PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 :
G01C 3/08, G02B 5/124

A1

(11) International Publication Number: **WO 95/30879**

(43) International Publication Date: 16 November 1995 (16.11.95)

(21) International Application Number: PCT/US95/05308

(22) International Filing Date: 28 April 1995 (28.04.95)

(30) Priority Data:
08/239,708 9 May 1994 (09.05.94) US

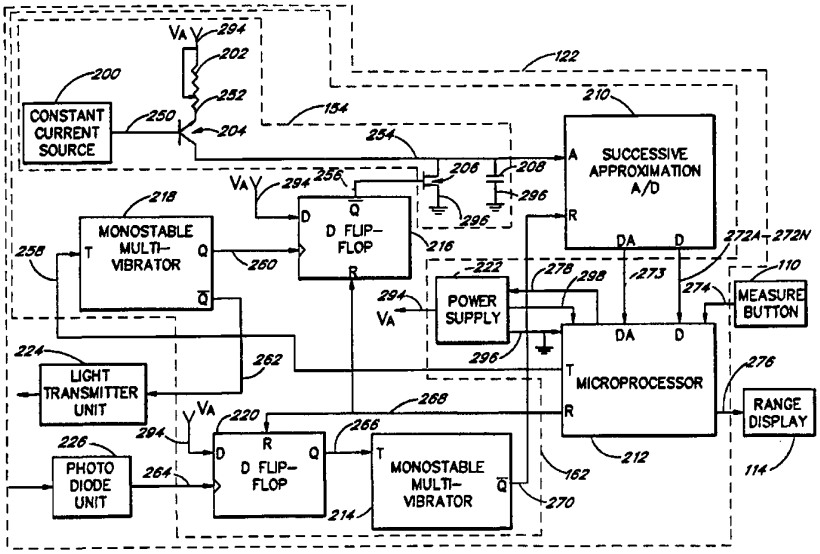
(71)(72) Applicants and Inventors: HINES, Robin, H. [US/US]; 102 Lake Circle Drive, Tullahoma, TN 37388 (US). MURPHY, Patrick, J. [US/US]; 209 Heritage Drive, Tullahoma, TN 37388 (US). GLASSCOCK, Michael, R. [US/US]; 223 Hillcrest Drive, Tullahoma, TN 37388 (US). GOODMAN, William, L. [US/US]; 555 Billy Goat Hill Road, Winchester, TN 37398 (US). KORBA, Anthony, R. [US/US]; 28 Navarre, Irvine, CA 92715 (US). HARRIS, Steven, E. [US/US]; 324 Fullerton Avenue, Newport Beach, CA 92663 (US).

(74) Agent: ALTMAN, Daniel, E.; Knobbe, Martens, Olson and Bear, 16th floor, 620 Newport Center Drive, Newport Beach, CA 92660 (US).

(81) Designated States: CA, JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: HAND-HELD DISTANCE-MEASUREMENT APPARATUS AND SYSTEM



(57) Abstract

The present invention relates to a portable, hand-held distance-measurement apparatus utilizing a laser range finder (100). The distance-measurement apparatus executes a number of distance-measurement cycles. In each cycle, a capacitor (208) begins charging at approximately the same time that a light pulse is generated (224). An analog-to-digital converter (210) generates a digital representation of the capacitor voltage at approximately the same time that a reflected light pulse is received (226). The lowest and the highest digital values are discarded and the remaining digital values are averaged (430) and scaled to produce a distance measurement. A reflective target (500, 600) may be used at a remote location to reflect the light beam back to the distance-measurement apparatus. The distance-measurement apparatus has several power saving features that facilitate convenient battery operation (404). The distance-measurement apparatus may also have a view finder (108).

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	**GB**	United Kingdom	**MR**	Mauritania
AU	Australia	**GE**	Georgia	**MW**	Malawi
BB	Barbados	**GN**	Guinea	**NE**	Niger
BE	Belgium	**GR**	Greece	**NL**	Netherlands
BF	Burkina Faso	**HU**	Hungary	**NO**	Norway
BG	Bulgaria	**IE**	Ireland	**NZ**	New Zealand
BJ	Benin	**IT**	Italy	**PL**	Poland
BR	Brazil	**JP**	Japan	**PT**	Portugal
BY	Belarus	**KE**	Kenya	**RO**	Romania
CA	Canada	**KG**	Kyrgystan	**RU**	Russian Federation
CF	Central African Republic	**KP**	Democratic People's Republic of Korea	**SD**	Sudan
CG	Congo			**SE**	Sweden
CH	Switzerland	**KR**	Republic of Korea	**SI**	Slovenia
CI	Côte d'Ivoire	**KZ**	Kazakhstan	**SK**	Slovakia
CM	Cameroon	**LI**	Liechtenstein	**SN**	Senegal
CN	China	**LK**	Sri Lanka	**TD**	Chad
CS	Czechoslovakia	**LU**	Luxembourg	**TG**	Togo
CZ	Czech Republic	**LV**	Latvia	**TJ**	Tajikistan
DE	Germany	**MC**	Monaco	**TT**	Trinidad and Tobago
DK	Denmark	**MD**	Republic of Moldova	**UA**	Ukraine
ES	Spain	**MG**	Madagascar	**US**	United States of America
FI	Finland	**ML**	Mali	**UZ**	Uzbekistan
FR	France	**MN**	Mongolia	**VN**	Viet Nam
GA	Gabon				

HAND-HELD DISTANCE-MEASUREMENT APPARATUS AND SYSTEM

Background of the Invention

Field of the Invention

The present invention pertains to the field of laser range finding devices for measuring the distance between the device and a remote object or surface. In particular, the present invention pertains to portable, hand-held distance-measurement devices.

Background Information

There are several prior art distance-measurement systems that have utilized a laser range finder. These systems generally transmit a beam of light energy, receive a reflection of the light beam, and measure the difference in time between the transmission and reception of the light beam.

Most laser range finding systems utilize a high-speed clock to count the time lapse between the transmission and reception of light pulses. High-speed clocks and other high-speed components required to implement such a technique consume too much electrical energy for practical use in a portable, battery-operated range finder. Most of the prior art range finder systems cannot operate for an adequate period of time using conventional batteries that are small enough for truly portable use.

In addition, most of the prior art distance-measurement systems require that the light beam from the range finder be incident on the intended target for a specified minimum period of time. If the user of the range finder even slightly moves the range finder so that the light beam no longer contacts the intended target, the measurements obtained by the range finder are generally inaccurate. Thus, most distance-measurement systems require that the range finder be mounted on a steady and secure surface, which prevents their use in an application that calls for a hand-held device.

Summary of the Invention

The present invention comprises a portable, hand-held distance-measurement apparatus. The distance-measurement apparatus comprises a light transmitter, a light receiver, a time measurement circuit, a power supply, and a processor. The light transmitter generates pulses of light for transmission to and reflection by a remote surface. The light receiver receives pulses of light that have reflected off the remote surface, and detects such reflected pulses of light. The time measurement circuit generates a digital value that represents an analog value, where the analog value is determinatively related to the elapsed time between the generation of one of the light pulses by the light transmitter and the detection of the one light pulse by the light receiver. The time measurement circuit comprises a charging capacitor, a current source, a charge/discharge circuit, a latch, a reference voltage generator, a comparator, and a digital value generator. The current source provides an electronic current to charge the charging capacitor. The charge/discharge circuit comprises one or more charge/discharge switches connected to control the charging and discharging of the charging capacitor. The charge/discharge circuit causes the charging capacitor to discharge before the generation of the transmitted light pulse and to begin charging substantially at a first predetermined time relative to the generation of the transmitted light pulse. The latch latches a first voltage representative of the charge across the charging capacitor substantially at a second predetermined time relative to

the detection of the reflected light pulse. The reference voltage generator generates a reference voltage signal having a magnitude that varies over time. The comparator generates a compare signal corresponding to the relative magnitudes of the first voltage and the reference voltage signal. The digital value generator monitors the compare signal and, in response thereto, generates the digital value. The power supply provides electrical power to the time measurement circuit. The electrical power is disabled when the time measurement circuit is not in use. The processor receives the digital value from the time measurement circuit and, in response thereto, determines a distance measurement between the distance-measurement apparatus and the remote surface.

The present invention also comprises a method of performing a plurality of distance-measurement operations to determine distances between a distance-measurement apparatus and one or more remote surfaces. The method comprises the steps of detecting one or more requests for a distance-measurement operation and, for each detected request, performing a distance-measurement operation. The distance-measurement operation comprises the steps of performing a plurality of distance-measurement cycles to obtain a first plurality of digital values, discarding a second plurality of the first plurality of digital values, discarding a third plurality of the first plurality of digital values, computing an average digital value from a fourth plurality of digital values, and obtaining a corresponding distance-measurement value from the average digital value. The distance-measurement value represents the distance between the distance-measurement apparatus and the remote surface. Each distance-measurement cycle comprises the steps of generating a light pulse and directing the light pulse toward a remote surface for reflection from the surface as a reflected light pulse, receiving the reflected light pulse, and generating a digital value that represents an analog value that is determinatively related to the elapsed time between the generation of the light pulse and the reception of the reflected light pulse. The second plurality of digital values comprises the lowest of the digital values. The third plurality of digital values comprises the highest of the digital values. The fourth plurality of digital values comprises all of the first plurality of digital values that have not been discarded.

The present invention also comprises a distance-measurement system. The distance-measurement system comprises a reflective target and a portable, hand-held distance-measurement apparatus. The reflective target comprises a sheet of reflective material. The reflective target has a reflectivity that is at least 1000 times greater than the reflectivity of a Lambertian surface for substantially all horizontal entrance angles. The distance-measurement apparatus comprises a light transmitter, a light receiver, a time measurement circuit, a digital value generator, and a processor. The light transmitter generates a pulse of light and directs the pulse of light toward the reflective target for reflection as a reflected pulse of light. The light receiver receives the reflected pulse of light. The time measurement circuit measures the elapsed time between the generation of the light pulse by the light transmitter and the reception of the reflected light pulse by the light receiver. The digital value generator generates a digital value that represents an analog value that is determinatively related to the elapsed time. The processor receives the digital value and, in response thereto, computes the distance between the distance-measurement apparatus and the reflective target.

The present invention also comprises a portable, hand-held distance-measurement apparatus. The distance-measurement apparatus comprises a light transmitter, a light receiver, a time measurement circuit, a digital value

generator, a power supply, a processor, and a view finding device. The light transmitter generates a pulse of light for reflection off a remote surface as a reflected pulse of light. The light receiver receives the reflected pulse of light. The time measurement circuit measures the elapsed time between the generation of the light pulse by the light transmitter and the reception of the reflected light pulse by the light receiver. The digital value generator generates a digital value that represents an analog value that is substantially proportional to the elapsed time. The power supply provides electrical power to the time measurement circuit. The electrical power is disabled when the time measurement circuit is not in use. The processor receives the digital value from the time measurement circuit and, in response thereto, computes a distance measurement between the distance-measurement apparatus and the remote surface. The view finding device facilitates aiming the pulse of light toward the remote surface.

Brief Description of the Drawings

Figure 1 is a perspective view of the distance-measurement apparatus, showing an end of the apparatus which, in use, is directed away from the user.

Figure 2 is a perspective view of the distance-measurement apparatus, showing an end of the apparatus which, in use, is directed towards the user.

Figure 3 is a cross-sectional view of the distance-measurement apparatus taken along the lines 3-3 of Figure 1.

Figure 4 is a cross-sectional view of the view finder taken along the lines 4-4 of Figure 1.

Figure 5 is a functional block diagram of a first embodiment of an electronic unit of the distance-measurement apparatus.

Figure 6 is a functional block diagram of a successive approximation analog-to-digital converter of the electronic unit of Figure 5.

Figure 7 is a functional block diagram of a second embodiment of an electronic unit of the distance-measurement apparatus.

Figures 8A, 8B, and 8C form a flow chart that illustrates a method performed by the microprocessor of Figures 5 and 7 to cause the distance-measurement apparatus to perform distance measurements.

Figure 9 is a perspective view of a first embodiment of a target that can be used in connection with the distance-measurement apparatus.

Figure 10 illustrates a preferred reflective surface of the target of Figure 9.

Figure 11 is a perspective view of a second embodiment of a target that can be used in connection with the distance-measurement apparatus.

Detailed Description of the Preferred Embodiment

As illustrated in Figure 1, a distance-measurement apparatus 100 comprises an operational end 102, a transmit lens 104, a receive lens 106, a superimposed light beam view finder 108, and a measure button 110.

As illustrated in Figure 2, the distance-measurement apparatus 100 further comprises a user end 112, a range display 114, a low battery indicator 142, and a view finder switch 144. Figure 2 also illustrates the view finder 108 and the measure button 110.

As illustrated in Figure 3, the distance-measurement apparatus 100 further comprises a photodiode receiver 118, a laser diode 120, and an electronic unit 122. Figure 3 also illustrates the transmit lens 104, the receive lens 106, the view finder 108, the range display 114, and the low battery indicator 142. As illustrated in Figure 3, the view finder 108 comprises a view finder light 124, a reflector/window tube 126, a pivot O-ring 128, an X-axis adjustment screw 130, and a reflector/window 134.

As illustrated in Figure 4, the view finder 108 further comprises a Y-axis adjustment screw 132. Figure 4 also illustrates the view finder light 124, the reflector/window tube 126, the pivot O-ring 128, and the reflector/window 134.

As shown in Figure 5, a first embodiment of the electronic unit 122 comprises a time-measurement circuit 162, a light transmitter unit 224, a photodiode unit 226, a microprocessor 212, and a power supply 222. The time-measurement circuit 162 comprises a ramp generator 154, a successive approximation analog-to-digital converter (S/A A/D) 210, a monostable multivibrator 214, a D flip-flop 216, a monostable multivibrator 218, and a D flip-flop 220. The ramp generator 154 comprises a constant current source 200, a charge rate selection resistor 202, a constant current transistor 204, a charge/discharge switch 206, and a charging capacitor 208. In the preferred embodiment, the electronic unit 122 comprises a number of components that have relatively low power consumption. For example, the D flip-flops 216 and 220 and the monostable multivibrators 214 and 218 are preferably CMOS type components. Figure 5 also illustrates the measure button 110 and the range display 114.

A first terminal of the charge rate selection resistor 202 is connected to the power supply 222 by an analog power line 294. The analog power line 294 is also connected to the constant current source 200, the S/A A/D 210, the monostable multivibrator 214, the D flip-flop 216, the monostable multivibrator 218, the D flip-flop 220, the light transmitter unit 224, and the photodiode unit 226 to provide power to these components, although, to simplify the drawing, these connections are not illustrated in Figure 5. A second terminal of the charge rate selection resistor 202 is connected to an emitter terminal of the constant current transistor 204 by a charge rate line 252. The constant current source 200 is connected to a base terminal of the constant current transistor 204 by a constant current line 250. A collector terminal of the constant current transistor 204 is connected to a drain terminal of the charge/discharge switch 206, to a positive terminal of the charging capacitor 208, and to an analog input of the S/A A/D 210 by a ramp voltage line 254. A source terminal of the charge/discharge switch 206 is connected to the power supply 222 by a ground line 296. A negative terminal of the charging capacitor 208 is also connected to the ground line 296. In addition, the ground line 296 is connected to the constant current source 200, the S/A A/D 210, the microprocessor 212, the monostable multivibrator 214, the D flip-flop 216, the monostable multivibrator 218, the D flip-flop 220, the light transmitter unit 224, and the photodiode unit 226. A gate terminal of the charge/discharge switch 206 is connected to an inverted output of the D flip-flop 216 by a charge/discharge line 256. A clock input of the D flip-flop 216 is connected to an active high output of the monostable multivibrator 218 by a charge line 260, while a D input of the D flip-flop 216 is connected to the analog power line 294. An inverted output of the monostable multivibrator 218 is connected to the light transmitter unit 224 by a transmit pulse line 262. A reset input of the D flip-flop 216 is connected to a reset input of the D flip-flop 220 and to a reset

output of the microprocessor 212 by a reset analog line 268. A trigger input of the monostable multivibrator 218 is connected to a trigger output of the microprocessor 212 by a trigger line 258. A clock input of the D flip-flop 220 is connected to the photodiode unit 226 by a receive pulse line 264, while a D input of the D flip-flop 220 is connected to the analog power line 294. An active high output of the D flip-flop 220 is connected to a trigger input of the monostable multivibrator 214 by a receive detection line 266. An inverted output of the monostable multivibrator 214 is connected to a read input of the S/A A/D 210 by a read A/D line 270. A set of digital data outputs of the S/A A/D 210 is connected to a set of digital data inputs of the microprocessor 212 by a set of digital data lines 272A-272N. A data available output of the S/A A/D 210 is connected to a data available input of the microprocessor 212 by a data available line 273. An analog power control output of the microprocessor 212 is connected to the power supply 222 by an analog power control line 278. A power input of the microprocessor 212 is connected to the power supply 222 by a microprocessor power line 298. An interrupt input of the microprocessor 212 is connected to the measure button 110 by a measure line 274. A set of display outputs of the microprocessor 212 is connected to the range display 114 by a range display bus 276.

The light transmitter unit 224 preferably comprises the laser diode 120 (shown in Figure 3), although other light transmitter devices can also be used. The light transmitter unit 224 also preferably comprises a laser driver (not shown) for driving the laser diode 120 with a desired voltage and current. The desired voltage and current depends on the particular application involved. The photodiode unit 226 preferably comprises the photodiode receiver 118 (shown in Figure 3), a transimpedance amplifier (not shown), a video amplifier (not shown), and a comparator (not shown).

As shown in Figure 6, the successive approximation analog-to-digital converter 210 of Figure 5 comprises a comparator 280, a digital-to-analog converter (D/A) 282, a successive approximation register 284, an A/D control unit 290, and a sample and hold latch 291. The ramp voltage line 254 is connected to an analog data input of the sample and hold latch 291. An analog data output of the sample and hold latch 291 is connected to a first compare input of the comparator 280 by a sampled analog voltage line 293. A reference voltage line 286 is connected between an analog output of the D/A 282 and a second compare input of the comparator 280. A compare line 288 is connected between a compare output of the comparator 280 and a compare input of the A/D control unit 290. A sample line 295 is connected between the A/D control unit 290 and the sample and hold latch 291. The read A/D line 270 is connected to a read input of the A/D control unit 290. A successive approximation register control bus 292 is connected between the A/D control unit 290 and the successive approximation register 284. The digital data lines 272A-272N are connected between a set of data outputs of the successive approximation register 284 and a set of digital data inputs of the D/A 282. The data available line 273 is connected to a data available output of the A/D control unit 290.

The latch 291 is an important element of the electronic unit 122 of the preferred embodiment. The latch 291 stores the analog voltage that has accumulated across the charging capacitor 208 at approximately the time that the reflected light pulse is received at the photodiode receiver 118. The analog storage of this voltage allows the S/A A/D 210 to determine a digital representation of the analog voltage over a relatively large period of time.

For example, in the preferred embodiment, the S/A A/D 210 takes approximately 25 microseconds to generate a digital value. This relatively slow analog to digital conversion time can be achieved by a S/A A/D 210 that has low power consumption. For example, the S/A A/D 210 of the preferred embodiment is a CMOS component that requires a current in the range of microamperes. Preferably, the S/A A/D 210 has a 12 bit resolution.

As shown in Figure 7, a second embodiment of the electronic unit 122 comprises a time-measurement circuit 302, the light transmitter unit 224, the photodiode unit 226, and the power supply 222. The time-measurement circuit 302 comprises a ramp generator 300, the microprocessor 212, a monostable multivibrator 318, a D flip-flop 320, a slow-charge resistor 309, a slow-charge capacitor 310, and a voltage comparator 312. The ramp generator 300 comprises the constant current source 200, the charge rate selection resistor 202, the constant current transistor 204, a charge switch 304, a discharge switch 306, and a charging capacitor 308. Again, in the preferred embodiment, the electronic unit 122 comprises a number of components that have relatively low power consumption. Figure 7 also illustrates the measure button 110 and the range display 114.

The first terminal of the charge rate selection resistor 202 is connected to the power supply 222 by the analog power line 294. The analog power line 294 is also connected to the constant current source 200, the monostable multivibrator 318, the D flip-flop 320, the light transmitter unit 224, and the photodiode unit 226 to provide power to these components, although these connections are not illustrated in Figure 7. The second terminal of the charge rate selection resistor 202 is connected to the emitter terminal of the constant current transistor 204 by the charge rate line 252. The constant current source 200 is connected to the base terminal of the constant current transistor 204 by the constant current line 250. The collector terminal of the constant current transistor 204 is connected to a drain terminal of the charge switch 304 by a constant current line 353. A collector terminal of the charge switch 304 is connected to a drain terminal of the discharge switch 306, to a positive terminal of the charging capacitor 308, and to a first input of the voltage comparator 312 by a ramp voltage line 356. A source terminal of the discharge switch 306 is connected to the power supply 222 by the ground line 296. A negative terminal of the charging capacitor 308 and a negative terminal of the slow-charge capacitor 310 are also connected to the ground line 296. In addition, the ground line 296 is connected to the constant current source 200, the microprocessor 212, the monostable multivibrator 318, the D flip-flop 320, the light transmitter unit 224, and the photodiode unit 226. A gate terminal of the charge switch 304 is connected to an inverted output of the D flip-flop 320 by a charge line 368. A gate terminal of the discharge switch 306 is connected to a transmit output of the microprocessor 212 and to an active low trigger input of the monostable multivibrator 318 by a discharge/trigger line 358. An active high output of the monostable multivibrator 318 is connected to the light transmitter unit 224 and to a reset input of the D flip-flop 320 by a transmit pulse line 362. A clock input of the D flip-flop 320 is connected to the photodiode unit 226 by a receive pulse line 364, while a D input of the D flip-flop 320 is connected to the analog power line 294. An active high output of the D flip-flop 320 is connected to a receive input of the microprocessor 212 by a receive detection line 366. A first terminal of the slow-charge resistor 309 is connected to the analog power line 294. A second terminal of the slow-charge resistor 309 is connected to a positive terminal of the slow-charge capacitor 310, to a second input of the comparator 312, and to a reset output of the

microprocessor 212 by a ramp voltage line 372. An output of the voltage comparator 312 is connected to an equal input of the microprocessor 212 by a compare-equal line 370. The analog power control output of the microprocessor 212 is connected to the power supply 222 by the analog power control line 278. The power input of the microprocessor 212 is connected to the power supply 222 by the microprocessor power line 298. An interrupt input of the microprocessor 212 is connected to the measure button 110 by the measure line 274. The set of display outputs of the microprocessor 212 is connected to the range display 114 by the range display bus 276.

The charging capacitor 308 of the second embodiment of the electronic unit 122 comprises both a charging device and a latching device. Thus, the charging capacitor 308 serves the same general purpose as both the charging capacitor 208 and the latch 291 serve in the first embodiment of the electronic unit 122. Generally, the charging capacitor 308 and the charging capacitor 208 each accumulate a charge to provide a ramp voltage, and the charging capacitor 308 and the latch 291 each latch the accumulated voltage at approximately the time that the reflected light pulse is received at the photodiode receiver 118. Similar to the first embodiment, in the second embodiment, the analog storage of the ramp voltage allows the slow-charge resistor 309, the slow-charge capacitor 310, the voltage comparator 312, and the microprocessor 212 to determine a digital representation of the analog voltage over a relatively large period of time. Without the analog storage, a much faster analog-to-digital conversion technique would be required, causing increased power consumption.

Referring generally to Figures 1 to 7, the laser 120 of the distance-measurement apparatus 100 generates a beam of light that is emitted from the transmit lens 104. The light travels away from the distance-measurement apparatus 100 in a direction that is substantially perpendicular to the operational end 102. If there is an object or surface in front (toward the operational end 102) of the distance-measurement apparatus 100, a portion of the light is typically reflected back toward the distance-measurement apparatus 100. Some of the reflected light that reaches the receive lens 106 is focused onto the photo-diode receiver 118, which generates an electronic signal in response to the quantity of incident light within the operating range of the photo-diode receiver 118.

The electronic unit 122 controls the laser 120 to generate the light pulse. The electronic unit 122 then determines the time between the transmitted light pulse and a received light pulse at the photo-diode receiver 118. This time calculation represents the time required for the light to travel from the distance-measurement apparatus 100 to the remote object or surface, and back. Based on the speed of light and the calculated travel time, the electronic unit 122 calculates the distance between the distance-measurement apparatus 100 and the remote object or surface.

In the preferred embodiment of the present invention, the electronic unit 122 executes a number of distance-measurement cycles to calculate a single distance value. A distance-measurement cycle is a process comprising the steps of generating a transmit light pulse, waiting for a receive light pulse, and, if a receive light pulse is detected, calculating the distance represented by the time delay between the transmit pulse and the receive pulse. If a receive light pulse is not detected within a predetermined period of time after generating a transmit pulse, the distance-measurement cycle is terminated with no resulting data value.

In the preferred embodiment, the electronic unit 122 continues to execute distance-measurement cycles until a predetermined number of data values has been obtained. The electronic unit 122 then discards a number of the data values with the highest numerical values and a number of the data values with the lowest numerical values, and determines the average of the remaining data values. In the preferred embodiment, the distance-measurement apparatus 100 computes the distance between the distance-measurement apparatus 100 and the remote object or surface with an accuracy of approximately 0.5 yards. However, in some applications, such as golf, the distance may be indicated on the range display 114 only to the nearest yard. In one preferable embodiment, for example, distance-measurement cycles may be repeatedly executed until 64 data values have been obtained. Then, the lowest 16 data values and the highest 16 data values are discarded. The remaining 32 data values are averaged to determine the distance to the remote object or surface.

The distance-measurement apparatus 100 of the present invention is particularly useful as a portable, hand-held distance-measurement device. In particular, the distance-measurement apparatus 100 can obtain accurate distance measurements without the assistance of a tripod or other secure foundation. In most prior art distance-measurement devices, such a secure foundation is required to ensure that the transmitted pulse consistently reflects off the desired object or surface. However, with the distance-measurement apparatus 100 of the present invention, the user need not continuously maintain the direction of the transmitted light beam toward the desired object or surface. If the user does not continuously hit the desired target with the light beam, the light beam may occasionally fail to hit any surface, so that it is not reflected back to the distance-measurement apparatus 100 at all. This occurrence is termed a "miss." Alternatively, the light pulse may be reflected back to the distance-measurement apparatus 100 by contact with an incorrect object or surface. This occurrence is termed an "incorrect hit." If the light beam is reflected back to the distance-measurement apparatus 100 by reflection off the desired object or surface, a "correct hit" occurs. Of course, the light beam may also hit an object or surface at an angle or position so that insufficient light is reflected for detection at the distance-measurement apparatus 100. Such an occurrence is considered a miss. The present description assumes either that a light beam hits an object or surface so that sufficient light is reflected for detection, or the light beam completely misses the object or surface.

If a miss occurs, no receive pulse is detected at the distance-measurement apparatus 100, no data value is obtained, and the distance-measurement cycle is ignored. In this situation, the distance-measurement operation continues until the user correctly aims the light beam at the desired object or surface. Thus, an occurrence of a miss does not affect the distance-measurement operation, except for delaying the operation until the user correctly aims the light beam at the desired object or surface.

If an incorrect hit occurs, the data value obtained by the distance-measurement apparatus 100 is likely to be inaccurate, as the object or surface that is hit may be closer or further than the desired object or surface. However, as described above, the distance-measurement apparatus 100 discards the highest and the lowest data values before taking an average of the remaining data values. Thus, as long as the user is generally able to aim the light beam toward the desired object or surface, data values obtained by incorrect hits are likely to be discarded as the highest or the lowest data values. Thus, incorrect hits generally have no effect on the distance-measurement

operation. In addition, the discarding of the highest and lowest data values, and the averaging of the remaining data values also reduces the effect of noise on the distance-measurement operation.

The number of data values obtained and the number of minimum and maximum values that are discarded can be varied for various applications and circumstances. Generally, in situations in which incorrect hits are more likely to occur, the number of data values that are discarded should be increased. Alternatively, the distance-measurement apparatus 100 of the present invention may also be used in conjunction with a secure foundation. In this situation, the number of discarded data values can generally be decreased.

The distance-measurement apparatus 100 of the present invention also has several power conservation features that further facilitate portable, hand-held operation. First, the distance-measurement apparatus 100 utilizes a ramped voltage and analog-to-digital conversion, instead of a high frequency clock, to determine the time of flight of the light pulse. A high frequency clock circuit requires substantially more electrical energy than the present invention. Second, the design uses low power components such as CMOS components and a relatively slow analog-to-digital conversion technique. Third, the distance-measurement apparatus 100 powers down most of the electronic circuitry in the electronic unit 122, whenever practicable, to reduce power consumption. Fourth, the microprocessor 212 enters a sleep mode, whenever practicable, to further reduce power consumption. These power saving features conserve battery life, so that a relatively small and lightweight battery provides sufficient electrical energy to power the distance-measurement apparatus 100 for a useful period of time. In the preferred embodiment, the distance-measurement apparatus 100 requires approximately 100 milliamperes of current for a time period between approximately 20 milliseconds and approximately 160 milliseconds (depending on the distance to be measured) when performing a distance-measurement cycle, and approximately 50 microamperes when the distance-measurement apparatus 100 is inactive. In the preferred embodiment of the present invention, the power supply 222 comprises a common 9-volt battery.

The microprocessor 212 controls the electronic unit 122 to perform distance-measurement operations. Referring to Figure 5 and the first embodiment of the electronic unit 122, the microprocessor 212 receives power and ground signals from the power supply 222. The power and ground signals are provided to the microprocessor 212 on the microprocessor power line 298 and the ground line 296, respectively. The power supply 222 also provides power and ground signals to the remaining components in the electronic unit 122 on the analog power line 294 and the ground line 296, respectively. The supply of power on the analog power line 294 can be controlled by the microprocessor 212 by controlling a signal on the analog power control line 278.

The microprocessor 212 begins a distance-measurement cycle by generating a reset pulse on the reset analog line 268. The reset pulse is received by the D flip-flops 216 and 220, and the D flip-flops 216 and 220 are reset so that their active high outputs are at a logic zero. The resetting of the D flip-flop 220 enables the D flip-flop 220 to detect a receive pulse from the photo-diode unit 226. The resetting of the D flip-flop 216 causes a logic one signal at the inverted output of the D flip-flop 216. This logic one signal is applied to the gate terminal of the charge/discharge switch 206, which closes the switch 206 and effectively connects the ramp voltage line 254 to the ground line 296. This causes the charging capacitor 208 to discharge any previously accumulated charge to

ground through the switch 206. The constant current source 200 generates a substantially constant current on the constant current line 250 that flows into the base terminal of the constant current transistor 204. The constant current at the base terminal of the constant current transistor 204 produces a current at the collector terminal of the constant current transistor 204 that flows away from the constant current transistor 204. However, while the switch 206 is closed, the current from the collector terminal of the constant current transistor 204 does not cause the charging capacitor 208 to charge because the current from the constant current transistor 204 also goes directly to ground through the switch 206. The D flip-flop 216 is ready for a transmit pulse from the monostable multivibrator 218.

After delaying a sufficient amount of time to allow the charging capacitor 208 to discharge any accumulated voltage, the microprocessor 212 generates a trigger pulse on the trigger line 258. The monostable multivibrator 218 receives the trigger pulse and generates a logic high pulse on its active high output and a logic low pulse on its inverted output, at approximately the same time. The D flip-flop 216 receives the logic high pulse at its clock input. This causes the D flip-flop 216 to become set to a logic one, as the D input is tied to the analog power line 294. The setting of the D flip-flop 216 generates a logic zero on the charge/discharge line 256, which opens the charge/discharge switch 206.

When the switch 206 is open, current from the constant current source 200 flows through the constant current transistor 204 to the charging capacitor 208. The charge rate selection resistor 202 is a variable resistor that controls the magnitude of current that is applied to the charging capacitor 208. The resistor 202 can be adjusted to apply a current to the charging capacitor 208 that is appropriate for the application for which the distance-measurement apparatus 100 is to be used. An appropriate current magnitude depends on the maximum distance for which a measurement is desired, the maximum voltage that can be converted to digital format by the S/A A/D 210, and the capacitance of the charging capacitor 208. For a golf application, a preferred maximum distance is about 300 yards. This corresponds to a maximum round trip travel time for a light pulse of approximately 1.8 micro-seconds. In this application, a maximum analog input voltage for the S/A A/D 210 is preferably 2.5 volts, the capacitance of the capacitor 208 is preferably 500 picofarads, and the charging current is preferably approximately 1 milliampere. Preferably, the current supplied to the charging capacitor 208 is substantially constant, so that the capacitor 208 charges in a substantially linear manner. The linear charging of the capacitor 208 reduces the complexity of the equation that must be implemented in the microprocessor 212 to convert a measured voltage into a corresponding physical distance, and it reduces the magnitude of error introduced into the measurement. The charge/discharge switch 206 remains open until the microprocessor 212 generates another reset pulse on the reset analog line 268.

The light transmitter unit 224 receives the logic zero pulse generated by the monostable multivibrator 218 on the transmit pulse line 262, and generates a pulse of light. As illustrated in Figure 3, the light pulse from the laser diode 120 is directed toward an inner surface of the transmit lens 104. The light energy diverges between the laser diode 120 and the transmit lens 104. The transmit lens 104 redirects the light energy into a substantially

parallel beam of radiation. This beam of radiation is emitted from an outer surface of the transmit lens 104 in a direction that is substantially perpendicular to the operational end 102.

The optical characteristics of the distance-measurement apparatus 100 are preferably designed for use in a particular application. The distances of interest in the application and the particular type or types of objects or surfaces to which distances are to be measured are considered. In particular, the effective reflective size and the overall reflectivity of the intended objects and surfaces are important. The effective reflective size of an object or surface is the surface area of the object or surface that generally reflects incident light back in the direction from which it arrived. Some objects, such as a sphere, may be relatively large, but have a relatively small effective size. When the light beam is directed toward a sphere, only a relatively small surface area of the sphere reflects light back toward the distance-measurement apparatus 100, while other areas of the sphere direct light in different directions. Thus, the effective reflective size of the sphere is limited to the relatively small surface area that reflects light back toward the distance-measurement apparatus 100. The reflectivity of an object or surface is a measure of the amount of incident light that is reflected back in the opposite direction from which the light arrived. The reflectivity of an object or surface may depend on the incident angle and location of the light on the object or surface.

The optical characteristics of the distance-measurement apparatus 100 include the characteristics of the optical components related to the transmission of light and the characteristics of the optical components related to the reception of light. These optical characteristics are selected to complement the optical characteristics of the intended objects or surfaces and the distances of interest in the particular application. For the transmission of light, the type of laser 120, the distance between the laser 120 and the transmit lens 104, and the size and optical characteristics of the transmit lens 104 are selected to maximize the amount of light that is reflected from the objects or surfaces for which distance measurements are desired, based on the expected distances to be measured and on the effective reflective size of the intended objects or surfaces. The amount of light energy generated at the laser 120 is controlled to obtain sufficient light reflection at the intended objects or surfaces, while also achieving adequate eye safety restrictions. For effectively larger objects or surfaces or for shorter distances, the beam of light need not be focused as narrowly nor contain as much energy as for effectively smaller objects or surfaces or for longer distances. For the reception of light, the size and optical characteristics of the receive lens 106, the distance between the receive lens 106 and the photodiode receiver 118, and the type of photodiode receiver 118 are selected to maximize the signal to noise ratio of the electronic pulse that is generated in response to receiving a reflected beam of light. The optical characteristics of the light transmission components of the distance-measurement apparatus 100 and the effective size, reflectivity, and expected distances of the intended objects or surfaces are considered in determining appropriate characteristics for the light reception components. The considerations for both transmission and reception of light are described in greater detail below with reference to Figures 9 and 11.

If a hit occurs, so that sufficient light is reflected back to the distance-measurement apparatus 100 for detection, a portion of the reflected light contacts the outer surface of the receive lens 106. The receive lens 106 focuses incident light onto the photo-diode receiver 118. Referring again to Figure 5, the photo-diode unit 226

generates an active high electronic pulse on the receive pulse line 264 upon receiving the reflected beam of light. The D flip-flop 220 receives the active high pulse at its clock input. This causes the D flip-flop 220 to become set to a logic one, as the D input is tied to the analog power line 294. The setting of the D flip-flop 220 generates a logic one on the receive detection line 266. The monostable multivibrator 214 receives the logic one at its trigger input and generates an active low pulse on the read A/D line 270. The S/A A/D 210 receives the active low pulse on the read A/D line 270 and performs an analog to digital conversion of the instantaneous voltage at the ramp voltage line 254. The voltage at the ramp voltage line 254 is the voltage across the charging capacitor 208. The charging capacitor 208 begins charging at approximately the same time that the light pulse is generated by the laser 120 and stops charging at approximately the same time that the light pulse is received by the photo-diode receiver 118. Thus, the voltage across the charging capacitor 208 is substantially proportional to the travel time of the light pulse in travelling from the distance-measurement apparatus 100 to the intended object or surface, and back. The voltage across the charging capacitor 208 is also substantially proportional to the distance between the distance-measurement apparatus 100 and the remote object or surface.

Referring to Figure 6, the A/D control unit 290 receives the active low pulse on the read A/D line 270 and controls the S/A A/D 210 to convert the instantaneous voltage at the ramp voltage line 254 into a digital representation. The A/D control unit 290 generates a signal on the sample line 295. In response, the sample and hold latch 291 latches the instantaneous voltage at the ramp voltage line 254 and holds the analog voltage. The analog voltage is applied to a compare input of the comparator 280 over the sampled analog voltage line 293.

The A/D control unit 290 also loads the successive approximation register (SAR) 284 to a variety of different values to determine an appropriate digital representation of the analog voltage at the sampled analog voltage line 293. First, the A/D control unit 290 determines the appropriate logic level for the most significant bit (MSB) of the digital representation by loading the SAR 284 with a value having a logic one in the MSB and all zeros in the remaining bits. Thus, for a 12 bit S/A A/D 210, the initial value for the SAR 284 is 800 in hexadecimal notation (800h). This value is applied to the D/A 282 over the digital data lines 272A to 272N. The D/A 282 converts the digital value from the SAR 284 into a corresponding analog voltage and applies the resulting voltage to the second compare input of the comparator 280 over the reference voltage line 286. The comparator 280 generates a signal on the compare line 288 that reflects the relative voltages on the sampled analog voltage line 293 and the reference voltage line 286. The A/D control unit 290 monitors the compare line 288 to determine the relative voltages. If the voltage on the sampled analog voltage line 293 is greater than or equal to the voltage on the reference voltage line 286, the A/D control unit 290 leaves the MSB of the SAR 284 set. Otherwise, the A/D control unit 290 clears the MSB of the SAR 284. At this point the appropriate logic level for the MSB for representing the sampled analog voltage has been established.

Next, the A/D control unit 290 determines an appropriate logic level for the next most significant bit of the digital representation. The SAR 284 is loaded with a value having a MSB as determined above, a next most significant bit that is a logic one and all zeros in the remaining bits. Thus, for a 12 bit S/A A/D 210, the next value for the SAR 284 is C00h if the MSB has been determined to be a logic one, or 400h if the MSB has been

determined to be a logic zero. Again, this value is applied to the D/A 282 over the digital data lines 272A to 272N. The D/A 282 converts the digital value from the SAR 284 into a corresponding analog voltage and applies the resulting voltage to the second compare input of the comparator 280 over the reference voltage line 286. The comparator 280 generates a signal on the compare line 288 that reflects the relative voltages on the sampled analog voltage line 293 and the reference voltage line 286. The A/D control unit 290 monitors the compare line 288 to determine the relative voltages. If the voltage on the sampled analog voltage line 293 is greater than or equal to the voltage on the reference voltage line 286, the A/D control unit 290 leaves the next most significant bit of the SAR 284 set. Otherwise, the A/D control unit 290 clears the next most significant bit of the SAR 284. At this point the appropriate logic level for the MSB and the next most significant bit have been established.

The remaining bits of the digital representation are determined in the same manner. For each successive bit from the MSB to the least significant bit (LSB), the bit is set in the SAR 284, the resulting analog voltage on the reference voltage line 286 is compared with the sampled analog voltage, and the A/D control unit 290 leaves the bit set or clears the bit, depending on the result of the comparison. After each of the bits of the digital representation have been established using the above-described procedure, the final value is applied to the digital data lines 272A to 272N, and the A/D control unit 290 asserts a signal on the data available line 273.

The microprocessor 212 receives the digital representation of the sampled analog voltage on the digital data lines 272A to 272N when the signal on the data available line 273 is activated. The microprocessor 212 computes the distance between the distance-measurement apparatus 100 and the remote target using the digital value received from the S/A A/D 210, and the present distance-measurement cycle is complete. As described above, a number of distance-measurements are averaged to more accurately determine the desired distance.

The second embodiment of the electronic unit 122 of Figure 7 operates in the same manner as the first embodiment of the electronic unit 122 of Figure 5, except as indicated immediately below. The microprocessor 212 begins a distance-measurement cycle by generating a positive transmit pulse on the discharge/trigger line 358. When the pulse on the discharge/trigger line 358 is high, the discharge switch 306 is closed, causing the charging capacitor 308 to discharge. When the signal on the discharge/trigger line 358 goes low again, the discharge switch 306 is opened, so that the charging capacitor 308 no longer discharges. Also, the monostable multivibrator 318 is triggered at the active low trigger input. The pulse on the discharge/trigger line 358 must be high long enough to allow the charging capacitor 308 to discharge any accumulated voltage.

The monostable multivibrator 318 generates a pulse on the transmit pulse line 362 in response to the high-to-low transition of the discharge/trigger line 358. The D flip-flop 320 receives the pulse from the monostable multivibrator 318 at the reset input, and the D flip-flop 320 is reset. The light transmitter unit 224 also receives the pulse generated by the monostable multivibrator 318 and generates a pulse of light. The resetting of the D flip-flop 320 generates a logic one at the charge line 368. The logic one at the charge line 368 closes the charge switch 304, which causes the charging capacitor 308 to begin charging.

If a hit occurs, the photo-diode unit 226 generates an active high electronic pulse on the receive pulse line 364 upon receiving the reflected beam of light. The D flip-flop 320 receives the active high pulse at its clock input.

This causes the D flip-flop 320 to become set to a logic one, as the D input is tied to the analog power line 294. The setting of the D flip-flop 320 generates a logic one on the receive detection line 366, which notifies the microprocessor 212 that a hit has occurred. The setting of the D flip-flop 320 also generates a logic zero on the charge line 368, which opens the charge switch 304 to cause the charging capacitor 308 to stop charging. Thus, the charging capacitor 308 begins to charge at approximately the same time that a pulse of light is transmitted and the charging capacitor 308 stops charging at approximately the same time that a reflected light pulse is detected. At this point, the charge across the charging capacitor 308 is substantially proportional to the distance between the distance-measurement apparatus 100 and the remote surface off which the light pulse reflected.

Now, the slow-charge resistor 309, the slow-charge capacitor 310, the voltage comparator 312, and the microprocessor 212 perform an analog-to-digital conversion of the voltage across the charging capacitor 308. After receiving the logic one on the receive detection line 366, the microprocessor 212 generates an activate low reset pulse at the reset output. The active low pulse discharges any accumulated charge on the slow-charge capacitor 310. Next, the microprocessor 212 tri-states the reset output, which allows the slow-charge capacitor 310 to begin to charge by current flowing through the slow-charge resistor 309. The microprocessor 212 also begins an internal counter at the same time that the slow-charging capacitor 310 begins to charge. The value of the resistor 309 and the capacitor 310 are selected so that the capacitor 310 charges slowly enough to allow an analog-to-digital conversion using the relatively slow clock of the microprocessor 212. As the capacitor 310 charges, the voltage at the ramp voltage line 372 gradually increases. Initially, the voltage comparator 312 generates a signal on the compare-equal line 370 indicating that the respective input voltages are not equal to one another. When the voltage at the ramp voltage line 372 reaches the voltage level stored in the capacitor 308, the voltage comparator 312 generates a signal on the compare-equal line 370 indicating that the two input voltages are equal. At this point, the microprocessor 212 stops the internal counter. Based on the charging rate of the slow-charge capacitor 310, the clock frequency of the microprocessor 212 and the digital count of the internal counter of the microprocessor 212, the microprocessor 212 determines the voltage across the charging capacitor 308. Based on the voltage across the charging capacitor 308, the microprocessor 212 determines the distance between the distance-measurement apparatus 100 and the remote surface, which is substantially proportional to the voltage across the charging capacitor 308. Although in the preferred embodiment the microprocessor 212 determines a digital value that represents the voltage across the charging capacitor 308, the values of the slow-charge resistor 309 and the slow-charge capacitor 310 may be selected, in conjunction with the clock speed of the microprocessor 212, so that the digital value produced by the internal clock of the microprocessor 212 directly represents the distance between the distance-measurement apparatus 100 and the remote surface. The current used to charge the slow-charge capacitor 310 need not be constant, because the adjustment for the nonlinear charging of the capacitor 310 is relatively simple and accurate because of the longer charging time, in comparison to the charging capacitor 308.

Figures 8A, 8B, and 8C form a flowchart that illustrates a method performed by the microprocessor 212 in the embodiment of Figure 5 and a similar method performed by the microprocessor 212 in the embodiment of Figure 7 to perform distance-measurement operations. During the method of Figures 8A, 8B and 8C, the

microprocessor 212 controls the distance-measurement apparatus 100 to perform distance measurements and to display the results on the range display 114. The method begins at an initial block 400.

At a process block 402, the microprocessor 212 initializes the distance-measurement apparatus 100. The process block 402 is executed when power is initially applied to the distance-measurement apparatus 100. In the preferred embodiment, for example, the process block 402 is executed when a rechargeable battery is inserted into the distance-measurement apparatus 100. During the process block 402, the microprocessor 212 controls the power supply 222 using the analog power control line 278 to disable power to the analog power line 294. Thus, the microprocessor 212 removes power from the time measurement circuit 162 or 302, the light transmitter unit 224 and the photodiode unit 226. Next, the microprocessor 212 tests the range display 114 by driving it to display a sequence of digits from zero to nine for each digit location of the range display 114. The microprocessor 212 also checks the voltage level provided by the power supply 222 on the microprocessor power line 298. If the voltage at the microprocessor power line 298 is below a predetermined threshold, the microprocessor 212 illuminates the low-battery indicator 142 (Figures 2 and 3).

At a process block 404, the microprocessor 212 enters a sleep mode in which the power consumed by the microprocessor 212 is substantially reduced.

At a decision block 406, the microprocessor 212 determines whether the measure button 110 has been activated. The measure button 110 is connected to an interrupt input of the microprocessor 212 that causes the microprocessor 212 to exit the sleep mode and return to operational mode upon activation of the measure button 110. If the measure button 110 has not been activated, the microprocessor 212 remains in the sleep mode and continues to execute the decision block 406 until the measure button 110 is activated. When the measure button 110 is activated, the microprocessor 212 advances to a process block 408.

At the process block 408, after being interrupted by the activation of the measure button 110, the microprocessor 212 begins a distance-measurement operation. The microprocessor 212 controls the power supply 222 using the analog power control line 278 to enable power to the analog power line 294. Thus, the microprocessor 212 causes the power supply 222 to supply power to the time measurement circuit 162 or 302, the light transmitter unit 224 and the photodiode unit 226.

At a process block 410, the microprocessor 212 begins a distance-measurement cycle. First, referring to Figure 5, the distance-measurement cycle is described in terms of the first embodiment of the electronic unit 122. The microprocessor 212 generates a reset pulse on the reset analog line 268 to reset the D flip-flops 220 and 216. The resetting of the D flip-flop 220 enables the time measurement circuit 162 to receive a return pulse of light. The resetting of the D flip-flop 216 closes the charge/discharge switch 206 to discharge the charging capacitor 208.

At a process block 412, the microprocessor 212 generates a transmit pulse on the trigger line 258, which is received by the monostable multivibrator 218. The monostable multivibrator 218 causes the light transmitter unit 224 to generate a pulse of light, and it opens the charge/discharge switch 206. Opening the charge/discharge switch 206 allows the constant current source 200, as controlled by the charge rate selector resistor 202 and the constant current transistor 204, to charge the charging capacitor 208 in a substantially linear manner.

At a decision block 414, the microprocessor 212 determines whether a receive pulse has been detected. If the light beam from the transmit lens 104 reflects off an object or surface and reflects back to the receive lens 106, the receive lens 106 focuses the return beam of light toward the photodiode receiver 118. The photodiode unit 226 generates an electronic signal at the receive pulse line 264 that is responsive to the amount of electromagnetic radiation contacting an active surface of the photodiode receiver 118 that is within the range of detection of the photodiode receiver 118. If the photodiode unit 226 generates an electronic pulse of sufficient magnitude, in response to a sufficient quantity of reflected light, the D flip-flop 220 is set. In response to the setting of the D flip-flop 220, the monostable multivibrator 214 causes the S/A A/D 210 to convert the instantaneous voltage across the charging capacitor 208 into a digital value. The S/A A/D 210 generates a corresponding digital value on the digital data lines 272A to 272N, and asserts the data available line 273. Thus, if the microprocessor 212 receives an active signal on the data-available line 273, the microprocessor 212 determines that a receive pulse was detected by the photodiode unit 226.

Next, referring to Figure 7, the distance-measurement cycle is described in terms of the second embodiment of the electronic unit 122. At the process block 410, the microprocessor 212 generates a transmit pulse on the discharge/trigger line 358 to discharge the charging capacitor 308.

At a process block 412, the microprocessor 212 generates a falling edge on the discharge/trigger line 358 to trigger the monostable multivibrator 318. The monostable multivibrator 318 causes the light transmitter unit 224 to generate a pulse of light, and it resets the D flip-flop 320. After the falling edge on the discharge/trigger line 358, the discharge switch 308 is open, so that the charging capacitor 308 no longer discharges. Also, the resetting of the D flip-flop 320 closes the charge switch 304, which causes the charging capacitor 308 to begin charging.

At a decision block 414, the microprocessor 212 determines whether a receive pulse has been detected. Again, if the photodiode unit 226 generates an electronic pulse of sufficient magnitude, in response to a sufficient quantity of reflected light, the D flip-flop 320 is set. In response to the setting of the D flip-flop 320, the charge switch 304 is opened to stop the charging of the charging capacitor 308. Also, the microprocessor 212 detects the setting of the D flip-flop 320 by monitoring the receive detection line 366. The microprocessor 212 controls the discharging and charging of the slow-charge capacitor 310, and uses an internal counter to effectively determine the analog voltage across the charging capacitor 308. The microprocessor 212 determines that a receive pulse was detected by the photodiode unit 226 by receiving an active signal on the receive detection line 366.

Referring again to both of the illustrated embodiments of the electronic unit 122, as illustrated in Figures 5 and 7, if no receive pulse is detected at the decision block 414, the microprocessor 212 advances to a decision block 418. At the decision block 418, the microprocessor 212 checks an internal timer to determine whether the cycle time for the present transmit pulse is complete. In the preferred embodiment, the cycle time is approximately 2.5 ms. An appropriate cycle time can be determined based on government regulation of devices that emit electromagnetic radiation. If the cycle time is not complete, the microprocessor 212 returns to the decision block 414. If the cycle time is complete, the microprocessor 212 advances to a decision block 424. At this point the

transmit pulse was sent, but a return pulse was not received. Thus, the distance-measurement cycle is complete, but no current data value has been obtained.

At the decision block 424, the microprocessor 212 determines whether the measure button 110 remains activated. If the measure button remains activated, the microprocessor 212 returns to the process block 410 (Figure 8A). If the measure button 110 is no longer activated, the microprocessor 212 discards any previously obtained data, checks the voltage level provided by the power supply 222, momentarily illuminates the low-battery indicator 142, if necessary, and returns to the process block 404 (Figure 8A).

If a receive pulse is detected at the decision block 414, the microprocessor 212 advances to a process block 416. At the process block 416, the microprocessor 212 reads the digital representation of the sampled voltage either on the digital data lines 272A to 272N or from the internal counter. The microprocessor 212 may need to adjust the value obtained from the internal counter to compensate for nonlinear charging of the slow-charge capacitor 310. This completes the present distance-measurement cycle with the microprocessor 212 having obtained a current data value.

At a decision block 420, the microprocessor 212 determines whether the last data value for the current distance-measurement operation has been obtained. As indicated above, in the preferred embodiment, the last data value is the sixty fourth data value.

If the last data value has not been obtained, the microprocessor 212 advances to a decision block 422. At the decision block 422, the microprocessor 212 checks an internal timer to determine whether the cycle time has been completed. If the cycle time has not been completed, the microprocessor 212 continues to execute the decision block 422 until the cycle time is complete. When the cycle time is complete, the microprocessor 212 advances to the decision block 424.

If the last data value has been obtained at the decision block 420, the microprocessor 212 advances to a process block 426 (Figure 8C). At this point, the microprocessor 212 has obtained all of the required data values and can proceed to accurately determine the distance between the distance-measurement apparatus 100 and the remote object or surface. At the process block 426, the microprocessor 212 controls the power supply 222 using the analog power control line 278 to disable power on the analog power line 294 to power down the time measurement circuit 162 or 302, the light transmitter unit 224 and the photodiode unit 226.

At a process block 428, the microprocessor 212 rearranges all the data values that have been obtained so that the data values are in ascending order from the lowest value to the highest value.

At a process block 430, the microprocessor 212 determines the average of a block of data values that is within the extremes of the ascending order. Thus, the microprocessor 212 discards a block of data values at the lower end of the ascending order and another block at the higher end of the ascending order. As indicated above, for the preferred embodiment, the lowest 16 data values and the highest 16 data values are discarded. The remaining 32 data values are averaged.

At a process block 432, the microprocessor 212 applies a scale factor to convert the average voltage into a corresponding distance measurement. An appropriate scale factor is determined from the speed of light and the

charging rate of the charging capacitor 208 or 308. The microprocessor 212 also adjusts the resulting distance measurement by an offset to account for delays and other variations in the distance-measurement apparatus 100. The sequence of calculations for determining an accurate value for the desired distance measurement can be altered without changing the overall result. For example, the time measurements can be converted to corresponding distance measurements before the values are sorted and averaged.

At a process block 434, the microprocessor 212 generates appropriate electronic signals on the range display bus 276 to cause the range display 114 to display the resulting distance measurement. The microprocessor 212 maintains the display of the distance-measurement result for approximately 5 seconds.

After the process block 434, the microprocessor 212 advances to a decision block 436. At the decision block 436, the microprocessor 212 determines whether the measure button 110 is still active. If the measure button 110 is still active, the microprocessor 212 returns to the process block 408 (Figure 8A). Otherwise, the microprocessor 212 returns to the process block 404 (Figure 8A).

In summary, in the method of Figures 8A, 8B, and 8C, the microprocessor 212 enters a sleep mode when the distance-measurement apparatus 100 is not performing a distance-measurement operation. A distance-measurement operation generally comprises the steps of discharging the charging capacitor 208 or 308, generating a pulse of light at the laser diode 120, beginning to charge the charging capacitor 208 or 308, detecting whether a reflected light pulse has been received at the photodiode receiver 118, and converting the accumulated voltage across the charging capacitor 208 or 308 to a digital value upon reception of a reflected light pulse. When a predetermined number of digital values have been obtained, the microprocessor 212 powers down most of the components of the electronic unit 122, sorts the digital values into ascending order, discards a predetermined number of digital values having the lowest numerical values, discards a predetermined number of digital values having the highest numerical values, averages the digital values that have not been discarded, applies a scale factor and an offset to the average of the digital values to obtain a distance-measurement value, and displays the distance-measurement value on the range display 114. A person of skill in the art will understand that the sequence of the data manipulations and calculations required to determine a distance-measurement value from the obtained set of digital values can be altered without effectively changing the method of obtaining a distance-measurement value.

A reflective target may be used in conjunction with the distance-measurement apparatus 100 to form a distance-measurement system. The reflective target is preferably substantially more efficient at reflecting light back towards a light source than most other surfaces. Thus, the light beam from the distance-measurement apparatus 100 can be directed toward the target, so that the target reflects a relatively high proportion of the incident light back toward the distance-measurement apparatus 100. Use of a target that is substantially more reflective than other surfaces that are encountered in a specific application is generally advantageous in that the distance-measurement apparatus 100 can generally be designed to detect light pulses that are reflected off the target, but to ignore light pulses that reflect off other surfaces. Light pulses that have reflected off the target will generally have substantially greater magnitude than light pulses that have reflected off other surfaces. Thus, the sensitivity

of the photodiode unit 226 can be designed to only detect the light pulses with greater magnitudes. In some applications, however, use of a target is either not possible, or not practical.

The size, shape, and other characteristics of the reflective target may vary substantially, depending on the application involved. Figure 9 illustrates a preferable reflective target 500 for use in a golf environment. The reflective target 500 may also be used in numerous other environments. The reflective target 500 comprises a substantially cylindrical tube. Alternatively, the reflective target 500 may have an elongated octagonal shape, or other similar shape. The reflective target 500 has a diameter of approximately 1.5 inches. The reflective target 500 comprises a reflective surface 502 that circumferentially encompasses the reflective target 500. The reflective surface 502 has a length of approximately 12 inches. In the preferred embodiment, the reflective surface 502 comprises a material that, when mounted on a planar surface, is at least 1000 times more reflective than a Lambertian target.

Many reflective surfaces only provide sufficient reflectivity for relatively small entrance angles. Such reflective surfaces are not desirable in a golf application and many other applications. In a golf application, for example, the angle between the golfer using the distance-measurement apparatus 100 and the target 500 may be any horizontal angle, from 0 to 360 degrees. Thus, the target 500 should preferably provide sufficient reflectivity at any horizontal entrance angle. On the other hand, providing sufficient reflectivity at a wide range of vertical entrance angles in a golf application is not as important. The substantially cylindrical shape of the preferred embodiment of the reflective target 500 provides reflectivity at substantially all horizontal entrance angles. Thus, a light beam reflects off the reflective target 500 and back toward the distance-measurement apparatus 100, regardless of the direction from which a golfer is approaching the target 500. In the preferred embodiment, the reflective target 500 is at least 1000 times more reflective than a Lambertian target for any entrance angle in a 360 degree circumference about the reflective target 500. In an application for which vertical entrance angles are more important, a ring-shaped target or a spherical target may be preferred. The reflective target 500 may also comprise strips 504 and 506 that can be used for advertising. Each of the strips 504 and 506 is preferably 0.75 inches wide.

Figure 10 illustrates the structure of the reflective surface 502 of the preferred embodiment. The reflective surface 502 is preferably a reflective tape material that can be applied to various surfaces. The reflective surface 502 preferably comprises a large number of closely spaced micro retro-reflectors 508. Each micro retro-reflector 508 is preferably a three dimensional structure having a cross-sectional area on the order of tens or hundreds of microns. Each micro retro-reflector 508 simulates the reflective characteristics of a cube corner. Namely, each micro retro-reflector 508 preferably reflects substantially all incident light back in precisely the same direction from which the light came. The micro retro-reflectors 508 of the reflective surface 502 may be covered by a transparent coating. The reflective surface 502 may, for example, comprise a strip of reflective tape sold by the 3M Packaging Systems Division, and described as "2000X RetroReflective Targets." Other reflective materials may also be used for the reflective surface 502.

Figure 11 illustrates a second embodiment of a reflective target 600 that can be used with the distance-measurement apparatus 100. The reflective target 600 comprises a set of three panels 602, 604, and 606. All of the panels 602, 604, and 606 are connected together along a central axis. Each of the panels 602, 604, and 606 extend outwardly from the central axis to form three horizontal angles of approximately 120 degrees each. The reflective target 600 also preferably comprises a top ring 608 and a bottom ring 610. The top ring 608 is preferably connected to an outside edge of each of the panels 602, 604, and 606 at the top of the reflective target 600. The bottom ring 610 is preferably connected to an outside edge of each of the panels 602, 604, and 606 at the bottom of the reflective target 600. Thus, the outside dimensions of the reflective target 600 defined by the rings 608 and 610 and the panels 602, 604, and 606 is a generally cylindrical shape. The diameter of the generally cylindrical shape of the reflective target 600 is preferably approximately 2 inches, while the length is preferably approximately 4.5 inches. The rings 608 and 610 serve to protect the panels 602, 604, and 606 from damage. Each of the panels 602, 604, and 606 is preferably covered, on both sides, with the same reflective surface 502 that is illustrated and described above with reference to Figures 9 and 10.

Either of the targets 500 or 600, or targets having other shapes and sizes, may, for example, be attached to the top of a pole in a variety of applications. In a golf application, either of the targets 500 or 600 may be attached to the top of the pin at each hole of the course. Either of the targets 500 or 600 may also be used for other purposes on a golf course. For example, a target 500 or a target 600 may be placed at or near a "hazard", such as a sand trap, so that the golfer can determine the distance to the hazard. Also, a target 500 or a target 600 may be placed at or near the tee area. In this situation, after a golfer hits an initial drive from the tee area, the golfer can go to the location of the ball and measure the distance from the golf ball back to the tee, to determine how far he hit the ball. A substantially cylindrical reflective target having a diameter that is larger than 1.5 inches may be preferable for marking hazards and tee areas.

The reflective target 500 is preferable in a golf application, at least for placement on top of each pin on the course, because the reflective target 500 has a uniform reflectivity for all horizontal entrance angles. The reflectivity of the reflective target 600, on the other hand, is not uniform for all horizontal entrance angles. However, the reflective target 600 may be preferable in other applications because the reflective target 600 is more effective at reflecting light for some entrance angles than the reflective target 500.

A distance-measurement system for a golf environment preferably comprises a distance-measurement apparatus 100 and a plurality of targets 500. A reflective target 500 is preferably mounted on each of the pins on the golf course, near the top of the pin. Then, a golfer can determine the distance from any location on the golf course to any pin on the course, by standing at the desired location on the course and directing the light beam of the distance-measurement apparatus 100 toward the desired pin. The light beam from the distance-measurement apparatus 100 reflects off the target 500, back toward the distance-measurement apparatus 100. The distance-measurement apparatus 100 will then compute and display the distance between the distance-measurement apparatus 100 and the target 500.

As described above, the distance-measurement apparatus 100 is preferably designed to have an optimal optical relation with the type or types of objects or surfaces to which distances are to be measured in a specific application. Thus, in a golf environment, the optical characteristics of the distance-measurement apparatus 100 are selected to be compatible with the golf pin reflective target 500. In the preferred embodiment, for a golf environment, the laser diode 120 comprises an EG&G part number PGAU1S12 laser diode. The laser diode 120 is preferably driven with a peak power of 10 watts, a pulse width of 30 nanoseconds, and a cycle time of 400 pulses per second. The transmit lens 104 has a diameter of 25 millimeters and a back focal length of 26.5 millimeters. The transmit lens 104 is a positive or converging lens that effectively gathers light from the laser diode 120 for transmission toward the target 500, and it satisfies eye safety considerations. The receive lens 106 has a diameter of 40 millimeters and a back focal length of 42.5 millimeters. The receive lens 106 is preferably an aspheric lens that is highly corrected to obtain a small spot size at the photodiode receiver 118. The receive lens 106 is a positive or converging lens that efficiently gathers incident light and focuses it onto the photodiode receiver 118. The photodiode receiver 118 is preferably a SFH217 component, with or without filtering, as sold by Siemens.

An operator of the distance-measurement apparatus 100 can determine the distance between the distance-measurement apparatus 100 and a remote object or surface by pointing the distance-measurement apparatus 100 toward the remote object or surface and pressing and holding the measure button 110. If a correct hit occurs, the distance-measurement apparatus 100 displays the distance to the remote object or surface on the range display 114. To achieve a correct hit, the distance-measurement apparatus 100 must be positioned so that the remote object or surface is directly in front of the transmit lens 104, so that the transmit lens 104 directs the light from the laser diode 120 directly toward the remote object or surface.

In the preferred embodiment, the distance-measurement apparatus 100 comprises the viewfinder 108, as illustrated in Figures 1, 2, 3, and 4. The viewfinder 108 assists an operator in directing the light beam from the distance-measurement apparatus 100 toward a remote object or surface. Referring to Figure 4, the length 146 of the reflector/window tube 126 is selected to be as long as practical. The distance 148 between the view finder light 124 and the reflector/window 134 is greater than the length 146. The reflector/window 134 is a spherical lens of uniform thickness, with a radius of curvature equal to twice the distance 148. The light from the view finder light 124 is directed toward a concave surface of the reflector/window 134. This concave surface of the reflector/window 134 has a coating that has a reflectivity of 0.25 to 0.50. Thus, generally, less than half the light from the view finder light 124 is reflected back into the view finder 108, while the remaining light passes through the reflector/window 134 and outside the view finder 108. In addition, the reflector/window 134 generally allows more than half of the light that is incident on the reflector/window 134 from outside the view finder 108, toward the operational end 102, to travel through the reflector/window 134 and into the view finder 108. The distance between the vertical center of the view finder light 124 and the vertical center of the reflector/window tube 126 is defined as a vertical travel distance 147 for reflected light. As illustrated in Figure 4, the reflector/window 134 is not perpendicular to the reflector/window tube 126. Instead, the reflector/window 134 forms a bevel angle 143 with the reflector/window tube 126. The bevel angle 143 is selected so that the vertical travel distance 147 equals

the distance 148 multiplied by the tangent of twice the bevel angle 143. The shape, position and orientation of the reflector/window 134 relative to the view finder light 124 substantially collimates the light from the view finder light 124 and directs the collimated light in a direction that is substantially parallel to the reflector/window tube 126. The reflector/window tube 126 is adjusted using the x-axis adjustment screw 130 and the y-axis adjustment screw 132 so that the reflector/window tube 126 is substantially parallel to the path of the light emitted from the transmit lens 104.

To use the view finder 108, an operator first activates the view finder switch 144 (Figure 2), which activates the view finder light 124. Next, the operator looks through the view finder 108 from the user end 112. As described above, the reflector/window 134 allows light from the operational end 102 of the view finder 108 through to the inside of the view finder 108. Thus, the operator can see through the view finder 108 and observe anything that is directly in front of the view finder 108 toward the operational end 102. In addition, the view finder light 124 produces a beam of colored light that travels toward the reflector/window 134. Some of the light from the view finder light 124 is collimated and reflected back toward the eye of the operator. However, the reflector/window 134 does not reflect enough of the light for the operator to determine that the light has been reflected. Consequently, the light appears to be coming from in front of the view finder 108, toward the operational end 102. Thus, the operator sees a colored dot of light from the view finder light 124 superimposed on the view in front of the view finder 108. In addition, because the reflected light from the view finder light 124 is collimated, the colored dot appears to be very far away, allowing the operator's eye to focus on the object or surface to which the distance is to be measured. If the operator aligns the image of the colored dot with the image of the remote object or surface, the light beam of the distance-measurement apparatus 100 is directed toward the remote object or surface. Next, the operator presses and holds the measure button 110 to perform a distance-measurement operation, and the distance-measurement apparatus 100 displays the distance to the remote object or surface on the range display 114. Other view finding devices may also be used in connection with the distance-measurement apparatus 100, instead of the superimposed light beam view finder 108 of the preferred embodiment.

WHAT IS CLAIMED IS:

1. A portable, hand-held distance-measurement apparatus comprising:

a light transmitter, said light transmitter generating pulses of light for transmission to and reflection by a remote surface;

a light receiver, said light receiver receiving pulses of light that have reflected off the remote surface, said light receiver detecting such reflected pulses of light;

a time measurement circuit, said time measurement circuit generating a digital value that represents an analog value, said analog value being determinatively related to the elapsed time between the generation of one of the light pulses by said light transmitter and the detection of said one light pulse by said light receiver, said time measurement circuit comprising:

a charging capacitor;

a current source, said current source providing an electronic current to charge said charging capacitor;

a charge/discharge circuit comprising one or more charge/discharge switches connected to control the charging and discharging of said charging capacitor, said charge/discharge circuit causing said charging capacitor to discharge before the generation of the transmitted light pulse and causing said charging capacitor to begin charging substantially at a first predetermined time relative to the generation of the transmitted light pulse;

a latch which latches a first voltage representative of the charge across said charging capacitor substantially at a second predetermined time relative to the detection of the reflected light pulse;

a reference voltage generator, said reference voltage generator generating a reference voltage signal having a magnitude that varies over time;

a comparator, said comparator generating a compare signal corresponding to the relative magnitudes of said first voltage and said reference voltage signal; and

a digital value generator, said digital value generator monitoring said compare signal and, in response thereto, generating said digital value;

a power supply which provides electrical power to said time measurement circuit, said electrical power being disabled when said time measurement circuit is not in use; and

a processor, said processor receiving said digital value from said time measurement circuit and, in response thereto, determining a distance measurement between said distance-measurement apparatus and said remote surface.

2. The distance-measurement apparatus of Claim 1, wherein said light transmitter comprises a laser diode.

3. The distance-measurement apparatus of Claim 1, wherein said light receiver comprises a photodiode receiver.

4. The distance-measurement apparatus of Claim 1, wherein said analog value directly represents said elapsed time.

5. The distance-measurement apparatus of Claim 1, wherein said current source provides a substantially constant current to charge said capacitor in a substantially linear manner.

6. The distance-measurement apparatus of Claim 1, wherein said reference voltage generator, said comparator, and said digital value generator comprise an analog-to-digital converter.

7. The distance-measurement apparatus of Claim 6, wherein said latch and said analog-to-digital converter are implemented in a single electronic component.

8. The distance-measurement apparatus of Claim 7, wherein said single electronic component comprises a successive approximation analog-to-digital converter.

9. The distance-measurement apparatus of Claim 1, wherein said charging capacitor and said latch comprise a single capacitor.

10. The distance-measurement apparatus of Claim 1, wherein said reference voltage generator comprises a resistor, a capacitor, and one or more charge/discharge switches.

11. The distance-measurement apparatus of Claim 1, wherein said digital value generator comprises a counter.

12. The distance-measurement apparatus of Claim 11, wherein said processor comprises a microprocessor, said microprocessor comprising said counter.

13. The distance-measurement apparatus of Claim 1, wherein said processor comprises a microprocessor.

14. The distance-measurement apparatus of Claim 13, wherein:

said microprocessor receives a first plurality of digital values from said time measurement circuit;

said microprocessor discards a second plurality of said first plurality of digital values, said second plurality having the highest numerical values;

said microprocessor discards a third plurality of said first plurality of digital values, said third plurality having the lowest numerical values; and

said microprocessor determines a distance measurement between said distance-measurement apparatus and said remote surface by averaging a fourth plurality of digital values, said fourth plurality of digital values comprising all of said first plurality of digital values that have not been discarded.

15. The distance-measurement apparatus of Claim 13, wherein said microprocessor has a sleep mode for conserving electrical power when said microprocessor is not active.

16. The distance-measurement apparatus of Claim 1, wherein said power supply comprises a battery.

17. The distance-measurement apparatus of Claim 1 additionally comprising a view finding device.

18. The distance-measurement apparatus of Claim 17, wherein said view finding device comprises a superimposed light beam view finder.

19. The distance-measurement apparatus of Claim 1 additionally comprising a transmit lens and a receive lens, wherein the optical characteristics of said light transmitter, said light receiver, said transmit lens and said receive lens are selected to substantially maximize the quantity of light reflected by the remote surface and received by the light receiver.

20. A method of performing a plurality of distance-measurement operations to determine distances between a distance-measurement apparatus and one or more remote surfaces, said method comprising the steps of:

detecting one or more requests for a distance-measurement operation; and

for each detected request, performing a distance-measurement operation, said distance-measurement operation comprising the steps of:

performing a plurality of distance-measurement cycles to obtain a first plurality of digital values, each distance-measurement cycle comprising the steps of:

generating a light pulse and directing the light pulse toward a remote surface for reflection from said surface as a reflected light pulse;

receiving the reflected light pulse; and

generating a digital value that represents an analog value that is determinatively related to the elapsed time between the generation of the light pulse and the reception of the reflected light pulse;

discarding a second plurality of said first plurality of digital values, said second plurality having the lowest of the digital values;

discarding a third plurality of said first plurality of digital values, said third plurality having the highest of the digital values;

computing an average digital value from a fourth plurality of digital values, said fourth plurality of digital values comprising all of said first plurality of digital values that have not been discarded; and

obtaining a corresponding distance-measurement value from said average digital value, said distance-measurement value representing the distance between said distance-measurement apparatus and said remote surface.

21. The method of Claim 20, wherein the step of generating a digital value comprises the steps of:

discharging a capacitor before the generation of the light pulse;

charging said capacitor beginning substantially at a first predetermined time relative to the generation of the light pulse;

latching the voltage across said capacitor substantially at a second predetermined time relative to the reception of the reflected light pulse; and

generating a digital value that represents said latched voltage.

22. The method of Claim 20, wherein the number of digital values in said second plurality is equal to the number of digital values in said third plurality.

23. The method of Claim 20, wherein said step of obtaining a corresponding distance-measurement value from said average digital value comprises the steps of:

multiplying said average digital value by a scale factor; and

adding an offset value to the product of the multiplication.

24. The method of Claim 20, additionally comprising the step of disabling power to a time measurement circuit when said time measurement circuit is not active, said time measurement circuit performing said plurality of distance-measurement cycles.

25. The method of Claim 20, additionally comprising the step of causing a microprocessor to enter a sleep mode to conserve electrical power when said microprocessor is not active, said microprocessor controlling the performance of each of said distance-measurement operations.

26. A distance-measurement system comprising:

a reflective target, said reflective target comprising a sheet of reflective material, said reflective target having a reflectivity that is at least 1000 times greater than the reflectivity of a Lambertian surface for substantially all horizontal entrance angles; and

a portable, hand-held distance-measurement apparatus, said distance-measurement apparatus comprising:

a light transmitter, said light transmitter generating a pulse of light and directing said pulse of light toward said reflective target for reflection as a reflected pulse of light;

a light receiver, said light receiver receiving the reflected pulse of light;

a time measurement circuit, said time measurement circuit measuring the elapsed time between the generation of the light pulse by said light transmitter and the reception of the reflected light pulse by said light receiver;

a digital value generator, said digital value generator generating a digital value that represents an analog value that is determinatively related to said elapsed time; and

a processor, said processor receiving said digital value and, in response thereto, computing the distance between said distance-measurement apparatus and said reflective target.

27. The distance-measurement system of Claim 26, wherein said reflective target comprises a reflective material comprising a plurality of micro retroreflectors.

28. The distance-measurement system of Claim 26, wherein said reflective target has a substantially cylindrical-shape.

29. The distance-measurement system of Claim 26, wherein said processor comprises a microprocessor.

30. The distance-measurement system of Claim 26, wherein:

said distance-measurement apparatus additionally comprises a transmit lens and a receive lens; and

the optical characteristics of said light transmitter, said light receiver, said transmit lens, said receive lens and said reflective target are selected to substantially maximize the quantity of light reflected by said reflective target and received by the light receiver.

31. A portable, hand-held distance-measurement apparatus comprising:

a light transmitter, said light transmitter generating a pulse of light for reflection off a remote surface as a reflected pulse of light;

a light receiver, said light receiver receiving the reflected pulse of light;

a time measurement circuit, said time measurement circuit measuring the elapsed time between the generation of the light pulse by said light transmitter and the reception of the reflected light pulse by said light receiver;

a digital value generator, said digital value generator generating a digital value that represents an analog value that is substantially proportional to said elapsed time;

a power supply, said power supply providing electrical power to said time measurement circuit, said electrical power being disabled when said time measurement circuit is not in use; and

a processor, said processor receiving said digital value from said time measurement circuit and, in response thereto, computing a distance measurement between said distance-measurement apparatus and said remote surface; and

a view finding device which facilitates aiming the pulse of light toward said remote surface.

32. The distance-measurement apparatus of Claim 31, wherein said view finding device comprises a superimposed light beam view finder.

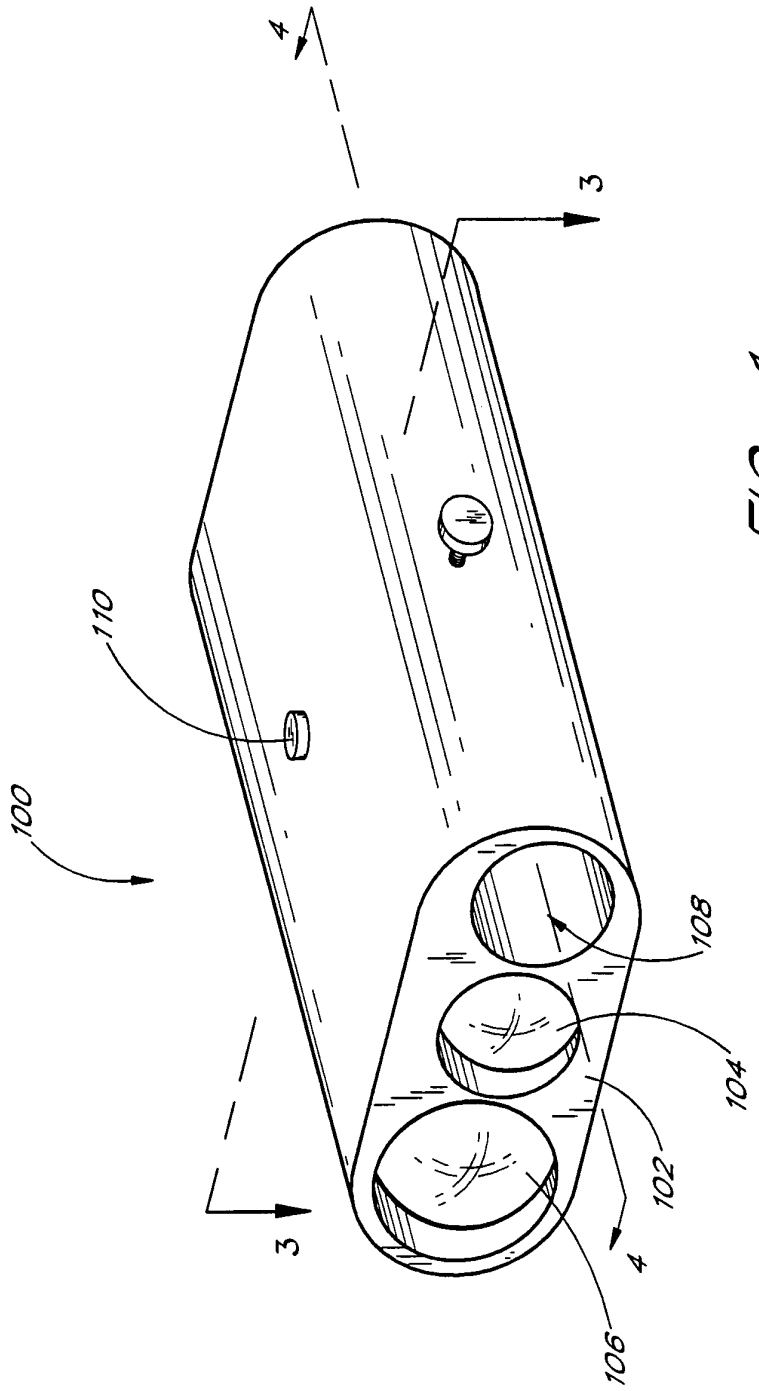


FIG. 1

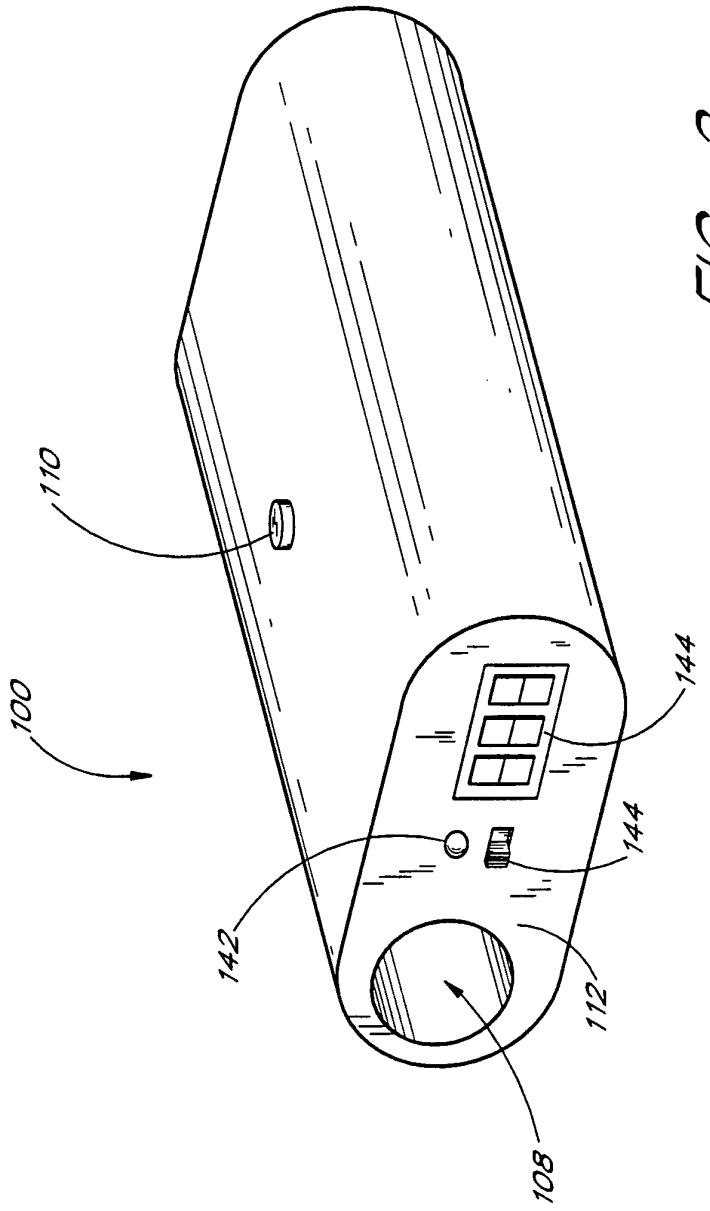


FIG. 2

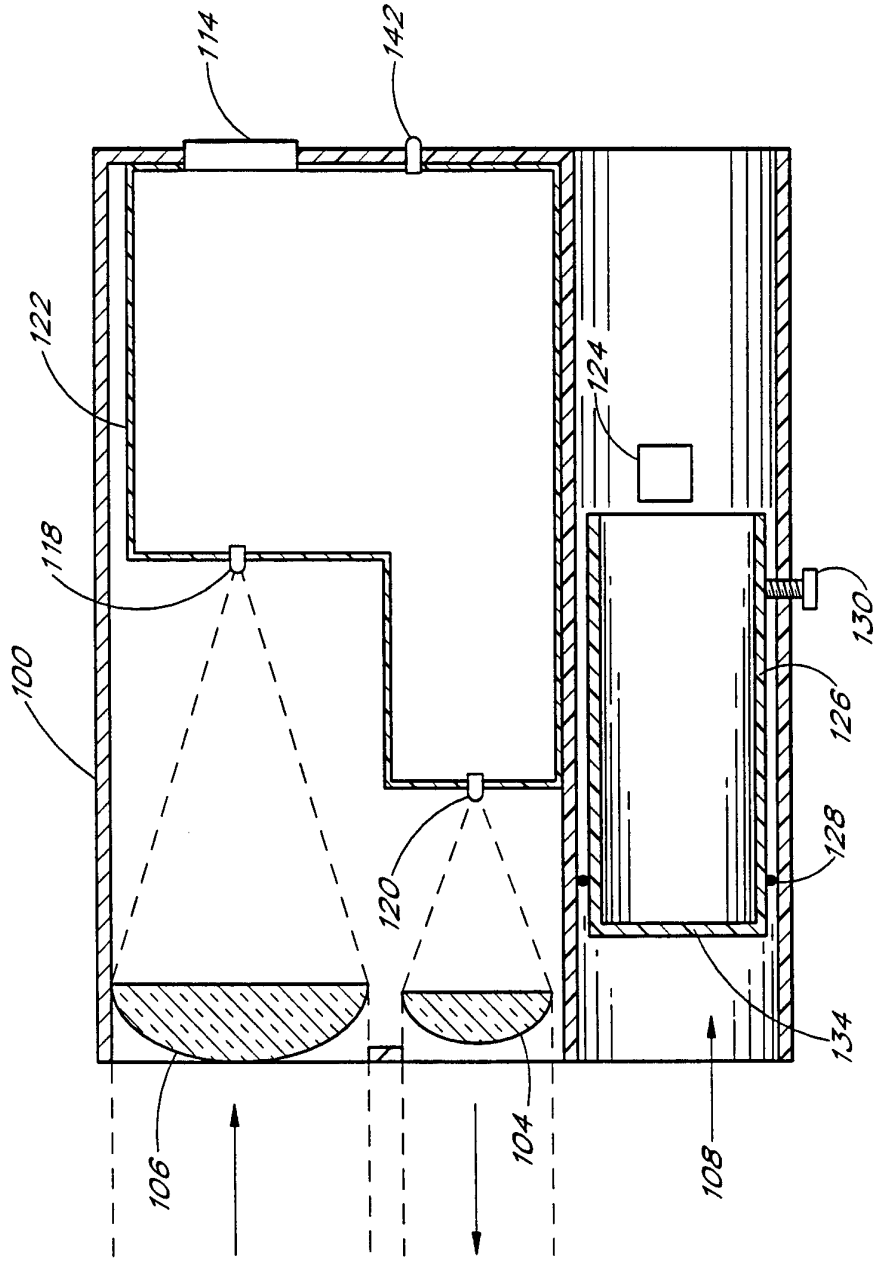


FIG. 3

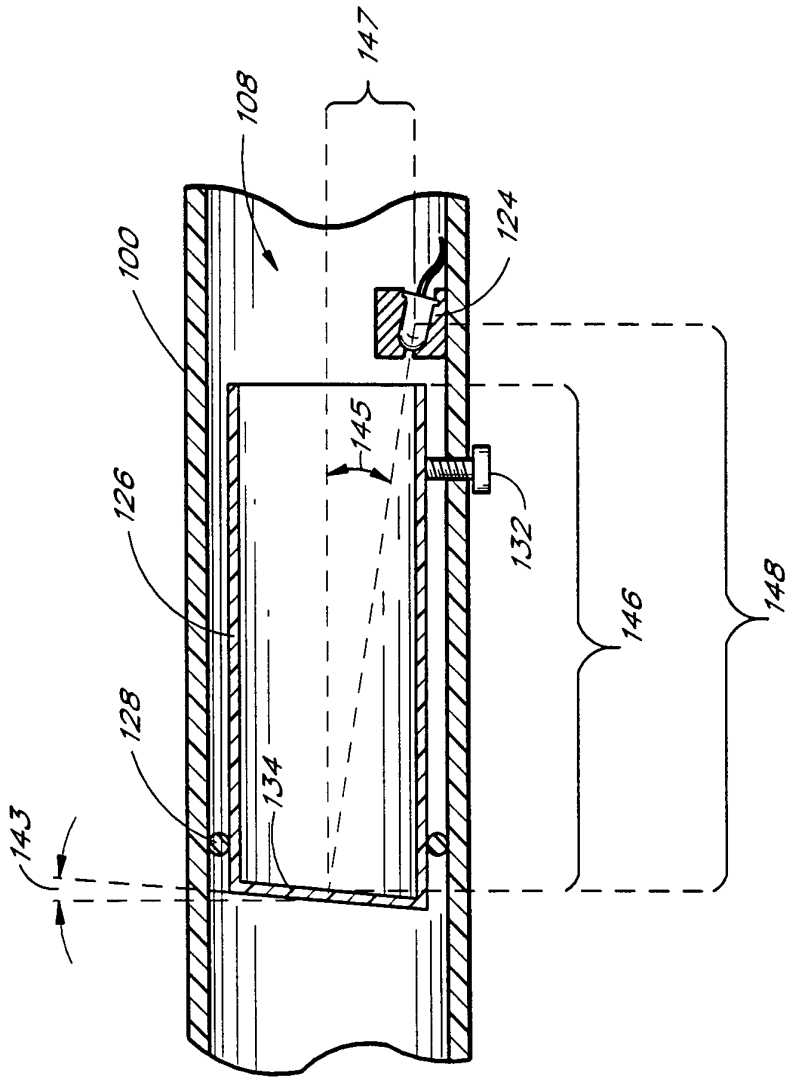
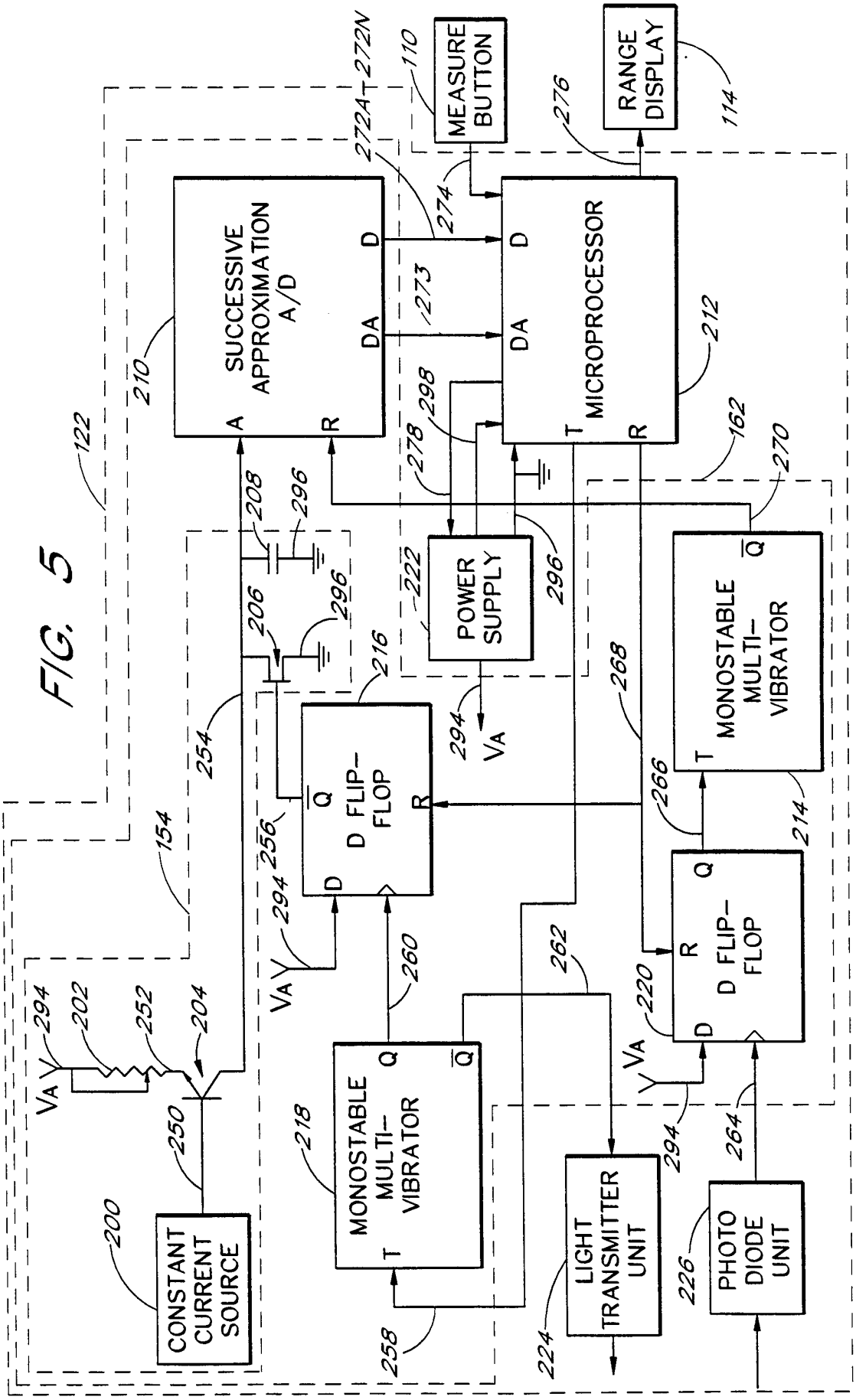


FIG. 4

FIG. 5


MEASURE BUTTON
110
RANGE DISPLAY
114
272A
272N
276
274
SUCCESSIVE APPROXIMATION A/D
210
A
R
D
DA
273
MICROPROCESSOR
212
T
122
208
296
298
278
162
270
206
216
POWER SUPPLY
222
294
VA
268
MONOSTABLE MULTI-VIBRATOR
Q
D FLIP-FLOP
254
256
266
214
154
202
252
204
250
200
CONSTANT CURRENT SOURCE
218
MONOSTABLE MULTI-VIBRATOR
260
262
220
258
LIGHT TRANSMITTER UNIT
224
PHOTO DIODE UNIT
226
264

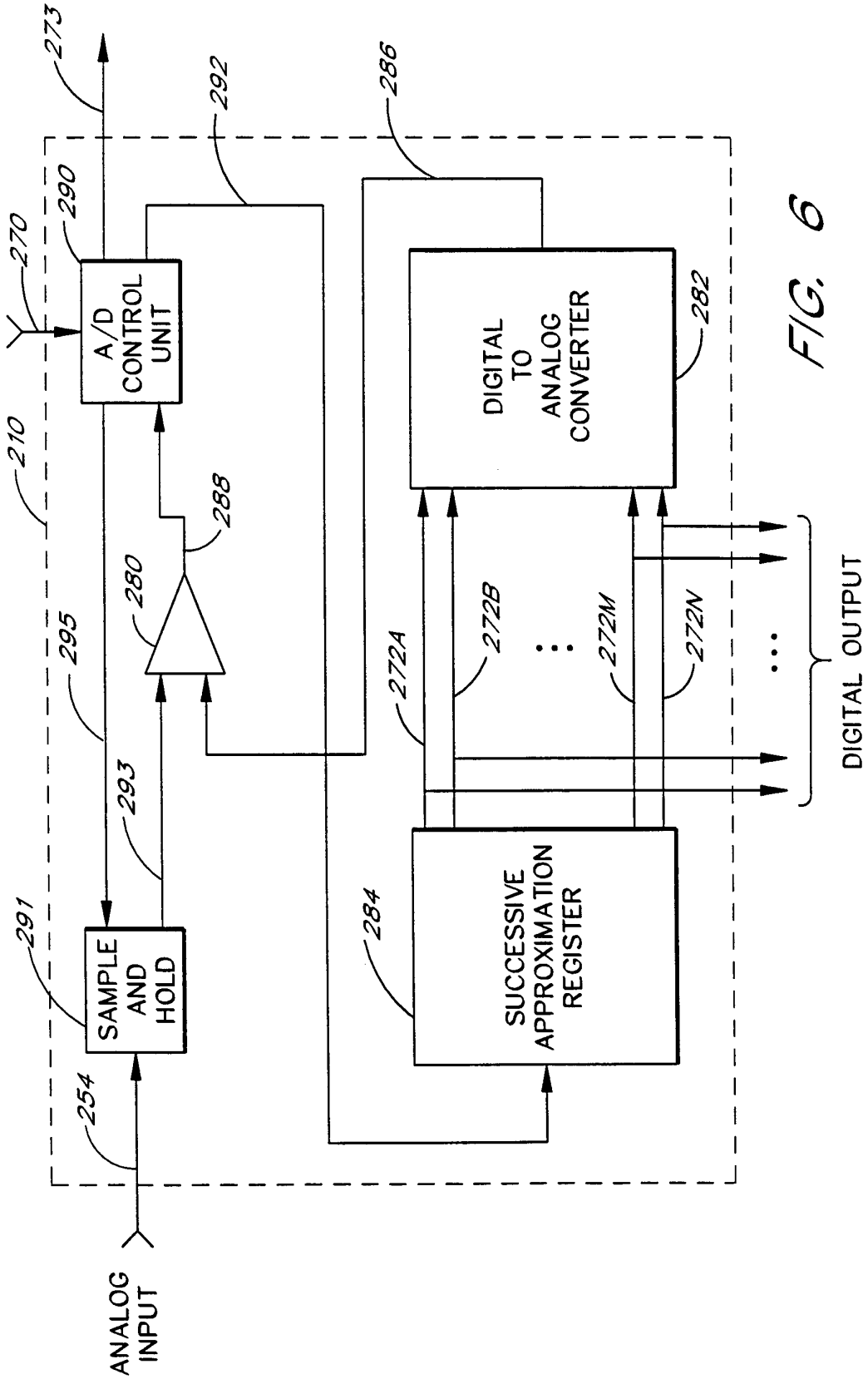

273
292
286
290
270
A/D CONTROL UNIT
DIGITAL TO ANALOG CONVERTER
282
210
288
280
295
272A
272B
272M
272N
DIGITAL OUTPUT
293
291
SAMPLE AND HOLD
284
SUCCESSIVE APPROXIMATION REGISTER
254
ANALOG INPUT

FIG. 6

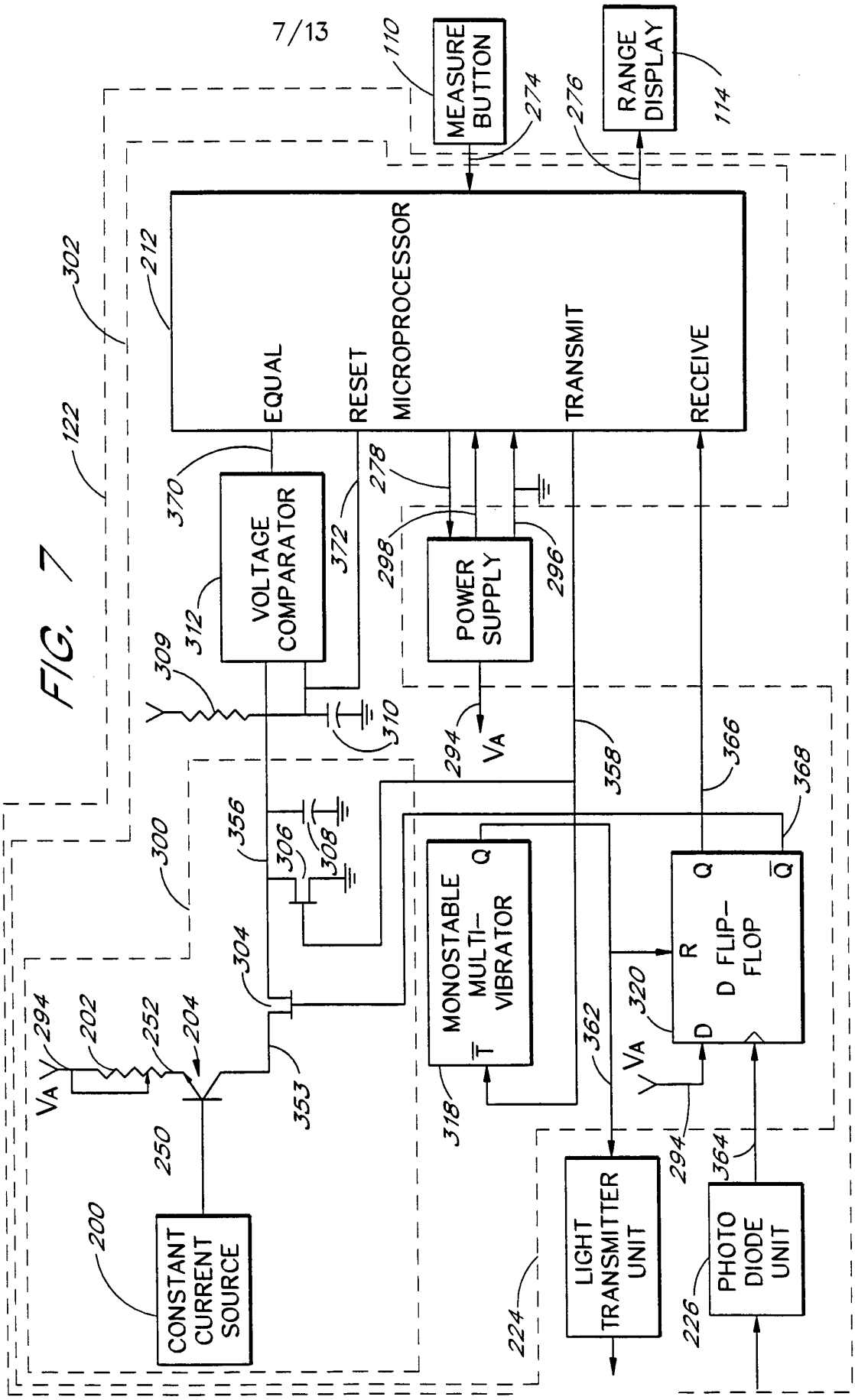

MEASURE BUTTON
110
274
276
RANGE DISPLAY
114
302
212
MICROPROCESSOR
EQUAL
RESET
TRANSMIT
RECEIVE
122
370
278
VOLTAGE COMPARATOR
372
298
296
POWER SUPPLY
312
309
310
294
VA
358
366
368
300
356
306
308
304
MONOSTABLE MULTI-VIBRATOR
Q
T
R
D FLIP-FLOP
D
Q
320
362
318
294
364
202
252
204
353
250
200
CONSTANT CURRENT SOURCE
LIGHT TRANSMITTER UNIT
224
PHOTO DIODE UNIT
226

FIG. 7

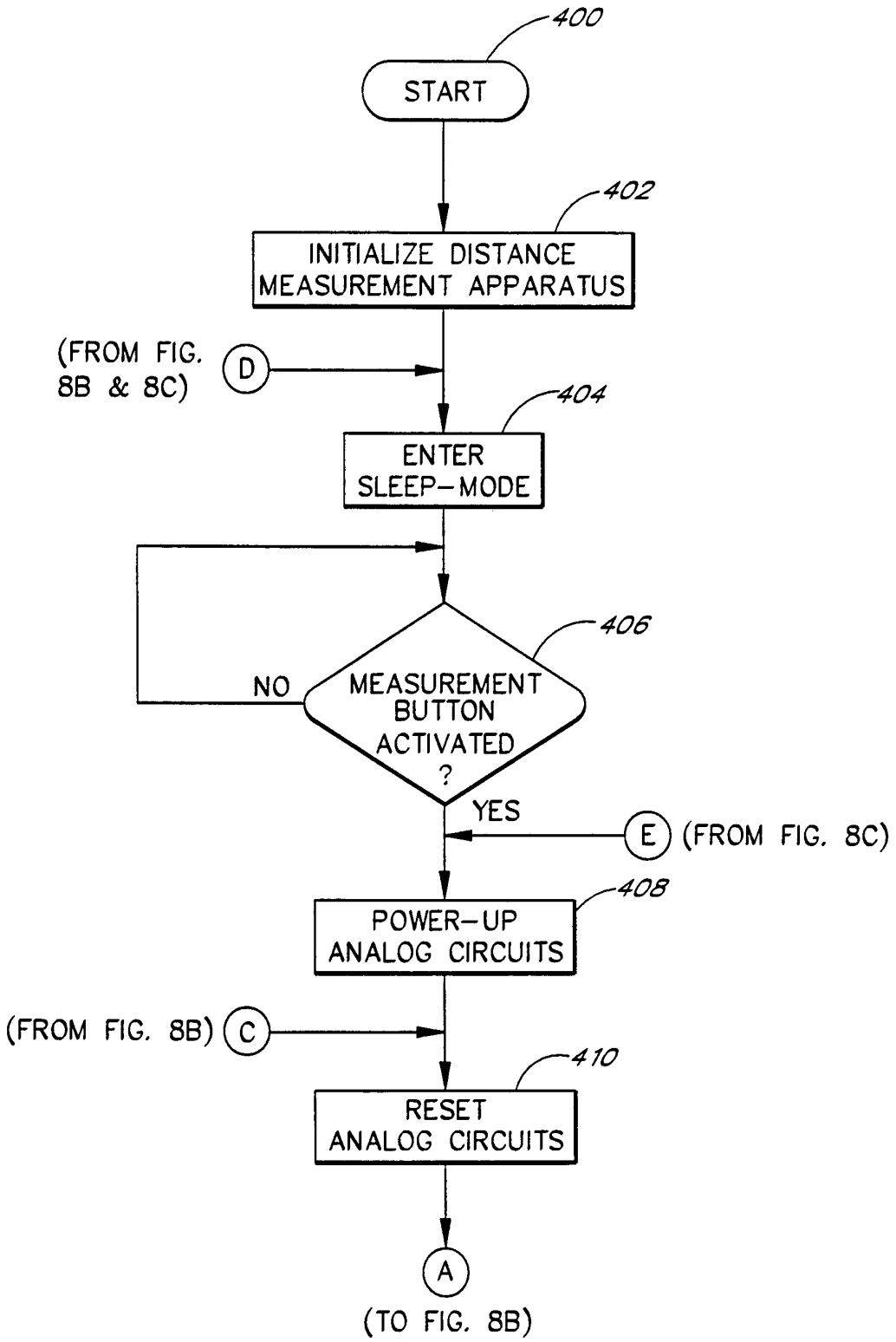

400
START
402
INITIALIZE DISTANCE MEASUREMENT APPARATUS
(FROM FIG. 8B & 8C)
D
404
ENTER SLEEP-MODE
406
NO
MEASUREMENT BUTTON ACTIVATED ?
YES
E
(FROM FIG. 8C)
408
POWER-UP ANALOG CIRCUITS
(FROM FIG. 8B)
C
410
RESET ANALOG CIRCUITS
A
(TO FIG. 8B)

FIG. 8A

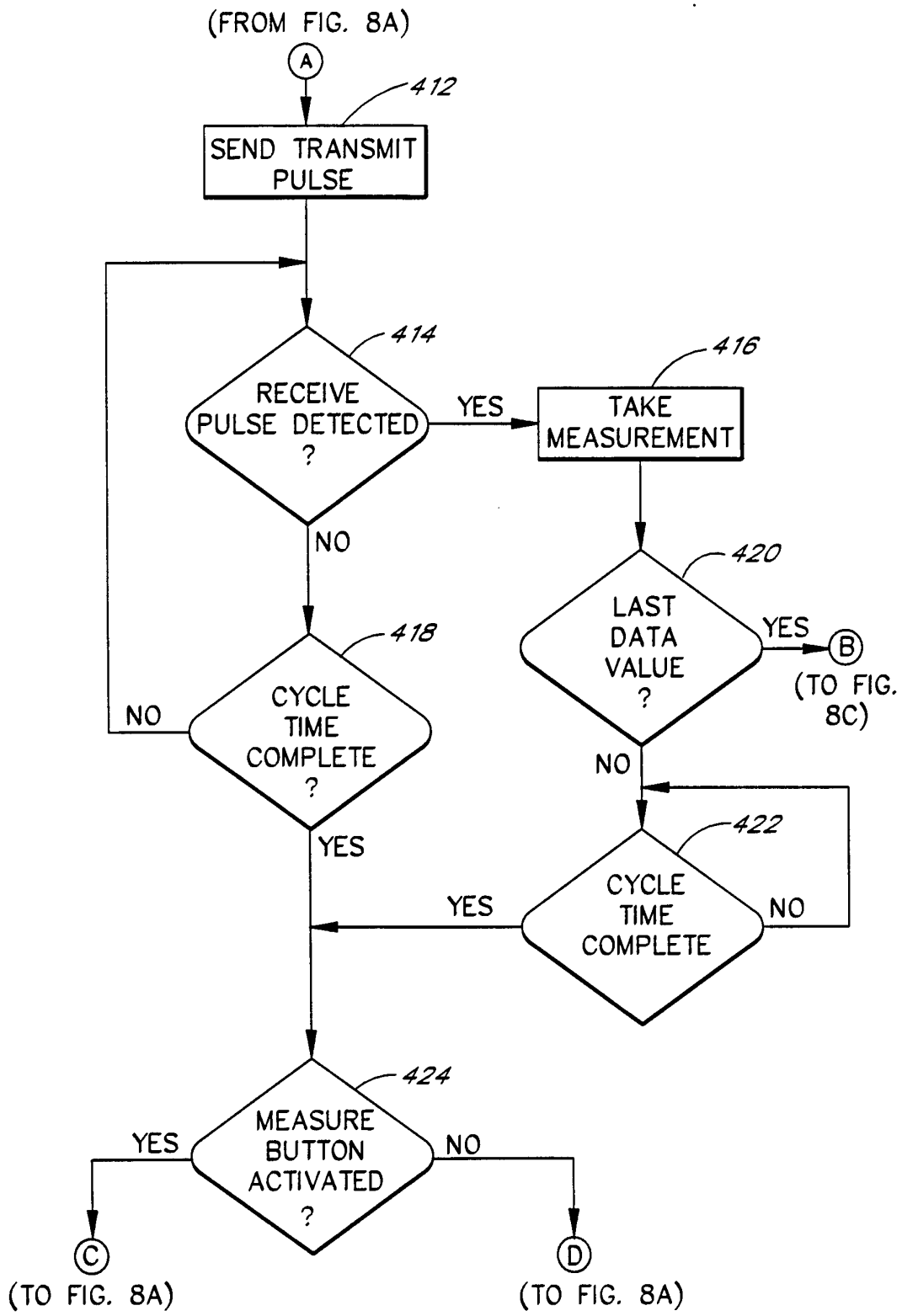

(FROM FIG. 8A)
A
412
SEND TRANSMIT PULSE
414
RECEIVE PULSE DETECTED ?
YES
416
TAKE MEASUREMENT
NO
420
LAST DATA VALUE ?
YES
B
(TO FIG. 8C)
418
CYCLE TIME COMPLETE ?
NO
NO
422
CYCLE TIME COMPLETE
YES
NO
YES
424
MEASURE BUTTON ACTIVATED ?
YES
NO
C
(TO FIG. 8A)
D
(TO FIG. 8A)

FIG. 8B

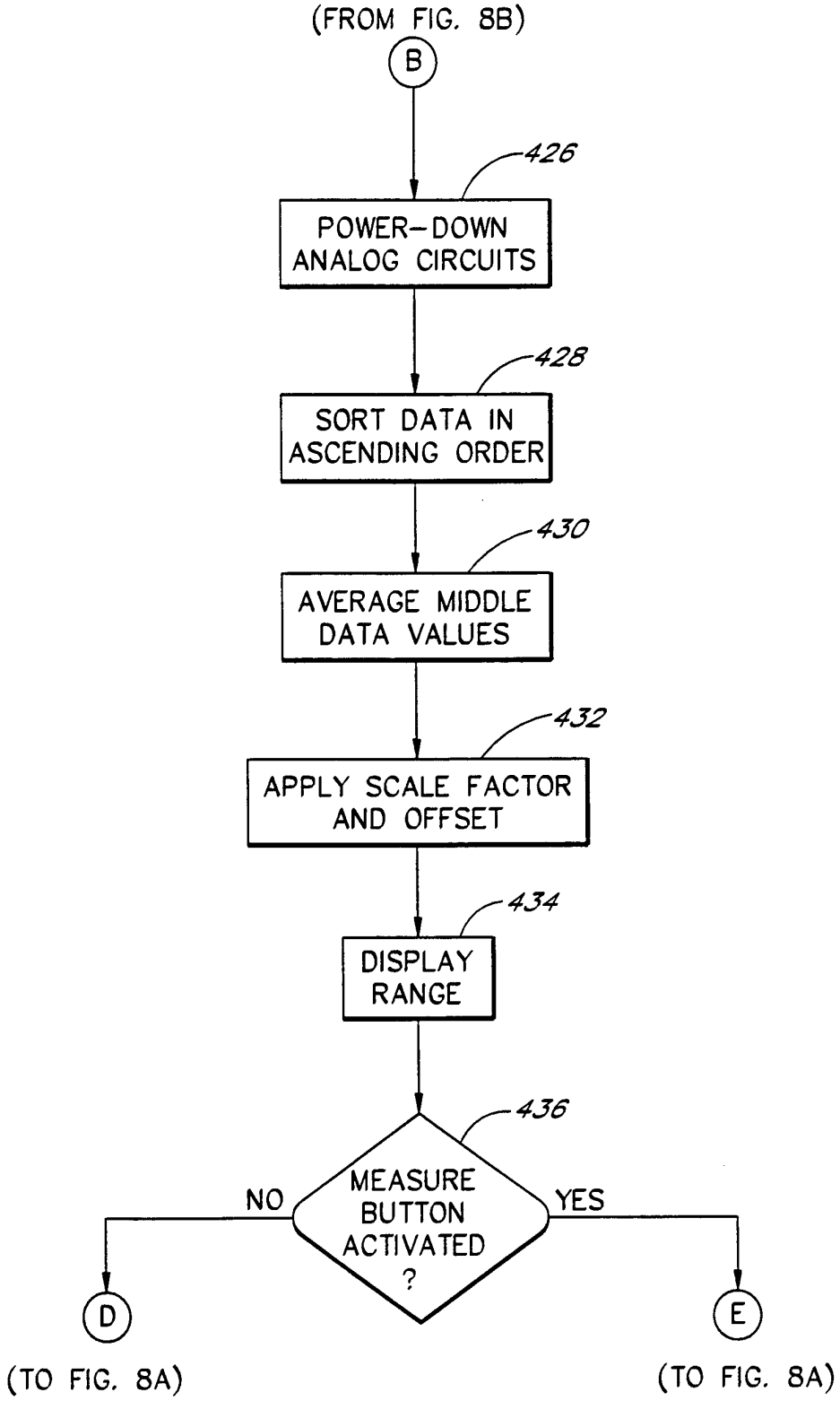

(FROM FIG. 8B)
B
426
POWER-DOWN ANALOG CIRCUITS
428
SORT DATA IN ASCENDING ORDER
430
AVERAGE MIDDLE DATA VALUES
432
APPLY SCALE FACTOR AND OFFSET
434
DISPLAY RANGE
436
MEASURE BUTTON ACTIVATED ?
NO
YES
D
E
(TO FIG. 8A)
(TO FIG. 8A)

FIG. 8C

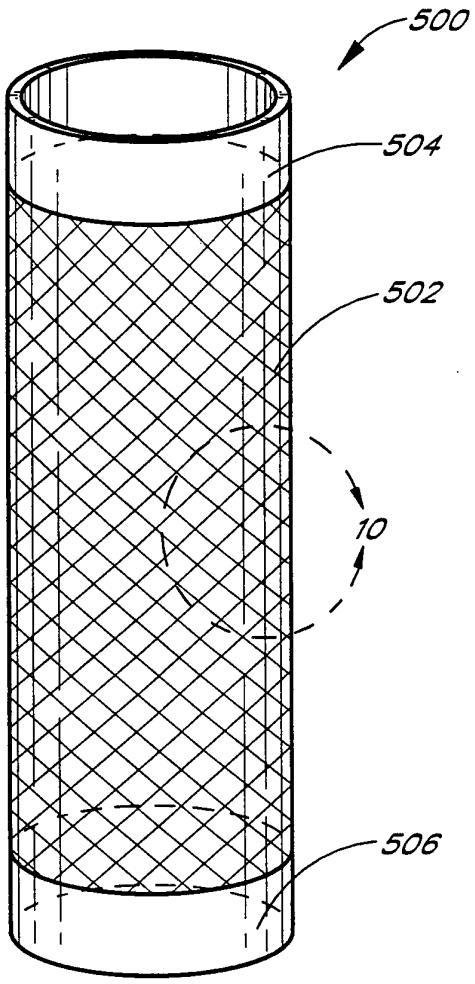


FIG. 9

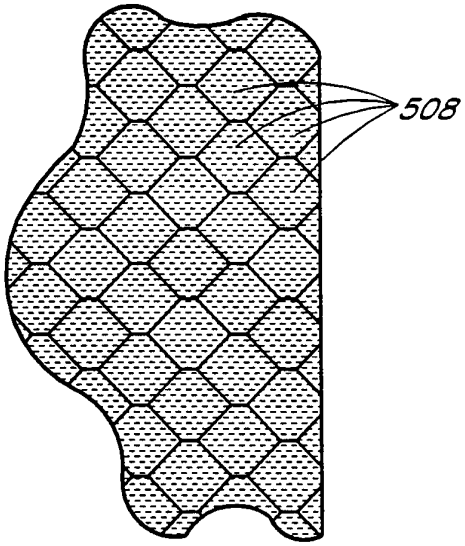


FIG. 10

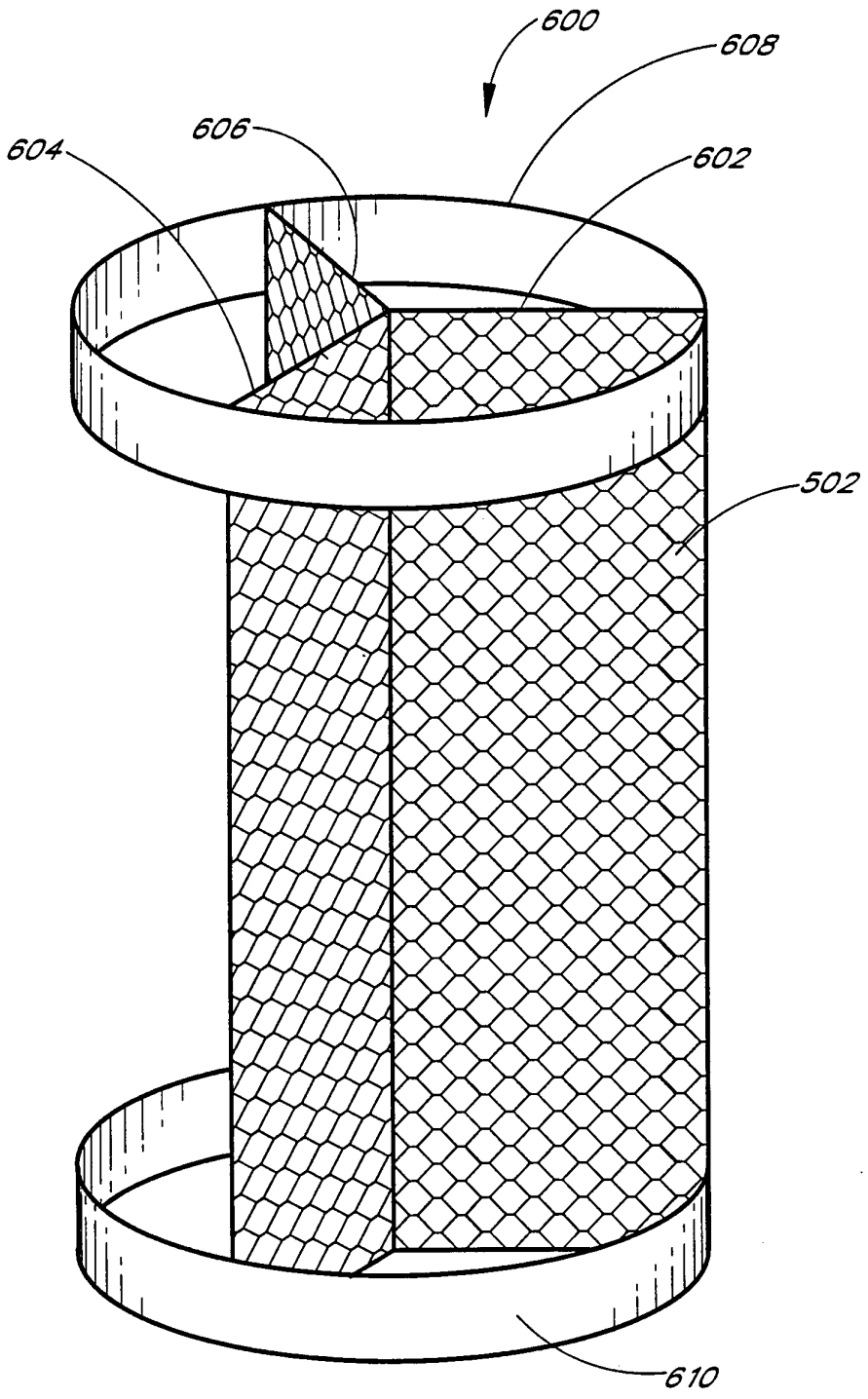


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/05308

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G01 C 3/08; GO2B 5/124
US CL :356/5.01, 5.08, 5.09, 5.10; 359/530
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)

U.S. : 356/5.01, 5.08, 5.09, 5.10; 359/530
342/134, 135; 367/99; 359/527; 356/4.01

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS Messenger: sight?, cylind? retroreflect?, charge, digital, pulse?, capacitor, range, distance, discard, average, sheet, view (w) finder, viewfinder, standby, sleep, power.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,346,989 (GORT ET AL) 31 August 1982, (11:45, Fig. 21)	1-19, 26-32, 15, 17
Y	US, A, 5,082,364 (RUSSELL) 21 January 1992, Fig. 5.	1-19, 26-30
Y, P	US, A, 5,359,404 (DUNNE) 25 October 1994	1-19, 26-30
A	US, A, 5,157,403 (URKOWITZ) 20 October 1992, Element 414	14, 20-25
A	US, A, 4,975,889 (PETRUCELLI ET AL) 04 DECEMBER 1990	1-19
Y	US, A, 4,888,477 (NANKIVIL) 19 December 1989, See entire document	1-19, 26-30

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

*	Special categories of cited documents:	"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
"A"	document defining the general state of the art which is not considered to be of particular relevance	"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
"E"	earlier document published on or after the international filing date	"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
"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)	"&"	document member of the same patent family
"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		

Date of the actual completion of the international search 25 JULY 1995	Date of mailing of the international search report 11 AUG 1995
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer STEPHEN C. BUCZINSKI Telephone No. (703) 308-0476

Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/05308

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	RCA Government and Commercial Systems AN/GS-5 "Light 'n easy"; 30 August 1976; Burlington, MA 01803	31, 32
Y,P	US, A, 5,311,271 (HURT ET AL) 10 May 1994, See entire document	26-32
Y	US, A, 3,620,626 (DALY ET AL) 16 November 1971, See entire document	26-30
Y	US, A, 3,716,445 (LEMELSON) 13 February 1973, See entire document	26-30
Y	US, A, 5,171,624 (WALTER) 15 December 1992, See entire document	26-30
Y	TASCO Propoint III; 1991; Tasco Sales Inc; Miami Fl; See entire document	15, 17, 21, 32
Y	US, A, 5,046,839 (KRANGLE) 10 September 1991, See entire document	31, 32
Y	US, A, 5,083,861 (CHI) 28 January 1992, See entire document	1-19

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/05308

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

This application contains following groups of inventions not so linked as to form a single inventive concept.

Group I, Claims 1-25, 31, 32, drawn to ranging by accumulated charge and/or averaging by discarding extrema and/or ranging with a sight.

Group II claims 26-30, drawn to ranging with sheet reflectors.

The inventions of Groups I and II do not meet the requirement for unity of invention since the ranging techniques of anyone of the two groups do not require the particulars of the other to be complete. The use of sheet reflectors does not require accumulated charge ranging, a sight, or averaging to function and vice versa.