IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent of:	Theodore L. Brann
U.S. Patent No.:	6,059,576 Attorney Docket No.: 50095-0041IP1
Issue Date:	May 9, 2000
Appl. Serial No.:	08/976,228
Filing Date:	November 21, 1997
Title:	TRAINING AND SAFETY DEVICE, SYSTEM AND METHOD TO AID IN PROPOER MOVEMENT DURING PHYSICAL ACTIVITY

DECLARATION OF DR. KENNY

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

By: ____________________________
Thomas W. Kenny, Ph.D.

Date: October 7, 2021

TABLE OF CONTENTS

I. QUALIFICATIONS AND BACKGROUND INFORMATION

1. My education and experience are described more fully in the attached curriculum vitae (APPENDIX A). For ease of reference, I have highlighted certain information below.

2. My academic and professional background is in Physics, Mechanical Engineering, Sensing, and Robotics, with a research specialization focused on micro-fabricated physical sensors, and I have been working in those fields since the completion of my Ph.D. more than 30 years ago. The details of my background and education and a listing of all publications I have authored in the past 35 years are provided in my curriculum vitae. Below I provide a short summary of my education and experience, which I believe to be most pertinent to the opinions that I express here.

3. I received a B.S. in Physics from University of Minnesota, Minneapolis in 1983, and a Ph.D. in Physics from University of California at Berkeley in 1989. I was educated as a Physicist specializing in sensors and measurement. My Physics Ph.D. thesis involved measurements of the heat capacity of monolayers of atoms on surfaces, and relied on precision measurements of temperature and power using time-varying electrical signals, and also on the design and construction of miniature sensor components and associated electrical circuits for conditioning and conversion to digital format.

4. After completion of my Ph.D. in Physics at U.C. Berkeley in 1989, I joined the Jet Propulsion Laboratory (JPL) in Pasadena, CA, as a staff scientist, and began working on miniature sensors and instruments for small spacecraft. This work involved the use of silicon microfabrication technologies for miniaturization of the sensors, and served as my introduction to the field of micro-electromechanical systems (MEMS), or the study of very small mechanical sensors powered by electricity and used for detection of physical and chemical signals.

5. While at JPL, we developed accelerometers, gyroscopes, uncooled infrared sensors, magnetometers, seismometers, force and displacement sensors, soil chemistry sensors, miniature structures for trapping interstellar dust, and many other miniature devices. Some of these projects led to devices that were launched with spacecraft headed for Mars and for other interplanetary missions. Much of this work involved the use of physical sensors for detection of small forces and displacements using micromechanical sensors.

6. I am presently the Richard Weiland Professor at the Department of Mechanical Engineering at Stanford University, where I have taught for the past 27 years. I am also on leave from my position as Senior Associate Dean of Engineering for Student Affairs at Stanford. I am currently on partial leave from this position to serve as CEO of Applaud Medical, a startup company that I co-founded which is focused on developing new treatments for Kidney Stones.

7. For 27 years, I have taught courses on Sensors and Mechatronics at Stanford University. The "Introduction to Sensors" course is a broad overview of all sensing technologies, from thermometers, to inertial sensors, ultrasound devices, flow sensors, optical and IR sensors, chemical sensors, pressure sensors, and many others, and has included sensors based on changes in capacitance, resistance, piezoelectricity. This course specifically included different mechanisms for sensing heart rate, blood pressure, blood chemistry, cardiovascular blood flow and pressure drops, intraocular pressure and other physiological measurements, as well as activity monitoring (step counting, stair-counting, etc.) I first taught this course at Stanford in the Spring of 1994, and I offered this course at least annually until 2016, when my duties as Senior Associate Dean made this impractical.

8. The "Introduction to Mechatronics" course is a review of the mechanical, electrical and computing technologies necessary to build systems with these contents, which include everything from cars and robots to cellphones and other consumer electronics devices. In this class, we routinely use IR, LEDs, and photosensors as a way of detecting proximity to objects in the space around miniature robots. We also use inertial sensors to detect movement, and a number of sensors, such as encoders to measure changes in position and trajectory. Accelerometers and gyroscopes are used in this course for helping with navigation of autonomous robots in the class project. I was one of the instructors for the first offering of this course in 1995, and this course has been offered at least once each year ever since (except in 2021, when the pandemic made this impractical), with plans already underway for the Winter 2022 offering.

9. I am co-author of a textbook titled "Introduction to Mechatronic Design," which broadly covers the topic of integration of mechanical, electronic and computer systems design into "smart products." This textbook includes chapters on Microprocessors, Programming Languages, Software Design, Electronics, Sensors, Signal Conditioning, and Motors, as well as topics such as Project Management, Troubleshooting, and Synthesis.

10. My research group has focused on the area of microsensors and microfabrication—a domain in which we design and build micromechanical sensors using silicon microfabrication technologies. The various applications for these technologies are numerous. Much of this work has focused on the design, fabrication and characterization of inertial sensors, such as accelerometers and gyroscopes.

11. I have advised 74 Ph.D. students that have completed Ph.D. degrees and many more M.S. and B.S. students in Engineering during my time at Stanford.

12. I have published over 250 technical papers in refereed journals and conferences in the field of sensors, MEMS, and measurements. I have further presented numerous conference abstracts, posters, and talks in my field. I am a named inventor on more than 50 patents in my areas of work. Through my research and teaching in the area of Sensors and Measurement, I was directly involved in or well-aware of developments in the micromechanical sensing community, such as the research and development efforts on miniature inertial sensors for automotive safety systems, such as the accelerometers developed for crash detection and gyroscopes developed for skid detection and control. At the time of the filing date of U.S. Patent No. 6,059,576, the emergence of miniature inertial sensors was widely appreciated.

13. I have previously served as an expert on a patent infringement case involving the design and use of miniature inertial sensors for detection of movement and free-fall. That case involved the design and operations of micromechanical sensors, and particularly the use of inertial sensors for detection of states of movement and rest. I have also served as an expert in a patent infringement case involving the use of sensors on athletic shoes for determining athletic performance. I served as an expert in a patent infringement case involving optical proximity sensors in smartphones. More recently, I have served as an expert witness in a case involving use of physiological sensors to diagnose a user's condition and possible interest in products or services. My CV, Appendix A, includes a full listing of all cases in which I have testified at deposition or trial in the preceding four years.

14. I have been retained on behalf of Apple Inc. to offer technical opinions relating to U.S. Patent No. 6,059,576 ("**the '576 Patent**") and prior art references relating to its subject matter. I have reviewed the '576 Patent (APPLE-1001), relevant excerpts of the prosecution history of the '576 Patent (APPLE-1002), *ex parte* reexamination certificate of the '576 Patent (APPLE-1006), and relevant excerpts of the prosecution history of the *ex parte* reexamination of the '576 Patent (APPLE-1007). I have also reviewed the following references:

Prior Art Reference
U.S. Patent No. 5,778,882 ("Raymond" or APPLE-1009)
U.S. Patent No. 5,573,013 ("Conlan" or APPLE-1010)
U.S. Patent No. 5,803,740 ("Gesink" or APPLE-1014)
U.S. Patent No. 4,962,469 ("Ono" or APPLE-1101)
U.S. Patent No. 5,899,963 ("Hutchings" or APPLE-1102)
U.S. Patent No. 5,941,837 ("Amano" or APPLE-1103)
U.S. Patent No. 6,059,692 ("Hickman" or APPLE-1104)
U.S. Patent No. 5,857,939 ("Kaufman" or APPLE-1105)
U.S. Patent No. 5,808,903 ("Schiltz" or APPLE-1106)
U.S. Patent No. 5,976,083 ("Richardson" or APPLE-1107)
U.S. Patent No. 5,553,007 ("Brisson" or APPLE-1108)

U.S. Patent No. 5,916,181 ("Socci" or APPLE-1109)
U.S. Patent No. 5,593,431 ("Sheldon" or APPLE-1110)
U.S. Patent No. 5,511,045 ("Sasaki" or APPLE-1111)
U.S. Patent No. 4,387,437 ("Lowrey" or APPLE-1112)
Warwick, "Trends and Limits in the 'Talk Time' of Personal Communicators," Proceedings of the IEEE, Vol. 83, No. 4 (April 1995) ("Warwick" or APPLE-1113)

15. I have also reviewed various supporting references and other documentation as further noted in my opinions below.

16. Counsel (Fish & Richardson) has informed me that I should consider these materials through the lens of one of ordinary skill in the art related to the '576 Patent at the time of the earliest possible priority date of the '576 Patent, and I have done so during my review of these materials. The '576 Patent was filed on November 21, 1997 ("**the '576 Patent Filing Date**"). I have therefore used this date in my analysis below.

17. I have no financial interest in the outcome of this proceeding. I am being compensated for my work as an expert on an hourly basis. My compensation is not dependent on the outcome of these proceedings or the content of my opinions.

18. In writing this declaration, I have considered the following: my own knowledge and experience, including my work experience in the fields of mechanical engineering, computer science, biomedical engineering, and electrical engineering; my experience in teaching those subjects; and my experience in working with others involved in those fields. In addition, I have analyzed various publications and materials, in addition to other materials I cite in my declaration.

19. My opinions, as explained below, are based on my education, experience, and expertise in the fields relating to the '576 Patent. Unless otherwise stated, my testimony below refers to the knowledge of one of ordinary skill in the art as of the '576 Patent Filing Date, or before. Any figures that appear within this document have been prepared with the assistance of Counsel and reflect my understanding of the '576 Patent and the prior art discussed below.

II. OVERVIEW OF CONCLUSIONS FORMED

20. This declaration explains the conclusions that I have formed based on my analysis. To summarize those conclusions, based upon my knowledge and experience and my review of the prior art references listed above, I believe that:

- Claims 1, 3-5, 8, 10, 20, 25, 30, 39, 41, 42, and 61-65 are Obvious based on Ono in view of Hutchings.
- Claims 1, 3-5, 8-11, 20, 25, 30, 36, 39-42, and 61-65 are Obvious based on Ono in view of Hutchings and Amano.
- Claims 1-5, 8, 10, 20, 25, 30, 31, 39, 41, 42, 45-47, 49, and 61-65 are Obvious based on Ono in view of Hutchings and Conlan.

- Claims 48, 50, and 51 are Obvious based on Ono in view of Hutchings, Conlan, and Hickman.
- Claims 1, 3-5, 8, 10, 20, 25, 30, 39, 41, 42, 61-65, 144, and 147 are Obvious based on Ono in view of Hutchings and Kaufman.
- Claims 1-5, 8-11, 20, 25, 30-32, 36, 39-42, 45-47, 49, 61-65, 144, and 147 are Obvious based on Ono in view of Hutchings, Amano, Conlan, and Kaufman.
- Claims 48, 50, and 51 are Obvious based on Ono in view of Hutchings, Amano, Conlan, Kaufman, and Hickman.
- Claims 1-5, 8-11, 20, 25, 30, 31, 36, 39-42, 45-47, 49, and 61-65 are Obvious based on Ono in view of Hutchings, Amano, and Conlan.
- Claims 48, 50, and 51 are Obvious based on Ono in view of Hutchings, Amano, Conlan, and Hickman.
- Claims 1, 3-5, 8-11, 20, 25, 30, 36, 39-42, 61-65, 144, and 147 are Obvious based on Ono in view of Hutchings, Amano, and Kaufman.
- Claims 1-5, 8, 10, 20, 25, 30, 31, 39, 41, 42, 45-47, 49, 61-65, 144, and 147 are Obvious based on Ono in view of Hutchings, Conlan, and Kaufman.
- Claims 48, 50, and 51 are Obvious based on Ono in view of Hutchings, Conlan, Kaufman, and Hickman.

21. In support of these conclusions, I provide an overview of the references and more detailed comments regarding the obviousness of claims 1-5, 8-11, 20, 25, 30-32, 36, 39-42, 45-51, 61-65, 144, and 147 ("**the Challenged Claims**") of the '576 Patent below.

III. LEVEL OF ORDINARY SKILL IN THE ART

22. In my opinion, one of ordinary skill in the art relating to, and at the time of, the invention of the '576 Patent (POSITA) would have been someone with a working knowledge of activity monitoring technologies. The person would have had a Bachelor of Science degree in an academic discipline emphasizing the design of electrical, computer, or software technologies, in combination with training or at least one to two years of related work experience with capture and processing of data or information, including but not limited to activity monitoring technologies. Alternatively, the person could have also had a Master of Science degree in a relevant academic discipline with less than a year of related work experience in the same discipline.

23. Based on my experiences, I have a good understanding of the capabilities of a POSITA. Indeed, I have taught, mentored, participated in organizations, and worked closely with many such persons over the course of my career. Based on my knowledge, skill, and experience, I have an understanding of the capabilities of a POSITA. For example, from my industry consulting or conference interactions, I am familiar with what a POSITA would have known and found predictable in the art. From teaching and supervising my post-graduate students, I also have an understanding of the knowledge that a person with this academic experience possesses. Furthermore, I possess those capabilities myself.

IV. LEGAL STANDARDS

A. Terminology

24. I have been informed by Counsel and understand that the best indicator of claim meaning is its usage in the context of the patent specification as understood by one of ordinary skill. I further understand that the words of the claims should be given their plain meaning unless that meaning is inconsistent with the patent specification or the patent's history of examination before the Patent Office. Counsel has also informed me, and I understand that, the words of the claims should be interpreted as they would have been interpreted by one of ordinary skill at the time of the invention was made (not today). I have been informed by Counsel that I should use '576 Patent Filing Date as the point in time for claim interpretation purposes with respect to this declaration.

B. Legal Standards

25. I have been informed by Counsel and understand that documents and materials that qualify as prior art can render a patent claim unpatentable as being anticipated or obvious.

26. I am informed by Counsel and understand that all prior art references are to be looked at from the viewpoint of a person of ordinary skill in the art at the time of the invention, and that this viewpoint prevents one from using his or her own insight or hindsight in deciding whether a claim is anticipated or rendered obvious.

1. Anticipation

27. I understand that patents or printed publications that qualify as prior art can be used to invalidate a patent claim as anticipated or as obvious.

28. I understand that, once the claims of a patent have been properly construed, the second step in determining anticipation of a patent claim requires a comparison of the properly construed claim language to the prior art on a limitation-by-limitation basis.

29. I understand that a prior art reference "anticipates" an asserted claim, and thus renders the claim invalid, if all limitations of the claim are disclosed in that prior art reference, either explicitly or inherently (i.e., necessarily present).

2. Obviousness

30. I understand that even if a patent is not anticipated, it is still invalid if the differences between the claimed subject matter and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a POSITA.

31. I have been informed by Counsel and understand that a claim is unpatentable for obviousness and that obviousness may be based upon a combination of prior art references. I am informed by Counsel and understand that the combination of familiar elements according to known methods is likely to be obvious when it does no more than yield predictable results. However, I am informed by Counsel and understand that a patent claim composed of several elements is not proved obvious merely by demonstrating that each of its elements was, independently, known in the prior art.

32. I am informed by Counsel and understand that when a patented invention is a combination of known elements, a court determines whether there was an apparent reason to combine the known elements in the fashion claimed by the patent at issue by considering the teachings of prior art references, the effects of demands known to people working in the field or present in the marketplace, and the background knowledge possessed by a person having ordinary skill in the art.

33. I am informed by Counsel and understand that a patent claim composed of several limitations is not proved obvious merely by demonstrating that each of its limitations was independently known in the prior art. I am informed by Counsel and understand that identifying a reason those elements would be combined can be important because inventions in many instances rely upon building blocks long since uncovered, and claimed discoveries almost of necessity will be combinations of what, in some sense, is already known. I am informed by Counsel and understand that it is improper to use hindsight in an obviousness analysis, and that a patent's claims should not be used as a "roadmap."

34. I am informed by Counsel and understand that an obviousness inquiry requires consideration of the following factors: (1) the scope and content of the prior art, (2) the differences between the prior art and the claims, (3) the level of ordinary skill in the art, and (4) any so called "secondary considerations" of non-obviousness, which include: (i) "long felt need" for the claimed invention, (ii) commercial success attributable to the claimed invention, (iii) unexpected results of the claimed invention, and (iv) "copying" of the claimed invention by others.

35. I have been informed by Counsel and understand that an obviousness evaluation can be based on a single reference or a combination of multiple prior art references. I understand that the prior art references themselves may provide a suggestion, motivation, or reason to combine, but that the nexus linking two or more prior art references is sometimes simple common sense. I have been informed by Counsel and understand that obviousness analysis recognizes that market demand, rather than scientific literature, often drives innovation, and that a motivation to combine references may be supplied by the direction of the marketplace.

36. I have been informed by Counsel and understand that if a technique has been used to improve one device, and a person of ordinary skill at the time of invention would have recognized that it would improve similar devices in the same way, using the technique is obvious unless its actual application is beyond his or her skill.

37. I have been informed by Counsel and understand that practical and common sense considerations should guide a proper obviousness analysis, because familiar items may have obvious uses beyond their primary purposes. I have been informed by Counsel and understand that a person of ordinary skill looking to overcome a problem will often be able to fit together the teachings of multiple prior art references. I have been informed by Counsel and understand that obviousness analysis therefore takes into account the inferences and creative steps that a person of ordinary skill would have employed at the time of invention.

38. I have been informed by Counsel and understand that a proper obviousness analysis focuses on what was known or obvious to a person of ordinary skill at the time of invention, not just the patentee. Accordingly, I understand that any need or problem known in the field of endeavor at the time of invention and addressed by the patent can provide a reason for combining the elements in the manner claimed.

39. I have been informed by Counsel and understand that a claim can be obvious in light of a single reference, without the need to combine references, if the elements of the claim that are not found explicitly or inherently in the reference can be supplied by the common sense of one of skill in the art.

40. I have been informed by Counsel and understand that there must be a relationship between any such secondary considerations and the invention, and that contemporaneous and independent invention by others is a secondary consideration supporting an obviousness determination.

41. In sum, my understanding is that prior art teachings are properly combined where one of ordinary skill having the understanding and knowledge reflected in the prior art and motivated by the general problem facing the inventor, would have been led to make the combination of elements recited in the claims. Under this analysis, the prior art references themselves, or any need or problem known in the field of endeavor at the time of the invention, can provide a reason for combining the elements of multiple prior art references in the claimed manner.

42. I have been informed by Counsel and understand that in an *inter partes* review (IPR), "the petitioner shall have the burden of proving a proposition of unpatentability," including a proposition of obviousness, "by a preponderance of the evidence." 35 U.S.C. § 316(e).

V. THE ’576 PATENT

A. Overview of the ’576 Patent

43. The ’576 Patent is directed to an “electronic device, system and method to monitor and train an individual on proper motion during physical movement.” APPLE-1001, Abstract. The ’576 Patent recognizes that “a variety of sensing, monitoring, and notification devices” have been previously created “[i]n order to study and better understand safe human movement.” *Id.*, 1:18-21. Such known devices could “quantitatively determine a range of motion of a human joint in angular degrees” and “provide a warning to the wearer through an audible alarm or flashing light . . . when a predetermined angle of flexion or extension has been exceeded.” *Id.*, 1:30-41. Accordingly, the ’576 Patent acknowledges that it was previously well-known to determine whether human motion exceeds a threshold and, if so, provide a notification.

44. The ’576 Patent’s specification describes a “self-contained movement measuring device 12” with a “movement sensor 13.” APPLE-1001, 3:32-50. The movement sensor 13 is illustrated as being both together with the other components of the device (FIGS. 2A, 2B) and also as being “separate from the remaining components 15 of the device 12” (FIG. 2C). *Id.* FIGS. 2B and 2C are annotated below based on the description in the specification.

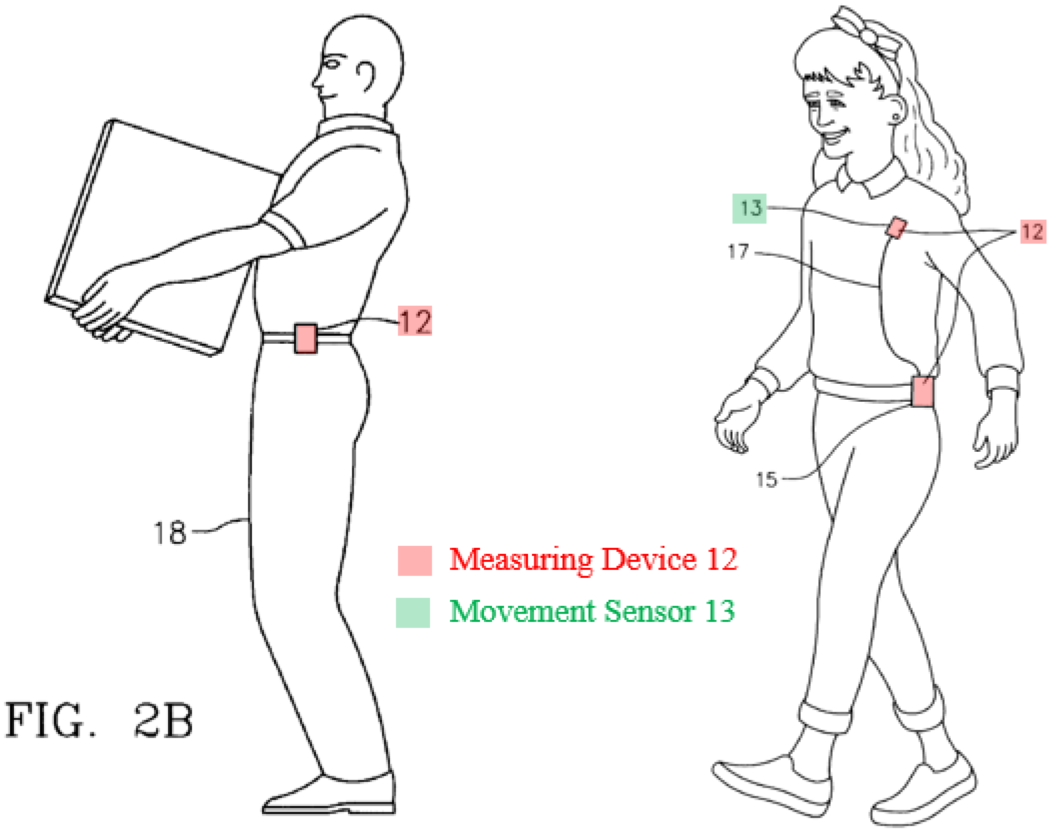


FIG. 2B

APPLE-1001 ('576 Patent), FIGS. 2B, 2C[1]

45. According to the specification, the movement sensor "detects movement and measures associated data such as angle, speed, and distance" and, in particular, measures "angular velocity of physical movement for subsequent interpretation." APPLE-1001, 4:38-45, 2:40-41. In various embodiments, the movement sensor may be an "accelerometer which is capable of detecting angles of movement in multiple planes" or "multiple accelerometers each capable of measuring angles of movement in only one plane." *Id.*, 4:38-48.

[1] I have annotated the figures throughout my declaration in color.

46. The ’576 Patent further explains that the “movement sensor 30 is electronically connected to a microprocessor 32 which receives the signals generated by the movement sensor 30 for analysis and subsequent processing.” APPLE-1001, 4:52-55. Once the microprocessor has received and analyzed the movement data, the microprocessor responds based on “user-programmable configuration information” such as “an event threshold.” *Id.*, 4:40-65, 5:67-6:9. For example, the device may respond by using indicators (visual, audible, or vibration-based) that are “activated to notify the wearer when a predetermined angle of motion has been exceeded.” *Id.*, 4:4-25.

47. According to the ’576 Patent, data collected by the movement measurement device may be downloaded to a computer. APPLE-1001, 8:31-34. And, “[o]nce the data from the device 12 has been downloaded to the computer 16, software running on the computer 16 is used to interpret the data and produce a number of reports and histories.” *Id.*, 8:40-43.

48. As I show in the following sections, all of the above concepts were well-known before the ’576 Patent.

B. Prosecution History of the ’576 Patent

49. The ’576 Patent issued from U.S. App. No. 08/976,228. During prosecution, the three independent claims were each amended to describe the measuring device as a “portable, self-contained” device capable of measuring data associated with "unrestrained movement in any direction." APPLE-1002, 40-42. Responsive to these amendments, the Examiner allowed the pending 29 claims. *Id*., 29.

50. Fourteen years after issuance of the '576 Patent, Patent Owner filed a request for reexamination, seeking to add 129 new claims without disturbing the original 29 claims. APPLE-1007, 438-543. The reexamination request included prior art that, according to Patent Owner, raised a substantial new question of patentability yet did not teach every element of the independent claims. *See, e.g., id*., 494, 499, 502. The Examiner, however, disagreed and found that the cited prior art did teach every limitation of the independent claims, including the "portable, self-contained" and "unrestrained movement in any direction" features. *Id*., 246-300. In response, Patent Owner amended the independent claims to include "detecting a first user- defined event …" and "storing first event information …." *Id*., 34-39. Notably, as part of these amendments, Patent Owner added an additional 27 new claims beyond the 129 new claims presented in the reexamination request, bringing the total number of new claims to 156. *Id*. at 168-206. The reexamination resulted in a reexamination certificate with 185 claims (*see* APPLE-1006). The claims address in my Declaration are those found in the reexamination certificate.

51. As I explain below in Section VI, all of these original and newly-claimed features were known and rendered obvious by prior art references.

C. Claim Construction

1. "a movement sensor" (claim 1 and claims depending therefrom)

52. The '576 Patent describes a movement sensor in the following passage:

> Reference is now made to a block diagram in FIG. **4** which shows the major internal components of the movement measuring device **12** and their interconnections. The device **12** includes a movement sensor **30** which detects movement and measures associated data such as angle, speed, and distance. The movement sensor **30** generates signals corresponding to the measurement data collected. In a preferred embodiment, the movement sensor **30** is an accelerometer which is capable of detecting angles of movement in multiple planes as well as the velocity at which the movement occurs. Alternatively, multiple accelerometers, each capable of measuring angles of movement in only one plane, may be oriented within the device **12** so that movement in multiple planes may be detected. Although many

APPLE-1001, 4:35-48. As noted above, in some implementations, the movement sensor is *an* accelerometer capable of detecting velocity and angles of movement in multiple planes. *Id*. In some implementations, a movement sensor includes "*multiple* accelerometers, each capable of measuring angles of movement in only one plane." *Id*. Consistent with both implementations, claim 170 recites "wherein said movement sensor comprises ***at least one*** accelerometer." APPLE-1001, 11:19-21. In view of the intrinsic description of "a movement sensor," a POSITA would have understood that "a movement sensor" encompasses ***one or more sensors capable of detecting movement and measuring movement data associated***

with the detected movement. The movement data may include rotation rate, angle, velocity, and/or distance measurements.

53. The ’576 prosecution history supports this construction. In the Patent Owner-filed reexamination request, Patent Owner argued that a plurality of sensors (speed sensor 18 and loft sensor 20) in a prior art reference (U.S. Patent No. 5,636,146) together disclose the “movement sensor” in the claims. APPLE-1007, 491-99. In the Office Action following the reexamination request, the Examiner agreed. APPLE-1007, 248, 250-51. Accordingly, the construction in my declaration is supported by intrinsic evidence, the prosecution history, the Patent Owner’s remarks, and the Examiner.

VI. MANNER IN WHICH THE PRIOR ART REFERENCES RENDER THE ’576 CLAIMS UNPATENTABLE

A. GROUND 1—Claims 1, 3-5, 8, 10, 20, 25, 30, 39, 41, 42, and 61-65 are Obvious based on Ono in view of Hutchings

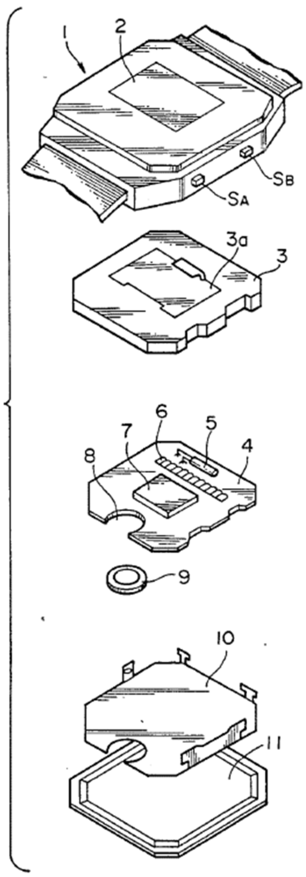
1. Overview of Ono[2]

54. Ono describes “an exercise measuring instrument in which exercise in walking, jogging, running, and the like is measured utilizing an acceleration sensor.” APPLE-1101, 1:5-10. Ono’s exercise measuring instrument is

[2] General descriptions that I have provided for references and combinations are incorporated into each subsection addressing/applying those references, as are the discussions of combinations.

implemented as “an electronic wrist watch to which a pedometer is installed.” APPLE-1101, 3:10-11, FIG. 1. An exploded perspective view of an example of Ono’s device is shown in FIG. 1, reproduced below. APPLE-1101, 2:30-32, 3:10-11.

FIG. 1



Ono, FIG. 1

A block diagram of an example of Ono’s device is shown in FIG. 14, reproduced below. APPLE-1101, 2:59-60, 13:18-19.

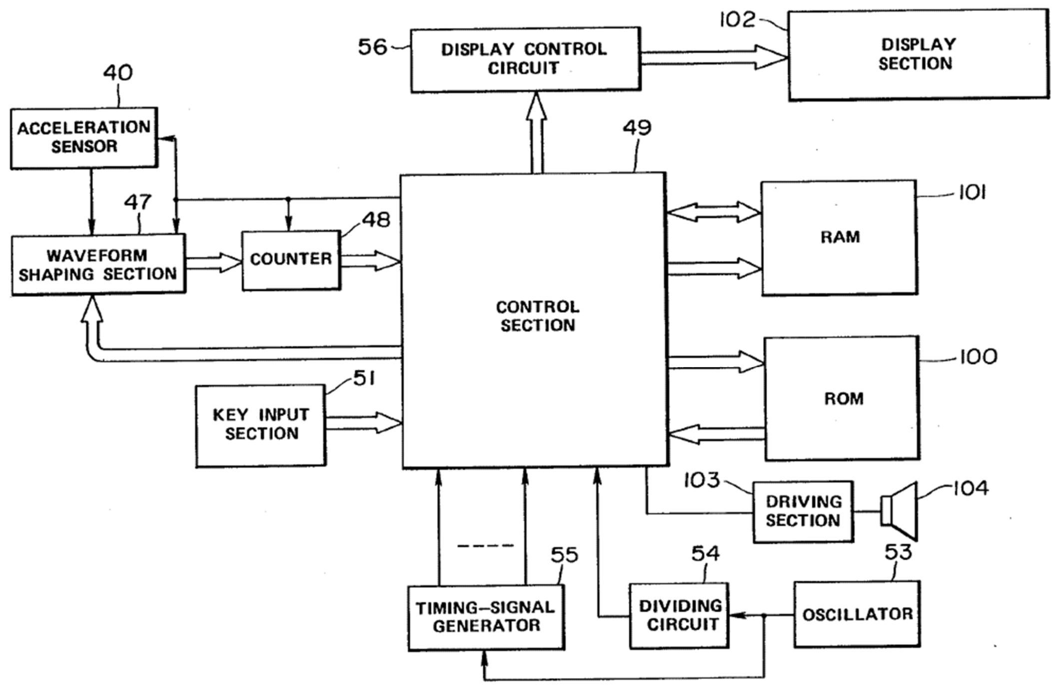


FIG.14

Ono, FIG. 14

55. As shown in FIG. 14, Ono's device includes a "key-input section 51 compris[ing] switches S_1 to S_6." APPLE-1101, 13:25-27. The switches allow a user to select one of five display modes: (1) time-display mode, (2) step-counting mode, (3) present data display mode, (4) data-recall mode, and (5) data-setting mode. APPLE-1101, 13:34-42, 13:55-57, 16:18-17:23, 19:18-67, FIGS. 20-21. The switches also allow the user to select one of three exercising modes: (1) walking mode, (2) exercising-walking mode, and (3) jogging mode. APPLE-1101, 13:51-57, 18:14-19, 18:67-19:6. In the data-setting mode, the switches allow the user to set a stride length for each of the three exercising modes, sex, age, weight, and target numbers. APPLE-1101, 13:40-42, 13:55-61, 18:28-19:17, 20:8-15, FIGS. 20-21. In the step-counting mode, switch S_2 functions to start and/or stop the step-counting operation. APPLE-1101, 17:24-50. The modes and the data set by the user are stored in registers of random access memory RAM 101. APPLE-1101, 13:30-63, FIG. 15.

56. When the device is in the step-counting mode operation, Ono's "control section 49 compris[ing] a CPU" (central processing unit) calculates the number of steps, number of steps per minute (walking pitches), mean walking speed, and distance-walked based on the acceleration sensor signal and the stride-length data corresponding to the exercise mode previously set through the key-input section 51. APPLE-1101, 8:60-9:12, 12:17-35, 14:44-45, 15:10-13, 15:33-46, 15:61-66, 17:26-34. The processor calculates "distance-walked every time period of 10 sec... from the stride length and the number of steps taken." APPLE-1101, 15:61-66, 14:1-15, FIG. 18 (step a_{16}). The processor then "discriminate[s] whether or not the distance-walked has reached the target distance." APPLE-1101, 15:66-68, FIG. 18 (step a_{17}). "[I]f the distance-walked has reached the target distance," the processor outputs a signal to the alarm-driving section 103 for generating an alarm sound from speaker 104. APPLE-1101, 13:23-25, 15:26-28, 16:2-4, FIG. 18 (steps a_{18}).

57. The processor stores the calculated data into RAM 101, which includes "[r]egisters A and B... for storing walking speeds and walking pitches" and "[a] step-register G, a distance-walked register H and a calorie-consumption register I...

for storing accumulative number of steps taken, accumulative distance walked and accumulative calorie-consumption which are under measurement, respectively." APPLE-1101, 14:1-15. The processor sends the calculated data to the display, through which "various data obtained in the step-counting mode are displayed," including "data of the step-register G and the distance register [H] which are sequentially renewed every 10 seconds are displayed." APPLE-1101, 16:21-22, 17:42-50, 5:21-36, 9:12-14, 12:35-38, FIG. 22. When the step-counting mode operation is stopped, the processor stores the date, duration, total step count, total distance-walked, and total calorie-consumption in registers D of RAM 101 for later retrieval and display in the data-recall mode. APPLE-1101, 13:65-14:29, 16:24-25, 17:10-50, 18:20-24, 20:37-53, FIGS. 15, 20 (steps C_{14}-C_{15}), 23. An example of the registers of RAM 101 is shown in FIG. 15, reproduced below. APPLE-1101, 13:30-31, 2:61-62.

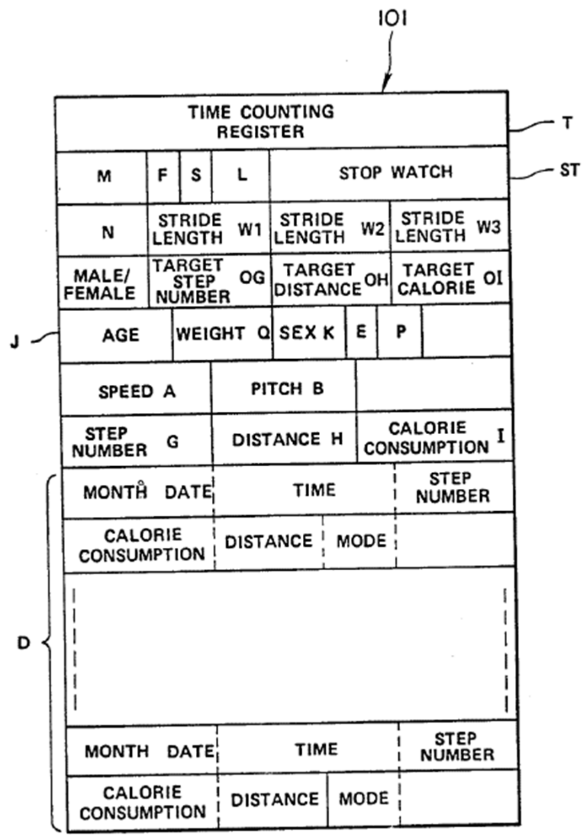


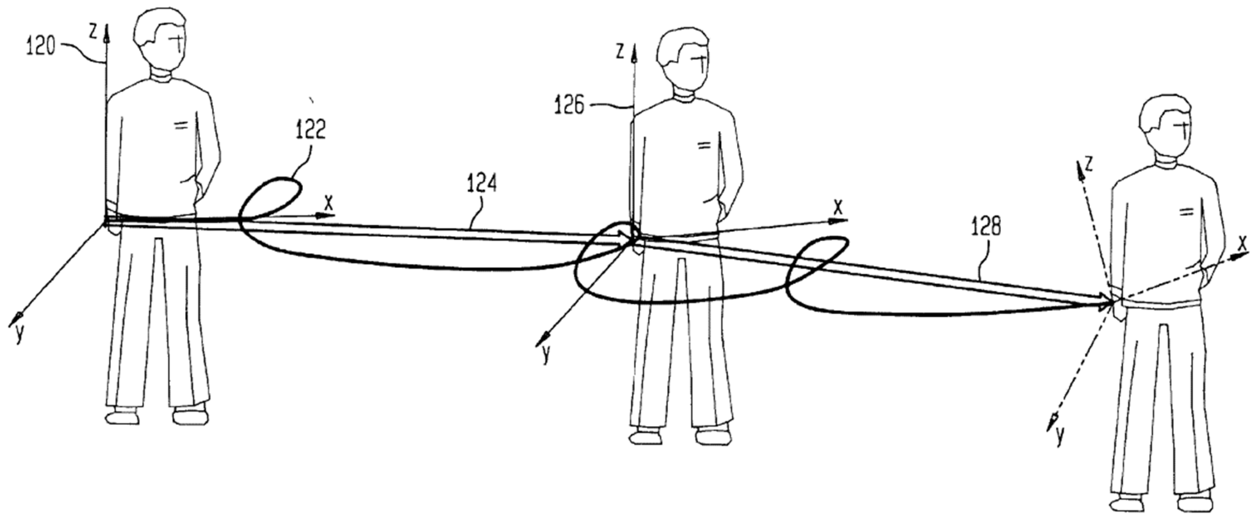
FIG. 15

Ono, FIG. 15

2. Overview of Hutchings

58. Hutchings describes "a device for measuring the performance of a runner [that] utilizes accelerometers and rotational sensors to measure the speed, distance traveled, and height jumped of a person." APPLE-1102, 3:5-8. In Hutchings, "a measuring system 10" may be located at the wrist of the user, as shown in FIG. 7 reproduced below. APPLE-1102, 3:32-44, 4:7-26, 10:43-51, FIGS. 7-9.

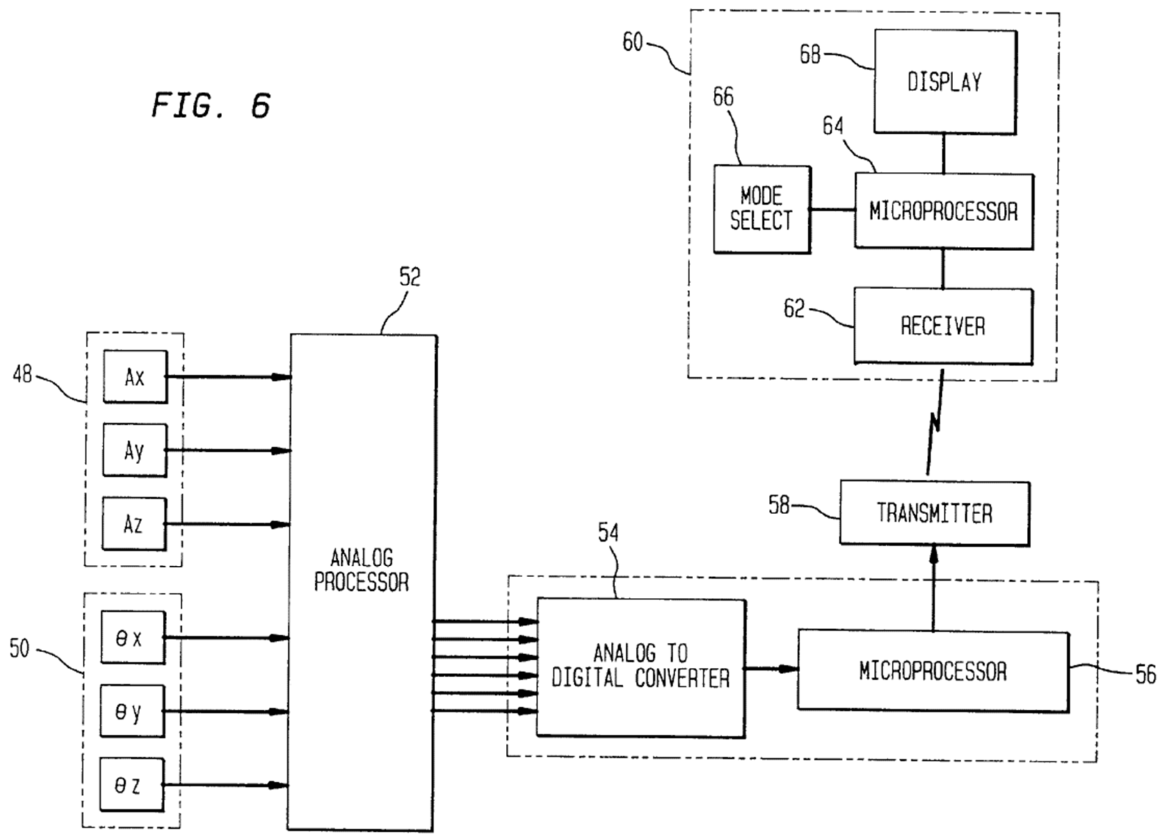
FIG. 7



Hutchings, FIG. 7

59. Hutchings' measuring system includes linear accelerometers to measure accelerations in three dimensions, rotational sensors to provide the angle of rotation along each axis of the translational coordinate, and a microprocessor to measure distance traveled during each cycle. APPLE-1102, 4:21-32, 4:55-65, 5:3-16, 8:44-9:17, 9:48-10:42, FIGS. 6-7. A block diagram of an example of Hutchings' device is shown in FIG. 6, reproduced below. APPLE-1102, 4:4-6.

FIG. 6



Hutchings, FIG. 6

60. With respect to FIG. 6, Hutchings describes that analog processor 52 determines the components of motion in the reference frame and the angle from the vertical coordinate, and measures instantaneous acceleration of the device along the reference coordinates during each cycle. APPLE-1102, 7:5-65, 8:61-64, 9:62-65, 10:43-12:14. Alternately, the analog processor 52 may employ an analog to digital converter and a microprocessor to determine the components of motion. APPLE-1102, 9:1-7. Microprocessor 56 measures the distance L traversed during each cycle by integrating the acceleration signals. APPLE-1102, 9:13-17, 9:65-67, 12:15-37. Microprocessor 64 maintains the running elapse time, calculates the distance traversed by summing the length of all steps taken, and calculates the instantaneous and average speed of the user. APPLE-1102, 10:10-14. "The running elapsed time, the distance traversed and the speed may be selectively displayed on display 68. These values may also be stored in a non-volatile memory (not shown) associated with microprocessor 64 for virtually an indefinite period of time." APPLE-1102, 10:14-18.

61. Hutchings explains that "many modifications and variations" to the device are possible, such as "all electronic components [being] disposed" at the same location of a user's body, in which case "there may be no desire for a transmitter and receiver circuit." APPLE-1102, 10:31-37. As further examples of modifications, Hutchings describes that "processor 52 may process the received signals digitally by employing an analog to digital converter and a microprocessor," "the output terminals of units 48 and 50 may be coupled directly to a microprocessor 56, via an analog to digital converter 54," "analog to digital converter 54 may be part of microprocessor 56," "[i]t may also be possible to combine the functions performed by microprocessors 56 and 64 into one microprocessor," and "it is also possible to combine the functions performed by signal processor 52, and microprocessors 56 and 64 into one such microprocessor." APPLE-1102, 9:10-12, 10:37-42.

3. Ono-Hutchings Combination

62. A POSITA would have been motivated and would have found it obvious to implement Ono's device with a measuring system that includes accelerometers to measure accelerations in three dimensions, and rotational sensors to provide the angle of rotation along each axis of the translational coordinate, and a microprocessor to calculate distance traveled during each cycle, as suggested by Hutchings. APPLE-1102, 4:21-32, 4:55-65, 5:3-16, 8:44-9:17, 9:48-12:37, FIGS. 6-7. Further, to the extent that Ono's control section 49 were considered to not be a microprocessor, a POSITA would have found it obvious to implement Ono's control section 49 using a microprocessor that performs the functions of Ono's control section 49 and the functions of Hutchings' microprocessor 64, as suggested by Hutchings. APPLE-1102, 10:10-14, 10:31-37. The block diagram below shows an example of Ono's device that includes Hutchings' measuring system and a microprocessor as control section 49.

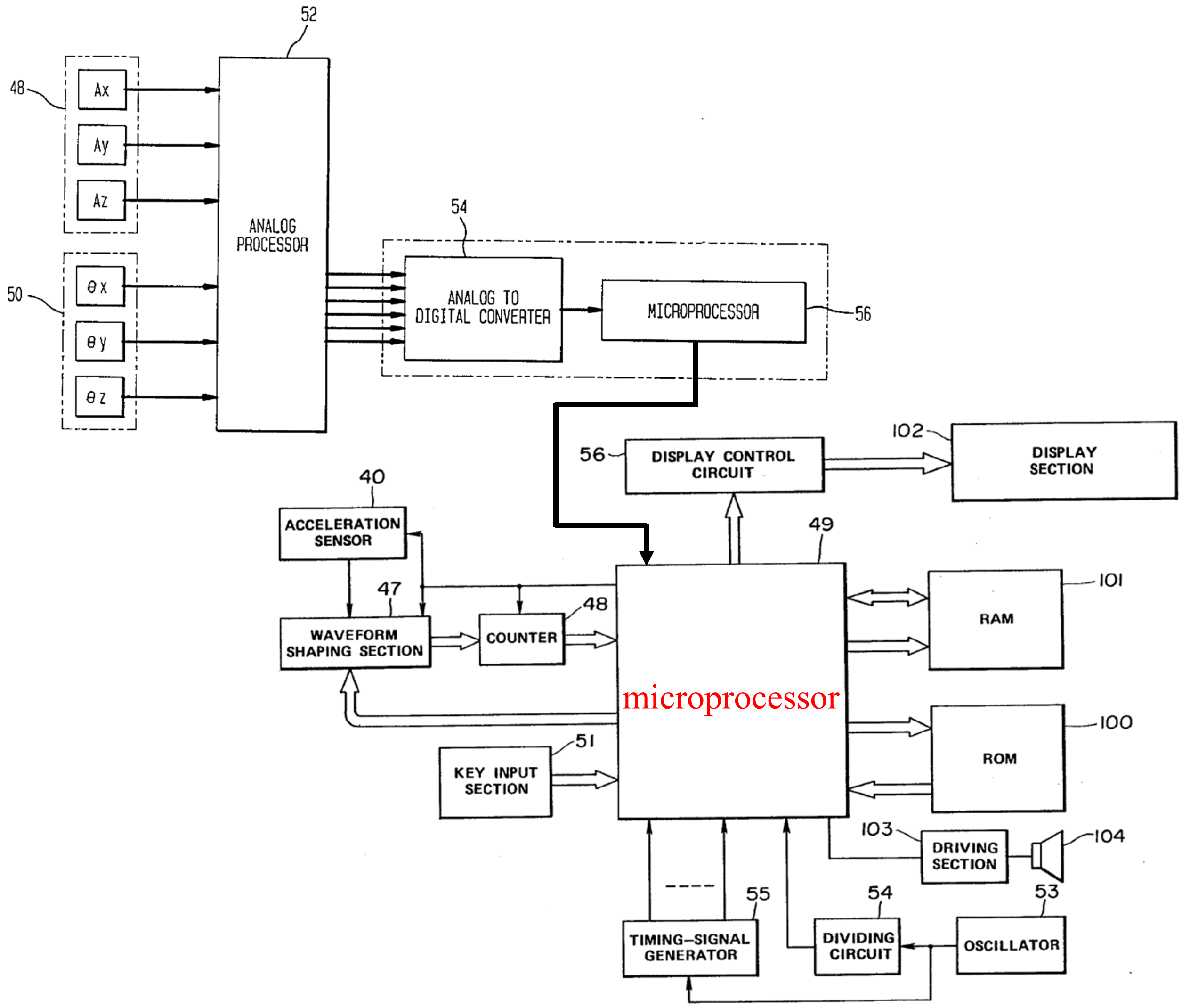


FIG.14

Ono's FIG. 14 device modified in view of Hutchings[3]

63. In pursuing specific design options for such a device, the POSITA would have explored prior art references like Hutchings that describe movement measuring devices that are also worn on the user's wrist and are expressly directed to improving pedometer devices like Ono's that "count the number of steps taken

[3] Annotations and color are added to the figures unless otherwise noted.

and for a particular stride length, the approximate distance traversed can be determined." APPLE-1102, 1:60-64, 3:32-44, 4:7-26, 10:43-51, FIGS. 7-9; APPLE-1101, 15:61-66, 14:1-15, FIG. 18 (step a_{16}). Hutchings explains that "stride length... is different for each person and will vary for different speeds of running," and "[i]t is, therefore, a difficult task to determine the correct stride length for an individual runner at various speeds," and thus "pedometer measurements are only useful as an approximation of distance traversed." APPLE-1102, 2:15-31. The POSITA would have been motivated to use Hutchings' measuring system to leverage the stated benefits of providing "accurate measurements" of speed and distance traversed without manually setting stride lengths for different exercise modes. APPLE-1102, 2:45-61; APPLE-1101, 13:40-42, 18:28-19:6.

64. The POSITA would have also been motivated to use Hutchings' measuring system for the benefit of providing the user with different options for obtaining measurements of speed and distance based on the user's desire in accuracy and battery conservation. *Id*. Hutchings describes a mode select switch that a user depresses to use Hutchings' measuring system to calculate speed and distance. APPLE-1102, 9:48-10:18. A POSITA would have found obvious to turn off Hutchings' measuring system to conserve battery when Hutchings' measuring system is not being used. *See, e.g.,* APPLE-1106, 8:12-18; APPLE-1014, 7:40-44, 9:46-49, 16:10-15; APPLE-1010, 4:20-25. The user is advantageously provided the option to select between accurate distance/speed/velocity measurements using Hutchings' measuring system at the expense of higher battery consumption or less accurate distance/speed/velocity measurements using Ono's calculations for the benefit of lower battery consumption. *Id*.

65. Moreover, a POSITA would have viewed the implementation of Ono's device in a manner that applied Hutchings' suggested measuring system as merely the predictable result (e.g., a pedometer that includes accelerometers to measure accelerations in three dimensions, rotational sensors to provide the angle of rotation along each axis of the translational coordinate, and microprocessors to calculate the speed and distance traveled during each cycle) of combining known prior elements according to known methods. The POSITA would have appreciated that the Ono-Hutchings combination does not change the hallmark aspects of either of these references, and any modifications needed to incorporate Hutchings' teachings into Ono's device to provide the above benefits would have been predictable with a foreseeable chance of success and within the skill of a POSITA. The respective teachings would work together in combination just as they did apart, with Hutchings' suggestion merely improving/adding to Ono's device.

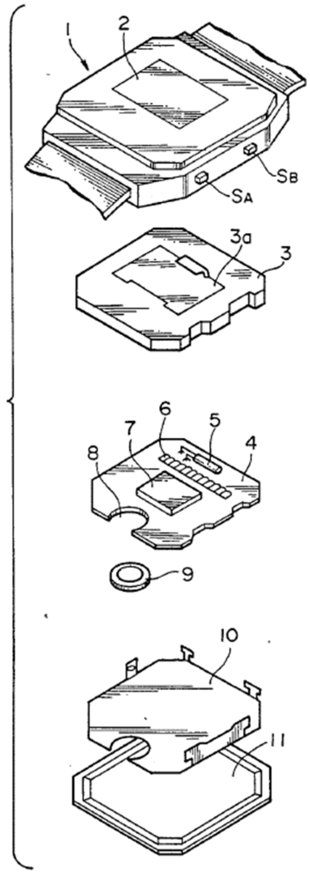
4. Analysis of Claims 1, 3-5, 8, 10, 30, 39, 41, 42, and 61-65

a) Claim 1

[1pre] A portable, self-contained device for monitoring movement of body parts during physical activity, said device comprising:

66. To the extent the preamble is limiting, Ono describes a portable, self-contained device for monitoring movement of body parts during physical activity. Ono describes "an exercise measuring instrument in which exercise in walking, jogging, running, and the like is measured utilizing an acceleration sensor." APPLE-1101, 1:5-10. Ono's exercise measuring instrument is implemented as "an electronic wrist watch to which a pedometer is installed," includes a battery, is "to be worn on a body of an exerciser," and "made compact in size." APPLE-1101, 3:10-11, 2:1-4, 2:22-26, 3:24-26, FIG. 1. An exploded perspective view of an example of Ono's device is shown in FIG. 1, reproduced below. APPLE-1101, 2:30-32, 3:10-11.

FIG. 1



Ono, FIG. 1

[1a] a movement sensor capable of measuring data associated with unrestrained movement in any direction and generating signals indicative of said movement;

67. Ono's device includes "an acceleration sensor... for outputting a waveform signal representative of an acceleration which is received by said acceleration sensor in response to movements of said exerciser." APPLE-1101, 2:1-7, 3:10-4:13, 5:64-6:1, 6:41-48, 7:20-27, 7:61-68, 8:16-42, 8:58-60, 13:18-29. Ono describes that "when the user of the device wears the electronic wrist watch... on his or her wrist and walks or runs moving his or her wrist up and down,... the acceleration sensor 5 vibrates." APPLE-1101, 3:49-4:9. "The output signal of the acceleration sensor 40 is applied to a waveform-shaping section 47 and the waveform-shaping section 47 shapes the output signal of the acceleration sensor 40 into a pulse signal having a square waveform. The pulse signal outputted from the waveform-shaping section 47 is counted by a counter 48 and the count data is supplied to a control section 49." APPLE-1101, 8:60-67. "The control section 49 calculates the number of steps on the basis of the count data delivered from the counter 48." APPLE-1101, 9:5-7. Ono's acceleration sensor 40, waveform-shaping section 47, and counter 48 form a movement sensor that measures data and generates signals indicative of movement.

68. If Ono's movement sensor were considered to not be capable of measuring data associated with unrestrained movement in any direction, Ono-Hutchings yields a device including accelerometers to measure accelerations in three dimensions and rotational sensors to provide the angle of rotation along each axis of the translational coordinate. APPLE-1102, 3:22-26 ("One set of three-component linear accelerometers and one set of three-component rotational sensors may be employed to resolve the absolute motion of a person..."), 4:44-6:54, 8:44-59, 9:59-10:2, FIG. 6; *supra* Section VI.A.3; *infra* Ground 1, claim 5. "Each accelerometer may convert the measured acceleration into a corresponding signal, which may be preferably employed by microprocessor 6 to accomplish movement measurements." APPLE-1102, 5:9-12. "Each rotational sensor converts the measured angle into a corresponding signal, which is employed by a microprocessor 6 to calculate information related to the user's movements, such as user's speed, distance traveled and the height jumped." APPLE-1102, 4:60-65.

69. Hutchings further discloses that "unit 48 may preferably contain the linear accelerometers employed to measure accelerations... in three dimensions." APPLE-1102, 8:49-55. "Unit 50 may preferably contain rotational sensors employed to... provide the angle of rotation along each axis of the translational coordinate. The output terminals of units 48 and 50 are coupled to input terminals of a processor 52." APPLE-1102, 8:56-61. Processor 52 determines the components of motion in the reference frame and the angle from the vertical coordinate, and measures instantaneous acceleration of the device along the reference coordinates during each cycle. APPLE-1102, 7:5-65, 8:61-64, 9:62-65, 10:43-12:14. Microprocessor 56 measures the distance L traversed during each cycle by integrating the acceleration signals. APPLE-1102, 9:13-17, 9:65-67, 12:15-37.

70. Hutchings' measuring system forms a movement sensor capable of measuring data associated with unrestrained movement in any direction and generating signals indicative of the movement. For the reasons previously discussed, a POSITA would have been motivated and would have found it obvious to implement Ono's device with an improved multi-axis acceleration and rotation measuring system such as in Hutchings to leverage the stated benefits of providing "accurate measurements" of speed and distance traversed without manually setting stride lengths for different exercise modes. *Supra* Section VI.A.3; APPLE-1102, 2:45-61; APPLE-1101, 13:40-42, 18:28-19:6.

71. In accordance with the construction of "movement sensor" discussed in Section V.C, the block diagram below shows an example of a device with a movement sensor (enclosed in red) that includes Ono's acceleration sensor 40, waveform-shaping section 47, and counter 48, and Hutchings' measuring system:

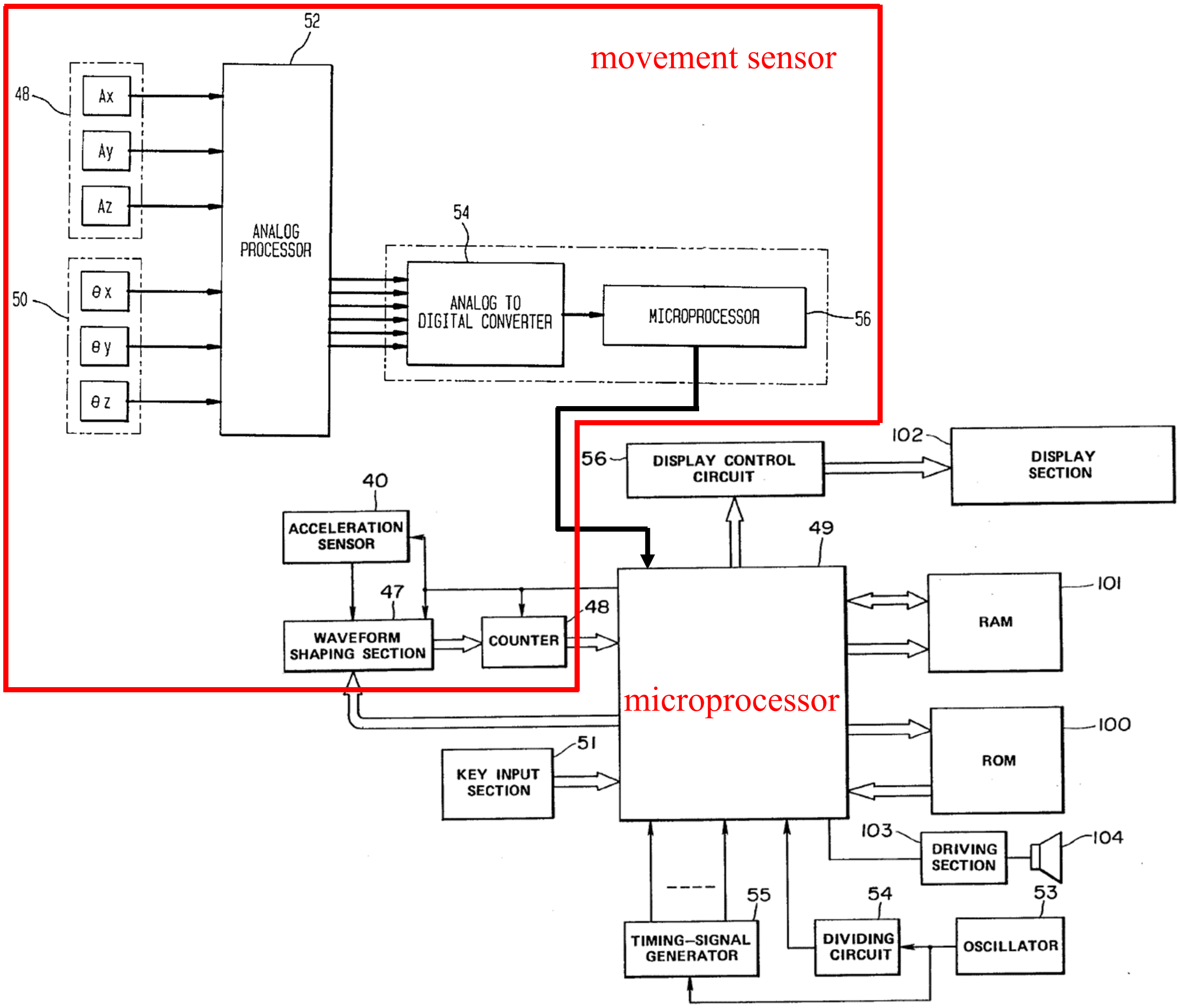
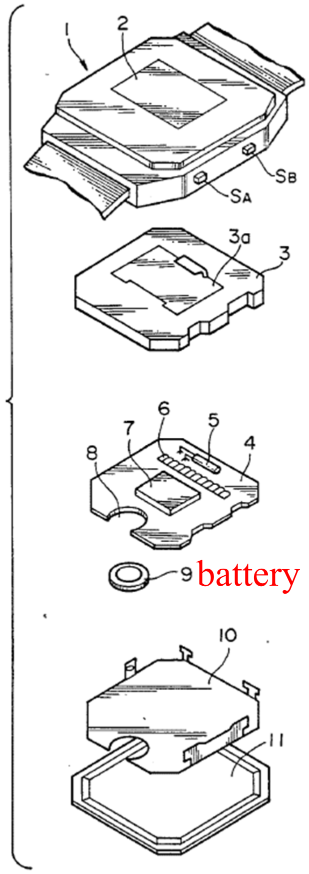


FIG.14

Ono's FIG. 14 device modified in view of Hutchings

[1b] a power source;

72. Ono's device includes a "circuit board 4 [that] is formed with a battery receiving portion 8 where a battery 9 is accommodated." APPLE-1101, 3:24-26. As shown in FIG. 1 below, Ono's device includes battery 9. APPLE-1101, FIG. 9. A POSITA would have understood or at least found obvious that battery 9 is a power source for Ono's device.



Ono, FIG. 1

[1c] a microprocessor connected to said movement sensor and to said power source,

73. Ono discloses that "[o]n the circuit board 4 are mounted an acceleration sensor 5 and a LSI [large-scale integration circuit/chip] 7" and "the circuit board 4 is formed with a battery receiving portion 8 where a battery 9 is accommodated." APPLE-1101, 3:18-26. Ono further discloses that battery is consumed "while the instrument is not turned off and is left turned on to operate" for counting the number of steps while the user is exercising. APPLE-1101, 14:30-64. Ono further describes a "control section 49 compris[ing] a CPU" (central processing unit) that "reads out from ROM 50 a micro-programme stored in the ROM 50 to operate the present system when the operator inputs a system-start signal" and "executes processes in accordance with the micro-programme", including calculating the number of steps, number of steps per minute (walking pitches), mean walking speed, and distance-walked based on the acceleration sensor signal and the stride-length data corresponding to the exercise mode previously set through the key-input section 51. APPLE-1101, 8:60-9:12, 12:17-35, 14:44-45, 15:10-13, 15:33-46, 15:61-66, 17:26-34.

74. Based on Ono's teachings regarding the operations that are executed by the control section 49 and the depiction of the input/output connections to control section 49 in FIG. 14, a POSITA would have understood that Ono used the phrase "control section" to describe a conventional microprocessor structure that was ubiquitous in such devices at the time. Indeed, this fact is confirmed by Ono's disclosure that the control section 49 must read out a micro-programme stored in the ROM and execute processes in accordance with the micro-programme. APPLE-1101, 8:60-9:12, 13:22-23. Based upon my knowledge and experience in this field and my review of these above-cited characteristics taught by Ono, a POSITA would have understood that Ono referred to the control section in the device in a manner that was interchangeable with the conventional microprocessor-controlled structure used in such devices—a typical usage at the time as corroborated by other publications. *See, e.g.,* APPLE-1010, 6:54-63, FIG. 6; APPLE-1102, 4:21-32; APPLE-1107, 16:35-38, FIG. 9; APPLE-1108, FIG. 6; APPLE-1109, FIG. 3, 8:35-9:44; APPLE-1110, FIG. 1, 7:33-36, 8:39-40; APPLE-1111, 12:13-21, FIGS. 11, 17. I refer to these other publications here merely for purposes of corroborating this common background knowledge recognizable to a POSITA at the time. For at least these reasons, Ono described a conventional microprocessor structure in the device.

75. Alternatively, even if Ono's teachings of a "control section" were considered to not expressly disclose the "microprocessor" recited in this element, other publications confirm that such microprocessors were implemented in such devices at that time for controlling operations—as demonstrated in Hutchings. Hutchings discloses that its measuring system includes "interrelated elements such as linear accelerometers; rotational sensors; a microprocessor to calculate distance and height of each step;... a battery...." APPLE-1102, 4:21-32. Hutchings describes a microprocessor 64 that operates a "run mode sequence" where it maintains the running elapse time, calculates the distance traversed by summing the length of all steps taken, and calculates the instantaneous and average speed of the user. APPLE-1102, 10:10-14. "The running elapsed time, the distance traversed and the speed may be selectively displayed on display 68. These values may also be stored in a non-volatile memory (not shown) associated with microprocessor 64 for virtually an indefinite period of time." APPLE-1102, 10:14-18. "In the watch mode, microprocessor 64 selectively provides to display 68, normal watch functions such as time of day, date, an alarm signal when a preselected time occurs." APPLE-1102, 10:28-30.

76. As discussed above, Ono-Hutchings yields a device including the movement sensor that generates signals that are used by a microprocessor to calculate information related to the user's movements. *Supra* Section VI.A.3; *supra* Ground 1, [1a]. Based on Ono's and Hutchings' teachings, a POSITA would have found obvious that the Ono-Hutchings' device further includes a battery that is consumed while the device is operating to measure and calculate movement information while the user is exercising. A POSITA would have recognized that the microprocessor, which calculates movement information, is connected to the battery which supplies power for operation of the microprocessor. *See, e.g.,* APPLE-1107, 16:35-38, FIG. 9; APPLE-1010, 6:54-63, FIG. 6; APPLE-1108, FIG. 6; APPLE-1109, FIG. 3, 8:35-9:44; APPLE-1110, FIG. 1, 7:33-36, 8:39-40; APPLE-1111, 12:13-21, FIGS. 11, 17.

77. As discussed above, a POSITA would have understood that Ono's control section is a microprocessor, or would have used a microprocessor to implement the described functions of the control section as suggested by Hutchings. Accordingly, the block diagram below shows an example of the Ono-Hutchings' device including a microprocessor connected to the movement sensor and the battery:

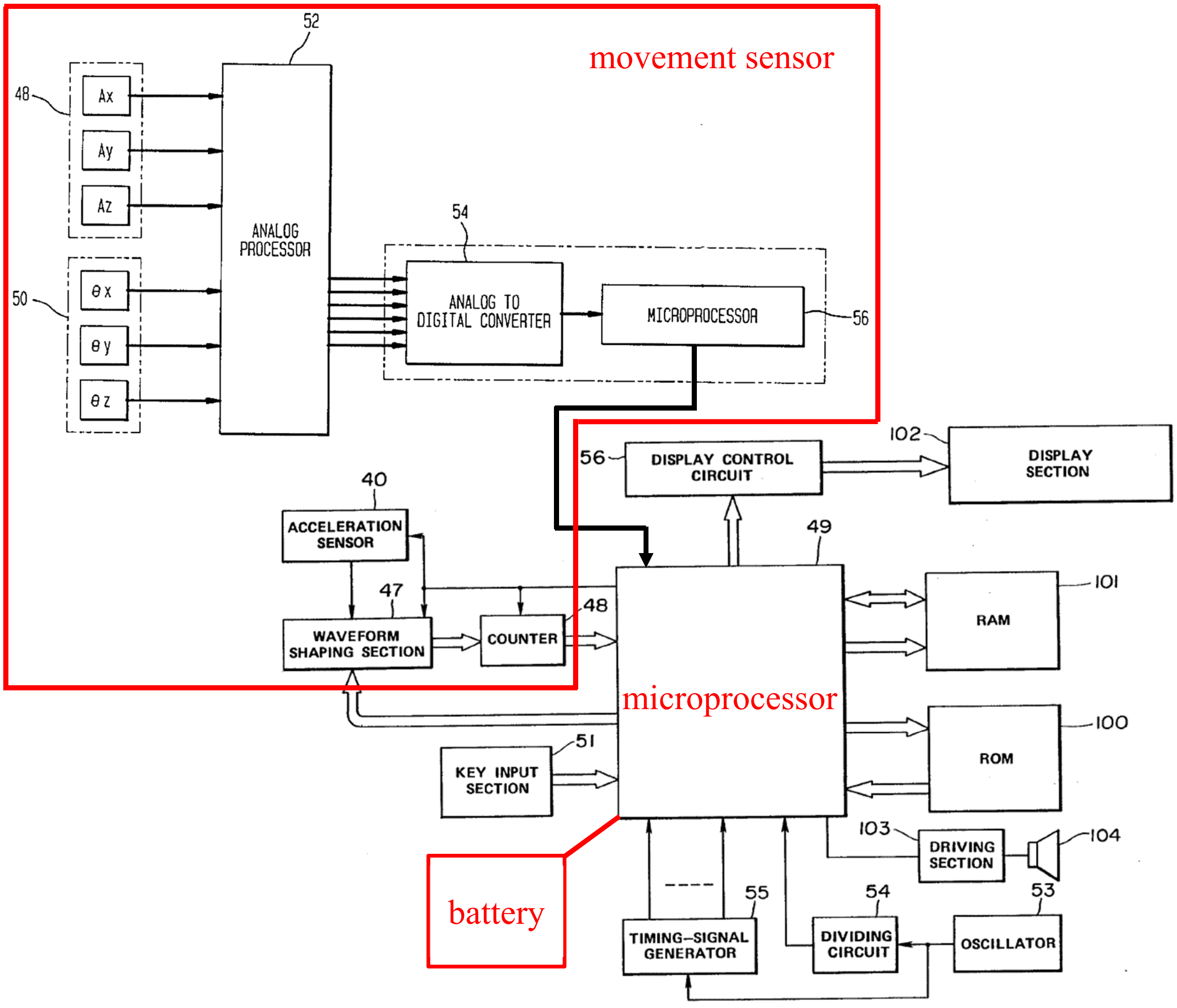


FIG.14

Ono's FIG. 14 device modified in view of Hutchings

[1d] said microprocessor capable of receiving, interpreting, storing and responding to said movement data based on user-defined operational parameters,

78. Ono's device includes a "key-input section 51 compris[ing] switches S_1 to S_6." APPLE-1101, 13:25-27. The switches allow a user to select one of five display modes: (1) time-display mode, (2) step-counting mode, (3) present data display mode, (4) data-recall mode, and (5) data-setting mode. APPLE-1101, 13:34-42, 13:55-57, 16:18-17:23, 19:18-67, FIGS. 20-21. The switches also allow the user to select one of three exercising modes: (1) walking mode, (2) exercising-walking mode, and (3) jogging mode. APPLE-1101, 13:51-57, 18:14-19, 18:67-19:6. In the step-counting mode, switch S_2 functions to start and/or stop the step-counting operation. APPLE-1101, 17:24-50. In the data-setting mode, the switches allow the user to set a stride length for each of the three exercising modes, sex, age, weight, and target numbers. APPLE-1101, 13:40-42, 13:55-61, 18:28-19:17, 20:8-15, FIGS. 20-21. A POSITA would have found obvious that, in addition to target number of steps and target calorie consumption, the switches allow the user to set target distance that the device stores in register OH and uses to "discriminate[] whether or not the distance-walked has reached the target distance OH." *Id.*; APPLE-1101, 15:61-16:4.

79. The selected display mode is stored in mode register M of RAM 101 as follows: "M=0 is set when a time-display mode is selected, M=1 is set when a step-counting mode is selected, M=2 is set when a display-mode is selected for displaying number of steps, a distance-walked, a mean speed, calorie consumption, M=3 is set when a display-mode is selected for displaying various data of each date and M=4 is set when a data-setting mode is selected." APPLE-1101, 13:30-

42. A "register S also is a flag which is set at '1' in the step-counting mode." APPLE-1101, 13:44-45. "A register N serves as a register for storing numerals corresponding to the exercise mode set by the user, such as the walking mode, the exercise-walking mode or the jogging mode." APPLE-1101, 13:51-54. "Stride-length registers W1, W2 and W3 are registers for storing stride-lengths set in the walking, exercise walking or jogging mode, respectively. Registers OG, OH and OI serve to store a target number of steps, a target distance and target calorie consumption." APPLE-1101, 13:55-61. Ono's FIG. 15 (below) illustrating the registers of RAM 101 is highlighted to show the registers that are set based on user input:

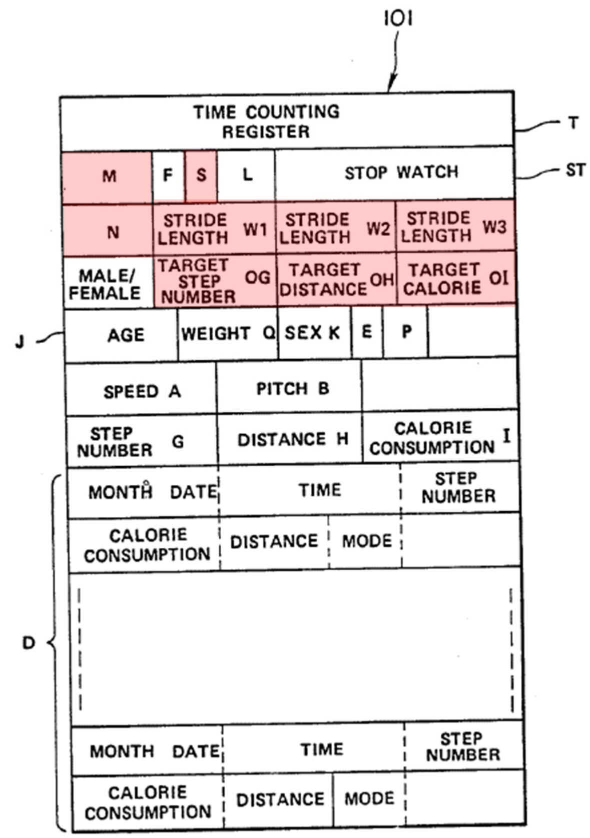


FIG. 15

Ono, FIG. 15

80. As illustrated in Ono's FIG. 18, only when register S=1, which is set when the user selects and has started the step-counting mode, the processor performs the following operations every 10 seconds:

Step	Operation
a_{10}	obtains/receives the number of steps taken in the last 10 seconds
a_{11}	calculates a mean walking speed from the stride-length corresponding to the exercise mode and the number of steps taken, and

	stores the mean walking speed at the register A
a_{12}	calculates pitches per minute (number of steps/minute), and stores it at the register B
a_{13}	calculates the calorie consumption and stores it at register I
a_{14}	discriminates whether or not the calorie consumption I has reached the target calorie consumption OI which has previously been set
a_{15}	causes an alarm sound to be generated if the calorie consumption I has reached the target calorie consumption OI
a_{16}	calculates distance-walked from the stride length and the number of steps taken, adds the calculated distance-walked to the value stored in the distance-walked register H, and stores the sum at the distance-walked register H
a_{17}	"discriminate[s] whether or not the distance-walked has reached the target distance OH"
a_{18}	causes an alarm sound to be generated "if the distance-walked has reached the target distance OH"
a_{19}	adds the number of steps taken to the value of the step register G to obtain the accumulative number of steps taken

a_{20}	"discriminate[s] whether or not the accumulative number of steps has reached the target number of steps OG"
a_{21}	causes an alarm sound to be generated "[i]f the above accumulative number of steps has reached the target number of steps OG"
a_{24}	causes "various data obtained in the step-counting mode" to be displayed

APPLE-1101, 8:57-9:14, 13:18-29, 13:44-45, 14:65-16:27, FIG. 18. The number of steps taken in the last 10 seconds, mean walking speed, steps/minute, distance-walked, and accumulative number of steps taken collectively form movement data that the microprocessor receives, interprets, stores, and responds to. *Id.*

81. As highlighted in Ono's FIG. 18 below, the processor receives (step a_{10}), interprets/analyzes (steps a_{11}, a_{12}, a_{16}, a_{17}, a_{19}, a_{20}), stores (steps a_{11}, a_{12}, a_{16}, a_{19}), and responds to (steps a_{18}, a_{21}, a_{24}) movement data when the user has selected and started the step-counting mode. *Id*. Additionally, the processor interprets/analyzes (steps a_{11}, a_{16}, a_{17}) and responds to (step a_{18}, a_{24}) movement data based on the exercise mode and the stride length previously set by the user. *Id.*; APPLE-1101, 13:40-42, 13:51-61, 18:28-19:17, 20:8-15, FIGS. 20-21. Further, the processor interprets/analyzes (steps a_{16}, a_{17}, a_{20}) and responds to (steps a_{18}, a_{21}) movement data based on the target distance OH and the target number of steps OG previously set by the user. *Id*. When the user stops the step-counting mode operation which sets register S=0, the processor stores the date, duration, total step count, total distance-walked, and total calorie-consumption in registers D of RAM 101 for later retrieval and display in the data-recall mode. APPLE-1101, 13:65-14:29, 16:24-25, 17:10-50, 18:20-24, 20:37-53, FIGS. 15, 20 (steps C_{14}-C_{15}), 23. The modes, the step-counting start/stop, the stride lengths, the target distance, and the target number of steps set by the user are user-defined operational parameters that affect the operations performed by the device. APPLE-1101, 13:44-61, 14:65-16:27; APPLE-1001, 7:6-16, 8:56-10:23, FIG. 5.

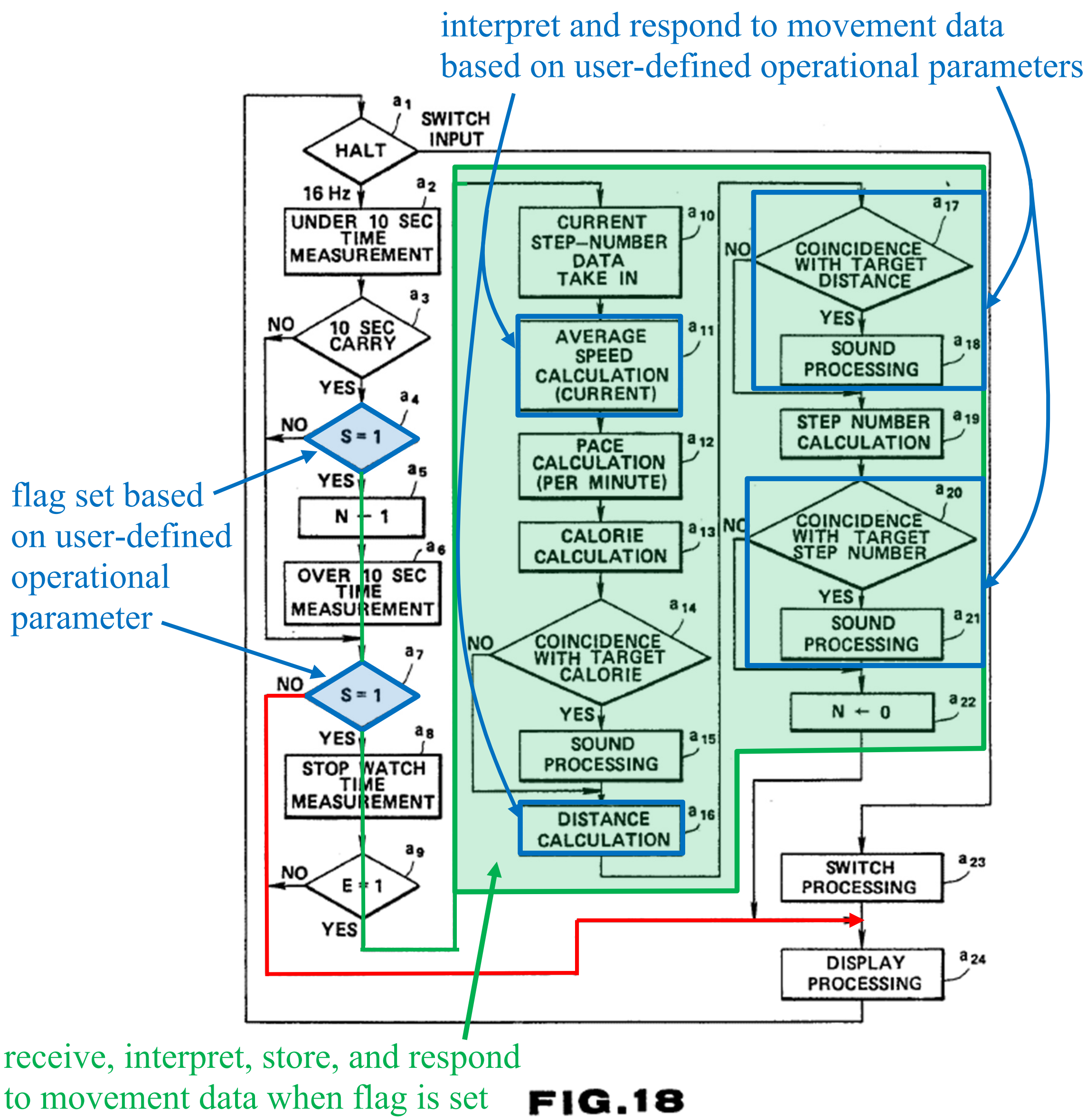


FIG.18

Ono, FIG. 18

82. Similarly, Hutchings describes that "[m]ode select unit 66 is employed at the start of the run or jog by depressing an appropriate switch... which is coupled to microprocessor 64...." APPLE-1102, 9:49-52. When the switch is not depressed and the device is "[i]n the watch mode, microprocessor 64 selectively provides to display 68, normal watch functions such as time of day, date, an alarm signal when a preselected time occurs." APPLE-1102, 10:28-30. When the switch is depressed, the device performs "a run mode sequence" where the accelerometer "unit 48 generates acceleration signals along the translational coordinates" and "[r]otational sensors contained in unit 50 begin to track the rotation of the [sensors] along the translational coordinate system." APPLE-1102, 9:48-62. "Each accelerometer may convert the measured acceleration into a corresponding signal, which may be preferably employed by microprocessor 6 to accomplish movement measurements." APPLE-1102, 5:9-12. "Each rotational sensor converts the measured angle into a corresponding signal, which is employed by a microprocessor 6 to calculate information related to the user's movements, such as user's speed, distance traveled...." APPLE-1102, 4:60-65. "The output terminals of units 48 and 50 are coupled to input terminals of a processor 52." APPLE-1102, 8:59-61. Processor 52 determines the components of motion in the reference frame and the angle from the vertical coordinate, and measures instantaneous acceleration of the device along the reference coordinates during each cycle. APPLE-1102, 7:5-65, 8:61-64, 9:62-65, 10:43-12:14. Microprocessor 56 measures the distance L traversed during each cycle by integrating the acceleration signals. APPLE-1102, 9:13-17, 9:65-67, 12:15-37.

83. Microprocessor 64 maintains the running elapse time, calculates the distance traversed by summing the length of all cycles, and calculates the instantaneous and average speed of the user. APPLE-1102, 10:10-14. Hutchings discloses that "[t]he total distance traveled is the sum of distances for all cycles. The velocity of travel is the distance of the cycle, or several cycles, divided by the time it takes to travel this distance." APPLE-1102, 10:47-11:3, 11:41-44, 12:15-38. "The running elapsed time, the distance traversed and the speed may be selectively displayed on display 68. These values may also be stored in a non-volatile memory (not shown) associated with microprocessor 64 for virtually an indefinite period of time." APPLE-1102, 10:14-18.

84. A POSITA would have found obvious that the microprocessor receives signals from the measuring system and calculates the total distance traveled, speed, and the velocity of travel when the mode select switch has been depressed by the user to select the run mode. APPLE-1102, 9:48-10:30; *see, e.g.,* APPLE-1106, 8:12-18; APPLE-1014, 7:40-44, 9:46-49, 16:10-15; APPLE-1010, 4:20-25. The distance traversed during each cycle, total distance, speed, and velocity collectively form movement data that the microprocessor receives, interprets, stores, and responds to. *Id.* Hutchings' run mode selected by the user is a user-defined operational parameter that affects the operations performed by the device. *Id.*; APPLE-1001, 7:6-16, 8:56-10:23, FIG. 5.

85. Based on Ono's and Hutchings' teachings discussed above, Ono-Hutchings yields a device that allows a user to define operational parameters, including selection of run mode, step-counting mode, step-counting mode start/stop, and exercise mode, and setting of stride lengths, target distance, and target number of steps. APPLE-1101, 13:25-27, 13:34-42, 13:51-61, 15:61-16:4, 16:18-17:50, 18:14-19, 18:28-19:67, 20:8-15, FIGS. 20-21; APPLE-1102, 9:49-52, 10:28-30, 9:48-62. When the user selects and starts the step-counting mode, the microprocessor receives movement data, including the number of steps taken in the last 10 seconds (as suggested by Ono's step a_{10}), interprets/analyzes movement data (as suggested by Ono's steps a_{11}, a_{12}, a_{16}, a_{17}, a_{19}, a_{20}), stores movement data (as suggested by Ono's steps a_{11}, a_{12}, a_{16}, a_{19}), and responds to movement data (as suggested by Ono's steps a_{18}, a_{21}, a_{24}). *Id.*; APPLE-1101, 13:44-45, 14:65-16:27, FIG. 18. Additionally, in the step-counting mode, the microprocessor interprets/analyzes (as suggested by Ono's steps a_{11}, a_{16}, a_{17}) and responds to (as suggested by Ono's step a_{18}, a_{24}) movement data based on the exercise mode and the stride length previously set by the user. *Id.*; APPLE-1101, 13:40-42, 13:51-61, 18:28-19:17, 20:8-15, FIGS. 18, 20-21. Further, in the step-counting mode, the microprocessor interprets/analyzes (as suggested by Ono's steps a_{17}, a_{20}) and responds to (as suggested by Ono's steps a_{18}, a_{21}) movement data based on the target distance OH and the target number of steps OG previously set by the user. *Id.*; APPLE-1101, 15:47-16:13. When the user stops the step-counting mode operation, the microprocessor stores the date, duration, total step count, total distance-walked, and total calorie-consumption in registers D of RAM 101 for later retrieval and display in the data-recall mode. APPLE-1101, 13:65-14:29, 16:24-25, 17:10-50, 18:20-24, 20:37-53, FIGS. 15, 20 (steps C_{14}-C_{15}), 23.

86. When the user has set the device to run mode, the microprocessor receives movement data, including distance traversed during a cycle from the measuring system (as suggested by Hutchings), interprets/analyzes movement data (as suggested by Ono's steps a_{11}, a_{16} and as suggested by Hutchings' calculation of the total distance traveled, speed, and the velocity of travel), stores movement data (as suggested by Ono's steps a_{11}, a_{16}), and responds to movement data (as suggested by Ono's step a_{18}, a_{24}). APPLE-1101, 13:44-45, 14:65-16:27, FIG. 18; APPLE-1102, 9:49-10:18. In the run mode, the microprocessor interprets/analyzes (as suggested by Ono's step a_{17}) and responds to (as suggested by Ono's step a_{18}) movement data from Hutchings' measuring system based on the target distance OH previously set by the user. *Id.*; APPLE-1101, 13:40-42, 13:55-61, 18:28-19:17, 20:8-15, FIGS. 20-21. When the user stops the run mode, the microprocessor stores the date, duration, total step count, total calorie-consumption, total distance traveled, speed, and velocity in registers D of RAM 101 for later retrieval and display in the data-recall mode. APPLE-1101, 13:65-14:29, 16:24-25, 17:10-50, 18:20-24, 20:37-53, FIGS. 15, 20 (steps C_{14}-C_{15}), 23; APPLE-1102, 10:14-18.

87. As previously discussed, a POSITA would have been motivated and would have found it obvious to implement Ono's device with a measuring system such as Hutchings to advantageously provide the user with the option to select between accurate distance/speed/velocity measurements using Hutchings' measuring system at the expense of higher battery consumption or less accurate distance/speed/velocity measurements using Ono's calculations for the benefit of lower battery consumption. *Supra* Section VI.A.3; APPLE-1102, 2:45-61; APPLE-1101, 13:40-42, 18:28-19:6; *see, e.g.,* APPLE-1106, 8:12-18; APPLE-1014, 7:40-44, 9:46-49, 16:10-15; APPLE-1010, 4:20-25.

[1e] detecting a first user-defined event based on the movement data and at least one of the user-defined operational parameters regarding the movement data, and

88. As discussed above, Ono-Hutchings yields a device in which the microprocessor interprets/analyzes (as suggested by Ono's steps a_{17}) and responds to (as suggested by Ono's step a_{18}, a_{24}) movement data based on user selection and starting of the step-counting mode, user selection of the exercise mode, and the user set stride length and target distance OH. *Supra* Ground 1, 1[d]; APPLE-1101, 13:40-42, 13:51-61, 15:47-16:13, 18:28-19:17, 20:8-15, FIGS. 18, 20-21. Additionally, the microprocessor interprets/analyzes (as suggested by Ono's step a_{20}) and responds to (as suggested by Ono's step a_{21}, a_{24}) movement data based on user selection and starting of the step-counting mode and based on the target number of steps OG previously set by the user. *Id*. Further, the microprocessor interprets/analyzes (as suggested by Ono's step a_{17}) and responds to (as suggested by Ono's step a_{18}, a_{24}) movement data from Hutchings' measuring system based on user selection of the run mode and based on the target distance OH previously set by the user. *Id.*; APPLE-1102, 9:48-10:18.

89. In the Ono-Hutchings device, the microprocessor detects a user-defined event (that "the distance-walked has reached the target distance OH" as suggested by Ono's step a_{18}) based on movement data (the distance-walked) and at least one of the user-defined operational parameters regarding the movement data (user selection and starting of the step-counting mode, user selection of the exercise mode, and user set stride length and target distance OH). APPLE-1101, 13:40-42, 13:51-61, 15:47-16:13, 18:28-19:17, 20:8-15, FIGS. 18, 20-21. Additionally, the microprocessor detects a user-defined event (that the "accumulative number of steps has reached the target number of steps OG" as suggested by Ono's step a_{21}) based on movement data (accumulative number of steps) and at least one of the user-defined operational parameters regarding the movement data (user selection and starting of the step-counting mode and user set target number of steps OG). *Id*. Further, the microprocessor detects a user-defined event (that "the distance-walked has reached the target distance OH" as suggested by Ono's step a_{18}) based on movement data (total distance traveled) and at least one of the user-defined operational parameters regarding the movement data (user selection of the run mode and user set target distance OH). *Id.*; APPLE-1102, 9:49-67.

90. As highlighted in Ono's FIG. 18 below, the microprocessor interprets/analyzes movement data based on user-defined operational parameters (as suggested by each of Ono's steps a_{17} and a_{20}), and detects a user-defined event based on the movement data and at least one of the user-defined operational parameters regarding the movement data (as suggested by Ono's steps a_{17}, a_{18}, and steps a_{20}, a_{21}):

interpret movement data based on
user-defined operational parameters and
detect a user-defined event
based on the movement data and
the user-defined operational parameters

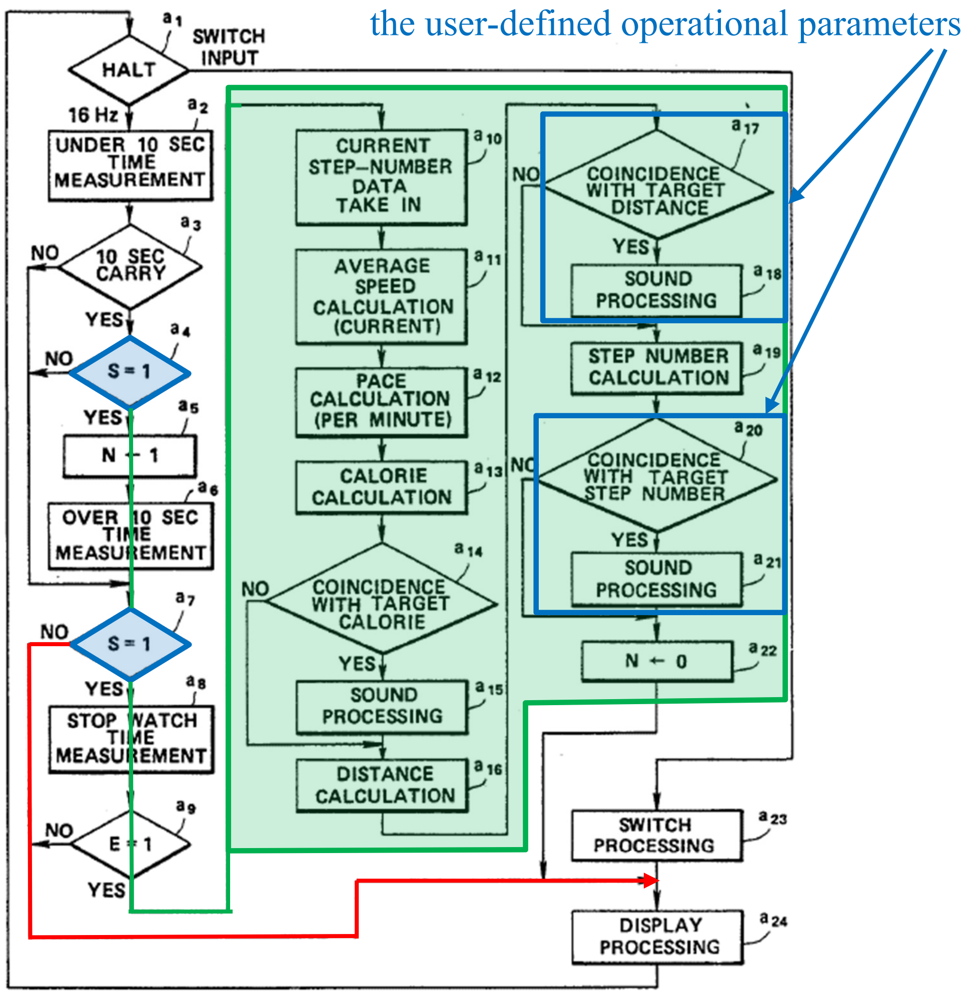


FIG.18

Ono, FIG. 18

[1f] storing first event information related to the detected first user-defined event along with first time stamp information reflecting a time at which the movement data causing the first user-defined event occurred;

91. As previously discussed, the user set modes, stride lengths, target distance, and target number of steps are user-defined operational parameters that affect the operations and calculations performed by the Ono-Hutchings device. *Supra* Ground 1, [1d]; APPLE-1101, 13:44-61, 14:65-16:27. These user-defined operational parameters are stored in registers of RAM as suggested by Ono's FIG. 15. *Id.*

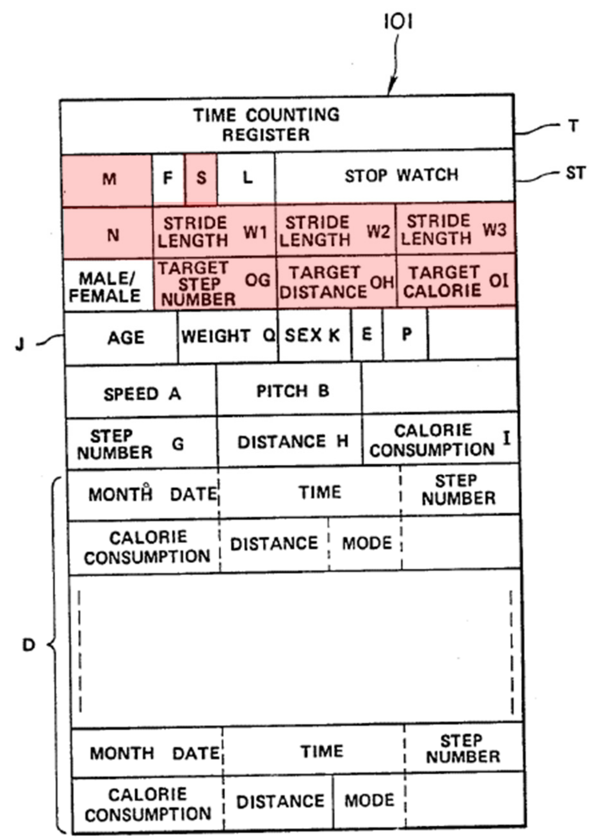


FIG. 15

Ono, FIG. 15

92. Also as previously discussed, the microprocessor interprets/analyzes movement data based on these user-defined operational parameters (as suggested by each of Ono's steps a_{17} and a_{20}), and detects a user-defined event based on the movement data and at least one of these user-defined operational parameters regarding the movement data (as suggested by Ono's steps a_{17}, a_{18}, and steps a_{20}, a_{21}). *Supra* Ground 1, [1e]; APPLE-1101, 13:44-45, 14:65-16:27, FIG. 18; APPLE-1102, 9:49-67. In addition, the microprocessor stores movement data (as suggested by Ono's steps a_{11}, a_{12}, a_{16}, a_{19}) related to the detected user-defined event. APPLE-1101, 13:44-45, 14:65-16:27, FIG. 18; APPLE-1102, 10:16-18. Ono's steps a_{11}, a_{12}, a_{16}, a_{19} that store movement data and the steps a_{17}, a_{18}, a_{20}, a_{21} that detect a user-defined event are illustrated in Ono's FIG. 18 below:

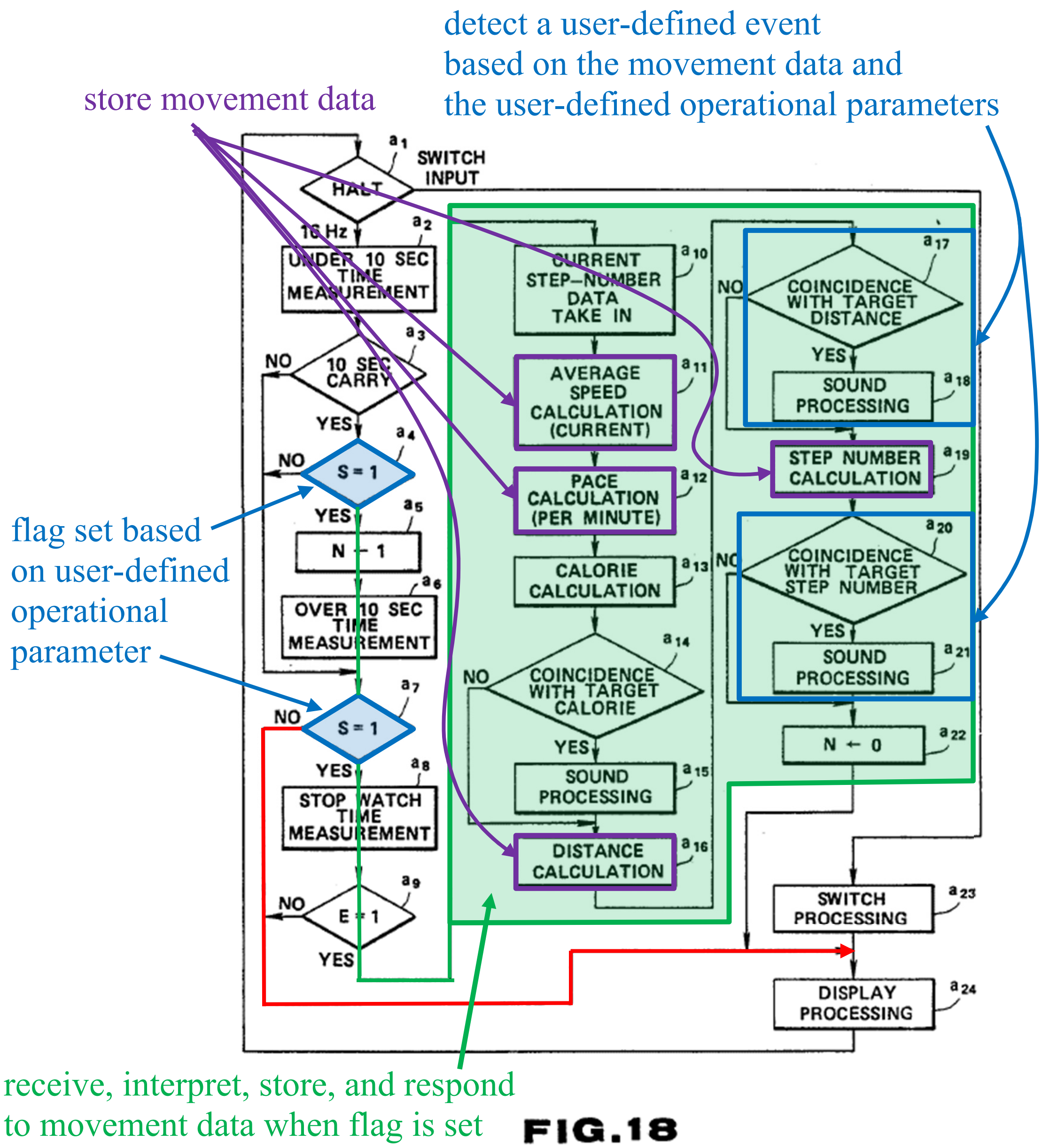


FIG.18

Ono, FIG. 18

93. Ono's processor stores movement data of steps a_{11}, a_{12}, a_{16}, a_{19} into RAM 101, which includes "[r]egisters A and B... for storing walking speeds and walking pitches calculated from number of steps taken" and "[a] step-register G, a distance-walked register H... for storing accumulative number of steps taken, accumulative distance walked." APPLE-1101, 13:65-14:15, 14:65-16:27, FIG. 15. As highlighted in Ono's FIG. 15 below, Ono suggests storing in RAM the user-defined operational parameters and the movement data used to detect the user-defined event, both of which are related to the detected user-defined event and thus are each event information related to the detected user-defined event. APPLE-1101, 13:44-14:15, 14:65-16:27; *supra* Ground 1, [1e].

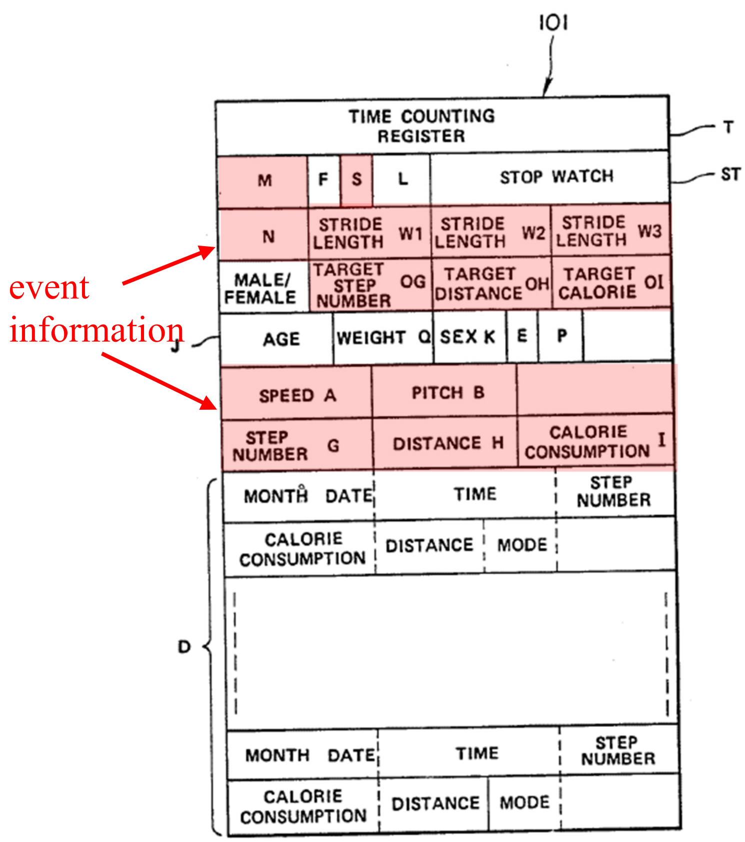


FIG. 15

Ono, FIG. 15

94. Ono further suggests storing time stamp information in RAM along with the event information: "RAM 101 is provided with a time-counting register T for storing the present-time data" and "a time-counting process is executed to count the present time... and renews the time-counting register in RAM." APPLE-1101, 13:31-33, 12:10-12. With respect to Ono's FIG. 18, Ono describes the time-counting process as step a_2 and the detection of a user-defined event based on the movement data and at least one of these user-defined operational parameters regarding the movement data as steps a_{17}, a_{18}, a_{20}, a_{21} as shown below. APPLE-1101, 15:1-5 ("the process advances to Step a_2 to effect a time-counting process in unit of 10 sec or less with respect to the present time."). Thus, Ono determines and stores the present time data at which the movement data causing the user-defined event occurred. *Infra* Ground 1, claim 30.

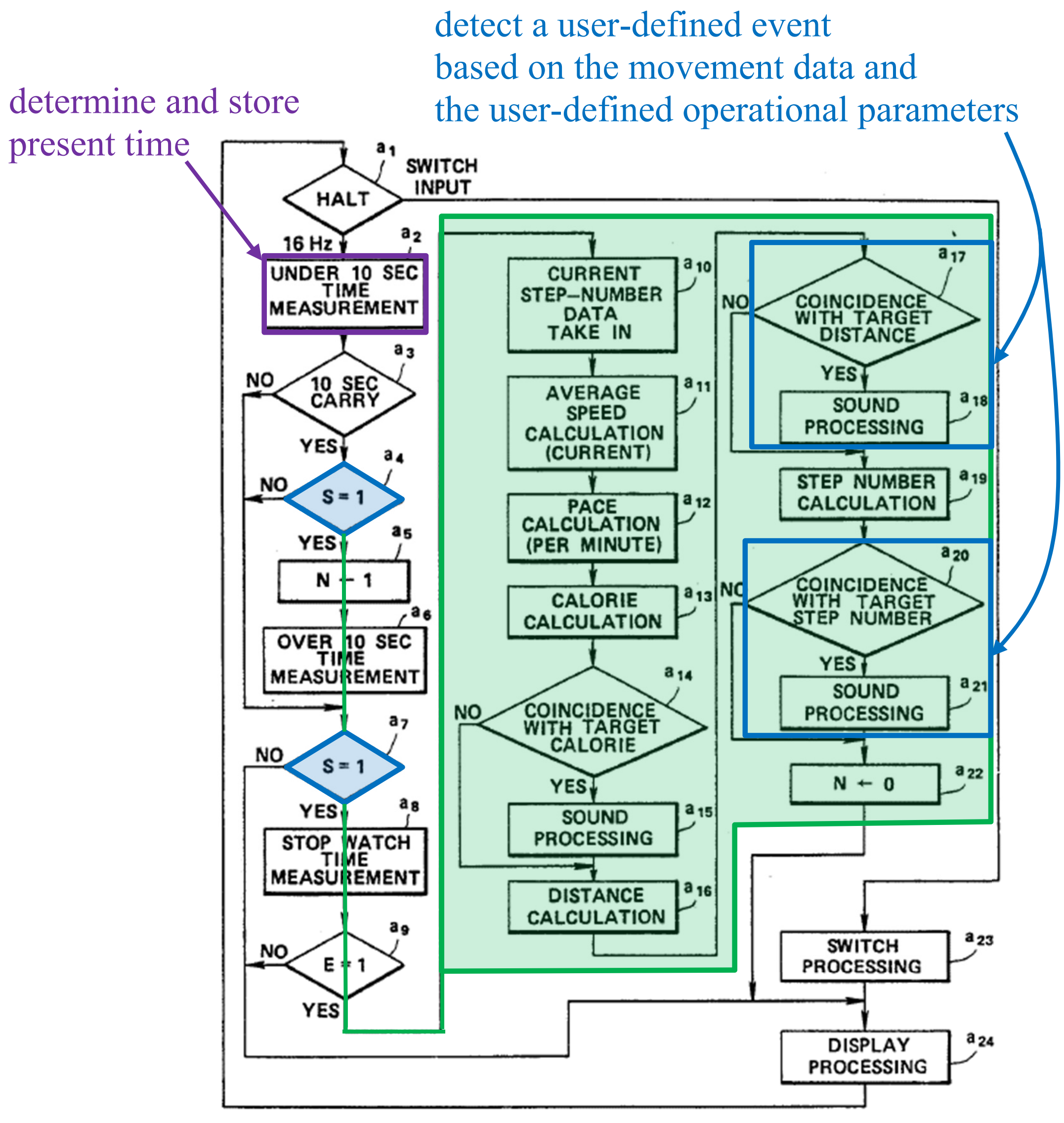


FIG.18

Ono, FIG. 18

95. As highlighted in Ono's FIG. 15 below, Ono suggests storing in RAM the event information related to the detected user-defined event along with the present time data at which the movement data causing the user-defined event occurred. APPLE-1101, 13:44-14:15, 14:65-16:27.

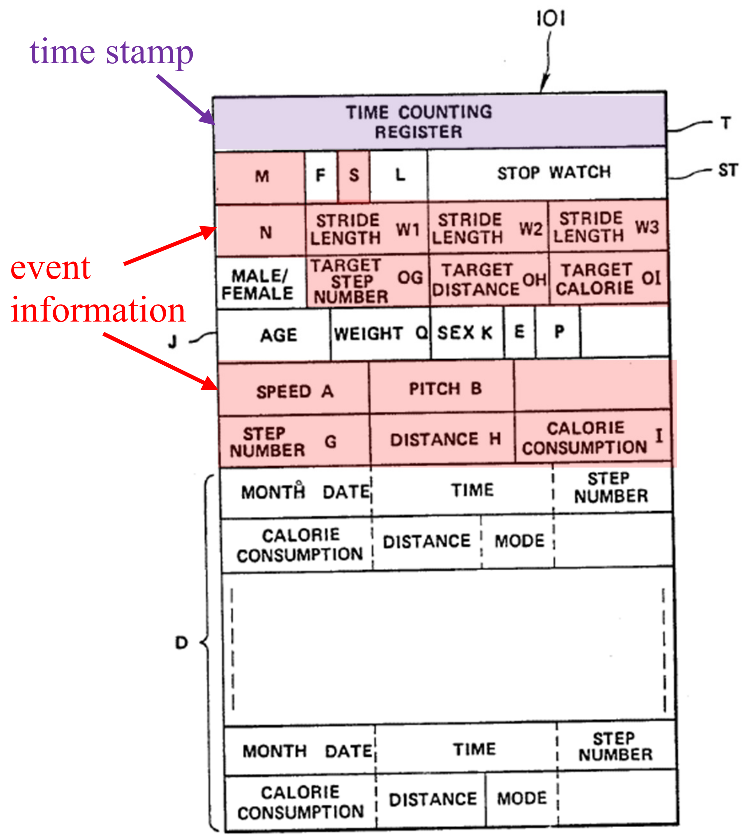


FIG. 15

Ono, FIG. 15

96. Ono supports instances where the user stops the step-counting mode operation using switch S_2 after the processor detects that "the distance-walked has reached the target distance OH" and/or that the "accumulated number of steps has reached the target number of steps OG" (user-defined event) and notifies the user by generating the alarm sound, as highlighted by the red path in FIGS. 18 and 20 below. APPLE-1101, 16:28-37, 17:3-59, FIGS. 18, 20.

detect a user-defined event
based on the movement data and
the user-defined operational parameters

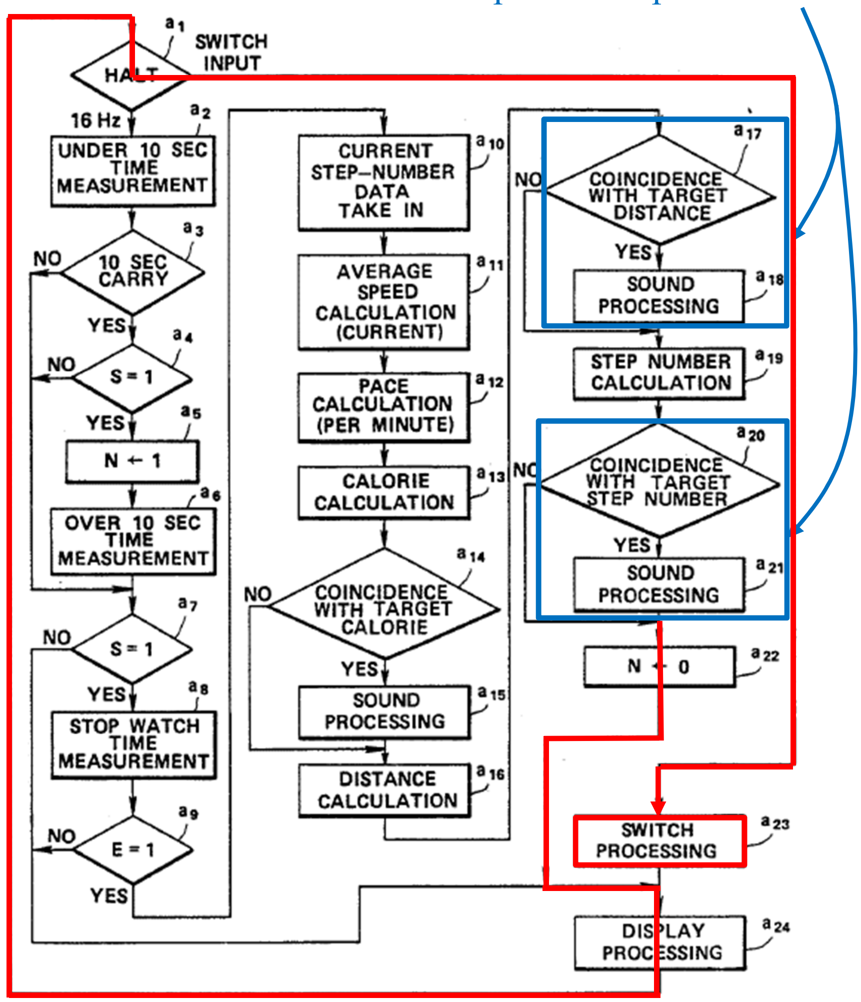


FIG.18

Ono, FIG. 18

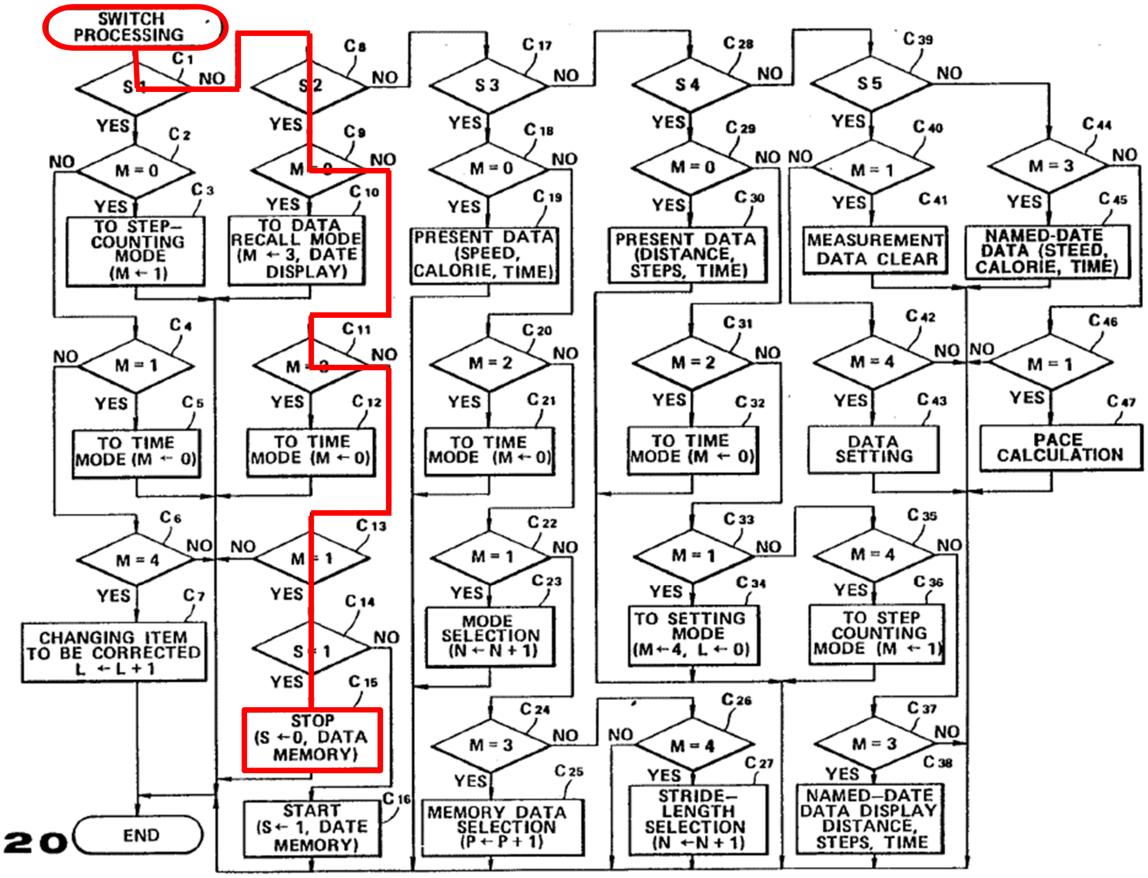


FIG.20

Ono, FIG. 20

97. As previously discussed, when the user stops the step-counting mode operation of the Ono-Hutchings device, the microprocessor stores the date, duration, total step count, total distance-walked, and total calorie-consumption in registers D of RAM 101 for later retrieval and display in the data-recall mode. APPLE-1101, 13:65-14:29, 16:24-25, 17:10-50, 18:20-24, 20:37-53, FIGS. 15, 20 (steps C_{14}-C_{15}), 23; *supra* Ground 1, [1d]. Additionally, when the user stops the run mode of the Ono-Hutchings device, the microprocessor stores the date, duration, total step count, total calorie-consumption, total distance traveled, speed, and velocity in registers D of RAM 101 for later retrieval and display in the data-recall mode. *Id.*; APPLE-1102, 10:14-18.

98. Based on Ono's and Hutchings' teachings, a POSITA would have found obvious that, in the instance where the user stops the step-counting or run mode after the microprocessor detects that "the distance-walked has reached the target distance OH" and/or that the "accumulative number of steps has reached the target number of steps OG" (user-defined event) and notifies the user by generating the alarm sound, the microprocessor stores at least the date, duration, total step count, total distance-walked, and calorie-consumption in registers D of RAM 101 for later retrieval and display in the data-recall mode. *Id*. In such instance, the date, duration, total step count, total distance-walked, and calorie-consumption stored in registers D would be related to the detected user-defined event, with the total step count, total distance-walked, and calorie-consumption being the event information related to the detected user-defined event, and the date and duration being time stamp information reflecting a time at which the movement data causing the first user-defined event occurred. *Id.*

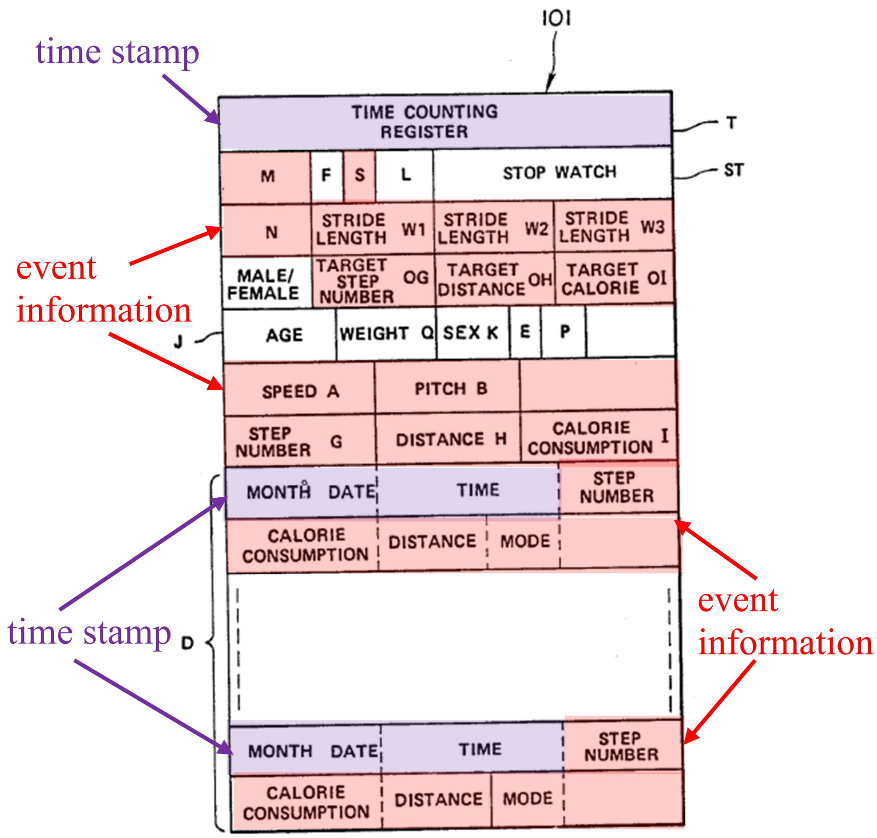
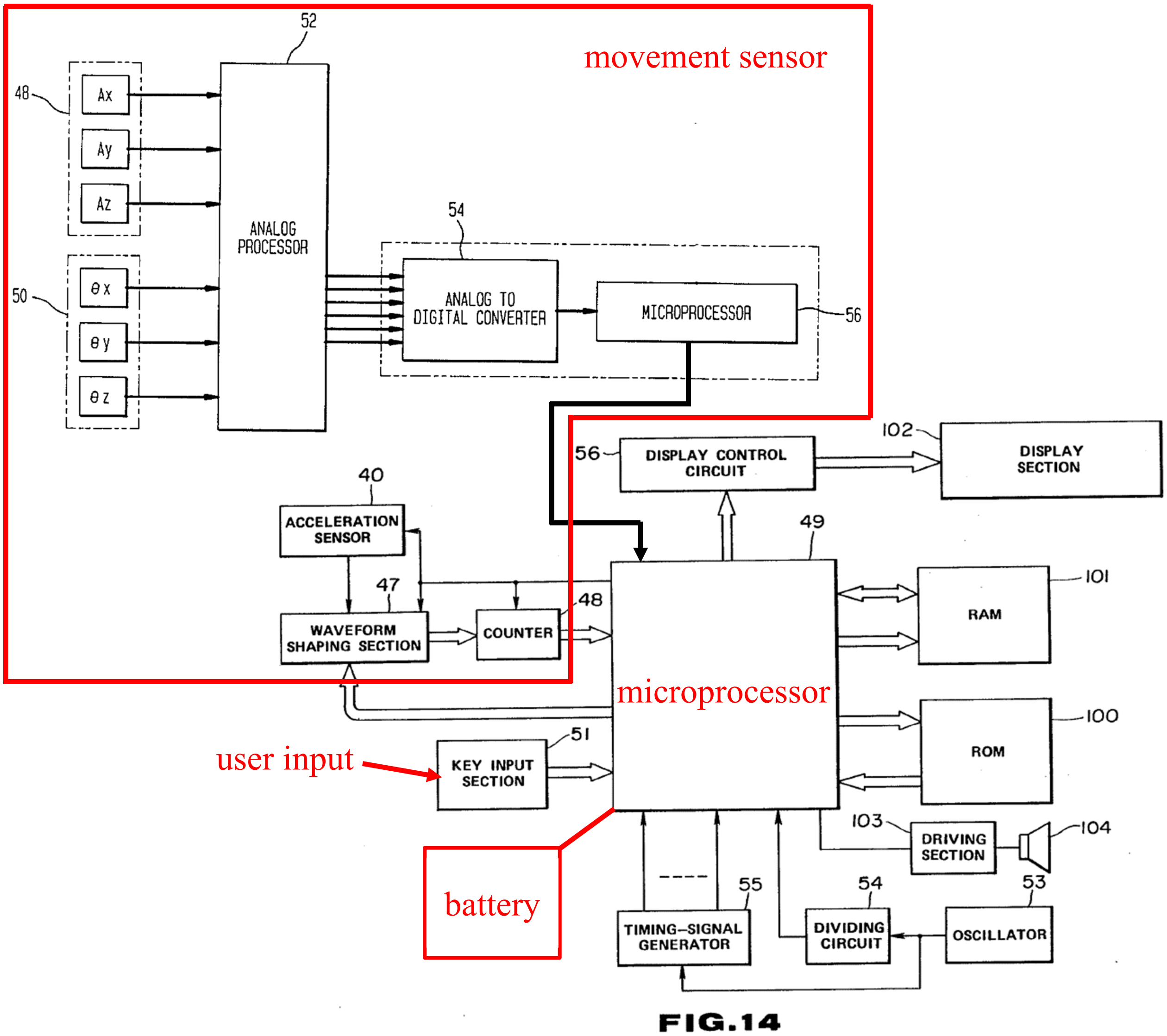


FIG. 15

Ono, FIG. 15

[1g] at least one user input connected to said microprocessor for controlling the operation of said device;

99. Ono-Hutchings renders [1g] obvious for similar reasons as discussed in Ground 1, [1d]. *Supra* Ground 1, [1d]. The block diagram below shows an example of the Ono-Hutchings' device including key input section 51 (a user input) connected to the microprocessor for controlling the operation of the device:

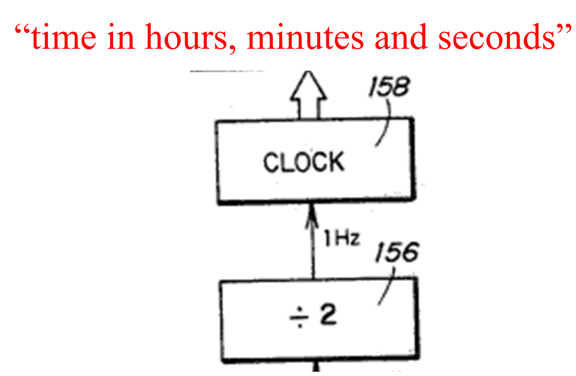


Ono's FIG. 14 device modified in view of Hutchings

[1h] a real-time clock connected to said microprocessor;

100. Ono's device includes an oscillator circuit 53 and a dividing circuit 54 that provide a one hertz signal to the processor for obtaining "time-data, i.e., the present-time data comprising minute-data, hour-data, date-data and month-data," and the processor stores the time-data at a register of RAM. APPLE-1101, 9:14-31. Based upon my knowledge and experience in this field, instead of relying on the processor to determine the time data from the one Hz signal, a POSITA would have found it obvious to consider implementing the Ono-Hutchings device with a discrete, external real-time clock connected to the microprocessor for obtaining "time-data, i.e., the present-time data comprising minute-data, hour-data, date-data and month-data," which was typical at the time as corroborated by other publications.

101. For example, Lowrey describes a "runners watch... worn on the wrist of the wearer." APPLE-1112, 3:14-21. As shown in Lowrey's FIG. 5, Lowrey's watch includes a "divider 156 which provides a 1 Hz signal to a clock 158" that provides "the time in hours, minutes and seconds in a conventional manner." APPLE-1112, 8:21-30, 2:8-13. A POSITA would have understood that the "clock 158" described by Lowrey is a Real Time Clock, based on the description provided by Lowrey as a device which receives a 1 Hz signal and provides the time in hours, minutes and seconds.



Lowrey, FIG. 5 (cropped, annotated)

In addition to the real time clock, Lowrey's watch also includes "[a] sensor... to detect the strides of the wearer" and "[c]ircuitry... to compute the rate of travel of the wearer in response to the sensor." APPLE-1112, 2:8-18. Lowrey describes options for implementing the "clock circuitry" and other circuitry in the watch including using "[a] variety of different types of circuits" or implementing "the functions... in a microprocessor chip." APPLE-1112, 8:32-41. A POSITA with such knowledge at the time would have found it obvious to implement the Ono-Hutchings device such that the dividing circuit 54 provides the one hertz signal to clock circuitry, which functions as a real-time clock by determining and providing the time data to the microprocessor. *See, e.g.,* APPLE-1103, 16:43-47, 20:38-43, 21:53-59, 26:29-58, 28:13-34, 30:19-22, FIG. 1.

102. A POSITA would have been motivated to achieve the benefit of using a real-time clock to provide the current clock time to the microprocessor, thereby advantageously reducing the calculations that are performed by the microprocessor and conserving power to the system when there are no processing tasks for the microprocessor. *See, e.g.,* APPLE-1009, 9:59-67 (describing using multiple clocks, including a real-time clock, "reaping the low power benefits of intermittent operation"), 10:66-11:8 (describing de-energizing circuits "when there are no postprocessing tasks" "in order to conserve power in the system"). A POSITA would have understood that the Ono-Hutchings device was readily available to be implemented using the predictable technology of a conventional real-time clock without significantly altering or hindering the functions performed by the Ono-Hutchings device. *Id.*

[1i] memory for storing said movement data; and

103. Ono-Hutchings renders [1i] obvious for similar reasons as discussed in Ground 1, [1d] and [1f]. *Supra* Ground 1, [1d] and [1f]. An example of the Ono-Hutchings device shown below includes a RAM 101, which is a memory, that stores movement data (as suggested by Ono's FIG. 18 steps a_{11}, a_{12}, a_{16}, a_{19} and FIG. 20 step C_{15}), which includes at least "[r]egisters A and B... for storing walking speeds and walking pitches calculated from number of steps taken," "[a] step-register G, a distance-walked register H... for storing accumulative number of steps taken, accumulative distance walked," and "a data register D comprising a plurality of memory areas where counted data of each date such as a time duration of walking, number of steps taken... are stored" (as suggested by Ono's FIG. 15). APPLE-1101, 13:18-20, 13:30-31, 13:65-14:20, 14:65-16:27, 20:37-53; FIGS. 15, 18.

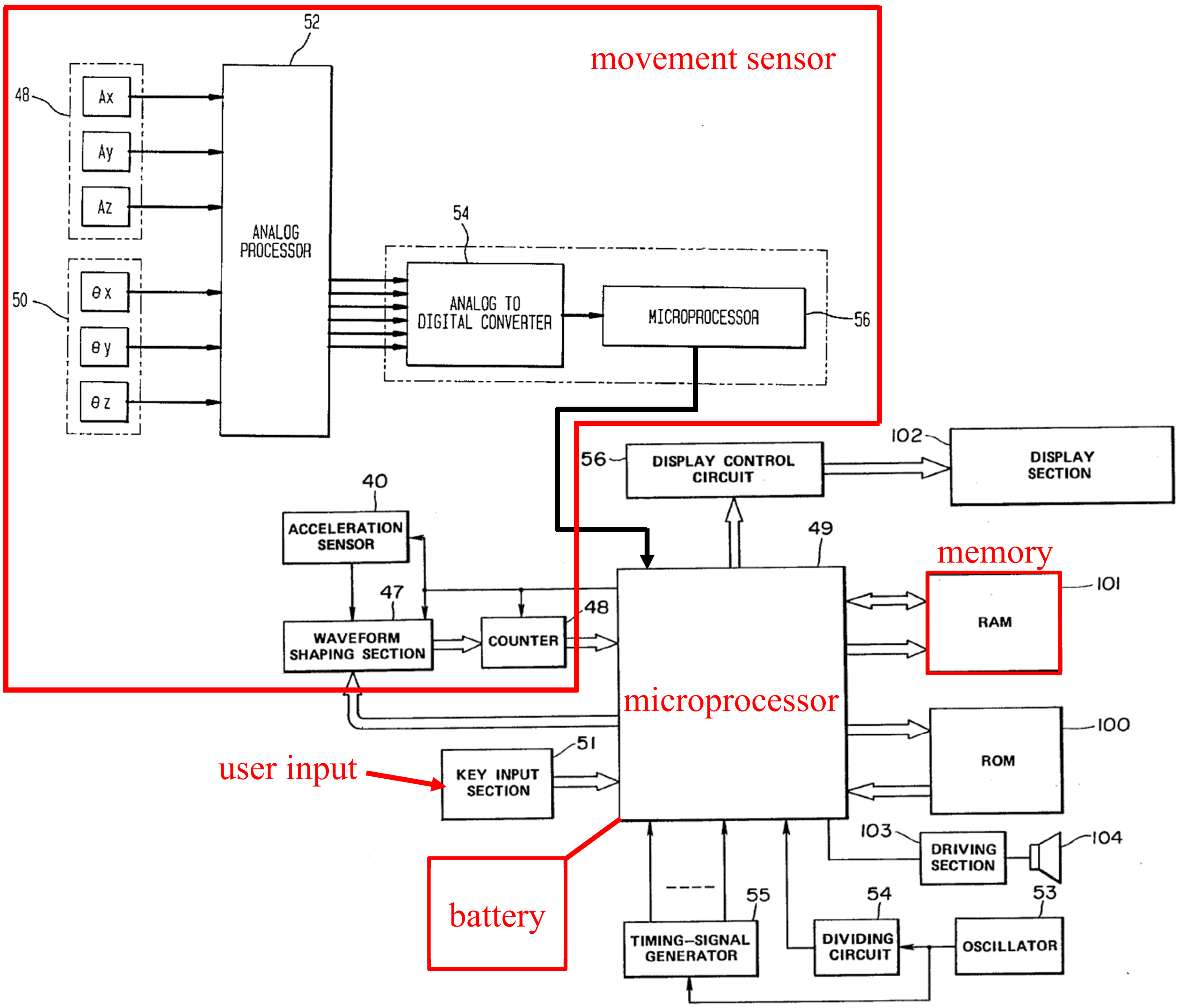


FIG.14

Ono’s FIG. 14 device modified in view of Hutchings

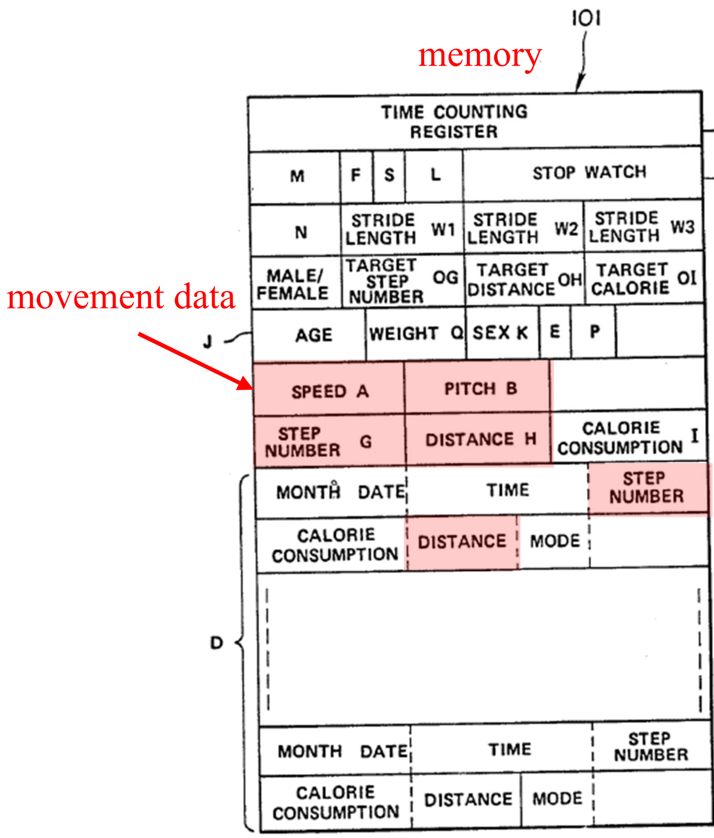


FIG. 15

Ono, FIG. 15

[1j] an output indicator connected to said microprocessor for signaling the occurrence of user-defined events;

104. Ono's device includes "an alarm-driving section 103 for generating an alarm and a speaker 104." APPLE-1101, 13:23-25. As discussed above and suggested by Ono's FIG. 18, Ono-Hutchings yields a device in which the microprocessor receives the movement data, including the number of steps taken in the last 10 seconds (as suggested by Ono's step a_{10}) and the distance traversed during a cycle from the measuring system (as suggested by Hutchings), calculates and stores the distance walked (as suggested by Ono's step a_{16}, and Hutchings' calculation and storage of the total distance traveled), "discriminate[s] whether or not the distance-walked has reached the target distance OH" (as suggested by Ono's step a_{17}), causes an alarm sound to be generated "if the distance-walked has reached the target distance OH" (as suggested by Ono's step a_{18}), calculates and stores the accumulative number of steps taken (as suggested by Ono's step a_{19}), "discriminate[s] whether or not the accumulative number of steps has reached the target number of steps OG" (as suggested by Ono's step a_{20}), and causes an alarm sound to be generated "[i]f the above accumulative number of steps has reached the target number of steps OG" (as suggested by Ono's step a_{21}). APPLE-1101, 14:65-16:27, FIG. 18; APPLE-1102, 9:49-67, 10:14-18; *supra* Ground 1, [1d]-[1e].

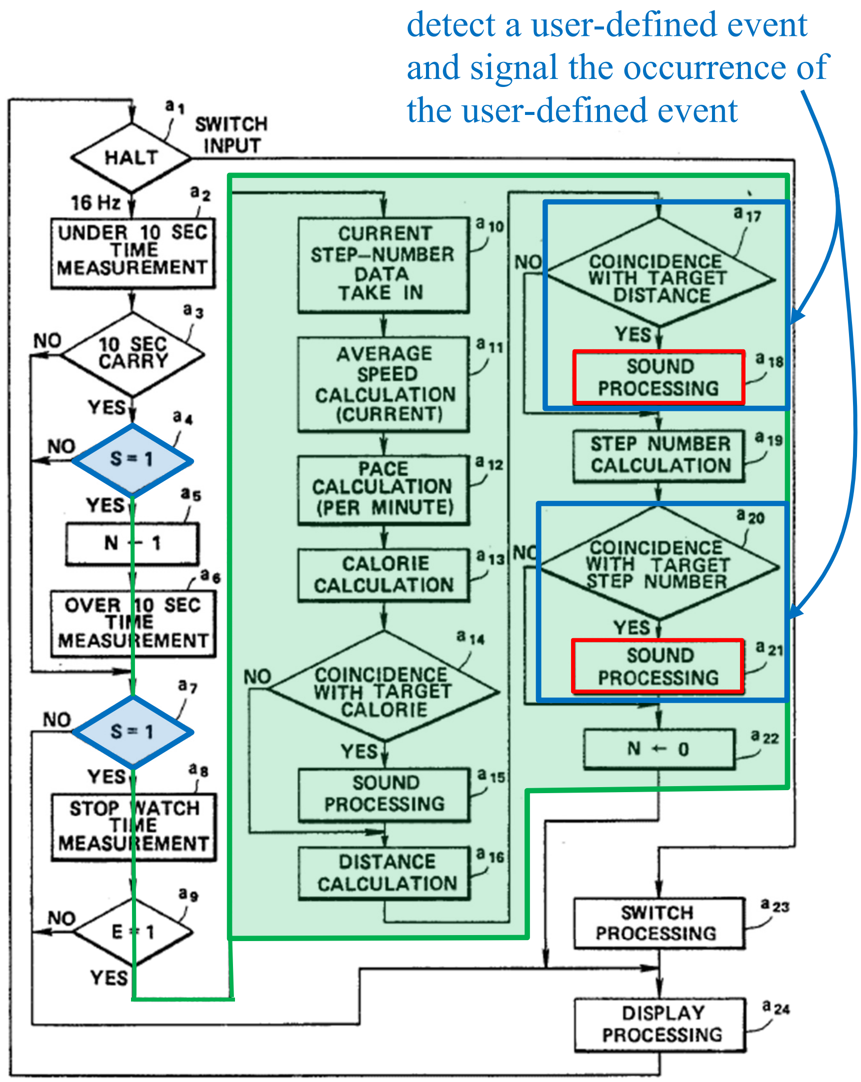
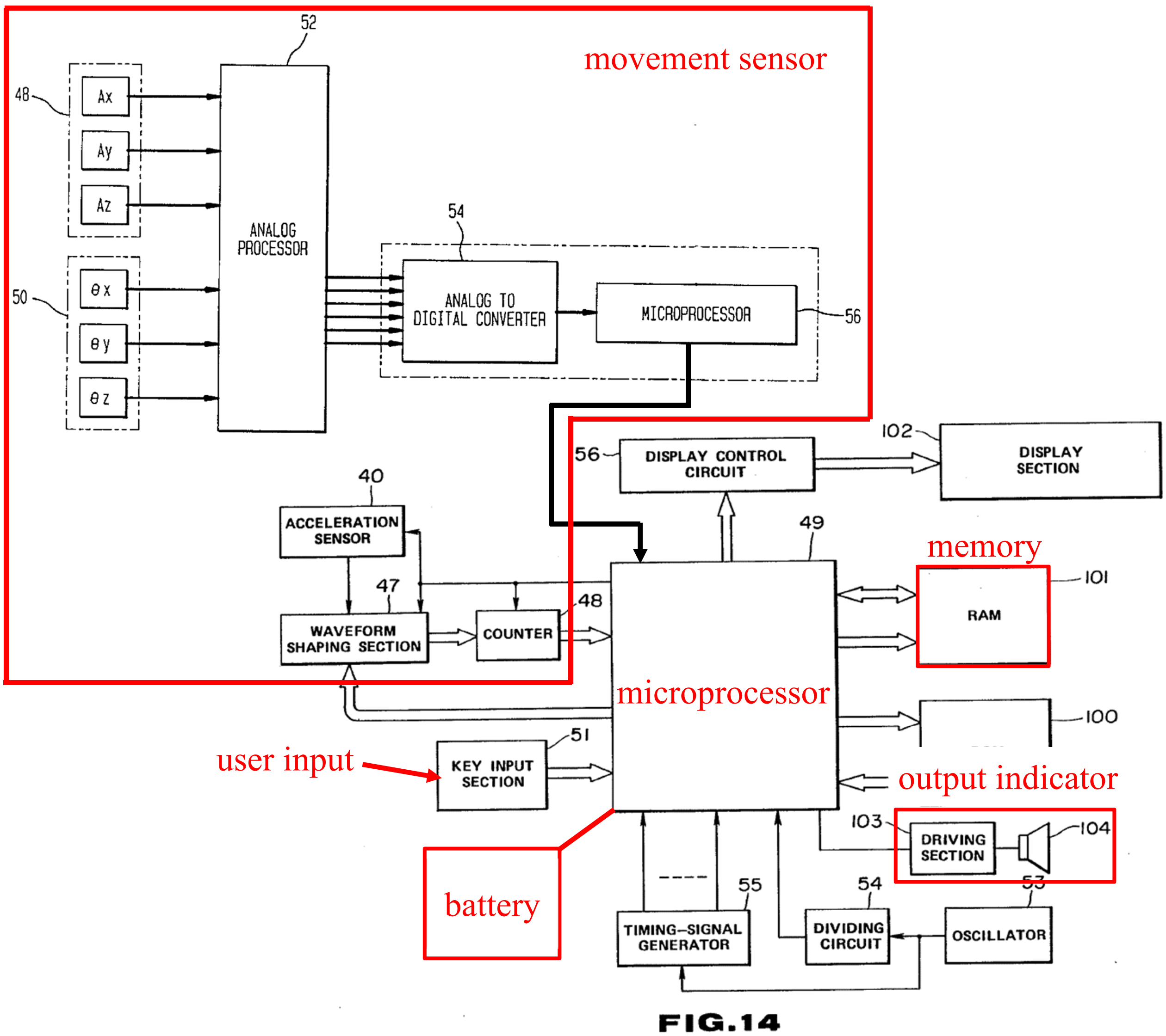


FIG.18

Ono, FIG. 18

105. As such, the microprocessor detects user-defined events (that "the distance-walked has reached the target distance OH" as suggested by Ono's step a_{18} and that "the above accumulative number of steps has reached the target number of steps OG" as suggested by Ono's step a_{21}) and signals the occurrence of the user-defined events by causing an alarm sound to be generated by driving section 103 and speaker 104 as suggested by Ono's steps a_{18} and a_{21}. APPLE-1101, 14:65-16:27; APPLE-1102, 9:49-67. An example of the Ono-Hutchings device including an output indicator connected to the microprocessor for signaling the occurrence of user-defined events is shown below:



Ono's FIG. 14 device modified in view of Hutchings

[1k] wherein said movement sensor measures the angle and velocity of said movement.

106. As discussed above, Ono-Hutchings yields a device with a movement sensor that includes the acceleration sensor (as suggested by Ono), and a set of three-component accelerometers and a set of three-component rotational sensors (as suggested by Hutchings). *Supra* Ground 1, [1a]; *supra* Section VI.A.3; APPLE-1101, 2:1-7, 3:10-4:13, 5:64-6:1, 6:41-48, 7:20-27, 7:61-68, 8:16-42, 8:58-60, 13:18-29, FIG. 14; APPLE-1102, 3:22-26 ("One set of three-component linear accelerometers and one set of three-component rotational sensors may be employed to resolve the absolute motion of a person..."), 4:44-6:54, 8:44-59, 9:59-10:2, FIG. 6. Also discussed above, Hutchings discloses that "[t]he total distance traveled is the sum of distances for all cycles. The velocity of travel is the distance of the cycle, or several cycles, divided by the time it takes to travel this distance." *Supra* Ground 1, [1d]; APPLE-1102, 10:67-11:3, 12:15-38. In Hutchings' calculations, "value of accelerations are integrated twice to obtain Lx, Ly, and Lz,... where V^{O}_{x}, V^{O}_{y}, and V^{O}_{z} are the values of velocity of the sensors at the initiation of a cycle." APPLE-1102, 12:15-38. A POSITA would have understood that velocities V_x, V_y, and V_z at any time after the start of the cycle can be obtained from the first integration of the acceleration signal if the velocities at the start of the cycle are also known. In fact, the first integration is an intermediate step in the double integration process described by Hutchings.

107. To the extent this limitation requires the movement sensor itself measure the velocity and if Ono's acceleration sensor and Hutchings' measurement system were considered to not measure velocity of the movement, Hutchings discloses that "instead of accelerometers[,] velocity sensors may be employed." APPLE-1102, 12:58-60. Hutchings explains that "[f]or a measuring system that employs a velocity sensor[,] the condition set forth by equation (16) becomes unnecessary. Thus a new cycle may advantageously begin at any time the velocity of the user is constant." APPLE-1102, 12:60-63.

108. Based on Hutchings' teachings, a POSITA would have found it obvious to substitute the accelerometers with velocity sensors. *Id.* The POSITA would have been motivated to use Hutchings' velocity sensors to leverage the stated benefits of simplifying the calculations ("the condition set forth by equation (16) becomes unnecessary") and advantageously allowing a new cycle to begin at any time the velocity of the user is constant. APPLE-1102, 12:60-63. The block diagram below shows an example of the Ono-Hutchings device with the movement sensor that includes the acceleration sensor (as suggested by Ono), and a set of three-component velocity sensors to measure velocity and a set of three-component rotational sensors to provide the angle of rotation along each axis of the translational coordinate (as suggested by Hutchings):

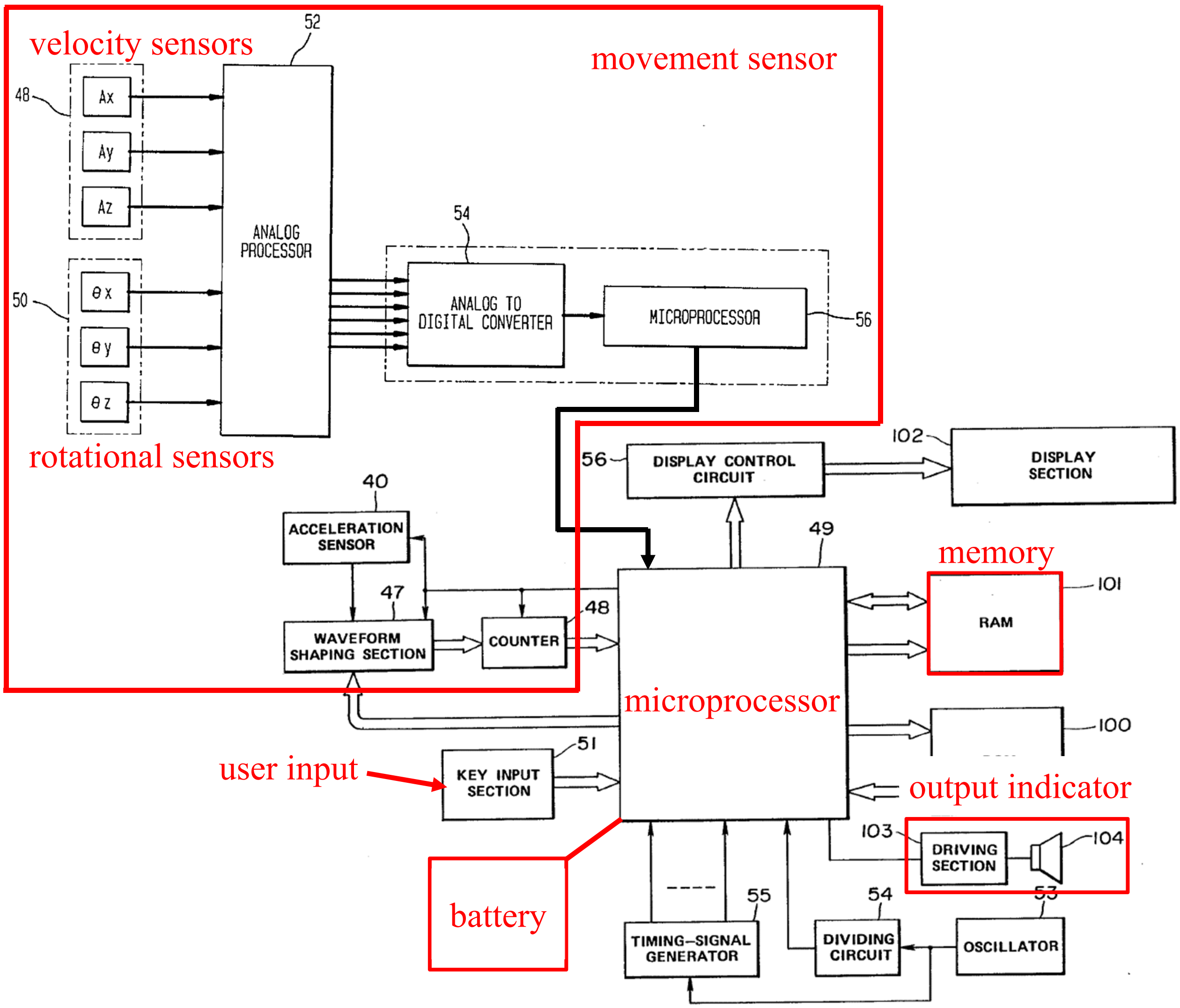


FIG.14

Ono's FIG. 14 device modified in view of Hutchings

b) Claim 3

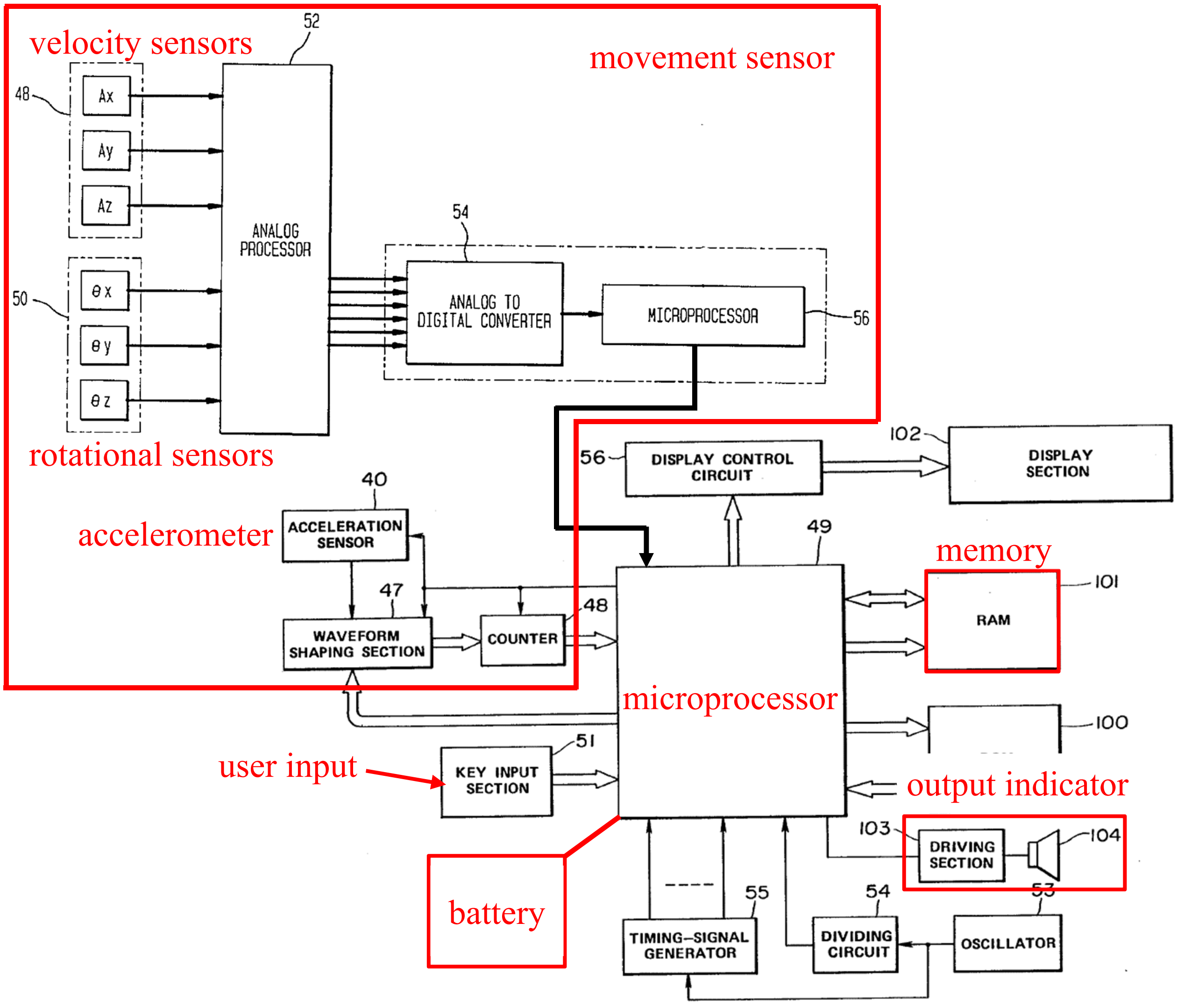
3. The device of claim 1 wherein said device is compact and weighs less than one pound.

109. As previously discussed, Ono's exercise measuring instrument is implemented as "an electronic wrist watch to which a pedometer is installed," is "to be worn on a body of an exerciser," and "made compact in size." APPLE-1101, 3:10-11, 2:1-4, 2:22-26, 3:24-26, FIG. 1; *supra* Ground 1, [1pre]. Hutchings also discloses that its "measuring system 10" may be located at the wrist of the user, "is light in weight, relatively inexpensive and convenient to use." APPLE-1102, 2:66-3:2, 3:32-44, 4:7-26, 10:43-51, FIGS. 7-9; *supra* Section VI.A.2. Ono-Hutchings yields a movement monitoring device implemented as a wrist watch that is compact in size and worn on the user's wrist. *Id.*; APPLE-1101, 3:10-11, 2:1-4, 2:22-26, 3:24-26, FIG. 1; *supra* Ground 1, [1pre]. A POSITA would have found obvious that such a wrist worn movement monitoring device that is "compact in size," "light in weight," and "convenient to use" weighs less than one pound so that it does not hinder the user's movement while exercising. *Id.*; *see, e.g.,* APPLE-1113, Fig. 2 (graph illustrating that wrist watches are less than 1 pound).

c) Claim 4

4. The device of claim 1 wherein said movement sensor comprises at least one accelerometer.

110. As previously discussed, Ono-Hutchings yields a device with a movement sensor that includes the acceleration sensor (as suggested by Ono), and a set of three-component velocity sensors to measure velocity and a set of three-component rotational sensors to provide the angle of rotation along each axis of the translational coordinate (as suggested by Hutchings). *Supra* Ground 1, [1k]. Ono discloses that the acceleration sensor outputs a voltage proportional to the acceleration applied to the acceleration sensor. APPLE-1101, 3:10-4:13, FIG. 4. Thus, the acceleration sensor is an accelerometer. The block diagram below shows an example of the Ono-Hutchings device with the movement sensor that includes the accelerometer (as suggested by Ono):



Ono's FIG. 14 device modified in view of Hutchings

d) Claim 5

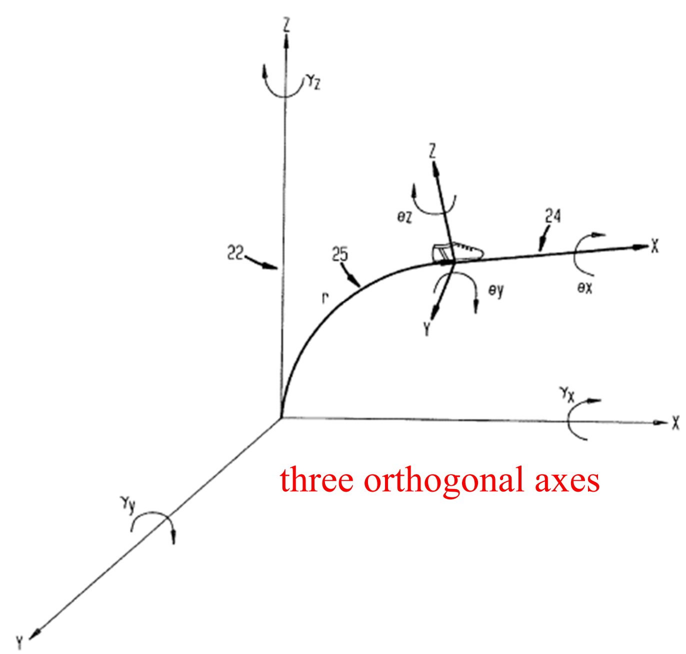
5. The device of claim 1 wherein said movement sensor can simultaneously detect real time movement along at least two orthogonal axes.

111. As previously discussed, Ono-Hutchings yields a device with a movement sensor that includes the acceleration sensor (as suggested by Ono), and a set of three-component velocity sensors to measure velocity and a set of three-component rotational sensors to provide the angle of rotation along each axis of the translational coordinate (as suggested by Hutchings). *Supra* Ground 1, [1k]. Ono discloses that the acceleration sensor outputs a voltage proportional to the acceleration applied to the acceleration sensor "while the user of the wrist watch is running." APPLE-1101, 3:10-4:13, FIG. 4. Additionally, Hutchings describes determining the speed, distance and height traversed by a person "while in motion." APPLE-1102, 1:15-18. Thus, Ono-Hutchings yields a device with a movement sensor that detects real time movement. *Id.*; APPLE-1101, 3:10-4:13, FIG. 4.

112. Hutchings discloses that the three rotational sensors are each configured to measure angle "with respect to a reference frame" and the three accelerometers are each configured to measure acceleration "with respect to a reference frame." APPLE-1102, 4:55-59, 5:3-6. Hutchings explains with respect to FIG. 3 that "a first coordinate system, such as (x, y, z) 22, is referred to as the reference frame coordinate system of the stationary ground. (γ_x, γ_y, γ_z) are the rotational coordinates about the x, y and z axis of the reference frame." APPLE-1102, 5:17-22. Hutchings further discloses that the y axis is in the same plane as the x axis and at right angles to the x axis, and the z axis is normal to the plane of the x and y axes. APPLE-1102, 5:28-35.

113. Hutchings FIG. 3 further illustrates "a second coordinate system, such as (x, y, z) 24, referred to as the translational coordinate system of the linear accelerometers." APPLE-1102, 5:41-43. The orientation of translational coordinate system is the same as the reference frame, but moves with the sensors and is centered at the location of the sensors. APPLE-1102, 5:43-45, 5:53-56. Rotational coordinates (θ_x, θ_y, θ_z) are used to keep track of the orientation of the translation coordinate system relative to the reference frame and to resolve the accelerations along the reference frame. APPLE-1102, 5:45-51. Hutchings FIG. 3 below shows the reference frame and translational coordinate system, each having three orthogonal axes.

FIG. 3



Hutchings, FIG. 3

114. As previously discussed, Hutchings' accelerometer "unit 48 generates acceleration signals along the translational coordinates" and "[r]otational sensors contained in unit 50 begin to track the rotation of the [sensors] along the translational coordinate system." APPLE-1102, 9:59-62; *supra* Ground 1, [1a], [1d]. "Each accelerometer may convert the measured acceleration into a corresponding signal, which may be preferably employed by microprocessor 6 to accomplish movement measurements." APPLE-1102, 5:9-12. "Each rotational sensor converts the measured angle into a corresponding signal, which is employed by a microprocessor 6 to calculate information related to the user's movements." APPLE-1102, 4:60-65. Hutchings describes using the reference frame and translational coordinate system with the measuring system employed at the wrist and with velocity sensors instead of accelerometers. APPLE-1102, 5:58-63, 11:38-12:63, FIG. 9; *supra* Ground 1, [1k]. Based on Ono's and Hutchings' teachings, Ono-Hutchings yields a device with a movement sensor that can simultaneously detect real time movement along three orthogonal axes. *Id.*

e) Claim 8

8. The device of claim 1 wherein said data measured by said movement sensor includes the distance of said movement.

115. Hutchings discloses that "[t]he accelerometers and the rotational sensors employed by the measuring system, measure the distance traveled by the user." APPLE-1102, 3:38-40. Hutchings measuring system includes processor 52 that determines the components of motion in the reference frame and the angle from the vertical coordinate, and measures instantaneous acceleration of the device along the reference coordinates during each cycle. APPLE-1102, 7:5-65, 8:61-64, 9:62-65, 10:43-12:14. Microprocessor 56 of the measuring system measures the distance L traversed during each cycle by integrating the acceleration signals. APPLE-1102, 4:21-32, 4:55-65, 5:3-16, 8:44-9:17, 9:65-67, 9:48-10:42, 12:15-37, FIGS. 6-7; *supra* Ground 1, [1a], [1k]. The block diagram below shows an example of the Ono-Hutchings device with the movement sensor that includes the microprocessor 56 that measures distance traveled during each cycle:

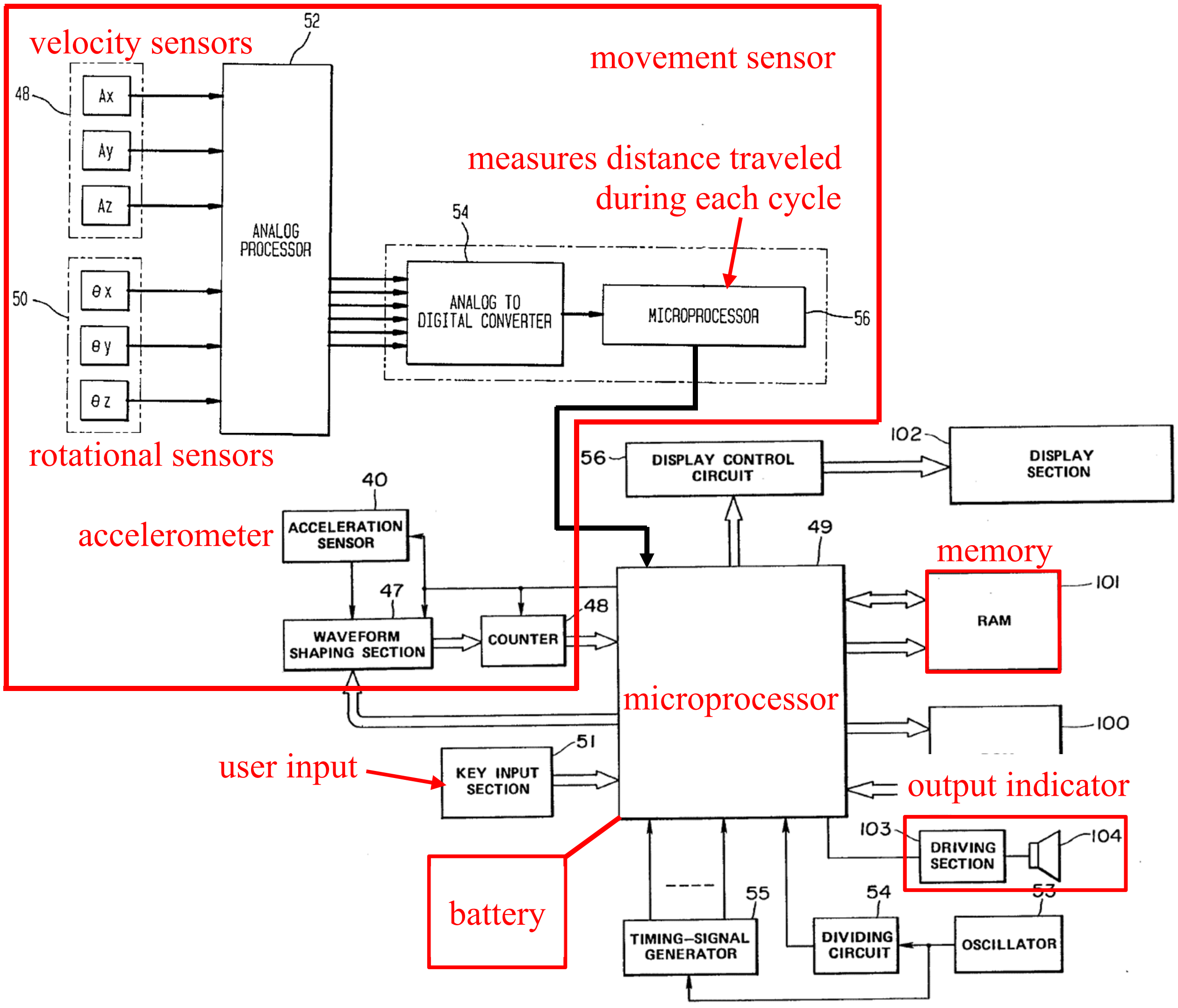


FIG.14

Ono's FIG. 14 device modified in view of Hutchings

f) Claim 10

10. The device of claim 1 wherein said output indicator is audible.

116. Ono-Hutchings renders claim 10 obvious for similar reasons as discussed in Ground 1, [1j]. *Supra* Ground 1, [1j].

g) Claim 30

30. The device of claim 1, wherein said microprocessor is configured to store, in said memory, date information associated with the first time stamp information.

117. As previously discussed, Ono discloses that the processor obtains "time-data, i.e., the present-time data comprising minute-data, hour-data, date-data and month-data" and stores the time-data at a register of RAM. APPLE-1101, 9:14-31; *supra* Ground 1, [1h]. Also previously discussed, Ono further suggests the processor storing time stamp information in RAM along with the event information: "RAM 101 is provided with a time-counting register T for storing the present-time data" and "a time-counting process is executed to count the present time... and renews the time-counting register in RAM." APPLE-1101, 13:31-33, 12:10-12; *supra* Ground 1, [1f]. With respect to Ono's FIG. 18, Ono describes the time-counting process as step a_2 and the detection of a user-defined event based on the movement data and at least one of these user-defined operational parameters regarding the movement data as steps a_{17}, a_{18}, a_{20}, a_{21} as shown below. APPLE-1101, 15:1-5 ("the process advances to Step a_2 to effect a time-counting process in unit of 10 sec or less with respect to the present time."). Thus, Ono determines and stores "the present-time data comprising minute-data, hour-data, date-data and month-data" at which the movement data causing the user-defined event occurred. *Id.* Further, in Ono, when the user stops the step-counting mode operation, the processor stores the date, duration, total step count, total distance-walked, and total calorie-consumption in registers D of RAM 101 for later retrieval and display in the data-recall mode. APPLE-1101, 13:65-14:29, 16:24-25, 17:10-50, 18:20-24, 20:37-53, FIGS. 15, 20 (steps C_{14}-C_{15}), 23; *supra* Ground 1, [1d]. Accordingly, Ono-Hutchings yields a device where the microprocessor stores in RAM date information associated with the time stamp information, as shown below.

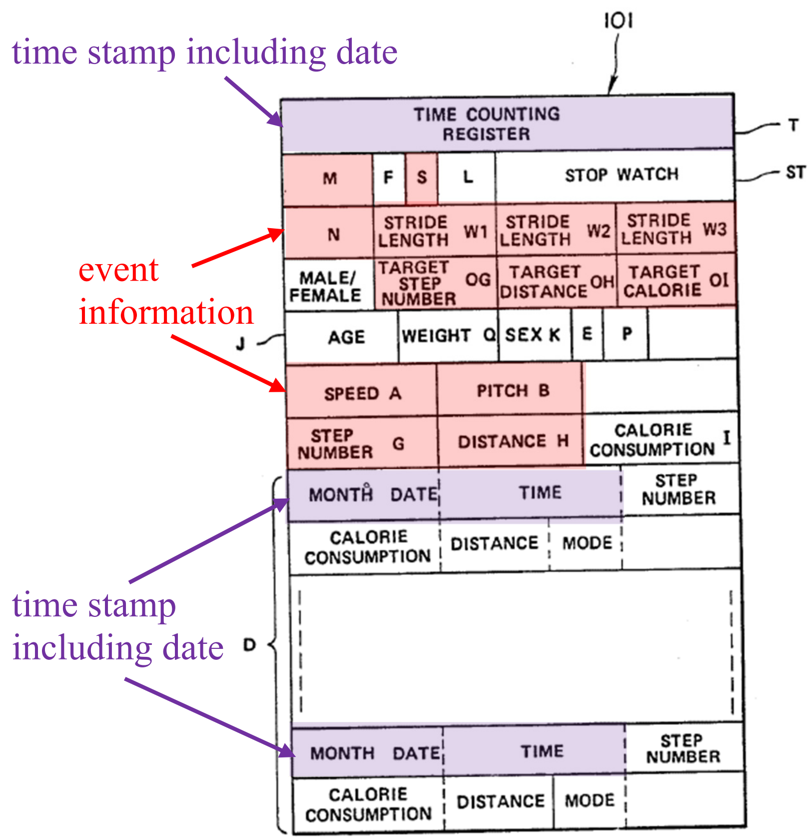


FIG. 15

Ono, FIG. 15

h) Claim 39

39. The device of claim 1, wherein said at least one of the user-defined operational parameters is a predetermined threshold, and said first user-defined event occurs when the movement data reaches the predetermined threshold.

118. As previously discussed, Ono-Hutchings yields a device in which the microprocessor detects a user-defined event (that "the distance-walked has reached the target distance OH" as suggested by Ono's step a_{18}) based on movement data (distance-walked) and at least one of the user-defined operational parameters regarding the movement data (user selection and starting of the step-counting mode, user selection of the exercise mode, and user set stride length and target distance OH). *Supra* Ground 1, [1d], [1e]; APPLE-1101, 13:40-42, 13:51-61, 15:47-16:13, 18:28-19:17, 20:8-15, FIGS. 18, 20-21. Additionally, the microprocessor detects a user-defined event (that "the distance-walked has reached the target distance OH" as suggested by Ono's step a_{18}) based on movement data (total distance traveled as suggested by Hutchings) and at least one of the user-defined operational parameters regarding the movement data (user selection of the run mode and user set target distance OH). *Id.*; APPLE-1102, 9:49-67.

119. The user set target distance is at least one of the user-defined operational parameters, and a user-defined event (that "the distance-walked has reached the target distance OH") occurs when the movement data ("distance-walked") reaches the user set target distance. *Id*. The target distance was previously set by the user before the user-defined event occurred and is a value that the distance-walked must exceed for the user-defined event to occur. *Id.* Therefore, the user set target distance is a predetermined threshold, and the user-defined event occurs when the movement data reaches the predetermined threshold. *Id.*

120. Also previously discussed, the microprocessor detects a user-defined event (that the "accumulative number of steps has reached the target number of steps OG" as suggested by Ono's step a_{21}) based on movement data (accumulative number of steps) and at least one of the user-defined operational parameters regarding the movement data (user selection and starting of the step-counting mode and user set target number of steps OG). *Id*.

121. The user set target number of steps also is at least one of the user-defined operational parameters, and a user-defined event (that the "accumulative number of steps has reached the target number of steps OG") occurs when the movement data (accumulative number of steps) reaches the user set target number of steps. *Id*. The target number of steps was previously set by the user before the user-defined event occurred and is a value that the number of steps taken must exceed for the user-defined event to occur. *Id.* Therefore, the user set target number of steps is a predetermined threshold, and the user-defined event occurs when the movement data reaches the predetermined threshold. *Id.*

i) Claim 41

41. The device of claim 39, wherein said memory is configured to store said first event information indicating that the predetermined threshold is met.

122. Ono-Hutchings renders claim 41 obvious for similar reasons as discussed in Ground 1, [1f]. *Supra* Ground 1, [1f]. As previously discussed, when the Ono-Hutchings device is operating in the step-counting and/or run mode or when the user stops the step-counting and/or run mode, the microprocessor stores the total step count and the total distance in registers of RAM. *Id.*; APPLE-1101, 13:65-14:29, 14:65-16:2717:10-50, 18:20-24, 20:37-53, FIGS. 15, 20 (steps C14-C15), 23. The total distance and/or the total step count that is stored, when the microprocessor detects that "the distance-walked has reached the target distance OH" and/or that the "accumulative number of steps has reached the target number of steps OG" (user-defined event) and notifies the user by generating the alarm sound, would be equal to or greater than the target distance and/or total step count, respectively. *Id.* Thus, the total distance and/or the total step count that is stored in RAM when the user-defined event is detected is part of the first event information and indicates that the target distance and/or the target number of steps, respectively, is met. *Id.*

j) Claim 42

42. The device of claim 41, wherein said memory is configured to store the first time stamp information in association with said first event information.

123. Ono-Hutchings renders claim 42 obvious for similar reasons as discussed in Ground 1, [1f]. *Supra* Ground 1, [1f].

k) Claim 61

61. The device of claim 39, wherein said microprocessor is configured to detect occurrence of the first user-defined event by comparing said movement data to said predetermined threshold.

124. As previously discussed, Ono-Hutchings' microprocessor detects that a user-defined event (that "the distance-walked has reached the target distance OH") occurs when the movement data ("distance-walked") reaches the user set target distance (predetermined threshold), which is a value that the distance-walked must exceed for the user-defined event to occur. *Supra* Ground 1, [1d], [1e], claim 39; APPLE-1101, 13:40-42, 13:51-61, 15:47-16:13, 18:28-19:17, 20:8-15, FIGS. 18, 20-21; APPLE-1102, 9:49-67. The microprocessor detects that the user-defined event occurred by "discriminat[ing] whether or not the distance-walked has reached the target distance OH." *Id.* A POSITA would have understood that "discriminat[ing] whether or not the distance-walked has reached the target distance OH" includes determining whether the distance-walked is greater than, less than, or equal to the target distance, which is a comparison of the distance-walked and the target distance. *Id.* Thus, the Ono-Hutchings' microprocessor detects the occurrence of the user-defined event by comparing the distance-walked (movement data) to the target distance (predetermined threshold). *Id.*

125. Ono-Hutchings' microprocessor also detects that a user-defined event (that the "accumulative number of steps has reached the target number of steps OG") occurs when the movement data ("accumulative number of steps") reaches the user set target number of steps (predetermined threshold), which is a value that the accumulative number of steps must exceed for the user-defined event to occur. *Supra* Ground 1, [1d], [1e], claim 39; APPLE-1101, 13:40-42, 13:51-61, 15:47-16:13, 18:28-19:17, 20:8-15, FIGS. 18, 20-21. The microprocessor detects that the user-defined event occurred by "discriminat[ing] whether or not the accumulative number of steps has reached the target number of steps OG." *Id.* A POSITA would have understood that "discriminat[ing] whether or not the accumulative number of steps has reached the target number of steps OG" includes determining whether the accumulative number of steps is greater than, less than, or equal to the target number of steps, which is a comparison of the accumulative number of steps and the target number of steps. *Id.* Thus, the Ono-Hutchings' microprocessor detects the occurrence of the user-defined event by comparing the accumulative number of steps (movement data) to the target number of steps (predetermined threshold). *Id.*

l) Claim 62

62. The device of claim 1, wherein said device is configured to be placed on said user's arm to monitor and record said movement data.

126. Ono-Hutchings renders claim 62 obvious for similar reasons as discussed in Ground 1, [1pre] and [1d]. *Supra* Ground 1, [1pre], [1d]. The Ono-Hutchings device is "an electronic wrist watch," which is worn on the wrist portion of the user's arm. APPLE-1101, 3:10-11, 2:1-4, 2:22-26, 3:24-26, FIG. 1; APPLE-1102, 3:32-44, 4:7-26, 10:43-51, FIGS. 7-9. Ono's acceleration sensor and Hutchings' measuring system in the Ono-Hutchings device measure movement of the user's arm, and the device monitors and records movement data relating to movement of the user's arm to determine the user's step count, pitch, distance, speed, and velocity while the user is walking/running. APPLE-1101, 8:1-9:48, 14:65-16:27; APPLE-1102, 10:43-12:63; *supra* Ground 1, [1a], [1d].

m) Claim 63

63. The device of claim 62, wherein said movement sensor is configured to measure movement of said user's arm.

127. Ono-Hutchings renders claim 63 obvious for similar reasons as discussed in claim 62. *Supra* Ground 1, claim 62.

n) **Claim 64**

64. The device of claim 1, wherein said movement sensor is configured to measure a walking distance.

128. Ono-Hutchings renders claim 64 obvious for similar reasons as discussed in Ground 1, claim 8. *Supra* Ground 1, claim 8. Hutchings teaches that the distance measured by the measuring system of the Ono-Hutchings device is a distance traversed while the user is walking. APPLE-1102, 2:49-61, 4:7-10.

o) **Claim 65**

65. The device of claim 64, wherein said device is configured to be wearable by the user, and said movement sensor is configured to measure said walking distance of said user.

129. Ono-Hutchings renders claim 65 obvious for similar reasons as discussed in Ground 1, [1pre] and claim 64. *Supra* Ground 1, [1pre], claim 64.

5. **Analysis of Claims 20 and 25**

a) **Claim 20**

[20pre] A method to monitor physical movement of a body part comprising the steps of:

130. To the extent the preamble is limiting, Ono-Hutchings renders [20pre] obvious for similar reasons as discussed in Ground 1, [1pre] and [1d]-[1f]. *Supra* Ground 1, [1pre], [1d]-[1f].

[20a] attaching a portable, self-contained movement measuring device to said body part for measuring unrestrained movement in any direction;

131. Ono-Hutchings renders [20a] obvious for similar reasons as discussed in Ground 1, [1pre] and [1a]. *Supra* Ground 1, [1pre], [1a].

[20b] measuring data associated with said physical movement;

132. Ono-Hutchings renders [20b] obvious for similar reasons as discussed in Ground 1, [1a]. *Supra* Ground 1, [1a].

[20c] interpreting, using a microprocessor included in the portable, self-contained movement measuring device, said physical movement data based on user-defined operational parameters and a real-time clock;

133. As discussed above, Ono-Hutchings yields a portable, self-contained movement measuring device that includes a microprocessor. *Supra* Ground 1, [1pre], [1c]; APPLE-1101, 3:18-26, 8:60-9:12, 12:17-35, 14:30-64, 15:10-13, 15:33-46, 15:61-66, 17:26-34; Hutchings, 4:21-32, 10:10-18, 10:28-30. The device allows a user to define operational parameters, including selection and starting of step-counting, selection of run mode, selection of exercise mode, and setting of stride length, target distance, and target number of steps. *Supra* Ground 1, [1d]; APPLE-1101, 13:25-27, 13:34-42, 13:51-61, 15:61-16:4, 16:18-17:23, 18:14-19, 18:28-19:67, 20:8-15, FIGS. 20-21. When the user selects and starts the step-counting mode, the microprocessor interprets/analyzes movement data (as suggested by Ono's steps a_{11}, a_{12}, a_{16}, a_{17}, a_{19}, a_{20}). *Id.*; APPLE-1101, 13:44-45, 14:65-16:27, FIG. 18. Additionally, in the step-counting mode, the microprocessor interprets/analyzes (as suggested by Ono's steps a_{11}, a_{16}, a_{17}) movement data based on the exercise mode and the stride length previously set by the user. *Id.*; APPLE-1101, 13:40-42, 13:51-61, 18:28-19:17, 20:8-15, FIGS. 18, 20-21. Further, in the step-counting mode, the microprocessor interprets/analyzes (as suggested by Ono's steps a_{17}, a_{20}) movement data based on the target distance OH and the target number of steps OG previously set by the user. *Id.*; APPLE-1101, 15:47-16:13.

134. When the user has set the device to run mode, the microprocessor interprets/analyzes movement data (as suggested by Ono's steps a_{11}, a_{16} and as suggested by Hutchings' calculation of the total distance traveled, speed, and the velocity of travel). APPLE-1101, 13:44-45, 14:65-16:27, FIG. 18; APPLE-1102, 9:49-10:18. In the run mode, the microprocessor interprets/analyzes (as suggested by Ono's step a_{17}) movement data from Hutchings' measuring system based on the target distance OH previously set by the user. *Id.*; APPLE-1101, 13:40-42, 13:55-61, 18:28-19:17, 20:8-15, FIGS. 20-21. Thus, the microprocessor interprets physical movement data based on user-defined operational parameters.

135. Also discussed above, a POSITA would have found it obvious to implement the Ono-Hutchings device to include a real-time clock connected to the microprocessor for providing "time-data, i.e., the present-time data comprising minute-data, hour-data, date-data and month-data" to the microprocessor. APPLE-1101, 9:14-31; *supra* Ground 1, [1h]. Ono further discloses that "the timing signal-generator circuit 55 delivers a timing signal to the control section 49 so as to synchronize the processing operations of the control section 49" and teaches, in some examples, that the processes are "executed in accordance with the time-counting timing, i.e., once per second." APPLE-1101, 9:44-48, 12:10-47. In Ono's FIG. 18, the processor interprets/analyzes the movement data "when a time period of 10 sec has lapsed" and "at which data are taken in every ten seconds" as shown below. APPLE-1101, 14:65-16:27.

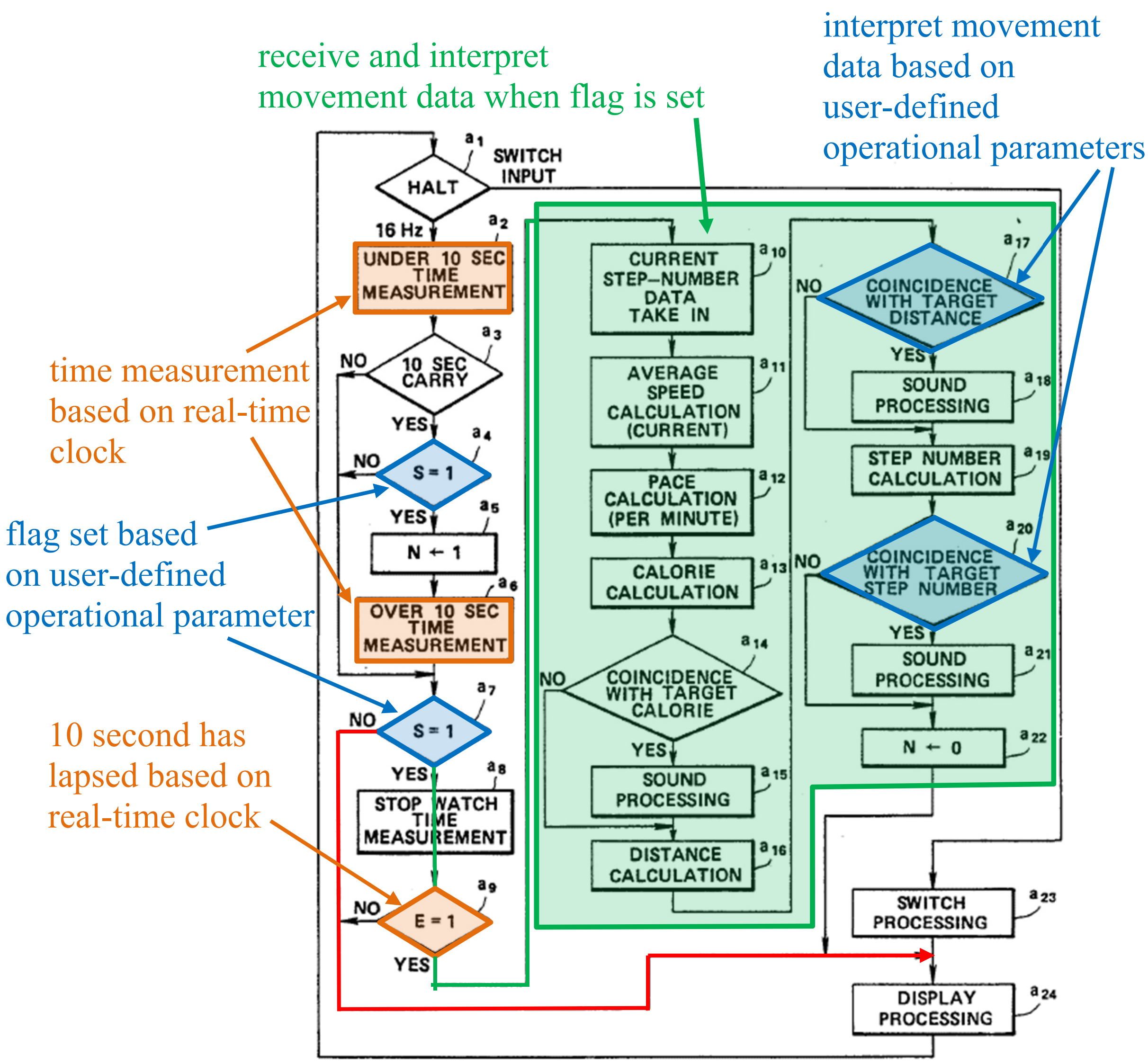


FIG.18

Ono, FIG. 18

136. Additionally, Ono-Hutchings interprets/analyzes movement data to calculate speed, which is the rate of change of distance with time, and velocity, which is the distance divided by time. APPLE-1101, 15:35-42; APPLE-1102, 3:18-21, 11:1-3. As described in Ono, distance can be determined based on user selected exercise mode and user set stride length, and the time is a "time period of 10 sec." APPLE-1101, 15:61-62. Thus, the microprocessor interprets physical movement data based on user-defined operational parameters, including selection and starting of step-counting, selection of run mode, selection of exercise mode, and setting of stride length, target distance, and target number of steps, and based on 10 seconds having lapse that is determined using a real-time clock.

[20d] storing said data in memory;

137. Ono-Hutchings renders [20d] obvious for similar reasons as discussed in Ground 1, [1d], [1f], and [1i]. *Supra* Ground 1, [1d], [1f], [1i].

[20e] detecting, using the microprocessor, a first user-defined event based on the movement data and at least one of the user-defined operational parameters regarding the movement data; and

138. Ono-Hutchings renders [20e] obvious for similar reasons as discussed in Ground 1, [1e]. *Supra* Ground 1, [1e].

[20f] storing, in said memory, first event information related to the detected first user-defined event along with first time stamp information reflecting a time at which the movement data causing the first user-defined event occurred.

139. Ono-Hutchings renders [20f] obvious for similar reasons as discussed in Ground 1, [1f]. *Supra* Ground 1, [1f].

b) Claim 25

25. The method of claim 20 wherein said movement measuring device is an accelerometer.

140. Ono-Hutchings renders claim 25 obvious for similar reasons as discussed in Ground 1, [1a] and claim 4. *Supra* Ground 1, [1a], claim 4.

B. GROUND 2—Claims 1, 3-5, 8-11, 20, 25, 30, 36, 39-42, and 61-65 are Obvious based on Ono in view of Hutchings and Amano

1. Overview of Amano

141. Amano describes "an exercise support device which provides appropriate suggestions and guidance to the user." APPLE-1103, 1:11-13. Amano's device is "incorporated in a wristwatch." APPLE-1103, 11:3-9, FIGS. 3-5. The device includes a "watch circuit 9" from which the CPU1 "reads out the current clock time" for "ordinary functions associated with a watch," for determining exercise start and stop times and duration, and for storing in RAM together with sensor data. APPLE-1103, 16:43-47, 20:38-43, 21:53-59, 26:29-58, 28:13-34, 30:19-22, FIG. 1.

142. The device includes a "[d]isplay device 7 [that] displays a variety of information such as messages and the like to the user." APPLE-1103, 16:36-38, FIG. 1. As examples, Amano describes that when the CPU1 determines that data reaches or exceeds a prespecified or targeted value, the CPU1 displays a message on the display device 7. *See, e.g.,* APPLE-1103, 19:41-46 ("if the output value of acceleration sensor 5 exceeds a prespecified value (0.1 G, for example), then CPU1 determines that the user is moving (i.e., not in a state of repose)" and "CPU1 displays a message on display device 7 alerting the user not to move."), 21:43-45 ("When an interrupt from watch circuit 9 is generated after the elapse of the targeted exercise duration, CPU1 outputs a directive to the user to stop exercising."), 26:40-44 ("CPU1 checks whether or not the exercise intensity... is within the range determined by the upper and lower limit values for exercise intensity, and outputs directive relating to the appropriate exercise intensity to the user."), 26:53-58 ("CPU1 determines whether the total amount and duration of the exercise just performed are within the prespecified limits based on the respective target values. When exercise has not been carried out as directed, then CPU1 notifies the user of this fact."), 28:53-57, 29:60-63 ("if the measured value has reached the targeted value for exercise..., then CPU1 displays a message on display device 7"), 30:39-42 ("A check is made to see if the difference between these two values exceeds a prespecified value. If the difference exceeds this value, then a warning message is displayed on display device 7.”). Amano also describes providing notifications to the user through a sound source (e.g., a speaker) “so that notification may be realized using an alarm or even a voice message” or “by means of a vibration.” APPLE-1103, 46:1-32.

2. Ono-Hutchings-Amano Combination

143. In pursuing specific design options for such a device, a POSITA would have explored prior art references like Amano that describe “an exercise support device” “incorporated in a wristwatch” that “provides appropriate suggestions and guidance to the user” including notifying the user when the user has reached exercise target values. APPLE-1103, 1:11-13, 8:11-30, 11:3-9, 21:43-45, 26:40-44, 26:53-58, 29:60-63 FIGS. 3-5. A POSITA would have been motivated and would have found it obvious to implement the Ono-Hutchings device as suggested by Amano to provide multiple means of signaling the occurrence of events, including displaying a visual message on a display screen, using an alarm sound through a speaker, and by vibration of the wristwatch. APPLE-1103, 19:41-46, 21:43-45, 26:40-44, 26:53-58, 28:53-57, 29:60-63, 30:39-42, 46:1-32; APPLE-1101, 13:23-25, 14:65-16:27, FIG. 18. Amano describes multiple ways to provide notifications to accommodate visually impaired and/or hearing impaired users. APPLE-1103, 46:1-32. A POSITA would have been motivated to implement the Ono-Hutchings device for the benefit of providing multiple means of signaling the occurrence of events, including displaying a visual message on a display screen, using an alarm sound through a speaker, and by vibration of the wristwatch, to accommodate users who are visually and/or hearing impaired. APPLE-1103, 19:41-46, 21:43-45, 26:40-44, 26:53-58, 28:53-57, 29:60-63, 30:39-42 46:1-32; APPLE-1101, 13:23-25, 14:65-16:27, FIG. 18.

144. Further, a POSITA would have found it obvious to implement the Ono-Hutchings device as suggested by Amano to include a watch circuit as a real-time clock that provides the current clock time. APPLE-1103, 16:43-47, 20:38-43, 21:53-59, 26:29-58, 28:13-34, 30:19-22, FIG. 1. A POSITA would have achieved this predictable result with a reasonable expectation of success. Ono describes the microprocessor obtaining "time-data, i.e., the present-time data comprising minute-data, hour-data, date-data and month-data." APPLE-1101, 9:14-31; *supra* Ground 1, [1h]. Similarly, Amano describes the processor reading out the current clock time from a watch circuit. APPLE-1103, 16:43-47, 20:38-43, 21:53-59, 26:29-58, 28:13-34, 30:19-22, FIG. 1. Based on the structural and functional similarities of Ono and Amano and the predictable technologies of such wristwatch exercise monitors at the time, a POSITA would have recognized that Amano provides an explicit teaching to include a watch circuit as a real-time clock that provides the current clock time to the microprocessor. *Id.*; *see e.g.,* APPLE-1009, 9:59-67, 10:66-11:8; APPLE-1112, 8:21-30 ("The output of the divider 148 is applied to a divide-by-ten divider 156 which provides a 1 Hz signal to a clock 158. The output of clock 158 is applied through the multiplexer 140 under the control of the 'M' button 22 to display the time in hours, minutes and seconds in the conventional manner."). A POSITA therefore would have understood that the Ono-Hutchings device was readily available to be implemented using the predictable technology of a conventional "watch circuit" or real-time clock as suggested by Amano without significantly altering or hindering the functions performed by the Ono-Hutchings device. *Id.* A POSITA would have been motivated to achieve the benefit of using a real-time clock to provide the current clock time to the microprocessor, thereby advantageously reducing the calculations that are performed by the microprocessor and conserving power to the system when there are no processing tasks for the microprocessor. *Id.*

145. Moreover, a POSITA would have viewed the implementation of the Ono-Hutchings device in a manner that applied Amano's suggested features as merely the predictable result (e.g., a pedometer that includes a real-time clock and a multiple means for providing notifications) of combining known prior elements according to known methods. The POSITA would have appreciated that the Ono-Hutchings-Amano combination does not change the hallmark aspects of these references, and any modifications needed to incorporate Amano's teachings into the Ono-Hutchings device to provide the above benefits would have been predictable with a foreseeable chance of success and within the skill of a POSITA. The respective teachings would work together in combination just as they did apart, with Amano's suggestion merely improving/adding to the Ono-Hutchings device.

3. Analysis of the Claims

146. Ground 2 relies on the additional disclosure of Amano for the claim elements below. Integration of Amano does not disturb the aspects of Ono-Hutchings mapped to the claim elements. The Ground 2 Ono-Hutchings analysis is substantively identical to and incorporates the Ground 1 Ono-Hutchings analysis in all respects. To avoid repetition, and because the analysis of Ono-Hutchings to the claim elements is identical, only selected claim elements are addressed below.

a) Claim 1

[1h] a real-time clock connected to said microprocessor;

147. As previously discussed, Ono-Hutchings yields a device that includes an oscillator circuit and a dividing circuit that provide a one hertz signal to the microprocessor for obtaining "time-data, i.e., the present-time data comprising minute-data, hour-data, date-data and month-data," and the processor stores the time-data at a register of RAM. APPLE-1101, 9:14-31; *supra* Ground 1, [1h]. If the Ono-Hutchings device were considered to not include a real-time clock connected to the microprocessor, Amano describes a "watch circuit" from which the processor "reads out the current clock time" for "ordinary functions associated with a watch," for determining exercise start and stop times and duration, and for storing in RAM together with sensor data. APPLE-1103, 16:43-47, 20:38-43, 21:53-59, 26:29-58, 28:13-34, 30:19-22, FIG. 1. This "watch circuit" would be understood by a POSITA as providing a Real Time Clock to the system. As previously discussed, a POSITA would have found it obvious to implement the Ono-Hutchings device as suggested by Amano with such a watch circuit as a real-time clock connected to the microprocessor from which the microprocessor "reads out the current clock time." *Id.*; *supra* Section VI.B.2; *supra* Ground 1, [1h].

b) Claim 9

9. The device of claim 1 wherein said output indicator is visual.

148. As previously discussed, Ono-Hutchings yields a device including an output indicator connected to the microprocessor for signaling the occurrence of user-defined events. *Supra* Ground 1, [1j]. Ono describes a device having a display connected to the processor for displaying information. APPLE-1101, 13:18-22, 14:30-64, 17:37-61, 18:37-66, 19:27-30, 20:24-53, FIGS. 14, 16-17, 21-23. As previously discussed, Amano provides an explicit teaching of a processor signaling the occurrence of events by displaying a visual message on a display screen. APPLE-1103, 16:36-38, 19:41-46, 21:43-45, 26:40-44, 26:53-58, 28:53-57, 29:60-63, 30:39-42, 46:1-32, FIG. 1; *supra* Section VI.B.1. A POSITA would have understood that a display screen is a visual output indicator. *Id.*

149. Based on Ono's and Amano's teachings, Ono-Hutchings-Amano yields a device in which the microprocessor signals the occurrence of user-defined events by displaying a visual message on the display screen. *Id.* As previously discussed, a POSITA would have been motivated to implement the Ono-Hutchings device for the benefit of providing multiple means of signaling the occurrence of events, including displaying a visual message on a display screen, using an alarm sound through a speaker, and by vibration of the wristwatch, to accommodate users who are visually and/or hearing impaired. *Id.*; *supra* Section VI.B.2.

c) Claim 11

11. The device of claim 1 wherein said output indicator is tactile.

150. As previously discussed, Ono-Hutchings yields a device including an output indicator connected to the microprocessor for signaling the occurrence of user-defined events. *Supra* Ground 1, [1j]. Amano provides an explicit teaching of a processor signaling the occurrence of events by vibration of the wristwatch. APPLE-1103, 16:36-38, 19:41-46, 21:43-45, 26:40-44, 26:53-58, 28:53-57, 29:60-63, 30:39-42, 46:1-32, FIG. 1; *supra* Section VI.B.1. A POSITA would have understood that vibration is perceptible by touch and is thus a tactile output indicator. *Id.*

151. Based on Ono's and Amano's teachings, Ono-Hutchings-Amano yields a device in which the microprocessor signals the occurrence of user-defined events by vibration of the wristwatch. *Id.* As previously discussed, a POSITA would have been motivated to implement the Ono-Hutchings device for the benefit of providing multiple means of signaling the occurrence of events, including displaying a visual message on a display screen, using an alarm sound through a speaker, and by vibration of the wristwatch, to accommodate users who are visually and/or hearing impaired. *Id.*; *supra* Section VI.B.2.

d) Claim 20

[20c] interpreting, using a microprocessor included in the portable, self-contained movement measuring device, said physical movement data based on user-defined operational parameters and a real-time clock;

152. As previously discussed, the Ono-Hutchings microprocessor interprets physical movement data based on user-defined operational parameters. APPLE-1101, 13:44-45, 14:65-16:27, FIG. 18; APPLE-1102, 9:49-10:18; *supra* Ground 1, [20c]. Ono further teaches, in some examples, that the processes are "executed in accordance with the time-counting timing, i.e., once per second." APPLE-1101, 9:44-48, 12:10-47. In Ono's FIG. 18, the processor interprets/analyzes the movement data "when a time period of 10 sec has lapsed" and "at which data are taken in every ten seconds." APPLE-1101, 14:65-16:27.

153. Also previously discussed, Ono-Hutchings-Amano yields a device with a watch circuit as a real-time clock connected to the microprocessor from which the microprocessor "reads out the current clock time." *Supra* Section VI.B.1-VI.B.2;

supra Ground 2, [1h]; APPLE-1103, 16:43-47, 20:38-43, 21:53-59, 26:29-58, 28:13-34, 30:19-22, FIG. 1. A POSITA would have found it obvious to implement the microprocessor to interpret/analyze the movement data "when a time period of 10 sec has lapsed" and "at which data are taken in every ten seconds" based on the current clock time read out from the watch circuit. *Id.*

e) Claim 36

36. The device of claim 1, wherein said output indicator is configured to display information signaling the occurrence of the first user-defined event based on the detection of the first user-defined event.

154. As previously discussed, Ono-Hutchings yields a device in which the microprocessor detects user-defined events (that "the distance-walked has reached the target distance OH" and that "the above accumulative number of steps has reached the target number of steps OG") and then signals the occurrence of the user-defined events, as suggested by Ono's steps a_{18} and a_{21}. APPLE-1101, 14:65-16:27; APPLE-1102, 9:49-67; *supra* Ground 1, [1j]. Also previously discussed, Ono-Hutchings-Amano yields a device in which the microprocessor signals the occurrence of user-defined events by displaying a visual message on the display screen. APPLE-1103, 16:36-38, 19:41-46, 21:43-45, 26:40-44, 26:53-58, 28:53-57, 29:60-63, 30:39-42, 46:1-32, FIG. 1; *supra* Section VI.B.1-VI.B.2; *supra* Ground 2, claim 9. Accordingly, the Ono-Hutchings-Amano device displays information signaling the occurrence of the user-defined event based on the detection of the user-defined event. *Id.*

f) Claim 40

40. The device of claim 39, wherein said output indicator is configured to display information signaling the occurrence of the first user-defined event when the movement data reaches the predetermined threshold.

155. As previously discussed, in Ono-Hutchings, the user-defined event is detected when the movement data reaches the predetermined threshold. *Supra* Ground 1, [1d], [1e], claim 39; APPLE-1101, 13:40-42, 13:51-61, 15:47-16:13, 18:28-19:17, 20:8-15, FIGS. 18, 20-21; APPLE-1102, 9:49-67. Also previously discussed, the Ono-Hutchings-Amano device displays information signaling the occurrence of the user-defined event based on the detection of the user-defined event. *Id.*; APPLE-1103, 16:36-38, 19:41-46, 21:43-45, 26:40-44, 26:53-58, 28:53-57, 29:60-63, 30:39-42, 46:1-32, FIG. 1; *supra* Section VI.B.1-VI.B.2; *supra* Ground 2, claim 9. Accordingly, the Ono-Hutchings-Amano device displays information signaling the occurrence of the user-defined event, which is detected when the movement data reaches the predetermined threshold. *Id.*

C. GROUND 3A—Claims 1-5, 8, 10, 20, 25, 30, 31, 39, 41, 42, 45-47, 49, and 61-65 are Obvious based on Ono in view of Hutchings and Conlan

1. Overview of Conlan

156. Conlan is directed to an "activity monitor adapted to be worn on the non-dominant wrist of a subject." APPLE-1010, Abstract. Conlan's activity monitor monitors activity "without restriction of the subject's movement" and "includes a movement sensor by which the full range of a subject's movement, even that which is visually imperceptible, can be detected." APPLE-1010, 2:52-63. Conlan explains that its activity monitor can be used to study "virtually any form of human mobility" including "athletic exertion." APPLE-1010, 17:35-40.

157. Conlan teaches that the activity monitor includes "user-input pushbutton switches" that "allow the subject to indicate the occurrence of a particular event." APPLE-1010, 6:38-46. When depressed, the switches "cause that occurrence to be recorded in the internal memory of the monitor." *Id*. These pushbutton switches are illustrated below in Conlan's FIG. 6.

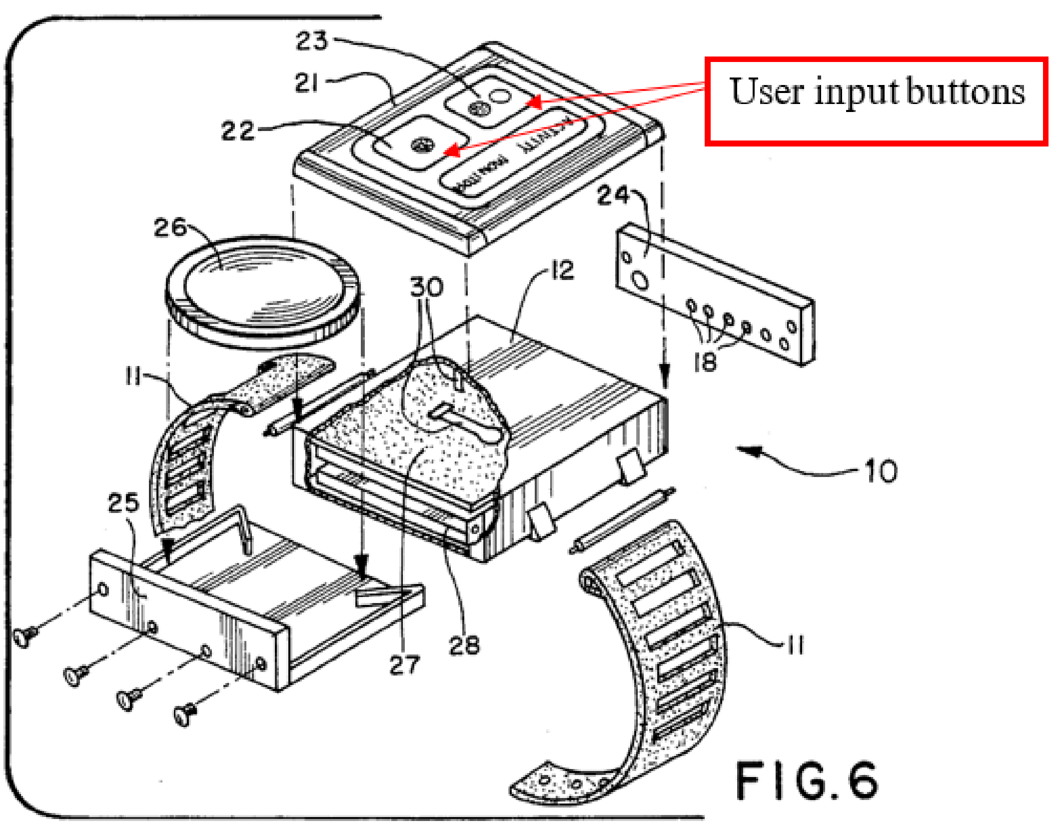
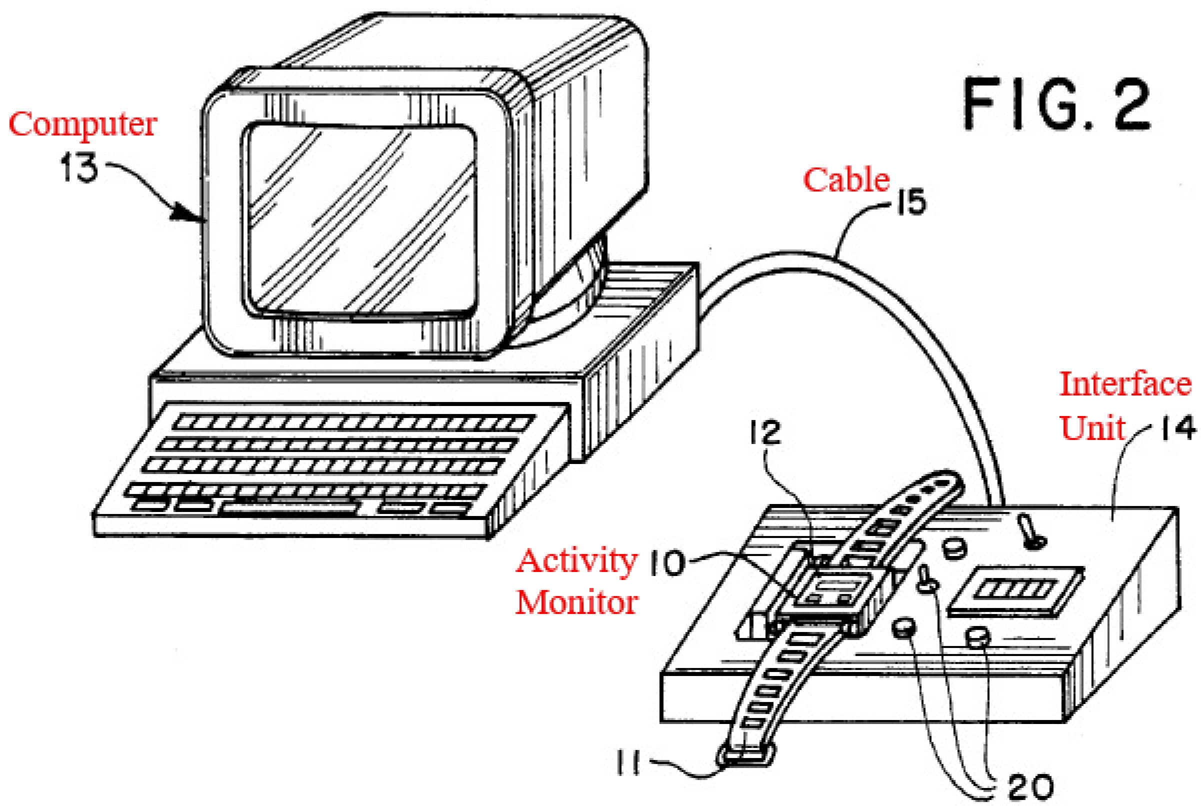


FIG. 6

APPLE-1010, FIG. 6

158. Conlan discloses that "the user may also choose the type of data which is to be recorded," including digitized data signals representative of the waveform from a sensor circuit. APPLE-1010, 8:62-65, 10:37-40, 11:64-12:13, 17:3-5, 18:66-19:2, 20:12-32, TABLE 2.

159. Conlan's activity monitor 10 can be connected to computer 13 via an interface unit 14 and cable 15. APPLE-1010, 5:55-6:23.



APPLE-1010, FIG. 2

160. Conlan teaches that software on the activity monitor 10 and the computer 13 executes operations for obtaining the movement data and transmitting it to computer 13 for display. APPLE-1010, 5:64-6:23. For example, Conlan's activity monitor includes a microprocessor that executes "software by which the configuration of the various circuits of the monitor are controlled" and a memory that stores "software to control the monitor components and… data obtained from the operation of the monitor." APPLE-1010, 4:5-46, 10:6-65. The software also includes instructions for transmitting data from the activity monitor to the computer for further processing. APPLE-1010, 4:20-57. The receiving computer 13 includes "necessary software for accomplishing the down-loading [*sic*] of data from the monitor and the uploading of operating instructions to the monitor." APPLE-1010, 6:1-17. The computer's software can also generate "a wide variety of written reports and displays… from the data collected by the [activity] monitor." APPLE-1010, 6:18-37.

2. Ono-Hutchings-Conlan Combination

161. In pursuing specific design options for the Ono-Hutchings device, the POSITA would have explored prior art references like Conlan that describe a wrist-mounted activity monitor for monitoring activity of the human body. APPLE-1010, 1:14-19, 2:48-63, 5:55-63, 17:35-40. A POSITA would have been motivated and would have found it obvious to implement the Ono-Hutchings device as suggested by Conlan to include user-input pushbuttons that are each assigned to an event (e.g., target step count or target distance has been reached) and when depressed causes the device to record the occurrence of the event specified by the user input button. APPLE-1010, 6:39-53, 11:58-62, 19:14-17, 20:3-11. Additionally, a POSITA would have found it obvious to implement the Ono-Hutchings device to allow the user to choose to record digitized data signals representative of a waveform from the movement sensor and the microprocessor to store such data in memory based on the user selection. APPLE-1010, 8:62-65, 10:37-40, 11:64-12:13, 17:3-5, 18:66-19:2, 20:12-32, TABLE 2. Further, a POSITA would have found it obvious to implement the device to communicate with a personal computer for downloading data collected by the device to the computer and for uploading operating parameters from the computer to the device. APPLE-1010, 4:47-56, 5:66-6:37.

162. The POSITA would have been motivated to include pushbuttons for recording occurrences of events as suggested by Conlan. APPLE-1010, 6:39-53, 11:58-62, 19:14-17, 20:3-11. Conlan discloses that "the user may assign definitions, or 'event variables' to user input switches" and "upon occurrence of dizziness or pain, the subject may... depress one of the push button switches to cause that occurrence to be recorded in the internal memory of the monitor" and "operation of the switches may cause one or more markers to appear in the data recorded in RAM 48 depending on the meaning assigned to them." *Id*. In other words, when an event occurs, such as dizziness or pain, the user can activate one of the buttons, which triggers recording of the event, along with the time of the event, in the RAM. *Id.* In this regard, the input pushbuttons of Conlan would be used in the Ono-Hutchings device as a means for causing user-defined event information to be stored, including the time of the event. *Id.*; *see, e.g.,* APPLE-1009, 2:38-40, 24:10-12, 24:20-24. This would advantageously allow the associated data to subsequently be retrieved, processed, or displayed in a particular way. *Id*. For example, movement data for a type of event may be stored separately from movement data for another type of event. *Id.* Movement data for a type of event may be displayed or provided to the user if the user is only interested in movement data related to that type of event. *Id.* The identification of event-specific data would allow the user to better understand and monitor patterns, trends, and progress in exercise activity related to the event and to vary the exercise program and targets based on occurrence of an event (e.g., reaching a target). *Id.*; *see, e.g.,* APPLE-1009, 1:34-37, 2:7-16, 2:40-44; APPLE-1104, 2:25-30.

163. The POSITA would have been also motivated to implement the Ono-Hutchings device to allow the user to choose to record digitized data signals representative of a waveform from the movement sensor and the microprocessor to store such data in memory based on the user selection as suggested by Conlan. APPLE-1010, 8:62-65, 10:37-40, 11:64-12:13, 17:3-5, 18:66-19:2, 20:12-32, TABLE 2. Doing so would beneficially provide the user with the option to choosing whether to save digitized data signals representative of a waveform from the movement sensor based on the user's desire for detail and memory conservation. *Id.* A POSITA would have found obvious to provide the user with the option of saving digitized data signals representative of a waveform from the movement sensor if the user desires more detail at the expense of using more memory. *Id.* Additionally, providing the user with the option to save digitized data signals representative of a waveform from the movement sensor allows the user to monitor and study detailed exercise activity and athletic exertion, such as time periods of resting, walking, jogging, and running. APPLE-1010, 17:35-40. As Ono demonstrates, the accelerometer produces different waveforms for various levels of physical exertion and different arm positions. APPLE-1101, 2:42-46, 5:63-6:1, 6:41-48, 7:20-27, 8:16-42, FIGS. 6A-6C, 7A-7D. By storing digitized data signals representative of a waveform, the user can later view, analyze, and compare the waveforms to better understand and monitor patterns, trends, and progress in exercise activity and to vary the exercise program. *See, e.g.,* APPLE-1009, 1:34-37, 2:7-16, 2:40-44; APPLE-1104, 2:25-30.

164. Additionally, Conlan discloses that the capacity of memory devices were constrained. APPLE-1010, 1:65-2:2, 8:65-67, 18:66-19:2. A POSITA would have been motivated to implement the device to communicate with a personal computer for downloading data collected by the device to the computer as suggested by

Conlan. APPLE-1010, 4:47-56, 5:66-6:37. Doing so would advantageously allow data to be transferred to and stored on the computer, thereby allowing the device's memory to be freed for storing data for subsequent exercise sessions. *Id.* Doing so would also beneficially allow data to be further analyzed by a computer with more processing capability, data to be printed via the computer, and more data to be viewed simultaneously on a larger display connected to the computer. *Id.* Further, the computer could correlate and combine the data with data from other exercise and health equipment connected to the computer to beneficially provide the user with comprehensive analysis and feedback concerning the user's progress in reaching his or her exercise goals. *Id.*; *see, e.g.,* APPLE-1104, 3:43-53, 3:63-65, 6:6-13, 11:5-34, FIGS. 8a-8c.

165. Further, Ono describes the user setting user-defined operational parameters using switches on Ono's device. APPLE-1101, 13:25-27, 13:34-42, 13:51-61, 16:18-17:50, 18:14-19, 18:28-19:67, 20:8-15, FIGS. 20-21. To set the user-defined operational parameters, the user presses specific combinations of switches and cycles through various display screens using the switches. *Id.* A POSITA would have been motivated to implement the device to communicate with a personal computer for uploading operating parameters from the computer to the device as suggested by Conlan to beneficially provide the user with an additional and more user-friendly user interface on the computer for setting the user-defined operational parameters. APPLE-1010, 4:47-56, 5:66-6:37. For instance, the computer could provide a single graphical user interface screen with all the user-defined operational parameters displayed, and the user could use a keyboard and mouse to quickly and easily set the operational parameters. *Id.*

166. Moreover, a POSITA would have viewed the implementation of the Ono-Hutchings device in a manner that applied Conlan's suggested features as merely the predictable result (e.g., a pedometer that includes pushbuttons for recording occurrences of events and the microprocessor storing in memory a digital waveform representative of raw movement data from the movement sensor, and that communicates with a personal computer for downloading data collected by the device to the computer and for uploading operating parameters from the computer to the device) of combining known prior elements according to known methods. The POSITA would have appreciated that the Ono-Hutchings-Conlan combination does not change the hallmark aspects of these references, and any modifications needed to incorporate Conlan's teachings into the Ono-Hutchings device to provide the above benefits would have been predictable with a foreseeable chance of success and within the skill of a POSITA. The respective teachings would work together in combination just as they did apart, with Conlan's suggestion merely improving/adding to the Ono-Hutchings device.

3. Analysis of the Claims

167. Ground 3A relies on the additional disclosure of Conlan for the claim elements below. Integration of Conlan does not disturb the aspects of Ono-Hutchings mapped to the claim elements. The Ground 3A Ono-Hutchings analysis is substantively identical to and incorporates the Ground 1 Ono-Hutchings analysis in all respects. To avoid repetition, and because the analysis of Ono-Hutchings to the claim elements is identical, only selected claim elements are addressed below.

a) Claim 1

[1d] said microprocessor capable of receiving, interpreting, storing and responding to said movement data based on user-defined operational parameters,

168. As previously discussed, Ono-Hutchings provides that the microprocessor receives, interprets, stores, and responds to movement data based on user-defined operational parameters. *Supra* Ground 1, 1[d]. To the extent that this claim element requires that the movement data stored by the microprocessor is data measured by the movement sensor and if Ono-Hutchings were considered to not disclose storing such data, Conlan describes that "the user may also choose the type of data which is to be recorded," including digitized data signals representative of the waveform from a sensor circuit. APPLE-1010, 8:62-65, 10:37-40, 11:64-12:13, 17:3-5, 18:66-19:2, 20:12-32, TABLE 2, FIG. 8. Conlan's processor transfers the digitized data signals to RAM for storage. *Id.* The user selection of recording certain data is a user-defined operational parameter that affects the operation of the device by dictating the data stored by the processor. *Id*. For the reasons previously discussed, a POSITA would have been motivated and would have found it obvious to implement the Ono-Hutchings device to allow the user to choose to record movement data measured by the movement sensor and the microprocessor to store such data in RAM based on the user selection as suggested by Conlan. *Supra* Section VI.C.2; APPLE-1010, 8:62-65, 10:37-40, 11:64-12:13, 17:3-5, 18:66-19:2, 20:12-32, TABLE 2, FIG. 8.

[1f] storing first event information related to the detected first user-defined event along with first time stamp information reflecting a time at which the movement data causing the first user-defined event occurred;

169. If the Ono-Hutchings storing in RAM of the user-defined operational parameters and the movement data used to detect the user-defined event along with time stamp information as previously discussed (*supra* Ground 1, 1[f]) were considered to not provide this claim element, Conlan teaches that the activity monitor includes "user-input pushbutton switches" that a user assigns to events and that "allow the subject to indicate the occurrence of a particular event." APPLE-1010, 6:39-53, 11:58-62, 19:14-17, 20:3-11. When depressed, the switches "cause that occurrence to be recorded in the internal memory of the monitor" by causing "one or more markers to appear in the data recorded in RAM" depending on the events assigned to the switches. *Id*. Additionally, "pressing the event button places a time marker in the event channel" and "[t]he event channel... and activity data are presented as overlapping data." *Id.*

170. As previously discussed, a POSITA would have found it obvious to implement the Ono-Hutchings device as suggested by Conlan to include a user-input pushbutton that when depressed causes the device to store in memory the occurrence of the event. *Id.*; *supra* Section VI.C.2. When the user is notified of the event (e.g., that the target distance or target number of steps has been reached) via an alarm sound and desires to record the occurrence of the event in RAM, the user presses a pushbutton which causes the microprocessor to indicate the occurrence of the event by storing markers, including a time marker, in the data recorded in RAM (as suggested by Conlan) along with and in association with the movement data and the date and time information of Ono-Hutchings (*supra* Ground 1, [1f]). *Id.* The marker indicating the occurrence of the event is event information, and the time marker is a timestamp that reflects either an absolute or relative time at which the movement data causing the first user-defined event occurred. *Id.*

[1i] memory for storing said movement data; and

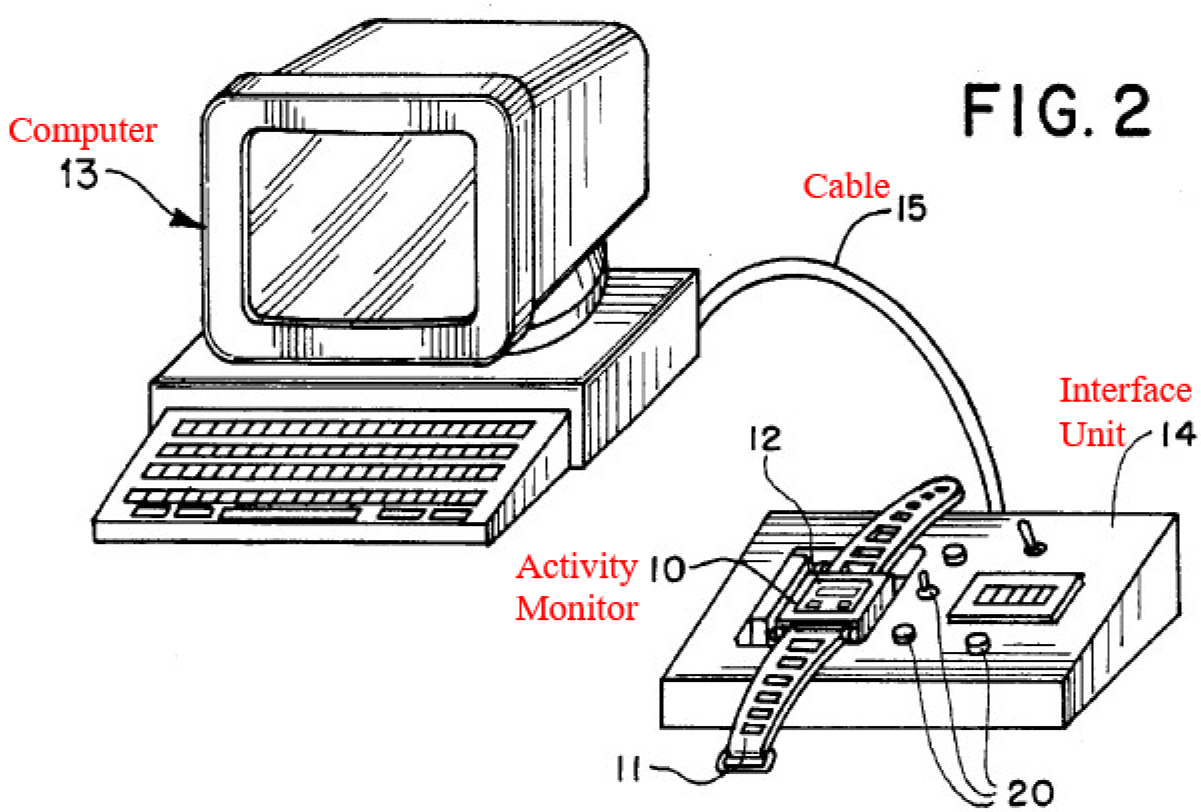
171. Ono-Hutchings-Conlan renders [1d] obvious for similar reasons as discussed in Ground 3A, [1d]. *Supra* Ground 3A, [1d].

b) Claim 2

2. The device of claim 1 further comprising at least one input/output port connected to said microprocessor for downloading said data and uploading said operational parameters to and from a computer.

172. Conlan discloses that its activity monitor 10 (monitoring device) and computer 13 are connected through "***a data port*** of computer 13 by means of a conventional RS-232 cable 15 or the like." APPLE-1010, 6:1-17, 10:55-56, FIG. 2 (reproduced below). A POSITA would have understood that a port would be needed on the computer and on the measuring device including the microprocessor to connect two ends of the cable.

FIG. 2



APPLE-1010, FIG. 2

173. Conlan further discloses that "[d]ata collected by the monitor over the collection period is downloaded at the end of the period to a personal computer 13 which... contain[s] necessary software for accomplishing the down-loading [*sic*] of data from the monitor and the uploading of operating instructions to the monitor." APPLE-1010, 5:66-6:37. For the reasons previously discussed, it would have been obvious to a POSITA to implement the Ono-Hutchings device as suggested by Conlan to include at least one port connected to the microprocessor for downloading movement data to and uploading operational parameters from the computer. *Id.*; *supra* Section VI.C.2.

c) Claim 20

[20d] storing said data in memory;

174. Ono-Hutchings-Conlan renders [20d] obvious for similar reasons as discussed in Ground 3A, [1d]. *Supra* Ground 3A, [1d].

[20f] storing, in said memory, first event information related to the detected first user-defined event along with first time stamp information reflecting a time at which the movement data causing the first user-defined event occurred.

175. Ono-Hutchings-Conlan renders [20f] obvious for similar reasons as discussed in Ground 3A, [1f]. *Supra* Ground 3A, [1f].

d) Claim 30

30. The device of claim 1, wherein said microprocessor is configured to store, in said memory, date information associated with the first time stamp information.

176. Ono-Hutchings-Conlan renders claim 30 obvious for similar reasons as discussed in Ground 3A, [1f]. *Supra* Ground 3A, [1f].

e) Claim 31

31. The device of claim 1, wherein said microprocessor is configured to retrieve said first time stamp information from said real-time clock and associate the retrieved first time stamp information with said first user-defined event.

177. As previously discussed, Ono-Hutchings yields a device including a real-time clock connected to the microprocessor for obtaining "time-data, i.e., the present-time data comprising minute-data, hour-data, date-data and month-data" and the microprocessor stores the present time data at which the movement data causing the user-defined event occurred. APPLE-1101, 9:14-31, 13:31-33, 12:10-12, FIG. 14; *supra* Ground 1, [1f], [1h], claim 30. Also previously discussed for Ono-Hutchings-Conlan, the microprocessor indicates the occurrence of the event by storing an event marker indicating the occurrence of the event and a time marker, which is a time stamp that reflects either an absolute or relative time at which the movement data causing the first user-defined event occurred, in the data recorded in RAM (as suggested by Conlan) along with and in association with the movement data and the date and time information of Ono-Hutchings. APPLE-

1010, 6:39-53, 11:58-62, 19:14-17, 20:3-11; *supra* Ground 1, [1f], Ground 3A, [1f]. Accordingly, the Ono-Hutchings-Conlan microprocessor retrieves the time stamp from the real-time clock, and associates the retrieved time stamp and user-defined event using a time marker stored with the event marker and movement data. *Id*.

f) Claim 41

41. The device of claim 39, wherein said memory is configured to store said first event information indicating that the predetermined threshold is met.

178. Ono-Hutchings-Conlan renders claim 41 obvious for similar reasons as discussed in Ground 3A, [1f]. *Supra* Ground 3A, [1f]. The event marker that is stored in RAM indicates that the target distance or the target number of steps (predetermined threshold) is met. *Id.*

g) Claim 42

42. The device of claim 41, wherein said memory is configured to store the first time stamp information in association with said first event information.

179. Ono-Hutchings-Conlan renders claim 42 obvious for similar reasons as discussed in Ground 3A, [1f]. *Supra* Ground 3A, [1f].

h) Claim 45

45. The device of claim 1, wherein said movement data stored in the memory is configured to be downloaded to a computer.

180. Ono-Hutchings-Conlan renders claim 45 obvious for similar reasons as discussed in Ground 3A, [1d] and claim 2. *Supra* Ground 3A, [1d], claim 2.

Additionally, Conlan discloses that the microprocessor "executes the instructions stored in the ROM and/or RAM by retrieving data and/or indications from the RAM or ROM, processing data, and returning data to the RAM [or] I/O ports in a manner well known to the art." APPLE-1010, 10:46-50. Accordingly, Ono-Hutchings-Conlan yields a device in which the movement data stored in RAM is downloaded to the computer.

i) Claim 46

46. The device of claim 45, further comprising: software configured to communicate with external software, wherein the external software is configured to present the downloaded movement data to the user.

181. Conlan discloses that its activity monitor includes a microprocessor that executes "software by which the configuration of the various circuits of the [activity] monitor are controlled" and "software to control the monitor components and in which data obtained from the operation of the [activity] monitor is stored." APPLE-1010, 4:5-46, 10:6-65. The software also includes instructions for transmitting data from the activity monitor to the computer for further processing. APPLE-1010, 4:20-57. The receiving computer includes "necessary software for accomplishing the down-loading [*sic*] of data from the monitor and the uploading of operating instructions to the monitor." APPLE-1010, 6:1-17. The computer's software can also generate "a wide variety of written reports and displays… from the data collected by the [activity] monitor." APPLE-1010, 6:18-37. Accordingly, Ono-Hutchings-Conlan yields a device including software that communicates with external software on the computer that presents the downloaded movement data to the user.

j) Claim 47

47. The device of claim 46, wherein said external software is configured to run on the computer.

182. Ono-Hutchings-Conlan renders claim 47 obvious for similar reasons as discussed in Ground 3A, claim 46. *Supra* Ground 3A, claim 46.

k) Claim 49

49. The device of claim 46, wherein said external software is configured to interpret said movement data and produce at least one report.

183. Ono-Hutchings-Conlan renders claim 47 obvious for similar reasons as discussed in claim Ground 3A, claim 46. *Supra* Ground 3A, claim 46.

D. GROUND 3B—Claims 48, 50, and 51 are Obvious based on Ono in view of Hutchings, Conlan, and Hickman

1. Overview of Hickman

184. Hickman describes a remote computer associated with a computerized exercise and health equipment. APPLE-1104, 2:9-16, 3:43-49. The remote computer is used to upload information from exercise and health equipment to be analyzed by a user at the remote computer. APPLE-1104, 2:30-41, 10:37-39, 10:57-64. Hickman's FIGS. 8a-8b illustrate examples of types of data analysis that can be performed, displayed, and printed by the remote computer. APPLE-1104, 3:32-33, 11:5-26, FIGS. 8a, 8b. FIG. 8a shows a graph of exercise activity, and FIG. 8b shows a summary of daily exercise activity. *Id.*

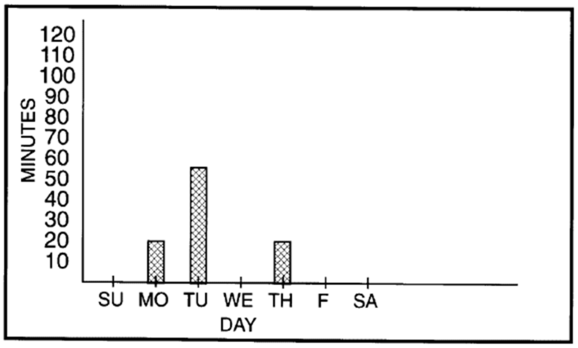


Fig. 8a

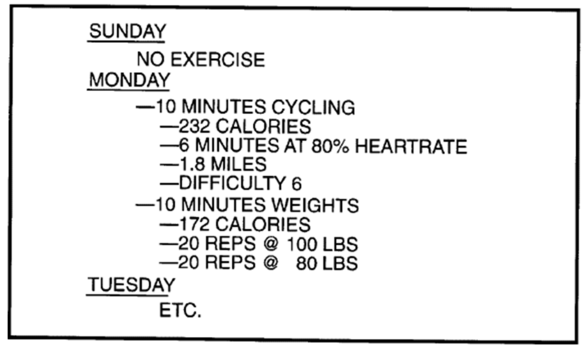


Fig. 8b

Hickman, FIGS. 8a-8b

2. Ono-Hutchings-Conlan-Hickman Combination

185. As previously discussed, Ono-Hutchings-Conlan yields a remote computer with software for downloading data from the monitoring device and generating "a wide variety of written reports and displays… from the data collected by the [device]." APPLE-1010, 6:1-17, 6:18-37. In pursuing specific design options for the Ono-Hutchings-Conlan system, the POSITA would have explored prior art references like Hickman that provide details regarding the types of analysis, printed reports, and displays that can be generated by the user of a remote computer from the data collected by the monitoring device. APPLE-1104, 11:5-26, FIGS. 8a, 8b. A POSITA would have found it obvious to implement the Ono-Hutchings-Conlan system as suggested by Hickman such that the remote computer's software allows the user to analyze the downloaded movement data and produce history reports. *Id.* A POSITA would have been motivated to implement the Ono-Hutchings-Conlan system to provide the printed reports and displays suggested by Hickman to beneficially provide the user with comprehensive analysis and feedback concerning the user's progress in reaching his or her exercise goals. APPLE-1104, 3:43-53, 3:63-65, 6:6-13, 11:5-34, FIGS. 8a-8c.

186. Moreover, a POSITA would have viewed the implementation of the Ono-Hutchings-Conlan device in a manner that applied Hickman's suggested features as merely the predictable result (e.g., a remote computer with software that allows the user to analyze the downloaded movement data and produce history reports) of combining known prior elements according to known methods. The POSITA would have appreciated that the Ono-Hutchings-Conlan-Hickman combination does not change the hallmark aspects of these references, and any modifications needed to incorporate Hickman's teachings into the Ono-Hutchings-Conlan device to provide the above benefits would have been predictable with a foreseeable chance of success and within the skill of a POSITA. The respective teachings would work together in combination just as they did apart, with Hickman's suggestion merely improving/adding to the Ono-Hutchings-Conlan device.

3. Analysis of the Claims

187. Ground 3B relies on the additional disclosure of Hickman for the claim elements below. Integration of Hickman does not disturb the aspects of Ono-Hutchings-Conlan mapped to the elements from which the elements below depend. The Ground 3B Ono-Hutchings-Conlan-Hickman analysis incorporates the Ground 3A Ono-Hutchings-Conlan analysis in all respects.

a) Claim 48

48. The device of claim 47, wherein said downloaded movement data is configured to be analyzed by said user via said external software.

188. Ono-Hutchings-Conlan-Hickman renders claim 48 obvious for similar reasons as discussed in Sections VI.D.1-VI.D.2. *Supra* Sections VI.D.1-VI.D.2.

b) Claim 50

50. The device of claim 46, wherein said external software is configured to interpret said movement data and produce at least one history report.

189. Ono-Hutchings-Conlan-Hickman renders claim 48 obvious for similar reasons as discussed in Sections VI.D.1-VI.D.2. *Supra* Sections VI.D.1-VI.D.2. Hickman's reports are history reports because they show the user's history of weekly and daily exercise activity. APPLE-1104, 3:32-33, 11:5-26, FIGS. 8a, 8b.

c) Claim 51

51. The device of claim 50, wherein said at least one history report includes dates and times of said movement data.

190. Ono-Hutchings-Conlan-Hickman renders claim 48 obvious for similar reasons as discussed in Sections VI.D.1-VI.D.2 and Ground 3B, claim 50. *Supra*

Sections VI.D.1-VI.D.2; *supra* Ground 3B, claim 50. As shown in Hickman's FIGS. 8a and 8b, the displayed history reports include days of the week (dates) and duration (times) of the movement data. APPLE-1104, 3:32-33, 11:5-26.

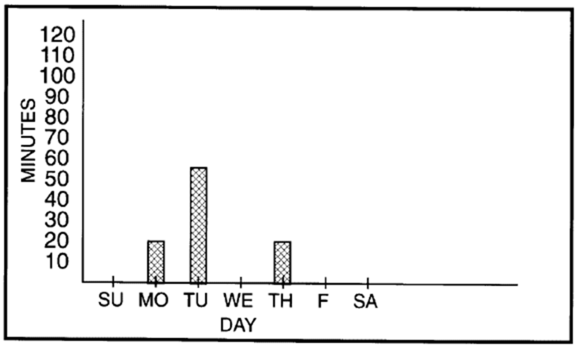


Fig. 8a

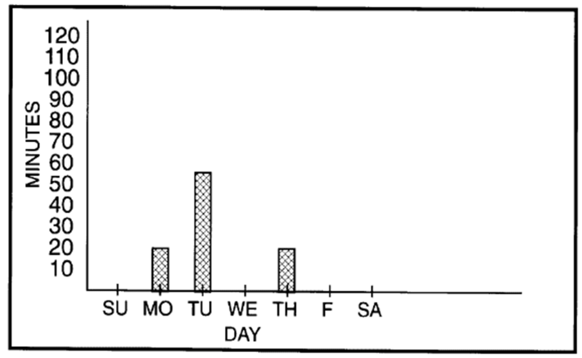


Fig. 8a

Hickman, FIGS. 8a-8b

191. Further, as previously discussed, Ono-Hutchings' microprocessor stores the date, duration, total step count, total distance-walked, and total calorie-consumption in registers D of RAM for later retrieval and display. APPLE-1101, 13:65-14:29, 16:24-25, 17:10-50, 18:20-24, 20:37-53, FIGS. 15, 20 (steps C_{14}-C_{15}), 23; *supra* Ground 1, [1d]. A POSITA would have found it obvious that such data stored in RAM of the Ono-Hutchings-Conlan-Hickman device is downloaded to the remote computer and analyzed by the remote computer's software to generate the history report, which would include the dates and times of the movement data. *Id.*; APPLE-1104, 3:32-33, 11:5-26, FIGS. 8a, 8b.

E. GROUND 4—Claims 1, 3-5, 8, 10, 20, 25, 30, 39, 41, 42, 61-65, 144, and 147 are Obvious based on Ono in view of Hutchings and Kaufman

1. Overview of Kaufman

192. Kaufman describes an "exercise monitor... provided in a case or package that may be worn on a user's wrist," as shown in FIG. 5. APPLE-1105, 4:51-54, 7:4-6, 16:54-55, FIG. 5.

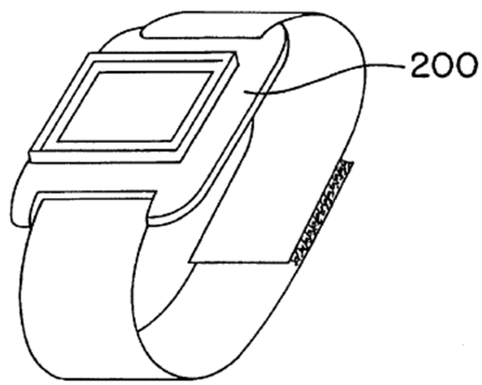


FIG. 5

Kaufman, FIG. 5

193. Kaufman discloses that "by providing the exercise monitor in a watch case, the device is capable of detecting exercises that involve arm movement, such as walking or running." APPLE-1105, 16:59-62. "The exercise monitor utilizes an exercise motion detector, such as an accelerometer, for detecting the repetitive motion associated with the performance of successive exercise repetitions." APPLE-1105, 4:47-51, 16:55-59. The exercise monitor "enable[s] the user to set a desired exercise rate" with "the selected rate being variable between a predetermined minimum value and a predetermined maximum value (i.e., a tempo)." APPLE-1105, 5:35-48. "The selection of the desired exercise rate, in repetitions per minute, is made by setting a repetition rate selector 12." APPLE-1105, 7:21-35. Kaufman's exercise monitor includes a microprocessor "programmed using a known clock routine to monitor the time duration between successively performed repetitions, and, by comparing this duration with the repetition rate selected on the repetition rate selector 12, determine whether the user is proceeding too slowly. In such cases, alarm indicia such as a beep or verbal warning may be issued. For example, if the exercise is being performed too slowly, the device could be programmed to synthesize the words 'pick up the pace', 'faster', and the like." APPLE-1105, 10:23-32. A schematic diagram of Kaufman's exercise monitor is shown in FIG. 1 reproduced below. APPLE-1105, 6:59-61, 7:10-27.

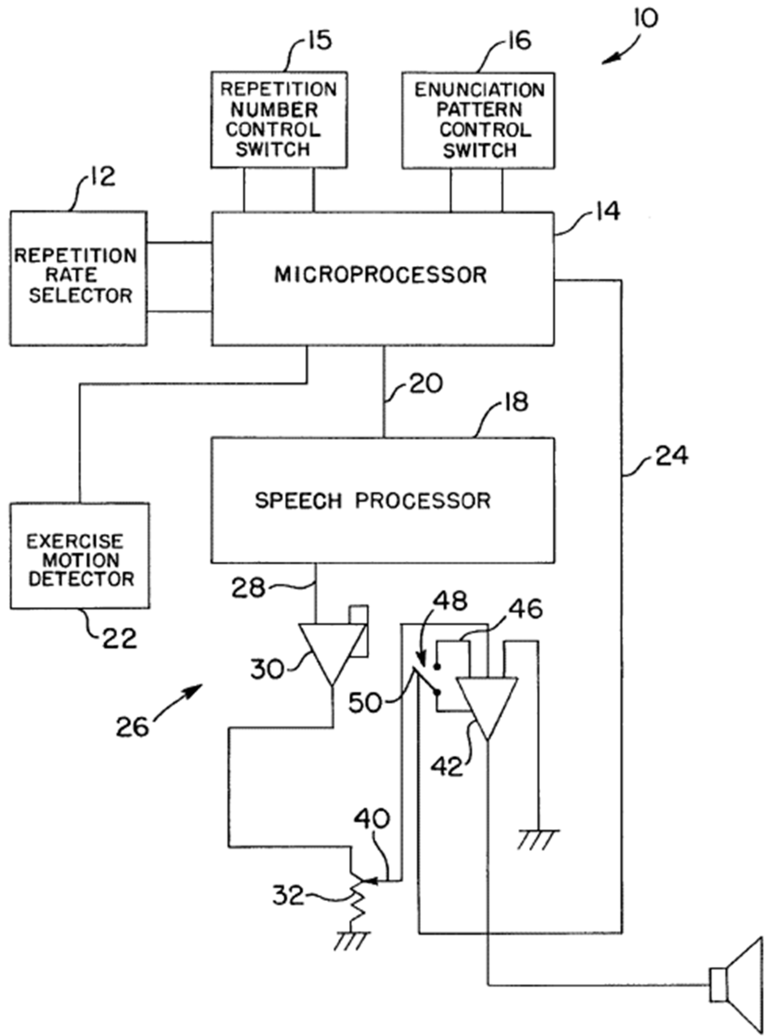


FIG. 1

Kaufman, FIG. 1

2. Ono-Hutchings-Kaufman Combination

194. As previously discussed, Ono describes calculating, storing, and displaying the number of steps per minute (also referred to as a pace or pitch). APPLE-1101, 14:65-68, 15:42-45, 20:26-36, FIG. 18 (step a_{12}); *supra* Ground 1, 1[d]. Ono discloses that by displaying the walking pace, "the user of the pedometer can confirm whether or not his or her own walking pace is kept in the range of the pace which has been previously set for walking, exercise walking or jogging." APPLE-1101, 20:26-36. The Ono-Hutchings device allows a user to define operational parameters, including selection of run mode, step-counting mode, step-counting mode start/stop, and exercise mode, and setting of stride lengths, target distance, and target number of steps. APPLE-1101, 13:25-27, 13:34-42, 13:51-61, 15:61-16:4, 16:18-17:50, 18:14-19, 18:28-19:67, 20:8-15, FIGS. 20-21; APPLE-1102, 9:48-62, 10:28-30; *supra* Ground 1 [1d].

195. In pursuing specific design options for the Ono-Hutchings device, a POSITA would have explored similar prior art references like Kaufman that describe an exercise monitor in a watch case that detects exercises that involve arm movement, such as walking or running. APPLE-1105, 4:51-54, 7:4-6, 16:54-59, FIG. 5. A POSITA would have been motivated and would have found it obvious to implement the Ono-Hutchings device as suggested by Kaufman to include a repetition rate selector for the user to select the desired exercise rate in steps per minute and to program the microprocessor to monitor the time duration between successive steps, to determine whether the user is traveling too slowly by comparing this duration with the step rate selected on the repetition rate selector, and to cause an alarm sound or synthesized words to be generated if the user is traveling too slowly. APPLE-1105, 5:35-48, 7:21-35, 10:23-32.

196. Kaufman explains that "the most beneficial results of any exercise are obtained when an individual is given a specific, easily understandable performance target, is informed of his or her exercise progress, and is given verbal motivation, coaching, encouragement and instruction." APPLE-1105, 1:56-60. Kaufman thus provides a device "for monitoring a user's performance and offering verbal motivation and encouragement" "to assist the user in maintaining a desired exercise rate" without "the individual [being] required to monitor his or her own performance." *Id.*; APPLE-1105, 3:16-21, 2:48-51, 4:26-29, 7:11-21. A POSITA would have been motivated to use Kaufman's features to leverage the stated benefits of assisting the user in maintaining a desired step rate without the user having to manually check the display and determine his or her own pace. *Id*.

197. Moreover, a POSITA would have viewed the implementation of the Ono-Hutchings device in a manner that applied Kaufman's suggested features as merely the predictable result (e.g., a pedometer that includes a repetition rate selector for the user to select the desired exercise rate in steps per minute and the microprocessor monitoring the time duration between successive steps, determining whether the user is traveling too slowly by comparing this duration with the step rate selected on the repetition rate selector, and causing an alarm sound or synthesized words to be generated if the user is traveling too slowly) of combining known prior elements according to known methods. The POSITA would have appreciated that the Ono-Hutchings-Kaufman combination does not change the hallmark aspects of these references, and any modifications needed to incorporate Kaufman's teachings into the Ono-Hutchings device to provide the above benefits would have been predictable with a foreseeable chance of success and within the skill of a POSITA. The respective teachings would work together in combination just as they did apart, with Kaufman's suggestion merely improving/adding to the Ono-Hutchings device.

3. Analysis of the Claims

198. Ground 4 relies on the additional disclosure of Kaufman for the claim elements below. Integration of Kaufman does not disturb the aspects of Ono-Hutchings mapped to the claim elements. The Ground 4 Ono-Hutchings analysis is substantively identical to and incorporates the Ground 1 Ono-Hutchings analysis in all respects. To avoid repetition, and because the analysis of Ono-Hutchings to the claim elements is identical, only selected claim elements are addressed below.

a) Claim 1

[1d] said microprocessor capable of receiving, interpreting, storing and responding to said movement data based on user-defined operational parameters,

199. As previously discussed, Ono-Hutchings yields a device in which the microprocessor receives movement data, including the number of steps taken in the last 10 seconds, and calculates, stores, and displays the number of steps per minute (also referred to as a pace or pitch) after the user selects and starts the step-counting mode. APPLE-1101, 14:65-16:27, 20:26-36, FIG. 18; *supra* Ground 1, 1[d]. In addition to Ono's and Hutching's disclosure previously discussed, Kaufman describes an exercise monitor that "enable[s] the user to set a desired exercise rate" with "the selected rate being variable between a predetermined minimum value and a predetermined maximum value (i.e., a tempo)." APPLE-1105, 5:35-48. "The selection of the desired exercise rate, in repetitions per minute, is made by setting a repetition rate selector 12." APPLE-1105, 7:21-35. "The output signal of the repetition rate selector 12 is input to the programmed microprocessor 14." APPLE-1105, 7:48-50. The microprocessor is "programmed using a known clock routine to monitor the time duration between successively performed repetitions, and, by comparing this duration with the repetition rate selected on the repetition rate selector 12, determine whether the user is proceeding too slowly. In such cases, alarm indicia such as a beep or verbal warning may be issued. For example, if the exercise is being performed too slowly, the device could be programmed to synthesize the words 'pick up the pace', 'faster', and the like." APPLE-1105, 10:23-32. Kaufman's exercise rate selected by the user is a user-defined operational parameter that affects the operations performed by the device.

200. Based on Ono's, Hutchings', and Kaufman's teachings, Ono-Hutchings-Kaufman yields a device that allows a user to define operational parameters, including selection of exercise rate in steps per minute. APPLE-1105, 5:35-48, 7:21-35. When the user selects and starts the step-counting mode, the microprocessor receives movement data including the number of steps taken in the last 10 seconds (as suggested by Ono's step a_{10}), interprets/analyzes movement data including determining the time duration between successive steps using the clock, comparing this duration with the step rate previously selected by the user, and determining whether the user is proceeding too slowly (as suggested by Kaufman), stores movement data including storing the steps per minute and cumulative number of steps (as suggested by Ono's step a_{12}, a_{19}), and responds to movement data including causing an alarm sound or synthesized words to be generated if the user is traveling too slowly (as suggested by Kaufman). APPLE-1101, 14:65-16:27, 20:26-36, FIG. 18; APPLE-1105, 10:23-32. As previously discussed, a POSITA would have been motivated and would have found it obvious to implement the Ono-Hutchings device as suggested by Kaufman to include the repetition rate features to leverage the stated benefits of assisting the user in maintaining a desired step rate without the user having to manually check the display and determine his or her own pace. APPLE-1105, 1:56-60, 3:16-21, 2:48-51, 4:26-29, 7:11-21; *supra* Section VI.E.2.

[1e] detecting a first user-defined event based on the movement data and at least one of the user-defined operational parameters regarding the movement data, and

201. As discussed above, Ono-Hutchings-Kaufman yields a device in which the microprocessor interprets/analyzes movement data including monitoring the time duration between successive steps using the clock, comparing this duration with the step rate previously selected by the user, and determining whether the user is proceeding too slowly (as suggested by Kaufman), and responds to movement data including causing an alarm sound or synthesized words to be generated if the user is traveling too slowly (as suggested by Kaufman) based on user selection and starting of the step-counting mode and based on the step rate previously set by the user. APPLE-1101, 14:65-16:27, 20:26-36, FIG. 18; APPLE-1105, 10:23-32; *supra* Ground 4, [1d]. In the Ono-Hutchings-Kaufman device, the microprocessor detects a user-defined event (that the user is traveling too slowly as suggested by Kaufman) based on movement data (number of steps in the last 10 seconds as suggested by Ono and time duration between successive steps as suggested by Kaufman) and at least one of the user-defined operational parameters regarding the movement data (user selection and starting of the step-counting mode as suggested by Ono and user selected step rate as suggested by Kaufman). *Id.*

[1f] storing first event information related to the detected first user-defined event along with first time stamp information reflecting a time at which the movement data causing the first user-defined event occurred;

202. As previously discussed, Ono-Hutchings yields a device in which the microprocessor stores in RAM user-defined operational parameters (the user set modes, stride lengths, target distance, and target number of steps) and movement data (speed, pitch, distance-walked, and accumulative number of steps) related to the detected user-defined event (target distance and/or target step count reached) along with time stamp information (date, time, duration) reflecting a time at which the movement data causing the user-defined event occurred. APPLE-1101, 13:44-14:15, 14:65-16:27, FIGS. 15, 18; APPLE-1102, 9:49-67; *supra* Ground 1, [1f]. Based on Ono's disclosure, a POSITA would have found obvious to implement the Ono-Hutchings-Kaufman device to store in RAM the user selected step rate in addition to the user set modes, stride lengths, target distance, and target number of steps. *Id.*; APPLE-1105, 5:35-48, 7:21-35, 7:48-50, 10:23-32. The selected step rate and the stored movement data are related to the detected user-defined event (that the user is traveling too slowly) and are each event information related to the detected user-defined event. *Id.*; *supra* Ground 4, [1e].

b) Claim 20

[20c] interpreting, using a microprocessor included in the portable, self-contained movement measuring device, said physical movement data based on user-defined operational parameters and a real-time clock;

203. Ono-Hutchings-Kaufman renders [20c] obvious for similar reasons as discussed in Ground 4, [1d]. *Supra* Ground 4, [1d].

[20e] detecting, using the microprocessor, a first user-defined event based on the movement data and at least one of the user-defined operational parameters regarding the movement data; and

204. Ono-Hutchings-Kaufman renders [20e] obvious for similar reasons as discussed in Ground 4, [1e]. *Supra* Ground 4, [1e].

[20f] storing, in said memory, first event information related to the detected first user-defined event along with first time stamp information reflecting a time at which the movement data causing the first user-defined event occurred.

205. Ono-Hutchings-Kaufman renders [20f] obvious for similar reasons as discussed in Ground 4, [1f]. *Supra* Ground 4, [1f].

c) Claim 42

42. The device of claim 41, wherein said memory is configured to store the first time stamp information in association with said first event information.

206. Ono-Hutchings-Kaufman renders claim 42 obvious for similar reasons as discussed in Ground 4, [1f]. *Supra* Ground 4, [1f].

d) Claims 144 and 147

144. The device of claim 1, wherein said first user-defined event is a predetermined type of movement.

147. The device of claim 144, wherein the predetermined type of movement is no movement for a predetermined amount of time.

207. As discussed above, Ono-Hutchings-Kaufman yields a device in which the microprocessor detects that the user is traveling too slowly (a user-defined event) by monitoring the time duration between successive steps using the clock and comparing this duration with the step rate previously selected by the user. APPLE-1105, 10:23-32; *supra* Ground 4, [1d], [1e]. A POSITA would have understood that the microprocessor detects that the user is traveling too slowly when it detects that no step was taken within the time duration required to meet the selected step rate, for example, when the user has stopped walking entirely. *See, e.g.,* APPLE-1104, 8:57-64.

F. GROUND 5A—Claims 1-5, 8-11, 20, 25, 30-32, 36, 39-42, 45-47, 49, 61-65, 144, and 147 are Obvious based on Ono in view of Hutchings, Amano, Conlan, and Kaufman

208. Ground 5A incorporates the Grounds 1, 2, 3A, and 4 analysis in all respects, including the reasons a POSITA would have been motivated to combine the references. To avoid repetition, and because the analysis of Ono-Hutchings-Amano-Conlan-Kaufman to the claim elements incorporates the Grounds 1, 2, 3A, and 4 analysis, only selected claim elements are addressed below.

a) Claim 31

31. The device of claim 1, wherein said microprocessor is configured to retrieve said first time stamp information from said real-time clock and associate the retrieved first time stamp information with said first user-defined event.

209. As previously discussed, Ono-Hutchings-Amano yields a device including a watch circuit as a real-time clock connected to the microprocessor from which the microprocessor "reads out the current clock time." APPLE-1103, 16:43-47, 20:38-43, 21:53-59, 26:29-58, 28:13-34, 30:19-22, FIG. 1; *supra* Section VI.B.2, Ground 2, [1h]. Also previously discussed, the Ono-Hutchings-Kaufman device stores in RAM the user selected step rate and the movement data related to the detected user-defined event (that the user is traveling too slowly), which are each event information related to the detected user-defined event. *Supra* Ground 1, [1f], Ground 4, [1e], [1f]; APPLE-1101, 13:44-14:15, 14:65-16:27, FIGS. 15, 18; APPLE-1102, 9:49-67; APPLE-1105, 5:35-48, 7:21-35, 7:48-50, 10:23-32. As previously discussed for Ono-Hutchings-Conlan, the microprocessor indicates the occurrence of the event by storing an event marker indicating the occurrence of the event and a time marker, which is a time stamp that reflects either an absolute or relative time at which the movement data causing the user-defined event occurred, in the data recorded in RAM (as suggested by Conlan) along with and in association with the movement data and the date and time information of Ono-Hutchings. APPLE-1010, 6:39-53, 11:58-62, 19:14-17, 20:3-11; *supra* Ground 1,

[1f], Ground 3A, [1f]. A POSITA would have found obvious that Ono-Hutchings-Amano-Conlan-Kaufman yields a device in which the microprocessor retrieves the time stamp from the watch circuit (real-time clock) and associates the retrieved time stamp and user-defined event (that the user is traveling too slowly) using a time marker stored with an event marker and movement data.

a) Claim 32

32. The device of claim 31, wherein said microprocessor is configured to retrieve said first time stamp information from said real-time clock based on the detection of the user-defined event.

210. Amano discloses that when "CPU1 recognizes that the user has begun to exercise" based on output from the acceleration sensor, "CPU1 then reads out the clock time from watch circuit 9 and stores this as the exercise-start time in RAM3." APPLE-1103, 20:36-43, 26:29-30. Similarly, when CPU1 "recognizes that the user has suspended exercise" based on output from the acceleration sensor, CPU1 "reads out the current clock time from watch circuit 9, which it records in RAM3 as the exercise-stop time." APPLE-1103, 21:43-56, 26:47-53. "CPU1 then calculates the total exercise duration based on the exercise-start time and the exercise-stop time, and stores this in RAM3 in the same manner." APPLE-1103, 21:56-59. "CPU1 then stores all these values in RAM3, and displays them on display device 7." APPLE-1103, 26:52-53.

211. As previously discussed for Ono-Hutchings-Kaufman, the microprocessor detects a user-defined event (that the user is traveling too slowly as suggested by Kaufman) based on movement data (number of steps in the last 10 seconds as suggested by Ono and time duration between successive steps as suggested by Kaufman) and at least one of the user-defined operational parameters regarding the movement data (user selection and starting of the step-counting mode as suggested by Ono and user selected step rate as suggested by Kaufman). APPLE-1101, 14:65-16:27, 20:26-36, FIG. 18; APPLE-1105, 10:23-32; *supra* Ground 4, [1d], [1e]. Based on Ono-Hutchings-Amano-Conlan-Kaufman's teachings, a POSITA would have found it obvious to implement the microprocessor to not only detect when the user falls below the desired pace (user-defined event), but to also detect when the user has reached the desired pace (user-defined event), based on movement data (number of steps in the last 10 seconds as suggested by Ono and time duration between successive steps as suggested by Kaufman) and at least one of the user-defined operational parameters regarding the movement data (user selection and starting of the step-counting mode as suggested by Ono and user selected step rate as suggested by Kaufman). *Id.*

212. As suggested by Amano, when the microprocessor detects that the user has reached the desired pace based on the movement data, the microprocessor reads out the clock time from watch circuit and stores this as the exercise/interval-start time in RAM. APPLE-1103, 20:36-43, 26:29-30. Similarly, when the microprocessor detects that the user has fallen below the desired pace based on the movement data, the microprocessor reads out the current clock time from watch circuit, which it records in RAM as the exercise/interval-stop time. APPLE-1103, 21:43-56, 26:47-53. Accordingly, a POSITA would have found obvious that Ono-Hutchings-Amano-Conlan-Kaufman yields a device in which the microprocessor retrieves the time stamp from the watch circuit (real-time clock) based on the microprocessor detecting a user-defined event (the user has reached the desired pace or has fallen below the desired pace). APPLE-1103, 20:36-43, 26:29-30, 21:43-56, 26:47-53, 21:56-59, 26:52-53.

213. For reasons previously discussed, a POSITA would have been motivated to implement the Ono-Hutchings-Amano-Conlan-Kaufman device to retrieve and record the start and stop times of the user traveling at the desired pace based on detecting that the user has reached the desired pace and detecting that the user has fallen below the desired pace, as suggested by Amano. *Id.*; *supra* Section VI.B.2. Additionally, Amano describes using its device "when carrying out interval training." APPLE-1103, 5:39-44, 7:51-56. A POSITA would have been motivated to implement Amano's teachings for the benefit of providing the user with interval start and stop times to allow the user to better understand and monitor exercise activity and progress and to vary the exercise program based on the interval start and stop times. *Id.*

G. GROUND 5B—Claims 48, 50, and 51 are Obvious based on Ono in view of Hutchings, Amano, Conlan, Kaufman, and Hickman

214. Ground 5B incorporates the Grounds 3B analysis in all respects.

H. GROUND 6A—Claims 1-5, 8-11, 20, 25, 30, 31, 36, 39-42, 45-47, 49, and 61-65 are Obvious based on Ono in view of Hutchings, Amano, and Conlan

215. Ground 6A incorporates the Grounds 1, 2, and 3A analysis in all respects.

I. GROUND 6B—Claims 48, 50, and 51 are Obvious based on Ono in view of Hutchings, Amano, Conlan, and Hickman

216. Ground 6B incorporates the Grounds 3B analysis in all respects.

J. GROUND 7—Claims 1, 3-5, 8-11, 20, 25, 30, 36, 39-42, 61-65, 144, and 147 are Obvious based on Ono in view of Hutchings, Amano, and Kaufman

217. Ground 7 incorporates the Grounds 1, 2, and 4 analysis in all respects.

K. GROUND 8A—Claims 1-5, 8, 10, 20, 25, 30, 31, 39, 41, 42, 45-47, 49, 61-65, 144, and 147 are Obvious based on Ono in view of Hutchings, Conlan, and Kaufman

218. Ground 8A incorporates the Grounds 1, 3A, and 4 analysis in all respects.

L. GROUND 8B—Claims 48, 50, and 51 are Obvious based on Ono in view of Hutchings, Conlan, Kaufman, and Hickman

219. Ground 8B incorporates the Grounds 3B analysis in all respects.

VII. CONCLUSION

220. For all the reasons I have noted in the foregoing paragraphs, the Challenged claims of the ’576 Patent are obvious in view of the references discussed above.

APPENDIX A

Thomas W. Kenny

Department of Mechanical Engineering, Stanford University, Stanford, CA 94305-4021
Home : 2820 Greenwich St #2, San Francisco, CA 94123
(415) 725-3805 kenny@cdr.stanford.edu

Education

- University of California, Berkeley
  Ph D Physics June 1989
- University of Minnesota, Minneapolis
  BS Physics March 1983

Experience

Senior Associate Dean of Engineering for Student Affairs, Stanford. 7/15-present.

CEO, Founder, BoD Member, Applaud Medical 11/14-present.

- Non-invasive therapy for Kidney Stones using unfocused energy and Acoustic Enhancer
- Appointed as CEO 2/2020, leading effort to launch Pivotal FDA Clinical Trial.

Founder, Member, Board of Directors, Chair of Technical Advisory Board, SiTime 8/04-11/14

- CMOS-Compatible MEMS Resonators for Electronic Products.
- SITM on Nasdaq, >$2B Market Cap, World-leading supplier of MEMS-based oscillators

CTO and Founder Cooligy, 6/02-3/05

- Liquid cooling of microprocessors and other high power-density electronic devices.

Program Manager, DARPA Microsystems Technology Office, 10/06-10/10

- Launched $250M program on Nanotechnology, Thermal Management and Nanomanufacturing.

Professor, Department of Mechanical Engineering, Stanford University, 1/94-Present

- Leading Micromechanical Systems Research Group, with emphasis on development of high-performance microsensors, and measurements of fundamental properties of microstructures.
- Active research in Micromechanical Resonators for Time References, Encapsulated Inertial Sensors, Optimal Design of MEMS Structures, Wafer-Scale Packaging of MEMS Devices.
- Teaching Mechatronics, Sensors and Measurement, and others

Staff Scientist, Technical Group Leader, Jet Propulsion Laboratory, 7/89-1/94.

- Led the design, construction, and characterization of novel micromachined Si infrared detectors magnetometers and accelerometers based on an electron tunneling displacement transducer. Fully packaged tunneling sensors were delivered to collaborators for characterization.
- Participated in development of meterological instrumentation (pressure, wind, temperature, humidity,...), seismological instrumentation, deformable optical elements, instrumented neurological probes, soil chemistry apparatus, calibration parts for space telescopes,...

Research Assistant, Physics Department, University of California, Berkeley. 1/84-7/89.

- Measured of the heat capacity of ^{4}He submonolayers on metallic films, showing them to be in a 2-dimensional Bose gas phase, in contradiction to similar measurements on other substrates.

Honors

Recipient	Stanford Presidential Award for Excellence in Diversity	6/19
Recipient	Tau Beta Pi Teaching Honor Roll	6/19
Recipient	IEEE Daniel Noble Award for Emerging Technologies	9/18
Recipient	IEEE Sensors Council Technical Achievement Award	9/11
Winner	Coed Ultimate Frisbee National and World Champion	11/98, 11/99
Recipient	NSF CAREER Award	7/95
Recipient	Terman Fellowship	7/94
Recipient	R+D 100 Award	5/93
Recipient	Distinguished Teaching Award	6/89
Recipient	AT&T Bell Laboratories Fellowship	8/86-6/89

Litigation Experiences

- 2019 retained as Expert witness in case related to wearable baby monitors, including motion and temperature sensors. Case settled during drafting of expert infringement report.
- 2018, retained as Expert witness by attorneys representing Apple in a case related to algorithms for sensing motion and other physiological parameters in wearable devices,. Case settled after going on hold for IPR evaluation of IP.
- 2016, Expert Witness in case involving optical proximity sensors in smartphones. I was retained by HTC America and Capella, who were defendants in the case. I was compensated by defendants for work involving Invalidity and Non-Infringement reports, and was deposed after expert reports on invalidity and non-infringement. This case settled just a few weeks before trial in march 2017. This was Case Action No. 2:15-cv-1524-JRG in Marshall Texas.
- 2015, Expert Witness in Mayfonk –vs- Nike patent infringement suit brought by Mayfonk. I prepared expert reports on validity and non-infringement. The case settled just before depositions were taken. I was compensated by Nike for this work. This was case # Civil No.3:14-cv-00423-MO in the District of Oregon.
- 2013-2014, Expert Witness in ST Microelectronics –vs- Invensense patent infringement suit brought by ST. I assisted in claim construction, prepared expert reports on claim construction, validity and infringement, and provided deposition testimony. I was compensated by Invensense for this work. This was ITC Investigation # 337-TA-876.
- 2011-2012, Expert Witness in St. Jude Medical-vs-Volcano Corp patent infringement suit and counter suit. Assisted in claim construction, prepared expert reports, provided deposition testimony and trial testimony. I was compensated by Volcano Corporation for this work.
- 2011, Retained by Maxim Integrated Systems to examine documents and prepare opinions as to the value of certain documents in the possession of former employees of ST Microelectronics. I was compensated by Maxim for this work. This was Italian proceeding Rg. 50253/2011.

Books :

J.E. Carryer, M.Ohline and T.W. Kenny, "Introduction to Mechatronic Design", Pearson (2011).

Refereed Journal Publications:

1. J.S. Katz, C. Zhang, M.T. Barako, **H.J.K. Kim**, M. Asheghi, T.W. Kenny, and K.E. Goodson, "Bicontinuous Mesoporous Metal Foams with Enhanced Conductivity and Tunable Pore Size and Porosity via Electrodeposition for Electrochemical and Thermal Systems", ACS Appl. Nano Mater. 2020, 3, 12, 12408 (2020)

2. V. Zega, G. Gattere, **S. Koppaka, A. Alter, G.D. Vukasin**, A. Frangi, and T.W. Kenny, "Numerical Modelling of Non-Linearities in MEMS Resonators", JMEMS 29, 1443 (2020).

3. **A.L. Alter, I.B. Flader, Y. Chen, L.C. Ortiz, D.D. Shin**, and T.W. Kenny, "Characterization of Accelerated Fatigue in Thick Epi-Polysilicon Vacuum Encapsulated MEMS Resonators", JMEMS 29, 1483 (2020).

4. **J.M.L. Miller**, H. Zhu, S. Sundaram, **G.D. Vukasin, Y. Chen, I.B. Flader, D.D. Shin**, and T.W. Kenny, "Limits to Thermal-Piezoresistive Cooling in Silicon Micromechanical Resonators", JMEMS 29, 677 (2020).

5. **H.K. Kwon, G.D. Vukasin, N.E. Bousse,** and T.W. Kenny, "Crystal Orientation Dependent Dual Frequency Ovenized MEMS Resonator With Temperature Stability and Shock Robustness", JMEMS 29, 1130 (2020).

6. **G.D. Vukasin, V.K. Sanchez, J. Glaze, N.E. Bousse**, N. Bissel, **D.D. Shin, H.K Kwon, D. Heinz,** E.T-T Yen, and T.W. Kenny, "Anchor Design Affects Dominant Energy Loss Mechanism in a Lamé Mode MEM Resonator", JMEMS 29, 860 (2020).

7. **J.M.L. Miller, D.D. Shin, H.K. Kwon**, S.W. Shaw, and T.W. Kenny, "Spectral narrowing of parametrically pumped thermomechanical noise", Applied Physics Letters 117, 033504 (2020).

8. **A.L. Alter, I.B. Flader, Y. Chen, D.D. Shin**, and T.W. Kenny, "Nonlinear Dissipation in Epitaxial SCS and Polysilicon MEMS Driven at Large Amplitudes", JMEMS 29, 1118 (2020).

9. **N.E. Bousse, J.M.L Miller, A.L. Alter, C.P. Cameron, H.K. Kwon, G.D. Vukasin**, and T.W. Kenny, "Negative Nonlinear Dissipation in Microelectromechanical Beams", JMEMS 29, 954 (2020).

10. **A.L. Alter, D.D. Gerrard, H.K. Kwon, G.D. Vukasin**, and T.W. Kenny, "Quality Factor Extraction and Enhancement Across Temperature in Ring Resonators", JMEMS 29, 1124 (2020).

11. Z. Mohammadi, T.L. Heugel, **J.M.L. Miller, D.D. Shin, H.K. Kwon**, T.W. Kenny, R. Chitra, Oded Zilberberg, and L.G. Villanueva, "On the effect of linear feedback and parametric pumping on a resonators frequency stability", arXiv preprint arXiv:2006.00650 (2020).

12. **L.C. Ortiz, H.K. Kwon, J. Rodriguez, Y. Chen, G.D. Vukasin, D.B. Heinz, D.D. Shin**, and T.W. Kenny, "Low-Power Dual Mode MEMS Resonators With PPB Stability Over Temperature", JMEMS 29, 190 (2020).

13. **N.E. Bousse, J.M.L. Miller, H.K. Kwon, G.D. Vukasin**, and T.W. Kenny, "Quality factor tuning of micromechanical resonators via electrical dissipation", Applied Physics Letters 116, 023506 (2020).

14. X. Zhou, C. Zhao, D. Xiao, J. Sun, G. Sobreviela, **D.D. Gerrard, Y. Chen, I. Flader**, T.W. Kenny, X. Wu, and A.A. Seshia, "Dynamic modulation of modal coupling in microelectromechanical gyroscopic ring resonators", Nature Communications 10, 1 (2019).

15. **J.M.L. Miller, D.D. Shin, H.K. Kwon**, S.W. Shaw, and T.W. Kenny, "Phase Control of Self-Excited Parametric Resonators", Physical Review Applied 12 (4), 044053 (2019).

16. **J.M.L. Miller, N.E. Bousse, D.B. Heinz, H.J. Kim, H.K. Kwon, G.D. Vukasin** and T.W. Kenny, "Thermomechanical-Noise-Limited Capacitive Transduction of Encapsulated MEM Resonators", JMEMS 28, 965 (2019).

17. Y. A. Pishchalnikov, W. M. Behnke-Parks, K. Schmidmayer, K. Maeda, T. Colonius, T.W. Kenny, D.J. Laser, "High-speed video microscopy and numerical modeling of bubble dynamics near a surface of urinary stone", The Journal of the Acoustical Society of America 146, 516 (2019).

18. **I.B. Flader, Y. Chen, Y. Yang, E.J. Ng, D.D. Shin, D.B. Heinz, L. Comenencia Ortiz, A.L Alter**, W. Park, K.E. Goodson, T.W. Kenny, "Micro-Tethering for Fabrication of Encapsulated Inertial Sensors with High Sensitivity", JMEMS 28, 372 (2019).

19. **H.J. Kim, K. Kaplan**, P. Schindler, S. Xu, **M.M. Winterkorn, D. Heinz, T. English**, J, Provine, F.B. Prinz, T. Kenny, "Electrical Properties of Ultrathin Platinum Films by Plasma Enhanced Atomic Layer Deposition", ACS Applied Materials and Interfaces, 11, 9594 (2019).

20. **J. Rodriguez**, S.A.Chandorkar, C.A. Watson, G.M, Glaze, **C.H. Ahn, E.J. Ng, Y. Yang**, T.W. Kenny, "Direct Detection of Akhiezer Damping in a Silicon MEMS Resonators", Scientific Reports 9, 2244 (2019).

21. **J.M.L. Miller**, A. Ansari, **D.B. Heinz, Y. Chen, I.B. Flader, D.D. Shin**, L.G. Villanueva and T.W. Kenny, "Effective Quality Factor Tuning Mechanisms in Micromechanical Resonators", Applied Physics Reviews 5, 041307 (2018).

22. **J.M.L. Miller**, H. Zhu, **D.B. Heinz, Y. Chen, I.B. Flader, D.D. Shin**, J.E-Y. Lee, T.W. Kenny, "Thermal-Piezoresistive Tuning of the Effective Quality Factor of a MicroMechanical Resonator", Physical Review Applied, 10, 044055 (2018).

23. **J. Rodriguez**, S.A.Chandorkar, G.M, Glaze, **D.D. Gerrard, Y. Chen, D.B. Heinz, I.B. Flader**, T.W. Kenny, "Direct Detection of Anchor Damping in MEMS Tuning Fork Resonators", JMEMS 27, 1 (2018).

24. M. Mellema, W. Behnke-Parks, A. Luong, M. Hopcroft, Claire Mills, S. Ho, R. Hsi, D. Laser, T. Kenny, R. Grubbs, M. Stoller, "Absence of Ureteral/Renal Injury Following Low-Intensty Extracorporeal Acoustic Energy Lithotripsy with Stone-Targeting Microbubbles in an in-vivo Swine Model", The Journal of Urology 199,4 pe479, (2018).

25. **L. Comenencia Ortiz, D.B. Heinz, I.B. Flader, A.L. Alter, D.D. Shin, Y. Chen** and T.W. Kenny, "Assessing failure in epitaxially encapsulated micro-scale sensors using micro and nano x-ray computed tomography", MRS Communications 8, 275 (2018).

26. M.T. Barako, **T.S. English**, S. Roy-Panzer, T.W. Kenny and Kenneth E Goodson, "Dielectric barrier layers by low-temperature plasma-enhanced atomic layer deposition of silicon dioxide", Thin Solid Films 649, 24 (2018).

27. **Y. Chen, I.B. Flader, D.D. Shin, C.H. Ahn, J. Rodriguez** and T.W. Kenny, "Robust Method of Fabricating Epitaxially Encapsulated MEMS Devices with Large Gaps", JMEMS 26, 1235 (2017).

28. W. Park, **D.D. Shin**, S.J. Kim, J.S. Katz, J. Park, **C.H. Ahn**, T. Kodama, M. Asheghi, T.W. Kenny, K.E. Goodson, "Phonon Conduction in Silicon Nanobeams", Appl, Phys. Lett. 110, 213102 (2017).

29. F. Purkl, A.Daus, **T. English**, J Provine, A. Feyh, G. Urban, T. Kenny, "Measurement of Young's modulus and residual stress of atomic layer deposited Al2O3 and Pt thin films", J. Micromech. Microeng. 27, 085008 (2017)

30. G.Agarwal, T. Kazior, T. Kenny, D. Weinstein, "Modeling and analysis for thermal management in Gallium Nitride HEMTs using microfluidic cooling", Journal of Electronic Packaging 139, 11001 (2017).

31. J. Atalaya, T.W. Kenny, M.L Roukes, M.I Dykman, "Nonlinear damping and dephasing in nanomechanical systems", Physical Review B, 94, 15440 (2016).

32. O. Shoshani, **D. Heywood, Y. Yang**, T.W. Kenny, and S.W. Shaw, "Phase Noise Reduction in an MEMS Oscillator Using a Nonlinearly Enhanced Synchronization Domain", JMEMS 25 (2016).

33. **Y. Yang, E.J. Ng,** P.M. Polunin, **Y.Chen, I.B. Flader**, S.W. Shaw, M.I. Dykman, and T.W. Kenny, "Nonlinearity of Degenerately Doped Bulk-Mode Silicon MEMS Resonators", JMEMS 25, 859 (2016).

34. **T.S. English**, J Provine, A.F. Marshall, A.L. Koh, T.W. Kenny, "Parallel preparation of plan-view transmission electron microscopy specimens by vapor-phase etching with integrated etch stops", Ultramicroscopy 166, 39 (2016).

35. **Y. Yang, E.J. Ng, Y. Chen, I.B. Flader**, T.W. Kenny, "A Unified Epi-Seal Process for Fabrication of High-Stability Microelectromechanical Devices", JMEMS 25, 489 (2016).

36. **D.B. Heinz, V.A. Hong, C.H. Ahn, E.J. Ng, Y. Yang**, and T.W. Kenny, "Experimental Investigation into Stiction Forces and Dynamic Mechanical Anti-Stiction Solutions in Ultra-Clean Encapsulated MEMS Devices", JMEMS 25, 469 (2016)

37. P.M. Polunin, **Y. Yang**, M.I. Dykman, T.W. Kenny, and S.W. Shaw, "Characterization of MEMS Resonator Nonlinearities Using the Ringdown Response", JMEMS 25, 297 (2016).

38. **C.H. Ahn, E.J Ng, V.A Hong, J. Huynh, S. Wang**, and T.W. Kenny, "Characterization of Oxide-Coated Polysilicon Disk Resonator Gyroscope Within a Wafer-Scale Encapsulation Process", JMEMS 24, 1687 (2015).

39. B.W. Soon, Y. Qian, **E.J. Ng, V.A. Hong, Y. Yang, C.H. Ahn**, T.W. Kenny, and C. Lee, "Investigation of a Vacuum Encapsulated Si-to-Si Contact Microswitch Operated From− 60° C to 400° C", JMEMS 24 1906, (2015).

40. **Y. Won**, Y. Gao, R. Guzman de Villoria, B.L. Wardle, R. Xiang, S. Maruyama, T.W. Kenny, and K.E. Goodson, "Nonhomogeneous morphology and the elastic modulus of aligned carbon nanotube films", Journal of Micromechanics and Microengineering 25, 115023 (2015).

41. M.T Barako, S. Roy-Panzer, T.S. English, T. Kodama, M. Asheghi, T.W. Kenny, and K.E. Goodson, "Thermal Conduction in Vertically Aligned Copper Nanowire Arrays and Composites", ACS Applied Materials and Interfaces, 34, 19251 (2015).

42. V. Zega, S.H. Nitzan, M. Li, **C.H. Ahn, E. Ng, V. Hong, Y.Yang**, T.W. Kenny, A. Corigliano, and D.A. Horsley, "Predicting the closed-loop stability and oscillation amplitude of nonlinear parametrically amplified oscillators", Appl. Phys. Lett. 106, 233111 (2015).

43. S.H. Nitzan, V. Zega, M. Li, **C.H. Ahn**, A. Corigliano, T.W. Kenny and D.A. Horsley, "Self-Induced Parametric Amplification arising from Nonlinear Elastic Coupling in a Micromechanical Resonating Disk Gyroscope", Scientific Reports 5:9036 (2015)

44. **C.H. Ahn, E.J. Ng, V.A. Hong, Y.Yang, B. Lee, I. Flader** and T.W. Kenny, "Mode-Matching of Wineglass-Mode Disk Resonator Gyroscope in (100) Single Crystal Silicon", JMEMS 24, 343 (2015).

45. **V.A. Hong, S. Yoneoka, M.W. Messana, A.B. Graham, J.C. Salvia, T.T. Branchflower, E.J. Ng** and T.W. Kenny, "Fatigue Experiments on Single-Crystal Silicon in an Oxygen-Free Environment", JMEMS 24, 351 (2015).

46. **E.J. Ng, V.A. Hong, Y. Yang, C.H. Ahn, C.L.M. Everhart** and T.W. Kenny, "Temperature Dependence of the Elastic Constants of Doped Silicon", JMEMS 24 730, (2015)

47. C.L. Roozeboom, B.E. Hill, **V.A. Hong, C.H. Ahn, E.J. Ng, Y. Yang**, T.W. Kenny, M.A. Hopcroft and B.L. Pruitt, "Multifunctional Integrated Sensors for MultiParameter Monitoring Applications", JMEMS 24, (2015).

48. **S. Ghaffari, E.J. Ng, C.H. Ahn, Y.Yang, S. Wang, V.A. Hong**, and T.W. Kenny, "Accurate Modeling of Quality Factor Behavior of Complex MEMS Resonators", JMEMS 24, 276 (2015)

49. **C.H. Ahn**, S. Nitzan, **E.J. Ng, V.A. Hong, Y. Yang, T. Kimbrell**, D.A. Horsley, and T.W. Kenny, "Encapsulated High Frequency (235 kHz), High-Q (100k) Disk Resonator Gyroscope with Electrostatic Parametric Pump", Applied Physics Letters, 105, 243504 (2014).

50. B.W. Soon, **E.J. Ng, V.A. Hong, Y. Yang, C.H. Ahn**. Y. Quan, T.W. Kenny and C. Lee, "Fabrication and Characterization of a Vacuum-Encapsulated Curved Beam Switch for Harsh Environment Application", JMEMS 23, 1121 (2014).

51. Y.Won, Y. Gao, M.A. Panzer, R.Xiang, S. Maruyama, T.W. Kenny, W. Cai, and K.E. Goodson, "Zipping, entanglement, and the Elastic Modulus of Aligned Single-Walled Carbon Nanotube Films", Proceedings of the National Academy of Sciences, 110, 20426 (2013).

52. **M.A. Philippine**, H. Zareie, O. Sigmund, G.M. Rebeiz, and T.W. Kenny, "Experimental Validation of Topology Optimization for RF MEMS Capacitive Switch Design", JMEMS 22, 1296 (2013).

53. **S. Ghaffari, S.A. Chandorkar, S. Wang, E.J. Ng, C.H Ahn, V. Hong, Y. Yang**, and T.W. Kenny, "Quantum Limit of Quality Factor in Silicon Micro and Nano Mechanical Resonators", Scientific Reports, 3:3244 (2013).

54. M. Li, **E.J. Ng, V.A. Hong, C.H. Ahn, Y. Yang**, T.W. Kenny and D.A. Horsley, “Lorentz Force Magnetometer using a Micromechanical Oscillator”, Appl. Phys. Lett 103, (2013)

55. **H.K. Lee, R. Melamud, B. Kim, S. Chandorkar, J.C. Salvia** and T.W. Kenny, “The effect of Temperature-Dependent Nonlinearities on the Temperature Stability of Micromechanical Resonators”, J. Appl. Phys. 114, (2013)

56. R.G. Hennessy, M.M. Shulaker, **M. Messana, A.B. Graham**, N. Klewa, J. Provine, T.W. Kenny and R.T. Howe, “Vacuum Encapsulated Resonators for Humidity Measurement”, Sensors and Actuators B-Chemical 185, 575 (2013)

57. **S. Ghaffari, C.H. Ahn, E.J. Ng, S. Wang** and T.W. Kenny, “Crystallographic Effects in Modeling Fundamental behavior in MEMS Silicon Resonators”, Microelectronics Journal 44, 586 (2013)

58. **E. Ng, H-K Lee, C-H Ahn, R. Melamud** and T.W. Kenny, “Stability of Silicon Microelectromechanical Systems Resonant Thermometers”, IEEE Sensors 13, (2013).

59. **M.A. Philippine**, O. Sigmund, G.M Rebeiz, and T.W. Kenny, “Topology Optimization of Stressed Capacitive RF MEMS Switches,” JMEMS 22, 206 (2013).

60. J.C. Duda, **T.S. English**. E.S. Piekos, T.E. Beechem, T.W. Kenny and P.E. Hopkins, “Bidirectionality tuning Kapitza conductance through the inclusion of Substitutional Impurities”, J. Appl. Phys 112, (2012).

61. **S. Yoneoka**, J. Lee, M. Liger, G. Yama, T. Kodama, M. Gunji, R.T. Howe, K.E. Goodson and T.W. Kenny, “Electrical and Thermal Conduction in Atomic Layer Deposition Nanobridges down to 7nm Thickness”, NanoLett, 12 (2) 683 (2012).

62. **Y. Won**, J.Lee, M. Asheghi, T.W. Kenny, and K.E. Goodson “Phase and thickness dependent modulus of $Ge_2Sb_2Te_5$ films down to 25 nm thickness”, Appl. Phys. Lett 100, 161905 (2012).

63. **Y. Won**, Y. Gao. M.A. Panzer, S. Dogbe, L. Pan, T.W. Kenny, and K.E. Goodson, “Mechanical Characterization of Aligned Milti-Walled Carbon Nanotube Films using Microfabricated Resonators”, Carbon 50, 347 (2012)

64. **H.K. Lee, R. Melamud, S. Chandorkar, J.G. Salvia, S. Yoneoka** and T.W. Kenny, “Stable Operation of MEMS Oscillators Far Abve the Critical Vibration Amplitude in the Nonlinear Regime”, JMEMS Letters 20,1228 (2011).

65. K.P. Bloschock, A.R. Schofield, and T.W Kenny, “Tip-Based Nanofabrication : An Approach to True Nanotechnology”, Proceedings of the SPIE 8031, 803102 (2011).

66. **H.K. Lee, R. Melamud, B. Kim, M.A. Hopcroft, J.G. Salvia**, and T.W. Kenny, “Electrostatic Tuning to Achieve Higher Stability Micromechanical Composite Resonators”, JMEMS 20, 1355 (2011).

67. **G. Bahl, S. Wang, J.C. Salvia, R. Melamud**, R.T. Howe and T.W. Kenny, “AC Polarization for Charge-Drift Elimination in Resonant Electrostatic MEMS and Oscillators”, IEEE JMEMS 20, 355-364 (2011).

68. **H.K. Lee, B. Kim, R. Melamud, M.A. Hopcroft, J.C. Salvia and T.W. Kenny, “**Influence of the Temperature-Dependent Nonlinearities on the Performance of Micromechanical Resonators”, Appl. Phys. Lett 99, 194102 (2011).

69. **Y. Won, E.N. Wang,** K.E. Goodson and T.W. Kenny, "3-D Visualization of Flow in Microscale Jet Impingement Systems", International Journal of Thermal Sciences, 50, 325 (2011).

70. **K-L. Chen, S. Wang, J.C. Salvia. R. Melamud** R.T. Howe and T.W. Kenny, "Wafer-Level Epitaxial Silicon Packaging for Out-of Plane RF MEMS Resonators with Integrated Actuation Electrodes", IEEE Transactions on Components, Packaging and Manufacturing Technology Vol 1, 310-317 (2011).

71. **G. Hill, D. Soto**, A. Peattie, R.J. Full, T.W. Kenny, "Orientation angle and the adhesion of single gecko setae", Journal of the Royal Society Interface, Vol 8 926-933 (2011).

72. **S. Yoneoka, J.C. Salvia, G. Bahl, R. Melamud, S.A, Chandorkar**, and T.W. Kenny, "Active Electrostatic Compensation of Micromechanical Resonators under Random Vibrations", IEEE JMEMS 19, 1270 (2010).

73. A.R. Schofield, K,P, Bloschock, and T.W Kenny, "Tip-Based Nanofabrication : An Approach to True Nanotechnology", Proceedings of the SPIE 7637, 76371 (2010).

74. **D. Soto, G. Hill**, A. Parness, N. Esparza, M. Cutkosky, and T. Kenny, "Effect of Fibril Shape on Adhesive Properties", Appl. Phys Lett 97, 153701 (2010).

75. **M.A. Hopcroft**, W.D. Nix, T.W. Kenny, "What is the Young's Modulus of Silicon?", IEEE JMEMS 19, 229 (2010).

76. **S. Yoneoka,** C.S. Roper**, R.N. Candler, S.A. Candorkar, A.B. Graham**, J. Provine, R. Maboudian, R.T. Howe, and T.W. Kenny, "Characterization of Encapsulated Micromechanical Resonators Sealed and Coated with Polycrystalline SiC", IEEE JMEMS 19, 357 (2010).

77. **A.B. Graham, M.W. Messana**, P.G. Hartwell, J. Provine, **S. Yoneoka, R. Melamud, B. Kim**, R.T. Howe and T.W. Kenny, "A Method for Wafer-Scale Encapsulation of Large Lateral-Deflection MEMS Devices", IEEE JMEMS 19, 28 (2010).

78. **G. Bahl, R. Melamud, B. Kim, S.A. Chandorkar, J.C. Salvia, M.A. Hopcroft**, D. Elata, R.G. Hennessy, R.N. Candler, R.T. Howe and T.W. Kenny, "Model and Observations of Dielectric Charge in Thermally-Oxidized Silicon Resonators", IEEE JMEMS 19, 162, (2010).

79. **J.C. Salvia, R. Melamud, S.A. Chandorkar, S.F. Lord** and T.W. Kenny, "Real-Time Temperature Compensation of MEMS Oscillators using an Integrated Micro-Oven and a Phase-Locked Loop", IEEE JMEMS 19, 192 (2010).

80. **R. Melamud, S.A. Chandorkar, B. Kim, HK Lee, J. Salvia, G. Bahl, MA Hopcroft**, and TW Kenny, "Temperature-Insensitive Composite Micromechanical Resonators", IEEE JMEMS 18, 1409 (2009).

81. **V. Ayanoor-Vitikkate, K-L Chen, W.T. Park,** T.W. Kenny, "Development of Wafer-Scale Encapsulation Process for Large Displacement Piezoresistive MEMS Device", Sensors and Actuators A 156, 275 (2009).

82. **K-L Chen, J. Salvia,** R. Potter, R.T. Howe, and T.W. Kenny, "Performance evaluation and equivalent model of silicon interconnects for fully-encapsulated RF MEMS devices", IEEE Transactions on Advanced Packaging 32, p. 402-9 (2009).

83. **S.A. Chandorkar, R.N Candler, A. Duwel, R. Melamud, M. Agarwal**, K.E. Goodson, T.W. Kenny, "Multimode thermoelastic dissipation", Journal of Applied Physics105, P 043505 (13 pp.) **(**2009).

84. **B. Kim, R.N. Candler, R. Melamud, M.A. Hopcroft, S. Yoneoka, H-K Lee, M. Agarwal, S.A. Chandorkar,** G. Yama, and T.W. Kenny, "Hermeticity and diffusion investigation in polysilicon film encapsulation for microelectromechanical systems", Journal of Applied Physics105 pp. 013514 (10 pp.), (2009).

85. **C.M. Jha, J. Salvia, S.A. Chandorkar, R. Melamud**, E. Kuhl, T.W. Kenny, "Acceleration insensitive encapsulated silicon microresonator", Applied Physics Letters 93 P. 234103 (3 pp.) (2008)

86. **B. Kim, M.A. Hopcroft, R.N. Candler, C.M. Jha, M. Agarwal, R. Melamud, S.A. Chandorkar**, G. Yama, T.W. Kenny, "Temperature Dependence of Quality Factor in MEMS Resonators", JMEMS 17, 755 (2008).

87. **M. Agarwal, SA Chandorkar, H. Mehta, RN Candler, B, Kim, MA Hopcroft, R. Melamud**, TW Kenny, and B. Muhrmann, "A Study of Electrostatic Force nonlinearities in Resonant Microstructures", Appl. Phys Lett. 92, 104 (2008).

88. **M. Swartwout**, C Kitts, R. Twiggs, T.W. Kenny, B.R. Smith, R. Lu, K. Stattenfield, F. Pranajaya, "Mission Results for a Student-Built Satellite", ACTA Astronautica 62, 521 (2008).

89. **C.M. Jha, M.A. Hopcroft, S.A. Chandorkar, J.C. Salvia, M. Agarwal, R.N Candler, R. Melamud, B. Kim,** and T.W. Kenny, "Thermal Isolation of Encapsulated MEMS Resonators", JMEMS 17, 175 (2008).

90. **W.T. Park**, K.N. O'Connor**, K.L. Chen,** J.R. Mallon, T. Maetani**, P. Dalal, R.N. Candler, V. Ayanoor-Vitikkate**, J.B. Roberson, S. Puria, and T.W. Kenny**, "**Ultraminiature Encapsulated Accelerometers as a Fully-Implantable Sensors for Implantable Hearing Aids", Biomedical MicroDevices 9, 939 (2007).

91. **M. Bartsch**, W. Federle, R.J. Full and T.W. Kenny, "A Multi-Axis Force Sensor for the Study of Insect Biomechanics", JMEMS 16, 709 (2007).

92. **M.Agarwal, H.Mehta, R.N. Candler, S.A. Chandorkar, B. Kim, M.A. Hopcroft, R.Melamud, G. Bahl,** G. Yama[2], T. W. Kenny and B. Murmann, "Scaling of A-f nonlinearities in electrostatically transduced microresonators", Journal of Applied Physics 102, 74903 (2007).

93. **B. Kim, R.N. Candler, M.A. Hopcroft; M. Agarwal, WT Park**, T.W. Kenny, "Frequency stability of wafer-scale film encapsulated silicon based MEMS resonators " Sensors and Actuators A (Physical), 136, 125 (2007).

94. **M.A. Hopcroft, B. Kim, S. Chandorkar, R. Melamud, M. Agarwal, C.M. Jha, G. Bahl, J.Salvia, H.Mehta, H.K.Lee, R.N.Candler,** T.W.Kenny, "Using the Temperature Dependence of Resonator Quality Factor as a Thermometer", Appl. Phys. Lett. **91**, 13505 (2007).

95. **J. Bower,** C. Mehls, N. Vora, R. Torii, and T Kenny, "Effect of Surface Roughness on Thin Film Niobium Coatings", IEEE Transactions on Applied Superconductivity 2, 768 (2007).

96. **O. Ajakaiye, J. Grade, C. Shin**, and T. Kenny, "Wafer-Scale Fabrication of Infrared Detectors based on Tunneling Displacement Transducers", Sensors and Actuators A (Physical) 134, 575 (2007).

97. **C. M. Jha, G. Bahl, R. Melamud, S. A. Chandorkar, M. A. Hopcroft, B. Kim, M. Agarwal, J. Salvia, H. Mehta**, and T. W. Kenny, "High Resolution microresonator-based digital temperature sensor", Appl. Phys. Lett 91, 74101 (2007).

98. **R. Melamud, B. Kim, S.A. Chandorkar, M.A. Hopcroft, M. Agarwal, C.M. Jha** and T.W. Kenny, "Temperature Compensated High-Stability Silicon Resonators", Appl. Phys. Lett. **90**, 244107 (2007).

99. **C.M. Jha, M.A. Hopcroft, S.A. Chandorkar, J.Salvia, M.Agarwal,R.N. Candler, R.Melamud, B.Kim**, and Thomas W. Kenny, "Thermal Isolation of Encapsulated MEMS Resonators" Accepted with Minor Revision JMEMS (2007).

100. **M. Agarwal, K.K. Park, S.A. Chandorkar, R.N. Candler, B. Kim, M.A. Hopcroft, R. Melamud,** T.W. Kenny, and B. Murmann**,** "Acceleration sensitivity in beam-type electrostatic microresonators", Appl. Phys. Lett. 90, 14103 (2007).

101. **M. Agarwal, S.A. Chandorkar, R.N. Candler, B. Kim, M.A. Hopcroft, R. Melamud, C.M. Jha,** T.W. Kenny and B. Murmann "Optimal drive condition for nonlinearity reduction in electrostatic MEMS resonators", Appl. Phys. Lett., 89, (2006)

102. **R.N. Candler, M.A. Hopcroft, B. Kim, W.-T. Park, R. Melamud, M. Agarwal,** G. Yama, A. Partridge, M. Lutz, and T.W. Kenny, "Long-Term and Accelerated Life Testing of a Novel Single-Wafer Vacuum Encapsulation for MEMS Resonators", JMEMS 15, 1446 (2006).

103. **E.N. Wang**, S. Devasenathipathy, H. Lin, C.H. Hidrovo, J.G. Santiago, K.E. Goodson, and T.W. Kenny, "A Hybrid Method for Bubble Geometry Reconstruction in Two-Phase Microchannels", Experiments in Fluids 40, 847 (2006).

104. C.H. Hidrovo, T.A. Kramer, **E.N. Wang,** S.Vigneron, **J.E. Steinbrenner**, J.M. Koo, F.M. Wang, **D.W. Fogg, R.D. Flynn**, E.S. Lee, C.H. Cheng, T.W. Kenny, J.K. Eaton, and K.E. Goodson, "Two-Phase Microfluidics for Semiconductor Circuits and Fuel Cells," Heat Transfer Engineering, 27, 53 (2006).

105. T.W. Kenny, K.E. Goodson, J.G Santiago, **E.N.Wang,** J-M Koo, L. Jiang, E. Pop, S. Sinha**, L. Zhang,** D. Fogg, S. Yao, R. Flynn, CH Chang, C.H. Hidrovo, "Advanced Cooling Technologies for Microprocessors", International Journal of High Speed Electronics and Systems, 15, 301 (2006).

106. A**.** Duwel, **R.N. Candler**, T.W. Kenny, M. Varghese, "Engineering MEMS Resonators with Low Thermoelastic Damping", IEEE JMEMS 15, 1437 (2006).

107. **R.N. Candler**, A. Duwel, M. Varghese, **S. Chandorkar, M. Hopcroft, W.T. Park, B. Kim**, G. Yama, A. Partridge, M. Lutz, and T.W. Kenny, "Impact of Geometry on Thermoelastic Dissipation in Micromechanical Resonant Beams", IEEE JMEMS 15, 927 (2006).

108. **W.T. Park,** A. Partridge, **R.N. Candler, V. Ayanoor-Vitikkate,** G. Yama, M. Lutz, and T.W. Kenny, "Encapsulated Sub-Millimeter Piezoresistive Accelerometers", JMEMS 15, 507 (2006).

109. **E.N. Wang,** S. Devasenathipathy, J.G. Santiago, K.E. Goodson, and T.W. Kenny, "Nucleation and Growth of Vapor Bubbles in a Heated Silicon Microchannel," ASME *Journal of Heat Transfer*, Vol. 128, p. 497. (2004)

110. B.W. King, T.W. Kenny, and K.E Goodson, "Comparison of Thermal and Piezoresistive Sensing Approaches for Atomic Force Microscopy Topography Measurements", Appl. Phys. Lett. 85, 2086 (2004).

111. **E.N. Wang, L. Zhang,** L. Jiang, J.M. Koo, J.G. Maveety, E.A. Sanchez, K.E. Goodson, and T.W. Kenny, "Micromachined Jets for Liquid Impingement Cooling of VLSI Chips", JMEMS 13, 833 (2004).

112. **L. Zhang, E.N. Wang**, K.E. Goodson, and T.W. Kenny, "Phase Change Phenomena in Silicon Microchannels", International Journal of Heat and Mass Transfer 48, 1572 (2005).

113. E.N. Renuart, **A.M. Fitzgerald**, T.W. Kenny, R. H. Dauskardt, "Fatigue Crack Growth in Micromachined Silngle Crystal Silicon", Journal of Materials Research 19, 2635 (2004).

114. J.P. Lynch, A. Sundararajan, K.H. Law, A.S. Kiremidjian, T. Kenny and S. Carryer, "Embedment of structural monitoring algorithms in a wireless sensing unit", Structural Engineering and Mechanics, 15, 285-97 (2003).

115. **R.N. Candler, W.T. Park, H.M. Li**, G. Yama, A. Partridge, M. Lutz, and T.W. Kenny, "Single Wafer Encapsulation of MEMS Devices", IEEE Transactions on Advanced packaging 26, 227 (2003).

116. **J.P. Lynch, A. Partridge**, K.H. Law, T.W. Kenny, A.S. Kiremidjian,E. Carryer, "Design of Piezoresistive MEMS-based Accelerometer for Integration with Wireless Sensing Unit for Structural Monitoring", Journal of AeroSpace Engineering, 16, 108 (2003).

117. **Y. Hishinuma**, T. Geballe, B. Moyzhes, and T.W. Kenny, "Measurements of Cooling by Room-Temperature Thermionic Emission across a Nanometer Gap" Journal of Applied Physics 94,4690 (2003).

118. **E.M. Chow, A. Partridge,** V. Chandrasekaran**,** M. Sheplak, C.F. Quate, and T.W. Kenny, "Process-Compatible Polysilicon-Based Through-Wafer Interconnects in Silicon Substrates", JMEMS, 11,631 (2002).

119. K. Autumn, M. Sitti, **Y.A. Liang**, A.M. Peattie, W.R. Hansen, S. Sponberg, T.W. Kenny, R. Fearing, J.N. Israelachvili, and R.J. Full, "Evidence for van der Waals adhesion in gecko setae", Proceedings of the National Academy of Science, 99, 12252 (2002).

120. K.E. Goodson, J.G. Santiago, T.W. Kenny, L. Jiang,, S. Zeng, J.M. Koo**, L. Zhang,** S. Yao, and **E.N. Wang,** "Electroosmotic Microchannel Cooling System for Microprocessors," *Electronics Cooling*, Vol. 8, No. 4, pp. 46-47. (2002)

121. **A.M. Fitzgerald**, T.W. Kenny, and R.H Dauskardt, "Stress wave interference effects during fracture of silicon micromachined specimens," IEEE Special Issue on Experimental Mechanics 43,317, (2003).

122. **B.L. Pruitt, W.-T. Park**, T. Kenny. Measurement System for Low Force and Small Displacement Contacts." *Journal of Micro-electro-mechanical Systems*. 13, 220 (2004).

123. W.P. King, T.W. Kenny, K.E. Goodson, G.L.W. Cross, M. Despont, U.T. Dürig, H. Rothuizen, G.K. Binnig, and P. Vettiger, "Design of Atomic Force Microscope Cantilevers For Combined Thermomechanical Writing and Thermal Reading in Array Operation," *Journal of MicroElectroMechanical Systems* 11, 765 (2002).

124. **A.E. Herr, J.I. Molho**, K.A. Drouvalakis, J.C. Mikkelsen, P.J. Utz, J.G. Santiago, and T.W. Kenny, "On-Chip Coupling of Isoelectric Focusing and Free Solution Electrophoresis for Multi-Dimensional Separations", Analytical Chemistry 75, 1180 (2003)

125. Jiang, L., Mikkelsen J., Koo J.-M., Huber D., Yao S., **Zhang L.,** Zhou P., Maveety J.G., Prasher R., Santiago J.G., Kenny T.W., & Goodson K.E., "Closed-loop electroosmotic microchannel cooling system for VLSI circuits", IEEE Transactions on Components & Packaging Technologies 25, 347 (2002).

126. **Y. Hishinuma**, B.Y. Moyzhes, T.H. Geballe, and T.W. Kenny, "Vacuum Thermionic Refrigeration with a Semiconductor Heterojunction Structure", Appl. Phys. Lett. 81, 4242 (2002).

127. **B.L. Pruitt**, T. Kenny. "Piezoresistive Cantilevers and Measurement System for Low Force Electrical Contact Measurements." *Sensors and Actuators, A* 104, 68 (2003).

128. **J.Grade**, H. Jerman, and T.W. Kenny, Design and Characterization of Large Displacement Electrostatic Actuators, JMEMS, 12, 335 (2003).

129. **E.M. Chow**, G. Yaralioglu, C.F. Quate, and T.W. Kenny, Characterization of a Two-Dimensional Cantilever Array with Through-Wafer Electrical Interconnects, Appl. Phys Lett. 80, 664 (2002).

130. B.C. Stipe, H.J. Mamin, C.S. Yannoni**, T.D. Stowe**, T.W. Kenny and D. Rugar "Electron Spin Relaxation near a Micron-Sized Ferromagnet", Phys. Rev. Lett. 87, 2776 (2001).

131. B.C. Stipe, H.J. Mamin**, T.D. Stowe**, T.W. Kenny and D. Rugar, Non-contact friction and force fluctuations between closely spaced bodies, Phys. Lett. Rev. 8709, 6801 (2001).

132. Rugar, B.C. Stipe, H.J. Mamin, C.S. Yannoni, **T.D. Stowe, K.Y. Yasumura** and T.W. Kenny Adventures in Attonewton Force Detection, Applied Physics A 72 [Suppl] S3-S10 (2001).

133. B. C. Stipe, H.J. Mamin, **T.D.Stowe**, T.W. Kenny and D. Rugar, Magnetic dissipation and fluctuations in individual nanomagnets measured by ultrasensitive cantilever magnetometry, Phys. Rev. Lett. 86 2874 (2001)

134. **L. Zhang,** J.M. Koo, L. Jiang, K.E. Goodson, J.G. Santiago, and T.W. Kenny, Measurements and Modeling of Two-Phase Flow in Microchannels with Nearly-Constant Heat Flux Boundary Conditions, JMEMS 11,12 (2002).

135. B.W. King, T.W. Kenny, K.E. Goodson, G. Cross, M. Despont, U. Durig, H. Rothuizen, G.K. Binnig, and P. Vettiger, Atomic Force Microscope Cantilevers for Combined Thermomechanical Data Writing and Reading, Appl. Phys. Lett. 78, 1300 (2001).

136. T.W. Kenny, Nanometer-Scale Force Sensing with MEMS Devices, Invited Review , IEEE Sensors 1,148 (2001).

137. **J.A. Harley** and T.W. Kenny, A High-Stiffness Axial Resonant Probe for Atomic Force Microscopy, JMEMS 10, 434 (2001)

138. **Y. Hisunuma**, T.H. Geballe , B.Y. Moyzhes, , and T.W Kenny, Refrigeration by Combined Tunneling and Thermionic Emission in Vacuum: Use of Nanometer Scale Design", Appl. Phys. Lett. 78, 2572 (2001).

139. **J.I. Molho, A.E. Herr,** B.P. Mosier, J.G. Santiago, T.W. Kenny, R.A Brennen, G.B. Gordon, B. Mohammadi, Optimization of Turn Geometries for On-Chip Electrophoresis, Analytical Chemistry 73, 1350 (2001).

140. **A.M. Fitzgerald**, R.S. Iyer, R.H. Dauskardt, and T.W. Kenny, Sub-Critical Crack Growth in Single Crystal Silicon Using Micromachined Specimens, Journal of Materials Research 17, 683 (2002).

141. **C.H. Liu**, and T.W. Kenny, A High-Precision, Wide-Bandwidth Micromachined Tunneling Accelerometer, JMEMS, 10,425 (2001)

142. K. Autumn, **Y. Liang**, W.P. Chan, T. Hsieh, R. Fearing, T.W. Kenny, and R. Full, Dry Adhesive Force of a Single Gecko Foot-Hair, Nature. 405: 681-685 (2000).

143. **A.E. Herr, J.I. Molho**, J.G. Santiago, M.G. Mungal, T.W. Kenny, and M.G. Garguilo, Electroosmotic Capillary Flow with Non-Uniform Surface Potential, Analytical Chemistry 72, 1053-1057 (2000).

144. **E.M. Chow**, H.T. Soh, H.C. Lee, J.D. Adams, S.C. Minne, G. Yaralioglu, A. Atalar, C.F. Quate, and T.W. Kenny, Integration of Through-Wafer Interconnects with a Two-Dimensional Cantilever Array, Sensors and Actuators 83, 118-123 (2000).

145. **K.Y. Yasumura, T.D. Stowe, E.M. Chow**, T.E. Pfafman, T.W. Kenny, B. Stipe, and D. Rugar, Quality Factors in Micron- and Submicron-Thick Cantilevers, JMEMS 9, 117-125 (2000).

146. **J.K. Reynolds**, D.C. Catling, R.C. Blue, N. Maluf, T.W. Kenny, Packaging a piezoresistive pressure sensor for pressure and temperature stability in a Martian environment, Sensors and Actuators 83, 142-149 (2000).

147. **R. G. Rudnitsky, E.M. Chow**, and T.W. Kenny, High-Speed Biological Screening with Magnetic Force Microscope Cantilever Arrays, Sensors and Actuators 83, 256-262 (2000).

148. **A.M. Fitzgerald**, T.W. Kenny, S.Iyer, R. Dauskard, Fracture Toughness and Crack-Growth Phenomena of Plasma-Etched Single Crystal Silicon, Sensors and Actuators 83, 194-199 (2000)

149. **J.A. Harley** and T.W. Kenny, Design and Process Optimization of Piezoresistive Cantilevers, JMEMS 9, 226-235 (2000).

150. **T.D. Stowe**, T.W. Kenny, D.J. Thompson, and D. Rugar, Silicon Dopant Imaging by Dissipation Force Microscopy, Appl. Phys Lett, 75, 2785-2787 (1999).

151. **A. Partridge, J.K. Reynolds, B.W. Chui, E.M. Chow, A.M. Fitzgerald, L. Zhang**, N.I. Maluf, and T.W. Kenny, A High-Performance Planar Piezoresistive Accelerometer JMEMS 9, 58-66 (2000).

152. **J.A. Harley**, and T.W. Kenny, High Sensitivity Piezoresistive Cantilevers under 1000Å Thick, Appl. Phys. Lett. 75, 289-291 (1999).

153. **B.W. Chui, M. Asheghi, Y.S. Ju**, K.E. Goodson, T.W. Kenny and H.J. Mamin, Intrinsic-Carrier Thermal Runaway in Silicon Microcantilevers, Microscale Thermophysical Engineering 3, 217-228 (1999).

154. G. Binnig, M. Despont, U. Drechsler, W. Haberle, M. Lutwyche, P. Vettiger, H.J. Mamin, **B.W. Chui**, and T.W. Kenny, High-Density Data Read, Write, and Erase using Heated Atomic Force Microscopy Cantilevers, Appl. Phys Lett, 74 1329-1331 (1999)

155. **A. Partridge, J.K. Reynolds, J.D. Grade,** B.J. Kane, N.I. Maluf, G.T.A. Kovacs, and T.W. Kenny, An Integrated Controller for Tunnel Sensors, J. Solid State Circuits 34, 1099-1107 (1999).

156. T.E. Pfafman, **A.M. Fitzgerald** and T.W. Kenny, A Micromachined Calorimeter for Spacecraft Exposure Monitoring, J. Vac. Sci. Technol., In review (8/99).

157. **B.W. Chui**, T.W. Kenny, H.J. Mamin, B.D. Terris, and D. Rugar, Independent Detection of Vertical and Lateral Forces with a Sidewall-Implanted Dual-Axis Piezoresistive Cantilever, Appl. Phys Lett. 72, 1388-1390 (1998).

158. **C.H. Liu, A.M. Barzilai, J.K. Reynolds, A. Partridge**, T.W. Kenny, **J.D. Grade** and H.K. Rockstad, Characterization of a High-Sensitivity Micromachined Tunneling Accelerometer with Micro-g Resolution, J. MicroElectroMechanical Systems 7, 235-244 (1998).

159. **A.M. Barzilai**, T.R. VanZandt, T. Kenny, Measurement of the Noise of a Geophone in the Presence of Large Background Signals, Rev. Sci. Instrum. 69, 2767-2772 (1998).

160. **B.W. Chui, T.D. Stowe,** Y.S. Ju, K.E. Goodson, T.W. Kenny, H.J. Mamin, B.D. Terris, R.P.Ried, and D. Rugar, Low-stiffness Silicon Cantilevers with Integrated Heaters and Piezoresistive Sensors for High-Density AFM Thermomechanical Data Storage, IEEE Journal of MicroElectroMechanical Systems, 7, 69-78 (1998).

161. **T.D. Stowe, K. Yasumura**, T. Pfafman, T. Kenny, D. Botkin, and D. Rugar, Attonewton Force Detection using Ultrathin Silicon Cantilevers, Appl. Phys. Lett. 71, 288-290 (1997).

162. R.A. Brennen, M.H. Hecht, D.V. Wiberg, S.J. Manion, W.D. Bonivert, J.M. Hruby**, M.L. Scholz, T.D. Stowe**, T.W. Kenny, K.H. Jackson, and C.K. Malek, Fabrication of Collimating Grids for an X-Ray Solar Telescope using LIGA Methods, Microsystem Technologies 3, 91-96 (1997).

163. D.Dilella, L.J. Whitman, R.J. Colton, T.W. Kenny, W.J. Kaiser, E.C. Vote, J.A. Podosek, and L.M. Miller, A Micromachined Magnetic-Field Sensor based on an Electron Tunneling Displacement Transducer, Sensors and Actuators A, 86, 8 (2000).

164. **B.W. Chui, T.D. Stowe**, T.W. Kenny, H.J., Mamin, B.D. Terris, and D.Rugar, Low-Stiffness Silicon Cantilevers for Thermal Writing and Piezoresistive Readback with the Atomic Force Microscope, Appl. Phys Lett., 69, 2767-2769 (1996).

165. H.K. Rockstad, T.K.Tang, **J.K. Reynolds**, T.W. Kenny, W.J. Kaiser, and T.B. Gabrielson, A Miniature, High-Sensitivity, Electron Tunneling Accelerometer, Sensors and Actuators A53, 227-231 (1996).

166. T.W. Kenny**, J.K. Reynolds**, J.A. Podosek, E.C. Vote, L.M. Miller, H.K. Rockstad, and W.J. Kaiser, Micromachined Infrared Sensors using Tunneling Displacement Transducers, Rev. Sci. Instrum. 67, 112-128 (1996).

167. T.W. Kenny, W.J. Kaiser, H.K. Rockstad, J.K. Reynolds, J.A. Podosek, and E.C. Vote, Wide-Bandwidth Mechanical Elements for Tunneling Transducers, J. MicroElectroMechanical Systems 3, 97-104 (1994).

168. R.E. Stalder, S. Boumsellek, T.R. VanZandt, T.W. Kenny, M.H. Hecht and F.E Grunthaner, Micromachined Array of Electrostatic Energy Analyzers for Charged Particles, J. Vac. Sci. Technol. A12, 2554-2558 (1994).

169. H.K. Rockstad, T.W. Kenny, J.K. Reynolds, W.J. Kaiser, and T.B. Gabrielson, A Miniature High-Sensitivity Broad-Band Accelerometer Based on Electron Tunneling Transducers, Sensors and Actuators A 43, 107-114 (1994).

170. T.W. Kenny, W.J. Kaiser, J.A. Podosek, H.K. Rockstad, J.K. Reynolds, and E.C. Vote, Micromachined Tunneling Displacement Transducers for Physical Sensors, J. Vac. Sci. Technol. A11, 797-803 (1993).

171. T.W. Kenny, W.J. Kaiser, J.K. Reynolds, J.A. Podosek, H.K. Rockstad, E.C. Vote, and S.B. Waltman, Electron Tunnel Sensors, J. Vac. Sci. Technol. A 10(4), 2114-2118 (1992)

172. T.W. Kenny, W.J. Kaiser, S.B. Waltman, J.K. Reynolds, A Novel Infrared Detector Based on a Tunneling Displacement Transducer, Appl. Phys. Lett. 59, 1820-1822 (1991).

173. T.W. Kenny, S.B. Waltman, J.K. Reynolds, and W.J. Kaiser, A Micromachined Silicon Tunnel Sensor for Motion Detection, Appl. Phys. Lett. 58, 100-102 (1991).

174. T.W. Kenny and P.L. Richards, Heat Capacity and Sticking Probability Measurements of ^{4}He Submonolayers Adsorbed on Evaporated Ag Films: Bose Statistics in Two Dimensions, Phys. Rev. Lett. 64, 2386-2389 (1990).

175. T.W. Kenny and P.L. Richards, AC Calorimeter for Measurements of Adsorbed Gases on Metal Films at ^{4}He Temperatures, Rev. Sci. Instr. 61, 822-829 (1990).

176. T.W. Kenny, P.L. Richards, I.S. Park, E.E. Haller, and J.W. Beeman, Bias Induced Nonlinearities in Neutron Transmutation Doped Germanium at ^{4}He Temperatures, Phys. Rev. B 39, 8476-8482 (1989)

177. M. Berg, C.B. Harris, T.W. Kenny, and P.L. Richards, Generation of Intense Tunable Picosecond Pulses in the Far-Infrared, Appl. Phys. Lett. 47, 206-208 (1985).

178. U. Frick, T.W. Kenny, R.O. Pepin, "The Irradiation History of Lunar Breccia 79035", Meteoritics 17, 216 (1982).

Refereed Symposia and Conference Proceedings:

1. C.H. Hidrovo, T.A. Kramer, **E.N. Wang**, S. Vigneron, J.E. Steinbrenner, J.-M. Koo, F.-M. Wang, D. Fogg, R. Flynn, E.S. Lee, C.-H. Cheng, T.W. Kenny, J.K. Eaton, K.E. Goodson, "Two-phase Microfluidics for Semiconductor Circuits and Fuel Cells," 3rd International Conference on Microchannels & Minichannels, Toronto, Canada, June 13-15, ICMM2005-75085. 2005

2. **E.N. Wang,** J.G. Santiago, K.E. Goodson, T.W. Kenny. "Microjet Impingement Cooling with Phase Change," ASME International Mechanical Engineering Congress & Exposition, November 13-19, Anaheim, CA, USA, IMECE2004-62176. 2004.

3. **E.N. Wang,** S. Devasenathipathy, C.H. Hidrovo, D.W. Fogg, J.-M. Koo, J.G. Santiago, K.E. Goodson, T.W. Kenny. "Liquid Velocity Fields in Two-Phase Microchannel Convection," 3rd International Symposium on Two-Phase Flow Modelling and Experimentation, September 22-24, 2004, Pisa, Italy.

4. **E.N. Wang,** S. Devasenathipathy, J.G. Santiago, K.E. Goodson, T.W. Kenny. "Nucleation and Growth of Vapor Bubbles in a Heated Silicon Microchannel," ASME International Mechanical Engineering Congress & Exposition, Washington, D.C., USA, Nov. 15-21, 2003.

5. Koo, J.-M., Jiang, L., Bari, A., **Zhang, L., Wang, E**., Kenny, W., Goodson, K.E., and Santiago, J.G., "Convective Boiling in Microchanenl Heat Sinks with Spatially-varying Heat Flux", *ITHERM 2002*, San Diego, CA, USA, May, 2002.

6. Jiang, L., Koo, J.-M., Bari, A.**, Wang, E**., Prasher, R.S., Maveety, J., Kenny, T.W., Goodson, K.E., and Santiago J.G., "Cross-linked Microchannels for VLSI Hotspot Cooling", *2002 ASME International Mechanical Engineering Congress & Exposition*, New Orleans, USA, Nov.17-22, 2002.

7. Koo, J.-M., Im, S., Goodson, K.E., Cho, E., Prashe,r R.S., **Wang, E**., Jiang, L., Bari, A., Campion, D., Fogg, D., Kim, M., Kenny, T.W., and Santiago, J.G., "VLSI Hotspot Cooling Using Two-phase Microchannel Convection", *2002 ASME International Mechanical Engineering Congress & Exposition*, New Orleans, USA, Nov. 17-22, 2002.

8. Jiang, L., Mikkelsen, J., Koo, J-M**, Zhang, L.,** Huber, D., Yao, S., Bari, A., Zhou, P**.,** Santiago, J., and Kenny, T.W. and Goodson, K.E., "Transient and Sub-atmospheric Performance of A Closed-loop Electroosmotic Microchannel Cooling System", Proceeding of Thermal Challenges in Next Generation Electronic Systems, THERMES 2002, Santa Fe, New Mexico, USA, pp. 133-139, Jan. 13-16, 2002.

9. J.M. Koo**,** S. Im., S.S. Banerjee, D. Fogg**, E.N. Wang, L. Zhang,** L. Jiang, A. Bari, T.W. Kenny, K.E. Goodson, and J.G. Santiago, "Two-phase Microchannel Heat Sinks for Sub-100nm High Performance VLSI," Proc. ISLPED. 2002.

10. L. Jiang, J.M. Koo S. **L. Zhang., S. Banerjee,** P. Zhou. J.G, T.W. Kenny, K.E. Goodson,, "An Electrokinetic Closed-Loop Micro Cooler for High-Power VLSI Chips," presented at SEMI-THERM, San Jose, CA, USA, March. 2001.

11. R.M. Zeighami**, D. Laser**, P. Zhou**,** M. Asheghi., S. Devasenathipathy, T.W. Kenny, J.G. Santiago and K.E. Goodson, "Experimental Investigation of Flow Transition in Microchannels using Micron Resolution Particle Image Velocimetry," Proc. ITherm, Las Vegas, Nevada, May. 2000.

12. **C.H.Liu**, T.W. Kenny and H.K. Rockstad, Robust Controller Design via μ-synthesis for High-Performance Micromachined Tunneling Accelerometers, 1999 American Controls Conference Digest (1999)

13. W.P. King**,** J.G. Santiago, T.W. Kenny, and K.E. Goodson, "Modeling and Simulation of Sub-Micrometer Heat Transfer in AFM Thermomechanical Data Storage," ASME MEMS-Vol. 1, pp. 583-588. 1999.

14. **J.I. Molho, A.E. Herr,** T.W. Kenny, M.G. Mungal, M.G. Garguilo, P.H. Paul, M. Desphande, J.R. Gilbert, P.M. St.John, T.M. Woudenberg, and C. Connell, Fluid Transport Mechanisms in MicroFluidic Devices, Proceedings 1998 ASME Winter Meeting DSC Vol 66, 69 (1998).

15. S.M. Kumar**,** W.C. Reynolds, and T.W. Kenny, MEMS Based Actuators for Boundary Layer Control, Proceedings 1998 ASME Winter Meeting DSC Vol 66, 103 (1998).

16. **J.A. Harley, E.M Chow**, and T.W. Kenny Design of Resonant Beam Force Transducers; An Axial Force Probe for Atomic Force Microscopy, Proceedings 1998 ASME Winter Meeting DSC Vol 66, 247 (1998).

17. **Y. Liang** and T.W. Kenny, Mechanical Optimization of a Dual-Axis Piezoresistive Force Sensor, Proceedings 1998 ASME Winter Meeting DSC Vol 66, 389 (1998).

18. **A.M. Fitzgerald**, R.S. Iyer, R.H. Dauskardt, and T.W. Kenny, Fracture and Sub-Critical Crack Growth Behavior of Micromachined Single Crystal Silicon Structures, Proceedings 1998 ASME Winter Meeting DSC Vol 66, 395 (1998).

19. **J.K. Reynolds**, D.C Catling, R.C. Blue, N.I. Maluf, and T.W. Kenny Packaging and Instrumentation of a Commercial Pressure Sensor for a High-G Impact and the Martian Environment, Proceedings 1998 ASME Winter Meeting DSC Vol 66, 401 (1998).

20. **B.W. Chui,** T.W. Kenny, H.J. Mamin, B.D. Terris, and D. Rugar, A Novel AFM Cantilever with Independent Piezoresistive Sensors for Simultaneous Lateral and Vertical Force Detection, ASME Winter Exposition 1997.

21. **C.H. Liu, A. Barzilai, J.K. Reynolds, J.Grade**, H.K.Rockstad, T.W. Kenny, Feedback Control Strategies for High-Sensitivity Micromachined Tunneling Accelerometer, ASME Winter Exposition 1997.

Non-Refereed Symposia and Conference Publications:

1. **C.P. Cameron, T. Imamura, C. Devmalya, G. Vukasin, A. Alter**, T.W. Kenny, "Design Comparison and Survivability of Epitaxially Encapsulated MEMS Disc Resonating Gyroscopes at High Shock (>27,000g)", Proceedings 2019 International Symposium on Inertial Sensors and Systems, (2020).

2. **K.E. Kaplan**, M.W. Winterkorn, **H.J.K Kim, C.L.M. Everhart**, F.B. Prinz, and T.W. Kenny, "Thermal Accelerometer Performance Enhancements through AC Biasing Schemes", Proceedings 2020 IEEE MEMS (2020).

3. J. Yu, H**.K. Kwon, G.D. Vukasin**, T.W. Kenny, and Hanna Cho, "Frequency Stabilization in an Encapsulated High-Q Micromechanical Resonator via Internal Resonance", Proceedings 2020 IEEE MEMS (2020).

4. V. Zega, A. Opreni, G. Mussi, H**.K. Kwon, G. Vukasin**, G. Gattere, G. Langfelder, A. Frangi, and T.W. Kenny, "Thermal Stability of DETF MEMS Resonators: Numerical Modelling and Experimental Validation", Proceedings 2020 IEEE MEMS (2020).

5. J. Sun, H. Zhang, D. Chen, M. Pandit, G. Sobreviela, D. Xiao, M. Zhuo, **D.D. Gerrard, R. Kwon, G. Vukasin**, T.W. Kenny, and Ashwin Seshia, "Nonlinear Modal Interactions and Internal Resonance in a Micromachined Disk Resonator", Proceedings 2020 IEEE MEMS (2020).

6. D.A. Kassie, **I.B. Flader**, S. Shmulevich, **H.K. Kwon**, T.W. Kenny, and D. Elata, "An Epi-Seal Encapsulated Franklin Oscillator Sustaining More Than 200,000,000 Electric Switching Cycles", Proceedings 2020 IEEE MEMS (2020).

7. **J.M.L. Miller**, Z. Zhang, **N.E. Bousse**, D. Coso, S. Sadat, **H.K. Kwon, G.D. Vukasin**, A. Majumdar, and T.W. Kenny, "Temperature Hysteresis in Piezoresistive Microcantilevers", Proceedings 2020 IEEE MEMS (2020).

8. S. Shin, H. Wen, **H.K. Kwon, G.D. Vukasin**, T.W. Kenny, and F. Ayazi, "A Dual-Axis Resonant Accelerometer Based on Electrostatic Stiffness Modulation in Epi-Seal Process", Proceedings 2019 IEEE Sensors (2019).

9. J**.M.L. Miller, N.E. Bousse, D.D. Shin, H.K. Kwon**, and T.W. Kenny, "Signal Enhancement in MEM Resonant Sensors Using Parametric Suppression", 2019 20th International Conference on Solid-State Sensors, Actuators and Microsystems and Eurosensors XXXIII, (2019).

10. **S. Koppaka, A.L. Alter, G.D. Vukasin, D.D. Shin, I.B. Flader, Y. Chen,** and T.W. Kenny, "Nonlinearity of Degenerately Doped Flexural Mode Silicon Micromechanical Resonators", 2019 20th International Conference on Solid-State Sensors, Actuators and Microsystems and Eurosensors XXXIII, (2019).

11. **H.K. Kwon, L.C. Ortiz, G.D. Vukasin, Y.Chen, D.D. Shin**, and T.W. Kenny, "An Oven-Controlled MEMS Oscillator (OCMO) With Sub 10mw, ± 1.5 PPB Stability Over

Temperature", 2019 20th International Conference on Solid-State Sensors, Actuators and Microsystems and Eurosensors XXXIII, (2019).

12. **G.D. Vukasin, V.K. Sanchez, C.P. Cameron, H.K. Kwon, J. Rodriguez, I.B. Flader, Y. Chen**, and T.W. Kenny, "Effect of Substrate Thickness on Anchor Damping in MEMS Devices", 2019 20th International Conference on Solid-State Sensors, Actuators and Microsystems and Eurosensors XXXIII, (2019).

13. **A.L. Alter, G.D. Vukasin, I.B. Flader, H.J. Kim, Y. Chen, D.D. Shin**, and T.W. Kenny, "Experimentally Observed Nonlinear Dissipation Linked to Contributions from Gas Damping and TED in Mems Flexural Mode Resonators", 2019 20th International Conference on Solid-State Sensors, Actuators and Microsystems and Eurosensors XXXIII, (2019).

14. I.P. Prikhodko, J.A. Gregory, **D. Shin, R. Kwon**, T.W. Kenny, and M.W. Judy, "Pseudo-Extensional Mode MEMS Ring Gyroscope", 2019 International Symposium on Inertial Sensors and Systems, (2019).

15. Y.A. Pishchalnikov, W. Behnke-Parks, K. Maeda, T. Colonius, M. Mellema, M. Hopcroft, A. Luong, S. Wiener, M.L. Stoller, T. Kenny, D.J. Laser, "Experimental observations and numerical modeling of lipid-shell microbubbles with calcium-adhering moieties for minimally-invasive treatment of urinary stones", Proceedings Meetings on Acoustics. 35, 020008 (2018).

16. M.H. Asadian, S. Askari, **I.B. Flader, Y. Chen, D.D. Gerrard, D.D. Shin, H.K. Kwon,** T.W. Kenny, and A.M. Shkel, "High Quality Factor Mode Ordered Dual Foucault Pendulum Gyroscope", 2018 IEEE Inertial Sensors (2018).

17. **J. Rodriguez, G.D. Vukasin**, G.M. Glaze, M.A. Hopcroft, **L.C. Ortiz, C.H. Ahn, E. Ng**, W. Park, T.W. Kenny, and C.A. Watson, "Investigation of Orientation Dependence of the Thermal Expansion Coefficient in Silicon MEMS Resonators" 2018 International Frequency Control Symposium, Olympic Valley, CA. Pg 1-4. (2018).

18. **L.C. Ortiz, H-K. Kwon, J. Rodriguez, D.B. Heinz, Y. Chen, G.D. Vukasin, D.D. Shin** and T.W. Kenny, "A New Low-Power MEMS Dual-Mode Clock with PPB Stability over Temperature", Proceedings 2018 Hilton Head Workshop on Solid State Sensors and Actuators, Hilton Head (2018).

19. **A.L. Alter, I.B. Flader, Y. Chen, L.C. Ortiz, D.D. Shin, D.B. Heinz** and T.W. Kenny, "First Fatigue Measurements on Thick Epi-Polysilicon MEMS in Ultra-Clean Environment", Proceedings 2018 Hilton Head Workshop on Solid State Sensors and Actuators, Hilton Head (2018).

20. **L.C. Ortiz, D.D. Gerrard, I.B. Flader, G.D. Vukasin, D.B. Heinz, J. Rodriguez, S. Koppaka, D.D. Shin, H-K Kwon**, S. Chandorkar, and T.W. Kenny, "Enhancing Micro-Oven Power and Stiffness in Encapsulated Devices for Timing Reference Applications", Proceedings 2018 Hilton Head Workshop on Solid State Sensors and Actuators, Hilton Head (2018).

21. **J.M.L. Miller**, A. Ansari, **D.B. Heinz, Y. Chen, I.B. Flader, D.D. Shin**, L.G. Villanueva, and T.W. Kenny, "What is Effective Quality Factor?", Proceedings 2018 Hilton Head Workshop on Solid State Sensors and Actuators, Hilton Head (2018).

22. Y. Wang, Y-W, Lin, **J. Rodriguez, G.D. Vukasin, D.D. Shin, H-K. Kwon, D.B. Heinz, Y. Chen, D.D. Gerrard**, T.W. Kenny and A.M. Shkel, "On Decoupled Quantification of Energy Dissipation Mechanisms in Toroidal Ring Gyroscopes", Proceedings 2018 Hilton Head Workshop on Solid State Sensors and Actuators, Hilton Head (2018).

23. **H-K. Kwon, D.B. Heinz, D.D. Shin, Y. Chen, L.C. Ortiz, G.D. Vukasin** and T.W. Kenny, "Precise Local Temperature Measurement of Fully-Encapsulated Ovenized MEMS Devices", Proceedings 2018 Hilton Head Workshop on Solid State Sensors and Actuators, Hilton Head (2018).

24. E. Cook, M. Tomaino-Iannucci, J. Bernstein, M. Weinberg, J. Choy, K. Hobart, L. Luna, M. Tadjer, R. Myers-Ward, F. Kub, **Y. Yang, E. Ng, I. Flader, Y. Chen**, and T. Kenny, "A High-Mass, Eight-Fold Symmetric Silicon Carbide MEMS Gyroscope", Proceedings 2018 Hilton Head Workshop on Solid State Sensors and Actuators, Hilton Head (2018).

25. **G.D. Vukasin, J. Rodriguez, L.C. Ortiz**, G.M. Glaze, **D.D. Gerrard, C.H. Ahn, Y. Yang**, J. Lake, R.N. Candler and T.W. Kenny, "Direct Measurement of Anchor Damping in Pressure-Limited Ring Resonators", Proceedings 2018 Hilton Head Workshop on Solid State Sensors and Actuators, Hilton Head (2018).

26. **D.D. Shin, D.B. Heinz, K-K. Kwon, Y. Chen**, and T.W. Kenny, "Lateral Diffusion Doping of Silicon for Temperature Compensation of MEMS Resonators", 2018 IEEE International Symposium on Inertial Sensors and Systems, (2018).

27. **K.E. Kaplan, M.W. Winterkorn, C.L.M. Everhart, D.D. Shin**, G.J, O'Brien, F.B. Prinz and T.W. Kenny, "Active Temperature Compensation of Thermal Accelerometer for Improved Stability", 2018 IEEE International Symposium on Inertial Sensors and Systems (2018).

28. **J. Rodriguez, D.D. Gerrard**, G.M. Glaze, S. Chandorkar, **L. Comenecia, Y. Chen, I.B. Flader**, T.W. Kenny, "Direct Measurement of Anchor Damping in MEMS Resonators", Proceedings IEEE Sensors P.1, October 29, 2017, Glasgow, Scotland (2017).

29. **I.B. Flader, Y. Chen, C.C. Shin, A.L. Alter, J. Rodriguez**, and T.W. Kenny, "Epitaxial Encapsulation of Fully-Differential Electrodes and Large Transduction Gaps for MEMS Resonant Structures", IEEE MEMS Glasgow 483 (2018).

30. V. Maiwald, **I.B. Flader**, M. Muller, **Y. Chen**, S. Lluss, **D.D. Shin**, C. Roman, **D.B. Heinz**, T.W. Kenny and C. Hierold, "Experimental Fractal-Like Instability Bands in Resonant Silicon-Silicon Contact Pull-In Vibration Detector", IEEE MEMS Glasgow 984 (2018).

31. **L.C. Ortiz, I.B. Flader, G.D. Vukasin, D.D. Gerrard**, S.A. Chandorkar, **J. Rodriguez, D.D. Shin, R. Kwon, D.B. Heinz, Y. Chen**, W. Park, K.E. Goodson and T.W. Kenny, "Thermal Effects of Ovenized Clocks on Episeal Encapsulated Inertial Measurement Units", IEEE MEMS Glasgow 980 (2018).

32. **J. Rodriguez, D.D. Gerrard**, G.M. Glaze, S. Chandorkar, **Y. Chen, I.B. Flader, D.D. Shin** and T.W. Kenny, "Unanticipated Results in the First Direct Measurements of Anchor Damping in MEMS Resonators", IEEE MEMS Glasgow 543 (2018).

33. C.L.M. Everhart, K.E. Kaplan, M.W. Winterkorn, H. Kwon, J. Provine, M. Asheghi, K.E. Goodson, F.B. Prinz, and T.W. Kenny, "High-Stability Thermal Accelerometer based on UltraThin Platinum ALD Nanostructures", IEEE MEMS Glasgow 976 (2018).

34. **D.D. Shin, Y. Chen, I.B. Flader** and T.W. Kenny, "Temperature Compensation of Resonant Accelerometer via Nonlinear Operation", IEEE MEMS Glasgow 1012 (2018).

35. M. Bauer, T. Ebefors, M.M. Visser Taklo, S. Moe, P. Pickering, C, Twanow, D. Spicer, S. Nasiri, S. Winkler, R. Ramadoss, A. Luque, C. Aracil**, J. Rodriguez**, T.W. Kenny, M. Esashi, S. Tanaka, Y-C. Su, H-A. Yang, C-W. Lin, W. Fang, Y.T. Cheng, Y.C. Su, L.Lin, E.M. Chow, C.L. Chua, C-M. Huang, A. Sai S. Vasan, Y. Huang, R. Doraiswami, M. Osterman, M. Pecht, Y.C. Lee, Y-T. Cheng, "Silex's TSV Technology: Overview of Processes and MEMS Applications", MEMS Packaging 5, 31 (2018).

36. **J. Rodriguez, D.D. Gerrard**, G.M. Glaze, S. Chandorkar, **L.C. Ortiz, Y. Chen, I.B. Flader** and T.W. Kenny, "Direct Measurements of Anchor Damping in MEMS Resonators", IEEE Sensors Belfast (2017).

37. S.Sonmezoglu, **I.B. Flader, Y. Chen, D. D Shin**, T.W. Kenny, and D.A. Horsley, "Dual-resonator MEMS magnetic sensor with differential amplitude modulation", Proceedings, 2017 International Conference on Solid-State Sensors, Actuators and Microsystems, June 18-22, 2017, Kaohsiung, Taiwan, P. 814 (2017).

38. **I.B. Flader, Y. Chen, D.D. Gerrard**, and T.W. Kenny, "Wafer-scale encapsulation of fully differential electrodes for mutli-axis inertial sensing", Proceedings, 2017 International Conference on Solid-State Sensors, Actuators and Microsystems, June 18-22, 2017, Kaohsiung, Taiwan, P. 591 (2017).

39. **J.M.L. Miller, D.B. Heinz, I.B. Flader, Y. Chen, D.D. Shin**, T.W. Kenny, "Effective quality factor and temperature dependence of self-oscillations in a thermal-piezoresistively pumped resonator", 2017 International Conference on Solid-State Sensors, Actuators and Microsystems, June 18-22, 2017, Kaohsiung, Taiwan, P. 1907 (2017).

40. **D.D. Gerrard, Y. Chen, S.A. Chandorkar, G.Yu, J.Rodriguez, I.B. Flader, D.D. Shin**, C.D. Meinhart, O.Sigmund, T.W Kenny, "Topology optimization for reduction of thermo-elastic dissipation in MEMS resonators", 2017 International Conference on Solid-State Sensors, Actuators and Microsystems, June 18-22, 2017, Kaohsiung, Taiwan, P. 794 (2017).

41. **D.B.Heinz, I.B. Flader, Y. Chen, G.D. Vukasin, L.C. Ortiz,** T.W. Kenny, "Direct comparison of stiction properties of oxide coated polysilicon and smooth single crystal silicon", 2017 International Conference on Solid-State Sensors, Actuators and Microsystems, June 18-22, 2017, Kaohsiung, Taiwan, P. 1203 (2017).

42. **J. Rodriguez, D.D. Gerrard, S. Chandorkar, Y. Chen**, G.M. Glaze, **I.B. Flader, C.H. Ahn, E.J. Ng**, T.W. Kenny, "Wide-range temperature dependence studies for devices limited

by thermoelastic dissipation and anchor damping", 2017 International Conference on Solid-State Sensors, Actuators and Microsystems, June 18-22, 2017, Kaohsiung, Taiwan, P. 1100 (2017).

43. **D.D. Shin, Y. Chen, I.B. Flader,** T.W. Kenny, "Epitaxially encapsulated resonant accelerometer with an on-chip micro-oven", 2017 International Conference on Solid-State Sensors, Actuators and Microsystems, June 18-22, 2017, Kaohsiung, Taiwan, P. 595 (2017).

44. V. Maiwald, **Y. Chen**, M. Müller, **I.B. Flader**, C. Roman, **D.B. Heinz, D.D. Shin**, T.W. Kenny, C. Hierold, "Transfer function tuning of a broadband shoaling mechanical amplifier near the electrostatic instability", 2017 International Conference on Solid-State Sensors, Actuators and Microsystems, June 18-22, 2017, Kaohsiung, Taiwan, P. 802 (2017).

45. **D.D. Shin, C.H. Ahn, Y. Chen, V.A. Hong, E.J. Ng, Y. Yang**, T.W. Kenny, "Electrostatic tuning of temperature coefficient of frequency of anisotropic disk-shaped resonators", 2017 IEEE International Symposium on Inertial Sensors and Systems (INERTIAL), Kauai, Hawaii, P. 264 (2017).

46. A. Efimovskaya, **Y. Yang, E. Ng, Y, Chen, I. Flader, T.W. Kenny**, A.M. Shkel, "Compact roll-pitch-yaw gyroscope implemented in wafer-level Epitaxial Silicon Encapsulation process", 2017 IEEE International Symposium on Inertial Sensors and Systems (INERTIAL), Kauai, Hawaii, P. 1 (2017).

47. S.Sonmezoglu, **I.B. Flader, Y. Chen, D.D. Shin**, T.W. Kenny, D.A. Horsley, "Dual-resonator MEMS Lorentz force magnetometer based on differential frequency modulation", 2017 IEEE International Symposium on Inertial Sensors and Systems (INERTIAL), Kauai, Hawaii, P. 160 (2017).

48. **Y.Chen, I.B. Flader, D.D. Shin, C.H. Ahn, L.C. Ortiz**, T.W. Kenny, "Fabrication of wide and deep cavities for silicon MEMS devices without wafer bonding", 2017 IEEE International Symposium on Inertial Sensors and Systems (INERTIAL), Kauai, Hawaii, P. 113 (2017).

49. P.Taheri-Tehrani, M.Defoort, **Y. Chen, I. Flader, D.D. Shin**, T.W. Kenny, D.A. Horsley, "Epitaxially-encapsulated quad mass resonator with shaped comb fingers for frequency tuning", Proceedings 2017 IEEE MEMS, January 22-25, 2017, Las Vegas, NV, P 1111. (2017).

50. **D.B. Heinz, V.A. Hong, Y. Yang, C.H. Ahn**, T.W. Kenny, "High-G (> 20,000 g) inertial shock survivability of epitaxially encapsulated silicon MEMS devices", Proceedings 2017 IEEE MEMS, January 22-25, 2017, Las Vegas, NV, P 1122. (2017).

51. **D.D. Shin, C.H. Ahn, Y. Chen, D.L. Christensen, I.B. Flader**, T.W. Kenny, "Environmentally robust differential resonant accelerometer in a wafer-scale encapsulation process", Proceedings 2017 IEEE MEMS, January 22-25, 2017, Las Vegas, NV, P 17. (2017).

52. **I.B Flader, Y. Chen, Dongsuk D. Shin, D.B. Heinz, L.C. Ortiz, A.L. Alter,** W. Park, K.E. Goodson, T.W. Kenny, "Micro-tethering for in-process stiction mitigation of highly

compliant structures", Proceedings 2017 IEEE MEMS, January 22-25, 2017, Las Vegas, NV, P 675. (2017).

53. **Y. Chen, D.D. Shin, I.B. Flader**, T.W. Kenny, "Tri-mode operation of highly doped silicon resonators for temperature compensated timing references", Proceedings 2017 IEEE MEMS, January 22-25, 2017, Las Vegas, NV, P 1158. (2017).

54. A. Efimovskaya, Y.W. Lin, **Y. Yang, E. Ng, Y. Chen, I. Flader, C.H. Ahn, V. Hong,** T.W. Kenny, A.M. Shkel, "On cross-talk between gyroscopes integrated on a folded MEMS IMU Cube", Proceedings 2017 IEEE MEMS, January 22-25, 2017, Las Vegas, NV, P 1142. (2017).

55. **D.D. Gerrard, J. Rodriguez, L.C. Ortiz, S.A. Chandorkar, I.B. Flader, Y. Chen, D.D. Shin,** T.W. Kenny, "Manipulation of heat flux paths in thermo-elastically damped resonators for Q optimization", Proceedings 2017 IEEE MEMS, January 22-25, 2017, Las Vegas, NV, P 1130. (2017).

56. **C.H Ahn, D.L Christensen, D.B Heinz, V.A Hong, E.J Ng, J. Rodriguez, Y. Yang,** G. O'Brien, T.W. Kenny, "Encapsulated Inertial Systems", 2016 IEEE International Electron Devices Meeting (IEDM), San Francisco, CA (2016).

57. **D.B. Heinz, V.A. Hong, C.H. Ahn. Y. Yang** and T.W. Kenny, "Stiction at High Temperature (>205C) in Encapsulated MEMS Devices for Harsh Environment Applications", Proceedings 2016 Hilton Head Workshop on Solid State Sensors and Actuators, Hilton Head (2016).

58. P. Polunin, **Y. Yang**, S. Shaw, T.W. Kenny and M. Dykman, "Revealing and Characterizing Noise Sources in MEMS Resonators", Proceedings 2016 Hilton Head Workshop on Solid State Sensors and Actuators, Hilton Head (2016).

59. O. Shoshani, **D. Heywood, Y. Yang**, T.W. Kenny and S. Shaw, "Phase Noise Reduction in a MEMS Oscillator usinf a Nonlinearity-Enhanced Synchronization Domain", Proceedings 2016 Hilton Head Workshop on Solid State Sensors and Actuators, Hilton Head (2016).

60. **I.B. Flader, C.H. Ahn, D.D. Gerrard, E.J. Ng, Y Yang, V.A. Hong**, M. Pavone, T.W. Kenny, "Autonomous calibration of MEMS disk resonating gyroscope for improved sensor performance", 2016 American Control Conference, P. 5803 (2016).

61. I.P. Prikhodko, J.A. Gregory, W.A. Clark, J.A. Geen, M.W. Judy, **C.H. Ahn**, and T.W. Kenny, "Mode-matched MEMS Coriolis vibratory gyroscopes: Myth or reality?", 2016 Position, Location and Navigation Symposium (PLANS) (2016).

62. **V.A. Hong, D.B. Heinz, D.L. Christensen, D.D. Shin, Y. Chen , C.H. Ahn, Y. Yang, E.J. Ng, I.B. Flader**, and T.W. Kenny, "Overcoming Stiction Forces with Resonant Over-Travel Stops", Proceedings 2016 IEEE MEMS, January 24-27, 2016, Shanghai China, p. 47-50.

63. **Y. Chen, E.J. Ng, D.D. Shin, C.H. Ahn, Y. Yang, I.B. Flader, V.A. Hong** and T.W. Kenny, "Ovenized Dual-Mode Clock (ODMC) based on Highly-Doped Single-Crystal Silicon Resonators", Proceedings 2016 IEEE MEMS, January 24-27, 2016, Shanghai China, p. 91-94.

64. S. Wisher, P. Shao, A. Norouzpour-Shirazi, **Y. Yang, E. Ng, I. Flader, Y. Chen, D. Heinz**,

T. Kenny, and F. Ayazi, "A High-Frequency Epitaxially-Encapsulated Single-Drive Quad-Mass Tri-Axial Resonant Tuning Fork Gyroscope", Proceedings 2016 IEEE MEMS, January 24-27, 2016, Shanghai China, p. 930-933.

65. **C.H. Ahn, D.D. Shin, V.A. Hong, Y. Yang, E.J. Ng, Y. Chen, I.B. Flader**, and T.W. Kenny, "Encapsulated Disk Resonator Gyroscope with Differential Internal Electrodes", Proceedings 2016 IEEE MEMS, January 24-27, 2016, Shanghai China, p. 962-969.

66. P. Taheri-Tehrani, M. Kline, I. Izyumin, B. Eminoglu. Y-C- Yeh, **Y. Yang, Y. Chen, I. Flader, E.J. Ng**, T.W. Kenny, B.E. Boser, and D.A. Horsley, "Epitaxially-Encapsulated Quad Mass Gyroscope with Nonlinearity Compensation", Proceedings 2016 IEEE MEMS, January 24-27, 2016, Shanghai China, p. 966-969.

67. **D.D. Gerrard, C.H. Ahn, I.B. Flader, Y. Chen, E.J. Ng, Y.Yang**, and T.W. Kenny "Q-Factor Optimization in Disk Resonator Gyroscopes via Geometric Parameterization", Proceedings 2016 IEEE MEMS, January 24-27, 2016, Shanghai China, p. 994-997.

68. **I.B. Flader, C.H. Ahn, E.J. Ng, Y. Yang, V.A. Hong**, and T.W. Kenny, "Stochastic Method for Disk Resonating Gyroscope Mode Matching and Quadrature Nulling", Proceedings 2016 IEEE MEMS, January 24-27, 2016, Shanghai China, p. 998-1001.

69. **C. H. Ahn, , V.A. Hong, W. Park, T. Yang, Y. Chen, E. Ng, J. Huynh,** A.D. Challoner, K.E Goodson and T.W. Kenny, "On-Chip Ovenization of Encapsulated Disk Resonator Gyroscope (DRG)", Proceedings, 2015 International Conference on Solid-State Sensors, Actuators and Microsystems, June 23-27, 2015, Anchorage, AK, p 39-42 (2015).

70. **V.A. Hong**, J. Stehle, **C.H. Ahn, D.B. Heinz**, G. Yama, B. Kim, G.J. O'Brien and T.W. Kenny, "Capacitive Sensor Fusion : Co-Fabricated X/Y and Z axis Accelerometers, Pressure Sensor and Thermometer", Proceedings, 2015 International Conference on Solid-State Sensors, Actuators and Microsystems, June 23-27, 2015, Anchorage, AK, p 295-298 (2015).

71. **Y. Yang, E.J. Ng, Y Chen, I.B. Flader, C.H. Ahn, V.A. Hong** and T.W. Kenny, "A Unified Epi-Seal Process for Resonators and Inertial Sensors", Proceedings, 2015 International Conference on Solid-State Sensors, Actuators and Microsystems, June 23-27, 2015, Anchorage, AK, p 1326-1329 (2015).

72. **D.D. Gerrard, E.J. Ng, C.H. Ahn, V.A. Hong, Yushi Yang**, and T.W. Kenny, "Modeling the Effect of Anchor Geometry on the Quality Factor of Bulk-Mode Resonators", Proceedings, 2015 International Conference on Solid-State Sensors, Actuators and Microsystems, June 23-27, 2015, Anchorage, AK, p 1997-2000 (2015).

73. **J. Rodriguez, Y. Yang, C.H. Ahn, Y. Chen, E.J. Ng, V.A. Hong, S. Ghaffari**, and T.W. Kenny, "Damping Mechanisms in Light and Heavy-Doped Dual-Ring and Double-Ended Tuning Fork Resonators (DETF)", Proceedings, 2015 International Conference on Solid-State Sensors, Actuators and Microsystems, June 23-27, 2015, Anchorage, AK, p 2005-2009 (2015).

74. B.W. Soon, Y. Qian, **E.J. Ng**, T.W. Kenny and C. Lee, "Silicon-to-Silicon Microswitch with Wide Operation Temperature Range", Proceedings, 2015 International Conference on Solid-State Sensors, Actuators and Microsystems, June 23-27, 2015, Anchorage, AK, p 2105-2108 (2015).

75. P. Polunin, **Y. Yang**, J. Atalaya, **E. Ng**, S. Strachan, O. Shoshani, M. Dykman, S. Shaw and

T.W. Kenny, "Characterizing MEMS Nonlinearities Directly : The Ring-Down Measurements", Proceedings, 2015 International Conference on Solid-State Sensors, Actuators and Microsystems, June 23-27, 2015, Anchorage, AK, p 2176-2179 (2015).

76. **C. H. Ahn, E. Ng, V.A. Hong, J. Huynh**, T.W. Kenny and **S. Wang**, "Oxide-coated Polysilicon Disk Resonator Gyroscope (DRG) within the Wafer-Scale Encapsulation Process", Proceedings 2nd IEEE International Symposium on Inertial Sensors and Systems, P. 127 (2015).

77. P.Taheri-Tehrani, O. Izyumin, **C.H. Ahn, E.J. Ng, V.A. Hong, Y. Yang**, T.W. Kenny, B.E. Bozer, D.A. Horsley, "Disk Resonator Gyroscope with Whole-Angle Mode Operation", Proceedings 2nd IEEE International Symposium on Inertial Sensors and Systems, P. 9 (2015).

78. **E. Ng, Y. Yang, V.A. Hong, C.H. Ahn, D.B. Heinz, I. Flader, Y. Chen, C.L.M. Everhart, B. Kim, R. Melamud, R.N. Candler, M.A. Hopcroft, J.C. Salvia, S. Yoneoka, A.B. Graham, M.Agarwal, M.W. Messana, K.L. Chen, H.K. Lee, S. Wang, G. Bahl, V. Qu, C.F. Chiang**, and T.W. Kenny, A. Partridge, M. Lutz, G. Yama, and G.J. O'Brien, "The Very Long Path from MEMS Resonators to Timing Products", Proceedings 2015 IEEE MEMS Conference, Estoril Portugal, P.1 (2015).

79. D. Senkal, **E.J. Ng, V.A Hong, Y. Yang, C.H. Ahn**, T.W. Kenny and A.M. Shkel, "Parametric Drive of a Toroidal MEMS Rate Ingegrating Gyroscope Demonstrating <20PPM Scale Factor Stability", Proceedings 2015 IEEE MEMS Conference, Estoril Portugal, P.33 (2015).

80. I.I. Izuymin, M.H. Kline, Y-C. Yeh, B. Eminoglu, **C.H. Ahn. V.A. Hong, Y. Yang, E.J. Ng,** T.W. Kenny and B.E. Bozer, "A 7PPM 6d/HR Frequency-Output MEMS Gyroscope", Proceedings 2015 IEEE MEMS Conference, Estoril Portugal, P.1 (2015).

81. **D.B. Heinz, V.A. Hong, T.S. Kimbrell, J. Stehle, C.H. Ahn, E.J. Ng, Y. Yang**, G. Yama, G.J. O'Brien and T.W. Kenny, "Stiction Forces and Reduction by Dynamic Contact in Ultra-Clean Encapsulated MEMS Devices", Proceedings 2015 IEEE MEMS Conference, Estoril Portugal, P.393 (2015).

82. **Y. Chen, E.J. Ng, Y. Yang, C.H. Ahn, I. Flader** and T.W. Kenny, **"**In-Situ Ovenization of Lame-Mode Silicon Resonators for Temperature Compensation**",** Proceedings 2015 IEEE MEMS Conference, Estoril Portugal, P.809 (2015).

83. **Y. Yang, E.J. Ng,** P. Polunin, **Y. Chen**, S. Strachan, **V.A. Hong, C.H. Ahn,** O. Shoshani, S. Shaw, M. Dykman and T.W. Kenny**, "Experimental Investigation on Mode Coupling of Bulk-Mode Silicon MEMS Resonators",** Proceedings 2015 IEEE MEMS Conference, Estoril Portugal, P.1008 (2015).

84. **Yushi Yang, Eldwin J. Ng, Vu A. Hong, Chae Hyuck Ahn, Yunhan Chen, Elia Ahadi**, Mark Dykman, and Thomas W. Kenny, "Measurement of the Nonlinear Elasticity of Doped Bulk-Mode MEMS Resonators", Proceedings 2014 Solid State Sensors and Actuators Workshop, 285-288, Hilton Head, SC (2014).

85. **Eldwin J. Ng, Yushi Yang, Yunhan Chen**, and Thomas W. Kenny, "An Etch Hole-Free Process for Temperature-Compensated, High-Q Encapsulated Resonators", Proceedings 2014 Solid State Sensors and Actuators Workshop, 99-100, Hilton Head, SC (2014).

86. J. Stehle, **V.A. Hong**, A. Feyh, G.J. O'Brien, G. Yama, O. Ambacher, B. Kim, and T.W.

Kenny, "Silicon Migration of Through-Holes in Single and Poly-Crystalline Silicon Membranes", Proceedings 2014 Solid State Sensors and Actuators Workshop, 32-35, Hilton Head, SC (2014).

87. M. Li, S. Sonmezoglu, **E.J. Ng, V.A. Hong, C. H. Ahn, Y. Yang,** T.W. Kenny and D.A. Horsley, "Lorentz Force magnetometer with Quadrature Frequency Moduation", Proceedings 2014 Solid State Sensors and Actuators Workshop, 52-55, Hilton Head, SC (2014).

88. **T.S. English**, F. Purkl, A. Daus, J Provine, Y. Won, G. Yama, A. Feyh, G. O'Brien, K.E. Goodson, O. Ambacher, and T.W. Kenny, "Atomic Layer Deposited Platinum as a Sensor Material: Uniformity, 1/F Noise and Young's Modulus", Proceedings 2014 Solid State Sensors and Actuators Workshop, 44-47, Hilton Head, SC (2014).

89. S. Nitzan, T-H. Su, **C. Ahn, E. Ng, V. Hong, Y. Yang**, T. Kenny, and D.A. Horsley, "Impact of Gyroscope Operation Above the Critical Bifurcation Threshold on Scale Factor and Bias Instability", Proceedings 2014 IEEE 27th International Conference on Micro Electro Mechanical Systems (MEMS), San Francisco, 749-752 (2014).

90. **David B. Heinz, Vu A. Hong, Eldwin J. Ng, Chae Hyuck Ahn, Yushi Yang**, Thomas W. Kenny, "Characterization of Stiction Forces in Ultra-Clean Encapsulated MEMS Devices", Proceedings 2014 IEEE 27th International Conference on Micro Electro Mechanical Systems (MEMS), San Francisco, 588-591 (2014).

91. Mo Li, **Eldwin J. Ng, Vu A. Hong, Chae H. Ahn, Yushi Yang**, Thomas W. Kenny and David A. Horsley "Single-Structure 3-Axis Lorentz Force Magnetometer with Sub-30 nT/√Hz Resolution", Proceedings 2014 IEEE 27th International Conference on Micro Electro Mechanical Systems (MEMS), San Francisco, 80-83 (2014).

92. **Eldwin J. Ng**, Kimberly L. Harrison, **Camille L. Everhart, Vu A. Hong, Yushi Yang, Chae Hyuck Ahn, David B. Heinz**, Roger T. Howe and Thomas W. Kenny, "Stable Charge-Biased Capacitive Resonators with Encapsulated Switches", Proceedings 2014 IEEE 27th International Conference on Micro Electro Mechanical Systems (MEMS), San Francisco, 1277-1280 (2014).

93. **Eldwin J. Ng, Yushi Yang, Vu A. Hong, Chae Hyuck Ahn, David L. Christensen**, Brian A. Gibson, Kamala R. Qalandar, Kimberly L. Turner, Thomas W. Kenny, "Stable Pull-In Electrodes for Narrow Gap Actuation", Proceedings 2014 IEEE 27th International Conference on Micro Electro Mechanical Systems (MEMS), San Francisco, 1281-1284 (2014).

94. D. Senkal, S. Askari, M.J. Ahamed, **E.J. Ng, V. Hong, Y. Yang, C.H. Ahn**, T.W. Kenny, A.M. Shkel, "100K Q-Factor Torodial Ring GyroscopeImplemented in Wafer-Level Epitaxial Silicon Encapsulation Process", Proceedings 2014 IEEE 27th International Conference on Micro Electro Mechanical Systems (MEMS), San Francisco, 24-27 (2014).

95. **E.J. Ng, C.H. Ahn, Y. Yang, V.A. Hong, C-F. Chiang, E. Ahadi, M.W. Ward** and T.W. Kenny, "Localized, Degenerately-Doped Epitaxial Silicon for Temperature Compensation of Resonant Microsystems", Proceedings, The 17th International Conference on Solid-State Sensors, Actuators and Microsystems, June 16-20, 2013, Barcelona. Spain, p 2419-2422.

96. **E.J. Ng, C-F. Chiang, Y. Yang, V.A. Hong, C.H. Ahn** and T.W. Kenny, "Ultra-High Aspect Ratio Trenches in Single Crystal Silicon with Epitaxial Gap Tuning", Proceedings, The 17th International Conference on Solid-State Sensors, Actuators and Microsystems, June 16-20, 2013, Barcelona. Spain, p 182-185.

97. **Y. Yang, E.J. Ng, C.H. Ahn, V.A. Hong, E. Ahadi** and T.W. Kenny, "Mechanical Coupling of Dual Breath-Mode Ring Resonator", Proceedings, The 17th International Conference on Solid-State Sensors, Actuators and Microsystems, June 16-20, 2013, Barcelona. Spain, p 502-505.

98. **C.H. Ahn, E.J. Ng, V.A. Hong. Y. Yang, B.J. Lee, M.W. Ward,** and T.W. Kenny, "Geometric Compensation of (100) Single Crystal Silicon Disk Resonating Gyroscope for Mode-Matching", Proceedings, The 17th International Conference on Solid-State Sensors, Actuators and Microsystems, June 16-20, 2013, Barcelona. Spain, p 1723-1726.

99. **V.A. Hong, B.J. Lee, D.L Christensen, E.J. Ng, C.H. Ahn, Y. Yang** and T.W. Kenny, "X-Y and Z-Axis Capacitive Accelerometers Packaged in an Ultra-Clean Hermetic Environment", Proceedings, The 17th International Conference on Solid-State Sensors, Actuators and Microsystems, June 16-20, 2013, Barcelona. Spain, p 618-621

100. **D.L. Christensen, C.H. Ahn, V.A. Hong, E.J. Ng, Y. Yang, B.J. Lee** and T.W. Kenny, "Hermetically-Encapsulated Differential Resonant Accelerometer", Proceedings, The 17th International Conference on Solid-State Sensors, Actuators and Microsystems, June 16-20, 2013, Barcelona. Spain, p 606-609.

101. **M.A. Philippine**, H. Zareie, O. Sigmund, G.M. Rebeiz and T.W. Kenny, "Topology Optimized RF MEMS Switches", Proceedings, The 17th International Conference on Solid-State Sensors, Actuators and Microsystems, June 16-20, 2013, Barcelona. Spain, p 2477-2480.

102. F. Purkl, **T.S. English**, G. Yama, J. Provine, A.K. Samaro, A. Feyh, B. Kim, G. O'Brien, O, Ambacher, R.T. Howe and T.W. Kenny, "Serpentine Geometry for Enhanced Performance of Nanometer-Thin Platinum Bolometers", Proceedings, The 17th International Conference on Solid-State Sensors, Actuators and Microsystems, June 16-20, 2013, Barcelona. Spain, p 1507-1510

103. **C-F Chiang**, A.B. Graham, **B.J. Lee, C-H Ahn, E. Ng**, G.J. O'Brien and T.W. Kenny "Resonant pressure sensor with on-chip temperature and strain sensors for error correction", Proceedings 2013 IEEE 26th International Conference on Micro Electro Mechanical Systems (MEMS), Taipei, Taiwan 45-48 (2013).

104. S. Nitzan, **C-H Ahn**, T-H Su, **E. Ng, S. Wang**, G. O'Brien, B.E. Boser, T.W. Kenny and D.A Horsley, "Epitaxially-encapsulated polysilicon disk resonator gyroscope", Proceedings 2013 IEEE 26th International Conference on Micro Electro Mechanical Systems (MEMS), Taipei, Taiwan 625-628 (2013).

105. F. Purkl, **T. English**, G. Yama, J. Provine, A.K. Samarao, A. Feyh, G. O'Brien, O. Ambacher, R.T. Howe and T.W. Kenny, " Sub-10 nanometer uncooled platinum bolometers via plasma enhanced atomic layer deposition", Proceedings 2013 IEEE 26th International Conference on Micro Electro Mechanical Systems (MEMS), Taipei, Taiwan 185-188 (2013).

106. Y. Won, Y. Gao, R.G. deVilloria, B.L. Wardle, T.W. Kenny and K.E. Goodson, "Crust Removal and Effective Modulus of Aligned Multi-Walled Carbon Nanotube Films", 13th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomana in Electronic Systems (ITHERM), San Diego, CA PP 1070-1076 (2012).

107. S. Seth, **S. Wang**, T. Kenny, and B. Murmann, "A −131-dBc/Hz, 20-MHz MEMS Oscillator with a 6.9-mW, 69-kΩ, Gain-Tunable CMOS TIA", SSCIRC 2012 - 38th European Solid State Circuits Conference, Bordeaux, France Pages: 249-52 ,(2012).

108. **B. Kim, R. Melamud, R.A. Candler, M.A. Hopcroft**, and T.W. Kenny, "MEMS Packaging for Reliable Resonators and Oscillators", 2012 IEEE/MTT-S International Microwave Symposium - MTT 2012, Montreal Canada (2012).

109. **C-F. Chiang, A.B. Graham, E.J. Ng, C.H. Ahn**, G.J. O'Brien and T.W. Kenny, "A Novel, High-Resolution Resonant Thermometer used for Temperature Compensation of a Cofabricated Pressure Sensor", Proceedings 2012 Solid State Sensors and Actuators Workshop, P54, Hilton Head, SC (2012).

110. **E.J. Ng, S. Wang, D. Buchman, C-F. Chiang**, T.W. Kenny, H. Muenzel, M. Fuertsch, J. Marek, U.M. Gomez, G. Yama and G.O'Brien, "Ultra-Stable Epitaxial Polysilicon Resonators", Proceedings 2012 Solid State Sensors and Actuators Workshop, P271, Hilton Head, SC (2012).

111. **V.A. Hong, S. Yoneoka, M.W. Messana, A.B. Graham, J.C. Salvia, T.T. Branchflower, E.J. Ng** and T.W. Kenny, "High-Stress Fatigue Experiments on Single Crystal Silicon in an Oxygen-Free Environment", Proceedings 2012 Solid State Sensors and Actuators Workshop, P553, Hilton Head, SC (2012).

112. **M.A. Philippine**, O. Sigmund, G.M Rebeiz and T.W. Kenny, "Reduction of Stress-Stiffening by Topology Optimization", Proceedings 2012 Design Test Integration and Packaging Workshop (DTIP 2012), 2012, Cannes France (2012).

113. **C-F. Chiang, A.B. Graham**, G.J. O'Brien, and T.W. Kenny, "A single process for building capacitive pressure sensors and timing references with precise control of released area using lateral etch stop", Proceedings IEEE MEMS 2012, P. 519, Paris (2012).

114. **E. Ng, H.K. Lee, C.H. Ahn, R. Melamud**, and T.W. Kenny, "Stability measurements of silicon MEMS resonant thermometers", Proceedings IEEE Sensors 2011, Limerick (2011).

115. **C-F. Chiang, A.B. Graham, M.W. Messana**, J. Provine, **D.T. Buchman**, G.J. O'Brien, and T.W. Kenny, "Capacitive Absolute Pressure Sensor with Independent Electrode and Membrane Sizes for Improved Fractional Capacitance Change", Proceedings Transducers 2011, P. 894, Beijing (2011).

116. **H.K. Lee, R. Melamud, S.A. Chandorkar, Y.Q. Qu, J.C. Salvia, B. Kim, M.A. Hopcroft**, and T.W. Kenny, "Influence of the A-F Effect on the Temperature Stability of Silicon Micromechanical Resonators", Proceedings Transducers 2011, P. 506, Beijing (2011).

117. **H.K. Lee**, P.A. Ward, A.E. Duwel, **J.C. Salvia, Y.Q. Qu, R. Melamud, S.A. Chandorkar, M.A. Hopcroft, B. Kim**, and T.W. Kenny, "Verification of the Phase-Noise Model for MEMS Oscillators Operating in the Nonlinear Regime", Proceedings Transducers 2011, P. 510, Beijing (2011).

118. R.G. Hennessy, M. M. Shulaker, **M. W. Messana, A. B. Graham**, N. Klejwa, J Provine, T. W. Kenny and R. T. Howe, "Temperature Dependence of Vacuum-Encapsulated Resonators for Humidity Measurement", Proceedings Transducers 2011, P. 1950, Beijing (2011).

119. **S. Wang, S. A. Chandorkar, A. B. Graham, M. W. Messana, J. Salvia**, and T.W. Kenny, "Encapsulated Mechanically-Coupled Fully-Differential Breathe-Mode Ring Filters with Ultra-Narrow Bandwidth", Proceedings Transducers 2011, P. 942, Beijing (2011).

120. **H.K. Lee, R. Melamud, S. Chandorkar, Y-Q Qu, J. Salvia** and T.W. Kenny, "Motional Impedance of Resonators in the Nonlinear Regime", Proceedings IEEE International Frequency Control Conference, 2011, San Francisco (2011).

121. **S. Yoneoka**, M. Liger, G. Yama, R. Schuster, F. Purkl, J. Provine, F.B. Prinz, R.T. Howe and T.W. Kenny, "ALD-Metal Uncooled Bolometer", Proceedings IEEE MEMS 2011 P. 676, Cancun, MX (2011).

122. J. Provine, N. Ferralis, **A.B. Graham, M.W. Messana**, R. Kant, R. Maboudian, T.W. Kenny, and R.T. Howe, "Time Evolution of Released Hole Arrays into Membranes via Vacuum Silicon Migration", Proceedings 2010 Solid State Sensors and Actuators Workshop, P344, Hilton Head, SC (2010).

123. **G. Bahl, J. Salvia, H-K. Lee, R. Melamud, B. Kim**, R.T. Howe and T.W Kenny, "Heterodyned Electrostatic Transduction Oscillators Evade Low-Frequency Noise Aliasing", Proceedings 2010 Solid State Sensors and Actuators Workshop, P384, Hilton Head, SC (2010).

124. **W.S. Smith**, P.G. Hartwell, R.G. Walmsley, and T.W. Kenny, "Contact Geometry Effects on Friction in MEMS Probe Arrays", Proceedings 2010 Solid State Sensors and Actuators Workshop, P198, Hilton Head, SC (2010).

125. **M.A. Philippine, C-F. Chang, J. Salvia, C.M. Jha, S. Yoneoka**, and T.W. Kenny, "Material Distribution Design for a Piezoelectric Energy Harvester Desplaying Geometric Nonlinearity", Proceedings 2010 Solid State Sensors and Actuators Workshop, P451, Hilton Head, SC (2010).

126. R.G. Hennessy, M.M. Shulaker, **R. Melamud**, N. Klejwa, **S. Chandorkar, B. Kim**, J. Provine, T.W. Kenny and R.T. Howe, "Vacuum Encapsulated Resonators for Humidity Measurement", Proceedings 2010 Solid State Sensors and Actuators Workshop, P487, Hilton Head, SC (2010).

127. **H.K. Lee, J.C. Salvia, S. Yoneoka, G. Bahl, Y.Q. Qu, R. Melamud, S. Chandorkar, M.A. Hopcroft, B. Kim** and T.W. Kenny, "Stable Oscillation of MEMS Resonators Beyond the Critical Bifuration Point", Proceedings 2010 Solid State Sensors and Actuators Workshop, P70, Hilton Head, SC (2010).

128. **M.W. Messana, A.B. Graham, S. Yoneoka**, R.T. Howe and T.W. Kenny, "Packaging of Large Lateral Deflection MEMS using a Combination of Fusion Bonding and Epitaxial Reactor Sealing", Proceedings 2010 Solid State Sensors and Actuators Workshop, P336, Hilton Head, SC (2010).

129. **B. Kim, R. Melamud, R.A. Candler, M.A Hopcroft, C.M. Jha, S. Chandorkar**, and T.W. Kenny, "Encapsulated MEMS Resonators – A technology path for MEMS into Frequency Control", (Invited) Proceedings 2010 International Frequency Control Symposium, 1 Newport Beach, CA, 2010.

130. **G. Bahl, J. Salvia, I. Bargatin, S. Yoneoka, R. Melamud, B. Kim, S. Chandorkar, M.A. Hopcroft,** R. Bahl, R.T. Howe, and T.W. Kenny, "Charge-drift elimination in resonant electrostatic MEMS", 23rd IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2010), Hong Kong January 2010, P. 108 (2010).

131. **S. Wang, C. Chandorkar, J. Salvia, R. Melamud, Y.Q. Qu, H.K. Lee**, and T.W. Kenny, "Nonlinearity of hermetically-encapsulated high-Q double-balanced breathe-mode ring resonator", 23rd IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2010), Hong Kong January 2010, P. 715 (2010).

132. **H.K. Lee, S. Yoneoka, G. Bahl, J. Salvia, Y.Q. Qu, R. Melamud, C. Chandorkar, B. Kim, M.A. Hopcroft**, and T.W. Kenny, "A novel characterization method for temperature compensation of composite resonators", 23rd IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2010), Hong Kong January 2010, P. 743 (2010).

133. **S. Yoneoka, Y.Q. Qu, S. Wang, M.W. Messana, A.B. Graham, J. Salvia, B. Kim, R. Melamud, G. Bahl** and T.W. Kenny, "High-cyclic fatigue experiments on single crystal silicon in an oxygen-free environment", 23rd IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2010), Hong Kong January 2010, P. 224 (2010).

134. **H.K. Lee, J.Salvia, G. Bahl, R. Melamud, S. Yoneoka, Y.Q. Qu, M.A. Hopcroft, B. Kim** and T.W. Kenny, "Influence of the temperature-dependent A-F effect on the design and performance of oscillators", 23rd IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2010), Hong Kong January 2010, P. 699 (2010).

135. **Y.Q. Qu, R. Melamud, S.A. Chandorkar, H.K. Lee** and T.W. Kenny, "Stress relaxation study of sputtered platinum films near room temperature using an ultrasensitive strain gauge", 23rd IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2010), Hong Kong January 2010, P. 548 (2010).

136. **K.L. Chen, S. Wang, J. Salvia**, R.T. Howe, and T.W. Kenny, "Encapsulated Out-Of-plane Differential Square-Plate Resonator with Integrated Actuation Electrodes", 15th International Conference on Solid-State Sensors, Actuators and Microsystems, Transducers 2009 June, 2009.

137. C.S. Roper, **R. Candler, S. Yoneoka**, T. Kenny, R.T Howe, R. Maboudian, "Simultaneous Wafer-Scale Vacuum-Encapsulation and Microstructure Cladding with LPCVD Pilycrystalline 3C-SiC", 15th International Conference on Solid-State Sensors, Actuators and Microsystems, Transducers 2009 June, 2009.

138. **Y.Q. Qu, R. Melamud** and T.W. Kenny, "Using Encapsulated MEMS Resonators to Measure Evolution in Thin Film Stress", 15th International Conference on Solid-State Sensors, Actuators and Microsystems, Transducers 2009 June, 2009.

139. M. Weinberg, **R. Candler, S. Chandorkar**, J Varasnik, T. Kenny, and A. Duwel, "Energy Loss in MEMS Resonators and the Impact on Inertial and RF Devices", 15th International Conference on Solid-State Sensors, Actuators and Microsystems, Transducers 2009 June, 2009.

140. **K.L. Chen, R. Melamud, S Wang** and T.W. Kenny, "An Integrated Solution for Wafer-Level packaging and Electrostatic Actuation of Out-Of Plane Devices", Proceedings 22nd International Conference on MicroElectro Mechanical Systems (IEEE MEMS), January 2009.

141. **S. Yoneoka, G. Bahl, J. Salvia, K.L. Chen, A.B Graham, H.K. Lee**, G. Yama, **R.N. Candler** and T.W. Kenny "Acceleration Compensation of MEMS Resonators using Electrostatic Tuning", Proceedings 22nd International Conference on MicroElectro Mechanical Systems (IEEE MEMS), January 2009.

142. **A.B. Graham, M. Messana,** P. Hartwell, J. Provine, **S. Yoneoka, B. Kim, R. Melamud**, R.T. Howe, and T.W. Kenny, "Wafer-Scale Encapsulation of Large Lateral Deflection MEMS Structures", Proceedings 22nd International Conference on MicroElectro Mechanical Systems (IEEE MEMS), January 2009.

143. **J. Salvia, R. Melamud, S Chandorkar, H.K.Lee, Y.Q.Qu, S.F. Lord**, B. Muhrmann, and T.W. Kenny, "Phase Lock Pool-Based Temperature Compensation for MEMS Oscillators", Proceedings 22nd International Conference on MicroElectro Mechanical Systems (IEEE MEMS), January 2009.

144. **K.L. Chen**, H. Chandrahalim, **A.B. Graham**, S.A. Bhave, R.T. Howe and T.W. Kenny, "Epitaxial Silicon Microshell Vacuum-Encapsulated CMOS-Compatible 200 MHz Bulk-Mode Resonator", Proceedings 22nd International Conference on MicroElecrtro Mechanical Systems (IEEE MEMS), January 2009.

145. **J. Salvia, M. Messana**, M. Ohline, **M.A. Hopcroft, R. Melamud, S. Chandorkar, H.K. Lee, G. Bahl**, B. Muhrmann, and T.W. Kenny, "Exploring the limits and practicality of Q-Based Temperature Compensation for Silicon Resonators", Proceedings 2008 IEDM Meeting, December 2008.

146. **S.A. Chandorkar, M. Agarwal, R. Melamud**, R.N. Candler, K.E. Goodson and T.W. Kenny, "Limits of Quality Factor in Bulk-Mode Micromechanical Resonators", Proceedings IEEE MEMS Conference, Tucson, AZ (2008).

147. **H.K. Lee, M.A. Hopcroft, R. Melamud, B. Kim, J. Salvia, S. Chandorkar**, and T.W. Kenny, "Electrostatic Tuning of Hermetically-Encapsulated Composite Resonator", Proceedings 2008 Solid State Sensors and Actuators Workshop, Hilton Head, SC (2008).

148. **G. Bahl, R. Melamud, B. Kim, S. Chandorkar, J. Salvia, M.A. Hopcroft, R.G. Hennessy, S. Yoneoka, C.M. Jha**, G. Yama, D. Elata, R.N. Candler, R.T. Howe, and T.W. Kenny, "Observations of Fixed and Mobile Charge in Composite MEMS Resonators", Proceedings 2008 Solid State Sensors and Actuators Workshop, Hilton Head, SC (2008).

149. **B. Kim, M.A. Hopcroft, R. Melamud, C.M. Jha, M. Agarwal, S.A. Chandorkar** and T.W. Kenny, " CMOS-Compatible wafer-scale encapsulation with MEMS Resonators", Proceedings of the ASME InterPACK 2007, 499 (2007).

150. **H-S. Kim**, **H.O. Song**, T.W. Kenny, "An improved method of thermal resistance measurement for variable thermal resistors", Proceedings of the ASME InterPACK 2007, 249 (2007).

151. **M.A. Hopcroft, H.K. Lee, B. Kim, R. Melamud, S. Chandorkar, M. Agarwal, C.M. Jha, J. Salvia, G. Bahl, H. Mehta,** and T.W. Kenny "A High-Stability MEMS Frequency Reference", Proceedings, 14th International Conference on Solid State Sensors Actuators and Mictosystems (Transducers '07), 1307 (2007).

152. **Ginel C. Hill, Daniel R. Soto, Stephanie J. Lue,** Anne M. Peattie, Robert J. Full, and Thomas W. Kenny, "Investigating the Role of Orientation Angle on Gecko Setae Adhesion using a Dual-Axis MEMS Force Sensor", Proceedings, 14th International Conference on Solid State Sensors Actuators and Mictosystems (Transducers '07), 2263 (2007).

153. **C. M. Jha, G. Bahl, R. Melamud, S. A. Chandorkar, M. A. Hopcroft, B. Kim, M. Agarwal, J. Salvia, H. Mehta and T. W. Kenny**, "CMOS Compatible Dual Resonator MEMS Temperature Sensor with Milli-degree Accuracy", Proceedings, 14th International Conference on Solid State Sensors Actuators and Mictosystems (Transducers '07), 229 (2007)

154. **B. Kim, M. Hopcroft, C.M Jha, R. Melamud, S. Chandorkar, M. Agarwal, K.L. Chen, W.T. Park, R. Candler**, G. Yama[2] A. Partridge, M. Lutz, T.W. Kenny, "Using MEMS to Build the Device and the Package", Invited Talk, Transducers '07 Lyon France (6/7/07)

155. **B. Kim, M.A. Hopcroft, R. Melamud, C.M. Jha. M. Agarwal, S.A. Chandorkar,** and T.W. Kenny, "MEMS Resonators in CMOS Compatible Wafer-Scale Encapsulation", Proceedings of IPACK2007 (2007).

156. **R. Melamud, B. Kim, M.A. Hopcroft, S.Chandorkar, M.Agarwal, C.M. Jha**, and T.W. Kenny, "Composite Flexural-Mode Resonator with Controllable Turnover Temperature", Proceedings 2007 International Conference on MEMS, Kobe, Japan (2007).

157. **S. A. Chandorkar[1], H. Mehta[1], M. Agarwa1[1], M.A. Hopcroft[1], C. M. Jha[1], R.N. Candler[2]**, G.Yama[2], **G. Bahl[1], B. Kim[1], R. Melamud[1]**, K. E. Goodson[1] and T. W. Kenny [1] "Non-Isothermal Micromechanical Resonators", Proceedings 2007 International Conference on MEMS, Kobe, Japan (2007).

158. **M.Agarwal , H. Mehta, R.N. Candler, S.A. Chandorkar, B. Kim , M.A. Hopcroft, R. Melamud, G. Bah**l, G. Yama, T.W. Kenny and B. Murmann, "Impact of Miniaturization on the Current Handling of MEMS Resonators", Proceedings 2007 International Conference on MEMS, Kobe, Japan (2007).

159. T.Kenny, M. Lutz, A. Partridge, G. Yama, **R.N. Candler, W.T. Park, M. Hopcroft, B. Kim, M. Agarwal, S. Chandorkar, R. Melamud, C. Jha**, "Advances in MEMS Integration: MEMS First or MEMS Last?", Proceedings 12th International Micromachine/Nanotech Symposium, Tokyo, Japan 11/06.

160. T.W.Kenny, A. Partridge, **R.N. Candler, W.T. Park, M. Hopcroft, B. Kim, M. Agarwal, S. Chandorkar, R. Melamud, C. Jha**, M. Lutz and G. Yama, "Manufacturable MEMS : Building the MEMS, the Package and the Circuit in the Same Technology" Proceedings, Second International Forum on Micro-nano Hetero System Integration (MHSI'06) and 2nd Fraunhofer Gesellschaft Symposium, Sendai, Japan 11/06.

161. **M. Agarwal, K.K. Park, R.N. Candler, B. Kim, M.A. Hopcroft, S.A. Chandorkar, C.M. Jha, R. Melamud,** T.W. Kenny, and B. Murmann, "Nonlinear Characterization of Electrostatic MEMS Resonators", 2006 Frequency Control Symposium (2006)

162. **M. Agarwal, K.K. Park, B. Kim, M.A. Hopcroft, S.A. Chandorkar, R.N. Candler, C.M. Jha, R. Melamud,** T.W. Kenny and B. Murmann, "Amplitude Noise Induced Phase Noise in Electrostatic MEMS Resonators", Proceedings of the 2006 Hilton Head Workshop in Solid State Sensors, Actuators, and Microsystems, p62 (2006).

163. **R Melamud, B. Kim, M.A. Hopcroft, S. Chandorkar, M. Agarwal, C. Jha, S. Bhat, K.K. Park**, and T.W. Kenny, "Composite Flexural Mode Resonators with Reduced Temperature Coefficient of Frequency", Proceedings of the 2006 Hilton Head Workshop in Solid State Sensors, Actuators, and Microsystems, p90 (2006).

164. **B. Kim, C.M. Jha, T. White, R.N. Candler, M. Hopcroft, M. Agarwal, K.K. Park, R. Melamud**, and T.W. Kenny, "Temperature Dependence of Quality Factor in MEMS Resonators", Proceedings 2006 International Conference on MEMS, Istanbul, Turkey (2006).

165. **M. Agarwal, K.K. Park, M. Hopcroft, S. Chandorkar, R.N. Candler, B. Kim, R. Melamud,** G. Yama, B. Murmann, and T.W. Kenny, "Effects of Mechanical Vibrations and Bias Voltage Noise on Phase Noise of MEMS Resonator-based Oscillators", Proceedings 2006 International Conference on MEMS, Istanbul, Turkey (2006).

166. **M.A. Hopcroft, M. Agarwal, K.K. Park, B. Kim, C.M. Jha, R.N. Candler,** G. Yama, B. Murmann, and T.W. Kenny, "Temperature Compensation of a MEMS Resonator using Quality Factor as a Thermometer", Proceedings 2006 International Conference on MEMS, Istanbul, Turkey (2006).

167. **M. Agarwal, K. Park, R. Candler, M. Hopcroft, C. Jha, R. Melamud, B. Kim**, B. Muhrman, and T. Kenny, "Nonlinearity Cancellation in MEMS Resonators for Improved Power Handling", 2005 International Electron Devices Meeting (2005).

168. **R. Melamud, M. Hopcroft, C. Jha, B. Kim, S. Chandorkar, R. Candler**, T.W. Kenny, "Effects of Stress on the Temperature Coefficient of Frequency in Double-Clamped Resonators", Proceedings Transducers '05, 392-395 (2005).

169. **W.T. Park**, K.N. O'Connor, J.R. Mallon, T. Maetani, **R.N. Candler, V. Ayanoor-Vitikkate**, J. Roberson, S. Puria, and T.W. Kenny, "Sub-Millimeter Encapsulated Accelerometers : A Fully Implantable Sensor for Cochlear Implants", Proceedings Transducers '05 109-112 (2005).

170. **R.N. Candler, W.T. Park, M. Hopcroft,, B. Kim**, and T.W. Kenny, "Hydrogen Diffusion and Pressure Control of Encapsulated MEMS Resonators", Proceedings, Transducers '05, 597-600 (2005).

171. **R.N. Candler, M. Hopcroft, C.W. Low, S. Chandorkar, B. Kim**, M. Varghese, A. Duwel, and T.W. Kenny, "Impact of Slot Location in Thermoelastic Dissipation in Micromechanical Resonators", Proceedings, Transducers '05, 920-923 (2005).

172. **B. Kim, R.N. Candler, M. Hopcroft, M. Agarwal, W.T. Park**, and T.W. Kenny, "Frequency Stability of Wafer-Scale Encapsulated MEMS Resonators", Proceedings, Transducers '05, 1965-1968 (2005).

173. **W.T. Park, R.N. Candler, V.A. Vittikkate**, M. Lutz, A. Partridge, G. Yama, T.W. Kenny, "Fully-Encapsulated Sub-MM Accelerometer", Proceedings18th IEEE International Conference on MEMS, 347, Miami, Fl (2005), 347-350 (2005).

174. **B. Kim, R.N. Candler, M. Hopcroft, M. Agarwal, W.T Park, J.T. Li**, and T. Kenny, "Investigation of MEMS Resonator Characteristics for Long-Term Operation and Wide Temperature Variation Condition", ASME Winter Annual Meeting, Anaheim CA, 2004.

175. **M. Hopcroft, R. Melamud, R.N. Candler, W-T. Park, B. Kim**, G. Yama, A. Partridge, M. Lutz, and T.W. Kenny, "Active Temperature Compensation for Micromachined Resonators", Proceedings 2004 Solid State Sensors and Actuators Workshop, 364-367 (2004).

176. **E.N. Wang,** S. Devasenathipathy, C.H. Hidrovo, D.W. Fogg, J.M. Koo, J.G. Santiago. K.E. Goodson and T.W. Kenny, "A Quantitative Understanding of Transient Bubble Growth in Microchannels using μPIV", Proceedings 2004 Solid State Sensors and Actuators Workshop, 101-102 (2004).

177. **R.N. Candler, M. Hopcroft, WT. Park, S.A. Chandorkar,** G. Yama, K.E. Goodson, M. Varghese, A.E. Duwel, A. Partridge, M. Lutz and T.W. Kenny, "Reduction in Thermoelastic Dissipation in Micromechanical Resonators by Disruption of Heat Transport", Proceedings 2004 Solid State Sensors and Actuators Workshop, 45-48 (2004).

178. T.W. Kenny, **Y. Liang, B.L. Pruitt, J.A. Harley, M. Bartsch, and R. Rudnitsky**, "Fundamental Noise in MEMS Force Sensors", Proceedings 2004 SPIE Conference on Fluctuations and Noise in Sensors and Measurements, Maspalomas Gran Canaria ,143-151 (2004).

179. G. Upadhya, P. Zhou, K. Goodson, M. Munch, and T.W. Kenny, "Closed-Loop Cooling Technologies for Microprocessors", Proceedings 2003 International Electronic Devices Meeting, Washington, 775-778 (2003).

180. **W.T. Park, R.N. Candler, J. Cho, H. Li, H. Li**, M. Lutz, A. Partridge, G. Yama, and T.W. Kenny, "Wafer-Scale Encapsulation of MEMS Devices", Proceedings InterPACK '03, Kanapaali, HI IPACK 2003-35032 (2003).

181. **W.T. Park, R.N. Candler**, S. Kronmueller, M. Lutz, A. Partridge, G. Yama, and T.W. Kenny, "Wafer-Scale Film Encapsulation of Micromachined Accelerometers", Proceedings Transducers '03, Boston, 1903-1906 (2003).

182. B.W. Chui, **Y. Hishinuma**, R. Budakian, H.J. Mamin, T.W. Kenny, and D. Rugar, "Mass-Loaded Cantilevers with Suppressed Higher-Order Modes for Magnetic Resonance Force Microscopy", Proceedings Transducers '03, Boston, 1120-1123 (2003).

183. **M.S. Bartsch**, W. Federle, R.J. Full, and T.W. Kenny, "Small Insect Force Measurements using a Custom MEMS Force Sensor", Proceedings Transducers '03, Boston, 1035-1038 (2003).

184. **R.N. Candler, H. Li**, M. Lutz, **W.T. Park**, A. Partridge, G. Yama, and T.W. Kenny, "Investigation of Energy Loss Mechanisms in Micromechanical Resonators", Proceedings Transducers '03, Boston, 332-335 (2003).

185. **D.J. Laser**, A.M. Meyeers, S. Yao, K.F. Bell, K.E. Goodson, J.G. Santiago, and T.W. Kenny, "Silicon ElectroOsmotic MicroPumps for Integrated Circuit Thermal Management", Proceedings Transducers '03, Boston, 151-154 (2003).

186. L. Jiang, J.M. Koo, S. Zheng, J.C. Mikkelsen, **L. Zhang**, J.G. Santiago, T.W. Kenny, K.E. Goodson, "Two-phase microchannel heat sinks for an electrokinetic VLSI chip cooling system" Seventeenth Annual IEEE Semiconductor Thermal Measurement and Management Symposium, (2001).

187. J.M. Koo, L. Jiang, A. Bari, L. Zhang, **E. Wang**, T.W. Kenny, J.G. Santiago, K.E. Goodson, "Convective boiling in microchannel heat sinks with spatially-varying heat generation", ITherm 2002. Eighth Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, 30 (2002).

188. J.P. Lynch, K.H. Law, A.S. Kiremidjian, E. Carryer, T.W. Kenny, A. Partridge, A. Sundararajan, "Validation of a Wireless Modular Monitoring System for Structures", Proceedings of the SPIE - The International Society for Optical Engineering 4696, 124 (2002)

189. T.W. Kenny, **R.N. Candler, H.J. Li, W.T. Park, J. Cho, H. Li**, A. Partridge, G. Yama, M. Lutz, "An Integrated Wafer-Scale Packaging Process for MEMS", 2002 ASME International Mechanical Engineering Congress and Exhibition, New Orleans (2002).

190. Jiang, L., Mikklsen, J., Koo, J-M, **Zhang, L.,** Huber, D., Yao, S., Bari, A., Zhou, P., Santiago, J., and Kenny, T.W. and Goodson, K.E., "Transient and Sub-atmospheric Performance of A Closed-loop Electroosmotic Microchannel Cooling System", *Proceeding of Thermal Challenges in Next Generation Electronic Systems, THERMES 2002*, Santa Fe, New Mexico, USA, 133-139, Jan. 13-16, 2002.

191. **A.E. Herr**, J.C. Mikkelsen, J.G. Santiago, and T.W. Kenny , "Two-Dimensional Chip-Based Protein Analysis using Coupled Isoelectric Focusing and Capillary Electrophoresis", Proceedings, 2002 Workshop on Solid State Sensors, Actuators and Microsystems, Hilton Head, 366-369 (2002).

192. **A. Tewary, K.Y. Yasumura, T.D. Stowe**, T.W. Kenny, and D. Rugar, "Quality Factor Enhancement of in situ Annealing Cantilevers", Proceedings, 2002 Workshop on Solid State Sensors, Actuators and Microsystems, Hilton Head, 337-340 (2002).

193. **B.L. Pruitt, W.-T. Park**, and T.W. Kenny , "Measurement System for Low Force and Small Displacement Contacts", Proceedings, 2002 Workshop on Solid State Sensors, Actuators and Microsystems, Hilton Head 297-300 (2002)

194. **D.J. Laser,** K.E. Goodson, J.G. Santiago, and T.W. Kenny , "High-Frequency Actuation with Silicon Electroosmotic Micropumps", Proceedings, 2002 Workshop on Solid State Sensors, Actuators and Microsystems, Hilton Head, 231-235 (2002)

195. **W.P. King**, T.W. Kenny, K.E. Goodson, M. Despont, U. Duerig, M. Lantz, H. Rothuizen, G. Binnig, and P. Vettiger, "Microcantilevers for Thermal NanoImaging and Thermomechanical Surface Modification", Proceedings, 2002 Workshop on Solid State Sensors, Actuators and Microsystems, Hilton Head, 210-213 (2002)

196. V. Chandrasekaran, **E.M. Chow**, T.W. Kenny, T. Nishida, L.N. Cattafesta, B.V. Sankar, and M.Sheplak, "Thermoelastically Actuated Acoustic Proximity Sensor with Integrated Through-Wafer Interconnects", Proceedings, 2002 Workshop on Solid State Sensors, Actuators and Microsystems, Hilton Head, 102-105 (2002)

197. T.W. Kenny, **Y. Liang, S-W Ueng, M. Bartsch and R. Rudnitsky**, "Micromechanical Force Sensing with Application to Biology", Proceedings, 2002 Workshop on Solid State Sensors, Actuators and Microsystems, Hilton Head, 62-65 (2002)

198. **E.N. Wang, L. Zhang,** L. Jiang, J-M. Koo, K.E. Goodson, and T.W. Kenny, "Micromachined Jet Arrays for Liquid Impingement Cooling of VLSI Chips", Proceedings, 2002 Workshop on Solid State Sensors, Actuators and Microsystems, Hilton Head, 46-49 (2002)

199. **L. Zhang, E.N. Wang,** J-M. Koo, L. Jiang, K.E. Goodson, J.G. Santiago, and T.W. Kenny, "Enhanced Nucleate Boiling in Microchannels", 2002 IEEE International Conference on MicroElectroMechanical Systems, Las Vegas, 89-92 (2002).

200. **L. Zhang, E.N. Wang,** J. Koch, J.Liu, J-M. Koo, L. Jiang, K.E. Goodson, J.G. Santiago, T.W. Kenny, "Microscale Liquid Impingement Cooling", 2001 ASME International Mechanical Engineering Congress and Exhibition, New York (2001).

201. **D.J. Laser,** K.E. Goodson, J.G. Santiago, and T.W. Kenny, "Impact of Pumping Surface Separation Distance on Micromachined Silicon Electrokinetic Pump Performance", 2001 ASME International Mechanical Engineering Congress and Exhibition, New York (2001).

202. **O. Ajakaiye**, and T.W. Kenny, "Performance Characterization of Micromachined Tunneling Infrarred Sensors", 2001 ASME International Mechanical Engineering Congress and Exhibition, New York (2001).

203. T. Kenny **A. Partridge, A. Rice** and M. Lutz, "An Integrated Wafer-Scale Packaging Process for MEMS", Proceedings IEEE/ASME InterPACK Conference, Kauai (2001).

204. **L. Zhang,** J. Koo, L, Jiang, K. Goodson,. J. Santiago, and T.W. Kenny, "Study of Boiling Regimes and Transient Signal Measurements in Microchannels", Proceedings Transducers '01, Munich Germany, 1514-1517 (2001).

205. **D. Laser,** S.Yao, C-H Chen, J. Mikkelsen, K.E. Goodson, J.Santiago, and T.W. Kenny, "A Micromachined Low-Voltage, Parallel-Plate Electrokinetic Pump", Proceedings Transducers '01, Munich Germany, 930-933 (2001).

206. **Y. Liang, S-W Ueng**, T.W. Kenny, "Performance Characteristics of Ultra-Thin n-Type Piezoresistive Cantilevers", Proceedings Transducers '01, Munich Germany, 998-1001 (2001).

207. **M. Bartsch**, T. Kenny, W. Federle, and R. Full, "Exploring insect Biomechanics with Micromachined Force Sensors", Proceedings Transducers '01, Munich Germany, 1662-1665 (2001).

208. **B. Pruitt,** D. Choi, J. Florando, W. Nix, T. Kenny, R. Martens, S. Wenzel, and C. Reynolds, "Low-Force Electrical Contact Measurements using Piezoresistive MEMS Cantilevers to Characterize Thin Film Metallization", Proceedings Transducers '01, Munich Germany, 1032 –1035 (2001).

209. J.M. Koo, L. Jiang, **L. Zhang,** P. Zhou, **S. Bannerjee**, T.W. Kenny, J.G. Santiago, and K.E. Goodson, "Modeling of Two-Phase Microchannel Heat Sinks for VLSI Chips", Proceedings 2001 IEEE International Conference on MicroElectromechanical Systems, 422-425 (2001)

210. **A. Partridge, A.E. Rice**, T.W. Kenny and M. Lutz, "New Thin Film Epitaxial Polysilicon Encapsulation for Piezoresistive Accelerometers", Proceedings 2001 IEEE International Conference on MicroElectromechanical Systems, 54-57 (2001)

211. **A.E. Herr**, J.C. Mikkelsen, J.G. Santiago, and T.W. Kenny, "Electroosmotic Flow Suppression and its Implications for a Miniaturized Full-Field Detection Approach to Capillary Isoelectric Focusing (cIEF)", Proceedings ASME 2000 Winter Annual Meeting, MEMS Vol. 2, 513 (2000).

212. **M.S. Bartsch, A. Partridge, B.L.. Pruitt**, R.J. Full and T.W. Kenny, "A Three-Axis Piezoresistive Micromachined Force Sensor for Studying Cockroach Biomechanics", Proceedings ASME 200 Winter Annual Meeting, MEMS Vol. 2, 443-448 (2000).

213. **B.L. Pruitt, A. Partridge, M. Bartsch, Y. Liang**, T.W. Kenny, S. Wenzel, and C. Reynolds, "Design of Piezoresistive Cantilevers for Low-Force Electrical Contact Measurements", Proceedings ASME 2000 Winter Annual Meeting, MEMS Vol. 2, 183-188 (2000).

214. **L. Zhang,** J.M. Koo**, L. Jiang, S. Bannerjee,** M. Asheghi**,** K.E. Goodson, J.G. Santiago, and T.W. Kenny, "Measurements and Modeling of Two-Phase Flow in Microchannels with Nearly-Constant Heat Flux Boundary Conditions", Proceedings ASME 2000 Winter Annual Meeting, MEMS Vol. 2, 129-135 (2000)

215. L. Jiang, J.M. Koo, S. Zeng, J.C. Mikkelsen, **L. Zhang,** P. Zhou, J.G. Santiago, T.W. Kenny, K.E. Goodson, J.G. Maveety, and Q.A. Tran, "An Electrokinetic Closed-Loop MicroCooler for High-Power VLSI Chips", Proceedings 2001 SEMI-Therm Conference.

216. W.P. King, T.W.Kenny, K.E. Goodson, G. Cross, M. Despont, U. Dürig, M. I. Lutwyche, H. Rothuizen, G.K.Binnig, and P. Vettiger, Design of AFM Cantilevers for Combined Thermomechanical Data Writing and Reading, Proceedings 2000 Hilton Head Workshop on Sensors and Actuators, 1-5 (2000).

217. **J.D. Grade**, J.H. Jerman, and T.W. Kenny, A Large-Deflection Electrostatic Actuator for Optical Switching Applications, Proceedings 2000 Hilton Head Workshop on Sensors and Actuators, 97-100 (2000).

218. **J.I. Molho, A.E Herr,** B.P. Mosier, J.G. Santiago, and T.W. Kenny, A Low-Dispersion Turn for Miniaturized Electrophoresis, Proceedings 2000 Hilton Head Workshop on Sensors and Actuators, 132-137 (2000).

219. **A.E. Herr, J.I. Molho**, J.G. Santiago, T.W. Kenny, D.A. Borkholder, G.J. Kintz, P. Belgrader, and M.A. Northrup, Optimization of a Miniaturized Capillary Isoelectric Focusing System using a Full-Field Detection Approach, Proceedings 2000 Hilton Head Workshop on Sensors and Actuators, 115-119 (2000).

220. **Y. Liang**, K. Autumn, S.T. Hsieh, W. Zesch, W.P. Chan, R.S. Fearing, R.J. Full and T.W. Kenny, Adhesion Force Measurements on Single Gecko Setae, Proceedings 2000 Hilton Head Workshop on Sensors and Actuators, 33-38 (2000).

221. **L Zhang, S.S. Banerjee**, J.M. Koo, **D.S. Laser**, M. Asheghi, K.E. Goodson, J.G. Santiago, and T.W. Kenny, A Micro Heat-Exchanger with Integrated Heaters and Thermometers, Proceedings 2000 Hilton Head Workshop on Sensors and Actuators, 275-280 (2000).

222. **E.M. Chow, A. Partridge**, C.F. Quate, and T.W. Kenny, Thru-Wafer Electrical Interconnects Compatible with Standard Semiconductor Processing, Proceedings 2000 Hilton Head Workshop on Sensors and Actuators, 343-346 (2000).

223. **A.M. Fitzgerald**, R.H. Dauskardt, T.W. Kenny, "High-Resolution Measurement of Crack Growth in Micromachined Single Crystal Silicon", 1999 MRS Symposium Proceedings : Materials Science of Microelectromechanical Systems, p. 43-48 (1999)

224. W.P. King, J.G. Santiago, T.W. Kenny, and K.E. Goodson, Modeling and Prediction of Sub-Micrometer Heat Transfer during Thermomechanical Data Storage, Proceedings 1999 ASME Winter Meeting (1999).

225. **Y. Liang, J.N. Welch, R.G. Rudnitsky**, and T.W. Kenny, Biological Force Measurements using Micromachined Cantilevers, Proceedings 1999 ASME Winter Meeting (1999).

226. **J.K. Reynolds**, T.W. Kenny, D.C. Catling, R.C. Blue, M.H. Hecht, and N.I. Maluf, Packaging of Micromachined Absolute Pressure Sensors for High-Accuracy Measurements, Proceedings InterPAK '99 137-142 (1999).

227. **K.Yasumura,** J.A. Chiaverini**,** and T.W. Kenny, Thermoelastic Dissipation in Silicon Nitride Microcantilevers, Proceedings 10th International Conference on Solid State Sensors and Actuators. 564-567 (1999)

228. **T. Stowe,** T.W. Kenny, D. Rugar, and D. Thompson, Dissipation Microscopy based on Electronic Drag, Proceedings 10th International Conference on Solid State Sensors and Actuators. 1208-1211 (1999)

229. **A.M. Fitzgerald,** R.H. Dauskardt, and T.W. Kenny, Fracture Toughness of Plasma-Etched Single-Crystal Silicon and Implications for MEMS Design, Proceedings 10th International Conference on Solid State Sensors and Actuators. 928-931 (1999).

230. **C.H. Liu, A. Barzilai, O. Ajakaiye,** H.K. Rockstad, and T.W. Kenny, Performance Enhancements for the Micromachined Tunneling Accelerometer, Proceedings 10th International Conference on Solid State Sensors and Actuators.1290-1293 (1999)

231. **J.K. Reynolds,** D.C. Catling, R.C. Blue, N. Maluf, and T.W. Kenny, Packaging and Calibration of a Piezoresistive Pressure Sensor for High-Accuracy at Low Temperatures and Pressures, Proceedings 10th International Conference on Solid State Sensors and Actuators. 1494-1497 (1999)

232. **E.M. Chow,** H.T. Soh, H.C. Lee, J.D. Adams, S.C. Minne, G. Yaralioglu, A. Atalar, C.F. Quate, and T.W. Kenny, Two-Dimensional Cantilever Arrays with Integrated Thru-Wafer Interconnects, Proceedings 10th International Conference on Solid State Sensors and Actuators. 1886-1889 (1999)

233. **R. Rudnitsky, E.M. Chow,** and T.W. Kenny, High-Speed Biochemical Screening with Magnetic Force Microscope Cantilever Arrays, Proceedings 10th International Conference on Solid State Sensors and Actuators. 706-709 (1999)

234. **J.A. Harley, T.D. Stowe,** and T.W. Kenny, Piezoresistive Cantilevers with Femtonewton Force Resolution, Proceedings 10th International Conference on Solid State Sensors and Actuators. 1628-1631 (1999)

235. **A.E. Herr, J.I. Molho,** T.W. Kenny, J.G. Santiago, M.G. Mungal and M.G. Garguilo, Variation of Capillary Wall Potential in Electrokinetic Flow, Proceedings 10th International Conference on Solid State Sensors and Actuators. 710-713 (1999)

236. **B.W. Chui,** M. Asheghi, Y.S. Ju, H.J. Mamin, K.E. Goodson, and T.W. Kenny, Measurement and Modeling of Thermal-Electrical Runaway in Silicon Cantilevers, Proceedings 10th International Conference on Solid State Sensors and Actuators. 1862-1865 (1999)

237. M. Ashegi, W.P. King, **B.W. Chui**, T.W. Kenny, and K.E. Goodson, Thermal Engineering of Doped Single-Crystal Silicon Microcantilevers for High Density Data Storage, Proceedings 10th International Conference on Solid State Sensors and Actuators. 1840-1843 (1999)

238. S.M Kumar**,** W.C. Reynolds, and T.W. Kenny, MEMS-Based Transducers for Boundary Layer Control, Proceedings 12th International Conference on Micro Electro Mechanical Systems, 135-138 (1999).

239. M.C. Deshpande, C. Ghaddar, J.R. Gilbert, P.M. St. John, T. Woudenberg, C. Connel**, J.I. Molho, A.E. Herr**, G. Mungal, and T.W. Kenny, "Numerical Framework for the Modeling of Electrokinetic Flows", Microfluidic Devices and Systems, Proceedings SPIE 217-223 (1998).

240. **K. Yasumura, T. Stowe, E. Chow,** T. Pfafman**,** T.W. Kenny, and D. Rugar, A Study of Microcantilever Mechanical Quality Factor, Proceedings 1998 Hilton Head Workshop on Sensors and Actuators, 65-68. (1998).

241. **A. Partridge, B.W. Chui, J.K. Reynolds, E. Chow, A.M. Fitzgerald, L. Zhang, S. Cooper,** T.W. Kenny, and N.I. Maluf, A High-Performance Planar Piezoresistive Accelerometer, Proceedings 1998 Hilton Head Workshop on Sensors and Actuators, 59-61. (1998).

242. E.M. Chow , H.T. Soh, **A. Partridge, J.A. Harley,** T.W. Kenny, and C.F. Quate, Fabrication of High-Density Cantilever Arrays and Thru-Wafer Interconnects, Proceedings 1998 Hilton Head Workshop on Sensors and Actuators, 220-223. (1998).

243. P.M. St. John, T. Woudenberg, C. Connell, **J, Molho, A. Herr**, T.W. Kenny, M.G. Mungal, M. Desphande, J.R. Gilbert, M. Garguilo, D. Rakestraw, and P. Paul, Metrology and Simulation of Chemical Transport in Microchannels, Proceedings 1998 Hilton Head Workshop on Sensors and Actuators, 106-109. (1998).

244. B.W. Chui, T.W. Kenny, H.J. Mamin, B.D. Terris, and D. Rugar, Independent Detection of Vertical and Lateral Forces with a Sidewall-Implaned Dual-Axis Piezoresistive Cantilever, Proceedings of IEEE MicroElectroMechanical Systems Workshop. 12-15 (1998).

245. **Grade, A. Barzilai, K. Reynolds, C.H. Liu, A. Partridge**, H. Jerman, and T.W. Kenny, Wafer-Scale Processing, Assembly, and Testing of Tunneling Infrared Detectors, Proceedings of Transducers '97 - The 9th International Conference on Solid State Sensors and Actuators 1241-1244 (1997)

246. **C.H. Liu, J. D. Grade, A. M. Barzilai, J. K. Reynolds, A. Partridge**, H. K. Rockstad, and T. W. Kenny , Characterization of a High-Sensitivity Micromachined Tunneling Accelerometer, Proceedings of Transducers '97 - The 9th International Conference on Solid State Sensors and Actuators Actuators. 471-472 (1997)

247. **J.Grade, C.H. Liu, K. Reynolds, A. Partridge, A. Barzilai**, L.Miller, and T.Kenny, Reducing the Low-Frequency Drift in Tunneling Transducers, Proceedings of Transducers '97 - The 9th International Conference on Solid State Sensors and Actuators 871-874 (1997)

248. **T.D. Stowe, K. Yasumura**, T. Pfafman, T. Kenny, D. Botkin, and D. Rugar, Ultrasensitive Torsional Probes Optimized for Higher-Order Mode Suppression, Proceedings of Transducers '97 - The 9th International Conference on Solid State Sensors and Actuators, P. 141-144 (1997).

249. **B.W. Chui, T.D. Stowe**, T.W. Kenny, H.J., Mamin, B.D. Terris, and D.Rugar, Micromachined Heaters with 1-μs Thermal Time Constants for AFM Thermomechanical Data Storage, Proceedings of Transducers '97 - The 9th International Conference on Solid State Sensors and Actuators 1085-1088 (1997).

250. P. Scheeper, **J.K. Reynolds**, and T.W. Kenny, Development of a Modal Analysis Accelerometer Based on a Tunneling Displacement Transducer, Proceedings of Transducers '97 - The 9th International Conference on Solid State Sensors and Actuators 867-870 (1997).

251. **P. Graven** and T.W. Kenny, Laboratory (and on-orbit) Magnetometer Calibration without Coil Facilities or Orientation Information, Proceedings 1996 AIAA Small Satellite Conference (1996).

252. **D.S. Clarke, M.T. Hicks, A.M. Fitzgerald, J.J. Suchman**, R.J. Twiggs, J.A. Randolph, and T.W. Kenny, Picosat Free Flying Magnetometer Experiment, Proceedings 1996 AIAA Small Satellite Conference (1996).

253. **Grade, A. Barzilai, J.K. Reynolds, C.H. Liu, A. Partridge**, T.W. Kenny, T.R. VanZandt, L.M. Miller, and J.A. Podosek, Progress in Tunnel Sensors, Proceedings 1996 IEEE Solid State Sensors and Actuators Workshop, 80-83 (1996).

254. **B.W. Chui**, H.J., Mamin, D. Rugar, B.D. Terris, R. Ried**, T.D. Stowe, S.C. Minne, H.T. Soh**, C.F. Quate, **Y.S.Ju**, O.W. Kaeding, K.E. Goodson, and T.W. Kenny, Improved Cantilevers for AFM Thermomechanical Data Storage, Proceedings 1996 IEEE Solid State Sensors and Actuators Workshop, 219-224 (1996).

255. **T. Stowe, K. Yasumura**, T. Kenny, D. Botkin, K. Wago, and D. Rugar, Ultrasensitive Vertical Force Probe for Magnetic Resonance Force Microscopy, Proceedings 1996 IEEE Solid State Sensors and Actuators Workshop, 225-230 (1996).

256. L.M. Miller, J.A. Podosek, E. Kruglick, T.W. Kenny, J.A. Kovacich, and W.J. Kaiser, A μ-Magnetometer Based on Electron Tunneling, Proceedings IEEE MEMS Workshop, 467-470 (1996).

257. **C.H. Liu, J.K. Reynolds, A. Partridge**, T.W. Kenny, L.M. Miller, J.A. Podosek, H.K. Rockstad, and W.J. Kaiser, High-Bandwidth Feedback Control of Micromachined Tunneling Sensors, Proceedings of ASME, DSC-57-2, 1001-1007 (1995).

258. H.K. Rockstad, **J.K. Reynolds**, T.K. Tang, T.W. Kenny, W.J. Kaiser, and T.B. Gabrielson, A Miniature, High-Sensitivity, Electron-Tunneling Accelerometer, Proceedings, Transducers '95, 675-679 (1995).

259. H.K. Rockstad, T.W. Kenny, P.J. Kelly, and T.B. Gabrielson, "A Micro-Fabricated Electron-Tunneling Accelerometer as a Directional Acoustic Sensor", Proceedings of Acoustic Particle Velocity Sensors : Design, Performance and Applications 9/95 Published in AIP Conf. Proc. 368, 57-62 (1996).

260. R.A. Brennen, M.H. Hecht, D.V. Wiberg, T.D. Stowe, T.W. Kenny, K.H. Jackson, C.K. Malek, "Fabricating Sub-Collimating Grids for X-Ray Solar Imaging Spectrometer using LIGA Technique", SPIE Microlithography and Metrology in Micromachining 10/95, SPIE Vol. 2640, 214-217 (1995).

261. A.W. Chen, P.A. Kaaret, T.W Kenny, "Micromachined Silicon X-Ray Optics", Proceedings SPIE 2279, 298-301 (1994).

262. A.W. Chen, P.A. Kaaret, T.W Kenny, "Focusing of X-Rays Using Micromachined Silicon Lobster-Eye Lenses", Proceedings SPIE 2011, 227-230 (1994).

263. L.M. Miller, M.L. Agronin, R.K. Bartman, W.J. Kaiser, T.W. Kenny, R.L. Norton, and E.C. Vote, "Fabrication and Characterization of a Micromachined Deformable Mirror for Adaptive Optics Applications", Proceedings SPIE V1945, 421-424 (1993).

264. H.K. Rockstad, T.W. Kenny, J.K. Reynolds, W.J. Kaiser, and T.R. VanZandt, A Miniature High-Resolution Accelerometer Utilizing Electron Tunneling, Proceedings 1992 ASME Winter Meeting, 41-52 (1992).

265. T.W. Kenny, W.J. Kaiser, J.A. Podosek, H.K. Rockstad, and J.K. Reynolds, Micromachined Electron Tunneling Infrared Sensors, Proceedings IEEE Solid State Sensors and Actuators Workshop, 174-177 (1992).

266. T.R. VanZandt, T.W. Kenny and W.J. Kaiser, Novel Position Sensor Technologies for Microaccelerometers, Proceedings of the SPIE 1694, 165-168 (1992).

267. T.W. Kenny and W.J. Kaiser, Electron Tunnel Sensors, Progress in Precision Engineering, 39-49, May, (1991).

268. T.W. Kenny, S.B. Waltman, J.K. Reynolds, and W.J. Kaiser, A Micromachined Silicon Electron Tunnel Sensor, Proceedings 1990 IEEE MEMS Workshop, 192-196 (1990).

DARPA Program Manager Portfolio (10/1/06 – 9/30/10)

DARPA MIATA Program (MicroAntenna Arrays – Technology and Applications).

- $40M Program Launched by Henryk Temkin in 2005
- Focused on microfabricated antennas for mm-wave radiation sensors, and on integration of antenna, sensor, amplifier and readout circuitry in same structure

DARPA TGP Program (Thermal Ground Plane).

- $50M Program Launched by Thomas Kenny in 2007
- Focused on microfabricated vapor chamber chamber heat spreaders with reduced dimensions, increased performance, and circuit-compatible materials

DARPA YFA Program (Young Faculty Award).

- $7M/year Program Launched by Henryk Temkin in 2006, re-run in 2007 and 2008.
- Provided small ($200K) grants to promising young faculty throughout the US with ideas and interests that could lead to new technologies for the DoD.

DARPA TBN Program (Tip-Based Nanofabrication)

- $50M Program Launched by Thomas Kenny in 2007
- Focused on controlled nanofabrication, with emphasis on controlling the size, shape, location and other properties of every nanostructure formed on a surface.

DARPA MACE Program (Microtechnologies for Air-Cooled Exchangers).

- $35M Program Launched by Thomas Kenny in 2008
- Focused on use of microtechnologies in air-cooled heat exchangers

DARPA NTI Program (NanoThermal Interfaces).

- $30M Program Launched by Thomas Kenny in 2009
- Focused on development of new nanostructured materials for enhanced thermal interfaces for electronics cooling.

DARPA CEE Program (Casimir Effect Enhancement).

- $10M Program Launched by Thomas Kenny in 2010
- Focused on demonstration of reduced adhesion at the nanoscale through the use of the Casimir effect

DARPA ACM Program (Active Cooling Modules).

- $30M Program Launched by Thomas Kenny in 2010)
- Focused on development of complete, high-performance cooling modules based on thermoelectric refrigeration, vapor compression refrigeration, and other novel refrigeration concepts.

DARPA NJTT Program (Near-Junction Thermal Transport).

- $25M Program Formulated by Thomas Kenny in 2010, Launched by Avram Bar-Cohen in 2011
- Program focus is on enhanced thermal conduction in the region immediately beneath the hot spots in high-power electronic devices.

DARPA "Seedlings" ($250K efforts to prove key initial pieces of technology)

- ~20 projects solicited, launched and managed
- Produced important early results for TGP, TBN, NTI and ACM programs.

Patents (>50 Issued US Patents)

1. Targeting Microbubbles, Robert H Grubbs, Marshall L Stoller, Hoyong Chung, Alissa M Fitzgerald, Thomas W Kenny, Renee M Thomas, **US Patent 10,357,565 (7/23/2019), US Patent 10,149,906B2 ((12/11/2018), EP3375435A1, EP2748299B1, CN103917637B, WO2013028942A1, KR102076069,**

2. Composite Mechanical Resonators and Method Therefor, R. Melamud, B. Kim, M. Hopcroft, S. Chandorkar, T, Kenny, **US Patent 7,806,586 (9/5/10), US Patent #7,824,098 (11/2/10).**

3. Cooling Systems Incorporating Heat Exchangers and Thermoelectric Layers, Thomas W. Kenny, Mark Munch, Peng Zhou, James Gill Shook, Kenneth Goodson, Dave Corbin, Mark McMaster, James Lovette, **US Patent 8,464,781 (6/18/13).**

4. Pump and Fan Control Concepts in a Cooling System, S. Sinha, M. Munch, K. Goodson, T. Kenny, **US Patent # 7,591,302 (9/22/09), US Patent #8,602,092 (12/10/13)**

5. Remedies to Prevent Cracking in a Liquid System, M. Munch, D. Werner, T. Kenny, K Goodson, **US Patent # 7,077,634 (7/18/06), US Patent # 7,201,214 (4/10/07), US Patent # 7,201,012 (4/10/07). US Patent # 7,278,549 (10/9/07), US Patent#7,344,363 (3/18/08)**, **US Patent # 7,402,029 (7/22/08),** Pending (US2005/0182845A1, US2005/0183445A1, US2005/0183444A1, US2005/0183443A1, US2005/0016715A1, WO0471139A3, WO04071139A2, US2004/0148959A1)

6. Apparatus for Conditioning Power and Managing Thermal Energy in an Electronic Device, T.W. Kenny, K.E. Goodson, J.G. Santiago.,G. K. Everett **US Patent # 7,061,104 (6/13/06)**

7. Boiling temperature Design in Pumped Microchannel Cooling Loops, P. Zhou, S. Zheng, T. Kenny, M. Munch. G. Upadhya, K. Goodson, J. Santiago, US 2004/0182551A1, WO04083742A2).

8. Method and Apparatus for achieving temperature uniformity and hot-spot cooling in a heat-producing device, K. Goodson, T. Kenny, P, Zhou, G. Upadhya, M. Munch, M. McMaster, J, Hom, **US Patent# 7,104,312 (9/12/06**), US2004/0112585A1, WO 04042306A3, WO 04042306A2.

9. Hermetic Closed-Loop Fluid System, D. Werner, M.. Munch, and T. Kenny, **US Patent # 7,021,369 (4/4/06).**

10. Removeable Heat Spreader support mechanism and method of manufacturing thereof, G. Upadhya, M. Munch, P. Zhou, K.E. Goodson and T.W. Kenny, US 2004/0233639A1, WO04070304A3, WO04070304A2,

11. Method and Apparatus for Low-Cost Electrokinetic Pump Manufacturing, J. Lovette, M. Munch, J.G. Shook, S. Zheng, T.W. Kenny, D. Werner, Z. Cichocki, TCE. Lin, 2004/0234378A1, WO04076857A2).

12. Apparatus and Method of Forming Channels in a Heat Exchanging Device, T. Kenny, M. McMaster, J. Lovette, **US Patent # 7,017,654 (3/28/06).**

13. Boiling Temperature Design in Pumped Microchannel Cooling Loops, P. Zhou, S. Zheng, T. Kenny, M. Munch, G. Upadhya, K. Goodson, J. Santiago, Pending

14. Method and Apparatus for Efficient Vertical Fluid Delivery for Cooling a Heat-Producing Device, T. Kenny, M. Munch, P. Zhou, J. Shook, K. Goodson, D. Corbin, M. McMaster, J. Lovette, **US Patent#7,000,684 (2/21/06)**, US 2004/0206477A1, US 2004/0112571A1, WO04042304A3, WO04042304A2, WO04042297A3, WO04042297A2,

15. Apparatus for Conditioning Power and Managing Thermal Energy in an Electronic Device, K. Goodson, J. Santiago, T. Kenny, and G Everett, **US Patent #6,882,543**, 10/882475, 10/883530, 10/882607

16. Interwoven Manifolds for Pressure Drop Reduction in Microchannel Heat Exchangers, G. Upadhya, M. Munch, P. Zhou, G. Shook, T. Kenny, K. Goodson, D. Corbin, **US Patent# 6,986,382 (1/17/06)** US 2004/0104010A1, WO04042303A3, WO04042303A2

17. Method and Apparatus for Flexible Fluid Delivery for cooling desired Hot Spots in a heat-producing device, T. Kenny, J.G. Shook, D. Corbin, M.Munch, K. Goodson, **US Patent# 6,988,534 (1/24/06),** US2004/0104022A1, WO04042313A1

18. Vapor Escape Microchannel Heat Exchanger, P. Zhou, K. Goodson, T. Kenny, J Santiago, Pending 10/366122.

19. Ultra-Miniature Accelerometers, T.W. Kenny and W.T. Park, **US Patent# 7,104,130, (9/12/06)**, WO0492746A1

20. Method and Apparatus for Removably Coupling a Heat Rejection Device to a Heat Producing Device, T.W. Kenny, K.E Goodson, US 2004/0076408A1.

21. Microfabricated Electrokinetic Pump with On-Frit Electrodes, T. Kenny, J.G. Shook, S. Zeng, D.J. Lenehan, J. Santiago, J. Lovette, **US Patent # 7,086,839 (8/8/06)**

22. Microfabricated Electrokinetic Pump, D. Corbin, K. Goodson, T. Kenny, J. Santiago, and S. Zheng, **US Patent # 6,881,039** (5/27/04), US 2005/0042110A1, US200500843385A1, **US Patent # 7,449,122 (11/11/08)**

23. Electroosmotic MicroPump with Planar Features, **D. Laser**, J.G. Santiago, K.E. Goodson, and T.W. Kenny, **US Patent 7,316,543 (1/8/08)**

24. UltraMiniature Pressure Sensor and Probes, **M. Bly**, T.W. Kenny, **S.A. Shaughnessey, M.S. Bartsch**, **US Patent #6,959,608**

25. Method of making a Nanogap for Variable Capacitive Elements, and Device having a NanoGap, M. Lutz, A. Partridge, and T.W. Kenny, WO 04095540A3, WO 04095540A2, US Patent **7,127,917 (2/6/07)**

26. System Including Power Conditioning Module, T.W. Kenny, K.E. Goodson, J.G. Santiago, C. K, Everett, R. Chaplinsky, J. Kim, **US Patent # 6,678,168**.

27. Power Conditioning Module, T.W. Kenny, K.E. Goodson, J.G. Santiago, C. K, Everett, **Patent # 6,606,251 (8/12/03)**, **US Patent # 7,050,308 (5/23/06).**

28. Closed-Loop Microchannel Cooling System, K.E. Goodson, **D.E. Huber**, L. Jiang, T.W. Kenny, **J-M Koo**, J.C. Mikkelsen, J.G. Santiago**, E. Wang, S. Zheng, L. Zhang, D. Laser, H. Chen, US Patent # 7,334,630 (2/26/08),** US20050205241A1.

29. Electroosmotic Microchannel Cooling System, K.E. Goodson, **D.E. Huber**, L. Jiang, T.W. Kenny, **J-M Koo**, J.C. Mikkelsen, J.G. Santiago**, E. Wang, S. Zheng, L. Zhang, D. Laser, H. Chen, US Patent # 7,185,697 (3/6/07), US Patent # 7,131,486 (12/7/06**), **Patent # 6,942,018 (9/13/05) US Patent#6,991,024 (1/24/06), US Patent #7,131,486 (11/7/06)** EP1576320A2, US2005/0098299A1, US2004/0089442A2, US2003/0164231A1, WO0302973A3, WO0302973A2, US2003/0062149A1,

30. Adhesive Microstructure and Method of Forming Same, B. Full, K. Autumn, R. Fearing, and T. Kenny, **US Patent # 6,737,160, US Patent # 7,011723 (3/14/06)**, **US Patent # 7,229,865 (7/11/07)**, US20050072509A1, US2004/0005454A1, EP1241930A4, WO0149776C2, EP1241930A2, WO 0149776A3, WO0149776A2.

31. Non-Contact Mechanical Resonance Method for Determining the Near-Surface Carrier Mobility in Semiconductors, **T.D.Stowe**, D. Rugar, and T.W, Kenny, **Patent #6,489,776** (12/3/02)

32. In-Plane Micromachined Accelerometer and Bridge Circuit having same**, A. Partridge, A. M. Fitzgerald, B.W. Chui, J. K. Reynolds** and T.W. Kenny, **Patent # 6,389,899** (5/21/02)

33. Method of Making Electrical Elements on the Sidewalls of Micromechanical Structures, **B.W. Chui** and T.W. Kenny, **Patent # 6,025,208** (2/15/00).

34. Micromachined Cantilever Structure Providing for Independent Multidimensional Force Sensing Using High Aspect Ratio Beams, **B.W. Chui** and T.W. Kenny, **Patent # 5,959,200** (9/28/99).

35. Tunnel Effect Measuring Systems and Particle Detectors, W.J. Kaiser, S.B. Waltman, and T.W. Kenny, **Patent #5,290,102 (3/1/94/94), Patent #5,265,470 (11/30/93), 5,293,781 (3/15/94)**.

36. Methods and Apparatus for Improving Sensor Performance, W.J. Kaiser, T.W. Kenny, S.B. Waltman, **J.K. Reynolds** and T.R. VanZandt. **Patent # 5,211,051 (5/18/93)**.

37. Tunnel Effect Wave Energy Detection, W.J. Kaiser, S.B Waltman, and T.W. Kenny. **Patent # 5,449,909** (9/12/95).

38. Uncooled Tunneling Infrared Sensor, T.W. Kenny, W.J. Kaiser, J.A. Podosek, E.C. Vote, H.K. Rockstad, and **J.K. Reynolds**. **Patent # 5,298,748** (3/29/94).

39. Uncooled Tunneling Infrared Sensor, T.W. Kenny, W.J. Kaiser, J.A. Podosek, E.C. Vote, R.E. Muller, and P.D. Maker. **Patent # 5,436,452** (7/25/95)

40. Dual Element Electron Tunneling Accelerometer, W.J. Kaiser, T.W. Kenny, H.K. Rockstad**, J.K. Reynolds**, and T.R. VanZandt. **Patent # 5,563,344** (10/8/96)

41. High Performance Miniature Hygrometer and Method Thereof, T.R. VanZandt, W.J. Kaiser, and T.W. Kenny, **Patent # 5,364,185** (11/15/94).

42. Method and Apparatus for Measuring a Magnetic Field using a Deflectable Energized Loop and a Tunneling Tip, W.J. Kaiser, S.B. Waltman, and T.W. Kenny, **Patent # 5,315,247 (1994)**