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**Al-Ali**

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(54) **BODY WORN MOBILE MEDICAL PATIENT MONITOR**

(71) Applicant: **MASIMO CORPORATION**, Irvine, CA (US)

(72) Inventor: **Ammar Al-Ali**, San Juan Capistrano, CA (US)

(73) Assignee: **MASIMO CORPORATION**, Irvine, CA (US)

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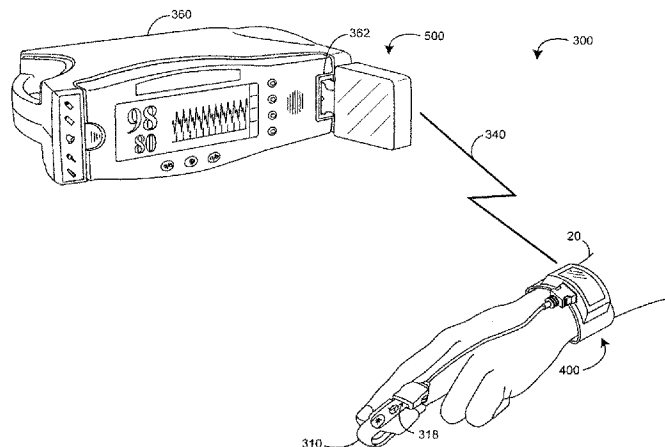
*Primary Examiner* — Eric Winakur

(74) *Attorney, Agent, or Firm* — Knobbe Martens Olson & Bear LLP

(57) **ABSTRACT**

A body worn mobile medical monitoring device configured to minimize cable wiring from a sensor by placement of one or more sensor communication ports. The body worn mobile medical monitoring device includes a housing securable on a lower arm of a patient, a display, and a sensor communication port positioned on a side of the housing and configured to face a hand of the lower arm of the patient when the mobile medical monitoring device is mounted to the lower arm of the patient. The sensor communication port provides wired communication with a pulse oximetry sensor attached to a digit of the hand of the patient, and is positioned on the side of the housing such that a path from the port on the side of the housing to the digit of the patient is shorter than any other path from any other side of the housing to the digit.

**20 Claims, 17 Drawing Sheets**



**Related U.S. Application Data**

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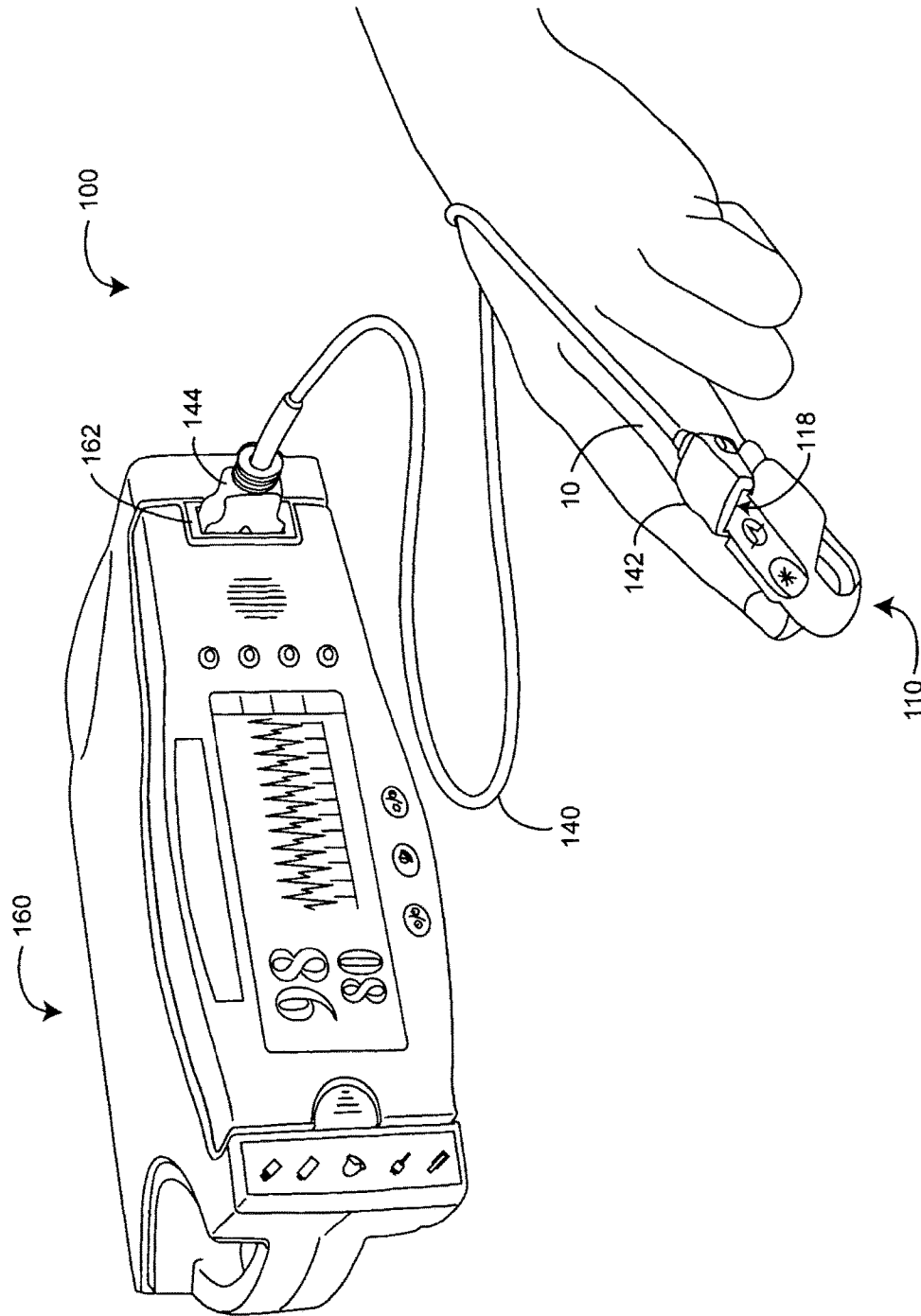


FIG. 1 (Prior Art)

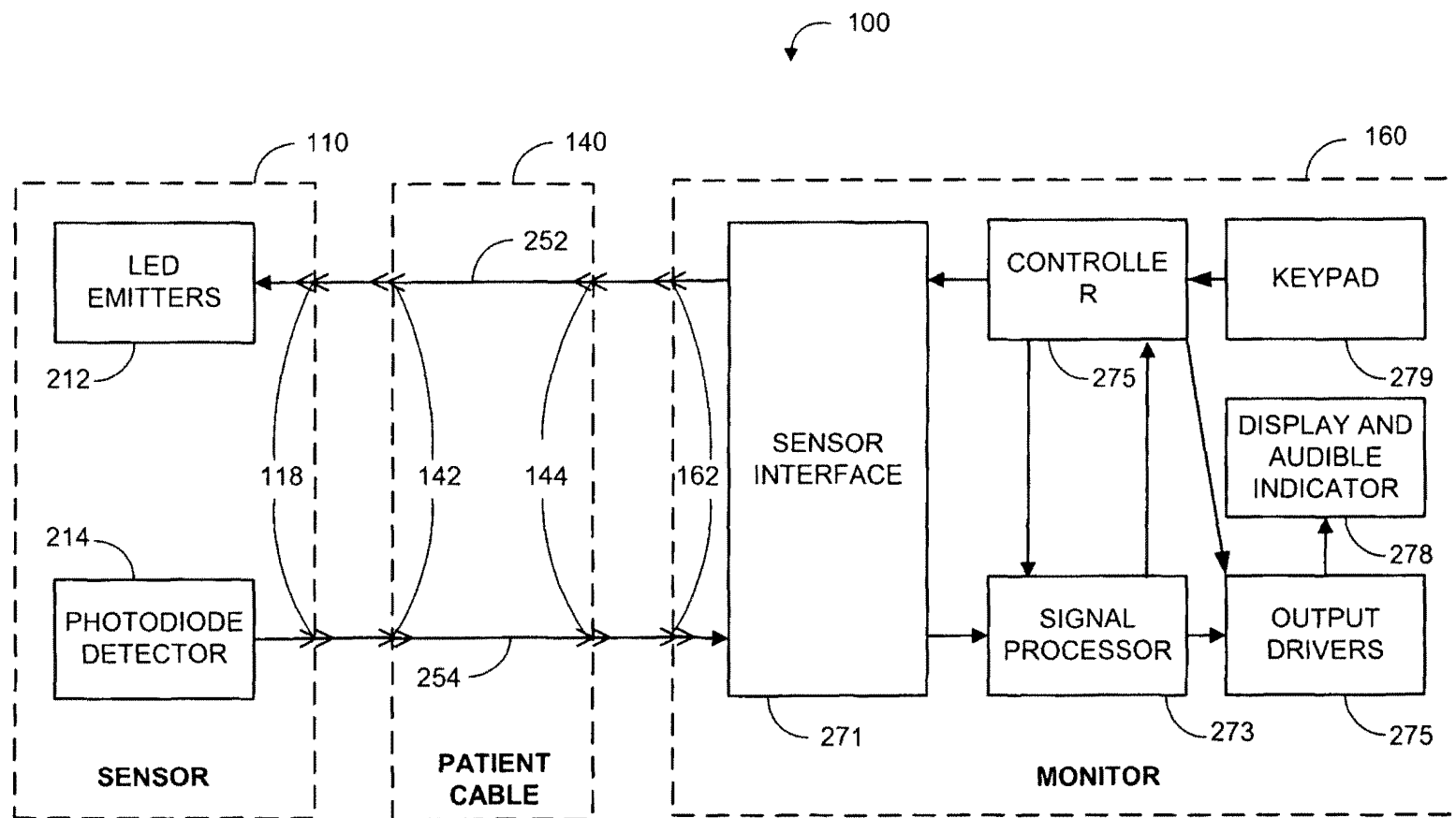


FIG. 2 (Prior Art)

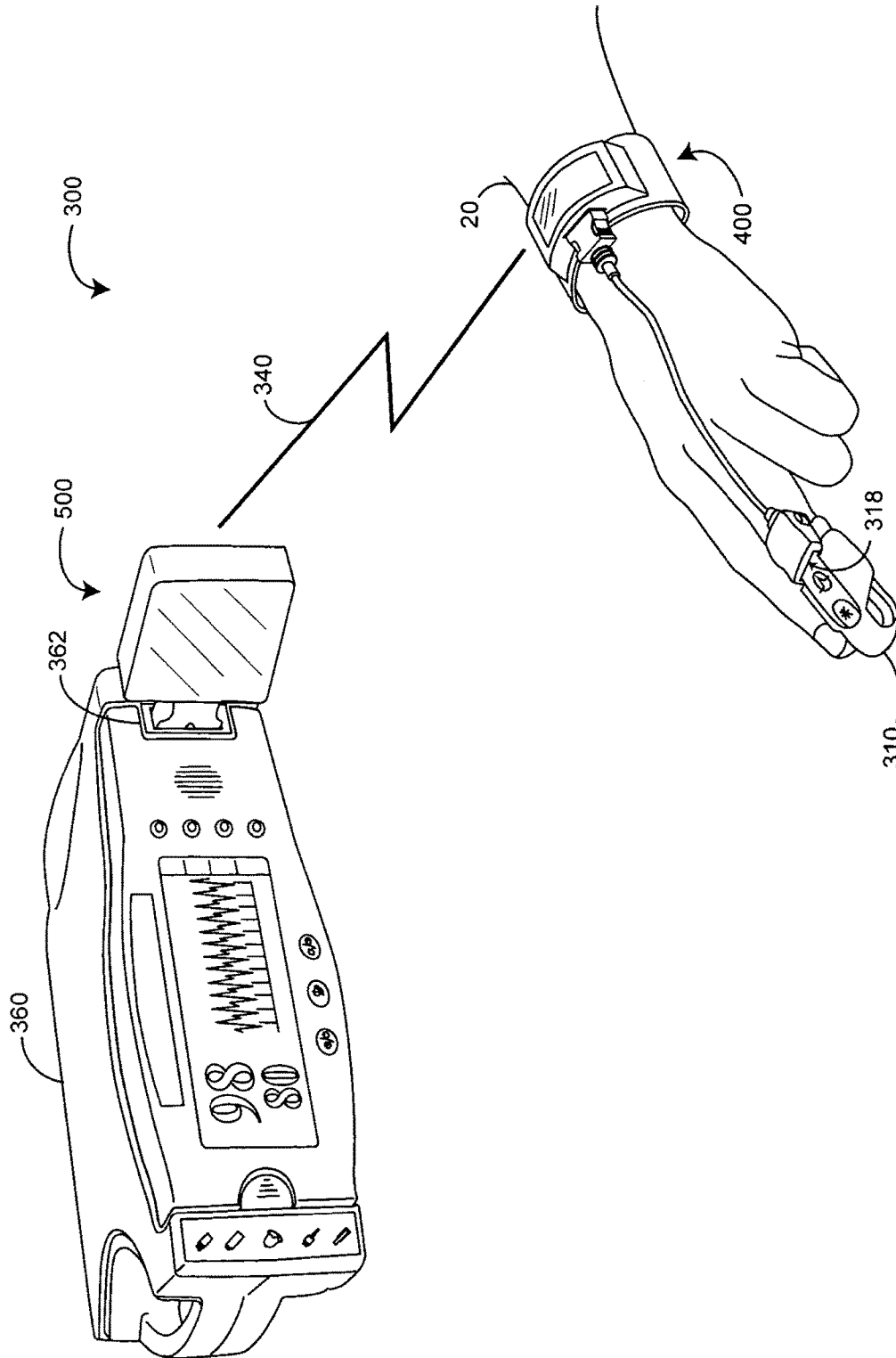


FIG. 3

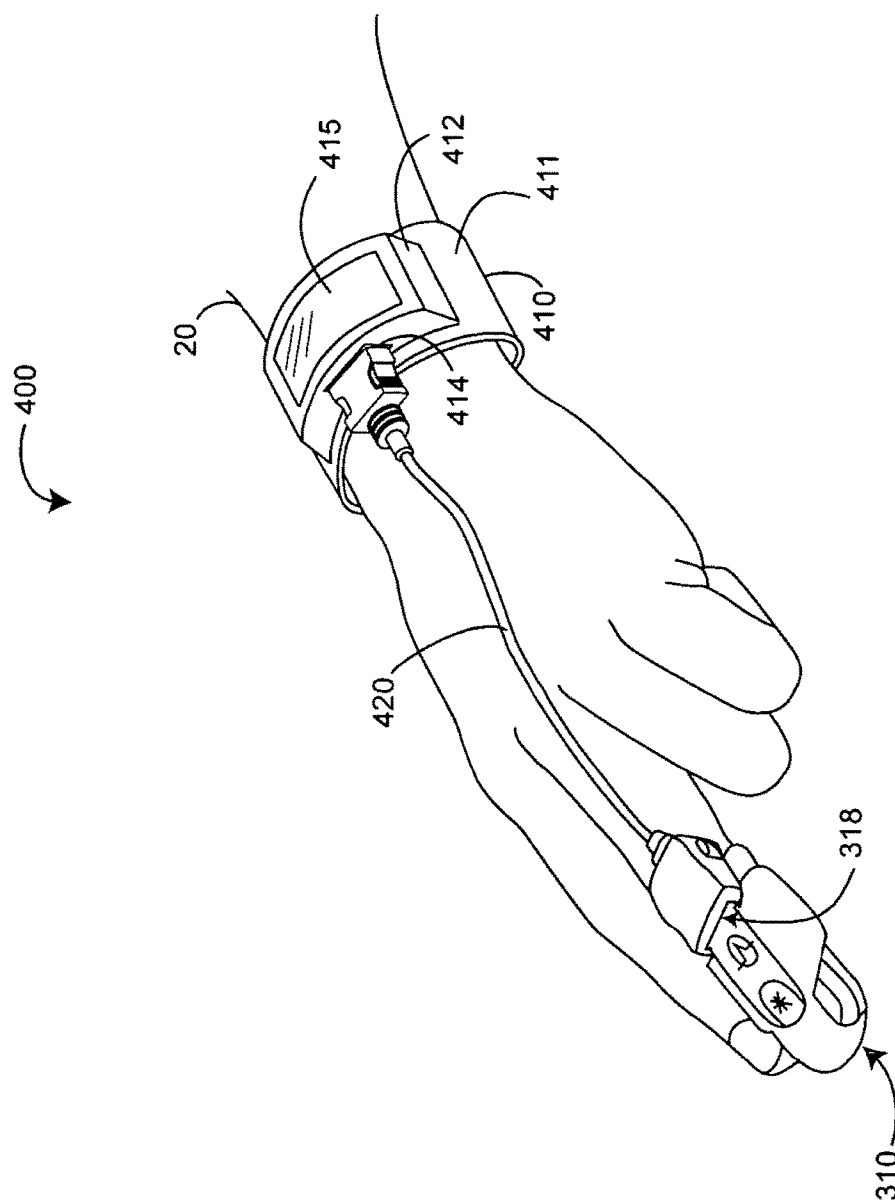


FIG. 4A



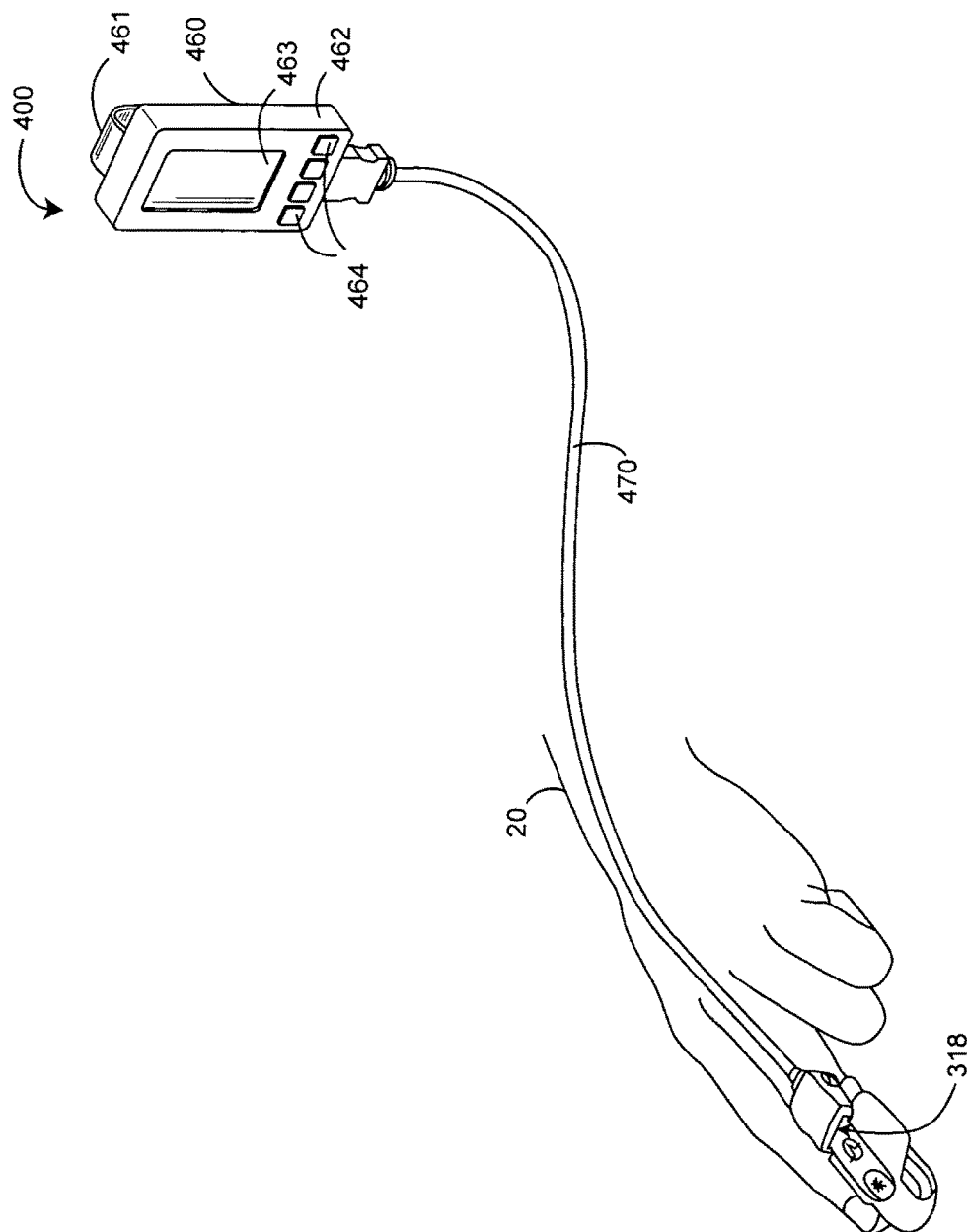


FIG. 4B

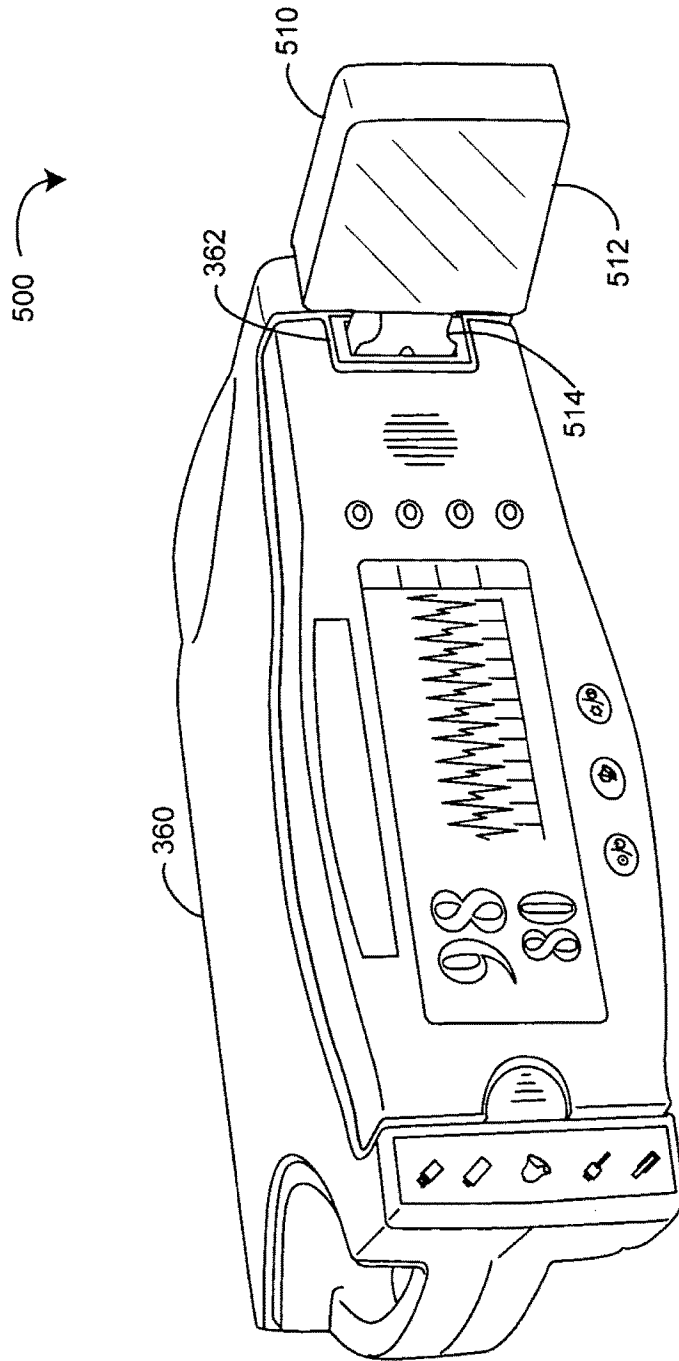


FIG. 5A

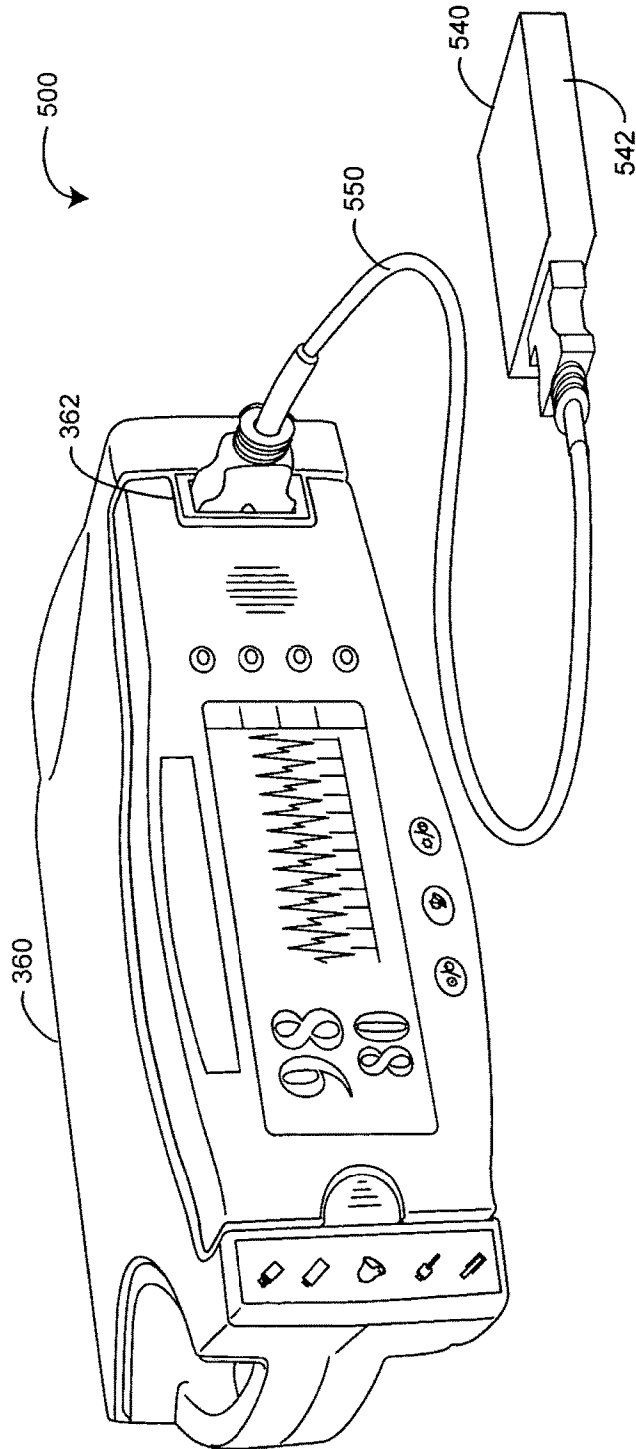


FIG. 5B

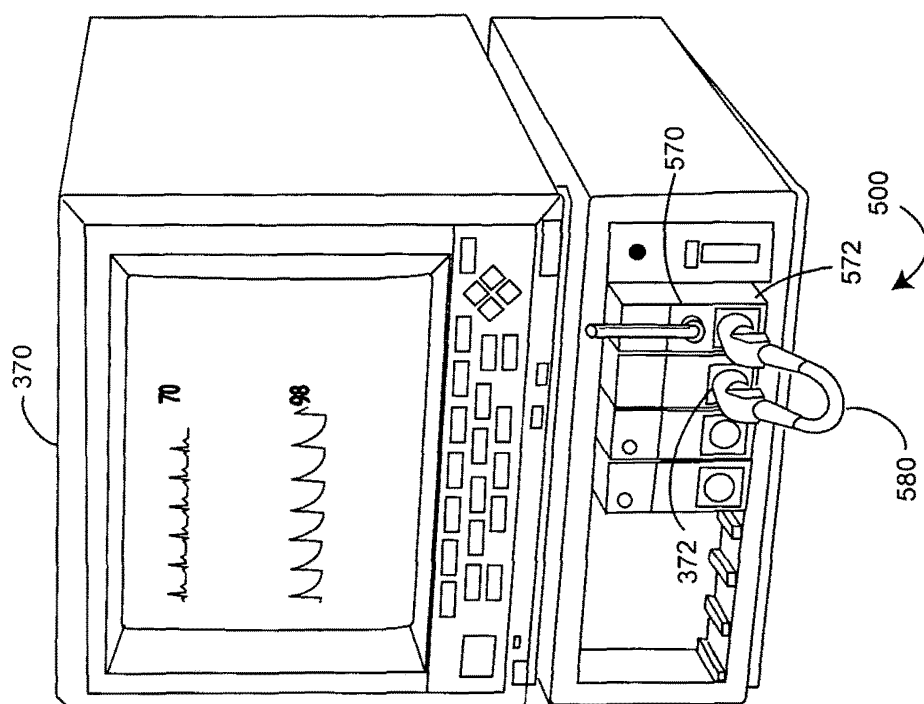


FIG. 5C

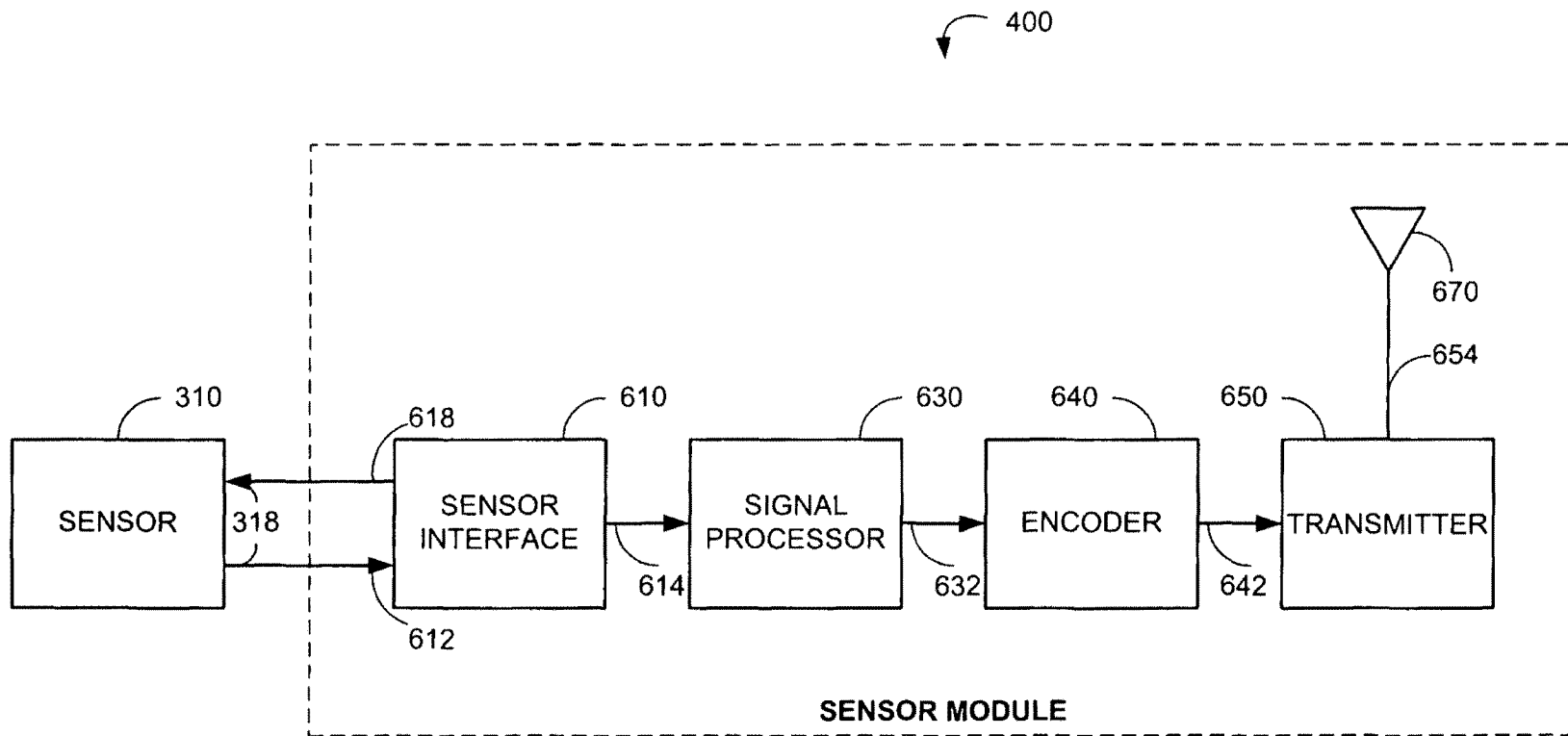


FIG. 6

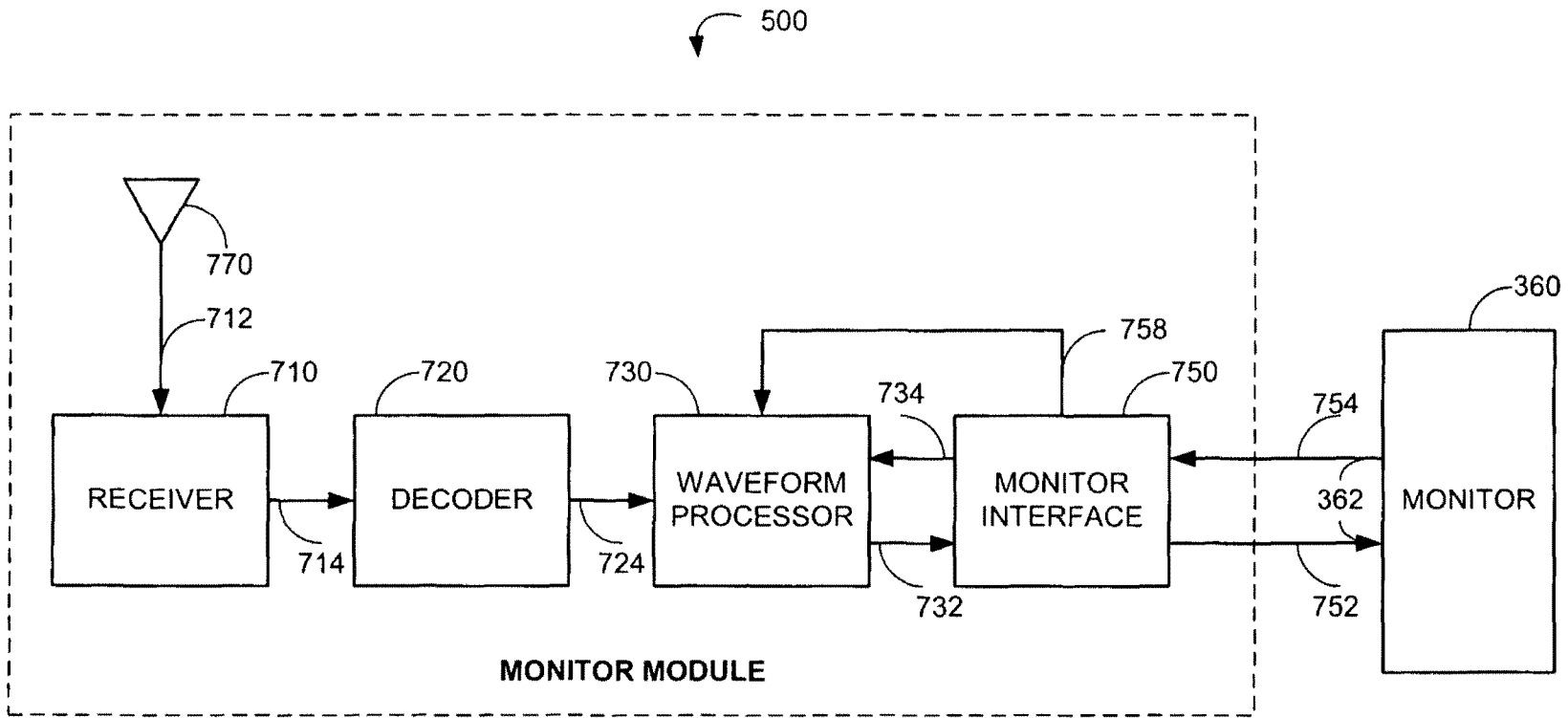


FIG. 7

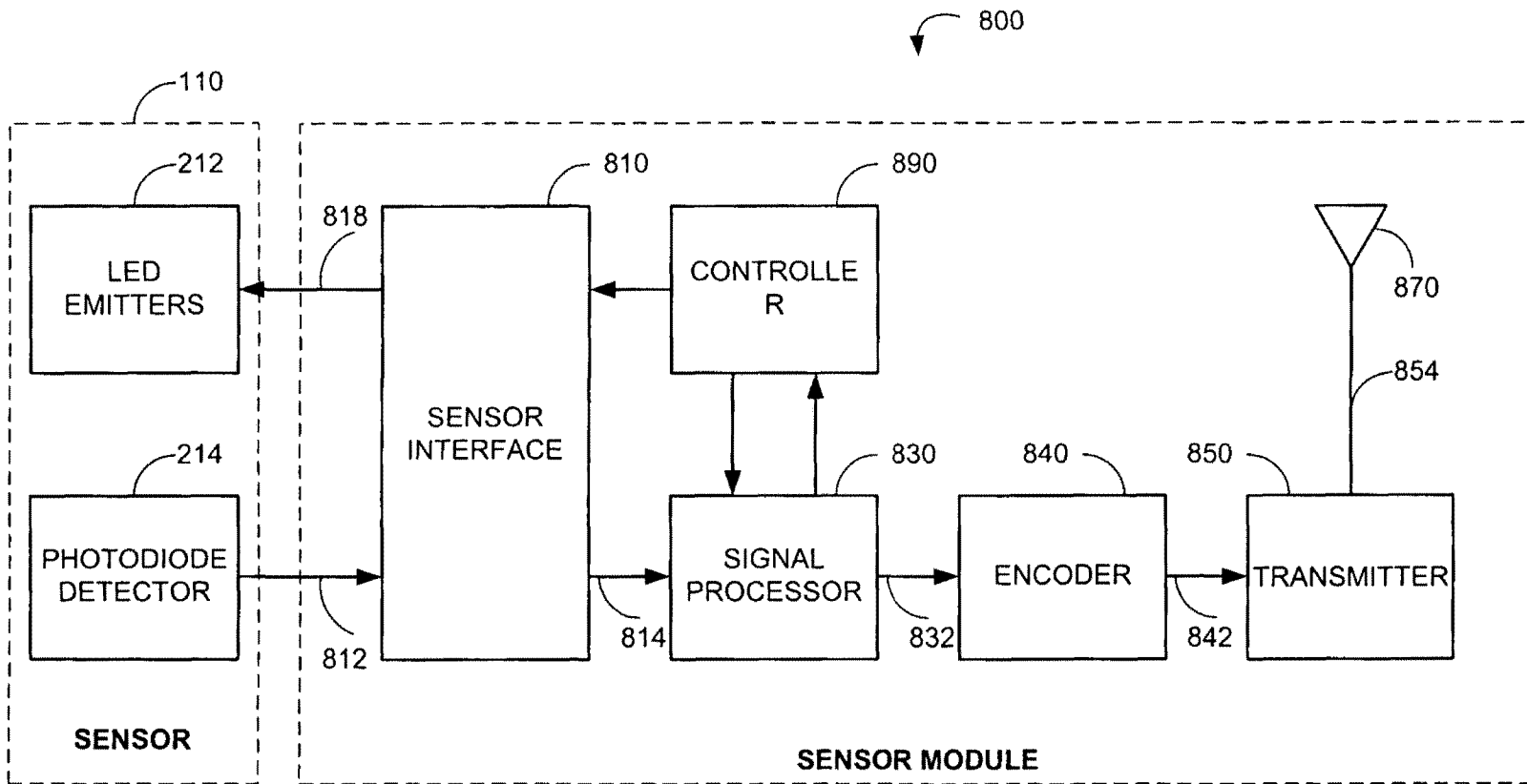


FIG. 8

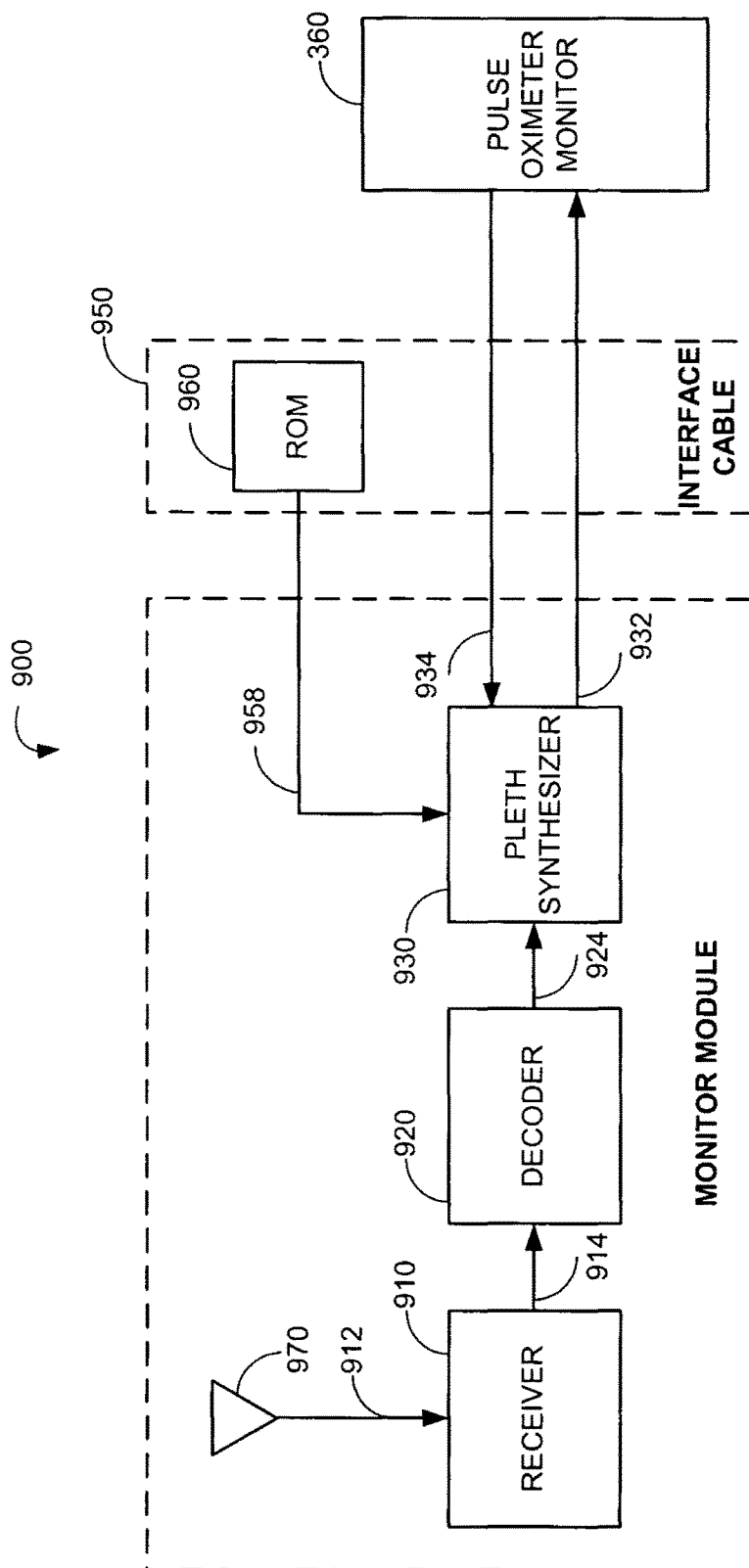


FIG. 9



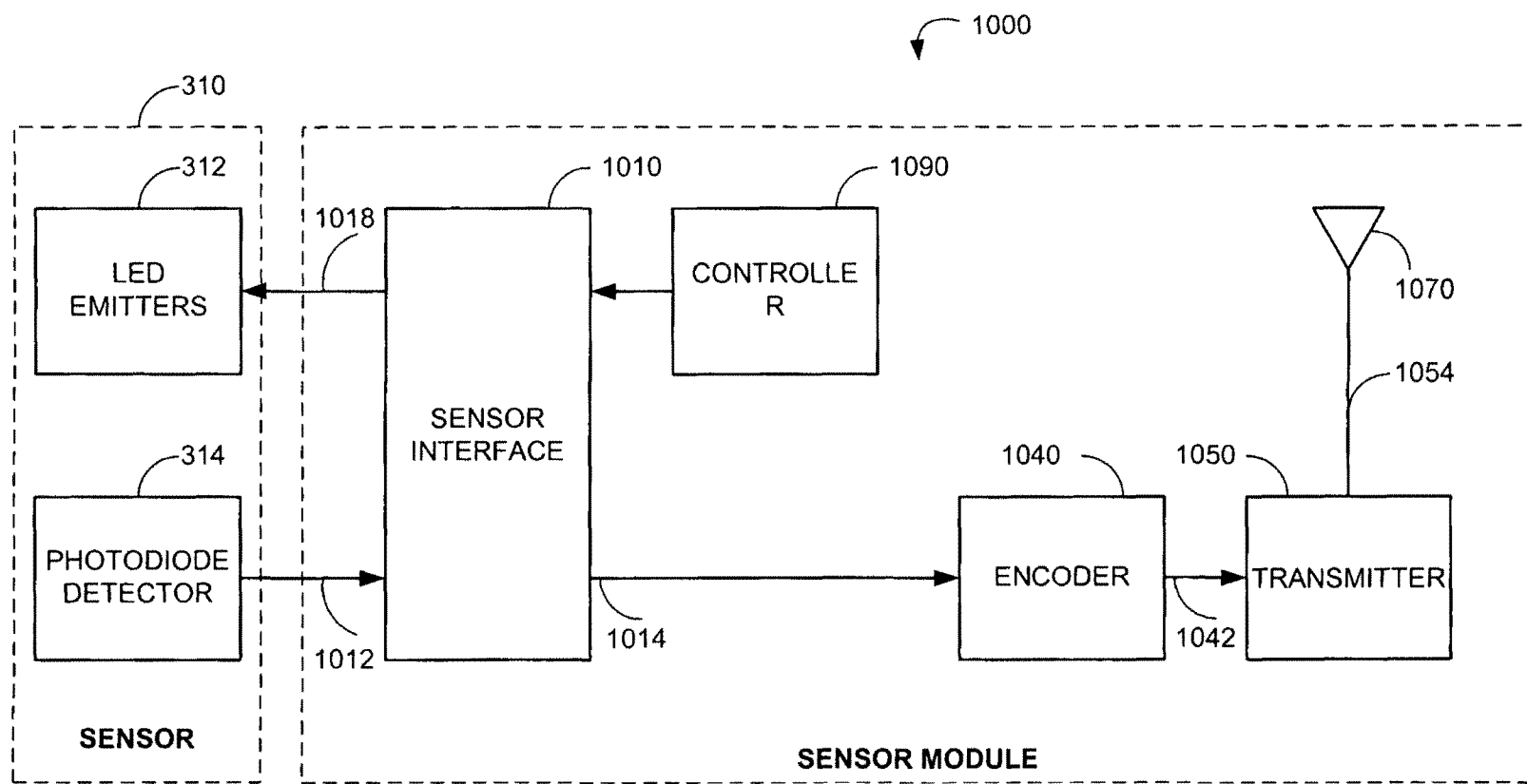


FIG. 10

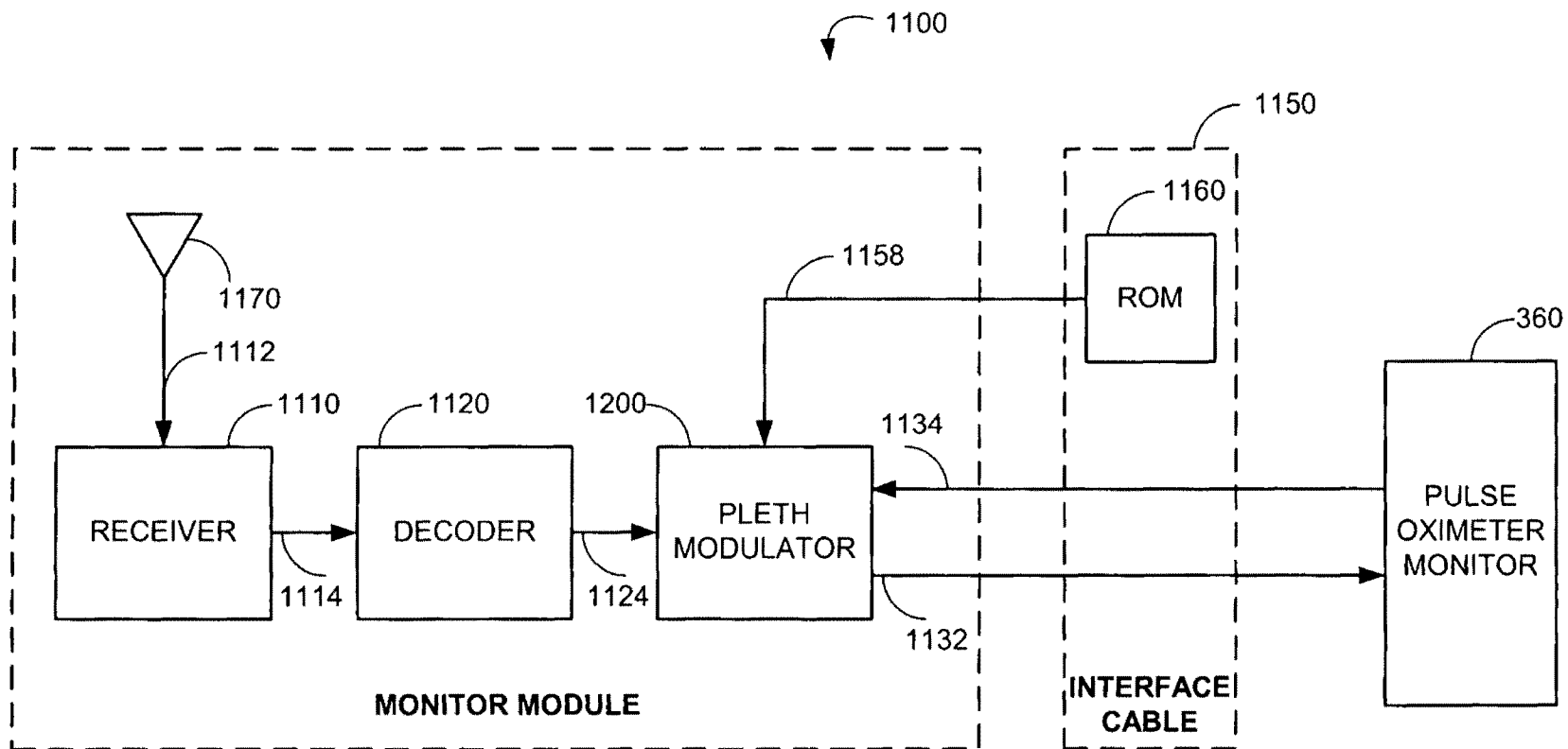


FIG. 11



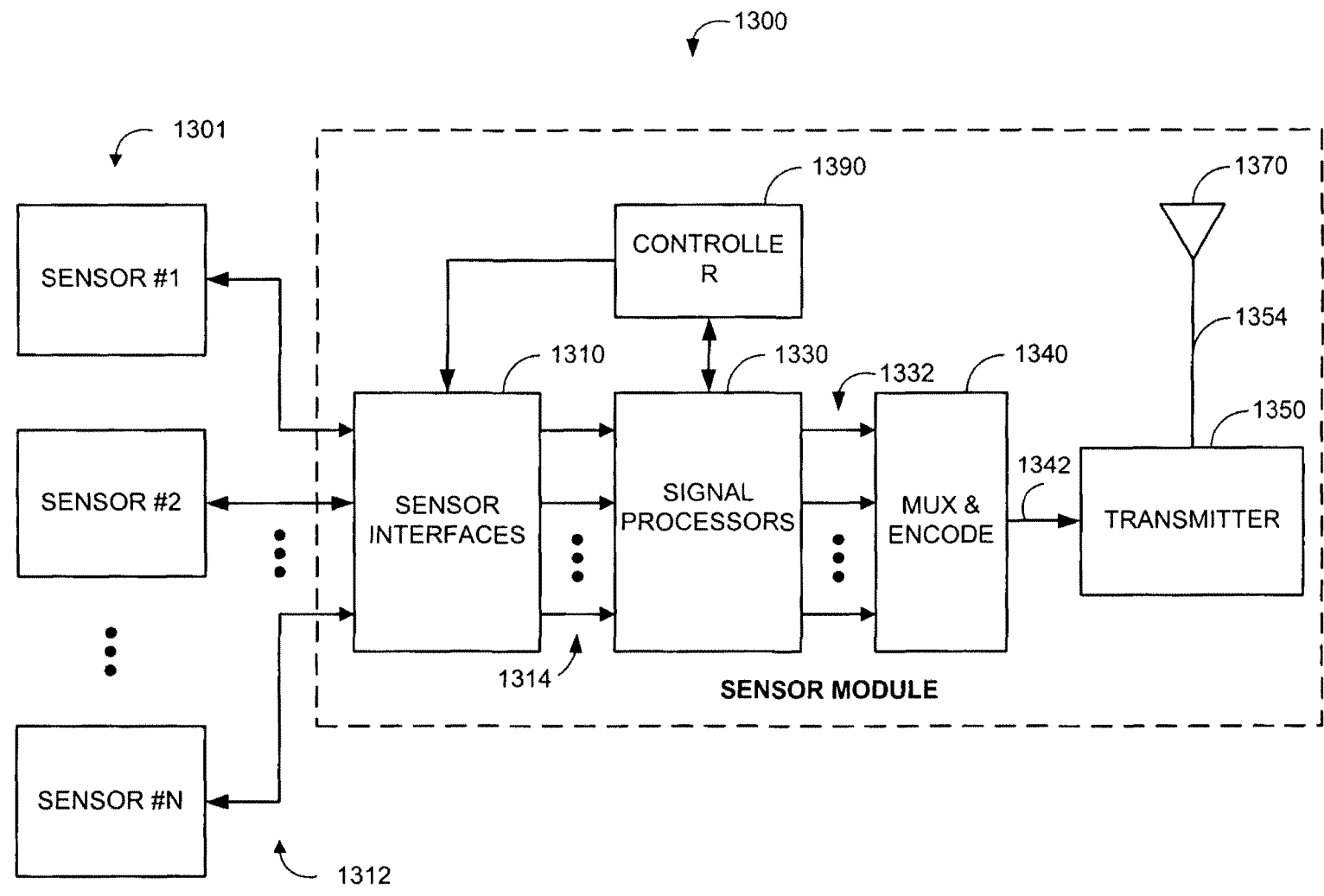


FIG. 13

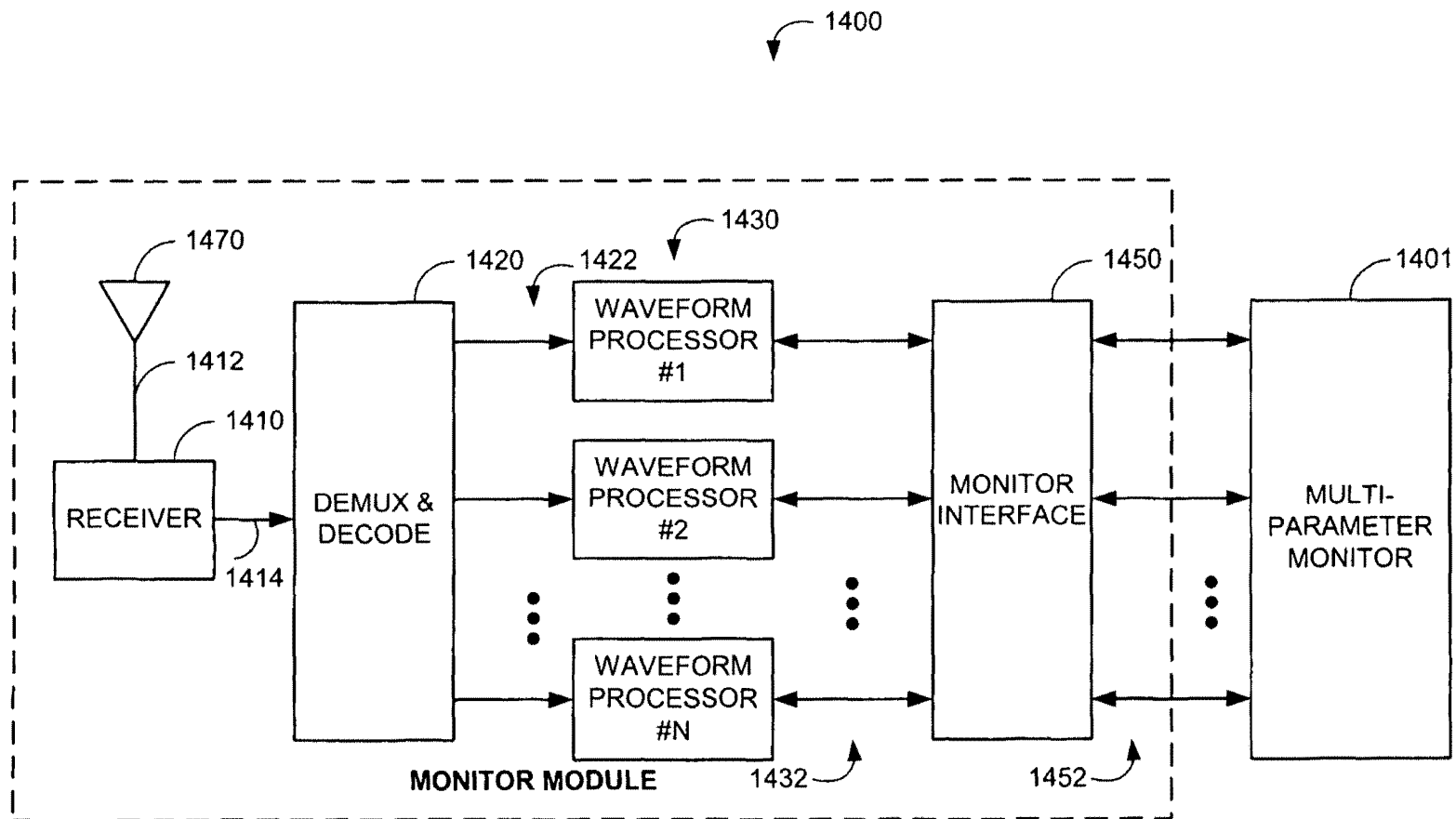


FIG. 14

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**BODY WORN MOBILE MEDICAL PATIENT  
MONITOR**

## REFERENCE TO RELATED APPLICATION

The present application is a continuation of U.S. patent application Ser. No. 15/448,989, filed on Mar. 3, 2017, entitled "Physiological Measurement Communications Adapter," which is a continuation of U.S. patent application Ser. No. 14/815,232, filed on Jul. 31, 2015, entitled "Physiological Measurement Communications Adapter," which is a continuation of U.S. patent application Ser. No. 14/217,788, filed on Mar. 18, 2014, entitled "Wrist-Mounted Physiological Measurement Device," now U.S. Pat. No. 9,113,832, which is a continuation of U.S. patent application Ser. No. 14/037,137, filed on Sep. 25, 2013, entitled "Physiological Measurement Communications Adapter," now U.S. Pat. No. 9,113,831, which is a continuation of U.S. patent application Ser. No. 12/955,826, filed on Nov. 29, 2010, entitled "Physiological Measurement Communications Adapter," now U.S. Pat. No. 8,548,548, which is a continuation of U.S. patent application Ser. No. 11/417,006, filed on May 3, 2006, entitled "Physiological Measurement Communications Adapter," now U.S. Pat. No. 7,844,315, which 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," now U.S. Pat. No. 7,844,314, which is a continuation of U.S. patent application Ser. No. 10/377,933, entitled "Physiological Measurement Communications Adapter," now U.S. Pat. No. 6,850,788, 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 requires 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

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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 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.

An aspect of a physiological measurement communications adapter comprises a sensor interface configured to receive a sensor signal. A transmitter modulates a first baseband signal responsive to the sensor signal so as to generate a transmit signal. A receiver demodulates a receive signal corresponding to the transmit signal so as to generate a second baseband signal corresponding to the first baseband signal. Further, a monitor interface is configured to communicate a waveform responsive to the second baseband signal to a sensor port of a monitor. The waveform is adapted to the monitor so that measurements derived by the monitor from the waveform are generally equivalent to measurements derivable from the sensor signal. The communications adapter may further comprise a signal processor having an input in communications with the sensor interface, where the signal processor is operable to derive a parameter responsive to the sensor signal and where the first baseband signal is responsive to the parameter. The parameter may correspond to at least one of a measured oxygen saturation and a pulse rate.

One embodiment may further comprise a waveform generator that synthesizes the waveform from a predetermined shape. The waveform generator synthesizes the waveform at a frequency adjusted to be generally equivalent to the pulse rate. The waveform may have a first amplitude and a second amplitude, and the waveform generator may be configured to adjusted the amplitudes so that measurements derived by the monitor are generally equivalent to a measured oxygen saturation.

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In another embodiment, the sensor interface is operable on the sensor signal to provide a plethysmograph signal output, where the first baseband signal is responsive to the plethysmograph signal. This embodiment may further comprise a waveform modulator that modifies a decoded signal responsive to the second baseband signal to provide the waveform. The waveform modulator may comprise a demodulator that separates a first signal and a second signal from the decoded signal, an amplifier that adjusts amplitudes of the first and second signals to generate a first adjusted signal and a second adjusted signal, and a modulator that combines the first and second adjusted signals into the waveform. The amplitudes of the first and second signals may be responsive to predetermined calibration data for the sensor and the monitor.

An aspect of a physiological measurement communications adapter method comprises the steps of inputting a sensor signal at a patient location, communicating patient data derived from the sensor signal between the patient location and a monitor location, constructing a waveform at the monitor location responsive to the sensor signal, and providing the waveform to a monitor via a sensor port. The waveform is constructed so that the monitor calculates a parameter generally equivalent to a measurement derivable from the sensor signal.

In one embodiment, the communicating step may comprise the substeps of deriving a conditioned signal from the sensor signal, calculating a parameter signal from the conditioned signal, and transmitting the parameter signal from the patient location to the monitor location. The constructing step may comprise the substep of synthesizing the waveform from the parameter signal. In an alternative embodiment, the communicating step may comprise the substeps of deriving a conditioned signal from said sensor signal and transmitting the conditioned signal from the patient location to the monitor location. The constructing step may comprise the substeps of demodulating the conditioned signal and re-modulating the conditioned signal to generate the waveform. The providing step may comprise the substeps of inputting a monitor signal from an LED drive output of the sensor port, modulating the waveform in response to the monitor signal, and outputting the waveform on a detector input of the sensor port.

Another aspect of a physiological measurement communications adapter comprises a sensor interface means for inputting a sensor signal and outputting a conditioned signal, a transmitter means for sending data responsive to the sensor signal, and a receiver means for receiving the data. The communications adapter further comprises a waveform processor means for constructing a waveform from the data so that measurements derived by a monitor from the waveform are generally equivalent to measurements derivable from the sensor signal, and a monitor interface means for communicating the waveform to a sensor port of the monitor. The communications adapter may further comprise a signal processor means for deriving a parameter signal from the conditioned signal, where the data comprises the parameter signal. The waveform processor means may comprise a means for synthesizing the waveform from the parameter signal. The data may comprise the conditioned signal, and the waveform processor means may comprise a means for modulating the conditioned signal in response to 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 EMBODIMENT

##### 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,

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below. The monitor connector 514 mimics that of the monitor end of a 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

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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. FIG. 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  $\text{SpO}_2$  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 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 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.

#### 5 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, gener-

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ating 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

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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 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 communi-

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cate 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 body worn mobile medical monitoring device configured to minimize cable wiring from a sensor by placement of one or more sensor communication ports, the mobile medical monitoring device comprising:

a housing configured to be secured on a lower arm of a patient being monitored via a strap extending around the lower arm of the patient;

a display positioned on a face of the housing, opposite the strap, so as to be visible to a user;

a first sensor communication port positioned on a side of the housing and configured to face a hand of the lower arm of the patient when the mobile medical monitoring device is mounted to the lower arm of the patient, wherein:

the side of the housing faces the hand of the lower arm of the patient of the patient when the mobile medical monitoring device is mounted to the lower arm of the patient,

the first sensor communication port is configured to provide wired communication with a pulse oximetry sensor attached to a digit of the hand of the patient, the wired communication with the pulse oximetry sensor provided at least partly in the analog domain, and

the first sensor communication port is positioned on the side of the housing such that a path from the first sensor communication port on the side of the housing to the digit of the patient is substantially perpendicular to the side of the housing and shorter than any other path from any other side of the housing to the digit of the patient;

a plurality of additional sensor communications ports positioned on the housing and configured to provide wired communication with a plurality of additional physiological sensors at least partly in the digital domain; and

one or more processors and a transmitter configured to: display, on the display, physiological measurements derived from the pulse oximetry sensor and the plurality of additional physiological sensors; and wirelessly transmit information indicative of the physiological measurements to a remote computing device.

2. The mobile medical monitoring device of claim 1, wherein the wired communication with the pulse oximetry sensor is provided via a tail extending from the pulse oximetry sensor.

3. The mobile medical monitoring device of claim 2, wherein the tail comprises a cable that is configured to be removably attachable to the first sensor communication port.

4. The mobile medical monitoring device of claim 3, wherein a length of the cable corresponds to the path from the sensor communication port on the side of the housing to the digit of the patient.

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5. The mobile medical monitoring device of claim 3, wherein the cable is appropriately sized based on the path from the sensor communication port on the side of the housing to the digit of the patient.

6. The mobile medical monitoring device of claim 3, wherein the path from the sensor communication port on the side of the housing to the digit of the patient runs at least partly along a backside of the hand of the patient.

7. The mobile medical monitoring device of claim 1, wherein the face of the housing comprises a single user interface.

8. The mobile medical monitoring device of claim 7, wherein the single user interface comprises the display.

9. The mobile medical monitoring device of claim 8, wherein:

the housing comprises a back side that is opposite the face of the housing,

the strap is mountable to the back side of the housing, and the face of the housing is raised from the strap and the lower arm of the patient to enable positioning of the first sensor communication port on the side of the housing between the lower arm of the patient and the face of the housing.

10. The mobile medical monitoring device of claim 9, wherein:

the front side of the housing comprises a bezel and the display, and

a top of the first sensor communication port is located below the face of the housing.

11. The mobile medical monitoring device of claim 10, wherein the display is positioned centrally on the face of the housing.

12. The mobile medical monitoring device of claim 11, wherein the display positioned on the face of the housing is sized such that the display covers most of a length of a shortest dimension of the face of the housing.

13. A body worn, battery-powered medical monitoring device configured to provide on-patient and remote monitoring of patient physiological parameters, the medical monitoring device comprising:

a battery configured to provide power to the medical monitoring device such that the medical monitoring device may operate without a wired power connection;

a case configured to house the battery;

a strap configured to attach the case to an arm of a patient and be mountable to the case;

a first communications port positioned on a face of a side of the case configured to be nearest to a hand of the arm of the patient when the case is mounted to the arm of the patient, the first communications port configured to removably couple with a cable of a finger- or thumb-type pulse oximetry sensor and positioned on the face of the side of the case to provide a path from the first communications port to a digit of the hand of the patient that avoids tangling of the cable, the first communications port configured such that the cable perpendicularly extends from the face of the side of the case when the cable is coupled to the first communications port;

a second communications port configured to provide wired communications with a second physiological sensor arrangement at least partly via digital communications;

a third communications port configured to provide wired communications with a third physiological sensor arrangement;

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a display configured to provide real time measurements of patient physiological parameters based at least in part on data obtained from at least the pulse oximetry sensor via the first communications port; and

a transmitter configured to wirelessly transmit information indicative of real time measurements of patient physiological parameters based at least in part on data obtained from the pulse oximetry sensor via the first communications port.

14. The medical monitoring device of claim 13, wherein the path from the first communications port to a digit of the hand is shorter than any path from any communications port located on any other side of the case to the digit of the hand.

15. The medical monitoring device of claim 13 further comprising:

one or more hardware processors configured to:

process the data obtained from the pulse oximetry sensor; and

determine, based at least in part on the data, the real time measurements of patient physiological parameters.

16. The medical monitoring device of claim 15, wherein: the one or more hardware processors are further configured to:

receive additional data from at least the second physiological sensor arrangement and the third physiological sensor arrangement;

determine, based at least in part on the additional data, real time measurements of additional patient physiological parameters; and

cause to be displayed, on the display, the real time measurements of additional patient physiological parameters; and

the transmitter is further configured to:

wirelessly transmit information indicative of real time measurements of additional patient physiological parameters based at least in part on the additional data.

17. The medical monitoring device of claim 16, wherein the display is positioned on a front, user-facing side of the case to enable a user to view the real time measurements of patient physiological parameters and the real time measurements of additional patient physiological parameters.

18. The medical monitoring device of claim 17, wherein the second physiological sensor arrangement comprises an EKG sensor arrangement and the third physiological sensor arrangement comprises a blood pressure sensor arrangement.

19. The medical monitoring device of claim 18, wherein: the first, second, and third communication ports are communicatively coupled to respective first, second, and third sensor interfaces; and

the first, second, and third sensor interfaces are uniquely configured to receive signals from the respective pulse oximetry sensor, EKG sensor arrangement, and blood pressure sensor arrangement.

20. A body worn portable patient monitoring device configured to provide on-patient and remote monitoring of patient physiological parameters, the portable patient monitoring device comprising:

a pulse oximetry sensor configured to be wrapped around a digit of a patient, the pulse oximetry sensor including at least:

a light emitter configured to emit light into a tissue site of the digit of the patient;

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a light detector configured output a first signal responsive to at least a portion of the emitted light after attenuation by tissue of the tissue site; and

a cable extending from the pulse oximetry sensor and configured to electrically convey the first signal;

a blood pressure sensor configured to output a second signal responsive to at least a blood pressure parameter of the patient;

an additional sensor arrangement configured to output a third signal responsive to at least one additional physiological parameter of the patient other than blood pressure or oxygen saturation, the at least one additional physiological parameter including at least one of: temperature or respiration rate;

a housing configured to be secured to a lower arm of the patient, the housing having a size and shape configured to be secured to the lower arm of the patient;

a strap mountable to the back side of the housing, the strap configured to secure the housing to the lower arm of the patient;

a display positioned on a front side of the housing that is opposite a back side of the housing, the display configured to show a status of the portable patient monitoring device and one or more parameter measurements so as to be viewable by a user, wherein the display is positioned centrally on the front side of the display and is sized such that the display spans most of a length of a shortest dimension of the front side of the housing, and wherein the front side of the housing comprises a single user interface and a bezel;

one or more user input mechanisms configured to control an operational mode of the portable patient monitoring device in response to inputs from a user;

a first sensor port positioned on a face of a first side of the housing, wherein:

the face of the first side of the housing is configured to face toward a hand having the digit of the patient under measurement when the housing is secured to the lower arm of the patient,

the first sensor port is configured to removably physically couple with the pulse oximetry sensor via the cable and to electrically receive the first signal from the pulse oximetry sensor,

the cable is configured to run from the first sensor port, at least part way along a path substantially perpendicular to the face of the first side of the housing, down the arm of the patient, and to the digit of the patient to which the pulse oximetry sensor is configured to be wrapped around,

the front side of the housing is raised from the strap and the lower arm of the patient to enable positioning of the first sensor port on the first side of the housing between the lower arm of the patient and the front side of the housing, and

a top of the first sensor port is located below the front of the housing;

a second sensor port positioned on the housing and configured to provide wired electrical communication with the blood pressure sensor arrangement and to electrically receive second signal from the blood pressure sensor arrangement;

a third sensor port positioned on the housing and configured to provide electrical wired communication with the additional sensor arrangement and to electrically receive the third signal from the additional sensor arrangement;

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a rechargeable battery positioned within the housing and configured to power the portable patient monitoring device such that the portable patient monitoring device is portable and wearable by the patient;

one or more signal processing arrangements positioned 5 within the housing and configured to:

receive the first signal from the pulse oximetry sensor via one or more sensor interfaces, wherein the first signal is provided at least partly as an analog signal;

process the first signal from the pulse oximetry sensor 10 to determine measurements of oxygen saturation and pulse rate;

receive the second signal from the blood pressure sensor arrangement via the one or more sensor interfaces, the second signal responsive to at least a 15 blood pressure parameter of the patient;

receive the third signal from the additional sensor arrangement via the one or more sensor interfaces, the third signal responsive to the at least one additional physiological parameter of the patient includ-

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ing at least one of: temperature or respiration rate, wherein the third signal is provided at least partly as a digital signal; and

cause the measurements of oxygen saturation, pulse rate, blood pressure, and the at least one additional physiological parameter to all be displayed on the display of the portable patient monitoring device; and

a transmitter positioned within the housing and configured to:

wirelessly transmit a transmit signal including the information indicating the measurements of oxygen saturation, pulse rate, blood pressure, and the at least one additional physiological parameter to a separate computing device configured to display, on a remote display, the measurements of oxygen saturation, pulse rate, blood pressure, and the at least one additional physiological parameter.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 9,788,735 B2  
APPLICATION NO. : 15/499619  
DATED : October 17, 2017  
INVENTOR(S) : Ammar Al-Ali

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page

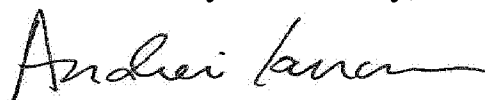
In Column 2 (page 11, item (56)) at Line 33, Under Other Publications, change “/2012/” to --/2014/--.

In Column 2 (page 11, item (56)) at Line 33, Under Other Publications, change “-me-” to -- -be- --.

In the Claims

In Column 13 at Line 29, In Claim 1, change “of the patient of the patient” to --of the patient--.

Signed and Sealed this  
Twentieth Day of February, 2018



Andrei Iancu  
*Director of the United States Patent and Trademark Office*