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(54) **MODULATED PHYSIOLOGICAL SENSOR**

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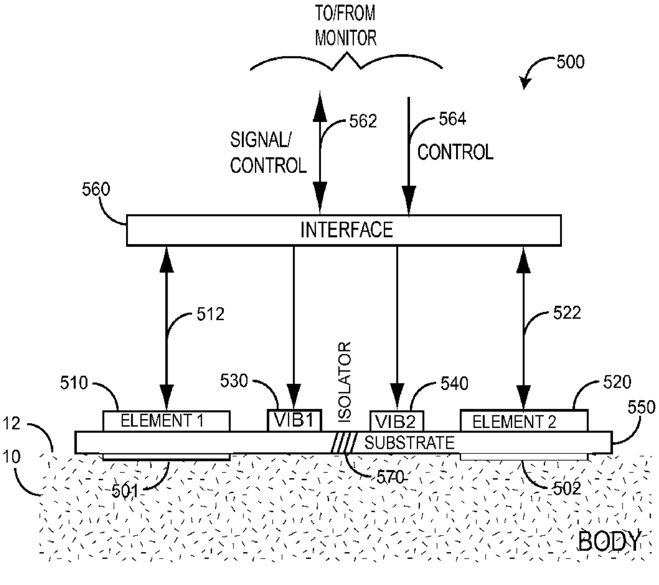
(57) **ABSTRACT**

A modulated physiological sensor is a noninvasive device responsive to a physiological reaction of a living being to an internal or external perturbation that propagates to a skin surface area. The modulated physiological sensor has a detector configured to generate a signal responsive to the physiological reaction. A modulator varies the coupling of the detector to the skin so as to at least intermittently maximize the detector signal. A monitor controls the modulator and receives an effectively amplified detector signal, which is processed to calculate a physiological parameter indicative of the physiological reaction.

8 Claims, 10 Drawing Sheets



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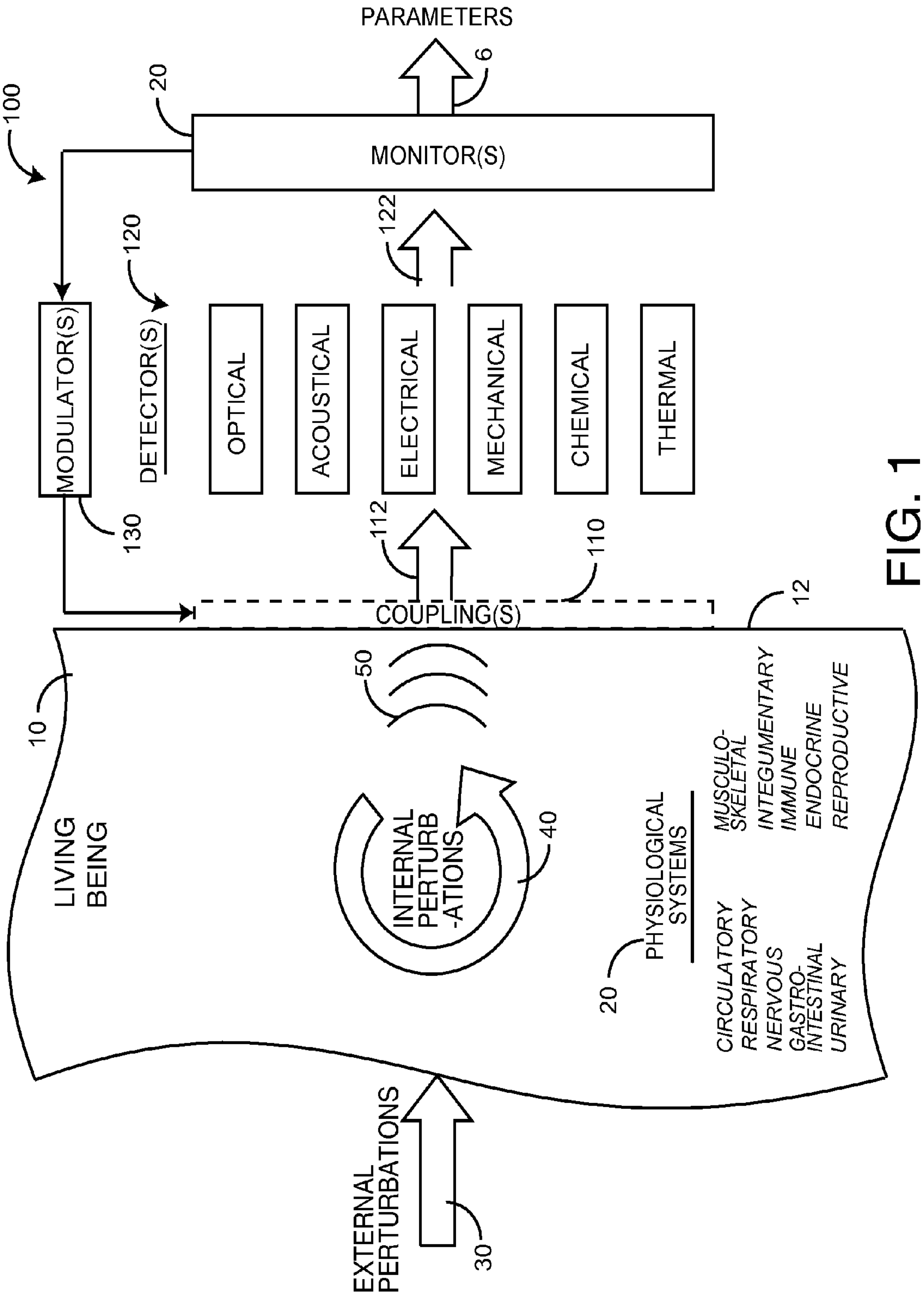
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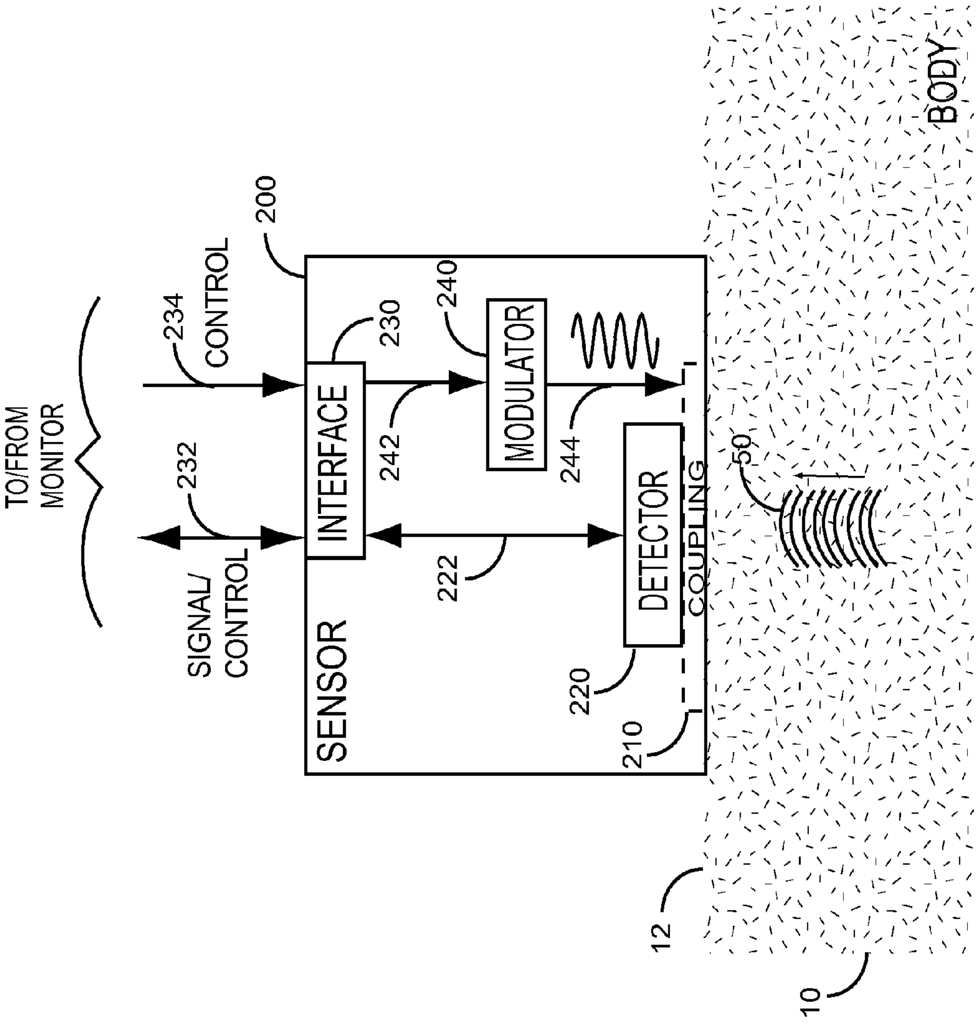
6
20
MONITOR(S)
100
122
120
MODULATOR(S)
DETECTOR(S)
OPTICAL
ACOUSTICAL
ELECTRICAL
MECHANICAL
CHEMICAL
THERMAL
130
112
110
COUPLING(S)
12
10
LIVING BEING
50
INTERNAL PERTURB-ATIONS
40
20
PHYSIOLOGICAL SYSTEMS
CIRCULATORY
RESPIRATORY
NERVOUS
GASTRO-INTESTINAL
URINARY
MUSCULO-SKELETAL
INTEGUMENTARY
IMMUNE
ENDOCRINE
REPRODUCTIVE
EXTERNAL PERTURBATIONS
30

FIG. 1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MONITOR
SIGNAL/
CONTROL
232
CONTROL
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200
SENSOR
INTERFACE
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MODULATOR
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244
222
DETECTOR
220
COUPLING
210
50
BODY
12
10

FIG. 2

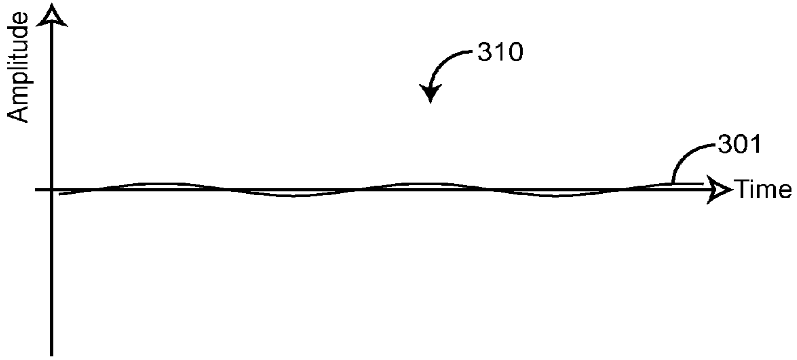


FIG. 3A

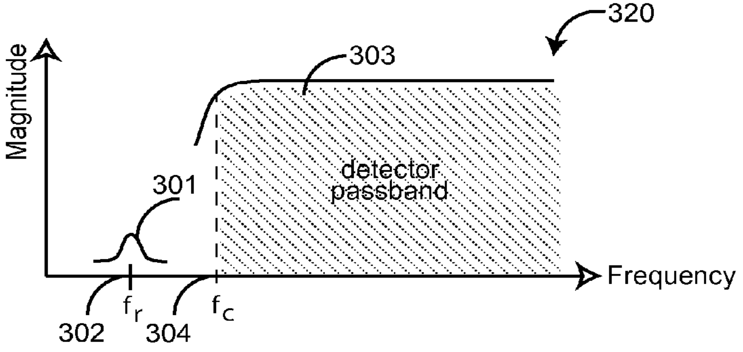


FIG. 3B

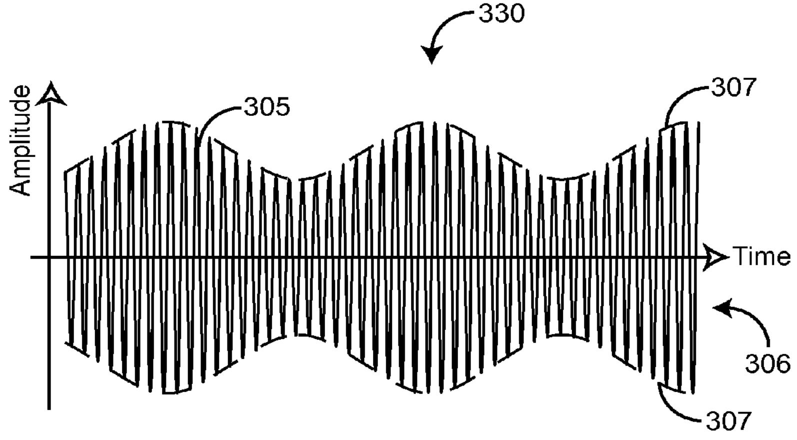


FIG. 3C

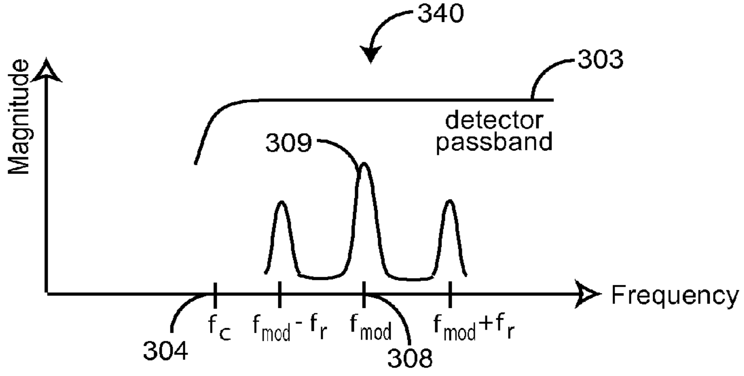
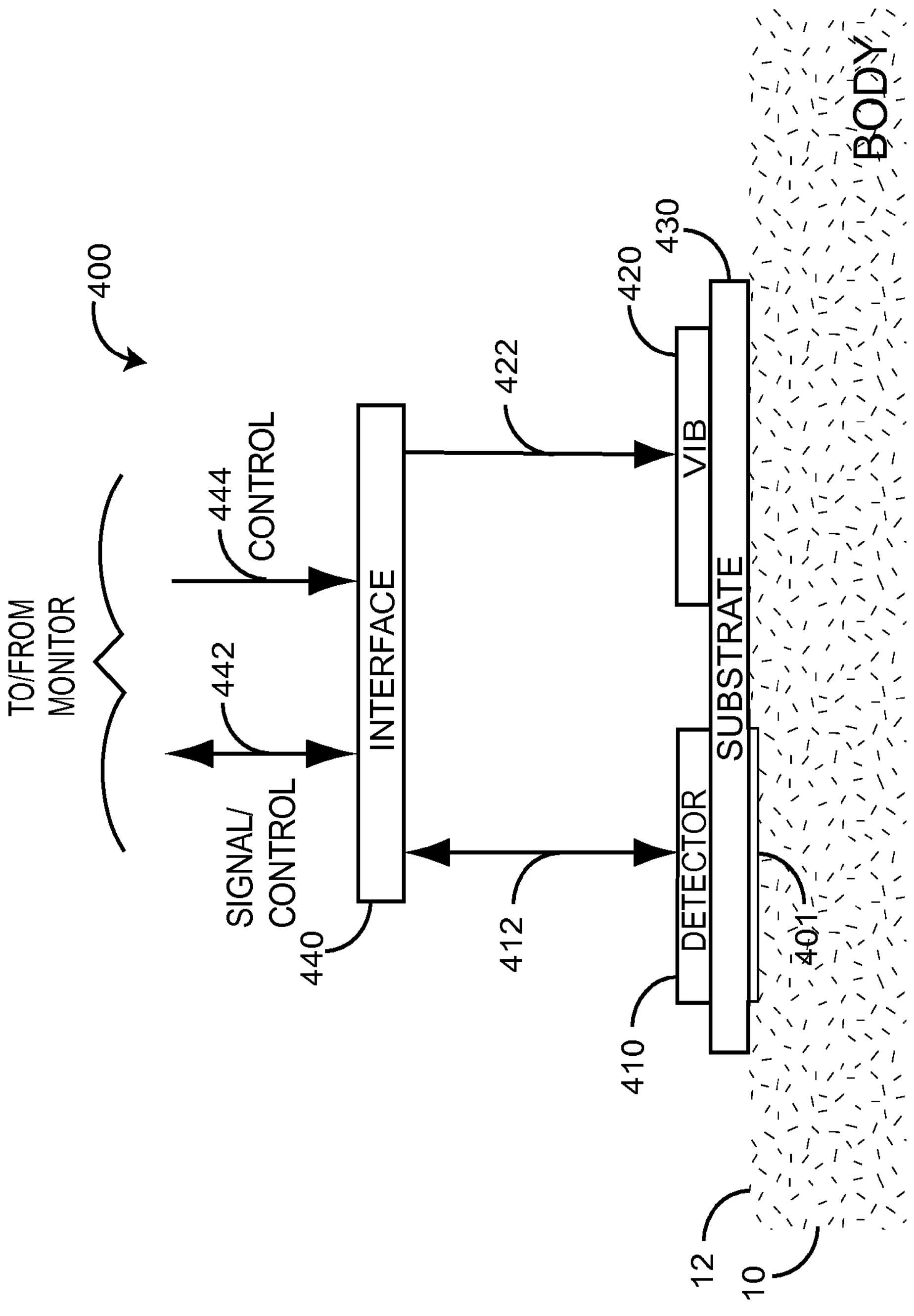


FIG. 3D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444
CONTROL
442
SIGNAL/ CONTROL
INTERFACE
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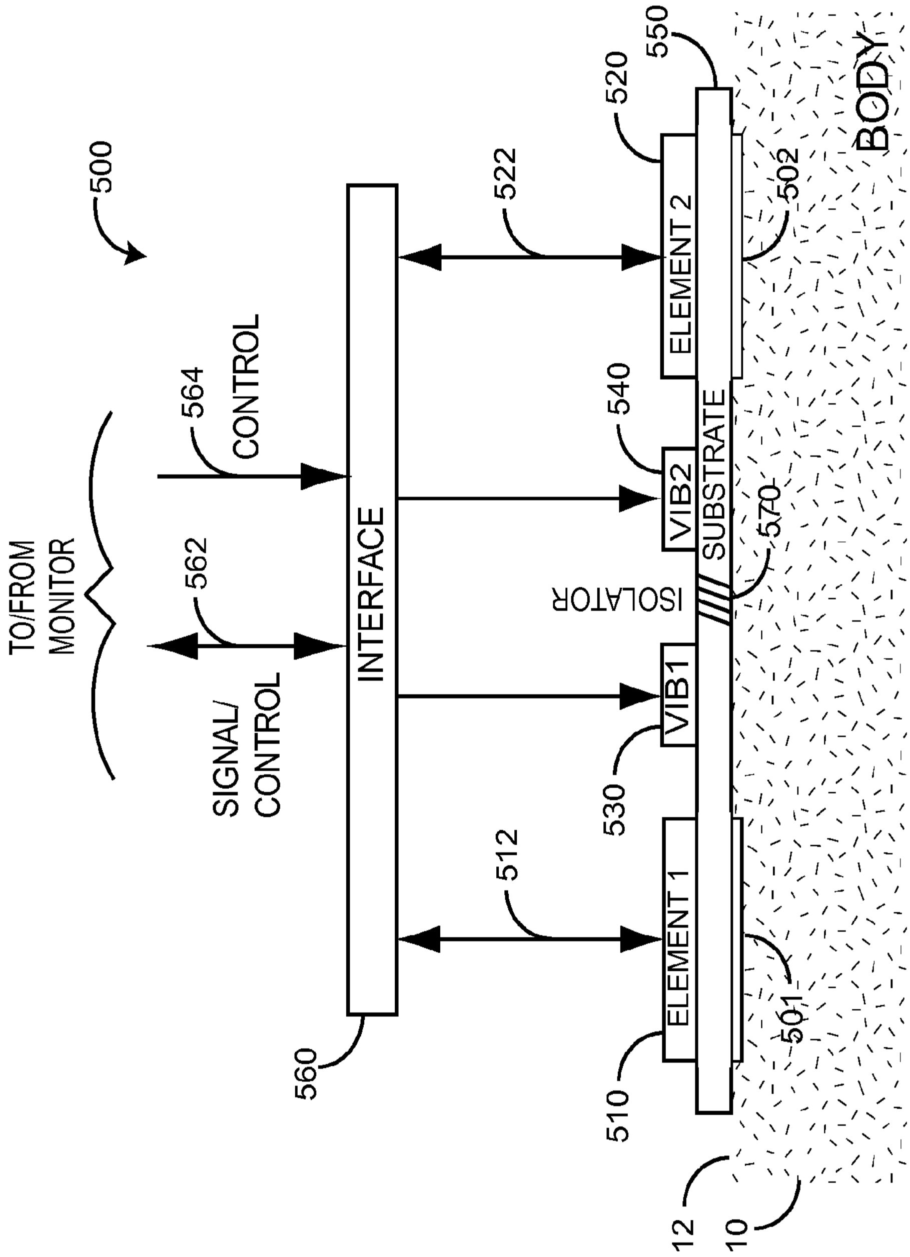
422
412
VIB
420
430
SUBSTRATE
DETECTOR
410
401
BODY
12
10

FIG. 4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SIGNAL/ CONTROL
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564
CONTROL
INTERFACE
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512
522
ELEMENT 1
ELEMENT 2
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520
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530
VIB2
540
SUBSTRATE
ISOLATOR
570
550
501
502
BODY
12
10

FIG. 5

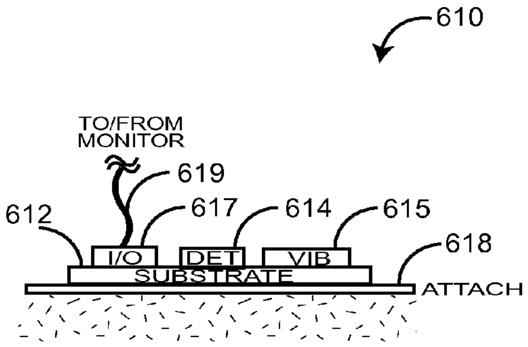

FIG. 6A

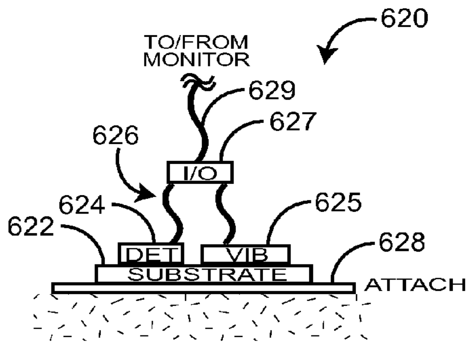

FIG. 6B

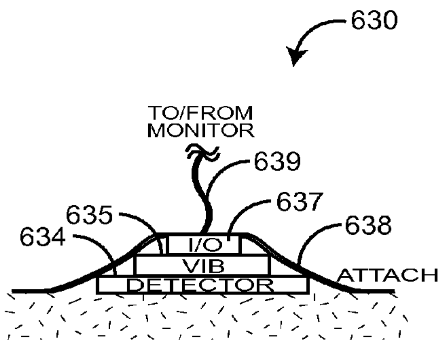

FIG. 6C

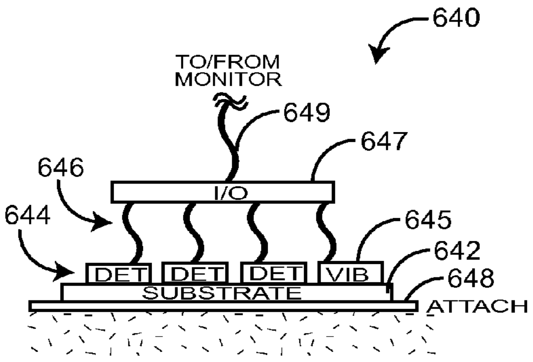

FIG. 6D

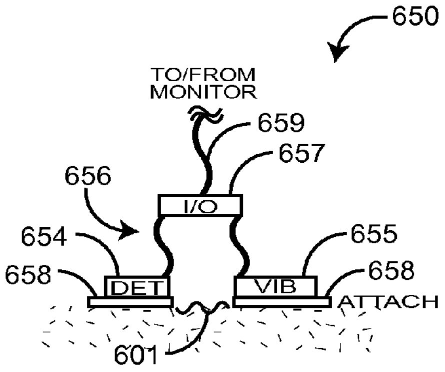

FIG. 6E

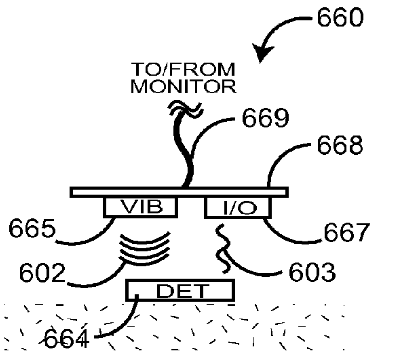

FIG. 6F

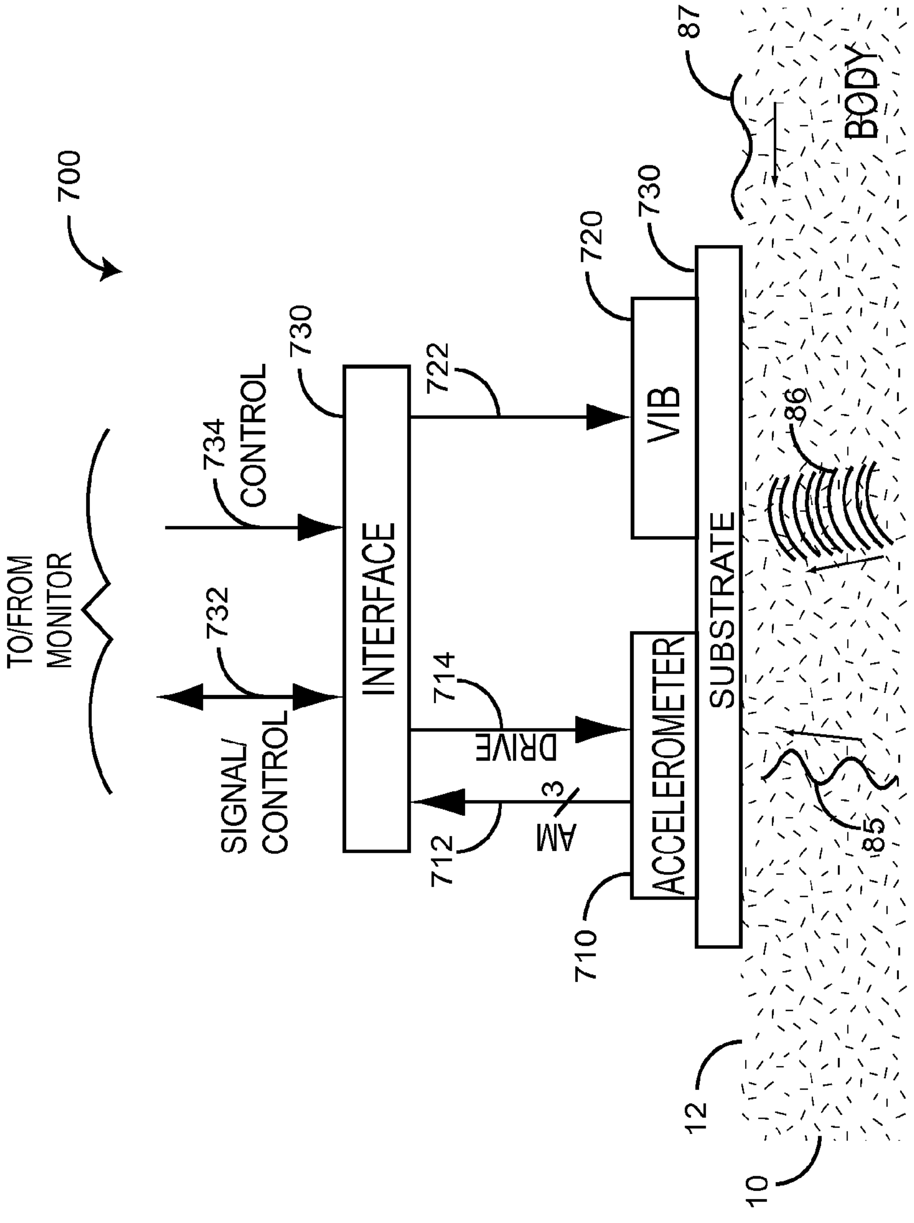
700
TO/FROM MONITOR
SIGNAL/ CONTROL
732
734
CONTROL
730
INTERFACE
722
714
DRIVE
712
AM
3
ACCELEROMETER
710
VIB
720
730
SUBSTRATE
86
85
87
BODY
12
10

FIG. 7

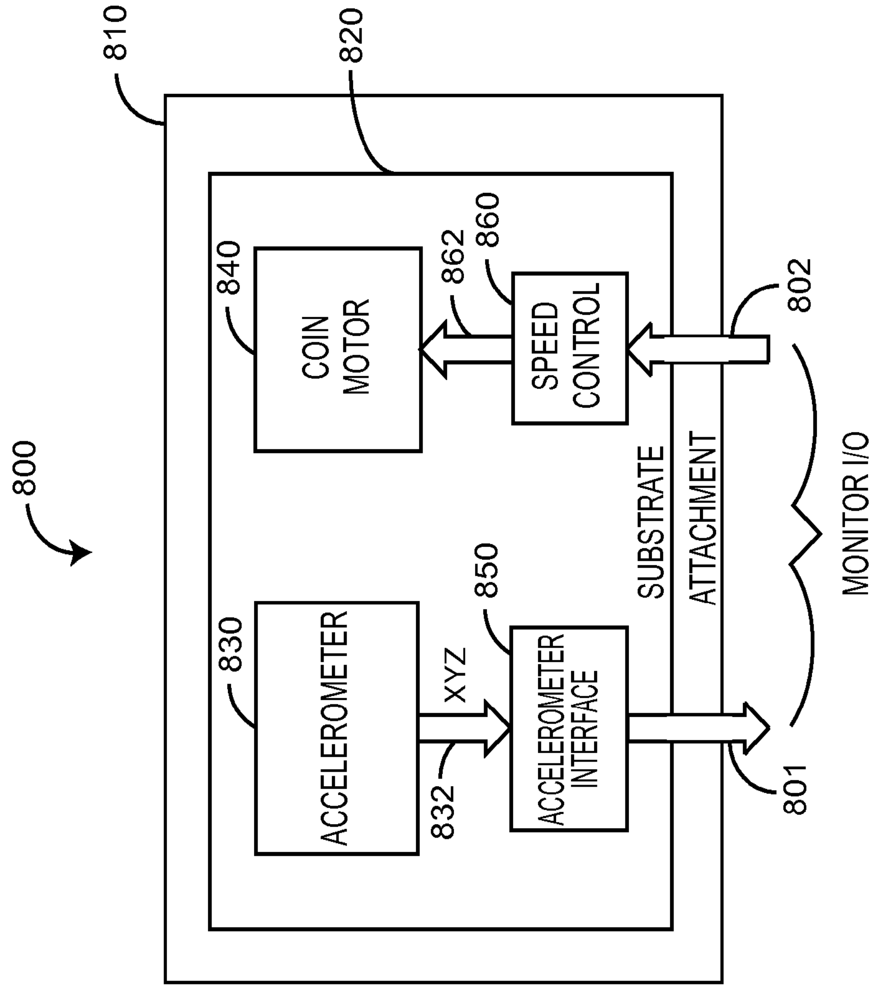
800
810
820
830
ACCELEROMETER
840
COIN MOTOR
XYZ
832
862
850
ACCELEROMETER INTERFACE
860
SPEED CONTROL
SUBSTRATE ATTACHMENT
801
802
MONITOR I/O

FIG. 8

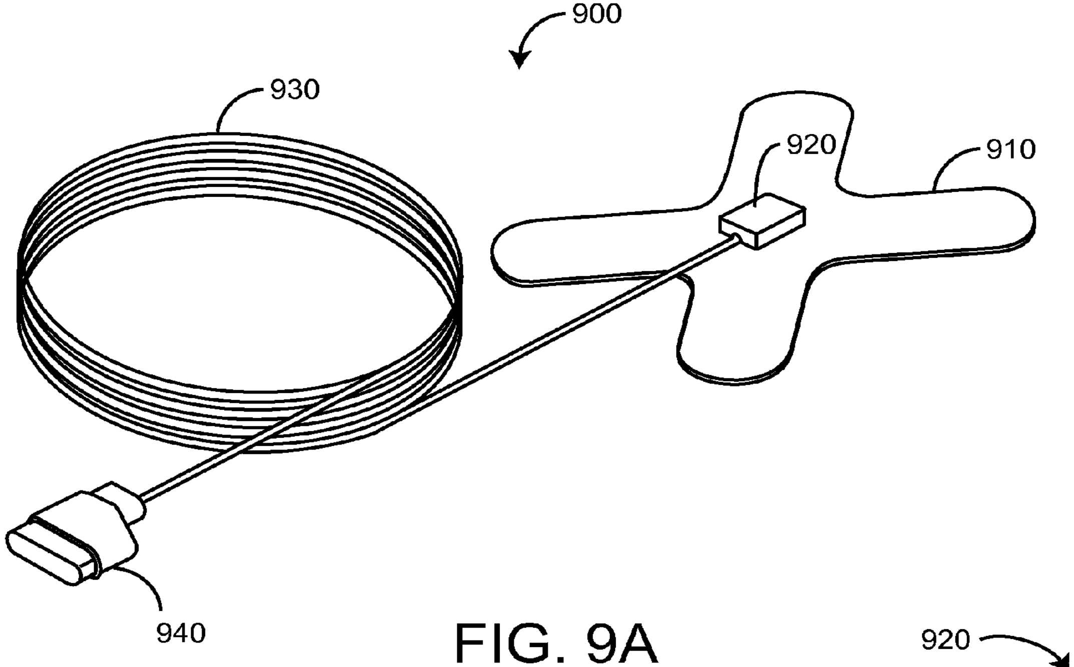

FIG. 9A

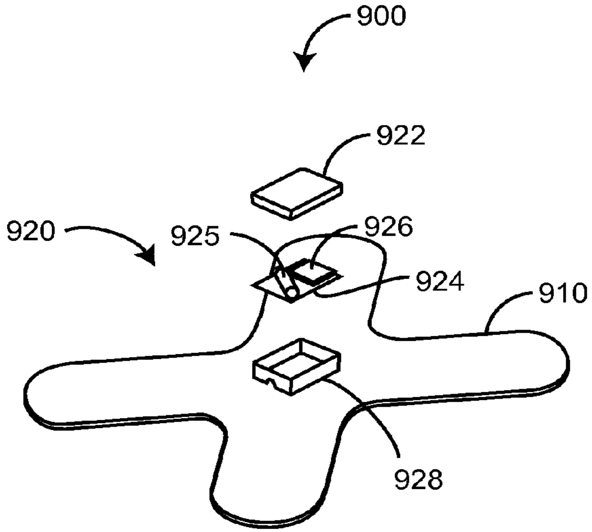

FIG. 9B

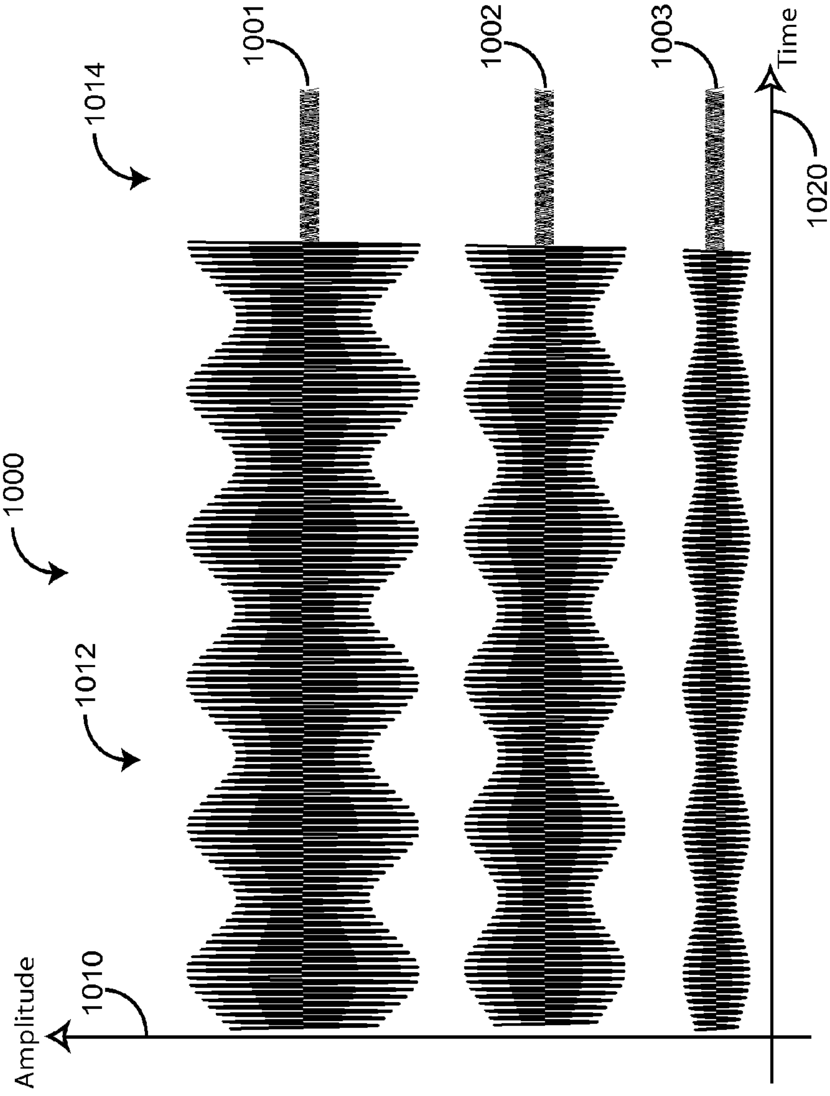

FIG. 10

MODULATED PHYSIOLOGICAL SENSOR

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority benefit under 35 U.S.C. §119(e) to U.S. Provisional Patent Application Ser. No. 61/524,744, filed Aug. 17, 2011, titled Modulating Physiological Sensor and U.S. Provisional Patent Application Ser. No. 61/639,985, filed Apr. 29, 2012, titled Modulated Physiological Sensor, both provisional applications hereby incorporated in their entirety by reference herein.

BACKGROUND OF THE INVENTION

From a physiological perspective, the human body comprises a set of interacting systems, each having specific functions and purposes. These systems maintain the body's internal stability by coordinating the response of its parts to any situation or stimulus that would tend to disturb its normal condition or function. The nervous system includes the central nervous system and the peripheral nervous system. The central nervous system is the brain and the spinal cord. The musculoskeletal system includes the skeleton and attached muscles and includes bones, ligaments, tendons, and cartilage. The circulatory system includes the heart and blood vessels, including arteries, veins and capillaries. The respiratory system includes the nose, trachea and lungs. The gastrointestinal system includes the mouth, esophagus, stomach, intestines, liver, pancreas and gallbladder. The integumentary system includes the skin, hair, nails, sweat glands and sebaceous glands. The urinary system includes the kidneys and bladder. The immune system includes white blood cells, thymus and lymph nodes. The endocrine system includes the pituitary, thyroid, adrenal and parathyroid glands.

Various sensors may be applied for analyzing and measuring the processes occurring in the above-cited physiological systems and for generating physiological parameters indicative of health or wellness as a result. As one example, a pulse oximetry sensor generates a blood-volume plethysmograph waveform from which oxygen saturation of arterial blood and pulse rate may be determined, among other parameters. As another example, an acoustic sensor may be used to detect airflow sounds in the lungs, bronchia or trachea, which are indicative of respiration rate.

SUMMARY OF THE INVENTION

The physiological systems cited above maintain the stability, balance and equilibrium of a living being. Modulation may be advantageously used to accentuate detection of processes occurring within these physiological systems. An example of natural modulation is tissue vibration in the trachea due to the inflow and outflow of air between the lungs and the nose and mouth. This vibration creates sound waves at a higher frequency than the underlying respiration. An acoustic sensor utilizing a piezoelectric device attached to the neck is capable of detecting these sound waves and outputting a modulated sound wave envelope that can be demodulated so as to derive respiration rate. An acoustic respiration rate sensor and corresponding sensor processor is described in U.S. patent application Ser. No. 12/904,789, filed Oct. 14, 2010, titled Acoustic Respiratory Monitoring Systems and Methods, assigned to Masimo Corporation, Irvine, Calif. ("Masimo") and incorporated by reference herein.

Another example of natural modulation is pulsatile arterial blood flow at a peripheral tissue site, such as a fingertip, resulting from pressure waves generated by the heart. An optical sensor generates a plethysmograph waveform responding to changes in a light absorption due to the pulsatile blood flow so as to measure blood composition, such as hemoglobin constituents. This plethysmograph also modulates a respiration envelope that can be demodulated so as to derive respiration rate.

An example of artificial modulation is a physiological sensor having an accelerometer and a vibration element mounted on a substrate so that the vibration element is in mechanical communications with the accelerometer. An interface communicates at least one axis of the accelerometer signal to a monitor. The substrate is attached to the skin surface of a living being, and the vibration element is activated so as to modulate the skin surface coupling at a modulation frequency. In an embodiment, an artificially-modulated sensor is responsive to respiratory-induced movements at the skin surface.

One aspect of a modulated physiological sensor is a noninvasive sensor responsive to a physiological reaction of a living being to an internal or external perturbation that propagates to a surface area of the living being. The modulated physiological sensor has a detector configured to communicate with a surface area of a living being so as to generate a signal responsive to a physiological reaction of the living being to the perturbation. A modulator varies the coupling of the detector to the surface area so as to at least intermittently maximize the detector signal. A monitor controls the modulator and receives a detector signal so as to calculate a physiological parameter indicative of a physiological state of the living being.

In various embodiments, the modulator is a vibration element that mechanically accentuates the coupling of the detector to the surface area. A substrate co-mounts the detector and the vibration element. An attachment releasably affixes the substrate, detector and vibration element to the surface area. In an embodiment, the detector is an accelerometer and the vibration element is a coin motor. The substrate is a circuit board that mechanically mounts and electrically interconnects the accelerometer and coin motor. The attachment is a tape having a sticky side that attaches to the surface area and a housing side that encloses the circuit board.

Another aspect of a modulated physiological sensor is a sensing method the provides a detector responsive to a physiological wave generated within a living being that propagates to a skin surface and couples the detector to the skin surface. The detector coupling is modulated so as to generate a modulated detector output indicative of the physiological wave. The detector signal is demodulated so as to derive a physiological signal, and a physiological parameter is determined from the physiological signal. In various embodiments, the modulation is vibration of the detector by co-mounting the detector and a vibration element. The detector and the vibration element may be co-mounted to a common substrate, which is attached to the skin surface. A second detector and a second vibration element may be mounted to the common substrate and isolated from the combination detector and vibration element.

A further aspect of a modulated physiological sensor is a detector means for responding to physiological propagations reaching a skin surface of a living being and a modulator means for varying the coupling of the detector means to the skin surface. A monitor demodulates a sensor signal from the detector means so as to analyze the physiological propagations and generate a physiological parameter output. In various embodiments, a substrate means mounts the detector means and the modulator means and an attachment means secures the substrate to the skin surface. A control signal from the monitor sets a frequency of the modulator means above a low frequency cutoff of the detector means. In an embodiment, the modulator means is a vibration element, the detector means is multiple detectors, the modulator means is multiple vibration elements and the substrate means incorporates at least one isolation element so as to isolate detector and vibration element pairs. In an embodiment, the vibration element remotely modulates the detector via an acoustic wave.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a general block diagram of a modulated physiological sensor in communications with the physiological systems of a living being;

FIG. **2** is general block diagram of a modulated physiological sensor embodiment;

FIGS. **3**A-D are amplitude vs. time and corresponding amplitude vs. frequency graphs of a physiological reaction and a corresponding modulated and detected reaction;

FIG. **4** is a general block diagram of a vibration-modulated physiological sensor embodiment;

FIG. **5** is a general block diagram of a multi-element, vibration-modulated sensor embodiment;

FIGS. **6**A-F are side views of various modulated physiological sensor embodiments;

FIG. **7** is a general block diagram of a vibration-accelerometer physiological sensor embodiment;

FIG. **8** is a detailed block diagram of a vibration-accelerometer physiological sensor embodiment;

FIG. **9**A-B are assembled and exploded perspective views, respectively, of a vibration-accelerometer physiological sensor embodiment; and

FIG. **10** is a graph of a vibration-accelerometer physiological sensor output versus time illustrating three-axis of respiration envelopes with the vibration turned on and off.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** generally illustrates a modulated physiological sensor **100** in communications with the physiological systems **20** of a living being **10**. Physiological reactions **50** to external **30** or internal **40** perturbations propagate to the body surface **12** and are coupled **110** to one or more detectors **120**. These physiological reactions **50** are indicative of states and processes of the physiological systems **20**. The detectors **120** are responsive to coupled physiological reactions **112** so as to generate detector outputs **122**. One or more monitors **20** are responsive to the detector outputs **122** so as to compute physiological parameters **6** that quantify the states and processes of the physiological systems **20**. The coupling(s) **110** is advantageously modulated **130** under control of the monitor(s) **20** so as to accentuate detection of the physiological reactions **50**, as described in further detail below.

As shown in FIG. **1**, detectors **120** include any device that is responsive to the coupled physiological reactions **112** such as optical, acoustical, electrical, mechanical, chemical and thermal mechanisms, to name a few. The detector outputs **122** may include blood photo-plethysmographs, ECG, EEG and body sound waveforms; indications of skin color, temperature, movement or pressure; and chemical responses and measurements of moisture, breath, sweat or odors, to name a few. The monitor(s) **20** may include any or all devices or combinations of devices that are responsive to the detector outputs **122** alone or in combination so as to calculate or otherwise derive physiological parameters **6** that measure, graph, quantify or otherwise indicate one or more aspects of the physiological systems **20** and corresponding states and processes corresponding to the physiological reactions **50**. Parameter examples include circulatory system measurements such as oxygen saturation, heart rate, blood glucose and blood pressure; and respiratory system measurements such as respiration rate and volume, to name but a few. Parameters **6** can also include indications of specific abnormal physiological conditions such as sleep apnea, anemia and hypoglycemia, to name a few.

Also shown in FIG. **1**, external perturbations **30** may be natural, such as changes to a person's physical environment including temperature, pressure, light and sound, for example. External perturbations **30** also may be artificial, such as the mechanical pressure induced by a respirator for breathing assistance or by a pulser on a fingertip for measuring venous oxygen saturation as examples. Internal perturbations **40** include normal and abnormal functioning and interactions of various physiological systems **20**, including circulatory and respiratory functions, to name a few. Internal perturbations **40** may also be artificial, such as due to a pacemaker or other implanted device. Physiological reactions **50** resulting from external perturbations **30** or internal perturbations **40** include, as examples, a body surface expansion or contraction due to, say, lung inflation/deflation; an acoustic wave arriving from within the body to the body surface due to a heart beat or bowel sound; or a transverse wave traveling along the body surface due to a muscle spasm. In general a physiological reaction **50** may be an optical, acoustical, electrical, mechanical, chemical or thermal impulse, wave or other variation or change. Further, external perturbations **30** or internal perturbations **40** need not be the same type or kind (e.g. optical, acoustical, electrical, mechanical, chemical or thermal) as the corresponding physiological reaction **50** or the detector element **120** responsive to the physiological reaction **50**. For example, an injection (external chemical perturbation) may trigger a heart arrhythmia that results in an acoustic and a mechanical wave (physiological reaction) that propagates to the skin surface and is detected by an acoustical or mechanical sensor, or both. Further, the heart arrhythmia may result in an arterial pulse abnormality that changes the optical characteristics of a tissue site as measured by an optical sensor attached to the tissue site.

FIG. **2** illustrates a modulated physiological sensor **200** embodiment that attaches to a body surface **12** and is configured to respond to physiological reactions **50**, as described above. The sensor **200** has a coupling **210**, a detector **220**, an interface **230** and a modulator **240**. A monitor (not shown) outputs controls **232**, **234** to the sensor **200** and receives signals **232** from the sensor **200**. The interface **230** communicates detector signals **222** to the monitor in response to drive controls **222** to the detector **220**. The interface **230** also communicates a modulator control **242** to the modulator **240**. The modulator **240** responds to the modulator control **242** so as to generate a modulation **244** to the coupling **210**.

As shown in FIG. **2**, the modulator **240** varies the coupling **210** of the detector **220** to the body surface **12** and hence to the physiological reaction **50**. In particular, the body surface **12** of a person, including skin and underlying tissues, varies by individual and, indeed, by location on a particular individual. These variations are in shape, texture, color and elasticity to name a few. As such, a fixed coupling is unlikely to provide an optimum body surface/detector interface. Indeed efficient and effective body surface/detector coupling is an issue for most if not all physiological sensors. For example, common ECG electrodes require a conductive gel so as to effectively couple to a skin surface. The modulator **240** advantageously continuously varies the detector coupling **210** to the skin surface across a range of contact forces at the skin/sensor interface. For an electrical detector, say, this varied coupling alters the detector electrical resistance at the skin surface over a range of values. For a mechanical detector, the varied coupling alters the mechanical impedance of the detector at the skin surface over a range of values. For an acoustic detector, for example, the varied coupling alters the acoustical impedance of the detector at the skin surface over a range of values. As a result of this variable detector coupling to the skin surface, the detector has maximal and minimal coupling each modulation cycle. Further, the modulation frequency may be set above any detector low frequency response cutoffs. Accordingly, the modulation advantageously amplifies the detector signal **222**, as described in further detail with respect to FIGS. **3**A-D, below.

FIGS. **3**A-D illustrate a physiological system reaction to perturbations and a corresponding modulated and detected sensing of the reaction. FIG. **3**A is an exemplar time domain graph **310** of a relatively low amplitude, low frequency physiological system reaction **301** to some form of internal or external perturbation. FIG. 3B is a corresponding exemplar frequency domain graph **320** of the physiological system reaction **301**. The physiological reaction **301** may be difficult to detect due to either a small amplitude signal **301** or a signal frequency f_r **302** less than the detector cutoff frequency f_c **304**, i.e. outside the detector passband **303**.

FIG. 3C is an exemplar time domain graph **330** of a modulated detector response **305** to the reaction **301** (FIG. 3A) described above. The response **305** has a modulation **306** and an envelope **307**. In particular, the physiological sensor **200** (FIG. **2**) has a modulated coupling **210** (FIG. **2**) that achieves or approaches a maximal coupling of a detector **220** (FIG. **2**) to a body surface **12** (FIG. **2**) at least once per modulation cycle, as described with respect to FIG. **2** above. Accordingly, the modulated detector **220** (FIG. **2**) accentuates the physiological signal **301** (FIG. **3**A) during the maximal coupling and de-accentuates the physiological signal **301** (FIG. **3**A) during the minimal coupling. This cyclical accentuation/de-accentuation generates an envelop **307** that is, effectively, an amplification of the physiological reaction **301** (FIG. **3**A).

FIG. 3D is an exemplar frequency domain graph **340** of a modulated physiological sensor response **305** (FIG. 3C). In various embodiments, the modulation frequency f_{mod} **308** is set substantially higher than any low frequency cutoff f_c **304** of the detector so that the sensor response **305** is well within the detector passband **303** (FIG. 3B).

As described with respect to FIGS. 3A-D, in various embodiments an amplified version of the physiological response **301** (FIG. 3A) is derived from the sensor response **305** (FIG. 3C) by any of various well-known AM demodulation techniques. These include envelope detection with a rectifier or product detection utilizing multiplication by a local oscillator, to name a few.

FIG. **4** illustrates a vibration-modulated physiological sensor **400** embodiment. The sensor **400** has a detector **410**, a vibration element ("vib") **420**, a substrate **430** and an interface **440** to a monitor. The detector **410** and the vib **420** are both mounted to the substrate **430**. In an embodiment, the detector **410** is mounted so as to directly couple **401** to the body surface **12**. For example, the detector **410** may be mounted through the substrate **430**, as shown. In other embodiments, the detector **410** is attached adjacent the substrate **430**. In additional embodiments, the detector **410** may not contact the body surface **12** at all, such as with an accelerometer-based detector described with respect to FIGS. **7**-**10**, below. In an embodiment, the vib **420** is a coin motor, as described with respect to FIGS. **7**-**10**, below. In other embodiments, the vib **420** is any of various off-balance motors, voice coils or similar electro-mechanical devices. In further embodiments, the vib **420** is any mechanical, electromagnetic, piezoelectric, pneumatic, electric, acoustic or magnetic device that vibrates in response to an electrical signal.

As shown in FIG. **4**, the detector **410**, and hence the coupling **401**, is vibration-modulated **420** via the substrate **430**. The substrate **430** may be any material that effectively transmits or conducts vibrations from the vib **420** to the detector **401**. In an advantageous embodiment, the substrate **430** is a circuit board material that provides mechanical mounts for and supports electrical interconnects between the sensor components.

Also shown in FIG. **4**, a monitor (not shown) outputs controls **442**, **444** to the sensor **400** and receives signals **442** from the sensor **400**. The interface **440** communicates detector signals **412** to the monitor in response to drive controls **412** to the detector **410**. The interface **440** also communicates a vibration control **422** to the vib **420**. The vib **420** responds to the vibration control **422** so as to generate a modulation to the coupling **401** via the substrate **430**. In various embodiments, the detector **410** may be mechanical, such as an accelerometer described with respect to FIGS. **7**-**10**, below. In other embodiments, the detector **410** may be electrical, such as an electrode for sensing ECG or EEG signals; or optical such as a photodiode; or acoustical, such as a piezoelectric device; or thermal, such as a thermopile, pyrometer, thermistor, thermocouple, IR photodiode or temperature diode, to name a few.

FIG. **5** illustrates a multiple-element, vibration-modulated sensor **500** embodiment having a two or more sensor elements **510**, **520**, one or more vibration elements (vibs) **530**, **540**, a substrate **550** and an interface **560** to a monitor. The sensor elements **510**, **520** may each be detectors or a combination of one or more detectors and one or more emitters. In an embodiment, the sensor elements **510**, **520** are different types of detectors. For example, element1 **510** may be mechanical and element2 may be electrical. In an embodiment, the sensor elements **510**, **520** may be an emitter and a corresponding detector. For example, element1 **510** may be an LED for illuminating a tissue site and element2 **520** may be a optical detector, such as a diode or diode array, for receiving the LED illumination after attenuation by the tissue site. Advantageously, multiple elements **510**, **520** on a single substrate **550** provide an array of like sensors for increased detection capability or for directional sensing capability, such as determining the source of a body sound as but one example. Advantageously, multiple elements **510**, **520** on a single substrate **550** provide an array of different sensors in a single sensor package for simultaneous detection and analyses of multiple types or kinds of physiological responses to the same or different external or internal perturbations.

As shown in FIG. **5**, multiple vibs **530**, **540** may be separated by a substrate isolator **570**. In this manner, vib1

530 solely effects the coupling **501** of element1 **510** to a body surface **12** and, likewise, vib2 **540** solely effects the coupling **502** of element2 **520** to a body surface **12**. Multiple isolated vibs **530**, **540** advantageously allow each vib **530**, **540** output to be adapted or otherwise suited to a particular element **510**, **520**, both in terms of amplitude and frequency. In an embodiment, the isolator **570** is a material that significantly attenuates mechanical/acoustical waves at the vib frequency or frequencies.

Also shown in FIG. **5**, a monitor (not shown) outputs controls **562** to the sensor **500** and receives signals **562** from the sensor **500**. The interface **560** communicates element signals **512**, **522** to the monitor in response to drive controls **512**, **522** to the elements **510**, **520**. The interface **560** also communicates vibration (vib) controls **564** to the vibs **530**, **540**. The vibs **530**, **540** respond to the vib controls **564** so as to generate a modulation to their respect couplings **501**, **502**.

FIGS. **6**A-F illustrate various modulated physiological sensor configurations. As shown in FIG. **6**A, an integrated sensor embodiment **610** has a substrate **612**, a detector **614**, a vibration element (vib) **615**, I/O (input/output) **617**, an attachment **618** and electrical communication **619** to a monitor or similar device (not shown). The substrate **612** mounts the detector **614**, vib **615** and I/O **617**. In an embodiment, the substrate **612** also provides electrical trace interconnects between the I/O and both the detector **614** and vib **615**. The I/O **617** transmits/receives sensor signals/controls and, in particular, drive to the vib **615** and signals from the detector **614**. The attachment **618** adheres the substrate **612** and mounted components **614**-**617** to a body surface. In an embodiment, the detector **614** is mounted through the substrate **612** so as to couple directly to a body surface or via the attachment **618**. The vib **615** advantageously modulates the coupling of the detector **614** to the body surface via the substrate **612** on which the detector **614** and vib **615** are co-mounted.

As shown in FIG. **6**B, a semi-integrated sensor embodiment **620** has a substrate **622**, a detector **624**, a vib **625**, I/O **627**, an attachment **628** and electrical communication **629** to/from a monitor or other control or display device. The semi-integrated sensor embodiment **620** is similar to the integrated sensor embodiment **610** except that the I/O **627** is external to the sensor **620** and may be mounted in the monitor (not shown) or in a pod (not shown) between the sensor **620** and monitor. The I/O **627** is in electrical communications **626** with the detector **624** and vib **625**, such as via cabling or other interconnect technology. The I/O **627** is also in electrical communications **629** with a monitor.

As shown in FIG. **6**C, a substrate-less sensor embodiment **630** has a detector **634**, a vib **635**, I/O **637**, an attachment **638** and electrical communications **639**, which transmits signals and controls between the I/O **637** and a monitor or similar device (not shown). In this embodiment, the detector **634** or more specifically the detector package, such as a chip carrier, substitutes for a substrate. Accordingly, the vib **635** and I/O **637** are mounted within or on or otherwise directly coupled to the detector **634** package so that the detector **634** package is directly coupled to the body surface and held in place with the attachment **638**. In an embodiment, the attachment **638** is simply an adhesive layer on the detector **634** package.

As shown in FIG. **6**D, a sensor array embodiment **640** has a substrate **642**, multiple detectors **644**, a vib **645**, I/O **647**, an attachment **648** and electrical communication **649**. The sensor array embodiment **640** is similar to the semi-integrated embodiment **620** (FIG. **6**B) except for the multiple detectors **644**. The detectors **644** may be all the same device type (mechanical, electrical, acoustical, etc.), all different or a mixture of one or more sub-arrays of the same device type with one or more different device types. Advantageously, multiple detectors **644** on a single substrate **642** provide an array of like sensors for increased detection capability or for directional sensing capability, such as determining the source of a body sound. Advantageously, multiple detectors **644** on a single substrate **642** provide an array of different detectors in a single sensor package for simultaneous detection and analyses of multiple types or kinds of physiological responses to the same or different external or internal perturbations. Advantageously, a mix of detectors and transmitters (not shown), such as one or more LEDs and one or more photodiode detectors, provide active sensing capabilities, such as illuminating and analyzing arterial (pulsatile) blood flow. Advantageously, one or more vibs **645** may provide both modulation and an active pulse for, say, analyzing non-pulsatile (venous) blood flow, as but one example.

As shown in FIG. **6**E, a non-integrated sensor embodiment **650** has a detector **654**, a vib **655** and attachments **658**. The detector **654** and vib **655** are separately attached **658** to a body surface. The I/O **657** is in electrical communications **656** with the detector **654** and vib **655**, such as via cabling or other interconnect technology, including wireless. Further, the I/O **657** is external to the sensor **650** and may be mounted in the monitor (not shown) or in a pod (not shown) between the sensor **650** and monitor with electrical communications **659** between the I/O **657** and the monitor. Advantageously, the vib **655** is attached to the body surface in close proximity to the detector **654** so that surface waves **601** generated by the vib in the body modulate the coupling between the detector **654** and the body surface.

As shown in FIG. **6**F, a remote sensor embodiment **660** has a detector **664** and a modulation module **665**. The modulation module **668** has a vib **665** and I/O **667**. Advantageously, the vib **665** remotely modulates the detector **664** when brought into proximity to the detector **664**. In particular, the vib **665** generates an acoustic wave **602** that vibrates the detector so as to modulate the detector coupling to the body surface. In particular, the acoustic wave **602** propagates through media intervening between the vib **665** and the detector **664**. That media may be an air gap when the module **668** is positioned immediately over the detector **664** or the media may be tissue when the module **668** is positioned immediately over or on the body surface proximate the detector **664**.

FIG. **7** generally illustrates a modulated physiological sensor **700** embodiment having an accelerometer **710** and a vibration element (vib) **720** mounted on a common substrate **730**. An attachment (not shown) adheres or otherwise couples the substrate **730** to a body surface **12**. The accelerometer **710** has three outputs **712** responsive to accelerations in three dimensions (x, y, z) advantageously enabling the sensor **700** to detect both the amplitude, direction and/or type of propagations (translational **85**, **87** and longitudinal **86**, **88**) and whether the propagations are body waves **85**, **86** or surface waves **87**. The vib **720** mechanically modulates the coupling of the substrate **730** and, accordingly, the coupling of the accelerometer **710** to the body surface **12**. The vib **720** frequency is selected to be substantially higher than the frequency of the propagations **85**-**88**. As such, the accelerometer x, y and z outputs **712** are each amplitude modulated (AM) representations of the propagations **85**-**87**. Advantageously, the modulated coupling substantially amplifies the propagations due to a peak AC coupling occurring once every cycle of the vib. That peak AC coupling is substantially greater than can be practically achieved with any static coupling of the accelerometer to the body surface **12**. Accordingly, very low amplitude propagations can be detected and measured to yield physiological parameters. See, for example, a respiration rate sensor described with respect to FIGS. **8-10**, below.

FIG. **8** is a detailed block diagram of a vibration-modulated physiological sensor **800** embodiment. The sensor **800** has an attachment **810**, a substrate **820**, an accelerometer **830**, a coin motor **840** that generates vibration modulation, an accelerometer interface **850**, a speed control **860** and monitor inputs/outputs (I/O) **801**, **802**. In an embodiment, the accelerometer **830** is an LIS352AX±2 g full scale, analog output, 3-axis (X, Y and Z) linear accelerometer available from STMicroelectronics, Geneva, Switzerland. In an embodiment, the coin motor **840** is a 10 mm coin motor **310-101** available from Precision Microdrives Ltd., London, UK. In an embodiment, the substrate **820** is a circuit board material that mechanically mounts and electrically interconnects the accelerometer **830**, the coin motor **840**, the accelerometer interface **850** and the speed control **860**. In an embodiment, the attachment **810** is a sticky tape that mounts the sensor **800** to a body surface of a living being. In an embodiment, the monitor I/O **802** to the speed control is via a I^2C bus. In an embodiment, the monitor I/O **801** to the accelerometer **830** includes a multiplexer control input to the accelerometer **830** to select one of the X, Y and Z axis for the accelerometer output **832** to the monitor. In another embodiment, all of X, Y and Z axes are simultaneously provided on the accelerometer output **832**.

FIGS. **9**A-B are assembled and exploded illustrations, respectively, of a vibration-modulated (vib) physiological sensor embodiment **900** that can be attached to a skin surface proximate various parts of a person's body, such as the chest, ribs, stomach, waist, arms or back so as to, for example, determine respiration-related parameters. In another embodiment, a modulated physiological sensor **900** may have an optical sensor (emitter and detector) combined with the accelerometer and vib. In this manner, the sensor can generate physiological measurements of pulsatile blood flow for blood constituent analysis, physiological measurements of non-pulsatile (venous) blood flow artificially pulsed by the vib and respiration measurements based upon either or both of pleth-modulated optical sensor waveforms and vib-modulated mechanical (accelerometer) waveforms.

FIG. **10** is a vibration-accelerometer physiological sensor output **1000** illustrating three-axis respiration envelope amplitudes **1010** versus time **1020**. The vibration continuously modifies the coupling of the accelerometer to the skin, which effectively multiples the measured acceleration due to respiration by that due to the vibration. This yields AM modulation waveforms **1001-1003** that display a (greatly magnified) respiration envelope. This effect is amply illustrated in comparing the difference in the accelerator response when the vibration (coupling modulator) is turned on **1012** and off **1014**.

There are various applications for a modulated physiological sensor, as described above. A chest mounted sensor could monitor for sleep apnea at home, as well as in the hospital for patients receiving narcotics in the general wards. An abdomen-mounted sensor could monitor bowel sounds to give a quantifiable measurement to peristalsis. A dual sensor configuration, with one sensor mounted on the upper part of the abdomen and one on the lower part, is used for diagnosing bowel obstruction, small bowel volvulus or intussusception. A sensor mounted over the radial artery would yield a semi-continuous blood pressure measurement.

Another configuration is a screening tool for sub-clinical stenosis of major vessels. For example, rather than placing a stethoscope over the carotid arteries or the abdomen to listen to flow through the aorta, a modulated sensor could give a more quantifiable measurement of stenosis, one level better than auscultation but one level below imaging. Another application is the differential diagnosis of heart murmurs aided by noise cancellation of breathing and other mechanical movements so as to distinguish distinctive murmur patterns (e.g. crescendo/decrescendo).

A modulated physiological sensor has been disclosed in detail in connection with various embodiments. These embodiments are disclosed by way of examples only and are not to limit the scope of the claims that follow. One of ordinary skill in art will appreciate many variations and modifications.

What is claimed is:

1. A modulated physiological sensor for determining a physiological parameter, the modulated physiological sensor comprising:

- an accelerometer coupled with a surface area of a skin of a living being, said accelerometer configured to detect a physiological signal responsive to a physiological process of the living being, wherein the physiological process comprises a respiration process;
- an emitter that emits light towards the surface area of the skin of the living being;
- a detector that detects the emitted light after attenuation from the skin of the living being, the detector having a cutoff frequency;
- a first modulator that varies a coupling of the detector to the surface area at a first modulation frequency greater than the cutoff frequency, thereby at least modulating the detected light attenuation signal at the first modulation frequency greater than the cutoff frequency;
- a second modulator that provides an active pulsation to the skin of living being, wherein the accelerometer, the emitter, the detector, the first modulator, and the second modulator are mounted on a single substrate; and
- a monitor that controls the first modulator to generate physiological measurement of pulsatile blood flow for blood constituent analysis and the physiological signal from the accelerator and controls the second modulator to generate physiological measurement of non-pulsatile blood flow.

2. The modulated physiological sensor according to claim **1** wherein the first modulator comprises a vibration element.

3. The modulated physiological sensor according to claim **2** further comprising a detector substrate that co-mounts the detector and the vibration element.

4. The modulated physiological sensor according to claim **3** further comprising an attachment that releasably affixes the detector substrate, the detector and the vibration element to the surface area.

5. The modulated physiological sensor according to claim **4** wherein the monitor further detects direction and type of propagations from at least one of X, Y, and Z axis components detected from the accelerometer.

6. The modulated physiological sensor according to claim **5** wherein the vibration element comprises a coin motor.

7. The modulated physiological sensor according to claim **6** wherein the substrate comprises a circuit board that mechanically mounts and electrically interconnects the detector and the coin motor.

8. The modulated physiological sensor according to claim **7** wherein the attachment comprises a tape having a sticky side that attaches to the surface area and a housing side that encloses the circuit board.

* * * * *

专利名称(译)	调制生理传感器		
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摘要(译)

调制的生理传感器是响应于生物对传播到皮肤表面区域的内部或外部扰动的生理反应的非侵入性设备。调制的生理传感器具有检测器，该检测器被配置为响应于生理反应产生信号。调制器改变检测器与皮肤的耦合，以便至少间歇地最大化检测器信号。监视器控制调制器并接收有效放大的检测器信号，该信号被处理以计算指示生理反应的生理参数。