THIS NASA INVENTION APPEARS TO HAVE
EXCELLENT COMMERCIAL POTENTIAL

NASA CASE NO. GSC-12,609-2
PRINT FIG. 1

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(NASA-Case-GSC-12609-2) GEODETIC DISTANCE
MEASURING APPARATUS Patent Application
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NASA Case No. 12,609-2

GEODETIC DISTANCE MEASURING APPARATUS

The invention relates generally to distance measuring apparatus and more particularly to geodetic distance measuring apparatus which compensates for the refractive index of the atmosphere.

As shown in Figure 1, a mode locked laser system (10) including a laser device (12, 14, 16, 18, 20) and its peripheral components (22, 24, 26) is utilized for deriving two mutually phase locked optical wavelength signals (27, 29) and one phase locked microwave CW signal (41) which respectively traverse the same distance measurement path. Preferably the optical signals are comprised of pulse type signals. Phase comparison of the two optical wavelength pulse signals (27, 29) is used to provide a measure of the dry air density while phase comparison of one of the optical wavelength pulse signals (27) and the microwave CW signal (41) is used to provide a measure of the wet or water vapor density of the air. From these measurements is computed the distance to be measured corrected for the atmospheric dry air and water vapor densities in the measurement path. This is provided by the phase meters 86 and 88 and the range computer 90. Additionally, a time interval unit (108) is included as illustrated in Figure 4 for measuring transit time of individual optical pulses over said distance measurement path for resolving the phase ambiguity needed with the phase measurements to give the true target distance.

Novelty is believed to reside in the utilization of a mode locked laser system and its peripheral components for generating two harmonically related phase locked optical wavelength signals and one harmonically related microwave signal which traverse a common distance measurement path and are thereafter used in computing apparatus for making a true measurement of the distance to be measured. Also means are provided for resolving any ambiguity in the range measurements.

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Serial No: 481,020

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FIG.1

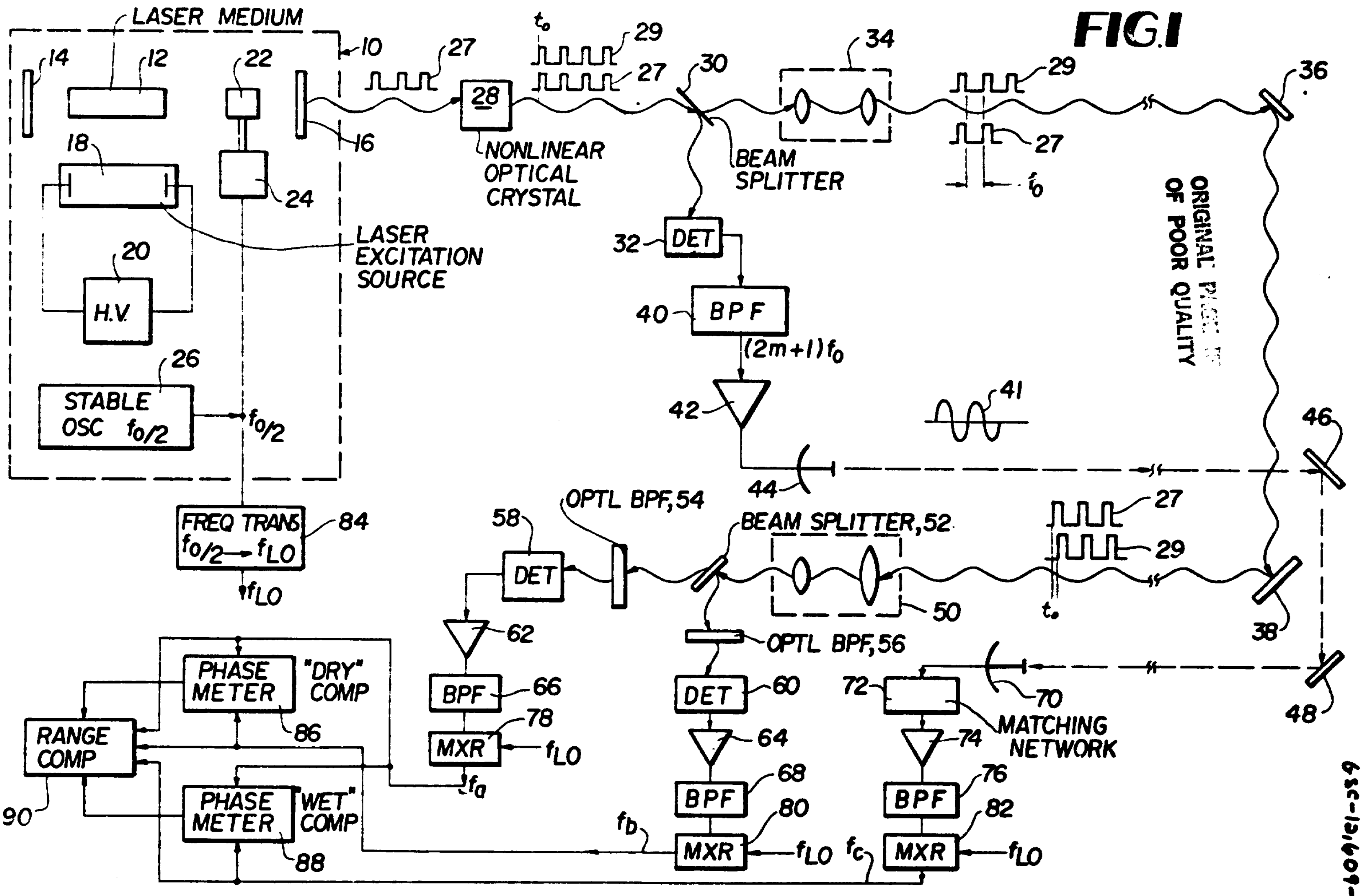

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FIG. 2

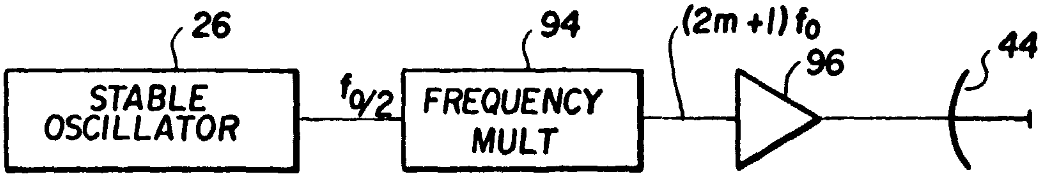
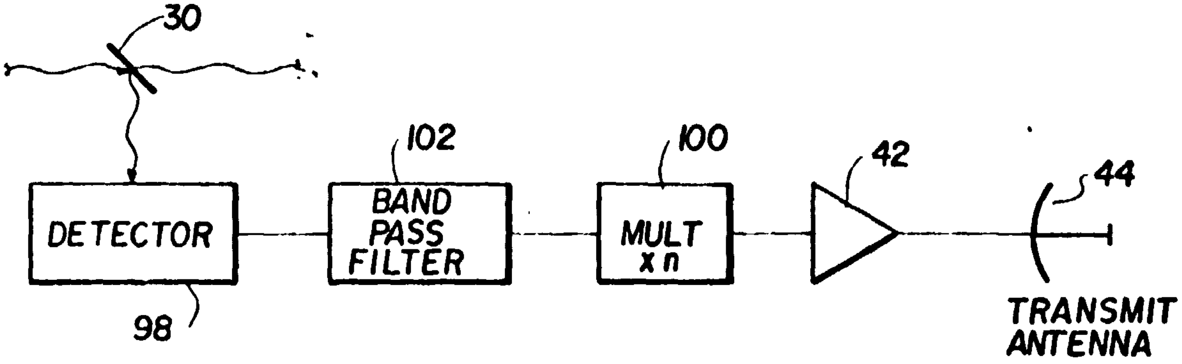


FIG. 3



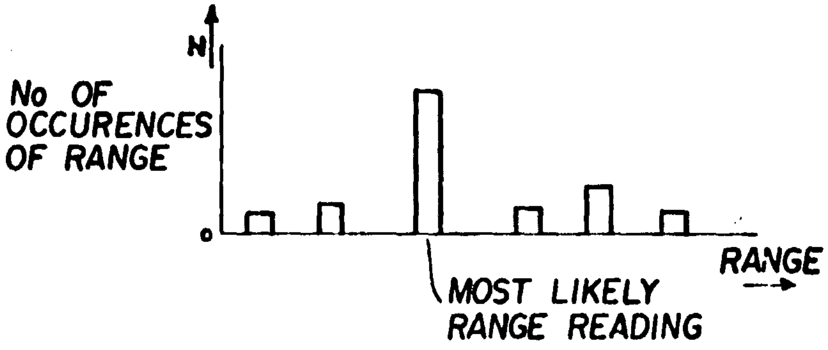


FIG. 5

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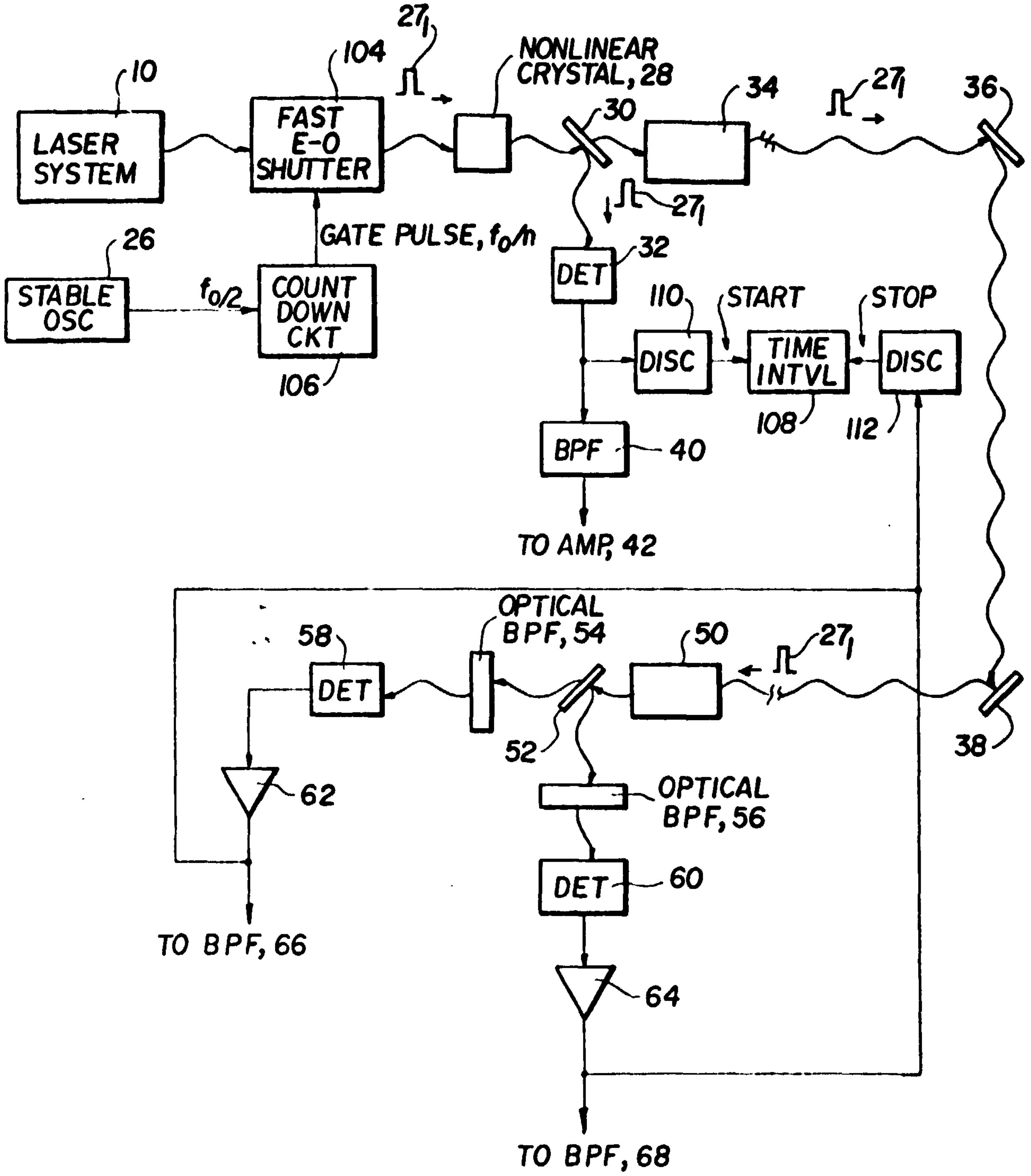

FIG. 4

Origin of the Invention

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

GEODETIC DISTANCE MEASURING APPARATUS

Technical Field

The invention relates generally to distance measuring apparatus and more particularly to geodetic distance measuring apparatus.

Background Art

The most convenient technique for geodetic distance measurement consists in utilizing an instrument which first measures the transit time of electromagnetic waves over the path to be measured, then multiplies transit time by the propagation velocity of the radiation. This propagation velocity depends upon the refractive index of the atmosphere along the path being measured. Typically, the transit time is found through the measurement of the phase difference occurring over the path to be measured between transmitted and received radio frequency signals. To provide directivity, this signal is conventionally transmitted as modulation on respective CW microwave or optical carrier waves.

Heretofore in order to provide the required correction for the refractive index of the atmosphere, this has been accomplished by measuring the barometric pressure and the wet and dry bulk temperatures at various points along the measurement path and converting these measures into an averaged refractive index and propagation velocity value, which is thereafter utilized. More recently, with the emergence of the laser as a radiation source, the phase difference between two different wavelengths of light energy, modulated with an RF signal and projected over an atmospheric path, has been utilized to provide a measure of the integrated dry air and water vapor density in the path. The total phase delay is still measured as before and then corrected by this integrated measurement to provide a measure of the true geometric range being measured.

Optical geodetic distance measurement apparatus, however, has the inherent limitation in that at the high modulation frequencies required for a precise distance measurement, typically in the range of 0.5 to 3GHz, optical modulators are very inefficient and as a result only a relatively small fraction of the light is modulated thereby. Since the modulated light is the only energy used, the majority of the transmitted power is wasted. The maximum range, therefore, is limited by the utilizable laser power. Moreover, when lasers are used as the optical sources, two laser systems are normally required, thus making the size of the system relatively large and cumbersome. Also precise alignment procedures are required for proper operation. Further, when two lasers are modulated the relative phase of the modulation waves must be carefully controlled.

Statement of the Invention

Accordingly, it is an object of the present invention to provide an improvement in apparatus for measuring distances.

Another object of the invention is to provide an improved system for measuring air density and water vapor for correcting for the atmospheric index of refraction required for the measurement of geodetic distances.

Still another object of the invention is to provide an improvement in geodetic distance measuring apparatus using optical means.

A further object of the invention is to provide an improvement in distance measuring equipment by using an optical pulse train for obtaining highly accurate range measurements.

These and other objects are provided in accordance with an optical distance measuring system utilizing a mode locked laser system and its peripheral components which are utilized for generating two harmonically related phase locked optical wavelength signals and one harmonically related microwave signal which respectively traverse the same distance measurement path. Phase comparison of the two optical wavelength signals is used to provide a measure of the dry atmospheric or air density while phase comparison of one of the optical wavelength signals and the microwave signal is used to provide a measure of the wet or water vapor density of the atmosphere. From these measured values a correction factor is provided for making a true measurement of distance to be measured. Also a time interval measurement means is provided to determine the transit time of a single optical pulse signal over the distance to be measured to resolve any ambiguity in range measurements and thereby to give the true geometric range to the target.

The foregoing as well as other objects, features and advantages of the present invention become more apparent from the following detailed description taken in conjunction with the appended drawings.

Brief Description of the Drawings

Figure 1 is a block diagram of the preferred embodiment of the invention;

Figures 2 and 3 are partial block diagrams of apparatus disclosing alternative circuitry for developing the microwave signal utilized in the embodiment shown in Figure 1;

Figure 4 is a partial block diagram illustrative of a circuit for resolving range ambiguity in the embodiment shown in Figure 1; and

Figure 5 is a diagram helpful in understanding the operation of the subject invention as it pertains to resolving range ambiguity.

Detailed Description of the Invention

Referring now to the drawings and more particularly to Figure 1, reference numeral 10 generally designates a mode locked laser system including a laser medium 12 consisting of, for example, a Nd:YAG laser rod situated in a cavity, not shown, terminated by two mirrors 14 and 16, where the mirror 16 acts as the output port in a manner well known to those skilled in the art. The laser medium 12 is excited by an external optical source 18 powered by a high voltage power supply 20. Intermediate the laser medium 12 and the output mirror 16, is located a loss or phase modulator 22 driven by a transducer 24 coupled to a signal $f_0/2$ generated by a stable oscillator 26.

When the laser medium 12 is excited by the excitation source 18, oscillation grows of the optical energy reflected between the two mirrors 14 and 16. The loss or phase modulator 22 is driven at the frequency $f_0/2$ where $f_0 = c/2L$ which is the optical round trip transit time through the cavity between the mirrors 14 and 16 and accordingly, the modulator 22 introduces a time varying loss in the cavity which is proportional to the instantaneous voltage applied to the modulator from the transducer 24. The modulator 22 operates to allow laser oscillation to occur only when the loss is below the laser gain. Because this point occurs at two times during each modulation cycle, it occurs at a repetition rate of the frequency f_0. The laser output from the mirror 16, therefore, consists of a pulse train 27 of optical pulses having a repetition rate of f_0. Where, for example, the laser medium is comprised of a Nd:YAG rod, typically the repetition rate f_0 is in the range of 200MHz-500MHz with the pulsewidth of the optical output pulses being in the order of 100 picoseconds (10×10^{-12}sec.). Alternative laser mediums may be gas mixtures excited by electrical discharges or solid state materials excited by electrical current flows.

For an optical pulse train 27 of the type described above, a Fourier analysis of this pulse train indicates that strong discrete harmonic frequency components are present, with the higher frequencies being odd harmonics of the fundamental frequency f_0. This characteristic is utilized as will be shown as the description of Figure 1 continues. Since the relative strength of the higher frequency components are inversely proportional to the pulsewidth of locked optical pulses, frequency components well into the GHz range exist in the optical pulses of the pulse train 27.

The output pulse train 27 from the mirror 16 of the mode locked laser system 10 comprises a train of optical pulses whose optical carrier has a wavelength λ. The pulses are focused into a non-linear optical device such as crystal 28, typically comprised of $LiNbO_3$ whereupon part of the incoming optical energy of wavelength λ is converted to its second harmonic $\lambda/2$ by means of a well known non-linear 2-photon process. The output of the crystal 28 thus comprises a dual harmonically related pulse train 27 and 29 of a fundamental and second harmonic carrier frequency, respectively, having the same repetition frequency f_0. The intensity vs. time profile of the second harmonic pulse train 29 whose wavelength is $\lambda/2$ is approximately the square of the intensity vs. time profile of the pulse train 27 of the fundamental carrier frequency whose wavelength is λ. Since the conversion process within the crystal 28 acts on the instantaneous laser energy of the λ pulse train input thereto, the $\lambda/2$ output pulse 29 train is inherently phase locked to the fundamental pulse train 27.

The phase locked pulse trains 27 and 29 outputted from the non-linear optical crystal 28 are next directed to a beam splitter 30 which reflects a small portion of the energy of one pulse train, preferably the fundamental pulse train 27, where it is applied to an optical detector 32 which comprises a relatively fast photo-detector such as a Gigahertz bandwidth photo-multiplier or an avalanche photo diode. The remaining optical energy for both pulse trains 27 and 29 is fed to a beam expanding telescope 34 in order to reduce the laser beam divergence following which the beams are directed over a transmission path of the distance to be measured where they impinge on an optical target corner reflector consisting of two reflector elements 36 and 38. Typically, these reflectors have three elements similar to the corner of a box, although only two are shown.

Referring now back briefly to the beam splitter 30 and the photo-detector 32, it was noted that the optical pulse train 27 out of the mode locked laser 10 contains odd harmonics of repetition rate f_0. Accordingly, the portion of the fundamental pulse train 27 applied to the detector 32, following detection, is applied to a bandpass filter 40 which is operable to provide a signal 41 having a carrier frequency of a predetermined odd harmonic, for example, $(2m + 1)f_0$ of the optical pulse repetition rate f_0. M is an integer normally chosen to give a convenient RF frequency (typically in the range of 2 - 10GHz). This harmonic is selected to be in the microwave region of the electromagnetic spectrum. The microwave signal 41 is harmonically related to the optical pulse trains 27 and 29 by the frequency f_0 is amplified in a suitable amplifier 42 and fed to a microwave antenna 44 where it is then transmitted over the same transmission path of the distance to be measured where it impinges upon a microwave corner reflector consisting of the reflective elements 46 and 48. Alternatively, it may be received and retransmitted by a microwave transponder. Thus the distance to be measured is traversed by three separate and distinct pulse trains, two of which 27 and 29, are in the optical region of the electromagnetic spectrum, while the third 41 is in the microwave region, yet all three are phase locked, having been derived from a common source, namely the mode locked laser 10.

Following reflection from the respective corner reflectors, the two optical pulse trains 27 and 29 and the microwave CW train 41 traverse the same distance to be measured back to receiver apparatus located preferably in the same instrument housing, not shown, which includes the transmitter apparatus incorporating all of the system components from the mode locked laser 10 up to the beam expanding telescope 34 and the microwave antenna 44. This is merely for the sake of simplifying operation of the overall system.

Because the two optical frequency pulse trains 27 and 29, traversing the distance path to be measured, will travel at slightly different velocities due to the dispersive nature of dry air of the atmosphere and because of the dispersive nature of water vapor on signals in the microwave region, the microwave CW train 41 will have a velocity of propagation which differs from that of both the optical pulse train signals. As is known, the magnitude of these velocity differences depends on the integrated dry air and water vapor densities in the path to be measured and can be observed as phase differences. These phase differences additionally contain sufficient information to calculate the total amount of signal retardation due to the air in the three respective pulse train paths from which a distance measurement is obtainable, as will be shown.

Considering now the receiver apparatus of Figure 1, the two optical pulse trains 27 and 29 reflected from the optical reflector element 38 are collected by a receiver telescope 50, wherein they are compressed and fed to a dichroic beam splitter 52. There the two optical pulse beams 27 and 29 are separated and fed to respective optical band-pass filters 54 and 56 which have center frequencies substantially at λ and $\lambda/2$, respectively. The optical pulse output from the band-pass filter 54 is fed to a first photo-detector 58, while a second photo-detector 60 is coupled to the output of the $\lambda/2$ band-pass filter 56. Both photo-detectors 58 and 60 are typically comprised of photomultipliers which have the proper spectral sensitivity which respond to the fundamental and second harmonic carrier frequencies of the light pulses. Either static crossed field, dynamic-crossed field or avalanche photo-diodes are illustrative examples of devices which exhibit sufficient bandwidth to detect the fundamental and second harmonic optical output of a Nd:YAG laser. Each detected optical return pulse train is then fed to respective amplifiers 62 and 64 and band-pass filters 66 and 68 which are operable to extract the same harmonic frequency $(2m + 1)f_0$ generated for the microwave signal transmission. The microwave return CW train 41 is similarly collected by a microwave antenna 70. The antenna 70 couples the received microwave pulse train 41 to a suitable microwave matching network 72, the output of which is fed to an amplifier 74. Coupled to the output of the amplifier 74 is a band-pass filter 76 which has a center frequency at the odd harmonic $(2m + 1)f_0$ of the transmitted microwave pulse train.

What has been developed up to this point are three separate signals at a frequency of $(2m + 1)f_0$ which are now coupled to respective microwave mixers 78, 80 and 82 which have applied thereto a local frequency f_{LO} which is derived from the stable oscillator 26 and a frequency translator circuit 84. The mixers 78, 80 and 82 output relatively lower frequency signals f_a, f_b and f_c, respectively, which are of the same frequency but which differ in phase with respect to one another. The signals f_a and f_b are fed to a first phase meter 86 which is operable to provide a dry air density component value while the signals f_a and f_c are fed to a second phase meter 88, which is operable to provide a wet air density component value. The dry and wet component value signals are fed to computer circuitry 90 along with the signals f_a, f_b and f_c which is operable to compute a distance measurement which is compensated for both the dry and wet density of the atmosphere. Such a computation is well known in the art and is expressed in several forms, one example of which is set forth in U.S. Patent 3,435,820 issued to M.C. Thompson, et al. on April 8, 1969, entitled, "Optical Distance Measuring Equipment Utilizing Two Wavelengths Of Light In Order To Determine And Compensate For The Density Of Air". Another example illustrating the use of three wavelength transit time measurements is set forth in a publication entitled, "Space Averages Of Air And Water Vapor Densities By Dispersion For Refractive Correction Of Electromagnetic Range Measurements", M.C. Thompson, Jr., Journal Of Geophysical Research, Vol. 73, May 15, 1968, pp. 3097-3102.

There has been disclosed the preferred embodiment of a multi-wavelength distance measurement apparatus for measuring geodetic distances wherein the signals transmitted over the path to be measured have an inherent phase synchronism as a result of the utilization of the mode locked oscillator and a frequency doubler. While the microwave signal in Figure 1 is shown derived directly from one of the optical pulse trains, e.g. pulse train 27. the invention contemplates alternative embodiments for developing the microwave signal as well as providing another operational mode.

As to the first consideration, reference is made to Figure 2 which discloses means of generating a microwave signal from the stable oscillator 26 rather than from one of the optical pulse trains 27 or 29. As shown in Figure 2, the stable oscillator 26 couples to a frequency multiplier 94 which is adapted to multiply the signal output frequency $f_0/2$ by a factor of $2(2m + 1)$ which is thereafter amplified in an amplifier 96 and radiated from the transmitter 44 as shown in Figure 1 as a continuous wave (CW) signal. When desirable the CW signal can be converted into a pulse signal by the addition of a pulse generator, not shown. Phase coherency and the harmonic relationship is still maintained with the optical pulse output of the mode locked laser 10 due to the fact that the oscillator 26 is utilized to drive the phase modulator 22 in the laser cavity.

The second alternative contemplated for developing the microwave signal consists in utilizing a detector 98 which is operable to be responsive to a lower frequency or wavelength from the beam splitter 30 shown in Figure 1 which is then subjected to a frequency multiplication in a frequency multiplier 100 following a band pass filter 102 as shown in Figure 3. The frequency multiplication provided by the multiplier 100 is operable to provide, for example, the $(2m + 1)f_0$ odd harmonic CW signal 41 which is then fed to the amplifier 42 and radiated from the transmit antenna 44 as shown in Figure 1.

The embodiment of the invention as shown in Figure 1 can, with a minor modification, also resolve any phase ambiguity in range measurement described above. This modification is shown in Figure 4 and can, when desirable, be directly incorporated into a system embodying the circuitry shown in Figure 1, along with suitable switching circuitry, not shown, but which is readily within the skill of a contemporary circuit designer. Referring to Figure 4, an electro-optical shutter 104 is located intermediate the laser system 10 and the non-linear crystal 28. The shutter 104 consists of a fast acting shutter; however, it is operated at a much lower pulse repetition rate, i.e. f_0/n ,than in the embodiment shown in Figure 1. This is achieved by the inclusion of a frequency divider circuit 106 coupled between the stable oscillator 26 (Figure 1) and the shutter 104. The division factor is chosen so that a single optical pulse 27_1 can travel over the transmission path and back before the immediately succeeding pulse is transmitted. Accordingly, a lower repetition rate optical pulse train 27 is applied to the non-linear crystal 28 and the beam splitter 30. A time interval measurement unit 108 is included in the present embodiment and is triggered to start a pulse transit time measurement by means of a discriminator circuit 110 coupled to the output of the detector 32. Accordingly, a transit time interval is started at the exit of one optical pulse 27_1 from the transmitter as it leaves the transmitter portion of the instrument via the beam expanding telescope 34. A second discriminator circuit 112 is coupled either to the output of the amplifier 62 or 64 in the receiver portion to provide a stop signal for the time interval unit 108. Thus the time interval unit 108 measures the propagation or transit time for a particular pulse 27_1 over the transmission path between the transmitting and receiving telescopes 34 and 50. Either output of the amplifiers 62 and 64 can be utilized inasmuch as the fundamental and second harmonic optical pulses are phase locked and therefore in synchronism. Preferably the fundamental wavelength (λ) pulse, i.e. the output of amplifier 62 is used to generate the stop pulse of the time interval unit 108 due to the fact there is less optical path loss in the atmosphere at lower optical frequencies. Theoretically, the measurements provided by the time interval unit 108 will provide range readings which are substantially the same; however, due to the low energy in each transmitter pulse, considerable scatter of the range readings will be provided from such sources as background light, etc.

In practice, a large number of range readings are made and the actual range is determined from the most frequent reading. This is graphically demonstrated by Figure 5. Since this mode of operation need only be used to resolve the ambiguity in range, it only needs to be accurate to better than one cycle of modulation frequency, that is the repetition rate frequency. For normal operation of the distance measuring instrument shown and described herein, no gate pulse would be applied to the shutter 104 and accordingly it would then remain in an open state and all laser pulses generated by the laser system 10 would pass through the shutter unattenuated and operation according to the configuration shown in Figure 1 would result as heretofore described.

Having thus shown and described what is at present considered to be the preferred embodiments of the invention, all modifications, changes and alterations coming within the spirit and scope of the invention as defined in the appended claims are herein meant to be included.

GEODETIC DISTANCE MEASURING APPARATUS

Abstract

A mode locked laser system (10) including a laser device (12, 14, 16, 18, 20) and its peripheral components (22, 24, 26) is utilized for deriving two mutually phase locked optical wavelength signals (27, 29) and one phase locked microwave CW signal (41) which respectively traverse the same distance measurement path. Preferably the optical signals are comprised of pulse type signals. Phase comparison of the two optical wavelength pulse signals (27, 29) is used to provide a measure of the dry air density while phase comparison of one of the optical wavelength pulse signals (27) and the microwave CW signal (41) is used to provide a measure of the wet or water vapor density of the air. From these measurements is computed in means (86, 88, 90) of the distance to be measured corrected for the atmospheric dry air and water vapor densities in the measurement path. Additionally, a time interval unit (108) is included for measuring transit time of individual optical pulses over said distance measurement path for resolving the phase ambiguity needed with the phase measurements to give the true target distance.