

**UNITED STATES PATENT AND TRADEMARK OFFICE**

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**BEFORE THE PATENT TRIAL AND APPEAL BOARD**

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PANASONIC SYSTEM NETWORKS CO., LTD.  
Petitioner

v.

6115187 CANADA, INC.  
Patent Owner

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Case IPR \_\_\_\_\_  
U.S. Patent No. 6,844,990  
Issue Date: January 18, 2005

Title: METHOD FOR CAPTURING AND DISPLAYING A  
VARIABLE RESOLUTION DIGITAL PANORAMIC IMAGE

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**DECLARATION OF JACK FEINBERG, PH.D.**

I, Jack Feinberg, declare as follows:

## **I. INTRODUCTION**

1. I have been retained by Panasonic System Networks Co., Ltd. (“Petitioner”) in this case as an expert in the relevant art.
2. I have been asked to provide my opinions concerning U.S. Patent No. 6,844,990 (“the ‘990 patent”)(Exhibit 1001), as well as the materials I have reviewed in this case that are related to the subject matter of the ‘990 patent.
3. I have also been asked to provide my opinions concerning the state of the relevant art prior to May 11, 2001, and the level and knowledge of one of ordinary skill in the art in the May 2001 time frame.
4. I have reviewed certain prior art references and analyzed whether certain elements of the claims of the ‘990 patent are disclosed in those prior art references.
5. My opinions and views set forth in this declaration are based on my education, training, and experience in the field of optics, as well as the materials I reviewed in this case.

## **II. QUALIFICATIONS**

6. I earned a bachelor of arts in Physics from Columbia University in 1972 and a Ph.D. in Physics from the University Of California, Berkeley in 1977. In 1981 I became an Assistant Professor at the University of Southern California. I

became an Associate Professor in 1986 and a Professor of Physics in 1991. I am currently a professor at the University of Southern California in the Department of Physics and Astronomy as well as the Department of Electrical Engineering.

7. I am a Fellow of the Optical Society of America and winner of the 1995 Discover Award for Technological Innovation in the Field of Sight. I hold a dozen patents in the field of imaging and lasers, I have served as a consultant to numerous optical companies, and I have authored approximately 90 original articles in the field of optics. In addition, I have trained dozens of Ph.D. students in optics-related fields, and taught thousands of students at the University of Southern California. A listing of my publications and research is included in my *curriculum vitae*, a copy of which is attached as Appendix A.

8. I am being compensated for my work. My fee is not contingent on the outcome of any matter or on any of the technical positions I explain in this declaration. I have no financial interest in Petitioner.

9. I have been informed that the assignee of the patent, 6115187 CANADA, INC., is also known as ImmerVision Inc. (hereinafter referred to as "Patentee"). I have no financial interest in the Patentee or the '990 patent.

### **III. DOCUMENTS REVIEWED**

10. I have reviewed the '990 patent(Exhibit 1001); U.S. Patent No. 5,686,957 ("Baker")(Exhibit 1002); U.S. Patent No. 6,128,145

(“Nagaoka”)(Exhibit 1003); U.S. Patent No. 3,953,111 (“Fisher”)(Exhibit 1004); and U.S. Patent No. 6,031,670 (“Inoue”)(Exhibit 1007).

#### **IV. THE PERSON OF ORDINARY SKILL IN THE RELEVANT FIELD IN THE RELEVANT TIMEFRAME**

11. I have been informed that “a person of ordinary skill in the relevant art” is a hypothetical person who is presumed to have known the relevant art at the time of the invention. Factors that may be considered in determining the level of ordinary skill in the art may include: (1) type of problems encountered in the art; (2) prior art solutions to those problems; (3) rapidity with which innovations are made; (4) sophistication of the technology; and (5) educational level of active workers in the field. In a given case, every factor may not be present, and one or more factors may predominate. In many cases a person of ordinary skill will be able to fit the teachings of multiple patents together like pieces of a puzzle.

12. I have been informed that the date for determining whether a document or information is considered “prior art” is May 11, 2001.

13. A person of ordinary skill in the subject matter claimed and disclosed in the ‘990 patent would have at least a bachelor’s degree in Physics and/or Electrical Engineering and at least five years’ experience working with lenses or related optical systems.

14. The prior art discussed herein demonstrates that a person of ordinary skill in the relevant art, before May 11, 2001, would have been aware of panoramic objective lenses, fish-eye lenses and other wide-angle lenses.

15. A person of ordinary skill in the relevant art would have been aware of panoramic objective lenses with non-linear distribution functions, *i.e.*, a distribution function of image points that is not linear relative to the field angle of the object points of the panorama.

16. A person of ordinary skill in the relevant art would have understood that a panoramic objective lens with a non-linear distribution function could have at least one zone where the image obtained is expanded and/or compressed.

17. A person of ordinary skill in the relevant art would have known that the expansion and/or compression of an image caused by the distribution function of a lens would depend on the slope of a plot of image height vs. field angle for that lens, and in particular how that slope compares to the constant slope of the straight line depicting the linear distribution function of a lens.

18. A person of ordinary skill in the relevant art would also have understood the desirability of, and how to, correct an image obtained from a panoramic objective lens having a non-linear distribution function.

19. Based on my education and experience, I have a very good understanding of the capabilities of a person of ordinary skill in the relevant art at the time of invention.

## **V. THE '990 PATENT**

20. The '990 patent proposes a panoramic objective lens having a non-linear distribution function of image height vs. field angle.

21. According to the '990 patent, the disclosed lenses allow "the physical limits of image sensors to be circumvented and the definition offered by digital enlargements concerning certain parts of a digital panoramic image to be improved, without the need to increase the number of pixels per unit of area of an image sensor or to provide an overlooking optical enlargement system in a panoramic objective lens." Exhibit 1001, '990 patent, col. 3, lines 34-42. Such lenses were known to a person of ordinary skill in the relevant art prior to May 2001.

22. The '990 patent states:

Thus, the present invention proposes a method for capturing a digital panoramic image, by projecting a panorama onto an image sensor by means of a panoramic objective lens, in which the panoramic objective lens has an image point distribution function that is not linear relative to the field angle of object points of the panorama, the distribution function having a

maximum divergence of at least  $\pm 10\%$  compared to a linear distribution function, such that the panoramic image obtained has at least one substantially expanded zone and at least one substantially compressed zone.

Exhibit 1001, '990 patent, col. 4, lines 11-21.

23. The '990 patent proposes the use of lenses that (1) expand the center of the image and compress the edges of the image; (2) expand the edges of the image and compress the center of the image; or, (3) compress the center and edges of the image and expand an intermediate zone of the image. Exhibit 1001, '990 patent, col. 4, lines 28-38.

24. The '990 patent suggests capturing the image points and "correcting the non-linearity of the initial image, performed by means of a reciprocal function of the non-linear distribution function of the objective lens or by means of the non-linear distribution function." Exhibit 1001, '990 patent, col. 4, lines 51-55.

25. The '990 patent states:

As is well known by those skilled in the art, the term "linearity" here refers to a ratio of proportionality between the distance of an image point measured relative to the center of the image and the field angle of the corresponding object point. The notion of "linearity" in the field of panoramic objective lenses is therefore different from that prevailing in the field of paraxial optics (in the vicinity of the optical axis) when the conditions of Gauss are met.

Exhibit 1001, '990 patent, col. 7, lines 24-31.

26. The '990 patent states:

FIG. 4B represents the curve of the corresponding distribution function  $F_{d1}$ . The classical linear distribution function, expressed by  $F_{dc}=K\alpha$  and in the form of a straight line of gradient  $K$ , is also represented as a guide mark (the constant  $K$  being equal to  $1/90$  for an objective lens having an aperture of  $180^\circ$ , i.e., a gradient of 0.111 per degree). [**sic: should be 0.0111 per degree**]. The field angle  $\alpha$  of the object points is represented on the X-axis and is between  $0$  and  $90^\circ$ . The relative distance  $dr$  of an image point in relation to the center of the image disk is represented on the Y-axis and is between  $0$  and  $1$ . The curve of the function  $F_{d1}$  has a higher gradient than the straight line  $F_{dc}$  for angles  $\alpha$  of between  $0$  and  $20^\circ$ , then a lesser gradient after  $20^\circ$  and up to  $90^\circ$ . A high gradient means an expansion of the image and a low gradient means a compression of the image.

Exhibit 1001, '990 patent, col. 8, lines 29-43.

27. As I will discuss below, lenses having non-linear distribution functions that project substantially expanded and compressed zones were well known in the prior art.

## VI. CLAIM INTERPRETATION

28. In reviewing the claims of the '990 patent, I understand that the claims are generally accorded their broadest reasonable interpretation in light of the patent



specification, and should be free from any limitations disclosed in the specifications that are not expressly listed in the claims.

29. I also understand that claimed terms should be accorded their ordinary and accustomed meaning unless the specification otherwise defines those terms.

30. A person of ordinary skill in the relevant art would have understood the term “panoramic objective lens” to mean a very wide-angle lens, *e.g.*, a “fisheye” lens, capable of projecting a panoramic image. Exhibit 1001, ‘990 patent, col. 1, lines 18-19.

31. A person of ordinary skill in the relevant art would have understood the term “object point” to mean a point on the object being viewed by the lens.

32. A person of ordinary skill in the relevant art would have understood the term “image point” to mean a point of light projected by the lens onto an image plane, said light coming from the corresponding object point of a viewed object.

33. A person of ordinary skill in the relevant art would have understood the phrase “field angle of an object point” to mean “the angle of an incident light ray passing through the object point considered and through the center of the panorama photographed, relative to the optical axis of the objective lens.” *See* Exhibit 1001, ‘990 patent, col. 2, lines 18-22.

34. A person of ordinary skill in the relevant art would have understood the phrase “maximum divergence” (DIVmax) of the distribution function from the linear function as it is defined in the ‘990 patent:

$$DIV_{max} \% = \frac{[dr(Pd) - dr(Pd1)]}{[dr(Pd1)]} * 100.$$

See Exhibit 1001, ‘990 patent, col. 8, line 57.

35. A person of ordinary skill in the relevant art would have looked to the specification of the ‘990 patent to understand the term “substantially,” as it appears in claims 1 and 17 of that patent, and would have learned that it means an amount of compression or expansion obtained using a lens with a non-linear “distribution function having a maximum divergence of at least  $\pm 10\%$  compared to a linear distribution function.” Exhibit 1001, ‘990 patent, col. 4, lines 11-21.

36. A person of ordinary skill in the relevant art would have looked to the specification of the ‘990 patent to understand the term “optical means for projecting” as it is used in that patent and would have understood that the structures disclosed in the specification corresponding to the optical means are one or more optical elements such as lenses. The specification does not limit the optical means to a specific number of optical elements, to specific shaped optical elements, to specific types of optical elements or to a specific arrangement of optical elements. The optical means are one or more optical elements that project a panorama onto an image plane of the objective lens. Exhibit 1001, ‘990 patent,

col. 5, lines 30-31. The '990 patent discloses "two examples of embodiments of non-linear panoramic objective lenses according to the present invention will be described, the first being a direct-type objective lens and the second of indirect type, that is using mirrors." Ex. 1001, 14:46-53. The structures corresponding to the optical means are shown in Figs. 16 and 18. The '990 patent broadly discloses optical elements, *e.g.*, lenses and/or mirrors, which perform the function of projecting a panorama onto an image plane of the objective lens. Exhibit 1001, '990 patent, Figs. 16 and 18.

37. A person of ordinary skill in the relevant art would have understood that an "apodizer" was generally understood as an optical element or "systems used to change the energy distribution (amount of light) of a source of light at the pupil." Exhibit 1001, '990 patent, col. 15, lines 55-57. However, as used in the '990 patent, a person of ordinary skill in the relevant art would have understood that the term "apodizer was used to control the angular distribution of a panoramic objective lens and to obtain the non-linearity sought." Exhibit 1001, '990 patent, col. 16, lines 1-4.

38. In other words, a person of ordinary skill in the relevant art would have understood the term "apodizer" as used in the '990 patent to mean an optical system which provides a non-linear distribution of image points relative to the field angle of the corresponding object points.

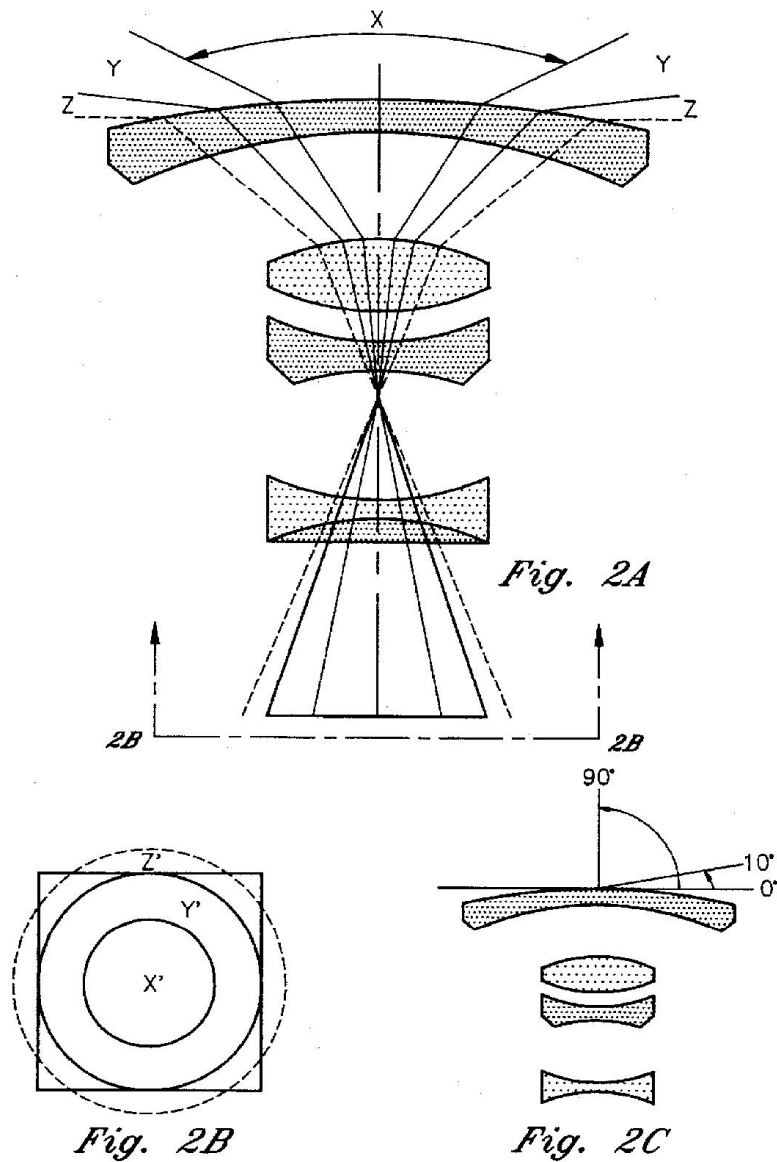
39. A person of ordinary skill in the relevant art would have understood that an “aspherical lens” was generally understood as a lens element with a non-spherical surface.

**VII. U.S. PATENT NO. 5,686,957 (“BAKER”)(Exhibit 1002)**

40. The Baker patent issued on November 11, 1997, based on an application filed on June 30, 1995. As such, it is prior art to the ‘990 patent.

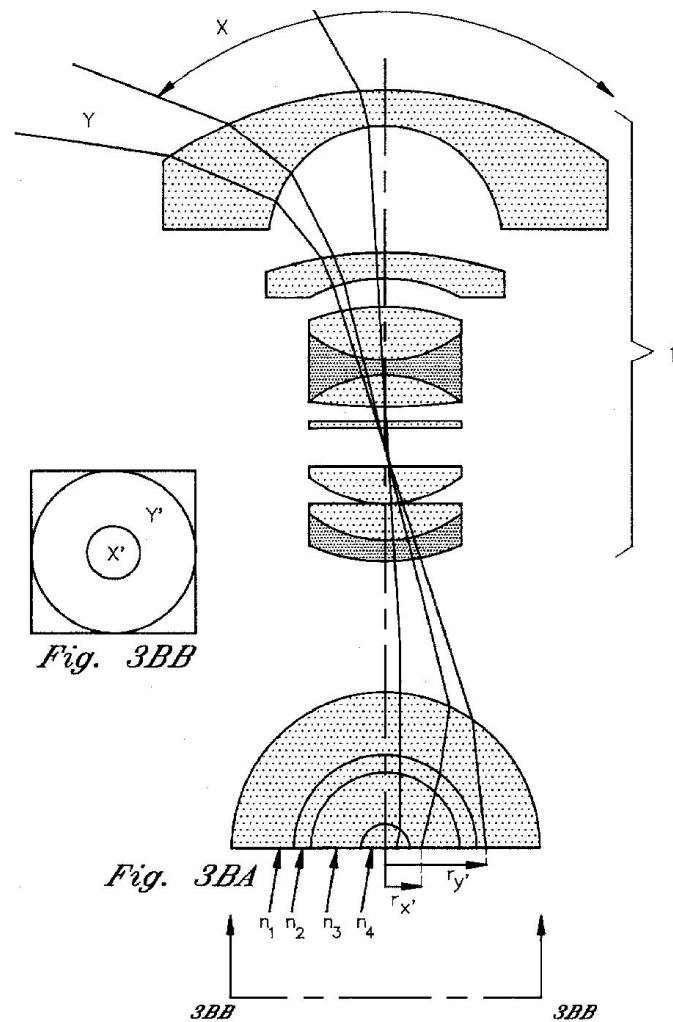
41. Baker discloses various wide-angle objective lenses. Some have the typical linear distribution function of image points, while others have a non-linear distribution function of image points, relative to the field angle of the object points of the panorama. For example, *see* Baker Figs. 2A and 3BA.

42. Baker Fig. 2A depicted below depicts, in cross section, a typical linear objective lens:



43. Baker Fig. 2B depicted above depicts the image obtained from the linear objective lens shown in Fig. 2A.

44. Baker Fig. 3BA depicted below depicts a non-linear objective lens:

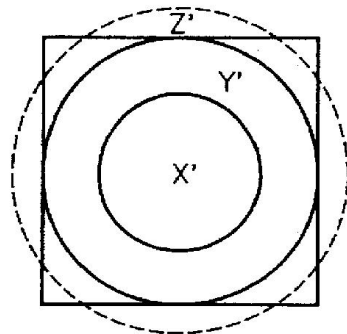


45. Baker Fig. 3BB depicted above depicts the image obtained from the non-linear objective lens shown in Fig. 3BA.

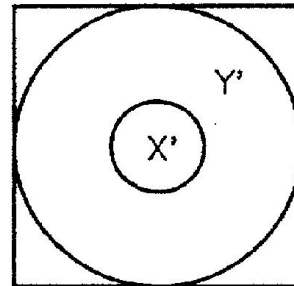
46. Baker discloses using a “hemispherical gradient index unit with a wide field multi-element lens” such that “the portion of the camera dedicated to the periphery is increased, thereby increasing the relative resolution of information

detectable by the imaging device sensing elements.” Exhibit 1002, Baker, col 12, lines 6-11.

47. For ease of comparison, Fig. 2B and Fig 3BB are positioned side-by-side below:



*Fig. 2B*



*Fig. 3BB*

48. The image obtained from the non-linear objective lens (Fig. 3BB) disclosed by Baker depicts a substantially expanded edge zone Y' and a substantially compressed center zone X' compared to the image obtained from the linear objective lens (Fig. 2B).

49. Baker discloses all of the elements recited in claims 1 and 17 of the '990 patent.

50. Baker discloses a panoramic objective lens and a method for capturing a digital panoramic image.

51. Baker discloses that “the visual imaging system can use a single camera to capture the relevant visual information within a panoramic field of view existing along the horizon.” Exhibit 1002, col. 6, lines 29-32.

52. Baker discloses that the “captured scene can be stored onto an assortment of media, e.g., photographic film 16, electronic storage 18, or other conventional storage means.” Exhibit 1002, col. 8, lines 62-65.

53. Baker discloses projecting a panorama onto an image sensor by means of a panoramic objective lens.

54. Baker discloses “the visual imaging system of the parent invention includes a still image or moving picture camera 10, having a lens, indicated generally at 14, designed to capture and enhance the peripheral content of a hemispheric scene.” Exhibit 1002, col. 8, lines 58-62.

55. Baker also discloses that a “CCD” may be used for digital storage. Exhibit 1002, col. 13, line 16.

56. Baker discloses a panoramic objective lens having an image point distribution function that is not a linear function of the field angle of object points of the panorama.

57. Baker discloses “a lens, indicated generally at 14, designed to capture and enhance the peripheral content of a hemispheric scene.” Exhibit 1002, col. 8, lines 60-62.

58. Baker states: “To maximize data collection and resolution for analysis and/or display of the relevant visual information located in this portion of the

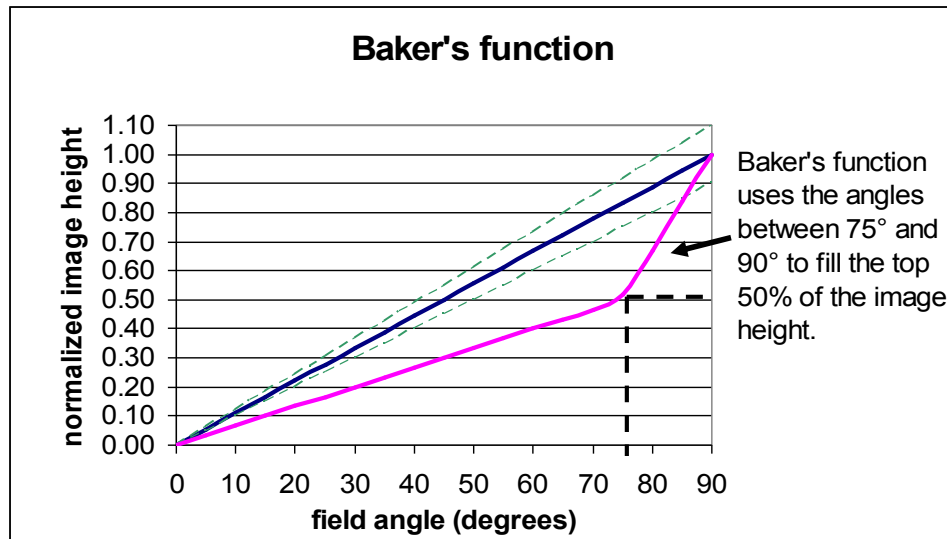


hemispheric scene, it is desirable to maximize the dedication of the available image detection area to this peripheral field portion.” Exhibit 1002, col. 8, lines 32-36.

59. Baker discloses “if an ordinary fisheye lens focuses the lowest 15 degrees up from the horizon on ten percent of the imager at the imaging plane and the peripheral-enhancing lens focuses that same 15 degrees on fifty percent of the imager, there is a five-fold increase in resolution using the same imaging device. Depending on the application and exact formulation of the lens equations, there will be at least a five times increase in resolving power by this lens/imager combination.” Exhibit 1002, col. 6, lines 48-56.

60. A person of ordinary skill in the art would have understood that such a lens that provides a five-fold increase in resolution for the lowest 15 degrees up from the horizon will always have a maximum divergence of at least  $\pm 10\%$  compared to a linear distribution function. It would also have been obvious to a person of ordinary skill in the art that such a lens would have a maximum divergence of at least  $\pm 10\%$  compared to a linear distribution function.

61. The plot below shows a function that replicates Baker. As the last 15° up from the horizon (which is at 90°) fills the top 50% of the image height, Baker’s function must extend outside the  $\pm 10\%$  boundary lines indicated (shown as green-dashed lines).



Thus, Baker discloses a panoramic objective lens with a distribution function having a maximum divergence of at least  $\pm 10\%$  compared to a linear distribution function.

62. Baker further discloses a panoramic objective lens that projects a panoramic image with at least one substantially expanded zone and at least one substantially compressed zone. Compare Figs. 2B and 3BB.

63. Baker additionally discloses all of the elements recited in claims 2, 4, 6, 18, 20 and 22 of the '990 patent.

64. The non-linear objective lens depicted in Fig. 3BA has a non-linear distribution function that is symmetrical relative to the optical axis of the objective lens.

65. In the non-linear objective lens depicted in Fig. 3BA, the position of an image point relative to the center of the image varies according to the field angle of the corresponding object point. Figs. 3BA and 3BB.

66. Baker further discloses a panoramic objective lens that expands the edges of the image and compresses the center of the image. Compare Figs. 2B and 3BB. Baker states: “The lens uniquely achieves this by filling the greater available area of an imager device with the peripheral areas rather than the central areas of the captured scene.” Exhibit 1002, col. 10, lines 57-60.

67. Baker also states: “The lens constructed according to the present invention has a fairly significant portion of the imaging surface dedicated to the peripheral field, and consequently less of the surface dedicated to the central field.” Exhibit 1002, col. 12, lines 29-32.

68. Baker discloses a panoramic objective lens in which a set of lenses form an apodizer as defined by the ‘990 patent. Specifically, the hemispherical lens elements at bottom of Fig. 3BA comprise an apodizer, as they control the angular distribution of the panoramic objective lens to obtain the desired non-linearity. Figs. 3BA and 3BB.

69. In view of the above, all of the elements disclosed by and/or recited in claims 1, 2, 4, 6, 17, 18, 20 and 22 of the ‘990 patent would have been obvious to a person of ordinary skill in the relevant art in view of the teachings of Baker.

### **VIII. U.S. PATENT NO. 6,128,145 (“NAGAOKA”)(Exhibit 1003)**

70. The Nagaoka patent issued on October 3, 2000, based on an application filed on April 28, 1999. As such, it is prior art to the '990 patent.

71. Nagaoka discloses a panoramic objective lens and capturing a digital panoramic image using a CCD that “can pick up an image of all the directions of the field of view around the optical axis at a field angle of at least  $90^\circ$  in each direction with respect to the optical axis.” Exhibit 1003, Nagaoka, col. 1, lines 19-21. Digital image data can be stored, *e.g.*, on a flashcard. Ex. 1003 9:18-21.

72. It is well known to those skilled in the relevant art that the lens distribution function  $h=f \cdot \tan \theta$  creates undistorted images, such as those produced by an ordinary (not a fisheye) camera lens. Nagaoka explains that the distribution function  $h=f \cdot \tan \theta$  shown in his Fig. 3A is impractical for a fisheye lens designed to work at angles  $\theta$  near  $90^\circ$ , since “at a field angle  $\theta$  of  $90^\circ$ ,  $\tan \theta$  becomes infinite. Since the fisheye lens is required to obtain an image of all the directions of the field of view around the optical axis at a field angle of at least  $90^\circ$  with respect to the optical axis, it can be said that the fisheye lens having the relationship of  $h=f \cdot \tan \theta$  is not suitable.” Exhibit 1003, Nagaoka, col. 6, lines 8-13.

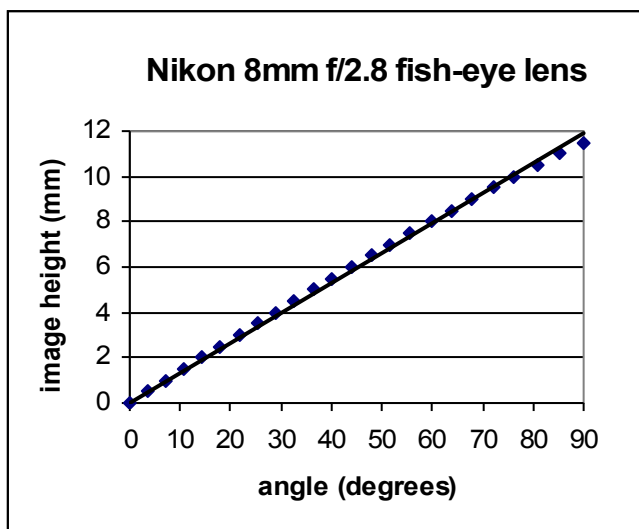
73. Nagaoka explains that the linear distribution function  $h=f \cdot \theta$  is used in the prior art so as to image field angles  $\theta$  near  $90^\circ$ . “The fisheye lens that has been

generally used in the prior art has a relationship of  $h=f\cdot\theta$ .” Exhibit 1003, Nagaoka, col. 5, lines 28-29.

74. Nagaoka discusses a commercially available Nikon lens as an example of the linear distribution function used in fisheye lenses of the prior art.

“Conventional fisheye lenses generally have a relationship of  $h=f\cdot\theta$  and Nikon’s 8 mm f/2.8 fisheye lens has the above relationship of  $h=f\cdot\theta$ .” Nagaoka, col. 1, lines 45-47.

75. Below is a graph of the measured height  $h$  of the image point vs. field angle  $\theta$  for the Nikon 8mm f/2.8 fisheye lens discussed by Nagaoka. The data confirms that this Nikon fisheye lens does indeed have a linear distribution function  $h=f\cdot\theta$ .

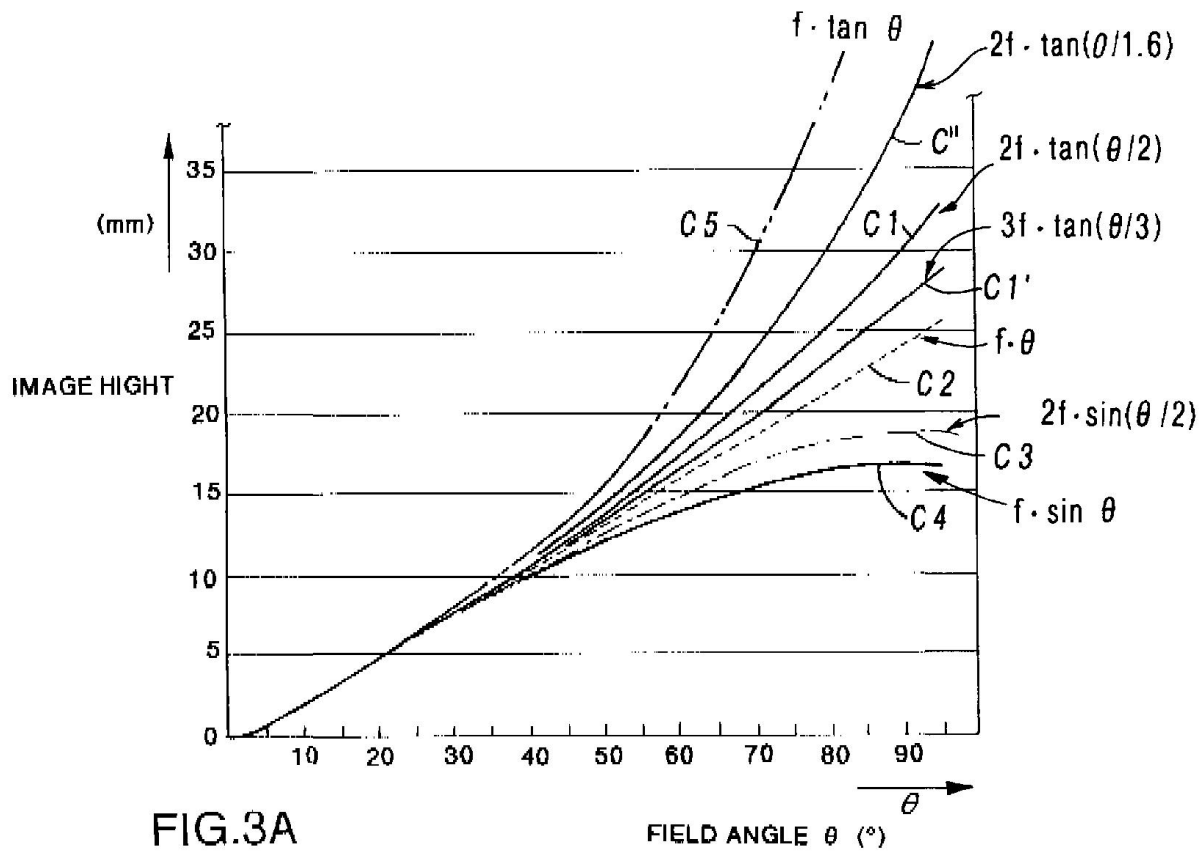


76. Nagaoka explains the disadvantage of a fisheye lens having the *linear* distribution function  $h=f\cdot\theta$ . “Since an image picked up by a fisheye lens having the above characteristics has a small volume of image data on its peripheral portion (field angle around  $90^\circ$  with respect to the optical axis of the fisheye lens), when the image is converted into a plane image, there are many missing portions of image data on the peripheral portion of the image and the missing portions must be interpolated.” Nagaoka, col. 1, lines 50-57.

77. Nagaoka discloses several wide-angle objective lenses, each of which has a *nonlinear* distribution function of image points relative to the field angle of the object points of the panorama. Exhibit 1003, Figs. 3A and 3B.

78. Nagaoka explains the advantage of a fisheye lens having a *nonlinear* distribution function. “Compared with an ordinary fisheye lens having a relationship of  $h=f\cdot\theta$ , an image at a peripheral portion (field angle of around  $90^\circ$  with respect to the optical axis of the fisheye lens) is enlarged and missing portions of image data on the peripheral portion can be minimized with the fisheye lens in accordance with the present invention. With this, when a picked-up image is to be converted into a plane image, the interpolating of image data can be reduced, thereby making it possible to obtain a more natural plane image.” Exhibit 1003, Nagaoka, col. 2, lines 44-53.

79. Fig. 3A of Nagaoka is depicted below:



80. “Fig. 3A is a diagram showing the relationship between field angle  $\theta$  and image height  $h$  with respect to fisheye lenses having relationships of  $h=f\theta$ ,  $h=2f \cdot \sin(\theta/2)$ ,  $h=f \cdot \sin \theta$ ,  $h=f \cdot \tan \theta$ ,  $h=3f \cdot \tan(\theta/3)$ ,  $h=2f \cdot (\tan \theta/1.6)$  and  $h=2f \cdot \tan(\theta/2)$ .” Exhibit 1003, Nagaoka, col. 3, lines 17-22.

81. In Figs. 3A and 3B, a high gradient (i.e. slope of the curve) compared to the slope of the linear distribution function  $h=f\theta$  means an expansion of the image, and a low gradient compared to the linear distribution function  $h=f\theta$  means a compression of the image. See Exhibit 1001, ‘990 patent, col. 8, lines 41-43.

82. Where the gradient of the graphed distribution function of a lens is *higher* than the gradient of the linear distribution function  $h=f\cdot\theta$ , the image obtained from that lens will have an expanded zone. Exhibit 1001, '990 patent, col. 8, lines 38-43.

83. Where the gradient of the graphed distribution function of a lens is *lesser* than the gradient of the linear distribution function  $h=f\cdot\theta$ , the image obtained from that lens will have a compressed zone. Exhibit 1001, '990 patent, col. 8, lines 38-43.

84. If the distribution function of a lens has a divergence of at least  $\pm 10\%$  compared to the linear distribution function  $h=f\cdot\theta$ , the image obtained from that lens will have a “substantially” expanded zone and/or a “substantially” compressed zone compared to the image produced by a lens having a linear distribution function, as that term is used in the '990 patent. Exhibit 1001, '990 patent, col. 4, lines 11-21.



85. Fig. 3B of Nagaoka is depicted below:

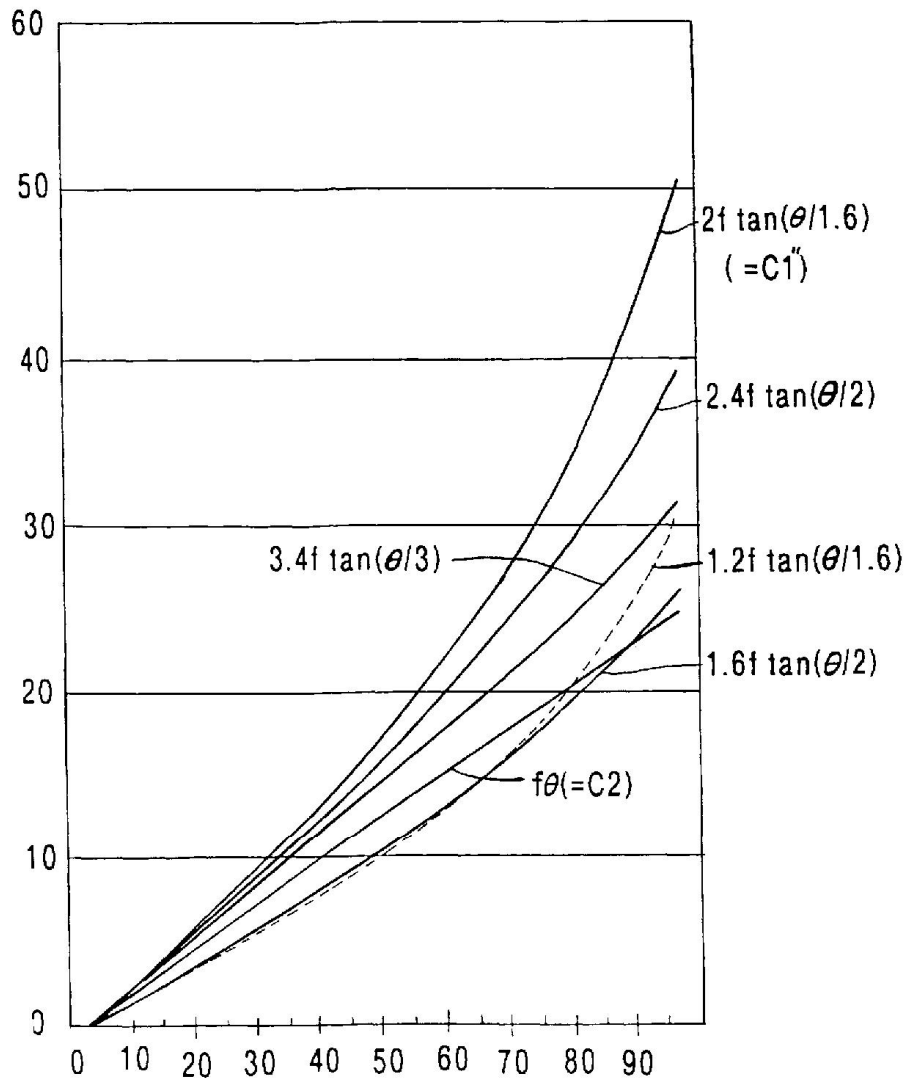


FIG.3B

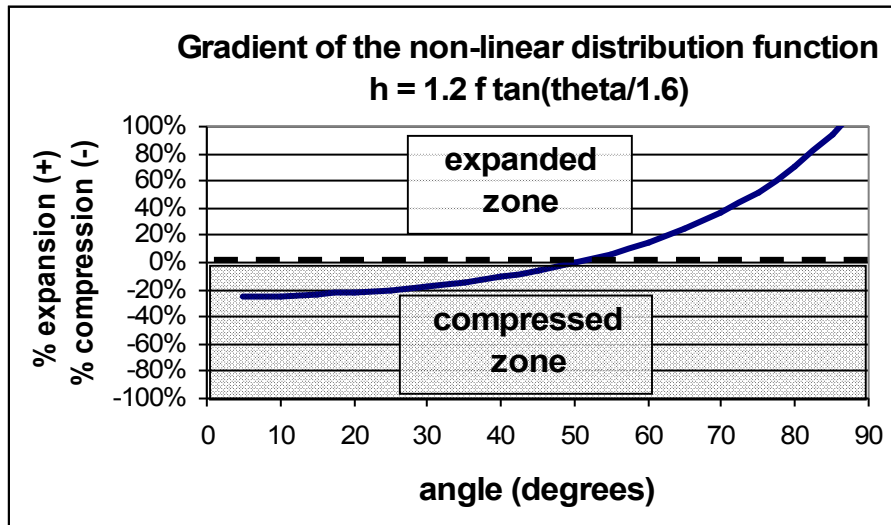
86. Fig. 3B is a diagram showing the relationship between field angle  $\theta$  and image height  $h$  with respect to fisheye lenses having relationships of  $h=2f \cdot \tan(\theta/1.6)$ ,  $h=2.4f \cdot \tan(\theta/2)$ ,  $h=3.4f \cdot \tan(\theta/3)$ ,  $h=1.2f \cdot \tan(\theta/1.6)$ ,  $h=1.6f \cdot \tan(\theta/2)$  and  $h=f \cdot \theta$ . Exhibit 1003, Nagaoka, col. 3, lines 23-27.

87. All of the lenses depicted in Figs. 3A and 3B other than  $h=f\cdot\theta$  have non-linear distribution functions.

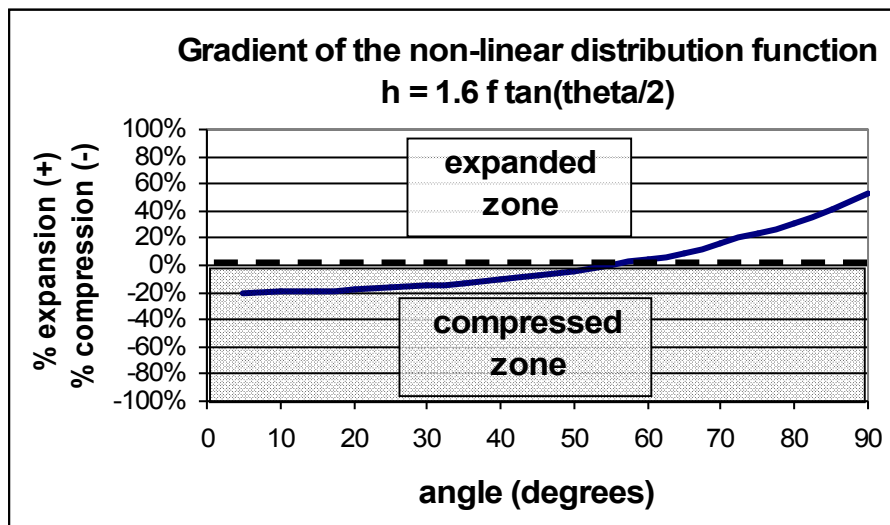
88. Nagaoka Figs. 3A and 3B show the distribution functions for lenses with the functions  $h=1.2f\cdot\tan(\theta/1.6)$ ,  $h=1.6f\cdot\tan(\theta/2)$ , and  $h=2f\cdot\tan(\theta/2)$ . Figs. 3A and 3B further show that each of these lenses has a maximum divergence of at least  $\pm 10\%$  compared to the linear distribution function. Additionally, to confirm what is shown in Nagaoka Figs. 3A and 3B, I have computed the actual maximum divergence compared to a linear distribution function for each of the following lens distribution functions disclosed by Nagaoka:  $h=1.2f\cdot\tan(\theta/1.6)$ ,  $h=1.6f\cdot\tan(\theta/2)$ , and  $h=2f\cdot\tan(\theta/2)$ . See paragraphs 92-94 below.

89. I have also determined whether the image obtained from each of these lens distribution functions has at least one substantially expanded zone and at least one substantially compressed zone.

90. Below is a plot of the gradient of a lens having the nonlinear distribution function  $h=1.2f\cdot\tan(\theta/1.6)$  compared to the gradient of the linear function  $h=f\cdot\theta$ . The plot shows that this lens produces an image having one substantially expanded zone and one substantially compressed zone.

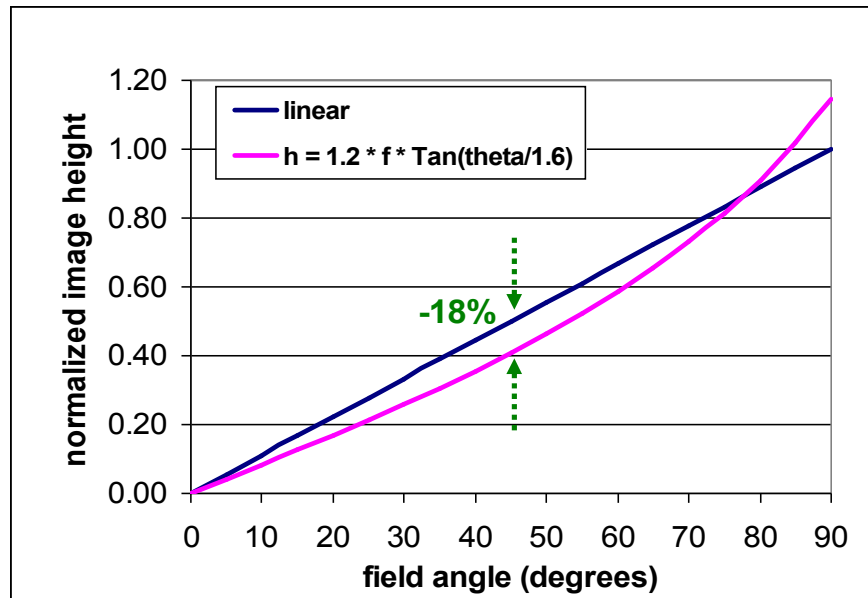


91. Below is a plot of the gradient of a lens having the nonlinear distribution function  $h=1.6f \cdot \tan(\theta/2)$ , compared to the gradient of the linear function  $h=f \cdot \theta$ . The plot shows that this lens produces an image having one substantially expanded zone and one substantially compressed zone.

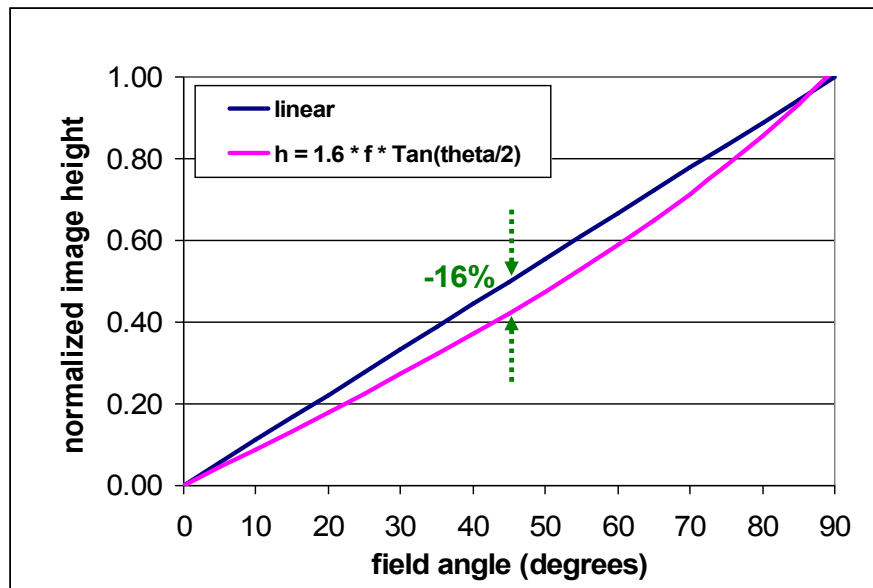


92. A lens having the function  $h=1.2f \cdot \tan(\theta/1.6)$  would have a maximum divergence of at least  $\pm 10\%$  compared to a linear distribution function. As shown

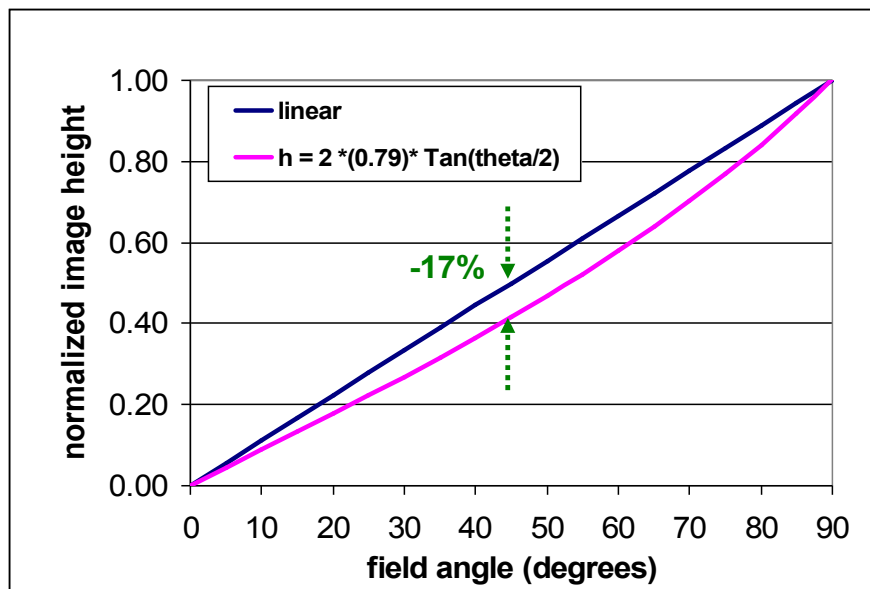
in the graph below, at 45° the divergence is ~18% compared to a linear distribution function.



93. A lens having the function  $h=1.6f \cdot \tan(\theta/2)$ , would have a maximum divergence of at least  $\pm 10\%$  compared to a linear distribution function. As shown in the graph below, at 45° the divergence is ~16% compared to a linear distribution function.



94. A lens having the function  $h=2f \cdot \tan(\theta/2)$  would have a maximum divergence of at least  $\pm 10\%$  compared to a linear distribution function. As shown in the graph below, at  $45^\circ$  the divergence is  $\sim 17\%$  compared to a linear distribution function when the focal length equals 0.79.



95. A lens having the function  $h=2f \cdot \tan(\theta/2)$  with a focal length  $f=1$  has at least one substantially expanded zone as shown in Fig. 4A of Nagaoka (Exhibit 1003):

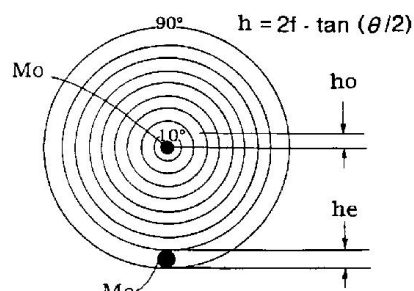


FIG.4A

96. In Fig. 4A above, the “image height  $he$  of the image  $Me$  at a peripheral portion of the fisheye lens 1 having the relationship of  $h=2f \cdot \tan(\theta/2)$  in accordance with the present invention is enlarged and larger than the image height  $ho$  of the image  $Mo$  near the optical axis, a larger volume of image data can be obtained in comparison with the conventional fisheye lens, and the obtained image is not distorted.” Exhibit 1003, Nagaoka, col. 6, lines 46-52.

97. A person of ordinary skill in the relevant art would have known how to fit an image projected by a lens onto an image sensor. Specifically, such person would know how to set the focal length  $f$  of a lens so that the size of the projected image approximately matches the size of the image sensor.

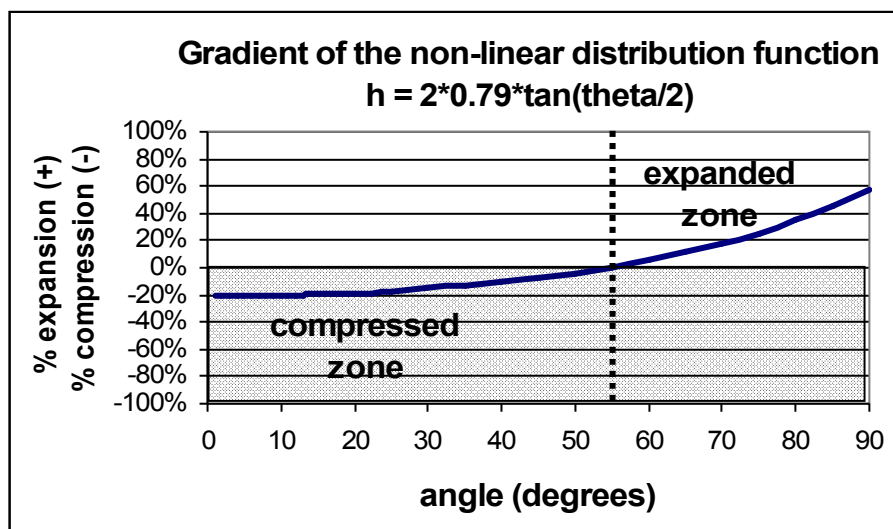
98. It was well within the knowledge of a person of ordinary skill in the relevant art to select the focal length of a lens having a non-linear distribution

function so that the size of the projected image was approximately the same size as the projected image of a lens having the linear distribution function  $h=f\cdot\theta$ .

99. A person of ordinary skill in the relevant art would have understood that, by selecting the focal length of a lens having the nonlinear distribution function  $h=2f\cdot\tan(\theta/2)$  to make its image size match that of a linear lens, the values of the gradients of that nonlinear lens would change.

100. A lens having the nonlinear distribution function  $h=2f\cdot\tan(\theta/2)$  with a focal length  $f=0.79$  will produce a fisheye image of approximately the same size as a lens having the linear distribution function  $h=f\cdot\theta$  with a focal length  $f=1$ .

101. A lens having the function  $h=2f\cdot\tan(\theta/2)$  with a focal length  $f=0.79$  has at least one substantially expanded zone and at least one substantially compressed zone, compared to the linear distribution function  $h=f\cdot\theta$  with a focal length  $f=1$ , as shown in the plot below.



102. Nagaoka (Exhibit 1003) discloses all of the elements recited in claims 1 and 17 of the '990 patent.

103. Nagaoka discloses a panoramic objective lens and a method for capturing a digital panoramic image. Specifically, Nagaoka discloses: "...an image processing system utilizing an image pick-up device comprising a fisheye lens..." Exhibit 1003, Nagaoka col. 3, lines 63-65. Nagaoka further discloses: "an image of half of the sphere is picked up by the fisheye lens." Ex. 1003 1:23-31.

104. Nagaoka discloses projecting a panorama onto an image sensor by means of a panoramic objective lens. Specifically, the panorama is projected onto a CCD image sensor by a panoramic objective lens. Exhibit 1003, Nagaoka col. 4, line 66 – col. 5, line 2 and Fig. 2.

105. Nagaoka discloses a panoramic objective lens having an image point distribution function that is not linear relative to the field angle of object points of the panorama. In fact, Nagaoka discloses several lenses each having an image point distribution function that is not linear relative to the field angle of object points of the panorama. As examples, the lenses having the functions  $h=1.2f \cdot \tan(\theta/1.6)$ ,  $h=1.6f \cdot \tan(\theta/2)$ , and  $h=2f \cdot \tan(\theta/2)$  are non-linear. Exhibit 1003, Nagaoka Figs. 3A and 3B.

106. Nagaoka further discloses "[T]he image height  $h$  of the image  $M$  at a peripheral portion of the fisheye lens 1 having the relationship of  $h=2f \cdot \tan(\theta/2)$  in



accordance with the present invention is enlarged and larger than the image height  $h_o$  of the image  $M_o$  near the optical axis, a larger volume of image data can be obtained in comparison with the conventional fisheye lens, and the obtained image is not distorted” Exhibit 1003, Nagaoka col. 6 lines 46-52, and Fig. 3A.

107. A person of ordinary skill in the relevant art would have understood that the fisheye lens 1 of Nagaoka having the relationship of  $h=2f \cdot \tan(\theta/2)$  would have a maximum divergence of at least  $\pm 10\%$  compared to a linear distribution function.

108. Nagaoka discloses a panoramic objective lens with a distribution function having a maximum divergence of at least  $\pm 10\%$  compared to a linear distribution function. Specifically, a lens having the function  $h=1.2f \cdot \tan(\theta/1.6)$  has a maximum divergence of at least 18% (*see* ¶ 92 above), a lens having the function  $h=1.6f \cdot \tan(\theta/2)$  has a maximum divergence of at least 16% (*see* ¶ 93 above), and a lens having the function  $h=2f \cdot \tan(\theta/2)$  has a maximum divergence of at least 24% when the focal length is  $f=1$ , and a maximum divergence of at least 17% when the focal length is  $f=0.79$  (*see* ¶ 94 above).

109. Nagaoka discloses a panoramic objective lens that projects a panoramic image with at least one substantially expanded zone and at least one substantially compressed zone. Specifically, the lenses having the functions  $h=1.2f \cdot \tan(\theta/1.6)$ ,

$h=1.6f \cdot \tan(\theta/2)$ , and  $h=2f \cdot \tan(\theta/2)$  (using  $f=0.79$ ) all have a substantially expanded zone and a substantially compressed zone compared to the linear function  $h=f \cdot \theta$ .

110. Nagaoka further discloses all of the elements recited in claims 2, 4, 6, 18, 20 and 22 of the '990 patent.

111. Nagaoka further discloses a panoramic objective lens with a non-linear distribution function that is symmetrical relative to the optical axis of the objective lens, the position of an image point relative to the center of the image varying according to the field angle of the corresponding object point. The lenses having the functions  $h=1.2f \cdot \tan(\theta/1.6)$ ,  $h=1.6f \cdot \tan(\theta/2)$ , and  $h=2f \cdot \tan(\theta/2)$  are symmetrical relative to the optical axis of the objective lens, and the position of an image point relative to the center of the image varies according to the field angle of the corresponding object point. Fig. 4A also shows that the non-linear distribution function  $h=2f \cdot \tan(\theta/2)$  is symmetrical relative to the optical axis.

112. Nagaoka further discloses a panoramic objective lens that expands the edges of the image and compresses the center of the image. The lenses having the functions  $h=1.2f \cdot \tan(\theta/1.6)$  and  $h=1.6f \cdot \tan(\theta/2)$  expand the edges of the image and compress the center of the image.

113. Nagaoka further discloses a panoramic objective lens in which a set of lenses form an apodizer. As shown in Fig. 2, the lens system controls the angular

distribution of the panoramic objective lens to obtain a nonlinear distribution function.

114. In view of the above, all of the elements disclosed by and/or recited in claims 1, 2, 4, 6, 17, 18, 20 and 22 of the '990 patent would have been obvious to a person of ordinary skill in the relevant art in view of the teachings of Nagaoka.

115. In particular, a person of ordinary skill in the relevant art would have known that the lenses having the functions  $h=1.2f \cdot \tan(\theta/1.6)$ ,  $h=1.6f \cdot \tan(\theta/2)$ , and  $h=2f \cdot \tan(\theta/2)$  (using  $f=.79$ ) have a substantially expanded zone and a substantially compressed zone.

#### **IX. U.S. PATENT NO. 3,953,111 ("FISHER")(Exhibit 1004)**

116. The Fisher patent issued on April 27, 1976, based on an application filed on November 4, 1974. As such, it is prior art to the '990 patent.

117. Fisher wants to solve a problem opposite to that faced by Nagaoka, namely, how to expand the resolution of the central portion of an image formed by a fisheye lens and compress the information displayed on the horizon. Fisher solves this problem by using a non-linear lens.

118. Fisher discloses: "A non-linear lens possesses distortion characteristics which are such that objects along the optical axis of the lens occupy disproportionately large areas of the image cast by the lens, whereas objects near

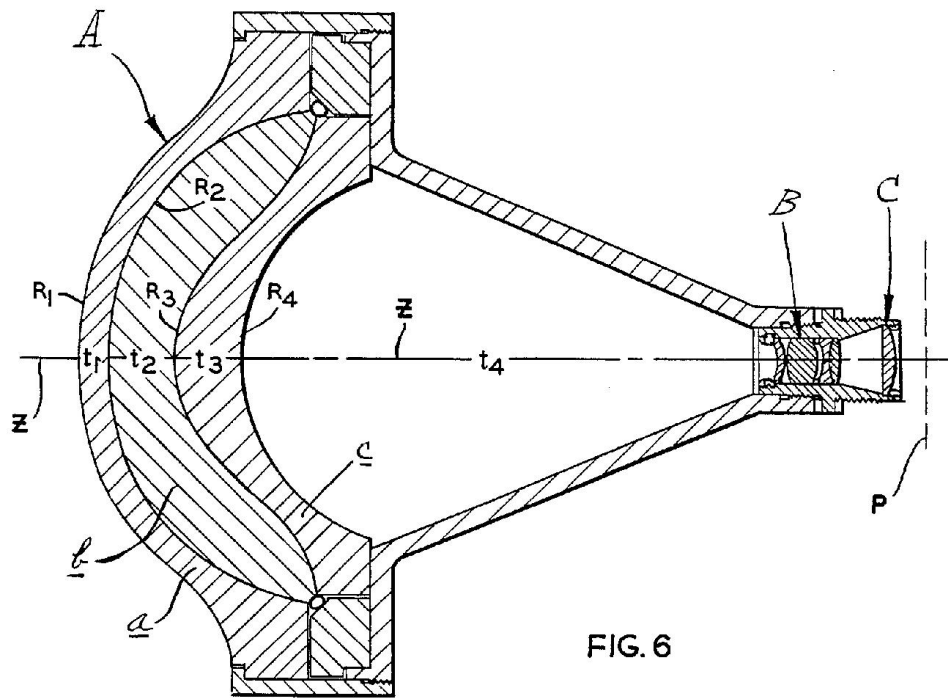
the periphery of the field of view occupy a disproportionately small area of the image.” Exhibit 1004, Fisher Abstract; col. 2, lines 5-10.

119. Fisher discloses: “The lens of the present invention (FIGS. 6 and 7) provides non-linear image distortion characteristics over an extremely wide field of view which approaches 160°.” Exhibit 1004, col. 2, lines 56-57.

120. Fisher also discloses “The image cast by the lens falls on the vidicon of a television camera where it is scanned and transmitted to a projector.” Exhibit 1004, Abstract. Fisher further discloses “The distorted image formed by the non-linear lens exists in an image plane  $p$  located beyond the third lens grouping C. The vidicon of the television camera should be at this plane  $p$ .” Exhibit 1004, col. 6, lines 51-54; Abstract; col. 4, lines 35-45.

121. A vidicon is a camera tube in which a charge-density pattern is formed by photoconduction and stored on a photoconductor surface that is scanned by an electron beam, usually of low-velocity electrons: used chiefly in industrial television cameras. *See McGraw-Hill Dictionary of Scientific and Technical Terms* (5th Ed., 1994, p. 2134) (copy attached as Appendix B).

122. Fisher Fig. 6 is depicted below:



123. Fisher Fig. 6 depicted above depicts a non-linear panoramic objective lens. Exhibit 1004, col. 5, lines 44-45.

124. Fisher discloses that the lens surfaces  $R_1$  and  $R_3$  in the above non-linear lens are non-spherical (aspherical): “The first lens grouping A (FIG. 6) consists of three lens elements a, b, and c with no air gaps between adjacent elements. The outside lens element a has a non-spherical surface  $R_1$  exposed outwardly and a spherical surface  $R_2$  presented inwardly against a matching surface  $R_2$  on the intermediate element b. The opposite surface  $R_3$  of the intermediate element b is non-spherical and abuts a matching surface  $R_3$  on the inside element c.” Exhibit 1004, Fisher col. 5, line 61 – col. 6, line 1.

125. In his graph in Fig. 3 shown below Fisher shows “the distortion characteristics of the lens of the present invention in terms of normalized image height and field of view and comparing such distortion characteristics with the distortion characteristics of a linear fisheye lens and a conventional camera lens.”

Ex 1004, Fisher col. 2, lines 38-43.

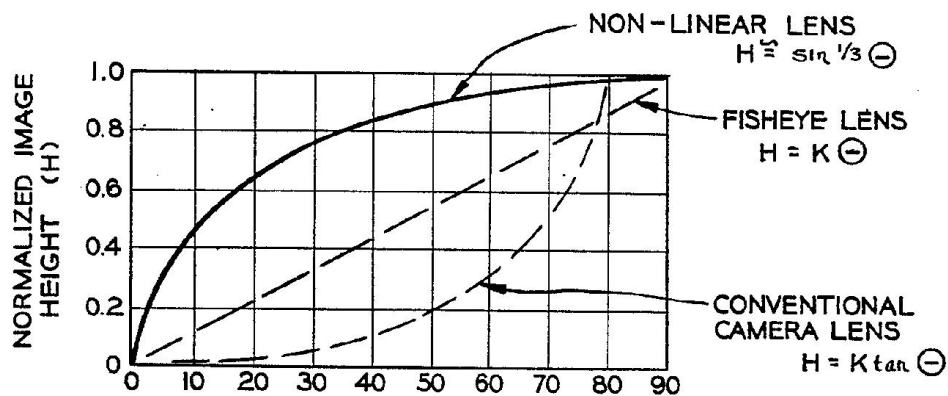
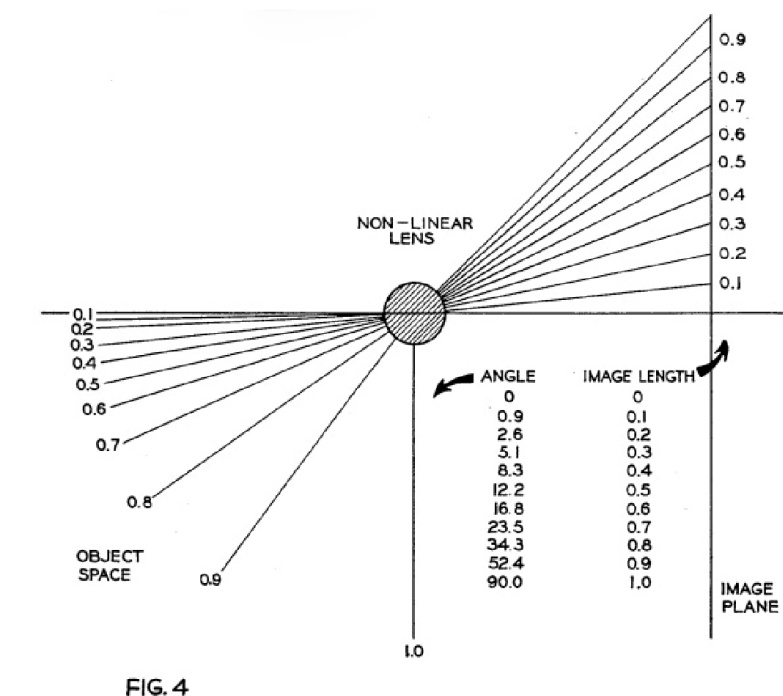


FIG. 3

126. “[W]ith a non-linear lens of the present invention the image height is equal to a variable function of the field angle (FIG. 3). The relationship is approximated by the formula  $H = \sin^{1/3} \theta$ .” Ex 1004, Fisher col. 3, lines 1-4.

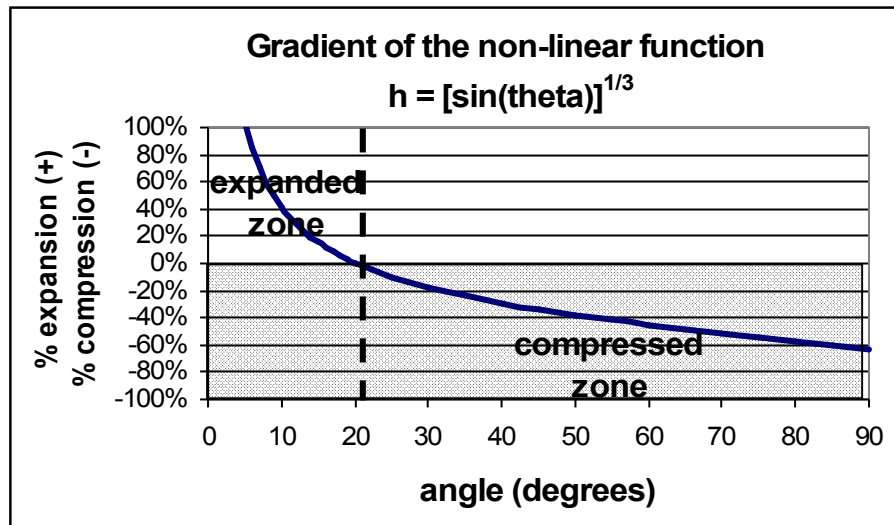
127. Based on the information depicted in Fig. 3, it is clear that this non-linear lens has a distribution function whose maximum divergence is much greater than 10% compared to a linear distribution function (fisheye lens).

128. “FIG. 4 below is a graphic representation of the non-linear distortion characteristics and showing how equal increments on the image plane correspond to unequal increments in the field of view.” Ex 1004, Fisher col. 2, lines 44-47.



129. As shown in Fisher Fig. 4 depicted above (Exhibit 1004), unequal angular increments in the object space of the non-linear lens produce equal image-length increments in the image plane of the lens. Adjacent rays in the object space separated by small angles (labeled as 0.1, 0.2, etc. on the left side of the figure) and those separated by large angles (labeled as 0.9 and 1.0 on the bottom left of the figure) all produce equal image increments in the image plane (shown on the right side of the figure).

130. The plot below further shows that a lens with the nonlinear distribution function  $H = \sin^{1/3} \theta$  noted in Fisher's Fig. 3 produces an expanded zone and a compressed zone relative to a linear distribution.



131. As shown in Fisher Fig. 4, as well as in the plot above, Fisher (Exhibit 1004) discloses a panoramic objective lens that projects a panoramic image with at least one substantially expanded zone and at least one substantially compressed zone. The expanded zone will be in the central region of the image, and the compressed zone will be on the periphery of the image.

132. Fisher discloses all of the elements recited in claims 1 and 17 of the '990 patent.

133. Fisher discloses a panoramic objective lens and a method for capturing a digital panoramic image. Fisher discloses that the camera is fitted with a non-linear lens. Exhibit 1004, Fisher col. 3, lines 48-49, Fig. 3.



134. Fisher discloses projecting a panorama onto an image sensor by means of a panoramic objective lens. Exhibit 1004, Fisher col. 3, lines 48-49, Fig. 3.

135. Fisher discloses a panoramic objective lens having an image point distribution function that is not linear relative to the field angle of object points of the panorama. Exhibit 1004, Fisher col. 3, lines 1-3, Fig. 3.

136. Fisher discloses “The present invention relates in general to lenses and more particularly to a lens having non-linear distortion characteristics.” Exhibit 1004, Fisher col. 1, lines 9-11.

137. Fisher discloses “One of the principal objects of the present invention is to provide a lens having non-linear distortion characteristics.” Exhibit 1004, Fisher col. 2, lines 6-8.

138. Fisher further discloses: “[W]ith a non-linear lens of the present invention the image height is equal to a variable function of the field angle (FIG. 3). The relationship is approximated by the formula  $H = \sin^{1/3}\theta$ . Thus, objects centered along the optical axis of the non-linear lens L cast a much larger image than objects located near the periphery of the field of view with the size diminishing as the angle from the optical axis increases. The result of the distortion is that objects along the optical axis occupy a disproportionately large share of the image cast by the lens when compared with other objects closer to the periphery of the field of view for the lens.” Exhibit 1004, Fisher col. 3, lines 1-12.

139. Fisher discloses a panoramic objective lens that projects a panoramic image with at least one substantially expanded zone and at least one substantially compressed zone. Exhibit 1004, Fisher Figs 3 and 4; col. 3, lines 1-12.

140. Fisher discloses: “The present invention is embodied in a lens which distorts a field of view such that objects in the vicinity of the optical axis occupy a disproportionately large area of the image cast by the lens and objects in the peripheral region of the field of view occupy a disproportionately small area of the image.” Exhibit 1004, Fisher col. 2, lines 19-24.

141. Fisher discloses all of the elements recited in claims 2, 3, 6, 7, 18, 19, 22 and 23 of the ‘990 patent.

142. Fisher discloses a panoramic objective lens with a non-linear distribution function that is symmetrical relative to the optical axis of the objective lens, the position of an image point relative to the center of the image varying according to the field angle of the corresponding object point. Exhibit 1004, Fisher Figs. 4 and 6.

143. Fisher discloses a panoramic objective lens that expands the center of the image and compresses the edges of the image. Exhibit 1004, Fisher Fig. 4; col. 2, lines 19-24.

144. Fisher discloses a panoramic objective lens in which a set of lenses form an apodizer. Exhibit 1004, Fisher Figs. 4 and 6.

145. Fisher discloses a panoramic objective lens in which a set of lenses forming an apodizer comprises at least one aspherical lens. Exhibit 1004, Fisher Fig. 6, col. 5, lines 63-68. As shown in Fig. 6, at least lens elements “a” and “c” are aspherical (*i.e.*,  $R_1$ ,  $R_3$ ).

146. Aspherical lenses were well known in the prior art. For example, see Fisher, Exhibit 1004, Fisher col. 5, line 61 – col. 6, line 1.

147. It would have been obvious to a person of ordinary skill in the relevant art as a matter of mere design choice to use at least one aspherical lens to change the angular distribution of a panoramic objective lens.

148. In view of the above, all of the elements disclosed by and/or recited in claims 1, 2, 3, 6, 7, 17, 18, 19, 22 and 23 of the ‘990 patent would have been obvious to a POSA in view of the teachings of Fisher.

149. In particular, a panoramic lens having a non-linear distribution function with a maximum divergence of at least  $\pm 10\%$  compared to a linear distribution function, where the projected panoramic image has at least one substantially expanded zone and at least one substantially compressed zone would have been obvious to a person of ordinary skill in the relevant art at the time of the invention in view of the teachings of Fisher.

## **X. U.S. PATENT NO. 6,031,670 (“INOUE”)(Exhibit 1007)**

150. U.S. Patent No. 6,031,670 discloses making wide angle lenses from PMMA. Exhibit 1007, Inoue, col. 2, lines 42-44. PMMA was thus well known in the prior art as a material which could be used to fabricate lenses. The ‘990 patent discloses, albeit in a grammatically unclear fashion, that PMMA and polymethacrylate are either the same or equivalent for use in wide angle lenses. Thus, it would have been obvious to a person of ordinary skill in the art that the lenses disclosed in Baker and Nagaoka could be interchangeably made from PMMA or polymethacrylate.

## **IX. CONCLUSIONS**

151. I have been informed and understand that a patent claim is anticipated if each element of that claim is present either explicitly or inherently in a single prior art reference. As explained in detail below, claims **1, 2, 4, 6, 7, 17, 18, 20, 22 and 23 of the ‘990 patent** are anticipated by one or more prior art references.

152. Baker (Exhibit 1002) discloses each and every element recited in claim 1, 2, 4, 6, 17, 18, 20 and 22 of the ‘990 patent. Therefore Baker anticipates claims 1, 2, 4, 6, 17, 18, 20 and 22 of the ‘990 patent.

153. Additionally, in view of the teachings of Baker (Exhibit 1002), claims 1, 2, 4, 6, 17, 18, 20 and 22 of the ‘990 patent would also have been obvious because a person of ordinary skill in the relevant art at the time of invention would

have understood that a lens that provides a five-fold increase in resolution for the lowest 15 degrees up from the horizon, as disclosed in Baker, will always have a maximum divergence of at least  $\pm 10\%$  compared to a linear distribution function.

154. Nagaoka (Exhibit 1003) discloses each and every element recited in claim 1, 2, 4, 6, 17, 18, 20 and 22 of the '990 patent. Therefore Nagaoka anticipates claims 1, 2, 4, 6, 17, 18, 20 and 22 of the '990 patent.

155. Additionally, in view of the teachings of Nagaoka (Exhibit 1003), claims 1, 2, 4, 6, 17, 18, 20 and 22 of the '990 patent would also have been obvious because a person of ordinary skill in the relevant art at the time of invention would have been able to determine the maximum divergence of a non-linear distribution function of a lens compared to a linear distribution function, and then determine whether such lens would project an image with a substantially expanded zone and a substantially compressed zone compared to the linear function  $h=f\cdot\theta$ .

156. Fisher (Exhibit 1004) discloses each and every element recited in claim 1, 2, 3, 6, 7, 17, 18, 19, 22 and 23 of the '990 patent. Therefore Fisher anticipates claims 1, 2, 3, 6, 7, 17, 18, 19, 22 and 23 of the '990 patent.

157. Additionally, in view of the teachings of Fisher (Exhibit 1004), claims 1, 2, 3, 6, 7, 17, 18, 19, 22 and 23 of the '990 patent would also have been obvious to a person of ordinary skill in the relevant art at the time of invention because

there are no differences between the prior art and the claims at issue. Additionally, at the time of invention, a person of ordinary skill in the relevant art would have known that electronic images could be stored digitally.

158. I have also been informed and understand that a patent claim is obvious if, at the time the invention was made, it would have been obvious to one of ordinary skill in the art in light of the teachings of the prior art to which the claimed invention pertains. I have further been informed that the analysis of obviousness involves several factual inquiries: the scope and content of the prior art, the differences between the prior art and the claims, the level of ordinary skill in the art at the time of the invention, and certain additional “secondary” considerations, to the extent that they may exist.

159. I have also been informed and understand that, in seeking to determine whether an invention, which is a combination of known elements, would have been obvious to a person of ordinary skill in the art at the time of the invention, one must consider references in their entirety to ascertain whether the disclosures in those references suggest the combination. When those references disclose the combination -- as is the case, for example, when all of the features of what the patent claims are old and the prior art collectively suggests the desirability of adding features to an old system, or modifying certain aspects of the old system, to achieve what the patent claims -- a finding of obviousness is warranted.

160. If it is determined that Fisher does not disclose capturing a “digital” panoramic image as recited in the beginning of claim 1, claims 1, 2, 3, 6 and 7 of the ‘990 patent would still have been obvious to a person of ordinary skill in the relevant art at the time of invention over Fisher (Exhibit 1004) in view of Baker (Exhibit 1002) because Baker discloses capturing a digital panoramic image (Ex. 1002 8:62-65; 2:35-39; 10:55-57; 14:32-36) and it would have been obvious to a person of ordinary skill in the relevant art to digitally capture the image projected by Fisher as disclosed by Baker.

161. Claim 25 would have been obvious to a person of ordinary skill in the relevant art as a matter of mere design choice in view of Baker (Exhibit 1002) or Nagaoka (Exhibit 1003) with Inoue (Exhibit 1007).

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

I declare that all statements made herein of 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.

I declare under penalty of perjury that the foregoing is true and correct.

AUG 12, 2014  
Date

Jack Feinberg  
Jack Feinberg, Ph. D.



# APPENDIX A

## Appendix A

### JACK FEINBERG

#### Professor

Departments of Physics and Astronomy  
and Electrical Engineering  
University of Southern California  
Los Angeles, California  
[feinberg@usc.edu](mailto:feinberg@usc.edu)  
213-740-1134

#### EMPLOYMENT

##### UNIVERSITY OF SOUTHERN CALIFORNIA, LOS ANGELES, CALIFORNIA:

Full Professor of Physics and Electrical Engineering (1991 - present)  
Associate Professor of Physics and Electrical Engineering (1990)  
Associate Professor of Physics with tenure (1986 to 1989)  
Assistant Professor of Physics (1981 to 1986)  
Research Assistant Professor (1979 to 1981)  
Post-Doctoral Research Associate (1977 to 1979)

#### EDUCATION

##### UNIVERSITY OF CALIFORNIA, BERKELEY:

Ph.D. Physics, December 1977.  
Thesis Advisor: Professor Sumner P. Davis.  
“Laser-Induced Fluorescence in Titanium Oxide: Lifetimes, Collisions, and Intercombinations.”

##### COLUMBIA UNIVERSITY, NEW YORK:

B. A. June 1972  
Summa Cum Laude, Physics.  
GPA: 3.9

#### SERVICE & HONORS

Co-Chairman: Meeting on Controlling Light with Light: Photorefractive Effects, Photosensitivity, Fiber Gratings, and Photonic Materials (2007).  
Winner: **Discover Award** for Technological Innovation in the field of Sight (1995).  
Co-Chairman: Meeting on Photorefractive Materials, Effects and Devices (1995).  
Guest Editor, Journal of the Optical Society of America (1990-1992).  
Fellow of the Optical Society of America (1990).  
Chairman: Gordon Research Conference on Nonlinear Optics (1989).  
Associate Editor, Optics Letters (1990 - 1995).

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11. "Tunable Dispersion Compensator Based on a Nonlinearly-Chirped Fiber Bragg Grating," United States Patent No. 5,982,963, issued November 9, 1999.
10. "Near-Ultra-Violet Formation Of Refractive-Index Grating Using Reflective Phase Mask," United States Patent No. 5,745,617, issued April 28, 1998.
9. "Optical Amplification System With Non-Orthogonal Signal And Distributed Multipump Beams And Photorefractive Cleanup," United States Patent No. 5,729,375 issued March 17, 1998.
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6. "Method of Imaging Through a Scattering Medium using Coherent Light," United States Patent No. 5,313,315 issued May 17, 1994.
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4. "Phase Conjugate Communication Using Mutually Incoherent Laser Beams," United States Patent No. 4,953,954 issued September 4, 1990.
3. "Optical Novelty Filter," United States Patent No. 4,773,719 issued September 27, 1988.
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## MOVIES AND VIDEOS

7. J. Feinberg, "Writing a grating in a fiber through its polymer coating," (Marmot Productions, Los Angeles, 1999).
6. V. Grubsky, S. MacCormack and J. Feinberg, "Dancing Domains," (Marmot Productions, Los Angeles, 1996).
5. V. Dominic and J. Feinberg, "Shape Of The Dc Electric Field Induced By Intense Light In Glass," VHS video (Marmot Productions, Los Angeles, 1993)
4. R. S. Cudney, R. M. Pierce, and J. Feinberg, "Nonlinear Optical Microscope (Dancing Bugs)," VHS video (Marmot Productions, Los Angeles, 1988).
3. D. Z. Anderson, D. Lininger, and J. Feinberg, "Optical Tracking Novelty Filter," VHS video (Boulder, 1987).
2. J. Feinberg, "Dancing Modes," 16mm color film (Marmot Productions, Los Angeles, 1986).
1. J. Feinberg and K. Thiel, "Laser with a Phase Conjugating Mirror," 16mm color film (Marmot Productions, Los Angeles, 1981).

## CURRENT AND PAST GRADUATE STUDENTS

H. Aydin  
 S. C. de la Cruz  
 G. D. Bacher  
 R. Cudney  
 S. P. Ducharme  
 V. Dominic  
 V. Grubsky  
 J. P. Jiang  
 M. Loebel  
 P. Lambelet (post doc)  
 S. MacCormack (post doc)  
 K. R. MacDonald  
 D. Mahgerefteh  
 D. Noraev  
 R. M. Pierce (post doc)  
 E. Salik  
 A. Skorucak  
 D. S. Starodubov (post doc)  
 X. S. Yao

## CONFERENCES

152. Invited talk, "Self-pumped Phase Conjugation and Laser Resonator Cavities" at the conference of Photorefractive Materials, Effects and Applications: Light in Nonlinear Structured Materials, in Ensenada, Mexico, Oct 13 – 15, 2011.
151. Contributed talk, "A Tunable Dispersion Compensator with Fixed Bandwidth for WDM Systems Using a Uniform FBG," Y.W. Song, D. Starodubov, Z. Pan, Y. Xie, A. E. Willner, and J. Feinberg, Conference on Lasers and Electro-Optics (CLEO), paper CThO1, Baltimore, MD, May 2001 (Optical Society of America, Wash., D.C., 2001).
150. Contributed talk, "Performance Optimization of Chirped Return-to-Zero Format in 10-Gb/s Terrestrial Transmission Systems," L. Yan, Y. Xie, Q. Yu, A. E. Willner, D. S. Starodubov, and J. Feinberg, Conference on Optical Fiber Communications '01, paper MF1, Anaheim, CA, March 2001 (Optical Society of America, Washington, D.C., 2001).
149. Contributed talk, "Chromatic Dispersion Monitoring and Automated Compensation for NRZ and RZ Data using Clock Regeneration and Fading Without Adding Signaling," Z. Pan, Q. Yu, Y. Xie, S.A. Havstad, A.E. Willner, D.S. Starodubov, and J. Feinberg, Conference on Optical Fiber Communications '01, paper WH5, Anaheim, CA, March 2001 (Optical Society of America, Washington, D.C., 2001).
148. Contributed talk, "A Single-Mode Erbium-Doped Fiber Ring Laser with 40-nm Tuning Range using a Stretchable FBG," Y.W. Song, S.A. Havstad, D. Starodubov, Y. Xie, A.E. Willner, and J. Feinberg, OSA Optical Amplifiers Meeting, paper OTuD5, Quebec City (Optical Society of America, Washington, D.C., 2000).
147. Contributed talk, "Spectrally-Efficient L-C Band EDFA Having a Continuous Inter-Band Channel Region Using Sampled FBGs," Y. Xie, Z. Pan, A.E. Willner, E. Salik, V. Grubsky, D. Starodubov, and J. Feinberg, Conference on Lasers and Electro-Optics (CLEO), paper CWJ4, San Francisco, May 2000 (Optical Society of America, Wash., D.C., 2000).
146. Contributed talk, "Efficient WDM Optical Crossconnect using Widely-Tunable FBGs," Y.W. Song, Z. Pan, D. Starodubov, V. Grubsky, E. Salik, S.A. Havstad, Y. Xie, A. E. Willner, and J. Feinberg, Conference on Lasers and Electro-Optics (CLEO), paper CWD6, San Francisco, May 2000 (Optical Society of America, Wash., D.C., 2000).
145. Contributed talk, "High-Birefringence Nonlinearly-Chirped Fiber Bragg Grating for Tunable Compensation of Polarization Mode Dispersion," S. Lee, R. Khosravani, J. Peng, and A.E. Willner, V. Grubsky, D.S. Starodubov, and J. Feinberg, Conference on Optical Fiber Communications '99, paper TuS3, San Diego, CA, Feb. 1999 (Optical Society of America, Washington, D.C., 1999).
144. Contributed talk, "Sampled Nonlinearly-Chirped Fiber-Bragg-Grating for the Tunable Dispersion Compensation of Many WDM Channels Simultaneously," J.-X. Cai, K.-M. Feng, A.E. Willner, V. Grubsky, D.S. Starodubov, and J. Feinberg, Conference on

- Optical Fiber Communications '99, paper FA7, San Diego, CA, Feb. 1999 (Optical Society of America, Washington, D.C., 1999).
143. Contributed talk, "Control Monitoring of Routing Bits and Data Packets in WDM Networks Using Wavelength-to-Time Mapping," X. Jiang, M. Cardakli, K.-M. Feng J.-X. Cai, A.E. Willner, V. Grubsky, D.S. Starodubov, and J. Feinberg, Conference on Optical Fiber Communications '99, paper TuJ7, San Diego, CA, Feb. 1999 (Optical Society of America, Washington, D.C., 1999).
  142. Contributed talk, "All-Optical Packet Header Recognition and Switching in a Reconfigurable Network Using Fiber Bragg Gratings for Time-to-Wavelength Mapping and Decoding," M.C. Cardakli, S. Lee, A.E. Willner, V. Grubsky, D. Starodubov, and J. Feinberg, Conference on Optical Fiber Communications '99, paper ThM4, San Diego, CA, Feb. 1999 (Optical Society of America, Washington D.C., 1999).
  141. Contributed talk, "Novel Fiber Amplitude Modulators in Dynamic Channel Power Equalization in WDM Systems," D.S. Starodubov, V. Grubsky, A. Skorucak, J. Feinberg, K.-M. Feng, J.-X. Cai, and A.E. Willner, Conference on Optical Fiber Communications '98, Post-Deadline Session, paper PD-8, San Jose, CA, Feb. 1998 (Optical Society of America, Washington, D.C., 1998).
  140. Contributed talk, "Dynamic Dispersion Compensation in a 10-Gb/s Optical System using a Novel Nonlinearly-Chirped Fiber Bragg Grating," J.-X. Cai, K.-M. Feng, A.E. Willner, V. Grubsky, D.S. Starodubov, and J. Feinberg, Conference on Optical Fiber Communications '98, San Jose, CA, Feb. 1998 (Optical Society of America, Washington, D.C., 1998).
  139. Contributed talk, "Tunable Nonlinearly-Chirped Fiber Bragg Grating for use as a Dispersion Compensator with a Voltage-Controlled Dispersion," K.-M. Feng, V. Grubsky, D.S. Starodubov, J.-X. Cai, A.E. Willner, and J. Feinberg, Conference on Optical Fiber Communications '98, San Jose, CA, Feb. 1998 (Optical Society of America, Washington D.C., 1998).
  138. Invited talk, "Fiber Bragg gratings for diode lasers," at the 1999 Diode Laser Technology Review, Ft. Walton Beach, Florida, May 11-13 (1999)
  137. Invited talk, "Fiber Bragg grating technology," J. Feinberg and D. S. Starodubov, OSA Annual Meeting, Santa Clara, CA Sept 26 - Oct 1 (1999)
  136. Contributed talk, "Long-period grating fiber sensor with fixed resonance wavelength," V. Grubsky and J. Feinberg, OSA Topical Meeting on Bragg Gratings, Photosensitivity, and Poling in Glass Waveguides, Stuart Florida, September 23-25 (1999).
  135. Contributed talk, "Novel fiber radiation sensor using long-period gratings," A. Skorucak, D. S. Starodubov, and J. Feinberg, OSA Topical Meeting on Bragg Gratings, Photosensitivity, and Poling in Glass Waveguides, Stuart Florida, September 23-25 (1999).

134. Contributed talk, "The role of oxygen deficient centers in hydrogen-loaded germanosilicate glass," D. S. Starodubov, V. Grubsky, M. Ewart, J. Feinberg, E. M. Dianov, A. A. Rybaltovskii, and A. O. Rybaltovskii, OSA Topical Meeting on Bragg Gratings, Photosensitivity, and Poling in Glass Waveguides, Stuart Florida, September 23- 25 (1999).
133. Invited talk, "Ultrastrong fiber gratings and their applications," D. S. Starodubov, V. Grubsky, and J. Feinberg, Proceeding of the SPIE Meeting on Optical Fiber Reliability and Testing, Boston, Massachusetts, September 20-21 (1999).
132. Contributed talk, "Picosecond pulse generation at two wavelengths by simultaneous active mode locking in an Er-doped fiber laser with wide-bandwidth ( $>1$  nm) nonchirped fiber Bragg gratings," O. Deparis, R. Kiyon, E. Salik, D. S. Starodubov, J. Feinberg, O. Pottiez, P. Megret, and M. Blondel, SPIE Meeting on Optical Devices for Fiber Communication, Boston, Massachusetts, September 20-21 (1999).
131. Contributed talk, "Optical fiber gratings: New fabrication techniques and components," D. S. Starodubov, V. Grubsky, and J. Feinberg, LEOS Summer Topical Meeting on WDM Components, San Diego, CA, July 26-30 (1999).
130. Contributed talk, "Fabrication of spectrally clean, long-period grating filters," V. Grubsky, A. Skorucak, J. Feinberg, and D. S. Starodubov, Optical Fiber Communication Conference OFC'99, San Diego, California February 21-26 (1999).
129. Contributed talk, "Sampled nonlinearly chirped fiber Bragg grating for the tunable dispersion compensation of many WDM channels simultaneously," J.-X. Cai, K. M. Feng, A. E. Willner, V. Grubsky, D. S. Starodubov, J. Feinberg, Optical Fiber Communication Conference OFC'99, San Diego, California February 21-26 (1999).
128. Contributed talk, "All-optical packet header recognition and switching in a reconfigurable network using fiber Bragg gratings for time-to-wavelength mapping and decoding," M. C. Cardakli, S. Lee, A. E. Willner, V. Grubsky, D. S. Starodubov, and J. Feinberg, Optical Fiber Communication Conference OFC'99, San Diego, California February 21-26 (1999).
127. Contributed talk, "All-fiber bandpass filter with adjustable transmission," D. S. Starodubov, V. Grubsky, and J. Feinberg, Optical Fiber Communication Conference OFC'99, San Diego, California February 21-26 (1999).
126. Contributed talk, "Thermally stable gratings in optical fibers without temperature annealing," E. Salik, D. S. Starodubov, V. Grubsky, and J. Feinberg, Optical Fiber Communication Conference OFC'99, San Diego, California February 21-26 (1999).
125. Contributed talk, "Effect of molecular water on thermal stability of gratings in hydrogenloaded optical fibers," V. Grubsky, J. Feinberg, and D. S. Starodubov, Optical Fiber Communication Conference OFC'99, San Diego, California February 21-26 (1999).

124. Contributed talk, "High-birefringence nonlinearly-chirped fiber Bragg grating for tunable compensation of polarization-mode dispersion," S. Lee, R. Khosravani, A. E. Willner, V. Grubsky, D. S. Starodubov, J. Feinberg, and J. Peng, Optical Fiber Communication Conference OFC'99, San Diego, California February 21-26 (1999).
123. Contributed talk, "Control monitoring of routing bits and data packets in WDM networks using wavelength-to-time mapping," X. Jiang, M. Carkakli, K. M. Feng, J. X. Cai, A. E. Willner, V. Grubsky, D. S. Starodubov, and J. Feinberg, Optical Fiber Communication Conference OFC'99, San Diego, California February 21-26 (1999).
122. Contributed talk, "All-Fiber bandpass filter using cladding mode coupling," D. S. Starodubov, V. Grubsky, and J. Feinberg, IEEE Lasers and Electro-Optical Society (LEOS'98), Orlando, Florida December 1-2, 1998.
121. Contributed talk, "Fabrication of long-period fiber gratings with no harmonics," V. Grubsky, A. Skorucak, D. S. Starodubov, and J. Feinberg, IEEE Lasers and Electro-Optical Society (LEOS'98), Orlando, Florida December 1-2, 1998.
120. Contributed talk, "Use of one-dimensional photonic crystal sequences as matched filters in fiber-optic CDMA systems," S. Wang, H. Erlig, H. Fetterman, E. Yablonovich, V. Grubsky, D. S. Starodubov, J. Feinberg, Annual Meeting of the Optical Society of America, Baltimore, Maryland, October 4-9 (1998).
119. Invited talk, "Grating fabrication through a polymer jacket," J. Feinberg, D. S. Starodubov, and E. M. Dianov, Annual Meeting of the Optical Society of America, Baltimore, Maryland, October 4-9 (1998).
118. Contributed talk, "Explanation of strong UV-induced index change in hydrogen-loaded germanosilicate fibers," V. Grubsky, D. S. Starodubov, A. Skorucak, and J. Feinberg, Annual Meeting of the Optical Society of America, Baltimore, Maryland, October 4-9 (1998).
117. Contributed talk, "Novel fiber amplitude modulator for dynamic channel power equalization in WDM systems," D. S. Starodubov, V. Grubsky, A. Skorucak, J. Feinberg, J.-X. Cai, K.-M. Feng, and A. E. Willner, Post-Deadline paper at the Optical Fiber Communication Conference OFC'98, San Jose, California February 22-27 (1998).
116. Contributed talk, "Dynamic dispersion compensation in a 10-Gbit/s optical system using a novel nonlinearly chirped fiber Bragg grating," J.-X. Cai, K.-M. Feng, A. E. Willner, V. Grubsky, D. S. Starodubov, and J. Feinberg, Optical Fiber Communication Conference OFC'98, San Jose, California February 22-27 (1998).
115. Contributed talk, "Tunable nonlinearly-chirped fiber Bragg grating for use as a dispersion compensator with a voltage-controlled dispersion," K.-M. Feng, V. Grubsky, D. S. Starodubov, J.-X. Cai, A. E. Willner, and J. Feinberg, Optical Fiber Communication Conference OFC'98, San Jose, California February 22-27 (1998).

114. Contributed talk, "Wide range and linearity of near-UV induced change in hydrogenloaded fibers: applications for Bragg grating formation," V. Grubsky, D. S. Starodubov, and J. Feinberg, in Bragg Gratings, Photosensitivity and Poling in Glass Fibers and Waveguides: Applications and Fundamentals, Williamsburg, Virginia, Oct 26-28, (1997).
113. Contributed talk, "Bragg grating formation in fibers by near-UV light," D. S. Starodubov, V. Grubsky, and J. Feinberg Bragg Gratings, Photosensitivity and Poling in Glass Fibers and Waveguides: Applications and Fundamentals, in Williamsburg, Virginia, Oct 26-28, (1997).
112. Contributed talk, "Mechanisms of index change induced by near-UV light in hydrogenloaded fibers," V. Grubsky, D. S. Starodubov, and J. Feinberg, Bragg Gratings, Photosensitivity and Poling in Glass Fibers and Waveguides: Applications and Fundamentals, in Williamsburg, Virginia, Oct 26-28, 1997.
111. Invited Talk, "Ballistic light imaging with temporal holography," in Current and Emerging Technologies in monitoring brain structures and function, sponsored by the FDA and NIH, March 28-29, (1996).
110. Contributed talk, "Dynamic mapping of 180° domains hidden in a photorefractive crystal," V. Grubsky, S. MacCormack, and J. Feinberg, Conference on Lasers and Electrooptics (CLEO), Anaheim, California, June 2-7, 1996.
109. Invited talk, "Photorefractive Materials," Insititute of Physics Technical Meeting on Nonlinear Optical Materials, Defense Research Agency, Malvern, Great Britain, April 17, 1996.
108. Contributed talk, "Frequency locking of two elements of a laser diode array using mutually pumped phase conjugation," S.-C. De La Cruz, S. MacCormack, P. Lambelet and J. Feinberg, Photorefractive Materials, Effects and Devices, Estes Park, Colorado, June 11- 14, 1995.
107. Contributed talk, "Yet another explanation for why a Cat-conjugator can emit a frequency shifted beam", D. Noraev, P. Lambelet, and J. Feinberg, Photorefractive Materials, Effects and Devices, Estes Park, Colorado, June 11-14, 1995.
106. Contributed talk, "The Swiss-cheese effect," S. MacCormack and J. Feinberg, Photorefractive Materials, Effects and Devices, Estes Park, Colorado, June 11-14, 1995.
105. Invited talk, "Seeing Through Chickens," W.V.T. Rusch Honors Program, USC, Feb. 10, 1995.
104. Invited talk, "Seeing Through Chickens," Loyola Marymount University, Feb. 10, 1995.
103. Invited talk, "Photorefractive Coupling of Multiple Lasers," Nonlinear Optics Conference of the AFOSR at Phillips Labs, Albuquerque, NM April 5, 1994.



102. Contributed talk (with S. MacCormack), "Self-locking of a laser diode bar using off-axis phase conjugation," Conference on Lasers and Electrooptics (CLEO), Anaheim, California, May 8-13, 1994.
101. Invited talk (with V. Dominic), "Frequency Doubling in Glasses," Conference on Lasers and Electrooptics (CLEO), Anaheim, California, May 8-13, 1994.
100. Contributed talk (with S. MacCormack, et al.), "Mutually Pumped Phase Conjugation in Photorefractive Crystals with Partially Coherent Beams," IEEE Conference on Nonlinear Optics, Waikoloa, Hawaii, July 25-29, 1994.
99. Contributed talk (with S. MacCormack, et al.), "Photorefractive Properties Of Rhodium - Doped Barium Titanate," IEEE Conference on Nonlinear Optics, Waikoloa, Hawaii, July 25-29, 1994.
98. Invited talk, "Photorefractive Physics: Locking Lasers, Doubling Light and Seeing through Chickens," Southern California Area Modern Physics Institute, Cal State Polytechnic University, December 11, 1993.
97. Invited talk, "Seeing Through Chickens", Optical Society of America Annual Meeting, October, 1992, Albuquerque, New Mexico.
96. Contributed talk (with V. Dominic) "Spatial Mapping of the DC Electric Field Induced in Optical Fiber Preforms by Intense Light," Optical Society of America Annual Meeting, October, 1992, in Albuquerque, New Mexico. We showed a new movie ("Spatial mode patterns of second harmonic light generated in glass," 6 minutes, © USC-1992).
95. Contributed talk (with V. Dominic), "How The DC Electric Field Photoinduced In Glass Varies With The Polarizations Of The Incident Optical Beams: Theory And Experiment," Conference on Lasers and Electrooptics (CLEO), Anaheim, California, May, 1993.
94. Contributed talk (with S. MacCormack), "High Brightness Output from a Laser Diode Array Coupled to a Self-Pumped Phase Conjugator," Conference on Lasers and Electrooptics (CLEO), Anaheim, California, May, 1993.
93. Contributed talk (with S. MacCormack), "Self-Aligning Injection Locking Of A Laser Diode Array," Conference on Lasers and Electrooptics (CLEO), Anaheim, California, May, 1993.
92. Contributed talk (with S. C. de la Cruz and S. MacCormack), "Effect of Beam Coherence on Mutually-Pumped Phase Conjugators," Conference on Lasers and Electrooptics (CLEO), Anaheim, California, May, 1993.
91. Invited talk, "Gated Holography," 22nd Annual Colloquium on Quantum Electronics, Snowbird, Utah, Jan 5-8, 1992.

90. Invited seminar, "Uses of Photorefractive Phase Conjugators," Institut d'Optique Théorique et Appliquée, Orsay, France, June 10, 1992.
89. Invited talk, "New Applications of Phase Conjugation in Imaging," Nonlinear Optics: Materials, Fundamentals and Applications Second Topical Meeting, Maui, Hawaii, August 17-21, 1992.
88. Invited talk, "Seeing Through Chickens", Optical Society of America Annual Meeting, 1992, Albuquerque, New Mexico.
87. Contributed talk (with V. Dominic) "Spatial mapping of the DC electric field induced in fiber preforms by intense light," Optical Society of America Annual Meeting, 1992, Albuquerque, New Mexico. We showed a new movie ("Spatial mode patterns of second harmonic light generated in glass," 6 minutes, © USC-1992).
86. Invited talk, "Photorefractive nonlinear optics," at the Material Research Society, April 27-May 3, 1991 in Anaheim, California.
85. Contributed talk (with X. S Yao) "Spectral pulse distortion from two-beam coupling of sub-picosecond pulses in a photorefractive crystal," Photorefractive Materials and Devices Topical Meeting, July 29-31, 1991, Beverly, Massachusetts
84. Contributed talk (with R. S. Cudney, G. D. Bacher, R. M. Pierce) "Origins of the photorefractive phase shift," Photorefractive Materials and Devices Topical Meeting, July 29-31, 1991, Beverly, Massachusetts
83. Contributed talk (with R. S. Cudney, R. M. Pierce, G. D. Bacher) "Absorption gratings with multiple levels," Photorefractive Materials and Devices Topical Meeting, July 29-31, 1991, Beverly, Massachusetts
82. Contributed talk (with V. V. Eliseev, A. A. Zozulya, G. D. Bacher) "Why light beams follow curved paths in photorefractive phase conjugators," Photorefractive Materials and Devices Topical Meeting, July 29-31, 1991, Beverly, Massachusetts
81. Seminar speaker at Stanford University, December 3, 1991.
80. Seminar speaker for the Optical Society of America-Ann Arbor, April 23, 1991
79. Invited talk, "Photorefractive nonlinear optics," at the Material Research Society, April 27- May 3, 1991 in Anaheim, California.
78. Invited talk, "Photorefractive materials and devices," at the Nonlinear Optics: Materials, Phenomena, and Devices meeting, July 16-20, 1990 in Kauai, Hawaii.
77. Invited plenary lecture, "Unraveling and using the photorefractive effect," French-Israeli Symposium on Nonlinear Optics, April 22-27, 1990 in Rehovot, Israel.

76. Contributed talk (with R. M. Pierce, R. S. Cudney, and G. D. Bacher), "Absorption gratings in BaTiO<sub>3</sub> crystals," at the Conference on Lasers and Electro-Optics (CLEO), May 21-26, 1990 in Anaheim, California.
75. Contributed talk (with X. S. Yao and V. Dominic), "Optical pulse shaping using a photorefractive crystal," at the Conference on Lasers and Electro-Optics (CLEO), May 21-26, 1990 in Anaheim, California.
74. Contributed talk (with V. Dominic, X. S. Yao, and R. M. Pierce), "Measuring the coherence length of modelocked laser pulses in real time," at the Conference on Lasers and Electro-Optics (CLEO), May 21-26, 1990 in Anaheim, California.
73. Contributed talk (with D. Mahgerefteh), "Shallow traps resolve the Ix mystery in photorefractive BaTiO<sub>3</sub>," at the Conference on Lasers and Electro-Optics (CLEO), May 21-26, 1990 in Anaheim, California.
72. Contributed talk (with R. M. Pierce, R. S. Cudney, G. D. Bacher) "Photorefraction without the electrooptic effect," OSA topical meeting on the Photorefractive Materials, Effects, and Devices, Jan, 1990 in Aussois, France.
71. Contributed Talk (with D. Mahgerefteh), "Shallow traps resolve the Ix mystery in photorefractive BaTiO<sub>3</sub>," OSA topical meeting on the Photorefractive Materials, Effects, and Devices, Jan, 1990 in Aussois, France.
70. Colloquium speaker at IBM Almaden Research Center, November 17, 1989.
69. **Chairman**, Gordon Research Conference on Nonlinear Optics and Lasers, July 24-28, 1989.
68. Colloquium speaker at Sandia National Laboratories, July 31, 1989.
67. Colloquium speaker at Stanford Linear Accelerator Center (SLAC), April 1, 1989.
66. Invited talk "Optical Phase Conjugation," Optcon '88, November 3, 1988, Santa Clara, California.
65. Contributed talk (with D. Mahgerefteh and R. M. Pierce) "On the photovoltaic effect in barium titanate," Optical Society of America Annual Meeting, Oct. 31 - Nov. 4, 1988, Santa Clara, California.
64. Contributed talk (with R. S. Cudney, G. D. Bacher, and R. M. Pierce) "Measuring the photorefractive phase shift using two-beam coupling," Optical Society of America Annual Meeting, Oct. 31 - Nov. 4, 1988, Santa Clara, California.
63. Contributed talk (with G. D. Bacher and R. S. Cudney) "Detecting sub-Angstrom vibration of a rough surface using real-time holography," Optical Society of America Annual Meeting, Oct. 31 - Nov. 4, 1988, Santa Clara, California.

62. Invited talk "Photorefractive Nonlinear Optics," Ontario Laser and Lightwave Research Centre Workshop, September 23, 1988, Toronto, Canada.
61. Invited talk "Transient Detection Microscope," Seventh Annual Symposium on Advances in Microscopy," September 23-25, 1988, Pine Knoll Shores, North Carolina.
60. Invited talk "Applications of Photorefractive Materials," at the Conference on Lasers and Electro-Optics (CLEO) , April 25-28, 1988, Anaheim, California.
59. Contributed talk (with D. Mahgerefteh and R. Pierce) "Effects of shallow traps on the photorefractive properties of BaTiO<sub>3</sub>," Conference on Lasers and Electro-Optics, April 25-28, 1988, Anaheim, California.
58. Contributed talk (with R.S. Cudney and R.M. Pierce) "Transient Detection Microscopy," Conference on Lasers and Electro-Optics, April 25-28, 1988, Anaheim, California.
57. Contributed talk (with D. Mahgerefteh) "Nanosecond response and "coasting" in photorefractive barium titanate," Topical Meeting on Photorefractive Materials, Effects, and Devices, August 12-14, (1987), Los Angeles, California.
56. Invited talk at the Gordon Conference on Lasers and Nonlinear Optics, August, 1987, Wolfeboro, New Hampshire.
55. Invited paper "Optical Phase Conjugation," at the USA-USSR Symposium on Lasers in Condensed Matter, June 1-10, 1987, Leningrad, USSR.
54. Contributed paper (with K. R. MacDonald), "All optical measurement of the photovoltaic Field in barium titanate," Optical Society of America Annual Meeting, October 19-24, 1986, Seattle, Washington.
53. Contributed paper (with S. P. Ducharme), "Electrooptic and Piezoelectric measurements in photorefractive materials," Optical Society of America Annual Meeting, October 19-24, 1986, Seattle, Washington.
52. Contributed paper (with J. P. Jiang,), "Controlling the frequency shift of a self-pumped phase conjugator," Optical Society of America Annual Meeting, October 19-24, 1986, Seattle, Washington.
51. Invited Lecture for summer school "Electrooptic and Photorefractive Materials," July 6-17, 1986, Erice, Sicily.
50. Contributed paper (with M. D. Ewbank and others), "Photorefractive properties of strontium barium niobate," Conference on Lasers and Electro-Optics (CLEO), June 9-13, 1986, San Francisco, California.

49. Invited paper "Phase conjugation and stimulated effects in photorefractive materials," International Quantum Electronics Conference (IQEC), June 9-13, 1986, San Francisco, California.
48. NSF/AFOSR Workshop on Nonlinear Materials, April 28-29, 1986, Annapolis, Maryland.
47. Invited to speak at the U. C. Irvine Undergraduate Physics Conference, "Reversing time with lasers," Irvine, California, April 5, 1986.
46. Colloquium speaker at Physics Department, University of Colorado, Boulder, Colorado, March 13, 1986.
45. Contributed paper, "Phase-conjugation and real-time holography," SPIE meeting on Practical Holography, January 22, 1986, Los Angeles.
44. Co-Chairman of SPIE meeting "Nonlinear Optics and Applications," January 21-22, 1986, Los Angeles, California.
43. (with R. Neurgaonkar) Materials Research Society, Fall Meeting, December 2, 1985, Boston, Massachusetts.
42. (with Ken MacDonald) Optical Society of America Annual Meeting, "Why Does a BaTiO<sub>3</sub> Self-Pumped Phase Conjugator Produce a Frequency-Shifted Output Beam?," October 17, 1985, Washington, DC.
41. Invited paper at Optical Society of America Annual Meeting, "Frequency Shifts and Laser Locking with Phase Conjugation," October 15, 1985, Washington, DC.
40. Invited paper at Gordon Research Conference on Nonlinear Optics and Lasers, in Wolfeboro, New Hampshire, "Phase-Locking Lasers with Phase Conjugation," July 28, - August 2, 1985.
39. Seminar at AFOSR, Bolling AFB, "Optical Phase Conjugation," July 10, 1985.
38. Seminar at the University of California, San Diego, "Almost Reversing Time with Optical Phase Conjugation," July 6, 1985.
37. Invited speaker at SPIE meeting on Holography: Critical Review of Technology, "Techniques and Applications of Real-Time Holography," January 25, 1985, Los Angeles, California.
36. Invited paper at SPIE "Holography: Critical Review of Technology," January 25, 1985.
35. Seminar at USC JSEP review, "Self Pumped Optical Phase Conjugating Laser Resonator Cavities," November 5-6, 1984.

34. Seminar at the Aerospace Corporation, "Passive Optical Phase Conjugation," October 10, 1984.
33. Optical Society of America, Annual Meeting, in San Diego, California, "Time-reversal experiment using a double-phase-conjugate Michelson interferometer," "Control of the density of photorefractive charge carriers in BaTiO<sub>3</sub> single crystals," "Anomalous frequency and phase shifts in self-pumped conjugators," "Self-scanning of a dye laser having a phase-conjugating resonator cavity," October, 1984. Abstracts published in conference proceedings.
32. Seminar at USC/Rockwell International meeting, "The Photorefractive Effect," September 25, 1984.
31. Speaker at the National Science Foundation, Washington, DC., July, 1984.
30. Invited paper at the Conference on Lasers and Electro-Optics (CLEO), Anaheim, California, "Phase Conjugation in Photorefractive Materials," May 7, 1984.
29. Seminar at the USC Industrial Associates Research Review, Los Angeles, California, "Phase Conjugating Coptic," May 7, 1984.
28. Seminar at UC Irvine Undergraduate Physics Conference, Irvine, California, April 7, 1984.
27. Condensed Matter Physics Seminar at USC, "Do I Have a Spontaneously Moving Superlattice in my BaTiO<sub>3</sub> Crystal?," March 9, 1984.
26. Seminar at the USC Joint Services Electronics Program, "Self-Pumped Phase-Conjugating Resonator Cavities," January 27, 1984.
24. Colloquium speaker at IBM Research Laboratory, Yorktown Heights, N.Y., November, 1983.
23. Invited paper and also a short course leader at the Optical Society of America, Annual Meeting, October 1983 in New Orleans, "Optical Information Processing with the Photorefractive Effect," and "Phase Conjugation in Photorefractive Materials."
22. Invited paper at Gordon Research Conference on Nonlinear Optics, in Wolfeboro, New Hampshire, "Theory and Applications of Self-Pumped Phase-Conjugation," August 1-5, 1983.
21. Speaker at Thomson-CSF, Orsay, France. June 17, 1983.
20. Speaker at Laboratorium für Festkörperphysik, Zürich, Switzerland. June 16, 1983.
19. Invited paper at Los Alamos National Laboratory meeting, "New Directions in Phase-Conjugate Optics," February 22-24, 1983.

18. Speaker at Lawrence Livermore National Laboratory, Livermore, California, November 12, 1982.
17. Optical Society of America, Annual Meeting, in Tucson, Arizona; "The photorefractive effect in KTN crystals," and "Self-pumped, continuous-wave, phase-conjugation using internal reflection," October, 1982. Abstract published in conference proceedings.
16. Invited paper at Electro-Optical Systems and Technology meeting, November 5-6, 1981 in Tokyo, Japan.
15. Invited paper at Optical Society of America, Annual Meeting, in Kissimmee, Florida, "Phase-conjugating mirrors with CW gain," October, 1981. Abstract published in J. Opt. Soc. Am. 17, (1981).
14. Invited paper at SPIE meeting in San Diego, California, "Self-correcting laser resonator using a phase conjugating mirror," August, 1981.
13. Invited paper at Gordon Research Conference on Nonlinear Optics, in Wolfeboro, New Hampshire, "Self-oscillating optical structures and optical processing using a photorefractive mirror," August 3-7, 1981.
12. Speaker at IBM Research Labs, San Jose, California. October 2, 1981.
11. Speaker at Air Force Office of Scientific Research, Bolling AFB, Washington, DC. July 31, 1981.
10. Speaker at the National Science Foundation, Washington, DC. July 30, 1981.
9. Speaker at Oak Ridge National Labs, Oak Ridge, Tennessee. July 29, 1981.
8. Lasers '80, New Orleans, Louisiana, "Phase-conjugating mirror with CW gain." December 15-19, 1980. Abstract published in conference proceedings.
7. International Quantum Electronics Conference in Boston, Massachusetts. "Four-wave mixing in photorefractive materials," and "CW phase conjugation of a nonuniformly polarized optical beam." June, 1980.
6. Optical Society of America, Annual Meeting in Rochester, New York, "Four-wave and two-wave mixing: theory and experiments in barium titanate," October, 1979. Abstract published in J. Opt. Soc. Am. 69, 1976 (1979).
5. Invited paper at Gordon Research Conference on Nonlinear Optics and Lasers, in Wolfeboro, New Hampshire, "Four-wave and two-wave mixing; theory and experiments in barium titanate." July 5, 1979.

4. Optical Society of America, Annual Meeting, in San Francisco, California, "CW generation of time-reversed waves in barium titanate," October, 1978. Abstract published in J. Opt. Soc. Am. 68, 1376 (1978).
3. Atomic Physics Seminar at Physics Department, University of California, Berkeley, California, "Continuous four-wave mixing: theory and experiment," October 27, 1978.
2. Astronomical Society of the Pacific, Annual Meeting in Claremont, California, "Laserinduced fluorescence in TiO: lifetimes, collisions, and forbidden transitions," June 20, 1977. Abstract published in Publications of the A.S.P. 89, 616 (1977).
1. Optical Society of America, Annual Meeting in Tucson, Arizona, "Molecular and atomic lifetime measurements," October, 1976. Abstract published in J. Opt. Soc. Am. 66, 1071 (1976).



# APPENDIX B

# **McGraw-Hill Dictionary of Scientific and Technical Terms**

## **Fifth Edition**

**Sybil P. Parker**

Editor in Chief

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On the cover: Photomicrograph of crystals of vitamin B<sub>1</sub>.  
(Dennis Kunkel, University of Hawaii)

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In addition, material has been drawn from the following references: R. E. Huschke, *Glossary of Meteorology*, American Meteorological Society, 1959; *U.S. Air Force Glossary of Standardized Terms*, AF Manual 11-1, vol. 1, 1972; *Communications-Electronics Terminology*, AF Manual 11-1, vol. 3, 1970; W. H. Allen, ed., *Dictionary of Technical Terms for Aerospace Use*, 1st ed., National Aeronautics and Space Administration, 1965; J. M. Gilliland, *Solar-Terrestrial Physics: A Glossary of Terms and Abbreviations*, Royal Aircraft Establishment Technical Report 67158, 1967; *Glossary of Air Traffic Control Terms*, Federal Aviation Agency; *A Glossary of Range Terminology*, White Sands Missile Range, New Mexico, National Bureau of Standards, AD 467-424; *A DOD Glossary of Mapping, Charting and Geodetic Terms*, 1st ed., Department of Defense, 1967; P. W. Thrush, comp. and ed., *A Dictionary of Mining, Mineral, and Related Terms*, Bureau of Mines, 1968; *Nuclear Terms: A Glossary*, 2d ed., Atomic Energy Commission; F. Casey, ed., *Compilation of Terms in Information Sciences Technology*, Federal Council for Science and Technology, 1970; *Glossary of Stinfo Terminology*, Office of Aerospace Research, U.S. Air Force, 1963; *Naval Dictionary of Electronic, Technical, and Imperative Terms*, Bureau of Naval Personnel, 1962; *ADP Glossary*, Department of the Navy, NAVSO P-3097.

#### McGRAW-HILL DICTIONARY OF SCIENTIFIC AND TECHNICAL TERMS, Fifth Edition

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signals suitable for driving a home television receiver. { 'vid-ē-ō ,plā-ər }

**video recorder** [ELECTR] A magnetic tape recorder capable of storing the video signals for a television program and feeding them back later to a television transmitter or directly to a receiver. { 'vid-ē-ō rī ,kōrd-ər }

**video replay** [ELECTR] Also known as videotape replay. 1. A procedure in which the audio and video signals of a television program are recorded on magnetic tape and then the tape is run through equipment later to rebroadcast the live scene. 2. A similar procedure in which the scene is rebroadcast almost immediately after it occurs. Also known as instant replay. { 'vid-ē-ō 'rē ,plā }

**video sensing** [COMPUT SCI] In optical character recognition, a scanning technique in which the document is flooded with light from an ordinary light source, and the image of the character is reflected onto the face of a cathode-ray tube, where it is scanned by an electron beam. { 'vid-ē-ō 'sens-ŋ }

**video signal** [COMMUN] In television, the signal containing all of the visual information together with blanking and synchronizing pulses. [ELECTROMAG] See target signal. { 'vid-ē-ō ,sīgnəl }

**videotape** [ELECTR] A magnetic tape designed primarily for recording of television programs. { 'vid-ē-ō ,tāp }

**videotape recorder** [ELECTR] A device for video recording and playing of a magnetic tape either in a video cassette or on an open reel. { 'vid-ē-ō ,tāp rī ,kōrd-ər }

**videotape recording** [ELECTR] A method of recording television programs on magnetic tape for later rebroadcasting or replay. Abbreviated VTR. { 'vid-ē-ō ,tāp rī ,kōrd-ŋ }

**videotape replay** See video replay. { 'vid-ē-ō ,tāp 'rē ,plā }

**video telephone** [COMMUN] A communication instrument which transmits visual images along with the attendant speech. Also known as videophone. { 'vid-ē-ō 'tel-ə ,fōn }

**videotex** [COMMUN] An electronic home information delivery system, either teletext or videotext. { 'vid-ē-ō ,teks }

**videotext** [COMMUN] A computer communication service which uses information from a database, and which allows the user, equipped with a limited computer terminal, to interact with the service in selecting information to be displayed, so as to provide electronic mail, teleshopping, financial services, calculation services, and such. { 'vid-ē-ō ,tekst }

**video transformer** [ELECTR] A transformer designed to transfer, from one circuit to another, the signals containing picture information in television. { 'vid-ē-ō ,tranz'fōrm-ər }

**video transmitter** See visual transmitter. { 'vid-ē-ō ,tranz'mīd-ər }

**vidicon** [ELECTR] A camera tube in which a charge-density pattern is formed by photoconduction and stored on a photoconductor surface that is scanned by an electron beam, usually of low-velocity electrons; used chiefly in industrial television cameras. { 'vid-ə ,kän }

**Vienna definition language** [COMPUT SCI] A language for defining the syntax and semantics of programming languages; consists of a syntactic metalanguage for defining the syntax of programming and data structures, and a semantic metalanguage which specifies programming language semantics operationally in terms of the computations to which programs give rise during execution. { vē'en-ə ,def-ə'nish-ən ,lāŋ ,gwij }

**view camera** [OPTICS] A camera that can be focused at both front and back, with adjustments for tilts, swings, shifts, and rise and fall, to control the shape of the subject in the image; it has a groundglass on the back which enables the photographer to view the image to be recorded. { 'vyü ,kamrə }

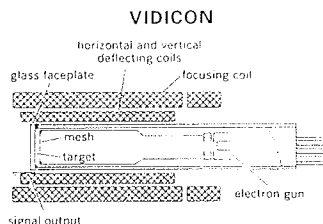
**viewdata** [COMMUN] Alphanumeric characters or graphics which are produced on a home television screen by a special decoder in response to digital signals sent over a telephone line. { 'vyü ,dad-ə }

**viewfinder** [ELECTR] An auxiliary optical or electronic device attached to a television camera so the operator can see the scene as the camera sees it. [OPTICS] A device which provides the user of a camera with the view of the subject that is focused by the lens. { 'vyü ,fīnd-ər }

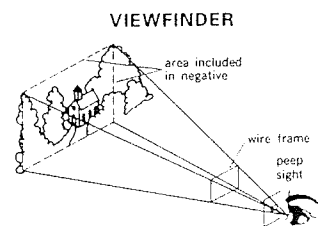
**viewing screen** See screen. { 'vyü-ŋ ,skrēn }

**viewing storage tube** See direct-view storage tube. { 'vyü-ŋ 'stōr-ij ,tüb }

**viewing time** [ELECTR] Time during which a storage tube is presenting a visible output corresponding to the stored information. { 'vyü-ŋ ,tīm }



Cross section of vidicon tube and its associated deflection and focusing coils. Target consists of transparent signal electrode deposited on faceplate of tube and thin layer of photoconductive material deposited over electrode. Mesh ensures uniform deceleration and collimation of electron beam.



Frame or peep-sight finder, the simplest type of viewfinder. (Illustration provided by Eastman Kodak Co., from Willard D. Morgan, ed., *The Complete Photographer*, National Educational Alliance, 1941-1943)

**viewport** See window. { 'vyü ,pōrt }

**view printer** [GRAPHICS] In microfilm technology, a printer with built-in facilities to expose and process enlargements. { 'vyü ,prīnt-ər }

**vigia** [NAV] 1. A rock or shoal whose existence or position is doubtful. 2. A warning note of a vigia condition on a coast. { vā'hē-ə }

**vignette** [GRAPHICS] To lighten the edges of a photograph or a halftone illustration so it gradually disappears into the surrounding white of the paper, leaving no sharp edge. { vīn-ig-nēt } [OPTICS] Reduction in intensity of illumination near the edges of an optical instrument's field of view caused by obstruction of light rays by the edge of the aperture. { vīn'yed-ŋ }

**vigoureux printing** [TEXT] Printing worsted fibers by spinning in order to achieve a mixture of light and dark spots in the finished fabric. { 'vē-gə ,rū ,prīnt-ŋ }

**Vigreux column** [ANALY CHEM] An obsolete apparatus used in laboratory fractional distillation; it is a long glass tube with indentation in its walls; a thermometer is placed at the top of the tube and a side arm is attached to a condenser. { vē'grō ,kōl-əm }

**Villari effect** [PHYS] A change of magnetic induction of a ferromagnetic substance in a magnetic field when the substance is subjected to mechanical stress. { vā'lār-ē ,ī ,fekt }

**Villari reversal** [PHYS] A change in the sign of the Villari effect which occurs with some ferromagnetic materials when the magnetic field strength reaches a certain value. { vā'rī ,vərsəl }

**villiaumite** [MINERAL] NaF A carmine, isometric mineral consisting of sodium fluoride; occurs in massive form. { vē'yō ,mīt }

**villous adenoma** [MED] A slow-growing, potentially malignant neoplasm of the mucosa of the rectum; manifests itself as bleeding and mucoid diarrhea. { 'vil-əs ,ad-ən-ō'mə }

**villous placenta** See epitheliochorial placenta. { 'plā'sen-tə }

**villous tenosynovitis** [MED] A chronic inflammatory condition of a tendon sheath producing hypertrophy of the lining, the formation of redundant folds and villi. { 'vil-əs ,ten-ə'sīn-əv-īt-əs }

**villus** [ANAT] A fingerlike projection from the surface of a membrane. { 'vil-əs }

**vinal** [TEXT] Any manufactured fiber made of a long-chain synthetic polymer composed of at least 50% by weight of alcohol units, with the total of the vinyl alcohol units and vinyl acetate units being at least 85% by weight of the fiber. { vīn-əl }

**vinasse** [MATER] Residue from the fermentation of molasses or grapes; used as a fertilizer and a source of potassium. Also known as schlempe. { vā'nās }

**vinblastine** [PHARM] C<sub>46</sub>H<sub>58</sub>O<sub>9</sub>N<sub>4</sub> An alkaloid obtained from the periwinkle plant (*Vinca rosea*) and used, as the sodium salt, as an antineoplastic drug. { vīn'blā ,stēn }

**Vincent's angina** See Vincent's infection. { 'vīn-səns ,'āŋ-jī-nə }

**Vincent's infection** [MED] A noncontagious bacterial infection of the oral mucosa characterized by ulceration and formation of a gray pseudomembrane; caused by certain fusiform bacteria and spirochetes; formerly known as Vincent's angina. Also known as fusospirochetosis; Plaut-Vincent's infection; trench mouth; ulcerative gingivitis. { 'vīn-səns ,īn ,fek-sh-ən }

**vincristine** [PHARM] C<sub>46</sub>H<sub>56</sub>O<sub>10</sub>N<sub>4</sub> An alkaloid extracted from the periwinkle plant (*Vinca rosea*) and used, as the sodium salt, as an antineoplastic drug. Also known as leurocristine. { vīn'krī ,stēn }

**Vindobonian** [GEOL] A European stage of geologic time, middle Miocene. { ,vīn-də'bō-nē-ən }

**vine** [BOT] A plant having a stem that is too flexible or too weak to support itself. { vīn }

**vinegar** [MATER] The product of the incomplete oxidation of acetic acid of ethyl alcohol produced by a primary fermentation of vegetable materials; contains not less than 4 grams of acetic acid per gallon; used in preparation of pickled fruits and vegetables and in salad dressing. { 'vīn-ə-gər }

**vinegar bacteria** See Acetobacter. { 'vīn-ə-gər bak,tīr-ē-ŋ }  
**vinegar eel** [INV ZOO] *Turbatrix aceti*. A very small nematode often found in large numbers in vinegar fermentations. Also known as vinegar worm. { 'vīn-ə-gər ,ēl }