaguchi’s Example 4 for claim 9. I explained in Section XIII.B.7 that Td equals 4.57 mm and HFOV equals 31.057 degrees in Yamaguchi’s Example 4. Thus, Td/tan(HFOV) equals 7.5886 mm. As I explained in Section XIII.A, it would have been obvious to a person of ordinary skill in the art at the time of the ’796 patent to scale the dimensions of Yamaguchi’s pickup lens. When the dimensions of Yamaguchi’s Example 4, including Td, are scaled, the value of HFOV remains the same. The angle HFOV is defined by the ratio of two lengths, Y and f, both of which scale by the same factor. Accordingly, when the dimensions of Yamaguchi’s Example 4 are scaled down, the value of Td/tan(HFOV) will be scaled down proportionally, because the numerator is scaled while the denominator remains constant.

307. In Section XIII.A.1, I explained that it would have been obvious at the time of the ’796 patent to scale the dimensions of Yamaguchi’s Example 4 to 49% of their original size, which would result in a Td of 2.2393 mm (4.57 mm x 0.49). In Section XIII.A.1, I also explained that Td of Yu’s first embodiment is 37.31% of the same distance in Yamaguchi’s Example 4 and that it would have been obvious to a person of ordinary skill in the art at the time of the ’796 patent to scale down the dimensions of Yamaguchi’s Examples 4 by that or a lesser amount. In fact, in view

of the teachings in Yamaguchi and Yu, discussed in Section XIII.A.1, that sensors sizes have been decreasing over time along with the associated lens assemblies, it would have also been obvious to a person of ordinary skill in the art at the time of the '796 patent to scale an older design even further. It would have been obvious to a person of ordinary skill in the art, for example to scale the dimensions of Yamaguchi's Example 4 to 36% of their original size, which is only slightly smaller than a 37.31% reduction. When the dimensions of Yamaguchi's Example 4 are scaled to 36% of their original size, Td equals 1.6452 mm (4.57 mm x 0.36).

308. The value of Td/tan(HFOV) for this scaled version of Yamaguchi's Example 4 equals 1.6452/tan(31.057°), which equals 2.732 mm and satisfies the condition "1.2 mm<Td/tan(HFOV)<2.75 mm."

309. As I explained in Section XIII.I, the shape of object-side surface of the first lens element remains convex when the dimensions of the pickup lens are scaled, so this further reduction to Yamaguchi's Example 4 would not change my conclusion in Section XIII.I that Yamaguchi in view of Yu renders claim 8 (from which claim 9 depends) obvious.

310. Further scaling Yamaguchi's Example 4 as discussed in this section would also not change my conclusion in Section XIII.B that Yamaguchi renders claim 1 (from which claims 8 and 9 depend) obvious. When Yamaguchi's Example 4 is scaled, it still discloses claim 1's preamble, and the disclosed lens system still has a

total of four lens elements with refractive power as recited in Element 1e, as I explained in Sections XIII.B.1 and XIII.B.6.

311. As I have explained before, the refractive power (positive or negative) and lens shapes (convex, concave, and aspheric surfaces) remain the same with scaling. Accordingly, Yamaguchi in view of Yu would still disclose Element 1a through Element 1d (as discussed in Sections XIII.B.2 through XIII.B.5) with this further scaling.

312. Element 1f is also disclosed when Yamaguchi's Example 4 is scaled to 36% of its original size. Td equals 1.6452 mm, which satisfies the condition "0.5 mm<Td<3.2 mm," and Td/tan(HFOV) equals 2.732 mm, which satisfies the condition "1.0 mm<Td/tan(HFOV)<3.75 mm." The ratios |f/f4| and f2/f3 are unaffected when the dimensions of the pickup lens are scaled, so they still satisfy the conditions "|f/f4|<1.20" and "f2/f3<-0.65," as I explained in Section XIII.B.7.

1. Conclusion for Claim 9

313. As I explained in Section XIII.I, Yamaguchi in view of Yu renders claim 8 obvious. As I explained in this section, Yamaguchi in view of Yu renders the additional element of claim 9 obvious. Accordingly, Yamaguchi in view of Yu renders claim 9 obvious.

K. Claim 10: “The image capturing lens system of claim 8, wherein a sum of the central thicknesses of the first lens element, the second lens element, the third lens element, and the fourth lens element is ∑CT, the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.80<∑CT/Td<0.95.”

314. Claim 10 depends from claim 8 and recites: “The image capturing lens system of claim 8, wherein a sum of the central thicknesses of the first lens element, the second lens element, the third lens element, and the fourth lens element is ∑CT, the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.80<∑CT/Td<0.95.” Ex. 1001, 31:59-67.

315. As discussed above, I analyze Yamaguchi’s Example 4 for claim 10. Yamaguchi’s Table 13 lists the “interval between refractive surfaces” (D) for Example 4. Ex. 1006 ¶¶ 0154, 0160, 0186. As I explained in Section XIII.B.7, Td equals 4.57 mm for Yamaguchi’s Example 4. Table 13 (Example 4) lists the center thickness of the first lens L1 as 0.93 mm, the center thickness of the second lens L2 as 1.20 mm, the center thickness of the third lens L3 as 0.80 mm, and the center thickness of the fourth lens L4 is 1.04 mm. Ex. 1006 ¶ 0186. I have highlighted these values in the annotated version of Yamaguchi’s Table 13 (Example 4) below.

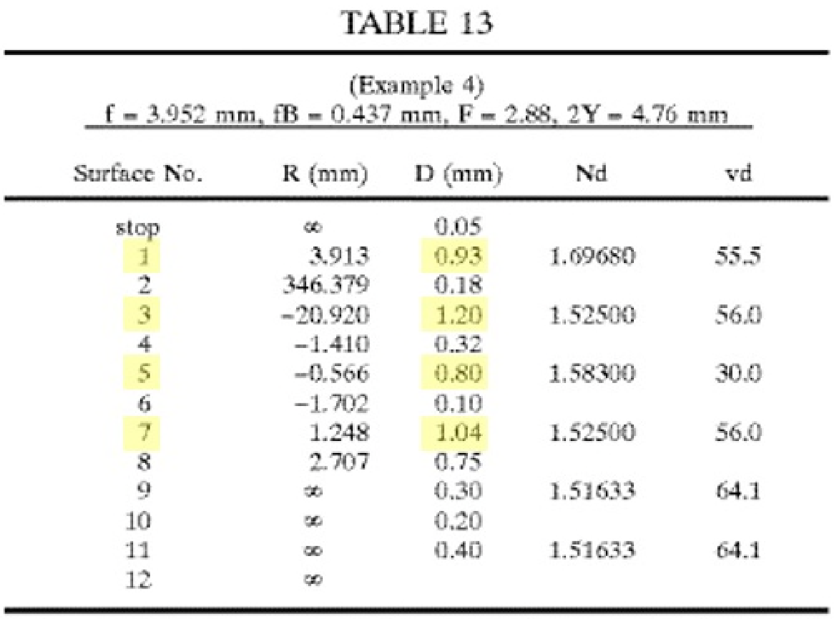


TABLE 13

(Example 4)
f = 3.952 mm, fB = 0.437 mm, F = 2.88, 2Y = 4.76 mm

Surface No.	R (mm)	D (mm)	Nd	νd
stop	∞	0.05		
1	3.913	0.93	1.69680	55.5
2	346.379	0.18		
3	−20.920	1.20	1.52500	56.0
4	−1.410	0.32		
5	−0.566	0.80	1.58300	30.0
6	−1.702	0.10		
7	1.248	1.04	1.52500	56.0
8	2.707	0.75		
9	∞	0.30	1.51633	64.1
10	∞	0.20		
11	∞	0.40	1.51633	64.1
12	∞			

316. Using these numbers, ∑CT equals 3.97 mm. Thus, ∑CT/Td equals 3.97 mm / 4.57 mm, which equals 0.8687 and satisfies the condition “0.80<∑CT/Td<0.95.” This ratio is unaffected when the dimensions of the pickup lens are scaled. The ratio does not change because the numerator and denominator are scaled by the same factor. Thus, Yamaguchi discloses that “a sum of the central thicknesses of the first lens element, the second lens element, the third lens element, and the fourth lens element is ∑CT, the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.80<∑CT/Td<0.95.”

1. Conclusion for Claim 10

317. As I explained in Section XIII.I, Yamaguchi in view of Yu renders claim 8 obvious. As I explained in this section, Yamaguchi discloses the additional element of claim 10. Accordingly, Yamaguchi in view of Yu renders claim 10 obvious.

L. Claim 11: "The image capturing lens system of claim 8, wherein an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1."

318. Claim 11 depends from claim 8 and recites: "The image capturing lens system of claim 8, wherein an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1." Ex. 1001, 32:1-5.

319. As discussed above, I analyze Yamaguchi's Example 4 for claim 11. The Abbe number of the first lens L1 in Yamaguchi's Example 4 is 55.5. Ex. 1006 ¶¶ 0154, 0162, 0186. I have highlighted the Abbe number of the first lens L1 in Example 4 in the annotated version of Yamaguchi's Table 13 below. As I explained above, the Abbe number of a lens characterizes the lens material, and the material does not change. Its refractive index remains the same at all wavelengths, so both N and the Abbe number V are not affected by scaling. Thus, Yamaguchi discloses that "an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1."

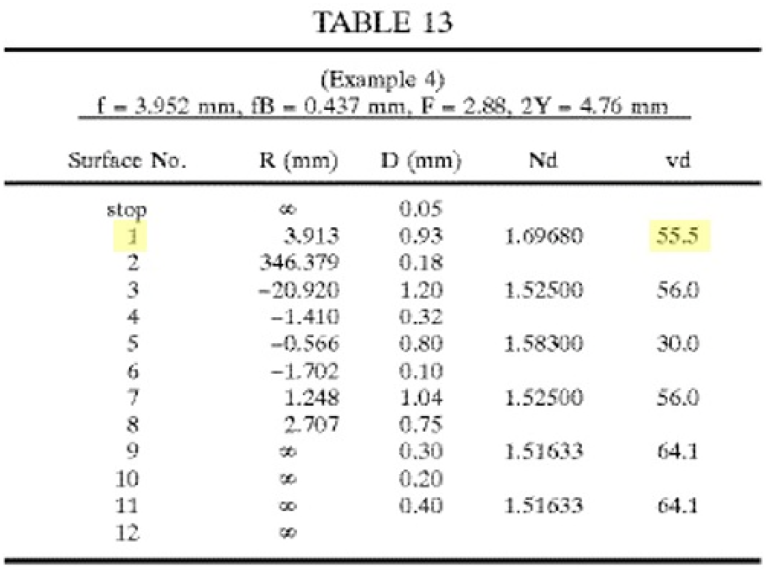


TABLE 13

(Example 4)
f = 3.952 mm, fB = 0.437 mm, F = 2.88, 2Y = 4.76 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.05		
1	3.913	0.93	1.69680	55.5
2	346.379	0.18		
3	−20.920	1.20	1.52500	56.0
4	−1.410	0.32		
5	−0.566	0.80	1.58300	30.0
6	−1.702	0.10		
7	1.248	1.04	1.52500	56.0
8	2.707	0.75		
9	∞	0.30	1.51633	64.1
10	∞	0.20		
11	∞	0.40	1.51633	64.1
12	∞			

1. Conclusion for Claim 11

320. As I explained in Section XIII.I, Yamaguchi in view of Yu renders claim 8 obvious. As I explained in this section, Yamaguchi discloses the additional element of claim 11. Accordingly, Yamaguchi in view of Yu renders claim 11 obvious.

M. Claim 15

1. Preamble: "An image capturing lens system comprising, in order from an object side to an image side:"

321. The preamble of claim 15 recites: "An image capturing lens system comprising, in order from an object side to an image side." Ex. 1001, 32:19-20. As discussed above, I analyze Yamaguchi's Example 3 for claim 15. This is identical to the preamble of claim 1. *Compare* Ex. 1001, 32:19-20 *with* Ex. 1001, 30:48-49. Because the preambles are identical, my analysis for the preamble of claim 1 in

Section XIII.B.1 applies equally to the preamble of claim 15. To the extent the preamble is limiting, Yamaguchi discloses the preamble of claim 15.

2. Element 15a: "a first lens element having refractive power;"

322. Element 15a recites: "a first lens element having refractive power." Ex. 1001, 32:21. This is identical to Element 1a. *Compare* Ex. 1001, 32:21 *with* Ex. 1001, 30:50. Because Element 1a and Element 15a are identical, my analysis for Element 1a in Section XIII.B.2 applies equally to Element 15a. Yamaguchi discloses Element 15a.

3. Element 15b: "a second lens element with positive refractive power having a convex image-side surface in a paraxial region thereof;"

323. Element 15b recites: "a second lens element with positive refractive power having a convex image-side surface in a paraxial region thereof." Ex. 1001, 32:22-24. This is identical to Element 1b. *Compare* Ex. 1001, 32:22-24 *with* Ex. 1001, 30:51-53. Because Element 1b and Element 15b are identical, my analysis for Element 1b in Section XIII.B.3 applies equally to Element 15b. Yamaguchi discloses Element 15b.

4. Element 15c: “a third lens element with negative refractive power having a concave object-side surface in a paraxial region thereof and a convex image-side surface in a paraxial region thereof; and”

324. Element 15c recites: “a third lens element with negative refractive power having a concave object-side surface in a paraxial region thereof and a convex image-side surface in a paraxial region thereof.” Ex. 1001, 32:25-28. This is identical to Element 1c. *Compare* Ex. 1001, 32:25-28 *with* Ex. 1001, 30:54-57. Because Element 1c and Element 15c are identical, my analysis for Element 1c in Section XIII.B.4 applies equally to Element 15c. Yamaguchi discloses Element 15c.

5. Element 15d: “a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof, wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric, and the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof;”

325. Element 15d recites: “a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof, wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric, and the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof.” Ex. 1001, 32:29-34. This is identical to Element 1d. *Compare* Ex. 1001, 32:29-34 *with* Ex. 1001, 30:58-63. Because Element 1d and Element 15d are identical, my analysis for Element 1d in Section XIII.B.5 applies equally to Element 15d. Yamaguchi discloses Element 15d.

6. Element 15e: "wherein the image capturing lens system has a total of four lens elements with refractive power,"

326. Element 15e recites: "wherein the image capturing lens system has a total of four lens elements with refractive power." Ex. 1001, 32:35-36. This is identical to Element 1e. *Compare* Ex. 1001, 32:35-36 *with* 30:64-65. Because Element 1e and Element 15e are identical, my analysis for Element 1e in Section XIII.B.6 applies equally to Element 15e. Yamaguchi discloses Element 15e.

7. Element 15f: "an axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, half of a maximal field of view of the image capturing lens system is HFOV, a focal length of the image capturing lens system is f, a focal length of the fourth lens element is f4, a focal length of the third lens element is f3, and the following conditions are satisfied: 0.5 mm<Td<3.2 mm; 1.0 mm<Td/tan(HFOV)<3.75 mm; |f/f4|<1.20; and -2.0<f/f3<-0.95."

327. Element 15f recites:

- "an axial distance between an object-side surface of the first lens element and the image-side surface of the fourth lens element is Td";
- "half of a maximal field of view of the image capturing lens system is HFOV";
- "a focal length of the image capturing lens system is f, a focal length of the fourth lens element is f4, a focal length of the third lens element is f3"; and
- "the following conditions are satisfied:

$0.5\ \text{mm} < Td < 3.2\ \text{mm}$;

$1.0\ \text{mm} < Td/\tan(HFOV) < 3.75\ \text{mm}$;

$|f/f4| < 1.20$; and

$-2.0 < f/f3 < -0.95$."

Ex. 1001, 32:36-51.

328. I explained in Section XIII.B.7 why it would have been obvious to a POSITA to scale the dimensions of Yamaguchi's Example 3 such that the values of Td, Td/tan(HFOV), and |f/f4| satisfy the first three conditions of Element 15f: "0.5 mm<Td<3.2 mm; 1.0 mm<Td/tan(HFOV)<3.75 mm; |f/f4|<1.20."

329. Yamaguchi discloses that "f = 5.309 mm" for Example 3. Ex. 1006 ¶ 0179. I explained in Section XIII.B.7 that f3 equals -4.7323 mm in Yamaguchi's Example 3. Accordingly, f/f3 for Yamaguchi's Example 3 equals 5.309 mm / -4.7323 mm, which equals -1.122 and satisfies the condition "-2.0<f/f3<-0.95." This ratio is unaffected when the dimensions of the pickup lens are scaled. The ratio does not change because both its numerator and denominator are scaled by the same factor.

8. Conclusion for Claim 15

330. As I have explained above in this section, Yamaguchi in view of Yu discloses all elements of claim 15. Accordingly, Yamaguchi in view of Yu renders claim 15 obvious.

N. Claim 16: "The image capturing lens system of claim 15, wherein an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1."

331. Claim 16 depends from claim 15 and recites: "The image capturing lens system of claim 15, wherein an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1." Ex. 1001, 32:52-56.

332. As discussed above, I analyze Yamaguchi's Example 3 for claim 16. The Abbe number of the first lens L1 in Yamaguchi's Example 3 is 55.5. Ex. 1006 ¶¶ 0154, 0162, 0179. I have highlighted the Abbe number of the first lens L1 in Example 3 in the annotated version of Yamaguchi's Table 9 below. As I explained above, the Abbe number of a lens characterizes the lens material, and it is unaffected when the dimensions of Yamaguchi's Example 3 are scaled. Thus, Yamaguchi's Example 3 discloses that "an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1."

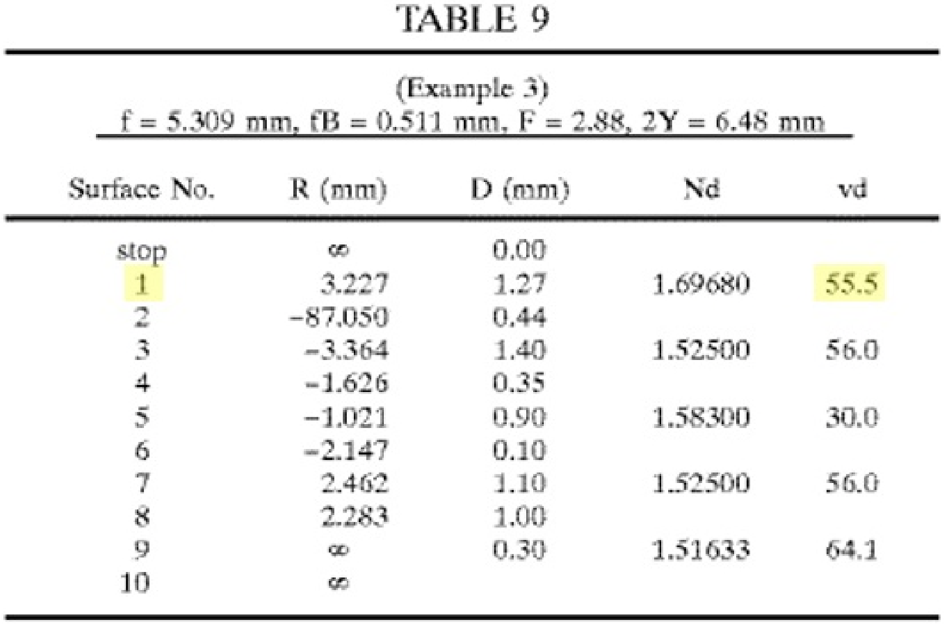


TABLE 9

(Example 3)
f = 5.309 mm, fB = 0.511 mm, F = 2.88, 2Y = 6.48 mm

Surface No.	R (mm)	D (mm)	Nd	vd
stop	∞	0.00		
1	3.227	1.27	1.69680	55.5
2	−87.050	0.44		
3	−3.364	1.40	1.52500	56.0
4	−1.626	0.35		
5	−1.021	0.90	1.58300	30.0
6	−2.147	0.10		
7	2.462	1.10	1.52500	56.0
8	2.283	1.00		
9	∞	0.30	1.51633	64.1
10	∞			

1. Conclusion for Claim 16

333. As I explained in Section XIII.M, Yamaguchi in view of Yu renders claim 15 obvious. As I explained in this section, Yamaguchi discloses the additional element of claim 16. Accordingly, Yamaguchi in view of Yu renders claim 16 obvious.

O. Claim 19: "The image capturing lens system of claim 15, wherein the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.8 mm<Td<2.5 mm."

334. Claim 19 depends from claim 15 and recites: "The image capturing lens system of claim 15, wherein the axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, and the following condition is satisfied: 0.8 mm<Td<2.5 mm." Ex. 1001, 33:1-6.

335. As discussed above, I analyze Yamaguchi's Example 3 for claim 19. I explained in Section XIII.B.7, that Td equals 2.224 mm when Yamaguchi's Example 3 is scaled to 40% of its original size. This satisfies the condition "0.8 mm<Td<2.5 mm."

1. Conclusion for Claim 19

336. As I explained in Section XIII.M, Yamaguchi in view of Yu renders claim 15 obvious. As I explained in this section, Yamaguchi in view of Yu discloses the additional element of claim 19. Accordingly, Yamaguchi in view of Yu renders claim 19 obvious.

P. Claim 20: "The image capturing lens system of claim 15, wherein a focal length of the second lens element is f2, the focal length of the third lens element is f3, and the following condition is satisfied: f2/f3<-0.75."

337. Claim 20 depends from claim 15 and recites: "The image capturing lens system of claim 15, wherein a focal length of the second lens element is f2, the focal length of the third lens element is f3, and the following condition is satisfied: f2/f3<-0.75." Ex. 1001, 33:7-12.

338. As discussed above, I analyze Yamaguchi's Example 3 for claim 20. I explained in Section XIII.B.7 that f2/f3 equals -0.9917 in Example 3 and that this ratio is unaffected when the dimensions of the pickup lens are scaled. This satisfies the condition "f2/f3<-0.75."

1. Conclusion for Claim 20

339. As I explained in Section XIII.M, Yamaguchi in view of Yu renders claim 15 obvious. As I explained in this section, Yamaguchi discloses the additional element of claim 20. Accordingly, Yamaguchi in view of Yu renders claim 20 obvious.

Q. Claim 21

1. Preamble: "An image capturing lens system comprising, in order from an object side to an image side:"

340. The preamble of claim 21 recites: "An image capturing lens system comprising, in order from an object side to an image side." Ex. 1001, 33:13-14. As discussed above, I analyze Yamaguchi's Example 4 for claim 21. This is identical to the preamble of claim 1. *Compare* Ex. 1001, 33:13-14 *with* Ex. 1001, 30:48-49. Because the preambles are identical, my analysis for the preamble of claim 1 in Section XIII.B.1 applies equally to the preamble of claim 21. To the extent the preamble is limiting, Yamaguchi discloses the preamble of claim 21.

2. Element 21a: "a first lens element having refractive power;"

341. Element 21a recites: "a first lens element having refractive power." Ex. 1001, 33:15. This is identical to Element 1a. *Compare* Ex. 1001, 33:15 *with* Ex. 1001, 30:50. Because Element 1a and Element 21a are identical, my analysis for Element 1a in Section XIII.B.2 applies equally to Element 21a. Yamaguchi discloses Element 21a.

3. Element 21b: “a second lens element with positive refractive power having a convex image-side surface in a paraxial region thereof;”

342. Element 21b recites: “a second lens element with positive refractive power having a convex image-side surface in a paraxial region thereof.” Ex. 1001, 33:16-18. This is identical to Element 1b. *Compare* Ex. 1001, 33:16-18 *with* Ex. 1001, 30:51-53. Because Element 1b and Element 21b are identical, my analysis for Element 1b in Section XIII.B.3 applies equally to Element 21b. Yamaguchi discloses Element 21b.

4. Element 21c: “a third lens element with negative refractive power having a concave object-side surface in a paraxial region thereof and a convex image-side surface in a paraxial region thereof; and”

343. Element 21c recites: “a third lens element with negative refractive power having a concave object-side surface in a paraxial region thereof and a convex image-side surface in a paraxial region thereof.” Ex. 1001, 33:19-22. This is identical to Element 1c. *Compare* Ex. 1001, 33:19-22 *with* Ex. 1001, 30:54-57. Because Element 1c and Element 21c are identical, my analysis for Element 1c in Section XIII.B.4 applies equally to Element 21c. Yamaguchi discloses Element 21c.

5. Element 21d: “a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof, wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric, and the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof;”

344. Element 21d recites: “a fourth lens element with refractive power having a concave image-side surface in a paraxial region thereof, wherein both of an object-side surface and the image-side surface of the fourth lens element are aspheric, and the image-side surface of the fourth lens element has at least one convex shape in an off-axis region thereof.” Ex. 1001, 33:23-28. This is identical to Element 1d. *Compare* Ex. 1001, 33:23-28 *with* Ex. 1001, 30:58-63. Because Element 1d and Element 21d are identical, my analysis for Element 1d in Section XIII.B.5 applies equally to Element 21d. Yamaguchi discloses Element 21d.

6. Element 21e: “wherein the image capturing lens system has a total of four lens elements with refractive power,”

345. Element 21e recites: “wherein the image capturing lens system has a total of four lens elements with refractive power.” Ex. 1001, 33:29-30. This is identical to Element 1e. *Compare* Ex. 1001, 33:29-30 *with* Ex. 1001, 30:64-65. Because Element 1e and Element 21e are identical, my analysis for Element 1e in Section XIII.B.6 applies equally to Element 21e. Yamaguchi discloses Element 21e.

7. Element 21f: "an axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td, half of a maximal field of view of the image capturing lens system is HFOV, a focal length of the image capturing lens system is f, a focal length of the fourth lens element is f4, an f-number of the image capturing lens system is Fno, and the following conditions are satisfied: 0.5 mm<Td<3.2 mm; 1.0 mm<Td/tan(HFOV)<3.75 mm; |f/f4|<1.20; and 1.40<Fno≤2.25."

346. Element 21f recites:

- "an axial distance between the object-side surface of the first lens element and the image-side surface of the fourth lens element is Td"
- "half of a maximal field of view of the image capturing lens system is HFOV";
- "a focal length of the image capturing lens system is f, a focal length of the fourth lens element is f4, an f-number of the image capturing lens system is Fno"; and
- "the following conditions are satisfied:

  0.5 mm<Td<3.2 mm;

  1.0 mm<Td/tan(HFOV)<3.75 mm;

  |f/f4|<1.20; and

  1.40<Fno≤2.25."

Ex. 1001, 33:30-34:7.

347. In Section XIII.B.7, I explained why it would have been obvious to a POSITA to scale the dimensions of Yamaguchi's Example 4 such that the values of Td, Td/tan(HFOV), and |f/f4| satisfy the first three conditions of Element 21f: "0.5 mm<Td<3.2 mm; 1.0 mm<Td/tan(HFOV)<3.75 mm; |f/f4|<1.20."

348. In Section XIII.F, I explained why it would have been obvious to a POSITA to enlarge the diameter of the opening in the stop in Yamaguchi's Example 4 such that the f-number (Fno) equals 2.245, which satisfies the condition "1.40<Fno≤2.25."

8. Conclusion for Claim 21

349. As I have explained above in this section, Yamaguchi in view of Yu renders obvious all elements of claim 21. Accordingly, Yamaguchi in view of Yu renders claim 21 obvious.

R. Claim 22: "The image capturing lens system of claim 21, wherein a focal length of the second lens element is f2, a focal length of the third lens element is f3, and the following condition is satisfied: f2/f3<-0.65."

350. Claim 22 depends from claim 21 and recites: "The image capturing lens system of claim 21, wherein a focal length of the second lens element is f2, a focal length of the third lens element is f3, and the following condition is satisfied: f2/f3<-0.65." Ex. 1001, 34:8-13.

351. As discussed above, I analyze Yamaguchi's Example 4 for claim 22. I explained in Section XIII.B.7 that the value of f2/f3 is -1.436 in Yamaguchi's Example 4 and that this ratio is unaffected when the dimensions of the pickup lens are scaled. This satisfies the condition "f2/f3<-0.65." Accordingly, Yamaguchi discloses that "a focal length of the second lens element is f2, a focal length of the third lens element is f3, and the following condition is satisfied: f2/f3<-0.65."

1. Conclusion for Claim 22

352. As I explained in Section XIII.Q, Yamaguchi in view of Yu renders claim 21 obvious. As I explained in this section, Yamaguchi discloses the additional element of claim 22. Accordingly, Yamaguchi in view of Yu renders claim 22 obvious.

S. Claim 23: "The image capturing lens system of claim 21, wherein an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1."

353. Claim 23 depends from claim 21 and recites: "The image capturing lens system of claim 21, wherein an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1." Ex. 1001, 34:14-17.

354. As discussed above, I analyze Yamaguchi's Example 4 for claim 23. I explained in Section XIII.L that Yamaguchi discloses that "an Abbe number of the first lens element is V1, and the following condition is satisfied: 45<V1" because the Abbe number of the first lens L1 in Yamaguchi's Example 4 is 55.5. Ex. 1006 ¶ 0154, 0162, 0186.

1. Conclusion for Claim 23

355. As I explained in Section XIII.Q, Yamaguchi in view of Yu renders claim 21 obvious. As I explained in this section, Yamaguchi discloses the additional element of claim 23. Accordingly, Yamaguchi in view of Yu renders claim 23 obvious.

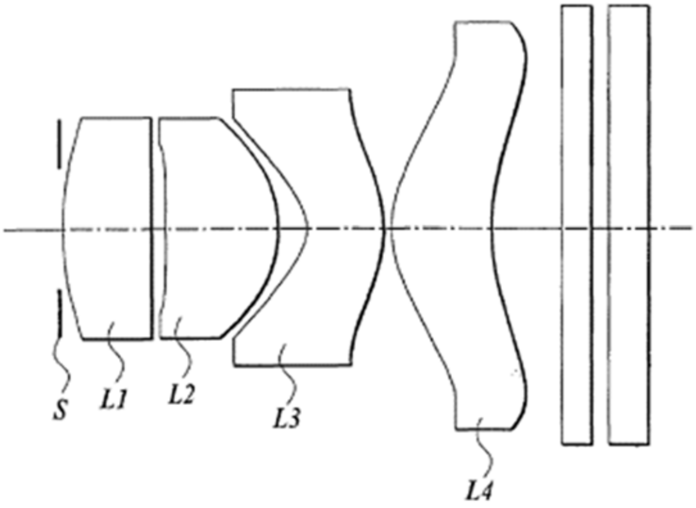
T. Claim 24: "The image capturing lens system of claim 21, wherein the first lens element has positive refractive power, the focal length of the image capturing lens system is f, a focal length of the first lens element is f1, and the following condition is satisfied: 0.25<f/f1<0.75."

356. Claim 24 depends from claim 21 and recites: "The image capturing lens system of claim 21, wherein the first lens element has positive refractive power, the focal length of the image capturing lens system is f, a focal length of the first lens element is f1, and the following condition is satisfied: 0.25<f/f1<0.75." Ex. 1001, 34:18-24.

357. As discussed above, I analyze Yamaguchi's Example 4 for claim 24. Yamaguchi discloses that "the first lens has positive refractive power." Ex. 1006 ¶¶ 0010, 0052. The shape of the first lens L1 in Fig. 10 (Example 4) confirms that it has positive refractive power, because the lens is thicker in the paraxial region. As I explained above, a lens with positive refractive power is thicker at its center. The positive refractive power of a lens is unaffected when the dimensions of the pickup lens are scaled. All convex and concave surfaces retain their same character and relative optical powers when scaled. Thus, a lens that is thicker at the center and has

positive refractive power will remain thicker at the center with positive refractive power.

FIG.10



358. I explained in Section XIII.D that f/f1 equals 0.6935 in Yamaguchi's Example 4 and that this is unaffected when the dimensions of the pickup lens are scaled. This satisfies the condition "0.25<f/f1<0.75. " Thus, Yamaguchi discloses that "the first lens element has positive refractive power, the focal length of the image capturing lens system is f, a focal length of the first lens element is f1, and the following condition is satisfied: 0.25<f/f1<0.75."

1. Conclusion for Claim 24

359. As I explained in Section XIII.Q, Yamaguchi in view of Yu renders claim 21 obvious. As I explained in this section, Yamaguchi discloses the additional

elements of claim 24. Accordingly, Yamaguchi in view of Yu renders claim 24 obvious.

XIV. SECONDARY CONSIDERATIONS

360. I am unaware of any objective evidence of secondary considerations of nonobviousness of the claims of the ’796 patent that Largan may attempt to introduce. I reserve the right to reply to any such evidence.

XV. CONCLUSION

361. As I explained above, in my opinion:

- Yu renders claims 1-11, and 15-25 of the ’796 patent obvious; and
- Yamaguchi in view of Yu renders claims 1-11, 15-16, and 19-24 obvious.

362. I understand that this declaration will be filed as evidence in a contested case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also understand that I may be subject to cross-examination in this *inter partes* review and that cross-examination will take place within the United States. If cross-examination is required of me, I will be available for any such cross-examination.

363. I reserve the right to supplement my opinions in the future to respond to any arguments that Largan raises and to take into account any new information that becomes available to me.

364. I declare that all statements made herein of my own knowledge are true, that believe all statements made on information and belief to be true, and that these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Date: March 9, 2021

By: William T. Plummer

William T. Plummer, Ph. D.

APPENDIX A

WILLIAM T. PLUMMER [7 April 2020]

WTP Optics, Inc.
129 Arena Terrace
Concord, MA 01742
(978) 369-3720

(978) 369-0711 fax
Bill_Plummer@mac.com
http://www.WTPoptics.com

Education:

B.A. Physics and Mathematics, Johns Hopkins University, 1960
Ph.D. Physics, Johns Hopkins University, 1965
Certificate, Tuck Executive Program, Dartmouth College, 1987

Employment:

Known for development of phenomenal new design and manufacturing technologies, notably the early introduction of quality plastic aspheric lens surfaces in photography, and for the first uses of generalized and free-form aspheric optical surfaces in high-volume cameras. Interests and contributions span the full range of product development, from unusual design concepts through all the analysis, tooling, instrumentation, and procedures needed for effective manufacture. Published more than 40 professional papers in optics, astronomy, acoustics, and other fields. Given more than 50 invited technical talks before university, scientific, industrial, government, and commercial groups in several countries. Received 102 U.S. Patents for optical, mechanical, electronic, and chemical inventions, designs for unique products, and effective ways to manufacture them.

March 2001 to Present - Consultant

Founder and President since June 2002 of WTP Optics Inc., offering innovative optical design, engineering, and manufacturing support.

Consultant in the development of an interferometer for measurement of surface quality and dimensions of certain non-spherical industrial surfaces. Provided clients with lens quality instrument evaluation; outside advice on acquisition of a startup telecom manufacturing company; design of an infrared scanner for paper and plastic sheeting; design, development, manufacture, and testing of optical parts for digital cameras; specifications for a teleconferencing camera system; improvement of barcode-reading optical hardware; improvement of illumination efficiency in fingerprint readers; advice on a proposed military optical product; new methods for manufacturing aspheric infrared optics; optical system design for a robotic laser-guidance application; tooling and testing for projection video systems; efficient combining of high output power from laser diodes; and many other subjects.

Technical expert witness in optical and mechanical patent suits, including testimony in Federal District Court in June, 2012, for a spectacle lens design and fabrication case brought by Zeiss against Signet Armorlite. Supported a consortium of six large companies with technical analysis, written report, and a deposition in May, 2014, for an International Trade Commission patent case about optical storage systems, asserted against them by Optical Devices, LLC. Provided technical analysis and written expert testimony in 2017 regarding a spectacle lens patent suit brought by EHS Lens Philippines against Essilor.

Since October, 2017, Senior Scientist/Advisory Board Member at BMF Material Technology Inc., a company having operations in Shenzhen, China, and Boston, Massachusetts, concentrating on the use of novel 3D printing technology to manufacture optical lenses and precision mechanical shapes.

1969 to March 2001 - Polaroid Corporation, Cambridge, MA

Scientist, Senior Scientist, Engineering Fellow, Senior Manager. From 1978 Director of Optical Engineering, and from 1997 Senior Director / Divisional Vice President. Built and maintained a center of excellence. Achieved technical integration across optical science, lens design, mechanics, electronics, and submicron precision engineering to support Polaroid hardware product development at the concept and system level. Guided optical component and subsystem manufacturing groups to develop new technologies and set product standards. Provided technical relationship with overseas suppliers to meet product goals. Enabled design teams to introduce new manufacturing concepts and functional advances to products. Managed Optical Engineering, Model Shops, Concept Engineering, Optical Storage, and CAD System groups.

Personally solved key development problems and contributed to the system design, optical design, and mechanical design of major high-volume photographic products. For the SX-70 Single Lens Reflex folding instant camera these included design, tooling, and quality test equipment for free-form optical components needed for its unusual geometric form, the tolerancing and automatic test equipment for its special taking lens, a patented technology using microscopic fluid droplets to produce optimum master tooling for its reflective focus screen, and the complete opto-mechanical design with screws and flexures for stable positioning and fine adjustment of several unique viewfinder components. Constructed a variable-power lens with a kitchen wrap membrane and a transparent fluid to illustrate the shape of a free-form optical part.

For the popular OneStep instant camera, introduced novel concepts including an inexpensive non-spherical taking lens. For the “Sun” camera series, and later models, introduced several novel concepts including the use of infrared reflectance sensing to control the exposure of flash photographs. For the Spectra System camera, introduced more novel concepts, including a new form of taking lens, using two free-form plastic focus components, that could be manufactured without the customary need for a final focus adjustment. Introduced two free-form optical parts in the viewfinder of the later Captiva camera and another new kind of picture taking lens.

Responsible for a high-power laser diode manufacturing group of about 30 engineers and technicians in the late 1990's. Guided opto-mechanical design for both enhanced function and cost reduction of high-resolution laser diode medical printers. Made innovative use of flexural hardware. Responsible for development of a high-power laser digital print head and product hardware for other medical and industrial applications of grouped laser diodes; included frequency doubling, development of a multi-watt single-mode fiber laser at 1.06 micron for commercial applications, development and manufacture of a microlensed laser diode product.

Member of management staffs of Engineering R & D, Product Engineering, and Central R&D divisions. Member of corporate engineering promotion board, 1981 to 1988. Member of Business Imaging marketing staff, 1990 to 1991. Member of manufacturing Plant Management Team for Optical and Precision Molding and Assembly, 1990 to 1993.

1991 to Present - M.I.T., Cambridge, MA
Senior Lecturer, Mechanical Engineering Department. Member of faculty search committee. Member of oral exam committees for graduate students selecting the optical engineering specialty. Member of PhD student dissertation committees, 2004 to present.

1984 to 1988 - Tufts University, Medford, MA
Visiting Industry Professor, Electro-Optics Technology Center; Electrical Engineering Department. Taught a course in optical engineering considerations for high-volume manufacturing.

1967 to 1969 - University of Massachusetts, Amherst
Assistant Professor, Physics and Astronomy. Researched infrared scattering properties of artificial cumulus clouds, of hydrocarbons, and of particulate materials suspected in planetary atmospheres. Studied optical properties of pinhole cameras, mechanics of simple knots, earth conductivity geophysical prospecting, and infrasonic oscillations in limestone caverns.

1965 to 1967 - U.S. Army, Washington, DC
Captain, Signal Corps. Scientific intelligence officer with Top Secret clearance.

1963 to 1965 - Johns Hopkins University Laboratory of Astrophysics and Physical Meteorology, Baltimore
Dissertation work with Professor John Strong. Responsible for construction and alignment of optical and data systems in a balloon-carried astronomical telescope and correlation spectrometer experiment to measure water vapor and other components of the Venus atmosphere, successfully flown to the stratosphere twice in 1964. Consulted for J.H.U. Applied Physics Laboratory to improve instruments for measuring optical and thermal properties of satellite surface coatings.

1963 to 1965 and 1967 to 1969 - Muffoletto Optical Company, Baltimore
Consultant. Designed lenses for laser research, ultraviolet spectroscopy, wide-angle underwater viewing, medical imaging, laser diode collimation, and other applications.

1960 to 1964 - Johns Hopkins University Physics Department
Teaching Assistant. Conducted Optics Laboratory courses for four years. Compiled a laboratory manual. Designed new laboratory facilities. Lectured in Geometrical and Physical Optics.

1957 to 1960 - Johns Hopkins University Laboratory of Astrophysics and Physical Meteorology
Research Assistant. Supported optical and mechanical preparation for early balloon astronomy experiments. Planned and appeared in a P.S.S.C. educational film, “The Photoelectric Effect.”

1957 and 1958 summers - National Bureau of Standards Fluids Laboratory, Washington, DC
Student Trainee. Supported preparation and optical instrumentation for experiments with induced gravity waves in layered salt water, and with the arrested wedge phenomenon experienced when fresh water flows over salt water at the mouth of a river.

Professional Associations / Society Memberships:

Optical Society of America (Fellow)
Society of Photo-Optical Instrumentation Engineers (Fellow)
National Speleological Society (Fellow)

Awards and Honors:

Phi Beta Kappa, 1960
Army Commendation Medal, 1967
David Richardson Medal for applied optics, Optical Society of America, 1980
Joseph Fraunhofer Award for optical engineering, O.S.A., 1997
Robert M. Burley Prize for optical engineering, O.S.A., 1997
Steve Benton Memorial Award, 2006, New England Section, O.S.A.

Elected to Membership in the National Academy of Engineering, 1999

R&D 100 Award, 1992, from R&D Magazine for "One of the 100 Most Technologically Significant New Products of the Year": the Pegasus 1010 Photon Tunneling Microscope (developed by a Polaroid team from our Patent No. 4,681,451)
Photonics Circle of Excellence Award, 1993, from Photonics Spectra Magazine, for developing one of the twenty-five best new products of the year: the Photon Tunneling Microscope.
Polaroid Technology Hall of Fame, 2000
American Men and Women of Science, Who's Who in Science and Engineering, Who's Who in America, Who's Who in the World
Member 2018, Expert Committees of Shanghai Additive Manufacturing Association, and Shanghai Additive Manufacturing Innovation Center

Ph.D. Dissertation Supervised:

C. Londoño, "Design and Fabrication of Surface Relief Optical Elements, or Kinoforms, with Examples for Optical Athermalization" Electro-Optics Technology Center, Electrical Engineering Department, Tufts University, 1992

Doctoral Committee Membership:

S. Awtar, "Analysis and Synthesis of Parallel Kinematic XY Flexure Mechanisms", Precision Engineering Research Group, Mechanical Engineering Department, Massachusetts Institute of Technology, 2004

P. Willoughby, "Elastically Averaged Precision Alignment", Precision Engineering Research Group, Mechanical Engineering Department, Massachusetts Institute of Technology, 2005

D. Golda, "Design and Fabrication of Micro-Fabricated Two-axis Electromagnetic Actuators for Small-scale Nanopositioners" Precision Systems Design and Manufacturing Laboratory, Mechanical Engineering Department, Massachusetts Institute of Technology, 2006

T. Wortman, "LesionAir: A Low-Cost Tool for Automated Skin Cancer Diagnosis and Mapping" Precision Engineering Research Group, Mechanical Engineering Department, Massachusetts Institute of Technology, 2016

Patents:

Dr. William T. Plummer

1. #3,704,617; December 5, 1972; “Method and Apparatus for Fabricating Imaging Means”
2. #3,709,131; January 9, 1973; “Method and Apparatus for Aligning a Viewing System”
3. #3,718,078; February 27, 1973; “Smoothly Granulated Optical Surface and Method for Making Same”
4. #3,735,685; May 29, 1973; “Reflective Imaging Apparatus”
5. #3,744,391; July 10, 1973; “Camera with a Stigmatic Fresnel Optical Element”
6. #3,754,458; August 28, 1973; “Light Seal for a Reflex Camera Viewfinder”
7. #3,761,179; September 25, 1973; “Mirror Testing Apparatus”
8. #3,797,922; March 19, 1974; “Azygous Ophthalmic Lens and Spectacles for Correcting Presbyopia”
9. #3,810,221; May 7, 1974; “Viewfinder for a Reflex Camera”
10. #3,821,767; June 28, 1974; “Light Seal for a Reflex Camera Viewfinder”
11. #3,836,931; September 17, 1974; “Eye Lens in a Single Lens Reflex Camera Viewfinder Providing Field Tilt Compensation”
12. #3,848,980; November 19, 1974; “Projector Apparatus and System Employing Unique Screen”
13. #3,872,749; March 25, 1975; “Ruling Engine for Generating Dies to Mold Anamorphic Fresnel Optics”
14. #3,877,044; April 8, 1975; “Reflex Camera Viewing System with Stigmatic Exit Pupil”
15. #3,900,858; August 19, 1975; (with Mary Conlin McCann and Vivian K. Walworth) “Camera to Microscope Adapter with a Special Optical Element”
16. #3,902,792; September 2, 1975; “Landscape Lens”
17. #3,904,294; September 9, 1975; (with Nathan Gold) “Automatic Lens Testing Apparatus”
18. #3,971,052; July 20, 1976; “Compact Galilean Viewfinder”
19. #3,976,368; August 24, 1976; (with Mary Conlin McCann and Vivian K. Walworth) “Special Optical Element for Camera to Microscope Adapter”

Patents (Cont'd):

20. #4,006,971; February 8,1977; “Reflective Imaging Apparatus”
21. #4,018,514; April 19, 1977; “Apparatus for Retinal Photography”
22. #4,021,825; May 3, 1977; (with John J. McCann, Mary C. McCann, Myron A. Seiden, and Vivian K. Walworth) “Adapter for Operatively Coupling an Automated Camera to an Optical Instrument”
23. #4,102,581; July 25, 1978; “Unicell Photoelectric Photometer”
24. #4,105,300; August 8, 1978; “Defocused Unicell Photometer with Aspheric Zone”
25. #4,105,308; August 8, 1978; (with R. Calvin Owen, Jr.) “Aspheric Plastic Triplet”
26. #4,111,561; September 5, 1978; “Defocused Unicell Photometer with Diffusion Zone”
27. #4,130,357; December 19, 1978; (with Irving Erlichman) “Flexible Shutter for Photographic Camera”
28. #4,147,408; April 3, 1979; “Back Projection Viewing Screen”
29. #4,157,216; June 5, 1979; “Adapter for Optically Coupling a Photographic Camera with a Viewing Device”
30. #4,162,833; July 31, 1979; “Photographic Camera”
31. #4,193,675; March 18, 1980; “Photographic Camera”
32. #4,204,269; May 20, 1980; “Optical Element for Redistributing the Light Output of a Photoflash Lamp Assembly or the Like”
33. #4,208,112; June 17, 1980; “Photographic Camera Accessory”
34. #4,226,515; October 7, 1980; “Photographic Camera”
35. #4,251,146; February 17, 1981; “Photographic Apparatus for Providing a Signal Visible in a Camera Viewfinder”
36. #4,264,167; April 28, 1981; “Adapter for Coupling a Camera with a Viewing Device”
37. #4,272,186; June 9, 1981; “Camera Method and Apparatus for Recording with Selected Contrast”
38. #4,282,548; August 4, 1981; “Method and Apparatus for Measuring and/or Setting Lens Focal Distance”
39. #4,293,892; October 6, 1981; “Zoom Light Apparatus”

Patents (Cont'd):

40. #4,299,468; November 10, 1981; (with Monis J. Manning) “Photoelectric Radiometer for Photographic Apparatus”

41. #4,356,538; October 26, 1982; “Photographic Lighting Apparatus”

42. #4,416,514; November 22, 1983; “Color Filter”

43. #4,443,067; April 17, 1984; (with R. Calvin Owen, Jr.) “Zone Focusing Optical System”

44. #4,457,618; July 3, 1984; “Optical System for Use in Electronic Enlarger”

45. #4,499,164; February 12, 1985; “Image Carrying Media Employing an Optical Barrier”

46. #4,498,748; February 12, 1985; (with Peter W. J. Jones and Dennis W. Purcell) “Camera for Photographing Scale Models”

47. #4,531,702; July 30, 1985; “Injection Mold for Forming Optical Fiber Connector”

48. #4,549,891; October 29, 1985; “Method for Forming a Non-symmetrical Optical Fiber”

49. #4,561,753; December 31, 1985; (with Philip G. Baker) “Selective Photoresponsive Sensing Circuit”

50. #4,589,745; May 20, 1986; “Geometric LED Layout for Line Exposure”

51. #4,610,536; September 9, 1986; (with William K. Smyth and Richard J. Chen) “Laser Scanning and Printing Apparatus”

52. #4,647,975; March 3, 1987; (with Lawrence E. Alston and Donald S. Levinstone) “Exposure Control System for an Electronic Imaging Camera Having Increased Dynamic Range”

53. #4,650,292; March 17, 1987; (with James G. Baker) “Analytic Function Optical Component”

54. #4,649,324; March 10, 1987; (with John M. Guerra) “Method and Apparatus for Adjusting CRT Geometry”

55. #4,675,531; June 23, 1987; (with Peter P. Clark) “Optical Scanner Having a Multi-Surfaced Lens Arrangement for Producing a Rotationally Symmetric Beam”

56. #4,687,926; August 18, 1987; “Spectrally Filtered Lens Producing Plural f-Numbers with Different Spectral Characteristics”

57. #4,701,045; October 20, 1987; “Method and Apparatus for Reducing Optical Artifacts”

58. #4,681,427; July 21, 1987; “Electronic Printing Method”

59. #4,681,451; July 21, 1987; (with John M. Guerra) “Optical Proximity Imaging Method and Apparatus”

Patents (Cont'd):

60. #4,689,184; August 25, 1987; “Method for Forming an Optical Connector”

61. #4,689,005; August 25, 1987; “Molding Apparatus”

62. #4,707,063; November 17, 1987; “Widely Spaced Fiber Optic Connector and Multiplexer / Demultiplexer Using Same”

63. #4,689,696; August 25, 1987; “Hybrid Image Recording and Reproduction System”

64. #4,759,596; July 26, 1988; (with Hong Po) “Wavelength Selective Optical Cavity Including Holographic Filter Layers”

65. #4,786,964; November 22, 1988; (with Hugh R. MacKenzie) “Electronic Color Imaging Apparatus with Prismatic Color Filter Periodically Interposed in Front of an Array of Primary Color Filters”

66. #4,806,034; February 21, 1989; “Write Head Controller with Grid Synchronization”

67. #4,814,118; March 21, 1989; (with Robert J. Boyea) “Method of Fabrication of Components for Connecting Optical Fibers”

68. #4,816,939; March 28, 1989; (with Vernon E. Ford, Jeremy K. Jones, and John J. Mader) “Magnetic Recording Media and Servo System Using Light-Transmitting Optical Gratings”

69. #4,843,481; June 27, 1989; “CCD Scanning Apparatus for Use with Rotary Head Printer”

70. #4,882,594; November 21, 1989; “Method for Making a Smooth, Uniform Image of a Laser Diode Array”

71. #4,925,267; May 15, 1990; (with Robert J. Boyea) “Structure and Fabrication of Components for Connecting Optical Fibers”

72. #5,028,110; July 2, 1991; “Fiber Optic Component”

73. #4,971,869; November 20, 1990; “Color Encoding Photographic Film”

74. #4,989,959; February 5, 1991; “Anti-Aliasing Optical System with Pyramidal Transparent Structure”

75. #4,992,824; February 12, 1991; “Apparatus and Method Utilizing an L.C.D. for Printing”

76. #5,176,972; January 5, 1993; (with Iris B. K. Bloom and Richard A. Minns) “Imaging Medium with Low Refractive Index Layer”

77. #5,260,828; November 9, 1993; (with Carmiña Londoño) “Methods and Means for Reducing Temperature-Induced Variations in Lenses and Lens Devices”

Patents (Cont'd):

78. #5,327,291; July 5, 1994; (with James G. Baker and Jon Van Tassell) “Compact Objective Lens”

79. #5,408,447; April 18, 1995; (with F. Richard Cottrell, A. K. Juenger, H. R. MacKenzie, and W. J. McCune) “Method and Apparatus for Scanning of Image in Integral Film Structure”

80. #5,449,586; September 12, 1995; (with F. Richard Cottrell, A. K. Juenger, H. R. MacKenzie, and W. J. McCune) “A Diffusion Transfer Integral Film Unit”

81. #5,652,612; July 29, 1997; (with Carl A. Chiulli and Yalan Mao) “Apparatus and Method for Enhancing Printing Efficiency to Reduce Artifacts”

82. #5,900,902; May 4, 1999; (with Carl A. Chiulli and Yalan Mao) “Apparatus and Method for Enhancing Printing Efficiency to Reduce Artifacts”

83. #5,933,278; August 3, 1999; (with Douglas S. Goodman and Jeffrey W. Roblee) “Monolithic Multi-faceted Mirror for Combining Multiple Beams from Different Light Sources by Reflection”

84. #6,011,577; January 4, 2000; (with Douglas S. Goodman and Jeffrey W. Roblee) “Modular Optical Print Head Assembly”

85. #6,061,372; May 9, 2000; (with Marc Thompson and Douglas S. Goodman) “Two-Level Semiconductor Laser Driver”

86. #6,066,857; May 23, 2000; (with Stephen D. Fantone, Luis A. Figarella, David A. Imrie, Harry McKinley, Howard Stern, and Jon E. Van Tassell) “Variable Focus Optical System”

87. #6,097,552; August 1, 2000; (with Wayne L. Gordon and James J. Zambuto) “Autofocus Actuator Device”

88. #6,101,333; August 8, 2000; (with Julian G. Bullitt, Jon Van Tassell, and George D. Whiteside) “Method and Apparatus for Acquiring Electronic and/or Photographic Images”

89. #6,104,533; August 15, 2000; (with Peter P. Clark) “Viewfinder with Diffractive Optical Element”

90. #6,122,115; September 19, 2000; (with Jeffrey W. Roblee and Douglas S. Goodman) “Method and Device for Mounting Optical Components”

91. #6,221,554; April 24, 2001; (with Philip R. Norris, Harry R. Parsons, Donald W. Preissler, and Robert J. Wadja) "Self Developing Film Unit"

92. #6,283,374; September 4, 2001; (with Stephen D. Fantone, David A. Imrie, Jon E. Van Tassell, Philip E. McKinley, Harry R. McKinley, Luis A. Figarella, Howard Stern, John H. Dowling, and Steve Meister) “Symbology Imaging and Reading Apparatus and Method”

Patents (Cont'd):

93. #6,595,427; July 22, 2003; (with Vivek K. Soni, J. Barry Mahoney, and Richard G. Egan) "Method and Apparatus for Encoding and Decoding Information in a Non-visible Manner"

94. #6,643,390; November 4, 2003; (with Peter P. Clark and Douglas S. Goodman) "Compact Fingerprint Identification Device"

95. #6,786,416; September 7, 2004; (with Vivek K. Soni, J. Barry Mahoney, and Richard G. Egan) “Method and Apparatus for Encoding and Decoding Information in a Non-visible Manner”

96. #6,994,257; February 7, 2006; (with Vivek K. Soni, J. Barry Mahoney, and Richard G. Egan) “Method and Apparatus for Encoding and Decoding Information in a Non-visible Manner”

97. #7,426,020; September 16, 2008; (with George W. McClurg and John F. Carver) “System for Print Imaging with Prism Illumination Optics”

98. #7,591,557; September 22, 2009; “Solid State Method and Apparatus for Making Lenses and Lens Components”

99. #7,926,942; April 19, 2011; "Solid State Lenses and Lens Components”

100. #7,959,286; June 14, 2011; "Solid State Lenses and Lens Components”

101. #9,008,137; April 14, 2015; (with Aland K. Chin, Richard H. Chin, and Jonah H. Jacob) “Method and Apparatus for Compact and Efficient Introduction of High Radiant Power into an Optical Fiber”

102. #9,496,675; November 15, 2016; (with Aland K. Chin) “Method and Reflective Apparatus for Combining High-Power Laser Beams”

Most of my listed patents were accompanied by issued foreign patent equivalents.

For my own US patents (98), (99), and (100) I have been issued these foreign equivalents:
Japanese patent JP5078880B2
Canadian patent CA_2607846A1
European patent EP 1 879 733 B1

Other patent applications are pending.

Publications:

1. Palmer, C.H. *Optics Experiments and Demonstrations* Johns Hopkins University Press, 1962 (Signed sections by W. T. Plummer)

2. Bottema, M., W. Plummer, and J. Strong, “Water Vapor in the Atmosphere of Venus” *Astrophys. J.* **139**(3), 1021-1022 (1964)

3. Bottema, M., W. Plummer, J. Strong, and R. Zander, “Composition of the Clouds of Venus” *Astrophys. J.* **140**(4), 1640-1641 (1964)

4. Bottema, M., W. Plummer, and J. Strong, “A Quantitative Measurement of Water Vapor in the Atmosphere of Venus” *Ann. Astrophys.* **28**(1), 225-228 (1965)

5. Bottema, M., W. Plummer, J. Strong, and R. Zander, “The Composition of the Venus Clouds and Implications for Model Atmospheres” *J. Geophys. Res.* **70**(17), 4401-4402 (1965)

6. Plummer, W.T., and J. Strong, “Conditions on the Planet Venus” *Astronautica Acta* **11**(6), 375-382 (1965)

7. Plummer, W.T., “Some Techniques for Cave Exploration” *Nat. Spel. Soc. Bul.* **28**(1), 22-37 (1966)

8. Plummer, W., and J. Strong, “A New Estimate for the Surface Temperatures of Venus” *Astrophys. J.* **144**(1), 422-424 (1966)

9. Plummer, W.T., “Hot Shadows on Jupiter” *Science* **153**(3742), 1418 (1966)

10. Plummer, W., and J. Strong, “An Answer to F. D. Drake” *Astrophys. J.* **149**, 463-464 (1967)

11. Plummer, W.T., “Ghost Lines in Spectra from an Interferometric Hologram” *Japan. J. Appl. Phys.* **6**, 1250-1251 (1967)

12. Plummer, W.T., and R.H. Hauck, “An Absorption Integral for Planetary Atmospheres” *Planet. and Space Sci.* **16**, 729-736 (1968)

13. Plummer, W.T., “Venus Clouds: Test for Hydrocarbons” *Science* **163**, 1191-1192 (1969)

14. Plummer, W.T., “Infrared Reflectivity of Frost and the Venus Clouds” *J. Geophys. Res.* **74**(13), 3331-3336 (1969)

15. Plummer, W.T., “Near Infrared Reflection Spectra of Artificial Cumulus Clouds” *Appl. Optics* **8**(10), 2079-2081 (1969)

16. Plummer, W.T., “Infrasonic Resonances in Natural Underground Cavities” *J. Acous. Soc. Am.* **46**(5)(Part 1), 1074-1080 (1969)

Publications (Cont'd):

17. Plummer, W.T., and R.K. Carson, “Mars: Is the Surface Colored by Carbon Suboxide?” Science **166**, 1141-1142 (1969)

18. Plummer, W.T., “The Venus Spectrum: New Evidence for Ice” Icarus 12, 233-237 (1970)

19. Plummer, W.T., and R.K. Carson, “Venus Clouds: Test for Carbon Suboxide” Astrophys. J. **159**(1), 159-163 (1970)

20. Plummer, W.T., “Theory of the Climbing Knot” Appendix B of “Prusiking”, by R. Thrun, pp. 61-74 (Speleo Press, Austin, Texas, 1973)

21. Plummer, W.T., “Focus Screen Optimization” Appl. Optics **14** (11), 2762-2765 (1975)

22. Plummer, W.T., “Fast Automatic Lens Testing for Extended-Field Image Quality” Appl. Optics **15** (3), 805-810 (1976)

23. Davidorf, F.H., W. Plummer, and E.H. Land, "Indirect Fundus Camera" Trans. Section on Ophthalmology. American Academy of Ophthalmology and Otolaryngology, **81** (5), 910-911 (1976)

24. Plummer, W.T., “The Martian Surface: Other Evidence Suggesting Carbon Suboxide” Proc. of Viking Conf. on Simulation of Mars Surface Properties, NASA Ames Research Center (May 5-6, 1977)

25. Plummer, W.T., “Photographic Shutters: Better Pictures with a Reconsideration of Shutter Efficiency” Appl. Optics **16**(7), 1914-1917 (1977)

26. Plummer, W.T., “Unusual Optics of the Polaroid SX-70 Land Camera” Appl. Optics **21**(2), 196-202 (1982)

27. Baker, J.G., S.D. Fantone, and W.T. Plummer, “In Memoriam, Dr. Edwin Herbert Land, May 7, 1909–March 1, 1991” Optics & Photonics News **2**(5), 5 (May, 1991)

28. Plummer, W.T., and L. Gardner, “A Mechanically Generated Hologram?” Appl. Optics **31**(31), 6585-6588 (1992)

29. Londoño, C., W.T. Plummer, and P.P. Clark, “Athermalization of a Single-Component Lens with Diffractive Optics” Appl. Optics **32**(13) 2295-2302 (1993)

30. Plummer, W.T., “Precision: How to Achieve a Little More of it, Even after Assembly” in Intelligent Automation and Soft Computing, Vol. **1**; M. Jamshidi, C. Nguyen, R. Lumia, and J. Yuh, Editors. TSI Press series, proceedings of the World Automation Congress, Albuquerque, NM, pp. 193-198 (1994)

31. Plummer, W.T., “The SX-70 Camera: The Optics” Optics & Photonics News **5**(10) 44-48 (Oct., 1994)

32. Plummer, W.T., “Leaving No Stone Unturned” Optics & Photonics News **5**(10) 39 (Oct., 1994)

Publications (Cont'd):

33. Plummer, W.T., “A New Optical Illusion?” Optics & Photonics News **6**(1) 42-43 (Jan., 1995)

34. Plummer, W.T., J.J. Mader, J.W. Roblee, and J. Van Tassell, “Precision Engineering at Polaroid” Proc. of the Pre-Conf. Day, pp. 24-29, Precision Engineering in Industry – International State of the Art, Eighth Int. Precision Eng. Seminar, Université de Technologie de Compiègne, France; M. Bonis, et al., Ed. (May 15, 1995)

35. Plummer, W.T., “Beyond Raytracing” Engineering Program, Optical Soc. of Am. 1995 Ann. Mtg., pp 307-343 (Sept., 1995)

36. Goodman, D.S., J.W. Roblee, W.T. Plummer, and P.P. Clark, “Multi-Laser Print Head”, SPIE **3430**, Novel Optical Systems Design and Optimization II, 21 pp (July, 1998)

37. Plummer, W.T., J.G. Baker, and J. Van Tassell, “Photographic Optical Systems Using Nonrotational Aspheric Surfaces” Appl. Optics **38** (16) 3572-3592 (1999)

38. Clark, P.P., D.S. Goodman, and W.T. Plummer, "Compact Finger Imager", SPIE **3789**, Current Developments in Optical Design & Optical Engineering VIII, 7 pp (July 1999

39. Singh, R., A.K. Chin, Q.X. Zu, F. Dabkowski, R. Jollay, D. Bull, J. Fanelli, D.S. Goodman, J. Roblee, and W.T. Plummer, "Description and Applications of High Brightness Multi-Laser-Diode System", SPIE **3945A**, presented at Photonics West, 22-28 Jan. 2000, San Jose, CA (LASE 2000)

40. Plummer, W.T., "Free-Form Optical Components in Some Early Commercial Products", Extended Abstract, *Proceedings* ASPE Winter Topical Meeting on Free-Form Optics: Design, Fabrication, Metrology, Assembly, pp 68-71 (Feb., 2004)

41. Plummer, W.T., "Free-Form Optical Components in Some Early Commercial Products", Proc. SPIE **5865**, Tribute to Warren Smith: A Legacy in Lens Design and Optical Engineering, pp 586509-1 to -7 (Aug. 2005)

42. Plummer, W.T. and S.D. Fantone, "James G. Baker", in *Memorial Tributes*, Volume 11, National Academy of Engineering, pp 6-11 (The National Academies Press, Washington, DC, 2007)

43. Plummer, W.T., "A New Way to Mold Lenses with Freeform and Structured Surfaces", Proc. ASPE Spring Topical Meeting on Structured and Freeform Surfaces, pp 11-12 (March 2011)

44. Plummer, W.T., “The Origin of Commercial Free-form Optics” SPIE Newsroom, 24 May 2016, http://spie.org/newsroom/6381-the-origins-of-commercial-free-form-optics)

45. Plummer, W.T., “Some Milestones in the Design, Development, and Manufacture of Freeform Optics”, AOMATT2018, the 9th International Symposium on Advanced Optical Manufacturing and Testing Technologies, ChengDu, China, June 26,2018. (To be published by SPIE.)

Invited Talks:

1. "Conditions on the Planet Venus" W.T. Plummer and J. Strong. Moon and Planets Session of the Am. Geophys. Union Mtg., Washington, DC., April 22, 1966.

2. "Infrared Studies of Mars and Venus" W.T. Plummer. Symposium on Planetary Atmospheres, NASA Goddard Inst. for Space Studies, New York, March, 1970.

3. "Method of Measuring Surface Micro-ripple of Finished Optics to 10-Å Accuracies" C.V. Muffoletto and W. Plummer, Opt. Soc. Am. Spring Mtg. 1971.

4. "Optical Component Design for the New Polaroid Land Camera" W.T. Plummer, Opt. Soc. Am. Fall Mtg., San Francisco, Oct. 1972.

5. "Testing of Lenses for Polaroid Land Photography" R.F. Weeks, W.T. Plummer, L.K. Ting, N. Gold. Opt. Soc. of Am. Fall Mtg., Rochester, NY., Oct. 1973.

6. "Rapid Evaluation of Extended-Field Photographic Quality of Lenses" W.T. Plummer. Seminar-in-depth on "Image Assessment and Specification", jointly sponsored by the Opt. Soc. of Am. and the Soc. of Photo-Opt. Inst. Engrs., Rochester, May 21, 1974.

7. "Solving Quality Control and Reliability Problems with Optics" W.T. Plummer. Panel Discussion at S.P.I.E. seminar at San Diego, Calif., May 1975.

8. "Fast Automatic Lens Testing for Extended-Field Image Quality" W.T. Plummer. S.P.I.E.-Sira Inst. course on Quality Assurance in Optical and Electro-Optical Engineering, Delft, Sept. 1975.

9. "Optics of the Polaroid SX-70 Land Camera" W.T. Plummer. Joint meeting, local chapters of the Opt. Soc. of Am. and the Soc. of Phot. Sci. and Engrs., Lexington, Mass., Jan. 22, 1976.

10. "Optical and Mechanical Intrigue in the Polaroid SX-70 Land Camera" W.T. Plummer. Boston chapter A.S.M.E., Dec. 9, 1976. Burlington, VT, A.S.M.E., April 21, 1978. Central Mass. A.S.M.E., Westminster, Mass., April 19, 1979.

11. "The Martian Surface: Other Evidence Suggesting Carbon Suboxide" W.T. Plummer. Viking Conf. on Simulation of Mars Surface Properties, NASA Ames Res. Cent., Calif., May 5-6, 1977.

12. "Replicated and Plastic Optics" W.T. Plummer. Panel Disc., S.P.I.E. Tech. Symp. at San Diego, Calif., Aug. 24, 1977. Also: Optical Fabrication Workshop, Opt. Soc. of Am., Framingham, Mass., June 9, 1978.

13. "Unusual Optics of the Polaroid SX-70 Land Camera" W.T. Plummer. Symp. in honor of Prof. John Strong, Univ. Mass., Amherst, March 1981.

14. "Unusual Optics of the Polaroid SX-70 Land Camera" W.T. Plummer. Visiting Physicist lecture, A.I.P., at the Johns Hopkins Univ., Baltimore, May 1981.

Invited Talks (Cont'd):

15. “Optics at Polaroid” W.T. Plummer. Physics Dept., Chekiang Univ., Hangchow, China, September 1981.

16. “Use of Optical Concepts to Design and Tolerance Non-Optical Parts of the Photographic System” W.T. Plummer. Opt. Soc. of Am. mtg. on Applied Optics, Rochester, NY, May 1982.

17. “Frontiers of Optical Engineering” W.T. Plummer. S.P.I.E. Mtg., Cambridge, Mass., Nov. 1984.

18. “Generalized Aspheres in High Volume Camera Production” W.T. Plummer. Opt. Soc. of Am. Fall Mtg., Washington, DC., Oct. 1985.

19. “Unusual Optics in Polaroid Photography” W.T. Plummer. Am. Assoc. of Physics Teachers, sectional mtg., Keene, NH, Nov. 1985.

20. “Generalized Aspheric Surfaces in Polaroid Photography” W.T. Plummer. Soc. of Phot. Sci. and Engrs., Ann. Conf., Minneapolis, May 20, 1986.

21. “Generalized Aspheric Surfaces in Polaroid Photography” W.T. Plummer. Univ. of Rochester Inst. of Optics, Colloq., Feb. 4, 1987.

22. “Obecné asférické cocky v polaroid-fotografii” W.T. Plummer. INTERKAMERA Aplikovaná Optika '87, Prague, March 1987.

23. “Non-Rotational Aspheric Lens Surfaces in Polaroid Photography” W.T. Plummer. Inventors Assoc. of New England, M.I.T., Cambridge, Mass., April 1987.

24. “Non-Rotational Aspheric Lens Surfaces in Polaroid Photography” W.T. Plummer. Opt. Soc. of Am. and Soc. of Phot. Sci. and Engrs., ann. joint dinner mtg. of New Eng. chapters, Waltham, Mass., Feb. 16, 1989. Tucson chapter, Opt. Soc. of Am., Univ. of Arizona, Dec. 1989.

25. “Strings, Ropes, and Infrasonic Resonances, with Applications to Underground Caverns” W.T. Plummer. Mechanical Engineering Colloquium, M.I.T., Cambridge, Mass., Oct. 30, 1992.

26. “Precision Engineering at Polaroid” W.T. Plummer. Weekly Seminar, Precision Engineering Section, Natl. Inst. of Sci. and Tech., Gaithersburg, MD, Nov. 10, 1992.

27. “Diffractive Optical Elements in the Real World” P.P. Clark, C. Londoño, and W.T. Plummer. Optical Design for Photonics Topical Mtg., Opt. Soc. of Am., Palm Springs, CA., March 1993.

28. “Precision Mechanical Assembly Issues in Polaroid Photographic Products” W.T. Plummer. ARPA Workshop on Precision Assembly, La Jolla, CA., July 1993.

29. “System Design and Manufacturing Issues” W.T. Plummer. Panel disc., Systems and Instrumentation Technical Group Mtg., Opt. Soc. of Am., Toronto, Oct. 6, 1993.

Invited Talks (Cont'd):

30. "Industrially Relevant Applications of Precision Engineering to Consumer Products" A.H. Slocum and W.T. Plummer. M.I.T. Symposium on University-Industry Research Partnerships, Cambridge, MA, Nov. 4, 1993.

31. "Precision Mechanical Design Experiences in High-Volume Polaroid Cameras" W.T. Plummer. Mechanical Engineering Colloquium, M.I.T., Cambridge, Mass., March 15, 1994.

32. "Innovations in Design for Manufacturing in the High Volume Camera Business" W.T. Plummer. Defense Science Research Council / ARPA Workshop on Low Cost Uncooled Infrared Systems, La Jolla, CA, July 6, 1994.

33. "Precision: How to Achieve a Little More of it Even After Assembly" W.T. Plummer. Fifth International Symposium on Robotics and Manufacturing, Wailea, Maui, HI, Aug. 16, 1994.

34. "Optical Design Concerns of some Unusual Polaroid Cameras" W.T. Plummer. Symposium on Optical Systems and Instrumentation, Opt. Soc. of Am. Annual Meeting, Dallas, TX, Oct. 3, 1994.

35. "Precision Engineering at Polaroid" W.T. Plummer, J.J. Mader, J.W. Roblee, and J. Van Tassell. 8th International Precision Engineering Seminar, Compiègne, France, May 15, 1995.

36. "Beyond Raytracing" W. T. Plummer, Opt. Soc. of Am. Annual Meeting, Portland, Oregon, Sept. 13, 1995. (Tutorial)

37. "Advanced Uses for Injection-Molded Plastic Optical Components" W.T. Plummer, Conference on Optical Manufacturing Technology, Dept. of Optics and Optoelectronics, Beijing Institute of Technology, China, Sept. 3-4, 1996.

38. "Some Controversial Topics in Opto-Mechanical Design" W.T. Plummer, LEAP session on the Product Development Process, CLEO mtg., Baltimore, MD, May 21, 1997.

39. "Precision Engineering at Polaroid" W.T. Plummer, J.J. Mader, J.W. Roblee, and J. Van Tassell. Am. Soc. for Precision Engineers Annual Meeting, St. Louis, Missouri, Oct. 27, 1998.

40. "Unusual Optical Designs and Components in Polaroid Cameras" W.T. Plummer, Physics Dept. Seminar, Harvard University, Nov. 4, 1998.

41. "Unusual Optical Components in High-Volume Polaroid Products" W.T. Plummer, Rochester chapter, Opt. Soc. of Am., Feb. 2, 1999.

42. "Unconventional Optics for Commercial Applications" W.T. Plummer, Staff Colloquium, Natl. Inst. of Standards and Tech., Gaithersburg, MD, Oct. 1, 1999.

Invited Talks (Cont'd):

43. “System Design for Manufacture: the Polychrome Laser Diode Platform” W.T. Plummer, Symposium, *The Future of Manufacturing: New Developments in Technology and System Design*, Laboratory for Manufacturing and Productivity, M.I.T., Cambridge, Mass., April 19, 2000.

44. “Free-form Optical Components in Some Early Commercial Products” W.T. Plummer, Keynote Address, Winter Topical Meeting, *Free-Form Optics: Design, Fabrication, Metrology and Assembly*, Am. Soc. for Precision Engineering, Chapel Hill, NC, Feb. 4, 2004.

45. “Free-form Optical Components in some Early Commercial Products” W.T. Plummer, *Tribute to Warren Smith: A Legacy in Lens Design and Optical Engineering*, SPIE Conference on Optics and Photonics, San Diego, CA, Aug. 1, 2005.

46. “Two Easy Pieces: a Double Program with Two Presentations” I. Physics of the Pinhole Camera. II. A New Way to Mold Aspheric Lenses for the Infrared. W.T. Plummer, New England Section / Opt. Soc. of Am., Lexington, MA, Sept. 21, 2006.

47. “A Cool New Way to Mold Infrared Lenses” W.T. Plummer, Optics & Optoelectronics Session Keynote Address, iMAPS New England 34th Annual Symposium, Boxborough, MA, May 1, 2007.

48. “A New Way to Mold Freeform and Structured Optical Surfaces” W.T. Plummer, Seminar, *Computational Optical Sensing and Imaging*, University of Colorado at Boulder, Feb. 7, 2011.

49. “A New Way to Mold Lenses with Freeform and Structured Surfaces” W.T. Plummer, Spring Topical Meeting, *Structured and Freeform Surfaces*, Am. Soc. for Precision Engineering, Univ. of North Carolina at Charlotte, March 7, 2011.

50. “Polachrome Laser Diode Platform” W.T. Plummer and Jeff Roblee, New England Section / Opt. Soc. of Am., Auburndale, MA, Oct. 18, 2012.

51. “Design of the Polaroid SX-70 Camera” W.T.Plummer, Seminar, New England School of Photography, Boston, MA, Nov. 7, 2012.

52. “Freeform Optical Surfaces in Commercial Products and a New Molding Process for the Infrared” W.T. Plummer, Colloquium, Institute of Optics, University of Rochester, Rochester, NY, Oct. 28, 2013.

53. “Experience in the Design and Manufacture of Freeform Lenses” W.T. Plummer, 2018 International Forum on Precision Digital Manufacturing and the Future of Visual Science and Optometry, Beijing, China, April 7, 2018.

54. “Some Milestones in the Design, Development, and Manufacture of Freeform Optics” W.T. Plummer, Plenary Presentation, The 9th International Symposium on Advanced Optical Manufacturing and Testing Technologies, ChengDu, China, June 26, 2018.

55. “Surface Quality Requirements for 3D Printing Lenses and Mirrors” W.T. Plummer, The 3rd Shanghai Additive Manufacturing Association International Forum & 2018 World 3D Printing Annual Meeting, Shanghai, China, Oct. 26-28, 2018.

56. “Disruptive High Precision Projection Micro-Litho-Stereo-Exposure (P lse) 3D-Printing Capacity and Applications” W.T.Plummer and Zhifei Zhang, keynote address, The 4th Shanghai Additive Manufaturing Association International Forum & 2019 “Belt and Road” 3D Printing and Intelligent Manufacturing Annual Meeting, Shanghai, China, Aug. 16-18, 2019.

CITATION FOR THE 1980 DAVID RICHARDSON MEDAL, OPTICAL SOCIETY OF AMERICA

“The Polaroid SX-70 Land Camera is probably the most remarkable optical design ever placed in high-volume production. From 1969 through 1973 Dr. Plummer was part of a small design team, led by Dr. Edwin H. Land and including Dr. James G. Baker and Dr. Richard F. Weeks, that conceived of this folding catadioptric single-lens-reflex system and produced an optical design that evolved along with the camera's mechanical and electronic structure. Dr. Plummer made significant personal contributions and provided technical leadership for a small group of scientists and engineers who worked with Dr. Baker to relate his geometric design to the needs of the product, to create precise tooling for plastic molding of unusual optical components, and to set up a range of new manufacturing technologies for producing and assembling high-quality optical elements.

“Dr. Baker's design uses a four-element glass photographic objective, a plane mirror to fold the system, and a reflective Fresnel focus screen. The image formed on the screen is passed by a small aperture stop and relayed to the photographer by an aspheric concave mirror and eyelens. For structural reasons every viewfinder component from the focus screen onward is tilted, decentered, or both. Dr. Plummer introduced non-rotational aspheric surfaces on the eyelens and on a refractive corrector plate at the aperture stop, and designed an astigmatic Fresnel mirror. He built many functioning prototype systems as the design and aspheric tooling progressed so that a careful balance could be made among unfamiliar aberrations represented in the figure of merit, and guided the mechanical design of the camera so these optical parts would be positioned accurately each time the camera is unfolded. He designed a null tester that is used for controlling the shape of the molded concave mirrors and designed a series of instruments for simplifying quality measurements and all assembly adjustments in volume production.

“A surprising depth of investigation was needed to support design decisions. Dr. Plummer studied the basic function of a focus screen to understand a four-way compromise, which occurs in roughening the reflex focus screen. He personally devised the texture that has been replicated in production. In the case of the photographic objective, which moves through its focus range by displacement of the front element, he used analysis based on the modulation transfer function to derive the best subjective focus scale for different object distances with a changing aberration balance. He studied the optics of the shutter mechanism itself, and found that by using an expanding and contracting aperture stop as a shutter the SX-70 significantly improves upon the familiar compromise of motion-freezing against depth of field.

“Dr. Plummer numerically determined the sensitivity of the film plane image to field tilt caused by tilting and decentering of individual lens elements, and used a Monte Carlo computing procedure to relate manufacturing yield to piece-part tolerances in the objective lens. The analysis guided the mechanical design and demonstrated that the best economy requires culling some inferior lenses. To do this, he and his colleagues designed and built a machine capable of testing 1200 lenses per hour with a modulation-related figure of merit that correlates extremely well with subjective quality judgments. In an effort to understand the system tolerance budget he expanded upon and generalized a study begun in 1962 by Dr. R. Clark Jones, of the computed modulation transfer properties of diffusion transfer films, and applied it to a model representing the new SX-70 film. Certain details of the exposure characteristic curve led him to extend a 1953 study by Williams and Clapper on the effect of multiple internal reflections in a color print, and to apply it to the more complicated case of SX-70 film.

“For other manufacturing requirements Dr. Plummer studied the basic physics of bell centering, toleranced lens and mirror surface coatings by relating them to photographic tristimulus color coordinates, and built automatic machines sensitive to local irregularities for screening plane mirrors to a demanding performance criterion.”

CITATION FOR THE 1997 JOSEPH FRAUNHOFER AWARD, OPTICAL SOCIETY OF AMERICA

"For his exceptional accomplishments in the field of optical engineering, for making state-of-the-art optical technology affordable, bringing extremely sophisticated optics into the consumer marketplace, and for his expertise and willingness to participate in all aspects of engineering from technology and product development to manufacturing. Technical problems are seen by him as opportunities for invention, and his leadership inspires others to invent as well. He maintains an environment that encourages technical innovation. To do this consistently in a business world is a major accomplishment of engineering."

CITATION FOR THE 1999 ELECTION TO MEMBERSHIP, NATIONAL ACADEMY OF ENGINEERING

"For contributions to optical science and engineering, and for leadership in high-volume manufacturing of precision optics."

William T. Plummer: N. A. E. Statement of Technical Interest

One task of Engineering is to make commercial products of all kinds that are better, more versatile, smaller, cheaper, and earlier to market. My interest is to solve the resulting manufacturing problems far upstream through cross-disciplinary teamwork, before designs become viscous or rigid. This goal demands fighting for real clarity in the early concept stage of a design project, and requires doing so with the best and broadest technical team that can be nurtured or borrowed.

In the case of optical science and engineering, and precision engineering, this approach has led us to use a variety of unique and surprisingly sophisticated optical, mechanical, and electronic designs even in mass-produced camera products with molded plastic components. It has also led us to great simplification of the design and assembly of instruments, specialized laser hardware and other manufactured goods, through standard approaches, modularity, rational fixturing and procedures, and modern component fabrication.

I believe that competitive product engineering requires a solid grasp of the obvious, or at least of basic principles imaginatively applied early enough by the right team. We are surrounded by opportunities for better design practice and I am interested in teaching effective ideas through entertaining examples.

APPENDIX B

FUNDAMENTALS
OF
OPTICS

BY
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Professor of Physics
University of California

AND

HARVEY E. WHITE
Professor of Physics
University of California

SECOND EDITION

New York Toronto London
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1950

FUNDAMENTALS OF OPTICS

IV

THE MAPLE PRESS COMPANY, YORK, PA.

incident and refracted rays have been extended to their point of intersection. Transverse planes through these intersections constitute the *primary and secondary principal planes*. These planes cross the axis at points H and H', called the *principal points*. When this graphical construction is carried out for parallel rays at different heights above or below the axis, the positions of the principal points and focal points will be found to vary somewhat. This implies that the focal planes and principal planes are in reality curved surfaces. For paraxial rays, however, all four points F, F', H, and H' are to be regarded as fixed, and the corresponding "planes" as truly plane.

If the medium is the same on both sides of the lens, the primary focal length f is exactly equal to the secondary focal length f'. For this to be true the focal lengths must, as is shown in the figure, be measured from the focal points to their respective principal points H and H' and *not* to their respective vertices A_1 and A_2. In general the principal points and focal points are not located symmetrically with respect to the lens but are at different distances from the vertices. As a lens of a given focal length is "bent" (Fig. 5B), departing in either direction from the symmetrical shape of an equiconvex lens, the principal points shift in the opposite direction. For the equiconvex lens shown in the center, H and H' divide the lens thickness into three approximately equal parts. In the plano-convex lens one principal point falls exactly at the vertex of the convex surface, and the other falls about one-third of the thickness inside this vertex. For meniscus lenses of considerable thickness and curvature, H and H' may lie completely outside the lens.

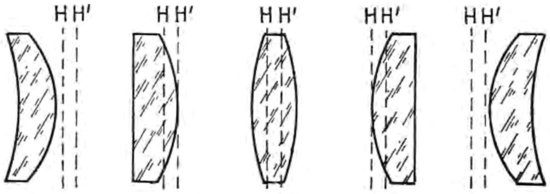

FIG. 5B. Illustrating the variation of the positions of the primary and secondary principal planes, as a thick lens of a given focal length is subject to "bending."

5.2. Conjugate Relations. In order to trace any ray through a thick lens, the positions of the focal points and principal points must first be determined. Once this has been done, either graphically or by computation, the parallel-ray construction can be used to locate the image as shown in Fig. 5C. The construction procedure follows that given in Fig. 3F for a thin lens, except that here all rays in the region between the two principal planes are drawn parallel to the axis. This requirement results from the fact that by definition the primary and secondary