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Al-Ali

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(54) **PHYSIOLOGICAL MEASUREMENT COMMUNICATIONS ADAPTER**

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(52) **U.S. Cl.** **600/323; 600/300; 600/502; 128/903**

(58) **Field of Classification Search** **600/310, 600/322, 323, 300, 504, 505, 506, 507; 128/903**
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,960,128 A 10/1990 Gordon et al.
4,964,408 A 10/1990 Hink et al.
5,041,187 A 8/1991 Hink et al.

5,069,213 A 12/1991 Polczynski
5,163,438 A 11/1992 Gordon et al.
5,337,744 A 8/1994 Branigan
D353,195 S 12/1994 Savage et al.
D353,196 S 12/1994 Savage et al.
5,431,170 A 7/1995 Mathews
D361,840 S 8/1995 Savage et al.
D362,063 S 9/1995 Savage et al.
5,452,717 A 9/1995 Branigan et al.
D363,120 S 10/1995 Savage et al.
5,482,036 A 1/1996 Diab et al.
5,490,505 A 2/1996 Diab et al.
5,494,043 A 2/1996 O'Sullivan et al.
5,533,511 A 7/1996 Kaspari et al.
5,562,002 A 10/1996 Lalin
5,590,649 A 1/1997 Caro et al.
5,602,924 A 2/1997 Durand et al.
5,632,272 A 5/1997 Diab et al.
5,638,816 A 6/1997 Kiani-Azarbayjany et al.
5,638,818 A 6/1997 Diab et al.
5,645,440 A 7/1997 Tobler et al.
5,685,299 A 11/1997 Diab et al.

(Continued)

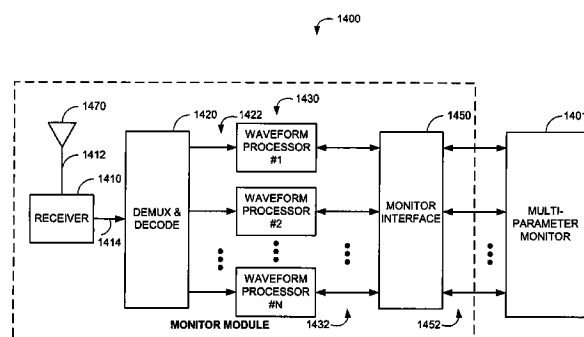
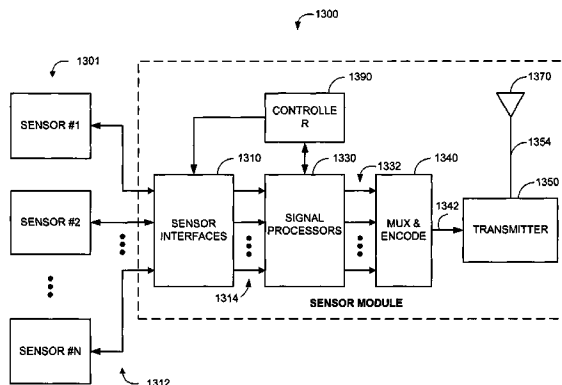
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(57) **ABSTRACT**

A sensor signal is input at a patient location and a physiological waveform responsive to the sensor signal is generated. The physiological waveform is wirelessly communicated from the patient location to a monitor location. The physiological waveform is adapted to a particular patient monitor at the monitor location. The adapted physiological waveform is output to a sensor port of the patient monitor. Accordingly, the patient monitor derives physiological measurements from the adapted physiological waveform that are generally equivalent to measurements derivable from the physiological waveform by a monitor compatible with the sensor signal.

11 Claims, 17 Drawing Sheets



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U.S. PATENT DOCUMENTS

D393,830 S	4/1998	Tobler et al.	6,584,336 B1	6/2003	Ali et al.
5,743,262 A	4/1998	Lepper, Jr. et al.	6,595,316 B2	7/2003	Cybulski et al.
5,758,644 A	6/1998	Diab et al.	6,597,933 B2	7/2003	Kiani et al.
5,760,910 A	6/1998	Lepper, Jr. et al.	6,606,511 B1	8/2003	Ali et al.
5,769,785 A	6/1998	Diab et al.	6,632,181 B2	10/2003	Flaherty et al.
5,782,757 A	7/1998	Diab et al.	6,640,116 B2	10/2003	Diab
5,785,659 A	7/1998	Caro et al.	6,643,530 B2	11/2003	Diab et al.
5,791,347 A	8/1998	Flaherty et al.	6,650,917 B2	11/2003	Diab et al.
5,810,734 A	9/1998	Caro et al.	6,654,624 B2	11/2003	Diab et al.
5,823,950 A	10/1998	Diab et al.	6,658,276 B2	12/2003	Kiani et al.
5,830,131 A	11/1998	Caro et al.	6,661,161 B1	12/2003	Lanzo et al.
5,833,618 A	11/1998	Caro et al.	6,671,531 B2	12/2003	Al-Ali et al.
5,860,919 A	1/1999	Kiani-Azarbayjany et al.	6,678,543 B2	1/2004	Diab et al.
5,890,929 A	4/1999	Mills et al.	6,684,090 B2	1/2004	Ali et al.
5,904,654 A	5/1999	Wohlmann et al.	6,684,091 B2	1/2004	Parker
5,919,134 A	7/1999	Diab	6,697,656 B1	2/2004	Al-Ali
5,934,925 A	8/1999	Tobler et al.	6,697,658 B2	2/2004	Al-Ali
5,940,182 A	8/1999	Lepper, Jr. et al.	RE38,476 E	3/2004	Diab et al.
5,995,855 A	11/1999	Kiani et al.	6,699,194 B1	3/2004	Diab et al.
5,997,343 A	12/1999	Mills et al.	6,714,804 B2	3/2004	Al-Ali et al.
6,002,952 A	12/1999	Diab et al.	RE38,492 E	4/2004	Diab et al.
6,011,986 A	1/2000	Diab et al.	6,721,585 B1	4/2004	Parker
6,027,452 A	2/2000	Flaherty et al.	6,725,075 B2	4/2004	Al-Ali
6,036,642 A	3/2000	Diab et al.	6,735,459 B2	5/2004	Parker
6,045,509 A	4/2000	Caro et al.	6,745,060 B2	6/2004	Diab et al.
6,067,462 A	5/2000	Diab et al.	6,760,607 B2	7/2004	Al-Ali
6,081,735 A	6/2000	Diab et al.	6,770,028 B1	8/2004	Ali et al.
6,088,607 A	7/2000	Diab et al.	6,771,994 B2	8/2004	Kiani et al.
6,110,522 A	8/2000	Lepper, Jr. et al.	6,792,300 B1	9/2004	Diab et al.
6,144,868 A	11/2000	Parker	6,813,511 B2	11/2004	Diab et al.
6,151,516 A	11/2000	Kiani-Azarbayjany et al.	6,816,741 B2	11/2004	Diab
6,152,754 A	11/2000	Gerhardt et al.	6,822,564 B2	11/2004	Al-Ali
6,157,850 A	12/2000	Diab et al.	6,826,419 B2	11/2004	Diab et al.
6,165,005 A	12/2000	Mills et al.	6,830,711 B2	12/2004	Mills et al.
6,167,258 A *	12/2000	Schmidt et al. 340/870.01	6,850,787 B2	2/2005	Weber et al.
6,184,521 B1	2/2001	Coffin, IV et al.	6,850,788 B2	2/2005	Al-Ali
6,206,830 B1	3/2001	Diab et al.	6,852,083 B2	2/2005	Caro et al.
6,229,856 B1	5/2001	Diab et al.	6,861,639 B2	3/2005	Al-Ali
6,236,872 B1	5/2001	Diab et al.	6,897,788 B2 *	5/2005	Khair et al. 128/903
6,256,523 B1	7/2001	Diab et al.	6,898,452 B2	5/2005	Al-Ali et al.
6,263,222 B1	7/2001	Diab et al.	6,920,345 B2	7/2005	Al-Ali et al.
6,278,522 B1	8/2001	Lepper, Jr. et al.	6,931,268 B1	8/2005	Kiani-Azarbayjany et al.
6,280,213 B1	8/2001	Tobler et al.	6,934,570 B2	8/2005	Kiani et al.
6,285,896 B1	9/2001	Tobler et al.	6,939,305 B2	9/2005	Flaherty et al.
6,321,100 B1	11/2001	Parker	6,943,348 B1	9/2005	Coffin IV
6,334,065 B1	12/2001	Al-Ali et al.	6,950,687 B2	9/2005	Al-Ali
6,343,224 B1	1/2002	Parker	6,961,598 B2	11/2005	Diab
6,349,228 B1	2/2002	Kiani et al.	6,970,792 B1	11/2005	Diab
6,360,114 B1	3/2002	Diab et al.	6,979,812 B2	12/2005	Al-Ali
6,371,921 B1	4/2002	Caro et al.	6,985,764 B2	1/2006	Mason et al.
6,377,829 B1	4/2002	Al-Ali	6,993,371 B2	1/2006	Kiani et al.
6,388,240 B2	5/2002	Schulz et al.	6,996,427 B2	2/2006	Ali et al.
6,397,091 B2	5/2002	Diab et al.	6,999,904 B2	2/2006	Weber et al.
6,430,525 B1	8/2002	Weber et al.	7,003,338 B2	2/2006	Weber et al.
6,463,311 B1	10/2002	Diab	7,003,339 B2	2/2006	Diab et al.
6,470,199 B1	10/2002	Kopotic et al.	7,015,451 B2	3/2006	Dalke et al.
6,470,893 B1 *	10/2002	Boesen 128/903	7,024,233 B2	4/2006	Al et al.
6,501,975 B2	12/2002	Diab et al.	7,027,849 B2	4/2006	Al-Ali
6,515,273 B2	2/2003	Al-Ali	7,030,749 B2	4/2006	Al-Ali
6,519,487 B1	2/2003	Parker	7,039,449 B2	5/2006	Al-Ali
6,525,386 B1	2/2003	Mills et al.	7,041,060 B2	5/2006	Flaherty et al.
6,526,300 B1	2/2003	Kiani et al.	7,044,918 B2	5/2006	Diab
6,541,756 B2	4/2003	Schulz et al.	7,067,893 B2	6/2006	Mills et al.
6,542,764 B1	4/2003	Al-Ali et al.	7,096,052 B2	8/2006	Mason et al.
6,580,086 B1	6/2003	Schulz et al.	7,096,054 B2	8/2006	Abdul-Hafiz et al.

* cited by examiner

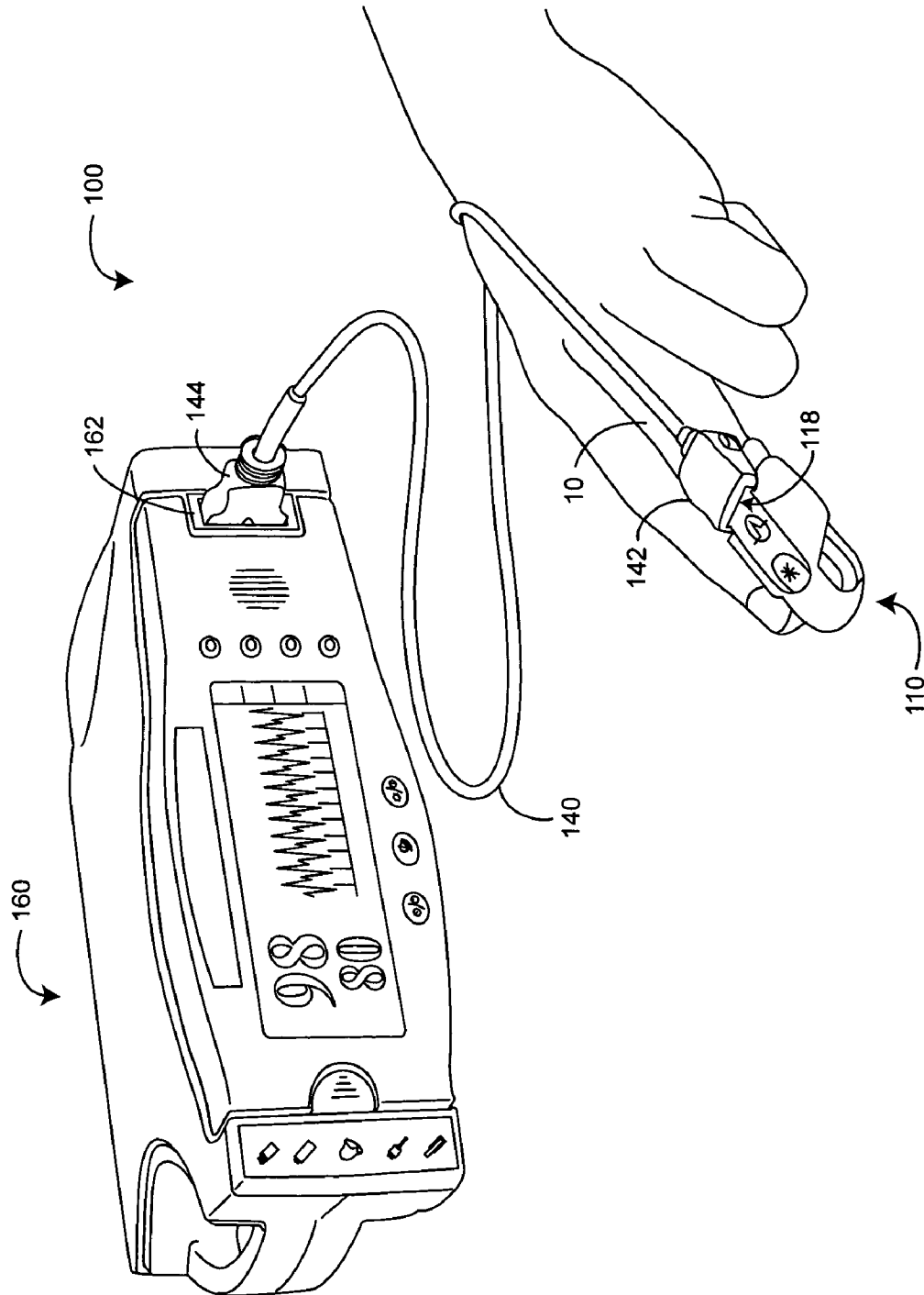


FIG. 1 (Prior Art)

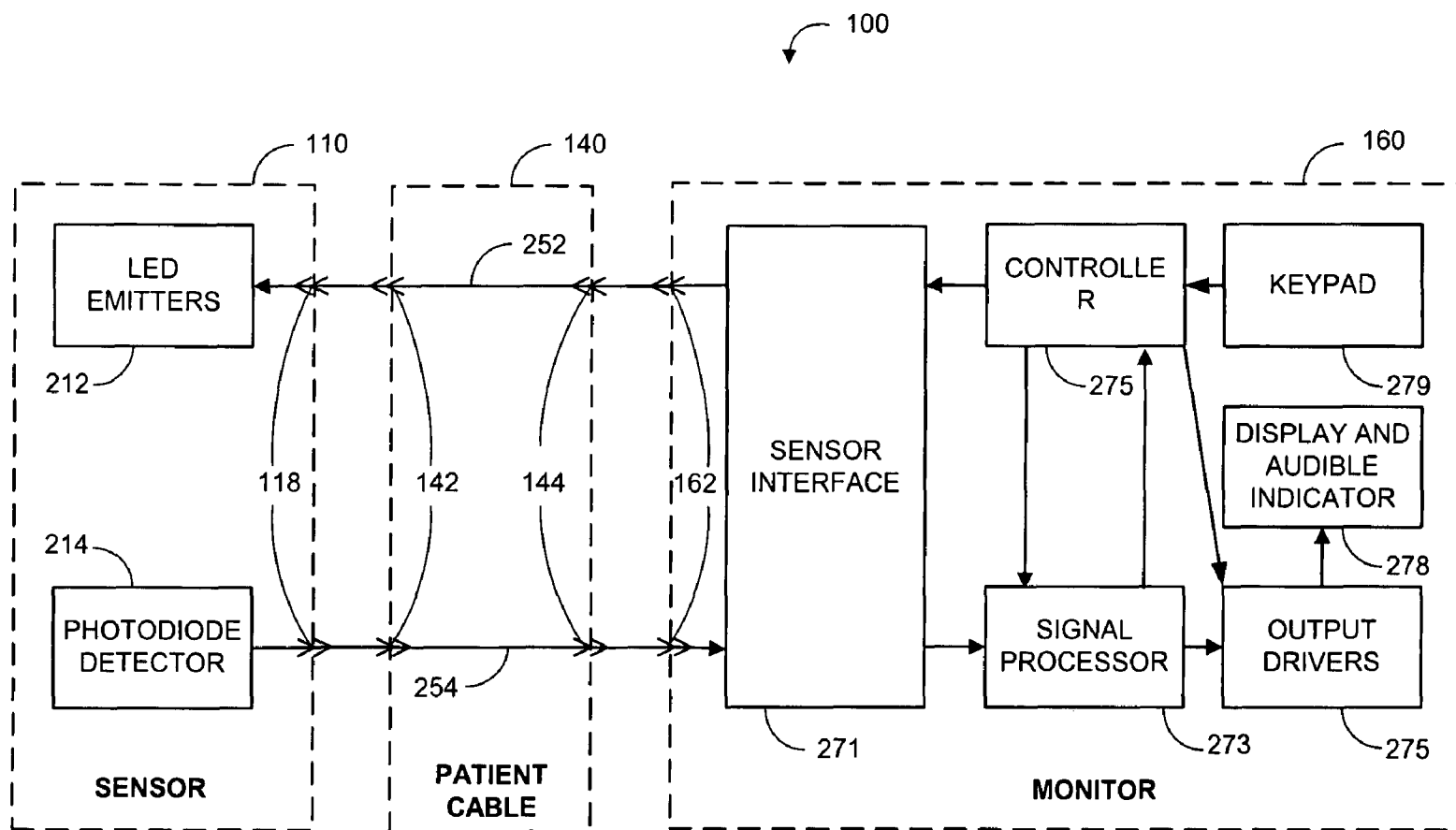


FIG. 2 (Prior Art)

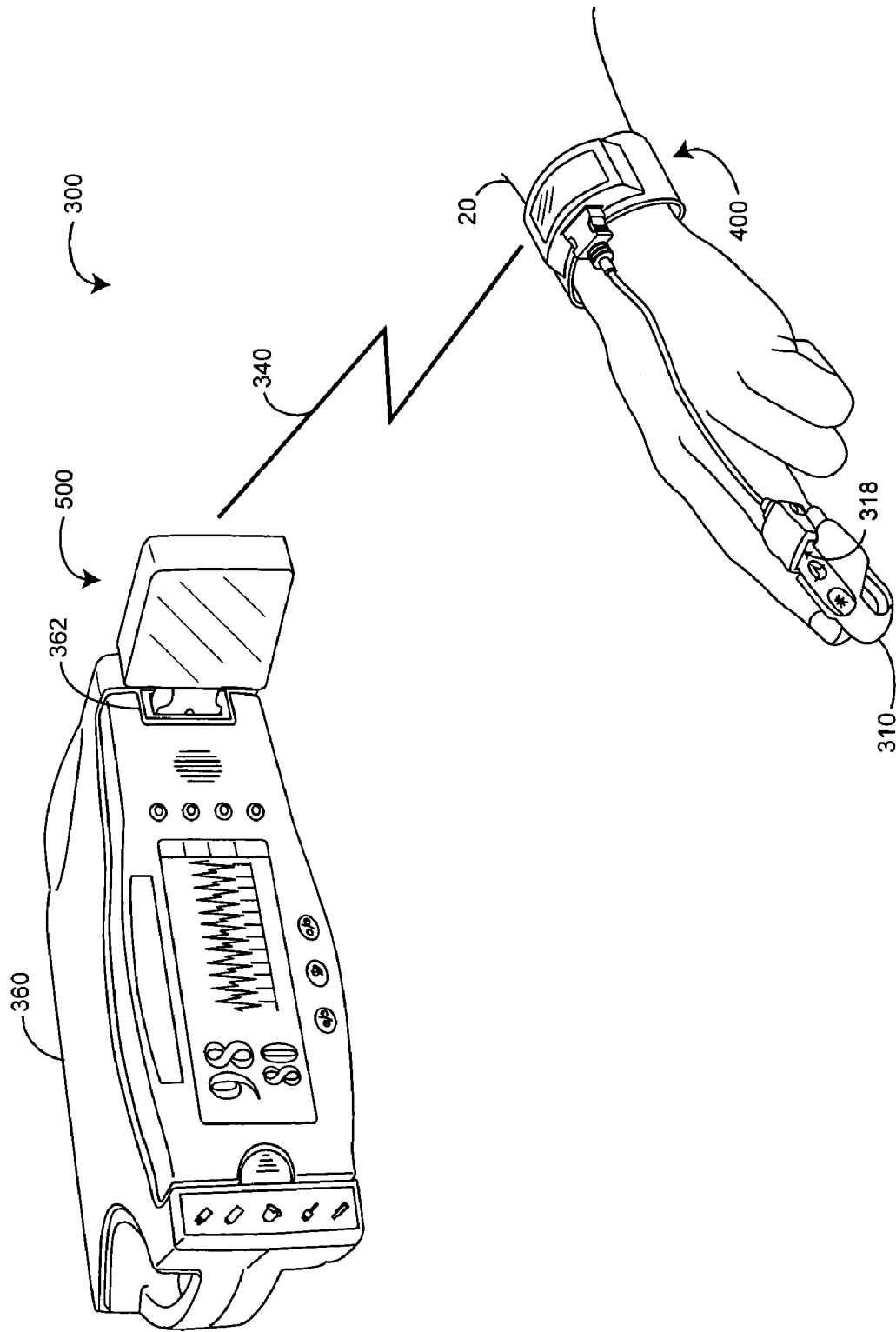


FIG. 3

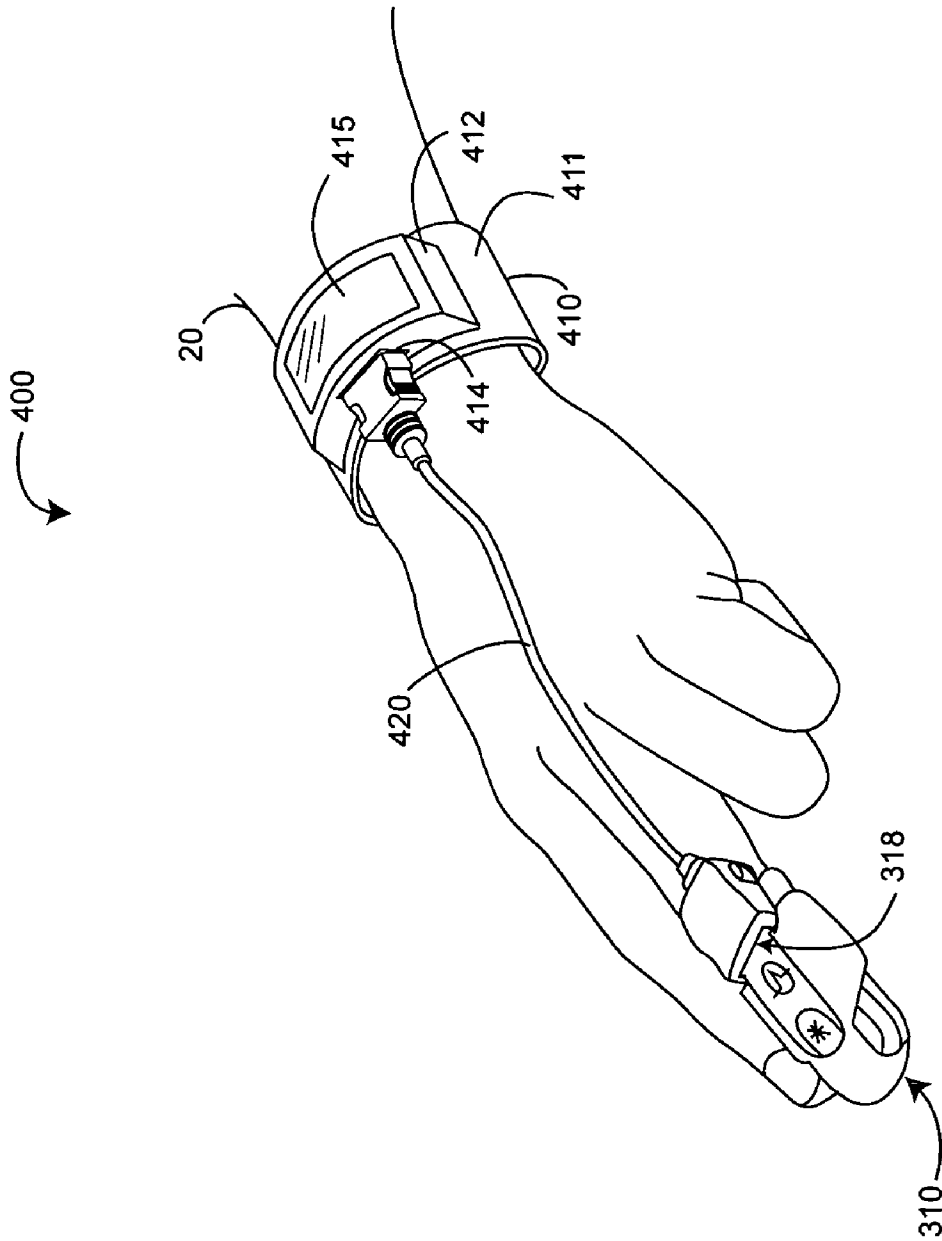


FIG. 4A

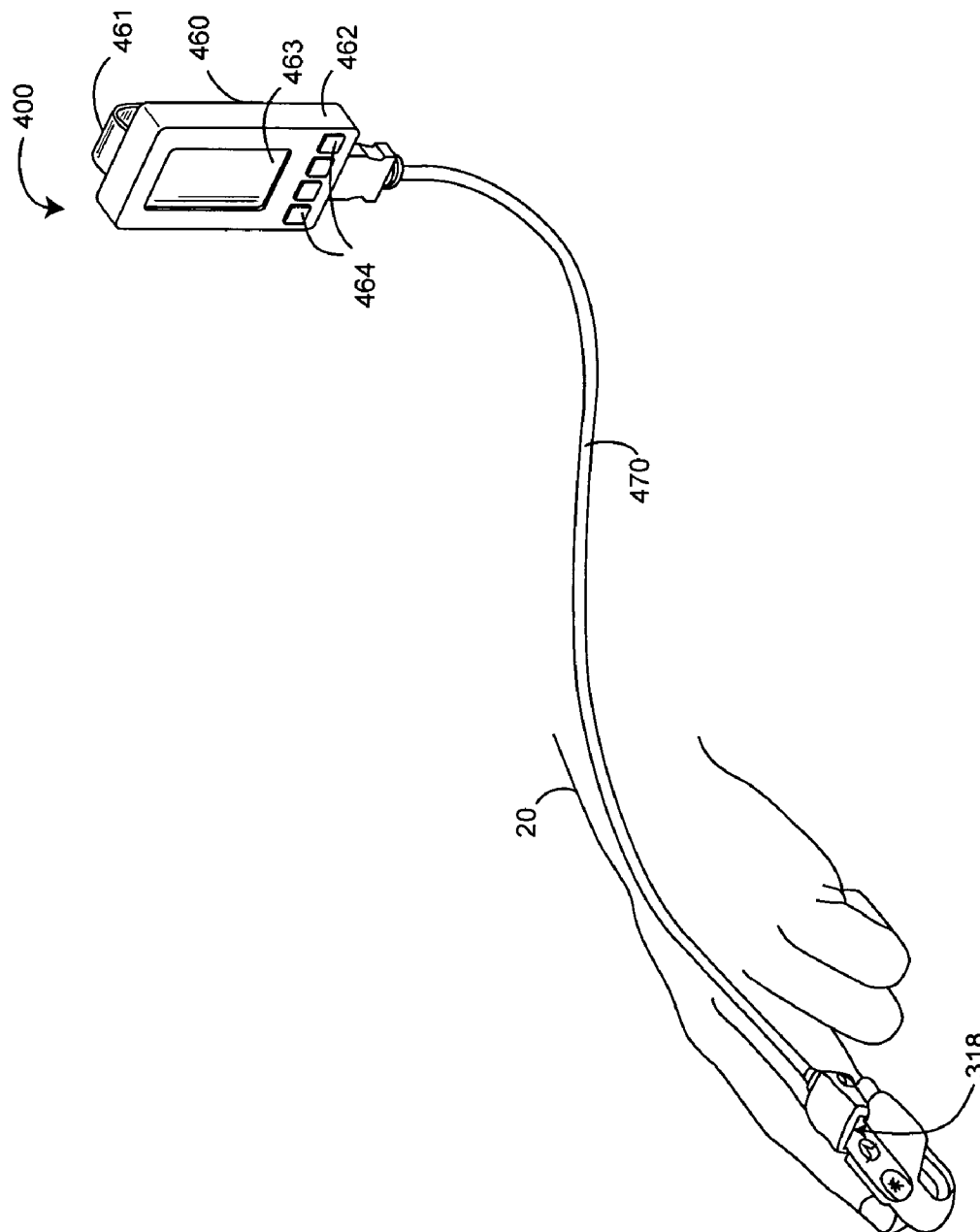


FIG. 4B

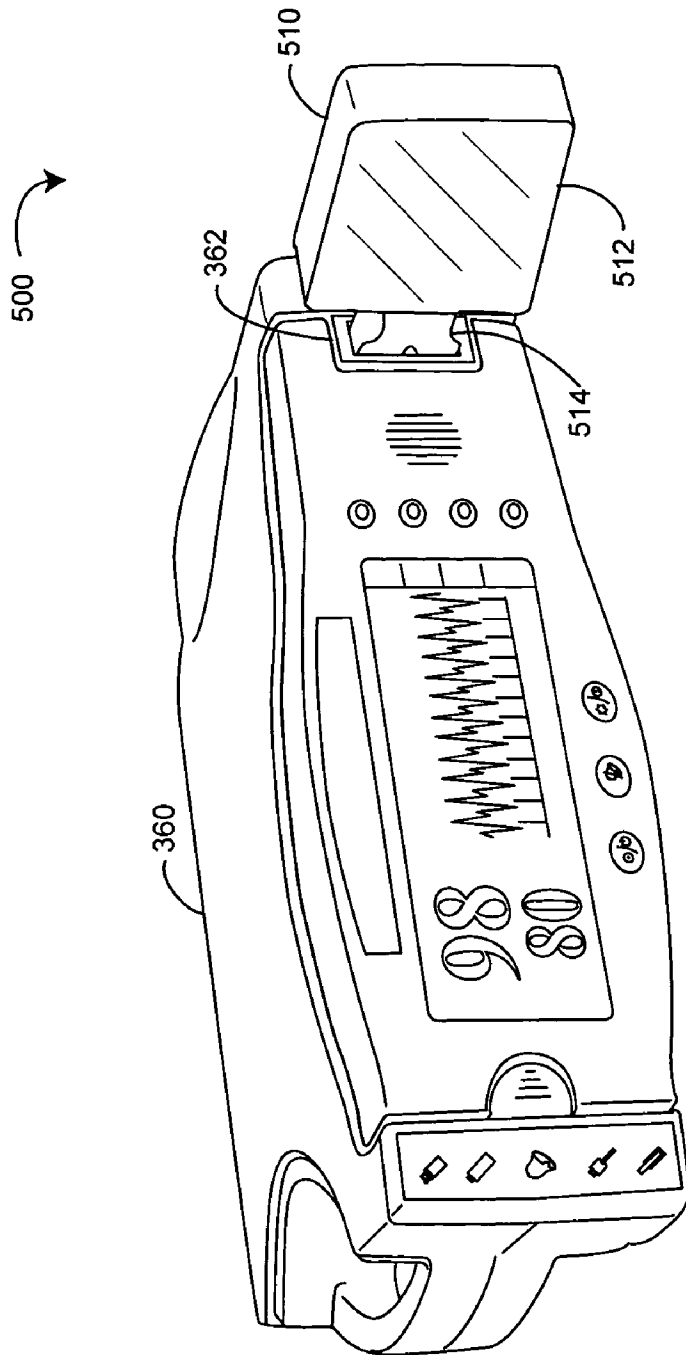


FIG. 5A

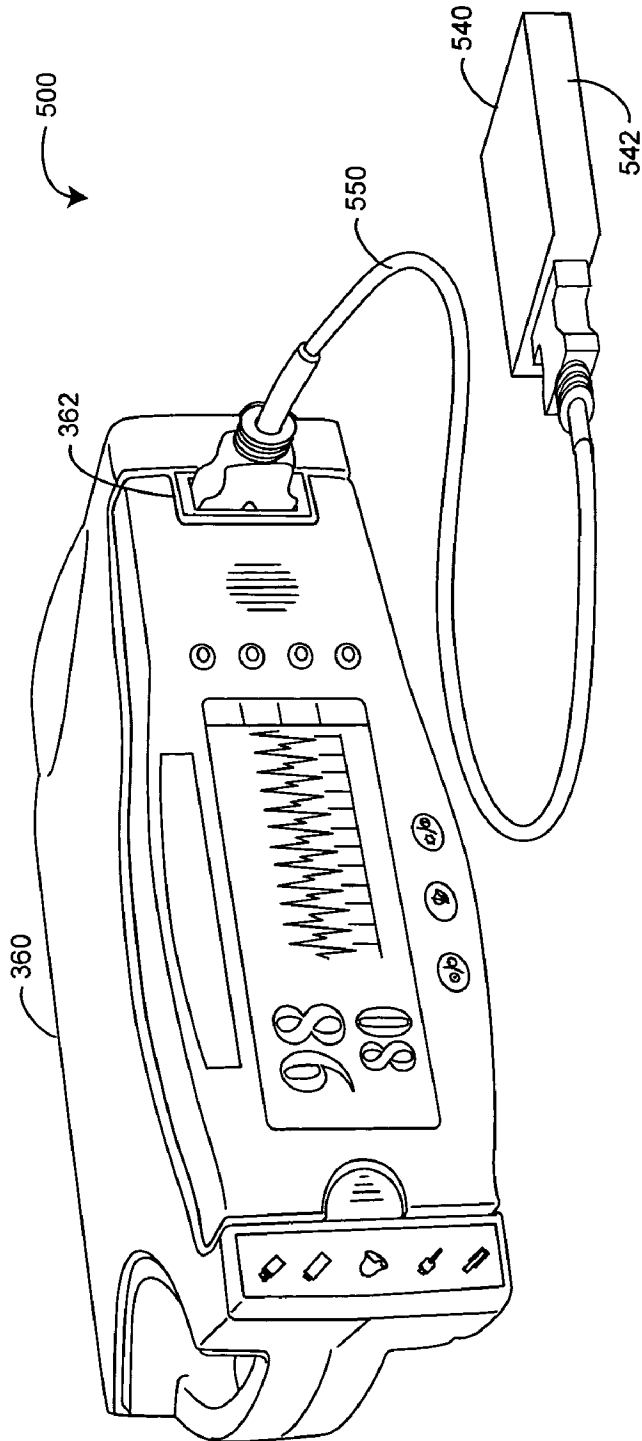


FIG. 5B

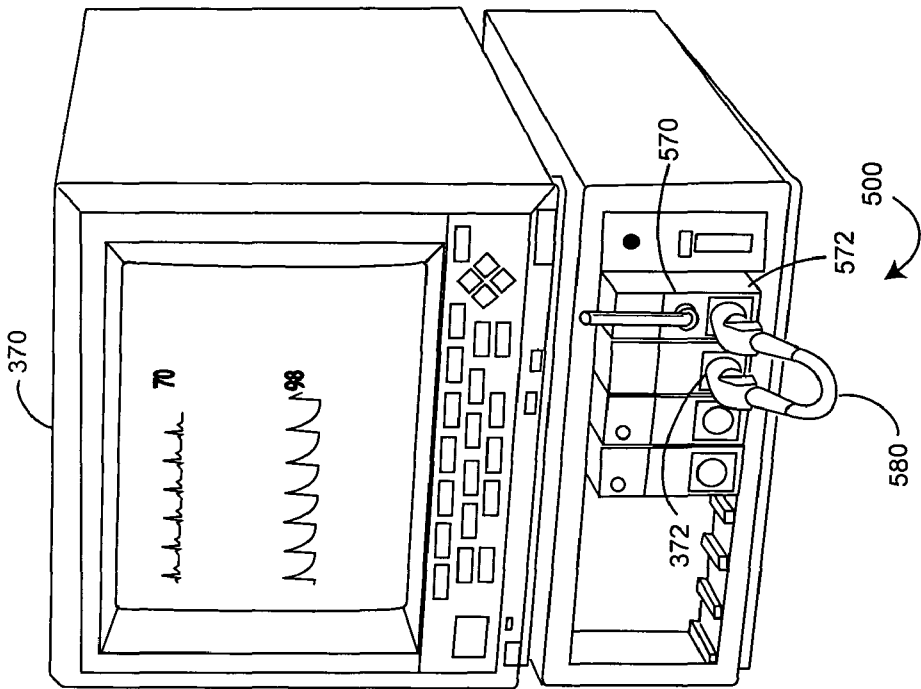


FIG. 5C

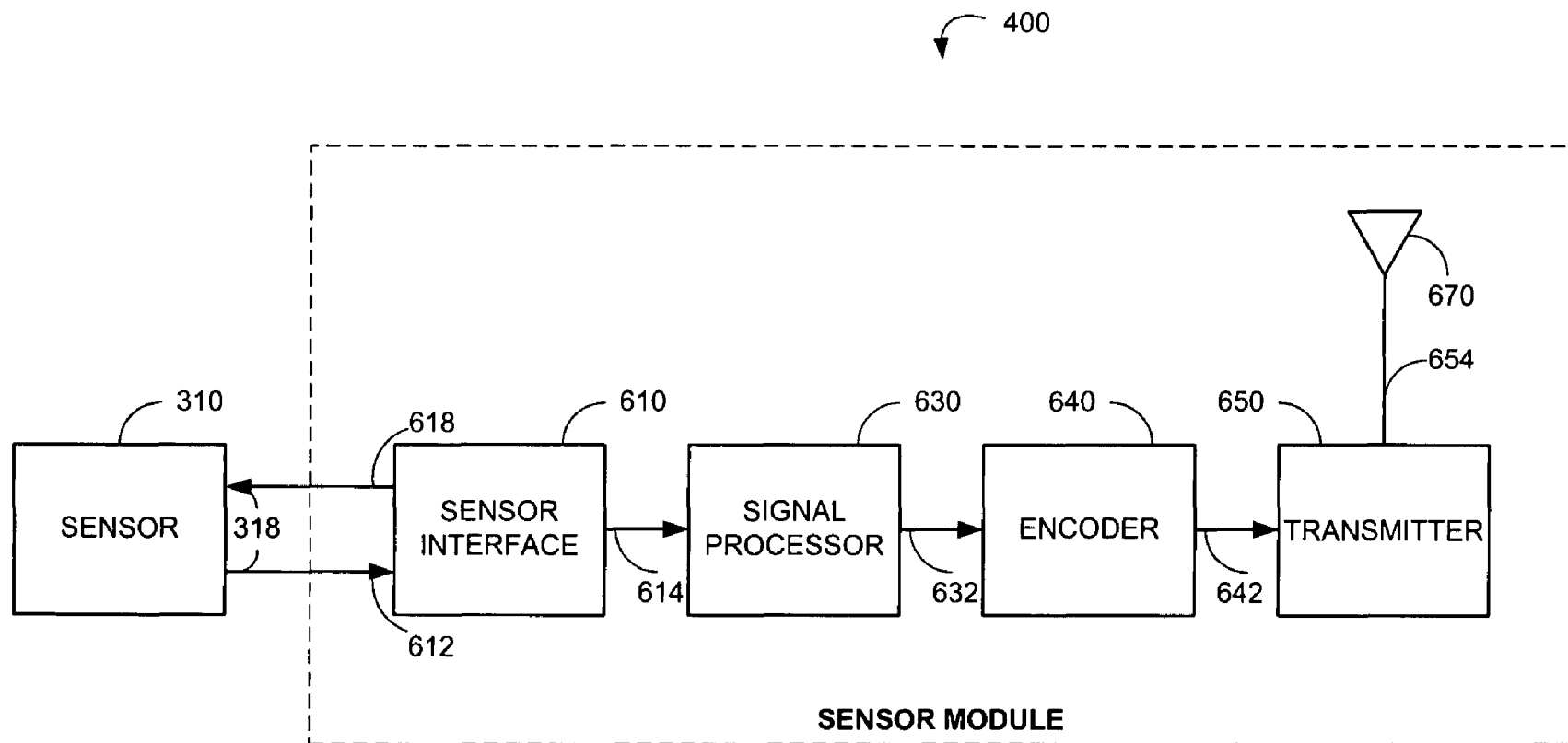


FIG. 6

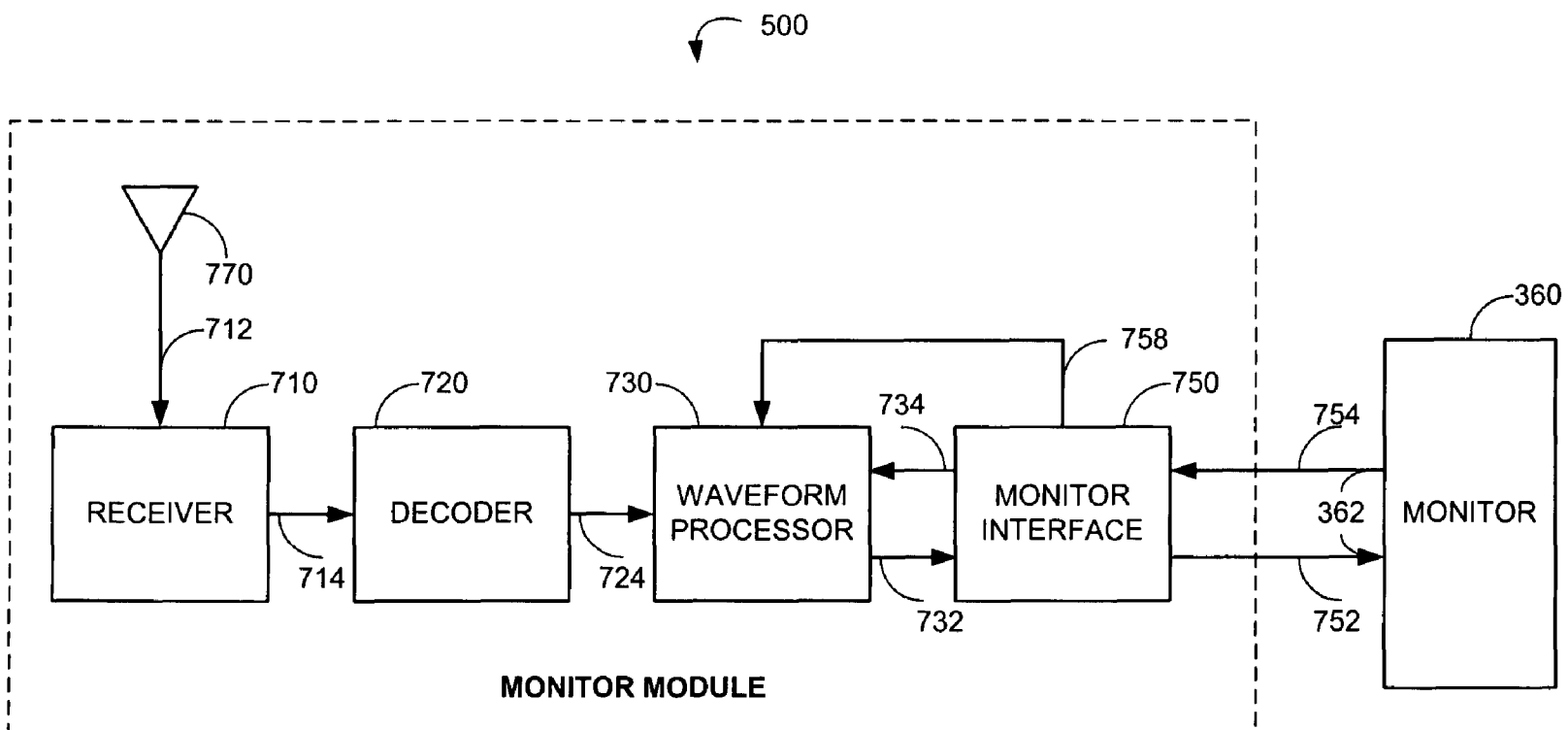


FIG. 7

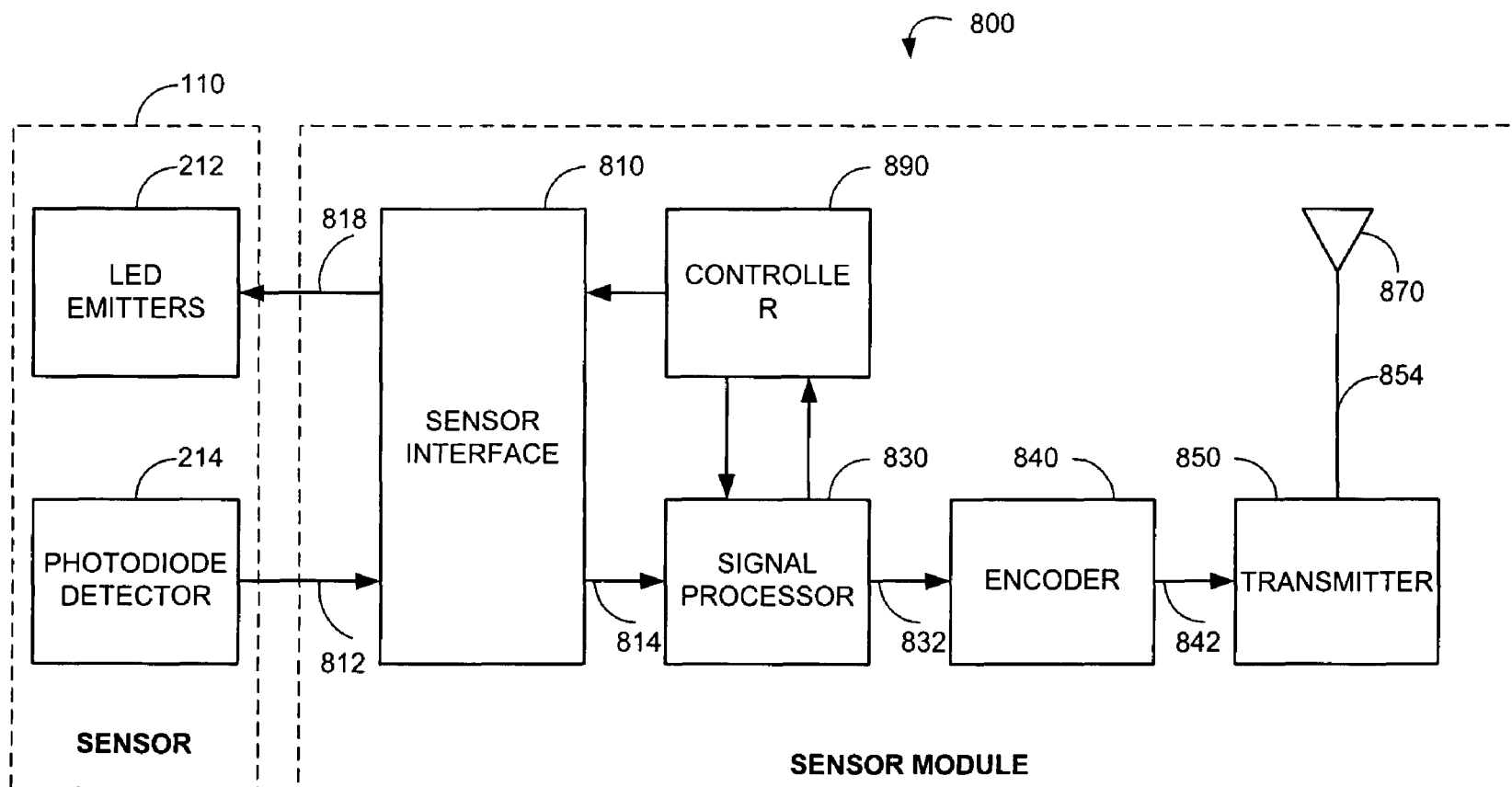


FIG. 8

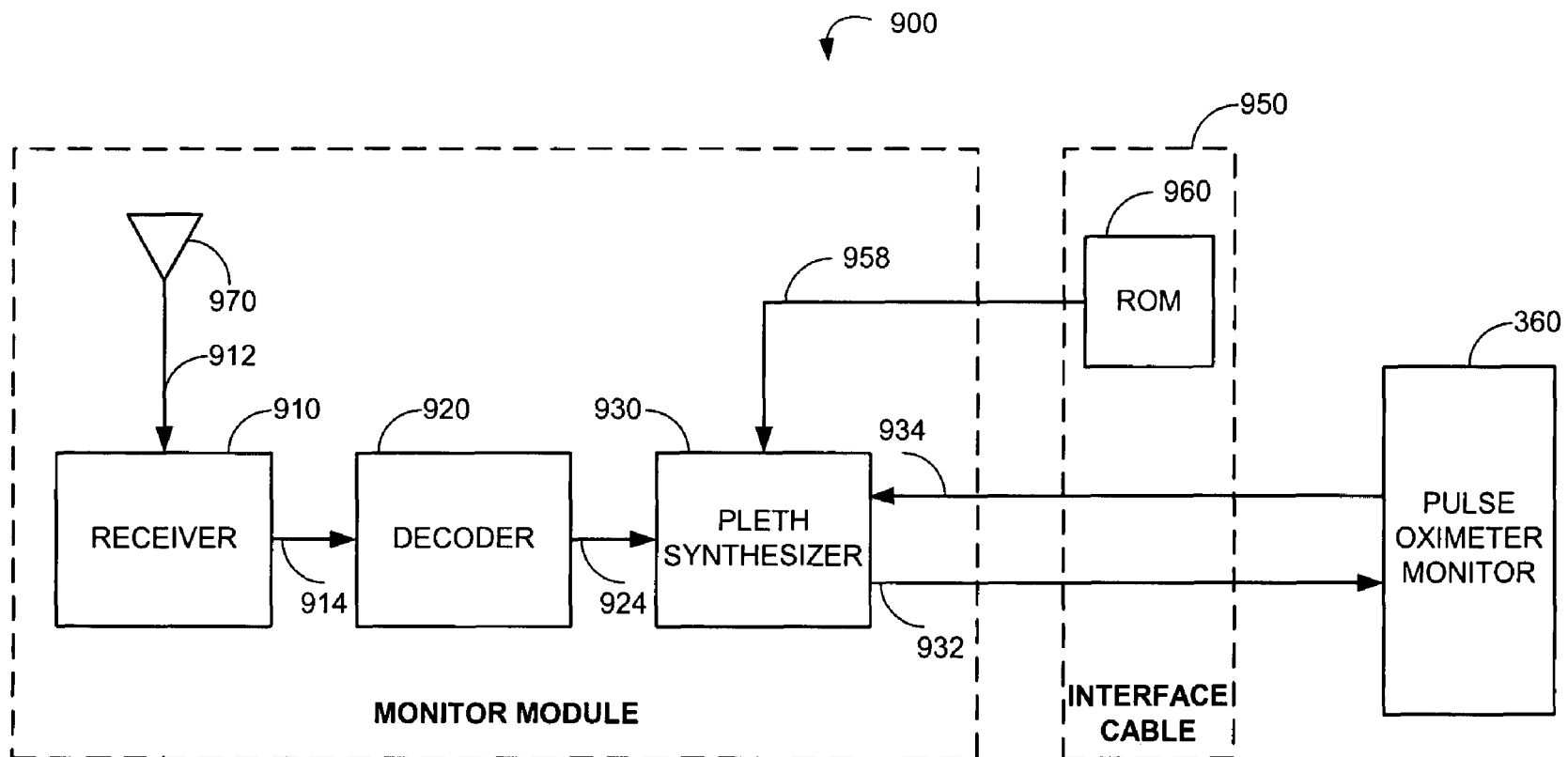


FIG. 9

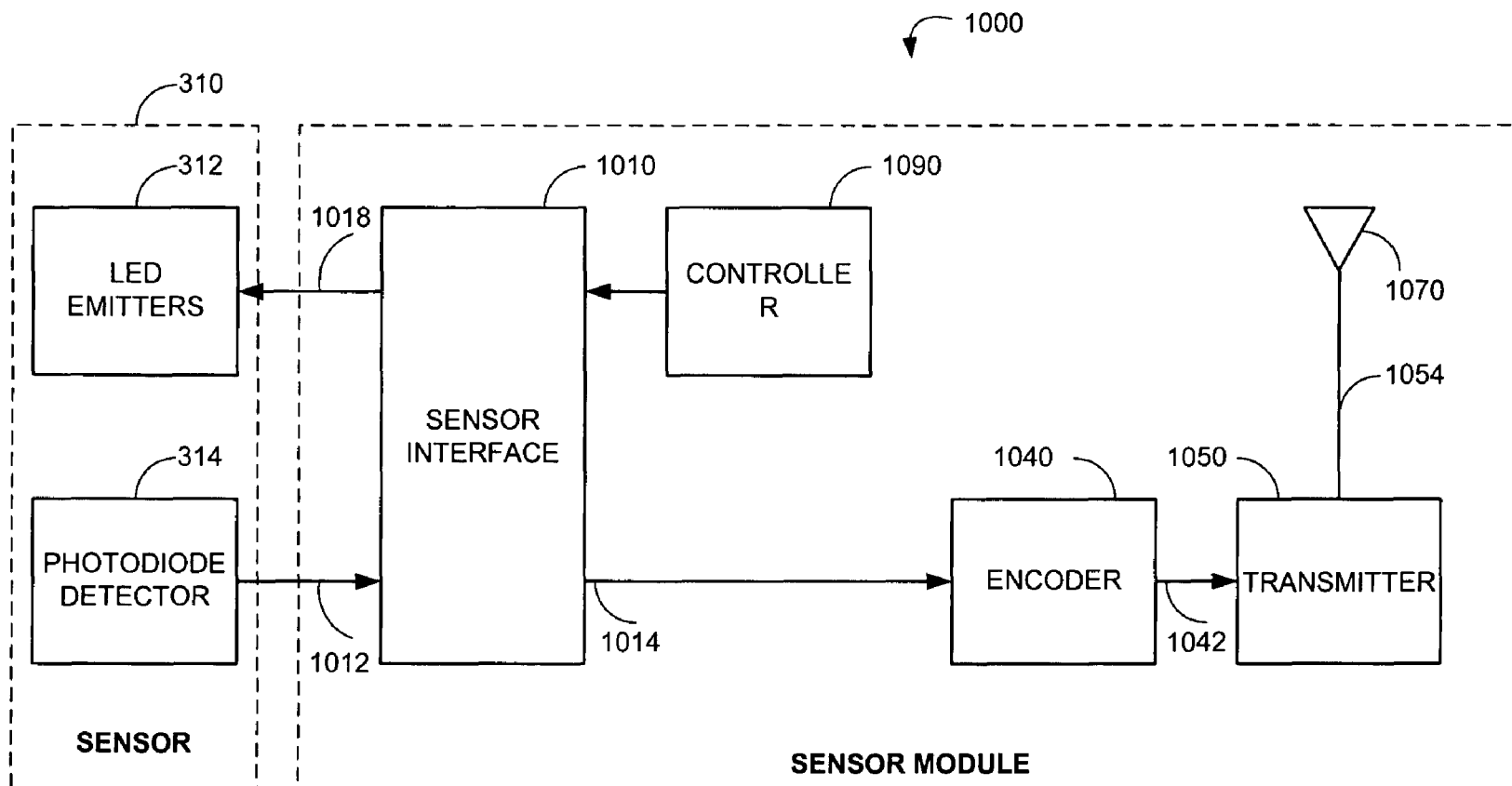


FIG. 10

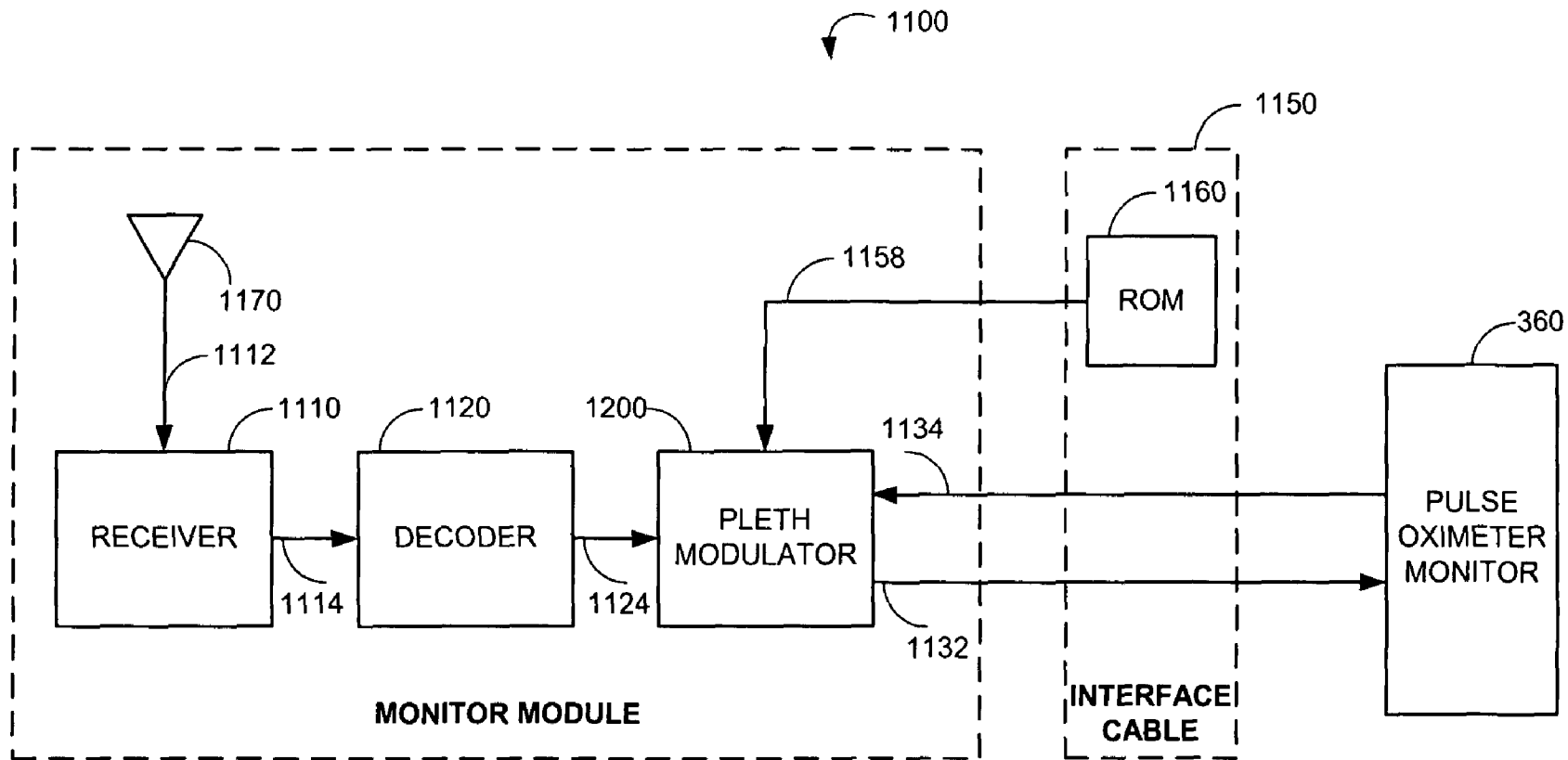


FIG. 11

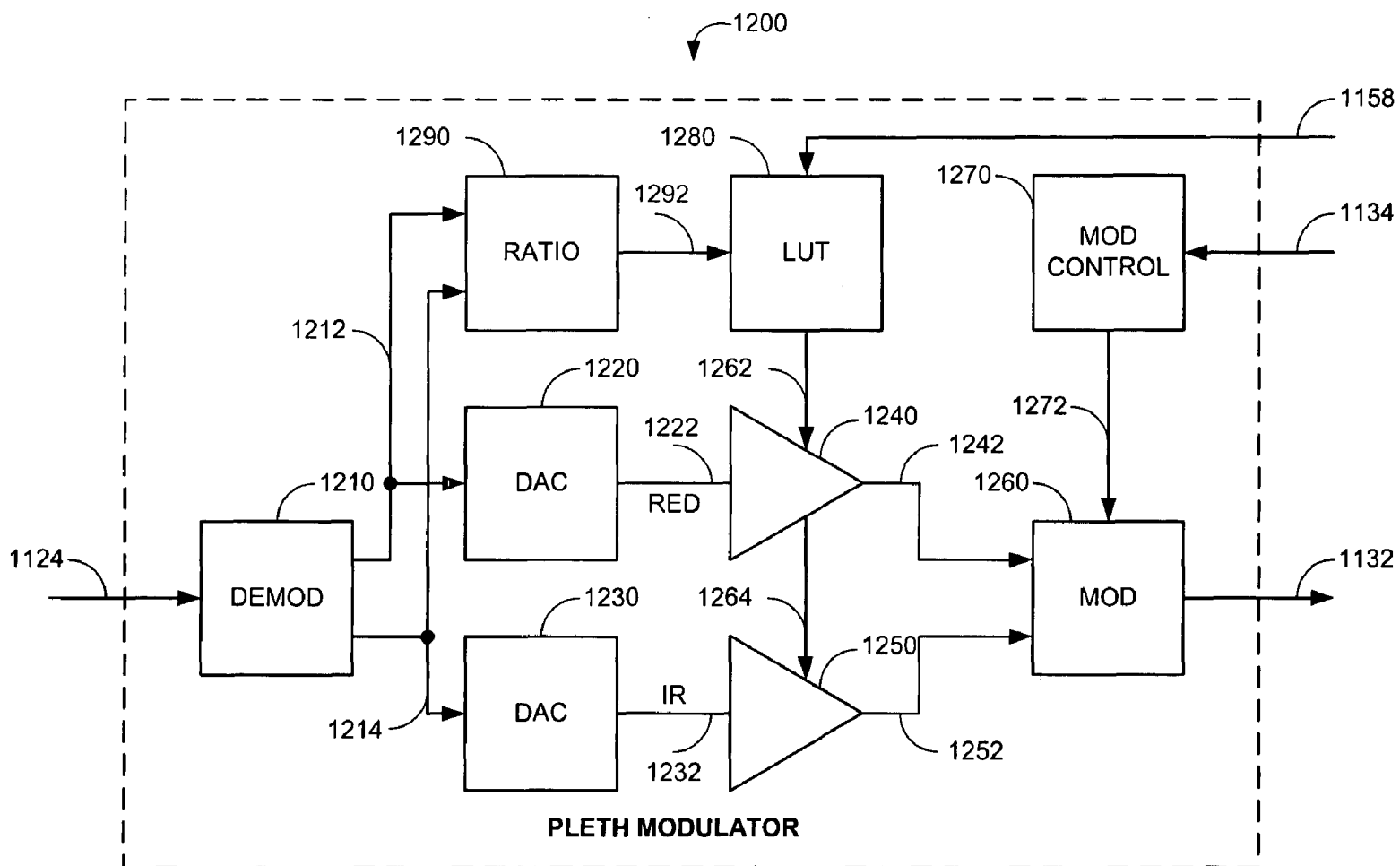


FIG. 12

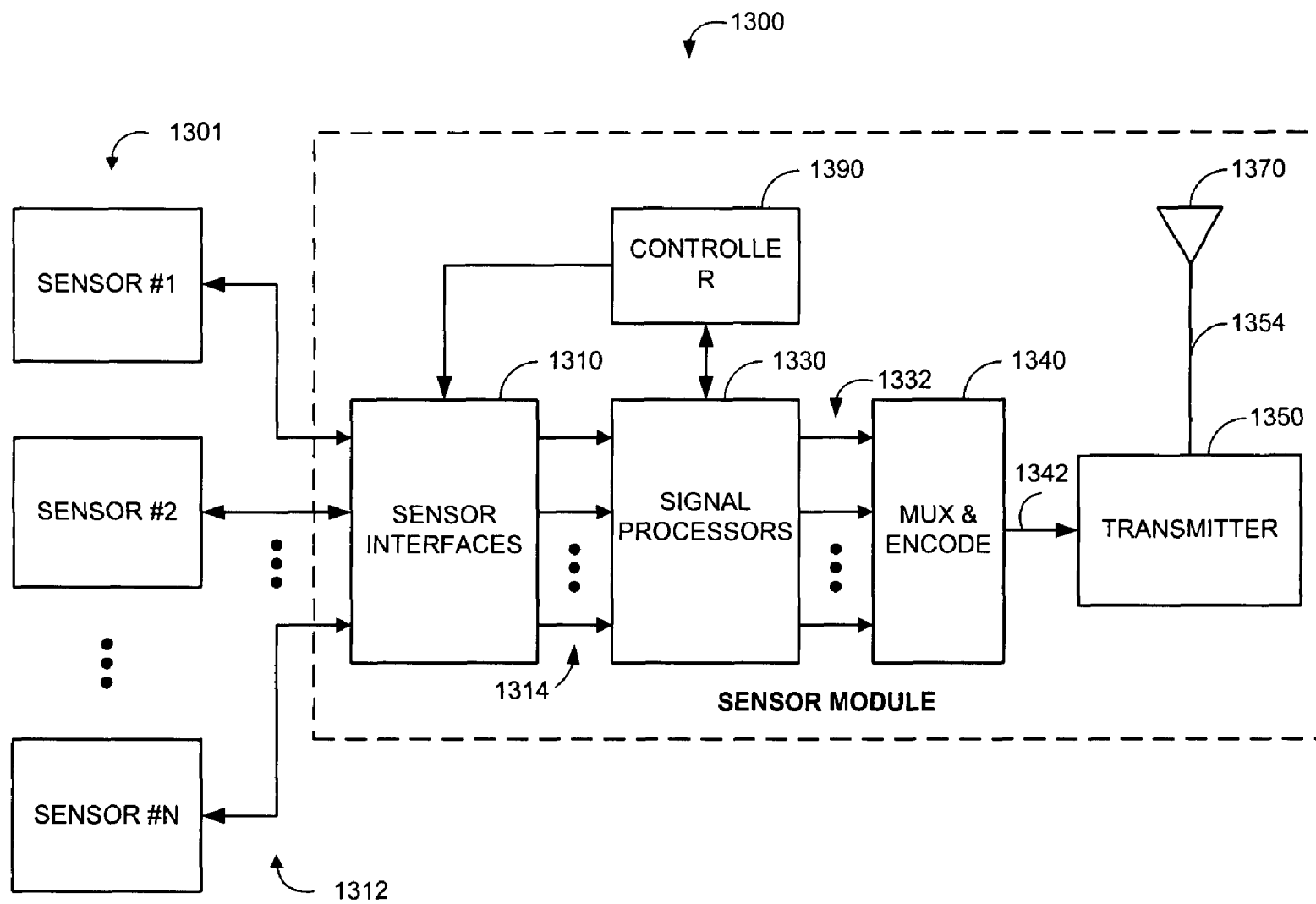


FIG. 13

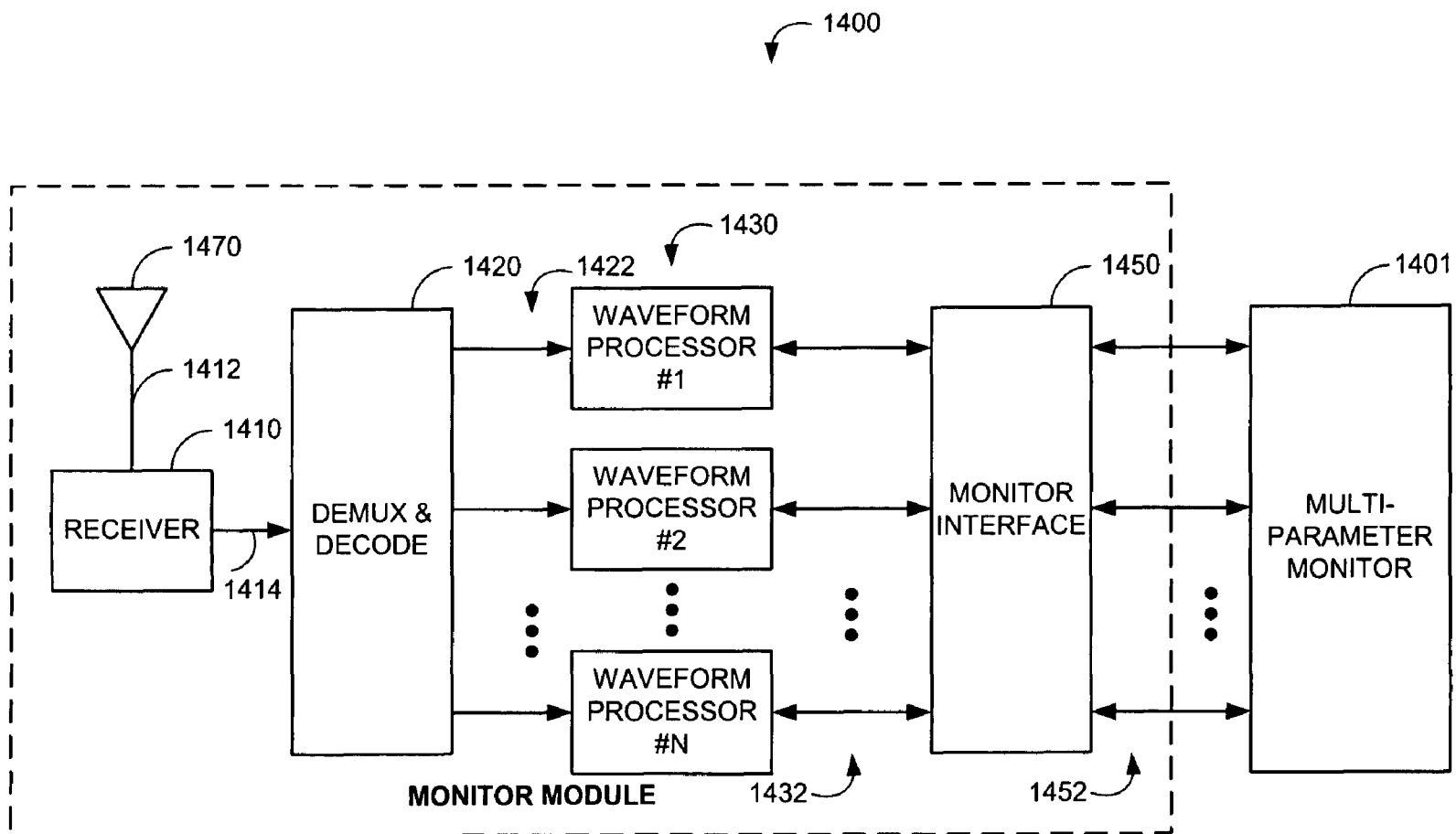


FIG. 14

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PHYSIOLOGICAL MEASUREMENT COMMUNICATIONS ADAPTER

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority benefit under 35 U.S.C. §120 to, and is a continuation of, U.S. patent application Ser. No. 11/048,330, filed Feb. 1, 2005 entitled “Physiological Measurement Communications Adapter,” which is a continuation of application Ser. No. 10/377,933, filed Feb. 28, 2003, now U.S. Pat. No. 6,850,788, entitled “Physiological Measurement Communications Adapter,” which claims priority benefit under 35 U.S.C. §119(e) from U.S. Provisional Application No. 60/367,428, filed Mar. 25, 2002, entitled “Physiological Measurement Communications Adapter.” The present application also incorporates the foregoing utility disclosures herein by reference.

BACKGROUND OF THE INVENTION

Patient vital sign monitoring may include measurements of blood oxygen, blood pressure, respiratory gas, and EKG among other parameters. Each of these physiological parameters typically require a sensor in contact with a patient and a cable connecting the sensor to a monitoring device. For example, FIGS. 1-2 illustrate a conventional pulse oximetry system 100 used for the measurement of blood oxygen. As shown in FIG. 1, a pulse oximetry system has a sensor 110, a patient cable 140 and a monitor 160. The sensor 110 is typically attached to a finger 10 as shown. The sensor 110 has a plug 118 that inserts into a patient cable socket 142. The monitor 160 has a socket 162 that accepts a patient cable plug 144. The patient cable 140 transmits an LED drive signal 252 (FIG. 2) from the monitor 160 to the sensor 110 and a resulting detector signal 254 (FIG. 2) from the sensor 110 to the monitor 160. The monitor 160 processes the detector signal 254 (FIG. 2) to provide, typically, a numerical readout of the patient's oxygen saturation, a numerical readout of pulse rate, and an audible indicator or “beep” that occurs in response to each arterial pulse.

As shown in FIG. 2, the sensor 110 has both red and infrared LED emitters 212 and a photodiode detector 214. The monitor 160 has a sensor interface 271, a signal processor 273, a controller 275, output drivers 276, a display and audible indicator 278, and a keypad 279. The monitor 160 determines oxygen saturation by computing the differential absorption by arterial blood of the two wavelengths emitted by the sensor emitters 212, as is well-known in the art. The sensor interface 271 provides LED drive current 252 which alternately activates the red and IR LED emitters 212. The photodiode detector 214 generates a signal 254 corresponding to the red and infrared light energy attenuated from transmission through the patient finger 10 (FIG. 1). The sensor interface 271 also has input circuitry for amplification, filtering and digitization of the detector signal 254. The signal processor 273 calculates a ratio of detected red and infrared intensities, and an arterial oxygen saturation value is empirically determined based on that ratio. The controller 275 provides hardware and software interfaces for managing the display and audible indicator 278 and keypad 279. The display and audible indicator 278 shows the computed oxygen status, as described above, and provides the pulse beep as well as alarms indicating oxygen desaturation events. The keypad

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279 provides a user interface for setting alarm thresholds, alarm enablement, and display options, to name a few.

SUMMARY OF THE INVENTION

Conventional physiological measurement systems are limited by the patient cable connection between sensor and monitor. A patient must be located in the immediate vicinity of the monitor. Also, patient relocation requires either disconnection of monitoring equipment and a corresponding loss of measurements or an awkward simultaneous movement of patient equipment and cables. Various devices have been proposed or implemented to provide wireless communication links between sensors and monitors, freeing patients from the patient cable tether. These devices, however, are incapable of working with the large installed base of existing monitors and sensors, requiring caregivers and medical institutions to suffer expensive wireless upgrades. It is desirable, therefore, to provide a communications adapter that is plug-compatible both with existing sensors and monitors and that implements a wireless link replacement for the patient cable.

One aspect of a physiological measurement communications adapter is a sensor signal input at a patient location. A physiological waveform responsive to the sensor signal is generated. The physiological waveform is wirelessly communicated from the patient location to a monitor location. The physiological waveform is adapted to a particular patient monitor at the monitor location. The adapted physiological waveform is output to a sensor port of the patient monitor. Accordingly, the patient monitor derives physiological measurements from the adapted physiological waveform that are generally equivalent to measurements derivable from the physiological waveform by a monitor compatible with the sensor signal.

Another aspect of a physiological measurement communications adapter is an input sensor signal at a patient location. A physiological waveform responsive to the sensor signal is generated. The sample rate of the physiological waveform is reduced, and the reduced sample rate physiological waveform is wirelessly transmitted from the patient location to a monitor location. The reduced sample rate physiological waveform is adapted to a particular patient monitor at the monitor location. The adapted physiological waveform is output to a sensor port of the patient monitor so that the patient monitor derives physiological measurements from the adapted physiological waveform that are generally equivalent to measurements derivable from the physiological waveform by a monitor compatible with the sensor signal.

A further aspect of a physiological measurement communications adapter is a sensor interface means for inputting a sensor signal from a noninvasive sensor attached to a patient tissue site and a first processor means for generating a physiological waveform responsive to the sensor signal. The communications adapter also has a wireless communications means for communicating the physiological waveform from a patient location to a monitor location and a second processor means for adapting the physiological waveform to a particular monitor at the monitor location. In addition, the communications adapter has a monitor interface means for outputting the adapted physiological waveform to a sensor port of the monitor.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an illustration of a prior art pulse oximetry system;

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FIG. 2 is a functional block diagram of a prior art pulse oximetry system;

FIG. 3 is an illustration of a physiological measurement communications adapter;

FIGS. 4A-B are illustrations of communications adapter sensor modules;

FIGS. 5A-C are illustrations of communications adapter monitor modules;

FIG. 6 is a functional block diagram of a communications adapter sensor module;

FIG. 7 is a functional block diagram of a communications adapter monitor module;

FIG. 8 is a functional block diagram of a sensor module configured to transmit measured pulse oximeter parameters;

FIG. 9 is a functional block diagram of a monitor module configured to receive measured pulse oximeter parameters;

FIG. 10 is a functional block diagram of a sensor module configured to transmit a plethysmograph;

FIG. 11 is a functional block diagram of a monitor module configured to receive a plethysmograph;

FIG. 12 is a functional block diagram of a waveform modulator;

FIG. 13 is a functional block diagram of a sensor module configured for multiple sensors; and

FIG. 14 is a functional block diagram of a monitor module configured for multiple sensors.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Overview

FIG. 3 illustrates one embodiment of a communications adapter. FIGS. 4-5 illustrate physical configurations for a communications adapter. In particular, FIGS. 4A-B illustrate sensor module configurations and FIGS. 5A-C illustrate monitor module configurations. FIGS. 6-14 illustrate communications adapter functions. In particular, FIGS. 6-7 illustrate general functions for a sensor module and a monitor module, respectively. FIGS. 8-9 functionally illustrate a communications adapter where derived pulse oximetry parameters, such as saturation and pulse rate are transmitted between a sensor module and a monitor module. Also, FIGS. 10-12 functionally illustrate a communications adapter where a plethysmograph is transmitted between a sensor module and a monitor module. FIGS. 13-14 functionally illustrate a multiple-parameter communications adapter.

FIG. 3 illustrates a communications adapter 300 having a sensor module 400 and a monitor module 500. The communications adapter 300 communicates patient data derived from a sensor 310 between the sensor module 400, which is located proximate a patient 20 and the monitor module 500, which is located proximate a monitor 360. A wireless link 340 is provided between the sensor module 400 and the monitor module 500, replacing the conventional patient cable, such as a pulse oximetry patient cable 140 (FIG. 1). Advantageously, the sensor module 400 is plug-compatible with a conventional sensor 310. In particular, the sensor connector 318 connects to the sensor module 400 in a similar manner as to a patient cable. Further, the sensor module 400 outputs a drive signal to the sensor 310 and inputs a sensor signal from the sensor 310 in an equivalent manner as a conventional monitor 360. The sensor module 400 may be battery powered or externally powered. External power may be for recharging internal batteries or for powering the sensor module during operation or both.

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As shown in FIG. 3, the monitor module 500 is advantageously plug-compatible with a conventional monitor 360. In particular, the monitor's sensor port 362 connects to the monitor module 500 in a similar manner as to a patient cable, such as a pulse oximetry patient cable 140 (FIG. 1). Further, the monitor module 500 inputs a drive signal from the monitor 360 and outputs a corresponding sensor signal to the monitor 360 in an equivalent manner as a conventional sensor 310. As such, the combination sensor module 400 and monitor module 500 provide a plug-compatible wireless replacement for a patient cable, adapting an existing wired physiological measurement system into a wireless physiological measurement system. The monitor module 500 may be battery powered, powered from the monitor, such as by tapping current from a monitor's LED drive, or externally powered from an independent AC or DC power source.

Although a communications adapter 300 is described herein with respect to a pulse oximetry sensor and monitor, one of ordinary skill in the art will recognize that a communications adapter may provide a plug-compatible wireless replace for a patient cable that connects any physiological sensor and corresponding monitor. For example, a communications adapter 300 may be applied to a biopotential sensor, a non-invasive blood pressure (NIBP) sensor, a respiratory rate sensor, a glucose sensor and the corresponding monitors, to name a few.

Sensor Module Physical Configurations

FIGS. 4A-B illustrate physical embodiments of a sensor module 400. FIG. 4A illustrates a wrist-mounted module 410 having a wrist strap 411, a case 412 and an auxiliary cable 420. The case 412 contains the sensor module electronics, which are functionally described with respect to FIG. 6, below. The case 412 is mounted to the wrist strap 411, which attaches the wrist-mounted module 410 to a patient 20. The auxiliary cable 420 mates to a sensor connector 318 and a module connector 414, providing a wired link between a conventional sensor 310 and the wrist-mounted module 410. Alternatively, the auxiliary cable 420 is directly wired to the sensor module 400. The wrist-mounted module 410 may have a display 415 that shows sensor measurements, module status and other visual indicators, such as monitor status. The wrist-mounted module 410 may also have keys (not shown) or other input mechanisms to control its operational mode and characteristics. In an alternative embodiment, the sensor 310 may have a tail (not shown) that connects directly to the wrist-mounted module 410, eliminating the auxiliary cable 420.

FIG. 4B illustrates a clip-on module 460 having a clip 461, a case 462 and an auxiliary cable 470. The clip 461 attaches the clip-on module 460 to patient clothing or objects near a patient 20, such as a bed frame. The auxiliary cable 470 mates to the sensor connector 318 and functions as for the auxiliary cable 420 (FIG. 4A) of the wrist-mounted module 410 (FIG. 4A), described above. The clip-on module 460 may have a display 463 and keys 464 as for the wrist-mounted module 410 (FIG. 4A). Either the wrist-mounted module 410 or the clip-on module 460 may have other input or output ports (not shown) that download software, configure the module, or provide a wired connection to other measurement instruments or computing devices, to name a few examples.

Monitor Module Physical Configurations

FIGS. 5A-C illustrate physical embodiments of a monitor module 500. FIG. 5A illustrates a direct-connect module 510 having a case 512 and an integrated monitor connector 514. The case 512 contains the monitor module electronics, which are functionally described with respect to FIG. 7, below. The monitor connector 514 mimics that of the monitor end of a

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patient cable, such as a pulse oximetry patient cable **140** (FIG. **1**), and electrically and mechanically connects the monitor module **510** to the monitor **360** via the monitor's sensor port **362**.

FIG. **5B** illustrates a cable-connect module **540** having a case **542** and an auxiliary cable **550**. The case **542** functions as for the direct-connect module **510** (FIG. **5A**), described above. Instead of directly plugging into the monitor **360**, the cable-connect module **540** utilizes the auxiliary cable **550**, which mimics the monitor end of a patient cable, such as a pulse oximetry patient cable **140** (FIG. **1**), and electrically connects the cable-connect module **540** to the monitor sensor port **362**.

FIG. **5C** illustrates a plug-in module **570** having a plug-in case **572** and an auxiliary cable **580**. The plug-in case **572** is mechanically compatible with the plug-in chassis of a multiparameter monitor **370** and may or may not electrically connect to the chassis backplane. The auxiliary cable **580** mimics a patient cable and electrically connects the plug-in module **570** to the sensor port **372** of another plug-in device. A direct-connect module **510** (FIG. **5A**) or a cable-connect module **540** (FIG. **5B**) may also be used with a multiparameter monitor **370**.

In a multiparameter embodiment, such as described with respect to FIGS. **13-14**, below, a monitor module **500** may connect to multiple plug-in devices of a multiparameter monitor **370**. For example, a cable-connect module **540** (FIG. **5B**) may have multiple auxiliary cables **550** (FIG. **5B**) that connect to multiple plug-in devices installed within a multiparameter monitor chassis. Similarly, a plug-in module **570** may have one or more auxiliary cables **580** with multiple connectors for attaching to the sensor ports **372** of multiple plug-in devices.

Communications Adapter Functions

FIGS. **6-7** illustrate functional embodiments of a communications adapter. FIG. **6** illustrates a sensor module **400** having a sensor interface **610**, a signal processor **630**, an encoder **640**, a transmitter **650** and a transmitting antenna **670**. A physiological sensor **310** provides an input sensor signal **612** at the sensor connector **318**. Depending on the sensor **310**, the sensor module **400** may provide one or more drive signals **618** to the sensor **310**. The sensor interface **610** inputs the sensor signal **612** and outputs a conditioned signal **614**. The conditioned signal **614** may be coupled to the transmitter **650** or further processed by a signal processor **630**. If the sensor module configuration utilizes a signal processor **630**, it derives a parameter signal **632** responsive to the sensor signal **612**, which is then coupled to the transmitter **650**. Regardless, the transmitter **650** inputs a baseband signal **642** that is responsive to the sensor signal **612**. The transmitter **650** modulates the baseband signal **642** with a carrier to generate a transmit signal **654**. The transmit signal **654** may be derived by various amplitude, frequency or phase modulation schemes, as is well known in the art. The transmit signal **654** is coupled to the transmit antenna **670**, which provides wireless communications to a corresponding receive antenna **770** (FIG. **7**), as described below.

As shown in FIG. **6**, the sensor interface **610** conditions and digitizes the sensor signal **612** to generate the conditioned signal **614**. Sensor signal conditioning may be performed in the analog domain or digital domain or both and may include amplification and filtering in the analog domain and filtering, buffering and data rate modification in the digital domain, to name a few. The resulting conditioned signal **614** is responsive to the sensor signal **612** and may be used to calculate or derive a parameter signal **632**.

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Further shown in FIG. **6**, the signal processor **630** performs signal processing on the conditioned signal **614** to generate the parameter signal **632**. The signal processing may include buffering, digital filtering, smoothing, averaging, adaptive filtering and frequency transforms to name a few. The resulting parameter signal **632** may be a measurement calculated or derived from the conditioned signal, such as oxygen saturation, pulse rate, blood glucose, blood pressure and EKG to name a few. Also, the parameter signal **632** may be an intermediate result from which the above-stated measurements may be calculated or derived.

As described above, the sensor interface **610** performs mixed analog and digital pre-processing of an analog sensor signal and provides a digital output signal to the signal processor **630**. The signal processor **630** then performs digital post-processing of the front-end processor output. In alternative embodiments, the input sensor signal **612** and the output conditioned signal **614** may be either analog or digital, the front-end processing may be purely analog or purely digital, and the back-end processing may be purely analog or mixed analog or digital.

In addition, FIG. **6** shows an encoder **640**, which translates a digital word or serial bit stream, for example, into the baseband signal **642**, as is well-known in the art. The baseband signal **642** comprises the symbol stream that drives the transmit signal **654** modulation, and may be a single signal or multiple related signal components, such as in-phase and quadrature signals. The encoder **640** may include data compression and redundancy, also well-known in the art.

FIG. **7** illustrates a monitor module **500** having a receive antenna **770**, a receiver **710**, a decoder **720**, a waveform processor **730** and a monitor interface **750**. A receive signal **712** is coupled from the receive antenna **770**, which provides wireless communications to a corresponding transmit antenna **670** (FIG. **6**), as described above. The receiver **710** inputs the receive signal **712**, which corresponds to the transmit signal **654** (FIG. **6**). The receiver **710** demodulates the receive signal to generate a baseband signal **714**. The decoder **720** translates the symbols of the demodulated baseband signal **714** into a decoded signal **724**, such as a digital word stream or bit stream. The waveform processor **730** inputs the decoded signal **724** and generates a constructed signal **732**. The monitor interface **750** is configured to communicate the constructed signal **732** to a sensor port **362** of a monitor **360**. The monitor **360** may output a sensor drive signal **754**, which the monitor interface **750** inputs to the waveform processor **730** as a monitor drive signal **734**. The waveform processor **730** may utilize the monitor drive signal **734** to generate the constructed signal **732**. The monitor interface **750** may also provide characterization information **758** to the waveform processor **730**, relating to the monitor **360**, the sensor **310** or both, that the waveform processor **730** utilizes to generate the constructed signal **732**.

The constructed signal **732** is adapted to the monitor **360** so that measurements derived by the monitor **360** from the constructed signal **732** are generally equivalent to measurements derivable from the sensor signal **612** (FIG. **6**). Note that the sensor **310** (FIG. **6**) may or may not be directly compatible with the monitor **360**. If the sensor **310** (FIG. **6**) is compatible with the monitor **360**, the constructed signal **732** is generated so that measurements derived by the monitor **360** from the constructed signal **732** are generally equivalent (within clinical significance) with those derivable directly from the sensor signal **612** (FIG. **6**). If the sensor **310** (FIG. **6**) is not compatible with the monitor **360**, the constructed signal **732** is generated so that measurements derived by the monitor **360** from

the constructed signal **732** are generally equivalent to those derivable directly from the sensor signal **612** (FIG. 6) using a compatible monitor.

Wireless Pulse Oximetry

FIGS. 8-11 illustrate pulse oximeter embodiments of a communications adapter. FIGS. 8-9 illustrate a sensor module and a monitor module, respectively, configured to communicate measured pulse oximeter parameters. FIGS. 10-11 illustrate a sensor module and a monitor module, respectively, configured to communicate a plethysmograph signal.

Parameter Transmission

FIG. 8 illustrates a pulse oximetry sensor module **800** having a sensor interface **810**, signal processor **830**, encoder **840**, transmitter **850**, transmitting antenna **870** and controller **890**. The sensor interface **810**, signal processor **830** and controller **890** function as described with respect to FIG. 2, above. The sensor interface **810** communicates with a standard pulse oximetry sensor **310**, providing an LED drive signal **818** to the LED emitters **312** and receiving a sensor signal **812** from the detector **314** in response. The sensor interface **810** provides front-end processing of the sensor signal **812**, also described above, providing a plethysmograph signal **814** to the signal processor **830**. The signal processor **830** then derives a parameter signal **832** that comprises a real time measurement of oxygen saturation and pulse rate. The parameter signal **832** may include other parameters, such as measurements of perfusion index and signal quality. In one embodiment, the signal processor is an MS-5 or MS-7 board available from Masimo Corporation, Irvine, Calif.

As shown in FIG. 8, the encoder **840**, the transmitter **850** and the transmitting antenna **870** function as described with respect to FIG. 6, above. For example, the parameter signal **832** may be a digital word stream that is serialized into a bit stream and encoded into a baseband signal **842**. The baseband signal **842** may be, for example, two bit symbols that drive a quadrature phase shift keyed (QPSK) modulator in the transmitter **850**. Other encodings and modulations are also applicable, as described above. The transmitter **850** inputs the baseband signal **842** and generates a transmit signal **854** that is a modulated carrier having a frequency suitable for short-range transmission, such as within a hospital room, doctor's office, emergency vehicle or critical care ward, to name a few. The transmit signal **854** is coupled to the transmit antenna **870**, which provides wireless communications to a corresponding receive antenna **970** (FIG. 9), as described below.

FIG. 9 illustrates a monitor module **900** having a receive antenna **970**, a receiver **910**, a decoder **920**, a waveform generator **930** and an interface cable **950**. The receive antenna **970**, receiver **910** and decoder **920** function as described with respect to FIG. 7, above. In particular, the receive signal **912** is coupled from the receive antenna **970**, which provides wireless communications to a corresponding transmit antenna **870** (FIG. 8). The receiver **910** inputs the receive signal **912**, which corresponds to the transmit signal **854** (FIG. 8). The receiver **910** demodulates the receive signal **912** to generate a baseband signal **914**. Not accounting for transmission errors, the baseband signal **914** corresponds to the sensor module baseband signal **842** (FIG. 8), for example a symbol stream of two bits each. The decoder **920** assembles the baseband signal **914** into a parameter signal **924**, which, for example, may be a sequence of digital words corresponding to oxygen saturation and pulse rate. Again, not accounting for transmission errors, the monitor module parameter signal **924** corresponds to the sensor module parameter signal **832** (FIG. 8), derived by the signal processor **830** (FIG. 8).

Also shown in FIG. 9, the waveform generator **930** is a particular embodiment of the waveform processor **730** (FIG. 7) described above. The waveform generator **930** generates a synthesized waveform **932** that the pulse oximeter monitor **360** can process to calculate SpO₂ and pulse rate values or exception messages. In the present embodiment, the waveform generator output does not reflect a physiological waveform. In particular, the synthesized waveform is not physiological data from the sensor module **800**, but is a waveform synthesized from predetermined stored waveform data to cause the monitor **360** to calculate oxygen saturation and pulse rate equivalent to or generally equivalent (within clinical significance) to that calculated by the signal processor **830** (FIG. 8). The actual intensity signal from the patient received by the detector **314** (FIG. 8) is not provided to the monitor **360** in the present embodiment. Indeed, the waveform provided to the monitor **360** will usually not resemble a plethysmographic waveform or other physiological data from the patient to whom the sensor module **800** (FIG. 8) is attached.

The synthesized waveform **932** is modulated according to the drive signal input **934**. That is, the pulse oximeter monitor **360** expects to receive a red and IR modulated intensity signal originating from a detector, as described with respect to FIGS. 1-2, above. The waveform generator **930** generates the synthesized waveform **932** with a predetermined shape, such as a triangular or sawtooth waveform stored in waveform generator memory or derived by a waveform generator algorithm. The waveform is modulated synchronously with the drive input **934** with first and second amplitudes that are processed in the monitor **360** as red and IR portions of a sensor signal. The frequency and the first and second amplitudes are adjusted so that pulse rate and oxygen saturation measurements derived by the pulse oximeter monitor **360** are generally equivalent to the parameter measurements derived by the signal processor **830** (FIG. 8), as described above. One embodiment of a waveform generator **930** is described in U.S. patent application Ser. No. 60/117,097 entitled "Universal/Upgrading Pulse Oximeter," assigned to Masimo Corporation, Irvine, Calif. and incorporated by reference herein. Although the waveform generator **930** is described above as synthesizing a waveform that does not resemble a physiological signal, one of ordinary skill will recognize that another embodiment of the waveform generator **930** could incorporate, for example, a plethysmograph simulator or other physiological signal simulator.

Further shown in FIG. 9, the interface cable **950** functions in a manner similar to the monitor interface **750** (FIG. 7) described above. The interface cable **950** is configured to communicate the synthesized waveform **932** to the monitor **360** sensor port and to communicate the sensor drive signal **934** to the waveform generator **930**. The interface cable **950** may include a ROM **960** that contains monitor and sensor characterization data. The ROM **960** is read by the waveform generator **930** so that the synthesized waveform **932** is adapted to a particular monitor **360**. For example, the ROM **960** may contain calibration data of red/IR versus oxygen saturation, waveform amplitude and waveform shape information. An interface cable is described in U.S. patent application Ser. No. 60/117,092, referenced above. Monitor-specific SatShare™ brand interface cables are available from Masimo Corporation, Irvine, Calif. In an alternative embodiment, such as a direct connect monitor module as illustrated in FIG. 5A, an interface cable **950** is not used and the ROM **960** may be incorporated within the monitor module **900** itself.

Plethysmograph Transmission

FIG. 10 illustrates another pulse oximetry sensor module 1000 having a sensor interface 1010, encoder 1040, transmitter 1050, transmitting antenna 1070 and controller 1090, which have the corresponding functions as those described with respect to FIG. 8, above. The encoder 1040, however, inputs a plethysmograph signal 1014 rather than oxygen saturation and pulse rate measurements 832 (FIG. 8). Thus, the sensor module 1000 according to this embodiment encodes and transmits a plethysmograph signal 1014 to a corresponding monitor module 1100 (FIG. 11) in contrast to derived physiological parameters, such as oxygen saturation and pulse rate. The plethysmograph signal 1014 is illustrated in FIG. 10 as being a direct output from the sensor interface 1010. In another embodiment, the sensor module 1000 incorporates a decimation processor, not shown, after the sensor interface 1010 so as to provide a plethysmograph signal 1014 having a reduced sample rate.

FIG. 11 illustrates another pulse oximetry monitor module 1100 having a receive antenna 1170, a receiver 1110, a decoder 1120 and an interface cable 1150, which have the corresponding functions as those described with respect to FIG. 9, above. This monitor module embodiment 1100, however, has a waveform modulator 1200 rather than a waveform generator 930 (FIG. 9), as described above. The waveform modulator 1200 inputs a plethysmograph signal from the decoder 1120 rather than oxygen saturation and pulse rate measurements, as described with respect to FIG. 9, above. Further, the waveform modulator 1200 provides an modulated waveform 1132 to the pulse oximeter monitor 360 rather than a synthesized waveform, as described with respect to FIG. 9. The modulated waveform 1132 is a plethysmographic waveform modulated according to the monitor drive signal input 1134. That is, the waveform modulator 1200 does not synthesize a waveform, but rather modifies the received plethysmograph signal 1124 to cause the monitor 360 to calculate oxygen saturation and pulse rate generally equivalent (within clinical significance) to that derivable by a compatible, calibrated pulse oximeter directly from the sensor signal 1012 (FIG. 10). The waveform modulator 1200 is described in further detail with respect to FIG. 12, below.

FIG. 12 shows a waveform modulator 1200 having a demodulator 1210, a red digital-to-analog converter (DAC) 1220, an IR DAC 1230, a red amplifier 1240, an IR amplifier 1250, a modulator 1260, a modulator control 1270, a look-up table (LUT) 1280 and a ratio calculator 1290. The waveform modulator 1200 demodulates red and IR plethysmographs ("pleths") from the decoder output 1124 into a separate red pleth 1222 and IR pleth 1232. The waveform modulator 1200 also adjusts the amplitudes of the pleths 1222, 1232 according to stored calibration curves for the sensor 310 (FIG. 10) and the monitor 360 (FIG. 11). Further, the waveform modulator 1200 re-modulates the adjusted red pleth 1242 and adjusted IR pleth 1252, generating a modulated waveform 1132 to the monitor 360 (FIG. 11).

As shown in FIG. 12, the demodulator 1210 performs the demodulation function described above, generating digital red and IR pleth signals 1212, 1214. The DACs 1220, 1230 convert the digital pleth signals 1212, 1214 to corresponding analog pleth signals 1222, 1232. The amplifiers 1240, 1250 have variable gain control inputs 1262, 1264 and perform the amplitude adjustment function described above, generating adjusted red and IR pleth signals 1242, 1252. The modulator 1260 performs the re-modulation function described above, combining the adjusted red and IR pleth signals 1242, 1252 according to a control signal 1272. The modulator control 1270 generates the control signal 1272 synchronously with the LED drive signal(s) 1134 from the monitor 360.

Also shown in FIG. 12, the ratio calculator 1290 derives a red/IR ratio from the demodulator outputs 1212, 1214. The

LUT 1280 stores empirical calibration data for the sensor 310 (FIG. 10). The LUT 1280 also downloads monitor-specific calibration data from the ROM 1160 (FIG. 11) via the ROM output 1158. From this calibration data, the LUT 1280 determines a desired red/IR ratio for the modulated waveform 1132 and generates red and IR gain outputs 1262, 1264 to the corresponding amplifiers 1240, 1250, accordingly. A desired red/IR ratio is one that allows the monitor 360 (FIG. 11) to derive oxygen saturation measurements from the modulated waveform 1132 that are generally equivalent to that derivable directly from the sensor signal 1012 (FIG. 10).

One of ordinary skill in the art will recognize that some of the signal processing functions described with respect to FIGS. 8-11 may be performed either within a sensor module or within a monitor module. Signal processing functions performed within a sensor module may advantageously reduce the transmission bandwidth to a monitor module at a cost of increased sensor module size and power consumption. Likewise, signal processing functions performed within a monitor module may reduce sensor module size and power consumption at a cost of increase transmission bandwidth.

For example, a monitor module embodiment 900 (FIG. 9) described above receives measured pulse oximeter parameters, such as oxygen saturation and pulse rate, and generates a corresponding synthesized waveform. In that embodiment, the oxygen saturation and pulse rate computations are performed within a sensor module 800 (FIG. 8). Another monitor module embodiment 1100 (FIG. 11), also described above, receives a plethysmograph waveform and generates a remodulated waveform. In that embodiment, minimal signal processing is performed within a sensor module 1000 (FIG. 10). In yet another embodiment, not shown, a sensor module transmits a plethysmograph waveform or a decimated plethysmograph waveform having a reduced sample rate. A corresponding monitor module has a signal processor, such as described with respect to FIG. 8, in addition to a waveform generator, as described with respect to FIG. 9. The signal processor computes pulse oximeter parameters and the waveform generator generates a corresponding synthesized waveform, as described above. In this embodiment, minimal signal processing is performed within the sensor module, and the monitor module functions are performed on the pulse oximeter parameters computed within the monitor module.

Wireless Multiple Parameter Measurements

FIGS. 13-14 illustrate a multiple parameter communications adapter. FIG. 13 illustrates a multiple parameter sensor module 1300 having sensor interfaces 1310, one or more signal processors 1330, a multiplexer and encoder 1340, a transmitter 1350, a transmitting antenna 1370 and a controller 1390. One or more physiological sensors 1301 provide input sensor signals 1312 to the sensor module 1300. Depending on the particular sensors 1301, the sensor module 1300 may provide one or more drive signals 1312 to the sensors 1301 as determined by the controller 1390. The sensor interfaces 1310 input the sensor signals 1312 and output one or more conditioned signals 1314. The conditioned signals 1314 may be coupled to the transmitter 1350 or further processed by the signal processors 1330. If the sensor module configuration utilizes signal processors 1330, it derives multiple parameter signals 1332 responsive to the sensor signals 1312, which are then coupled to the transmitter 1350. Regardless, the transmitter 1350 inputs a baseband signal 1342 that is responsive to the sensor signals 1312. The transmitter 1350 modulates the baseband signal 1342 with a carrier to generate a transmit signal 1354, which is coupled to the transmit antenna 1370 and communicated to a corresponding receive antenna 1470 (FIG. 14), as described with respect to FIG. 6, above. Alternatively, there may be multiple baseband signals 1342, and the transmitter 1350 may transmit on multiple frequency

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channels, where each channel conveys data responsive to one or more of the sensor signals **1314**.

As shown in FIG. **13**, the sensor interface **1310** conditions and digitizes the sensor signals **1312** as described for a single sensor with respect to FIG. **6**, above. The resulting conditioned signals **1314** are responsive to the sensor signals **1312**. The signal processors **1330** perform signal processing on the conditioned signals **1314** to derive parameter signals **1332**, as described for a single conditioned signal with respect to FIG. **6**, above. The parameter signals **1332** may be physiological measurements such as oxygen saturation, pulse rate, blood glucose, blood pressure, EKG, respiration rate and body temperature to name a few, or may be intermediate results from which the above-stated measurements may be calculated or derived. The multiplexer and encoder **1340** combines multiple digital word or serial bit streams into a single digital word or bit stream. The multiplexer and encoder also encodes the digital word or bit stream to generate the baseband signal **1342**, as described with respect to FIG. **6**, above.

FIG. **14** illustrates a multiple parameter monitor module **1400** having a receive antenna **1470**, a receiver **1410**, a demultiplexer and decoder **1420**, one or more waveform processors **1430** and a monitor interface **1450**. The receiver **1410** inputs and demodulates the receive signal **1412** corresponding to the transmit signal **1354** (FIG. **13**) to generate a baseband signal **1414** as described with respect to FIG. **7**, above. The demultiplexer and decoder **1420** separates the symbol streams corresponding to the multiple conditioned signals **1314** (FIG. **13**) and/or parameter signals **1332** (FIG. **13**) and translates these symbol streams into multiple decoded signals **1422**, as described for a single symbol stream with respect to FIG. **7**, above. Alternatively, multiple frequency channels are received to generate multiple baseband signals, each of which are decoded to yield multiple decoded signals **1422**. The waveform processors **1430** input the decoded signals **1422** and generate multiple constructed signals **1432**, as described for a single decoded signal with respect to FIGS. **7-12**, above. The monitor interface **1450** is configured to communicate the constructed signals **1432** to the sensor ports of a multiple parameter monitor **1401** or multiple single parameter monitors, in a manner similar to that for a single constructed signal, as described with respect to FIGS. **7-12**, above. In particular, the constructed signals **1432** are adapted to the monitor **1401** so that measurements derived by the monitor **1401** from the constructed signals **1432** are generally equivalent to measurements derivable directly from the sensor signals **1312** (FIG. **13**).

A physiological measurement communications adapter is described above with respect to wireless communications and, in particular, radio frequency communications. A sensor module and monitor module, however, may also communicate via wired communications, such as telephone, Internet or fiberoptic cable to name a few. Further, wireless communications can also utilize light frequencies, such as IR or laser to name a few.

A physiological measurement communications adapter has been disclosed in detail in connection with various embodiments. These embodiments are disclosed by way of examples only. One of ordinary skill in the art will appreciate many variations and modifications of a physiological measurement communications adapter within the scope of the claims that follow.

What is claimed is:

1. A communications adapter configured to wirelessly communicate a first signal from a patient site to a remote site and to adapt the first signal to a particular patient monitor at the remote site, the communications adapter comprising:

a first processor configured to generate said first signal responsive to a sensor signal received from a noninvasive sensor attached to a tissue portion of a patient,

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wherein said sensor signal is indicative of at least one physiological parameter of a patient;

a communications link configured to wirelessly transmit the first signal from a first site proximate the patient and to receive the first signal at a second site; and

a second processor that adapts the first signal to a usually incompatible particular patient monitor at the second site so that the particular patient monitor derives physiological measurements from the adapted first signal that are generally equivalent to measurements derivable from the first signal by a monitor compatible with the noninvasive sensor.

2. The communications adapter according to claim 1 wherein the second processor utilizes (i) measurement data representing a physiological measurement made at the first site, said measurement data transmitted to the second site and (ii) characterization information corresponding to said particular patient monitor that relates predetermined aspects of said first signal to predetermined physiological measurement values that said particular patient monitor would determine when provided with said aspects to generate said adapted first signal adapted to the particular patient monitor.

3. The communications adapter according to claim 2 further comprising: a monitor module housing at least a portion of the communications link and the second processor, the monitor module configured to communicate with a sensor port of the monitor; and a memory associated with the monitor module configured to store the characterization information.

4. The communications adapter according to claim 2 further comprising: a monitor module housing at least a portion of the communications link and the second processor; a cable configured to provide wired communications between the monitor module and a sensor port of the patient monitor; and a memory associated with the cable and configured to store the characterization information.

5. The communications adapter according to claim 2 wherein said second processor adapts said first signal so that said particular patient monitor derives said physiological measurements comprising at least one of oxygen saturation, blood pressure, EKG, respiration rate, body temperature and blood glucose.

6. The communications adapter according to claim 2 wherein said second processor adapts said first signal so that said particular patient monitor derives said physiological measurements comprising at least two of oxygen saturation, blood pressure, EKG, respiration rate, body temperature and blood glucose.

7. The communications adapter according to claim 5 wherein the physiological measurement is oxygen saturation and the first signal is a plethysmograph responsive to at least one of red and IR wavelengths emitted by the noninvasive sensor.

8. A physiological measurement method comprising:

inputting a sensor signal at a patient location; generating a physiological waveform responsive to the sensor signal;

reducing the sample rate of the physiological waveform; wirelessly communicating the reduced sample rate physiological waveform from the patient location to a monitor location;

adapting the reduced sample rate physiological waveform to a particular patient monitor at the monitor location; and

outputting the adapted physiological waveform to a sensor port of the patient monitor so that the patient monitor derives physiological measurements from the adapted

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physiological waveform that are generally equivalent to measurements derivable from the physiological waveform by a monitor compatible with the sensor signal.

9. A communications adapter comprising:

a means for inputting a sensor signal from a noninvasive sensor attached to a patient tissue site;

a means for generating a physiological waveform responsive to the sensor signal;

a means for communicating the physiological waveform from a patient location to a monitor location;

a means for adapting the physiological waveform to a particular monitor at the monitor location; and

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a means for outputting the adapted physiological waveform to a sensor port of the monitor.

10. The communications adapter according to claim **9** further comprising: a means for relating the adapted physiological waveform and physiological parameter measurements according to the particular monitor.

11. The communications adapter according to claim **10** further comprising a means for reducing the sampling rate of the physiological waveform prior to the wireless communications of the physiological waveform to the monitor location.

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