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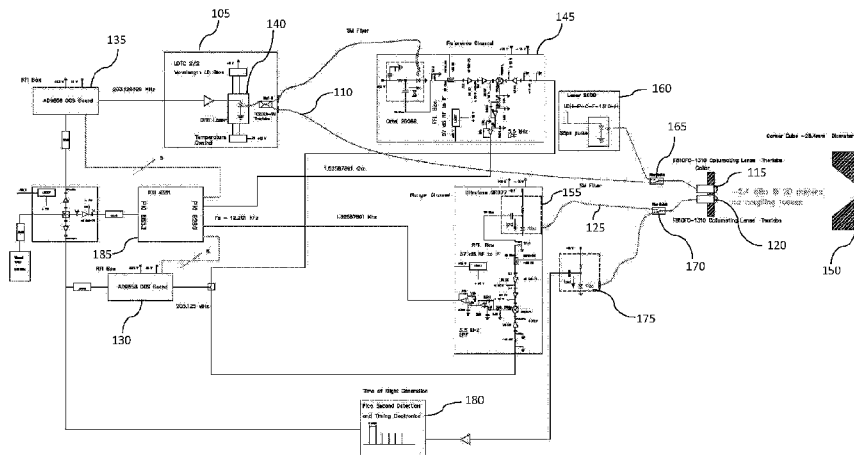


FIGURE 1

(57) Abstract: Laser rangefinders and methods of using laser rangefinders are disclosed. One embodiment of a laser rangefinder in-
cludes a first DDS (direct digital synthesizer) outputting a first reference signal, an isolated laser source that receives the first signal
and outputs an optical signal, a collimating lens coupled to the isolated laser source adapted to direct the optical signal to free space,
a collecting lens positioned adjacent to the collimating lens adapted to receive a modulated optical signal from free space, a pin di-
ode detector coupled to collecting lens, a second DDS outputting a second reference signal, and a computing device adapted to re-
ceive the first reference signal, the second reference signal, and the received modulated optical signal and calculate a distance.

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FIBER OPTIC BASED LASER RANGE FINDER

Rights in the Invention

This invention was made with government support under Cooperative
5 Agreements AST-0223851 and AST-0836064, between the National Science Foundation
and Associated Universities, Inc., and, accordingly, the United States government has
certain rights in this invention.

Reference to Related Applications

10 This application claims priority to U.S. Provisional Application No. 62/112,234,
filed February 5, 2015, which is entitled "Fiber Optic Based Laser Range Finder," and is
hereby specifically and entirely incorporated by reference.

Background

15 1. Field of the Invention

This invention is directed to a distance measuring apparatus and methods, and, in
particular, to a fiber optic based laser ranger finder.

2. Background of the Invention

Large-scale metrology includes the measurement of coordinates over large
20 distances, for example, greater than the volume of a conventional coordinate
measurement machine (CMM), which is typically limited to a cube of a few meters.
There are many instances, for example in the aircraft industry, radio telescope and linear
accelerator applications, where measuring such distances is preferably accomplished with
a high degree of accuracy. There are also field measurements of smaller scale which do
25 not lend themselves to placement in a CMM, such as in situ measurements of machinery,
outdoor measurements, shop floor measurements, and other well known approaches.

The measurement of coordinates is typically accomplished by measuring a
distance and two angles, as with a conventional surveying total station or laser tracking
interferometer; the measurement of three orthogonal distances, as with a CMM; the
30 measurement of angles from two locations on a known baseline, such as with theodolites;
the measurement of spacing on a two-dimensional image projection from multiple
locations, as with photogrammetry; the measurement of distance from three, or more,

known locations on a baseline, as with multilateration; and various other manners. “Large-Scale Metrology – An Update”, Estler, et. al., CIRP Annals - Manufacturing Technology 51(2), 2002, discusses various techniques for large scale metrology.

5 Laser rangefinders measure distance by measuring the time taken to propagate an optical wavefront from the emitter to target and back and inferring distance from a known or predicted propagation speed. One modality of time measurement is to modulate the amplitude of the CW emitted wavefront and measure the phase difference of the received wavefront modulation with respect to the transmitted one. Techniques of this type are described in Electronic Distance Measurement, J. M. Rueger, 3rd. Ed., Springer-Verlag, 10 New York, 1990. “Sources of error in a laser rangefinder”, K. S. Hashemi, et al., Rev. Sci. Instrum. 65(10) October 1994 discusses a laser rangefinder and the associated sources of error.

The National Radio Astronomy Observatory (NRAO) Robert C. Byrd Green Bank Telescope (GBT) is a 100m diameter advanced single dish radio telescope designed 15 for a wide range of astronomical projects with special emphasis on precision imaging. Open-loop adjustments of the active surface, and real-time corrections to pointing and focus on the basis of structural temperatures already allow observations at frequencies up to 50 GHz. Operation at higher frequencies requires more precise knowledge of optical element position and pose.

20 Limitations in the prior art do not permit the requisite length measurement accuracy. Limitations include variable phase delays in the detector due to beam spot position uncertainty, run-out of the steering mirror leading to systematic range errors, low rates of zero-point measurements (and equivalently, low chopping rates) leading to inclusion of low-offset frequency phase noise errors, and imprecise measurement of the 25 coupling from transmitter to receiver electronics and optics leading to cyclic errors. The ambiguity in absolute range in single modulation CW rangefinders is also problematic, necessitating prior knowledge of range to less than one-half of the ambiguity range. In addition, economies can be obtained if the control and electro-optics needed for measurement can be multiplexed amongst diverse baselines.

30

Summary of the Invention

The present invention overcomes the limitations and disadvantages associated with current strategies and designs and provides fiber optic based laser rangefinders and methods of using the laser rangefinders.

5 One embodiment of the invention is directed to a laser rangefinder. The laser rangefinder includes a first DDS (direct digital synthesizer) outputting a first reference signal, an isolated laser source that receives the first signal and outputs an optical signal, a collimating lens coupled to the isolated laser source adapted to direct the optical signal to free space, a collecting lens positioned adjacent to the collimating lens adapted to
10 receive a modulated optical signal from free space, a pin diode detector coupled to collecting lens, a second DDS outputting a second reference signal, and a computing device adapted to receive the first reference signal, the second reference signal, and the received modulated optical signal and calculate a distance.

Preferably, the laser rangefinder further includes a first single mode fiber optic
15 cable coupling the optically isolated laser source to the collimating lens and a second single mode fiber optic cable coupling the collecting lens to the pin diode detector. The computing device preferably calculates the distance by sampling the difference in frequency of the reference frequency and returned modulated optical signal. In a preferred embodiment, the first reference signal and the second reference signal are of
20 different frequencies.

Preferably, the isolated laser source is a diode laser. Preferably, the diode laser is intensity modulated by the first DDS. The laser rangefinder preferably further includes a double balance mixer. In a preferred embodiment, the collimating lens and the collecting
lens are directed toward a reflector.

25 Another embodiment of the invention is directed to a method of measuring a distance with a laser rangefinder. The method includes the steps of outputting a first reference signal at a first DDS (direct digital synthesizer), receiving the first reference signal at an isolated laser source, outputting an optical signal from the isolated laser source, directing the optical signal to free space with a collimating lens coupled to the
30 isolated laser source, receiving a modulated optical signal from free space at a collecting lens positioned adjacent to the collimating lens, detecting the modulated optical signal at

a pin diode detector coupled to the collecting lens, outputting a second reference signal at a second DDS, and calculating the distance on a computing device based on the first reference signal, the second reference signal, and the received modulated optical signal.

In a preferred embodiment a first single mode fiber optic cable couples the
5 optically isolated laser source to the collimating lens and a second single mode fiber optic cable couples the collecting lens to the pin diode detector. Preferably, the computing device calculates the distance by sampling the difference in frequency of the reference frequency and returned modulated optical signal. The first reference signal and the second reference signal are preferably of different frequencies. Preferably the isolated
10 laser source is a diode laser. The diode laser is preferably intensity modulated by the first DDS. The method preferably further includes the step of directing the collimating lens and the collecting lens toward a reflector.

Another embodiment of the invention is directed to a laser rangefinder. The laser rangefinder includes a first DDS (direct digital synthesizer) outputting a first reference
15 signal, an isolated laser source that receives the first signal and outputs an optical signal, a pulsed laser source outputting a pulsed laser, a first optical switch coupled to the isolated laser source and the pulsed laser source, a collimating lens coupled to the first optical switch adapted to direct the optical signal and pulsed laser to free space, a collecting lens positioned adjacent to the collimating lens adapted to receive a modulated
20 optical signal and a return pulse from free space, a second optical switch coupled to the collecting lens, a broad band pin diode detector coupled to the second optical switch adapted to received the return pulse, gating electronics coupled to the broad band pin diode detector adapted to determine the total time between when the pulsed laser was transmitted and the return pulse arrived and calculate an absolute distance, a pin diode
25 detector coupled to the second optical switch adapted to receive the modulated optical signal, a second DDS outputting a second reference signal, and a computing device adapted to receive the first reference signal, the second reference signal, and the received modulated optical signal and calculate a distance.

In a preferred embodiment the laser rangefinder further includes a first single
30 mode fiber optic cable coupling the optically isolated laser source to the collimating lens and a second single mode fiber optic cable coupling the collecting lens to the pin diode

detector. Preferably, the computing device calculates the distance by sampling the difference in frequency of the reference frequency and returned modulated optical signal. The first reference signal and the second reference signal are preferably of different frequencies.

5 Preferably, the isolated laser source is a diode laser. Preferably, the diode laser is intensity modulated by the first DDS. The laser rangefinder preferably further includes a double balance mixer. In a preferred embodiment, the collimating lens and the collecting lens are directed toward a reflector. Preferably, the pulsed laser is associated with the broad band pin diode detector and the isolated laser source is associated with the pin
10 diode detector. In a preferred embodiment, the pulsed laser is used to determine absolute distance and the isolated laser source is used to increase the accuracy of the distance measurement.

 Another embodiment is directed to a method of measuring a distance with a laser rangefinder. The method includes the steps of outputting a pulsed laser from a pulsed
15 laser source, directing the pulsed laser to free space with a collimating lens coupled to the pulsed laser source, receiving a return pulse from free space at a collecting lens positioned adjacent to the collimating lens, detecting the return pulse at a broad band pin diode detector, determining the total time between when the pulsed laser was transmitted and the return pulse arrived and calculate an absolute distance at gating electronics
20 coupled to the broad band pin diode detector, outputting a first reference signal at a first DDS (direct digital synthesizer), receiving the first reference signal at an isolated laser source, outputting an optical signal from the isolated laser source, directing the optical signal to free space with the collimating lens coupled to the isolated laser source, receiving a modulated optical signal from free space at the collecting lens, detecting the
25 modulated optical signal at a pin diode detector coupled to the collecting lens, outputting a second reference signal at a second DDS, and improving the accuracy of the absolute distance measurement on a computing device based on the first reference signal, the second reference signal, and the received modulated optical signal.

 In a preferred embodiment a first optical switch couples both the pulsed laser
30 source and the isolated laser source to the collimating lens and a second optical switch couples both the broad band pin diode detector and the pin diode detector to the

collecting lens. Preferably, the computing device calculates the distance by sampling the difference in frequency of the reference frequency and returned modulated optical signal. Preferably, the first reference signal and the second reference signal are of different frequencies. In a preferred embodiment, the isolated laser source is a diode laser. The diode laser is preferably intensity modulated by the first DDS. The method preferably further includes the step of directing the collimating lens and the collecting lens toward a reflector.

While the present invention may be embodied in many different forms, a number of illustrative embodiments are described herein with the understanding that the present disclosure is to be considered as providing examples of the principles of the invention and such examples are not intended to limit the invention to preferred embodiments described herein and/or illustrated herein.

Description of the Drawings

The invention is described in greater detail by way of example only and with reference to the attached drawings, in which:

Figure 1 depicts block diagram of an embodiment of a laser ranger.

Figure 2 depicts the measured error produced an embodiment of the phase detector. The data was taken by inserting a known phase shift 58.25° at difference absolute phase differences, $\Delta\theta$, between the LO and RF signals at frequency ω . The error indicates the nonlinearity across the entire range of 360° .

Figure 3 depicts the measured error of an embodiment of the range finder. The data is the deviation after a known linear systematic error is removed. The error indicates the nonlinearity in the measured range of -120 mm to 120 mm.

Description of the Invention

As embodied and broadly described herein, the disclosures herein provide detailed embodiments of the invention. However, the disclosed embodiments are merely exemplary of the invention that can be embodied in various and alternative forms.

Therefore, there is no intent that specific structural and functional details should be limiting, but rather the intention is that they provide a basis for the claims and as a

representative basis for teaching one skilled in the art to variously employ the present invention.

Large-scale metrology involves the measurement of coordinates over large distances. The measurement of coordinates over large distances is typically
5 accomplished by measuring a distance and two angles, as with a conventional surveying total station or laser tracking interferometer. One type of metrology device transmits an intensity modulated signal, and then, using a heterodyne receiver, measures the difference in phase of the received AM signal with that of a local oscillator that has the same phase as the transmitted signal. Based on the index of refraction of the medium the path length
10 from the transmitter to the receiver can be inferred. Measurements by conventional metrological devices are limited by the ambiguity modulo 2π radians between the phase of the AM signal and the phase of the local oscillator.

A ranging system for accurately measuring the distance to a retro-reflector for lengths greater than 100 meters is disclosed using fiber optic technology. To improve
15 accuracy and determine absolute distances, a time of flight measuring technique is preferably combined with a differential phase technique. Since the wavelength of a picosecond pulsed laser is the same as the intensity modulated laser diode, preferably an optical switch can switch between the measurement techniques. The differential phase method preferably has higher signal to noise ratio and is better suited for locating a retro-
20 reflector. The differential phase method allows a more accurate determination of position, but is limited to a relative measure constrained by the intensity modulation wavelength. The time of flight option is capable of measuring absolute distance but with less accuracy and more power consumption.

As depicted in figure 1, preferably, an optically isolated semiconductor laser is
25 intensity modulated at a frequency that determines the modular wavelength of the measurement. A single mode fiber optic cable 110 preferably connects the optically isolated laser source 105 to a collimating lens 115 where an adjacent collecting lens 120 preferably directs the returned laser power via another single mode fiber 125 to the pin diode detector 155. The returned de-modulated laser power preferably contains the phase
30 information necessary to accurately measure the desired relative distance. Currently, accuracy is not noise limited but rather limited from phase detection nonlinearities. The

phase measurement and distance calculation is preferably accomplished by sampling the difference frequency of the reference frequency and detected modulated laser signal. A proposed lock-in amplifier phase measurement could potentially improve the accuracy of the system.

5 The time of flight method preferably uses a pulsed laser and broad band pin diode detector. This method determines the round trip travel time of the pulse by tracking the number of clock pulse between the transmit time and arrival time of the detected pulse. An absolute distance then can be calculated from the travel time.

10 **Differential Phase DDS Synthesizer**

As depicted in figure 1, two DDS (direct digital synthesizer) chips 130 and 135 are set to 203.125 MHz and 203.125 MHz plus 1.52587891 KHz giving a measurement wavelength of $\lambda = 1.4758902447764064$ meters. The direct digital synthesizer's ICs (integrated circuits) are very temperature sensitive and prone to overheating. Preferably
15 each DDS is grounded to create good thermal path from the IC package to the heat sink. Each DDS is preferably mounted in thermally connected mechanical enclosures, which allow the phase of the devices to track as the temperature changes. The effective temperature coefficient for these devices is $\sim 100 \text{ um}/^\circ \text{C}$. Thus, the temperatures of the enclosures are preferably held within 1°C for 100 um accuracy. The DDS chips are
20 preferably programmed via a serial data input, a clock input and a control bit. These are optically isolated with Optical Isolator devices and then input to a serial to parallel registers. A frequency update (FUD), reset, and write control lines may also be used to program the devices. A National Instruments PXI platform computer, 185, samples the reference and returned signals then calculates the phase difference and converts to
25 distance using internal routines. This computer may be replaced with a lock-in amplifier detection to improve the accuracy of the measurement.

Differential Phase Optics

Often, reflected energy reentering the semiconductor laser cavity causes phase
30 instability. Diode lasers typically incorporate a Faraday isolator at the laser output to eliminate this effect. Preferably, a diode laser 140 of optical wavelength 1310

nanometers is utilized. The electronics', including the laser and photodetector's, noise limitation is preferably less than 10 micrometers rms distance ranging with the following parameters: bandwidth of about 100 Hz, integration time of about 0.167 mS, 20 dB optical loss, and 0 dBm RF input power. The signal to noise ratio with these parameters is 120 dB/Hz over a 20-meter distance. From this experiment, the RF signal level and optical power level must be increased by 14 dB to achieve the same accuracy at 100 meter ranging. The transmitter is preferably temperature controlled and biased with a controller mounted in an RFI tight enclosure to reduce cross coupling from the reference channel.

The diode laser is preferably intensity modulated with one of the DDS synthesizers. The optical signal is then preferably split by a 1% coupler, with the coupled path input to a reference detector 145. The 99% path is coupled to free space with a collimating lens 115 directed to a target, for example hollow corner cube 150. Preferably, transmit lens 115 and collecting lens 120 are fixed in place. However, transmit lens 115 and collecting lens 120 can be movable or use mirrors to focus on different targets. The transmit lens 115 preferably has a calculated optical loss of about 13 dB at 100 meters from the divergence of the beam. Metrology Lab experiments indicate that the actual path loss for 20 meters is about 20 dB, which indicates an extra 14 combined coupling and reflection loss. A photodetector 120 is preferably a photodetector chip and a collimating lens. The lens preferably has a 8.0mm clear aperture to captured sufficient reflected energy for 100 meter operation.

The ideal response is determined by:

$$A \times \text{Sin} (\omega t + \Delta \theta),$$

where, ω , is the frequency difference between the transmit and local oscillator frequencies, $\Delta\theta$ is the phase difference and the amplitude, A, is a function of signal amplitudes and detector gain. The term $\Delta\theta$ is a function of the absolute difference, which creates nonlinearities in response. The isolation between LO (local oscillator) and RF (radio frequency) ports of the mixer determines the magnitude of the nonlinearity. The mixer circuit design preferably reduces phase error caused by the random phase setting of the local oscillator. The device preferably utilizes an internally designed double

balance mixer, optimized for the ranger frequency, that is mounted in a block that reduces coupling between LO and RF. Additionally, Schottky diodes are preferably employed. The capacitance of the Schotky diodes determines the input impedance, and ultimately coupling loss. A surface mount package quad ring with a capacitance of 5 pf is preferably additionally included. The device is preferably constructed on 1/8" FR4 pc board material with the toroidal baluns wound on 11-040-K material. The phase accuracy over 360 degrees is shown in the Figure 2 with Figure 3 giving the corresponding range accuracy. Preferably, a 0.020" thick board is utilized. The design equations for the mixer are, $Z_{cap} = -j156 \Omega @ 201 \text{ MHz}$, $Z_{in} = 50$ with balun equation:

$$N^2 = \frac{Z_{in}}{2 * Z_{cap}} = 1.5 \text{ turns} .$$

Time of Flight Measurement

A pulsed laser 160 is preferably coupled to the fiber optic to free space optics 115 with the addition of an optical switch 165. Another optical switch 170 in the receive path 120 preferably directs the return pulse to a broad band pin diode detector and amplifier 175 used in the narrow band pulse. Gating electronics 180 preferably determine the total time between when the pulse was transmitted and the return pulse arrived. The absolute distance is preferably determined by the total travel time and assumptions of the integrated index of refraction along the flight path of the pulse. Accuracy is a function of the pulse width and sampling time of the gating electronics. With a pulse width of $t = 50$ picoseconds, the highest resolution of the measurement is,

$$\frac{c \tau}{2} = 7.5 \text{ mm}$$

This would preferably require a sampling frequency of 40 GHz. Since the differential phase method described herein can resolve distances less than $\lambda/2$, or 738 mm, the sampling frequency can by lowered by a factor of 100 to 400 MHz and still achieve the desired accuracy. The modulation frequency and sampling frequency can be adjusted to optimize the performance of the system.

Other embodiments and uses of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed

herein. All references cited herein, including all publications, U.S. and foreign patents and patent applications, are specifically and entirely incorporated by reference. It is intended that the specification and examples be considered exemplary only with the true scope and spirit of the invention indicated by the following claims. Furthermore, the
5 term “comprising of” includes the terms “consisting of” and “consisting essentially of.”

Claims

1. A laser rangefinder comprising:
a first DDS (direct digital synthesizer) outputting a first reference signal;
an isolated laser source that receives the first signal and outputs an optical signal;
a collimating lens coupled to the isolated laser source adapted to direct the optical signal to free space;
a collecting lens positioned adjacent to the collimating lens adapted to receive a modulated optical signal from free space;
a pin diode detector coupled to collecting lens;
a second DDS outputting a second reference signal; and
a computing device adapted to receive the first reference signal, the second reference signal, and the received modulated optical signal and calculate a distance.
2. The laser rangefinder of claim 1, further comprising a first single mode fiber optic cable coupling the optically isolated laser source to the collimating lens and a second single mode fiber optic cable coupling the collecting lens to the pin diode detector.
3. The laser rangefinder of claim 1, wherein the computing device calculates the distance by sampling the difference in frequency of the reference frequency and returned modulated optical signal.
4. The laser rangefinder of claim 1, wherein the first reference signal and the second reference signal are of different frequencies.
5. The laser rangefinder of claim 1, wherein the isolated laser source is a diode laser.
6. The laser rangefinder of claim 5, wherein the diode laser is intensity modulated by the first DDS.

7. The laser rangefinder of claim 1, further comprising a double balance mixer.
8. The laser rangefinder of claim 1, wherein the collimating lens and the collecting lens are directed toward a reflector.
9. A method of measuring a distance with a laser rangefinder, comprising:
outputting a first reference signal at a first DDS (direct digital synthesizer);
receiving the first reference signal at an isolated laser source;
outputting an optical signal from the isolated laser source;
directing the optical signal to free space with a collimating lens coupled to the isolated laser source;
receiving a modulated optical signal from free space at a collecting lens positioned adjacent to the collimating lens;
detecting the modulated optical signal at a pin diode detector coupled to the collecting lens;
outputting a second reference signal at a second DDS; and
calculating the distance on a computing device based on the first reference signal, the second reference signal, and the received modulated optical signal.
10. The method of claim 9, wherein a first single mode fiber optic cable couples the optically isolated laser source to the collimating lens and a second single mode fiber optic cable couples the collecting lens to the pin diode detector.
11. The method of claim 9, wherein the computing device calculates the distance by sampling the difference in frequency of the reference frequency and returned modulated optical signal.
12. The method of claim 9, wherein the first reference signal and the second reference signal are of different frequencies.
13. The method of claim 9, wherein the isolated laser source is a diode laser.

14. The method of claim 13, wherein the diode laser is intensity modulated by the first DDS.
15. The method of claim 9, further comprising directing the collimating lens and the collecting lens toward a reflector.
16. A laser rangefinder comprising:
 - a first DDS (direct digital synthesizer) outputting a first reference signal;
 - an isolated laser source that receives the first signal and outputs an optical signal;
 - a pulsed laser source outputting a pulsed laser;
 - a first optical switch coupled to the isolated laser source and the pulsed laser source;
 - a collimating lens coupled to the first optical switch adapted to direct the optical signal and pulsed laser to free space;
 - a collecting lens positioned adjacent to the collimating lens adapted to receive a modulated optical signal and a return pulse from free space;
 - a second optical switch coupled to the collecting lens;
 - a broad band pin diode detector coupled to the second optical switch adapted to received the return pulse;
 - gating electronics coupled to the broad band pin diode detector adapted to determine the total time between when the pulsed laser was transmitted and the return pulse arrived and calculate an absolute distance;
 - a pin diode detector coupled to the second optical switch adapted to receive the modulated optical signal;
 - a second DDS outputting a second reference signal; and
 - a computing device adapted to receive the first reference signal, the second reference signal, and the received modulated optical signal and calculate a distance.

17. The laser rangefinder of claim 16, further comprising a first single mode fiber optic cable coupling the optically isolated laser source to the collimating lens and a second single mode fiber optic cable coupling the collecting lens to the pin diode detector.
18. The laser rangefinder of claim 16, wherein the computing device calculates the distance by sampling the difference in frequency of the reference frequency and returned modulated optical signal.
19. The laser rangefinder of claim 16, wherein the first reference signal and the second reference signal are of different frequencies.
20. The laser rangefinder of claim 16, wherein the isolated laser source is a diode laser.
21. The laser rangefinder of claim 20, wherein the diode laser is intensity modulated by the first DDS.
22. The laser rangefinder of claim 16, further comprising a double balance mixer.
23. The laser rangefinder of claim 16, wherein the collimating lens and the collecting lens are directed toward a reflector.
24. The laser rangefinder of claim 16, wherein the pulsed laser is associated with the broad band pin diode detector and the isolated laser source is associated with the pin diode detector.
25. The laser rangefinder of claim 24, wherein the pulsed laser is used to determine absolute distance and the isolated laser source is used to increase the accuracy of the distance measurement.
26. A method of measuring a distance with a laser rangefinder, comprising:
outputting a pulsed laser from a pulsed laser source;

directing the pulsed laser to free space with a collimating lens coupled to the pulsed laser source;

receiving a return pulse from free space at a collecting lens positioned adjacent to the collimating lens;

detecting the return pulse at a broad band pin diode detector;

determining the total time between when the pulsed laser was transmitted and the return pulse arrived and calculate an absolute distance at gating electronics coupled to the broad band pin diode detector;

outputting a first reference signal at a first DDS (direct digital synthesizer);

receiving the first reference signal at an isolated laser source;

outputting an optical signal from the isolated laser source;

directing the optical signal to free space with the collimating lens coupled to the isolated laser source;

receiving a modulated optical signal from free space at the collecting lens;

detecting the modulated optical signal at a pin diode detector coupled to the collecting lens;

outputting a second reference signal at a second DDS; and

improving the accuracy of the absolute distance measurement on a computing device based on the first reference signal, the second reference signal, and the received modulated optical signal.

27. The method of claim 26, wherein a first optical switch couples both the pulsed laser source and the isolated laser source to the collimating lens and a second optical switch couples both the broad band pin diode detector and the pin diode detector to the collecting lens.
28. The method of claim 26, wherein the computing device calculates the distance by sampling the difference in frequency of the reference frequency and returned modulated optical signal.

29. The method of claim 26, wherein the first reference signal and the second reference signal are of different frequencies.
30. The method of claim 26, wherein the isolated laser source is a diode laser.
31. The method of claim 30, wherein the diode laser is intensity modulated by the first DDS.
32. The method of claim 26, further comprising directing the collimating lens and the collecting lens toward a reflector.

Phase Detector Error

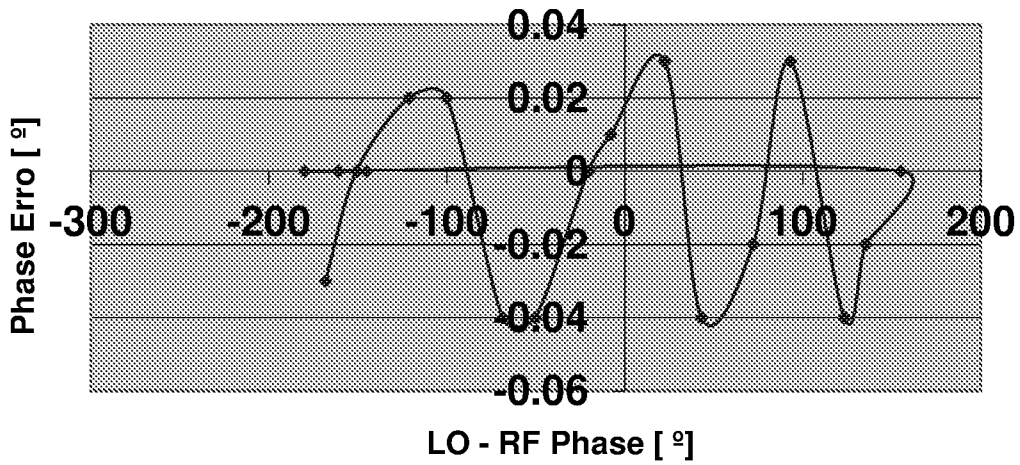


FIGURE 2

Ranger Error

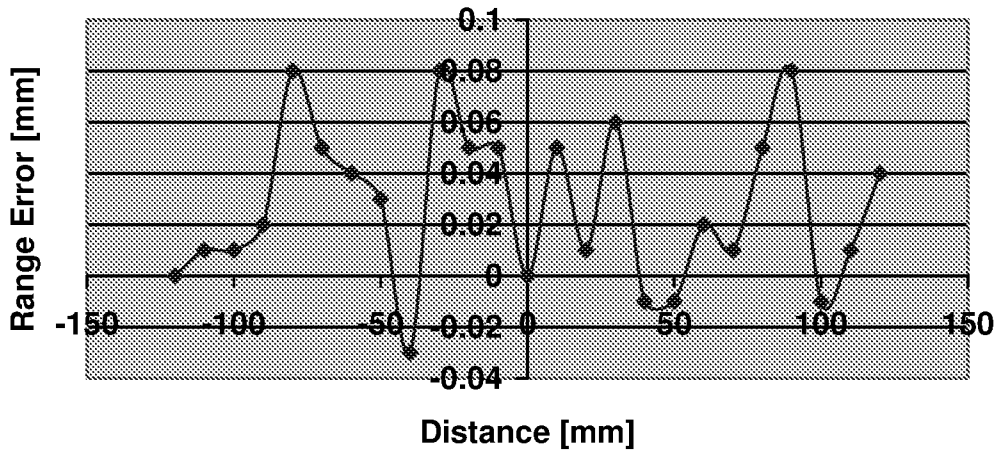


FIGURE 3

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/16092

A. CLASSIFICATION OF SUBJECT MATTER IPC(8) - G01S 7/481 (2016.01) CPC - G01S 7/4808; G01S7/4811; G01S 7/483; G01S 7/4865 According to International Patent Classification (IPC) or to both national classification and IPC		
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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched CPC: G01S 7/4808; G01S 7/4811; G01S 7/483; G01S 7/4865 USPC: 356/3,5.11,4.09,5.01,5.09; IPC(8): G01S 7/481 (2016.01) (text search - see terms below)		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) PatBase; PubWEST(USPT,PGPB,EPAB,JPAB); Google Search Terms: direct digital synthesizer, second, reference, rangefinder, range finder, fiber, collimate, pin diode, lens, double balance mixer, difference, frequency, sample, laser, pulse, fine tune, distance		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y --- A	US 2009/0046271 A1 (CONSTANTIQUES) 19 February 2009 (19.02.2009), Fig 1; paras [0045], [0047], [0051]-[0053]	1-6, 8-21, 23-32 ----- 7, 22
Y --- A	US 2011/0007328 A1 (WOLF et al.) 13 January 2011 (13.01.2011), para [0052]	1-6, 8-21, 23-32 ----- 7, 22
Y	US 2014/0118718 A1 (JUNGWIRTH) 01 May 2014 (01.05.2014), para [0007]	3, 11, 18, 28
Y	US 2011/0032509 A1 (BRIDGES) 10 February 2011 (10.02.2011), Fig 2B; paras [0052]-[0054]	4, 12, 16-21, 23-32 ----- 22
A	US 2009/0122296 A1 (OHISHI et al.) 14 May 2009 (14.05.2009), entire document	1-32
A	US 6,707,833 B1 (KIMBROUGH) 16 March 2004 (16.03.2004), entire document	1-32
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/>		
* 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 20 October 2015		Date of mailing of the international search report 04 NOV 2016
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300		Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774