US000001370H

United States Statutory Invention Registration [19]

[11] **Reg. Number:** **H1370**

Wolch et al.

[43] **Published:** **Nov. 1, 1994**

[54] **INTERFEROMETRIC VIBRATION AND THERMAL EXPANSION COMPENSATOR**

[75] Inventors: **John D. Wolch,** Versailles; **William J. Stachnik,** Griswold, both of Conn.

[73] Assignee: **The United States of America as represented by the Secretary of the Navy,** Washington, D.C.

[21] Appl. No.: **691,071**

[22] Filed: **Apr. 15, 1991**

[51] **Int. Cl.**^{5} **G01N 21/41**
[52] **U.S. Cl.** **356/361;** 356/130
[58] **Field of Search** 356/361, 130

[56] **References Cited**

U.S. PATENT DOCUMENTS

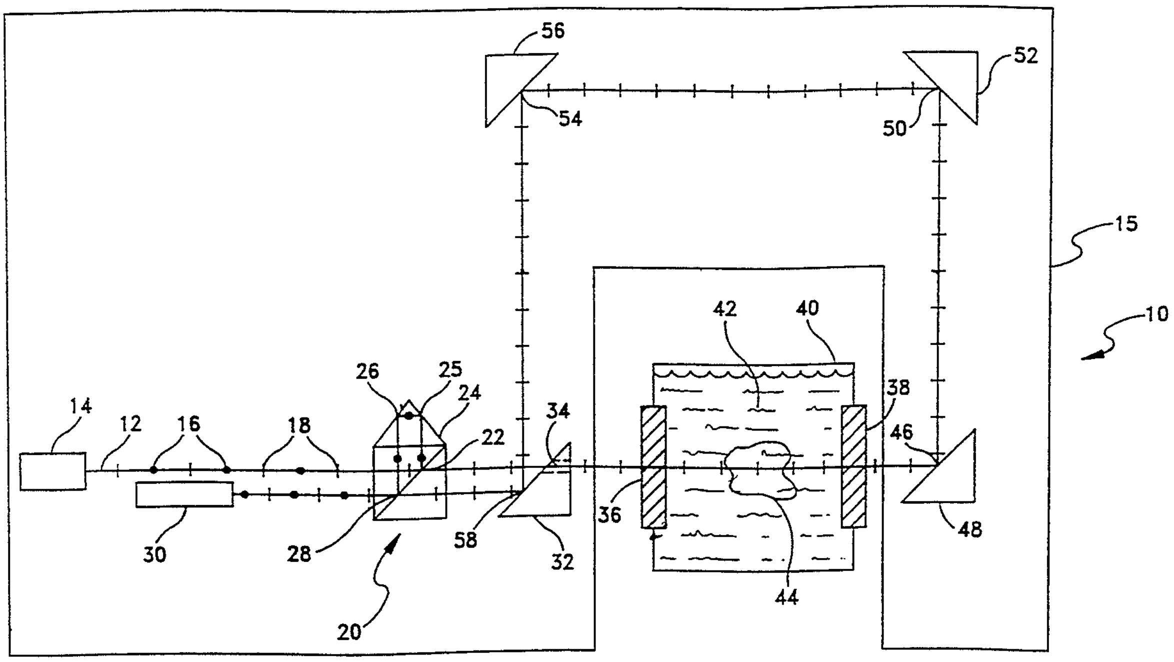
4,640,615 2/1987 Sasaki 356/361

Primary Examiner—Bernarr E. Gregory
Attorney, Agent, or Firm—Michael J. McGowan; Prithvi C. Lall

[57] **ABSTRACT**

A refractive index variability measuring system using a configuration of optical interferometers, mirrors, windows and receivers is desirable. The system provides an improved and a distinctive method for vibration and thermal expansion cancellation. Additionally, an improved matching of optical paths by using this system allows for growth of several measurement paths without additional mismatch of measurement and vibration canceling paths.

7 Claims, 5 Drawing Sheets



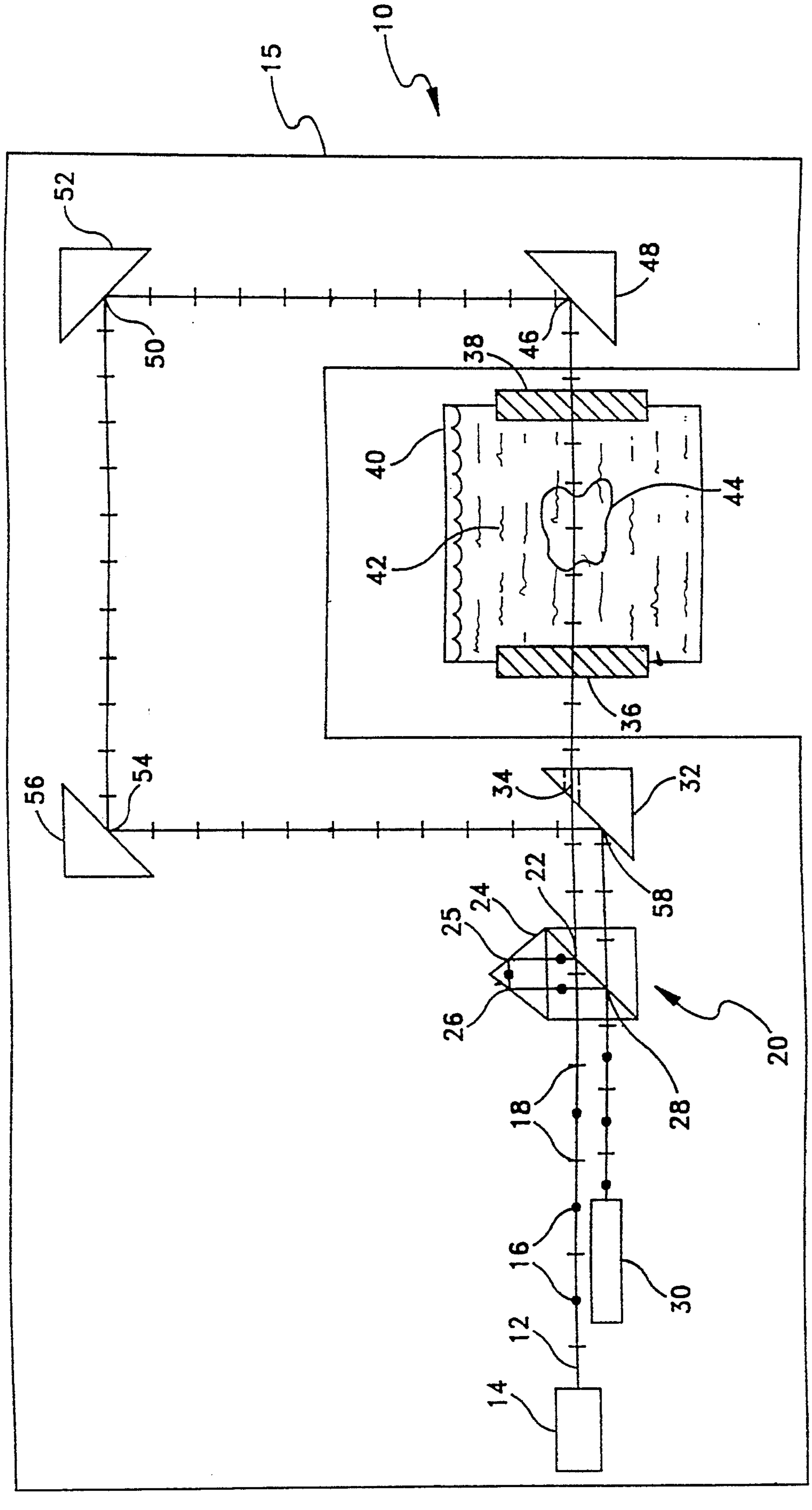

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FIG. 1

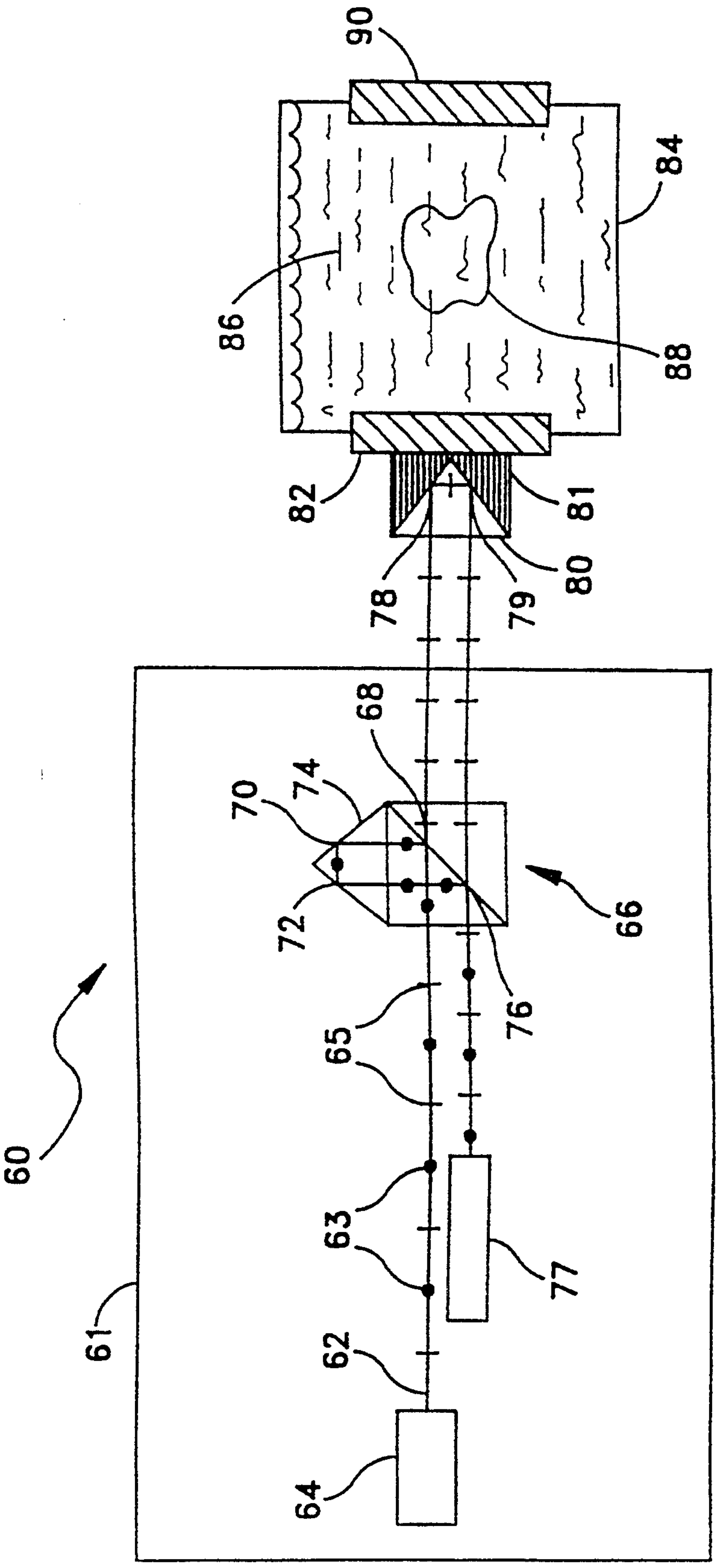

FIG. 2

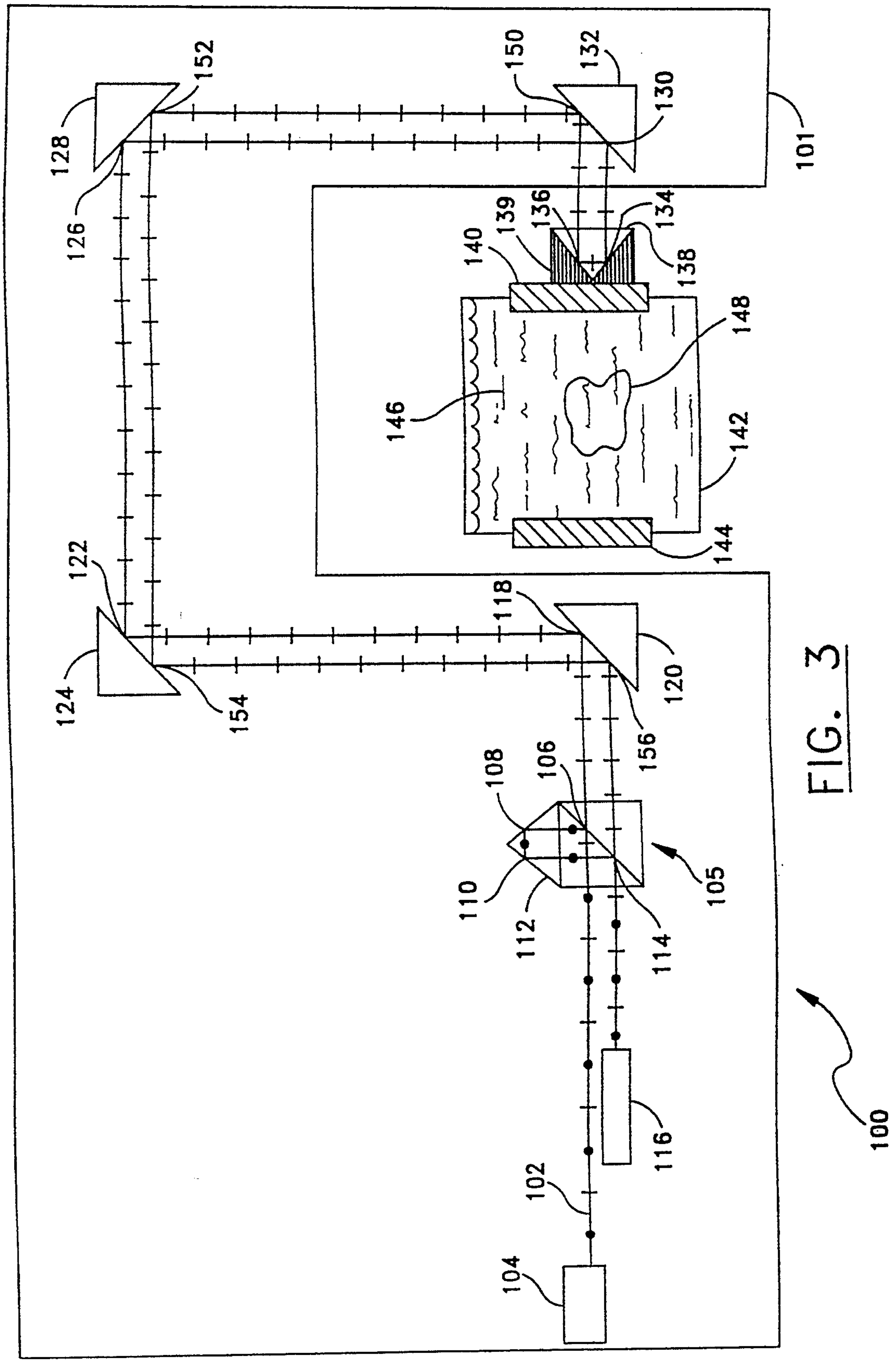
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FIG. 3

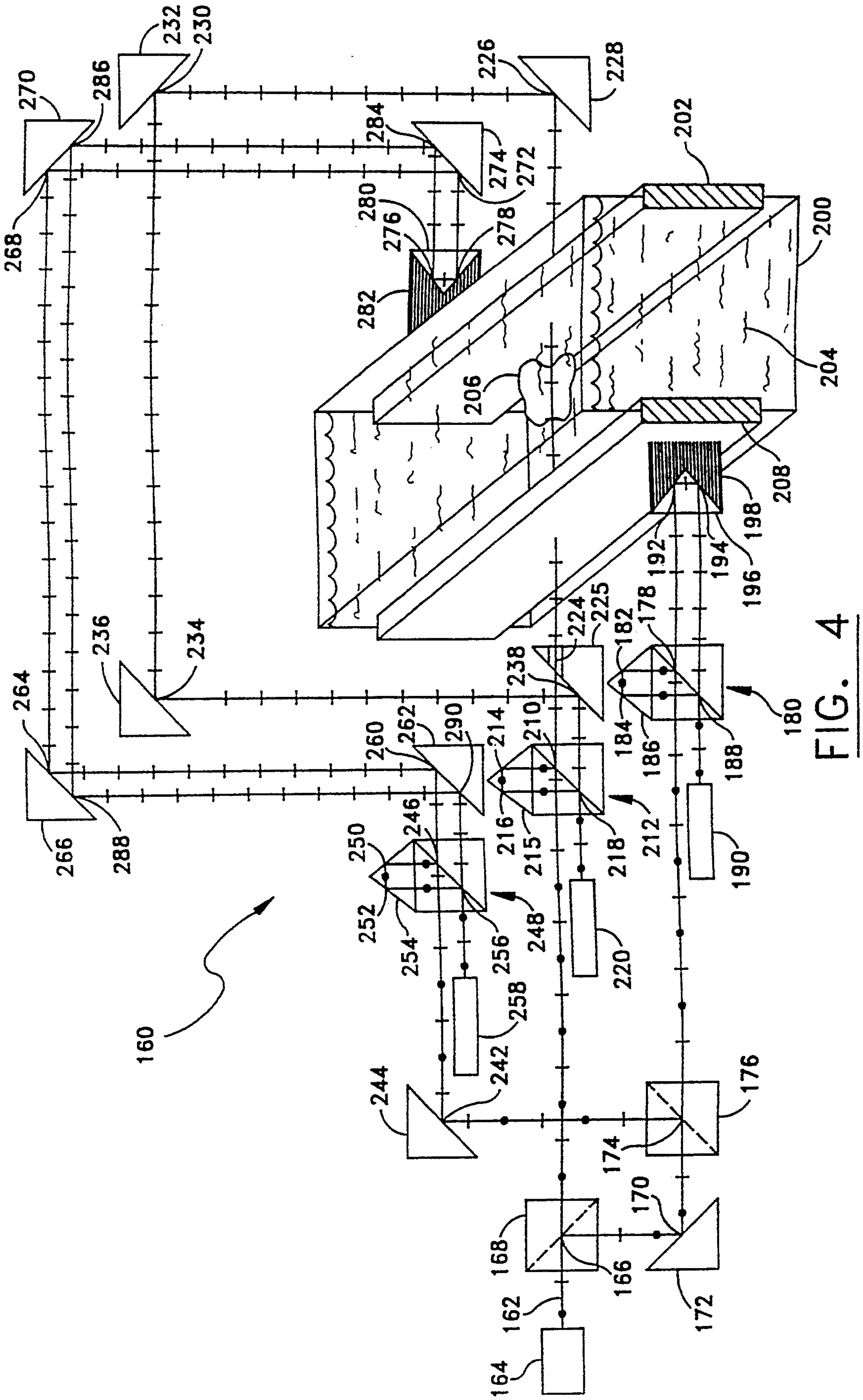
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FIG. 4

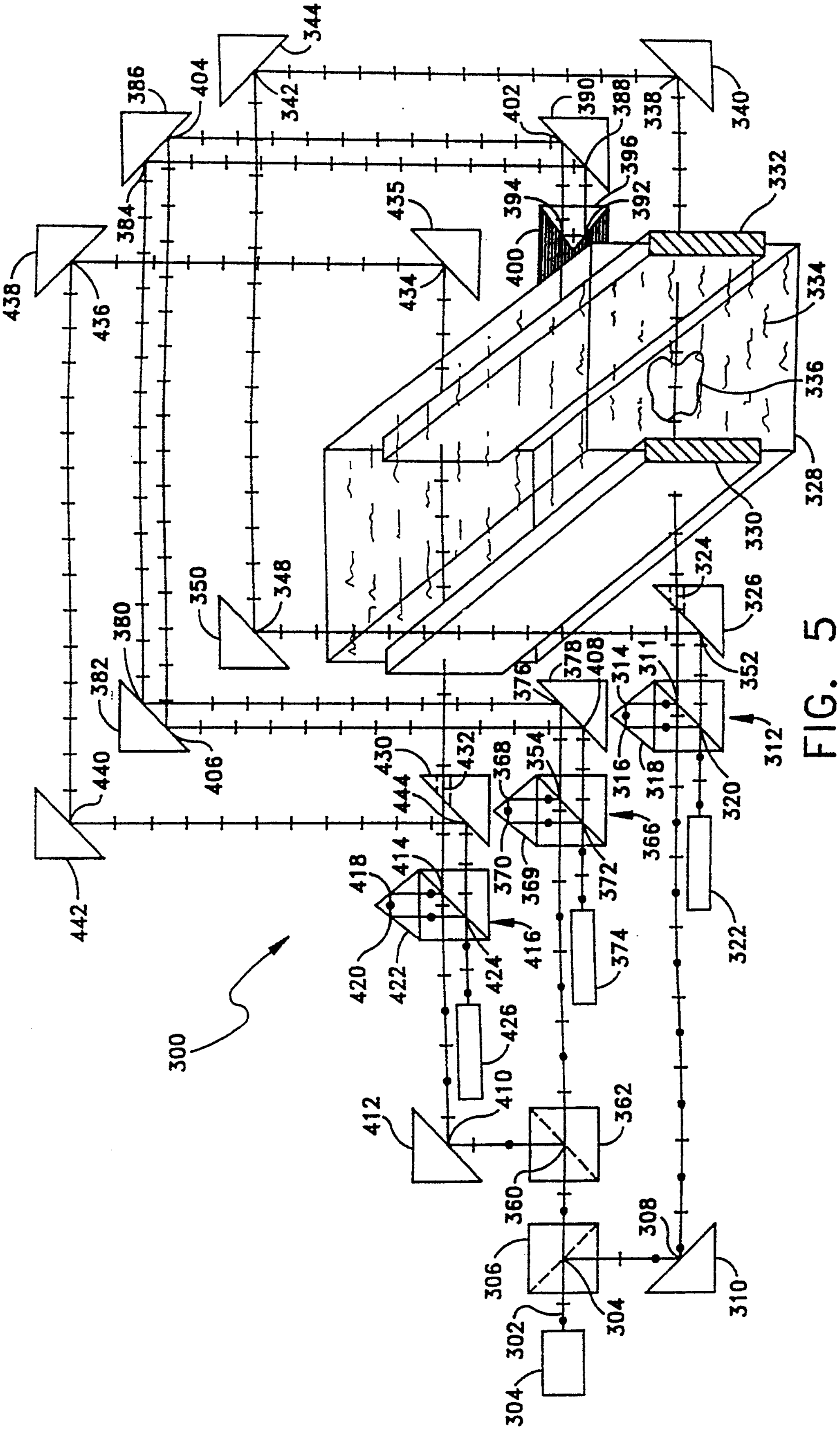
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FIG. 5

INTERFEROMETRIC VIBRATION AND THERMAL EXPANSION COMPENSATOR

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and by or for the Government of the United States of America for Governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

This invention relates to a refractive index variability measuring system and more particularly to a specific configuration which provides an improved method for active structural vibration and thermal expansion cancellation.

(2) Description of the Prior Art

This invention pertains in general to instruments for measurement of refractive index variability in natural waters. Such measurement is necessitated by the existence of refractive index inhomogeneities, or cells of refractive index variability, in the ocean and the like. These cells create acoustical interference phenomena when penetrated by acoustic waves as pointed out by Robert J. Urick in his book: *Principles of Underwater Sound,* 3rd Edition, McGraw-Hill Book Company, 1983 pp. 183–187. Measurements of these cells have applications involving performance of underwater optical systems which rely on the detection of phase changes in communication and imaging systems. General principles for the measurement of refractive index variability for both air and water are known in the field and have heretofore been described in the prior art such as Gibson et al.: "Optical Path Length Fluctuations in the Atmosphere", *Appl. Opt.,* 23,4383–4389 1984; and Buchave et al: "The Measurement of Turbulence with the Laser Doppler Anemometer", *Ann. Rev. Fluid Mech.,* 11,443–503, 1984. The measurement of refractive index fluctuations in air typically involves reflection of two sets of optical beams from plane parallel mirrors, with one set of beams passing through vacuum (thermal expansion and vibration canceling path) and the other set of beams passing through a medium such as air (measurement path). Instruments performing these measurements, are available commercially. For example, the Hewlett-Packard Wavelength Tracker HP1017A, and the measurements of changes in refractive index (dn) attained are described in Zygo Corporation, (Middlefield, Conn. 06455), Application Bulletin, of 22 Dec. 1987, "Optical Wavelength Compensator Description, Installation, and Alignment". Typical applications would be to use such an instrument to make corrections to displacement, velocity or angle measurements caused by fluctuations in the refractive index in the medium.

However, neither the instrumentation nor the methodology for atmospheric measurement of refractive index variability is directly transferable or can be easily modified for use in the ocean. To date differences in size of cells of refractive index variability and diffusion characteristics as well as technical deployment difficulties have hampered attempts to translate instrumentation and methods from the air to a medium such as water. An indirect method presently used is described in "Tow Chain Measurements of Ocean Microstructure", by Stephen A. Mack, J. Phys. *Oceanogra.,* 19,1108–1129, 1989. This method involves chains of microtemperature and microconductivity probes towed through the seawater by a ship. However, indirect methods use approximate equations of state to obtain the refractive index variability leading to inaccuracies, proposals have been made to attempt direct measurements with interferometers that measure optical phase. One such attempt is by Richard C. Honey, "A proposed program to monitor the fine structure and microstructure of the upper layers of the sea", Final Report, Stanford Research Institute Project 1189, Nov. 30, 1971. However, the self noise of the optical devices themselves can create phase changes as well as refractive index variations, with the result that the structural vibrations may dominate the measurements. There is thus a need for canceling the effect of structural vibrations and thermal expansion on measurements of refractive index variability of the medium such as ocean water.

SUMMARY OF THE INVENTION

Accordingly, it is the general purpose and object of the present invention to provide a compensator which corrects for measurements of changes in refractive index of a medium produced by structural vibrations of the measuring device.

Another object of subject invention is to correct measurements of the changes in the refractive index of the medium produced by the thermal expansion of the measuring device.

Still another object of subject invention is to have an optical system which uses a plurality of interferometers to measure accurately changes in the refractive index of the medium.

Yet another object of subject invention is to make a direct measurement of refractive index variability of the medium instead of using an indirect method using approximate equations of state.

These objectives are accomplished with the present invention by providing an interferometric vibration and thermal expansion compensator wherein a light source such as a laser provides two beams of light of two different frequencies and each being polarized in a direction perpendicular to that of the other. The paths of the two beams are so arranged that they are made to interfere in an optical receiver. One of the two optical beams traverses an optical path through the medium experiencing a phase change due to variation of refractive index, structural vibrations and thermal expansions. The polarization of the two optical beams in directions perpendicular to each other is used to filter the two optical beams and they are thus made to travel different optical paths.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the present invention and the attendant advantages therein may be gained from the following specification when read in conjunction with the appended drawings wherein:

FIG. 1 is a block diagram showing an optical path for a vertically polarized optical beam through the optical windows of a water tank and a horizontally polarized optical beam having an optical path internal to the system within a pressure housing.

FIG. 2 shows a vibration canceling optical path which measures vibrations at the window of a water tank, all optical path being internal to the system inside the pressure housing.

FIG. 3 is similar to FIG. 2 where the vibrations are measured at another optical window of the water tank.

FIG. 4 is a block diagram of a device built according to the teachings of subject invention; and

FIG. 5 shows another embodiment of subject invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows a basic Michelson linear interferometer arrangement **10**. The technique to be used in this case involves combining of two optical signals in a heterodyne arrangement. A coherent light beam **12** is obtained from a two frequency laser head **14** which consists of two colinear components; one component with horizontal polarization depicted by solid circles such as **16** and the other with vertical polarization represented by vertical lines such as **18** throughout; each polarized component having a slightly different frequency typically 2–20 megahertz (Mhz). This intermediate frequency is much less than the optical frequency of (5×10^8 Mhz) the laser light. The light beam **12** strikes a polarizing beamsplitter **20** which divides the two polarized optical beams with different orientation of polarizations and different frequencies. At point **22** of beamsplitter **20** the horizontally polarized optical beam (designated by dots **16**) is reflected while the vertically polarized optical beam (designated by vertical lines **18**) is transmitted. The horizontally polarized optical beam is reflected twice at points **25** and **26** of retroreflecting mirror **24** which is attached to the polarizing beamsplitter **20**. The retroreflector (corner cube mirror) **24**, has the property that any beam hitting it will return along a displaced path parallel to the direction of the incident beam. Consequently, the horizontally polarized beam returns to the beamsplitter **20** at point **28** parallel to its incident path but slightly displaced path. It gets reflected at **28** and is received by receiver **30**. The vertically polarized beam, designated by vertical lines **18** is transmitted through a beam reflector **32** through opening or notch **34** therein and is then transmitted through optical windows **36** and **38** of tank **40** filled with the medium **42** (water) and passes through a refractive index variability cell **44**. This beam is then reflected at point **46** of mirror **48**, reflected again at respective points **50** and **54** of right angle reflectors **52** and **56**. This beam then gets reflected at point **58** of mirror **32** and is mixed with the horizontally polarized beam in receiver **30** after being transmitted through beamsplitter **20**. The two optical beams then interfere with one another in receiver **30**. Any changes in the refractive index due to the transmission through the medium (water) of the vertically polarized optical beam are measured from the interference pattern, assuming that there are not structural vibration and thermal expansions in the optical system. It is to be noted that one of the optical beams (horizontally polarized) follows an internal (i.e., an optical path inside a pressure housing **15** in which all optical components are put together) path while the other optical beam (vertically polarized) mostly follows an internal path inside the housing **15** except it goes through the water cell. It is to be noted that the pressure housing in each of the five figures houses all the optical components and is shown by numerals **15**, **61** and **101** in FIGS. **1**, **2** and **3**, respectively. It is left out in FIGS. **4** and **5** to preserve clarity of the figures. It is also to be noted that the pressure housing is pressurized with an inert gas such as nitrogen to preserve the integrity of the optical components by keeping out moisture, etc. Furthermore, the packaging in pressure housing are such that the various interferometers used are very close to one another particularly in FIGS. **4** and **5**. Besides the retroreflector on the optical windows of the water tank are mounted so as to minimize the optical path for the beams outside the pressure housing.

FIG. 2 diagrammatically illustrates a setup which is similar to that of FIG. **1** where the pressure housing is designated by **61**. The objective is to measure the vibrations of optical window **82** as it affects the optical path as the vibrations transferred to the pressure housing. As in FIG. **1**, a coherent optical beam **62** is obtained from a two-frequency laser head **64** with horizontally polarized optical beam component designed by dots **63** and vertically polarized optical beam component designated by vertical lines **65**. The horizontally polarized component is reflected at **68** of beamsplitter **66** and after encountering reflections at **70** and **72** of cube corner mirror **74** is again reflected at point **76** of beamsplitter **66** and is received by receiver **77**. The vertically polarized component of the optical beam is transmitted through beamsplitter **66** and is reflected at points **78** and **79** of the retroreflector **80** which is mounted using mounting means **81** (e.g., as a glue) on optical window **82** which is a part of tank **84** filled with water medium **86** having refractive index variability cells such as **88**. The water tank has also another optical window **90**. It should be noted that each of optical receivers **30** and **77** includes a photodiode which responds to the sinusoidally changing light intensity. The frequency of the modulation is the difference frequency between the two orthogonally polarized components of the beam. The frequency of the laser light is changing too rapidly for the photodetector to respond so that only the difference frequency is detected. If the retroreflector **80**, moves with respect to the fixed retroreflector **74**, the difference frequency is Doppler shifted so that the modulation sensed by the photodiode in the receiver **77** changes. The change in the difference frequency is directly proportional to the velocity or phase rate of the moving retroreflector **80**. The optical path change is obtained by integrating the velocity over a measurement cycle. This can be done with the use of phase detection electronics well known in the prior art as described in Zygo Axiom 2/20 Laser Measurement System Service Manual SP-0085, Nov. 1988. The optical path change is directly related to the index of refraction and the displacement. The measurements obtained are digitized and stored by a computer. The measurement signals from the optical receivers are combined with a reference signal from the laser head and integrated to obtain phase change information. The measurement process occurs at MHz frequencies so that displacement and refractive index change data is sampled extremely rapidly. The sampling of the adjacent paths is assumed to be nearly simultaneous. The sampling is at a rate such that the dissipation and movement of the refractive index variability cells in the medium during the period between samples is negligible. Time series of the data from each receiver are sampled and stored in computer memory. Spectral analysis of the data from paths internal to the system reveal the frequencies at which structural vibrations are occurring within the instrument. Low frequency effects associated with thermal expansion would also be identified by examination of the time series of the compensating paths.

Calibration of the instrument is accomplished by placing the instrument in a temperature controlled container in which the refractive index effects are made negligible. The structure (pressure vessel) containing the optical components could then be excited by mechanical shakers or by introducing a flow in the container. Iterative combinations of subtracting the vibration canceling paths with appropriate scaling factors from the measurement paths would determine the spectral sensitivity of the apparatus.

After calibration the instrument would be placed in the medium of interest with microtemperature and microconductivity probes along with a current meter near the measurement path. The presence of refractive index variability cells moving through the optical measurement paths would be confirmed by a correlation between adjacent parallel paths.

It must be remembered that the effect to be measured can be quite small, even close to the resolution of the interferometers. This is contrasted with laboratory measurements where the effect of the refractive index variability cells can be made arbitrarily large with respect to other effects. Subject devices provide a means of compensating for the structural vibrations and thermal effects by use of a geometry which permits path matching and at the same time does not disrupt the flow which could break up the refractive index cells.

FIG. **3** shows window vibration cancellation due to the window path which is almost C-shaped. The purpose for this is to match the path internal to the pressure housing of FIG. **1** and at the same time stay away from the measurement path so that the refractive index variability cells are undisturbed. As shown in FIG. **3** a coherent light beam **102** is obtained from a two-frequency laser head **104** and thus having a horizontally polarized beam designated by dots and vertically polarized beam represented by vertical lines as shown in FIGS. **1** and **2**. The optical beam strikes the polarizing beamsplitter **105** at **106** dividing the horizontally and vertically polarized components of the beam. The horizontally polarized component of the beam is divided by the beamsplitter **105** at **106**, then reflected twice at points **108** and **110** of retroreflector **112**, reflected again at **114** of beamsplitter **105** and then goes to receiver **116**. The transmitted vertically polarized component of the beam is reflected at point **118** of right angle mirror **120**, reflected again at point **122** of mirror **124**, then reflected at point **126** of right angle mirror **128**, and reflected again at point **130** of right angle mirror **132**. This vertically polarized component of the beam is then reflected at points **134** and **136** of a retroreflecting mirror **138** which is secured by mounting means **139** to optical window **140** which is part of water tank **142** having also optical window **144**. Tank **142** contains water medium **146** which has refractive index cells such as **148**. The vertically polarized component of the beam reflected twice by the retroreflector **138** returns by way of the four respective right angle mirrors **132**, **128**, **124** and **120** after reflections at respective points **150**, **152**, **154** and **156** and then back to the beamsplitter **105** at **114**, this optical beam changing direction by ninety degrees at each reflection and is then recombined with the horizontally polarized beam in receiver **116**. The right angle mirrors **120**, **124**, **128** and **130** in FIG. **3** must be larger than those in FIG. **1** because the beam must reflect twice at each of these right angle mirrors. They will henceforth be referred to as large right angle mirrors in FIGS. **4** and **5**. The two optical beam components (horizontally and vertically polarized) interfere at the optical receiver **116**. The purpose of the arrangement described in FIG. **3** is to measure the vibrations of the far optical window **140** and the effects due to structural vibrations and thermal effects along the internal path inside the pressure housing. What makes this a difficult problem is that the structure must be stiff to reduce structural vibrations but should not disturb the flow which would break up the refractive index cells.

FIG. **4** shows a refractive index variability instrument that is configured to make very sensitive vibration measurements with a single water measurement path. By subtracting the vibration cancellation paths from the measurement paths it is possible to determine which fluctuations occur only in the water path. Because of the instruments unique geometry we have overcome the problem of canceling vibrations without blocking water flow. As before a two-frequency optical beam **162** is obtained from laser **164** head. Beam **162** strikes at point **166** of a non-polarizing beamsplitter which transmits approximately two thirds of the incident optical power and reflects one third. Both horizontally and vertically polarized components are present in the transmitted and reflected parts after beamsplitter **168**.

The reflected part at point **166** of non-polarizing beamsplitter **168** including both horizontally polarized and vertically polarized components is reflected at point **170** of right angle reflector **172** which then reaches point **174** of a non-polarizing beamsplitter **176**. It should be noted that the non-polarizing beamsplitters **168** and **176** are represented by square blocks with a dashed diagonal line indicating that they are non-polarized beamsplitters while the polarizing beamsplitters will be designated by square blocks each with a solid diagonal line. The transmitted part of the beam at point **174** of beamsplitter **176** includes both the horizontally polarized and vertically polarized components or portions of the optical beam which reaches point **178** of polarizing beamsplitter **180**. The horizontally polarized portion of this optical beam is reflected twice at points **182** and **184** of mirror **186** which is then reflected at point **188** of the beamsplitter **180** and then reaches receiver **190**. The transmitted portion of the optical beam through the beamsplitter **180** is then reflected at points **192** and **194** of reflector or mirror **196** which, using mounting means, **198** is attached to window **208** which is a part of water tank **200** having another optical window **202**. Tank **200** is filled with water **204** having refractive index variability cells such as **206** which provides a path for one of the optical beams as shown. The optical beam reflected at point **194** has only the vertically polarized components. It returns to the beamsplitter **180** and recombines with the horizontally polarized portion of the beam in receiver **190**.

The portion of the optical beam which is transmitted by beamsplitter **168** includes both horizontally polarized and vertically polarized components and falls at point **210** of polarizing beamsplitter **212**. The horizontally polarized portion of this beam is reflected at points **214** and **216** of reflector **215** and reaches point **218** of beamsplitter **212** and after reflection at point **218** is received by receiver **220**. The transmitted portion of the beam falling at point **210** is only vertically polarized and it passes through an opening or notch **224** in reflector **225**. This beam then passes through optical window **208**, refractive index variability cells such as **206** and through the optical window **202** and then falls at point **226** of the right angle reflector **228**. The beam reflected at **226** is then reflected at **230** of reflector **232**, reflected again at **234** of reflector **236**. This beam then falls on reflector **225** at point **238** where it is reflected. It then passes through point **218** of beamsplitter **212** and is recombined with the horizontally polarized beam in receiver **220**.

The optical beam reflected at point **174** of the non-polarizing beamsplitter **176** includes both horizontally polarized and vertically polarized components and is reflected at point **242** of a right angle reflector **244**. This beam then reaches point **246** of polarizing beamsplitter **248**. The horizontally polarized component of this optical beam is reflected at points **250** and **252** of reflector **254** and then after reflection at point **256** of beamsplitter **248** is received by receiver **258**. The transmitted portion of this beam which is only vertically polarized is then reflected at point **260** of right angle mirror **262**, again reflected at point **264** of reflector **266**, is then reflected at point **268** of reflector **270** and is reflected again at point **272** of reflector **274**. The beam reflected at point **272** is then reflected twice at respective points **278** and **276** of retroreflector **280** which is attached to optical window **202** of water tank **200** by using mounting **282**. This beam is then reflected at point **284** of reflector **274**. Thereafter, the beam is reflected at point **286** of reflector **270**, reflected at **288** of reflector **266** and reflected again at point **290** of reflector **262**. The beam then passes through point **256** of the beamsplitter **248** and is then recombined with the horizontally polarized beam in receiver **258**. Since the optical power in the beam decreases exponentially in water, most of the optical power is put through the measurement path in the water medium. In the present case, two thirds of the optical power minus appropriate losses is directed to optical receiver **220** and one sixth the optical power minus appropriate losses to optical receivers **258** and **190**. The three optical receivers **258**, **220** and **190** perform measurements in parallel. The noise effects measured in the optical receivers **258** and **190** are subtracted from optical receiver **220** to obtain the changes in the refractive index in the medium (water). Alternately, two (six interferometers) or more of the configuration shown in FIG. **4** could be sandwiched together in the pressure housing for the purpose of obtaining additional water paths to see if the movement of the refractive cells can be correlated between measurement paths assuming the cells are advected through the measurement region, providing a method of identifying the refractive index structure. This sandwiching arrangement provides a unique way to add additional water paths for correlation studies without degrading the vibration compensation.

An alternate configuration **300** of a refractive index variability instrument that we have invented is shown in FIG. **5**. In this configuration a two-frequency optical beam **302** emitted by laser head **304** with horizontally polarized and vertically components indicated by solid circles or dots and by vertical lines respectively which strike the non-polarizing beamsplitter **306**. At the non-polarizing beamsplitter **306** the reflected beam with one third of the incident laser power and having both horizontally and vertically polarized components strikes at point **308** mirror **310**. This light beam then strikes at point **311** of a polarizing beamsplitter **312** where the horizontally polarized and vertically polarized components are split so that the vertically polarized component is transmitted while the horizontally polarized component is reflected. The vertically polarized component passes is transmitted from the beamsplitter **312** undeviated through a notch **324** cut in a right angle mirror **326** and through an optical window **330**, then into the water medium **334** where it may penetrate refractive index variability cells such as **336**, and back into the pressure housing through the optical window **332**. From the optical window **332** the vertically polarized beam strikes at point **338** of a right angle mirror **340** being deviated by ninety degrees to the left hence striking at **342** of another right angle mirror **344** being again deviated by ninety degrees to the left, getting reflected again at a point **348** of a right a right angle mirror **350** again being deviated by ninety degrees to the left and then striking at point **352** of right angle mirror **326** below the notch **324** and then being deflected to the right and passing through points **320** of the polarizing beamsplitter **312**. The horizontally polarized component which is reflected at point **311** from the beamsplitter **312** then is reflected twice at points **314** and **316** of an attached retroreflecting mirror **318** and is recombined at the polarizing beamsplitter **312** with the vertical polarized component. The two frequency beam from beamsplitter **312** then enters the optical receiver **322** where the two polarized components are allowed to interfere. The signal from this receiver can be used to measured refractive index variability along the measurement path between the optical windows **330** and **332**. The light beam transmitted by non-polarizing beamsplitter **306** which contains two thirds of the incident laser optical power strikes at point **360** of a non-polarizing beamsplitter **362** with transmitted and reflected beams each having one third of the incident laser power. Part of this beam is transmitted by beamsplitter **362** which then strikes at point **354** polarizing beamsplitter **366** where the vertically polarized component is transmitted and the horizontally polarized component is reflected. The vertically polarized component after being transmitted by polarizing beamsplitter **366** strikes at point **376** of a large right angle mirror **378** where the beam is deviated by ninety degrees to the left, then striking at point **380** of another large right angle mirror **382** being again deviated by ninety degrees to the right, then traveling striking at point **384** of another large right angle mirror **386** being deviated ninety degrees to the right, thence to point **388** of another large right angle mirror **390** again being deviated by ninety degrees to the right. From the large right angle mirror **390** the vertically polarized beam gets deflected twice at points **392** and **394** of a retroreflector **396** attached to the optical window **332** by a mounting **400**. After reflected twice at retroreflecting mirror **396** the light beam is then reflected at point **402** of the large right angle mirror **390** being deviated by ninety degrees to the left, then getting reflected to point **404** of large right angle mirror **386** being deviated by ninety degrees to the left, hence again getting reflected to point **406** of the large right angle mirror **382**, again being deviated by ninety degrees to the left hence going again to point **408** of the large right angle mirror **378** being deviated by ninety degrees to the right and to point **372** of the beamsplitter **366**. The horizontally polarized beam reflected at **354** from beamsplitter **366** and is reflected twice at points **368** and **370** of the attached retroreflector **369** and is returned parallel but slightly displaced to point **372** of the polarizing beamsplitter **366**. From the polarizing beamsplitter **366** the recombined horizontally and vertically polarized components of the beam enter the optical receiver **374** where they are allowed to interfere. The interference signal in optical receiver **374** contains information about the vibrations of the far window **332** and the thermal expansion effects and structural vibrations along the path traveled by the horizontally polarized beam. From beamsplitter **362** the reflected beam which has horizontally and vertically polarized components strikes at point **410** the right angle mirror **412** where it is deflected ninety degrees to the right and hence to the point **414** of the polarizing beamsplitter **416**. At the beamsplitter **416**, the horizontally polarized and the vertically polarized components are divided at point **414** with the horizontally polarized component being reflected and the vertically polarized component being transmitted. From the beamsplitter **416** the transmitted vertically polarized component passes undeviated through a notch **432** cut in a right angle mirror **430** hence through an optical window **330** and into a water medium containing refractive index variability cells such as **336** in water tank **328** which has another optical window **332**. The vertically polarized beam reenters the pressure housing through optical window **332**, then strikes at **434** of a right angle mirror **435** being deviated by ninety degrees to the left, thence striking at point **436** of a right angle mirror **438** again being deviated by ninety degrees to the left, thence striking at point **440** of a right angle mirror **442** again being deviated by ninety degrees to the left and striking at point **444** of right angle mirror **430** below the notch **432**, then being deviated by ninety degrees to the right and striking at point **424** of the polarizing beamsplitter **416**. The reflected horizontally polarized beam from the polarizing beamsplitter **416** reflects twice at points **418** and **420** of the attached retroreflector **422** returning by a path parallel but slightly displaced to point **424** of the polarizing beamsplitter **416** where the two beams (horizontally polarized and vertically polarized beam) are recombined. The combined beam from the beamsplitter **416** enters the optical receiver **426** where the interference signal is produced. The signal from the optical receiver **426** contains information about the refractive index variability in a measurement path between the optical windows **330** and **332**.

The primary difference between FIG. **5** and FIG. **4** is that it has two water measurement paths in a three interferometer configuration. This invention would allow more paths to be used to track the movement of the refractive index variability cells for the given number of interferometers. The vibration compensation is somewhat less precise here than in FIG. **4** so that it might be necessary to make the structure containing the optics much more rigid on the near side optical window **330** as opposed to the far side optical windows **332**. As before, various optical beamsplitters and reflectors can be sandwiched together in a pressure housing to obtain additional water measurement paths. Trade offs between available laser power, water clarity, desired sampling rates, and refractive index variability cell size would dictate the optimum configuration.

FIGS. **4** and **5** contain details of the geometry for the embodiments of the invention described. The basic idea is that when light is traveling through a medium with a time changing refractive index (refractive index variability cells flowing through the measurement path), it will undergo changes in wavelength so that the number of light cycles in the optical path changes producing a phase change. Movement of optical components due to vibration and thermal expansion also produce phase changes. The device of subject invention corrects the measurements to more closely obtain the signal due to refractive index effects.

FIG. **4** contains a single measurement path and two vibration/thermal expansion compensating paths. The device in FIG. **4** works by measurements of phase changes in the measurement path. The phase changes contain information about the refractive index changes in the medium and vibration/thermal expansion effects in the pressure housing. The compensation paths contain only information about vibration and thermal expansion effects. A linear combination of the phase changes from the three receivers permits the phase changes due to refractive index changes in the medium to be extracted from unwanted phase changes due to other effects. By including two compensation paths which include mirrors mounted on both optical windows we can obtain a better correction for vibrations of the windows. Once phase changes due to vibration and thermal expansion are removed, the effect remaining is the change in the phase due to the refractive index cells.

As pointed out earlier, the device of FIG. **5** does not measure the vibrations as carefully but provides an additional path in the test medium (water) that can be used to correlate the movement of the refractive index variability cells and confirms that the device measures the advection of the cells with the medium current. FIG. **4** includes at least one internal path which permits identification of the frequency spectrum of effects unrelated to refractive changes in the medium. If the window which does not have an attached retroreflector is sufficiently stiff a linear combination of the compensating path with either measurement path will allow reduction of phase changes due to undesired effects.

The devices described herein could be constructed with commercially available components such as the Axiom 2/20 laser measurement system manufactured by Zygo Corporation or the Hewlett-Packard laser position transducer system HP 5527A with preference to the Axiom 2/20 system. The He-Ne laser head Model 7701 provides a two-frequency beam with an 20 MHz split. The optical power in the laser beam can be divided in $\frac{1}{3}$ and $\frac{2}{3}$ beams by beamsplitter Model 7000 and in $\frac{1}{2}$ and $\frac{1}{2}$ combinations with beamsplitter 7001. The Michelson linear interferometers Model 7002 allow the two frequencies to be split and recombined. The mirrors 7007 and mirrors 7007A with notch permit the beam to be folded by ninety degrees. The large fold mirrors Model 7009 equivalent to that described allow two reflections at each mirror. The retroreflectors used to measure the window vibrations and are equivalent to Model 7003. The optical receivers Model 7080 together with the power supply Model 7045 and Coupler Model 7040 are preferably used to obtain the phase change time series. A computer is required to be used as an instrument control and to store data on disk. A Hewlett-Packard HP 9000 work station with HPIB cable could be used for this purpose.

While we have shown and described certain embodiments of our invention, it is to be understood that it is capable of additional modifications. Changes, therefore, in the construction and arrangement of the basic building blocks can be made without departing from the spirit and scope of the invention as disclosed in the appended claims.

What is claimed is:

1. An interferometric vibration and thermal expansion compensator for a system to study changes in the refractive index of a medium in a test tank full of the medium using a two-frequency orthogonally polarized laser beam having a first horizontally polarized component and a second vertically polarized component, said compensator comprises:

- means for allowing second vertically polarized component of said laser beam to pass through the medium in said tank;
- means for providing different optical paths for the first horizontally polarized component and the second vertically polarized component of said two-frequency and orthogonally polarized laser beam;
- means for recombining the first horizontally polarized component and the second vertically polarized component of said two-frequency and orthogonally polarized laser beam so as to cause interference; and
- means for subtracting the changes in the refractive index measurements resulting from vibration and thermal expansion effects.

2. The compensator of claim **1** wherein the means for allowing the second vertically polarized component of said two-frequency and orthogonally polarized beam to pass through the medium includes at least a pair of optical windows, a first one for the incoming and a second one for outgoing of the vertically polarized component of said laser beam through the medium.

3. The compensator of claim **2** wherein said means for providing different optical paths includes a first beamsplitters-reflectors-receiver arrangement for said two components of said two-frequency and orthogonally polarized laser beam to be allowed to interfere after reflection at the first of said pair of optical windows of the tank.

4. The compensator of claim **3** wherein said means for providing different optical paths includes a second beamsplitters reflectors-receiver arrangement for the two polarized components of said two-frequency, orthogonally polarized laser beam to be allowed to interfere after reflection at the second of said pair of optical windows of the tank.

5. The compensator of claim **4** which includes at least a third beamsplitters-reflectors-receiver arrangement for the two components of said two-frequency orthogonally polarized laser beam to be allowed to interfere after traveling of the two components of said laser beam through the medium in the tank.

6. The compensator of claim **5** wherein said medium is water.

7. The compensator of claim **6** wherein said tank is configured to use ocean water as the medium.

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