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NASA CASE NO. LAR-13,389-1

PRINT FIG. 2

NOTICE

12 P.

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(NASA-Case-LAR-13387-1) PHASE LENGTH OPTICAL PHASE-LOCKED-LOOP SENSOR Patent Application (NASA) 12 p CSCL 20F

N88-25302

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PHASE LENGTH OPTICAL PHASE-LOCKED-LOOP SENSOR

NASA Case No. LAR 13387-1

AWARDS ABSTRACT

The invention is a device that provides a high resolution measurement of the change in optical phase length from the device optical system source to any optical reflector.

The invention consists essentially of a optical phase locked loop that uses a laser beam as a carrier of an intensity modulated energy source. In FIG. 1, a laser beam 12 from a laser 11 is intensity modulated by a modulator 13 that is frequency controlled by a modulation oscillator 17. The laser beam reflected by a target 16 is directed onto an optical detector 20 which converts the intensity signal into an electrical signal. The electrical signal is mixed by a mixer 22 with the oscillator 17 frequency and only the dc signal is passed through a filter 23. The dc signal is applied to an integrator 24 which controls the frequency of the modulation oscillator 17. At one quadrature point, the output of filter will be zero and the integrator 24 will provide a stable operation point for the system. At that point, the frequency of the modulator 13 sets up an exact number of wave lengths in the optical path. Then the target distance can be monitored by a frequency meter 25 by determining the frequency change of oscillator 17.

In an alternate embodiment of the invention as shown in FIG. 2 a gate is added to the modulation source so that the modulation is a tone burst at the modulation frequency of several cycles duration. Gate 26 is controlled by a logic network 27. Logic network 27 counts down the modulation oscillator frequency to generate the gate pulses to modulator 13. Logic network 27 also counts the number of modulation cycles that have occurred since a gate pulse. At a preset number of cycles the logic network strobes the sample hold 28. The sample hold 28 measures the voltage from filter 23 and provides a feedback signal to the integrator 29.

The novelty of the invention appears to lie in the overall combination of elements which provides high resolution

without loss of wide dynamic range. The invention does not depend on coherent reflection from a target, and thus can measure targets that do not have special preparation or corner reflectors. The use of carrier modulation achieves high resolution without the problems of high speed pulse duration systems. Thus the invention has the advantages of simplicity, low cost, and small size without sacrificing resolution.

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Serial No: 154,716
Filed: February 11, 1988

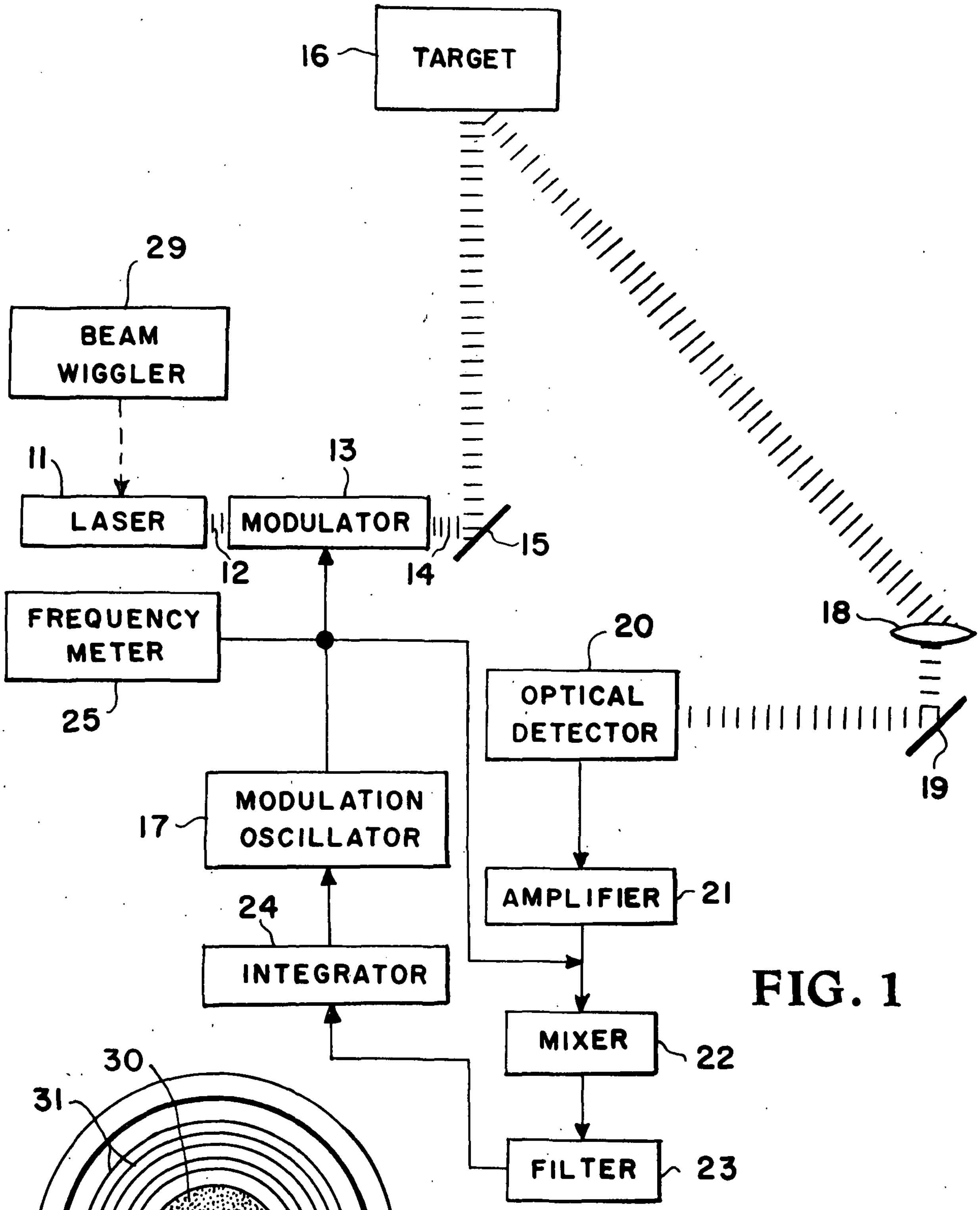
16
TARGET
29
BEAM
WIGGLER
11
LASER
12
13
MODULATOR
14
15
18
FREQUENCY
METER
25
20
OPTICAL
DETECTOR
19
17
MODULATION
OSCILLATOR
AMPLIFIER
21
24
INTEGRATOR
MIXER
22
FILTER
23

FIG. 1

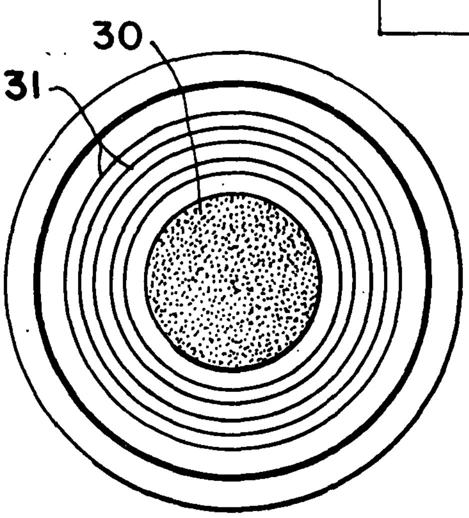
30
31

FIG. 3

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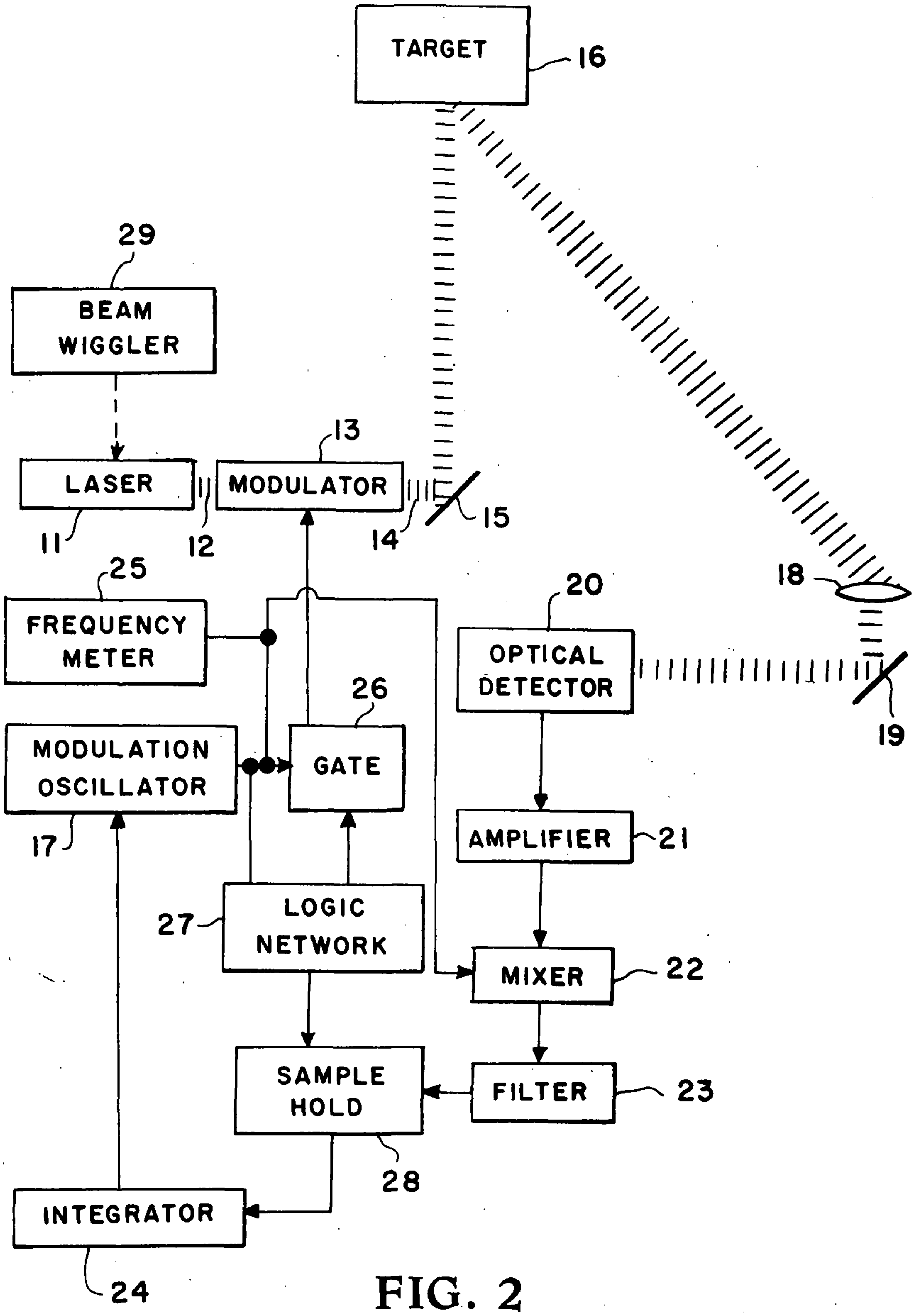
TARGET
16
29
BEAM WIGGLER
13
LASER
MODULATOR
15
11
12
14
25
FREQUENCY METER
20
18
OPTICAL DETECTOR
19
26
MODULATION OSCILLATOR
GATE
17
AMPLIFIER
21
27
LOGIC NETWORK
MIXER
22
SAMPLE HOLD
FILTER
23
28
INTEGRATOR
24

FIG. 2

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SHEET 2 OF 2
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PHASE LENGTH OPTICAL PHASE-LOCKED-LOOP SENSOR

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.

Background of the Invention

The invention relates generally to a remote sensor and more specifically concerns a sensor for providing high resolution measurements of the change in optical phase length from the sensor optical system source to any optical reflector including diffuse reflectors.

The prior art of remote sensing includes interferometry and time of flight using continuous wave and pulsed wave techniques covering the electromagnetic spectrum from optical to low frequency radio waves. For discussion, the prior art is divided into two categories--continuous wave (CW) and pulsed time domain reflectometry (TDR) technologies.

The prior art CW remote sensors have utilized single frequency/coherence of lasers in configurations based on interference. The simplest technique combines the reflected beam with a source reference producing a fringe pattern which can be "counted" to determine phase shifts in the propagation path. More sophisticated methodology combines a spacial filter at the fringe "frequency" with the interferometer and monitors changes in the optical intensity transmitted through the filter. Thus the technology can monitor phase length changes even less than a wavelength. Piezoelectric mirrors can be added to remove selected noise bandwidths as a feedback system. Pulsed techniques depend on time of flight and thus measure the change in group velocity propagation time for a wave packet. In general, a very short burst of optical energy (typically picoseconds) is directed to the target and reflects back to a receiver. The time of flight determines the distance to the target.

The disadvantages of the CW technology are that it can measure small phase changes or can fringe count but cannot maintain its resolution over a wide dynamic range. Also, the reflectors must preserve the phase coherence of the laser beam and thus tend to require optical surfaces such as corner reflectors. For large displacements, the optical CW techniques become error prone caused by missed counts--a fatal error which requires complete recalibration procedures. In addition, most of the optical interferometers are cumbersome, often requiring optical benches and sophisticated antivibration feedback systems to extract meaningful data.

The prior art TDR techniques depend on the rise time of the optical pulse and the rise time of the detector and thus have a specific limitation. A threshold detector determines the pulse timing. Such technology depends on the signal amplitude and thus includes an error term based on the noise threshold crossing. A secondary source of error can come from dispersion of the wave packet in the propagation medium leading to time of flight uncertainty.

An object of this invention is to provide an optical sensor that will make high resolution measurements of the changes in optical phase length from the sensor optical system source to any optical reflector without loss of wide dynamic range.

Another object of this invention is to provide an optical sensor that is simple, low cost, and small size without sacrificing resolution.

A further object of this invention is to provide an optical sensor that uses carrier modulation to achieve high resolution without the problems of high speed pulse duration systems.

Still another object of this invention is to provide an optical sensor that does not depend on coherent reflection from the target, and thus can measure targets that do not have special preparation or corner reflectors.

Other objects and advantages of this invention will become apparent hereinafter in the specification and drawings.

Brief Description of the Invention

The invention is a device that provides a high resolution measurement of the change in optical phase length from the device optical systems source to any optical reflector. The device has the flexibility to operate from micro-dimensional to macro-dimensional changes. It thus serves as an adjustable optical "ruler" providing both high resolution to small changes as well as extremely wide range for monitoring small displacements on systems that are undergoing large displacements.

Combined with finite element analysis tools, the device can determine structural strains and can be used for feedback control of space structures and monitoring of dynamic responses. In addition, the device can monitor changes in the optical index of the propagation path when used with fixed reflectors. Thus, the device can monitor, for example, small changes in humidity, or any other parameter that changes the optical phase velocity.

The device is an optical phase locked loop that uses a laser beam as a carrier of an intensity modulated energy source. The laser beam passes through a modulator and is directed by a mirror to a target. The modulator intensity modulates the laser beam at a frequency controlled by a modulation oscillator. The laser beams reflected by the target is directed onto an optical detector which converts the intensity signal into an electrical signal. The electrical signal is mixed with the oscillator frequency and only the dc signal is passed by a filter. The dc signal is applied to an integrator which controls the frequency of the modulation oscillator.

Brief Description of the Drawings

FIG. 1 is a block diagram of the invention;

FIG. 2 is a block diagram of an alternate embodiment of the invention; and

FIG. 3 is an example of a target identifier

Detailed Description of the Invention

Turning now to the embodiment of the invention selected for illustration in the drawings, the number 11 in FIG. 1 designates a laser. Laser 11 generates a laser beam 12 that is intensity modulated by a modulator 13. The resulting modulated beam 14 is directed by a mirror 15 onto a target 16. Modulator 13 intensity modulates the laser beam 12 at a frequency controlled by a modulation oscillator 17. Modulated laser beam 14 is reflected by the target 16 to a lens 18. Lens 18 focuses the reflected beam and is directed by a mirror 19 onto an optical detector 20 which converts the intensity signal into an electrical signal. The electrical signal is amplified by an amplifier 21 and then mixed with the frequency signal from modulation oscillator 17 by means of a mixer 22. The resulting sum frequency at the output of mixer 22 is removed by a filter 23. The difference frequency passed through filter 23 is used as a measure of the relative phase of the modulated signal with respect to the modulation oscillator 17 phase. The difference frequency passed through filter 23 is at zero frequency (or DC) and is either a positive voltage or a negative voltage depending on the phase difference between the modulation oscillator signal and the detected optical signal. The DC voltage at the output of filter 23 is integrated by an integrator 24 and is used to control the frequency of modulation oscillator 17. At one quadrature point, the output of filter 23 will be zero and the integrator 24 will provide a stable operation point for the system by feedback control to the frequency of the modulation oscillator 17. At that point, the frequency of the modulator 13 (neglecting phase shifts in the electronics) sets up an exact number of wave lengths in the optical path through the following equation:

$$F_M = MC/L \text{ or } L = MC/F_M$$

Where F_M is the modulation oscillator frequency, M is the harmonic number (the number of modulation cycle in the propagation path length), C is the optical phase velocity, and L is the optical path length. The value of M can be found using two consecutive quadrature lock points, and thus the length, L, is uniquely determined:

$$F_M - F_{M+1} = C/L; \; M = F_M/\delta F$$

With the phase locked loop locked, the condition of quadrature is maintained so that the phase, θ, of the system cannot change. Any change in L, therefore, must change the modulation frequency. The phase is determined from the following equations:

$$\theta = 2\pi F_M L/C \text{ and } \delta\theta/\delta L = [2\pi/c][F_M + L\delta F_M/\delta L] = 0.$$

Therefore, the fundamental relationship for movement of the target along the axis of the optical path for small displacements with respect to L is:

$$[\Delta F_M/F_M] = -[\Delta L/L] \text{ or } \Delta L = L[\Delta F_M/F_M]$$

As the target moves, the lock frequency will remain at quadrature and the target distance change can be monitored from the modulation frequency changed as measured by a frequency meter 25. For large displacements, it is necessary to integrate the equation over the path. With diode lasers or electro-optic modulations, frequencies up to GH_z are possible. That corresponds to a modulation envelope wavelength of less than thirty centimeters. Projected displacement resolution is $\Delta L/L = 10^{-8}$ or for this case 30Å. At the same time, it is known that the system is at quadrature, so that high resolution does not prevent broad dynamic range.

In an alternate embodiment of the invention as shown in FIG. 2 a gate 26 is added to the modulation source so that the modulation is a tone burst at the modulation frequency of several cycles duration to define the modulation phase. The output of modulation oscillator 17 passed through gate 26 acts on the modulator 13 or can act directly on the laser 11 as in controlling current to a laser diode. Gate 26 is controlled by a logic network 27. Logic network 27 has an input from modulation oscillator 17 and counts down the modulation oscillator frequency to generate the gate pulses to the modulator 13. Each gate pulse width is controlled by the logic network 27 to output a preset number of modulation cycles. The logic network 27 also counts the number of modulation cycles that have occurred since the gate pulse. At a preset number of cycles, corresponding to the time of the returned optical signal, the logic network strobes the sample hold 28. The sample hold 28 measures the voltage from the filter 23 at the user selected logic sample hold control time when the pulsed modulated wave is present and provides a feedback signal to the integrator 24.

In addition, the device can be aimed to specific targets spatially locking onto them with an X,Y beam wiggler 29 that operates in a bandwidth different from the modulator 13. The wiggler consists of a device for deflecting the laser 11 in two directions which are perpendicular (XY) for locating the target. The deflecting device may be a Bragg cell, a rotating mirror or a mechanical system for moving the body of the laser. These devices are commonly used in industrial instruments.

Specific targets will be identified with a unique code that can be read by the scanning laser beam. The code is generated at the detector 20 by the reflected laser beam as it scans the target. The code is produced at the target 16 by a series of concentric circles of high and low reflectivity which produce pulses of light at the detector as the laser scans across the circular pattern. The signal is analogous to that produced by a bar code except that it is two-dimensional rather than one-dimensional. Once the target is identified by its unique reflected signal, the laser can lock onto the target by scanning back and forth over the center of the circular pattern. The reflectivity at the center of the pattern is such that a sinusoidal signal intensity is generated at the detector for locking the laser to the target. An example of a target identifier with a center reflector 30 and concentric circles 31 of high and low reflectivity is shown in FIG. 3.

An additional embodiment of the invention includes a frequency mixed laser (using a Brag cell) that locks onto the laser frequency itself for wavelength locking.

The use of this invention is broad and includes most measurement situations requiring information of length, vibration and their derivatives. Thus the invention can determine distances, structural modal displacements, vibration from "DC" frequencies to GH_z frequencies. Applications include building dynamics, remote sensing of system vibrations such as turbine based machinery; structural dynamics monitoring, non-contacting surface contour sensor, measurements of large distance strains such as earthquake monitoring, measurement of atmospheric dynamics and turbulence, high resolution humidity sensor, detector of surface acoustic waves, optical microscopy microdistance maping tool, and related areas. Space use includes use for structural dynamics control, measurement of closing distances for docking systems, structural element length sensor combined with finite element analysis to determine full structural strain, antenna figure contour monitor, surveillance sensor for detection of vibration indicating activity, and related concepts.

The advantage of this invention is high resolution without loss of wide dynamic range. In effect by choosing the modulation frequency, one can choose the degree of sensitivity of the device. The device does not depend on coherent reflection from the target, and thus can measure targets that do not have special preparation or corner reflectors. The use of carrier modulations achieves high resolution without the problems of high speed pulse duration systems. Thus the invention has the advantage of simplicity, low cost, and small size without sacrificing resolution.

What is claimed is:

PHASE LENGTH OPTICAL PHASE-LOCKED-LOOP SENSOR

Abstract of the Disclosure

A laser beam 12 is intensity modulated by a modulator 13 at a frequency F from a modulation oscillator 17. The modulated beam is directed to a target 16 and the reflected beam is changed into an electrical signal by an optical detector 20. The detected electrical signal is mixed with the modulation oscillator 17 signal by a mixer 22. The difference frequency is obtained by a filter 23 to produce a DC signal. The DC signal is integrated by an integrator 24 and used to control the frequency of modulation oscillator 17. The system becomes stabilized when the mixed signals are in phase quadrature. Now the frequency of oscillator 17 is $F \pm \Delta F$, ΔF being indicative of measurements.