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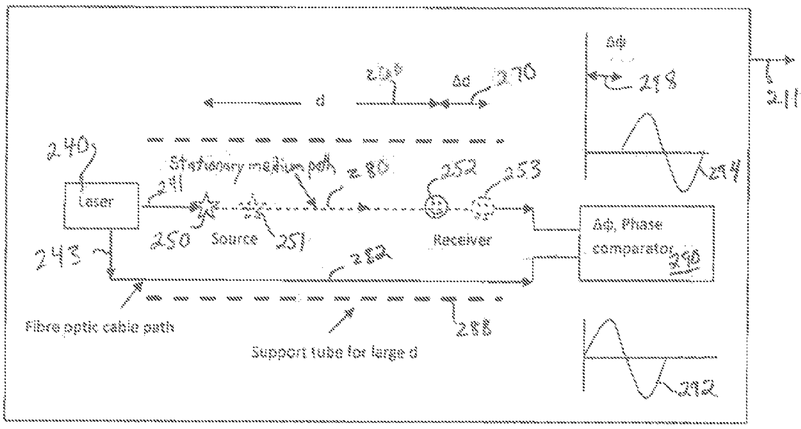

FIG. 4 Measurement System

(57) **Abstract**: An apparatus measures an electromagnetic signal (e.g., light) propagation time delay that varies with system speed relative to its propagation medium. A one-way light propagation time measurement in the medium between two fixed points moving relative to the medium is used. The delay is compared with light propagating in a constant reference path that is independent of motion. A two-way system is also used, as well as increasing sensitivity through a light zigzag and fiber optic coil delay. The apparatus is a compact and extremely sensitive speedometer.

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PROPAGATION MEDIUM VELOCITY MEASUREMENT SYSTEM

FIELD OF THE INVENTION

[0001] The present invention relates generally to measuring the speed of an apparatus on Earth or in outer space. More specifically, the present invention determines a phase difference of light beams in order to calculate speed of the apparatus.

BACKGROUND OF THE INVENTION

[0002] It is self evident that all measured motions require a reference. Although, according to Einstein (1905), there is no preferred reference frame, that is, no propagation medium or "ether" required for comparing (measuring) motion of objects or electromagnetic waves (light). Einstein claimed that only relative motion between systems was important, not motion relative to a propagation medium, without specifying any alternative transmission mechanism in place of the medium (inferring that light does not require a propagation medium). This claim is in direct conflict with the basic electromagnetic (EM) wave theory developed by Maxwell (1865) who established EM wave propagation, predicting the transmission of light based on a since-measured propagation medium. Further, an ether-less Universe is not supported by Lorentz's (1899) motional transform, which is also shown to be based on Maxwell's propagation medium. Techniques concerning measuring motion in space relative to such a medium, however, have been discouraged or believed not possible. Logically (according to these beliefs), if there is no propagation medium, and space is empty, then it should be impossible to measure motion in space.

[0003] The Michelson and Morley Experiment (MMX) (1887) designed to measure the Earth's motion with respect to the propagation medium, was an insensitive method of measuring motion. Even if there were relative motion with respect to the medium, at Earth orbital speeds of 30 km/s (or Mach number $M=v/c=10^{-4}$, where v is the system velocity and c is the speed of light), only a small fraction of an interference fringe (2π radians) would have been measured, and at Earth's rotation speed of 480 m/s ($M \approx 1.5x10^{-6}$) nothing would have been detected. Because the MMX failed to detect the relative motion of the Earth through any propagation medium, this negative result was interpreted as evidence against the existence of a propagation medium. Even if the system had been sensitive enough to detect relative motion, no motion would have been detected, as shown below, because the propagation medium moves with the Earth.

[0004] To establish motion with respect to the medium at practical speeds on Earth, as well as at higher speeds in outer space, a more sensitive measurement system would have been required. The MMX was insensitive because it was based on a second order velocity term (M^2) as explained below. The MMX relied on the difference in the propagation times in each direction in a round trip propagation measurement, where the propagation differences in each direction tended to cancel one another. One of the main reasons why the propagation medium is not readily detectable is that there is no existing dedicated measurement system sensitive enough to detect linear motion relative to the medium.

[0005] It is shown that Sagnac (1913) demonstrated rotary motion relative to the propagation medium. Sagnac split a beam of light into two beams traveling in opposite directions using a beam splitter. The beam splitter is used to measure the propagation delay in and against the direction of rotating mirrors, relative to the propagation medium. Sagnac reflected light, around a loop relative to the Earth's surface, using a rotating square of four mirrors. Figure 1 shows Sagnac's mirror system 10 including a rotating frame 20a and 20b, mirrors 31-34 (mirror 31 being a half-silvered mirror), a radius 42, a side length l 44, and an angular velocity 46. A light source 50 projects a beam of light which is split by mirror 31; both beams travel in opposite directions and end at a detector 55. One light beam propagates in the medium against the mirror motion, counter-clockwise. The other light beam propagates in the medium with the direction of mirror motion, clockwise, through the half-silvered mirror. The mirror system 10 must have caused the shift in interference fringes as a consequence of the different distances that light traveled in the propagation medium (stationary on the Earth's surface) due to the rotation of the mirror system relative to the propagation medium. If there had been no medium, or if the medium rotated with the mirrors, there would have been no effect, no relative motion, and no Propagation Time Asymmetry (PTA).

[0006] In system 10, light passes around the mirrors having a peripheral distance d ($d = 4l$) in a propagation time $t = \pm d/c$ (depending on the light direction), where c is the speed of light at the Earth's surface. If the mirror system rotates with an angular velocity v then the incremental distance travelled in time t (by the spinning mirrors) is $\Delta d = vt = \pm vd/c$.

The incremental prediction equation for the propagation time asymmetry (PTA) is shown below in Equation (1).

$$\Delta t=\Delta d/c=vd/c^2=Mt, \text{ where } M=v/c \ll 1 \qquad (1)$$

[0007] The incremental time Δt between the light beams was measured through interference fringe movement in an interferometer at the detector. By measuring Δt and knowing d and c, the angular velocity of the spinning mirrors at the Earth's surface can be calculated exactly according to Equation (1) and Maxwell's EM wave theory, providing the medium is at rest on the Earth's surface. Although Sagnac demonstrated that his result confirmed the existence of Maxwell's stationary propagation medium, others maintained that the Sagnac effect was consistent with special relativity and that the medium did not exist. This is not possible; unless Maxwell's wave theory, based on a propagation medium, is shown to be in error, which is not the case, as it has been reliably used for over 150 years. Also, any relativistic effects at these mirror speeds are negligible compared to Sagnac's classical PTA effect.

[0008] Recent patents for measuring motion in space are, for example, those of *Wang et al.* (U.S. Patent Nos. 6,813,006 and 7,586,587). In the first patent they proposed to measure motion by measuring the time difference of light passing through two different media. In the second they proposed to measure motion using two beams of interfering light. The resulting interference pattern (standing wave) is used to calculate the system speed. But these patents do not identify any mechanism by which the propagation occurs, *i.e.,* whether it is relative to the Earth's surface, to a vacuum medium or to some other unknown process. A non-preferred reference is not an option in electromagnetic theory; it is not a solution of Maxwell's EM wave equation, it is non-causal (non predictable). If the Earth's surface is assumed to be the reference then the motion will be defined relative to the propagation medium stationary on the Earth's surface. Therefore, it is recognized that improved and consistent techniques for measuring speed in outer space as well as on Earth are desirable.

SUMMARY OF THE INVENTION

[0009] To achieve the foregoing, and in accordance with the purpose of the present invention, a technique for measuring speed is disclosed.

[0010] A system measures a signal (*e.g.*, light) propagation time delay that varies with system speed relative to its propagation medium. This velocity measurement system uses a one-way light propagation time measurement in the medium between two fixed points moving relative to the medium. The delay is compared with light propagating in a constant reference path (*i.e.*, there is no relative motion between the source, transmission path and receiver), independent of motion, by a phase comparator. A two-way system and methods of increasing the sensitivity through a light zigzag and fiber optic coil delay are also described, creating a compact an extremely sensitive speedometer.

[0011] The system can measure motion with respect to the propagation medium moving with the Earth, or can measure motion relative to the propagation medium generally at rest away from gravitational bodies in outer space. The apparatus can determine the velocity of spacecraft, probes, satellites, rockets, *etc*. (even if they are light years from any object). It can also measure a system velocity with respect to the ground without the use of satellites (GPS), by measuring motion relative to the propagation medium stationary on the Earth's surface.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The invention, together with further advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 shows Sagnac's prior art mirror system.

FIG. 2 illustrates a propagation medium-based gravitational entrainment model.

FIG. 3 illustrates a linear velocity measurement system based on the Sagnac effect.

FIG. 4 is a block diagram showing a measurement system with a velocity v.

FIG. 5 is a block diagram showing a two-way measurement system with a velocity v.

FIG. 6A shows a standard measurement system.

FIG. 6B shows the propagation path length being increased in the stationary medium by reflecting the light beam sideways using mirrors.

FIG. 6C shows the propagation path length increased in the stationary medium by passing the light beam through a fiber optic coil.

FIG. 7 is a flow diagram describing one specific embodiment by which the speed of a moving apparatus is measured.

FIG. 8 is a block diagram of two-way measurement system comparing phase directly.

FIG. 9 is a block diagram showing two-way measurement system using a single laser.

FIG. 10 illustrates a source, observer, and bulk material all moving together.

FIG. 11 illustrates a system that uses a zigzag path to increase the distance of the reference path.

FIG. 12 illustrates a system that uses a coil of optical fiber as an invariant reference path.

FIGS. 13A and 13B illustrate a computer system suitable for implementing embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

As mentioned above, the MMX relied on the difference in the propagation times in each direction in a round trip propagation measurement, where the propagation differences in each direction tended to cancel one another. Moreover, the null result obtained by the MMX is now explained by the existence of a boundary layer propagation medium located between the medium moving with the rotating surface of the Earth and the surrounding stationary medium. In other words, the MMX demonstrated that light propagation on or near the surface of the Earth, through a fixed optical system, was unaffected by the Earth's motion through the Universe because the boundary layer rotates with the Earth's surface (on or near the Earth's surface), *i.e.*, there is no relative motion between a measuring optical system on the Earth's surface and the Earth's motion through the Universe.

Propagation Medium

[0013] Others have noted the presence of a propagation medium (historically, the "ether," "aether" or "luminiferous aether"). The medium was established by Maxwell in 1865, and the solution of the EM wave equation (the foundation of all electromagnetic theories) was based on a propagation medium. If the medium did not exist then Maxwell's theory and today's EM theories would be in error, which is not true. Dark Energy and the Higgs Field are both gaining acceptance based on the notion of a propagation medium; further, Maxwell's propagation medium and recent investigations (*Wright*, 2010-2013) have confirmed the medium's existence. Space, it appears, is not uniformly empty (homogeneous) as Einstein claimed. The propagation medium is found to be basically at rest in space, but does move with gravitational bodies (*e.g.*, planets), making EM propagating disturbances (light) predictable (causal). More specifically, it appears that a large gravitational body attracts not only a boundary layer propagation medium rotating with its surface, but also an orbital medium region above the boundary layer having a much larger extent; this orbital region is stationary around and moves with the body in orbit. Whereas Einstein's non-preferred, homogeneous, uniformly empty space, which underestimates the complexity, cannot without a medium describe the situation. A uniformly empty space (no medium) is not a solution of Maxwell's wave equation, it is non-causal, and it cannot be used to predict wave propagation or to distinguish between wave propagation in the various medium motional situations around a gravitational body (*e.g.*, a planet) or in outer space.

[0014] Figure 2 illustrates a propagation medium-based gravitational entrainment model that appears to fit all known data. Shown are propagation medium profiles around a rotating and orbiting planet 120. A boundary layer propagation medium 122 having width w rotates with the planet and is thus stationary with respect to the planet at the planet's surface. Being a boundary layer, there is a gradient from the planet's surface to the outer edge of the layer 122. At the outer edge the boundary layer is stationary with respect to the surrounding medium 124; while the inner edge at the planet's surface is not moving with respect to the planet's surface (it is rotating with the planet's surface). The layer 122 is smoothly graded between the two velocities (*i.e.*, there is no discontinuity). The extent of this boundary layer 122 on Earth is less than about 10km (from the Earth's surface), according to Hafele and Keating's (1972) measurements.

[0015] A propagation medium orbital region 124 is attracted to and orbits with the planet and is thus stationary with respect to the orbiting planet (*i.e.*, it is non-rotating, unlike the lower side of the boundary layer on the planet's rotating surface). This orbital region surrounding the Earth is confirmed further through Saburi *et al.* (1976) satellite communications and GPS (1992) satellite navigation systems operating in this orbital region. The extent of this region appears to be controlled by the planet's gravitational field of dominance (GFOD) in the presence of the Sun's gravitational field of influence. In the Earth's case, the orbital region 124 appears to have an extent of approximately W=50 Earth radii (calculated from the center of the Earth, as illustrated in Figure 2. Further, the predicted symmetry in time slowing of atomic clocks moving relative to the Earth's axis (but not to its rotating surface) according to Hafele and Keating (1972) confirms that the orbital region above an altitude of about 10km is stationary, *i.e.*, it is not rotating with the Earth's surface.

[0016] The orbital region 124 is shown to move relative to a propagation medium 126 surrounding the Sun which is stationary with respect to the Sun and its own gravitational field of dominance. Medium 126, in turn, is moving relative to a propagation medium at rest in outer space (*e.g.*.., space between solar systems and gravitational masses within their galaxy. If the planet rotates it forms a velocity gradient (boundary layer) above the planets' surface.

[0017] Therefore, the MMX (1887) demonstrated that light propagation on the Earth's surface, through a fixed optical system, was unaffected by the Earth's motion through the Universe because the boundary layer propagation medium on the Earth's surface separated the effects of Earth orbital motion through the stationary medium surrounding the Sun from the medium rotating with the Earth's surface. Sagnac (1913) showed that motion of his rotating mirrors, relative to the Earth's surface and stationary medium on the Earth, in and against the light direction, caused Propagation Time Asymmetry (PTA). Michelson and Gale (1925) established that the medium clings to the Earth's surface and moves progressively faster from the poles to the equator. This causes a measured difference in light propagation time (speed) over the same distance, at different latitudes on the Earth's surface, revealing the Earth's rotational speed relative to the surrounding stationary medium.

[0018] These three experiments establish that a boundary layer medium immediately above the Earth's surface exists and separates the Earth's surface from the orbital stationary medium region above (which surrounds and orbits with the Earth at higher altitudes). Again, these effects are based on classical physics; the relativistic effect at these speeds is negligible, unless integrated over a considerable period of time.

[0019] In the absence of gravitational matter, the propagation medium in the Universe appears to be stationary, on average, providing a universal reference for motion. The cosmic microwave background (CMB) detected by Penzias and Wilson (1965), is shown to be EM radiation, propagating uniformly in all directions, throughout the Universe, relative to the propagation medium basically at rest in space. The stationary medium has also been confirmed through the Cosmic Background Explorer COBE (1992). Here, the CMB energy collection increases with system motion relative to the stationary medium, similar to trawling fish nets catching more fish than stationary ones. This model, with the stationary medium surrounding the Earth, is supported by the results from NASA's Gravity Probe B (2011).

[0020] If the Universe is found to be expanding at an appreciable rate, then it is believed the propagation medium will expand with it. Although the exact nature of the propagation medium is not known, it has measurable properties in a vacuum in space. These properties are electrical permeability (inductance or "inertia") $\mu=1.25\text{x}10^{-6}$ N/A^2

and electrical permittivity (capacitance or "stiffness") ę (or ε) = 8.85×10^{-12} F/m, which enables EM waves to propagate or "bounce" through a vacuum medium in space.

[0021] Based on these observations, we have realized that the sensitivity can be increased by many orders of magnitude (e.g., 10^6) compared with the MMX, by measuring the propagation time in one direction only, given by Equation (2) below, or in opposite directions, separately. The proposed method is based on the Sagnac (1913) effect. Referring back to Figure 1, the reason why Sagnac's technique and the prediction equation work, is that it is predicted through a causal solution of Maxwell's EM wave equation based on the propagation medium at rest on the Earth's surface. In other words, Sagnac's rotating mirrors generated a propagation delay (Δd) through motion relative to this propagation medium, thus establishing the medium's presence. There is no other physical explanation to account for this result. If the medium were not present, or rotated with the mirrors, there would be no measured effect.

[0022] Relativistic effects have been offered to explain this motional effect of Sagnac. But, the relativistic explanation is lacking; not only do relativistic effects require a medium, but also these relativistic effects are negligible at the mirror speeds and small integration times compared to the instantaneous classical Propagation Time Asymmetry (PTA) calculated by the prediction Equation (1) above. This is shown in Section 3.5 using equations in Section 8 in a summary paper of the book *Unification of Electromagnetism and Gravity*, by Selwyn E. Wright, published 2014 by Trafford publishing, (included in the U.S. provisional application referenced above) both are hereby incorporated by reference.

[0023] Thus, it can be shown that a propagation medium does exist and that the Sagnac effect is based upon the existence of this medium. Having made this realization, other conclusions and the present invention are possible, including applying the invention to linear motion on and beyond the Earth's surface.

Velocity Measurement System

[0024] Figure 3 illustrates a linear velocity measurement system 100 based on the Sagnac effect and the realization that a propagation medium exists. The technique measures the speed of linear motion, without the need of the rotating mirror system. System 100 has a velocity, v 141, and includes a source 150 and a receiver 155 separated by distance d 160, a path 180 (through a vacuum or air, for example), a fiber optic path 182, and a phase comparator 190. Symbols 151 and 156 illustrate the movement of the system after a given time. Because the system has a velocity, a first light beam emitted from source 150 will actually travel a distance equal to d 160 plus Δd 170 before the light beam reaches the receiver 156. The beam can be split at source 150 and a second beam focused into, and travels via, a fiber optic path 182 directly to the phase comparator; this beam will travel a fixed distance because there is no relative motion on this path. At the comparator, a photo-electric converter (or first and second converters), for example, converts the first light beam and the second light beam, respectively, into electrical signals ready to be compared in the comparator. The second photo-electric converter can be moved directly in contact with the light source, with a metal wire connecting directly to the comparator, so as to eliminate the beam splitter and fiber optic cable. As is known, the comparator is able to measure and detect phase differences between two electrical sinusoidal signals.

[0025] The PTA between the two light beams may then be compared. In other words, a time measurement of the variable propagation distance via path 180 (in the direction of motion, via the propagation medium) is now compared with a fixed (invariant) propagation distance through the fiber optic cable path 182 connected directly between the light source 150 and the comparator 190 (the comparator being capable of comparing time or phase changes). There is no relative motion between the light source, the fiber optic cable and comparator, making this path phase invariant with respect to the speed of the system. It does not matter what the fiber optic cable length is as long as it is constant. We are not comparing exact propagation distances or times, only changes in times through motion. The actual phase difference is not important as long as the phase is constant in the fiber optic path, independent of system motion, which is the case because there is no relative motion in the source-fiber-comparator path; they all move together.

[0026] This one-way propagation time measurement is approximately one million times more sensitive than the round trip propagation used in the MMX. The invention works on the Earth's surface. Furthermore, accepting the propagation medium's presence and its non-homogeneity, allows the invention to measure motion with respect to the medium anywhere in the Universe, *e.g.*, not only on gravitational bodies but also in outer space.

[0027] Figure 4 is a block diagram showing a measurement system 200 having a velocity v, 211. Included is a coherent light source 240, such as a laser, emitting a narrow light beam 241 in the direction of the system motion from a source 250 through a vacuum path 280 (or through an air path on Earth). This first light beam is received at a receiver 252, which may be a photo-electric converter such as a photo cell, photo diode, PIN diode, PIN photodiode or equivalent, converting the light into an electrical signal, which is then transmitted to the comparator 290 through a metal wire. Distance d 260 is a fixed distance between the source and receiver within the system. Delta d 270 is the additional distance that the light beam 241 travels due to the system velocity.

[0028] The light beam is split producing a second beam 243, and a second light path 282 (a reference signal) connects the laser 240 directly through a fiber optic cable to another receiver at the comparator 290. The propagation time through the fiber optic cable will be independent of the system motion because the light source 240, the fiber optic cable and comparator all move together with the system, *i.e.*, there is no relative motion of the fiber optic cable with respect to the system 200. The two electrical outputs from the two receivers are compared at the comparator 290. Graph 292 represents the second light beam via path 282 and graph 294 represents the first light beam via path 280 relative to the second light beam. Shown is a phase difference 298. The two phases of both light beams are compared at the comparator 290 and are used to calculate the system speed v 211 as described below with respect to Figure 7. A support tube 288 may be provided for rigidity and protection for large separation distances d 260. Instead of a beam splitter, a light siphon may be used to siphon the second light beam from the first light beam. The comparator may even measure the phases of the light beams directly from the electrical laser signal without the need of a photo-electric converter.

[0029] In another embodiment, a fiber optic cable is not needed on path 282. The reference signal does not have to be sent down the path 282 as a light beam; it can be an electrical signal. In this embodiment, the laser source is monitored by a photo-electric converter at the light source, which converts the received second light beam into an electrical signal (measuring both the frequency and phase of the source) and transmits the signal directly to the phase comparator 290 through a metal wire (for example) to be compared with the electrical signal from the first light beam. Even thought there will be a very small air gap between the source of the second beam and the photo-electric converter at the light source (which will cause the second light beam to travel an extremely small distance in addition to d), this air gap will introduce a negligible error as long as the gap size is a small fraction of d. For example, if the air gap is 1% of d it will introduce a 1% error in the speed measurement. Further, the converter can be in direct contact with the light source, or its electrical signal derived directly from the light source.

[0030] In yet another embodiment, a mechanism other than a fiber optic cable may be used if the electromagnetic signal is other than a visible beam of light. For example, if the electromagnetic signal uses a microwave source, then path 282 may use metal wire instead of a fiber optic cable. Or, if the electromagnetic signal has a frequency higher than that of visible light (*e.g.*, ultraviolet light), then path 282 may use an optical cable with a UV bandwidth. One of skill in the art will be able to choose the appropriate mechanism for transmitting a suitable electromagnetic signal from source 240 to an appropriate receiver via path 282 in order to ensure that the distance traveled by the electromagnetic signal on path 282 is independent of the velocity of system 200.

[0031] Figure 5 is a block diagram showing a two-way measurement system 300 having a velocity v, 311. Distance d 360 is the distance between sources 350a,b and receivers 352a,b. In this embodiment, two one-way systems, each moving relative to the propagation medium, are shown facing in opposite directions. This arrangement creates phase differences in each direction in the two phase comparators 390a and 390b. The electrical outputs from the two comparators are transmitted via a communication channel 320 (the channel being conducting metal, a fiber optic cable, a wireless signal, *etc.*). A computing device (computer, laptop, handheld device, integrated circuit, analog circuit, *etc.*, not shown in this figure) receives the outputs from both comparators 390a and 390b via channel 320 and may perform the addition or subtraction of the two phase differences, as well as calculate the system speed v 311, as described below.

[0032] The first one-way system includes a laser 340a emitting a light beam from source 350a in the direction of the system motion, through a vacuum path (or air path) 380a. The light beam is received at a receiver 352a. Delta d 370a is the additional distance that the light beam travels because of the system motion. The light beam is split, and a second light path 382a connects the laser 340a directly through a fiber optic cable to the receiver. The output from the receiver (from both beams of light) is input to a phase comparator 390a located at the receiver.

[0033] The second one-way system includes a laser 340b emitting a light beam from source 350b in the opposite direction of the system motion, through a vacuum path (or air path) 380b. The light beam is received at a receiver 352b. Delta d 370b is the distance that the light beam does not have to travel because the beam is moving against the direction of system motion. The light beam is split, and a second light path 382b connects the laser 340b directly through a fiber optic cable to the receiver. The output from the receiver (from both beams of light) is input to a phase comparator 390b located at the receiver.

[0034] To improve sensitivity, or to keep the separation distance d small, the propagation path of the light beam (via the air path or vacuum path in the stationary medium, the variant path) may be increased over the original distance d, as illustrated in Figures 6A, 6B and 6C. The propagation path delay does not have to be in the direction of motion, as long as the resulting delay causes a propagation delay in the propagation medium in the direction of motion. Figure 6A shows a standard measurement system 410. A light beam travels from a source 250 to a receiver 252 via a path 280 through the stationary propagation medium, the source and receiver being separated by a distance d 260. When system 410 has a velocity, the light beam travels an extra Δd, 270.

[0035] Figure 6B illustrates the propagation path length being increased in the stationary medium by reflecting the light beam sideways using mirrors 425 forming a light zigzag path 481, all moving with the system 420 having a velocity v. The source and receiver are still separated by distance d 260. The propagation path length traveled by the light beam from source to receiver is increased over d, not only by the longer zigzag path 481, but also due to the extra movement of the receiver away from the source emission point, through the extra propagation delay (distance traveled in the zigzag), and the velocity of system 420.

[0036] Figure 6C shows the propagation path length increased in the stationary medium by passing the light beam through a fiber optic coil 435, also moving with system 430, for a portion of the propagation path. The light beam travels on a path 482 through the stationary medium (*e.g.*, via air or vacuum) before entering coil 435 and after exiting coil 435. In order to maximize the light transfer from the stationary medium to the fiber coil and from the fiber coil to stationary medium, light focusing devices 437 (lenses or equivalent) may be used, also moving with the system. The propagation path length traveled by the light beam from source to receiver is increased over d, not only by the longer path through the fiber optic coil, but also due to movement of the receiver away from the source emission point because of the velocity of system through the extra propagation delay (time traveled in the fiber optic coil), and the velocity of system 430. The fiber coil may be directly connected to the source as long as there exists an air gap (or vacuum gap) on the detector side, thus causing the light beam to travel farther in the medium when it is traveling in the direction of system motion.

Mode of Operation

[0037] The propagation distance in the propagation medium (whether in a vacuum in space or in an air path on Earth, for example), as illustrated in Figure 4, is d when the system 200 is stationary, *i.e.*, v=0. The propagation distance becomes d +Δd with the system in motion, the light beam moving in the direction of motion, relative to the propagation medium. This propagation distance increase (or decrease) produces a propagation time difference and therefore a phase difference at the phase comparator, compared with the light beam transmitted directly from the laser (source) to the phase comparator (receiver), through the fiber optic cable. Of course, if the system moves in the opposite direction the light beam will travel a distance d - Δd because the light beam is moving against the direction of motion.

[0038] The propagation time t between two stationary fixed points of separation d, is $t=d/c$. If the system moves at velocity v, then the incremental distance travelled by the system in time t' is $\Delta d = vt' = v(d+\Delta d)/c = M(d+\Delta d)$, *i.e.*, $\Delta d = [M/(1-M)]d \approx Md$ for $M = v/c \ll 1$, M is typically 10^{-6} at Earth speeds. The incremental propagation time is then $\Delta t=Mt$, as shown below in Equation (2):

$$\Delta t=\Delta d/c =Md/c=Mt, \text{ and phase change } \Delta\varphi=2\pi f\Delta t, \text{ where } M=v/c \text{ and } t=d/c \qquad (2)$$

[0039] If N is the number of interference fringes (2π phase rotations), f is the frequency and λ the wavelength of the source (e.g., a laser), then Equation (3) shows:

$$N=\Delta\varphi/2\pi= f\Delta t=fvd/c^2=fMd/c=Md/\lambda \qquad (3)$$

[0040] If v=300m/s (670 miles/hour), $c=3x10^8$m/s, $M=10^{-6}$, red laser $\lambda=6x10^{-7}$m, $f=c/\lambda=5x10^{14}$ Hz, distance d=3m, then $N= 10^{-6} x3x6^{-1}x10^7=5$ fringes. Whereas for the Michelson and Morley Experiment (MMX), the round trip propagation time, in and against the direction of motion is t_{MMX}, where α is the Lorentz contraction factor. The incremental propagation time is then $\Delta t \approx M^2 t$, as shown below in Equations (4) and (5):

$$t_{MMX}=\alpha dc^{-1}[\{1/(1-M)\}+\{1/(1+M)\}]=\alpha dc^{-1}2\alpha^{-2}=\alpha^{-1}2d/c\approx(1+M^2/2)(2d/c) \text{ and } \Delta t\approx M^2 t,\ t=d/c \quad (4)$$

$$\text{as } [\{1/(1-M)\}+\{1/(1+M)\}]=2/\alpha^2 \text{ and } \alpha^2=(1-M)(1+M)=(1-M^2) \quad (5)$$

[0041] Then, the number of expected fringes is shown by Equation (6):

$$N=f\Delta t=fM^2d/c=M^2d/\lambda=10^{-12}x3x6^{-1}x10^7=5x10^{-6} \text{ fringes} \quad (6)$$

[0042] In other words, the MMX system, because of the M^2 term (rather than the M term in the present invention), is one million times less sensitive than the present invention at practical speeds. To increase the sensitivity of the present invention further, a dual system can be used, as illustrated in Figure 5. Measuring the individual phase changes separately (both upstream and downstream) and adding their magnitudes increases the sensitivity to motion. The sensitivity can be increased still further, by increasing the propagation medium path length (thus increasing the propagation delay) without increasing the overall dimension d, by inserting a mirror zigzag or a coiled fiber optic cable, also moving with the system, as illustrated in Figures 6A, 6B and 6C.

Specific Embodiments

[0043] Figure 7 is a flow diagram describing one specific embodiment by which the speed of a moving apparatus is measured and is explained in the context of Figure 4, although the invention is not limited to the embodiment of that figure. In general, the system does not measure absolute velocity; it measures velocity relative to the propagation medium, whether the medium is stationary on the Earth's surface or at rest in space. For absolute motion the velocity of the propagation medium relative to absolute space has to be taken into account.

[0044] In a first step 504 light from a laser 240 is transmitted via two different paths from a source 250 to a receiver 252 when the apparatus is at rest with respect to the stationary medium (*e.g.*, with respect to the surface of the Earth). The laser may be split using a conventional beam splitter in order to direct the beam via two different paths, although other techniques such as a light siphoning may also be used to direct the laser beam down the two different paths. As mentioned above, the reference signal may instead use a photoelectric converter at the source to turn the light signal into an electrical signal. Preferably, the two beams are from a common source so if the phase of the source changes it will change in both paths. Further, although a laser is described as the light source, any coherent directional electromagnetic source with a short enough wavelength can be used, such as a microwave source (*e.g.*, a maser). In general, the smaller the wavelength of the electromagnetic source (the higher the frequency), the more accurate the measurement will be. Electromagnetic radiation having frequencies higher than that of visible light (*e.g.*, ultraviolet, x-rays and gamma rays) may also be used in principle.

[0045] The stationary medium path 280 is one of the two paths that the light beam traverses. On this path, there is relative motion (between the measurement system and the propagation medium) when the system is in motion and the light beam will travel a distance longer than d when the laser is shining in the direction of motion of the apparatus. When the apparatus is at rest with respect to the stationary medium (*e.g.*, at rest on the surface of the Earth), then the light beam will travel a distance d on this path. On this path the beam may be traveling through air, vacuum, a partial vacuum, a gas, etc. There will be relative motion between the measurement system and the propagation medium through which the light travels when the system is in motion. Via this path 280, the light beam travels a distance greater than d (when the apparatus is in motion) because of the relative motion.

[0046] By contrast, the second path, path 282, is a path in which the beam of light will always travel a fixed distance, regardless of the velocity of the apparatus. In this example, the beam of light on path 282 travels the entire distance on a fiber optic cable between the laser and the receiver. Because the fiber optic cable is attached to both the laser and the receiver, there is no relative motion as the beam of light travels from the laser to the receiver (*i.e.*, the source, fiber cable, and receiver all travel together). Accordingly, the distance traveled by the light beam (and the time it takes) is independent of the speed of the system and this path may be used as a reference. As mentioned previously, the light source may be converted to an electrical signal on this second path and transmitted in a metal wire directly to the comparator.

[0047] In addition, it is not strictly necessary that a light beam from a laser travel via path 282. Any electromagnetic signal that originates in conjunction with the laser source may be sent via a fixed propagation distance through which the electromagnetic signal can propagate. For example, an electrical signal generated at the laser source may be sent via a copper wire that connects the laser directly to the comparator. In this example, the phase comparator 290 would detect the phase difference between the laser beam arriving via path 280 and photo electric converter and the electrical signal arriving via path 282. Preferably, the signal has a very small wavelength making measurement more accurate. As mentioned above, the electromagnetic signal via path 282 be taken directly from the laser or a small air gap may be used.

[0048] Preferably, the laser via path 280 is shining in the direction of motion of the apparatus, that is, in the direction of velocity 211. Minor variations in the direction of the laser different from the direction of motion will affect the final speed calculation, making it appear as if the apparatus is traveling slower than it actually is. Depending upon the application, this error in the speed calculation may be within a margin of error that is acceptable for the application. In an alternative embodiment, it is contemplated that the laser via path 280 may be shining at a known angle off of the direction of motion of the apparatus. For example, the path from the source to the receiver may be at a 45° angle from the direction of motion. A straightforward mathematical calculation may then be used to adjust for this known angle in order to obtain the correct speed of the apparatus. Shining the laser at a known angle, however, will not result in a final speed calculation that is as accurate as shining the laser in the direction of motion.

[0049] In another alternative embodiment, the laser via path 280 may be scanned from side to side (or up and down) about a believed direction of motion in order to determine the actual direction of motion. Because the largest phase difference (with respect to the laser via path 282) will occur when the laser via path 280 is pointed in the direction of motion, the direction of motion can be determined when the largest phase difference is detected as the laser is scanned, either manually or automatically. This technique may be used to orient the laser in the direction of motion.

[0050] In step 508 the phase comparator 290 located at the receiver measures the phase difference between the two light beams received via paths 280 and 282 while the apparatus is at rest. As mentioned, these light signals may be converted to electrical signals through a photoelectric converter. In the case of electromagnetic radiation outside the spectrum of visible light other types of converters may be used. For example, for wavelengths longer than that of visible light (*e.g.*, a maser) a radio receiver may be used, and for wavelengths shorter than that of visible light (*e.g.*, for ultraviolet) a photoelectric converter with UV bandwidth may be used. For ease of explanation, all of these types of converters that convert electromagnetic radiation to an electrical signal will be referred to as "photoelectric converters." It is believed that most electrical phase comparators only work well up to frequencies of about 10^9 Hz. As laser light frequencies can be around 10^{14} Hz, for frequencies greater than about 10^9 Hz, phase comparison may use well-known optical interference. Although the phase difference between the two signals may not be measured directly, the phase difference is measured through an amplitude variation as a function of phase, using a PIN diode. Of course, other known techniques for measuring the phase difference of the two electromagnetic beams (or signals) may also be used. In fact, later developed technologies for measuring phase difference may also be used, such as improved electrical phase comparators able to measure frequencies greater than 10^9 Hz.

[0051] Then, any instrument or dedicated system able to measure electrical time histories, able to compare and measure different phases, may be used. Examples of types of phase comparators that may be used include a dual beam oscilloscope or a computer with a digital time history capture facility and phase comparison software. This phase difference is referred to as a reference phase difference because it measures the phase difference when the apparatus is at rest or at another known speed. The comparator need not necessarily be aware of how many times the phase repeats itself (number of 2π radians), it may simply measure the overall phase difference.

[0052] The system always measures the velocity of the apparatus compared to the surrounding propagation medium, *i.e.*, the final speed calculated in step 524 will be the speed of the apparatus with respect to the medium. If the medium is moving then its total (absolute) speed will be the system speed relative to the medium plus the medium's speed relative to the medium at rest in space away from any gravitational bodies (Universe). The reference phase difference (at zero velocity) can be measured while the apparatus is at rest with the medium on the surface of the Earth, or at rest with the medium in space.

[0053] In step 512 the light beam is again transmitted via the air path 280 and via the fiber optic path 282 while the apparatus is in motion with respect to the surface of the Earth (and with respect to the stationary propagation medium) and has a velocity v. In step 516 a phase difference is measured at the phase comparator 290 between the two beams that have traveled along different paths. Because the apparatus is now in motion, the distance traveled by the light beam over the air path 280 will now be a distance d plus a distance Δd (resulting in a phase difference with respect to the measurement made in step 508).

[0054] Accordingly, in step 520 a total phase difference is determined between the phase difference measurements in step 508 and the phase difference measured in step 516. In one embodiment, the reference phase difference from step 508 is subtracted from the velocity phase difference from step 516 to provide the total phase difference. For example, if L_v is the light source phase common to both paths 280 and 282, S_v is the vacuum signal path delay phase at a velocity v, and R is the reference path phase independent of v, then the comparator velocity phase difference at velocity v is given by:

$$\Delta\varphi_v = (L_v+S_v)-(L_v+R)=S_v-R \quad (7)$$

[0055] In other words, Equation (7) is independent of light source L_v phase variations. At zero velocity the reference phase difference at the comparator will be $(L_v'+S_o)-(L_v'+R)$ and the phase difference between this and Equation (7) is:

$$\Delta\varphi_v = [\ (L_v+S_v)-(L_v+R)]-[(L_v'+S_o)-(L_v'+R)]=S_v-R-(S_o-R)=S_v-S_o \quad (8)$$

If there is no reference path R then Equation (8) becomes

$$\Delta\varphi_v = (L_v+S_v)-(L_v'+S_o)=(L_v-L_v')+(S_v-S_o) \approx S_v-S_o \quad (9)$$

providing the light intensity variation $(L_v- L_v')$ is small compared to S_v-S_o.

This is the total phase difference (step 520) due to the velocity of the system. If the light source phase (frequency) is ultra stable, *i.e.*, L_v can be considered to be constant over the two measurements, the reference phase R, can be discarded. But this is not practical for light frequencies, where the phase differences that are being measured are very small indeed.

[0056] Next, in step 524 the speed of the apparatus (with respect to the surface of the Earth and the stationary propagation medium) is determined using the total phase difference, the frequency of the light beam, the speed of light via the air path and distance d 260. Because the phase difference is given by $\Delta\varphi=2\pi f\Delta t$, this means that $\Delta t=\Delta\varphi/2\pi f$. And, because $\Delta t=\Delta d/c=vt/c=vd/c^2$, where $t=d/c$, thus the velocity of the apparatus $v=\Delta tc^2/d$. Therefore, the velocity of the apparatus may be determined from the total phase difference, the light frequency, the speed of light and the fixed distance d.

[0057] In a similar fashion, the speed of a spacecraft or other object in outer space may also be calculated. The speed calculated will be relative to the propagation medium. The system does not measure absolute velocity; it only measures velocity relative to the propagation medium, whether the medium is stationary on the Earth's surface or at rest in space.

[0058] In another specific embodiment, the invention may be explained in the context of the two-way measurement system of Figure 5. In this embodiment, phase comparator 390a detects a phase difference $+\Delta\varphi$ while the system 300 has a velocity 311, and phase comparator 390b detects a phase difference $-\Delta\varphi$ also while the system has a velocity 311. The two phase differences may then be used to determine the velocity of system. In this example, a reference phase difference at each comparator is measured when the system is at rest as has been described above in steps 504 and 508. Next, a velocity phase difference is measured as in step 516 for each comparator. A total phase difference is then determined for each comparator as in step 520 (*i.e.*, a total phase difference in the direction of motion and a total phase difference against the direction of motion). The absolute value of each total phase difference is taken and half the value of the two values added together produces a final value, as given in Equation (10) below. This final total phase difference may then be used in step 524 to determine the velocity of the system.

[0059] A second embodiment of the two-way system measurement is given in Figure 8. Because two laser beams are used, and the distance each beam travels is dependent upon the velocity of the apparatus, no reference signal that travels a fixed distance is needed. As long as the two lasers are synchronized (*i.e.,* are in phase) they may reference to each other. The output from the two photo-electric converters (PECs) 791a,b are now fed to, and measured by, the same phase comparator 790. There is now a common ground wire connection 720 between all components to complete the circuit and the two lasers are now synchronized through a synchronization wire connection 730 connecting the two lasers. The two lasers may be synchronized by using a phase-locked loop or equivalent system.

[0060] Using the same terminology as Equation (9), if $|S_v\text{-}S_o|_U$ is the modulus or magnitude of source phase with velocity, minus the source phase with zero velocity, for the upstream propagation, and $|S_v\text{-}S_o|_D$ is the value for downstream propagation, then the total phase with velocity v will be given by Equation (10):

$$\Delta\varphi_v = \{|S_v-S_o|_U+|S_v-S_o|_D\}/2=\{|\Delta\varphi_v|_U+|-\Delta\varphi_v|_D\}/2 \qquad (10)$$

[0061] A third embodiment of the two-way system measurement is given in Figure 9. Here, a single laser 840 supplies the light for both light paths. Again, because two beams are used relative to each other, no reference signal that travels a fixed distance is needed. The beams are inherently synchronized because they emanate from the same laser. Laser 840 supplies the downstream path as usual (through a half-silvered glass 810), and the upstream path is caused by the half-silvered glass 810 and a mirror 812 to reverse the direction of the light. A common ground wire 820 is again provided to complete the connection. Again, the output from the two photo-electric converters (PECs) 891a,b are now fed to, and measured by, the same phase comparator 890.

[0062] In other specific embodiments, the invention may be explained in the context of systems 420 or 430 shown in Figures 6B and 6C. In the context of a system 420, the light beam follows a zigzag path 481 (or any other type of path other than a single linear path) from the source to the receiver via air or a vacuum. In other words, path 481 is substituted for path 280 in the measurement system of Figure 4 and then calculations may be performed as described in Figure 7 above. Path 481 may also be substituted for path 380a or 380b in the measurement system of Figure 5.

[0063] In the context of system 430, the light beam follows a path that includes not only an air gap 482 but also a fiber optic path 435. In other words, this path of system 430 may be substituted for path 280 in the measurement system of Figure 4 and then calculations may be performed as described in Figure 7 above. This path system 430 may also be substituted for path 380a or 380b in the measurement system of Figure 5.

Bulk Material as Invariant Reference Path

In an additional embodiment, a bulk material is used instead of optical fiber to transmit the light from the source (*e.g.*, a laser) to the observer along the time-invariant reference path. If one assumes that there is no relative motion between the source, observer and optical fiber (they all move together) then there would be complete light convection, *i.e.*, no phase change with system motion, giving an invariant propagation time along the reference path. It is realized, however, that the stationary propagation medium (whether the propagation medium in outer space or the medium at rest on the Earth's surface) can dominate, where the source and optical fiber (having a relatively low transparent mass), are compared relative to this medium. It is observed that mass on the order of a small planet may be required for the medium to dominate. The light may be only partially convected according to Fresnel (1818) and Fiseau (1851), possibly giving a variant propagation time for light along the optical fiber reference path and affecting accuracy of the measurement. For complete convection (an invariant propagation time) to occur, the source, observer and optical reference path are best contained within a bulk material reference path, of refractive index n>1, which allows for complete light convection.

[0064] Figure 10 illustrates a source, observer, and bulk material all moving together. Similar to Figure 1, system 100 has a velocity, v 141, and includes a source 150 (such as a laser) and a receiver 155 (such as a pin diode detector) separated by distance d 160, a stationary medium path 180 (through a vacuum or air, for example), a bulk material path 602, and a bulk material 604. Bulk material 604 may be any suitable material such as a large mass of a transparent solid material or transparent liquid material (such as water) where the refractive index is greater than one. Or, material 604 may be a large mass of a non-transparent liquid or non-transparent solid (such as lead), as long as its refractive index is greater than one. Preferably, material 604 is not a gas (such as air or other) whose refractive index is very close to 1. The type and mass of the bulk material may be adjusted so that complete convection occurs along path 602 and the propagation time is invariant.

[0065] Phase comparison may be accomplished using any of the techniques discussed above. As is known, phase comparison is used to detect and measure phase differences between the two signals on paths 180 and 602. As shown, the source, receiver and path 602 are all contained within bulk material 604, thus providing for complete light convection along path 602. The lower stationary medium path 180 (where the refractive index $n \approx 1$ when the path is through air or a gas), which has a variant propagation time depending upon speed, is used to help measure the system velocity v as has been described above.

Normal Round Trip Propagation Time as Invariant Reference Path

[0066] The invariant property of the round-trip propagation time (RTPT) normal (perpendicular) to the direction of motion may be also be used as the invariant reference path in order to measure the propagation difference through motion in the direction of motion, instead of using a fiber optic path or a bulk material path.

[0067] Figure 11 illustrates a system 610 that uses a zigzag path with mirrors in order to increase the propagation distance of the reference path and thus the measurement time (sensitivity). Shown is a source 620, a receiver 622, and mirrors 625 and 627 used to create stationary medium path 630, 631. Mirrors 635 and 637 are used to create the invariant round trip path 640, having a length, l, 644. The solid line 630 shows the original positions of the source 620 and receiver 622, while the dotted line 631 shows the full path traveled by light from the source when the system is in motion, showing the reception positions 621 and 623 of both the source and receiver. The two signals that propagate along the upper and lower paths 640 and 630, 631 arrive at receiver 622 where the phase difference is measured as has been discussed above.

[0068] Thus, the time t for light to travel the upper invariant zigzag path, where l is the length of the zigzag, and n is the number of zigzags, is:

$t=d/c = n2l/c \qquad (11)$

The additional distance Δd travelled in this time t in the lower path in the direction of motion is:

$\Delta d=vt, \quad \Delta t=\Delta d/c=(v/c)t=Mt=Mn2l/c \qquad (12)$

Here, Δt may be measured at the receiver (*e.g.*, a pin diode detector) through interference between the two optical paths. The number of interference fringes (2π radians) is then:

$N =\Delta tc/\lambda= (v/c)(d/c)\ (c/\lambda)=Md/\lambda \qquad (13)$

[0069] As an example, if l=1m, n=1, d=2m, v=30m/s (67 miles/hour), $M = v/c = 30/3x10^8 = 10^{-7}$, and $\lambda = 6x10^{-7}$, then $N = Md/\lambda = 1/3$ (120^O). Since 90^O corresponds to the first maximum (fringe), speeds well below 30 m/s may be easily be detected using this embodiment.

Fiber Optic Coil as Invariant Reference Path

[0070] Figure 12 illustrates a system 660 using a coil of optical fiber as an invariant reference path. The optical zigzag system of Figure 11 can be prone to vibration and thus alignment issues at these very small wavelengths, causing a loss in measurement accuracy. Accordingly, use of a fiber optic coil instead can improve accuracy because light is not appreciably convected by moving optical fibers. Although the light is guided in the fiber it behaves as though it were being transmitted in a vacuum (or in air).

[0071] System 660 includes a source 670 (e.g. a laser), a receiver 672 (e.g., a PIN diode) and a path 680. Positions 671 and 673 show positions of the source and receiver after movement of the system having a velocity, v. Light from the source passes through a polarizer 676 before traveling along path 680 or along path 690. Path 680 is the stationary medium path (the variant path), and may include a path through air, a vacuum or a direct connection. Light on the invariant path travels through polarizer 676, phase shifter 692 and coupler 694 before entering a coil 696 of optical fiber. The light is reflected back by mirror 698 before entering coupler 694 where it is passed on to the receiver 672.

[0072] The fixed propagation distance of path 690 is then $d=n2\pi r$, where n is the number of optical turns of single mode (SM) fiber in coil 696. The light from the source is polarized at 676, for example, through stress created in the fiber using several tight loops of the optical fiber, or by using a more expensive magnetic polarizer. The polarized light is bi-refringent, *i.e.*, it has two orthogonal modes, which, through random variations in fiber stress (by bending and construction of the fiber), create different mode speeds (refractive indices) along the fiber, depreciating its coherence. The polarized light is then split into two paths, the lower path 680 going directly to the receiver 672. This direct path is preferably as short as possible, *i.e.*, less than the polarization coherence length, where the polarization still remains substantially unaltered. An alternative method is to connect path 680 to the receiver via the coupler 694.

[0073] The upper path 690 passes through a phase shifter 692, for example, using a paddle wheel of several turns of optical fiber wound on a disk that can be rotated around the direction of motion, or by using a magnetic polarizer. The light is then passed through coupler 694 to the many turns of the optical fiber coil 696. It is then rotated by 45°, reflected back through the coil and rotated again by 45° by a Faraday rotator mirror 698 (for example), which rotates the orthogonal modes by 90°.

[0074] The light is then returned along the fiber coil to the light coupler 694 where the signal is passed on to the receiver 672. Use of this repeated replica path in reverse tends to undo the random polarization effects in the forward direction, restoring the coherent polarization of the light. This allows large lengths of optical fiber to be used in this invariant time delay path 690, with maintained coherence, so that interference with the time-variant direct path 680 can be obtained. An alternative to this embodiment (using the rotator mirror and a repeated replica path) is to use polarizing maintaining (PM) optical fiber which is very expensive when hundreds of meters are used in the optical fiber coil 696. In this alternative, path 690 passes through coupler 694, through a coil of PM fiber, and then directly into coupler 694 before being passed to the receiver 672 for interference with light from path 680.

Computer System Embodiment

[0075] FIGS. 13A and 13B illustrate a computer system 900 suitable for implementing embodiments of the present invention. FIG. 13A shows one possible physical form of the computer system. Of course, the computer system may have many physical forms including an integrated circuit, a printed circuit board, a small handheld device (such as a mobile telephone or PDA), a personal computer or a super computer. Computer system 900 includes a monitor 902, a display 904, a housing 906, a disk drive 908, a keyboard 910 and a mouse 912. Disk 914 is a computer-readable medium used to transfer data to and from computer system 900.

[0076] FIG. 13B is an example of a block diagram for computer system 900. Attached to system bus 920 are a wide variety of subsystems. Processor(s) 922 (also referred to as central processing units, or CPUs) are coupled to storage devices including memory 924. Memory 924 includes random access memory (RAM) and read-only memory (ROM). As is well known in the art, ROM acts to transfer data and instructions uni-directionally to the CPU and RAM is used typically to transfer data and instructions in a bi-directional manner. Both of these types of memories may include any suitable of the computer-readable media described below. A fixed disk 926 is also coupled bi-directionally to CPU 922; it provides additional data storage capacity and may also include any of the computer-readable media described below. Fixed disk 926 may be used to store programs, data and the like and is typically a secondary mass storage medium (such as a hard disk, a solid-state drive, a hybrid drive, flash memory, etc.) that can be slower than primary storage but persists data. It will be appreciated that the information retained within fixed disk 926, may, in appropriate cases, be incorporated in standard fashion as virtual memory in memory 924. Removable disk 914 may take the form of any of the computer-readable media described below.

[0077] CPU 922 is also coupled to a variety of input/output devices such as display 904, keyboard 910, mouse 912 and speakers 930. In general, an input/output device may be any of: video displays, track balls, mice, keyboards, microphones, touch-sensitive displays, transducer card readers, magnetic or paper tape readers, tablets, styluses, voice or handwriting recognizers, biometrics readers, or other computers. CPU 922 optionally may be coupled to another computer or telecommunications network using network interface 940. With such a network interface, it is contemplated that the CPU might receive information from the network, or might output information to the network in the course of performing the above-described method steps. Furthermore, method embodiments of the present invention may execute solely upon CPU 922 or may execute over a network such as the Internet in conjunction with a remote CPU that shares a portion of the processing.

[0078] In addition, embodiments of the present invention further relate to computer storage products with a computer-readable medium that have computer code thereon for performing various computer-implemented operations. The media and computer code may be those specially designed and constructed for the purposes of the present invention, or they may be of the kind well known and available to those having skill in the computer software arts. Examples of computer-readable media include, but are not limited to: magnetic media such as hard disks, floppy disks, and magnetic tape; optical media such as CD-ROMs and holographic devices; magneto-optical media such as floptical disks; and hardware devices that are specially configured to store and execute program code, such as application-specific integrated circuits (ASICs), programmable logic devices (PLDs) and ROM and RAM devices. Examples of computer code include machine code, such as produced by a compiler, and files containing higher-level code that are executed by a computer using an interpreter.

[0079] Although the foregoing invention has been described in some detail for purposes of clarity of understanding, it will be apparent that certain changes and modifications may be practiced within the scope of the appended claims. Therefore, the described embodiments should be taken as illustrative and not restrictive, and the invention should not be limited to the details given herein but should be defined by the following claims and their full scope of equivalents.

CLAIMS

We Claim:

1. A method of measuring a velocity of an apparatus, said method comprising:

while said apparatus is at a reference velocity, transmitting a coherent electromagnetic beam via a first path on said apparatus to a first receiver, wherein a distance said beam travels via said first path is dependent on any velocity of said apparatus;

while said apparatus is at said reference velocity, transmitting said beam via a second path on said apparatus to a second receiver, wherein a distance said beam travels via said second path is independent of any velocity of said apparatus;

determining a reference phase difference at said receivers between said beam traveling via said first path at said reference velocity and said beam traveling via said second path at said reference velocity;

while said apparatus is at said velocity, determining a velocity phase difference at said receivers between said beam traveling via said first path and said beam traveling via said second path;

determining a total phase difference between said velocity phase difference and said reference phase difference; and

calculating said velocity of said apparatus using at least said total phase difference, a frequency of said beam, and the speed of light.

2. The method as recited in claim 1 wherein said reference velocity is zero relative to the surface of the Earth.

3. The method as recited in claim 1 wherein said beam traveling via said first path travels in the direction of said velocity of said apparatus.

4. The method as recited in claim 1 wherein said beam traveling via said first path propagates in a propagation medium.

5. The method as recited in claim 1 wherein said first path includes a zigzag portion.

6. The method as recited in claim 1 wherein said first path includes a solid medium that is longer than the distance between a source of said beam and said first receiver.

7. An apparatus for calculating a velocity of said apparatus, said apparatus comprising:

a first receiver;

a second receiver;

a source that generates a coherent electromagnetic beam that is directed toward said first receiver via a first path and that is directed toward said second receiver via a second path, wherein a distance said beam travels via said first path is dependent on any velocity of said apparatus, and wherein a distance said beam travels via said second path is independent of any velocity of said apparatus;

a phase comparator coupled to said first and second receivers, said phase comparator being arranged to determine a reference phase difference between said beam traveling via said first path and said beam traveling via said second path when said apparatus is at a reference velocity, said phase comparator being further arranged to determine a velocity phase difference between said beam traveling via said first path and said beam traveling via said second path when said apparatus is at said velocity; and

a computing device arranged to calculate said velocity of said apparatus using at least said reference phase difference, said velocity phase difference, a frequency of said beam, and the speed of light.

8. The apparatus as recited in claim 7 wherein said reference velocity is zero relative to the surface of the Earth.

9. The apparatus as recited in claim 7 wherein said first path is a straight line.

10. The apparatus as recited in claim 7 wherein said beam traveling via said first path propagates in a propagation medium.

11. The apparatus as recited in claim 7 wherein said first path includes a zigzag portion.

12. The apparatus as recited in claim 7 wherein said first path includes a solid medium that is longer than the distance between said source and said first receiver.

13. The apparatus as recited in claim 7 further comprising:

a beam splitter that splits said beam from said source into a first beam traveling via said first path and a second beam traveling via said second path, wherein said second receiver is located at the end of said second path.

14. The apparatus as recited in claim 7 wherein said second receiver is located in physical contact with said source, said apparatus further comprising:

an electrical conductor that conducts a signal from said second receiver to said phase comparator.

15. A method of measuring a velocity of an apparatus, said method comprising:

while said apparatus is at a reference velocity, transmitting a first coherent electromagnetic beam via a first path on said apparatus to a first receiver, wherein a distance said first beam travels via said first path is dependent on any velocity of said apparatus;

while said apparatus is at said reference velocity, transmitting a second coherent electromagnetic beam via a second path on said apparatus in a direction opposite to said first beam to a second receiver, wherein a distance said second beam travels via said second path is dependent of any velocity of said apparatus, said second beam being in phase with said first beam;

determining a reference phase difference at said receivers between said first beam traveling via said first path at said reference velocity and said second beam traveling via said second path at said reference velocity;

while said apparatus is at said velocity, determining a velocity phase difference at said receivers between said first beam traveling via said first path and said second beam traveling via said second path;

determining a total phase difference between said velocity phase difference and said reference phase difference; and

calculating said velocity of said apparatus using at least said total phase difference, a frequency of said first beam, and the speed of light.

16. The method as recited in claim 15 wherein said first and second beams originate from different sources, said method further comprising:

synchronizing said different sources so that said second beam is in phase with said first beam.

17. The method as recited in claim 15 wherein said first and second beams originate from a single source.

18. An apparatus for calculating a velocity of said apparatus, said apparatus comprising:

a first receiver;

a second receiver;

a source that generates a coherent electromagnetic beam that is directed toward said first receiver via a first path and that is directed toward said second receiver via a second path, wherein a distance said electromagnetic beam travels via said first path and via said second path is dependent on any velocity of said apparatus;

a phase comparator coupled to said first and second receivers, said phase comparator being arranged to determine a reference phase difference between said electromagnetic beam traveling via said first path and said electromagnetic beam traveling via said second path when said apparatus is at a reference velocity, said phase comparator being further arranged to determine a velocity phase difference between said electromagnetic beam traveling via said first path and said electromagnetic beam traveling via said second path when said apparatus is at said velocity; and

a computing device arranged to calculate said velocity of said apparatus using at least said reference phase difference, said velocity phase difference, a frequency of said electromagnetic beam, and the speed of light.

19. The apparatus as recited in claim 18 wherein said electromagnetic beam propagates in a propagation medium.

20. The apparatus as recited in claim 18 wherein said source includes a first source that generates a first coherent electromagnetic beam via said first path and a second source that generates a second coherent electromagnetic beam via said second path, said apparatus further comprising:

a synchronization mechanism for synchronizing said first and second sources such that said first and second beams are in phase upon leaving said respective first and second sources.

21. A method as recited in claim 1 wherein a source of said beam, said second path and said second receiver are all contained in a bulk material having a refractive index greater than 1.

22. A method as recited in claim 1 wherein said second path is a zig-zag path perpendicular to said velocity of said apparatus.

23. A method as recited in claim 1 wherein said second path travels through a solid medium which maintains a coherent polarization of said beam.

24. An apparatus as recited in claim 7 wherein said source, said second path and said second receiver are all contained in a bulk material having a refractive index greater than 1.

25. An apparatus as recited in claim 7 wherein said second path is a zig-zag path perpendicular to said velocity of said apparatus.

26. An apparatus as recited in claim 7 wherein said second path travels through a solid medium which maintains a coherent polarization of said beam.

27. An apparatus as recited in claim 18 wherein said first and second paths are in opposite directions.

28. A method of measuring a velocity of an apparatus, said method comprising:

determining a first reference phase difference between a first coherent electromagnetic beam traveling via a first path at a reference velocity and said first beam traveling via a second path at said reference velocity, wherein a distance traveled via said first path is dependent upon said velocity, and wherein a distance traveled via said second path is independent of said velocity;

determining a second reference phase difference between a second coherent electromagnetic beam traveling via a third path at a reference velocity and said second beam traveling via a fourth path at said reference velocity, wherein a distance traveled via said third path being dependent upon said velocity, and wherein a distance traveled via said fourth path being independent of said velocity;

while said apparatus is at said velocity, determining a first velocity phase difference between said first beam traveling via said first path and said first beam traveling via said second path;

while said apparatus is at said velocity, determining a second velocity phase difference between said second beam traveling via said third path and said second beam traveling via said fourth path;

determining a first total phase difference between said first velocity phase difference and said first reference phase difference, and determining a second total phase difference between said second velocity phase difference and said second reference phase difference; and

calculating said velocity of said apparatus using at least said first total phase difference, said second total phase difference, frequencies of said first and second light beams, and the speed of light.

29. A method as recited in claim 28 wherein said reference velocity is zero relative to the surface of the Earth.

30. A method as recited in claim 28 wherein said first beam traveling via said first path travels in the direction of said velocity of said apparatus, and wherein said second beam traveling via said third path travels in the opposite direction of said velocity of said apparatus.

31. A method as recited in claim 28 wherein said first beam traveling via said first path and said second beam traveling via said third path propagate in a propagation medium.

32. A method as recited in claim 28 further comprising:

adding together the magnitude of said first total phase difference and the magnitude of said second total phase difference and using this sum to perform said calculating said velocity.

33. An apparatus for calculating a velocity of said apparatus, said apparatus comprising:

a first receiver;

a second receiver;

a third receiver;

a fourth receiver;

a first source that generates a first coherent electromagnetic beam that is directed toward said first receiver via a first path and that is directed toward said second receiver via a second path, wherein a distance said first beam travels via said first path is dependent on any velocity of said apparatus, and wherein a distance said first beam travels via said second path is independent of any velocity of said apparatus;

a second source that generates a second coherent electromagnetic beam that is directed toward said third receiver via a third path and that is directed toward said fourth receiver via a fourth path, wherein a distance said second beam travels via said third path is dependent on any velocity of said apparatus, and wherein a distance said second beam travels via said fourth path is independent of any velocity of said apparatus;

a first phase comparator coupled to said first and second receivers, said first phase comparator being arranged to determine a first reference phase difference between said first beam traveling via said first path and said first beam traveling via said second path when said apparatus is at a reference velocity, said first phase comparator being further arranged to determine a first velocity phase difference between said first beam traveling via said first path and said first beam traveling via said second path when said apparatus is at said velocity;

a second phase comparator coupled to said third and fourth receivers, said second phase comparator being arranged to determine a second reference phase difference between said second beam traveling via said third path and said second beam traveling via said fourth path when said apparatus is at said reference velocity, said second phase comparator being further arranged to determine a second velocity phase difference between said second beam traveling via said third path and said second beam traveling via said fourth path when said apparatus is at said velocity; and

a computing device arranged to calculate said velocity of said apparatus using at least said first and second reference phase differences, said first and second velocity phase differences, frequencies of said first and second beams, and the speed of light.

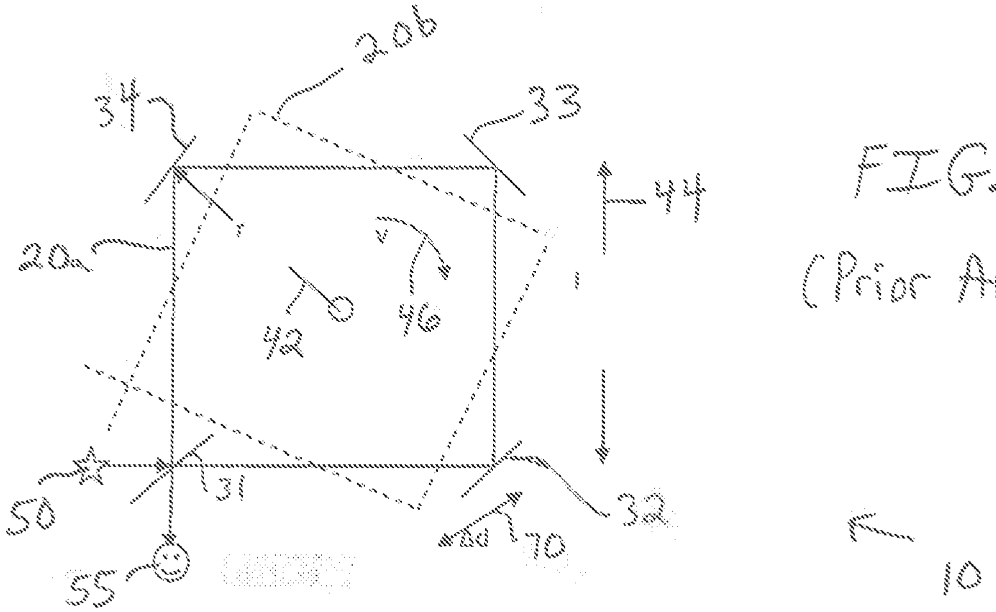
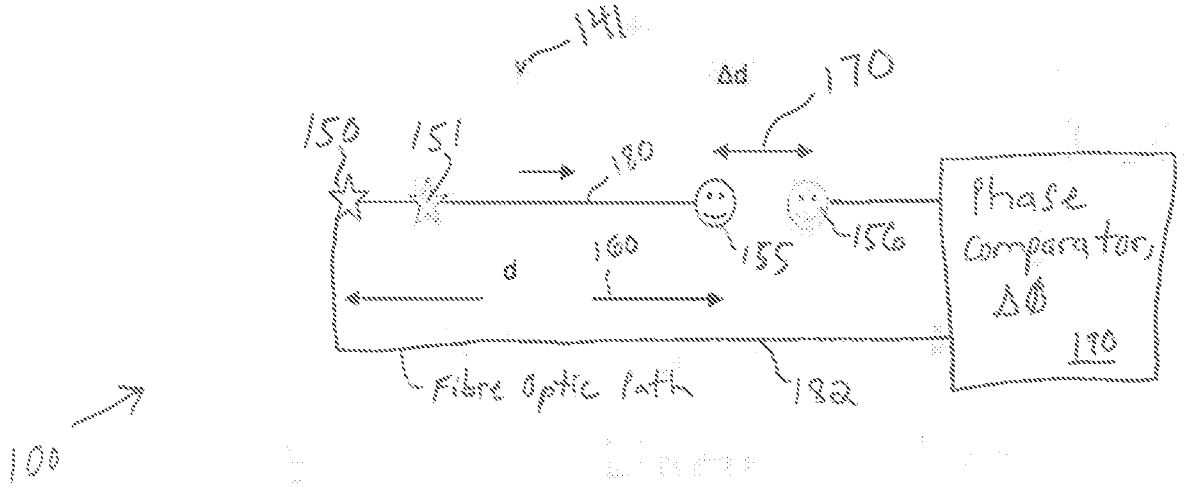


FIG. 1
(Prior Art)

Sagnac's Rotating mirrors



Linear System

FIG. 3

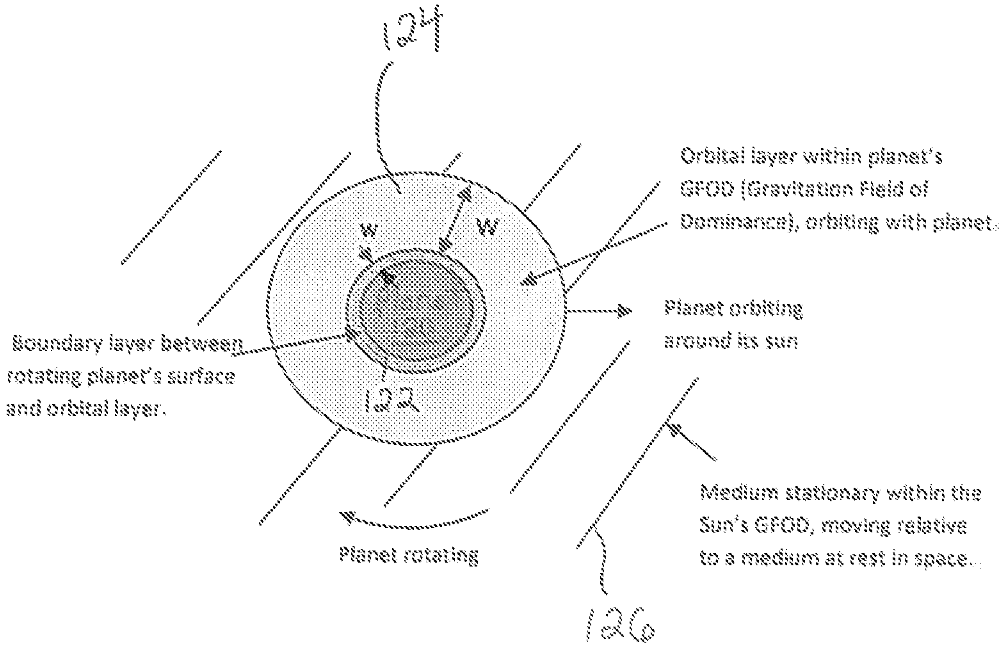


FIG. 2

Gravitational Entrainment Model

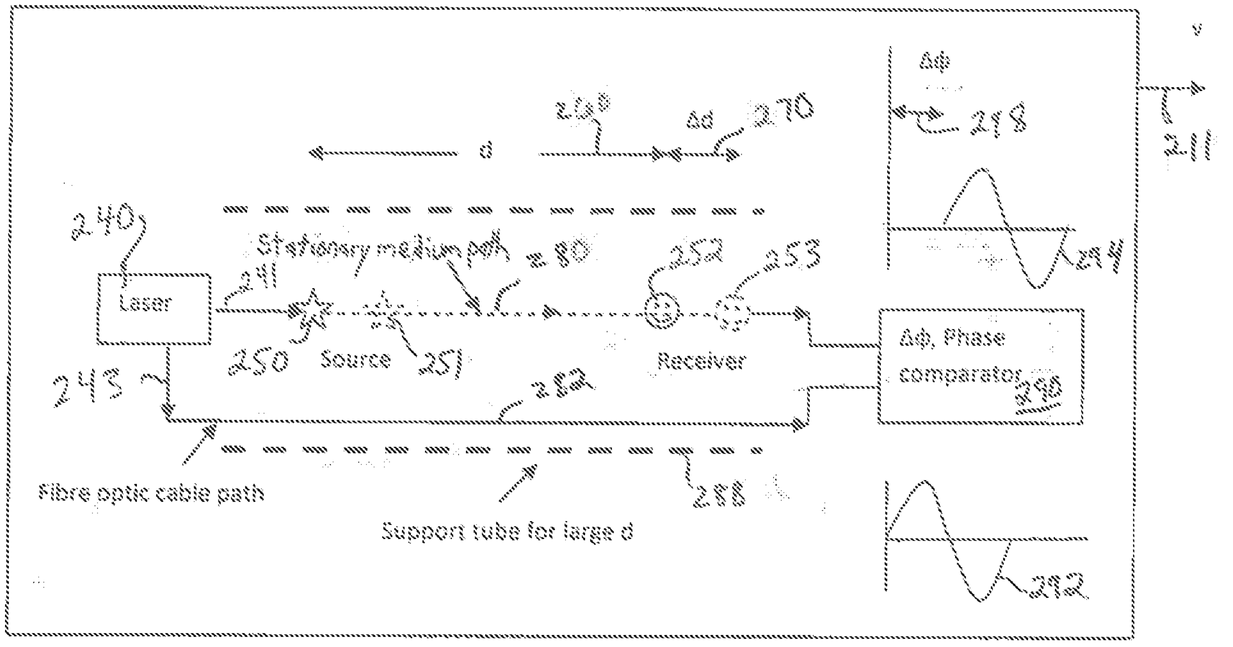


FIG. 4 Measurement System

200

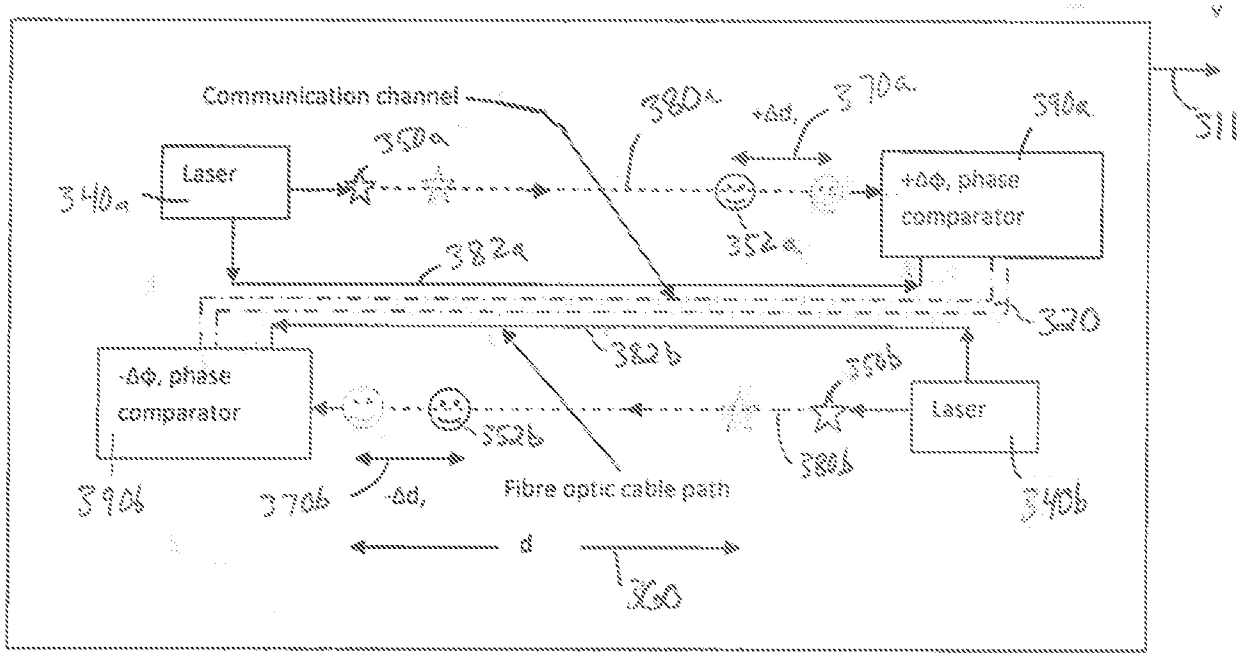


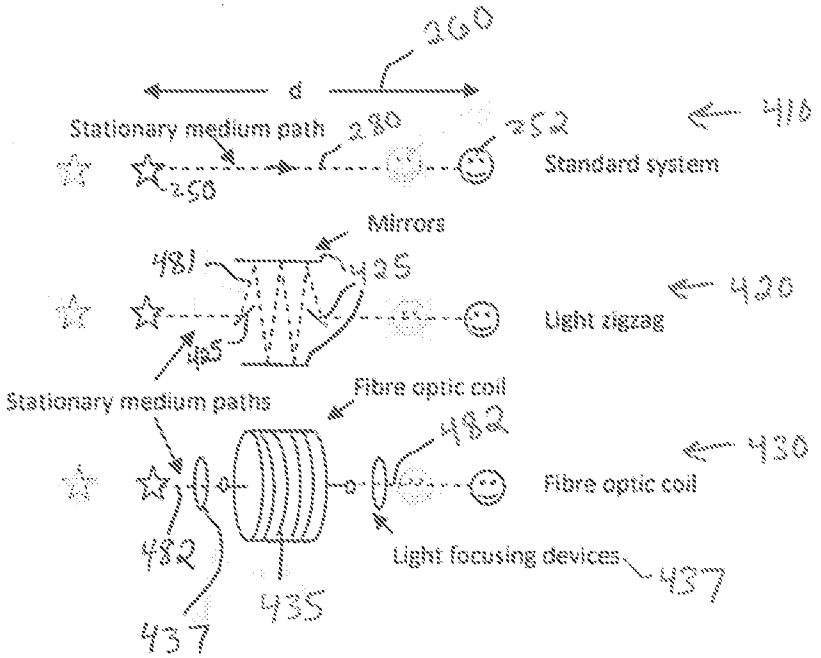
FIG. 5 Two-way Measurement System

300

FIG. 6A

FIG. 6B

FIG. 6C



Propagation Path
Delay ExtensionS

FIG. 7

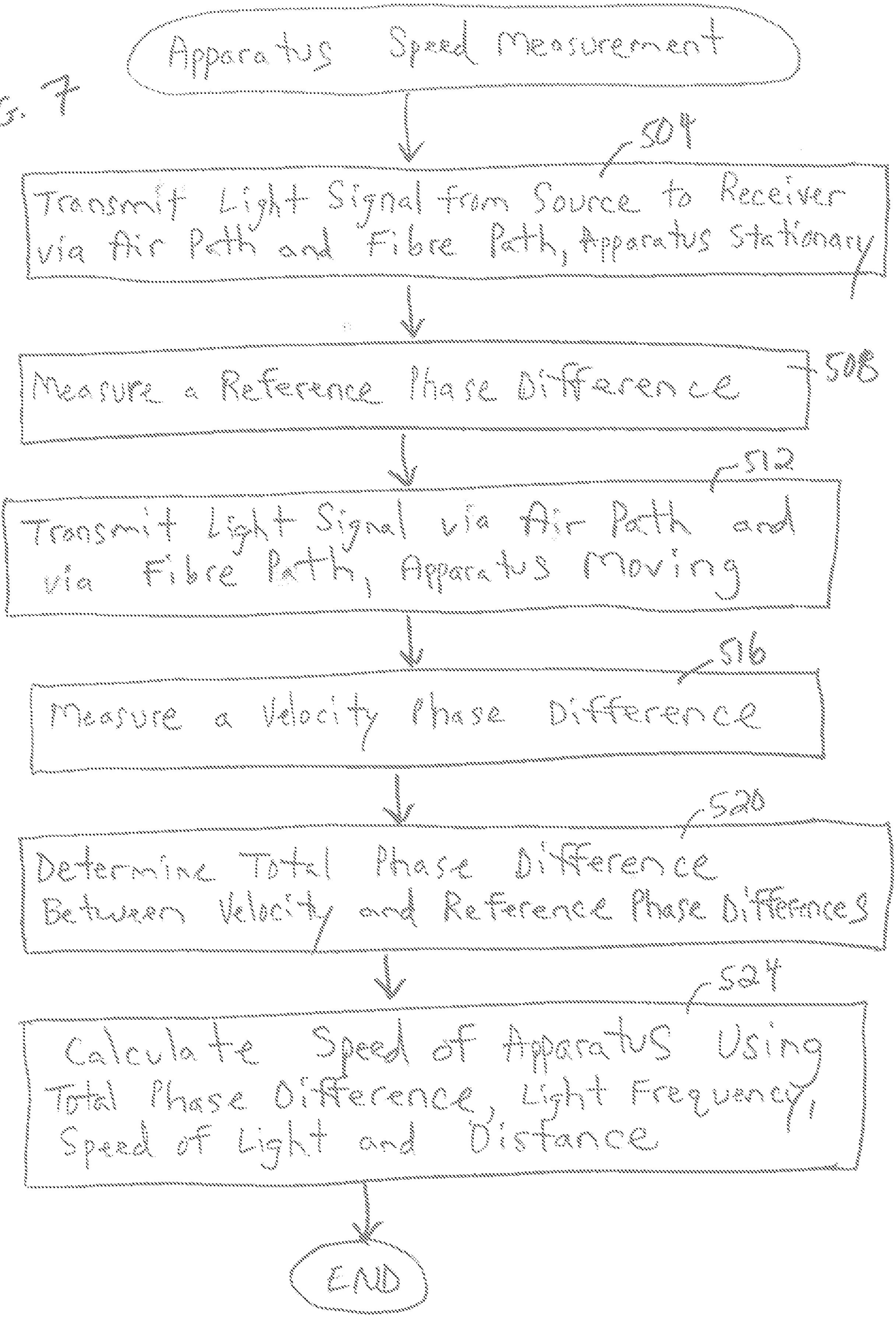
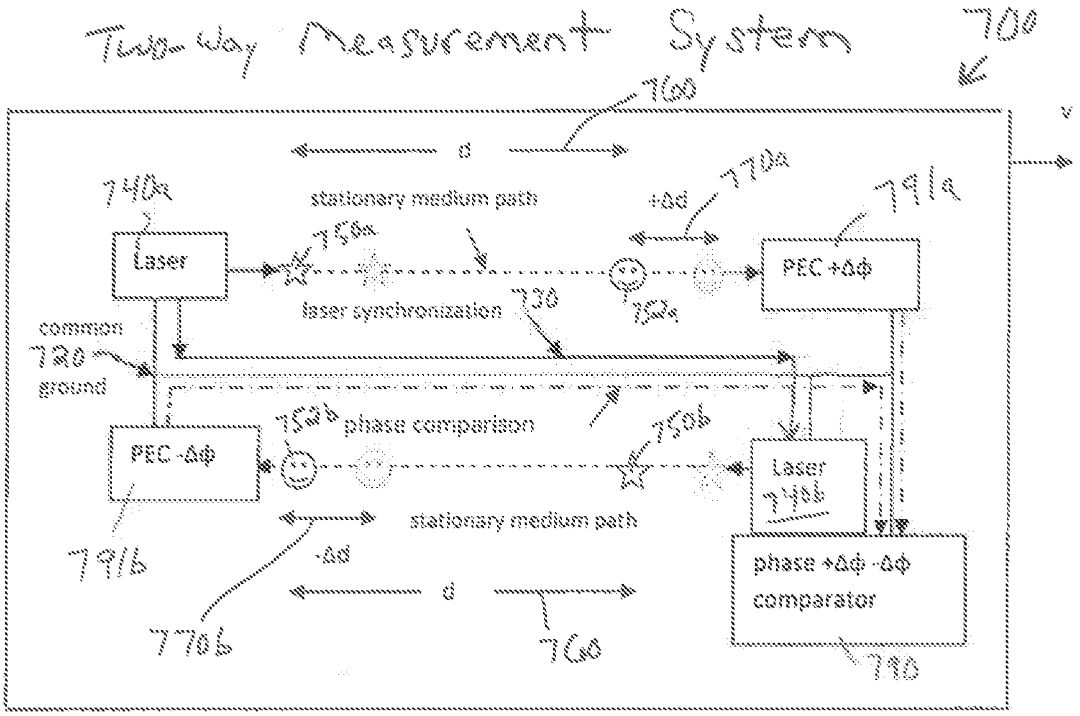
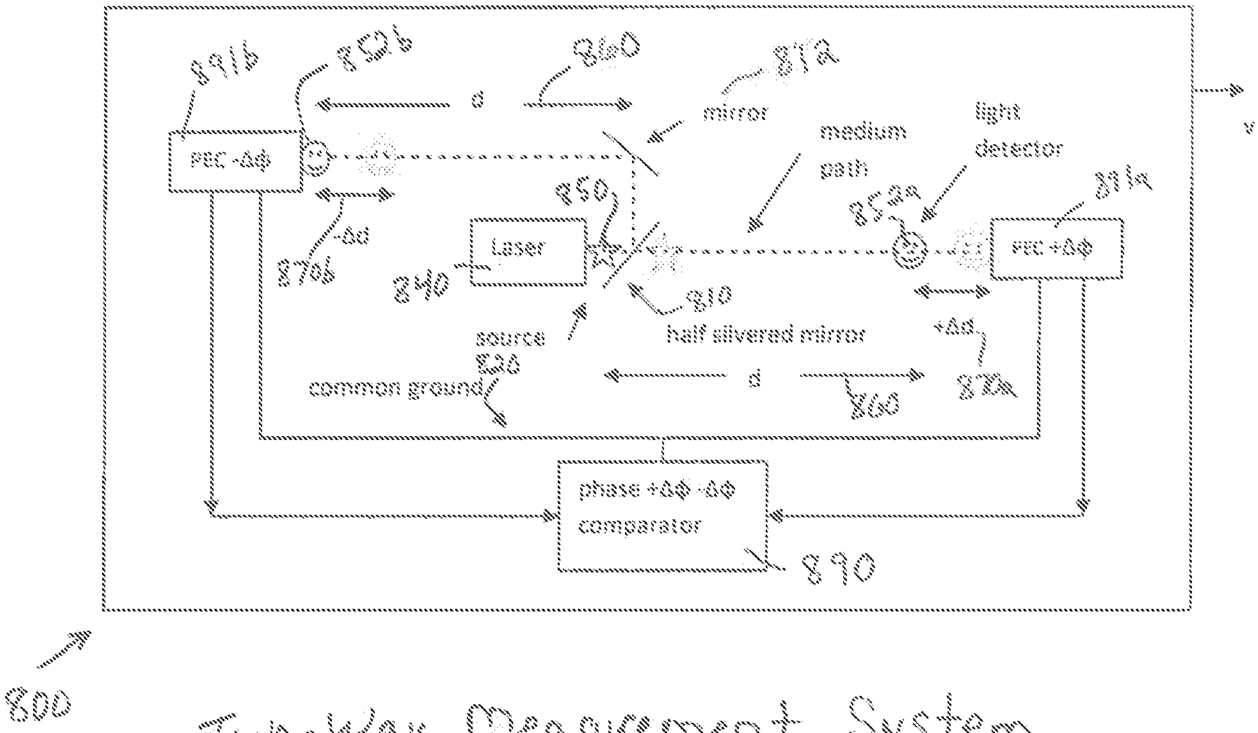

Apparatus Speed Measurement
504
Transmit Light Signal from Source to Receiver via Air Path and Fibre Path, Apparatus Stationary
508
Measure a Reference Phase Difference
512
Transmit Light Signal via Air Path and via Fibre Path, Apparatus Moving
516
Measure a Velocity Phase Difference
520
Determine Total Phase Difference Between Velocity and Reference Phase Differences
524
Calculate Speed of Apparatus Using Total Phase Difference, Light Frequency, Speed of Light and Distance
END

FIG. 8

Two-Way Measurement System





Two-Way Measurement System

FIG. 9

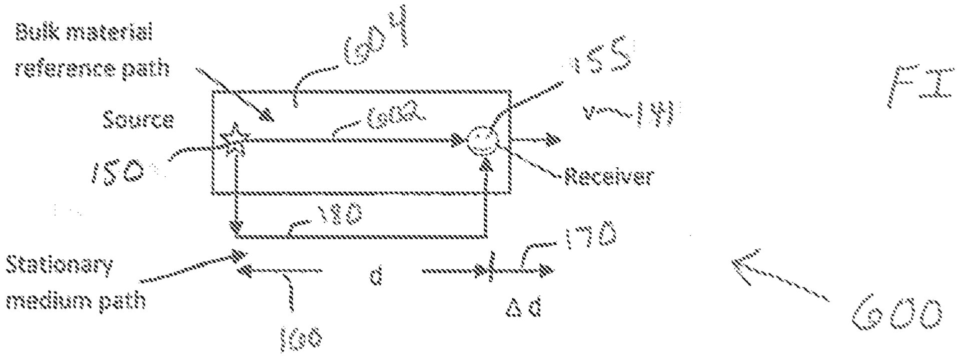

Bulk material reference path
604
155
Source
602
v~141
150
Receiver
180
Stationary medium path
170
d
Δd
160
600

FIG. 10

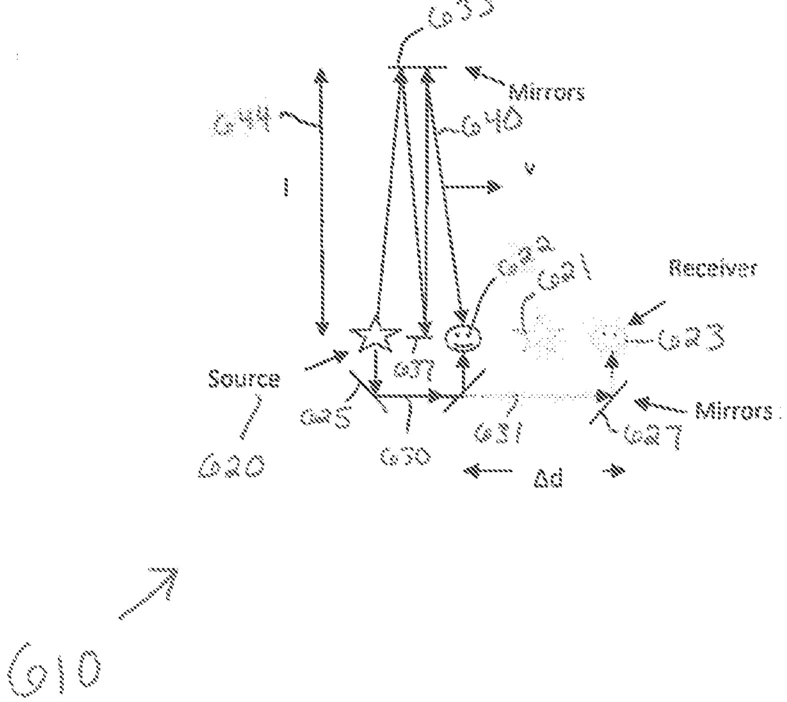

635
Mirrors
644
640
l
v
622
621
Receiver
623
Source
637
625
630
631
627
Mirrors
620
Δd
610

FIG. 11

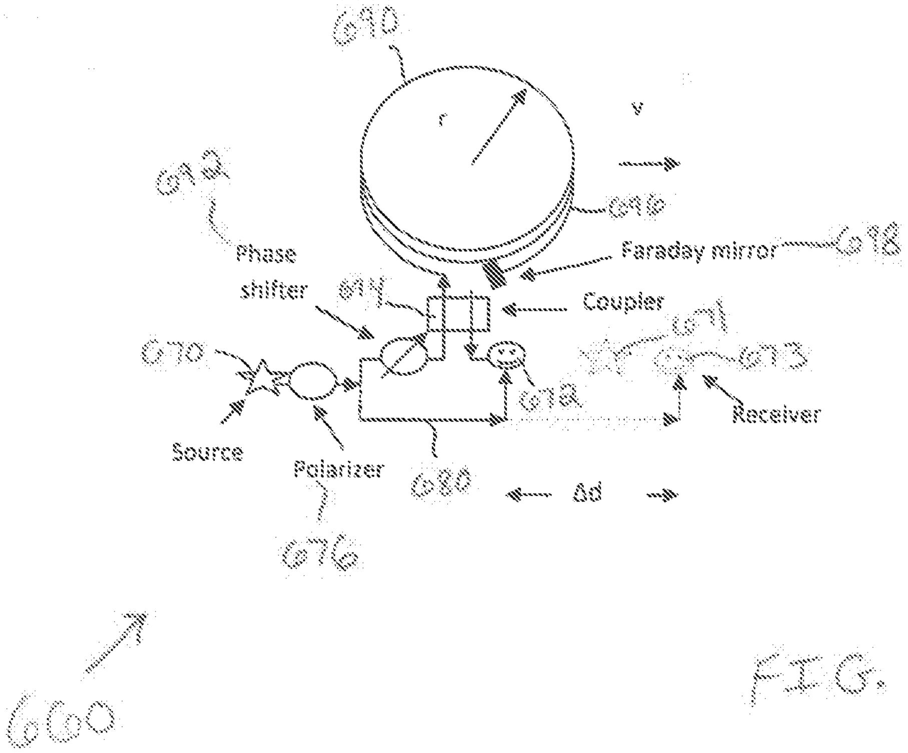

690
r
v
696
692
Phase shifter
694
Faraday mirror
698
Coupler
671
670
673
672
Receiver
Source
Polarizer
680
Δd
676
600

FIG. 12

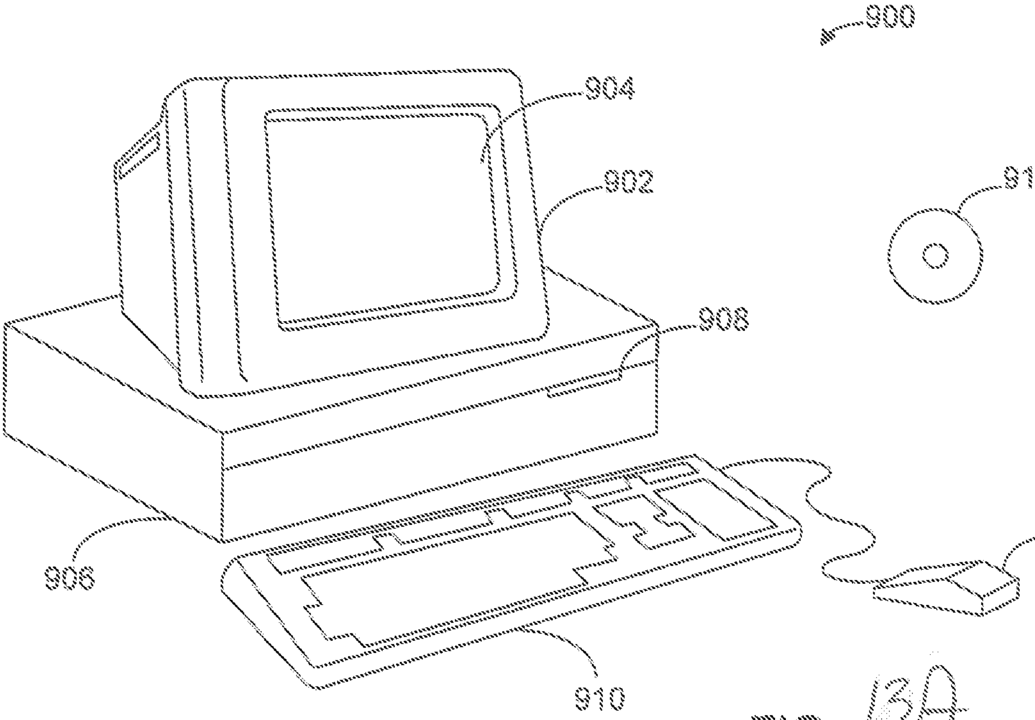


FIG. 13A

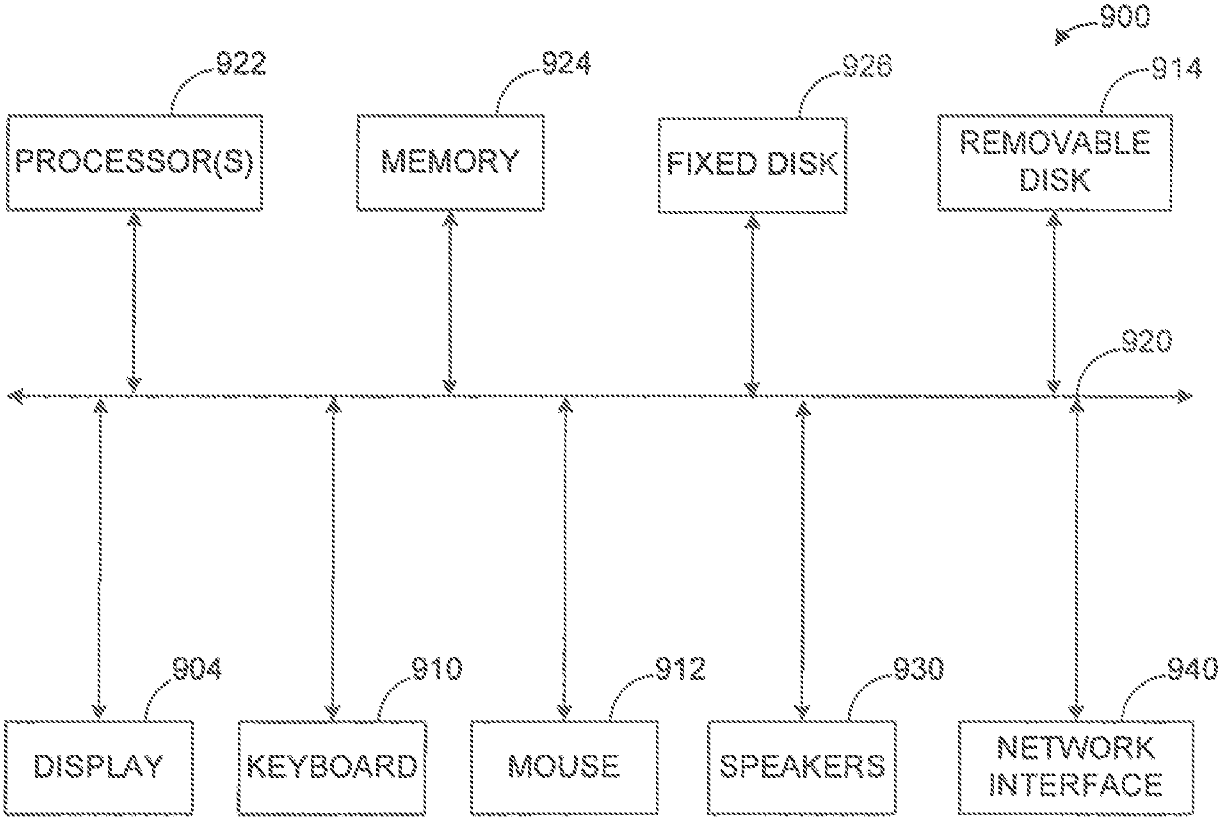


FIG. 13B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/015063

A. CLASSIFICATION OF SUBJECT MATTER

G01P 3/36(2006.01)i, G01P 3/42(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01P 3/36; H01S 3/00; G01C 3/06; G01N 21/55; G01J 3/28; G01S 13/90; G01S 3/48; G01P 3/42

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: velocity, speed, phase, difference, comparator, laser, beam

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5396510 A (MARK L. WILSON) 07 March 1995 See abstract, column 2, line 27 - column 4, line 7, claims 1, 5, 6 and figure 1.	1-33
A	US 2008-0100822 A1 (JAMES F. MUNRO) 01 May 2008 See abstract, paragraphs [0044]-[0054], [0092]-[0133] and figure 6.	1-33
A	US 2007-0186653 A1 (KLAUS WOLTER) 16 August 2007 See abstract and paragraphs [0033]-[0068].	1-33
A	US 5432602 A (MANISH SHARMA et al.) 11 July 1995 See abstract, claims 1-8 and figure 2.	1-33
A	US 4626860 A (GUS P. TRICOLES et al.) 02 December 1986 See abstract, claims 1-5 and figure 1.	1-33

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 21 May 2015 (21.05.2015)	Date of mailing of the international search report **21 May 2015 (21.05.2015)**
Name and mailing address of the ISA/KR International Application Division Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea Facsimile No. ++82 42 472 7140	Authorized officer KIM, Tae Hoon Telephone No. +82-42-481-8407

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		EP 0614074 B1	13/05/1998
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