US009192351B1

(12) United States Patent
Telfort et al.

(10) Patent No.: US 9,192,351 B1
(45) Date of Patent: Nov. 24, 2015

(54) **ACOUSTIC RESPIRATORY MONITORING SENSOR WITH PROBE-OFF DETECTION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 290 days.

(21) Appl. No.: **13/554,929**

(22) Filed: **Jul. 20, 2012**

Related U.S. Application Data

(60) Provisional application No. 61/510,926, filed on Jul. 22, 2011.

(51) **Int. Cl.**
A61B 7/00 (2006.01)
A61B 7/04 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC . ***A61B 7/003*** (2013.01); ***A61B 7/04*** (2013.01); *A61B 5/0006* (2013.01); *A61B 5/0205* (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC A61B 7/003; A61B 7/04; A61B 5/0006; A61B 5/02438; A61B 5/02444; A61B 5/08; A61B 5/0816; A61B 5/145; A61B 5/4818; A61B 5/6822; A61B 5/6833; A61B 5/721; A61B 5/6843; A61B 5/7203; A61B 2560/0412; A61B 2562/0204; A61B 2562/182; A61B 2562/227; A61B 5/0205; Y10T 29/49005; H04R 1/46
USPC .... 600/586, 301; 381/67, 150; 342/451, 342/463; 257/254, 416; 310/313 R, 322, 310/334; 340/856.4, 575
See application file for complete search history.

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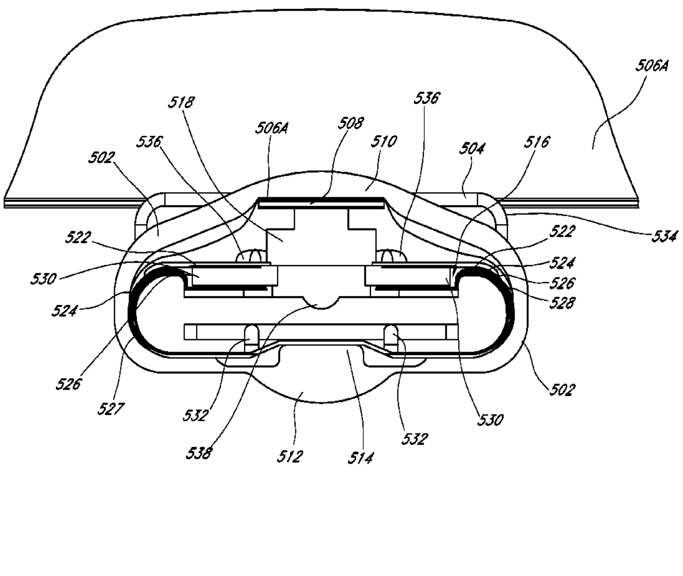
(57) **ABSTRACT**

An acoustic sensor configured to non-invasively detect acoustic vibrations associated with a medical patient. The acoustic vibrations are indicative of one or more physiological parameters of the medical patient. The acoustic sensor can include a sensor support and at least one sound sensing membrane supported by the sensor support. The membrane can be configured to detect acoustic vibrations associated with a medical patient. The membrane may also be configured to produce a membrane signal corresponding to the acoustic vibrations when the acoustic sensor is attached to the medical patient. The acoustic sensor can also include a probe-off assembly supported by the sensor support. The probe-off assembly can be configured to produce a probe-off signal responsive to attachment of the acoustic sensor to the medical patient and detachment of the acoustic sensor from the medical patient.

27 Claims, 14 Drawing Sheets



(51) **Int. Cl.**

A61B 5/08	(2006.01)
A61B 5/00	(2006.01)
A61B 5/024	(2006.01)
A61B 5/0205	(2006.01)
A61B 5/145	(2006.01)
H04R 1/46	(2006.01)

(52) **U.S. Cl.**

CPC *A61B 5/02438* (2013.01); *A61B 5/02444* (2013.01); *A61B 5/08* (2013.01); *A61B 5/0816* (2013.01); *A61B 5/145* (2013.01); *A61B 5/4818* (2013.01); *A61B 5/6822* (2013.01); *A61B 5/6833* (2013.01); *A61B 5/6843* (2013.01); *A61B 5/721* (2013.01); *A61B 5/7203* (2013.01); *A61B 2560/0412* (2013.01); *A61B 2562/0204* (2013.01); *A61B 2562/182* (2013.01); *A61B 2562/227* (2013.01); *H04R 1/46* (2013.01); *Y10T 29/49005* (2015.01)

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WO	WO 2008/148172		12/2008
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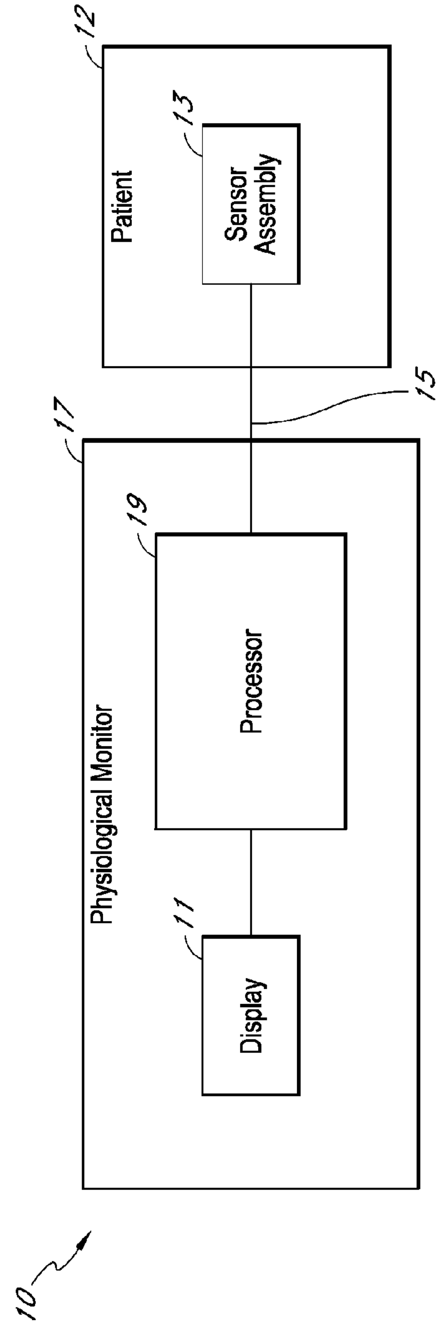

10
17
Physiological Monitor
Display
11
Processor
19
15
Patient
12
Sensor Assembly
13

FIG. 1A

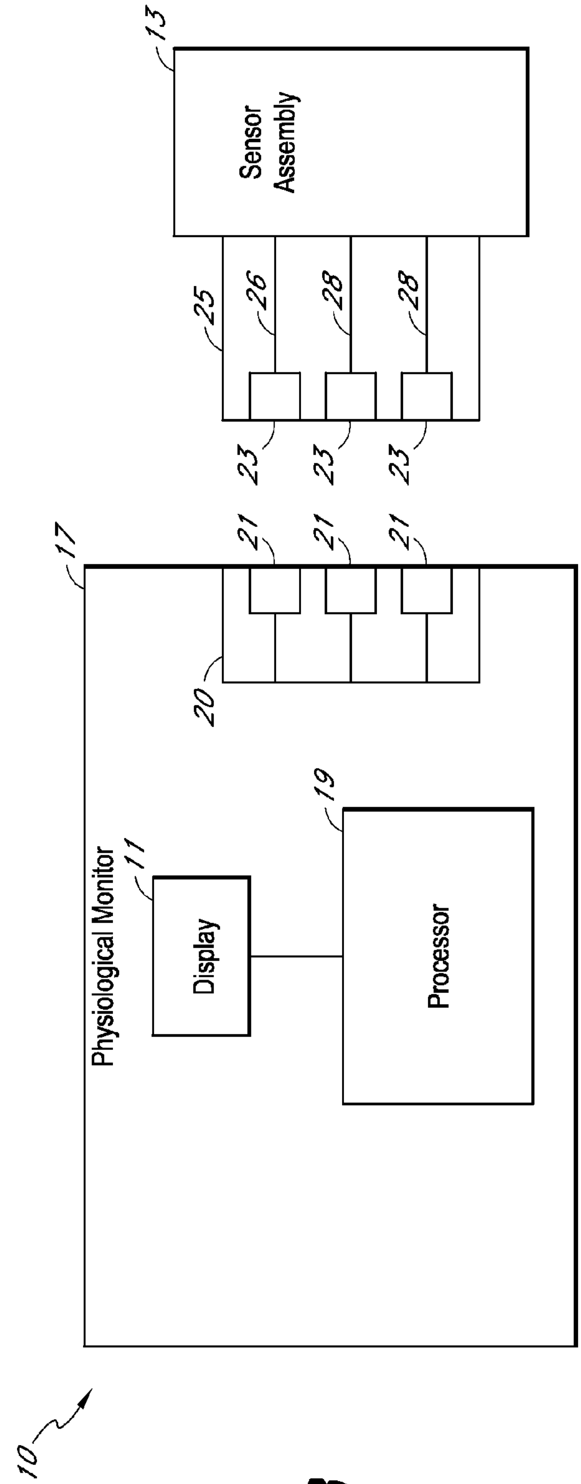
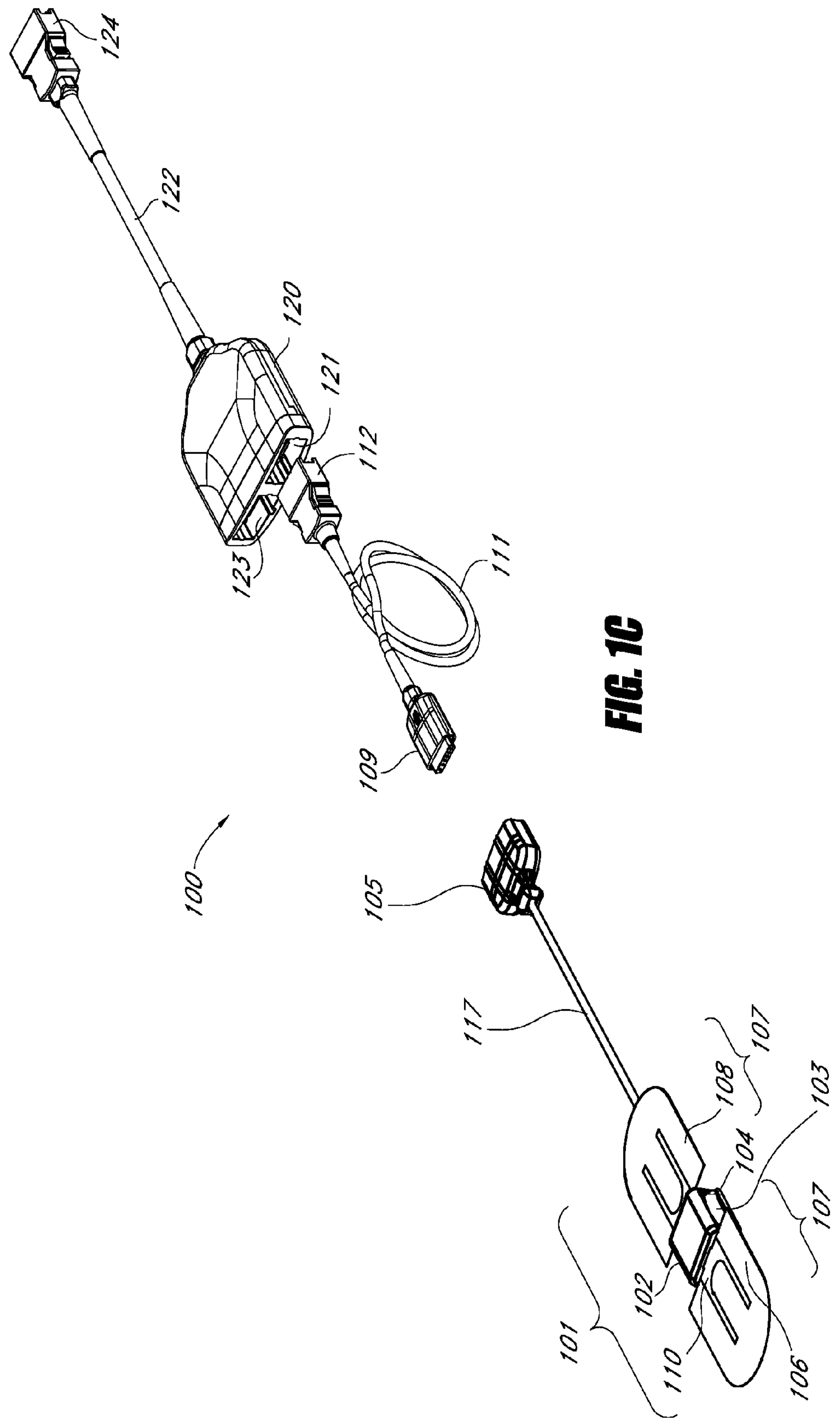

10
17
Physiological Monitor
Display
11
Processor
19
20
21
21
21
23
23
23
25
26
28
28
Sensor Assembly
13

FIG. 1B


124
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120
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112
123
111
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100
105
117
107
108
103
104
107
101
102
110
106

FIG. 1C

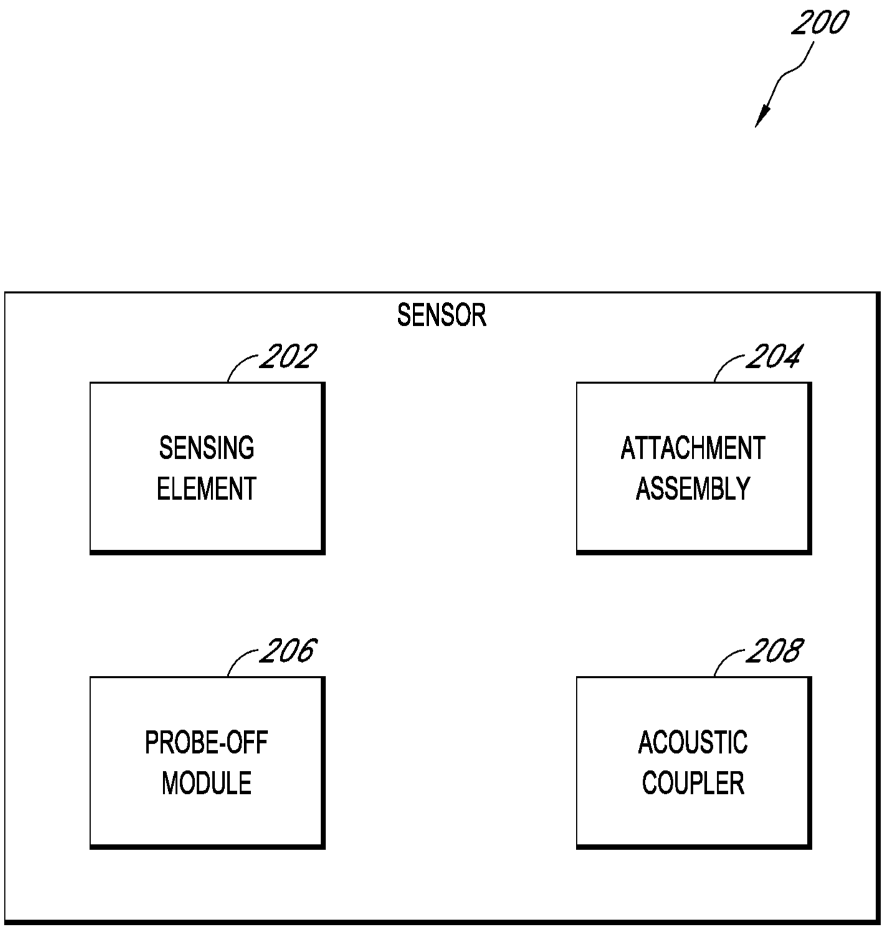

200
SENSOR
202
SENSING ELEMENT
204
ATTACHMENT ASSEMBLY
206
PROBE-OFF MODULE
208
ACOUSTIC COUPLER

FIG. 2

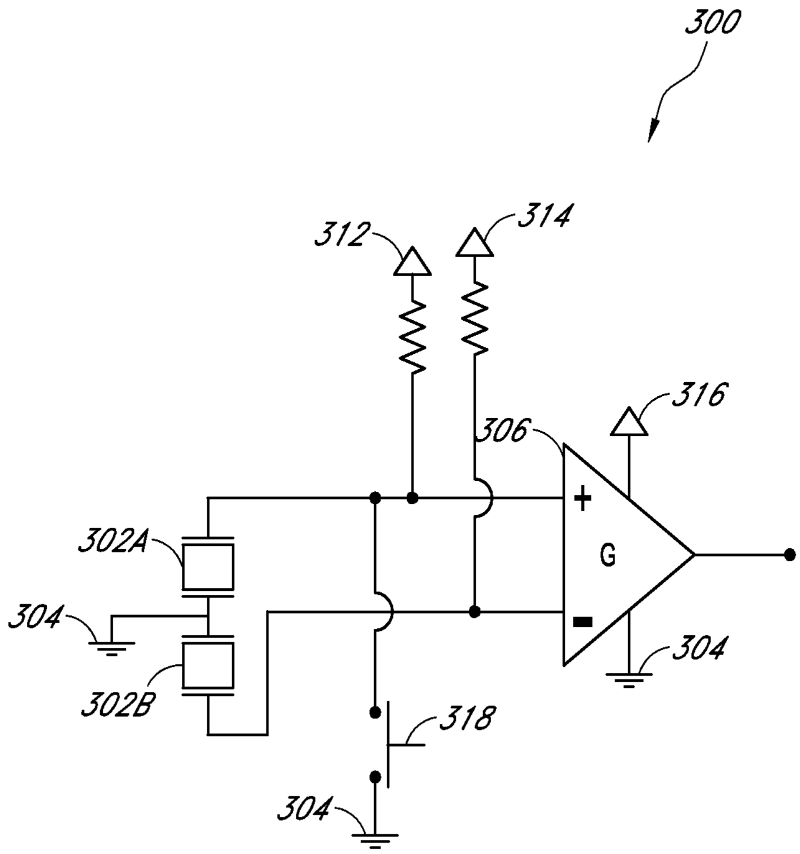


FIG. 3

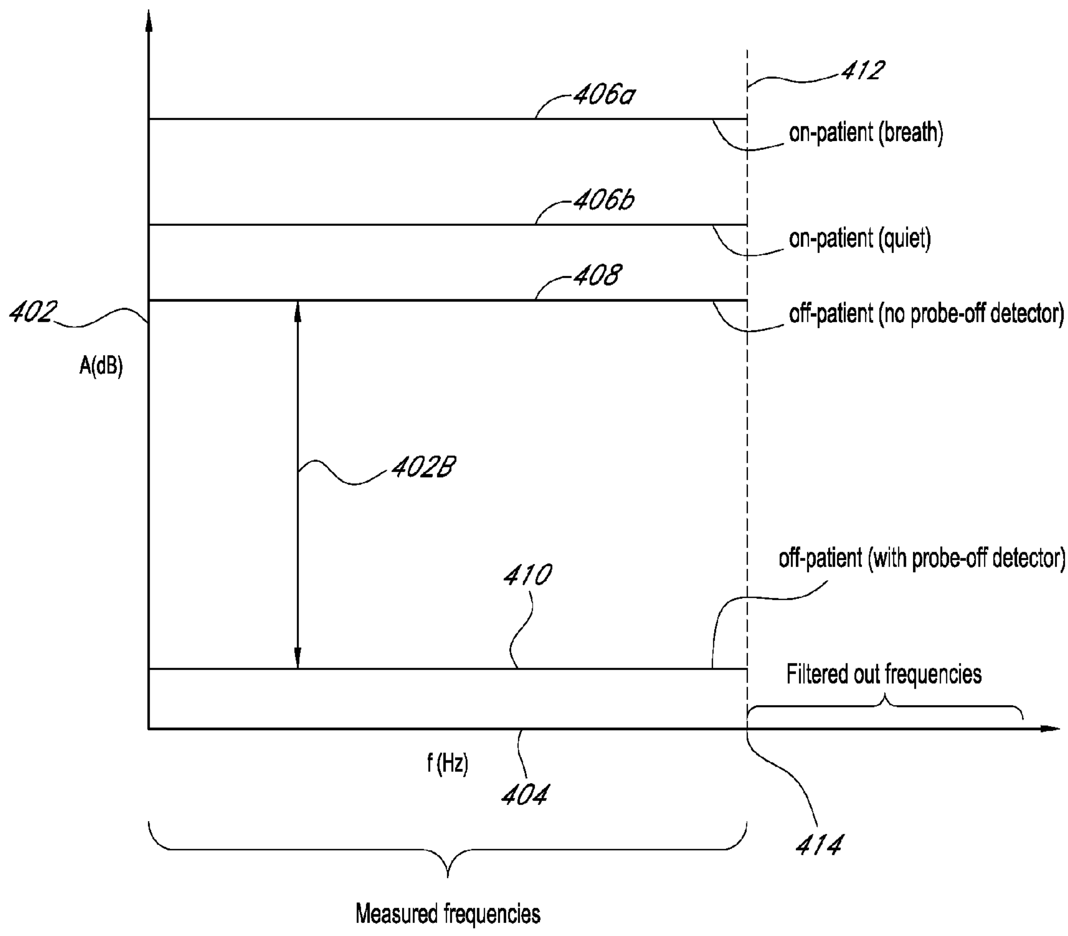

406a
406b
408
412
on-patient (breath)
on-patient (quiet)
off-patient (no probe-off detector)
402
A(dB)
402B
410
off-patient (with probe-off detector)
Filtered out frequencies
f (Hz)
404
414
Measured frequencies

FIG. 4

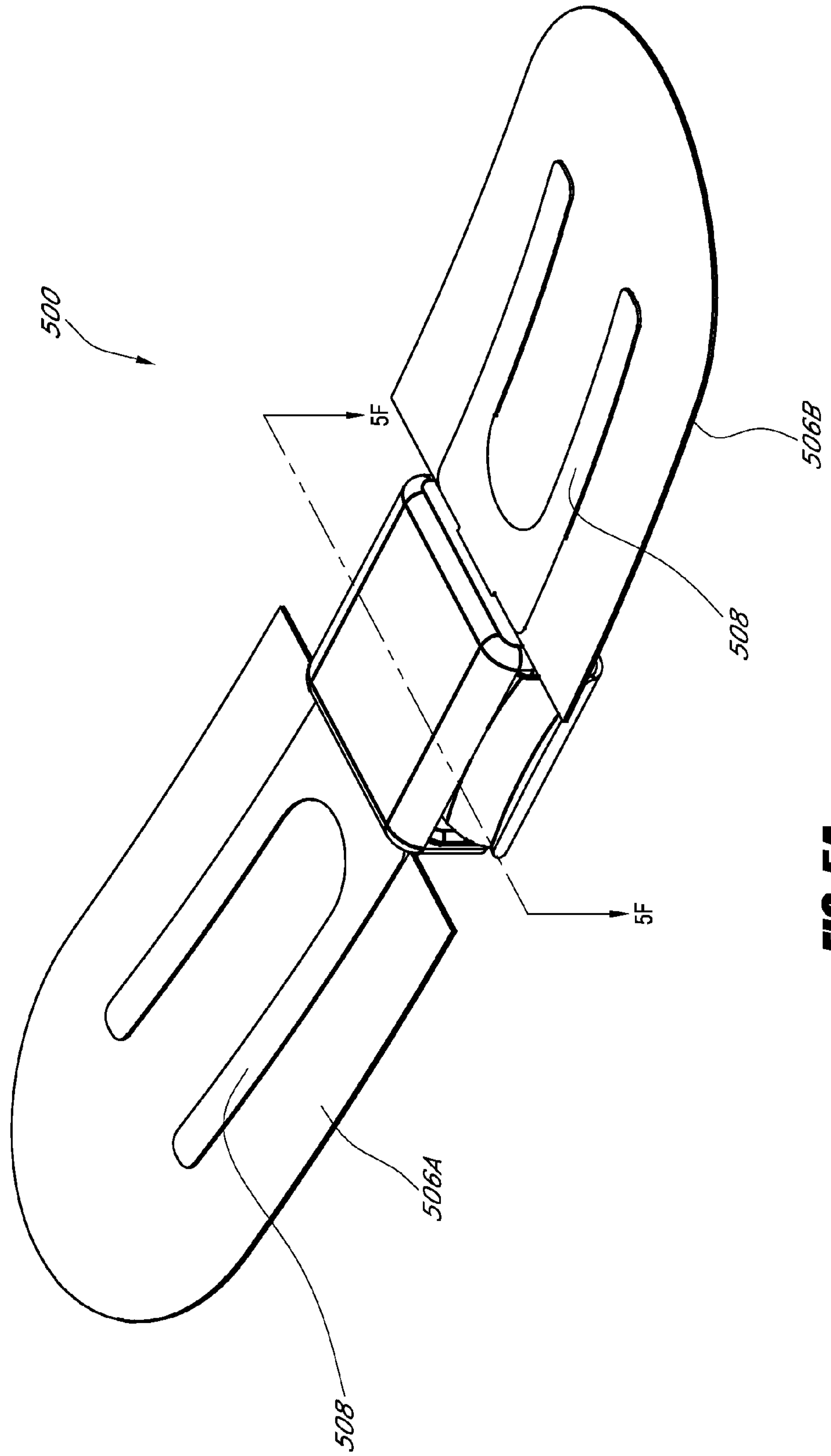
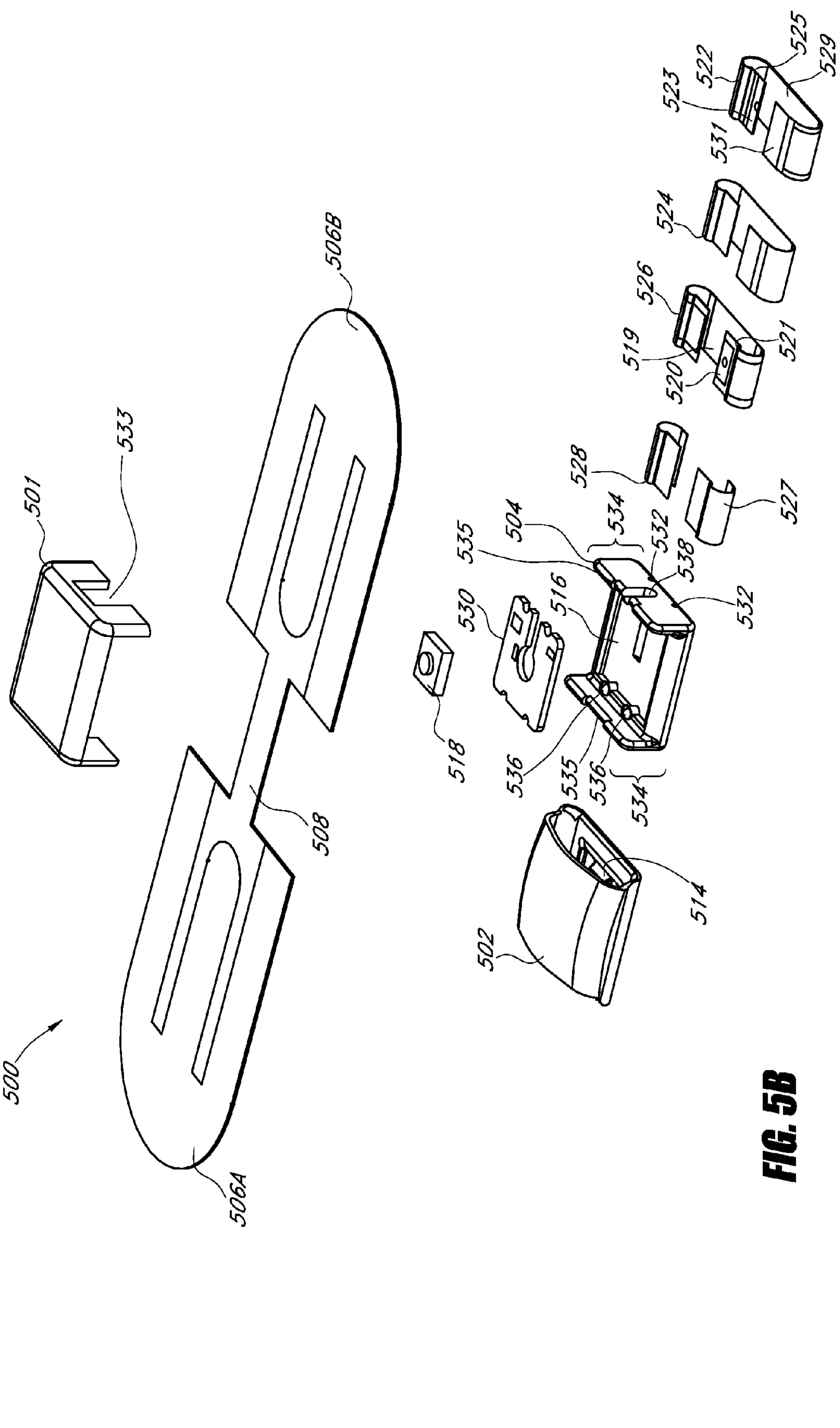


FIG. 5A


500
501
533
506A
506B
508
502
514
518
530
516
504
535
534
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538
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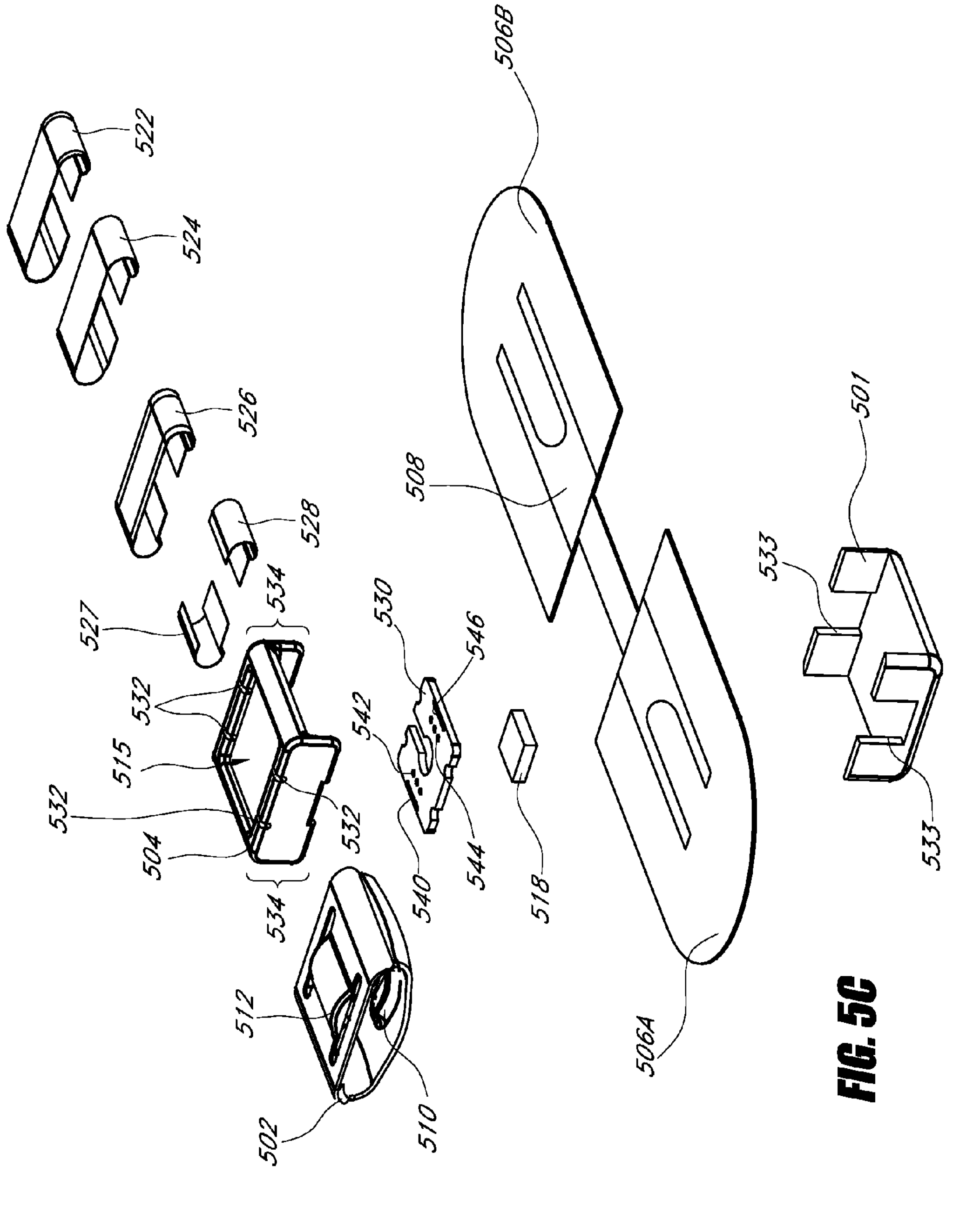
528
519
520
521
526
524
523
522
525
529
531

FIG. 5B


506B
522
524
526
508
528
527
534
530
546
501
533
532
542
515
532
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504
532
534
540
544
518
512
510
502
506A
533

FIG. 5C

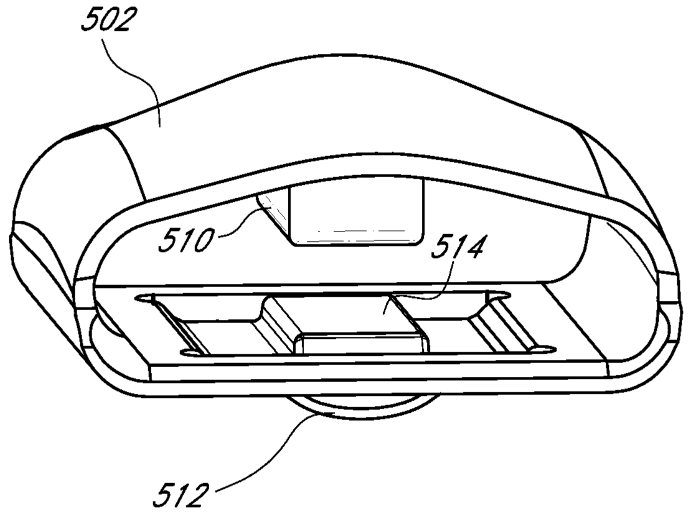
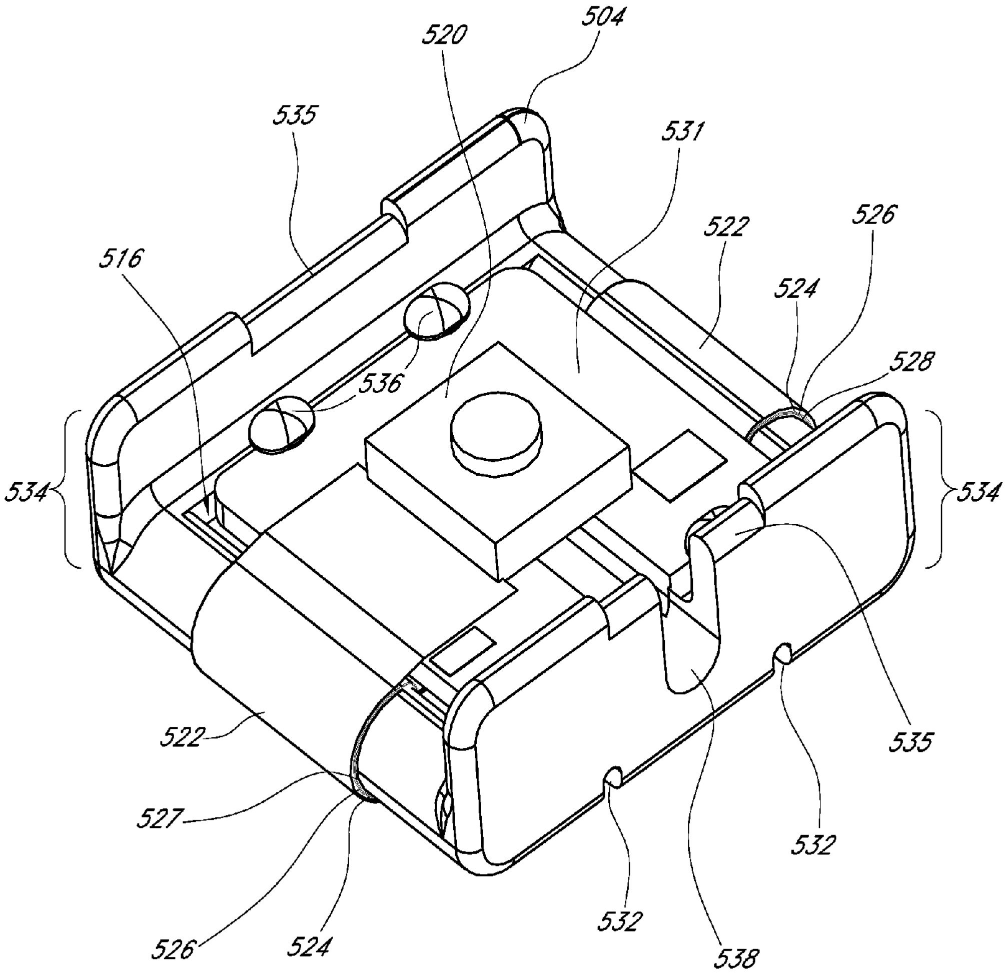


FIG. 5D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531
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524
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536
534
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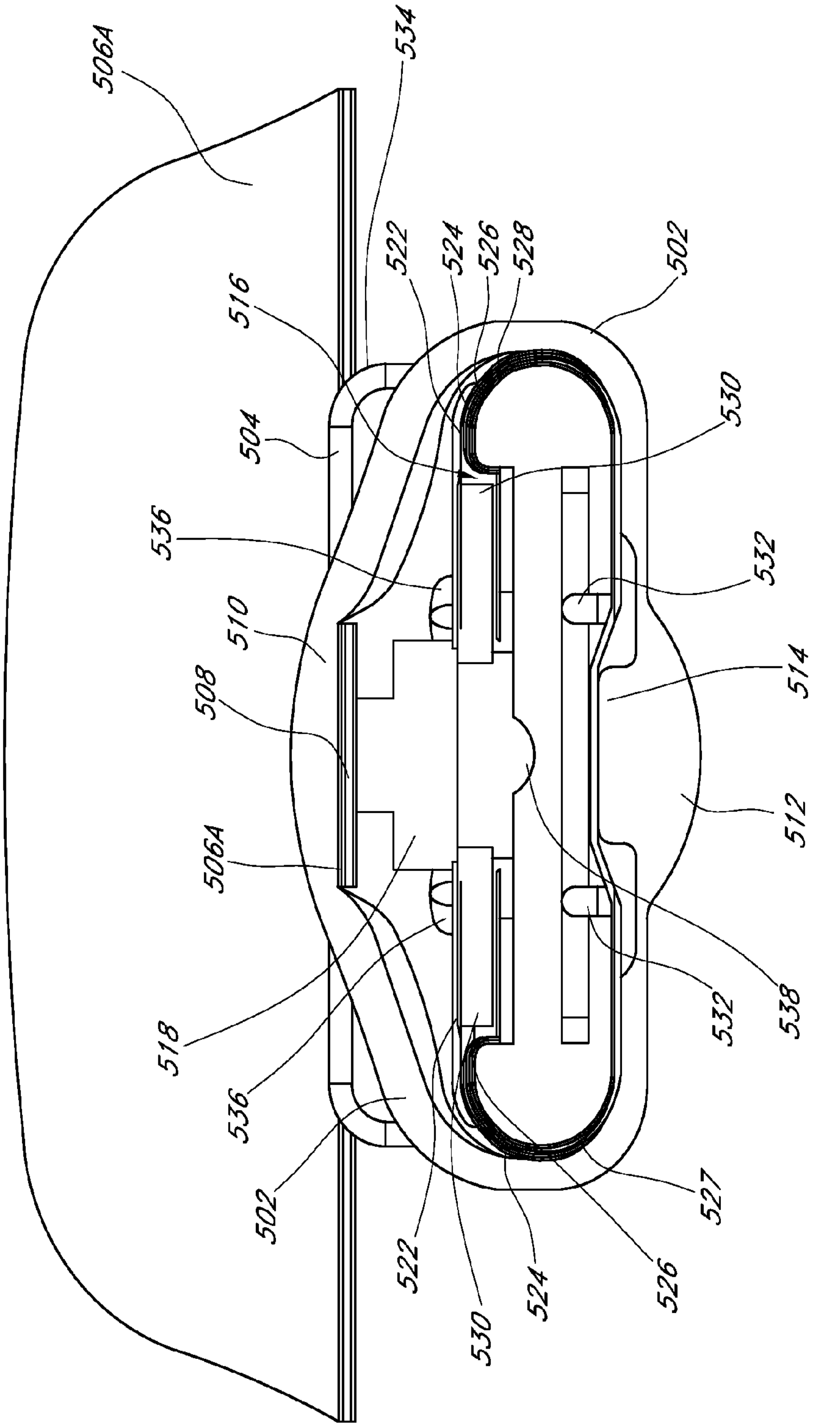
535
522
532
527
526
524
532
538

FIG. 5E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526
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502
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504
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536
532
510
514
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512
506A
538
518
532
536
502
527
522
524
526
530

FIG. 5F

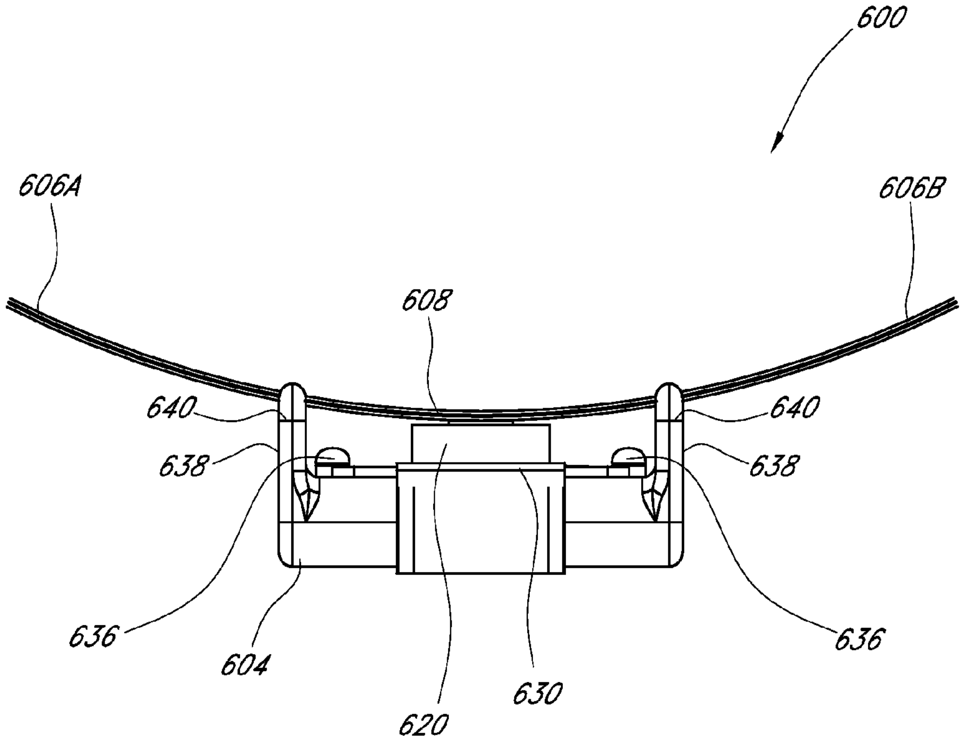
600
606A
606B
608
640
640
638
638
636
604
620
630
636

FIG. 6A

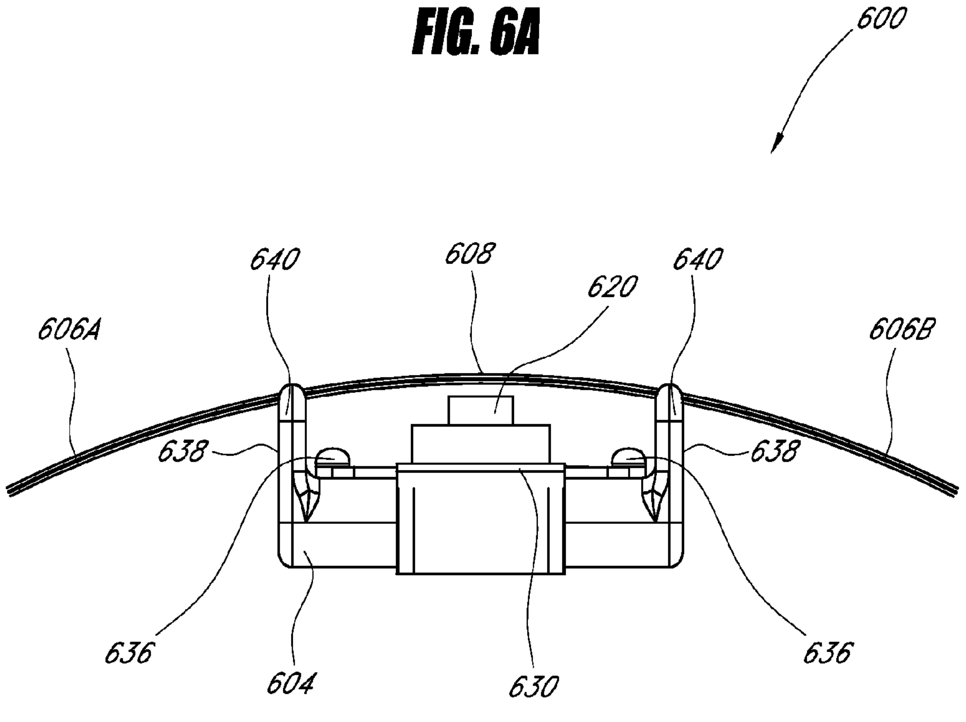
600
640
608
620
640
606A
606B
638
638
636
604
630
636

FIG. 6B

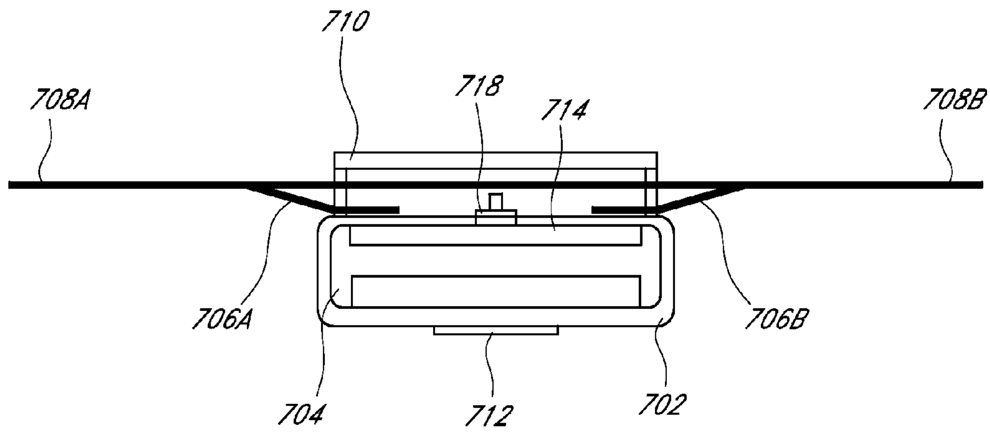
710
718
714
708A
708B
706A
706B
704
712
702

FIG. 7A

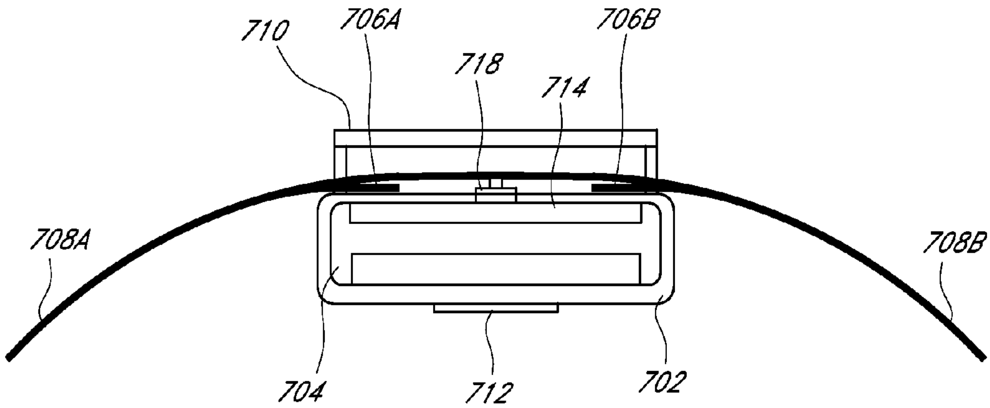
710
706A
706B
718
714
708A
708B
704
712
702

FIG. 7B

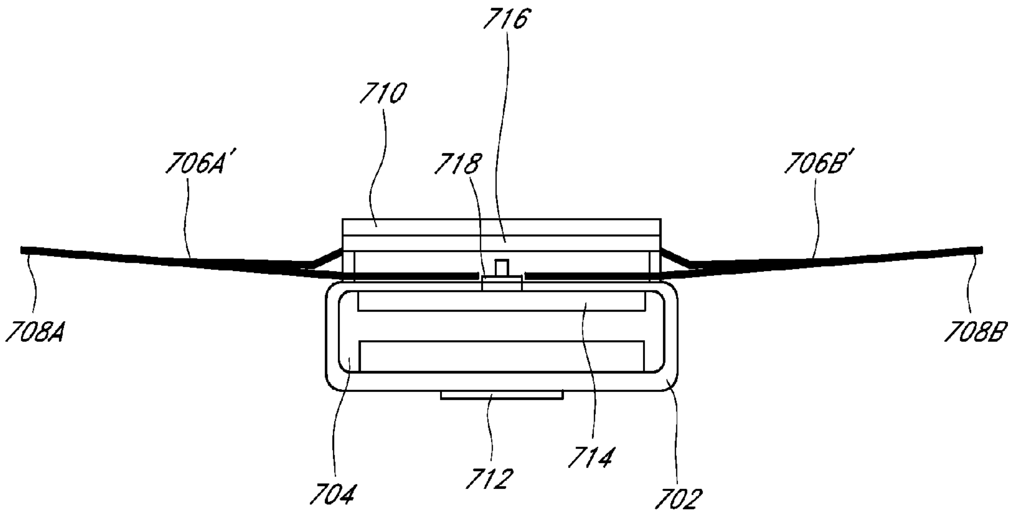
716
710
706A'
718
706B'
708A
708B
704
712
714
702

FIG. 8A

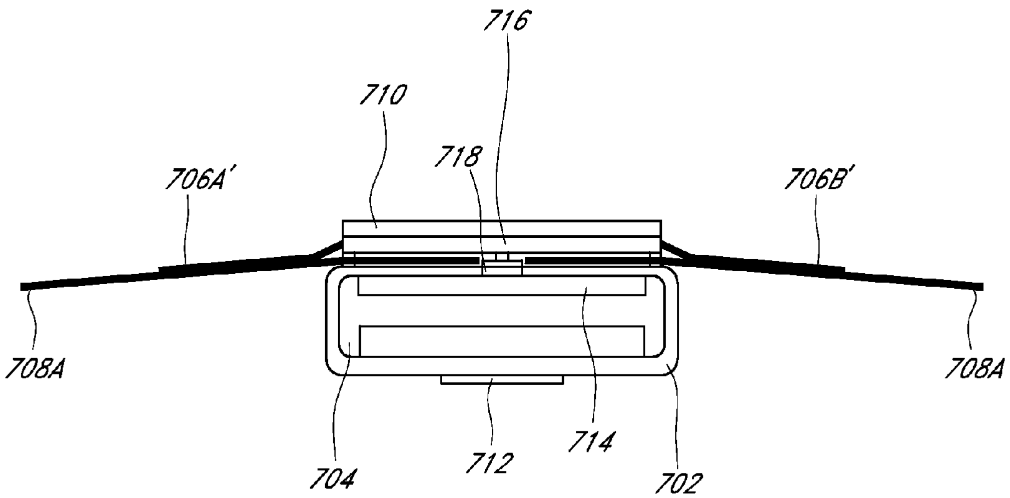
716
710
718
706A'
706B'
708A
708A
704
712
714
702

FIG. 8B

ACOUSTIC RESPIRATORY MONITORING SENSOR WITH PROBE-OFF DETECTION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priority from U.S. Provisional Application No. 61/510,926, filed Jul. 22, 2011, which is incorporated in its entirety by reference herein.

BACKGROUND

Certain existing patient monitoring systems include biological sound sensors that capture patient bodily sounds (e.g., heart, breathing, digestive system sounds, etc.) and physiological monitors which process the captured sounds to determine physiological parameters. Such systems generally rely on a robust connection between the sensor and the patient to reliably detect and process the targeted bodily sounds. As such, a faulty or unstable connection between the sensor and the patient (e.g., a "probe-off" condition) can lead to a number of problems, particularly where the patient monitor or medical personnel are not made aware of the issue.

When the physiological monitor is not aware of a faulty connection between the sensor and patient, the monitor may misinterpret readings detected by the sensor. For example, the monitor may indicate false alarm conditions. In one instance, where the system is configured to detect patient breathing sounds and determine a corresponding respiratory rate, the monitor may falsely determine that the patient is not breathing, instead of merely indicating that the sensor has detached from the patient's skin. The system may additionally detect significant amounts of environmental noise due to a probe-off condition, and then improperly present the detected noise as physiological signal. Moreover, medical personnel may similarly misinterpret results presented by the monitor when the personnel are not aware of a faulty connection, possibly leading to misdiagnoses or other issues.

For these and other reasons, there is a need for an acoustic physiological sensor having reliable and straightforward probe-off detection capability.

SUMMARY

Embodiments of systems including an acoustic sensor and/or physiological monitor described herein are configured to provide accurate and robust measurement of bodily sounds under a variety of conditions, such as in noisy environments or in situations in which stress, strain, or movement can be imparted onto the sensor with respect to a patient. For example, in certain embodiments the sensor and/or monitor include probe-off detection capability that indicates the connection quality between the sensor and patient.

For purposes of summarizing the disclosure, certain aspects, advantages and novel features of the inventions have been described herein. It is to be understood that not necessarily all such advantages can be achieved in accordance with any particular embodiment of the inventions disclosed herein. Thus, the inventions disclosed herein can be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught or suggested herein without necessarily achieving others.

An acoustic sensor is provided that is configured to non-invasively detect acoustic vibrations associated with a medical patient. The acoustic vibrations are indicative of one or more physiological parameters of the medical patient. According to various aspects, the sensor can include a sensor

support and at least one sound sensing membrane supported by the sensor support and configured to detect acoustic vibrations associated with a medical patient. The sensing membrane may also be configured to produce a membrane signal corresponding to the acoustic vibrations when the acoustic sensor is attached to the medical patient. The sensor can also include a probe-off assembly supported by the sensor support, where the probe off-assembly is configured to produce a probe-off signal responsive to attachment of the acoustic sensor to the medical patient and detachment of the acoustic sensor from the medical patient.

The probe-off signal may indicate a sensor connected condition when the sensor is attached to the patient and a sensor not connected condition when the sensor is not attached to the patient. The probe-off signal can also be indicative of the integrity of a connection between the acoustic sensor and the patient. In certain instances, the probe-off assembly has a switch configured to actuate in response to attachment of the sensor to the patient. The actuation of the switch can result in a corresponding change in the output of the probe-off assembly that is indicative of a probe-off condition. In certain embodiments, the probe-off assembly is positioned to actuate in response to a force that is in the direction of the patient's skin when the sensor is attached to the patient.

According to some aspects, a mechanically active portion of the at least one sound sensing membrane which moves in response to the acoustic vibrations is between the patient's skin and the probe-off assembly when the sensor is attached to the patient. Moreover, in some cases, at least a portion of the sensor support is between a patient contact surface of the sensor and the probe-off assembly.

The acoustic sensor may further include at least one attachment member supported by the sensor support and configured to move from a first position when not attached to the patient to a second position when attached to the medical patient. Moreover, the probe-off signal is responsive to the movement of the attachment member between the first position and the second position to indicate a change in the integrity of the connection between the acoustic sensor and the medical patient. In such cases, the probe-off assembly can further include a switch supported by the sensor support. Movement of the at least one attachment member from the first position to the second position may actuate the switch. The sensor can include a substantially rigid shell supported by the sensor support, where at least a portion of the shell is positioned over the switch.

The attachment member can include a resilient, elongate member, and in some cases the attachment member extends across the sensor support and beyond opposing sides of the sensor support. The attachment member may further include an adhesive adapted to secure the attachment member to the medical patient's skin.

The sensor may further include a resilient portion supported by the sensor support and arranged to bias the attachment member in the first position when the sensor is in an unattached state. The resilient portion can form a part of a casing stretched around and encasing at least a portion of the sensor support.

In some embodiments, a physiological monitor in communication with the acoustic sensor is responsive to the probe-off signal to determine either a sensor connected condition or a sensor not connected condition. The acoustic sensor can include an output that is responsive to both the membrane signal and to the probe-off signal. A sensing circuit responsive to the output may produce a sensor signal which is both indicative of the integrity of the connection between the acoustic sensor and the patient and which, when the acoustic sensor is attached to the medical patient, corresponds to the acoustic vibrations detected by the sensing membrane. In some cases, the sensing circuit is located on a cable positioned between the acoustic sensor and the physiological monitor. The cable may be configured to communicatively couple the acoustic sensor and the physiological monitor.

A method is also provided for determining a connection state between a non-invasive acoustic sensor and a medical patient. The method can include outputting from a non-invasive acoustic sensor, a signal indicating that the acoustic sensor is in an unattached state in response to at least one attachment member of the sensor being in a first position, the sensor configured to detect acoustic vibrations indicative of one or more physiological parameters of the medical patient. The method can further include outputting a signal from the sensor indicating that the acoustic sensor is in an attached state in response to the at least one attachment member moving from the first position to a second position. In some embodiments, the method includes outputting a signal from the sensor indicative of the one or more physiological parameters when the sensor is in the attached state.

According to additional aspects, a patient monitoring system is also provided that is configured to communicate with a non-invasive acoustic sensor. The monitoring system can include a communication port configured to receive at least one signal responsive to at least one output of a non-invasive acoustic sensor. The acoustic sensor may be configured to detect acoustic vibrations associated with a medical patient and include a probe-off assembly responsive to attachment and detachment of the acoustic sensor to and from a surface. The at least one output of the acoustic sensor can be responsive to the probe-off assembly and to the acoustic vibrations. The monitoring system can further include a processor communicatively coupled to the communication port and configured to, in response to the signal, determine whether the sensor is in an unattached state.

BRIEF DESCRIPTION OF THE DRAWINGS

Throughout the drawings, reference numbers can be re-used to indicate correspondence between referenced elements. The drawings are provided to illustrate embodiments of the inventions described herein and not to limit the scope thereof.

FIGS. **1**A-B are block diagrams illustrating physiological monitoring systems in accordance with embodiments of the disclosure.

FIG. **1**C is a top perspective view illustrating portions of a sensor system in accordance with an embodiment of the disclosure.

FIG. **2** is a block diagram illustrating a sensor incorporating probe-off componentry in accordance with an embodiment of the disclosure.

FIG. **3** is a schematic illustration of an embodiment of acoustic physiological sensing circuitry with a probe-off detection circuit.

FIG. **4** is a graphical illustration of the output of acoustic physiological sensing circuitry having a probe-off circuit detection circuit in accordance with certain embodiments as compared to the output of sensing circuitry not having a probe-off detection circuit.

FIG. **5**A is a top perspective view illustrating an embodiment of a sensor incorporating probe-off componentry in accordance with embodiments described herein.

FIGS. **5**B-**5**C are top and bottom exploded perspective views, respectively, of the sensor of FIG. **5**A.

FIG. **5**D is a side perspective view illustrating the acoustic coupler of the sensor of FIGS. **5**A-**5**C.

FIG. **5**E is a side perspective view illustrating the sensor of FIGS. **5**A-**5**C with the acoustic coupler and backbone removed.

FIG. **5**F is a partial cross-sectional view illustrating the sensor of FIGS. **5**A-**5**C along the dotted line shown in FIG. **5**A.

FIG. **6**A is a side perspective view illustrating an embodiment of a sensor in a sensor-off configuration.

FIG. **6**B is a side perspective view illustrating an embodiment of a sensor in a sensor-on configuration.

FIGS. **7**A-**7**B and **8**A-**8**B illustrate side perspective views of additional embodiments of sensors including probe-off componentry.

DETAILED DESCRIPTION

Various embodiments will be described hereinafter with reference to the accompanying drawings. These embodiments are illustrated and described by example only, and are not intended to be limiting.

Probe-Off Overview

Embodiments described herein include sensors and sensor systems having probe-off detection componentry. For example, sensors and physiological monitors described herein include dedicated mechanical components and/or circuitry capable of providing an indication of the integrity of the connection between the sensor and the patient.

Where an acoustic sensor does not incorporate separate probe-off functionality, physiological monitors can in some cases nonetheless be configured to process signals received from the sensor to determine the connection state. However, in such cases, it can be difficult to provide a reliable determination. For example, the sensor may detect significant environmental noise when it is not connected to the patient. The environmental noise may closely resemble target bodily sounds, or may otherwise not be sufficiently different from the bodily sounds for the monitor to determine the connection state to a desirable degree of certainty. Thus, from physiological signals (such as acoustic readings) alone, it can be difficult to determine a connection state. Moreover, to the extent that monitors can determine the connection state in such cases, monitors may employ relatively complex signal processing algorithms to make the determination.

To address these and other potential issues, certain sensors described herein advantageously include dedicated componentry to provide reliable and cost-effective probe-off detection. As a few examples, the sensor may provide the monitor with a signal usable to determine the connection state, the sensor may directly provide the monitor with an indication of the connection state, or the sensor may provide an indication of the connection state directly to medical personnel.

Moreover, some of the probe-off techniques described herein advantageously incorporate or cooperate with portions of the sensor that also serve other, non-probe functions. For example, sensors can include attachment arms or other mechanisms that have adhesive surfaces, allowing a user to affix the sensor to the patient. The state of the attachment element is naturally indicative of whether or not the sensor is attached to the patient. Thus, utilizing the attachment mechanism with probe-off detection helps provide robust and straightforward probe-off capability. In some cases, the probe-off componentry responds to actuation of such attachment mechanisms. For example, movement of the attachment elements to affix the sensor to the patient may trigger a probe-off detection switch. The switch in turn outputs a signal usable by the monitor to determine whether or not the sensor is connected to the patient. In some cases, the resilient nature of an elastomeric casing is used in the probe-off detection. For example, the casing or a portion thereof cooperates with the probe-off componentry (e.g., a switch) and/or sensor attachment elements to provide probe-off reliable detection. Such techniques are described in greater detail below with respect to specific embodiments.

Moreover, according to certain aspects, the probe-off componentry can be positioned on the sensor to provide improved accuracy and reliability in probe-off detection and/or physiological measurement. In one case, the sensor includes an active portion, which includes a piezoelectric membrane and a patient contact surface. The active portion is generally designed to interact with the patient and move in response to bodily sounds. A switch of a probe-off assembly may be advantageously spaced from the active portion of the sensor, thereby preventing the switch from interfering with the operation of the active portion. Such an arrangement can also prevent the switch from becoming soiled or otherwise damaged, from interaction with the patient's skin for example.

The probe-off techniques described herein can be used in a variety of ways to improve patient monitoring. For example, the patient monitor can provide medical personnel with an indication of the quality of the attachment state of the sensor, such as "sensor connected," "sensor disconnected," "sensor improperly connected," an indication (e.g., a percentage or other alphanumeric indication) as to the degree of the connection quality, or some other indication of the connection quality. Additionally, by alerting the monitor and/or medical personnel to probe-off conditions, the probe-off componentry described herein reduces the risk that targeted physiological sounds will go un-monitored for extended periods of time.

Moreover, the sensor, monitor, and/or user may use the indication of the attachment state to avoid false positive (e.g., alarm) conditions. For example, where a system is monitoring patient breathing sounds and the sensor becomes disconnected, the monitor can use the probe-off functionality to avoid reporting a false alarm to medical personnel that the patient is not breathing. Instead, the monitor can report the probe-off and/or false alarm condition to personnel, who will in turn fix the faulty connection. A wide variety of other uses or combinations of the uses described herein are possible. For example, in one embodiment, the sensor or monitor stops detecting and/or reporting sound information when the sensor is not properly attached to a patient. Moreover, by alerting medical personnel to probe-off conditions, the probe-off module reduces the risk that the targeted physiological sounds will go un-monitored for extended periods of time.

While described with respect to acoustic sensors configured to detect physiological sounds of a patient, many of the techniques described herein are compatible with other types of patient sensors (e.g., pulse oximetry sensors, capnography sensors, and the like). Additionally, the term "probe-off" is not to be interpreted as limiting. Rather, the meaning of the term "probe-off" as used herein will be appreciated in view of its usage throughout the disclosure, and is often used, for example, to refer generally to the components and processes capable of determining an integrity of the connection between the sensor and the patient.

A contextual system overview is provided below with respect to FIGS. **1**A-**1**C, and further embodiments incorporating probe-off functionality are then shown and described herein with respect to FIGS. **2**-**7**B.

System Overview

In various embodiments, an acoustic sensor configured to operate with a physiological monitoring system includes an acoustic signal processing system that measures and/or determines any of a variety of physiological parameters of a medical patient. For example, in an embodiment, the physiological monitoring system includes an acoustic monitor. The acoustic monitor may be an acoustic respiratory monitor which can determine any of a variety of respiratory parameters of a patient, including respiratory rate, expiratory flow, tidal volume, minute volume, apnea duration, breath sounds, riles, rhonchi, stridor, and changes in breath sounds such as decreased volume or change in airflow. In addition, in some cases the acoustic signal processing system monitors other physiological sounds, such as heart rate to help with probe off detection, heart sounds (S**1**, S**2**, S**3**, S**4**, and murmurs), and change in heart sounds such as normal to murmur or split heart sounds indicating fluid overload. Moreover, the acoustic signal processing system may (1) use a second probe over the chest for additional heart sound detection; (2) keep the user inputs to a minimum (example, height); and/or (3) use a Health Level 7 (HL7) interface to automatically input patient demography.

In certain embodiments, the physiological monitoring system includes an electrocardiograph (ECG or EKG) that measures and/or determines electrical signals generated by the cardiac system of a patient. The ECG includes one or more sensors for measuring the electrical signals. In some embodiments, the electrical signals are obtained using the same sensors used to obtain acoustic signals.

In still other embodiments, the physiological monitoring system includes one or more additional sensors used to determine other desired physiological parameters. For example, in some embodiments, a photoplethysmograph sensor determines the concentrations of analytes contained in the patient's blood, such as oxyhemoglobin, carboxyhemoglobin, methemoglobin, other dyshemoglobins, total hemoglobin, fractional oxygen saturation, glucose, bilirubin, and/or other analytes. In other embodiments, a capnograph determines the carbon dioxide content in inspired and expired air from a patient. In other embodiments, other sensors determine blood pressure, pressure sensors, flow rate, air flow, and fluid flow (first derivative of pressure). Other sensors may include a pneumotachometer for measuring air flow and a respiratory effort belt. In certain embodiments, these sensors are combined in a single processing system which processes signal output from the sensors on a single multi-function circuit board.

Referring to the drawings, FIGS. **1**A through **1**C illustrate example patient monitoring systems, sensors, and cables that can be used to provide acoustic physiological monitoring of a patient, such as respiratory monitoring, with probe-off detection. FIGS. **5**A-**5**F, **6**A-**6**G, and **7**A-**7**B illustrate additional embodiments of sensors and systems incorporating probe-off detection.

FIG. **1**A shows an embodiment of a physiological monitoring system **10**. In the physiological monitoring system **10**, a medical patient **12** is monitored using one or more sensors **13**, each of which transmits a signal over a cable **15** or other communication link or medium to a physiological monitor **17**. The physiological monitor **17** includes a processor **19** and, optionally, a display **11**. The one or more sensors **13** include sensing elements such as, for example, acoustic piezoelectric devices, electrical ECG leads, pulse oximetry sensors, or the like. The sensors **13** can generate respective signals by measuring a physiological parameter of the patient **12**. The signals are then processed by one or more processors **19**. The one or more processors **19** then communicate the processed signal to the display **11** if a display **11** is provided. In an embodiment, the display **11** is incorporated in the physiological monitor **17**. In another embodiment, the display **11** is separate from the physiological monitor **17**. The monitoring system **10** is a portable monitoring system in one configuration. In another instance, the monitoring system **10** is a pod, without a display, and is adapted to provide physiological parameter data to a display.

For clarity, a single block is used to illustrate the one or more sensors **13** shown in FIG. **1**A. It should be understood that the sensor **13** shown is intended to represent one or more sensors. In an embodiment, the one or more sensors **13** include a single sensor of one of the types described below. In another embodiment, the one or more sensors **13** include at least two acoustic sensors. In still another embodiment, the one or more sensors **13** include at least two acoustic sensors and one or more ECG sensors, pulse oximetry sensors, bio-impedance sensors, capnography sensors, and the like. In each of the foregoing embodiments, additional sensors of different types are also optionally included. Other combinations of numbers and types of sensors are also suitable for use with the physiological monitoring system **10**.

In some embodiments of the system shown in FIG. **1**A, all of the hardware used to receive and process signals from the sensors are housed within the same housing. In other embodiments, some of the hardware used to receive and process signals is housed within a separate housing. In addition, the physiological monitor **17** of certain embodiments includes hardware, software, or both hardware and software, whether in one housing or multiple housings, used to receive and process the signals transmitted by the sensors **13**.

As shown in FIG. **1**B, the acoustic sensor **13** can include a cable **25**. The cable **25** can include three conductors within an electrical shielding. One conductor **26** can provide power to a physiological monitor **17**, one conductor **28** can provide a ground signal to the physiological monitor **17**, and one conductor **28** can transmit signals from the sensor **13** to the physiological monitor **17**. For multiple sensors, one or more additional cables **115** can be provided.

In some embodiments, the ground signal is an earth ground, but in other embodiments, the ground signal is a patient ground, sometimes referred to as a patient reference, a patient reference signal, a return, or a patient return. In some embodiments, the cable **25** carries two conductors within an electrical shielding layer, and the shielding layer acts as the ground conductor. Electrical interfaces **23** in the cable **25** can enable the cable to electrically connect to electrical interfaces **21** in a connector **20** of the physiological monitor **17**. In another embodiment, the sensor **13** and the physiological monitor **17** communicate wirelessly.

FIG. **1**C illustrates an embodiment of a sensor system **100** including a sensor **101** suitable for use with any of the physiological monitors shown in FIGS. **1**A and **1**B. The sensor system **100** includes a sensor **101**, a sensor cable **117**, and a connector **105** attached to the sensor cable **117**. The sensor **101** includes a shell **102**, an acoustic coupler, **103** and a frame **104**, which may also be referred to as a sensor support, configured to house certain componentry of the sensor **101**, and an attachment portion **107** positioned on the sensor **101** and configured to attach the sensor **101** to the patient.

The sensor **101** can be removably attached to an instrument cable **111** via an instrument cable connector **109**. The instrument cable **111** can be attached to a cable hub **120**, which includes a port **121** for receiving a connector **112** of the instrument cable **111** and a second port **123** for receiving another cable. In certain embodiments, the second port **123** can receive a cable connected to a pulse oximetry or other sensor. In addition, the cable hub **120** could include additional ports in other embodiments for receiving additional cables. The hub includes a cable **122** which terminates in a connector **124** adapted to connect to a physiological monitor (not shown). In another embodiment, no hub is provided and the acoustic sensor **101** is connected directly to the monitor, via an instrument cable **111** or directly by the sensor cable **117**, for example. Examples of compatible hubs are described in U.S. patent application Ser. No. 12/904,775, which is incorporated by reference in its entirety herein.

The component or group of components between the sensor **101** and the monitor in any particular embodiment may be referred to generally as a cabling apparatus. For example, where one or more of the following components are included, such components or combinations thereof may be referred to as a cabling apparatus: the sensor cable **117**, the connector **105**, the cable connector **109**, the instrument cable **111**, the hub **120**, the cable **122**, and/or the connector **124**. It should be noted that one or more of these components may not be included, and that one or more other components may be included between the sensor **101** and the monitor, forming the cabling apparatus.

In an embodiment, the acoustic sensor **101** includes one or more sensing elements (not shown), such as, for example, a piezoelectric device or other acoustic sensing device. Where a piezoelectric membrane is used, a thin layer of conductive metal can be deposited on each side of the film as electrode coatings, forming electrical poles. The opposing surfaces or poles may be referred to as an anode and cathode, respectively. Each sensing element can be configured to mechanically deform in response to sounds emanating from the patient (or other signal source) and generate a corresponding voltage potential across the electrical poles of the sensing element.

The shell **102** according to certain embodiments houses a frame (not shown) or other support structure configured to support various components of the sensor **101**. The one or more sensing elements can be generally wrapped in tension around the frame. For example, the sensing elements can be positioned across an acoustic cavity disposed on the bottom surface of the frame. Thus, the sensing elements according to some embodiments are free to respond to acoustic waves incident upon them, resulting in corresponding induced voltages across the poles of the sensing elements.

Additionally, the shell **102** can include an acoustic coupler not shown), which advantageously improves the coupling between the source of the signal to be measured by the sensor (e.g., the patient's body) and the sensing element. The acoustic coupler **102** of one embodiment includes a bump positioned to apply pressure to the sensing element so as to bias the sensing element in tension. For example, the bump can be positioned against the portion of the sensing element that is stretched across the cavity of the frame. In one embodiment, the acoustic coupler further includes a protrusion (not shown) on the upper portion of the inner lining, which exerts pressure on the backbone **110** (discussed below) and other internal components of the sensor **101**.

The attachment portion **107** helps secure the sensor assembly **101** to the patient. The illustrated attachment portion **107** includes first and second attachment arms **106**, **108**. The attachment arms can be made of any number of materials, such as plastic, metal or fiber. Furthermore, the attachment arms can be integrated with the backbone (discussed below). The underside of the attachment arms **106**, **108** include patient adhesive (e.g., in some embodiments, tape, glue, a suction device, etc.), which can be used to secure the sensor **101** to a patient's skin. The example attachment portion **107** further includes a resilient backbone member **110** which extends into and forms a portion of the attachment arms **106**,

108. The backbone 110 can be placed above or below the attachment arms 106, 108, or can be placed between an upper portion and a lower portion of the attachment arms 106, 108. Furthermore, the backbone can be constructed of any number of resilient materials, such as plastic, metal, fiber, combinations thereof, or the like.

As the attachment arms 106, 108 are brought down into contact with the patient's skin on either side of the sensor 102, the adhesive affixes to the patient. Moreover, the resiliency of the backbone 110 causes the sensor 101 to be beneficially biased in tension against the patient's skin and/or reduces stress on the connection between the patient adhesive and the skin. Further examples of compatible attachment portions, associated functionality and advantages are described in U.S. application Ser. No. 12/643,939 (the '939 application) previously incorporated by reference. For example, embodiments of attachment portions are shown in and described with respect to FIGS. 2B, 2C, 9A-9D and 10 of the '939 application, and are explicitly incorporated by reference herein.

Moreover, as will be described in greater detail, the attachment portion 107 can also advantageously work together with other sensor componentry to provide an indication to the monitor or to the user as to the attachment state of the sensor.

The acoustic sensor 101 can further include circuitry for detecting and transmitting information related to biological sounds to the physiological monitor. These biological sounds can include heart, breathing, and/or digestive system sounds, in addition to many other physiological phenomena. The acoustic sensor 101 in certain embodiments is a biological sound sensor, such as the sensors described herein. In some embodiments, the biological sound sensor is one of the sensors such as those described in U.S. patent application Ser. No. 12/044,883, filed Mar. 7, 2008, which is incorporated in its entirety by reference herein (the '883 application). In other embodiments, the acoustic sensor 101 is a biological sound sensor such as those described in U.S. Pat. No. 6,661,161 or U.S. patent application Ser. No. 12/643,939, filed on Dec. 21, 2009 (the '939 application), both of which are incorporated by reference herein in their entirety. Other embodiments include other suitable acoustic sensors. For example, in certain embodiments, compatible acoustic sensors can be configured to provide a variety of auscultation functions, including live and/or recorded audio output (e.g., continuous audio output) for listening to patient bodily or speech sounds. Examples of such sensors and sensors capable of providing other compatible functionality can be found in U.S. patent application Ser. No. 12/905,036 entitled PHYSIOLOGICAL ACOUSTIC MONITORING SYSTEM, filed on Oct. 14, 2010, previously incorporated by reference herein in its entirety.

While an example sensor system 100 has been provided, embodiments described herein are compatible with a variety of sensors and associated components.

Example Systems and Sensors Incorporating Probe-Off Functionality

FIG. 2 is a block diagram illustrating an acoustic sensor assembly 200 incorporating probe-off componentry, also referred to as a probe-off assembly, in accordance with an embodiment of the disclosure. The sensor assembly 200 includes a sensing element 202, an attachment assembly 204, a probe-off module 206 and an acoustic coupler 208. The sensing element 202 of the example sensor 200 detects patient bodily sounds, and can be any of the acoustic sensing elements described herein, or some other type of sensing element.

The attachment assembly 204 generally attaches the sensor assembly to the patient, and can include an adhesive, such as glue, tape, or the like. For example, the attachment assembly 204 can include the attachment arms 106, 108 described above with respect to FIG. 1C, or may be one of the attachment assemblies described below with respect to FIGS. 5A-5B and 6A-8B.

The probe-off module 206 generally provides an indication as to the quality of the connection between the sensor and the patient, such as whether or not the sensor 200 is properly attached to the patient. Compatible probe-off module 206 will be described in greater detail below. For example, as described with reference to FIGS. 4, 5A-5B, and 6A-8B, in certain embodiments, the probe-off module 206 includes a switch (e.g., an electromechanical switch) that actuates in response to attachment and disconnection of the sensor from the patient.

Moreover, in various embodiments, the probe-off module 206 can be implemented using a variety of technologies and techniques, such as passive, active, electrical, electromagnetic, mechanical, or chemical technologies. For example, the probe-off module 206 can be implemented using skin resistance, capacitive touch, heat, IR light from the patient, ambient visible light, reflected or refracted light from the patient, frequency detection from a patient, magnetic field detection, EKG, ECG, magnetic switches, acoustic cavities, acoustic impedance, mechanical impedance, physical push-buttons, physical switches, chemical reaction, combinations of the same and the like. In one embodiment, a IR (or heat) sensor detects the proximity of the patient to the sensor. As the sensor nears the patient and is attached to the patient, the IR sensor readings change. Once a threshold heat level is reached, a switch is activated. The threshold level can be set based on expected heat levels of the patient.

In an alternative embodiment, a chemical reaction between the patient's skin and the sensor causes the sensor to begin outputting data. For example, the patient's skin or oil from the patient's skin can be used to create a chemical reaction that activates the switch. In yet another embodiment, the probe-off module 206 can include an ohmmeter to detect the amount of resistance (or impedance) between two conductive points on the sensor. The two conductive points can be located on the portion of the sensor that comes in contact with the patient's skin. When the resistance between the two points meets a threshold level, the switch is activated. The threshold level can be set based on skin conductance or resistance. Similarly, a capacitive sensor disposed, for example, on the sensor 101 or positioned elsewhere on the patient can be used to detect when the patient's skin comes in contact with the sensor. Based on the readings, the switch can activate.

For example, in one embodiment, a conductive element or material is disposed on one or more of the following locations of the sensor 101 to thereby act as one or both of the two conductive points for determining resistance: one or both of the attachment arms 106/108, the backbone 110, the shell 102, or the frame 104. In one embodiment, the conductive element is a conductive film. A conductive film can be disposed on the skin-facing surface of the attachment arms 106, 108, for example. One material that may be used for the conductive film is silver chloride, although other materials may also be used. Instead of a conductive film, the conductive element may be a metal material. For instance, the backbone 110 can be made of conductive material such as copper or aluminum. One or both of the two conductive points on the sensor can also act as an ECG sensor. In another embodiment, one conductive point or element is disposed on the sensor, and a second conductive element is disposed elsewhere on the body, such as in a separate ECG lead.

To improve conductivity between the conductive element or elements and the patient's skin, a gel material can be applied on the patient's skin prior to applying the conductive element to the patient's skin. In one embodiment, the sensor can include a gel layer on top of the conductive element or elements disposed on the sensor. The gel layer, if disposed on the shell **102** or frame **104**, can also act as an acoustic medium that improves acoustic coupling between the sensor and the patient.

In yet another embodiment, a light meter is used to detect when the sensor is connected to the patient. The light meter can be located on the side of the sensor closest to the patient. When the sensor is in contact with the patient, light is obstructed from reaching the light meter. Based on a threshold light meter level, the switch is activated. Similarly, the light meter can measure reflected or refracted light from the patient to determine if the sensor is attached to the patient. An EKG or ECG device can also be used to detect whether the sensor is attached to the patient. Once the EKG or ECG device detects electrical activity from the patient's heart, the switch can be activated. Alternatively, a bioelectric sensor can attached to the sensor and used to detect electric potential or electromagnetic fields from the patient or the patient's skin. When the electric potential or electromagnetic field measurements reach a threshold level, the switch is activated. Furthermore, the sensor can be configured to activate when sounds within a particular frequency range and/or magnitude are observed by the sensor. In addition, a push button switch can be provided that is activated by a medical caregiver when the sensor is attached. Other methods can be used to implement the switch without departing from the spirit and scope of the description.

The acoustic coupler **208** generally improves the coupling between the source of the signal and the sensing element **202**, and may comprise an elastomeric casing or any of the couplers described herein (e.g., with respect to FIGS. **5**A-**5**F).

FIG. **3** is a schematic illustration of an embodiment of an acoustic sensing circuit **300**. Certain portions of the illustrated circuit **300** form a part of an acoustic sensor which incorporates probe-off componentry. The example sensor has two sensing elements **302**A, **302**B (e.g., piezoelectric membranes) connected in the manner described below to provide a physiological signal. For example, certain portions of the sensing circuitry **300** may be included in any of the sensors described herein. In some embodiments, the sensing elements are arranged in a stacked configuration on a frame, as shown in and described herein with respect to FIGS. **5**A-**5**F and **6**A-**6**B. As will be described in further detail, certain other portions of the example sensing circuitry **300** may not be located on the sensor itself, but may instead be located on one or more other components of the physiological sensing system.

In addition, the example sensing circuit **300** includes probe-off circuitry configured to provide an indication as to the quality of the connection between the patient and the sensor. For example, the sensing circuit **300** or portions thereof may form a part of any of the probe-off componentry described herein.

The example sensing circuit **300** includes piezoelectric membranes **302**A, **302**B, a sensing device **306**, power sources connections **312**, **314**, **316**, and a switch **318**. The output of the piezoelectric membrane **302**A is connected to a positive terminal of the sensing device **306** and the output of the piezoelectric membrane **302**B is connected to a negative, or inverting, terminal of the sensing device **306**. The membranes **302**A, **302**B are also connected to a common ground **304**. The sensing device **306** can include additional components, such as feedback loops, feedback resistors, capacitors, and the like, which are not shown for the purposes of illustration. The piezoelectric membranes **302**A, **302**B generally detect mechanical vibrations (e.g., from patient physiological sounds) and generate corresponding electrical waveforms.

Referring to FIGS. **1** and **3**, in the illustrated embodiments, the piezoelectric membranes **302**A, **302**B and the switch **318** are physically located on the sensor **101** itself, while the sensing device **306** is physically located on the instrument cable **111**. For example, in one embodiment, the sensing device **306** is located on the sensor connector **109** of the instrument cable **111** which connects to the sensor cable **117**. In another embodiment, the sensing device is located on the connector **112** of the instrument cable which connects to the hub **120**. In other cases, the arrangement of the various components of the sensing circuitry can vary. For example, in various configurations, the sensing device **306** or a portion thereof may be positioned on the sensor **101** itself, on the connector **105** of the sensor cable **105**, on the hub **120**, on the monitor connector **124**, the physiological monitor itself, or on any of the cables **117**, **111**, **122**.

Moreover, the membranes **302**A, **302**B are configured such that the waveforms generated by the piezoelectric membranes **302**A, **302**B are of opposite polarity, or 180° or approximately 180° out of phase, providing improved signal-to-noise ratio as compared to embodiments including a single membrane. For example, the sensing device **306** is arranged as a differential amplifier and generally constructively combines the waveforms from the two piezoelectric membranes to create an output signal indicative of the sensed physiological sounds. In one example embodiment, the sensing device **306** is arranged as a differential amplifier, the power source connections **312**, **314** provide 2.5V DC reference voltages, and the power source connection **316** is connected to a 5V DC power source. In such a configuration, during normal operation, when the switch **318** is open, the sensing device **306** provides an AC output signal representative of sounds detected by the sensing elements **302**A, **302**B, which swings around the 2.5V DC reference value between 0V and 5V. In other embodiments, the sensor **300** includes a single membrane, or includes more than two membranes.

The sensing device **306** can include one or more operational amplifiers. U.S. application Ser. No. 12/904,931 (the '931 application) includes further examples of sensing circuits that are compatible with the embodiments described herein (e.g., as shown in and described with respect to FIGS. 3A and 3B of the '931 application), and each of which are explicitly incorporated in their entirety by reference herein.

The circuit **300** can include componentry used in the probe-off determination, providing an indication as to the quality of the connection between the patient and the sensor. For example, the sensor may be configured such that the switch **318** closes when the sensor is not properly attached to the patient. When closed, the switch **318** is configured to electrically couple the positive terminal of the sensing device **306** to ground **304** (e.g., 0V). In certain configurations, such as where the sensing device **306** comprises a differential amplifier, the 0V input on the positive terminal will force the output of the sensing device **306** to 0V or substantially 0V. Thus, the output characteristic (e.g., frequency profile) of the sensing device **306** is advantageously significantly altered when the switch **318** is closed (probe-off condition) as compared to when the switch **318** is open (probe-on condition). In turn, the resulting change in the output characteristic can be used to determine the connection state of the sensor in a reliable and straightforward manner. For example, the monitor may receive and process the output of the sensing device

306 or a version thereof to determine the sensor connection state. Thus, the use of the switch **318** to indicate whether the sensor is in an attached state can significantly improve the robustness of the probe-off detection, reducing possible instances where the monitor and/or medical personnel misinterpret sensor readings. Furthermore, the use of the switch **318** can allow care providers to be able to place greater confidence in error or warning signals provided by the monitor. While one terminal of the switch **318** is tied to ground **304** (e.g., 0V) in the illustrated embodiment, in other configurations that terminal is tied to some other potential. For instance, the switch **318** may be connected to a node having some DC bias (e.g., 0.5V, 1V, 1.5V, 2V, or any other appropriate value). In such cases, and in a manner similar to the embodiment where 0V is used, the output characteristic (e.g., frequency profile) of the sensing device **306** will be significantly altered, providing a robust indication as to whether the sensor is in an attached state. In some embodiments, the sensing circuit **316** enters a saturation region when the sensor is in the probe-off state, when the switch **318** closes. For instance, in one configuration, the sensing device **306** comprises an operational amplifier, and when the switch **318** closes (e.g., due to a probe-off condition), the non-inverting terminal of the amplifier that is connected to the output of the first sensing element **302**A and the output of the switch **318** is driven to the DC level represented by the node **304**. In response, the operational amplifier attempts to set its inverting input to the same DC level as the non-inverting input, causing the amplifier to saturate. The saturation can be readily detected by subsequent componentry to determine a probe-off condition.

Moreover, the output of the sensing device **306** provides both the sensed physiological signal (when the sensor is connected), and an a reliable indication of the sensor connection state. Thus, this technique reduces cost and complexity associated with providing the probe-off functionality. For example, both the sensed signal and the probe-off indication can be communicated from the sensor to the monitor via a single output line, reducing cabling and interface complexity. In another embodiment, the sensor and monitor cable include an additional signal line for communicating the indication of the connection state to the monitor.

In some alternative implementations, the circuit **300** is configured such that the switch **318** or other probe-off componentry affects the frequency of the sensing circuit **306** output instead of, or in addition to, the level of the output voltage. For example, the sensing circuit **306** may output a signal having a predetermined frequency when the sensor is not properly connected to the patient. In such a case, the patient monitor recognizes the predetermined frequency as indicating that the circuit **300** is not properly connected.

In addition, the electrical arrangement of the switch **318** is not limited to the arrangement shown in FIG. **3**, and can be coupled to the circuit **300** in a variety of ways. For example, in various embodiments, the switch **318** can be connected to the output of the sensing device **306** or to the negative terminal of the sensing device **306**. This arrangement may be used in a configuration where sensing device **306** is located on the sensor **101**, for example. In some instances, the output of the switch **318** is coupled to a separate control line that is dedicated to probe-off detection. This arrangement can simplify the processing done by the monitor in making the probe-off determination. In one such case, the separate control line (e.g., the output of the switch **318**) is sent directly to the monitor from the sensor via a first lead and the physiological signal (e.g., the output of the sensing device **306**) is sent to the monitor via a second lead. In yet another arrangement, the switch is tied to both of the input lines to the sensing device **306** (the outputs of both sensing elements **302**A, **302**B). In some embodiments, the switch **318** is closed in the probe-off state, and open in the probe-on state. In certain embodiments, the switch **318** is open in the probe-off state, and closed in the probe-on state. Moreover, more than one switch connected in series or in parallel may be used in some other embodiments.

FIG. **4** shows a chart **400** including plots **406***a*, **406***b*, **408**, **410** illustrating output characteristics of example sensing circuitry for example monitoring scenarios. The graph **400** includes an x-axis **402** corresponding to the input frequency of the detected sound signals, and a y-axis **404** corresponding to the amplitude, energy, or other measure of the output signal of the sensor. While the chart **400** will be described with respect to the sensing circuit **300** of FIG. **3** for the purposes of illustration, other compatible sensing circuits may operate in a similar manner.

Referring to FIGS. **3** and **4**, in one embodiment, the x-axis **404** corresponds to the frequency of sounds incident on the sensing elements **302**A, **302**B, while the y-axis **402** corresponds to the detected acoustic signal or a modified version thereof. For example, the y-axis **402** may correspond to an amplified, filtered, attenuated, or otherwise processed version of the detected acoustic signal.

The plot **406***a* corresponds to the amplitude of the detected acoustic signal when the sensor is attached to the patient and is detecting relatively loud patient bodily sounds, such as breathing or heart sounds. For example, the plot **406** may correspond to the detected acoustic signal or a modified version thereof when the sensor is attached to the patient and the switch **318**. The plot **406***b*, on the other hand, corresponds to the amplitude of the detected acoustic signal when the sensor is attached to the patient and is detecting relatively quiet patient bodily sounds. For example, the plot **406***b* may represent a situation where the sensor is positioned on a region of the patient (e.g., an appendage) that produces relatively quiet sounds. The plot **406***b* may alternatively represent a situation where the sensor is positioned on a region of the patient that normally produces relatively loud bodily sounds (e.g., throat or chest), but where the bodily sounds are not currently emanating from the patient, such as where the patient is not breathing.

The plot **408**, on the other hand corresponds to the amplitude of the detected signal when the sensor is not attached to the patient, and for an embodiment in which the sensor does not include separate, distinct probe-off componentry. For example, the plot **408** may correspond to the output of the sensing device **306** for an embodiment of the circuit **300** not including the switch **318**. In one monitoring scenario, the plot **408** corresponds to a moderate level of environmental noise being detected by a disconnected sensor.

Finally, the plot **410** corresponds to the detected acoustic signal when the sensor is not attached to a patient and where the sensor does include probe-off componentry. For example, the plot **410** corresponds to the detected acoustic signal where the switch **318** is closed.

As discussed, when the sensor is attached to a patient, the output generally corresponds to the detected physiological sounds of the patient. This is true in certain embodiments for input sounds corresponding to sounds in a range of frequencies below a first frequency **414**, as indicated by the dotted line **412**. For example, sounds below the first frequency **414** may correspond to a desired range of target physiological sounds (e.g., heart, breathing and/or digestive sounds), or to a range of sounds that are otherwise not filtered out by the physiological monitoring system during processing. On the other hand, sounds above the first frequency **414** are filtered out by the system (e.g., by the sensing circuitry **300** or the processing algorithm implemented by the physiological monitor). In one embodiment, the first frequency is about 1 kHz, and the desired range of target physiological sounds correspond to sounds having a frequency of less than about 1 kHz. Other values for the first frequency **414** are possible, such as, for example, about 500 Hz, 1.5 kHz, 2 kHz, 5 kHz, 10 kHz, 50 kHz, 100 kHz, or some other value.

However, as shown by the second plot **408**, when the sensor does not include separate, distinct probe-off componentry, the sensor may also produce a relatively highly amplified output signal for desired input frequencies (e.g., below the first frequency **414**) even when the sensor is not attached to a patient. For example, the sensor may detect and amplify ambient noise or other sounds at frequencies in the desired range. Because the signal is still amplified significantly, the monitor or user may remain unaware of the probe-off condition and misinterpret the readings made by the sensor. Moreover, to the extent the monitor can determine the quality of the sensor connection, the determination may be relatively difficult to make and may be relatively unreliable.

Thus, it is desirable for the output characteristic of the sensor to provide a clear indication to the monitor (or user) when the sensor is not attached to a patient. For example, the plot **410** indicates that when separate, distinct probe-off componentry is used, the sensing circuitry **300** amplifies the ambient noise (or other un-targeted sounds) for the desired input frequencies much less than where no probe-off componentry is included (plot **408**). Because there is a greater differentiation between the output characteristic of the sensor for when the sensor is attached versus when the sensor is not attached, the connection state of the sensor can be more readily determined, reducing erroneous alarms, improving monitoring reliability, etc.

As illustrated by the third plot **410**, with the addition of probe-off circuitry, such as that described above with reference to FIG. **3**, the detected output is advantageously significantly reduced when the sensor is not connected to the patient. For example, the output is reduced by an amount **402**B as compared to embodiments where the sensor does not include probe-off functionality (plot **408**), thereby reducing the likelihood of false readings and the like. For example, in one embodiment, the output is reduced by at least about 10 dB.

While the example sensing circuit **300** and the chart **400** have been provided for the purposes of illustration, a variety of compatible alternative configurations are possible. For example, in one embodiment, unlike the illustrated switch **318**, the probe-off circuitry does not have a binary ("on", "off") output and instead provides an output having more granularity and corresponding to a degree of the quality of connection.

The mechanism for actuating the switch **318** and the switch **318** can be implemented using a variety of passive, active, electrical, electromagnetic, thermal, mechanical, and/or chemical techniques as mentioned above, with reference to FIG. **2**. For example, the switch **318** or any of the switches described herein (e.g., the switches described with respect to FIGS. **5**A-**7**B) may be implemented using a push-button, surface mount switch, transistor, MOSFET, metallic contact, spring, chemical compound, electromagnetic switch, optical switch, thermal switch, thermistor, etc.

Additionally, the circuit **300** may include a single sensing element in some instances, the sensing device **306** may include a different type of amplifier (e.g., a summing amplifier) or may be include some other type of appropriate circuitry for producing the physiological signal.

Example Sensor

FIG. **5**A shows a top perspective view of an embodiment of a sensor **500** including probe-off detection capability. The sensor **500** and its corresponding components may be the sensor **101** as shown in FIG. **1**C. The sensor **500** includes a sensor cover **501**, acoustic coupler **502**, and frame **504**. The sensor **500** further includes an attachment portion having attachment arms **506**A, **506**B and a backbone **508**, similar to the attachment arms **106**, **108** and backbone **110** of FIG. **1**C.

FIGS. **5**B-**5**C illustrate exploded views of the example sensor **500** configured for probe-off detection and to detect acoustic physiological sounds from the patient. The example sensor **500** additionally provides improved signal-to-noise ratio ("SNR") using multiple sensing elements according to techniques described in greater detail in the '931 application, previously incorporated by reference in its entirety. Moreover, the sensor **500** includes a stacked, multiple sensing element configuration providing enhanced shielding and compatible with the techniques described above in greater detail in the '931 application.

The sensor **500** is generally attachable to a patient and can be coupled to a patient monitor. For example, the sensor **500** can be used with the system **10** of FIGS. **1**A-**1**B. Moreover, the sensor **500** can be compatible with the sensor system **100** of FIG. **1**C, and may be the sensor **101** of FIG. **1**C.

Referring to FIG. **5**B, the sensor **500** of certain embodiments includes an acoustic coupler **502**, a printed circuit board (PCB) **530**, a frame **504** with riser portions **534**, first and second acoustic sensing elements **522**, **526**, and multiple adhesive layers **524**, **527**, **528**. The sensor can further include a cover or shell **501**. The acoustic coupler **502** houses the frame **504**, which is generally configured to support various components of the sensor **500** in an assembled state, including the PCB **530**, switch **518**, sensing elements **522**, **526**, and adhesive layers **524**, **527**, **528**. The sensing elements **522**, **526**, are piezoelectric films in the illustrated embodiment, although other types of sensing elements can be used. Moreover, while the sensor **500** includes multiple sensing elements beneficially arranged for improved sensing, the probe-off functionality and other aspects described herein are generally compatible with other designs, including single-sensing element designs. Further example sensing elements are described in both the '931 and '939 applications, and are explicitly incorporated by reference herein.

Furthermore, the sensor **500** includes a switch **518** configured to provide an indication of the integrity of the connection state of the sensor. The sensor **500** may include sensing circuitry, such as the sensing circuit **300** shown in and described above with respect to FIG. **3**, for example, and the switch **518** may correspond to the switch **318** of FIG. **3**.

The switch **518** is positioned in an upper cavity **516** (FIG. **5**A) of the frame **504** above the PCB **530** such that the underside of the switch **518** comes in contact with an upper portion of the PCB **530**. The switch **518** is advantageously spaced away from the skin (e.g., on top of the PCB **530** and below the coupler **502**, as shown), which can increase reliability in probe-off detection. Where the switch **518** or other probe-off componentry are not spaced from the skin, but are instead placed in proximity to or touching the skin, there may be an increase in false probe-off readings. For example, in some cases the elasticity of the skin may allow the switch **518** to toggle even when the sensor **500** is properly attached to the patient. However, in some embodiments, the switch **518** can be placed in proximity to the skin.

Furthermore, placement of the switch **518** and/or other components of the probe-off assembly away from active portions of the sensor which interact with the patient (e.g., the membranes **522**, **526** and bottom portions of the coupler **502** and frame **504**) can provide certain advantages. For example, the switch **518** in certain embodiments faces in a direction that is substantially opposite the patient contact surface of the sensor **500**. For example, the switch **518** faces generally opposite the underside of the coupler **502**, frame **504** and/or sensing elements **522**, **526**. In this manner, when the sensor **500** is attached to the patient's skin, actuation forces incident on the switch **518** are in the direction of the patient's skin, rather than away from the patient's skin. Thus, actuation of the switch **518** will tend to improve the coupling between the patient and sensor **500** rather than tending to separate the patient and the sensor **500**. For example, such an arrangement can reduce the risk that the probe-off detection components will interfere with the active portions of the sensor, or vice versa, improving the accuracy and reliability of both probe-off detection and physiological measurement. Such placement can also reduce the risk that the probe-off componentry will become soiled or otherwise damaged from frequent interaction with the patient's skin, improving reliability. In some alternative embodiments, however, the switch **518** or other components of the probe-off assembly are placed on or near the skin or near the active portions of the sensor **500**.

In the illustrated embodiment, the switch **518** is electrically closed when the button is depressed, causing the sensing circuitry (not shown) to provide an indication that the sensor is in an unattached state. Once the sensor **500** is attached to a patient, the push-button releases, and the switch **518** electrically opens, allowing the sensor to output the detected physiological parameters. In another embodiment, the push button of the switch **518** releases in the unattached state and is depressed in the attached state.

Although illustrated as a push-button mechanical switch, the probe-off componentry can include a variety of different types of components instead of, or in addition to such a switch. Examples of some such alternative components are described above with reference to FIGS. **2** and **3**. In one embodiment, the backbone **508** includes a strain gauge configured to provide an output signal corresponding to an amount or characteristic of the flex in the backbone **508**. The output signal can be used to determine the attachment state of the sensor **500**.

The coupler shell **502** is generally configured to transmit vibrations received from the patient to the films **522**, **526** in the piezoelectric stack. The acoustic coupler **502** can include a lower exterior protrusion or bump **512** (FIGS. **5**C, **5**D) configured to press against the patient's body when the acoustic sensor **500** is fastened into place on the patient. The acoustic coupler **502** can also include a lower interior protrusion **514** (FIGS. **5**B, **5**D) designed to abut against the films **522**, **526** and to bias them in tension across the acoustic cavity **515** (FIG. **5**B).

The coupler **502** can further form a part of the probe-off componentry. For example, the coupler **502** includes an upper interior protrusion **510** (FIGS. **5**C, **5**D) designed to interact with the backbone **508** and the attachment arms **506**A, **506**B to toggle the switch **518**, depending on the attachment state of the sensor **500**.

Referring to FIGS. **5**A and **6**A, the attachment arms **506**A, **506**B, **606**A, **606**B (and the distal portions of the backbone **508**, **608** which extend into the attachment arms **506**A, **506**B, **606**A, **606**B, respectively) are biased upwards with respect to the sensor **600** in the unattached state. This is due to interior protrusion **510** of the coupler **502** (FIG. **5**D) abutting and exerting a downward force on the middle portion of the backbone **508**, **608**. For example, during assembly, the coupler **502** is stretched around the frame **504**, **604** and over the backbone **508**, **608** which extends across the frame **504**, **604** and sits in the cutouts **535**. When the coupler **502** is allowed to "snap" or return back into its original shape, the inner protrusion **510** of the coupler **502** presses against the middle portion backbone **508**, **608**, thereby causing the backbone **508**, **608** to flex. The downward force also causes the center portion of the backbone **508**, **608** to depress the switch **518**, **620** in the default, detached configuration (FIGS. **5**A and **6**A). As such, the sensor **500**, **600** outputs a signal indicating the probe-off condition. Moreover, the cutouts **535** on the frame **504**, **604** exert a corresponding upward force on the portions of the backbone **508**, **608** that rest on the notches **535** (FIG. **5**B) of the frame **504**, **604** causing the arms **506**A, **506**B, **606**A, **606**B to flex upwards.

Conversely, as the attachment arms **506**A, **506**B, **606**A, **606**B are brought into contact with the patient during attachment of the sensor **500**, **600** to the patient, the backbone **508**, **608** flexes in generally the opposite direction. In this state, the center portion of the backbone **508**, **608** exerts an upward force against the upper interior protrusion **510** of the coupler **502**, causing the switch **518**, **620** to release (FIG. **6**B). The sensor then outputs a signal indicating that the sensor is properly attached to the patient.

The above-described flexed configuration provides a robust probe-off detection mechanism. For example, due to the flexed configuration, the attachment arms **506**A, **506**B, **606**A, **606**B and the center portion of the backbone **508**, **608** travel an increased distance during the transition from the unattached state to the attached state (FIGS. **6**A and **6**B). Moreover, the backbone **508**, **608** may generally "snap" between the two flexed configurations. The increased travel and/or snapping behavior can cause the backbone **508**, **608** to have two relatively discrete mechanical states based on the attachment state of the sensor. As such, the backbone **508**, **608** will toggle the switch in a relatively reliable manner when the sensor is attached and detached from the patient.

The coupler shell **502** can be similar to any of the acoustic couplers described in greater detail in the '931 application, for example. Use of the coupler to bias the backbone **508**, **608** and actuate the switch **518**, **620** can reduce the complexity of manufacturing process and/or the design of the switch **518**, **620** and can reduce the number of parts used to implement the probe-off capability. However, other compatible designs incorporate additional components to bias the backbone **508** and actuate the switch **518**, **620**.

Referring to FIG. **5**A, the sensor cover or shell **501** fits over the acoustic coupler **502** of the assembled sensor **500**, and has notches, or cutouts **533**, for the backbone **508** and the attachment arms **506**A, **506**B. The cover **501** is formed of a relatively rigid material (e.g., plastic) in some cases. The sensor cover **501** provides additional protection for the sensor **500**. For example, the cover **501** can prevent unwanted interaction with the probe-off componentry, reducing the risk of possible probe-off detection errors. For example, as discussed, when the sensor is in an attached state, the button **520** on the switch **518** is released. Without the cover **601**, if the patient, medical personnel or other source were to push down on the top of the acoustic coupler **502**, the coupler **502** and backbone **508** could move downwards, depressing the button **520**. The sensor would then improperly indicate that the sensor was in an unattached state. The cover **601** reduces the likelihood of such a situation occurring by providing a relatively rigid barrier between the external environment and the coupler **502**.

The remaining components of the sensor **500** can be assembled similarly to the sensors described in the '931 application. For example, the first piezoelectric film **526** is wrapped around a portion of the frame **504** and extends across an acoustic cavity **515** (FIG. **5**B) of the frame **504** in tension. When assembled, the adhesive portions **527**, **528** are positioned between interior opposing sides of the first film **526** and corresponding sides of the sensor frame **504**, thereby adhering the first film **526** in place with respect to the frame **504**.

The adhesive layer **524** is wrapped around the first sensing element **526**, and the second sensing element **522** is in turn wrapped around the adhesive layer **524**, generally forming a piezoelectric stack. As discussed in greater detail in the '931 application, the active portions of the films **522**, **526** that extend across the acoustic cavity **515** (FIG. **5**B) are thus generally free to move in response to received vibrations, enabling detection of a physiological signal when the sensor **500** is in an attached state. In certain embodiments, the acoustic cavity **515** (FIG. **5**B) or a portion thereof extends all the way through the frame **504**. For example, the cavity may form one or more holes in the interior portion of the frame **504**.

The PCB **530** is positioned in the upper cavity **516** (FIG. **5**A) such that the underside of the PCB **530** comes into contact with the regions **523**, **525** of the second film **522** and the regions **520**, **521** of the first film **526**. The flap **531** of the second film **522** rests on top of the PCB **530** in the illustrated embodiment, allowing electrical coupling of the first sensing element **526** to the PCB **530** and associated circuitry.

Generally, the piezoelectric films **522**, **526** can be any of those described herein. In the illustrated embodiment, for example, the films **522**, **526** are the piezoelectric films described in greater detail in the '931 application, previously incorporated by reference in its entirety, having flooded electrode surfaces **519**, **529**, respectively, which form the outer surfaces of the piezoelectric stack. Moreover, the films **522**, **526** include one or more vias or through holes extending an electrode from one surface of the films **522**, **526** to a corresponding region **520**, **523** on the opposing surface of the respective film **522**, **526**. As discussed above, this configuration enables coupling of the four electrodes (e.g., the anode and cathode for each film **526**, **522**) to the appropriate contacts on the underside of the PCB **222**.

For example, in one embodiment, the region **525** (FIG. **5**B) of the flooded cathode coating on the outer surface of the second film **522** touches one or more of the contacts **546** on the underside of the PCB **530** (FIG. **5**C Meanwhile, the through-holed region **523** (FIG. **5**B) of the outer surface of the second film **522**, which includes an anode coating, touches the contact **544** on the underside of the PCB **530** (FIG. **5**C). Regarding the first film **526**, the region **521** (FIG. **5**B) of the cathode coating touches one or more of the contacts **540** on the underside of the PCB **530** (FIG. **5**C). Meanwhile, the through-holed region **520** (FIG. **5**B) of the inner surface of the first film **526**, which includes an anode coating, touches one or more of the contacts **542** on the underside of the PCB **530** (FIG. **5**C).

According to the above-described connection scheme, the films **522**, **526** can be coupled to circuitry (not shown) residing on the PCB **222** or other system component (e.g., the hub or monitor) to provide improved SNR and/or electrical shielding. For example, the electrodes of the films **522**, **526** can each be coupled to an input of an attenuation circuit (e.g., a differential amplifier) or ground (or other common potential), such as in the manner illustrated schematically with respect to FIG. **3** above. Specifically, although other connections schemes are possible, in one embodiment, the contact **540** (FIGURE C) on the PCB **530** couples the flooded, outer cathode of the second, exterior film **522** to ground, and the contact **544** couples the outer, flooded anode of the first, interior film **526** to ground. Moreover, the contacts **544** couple the inner, un-flooded anode of the second, exterior film **522** to a first (e.g., positive) terminal of a difference amplifier or other noise attenuation circuit. Finally, the contacts **542** couple the un-flooded, inner cathode of the first, interior film **526** to a second (e.g., negative) terminal of the difference amplifier.

The frame **504** can include one or more pressure equalization pathways **532**. The pressure equalization pathways **532** provide an air communication pathway between the lower acoustic cavity **515** and ambient air pressure, and allow the sensor's membrane(s) or film(s) **522**, **526** to vibrate within the acoustic cavity **515** independent of skin elasticity or the force used to attach the sensor to a patient's skin. Further examples of pressure equalization pathways **532** are described in the '931 application, and are explicitly incorporated in their entirety by reference herein.

FIG. **5**D shows a side perspective view of an embodiment of an acoustic coupler **502**. As mentioned previously, the acoustic coupler **502** is configured to transmit vibrations received from the patient to the sensor membranes **522**, **526**, and houses the frame **504** and various components of the sensor including the switch **518**, PCB **530**, sensor membranes **522**, **526** and adhesive layers **524**, **527**, and **528**. The acoustic coupler **502** may be made of a flexible, resilient, substance that is easily stretched or otherwise manipulated but returns to its original shape when no force is exerted against it. Possible materials may include, but are not limited to rubber, silicone, and other elastomers.

FIG. **5**E shows a side perspective view of the sensor **500** assembled, with the coupler **502**, attachment arms **506**A, **506**B, and backbone **508** removed. The frame **504** includes riser portions **534** with notches, or cutouts **535**, where the backbone **508** and attachment arms **506**A, **506**B rest when assembled. The frame **504** also includes a pathway **538** for a wire (not shown) to be coupled with the PCB **530**. As discussed previously, the frame **504** further includes equalization pathways **532**. Resting in the cavity **516** of the frame **504** lies the PCB **530**, secured by posts **536**. As mentioned above, with respect to FIGS. **5**B and **5**C, the sensor membranes **522**, **526** and adhesive layers **524**, **527**, **528** are wrapped around the frame **504**. The switch **518** sits atop the PCB **530** and sensor membrane **522**. As mentioned previously, when the sensor **500** is in an unattached state, a downward force is exerted on the switch **518** by the upper interior portion **510** of the acoustic coupler **502**, the attachment arms **506**A, **506**B and the backbone **508**.

FIG. **5**F, shows a cross-sectional view of an embodiment of the assembled sensor **500** along the line **5**F, illustrated in FIG. **5**A. In FIG. **5**F, the protrusion **510** of the coupler **502** urges the middle portion of the backbone **508** downward, depressing the switch. Downward movement of the attachment arms would cause the protrusion **510** to compress and/or cause the coupler **502** to stretch upwards with respect to the frame, allowing the switch **518** to release (FIG. **6**B).

FIG. **5**F further illustrates the placement of the various components of the sensor **500** in relation to each other in the assembled state. For example, the adhesives **527**, **528** wrap around rounded ends of the frame **504**. The first sensor membrane **526** wraps around the adhesives **527**, **528**, and the adhesive **524** wraps around the first sensor membrane **526**. Finally, a second sensor membrane **522** wraps around the adhesive **524**. The PCB **530** is secured by posts **536** to the frame **504**, and sits within the cavity **516** atop the wrapped sensor membranes **522**, **526** and adhesives **524**, **527**, **528**. The switch **518** sits atop the PCB **530**.

FIG. **5**F further illustrates the groove **538** formed in the frame **504** for accommodating the cable (not shown) and the frame equalization pathways **532**, described previously. Furthermore, FIG. **5**F illustrates the lower exterior protrusion **512** of the acoustic coupler **502** configured to improve the coupling between the source of the signal and the sensing element, and the lower interior protrusion **514** of the acoustic coupler **502** creating tension in the sensor membranes **522**, **526**, and adhesive **524**.

FIGS. **6**A-**6**B described above show side perspective views of a sensor **600** in detached and attached states, respectively. The sensor **600** is similar to the sensor **500** of FIGS. **5**A-**5**F, and includes attachment arms **606**A, **606**B, a backbone **608**, a frame **604** having riser portions **638** with notches **640**, and a switch **620**. For the purposes of illustration, the sensor is shown without the cover and acoustic coupler with the PCB **630** secured to the frame **604** by posts **636**.

Additional Embodiments

FIGS. **7**A-**7**B and **8**A-**8**B are side perspective views of additional embodiments of the sensor described above. FIGS. **7**A-**7**B are block diagrams illustrating a sensor **700** wherein the springs **706**A, **706**B are used to toggle the switch **718**, depending on the attachment state of the sensor **700**. FIG. **7**A illustrates the sensor **700** in an unattached state, and FIG. **7**B illustrates the sensor **700** in an attached state.

Similar to sensor **500** of FIGS. **5**A-**5**F, sensor **700** includes an acoustic coupler **702** with a lower exterior protrusion **712**, frame **704**, attachment arms **706**A, **706**B, a sensor cover **710**, and a switch **718** placed on a PCB **714**, all of which are described in greater detail above. Although not illustrated in FIGS. **7**A and **7**B, the sensor **700** can further include a piezoelectric stack, described in greater detail above, additional protrusions in the coupler, and other components described above with reference to FIGS. **5**A-**5**F. Additionally, the sensor **700** includes springs **706**A, **706**B. A proximal side of the springs **706**A, **706**B is attached to the PCB **714**, the frame **704** and/or the coupler **702**. A distal side of the springs **706**A, **706**B is attached to an underside of the attachment arms **708**A, **708**B.

Moreover, when in an unattached state, the springs **706**A, **706**B exert an upward force against the attachment arms **708**A, **708**B, respectively. The upward force from the springs **706**A, **706**B raises the attachment arms **708**A, **708**B and the sensor cover **710**. The upward force also urges the attachment arms **708**A, **708**B and the cover **710** upward, preventing them from contacting the switch **718**. In this configuration, the switch **718** is released, causing the sensing circuitry (not shown) to output an indication that the sensor is in an unattached state. The attachment arms can be configured similar to the attachment arms and/or the backbone described above with reference to FIGS. **5**A-**5**F, **6**A, and **6**B. Furthermore, the attachment arms **708**A, **708**B can be upward biased similar to the attachment arms and backbone described above with reference to FIGS. **5**A-**5**F, **6**A, and **6**B.

FIG. **7**B is a side perspective view of the sensor **700** illustrating the situation where the sensor **700** is in an attached state, and where the spring **706**A, **706**B and distal portions of the attachment arms **708**A, **708**B are therefore downwardly biased, exerting a downward force against the switch **718**. When placing the sensor **700** in an attached state, the attachment arms **708**A, **708**B are biased downward with sufficient force to overcome the inherent upward bias of the springs **706**A, **706**B. The distal portions of the attachment arms **708**A, **708**B can be affixed to a patient using an adhesive on the underside of the attachment arms **708**A, **708**B. As the distal portions of the attachment arms **708**A, **708**B are biased downwards, the space between the switch **718** and attachment arms **708**A, **708**B decreases until the middle portion of the attachment arms **708**A, **708**B exert a downward force against the switch **718**. The downward force of the attachment arms **708**A, **708**B on the switch **718** closes the switch **718**, and causes the sensing circuitry (not shown) to output an indication that the sensor **700** is in an attached state and/or allows the physiological parameters to be monitored.

FIGS. **8**A and **8**B illustrate additional embodiments of sensor **700**. For instance, in FIGS. **8**A and **8**B sensor **700** further includes a plastic plate **716**, and the springs **706**A', **706**B' are located above the attachment arms **708**A, **708**B and connect to the topside of attachment arms **708**A, **708**B. The attachment arms can be constructed similar to the attachment arms above with reference to FIGS. **7**A and **7**B. Furthermore, the attachment arms **708**A, **708**B can be upward biased similar to the attachment arms and backbone described above with reference to FIGS. **5**A-**5**F, **6**A, and **6**B.

FIG. **8**A illustrates the sensor **700** in a situation when it is not in an attached state. In this situation, the plastic plate **716** and cap **710** reside above the coupler **702** and switch **718**. The springs **706**A', **706**B' extend outwardly from the plastic plate **716** and are attached to the topside of distal portions of the attachment arms **708**A, **708**B. The switch **718** can be located above, below or protrude through a hole of the attachment arms **708**A, **708**B. The springs **706**A', **706**B' are upwardly biased causing an upward force to be exerted on the attachment arms **708**A, **708**B, forcing the distal portions of the attachment arms **708**A, **708**B upward. The space between the plastic plate **716** and the switch **718** allows the switch **718** to release, causing the sensing circuitry (not shown) to output an indication that the sensor **700** is in an unattached state.

FIG. **8**B illustrates the sensor **700** in an attached state. When the sensor **700** is placed in an attached state, the attachment arms **708**A, **708**B are biased downward with sufficient force to overcome the inherent upward bias of the springs **706**A, **706**B. The distal portions of the attachment arms **708**A, **708**B can be affixed to a patient using an adhesive on the underside of the attachment arms **708**A, **708**B. As the distal portions of the attachment arms **708**A, **708**B are biased downwards, the space between the switch **718** and plastic plate **716** decreases until the plastic plate **716** exerts a downward force against the switch **718**. The downward force of the plastic plate **716** on the switch **718** closes the switch **718** and causes the sensing circuitry (not shown) to output an indication that the sensor **700** is in an attached state and/or allows the physiological parameters to be monitored. Alternatively, when the attachment arms **708**A, **708**B are positioned above the switch **718**, the attachment arms **708**A, **708**B can be used to exert a downward force on the switch **718**.

Terminology

Embodiments have been described in connection with the accompanying drawings. However, it should be understood that the figures are not drawn to scale. Distances, angles, etc. are merely illustrative and do not necessarily bear an exact relationship to actual dimensions and layout of the devices illustrated. In addition, the foregoing embodiments have been described at a level of detail to allow one of ordinary skill in the art to make and use the devices, systems, etc. described herein. A wide variety of variation is possible. Components, elements, and/or steps can be altered, added, removed, or rearranged. While certain embodiments have been explicitly described, other embodiments will become apparent to those of ordinary skill in the art based on this disclosure.

Conditional language used herein, such as, among others, "can," "could," "might," "may," "e.g.," and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or states. Thus, such conditional language is not generally intended to imply that features, elements and/or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or states are included or are to be performed in any particular embodiment.

Depending on the embodiment, certain acts, events, or functions of any of the methods described herein can be performed in a different sequence, can be added, merged, or left out all together (e.g., not all described acts or events are necessary for the practice of the method). Moreover, in certain embodiments, acts or events can be performed concurrently, e.g., through multi-threaded processing, interrupt processing, or multiple processors or processor cores, rather than sequentially.

The various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein can be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. The described functionality can be implemented in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the disclosure.

The various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein can be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor can be a microprocessor, but in the alternative, the processor can be any conventional processor, controller, microcontroller, or state machine. A processor can also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

The blocks of the methods and algorithms described in connection with the embodiments disclosed herein can be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module can reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, a hard disk, a removable disk, a CD-ROM, or any other form of computer-readable storage medium known in the art. An exemplary storage medium is coupled to a processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium can be integral to the processor. The processor and the storage medium can reside in an ASIC. The ASIC can reside in a user terminal. In the alternative, the processor and the storage medium can reside as discrete components in a user terminal.

While the above detailed description has shown, described, and pointed out novel features as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the devices or algorithms illustrated can be made without departing from the spirit of the disclosure. As will be recognized, certain embodiments of the inventions described herein can be embodied within a form that does not provide all of the features and benefits set forth herein, as some features can be used or practiced separately from others. The scope of certain inventions disclosed herein is indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed is:

1. An acoustic sensor configured to non-invasively detect acoustic vibrations associated with a medical patient, said acoustic vibrations indicative of one or more physiological parameters of the medical patient, said acoustic sensor comprising:

a sensor support;

at least one sound sensing membrane supported by the sensor support and configured to detect acoustic vibrations associated with a medical patient and produce a membrane signal corresponding to the acoustic vibrations based at least in part on an attached state of the acoustic sensor; and

a probe-off assembly supported by the sensor support, the probe-off assembly configured to produce a probe-off signal responsive to the attached state of the acoustic sensor and/or to a detached state of the acoustic sensor, wherein at least a portion of the sensor support is between a patient contact surface of the acoustic sensor and the probe-off assembly.

2. The acoustic sensor of claim **1**, wherein the probe-off signal indicates a sensor connected condition based at least in part on the attached state of the acoustic sensor and a sensor not connected condition based at least in part on the detached state of the acoustic sensor.

3. The acoustic sensor of claim **1**, wherein the probe-off signal is indicative of an integrity of a connection between the acoustic sensor and the medical patient.

4. The acoustic sensor of claim **1**, wherein the probe-off assembly comprises a switch configured to actuate in response to the attached state of the acoustic sensor.

5. The acoustic sensor of claim **1**, wherein the probe-off assembly is positioned to actuate in response to a force that is in a direction of the medical patient's skin to place the acoustic sensor in the attached state.

6. The acoustic sensor of claim **1**, wherein a physiological monitor in communication with the acoustic sensor is responsive to the probe-off signal to determine a sensor connected condition or a sensor not connected condition.

7. The acoustic sensor of claim **6**, wherein the acoustic sensor comprises an output that is responsive to both the membrane signal and to the probe-off signal.

8. The acoustic sensor of claim **7**, wherein a sensing circuit responsive to the output produces a sensor signal indicative of an integrity of a connection between the acoustic sensor and the medical patient and based at least in part on the acoustic sensor being in the attached state corresponds to the acoustic vibrations detected by the sensing membrane.

9. The acoustic sensor of claim **8**, wherein the sensing circuit is located on a cable positioned between the acoustic sensor and the physiological monitor, wherein the cable communicatively couples the acoustic sensor to the physiological monitor.

10. An acoustic sensor configured to non-invasively detect acoustic vibrations associated with a medical patient, said acoustic vibrations indicative of one or more physiological parameters of the medical patient, said acoustic sensor comprising:

a sensor support;

at least one sound sensing membrane supported by the sensor support and configured to detect acoustic vibrations associated with a medical patient and produce a membrane signal corresponding to the acoustic vibrations based at least in part on an attached state of the acoustic sensor; and

a probe-off assembly supported by the sensor support, the probe-off assembly configured to produce a probe-off signal responsive to the attached state of the acoustic sensor and to a detached state of the acoustic sensor,

wherein a mechanically active portion of the at least one sound sensing membrane configured to move in response to the acoustic vibrations is further configured to be located between the medical patient's skin and the probe-off assembly when the sensor is in the attached state.

11. An acoustic sensor configured to non-invasively detect acoustic vibrations associated with a medical patient, said acoustic vibrations indicative of one or more physiological parameters of the medical patient, said acoustic sensor comprising:

a sensor support;

at least one sound sensing membrane supported by the sensor support and configured to detect acoustic vibrations associated with a medical patient and produce a membrane signal corresponding to the acoustic vibrations based at least in part on an attached state of the acoustic sensor;

a probe-off assembly supported by the sensor support, the probe-off assembly configured to produce a probe-off signal responsive to the attached state of the acoustic sensor and to a detached state of the acoustic sensor; and

at least one attachment member supported by the sensor support and located in a first position in the detached state of the acoustic sensor and located in a second position in the attached state of the acoustic sensor that is different than the first position,

wherein the probe-off signal is responsive to movement of the attachment member between the first position and the second position to indicate a change in an integrity of a connection between the acoustic sensor and the medical patient.

12. The acoustic sensor of claim **11**, wherein the probe-off assembly further comprises a switch supported by the sensor support, and wherein movement of the at least one attachment member from the first position to the second position actuates the switch.

13. The acoustic sensor of claim **12**, further comprising a rigid shell supported by the sensor support, at least a portion of the shell positioned over the switch.

14. The acoustic sensor of claim **11**, wherein the attachment member comprises a resilient, elongate member.

15. The acoustic sensor of claim **11**, wherein the attachment member extends across the sensor support and beyond opposing sides of the sensor support.

16. The acoustic sensor of claim **11**, wherein the attachment member comprises an adhesive adapted to secure the attachment member to the medical patient's skin.

17. The acoustic sensor of claim **11**, further comprising a resilient portion supported by the sensor support and arranged to bias the attachment member in the first position in the detached state of the acoustic sensor.

18. The acoustic sensor of claim **17**, wherein the resilient portion forms a part of a casing stretched around and encasing at least a portion of the sensor support.

19. A method for determining a connection state between a non-invasive acoustic sensor and a medical patient, the method comprising:

outputting from a non-invasive acoustic sensor comprising a sensor support and a probe-off assembly, an attachment state signal indicating that the acoustic sensor is in an unattached state based at least in part on at least one attachment member of the acoustic sensor being in a first position, the acoustic sensor further comprising at least one sound sensing membrane configured to detect acoustic vibrations indicative of one or more physiological parameters of the medical patient;

outputting the attachment state signal from the acoustic sensor indicating that the acoustic sensor is in an attached state based at least in part on the at least one attachment member moving from the first position to a second position, wherein the attachment state signal indicates a change in an integrity of a connection between the acoustic sensor and the medical patient; and

outputting a data signal from the sensor indicative of the one or more physiological parameters based at least in part on the attachment state signal indicating that the acoustic sensor is in the attached state.

20. An acoustic sensor configured to non-invasively detect a probe-off condition, said acoustic sensor comprising:

a sensor support;

a sound sensing device supported by the sensor support and configured to detect acoustic vibrations associated with a medical patient and produce an acoustic signal corresponding to the acoustic vibrations; and

one or more probe-off elements coupled to at least one of the sensor support or the sound sensing device, the one or more probe-off elements configured to produce a signal indicative of a probe-off condition responsive to the acoustic sensor in a detached state and/or in an attached state, wherein at least a portion of the sensor support is between a patient contact surface of the acoustic sensor and the one or more probe-off elements.

21. The acoustic sensor of claim **20**, wherein the one or more probe-off elements comprise a switch configured to actuate in response to attachment of the sensor to the medical patient.

22. The acoustic sensor of claim **20**, wherein the one or more probe-off elements comprise two conductive elements applied to one or both of the sensor support and the sound sensing device.

23. The acoustic sensor of claim **22**, wherein the two conductive elements comprise conductive films.

24. The acoustic sensor of claim **22**, wherein the signal indicative of the probe-off condition comprises a resistance signal measured with respect to the two conductive elements.

25. The acoustic sensor of claim **24**, wherein a value of the resistance signal that meets a threshold resistance is configured to indicate the probe-off condition.

26. An acoustic sensor configured to non-invasively detect a probe-off condition, said acoustic sensor comprising:

a sensor support;

a sound sensing device supported by the sensor support and configured to detect acoustic vibrations associated with a medical patient and produce an acoustic signal corresponding to the acoustic vibrations; and

one or more probe-off elements coupled to at least one of the sensor support or the sound sensing device, the one or more probe-off elements configured to produce a signal responsive to the acoustic sensor in a detached state and/or in an attached state,

wherein a mechanically active portion of the sound sensing device is configured to move in response to the acoustic vibrations is further configured to be located between the medical patient's skin and the one or more probe-off elements based at least in part on the sensor being in the attached state.

27. An acoustic sensor configured to non-invasively detect a probe-off condition, said acoustic sensor comprising:

a sensor support;

a sound sensing device supported by the sensor support and configured to detect acoustic vibrations associated with a medical patient and produce an acoustic signal corresponding to the acoustic vibrations;

one or more probe-off elements coupled to at least one of the sensor support or the sound sensing device, the one or more probe-off elements configured to produce a signal responsive to the acoustic sensor in a detached state and/or in an attached state; and

at least one attachment member supported by the sensor support and located in a first position in the detached state of the acoustic sensor and located in a second position in the attached state of the acoustic sensor that is different than the first position,

wherein the signal is responsive to movement of the attachment member between the first position and the second position to indicate a change in an integrity of a connection between the acoustic sensor and the medical patient.

* * * * *

专利名称(译)	带探头关闭检测的声学呼吸监测传感器		
公开(公告)号	US9192351	公开(公告)日	2015-11-24
申请号	US13/554929	申请日	2012-07-20
[标]申请(专利权)人(译)	TELFORT VALERY摹 季米特洛夫贝尔巴托夫 WYLIE MARK		
申请(专利权)人(译)	TELFORT瓦列里G. 季米特洛夫，贝尔巴托夫 WYLIE，MARK		
当前申请(专利权)人(译)	Masimo公司		
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发明人	TELFORT, VALERY G. DIMITROV, DIMITAR WYLIE, MARK		
IPC分类号	A61B7/00 A61B7/04 A61B5/145 A61B5/0205 A61B5/024 A61B5/00 A61B5/08 H04R1/46		
CPC分类号	A61B7/04 A61B7/003 A61B5/7203 A61B5/6822 H04R1/46 A61B5/08 A61B5/6833 Y10T29/49005 A61B5/4818 A61B5/0006 A61B5/721 A61B2562/182 A61B5/0816 A61B5/02438 A61B2562/227 A61B5/0205 A61B5/6843 A61B5/145 A61B2562/0204 A61B5/02444 A61B2560/0412		
优先权	61/510926 2011-07-22 US		
外部链接	Espacenet USPTO		

摘要(译)

一种声学传感器，被配置为非侵入性地检测与医疗患者相关联的声学振动。声学振动指示医学患者的一个或多个生理参数。声学传感器可包括传感器支撑件和由传感器支撑件支撑的至少一个声音传感膜。膜可以配置成检测与医疗患者相关的声学振动。膜还可以配置成当声学传感器附接到医疗患者时产生对应于声学振动的膜信号。声学传感器还可以包括由传感器支撑件支撑的探针组件。探针组件可以被配置为响应于声学传感器附接到医疗患者以及声学传感器与医疗患者的分离而产生探针关闭信号。