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Evans et al.

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(54) **ELECTRODE UNITS FOR SENSING
PHYSIOLOGICAL ELECTRICAL ACTIVITY**

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(Continued)

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A61B 5/0408 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC **A61B 5/0006** (2013.01); **A61B 5/0416** (2013.01); **A61B 5/0428** (2013.01);
(Continued)

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(Continued)

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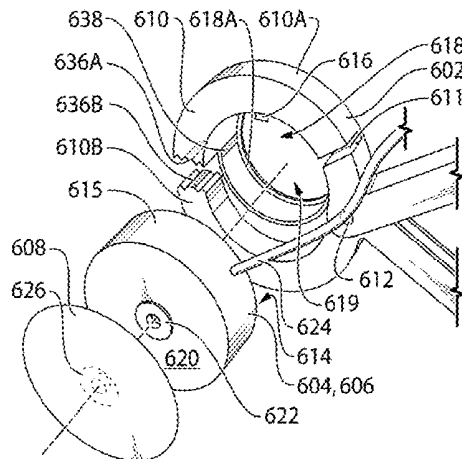
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(57) **ABSTRACT**

Systems and apparatus for monitoring physiological electrical activity of an individual include a first electrode unit for receiving a first signal indicative of electrical activity at a first location on a body of the individual and a second electrode unit for receiving a second signal indicative of electrical activity at a second location on the body of the individual. Each of the first and second electrode units may be operated in a field-sensing mode wherein the electrode unit is placed on or in proximity to the individual's skin. The first and second electrode units comprise a capacitive sensor element, and the capacitive sensor element of each of the electrode units comprising an electrodynamic sensor which is sensitive to electromagnetic waves; and an antenna comprising an electrically conductive radiating element for receiving electromagnetic waves. The field-sensing mode can be either non-contact field-sensing mode wherein the electrode unit is placed on the individual's clothing or a contact field-sensing mode wherein the electrode unit is placed directly on the individual's skin.

46 Claims, 12 Drawing Sheets



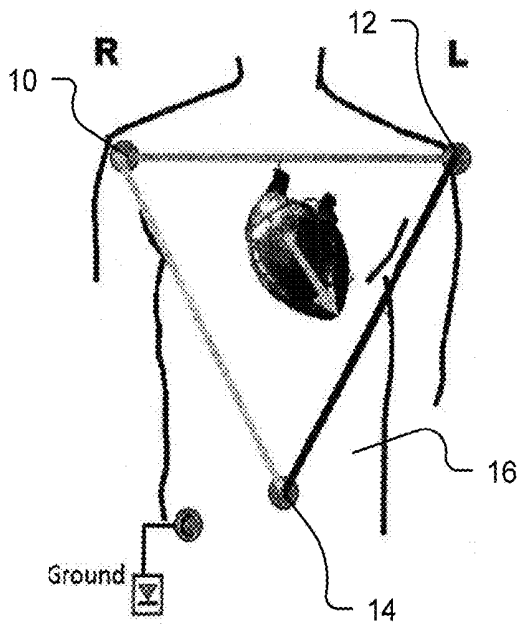


FIGURE 1

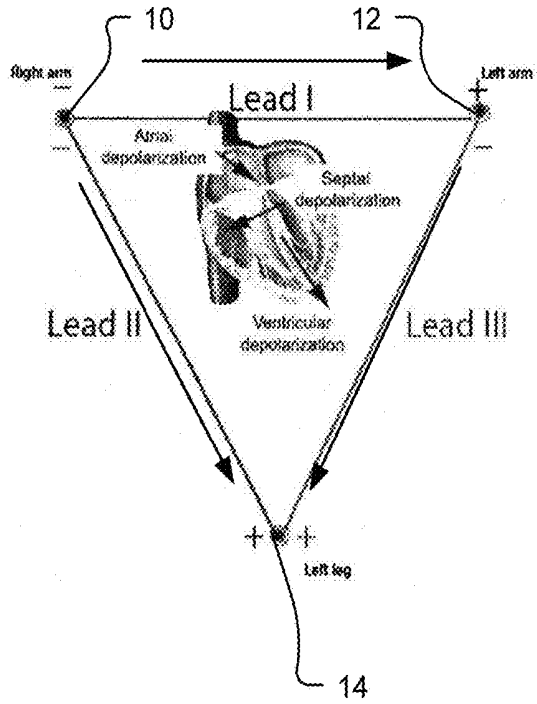


FIGURE 2

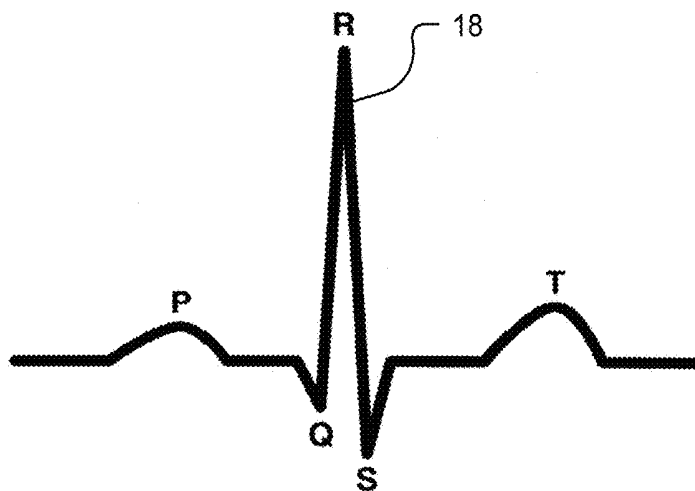
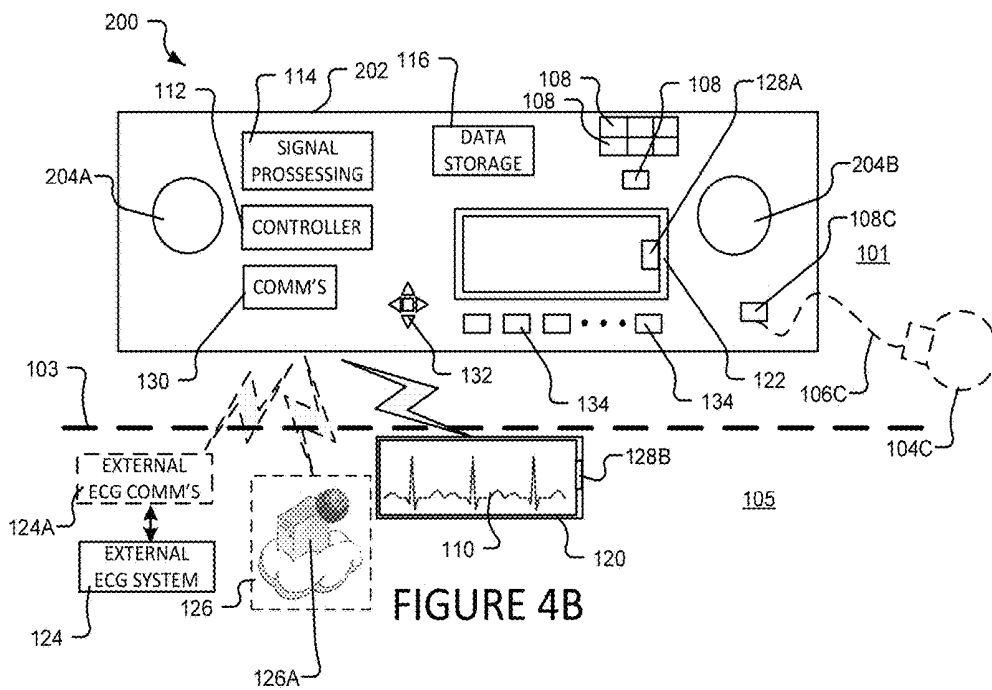
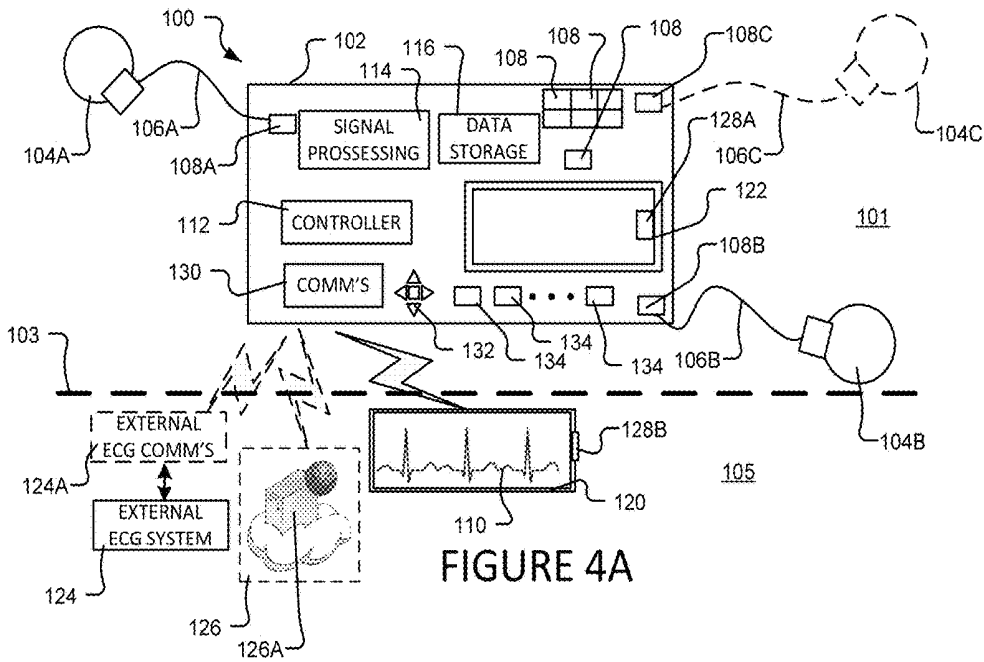
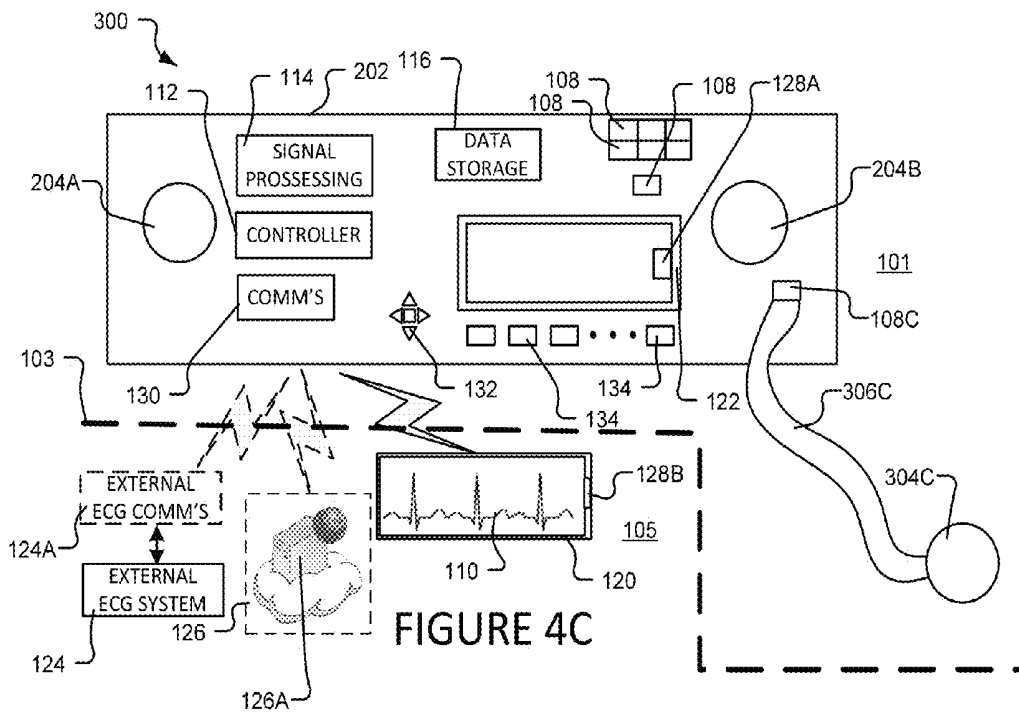


FIGURE 3





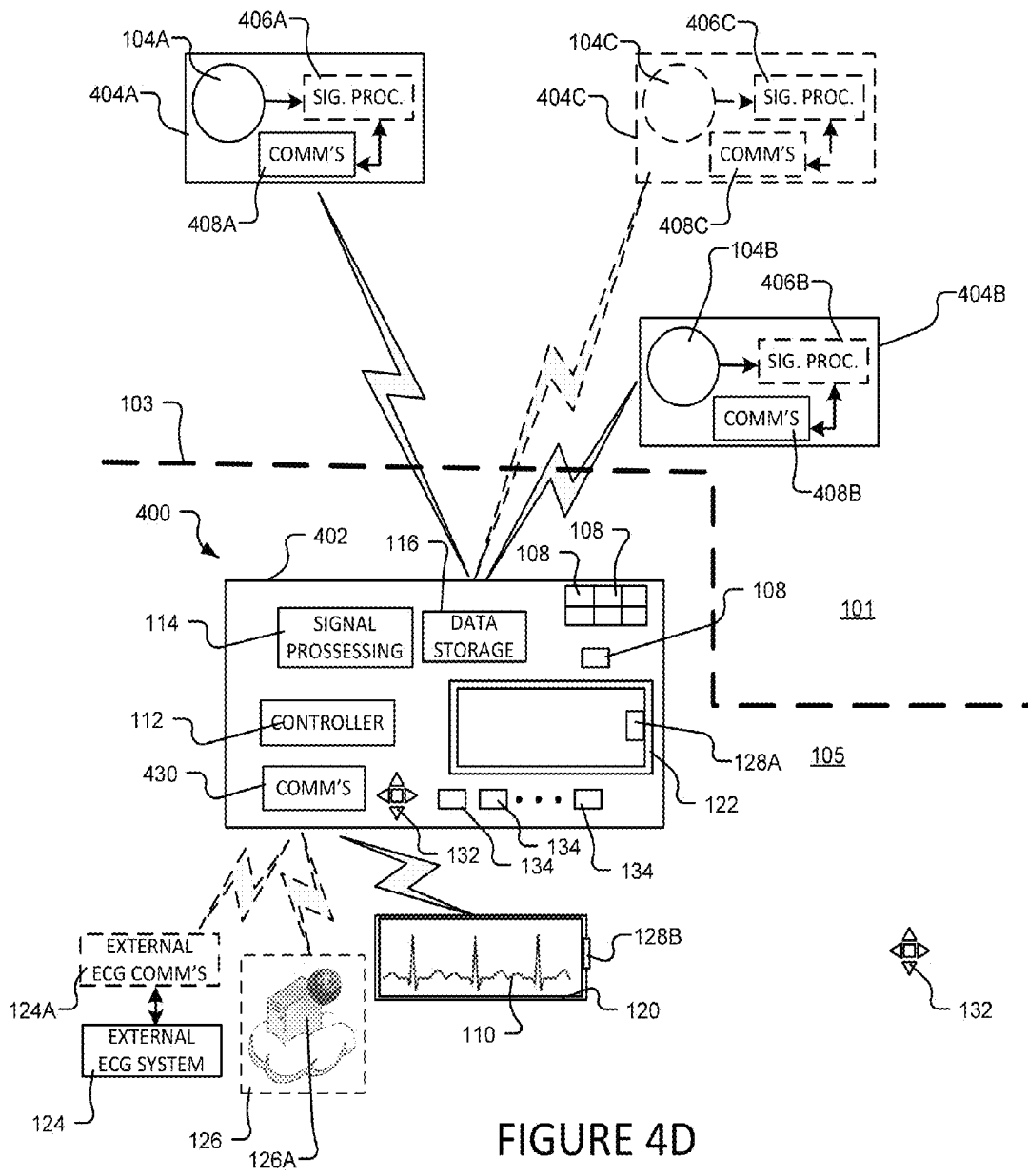


FIGURE 4D

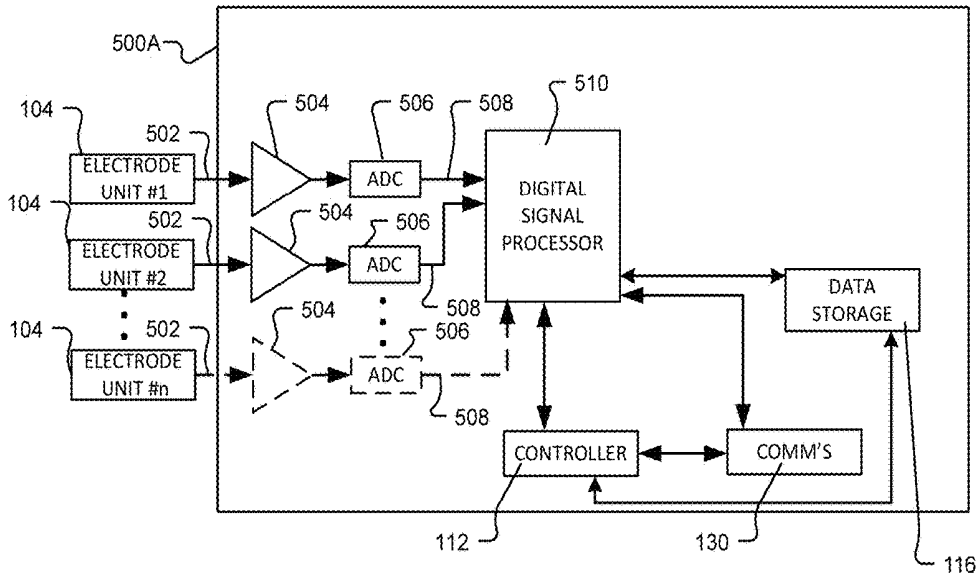


FIGURE 5A

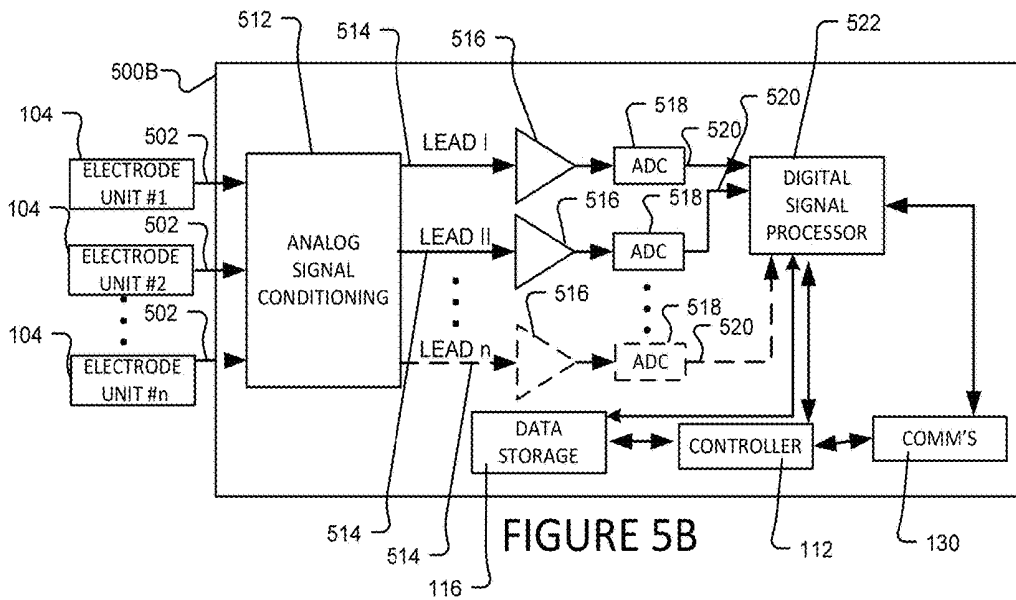


FIGURE 5B

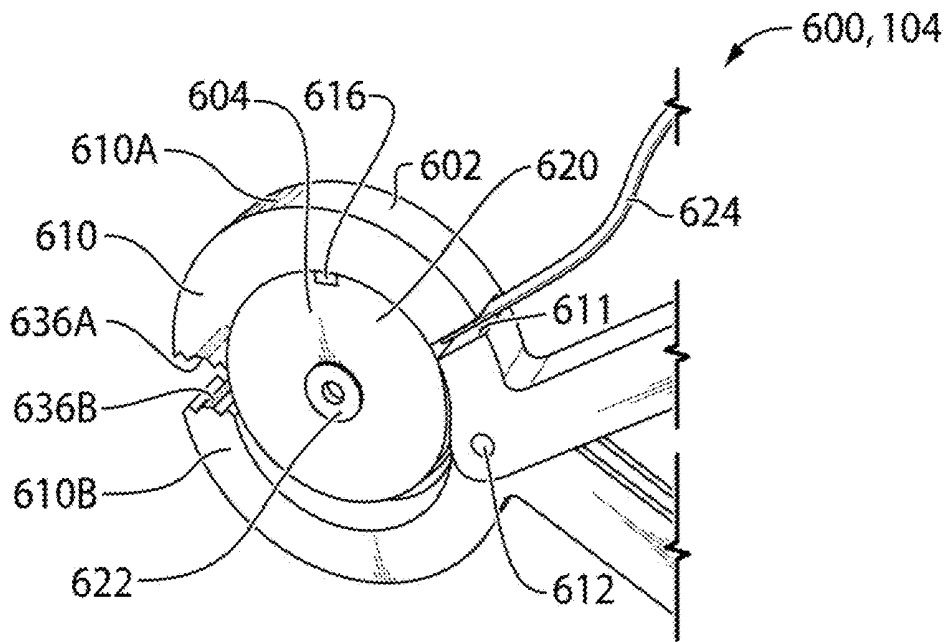


FIG. 6A

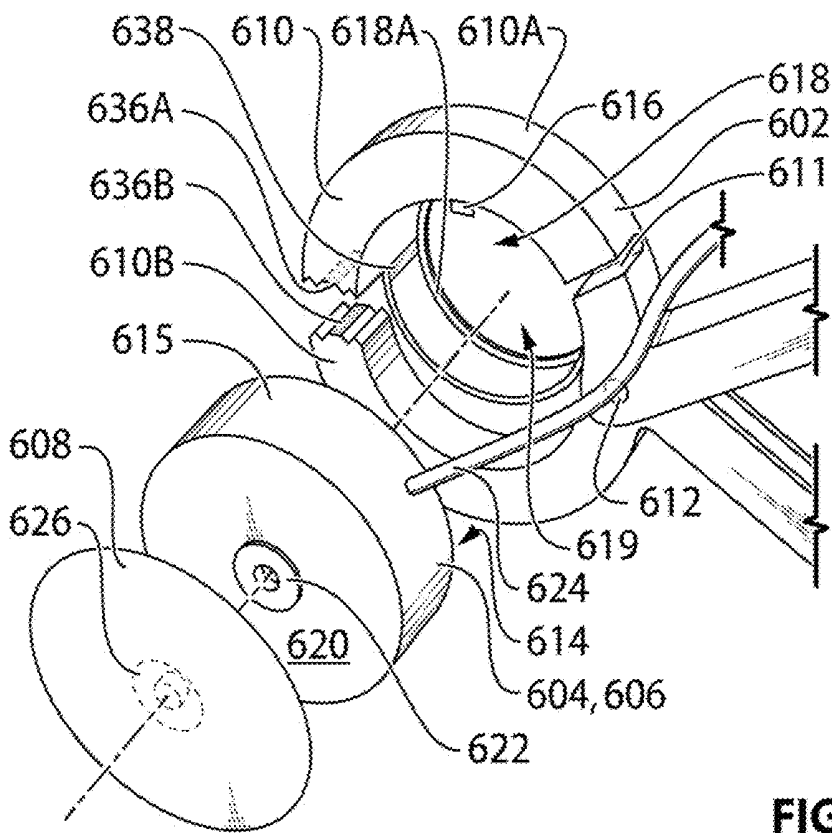


FIG. 6B

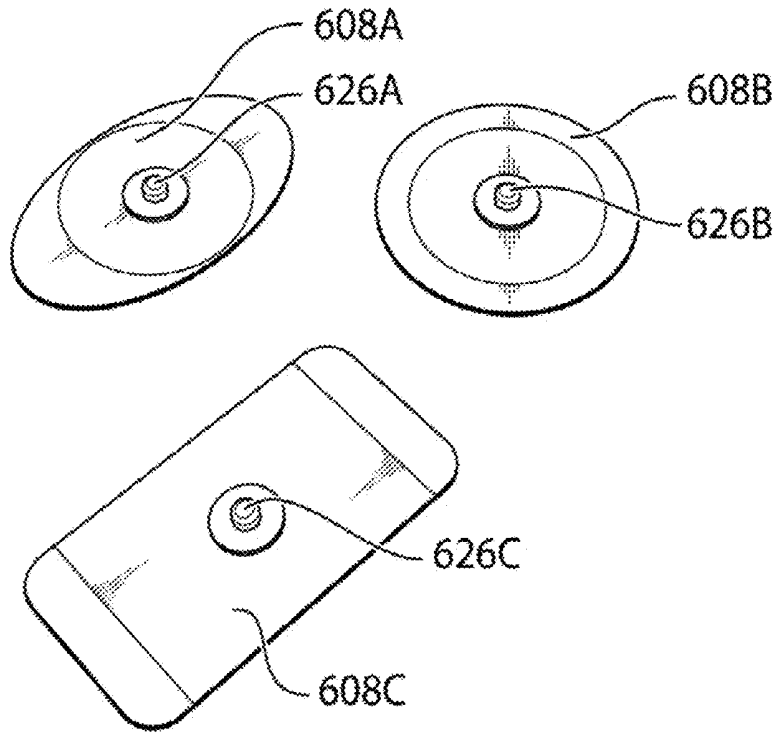


FIG. 7A

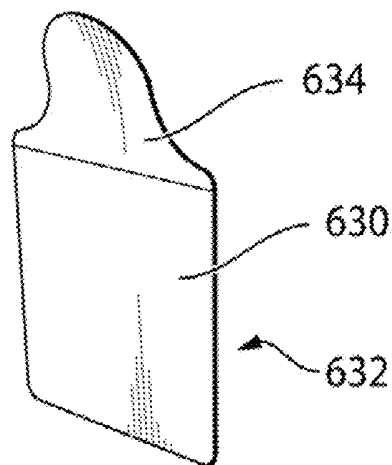


FIG. 7B

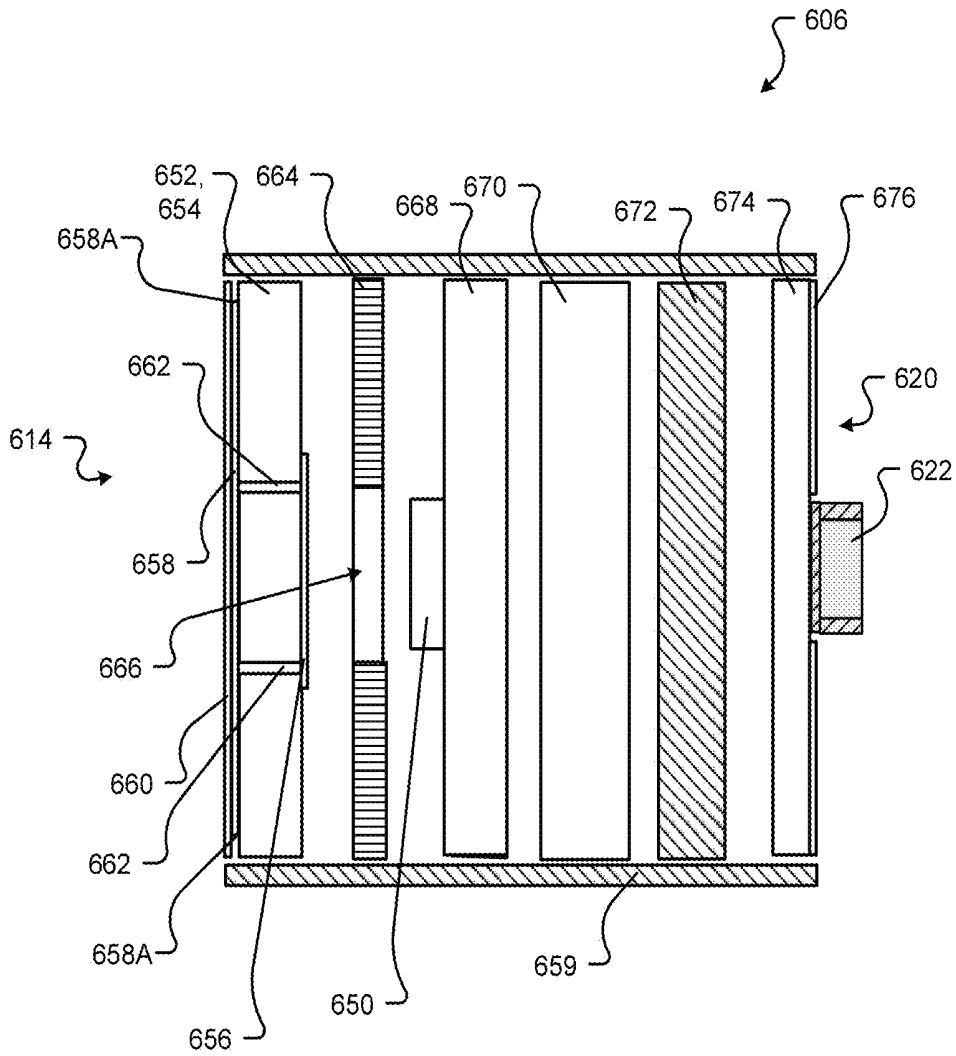


FIG. 8

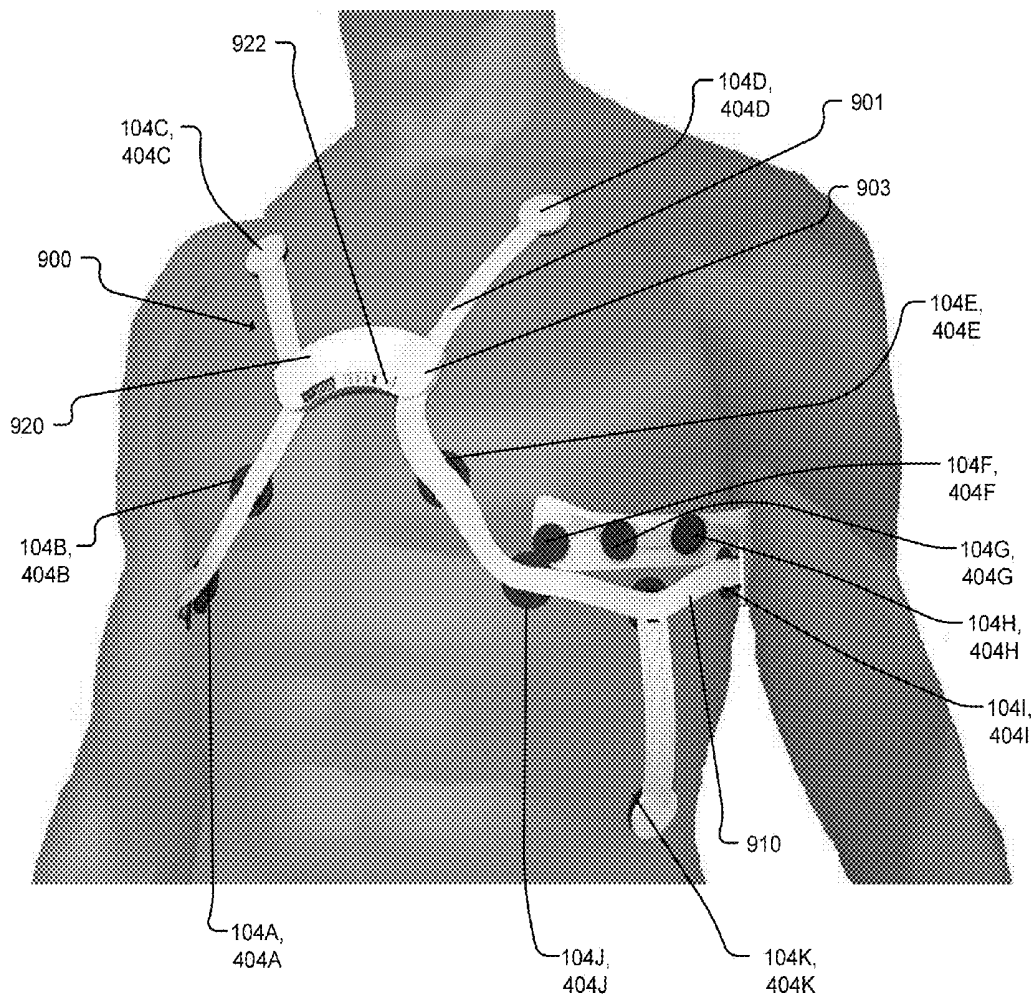


FIG. 9

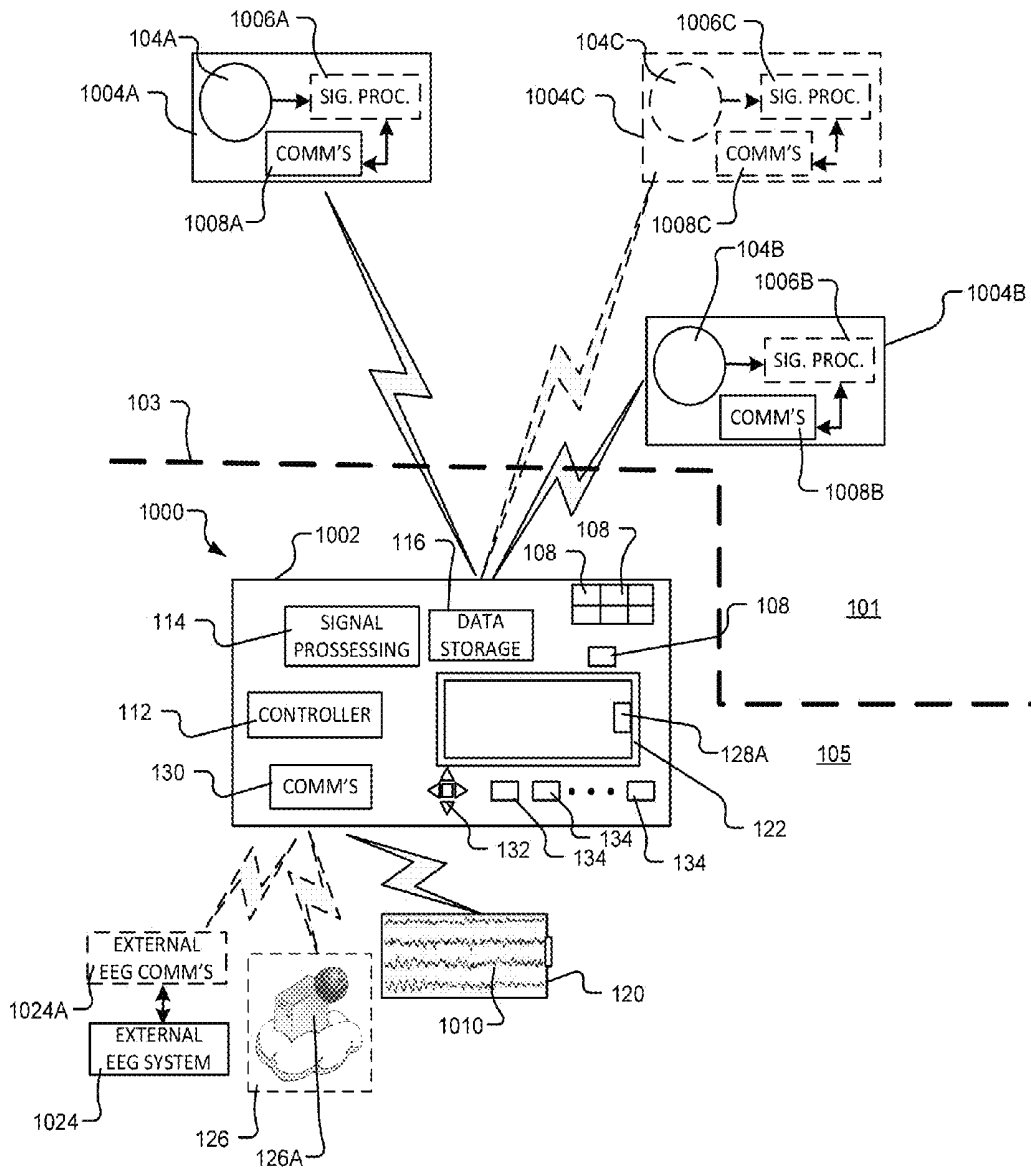


FIGURE 10

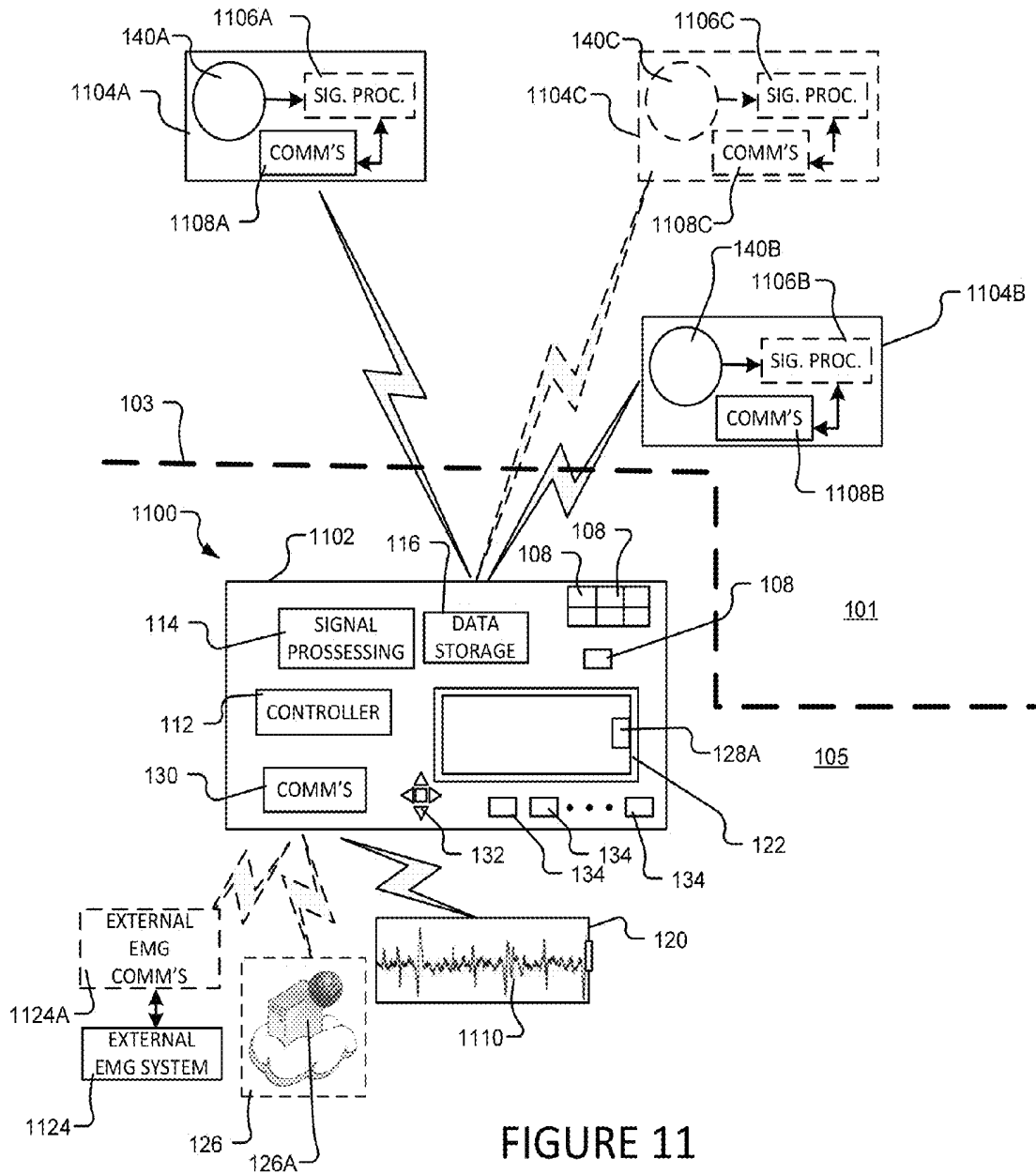


FIGURE 11

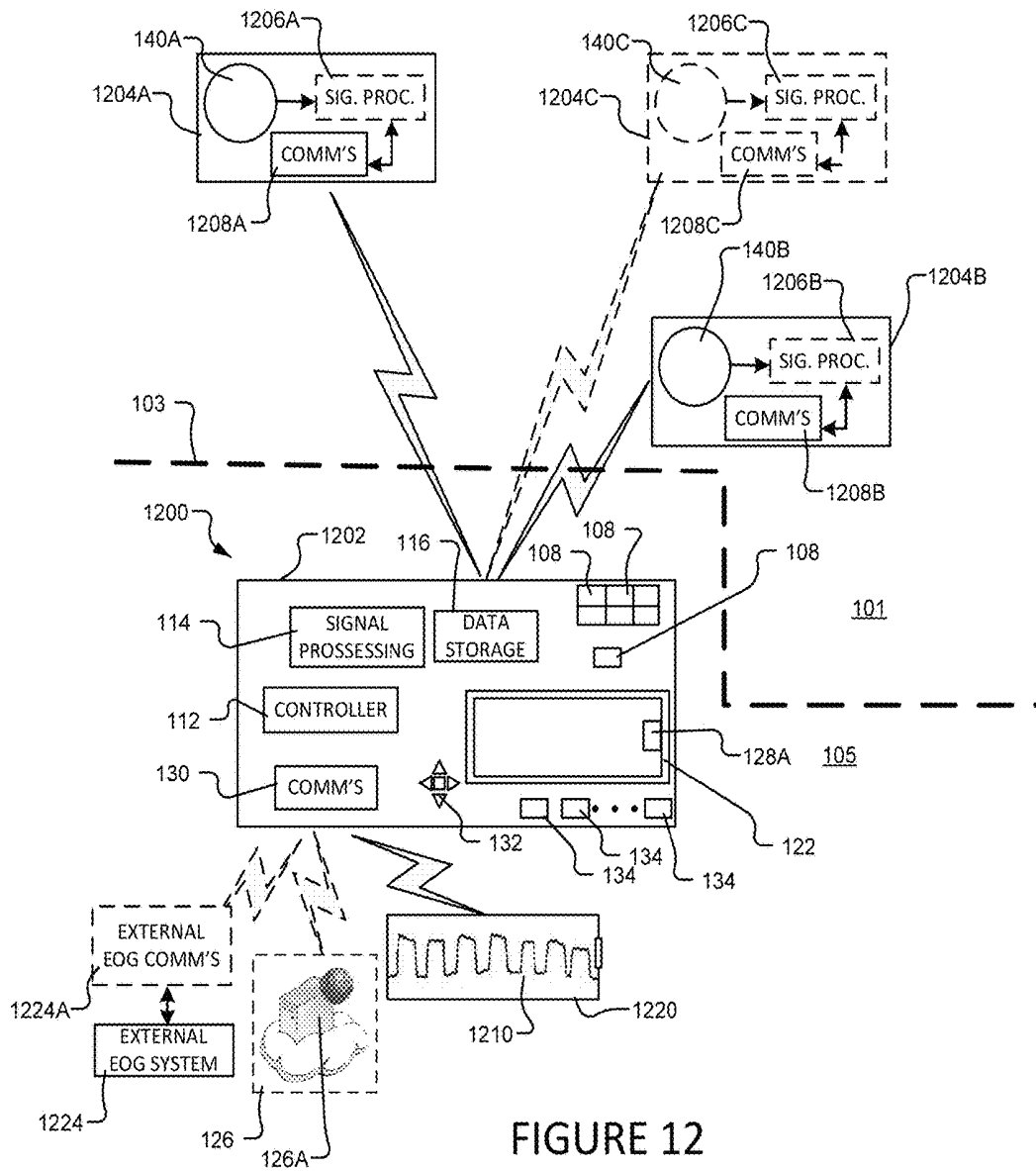


FIGURE 12

ELECTRODE UNITS FOR SENSING PHYSIOLOGICAL ELECTRICAL ACTIVITY

CROSS-REFERENCE TO RELATED APPLICATION

This is a continuation-in-part of U.S. patent application Ser. No. 14/377,255 which is a 35 U.S.C. § 371 national phase entry application of Patent Cooperation Treaty Application No. PCT/US2013/025432 filed 8 Feb. 2013 entitled ECG SYSTEM WITH MULTI MODE ELECTRODE UNITS, which in turn claims priority from U.S. provisional application No. 61/596,543 filed 8 Feb. 2012 entitled REMOTE MONITORING ECG SYSTEM. PCT/US2013/025432 and U.S. 61/596,543 are both hereby incorporated herein by reference.

TECHNICAL FIELD

The technology described herein relates to electrocardiography (ECG) systems, electroencephalography (EEG) systems, electromyography (EMG) systems, electrooculography (EOG) systems and/or similar systems, which detect physiological electrical activity at locations on, or within, an individual's body.

BACKGROUND

A conventional ECG system typically consists of between 3 and 10 electrodes placed on areas of an individual's body to detect electrical activity. The electrodes are connected to an ECG monitor by a commensurate number of wires/cables. A conventional ECG electrode typically comprises a resistive sensor element which is placed directly against the individual's skin. A number of electrodes are placed against the individual's skin to detect the electrical characteristics of the heart (e.g. the current through or voltage across the resistive sensor element) at desired vantage points on the individual's body. The detected signals are relayed through the wires to the ECG monitor, which is typically located on a lab table or the like, away from the individual's body. A signal processing unit within the ECG monitor processes the signals to generate an ECG waveform which can be displayed on a display of the ECG monitor.

FIGS. 1 and 2 show three electrodes **10**, **12**, **14** arranged in the so-called Einthoven's triangle on an individual's body **16**. As is known in the art, electrodes **10**, **12** and **14** may be respectively referred to as the Right Arm (RA), Left Arm (LA) and Left Leg (LL) electrodes because of the locations that they are commonly placed on body **16**. To generate an ECG signal, various potential differences are determined between the signals from electrodes **10**, **12**, **14**. These potential differences are referred to as "leads". Leads have polarity and associated directionality. The common leads associated with the Einthoven's triangle shown in FIGS. 1 and 2 include: lead I (where the signal from RA electrode **10** is subtracted from the signal from LA electrode **12**); lead II (where the signal from RA electrode **10** is subtracted from the signal from LL electrode **14**); and lead III (where the signal from LA electrode **12** is subtracted from the signal from LL electrode **14**). In addition to the leads shown in FIG. 2, other common leads associated with the Einthoven's triangle configuration include: the AVR lead (where one half of the sum of the signals from LA and LL electrodes **12**, **14** is subtracted from the signal for RA electrode **10**); the AVL lead (where one half of the sum of the signals from RA and LL electrodes **10**, **14** is subtracted from the signal for LA

electrode **12**); and the AVF lead (where one half of the sum of the signals from RA and LA electrodes **10**, **12** is subtracted from the signal for LL electrode **14**). As is known in the art, the AVR lead is oriented generally orthogonally to lead III, the AVL lead is oriented generally orthogonally to lead II and the AVF lead is oriented generally orthogonally to lead I. The signals from each of these leads can be used to produce an ECG waveform **18** as shown in FIG. 3. Additional sensors can be added to provide different leads which may be used to obtain different views of the heart activity. For example, as is well known in the art, sensors for precordial leads V1, V2, V3, V4, V5, V6 may be added and such precordial leads may be determined to obtain the so-called 12 lead ECG.

Some issues with traditional ECG technology make it an impediment for use, particularly in emergency response situations. The multiple electrodes and their corresponding wires may require extensive time to set up which may be critical in emergency circumstances. Having to maneuver around and detangle a large number of wires can be a nuisance. Multiple electrodes and wires can make it difficult to move an individual or administer medical aid to an individual. Signal noise from movement of the wires and wire tension can also degrade the quality of the ECG reading. Multiple wires can be particularly problematic during cardiac monitoring, where the ECG wires are attached to an individual for a long time. These issues with traditional ECG technology are exacerbated where there is a significant distance between the individual and the ECG monitor (i.e. where the electrode wires are long). EEG systems (which measure electrical activity of the brain), EMG systems (which measure electrical activity of skeletal and/or other muscles) and/or EOG systems (which measure electrical activity within the eye) may face similar problems. In addition to the problems with wires, current ECG systems use contact electrodes with resistive sensor elements. Such contact electrodes must be placed in direct contact with the individual's skin to obtain accurate signals. Typically, these contact electrodes are stuck to the individual's skin using an adhesive. The use of contact electrodes can be problematic in some circumstances. By way of non-limiting example, it may be undesirable or difficult to remove the individual's clothing in certain situations—e.g. where the individual may have privacy concerns, where the individual is suspected of having a spinal cord injury and/or the like. As another example, the individual may have a condition which makes it undesirable or difficult to apply current-sensing electrodes to the skin—e.g. the individual is suffering from burns to the individual's skin, the individual has body hair which must be removed prior to using the contact electrodes, the individual is allergic to the adhesive and/or the like. Also, EEG systems often require conductive gels to be used between the sensor and the skin of the individual and/or abrasion of the individual's skin to create electrical contact between the sensor and the skin. It can take a long time (e.g. up to an hour or more) to apply the gel into EEG caps and/or nets that are used in EEG sensing systems. The gel used in EEG systems can diffuse through hair to create shorts between sensors and can dry out over time. Whether gel-coated or not, the caps or nets which hold EEG sensors in contact with skin can be uncomfortable for the individual being tested, making long term monitoring (e.g. a desire when evaluating certain conditions such as epilepsy) difficult.

There is a general desire for improved ECG, EEG, EMG, and/or EOG systems. By way of non-limiting example, there is a general desire for an ECG system that can provide

greater flexibility for use by medical professionals in a variety of different circumstances, such as might be the case for emergency response technicians (EMTs). There is a general desire for ECG, EEG, EMG and/or EOG systems that may be more convenient and/or simple to use than existing systems. There is also a general desire for improved systems for detecting electrical activity in different locations on and/or within an individual's body, such as the heart (e.g. heart muscle), brain, the eyes, and skeletal and/or other muscles.

The foregoing examples of the related art and limitations related thereto are intended to be illustrative and not exclusive. Other limitations of the related art will become apparent to those of skill in the art upon a reading of the specification and a study of the drawings.

SUMMARY

One aspect of the invention provides an electrode unit for sensing physiological electrical activity of an individual. Such an electrode unit may be used, for example, in an ECG, EEG, EOG, or EMG system. The electrode unit comprises a capacitive sensor element for sensing electrical field associated with the physiological electrical activity. The capacitive sensor element of the electrode unit comprises an electrodynamic sensor which is sensitive to electromagnetic waves (e.g. electric field) and an antenna comprising an electrically conductive radiating element for receiving electromagnetic waves. The radiating element is in electrical contact with a sensing surface of the electrodynamic sensor and has a surface area which is larger than a surface area of the sensing surface of the electrodynamic sensor. The antenna is located relatively more proximate than the electrodynamic sensor to the individual's skin during operation of the electrode unit in the field-sensing mode.

In some embodiments, the electrode unit may operate in current sensing, field-sensing non-contact, or field-sensing contact modes. In other embodiments, the electrode unit may operate in field-sensing mode only. In some embodiments, the electrode unit is incorporated into the interior of a vehicle for use with a system for sensing physiological electrical activities in an individual. In some embodiments, the electrode unit may be embedded or mounted within or incorporated in the backrest or bottom portion of a seat or chair (e.g., seats (e.g. operator seat(s) and/or other seat(s)) in a vehicle such as a car, plane, helicopter, motorcycle, truck, boat, cart, or the like, car seats, strollers, and/or the like), in the controls of a vehicle (e.g., in the handle bars of a motorcycle, in the steering wheel of a car, and/or the like), in a bed (e.g. a hospital bed, crib, bed frame, and/or the like), and/or the like. In some embodiments, the electrode unit may be embedded in seat restraints, such as a seat belt, safety belt, and the like.

In some embodiments, at least two of these electrode units, each comprising a capacitive sensor element that comprises an electrodynamic sensor and an antenna, are used in a system for sensing physiological electrical activities in an individual, such as an ECG, EMG, EEG, or EOG system. In some embodiments, only one such electrode unit is used in such systems. In some embodiments, a plurality of such electrode units is used in such systems. In some embodiments, the system for sensing physiological electrical activities is incorporated into or embedded or mounted within a vehicle, such as a car, plane, helicopter, motorcycle, truck, boat, cart, or the like, car seats, strollers, and/or the like. In some embodiments, the vehicle may be a police car, an ambulance, a fire engine, and/or the like, or a military

vehicle, such as a tank, armored vehicle, infantry vehicle, amphibious vehicle, troop carrier, engineering vehicle, military aircraft and/or the like.

Another aspect of the invention provides a method for sensing physiological electrical activities of an individual, the method comprises the steps of providing a first electrode unit for generating a first signal indicative of the electrical activity at a first location on a body of the individual; and providing a second electrode unit for generating a second signal indicative of the electrical activity at a second location on the body of the individual. The electrode units are then operated in field-sensing mode to generate the first signal and the second signal, and the first signal and the second signal are used to generate waveforms indicative of the electrical activity. In some embodiments, one or more of the electrode units comprises a capacitive sensor element, and the capacitive sensor element comprises an electrodynamic sensor which is sensitive to electromagnetic waves, and an antenna comprising an electrically conductive radiating element for receiving electromagnetic waves.

In some embodiments, the method comprises providing a plurality of electrode units. In some embodiments, the electrode units operate only in field sensing mode. In some embodiments, some electrode units may operate in field sensing mode and some electrode units may operate in current sensing mode. In some embodiments, electrode units operating in field sensing mode may be in field-sensing contact mode or field-sensing non-contact mode or either mode depending on the instructions provided to the electrode units. In some embodiments, the physiological electrical activity measured comprises electrical activity of the heart muscle (ECG), the brain (EEG), skeletal muscles (EMG), or the eye (EOG).

In some embodiments, the method for sensing physiological electrical activity is used to sense physiological electrical activity of an individual in a vehicle, such as the vehicle operator, passenger, and/or the like. In some embodiments, the vehicle comprises a car, plane, helicopter, motorcycle, truck, boat, cart, or the like, emergency responder vehicles such as a police car, an ambulance, a fire engine, and/or the like, or a military vehicle, such as a tank, armored vehicle, infantry vehicle, amphibious vehicle, troop carrier, engineering vehicle, military aircraft and/or the like. In some embodiments, the method is used to sense physiological electrical activities of babies, infants, or young children in car seats, strollers, and/or the like.

Another aspect of the invention provides a system for monitoring heart muscle activity of an individual comprising: a first electrode unit for generating a first signal indicative of electrical activity of the heart muscle at a first location on a body of the individual; and a second electrode unit for generating a second signal indicative of electrical activity of the heart muscle at a second location on the body of the individual. Each of the first and second electrode units is configurable to operate in: a field-sensing mode wherein the electrode unit is configured to generate its corresponding signal based on a detected electric field at a location on or in proximity to the individual's skin; and a current-sensing mode wherein the electrode unit is configured to generate its corresponding signal based on current flow through a resistive sensor element placed directly on the individual's skin.

Another aspect of the invention provides an electrode unit for use in an ECG system comprising: a capacitive sensor element for detecting electric field; a spring-biased clamp for attachment of the electrode unit to an individual's clothing when operating in a non-contact field-sensing mode; and an attachment means for physical and electrical

attachment of the electrode unit to a resistive sensor element when operating in a resistive mode.

Another aspect of the invention provides a system for monitoring heart muscle activity of an individual comprising: a first electrode unit for generating a first signal indicative of electrical activity of the heart muscle at a first location on a body of the individual, the first electrode unit comprising a first capacitive sensing element for detecting electric field; a second electrode unit for generating a second signal indicative of electrical activity of the heart muscle at a second location on the body of the individual, the second electrode unit comprising a second capacitive sensing element for detecting electric field; and a plurality of inputs, each input adapted to receive a corresponding signal from a current-sensing electrode unit indicative of electrical activity at a corresponding location on the body of the individual.

Another aspect of the invention provides a system for monitoring heart muscle activity of an individual comprising: a first input for receiving a first signal indicative of electrical activity of the heart muscle at a first location on a body of the individual; a second input for receiving a second signal indicative of electrical activity of the heart muscle at a second location on the body of the individual; wherein each of the inputs is adapted to receive a signal from a field-sensing electrode unit or from a current-sensing electrode unit and the system is configured to differentiate between signals received from field-sensing electrode units and signals received from current-sensing electrode units and to generate one or more ECG waveforms based on the received signals.

Another aspect of the invention provides a system for monitoring heart muscle activity of an individual comprising: a first field-sensing electrode unit for generating a first signal indicative of electrical activity of the heart muscle at a first location on a body of the individual, the first field-sensing electrode unit configured to generate the first signal based on a detected electric field at a location on or in proximity to the individual's skin; and a second current-sensing electrode unit for generating a second signal indicative of electrical activity of the heart muscle at a second location on the body of the individual, the second current-sensing electrode unit configured to generate the second signal based on current flow through a resistive sensor element placed directly on the individual's skin; wherein the system is configured to combine the first signal and the second signal to generate an ECG waveform.

Another aspect of the invention provides a method for generating a ECG waveform related to heart muscle activity of an individual, the method comprising: providing a plurality of electrode units, each electrode unit configured to generate a corresponding signal indicative of electrical activity of the heart muscle at a corresponding location on a body of the individual; operating at least one first one of the plurality of electrode units in a field-sensing mode, wherein the at least one first one of the electrode units is configured to generate its corresponding signal based on a detected electric field at a location on or in proximity to the individual's skin; operating at least one other one of the plurality of electrode units in a current-sensing mode, wherein the at least one other one of the plurality of electrode units is configured to generate its corresponding signal based on current flow through a resistive sensor element placed directly on the individual's skin; and using the signals generated by the at least one first one of the plurality of electrode units and generated by the at least one other one of the plurality of electrode units to generate one or more ECG waveforms.

Another aspect of the invention provides a system for monitoring physiological electrical activity of an individual (e.g. of an organ, such as the heart (e.g. the heart muscle), brain, eye, or skeletal and/or other muscle) comprising: a first electrode unit for generating a first signal indicative of the physiological electrical activity (e.g. electrical activity of the heart muscle, brain, eye, or skeletal and/or other muscle, as applicable) at a first location on a body of the individual; and a second electrode unit for generating a second signal indicative of physiological electrical activity (e.g. electrical activity of the heart muscle, brain, eye, or skeletal and/or other muscle, as applicable) at a second location on the body of the individual. Each of the first and second electrode units is configurable to operate in: a field-sensing mode wherein the electrode unit is configured to generate its corresponding signal based on a detected electric field at a location on or in proximity to the individual's skin; and a current-sensing mode wherein the electrode unit is configured to generate its corresponding signal based on current flow through a resistive sensor element placed directly on the individual's skin.

Another aspect of the invention provides an electrode unit for use in a system for measuring physiological electrical activity (e.g. an ECG, EEG, EMG and/or EOG system) comprising: a capacitive sensor element for detecting electric field; a spring-biased clamp for attachment of the electrode unit to an individual's clothing when operating in a non-contact field-sensing mode; and an attachment means for physical and electrical attachment of the electrode unit to a resistive sensor element when operating in a resistive mode.

Another aspect of the invention provides a system for monitoring physiological electrical activity of an individual (e.g. electrical activity of an organ, such as the heart (e.g. the heart muscle), brain, eye, or skeletal and/or other muscle) comprising: a first electrode unit for generating a first signal indicative of the physiological electrical activity (e.g. electrical activity of the heart muscle, brain, eye, or skeletal and/or other muscle, as applicable) at a first location on a body of the individual, the first electrode unit comprising a first capacitive sensing element for detecting electric field; a second electrode unit for generating a second signal indicative of the physiological electrical activity (e.g. electrical activity of the heart muscle, brain, eye, or skeletal and/or other muscle, as applicable) at a second location on the body of the individual, the second electrode unit comprising a second capacitive sensing element for detecting electric field; and a plurality of inputs, each input adapted to receive a corresponding signal from a current-sensing electrode unit indicative of electrical activity at a corresponding location on the body of the individual.

Another aspect of the invention provides a system for monitoring physiological electrical activity of an individual (e.g. electrical activity of an organ, such as the heart (e.g. the heart muscle), brain, eye, or skeletal and/or other muscle) comprising: a first input for receiving a first signal indicative of the physiological electrical activity of the individual (e.g. electrical activity of the heart muscle, brain, eye, or skeletal and/or other muscle, as applicable) at a first location on a body of the individual; a second input for receiving a second signal indicative of the physiological electrical activity of the individual (e.g. electrical activity of the heart muscle, brain, eye, or skeletal and/or other muscle, as applicable) at a second location on the body of the individual; wherein each of the inputs is adapted to receive a signal from a field-sensing electrode unit or from a current-sensing electrode unit and the system is configured to differentiate between signals received from field-sensing electrode units

and signals received from current-sensing electrode units. The system may generate one or more ECG, EEG, EOG, or EMG waveforms, as applicable, based on the received signals.

Another aspect of the invention provides a system for monitoring the physiological electrical activity of an individual (e.g. electrical activity of an organ, such as the heart (e.g. the heart muscle), brain, eye, or skeletal and/or other muscle) comprising: a first field-sensing electrode unit for generating a first signal indicative of the physiological electrical activity (e.g. electrical activity of the heart muscle, brain, eye, or skeletal and/or other muscle, as applicable) at a first location on a body of the individual, the first field-sensing electrode unit configured to generate the first signal based on a detected electric field at a location on or in proximity to the individual's skin; and a second current-sensing electrode unit for generating a second signal indicative of the physiological electrical activity (e.g. electrical activity of the heart muscle, brain, eye, or skeletal and/or other muscle, as applicable) at a second location on the body of the individual, the second current-sensing electrode unit configured to generate the second signal based on current flow through a resistive sensor element placed directly on the individual's skin. The system may be configured to combine the first signal and the second signal to generate an ECG, EEG, EOG, or EMG waveform, as applicable.

Another aspect of the invention provides a method for sensing physiological electrical activity of an individual (e.g. electrical activity in the heart (e.g. the heart muscle), brain, eye, or skeletal and/or other muscle of an individual) and, optionally, generating ECG, EEG, EOG, or EMG waveforms related to the physiological electrical activity. The method comprises: providing a plurality of electrode units, each electrode unit configured to generate a corresponding signal indicative of the physiological electrical activity (e.g. electrical activity of the heart muscle, brain, eye, or skeletal and/or other muscle, as applicable) at a corresponding location on a body of the individual; operating at least one first one of the plurality of electrode units in a field-sensing mode, wherein the at least one first one of the electrode units is configured to generate its corresponding signal based on a detected electric field at a location on, or in proximity to, the individual's skin; operating at least one other one of the plurality of electrode units in a current-sensing mode, wherein the at least one other one of the plurality of electrode units is configured to generate its corresponding signal based on current flow through a resistive sensor element placed directly on the individual's skin. The method may comprise using the signals generated by the at least one first one of the plurality of electrode units and generated by the at least one other one of the plurality of electrode units to generate one or more ECG, EEG, EOG, or EMG waveforms, as applicable.

In addition to the exemplary aspects and embodiments described above, further aspects and embodiments will become apparent by reference to the drawings and by study of the following detailed descriptions.

BRIEF DESCRIPTION OF DRAWINGS

Exemplary embodiments are illustrated in referenced figures of the drawings. It is intended that the embodiments and figures disclosed herein are to be considered illustrative rather than restrictive.

FIG. 1 is a schematic illustration of the electrodes of a conventional ECG system arranged on the individual's body in an Einthoven's triangle configuration.

FIG. 2 is a schematic illustration of the electrodes of a conventional ECG system arranged in an Einthoven's triangle configuration and a number of the corresponding leads.

FIG. 3 is a typical ECG waveform of the type that might be displayed on an ECG system.

FIG. 4A schematically illustrates an ECG system architecture according to a particular embodiment. FIG. 4B schematically illustrates an ECG system architecture according to another particular embodiment. FIG. 4C schematically illustrates an ECG system architecture according to another particular embodiment. FIG. 4D schematically illustrates an ECG system architecture according to another particular embodiment.

FIG. 5A is a block diagram showing one implementation of a signal processing system for processing data from the electrode units of the FIGS. 4A-4D ECG systems according to a particular embodiment. FIG. 5B is a block diagram showing one implementation of a signal processing system for processing data from the electrode units of the FIGS. 4A-4D ECG systems according to another particular embodiment.

FIGS. 6A and 6B are respectively assembled and exploded isometric views of a multi-mode electrode unit according to a particular embodiment.

FIGS. 7A and 7B illustrate different resistive sensor elements that may be used with the FIGS. 6A, 6B electrode unit.

FIG. 8 is an exploded cross-sectional view of a capacitive sensor element that may be used with the FIG. 6A, 6B electrode unit according to a particular embodiment.

FIG. 9 illustrates a harness comprising electrode assemblies according to a particular embodiment.

FIG. 10 schematically illustrates an EEG system architecture according to a particular embodiment.

FIG. 11 schematically illustrates an EMG system architecture according to another particular embodiment.

FIG. 12 schematically illustrates an EOG system architecture according to another particular embodiment.

DESCRIPTION

Throughout the following description, specific details are set forth in order to provide a more thorough understanding to persons skilled in the art. However, well known elements may not have been shown or described in detail to avoid unnecessarily obscuring the disclosure. Accordingly, the description and drawings are to be regarded in an illustrative, rather than a restrictive, sense.

One aspect of the invention provides an electrode unit for sensing physiological electrical activity of an individual. Such an electrode unit may be used, for example, in an ECG, EEG, EOG, or EMG system. The electrode unit comprises a capacitive sensor element for sensing electrical field associated with the physiological electrical activity. In some embodiments, the capacitive sensor element of the electrode unit comprises an electrodynamic sensor which is sensitive to electromagnetic waves (e.g. electric field) and an antenna comprising an electrically conductive radiating element for receiving electromagnetic waves. In further embodiments, the radiating element is in electrical contact with a sensing surface of the electrodynamic sensor and has a surface area which is larger than a surface area of the sensing surface of the electrodynamic sensor. The antenna may be located relatively more proximate than the electrodynamic sensor to the individual's skin during operation of the electrode unit in the field-sensing mode. In some embodiments, the electrode

unit may operate in current sensing, field-sensing non-contact, and field-sensing contact modes. In other embodiments, the electrode unit may operate in field-sensing mode only. In some embodiments, the electrode unit is incorporated into systems for sensing physiological electrical activities of an individual, such as an ECG, EEG, EMG, or EOG system. In some embodiments, the electrode unit is provided as part of a method for sensing physiological electrical activities of an individual.

FIG. 4A schematically illustrates an ECG system 100 according to a particular embodiment. ECG system 100 comprises a base unit 102 and two or more electrode units 104A, 104B, 104C (collectively and individually, electrode units 104). Electrode units 104 may be located relative to an individual's body 101 (as discussed in more detail below) to generate signals indicative of electrical activity of the individual's heart at their corresponding locations. In the schematic illustration of FIG. 4A, locations 101 on the individual's body are shown as being above the thick dashed line 103 and locations 105 away from the individual's body are shown as being below the thick dashed line 103. In currently preferred embodiments, electrode units 104 are multi-function electrode units of the type described below, although this is not necessary. In the illustrated embodiment of FIG. 4A, ECG system 100 is shown as having three electrode units 104A, 104B, 104C which may be used in an Einthoven's triangle configuration. In some embodiments, third electrode unit 104C is not necessary and system 100 may use as few as two electrode units 104. In some embodiments, system 100 may be provided with more than three electrode units 104 (as discussed in more detail below) to provide additional leads and corresponding additional views of heart muscle electrical activity. In some embodiments, discussed in more detail below, electrode units 104 may additionally or alternatively be used to sense other types of electrically-based physiological phenomena (referred to herein as physiological electrical activity), such as, by way of non-limiting example, electrical activity of the brain (e.g. EEG data), electrical activity associated with skeletal muscles (e.g. EMG data), electrical activity of the eye (e.g. EOG data) and/or the like.

In the FIG. 4A embodiment, electrode units 104 are removably connected to base unit 102 by corresponding cables 106A, 106B, 106C (collectively and individually, cables 106) which may be removably connected to base unit 102 using suitable electrical, signal transmission connectors 108A, 108B, 108C (collectively and individually, connectors 108). Connectors 108 may comprise, for example: slidable locking electric connectors, spring-biased electric connectors, magnetic connectors and/or the like. Base unit 102 is preferably constructed to be sufficiently small and lightweight that it can comfortably rest on an individual's body 101 without discomfort and without impacting the individual's ECG waveform. By way of non-limiting example, base unit 102 could be rested on an individual's chest, strapped or clipped (using suitable straps (not shown) or clips (not shown)) to the individual's clothing, arm or leg, and/or the like. With base unit 102 being so proximate to the individual, cables 106 may be correspondingly short. In some embodiments, cables 106 are less than 50 cm in length. In some embodiments, cables 106 are less than 30 cm in length.

In the illustrated embodiment, ECG waveforms 110 generated by ECG system 100 are displayed on a display 120. In some embodiments, display 120 may be integral with base unit 102. However, in the illustrated embodiment, display 120 is removably attached to base unit 102 at cradle

122, so that display 120 can be separated from base unit 120 to a location 105 away from the individual's body to permit easy reading by medical professionals without requiring the medical professionals to lean over top of or otherwise crowd the individual's body 101. In the illustrated embodiment, ECG waveforms 110 are wirelessly communicated to display 120 when display 120 is detached from base unit 102. When display 120 is located in cradle 122, ECG waveforms 110 may be provided directly (via a suitable complementary connectors 128A, 128B) to display 120—i.e. without wireless communication.

Base unit 102 may comprise suitably configured hardware and/or software components for processing signals from electrode units 104 and for generating corresponding ECG waveform(s) 110 for display on display 120. In the illustrated embodiment, such components include: a controller 112, signal processing hardware 114, data storage 116, communications hardware 130 and user interface components 132. For simplicity, only a number of components germane to the present invention are described in detail here. It will be appreciated by those skilled in the art that base unit 102 may comprise other electronic components suitable for operation as described herein. These components may be configured to provide particular functionality using suitably coded software (not explicitly shown). Controller 112 may interact with and control the other functional components of ECG system 100. By way of non-limiting example, controller 112 may comprise any suitable controller, such as, for example, a suitably configured computer, microprocessor, microcontroller, field-programmable gate array (FPGA), other type of programmable logic device, pluralities of the foregoing, combinations of the foregoing, and/or the like. Controller 112 may have access to software which may be stored in computer-readable memory (not shown) accessible to controller 112 and/or in computer-readable memory that is integral to controller 112. Controller 112 may be configured to read and execute such software instructions and, when executed by controller 112, such software may cause controller 112 to implement one or more of the methods described herein.

Signal processing hardware 114 may comprise any suitable analog or digital signal conditioning and/or signal processing components for generating ECG waveforms 110 from the signals obtained from electrode units 104. By way of non-limiting example, signal processing hardware 114 may comprise amplifiers, buffers, filters, analog to digital converters, suitably configured digital signal processors and/or the like. Data storage 116 may comprise any suitable memory (e.g. solid state memory) that may be used to store digital ECG data. In some embodiments, data storage 116 may be integrated into other components (e.g. controller 112 or signal processing hardware 114). In some embodiments, data storage 116 is not necessary.

Communications hardware 130 may comprise suitable hardware (e.g. WAN interfaces, LAN interfaces) for wireless communication according to one or more wireless digital communications protocols. Non-limiting examples of such protocols, include: a suitable Bluetooth communication protocol; wireless USB protocol; 802.11 wireless protocol; Zigbee protocol and/or the like. In some embodiments, display 120 may not be detachable from base unit 102 in which case display 120 may be connected via suitable electrical contacts. In some embodiments, display 120 may be removable from cradle 122, but attached to base unit 102 with a signal communication cable or the like. In such embodiments, some or all of communications hardware 130 may not be required. In some embodiments, communica-

tions hardware **130** may facilitate communication of ECG data (e.g. data stored in data storage **116**, real time ECG waveforms **110** and/or the like) from base unit **102** to an external ECG system **124**. In some embodiments, where external ECG system **124** is not capable of wireless communications or of wireless digital communications, ECG system **100** may comprise a suitable external ECG system communications component **124A** which may be used to communicate with communications hardware **130** and to convert any received data/signals from communications hardware into a format capable of being interpreted by external ECG system **124**. External ECG system communications component **124A** may comprise hardware similar to any of the hardware described herein for base unit **102**.

In some embodiments, communications hardware **130** may facilitate communication of ECG data (e.g. data stored in data storage **116**, real time ECG waveforms **110** and/or the like) from base unit **102** to another device **126A** (e.g. a computer or the like) via a network **126** or via a direct communication link (not shown) for further processing and/or display. By way of non-limiting example, network **126** may comprise: a local area network (LAN), such as a hospital network, a work place network or the like; or a wide area network (WAN), such as the internet, a cellular network or the like). In some embodiments, communications hardware **130** may additionally or alternatively facilitate wired communication with external ECG system **124** or with another device **126A** (e.g. a computer or the like) via a network **126**.

Display **120** together with user interface inputs **130** may be used (by controller **112**) to implement a text-based or graphical user interface (UI). User interface inputs **130** may comprise any suitable pointing device, buttons, touch screen and/or the like through which an individual (e.g. a medical professional) can interact with and control ECG system **100**. By way of non-limiting example, a medical professional could control such a user interface to: freeze ECG waveform **110** on display **120**; view historical waveforms **110** or pulses; switch between the waveforms **110** of different leads; toggle between views of single ECG waveforms **110** or multiple ECG waveforms **110**; zoom in on ECG waveform **110** on display **120**; measure characteristics (e.g. amplitude and/or frequency) of ECG waveform **110**; communicate with other devices (e.g. external ECG system **124** and/or another device via network **126**); print to suitably configured printer device; toggle a “graph-paper” background on display **120**; identify abnormal ECG rhythms; display measurements associated with other diagnostic equipment (explained in more detail below) which may be connected to ECG system **100** (e.g. blood pressure, blood sugar, pulse oximetry (SpO₂), body temperature and/or the like); display alarms or alerts associated with abnormalities measured by such other diagnostic equipment; provide temporal information (e.g. clocks or stopwatches), alarms and/or alerts; and/or the like.

Base unit **102** may comprise a number of additional connectors **108** for optional connection to additional electrode units **104** (not shown). For example, in the illustrated embodiment, base unit comprises seven additional connectors **108** for connection to seven additional electrode units **104**. With a total of ten electrode units **104**, ECG system can be configured to provide the so-called “12 lead” ECG functionality. In some embodiments, additional connectors **108** may be used to connect to one or more additional electrode units **104** which may be used to sense other types of electrically-based physiological phenomena (physiological electrical activity), such as electrical activity of the brain

(e.g. EEG data), electrical activity associated with skeletal muscles (e.g. EMG data), electrical activity of the eye (e.g. EOG data) and/or the like.

Base unit **102** may also comprise suitable connections **134** for connecting to other medical equipment (not shown). Such connections **134** may be used to accept data from such equipment (e.g. from medical diagnostic equipment). By way of non-limiting example, such medical diagnostic equipment may comprise a blood pressure cuff, a glucometer, a pulse oximetry (SpO₂) monitor, and end-tidal carbon dioxide (ETCO₂) monitor, a thermometer and/or the like. Connections **134** may also be used for other medical equipment. In some embodiments, connections **134** may be used to connect to a pair of defibrillator pads or paddles which may be used to deliver defibrillation shock(s) (e.g. pacing defibrillation, cardio version defibrillation and/or automatic external defibrillation) to an individual. In some embodiments, connections **134** may be used to provide other electrically sensitive electrode units, which may be similar to electrode units **104** and may be used to sense heart muscle activity (e.g. ECG data), but may additionally or alternatively be used to sense other types of electrically-based physiological phenomena (physiological electrical activity), such as electrical activity of the brain (e.g. EEG data), electrical activity associated with skeletal muscles (e.g. EMG data), electrical activity of the eye (e.g. EOG data) and/or the like. While not expressly shown, base unit **102** may comprise a separate rechargeable battery which may be used to deliver such defibrillation shock(s).

FIG. 4B schematically illustrates an ECG system **200** according to a particular embodiment. ECG system **200** is similar in many respects to ECG system **100** described above and the same reference numerals are used to refer to features of ECG system **200** that are similar to features of ECG system **100**. Like ECG system **100**, ECG system **200** comprises a base unit **202** and two or more electrode units **204A**, **204B** (collectively and individually, electrode units **204**). ECG system **200** differs from ECG system **100** principally in that electrode units **204** are integral with base unit **202**. Other than being located within base unit **202**, electrode units **204** may be substantially similar to electrode units **104** described herein and may comprise any features and/or variations of electrode units **104** described herein.

In the illustrated embodiment, ECG system is shown as having a third electrode unit **104C** which attaches to base unit **202** via cable **106C** and connector **108C** to facilitate operation of ECG system **200** in an Einthoven’s triangle configuration. Third electrode unit **104C** may be substantially similar to electrode units **104** described herein and may comprise any features and/or variations of electrode units **104** described herein. In some embodiments, third electrode unit **104C** is not necessary and system **100** may use as few as two electrode units **204**. In some embodiments, a third electrode unit **204** may be provided as an integral part of base unit **202** (i.e. similar to electrode units **204** of the FIG. 4B embodiment). Like ECG system **100**, ECG system **200** comprises connectors **108** for accepting additional electrode units **104** to provide additional leads and corresponding additional views of heart muscle electrical activity.

In some embodiments, electrode units **204** may be detachable from base unit **202**—e.g. to sense electrical activity of the heart at different locations away from base unit **202**. For example, electrode units **204** may be provided in suitable sockets (not expressly shown), so that they can function to sense heart activity within their corresponding sockets. But electrodes **204** may be removed from their sockets, so that they can be connected to base unit **202** by suitable cables and

connectors (similar to cables **106** and connectors **108** described above for electrode units **104**). In this manner, electrode units **204** may also be able to sense electrical activity at locations away from base unit **202**.

In other respects, ECG system **200** may be substantially similar to ECG system **100** described herein.

FIG. 4C schematically illustrates an ECG system **300** according to a particular embodiment. ECG system **300** is similar in many respects to ECG systems **100**, **200** described above and the same reference numerals are used to refer to features of ECG system **300** that are similar to features of ECG systems **100**, **200**. Like ECG system **200**, ECG system **300** comprises a base unit **202** and two or more electrode units **204** that are integral with base unit **202**. ECG system **300** differs from ECG systems **100**, **200** described herein in that ECG system comprises a third electrode unit **304C** which is connected to base unit **202** via connector **108C** and extension arm **306C**. Third electrode unit **304C** may be substantially similar to electrode units **104** described herein and may comprise any features and/or variations of electrode units **104** described herein. Third electrode unit **304C** may permit ECG system **300** to operate in an Einthoven's triangle configuration. However, in ECG system **300** of the FIG. 4C embodiment, extension arm **306C** is fabricated from flexible, semi-rigid (e.g. limited elasticity) material that may be deformed by the ECG operator and, once deformed, may retain its shape so that electrode unit **304C** remains in a desired location relative to the individual's body **101** until extension arm **306C** is intentionally reshaped or repositioned by the ECG operator. Suitable materials for extension arm **306C** may include, for example, memory plastic and/or the like. In some embodiments, extension arm **306C** may comprise a casing having the flexible, semi-rigid (e.g. limited elasticity) properties which may in turn house a cable (e.g. similar to cable **106** described herein). It will be appreciated that in some embodiments, any electrode units **104** described as being connected to their respective base units may be connected via flexible, semi-rigid (e.g. inelastic) extension arms similar to extension arm **306C**.

In other respects, ECG system **300** may be substantially similar to ECG systems **100**, **200** described herein.

FIG. 4D schematically illustrates an ECG system **400** according to a particular embodiment. ECG system **400** is similar in many respects to ECG systems **100**, **200**, **300** described above and the same reference numerals are used to refer to features of ECG system **400** that are similar to features of ECG systems **100**, **200**, **300**. ECG system **400** comprises a base unit **402** and two or more electrode assemblies **404A**, **404B**, **404C** (collectively and individually, electrode assemblies **404**). Each electrode assembly **404A**, **404B**, **404C** may comprise a corresponding electrode unit **104A**, **104B**, **104C** which may be similar to electrode units **104** described herein and which may comprise any features and/or variations of electrode units **104** described herein. Each electrode assembly **404A**, **404B**, **404C** may also comprise corresponding signal processing components **406A**, **406B**, **406C** (collectively and individually, signal processing components **406**) and communications components **408A**, **408B**, **408C** (collectively and individually, communications components **408**). Signal processing components **406** may comprise any suitable analog or digital signal components for conditioning and/or processing the signals obtained from electrode units **104**. By way of non-limiting example, signal processing components **408** may comprise amplifiers, buffers, filters, analog to digital converters, suitably configured digital signal processors and/or the like. Communications components **408** may comprise

any suitable hardware for analog or digital wireless communication of signals obtained from electrode units **104** (and processed by signal processing components **406**) back to base unit **402**. In this manner, base unit **402** may be positioned at a location **105** away from the individual's body **101**. In some embodiments, electrode assemblies **404** may be electrically connected to one another (e.g. to provide a common ground or reference potential). In some embodiments, electrode assemblies **404** may share some of signal processing components **406** and/or communications components **408**.

Electrode assemblies **404** may be located relative to an individual's body **101** (as discussed in more detail below) to generate signals indicative of electrical activity of the individual's heart at their corresponding locations and may wirelessly communicate these signals back to base unit **402** at a location **105** away from the individual's body **101**. In the illustrated embodiment of FIG. 4D, ECG system **400** is shown as having three electrode assemblies **404A**, **404B**, **404C** which may be used in an Einthoven's triangle configuration. In some embodiments, third electrode assembly **404C** is not necessary and system **400** may use as few as two electrode assemblies **404**. In some embodiments, system **400** may be provided with more than three electrode assemblies **404** to provide additional leads and corresponding additional views of heart muscle electrical activity. In some embodiments, electrode assemblies **404** may comprise suitably configured controllers (not shown) which may control signal processing components **406** and/or communications components **408**.

Communications hardware **430** (and associated software) of ECG system **400** may differ from that of ECG systems **100**, **200**, **300** in that communications components **430** of ECG system **400** may be additionally configured to communicate wirelessly with electrode assemblies **404**. In other respects, ECG system **400** may be substantially similar to ECG systems **100**, **200**, **300** described herein.

In some embodiments, ECG system **400** is operatively connected to a vehicle's embedded software system such that ECG system **400** can communicate with the vehicle's systems to effect changes in the vehicle's physical parts, such as the brakes, engine, and the like. When a vehicle operator steps into the vehicle (e.g. possibly, but not necessarily before starting the vehicle), a vehicle operator may, in one embodiment, be asked to place one electrode unit **104** and/or one electrode assembly **404** onto the vehicle operator's chest (e.g. via a vehicle restraint (seat belt) and/or the like operating in a current sensing mode, a contact field-sensing mode or a non-contact field-sensing mode, in some embodiments) and one or more electrode units **104** and/or electrode assemblies **404** embedded in the back of the vehicle operator's seat (operating in a non-contact field sensing mode, in some embodiments). It will be appreciated that, in some embodiments, additional or alternative locations of electrode units **104** and/or electrode assemblies **404** could be used and that such electrode units (depending on their locations) could operate in current-sensing mode, field-sensing contact mode or field sensing non-contact mode. In some embodiments, electrode assemblies **404** operating only in field sensing non-contact mode are used in the vehicle and the vehicle operator will not need to physically attach electrode units **104** and/or electrode assembly **404** to the operator's chest. Signals detected by electrode units **104** and/or electrode assemblies **404** may be used to generate corresponding ECG signals (e.g. ECG waveforms **110**), which may be analyzed (e.g. by controller **112**, other controllers in ECG system **400**, or external ECG systems **124**

(communicating with ECG system 400 through communications component 124A)) to determine the state of the vehicle operator's heart and the vehicle operator's respiration patterns. The analysis may be done through the use of software algorithms and may include comparison to other data sets. Where the ECG waveforms 110 indicate the individual is incapacitated or is not in the proper condition to operate the vehicle, controller 112 communicates with the vehicle's on board system, which may act in accordance with instructions from controller 112. In some embodiments, if the ECG waveform 110 indicates that the vehicle operator is going to fall asleep, is drowsy, or is already asleep, controller 112 may communicate an alarm instruction to the vehicle system, and the vehicle system, upon receiving the instruction, will sound an alarm insides the vehicle or increase the volume of the radio and/or music playing in the entertainment system to wake the vehicle operator. In some embodiments, the alarm may comprise a vibration of the operator's seat to wake the vehicle operator. In some embodiments, the vehicle's infotainment system may ask the vehicle operator questions or require the vehicle operator to issue commands in order to wake, keep awake or otherwise maintain the alertness of the vehicle operator. In some embodiments, if the ECG waveform 110 indicates that the vehicle operator is incapacitated, controller 112 will not permit the vehicle to start or will communicate a stop instruction to the vehicle's system, and the vehicle's system will turn on the vehicle's emergency stop lights and slowly brake the vehicle to a stop. In some embodiments, ECG system 400 may interface or communicate with a vehicle's safety systems, such as active cruise control system, lane departure warning system, frontal collision warning system, precrash system, collision mitigating system, collision avoidance system, and/or the like to reduce the likelihood of an accident's occurrence while the vehicle operator is incapacitated or otherwise unable to operate the vehicle. ECG system 400 may also communicate the vehicle operator's location and condition to emergency dispatchers such that emergency personnel can attend to the vehicle's vehicle operator quickly. Data from such vehicular ECG systems may be recorded—e.g. for forensic analysis, data analytics and/or the like. Systems 100, 200 and/or 300 and/or any of the EEG, EOG or EMG systems described herein could be used in vehicle in a similar way to system 400 described herein.

FIG. 5A is a block diagram showing one implementation of a signal processing system 500A for processing data from electrode units 104 according to a particular embodiment. Signal processing system 500A may provide some of signal processing hardware 114 used with any of the ECG systems (e.g. ECG systems 100, 200, 300, 400) described herein. In some implementations, various portions of signal processing system 500A (e.g. amplifiers 504, ADCs 506 and/or the like) could be implemented as parts of electrode units 104 (as opposed to being implemented as parts of base units 102, 202, 302, 402). In general, it will be appreciated that the components shown in the FIG. 5A schematic illustration are functional components which could be implemented by various forms of suitably configured hardware.

Signal processing system 500A receives analog data from electrode units 104. Each electrode unit 104 generates a corresponding analog signal 502 which is amplified by a corresponding amplifier 504 and digitized by a corresponding analog-to-digital converter (ADC) 506 before being provided (as a digital signal 508) to digital signal processor (DSP) 510. In some embodiments, DSP 510 may include integral ADC converters 506. DSP 510 may be configured to

generate leads from digital signals 508 and to generate corresponding ECG data (e.g. ECG waveform 110). Digital signal processor 510 may additionally be configured to filter the various digital signals 508 (and/or combinations of such signals). For example, DSP 510 may be configured to filter various signals (or combinations of signals) to remove or mitigate the effects of breathing and/or other sources of artifacts. DSP 510 may additionally or alternatively function to apply active noise cancellation algorithms, based on inverted ambient noise data. DSP 510 may additionally or alternatively scale signals 508 received from electrode units 104 operating in different modes (explained in more detail below). DSP 510 may additionally or alternatively provide synchronization functionality by introducing time delays to one or more of signals 508. Such time delays may be determined based on temporal correlation functions as between signals 508 and/or based on feature (e.g. edges, peaks and/or the like) detection within signals 508. DSP 510 may also combine the various signals 508 to generate leads and corresponding ECG waveforms.

As is known in the art of digital signal processing, DSP 510 may be configured to process signals using functionality such as sample and hold functions, data acquisition functions, multi stage filtering and bandwidth limiting, filtering based, for example, on a rolling window, averaging functions, peak detection, temporal alignment of signals provided by different electrode units 104, positive and negative edge detection, time duration of PQRST portion of the ECG signal and relationship between them. Digital signal processor 510 may be controlled by controller 112. In some embodiments, however, DSP 510 and controller 112 may be implemented by the same hardware. In the FIG. 5A embodiment, DSP 510 has access to data storage 116. In some embodiments, all or part of data storage 116 may be integral to DSP 510. DSP 510 may output ECG data to data storage 116 and/or to display 120 (via communications components 130) and may provide the background functionality for such outputs. As discussed above, in some embodiments when display 120 is located in cradle 122 or when display is integral with base unit 102, ECG data may be provided directly to display 120 without involving communications hardware 130.

FIG. 5B is a block diagram showing one implementation of a signal processing system 500B for processing data from electrode units 104 according to another particular embodiment. Signal processing system 500B may provide some of signal processing hardware 114 used with any of the ECG systems (e.g. ECG systems 100, 200, 300, 400) described herein. Signal processing system 500B receives analog data from electrode units 104. Each electrode unit 104 generates a corresponding analog signal 502 which is received at analog signal conditioning block 512. Analog signal conditioning block 512 comprises various amplifiers (e.g. summing amplifiers and/or differential amplifiers and/or inverting amplifiers) which combine analog signals 502 in various ways known in the art to generate leads 514. Each lead 514 is then amplified by a corresponding amplifier 516 and digitized by a corresponding analog-to-digital converter (ADC) 518 before being provided (as a digital lead signal 520) to digital signal processor (DSP) 522. Digital signal processor 522 may then be configured to use digital lead signals 520 to generate corresponding ECG data (e.g. ECG waveform 110). Other than for receiving leads (as opposed to signals from electrode units 104), DSP 522 may comprise and provide functionality similar to that described above for DSP 510. In some embodiments, signal processing system 500B may be used to generate data from other types of

electrically-based physiological phenomena (physiological electrical activity), such as electrical activity of the brain (e.g. EEG data), electrical activity associated with skeletal muscles (e.g. EMG data), electrical activity of the eye (e.g. EOG data) and/or the like.

A description of electrode units is now provided. For the sake of brevity, the description of electrode units refers to electrode units **104**, it being understood that electrode units **204**, **304** may have similar features. For the sake of brevity, the bulk of the description of electrode units **104** assumes that electrode units **104** are used to measure the electrical activity of the heart muscle (e.g. ECG data). However, as mentioned above and discussed in more detail below, electrode units **104** may additionally or alternatively be used to sense other types of electrically-based physiological phenomena (physiological electrical activity), such as electrical activity of the brain (e.g. EEG data), electrical activity associated with skeletal muscles (e.g. EMG data), electrical activity of the eye (e.g. EOG data) and/or the like. In some embodiments, one or more of electrode units **104** comprise resistive sensor elements for sensing the current through or voltage across the resistive sensor element. Electrode units **104** which comprise resistive sensor elements may be referred to herein as current-sensing electrode units (without loss of generality that the voltage across resistive sensor elements could be detected). Current sensing electrode units **104** operate by placing the resistive sensor element in direct contact with a person's skin. In some embodiments, one or more of electrode units **104** comprise capacitive sensor elements which detect the presence of electric field. Electrode units **104** which comprise capacitive sensor elements may be referred to herein as field-sensing electrode units. Unlike resistive sensor elements, the capacitive sensor elements of field-sensing electrode units **104** do not require direct contact with the skin and may function by being placed close to the person's body (e.g. overtop of clothes, clothing accessories, equipment (including sports and soldier equipment) and/or the like), in (including embedded or mounted within) the backrest or bottom portion of a seat or chair (e.g., seats (e.g. operator seat(s) and/or other seat(s)) or seat restraints (e.g. seat restraints, such as a seat belt, safety belt, and/or the like) in a vehicle such as a car, plane, helicopter, motorcycle, truck, boat, cart, or the like, car seats, strollers, and/or the like), in the controls of a vehicle (e.g., in the handle bars of a motorcycle, in the steering wheel of a car, and/or the like), in a bed (e.g. a hospital bed, crib, bed frame, and/or the like), and/or the like. In some embodiments, electrode units **104** are incorporated into emergency response vehicles, such as police cars, ambulance, fire engines, and/or the like, and military vehicles, such as tanks, armored vehicles, infantry vehicles, amphibious vehicles, trooper carriers, engineering vehicles, military aircraft and/or the like. As discussed in more detail below, field-sensing electrode units may operate in a contact mode (i.e. in direct contact with a person's skin) or a non-contact mode (i.e. not in direct contact with a person's skin).

ECG systems **100**, **200**, **300**, **400** described herein may use either (or both) of current-sensing electrode units **104** and field-sensing electrode units **104**. Each of connectors **108** may be capable of accepting either current-sensing electrode units **104** or field-sensing electrode units **104**. In particular embodiments, a combination of current-sensing electrode units **104** and field-sensing electrode units **104** may be used in any of ECG systems **100**, **200**, **300**, **400** to monitor the heart muscle electrical activity of an individual. The choice of which particular electrode unit **104** may depend on the preferences of the system's operator, the

circumstances (e.g. whether it is difficult to remove the individual's clothing, or whether the individual already has exposed skin at the desired vantage points).

In particular embodiments, one or more of electrode units **104** that is used in systems **100**, **200**, **300**, **400** may comprise a multi-mode electrode unit **104** which can be configured to operate in one of a plurality of different modes. Such multi-mode electrode units **104** may operate as current-sensing electrode units by providing a resistive sensor element placed in direct contact with an individual's skin (i.e. under the individual's clothing (or at least with no intervening clothing between the sensor and the individual's skin)). Such multi-mode electrode units **104** may also operate as field-sensing electrode units which involve placing a capacitive sensor element in direct contact with an individual's skin (i.e. under the individual's clothing (or at least with no intervening clothing between the sensor and the individual's skin)). When such field-sensing electrode units are placed in direct contact with an individual's skin (i.e. under the individual's clothing (or at least with no intervening clothing between the sensor and the individual's skin)), such electrode units may be referred to herein as operating in "contact" mode. Such multi-mode electrode units **104** may also operate as field-sensing electrode units which involve placing a capacitive sensor element on top of the individual's clothing and not directly against the skin. When the individual's clothing is located between the electrode unit and the individual's skin, the electrode unit may be referred to herein as operating in "non-contact" mode. Since current-sensing electrode units typically require direct contact with the skin (i.e. no intervening clothing) to detect a signal, it is not necessary to describe current-sensing electrode units as operating in contact mode or non-contact mode, it being understood that when a current-sensing electrode unit **104** is operative, it operates in contact mode.

FIGS. **6A** and **6B** show a multi-mode electrode unit **600**, which may be used for electrode unit **104** of any of ECG systems **100**, **200**, **300**, **400**. Multi-mode electrode unit **600** may be configured for operation in field-sensing contact mode, field-sensing non-contact mode and/or current-sensing mode. Any one or more of electrode units **104**, **204**, **304** may comprise an electrode unit **600** of the type shown in FIGS. **6A** and **6B**. Electrode unit **600** comprises a clamp portion **602** and a sensor portion **604** which is removably attached to clamp portion **602**. As discussed in more detail below, sensor portion **604** comprises a capacitive sensor element **606** which permits electrode unit **600** to operate in a field-sensing contact mode (where sensor portion **604** is in direct contact with the individual's skin) or a field-sensing non-contact mode (where sensor portion **604** is located outside of the individual's clothing or otherwise is not in contact with the individual's skin). Further, at least one of clamp portion **602** and sensor portion **604** comprise a mechanism for electrical connection with a resistive sensor element **608** (FIG. **6B**) which permits electrode unit **600** to operate in a current-sensing mode. Because electrode unit **600** can be placed either on skin or atop clothing and because electrode unit **600** can operate as a current-sensing electrode unit or a field-sensing electrode unit, electrode unit **600** is versatile and can be used in a range of different situations. For example, in some situations it may be desirable or more convenient to leave the clothing on an individual and to place the electrode unit **600** on top of the individual's clothing. In other situations the individual's skin may be exposed at desired vantage points—for example, the individual's torso may be exposed to allow the

performance of a procedure (such as, by way of non-limiting example, defibrillation, CPR, insertion of a chest tube and/or the like) which requires direct contact with or exposure of the skin—and so in those cases it may be convenient to place electrode unit **600** directly against the skin.

When electrode unit **600** operates in a field-sensing, non-contact mode, electrode unit **600** is placed over the individual's clothing. As seen in FIGS. **6A** and **6B**, electrode unit **600** comprises a clamp **610**. In the illustrated embodiment of FIGS. **6A** and **6B**, clamp **610** comprises a pair of arms **610A**, **610B** which are pivotally connected to one another at pivot joint **612** and which are biased toward each other (e.g. by a suitably connected spring, a suitable deformable element and/or the like (not shown)) so that clamp **610** is biased toward a closed configuration. Arms **610A**, **610B** can be used to grip a part of the individual's clothing to attach the electrode unit **600** to the individual's clothing at the desired vantage point while the electrode unit **600** is being operated in field-sensing, non-contact mode. More particularly, when electrode unit **600** is operated in field-sensing, non-contact mode, a portion of the individual's clothing may be grasped between arms **601A**, **601B** of clamp **610** and proximate surface **614** of sensor portion **604** may be positioned directly atop the individual's clothing. This permits capacitive sensor element **606** to sense the electric field associated with the individual's heart-muscle activity and to provide a corresponding signal on one or more conductors of cable **624** which may be conveyed back to the base unit of the ECG system. Cable **624** may comprise one of cables **106** described above (see FIG. **4A**, for example).

In some embodiments, sensor portion **604** is removably attached to clamp portion **602**, so that sensor portion **604** may optionally be detached from clamp portion **602** (FIG. **6B**)—e.g. for use of sensor portion **604** in field-sensing, contact mode. More particularly, as can be seen by comparing FIGS. **6A** and **6B**, sensor portion **604** may be attached to clamp portion **602** (e.g. retained in cavity **618** in the particular case of the illustrated embodiment) to provide a unitary electrode unit **600** and sensor portion **604** may also be detached from clamp portion **602** to provide sensor portion **604** separately. When sensor portion **604** is separated from clamp portion **602**, the proximate surface **614** of sensor portion **604** may be placed into contact with an individual's skin to permit capacitive sensor element **606** to sense the electric field associated with the individual's heart-muscle activity in a contact mode and to provide a corresponding signal on one or more of the conductors of cable **624** which is conveyed back to the base unit of the ECG system.

It is not necessary that sensor portion **604** be removed from clamp portion **602** for operation of electrode unit **600** in field-sensing, contact mode. In some embodiments, electrode unit **600** (including clamp portion **602** and sensor portion **604**) may be located such that proximate surface **614** of sensor portion **604** is adjacent the individual's skin. For example, as shown in FIG. **6B**, cavity **618** (in which sensor portion **604** is retained) comprises a rim **618A** around its peripheral edge, but rim **618A** defines an opening **619** which permits proximate surface **614** of sensor portion **604** to directly contact an individual's skin. With this configuration, capacitive sensor element **606** is able to sense the electric field associated with the individual's heart-muscle electrical activity in a field-sensing, contact mode (and to provide a corresponding signal to the ECG base unit on cable **624**) even when sensor portion **604** is attached to clamp portion **602**. Similarly, it is not necessary to operate in a field-sensing contact mode when sensor portion **604** is separated

from clamp portion **602**. When sensor portion **604** is separated from clamp portion **602**, it is still possible to use sensor portion **604** in a field-sensing non-contact mode.

Sensor portion **604** and/or clamp portion **602** may comprise a locking mechanism **616** for keeping sensor portion **604** attached to clamp portion **602**. In the FIG. **6A**, **6B** embodiment, sensor portion **604** is received in cavity **618** of clamp portion **602** and a spring-biased locking mechanism **616** extends (radially inwardly in the case of the illustrated embodiment) over an edge of distal surface **620** of sensor portion **604**. When spring-biased locking mechanism **616** extends over the edge of distal surface **620** of sensor portion, locking mechanism **618** holds sensor portion **604** in cavity **618** (e.g. against rim **618A**) and thereby locks sensor portion **604** into attachment with clamp portion **602**. To detach sensor portion **604** from clamp portion **602**, an operator may slide locking mechanism **616** against the spring bias (radially outwardly in the case of the illustrated embodiment) to remove sensor portion **604** from cavity **618**. Some embodiments may comprise a plurality of spring-biased locking mechanisms **616**. In some embodiments, sensor portion **604** may be locked to clamp portion **602** using different additional or alternative locking mechanisms. In the illustrated embodiment, when sensor portion **602** is located in cavity **618**, cable **624** which is attached to sensor portion **604** runs through a channel **611** formed in a sidewall of cavity **618** of clamp portion **602**. In other embodiments, cable **624** may run through different features when sensor portion **604** is attached to clamp portion **602**.

In some embodiments, when electrode unit **600** is being used in field-sensing, contact mode, electrode unit **600** (or sensor portion **604** of electrode unit **600**) may be adhered to the skin of the individual using adhesive tape, adhesive stickers, a suctioning mechanism or other means. For example, a double-sided adhesive sticker or tape can be placed between the individual's skin and electrode unit **600** (or sensor portion **604** of electrode unit **600**) to adhesively connect electrode unit **600** (or sensor portion **604** of electrode unit **600**) to the individual's skin. Similarly, adhesive tape can be applied over top of electrode unit **600** to tape electrode unit **600** in contact with an individual's skin and to permit electrode unit **600** to be used in field-sensing contact mode. In some embodiments, electrode unit **600** (or sensor portion **604** of electrode unit **600**) may comprise a suction cup or suction hole (not shown) fluidly coupled to a suctioning bulb (not shown). The bulb may be squeezed prior to placement of the suction cup/hole on the individual's skin. Once the suction cup/hole is placed on the skin, the bulb is released to create a suctioning connection between the suction cup/hole and the skin, thereby holding electrode unit **600** (or sensor portion **604** of electrode unit **600**) against the individual's skin. In some embodiment, a piece of tape may be applied to the individual's skin with an end portion of the tape extending away from the individual's skin. The end portion of the tape may then be adhered to a side surface **615** of sensor portion **604** or the end portion of the tape may be gripped between arms **610A**, **610B** of clamp **610** to help hold electrode unit **600** (or sensor portion **604** of electrode unit **600**) against the individual's skin to thereby facilitate operation in field-sensing contact mode.

In addition to operating in field-sensing non-contact mode and field-sensing contact mode as discussed above, electrode unit **600** also operates in current-sensing mode. More particularly, at least one of clamp portion **602** and sensor portion **604** comprise a mechanism for electrical connection with a resistive sensor element **608** (FIG. **6B**) which permits electrode unit **600** to operate in a current-sensing mode. In

the illustrated embodiment, sensor portion **604** of electrode unit **600** comprises a snap-mechanism **622** for connection to a complementary snap-mechanism **626** on resistive sensor element **608**. In the illustrated embodiment, snap-mechanism **622** is located on distal surface **620** of sensor portion **604**. In other embodiments, snap mechanism **622** may be located on other surface(s) of sensor portion **604** and/or clamp portion **602**. Snap mechanism **622** is in electrical contact with one or more conductors in cable **624** so that a signal may be conveyed back to the base unit of the ECG system via cable **624**. The cable **624** conductor that is in electrical contact with snap mechanism **622** may be (but need not be) the same cable **624** conductor that is in electrical contact with the capacitive sensor element **606**.

FIG. 7A shows a variety of resistive sensor elements **608A**, **608B**, **608C** (collectively and individually, resistive sensor elements **608**) of different shapes and sizes, each with a corresponding snap-mechanism **626A**, **626B**, **626C** (collectively and individually, snap-mechanisms **626**). In the current North American industry standard, snap-mechanisms **626** of resistive sensor elements are male snap-mechanisms **626**. Accordingly, snap-mechanism **622** of electrode unit **600** may comprise a female snap-mechanism sized and shaped to mate with male snap-mechanisms **626** of resistive sensor elements **608**. Snap-mechanisms **622**, **626** are complimentary to one another, so that when they are engaged, there is a small amount of deformation of one or both of snap-mechanisms **622**, **626** such that restorative forces associated with that deformation tend to lock snap-mechanisms **622**, **626** to one another.

In use, a resistive sensor element **608** is connected to electrode unit **600** via a connection of snap-mechanisms **622**, **626** and then the side of resistive sensor element **608** opposite snap-mechanism **626** is adhered to the skin of the individual for operative in current-sensing contact mode. Typically, resistive sensor elements **608** comprise an adhesive “peel and stick” type backing which may be used for this purpose. The heart muscle electrical activity signal detected by resistive sensor element **608** is conveyed via the contact between snap-mechanism **622**, **626** to cable **624** and to the base unit of the ECG system. When operating in current-sensing mode, sensor portion **604** of electrode unit **600** may be removed from clamp portion **602** of electrode unit **600** in the same manner discussed above. This is not necessary, however, and electrode unit **600** may operate in current-sensing mode with sensor portion **604** connected to clamp portion **602**.

Resistive sensor elements **608** having snap-mechanisms **626** are common, but are not the only type of resistive sensor element. FIG. 7B depicts another type of resistive sensor element **630** which comprises an active surface **632** which may be adhered to the individual’s skin (e.g. with a peel and stick type adhesive or a suitable external adhesive). Resistive sensor element **603** also comprises a tab **634**, such that when active surface **632** is adhered to the individual’s skin, tab **634** may be bent (or may otherwise extend) away from the individual’s body. Multimode electrode unit **600** may also function in a current-sensing contact mode with resistive sensor elements **630**. More particularly, tab **634** of resistive sensor element may be clamped between the arms **610A**, **610B** of clamp **610**. One or both of the engagement surfaces of clamp **610** may be provided with electrical contacts **636A**, **636B** (collectively and individually, clamp contacts **636**). Clamp contacts **636** may be electrically connected to transmit a current-sensing contact signal through electrode unit **600** and a conductor of cable **624** back to the base unit of the ECG system.

In the case of the illustrated embodiment, clamp contacts **636** are in electrical contact with electrical contact **638** (e.g. via a suitable wire or other conductor within one or both arms **610A**, **610B** of clamp **610**). Electrical contact **638** may comprise any suitable electrical contact pin, plate, socket, shoe and/or the like. In the illustrated embodiment, electrical contact **638** is located on a wall of cavity **618**. Sensor portion **604** may be provided with a complementary electrical contact (not shown in the illustrated view) which is in electrical contact with one of the conductors of cable **624**. The electrical contact in sensor portion **604** may be complementary to electrical contact **638** and may comprise any suitable electrical contact pin, plate, socket, shoe and/or the like. In some embodiments, one or both of contact **638** and the contact in sensor portion **604** may be spring-loaded. When sensor portion **604** is connected to clamp portion **602** (e.g. sensor portion **604** is located in cavity **618** as shown in FIG. 6A of the illustrated embodiment), the electrical contact shoe of sensor portion **604** makes electrical contact with electrical contact shoe **638** of clamp portion **602**, thus completing an electrical contact from clamp contacts **636**, through electrical contact shoe **638** of clamp portion **602** and the electrical contact shoe of sensor portion **604** to a conductor of cable **624** and back to the base unit of the ECG system. In this manner, electrode unit **600** may work in current-sensing contact mode with resistive sensor element **630** and may convey heart activity signals back to the base unit of the ECG system.

In electrode unit **600** of the FIG. 6A, 6B embodiment, clamp **610** serves two functions. As described above, clamp **610** can be used to attach (e.g. electrically and physically couple) to a current-sensing element **630** so that electrode unit **600** can be operated in a current-sensing mode. Alternately, clamp **610** can be used to attach electrode unit **600** to clothing when the electrode unit **600** is being operated in a field-sensing non-contact mode. In other embodiments a separate clamping structure may be provided for each of these functions.

In the illustrated embodiment of FIGS. 6A and 6B, sensor portion **604** is connected to clamp portion **602** at a location between arms **610A**, **610B** of clamp portion **602**. This is not necessary. In some embodiments, sensor portion **604** may be connected to other locations on clamp portion **602**. By way of non-limiting example, sensor portion **604** may be connected to an outside of one of arms **610A**, **610B** of clamp portion **602** or within one of arms **610A**, **610B** of clamp portion **602**—i.e. such that sensor portion **604** is not located between arms **610A**, **610B**. In the illustrated embodiment, sensor element **606** is generally round in cross-section. In other embodiments, sensor element **606** may have a keyed-shape (e.g. a protrusion from its sidewall **615** (or one of its sidewalls) and a corresponding groove in the sidewall of cavity **618** or vice versa) or some other cross-sectional shape. In some embodiments, sidewall of cavity **618** may have a socket shaped to fit sensor element **606**. This may help to ensure alignment between electrical contact shoe **638** and the complementary electrical contact shoe on sensor portion **604**.

In the description of FIGS. 6A and 6B above, signals from resistive sensor elements **608**, **630** and from capacitive sensor elements **606** are conveyed back to the base unit of the ECG system via cable **624**. Cable **624** may comprise one of cables **106** described above. Cable **624** may be connected to the base unit using a corresponding connector **108** (see FIG. 4A, for example). Connectors **108** may comprise multi-conductor (e.g. multi-pin) connectors. Such conductors/pins may comprise, without limitation: a ground pin;

one or more current-sensing signal pins (e.g. one pin connected to snap-mechanism **622**, one pin connected clamp contacts **636** or one pin connected to both snap-mechanism **622** and clamp contacts **636**); and one or more field-sensing signal pins (e.g. connected to field-sensing element **606**). In some embodiments, signals from both field-sensing element **606**, snap mechanism **622** and clamp contacts **636** may be connected to the same pin of connectors **108**. Cable **624** and connectors **108** may comprise additional pins for conveying additional information from electrode unit **600**. For example, cable **624** may comprise conductors and connectors **108** may comprise pins for signals from proximity sensor(s) which may assist with determining the operational mode electrode unit **600**, as explained below. As discussed above in FIG. 4D, electrode unit **600** may be provided as part of an electrode assembly **404** where signals are wirelessly conveyed from electrode assemblies **404** to the base unit of the ECG system. In such embodiments, cable **624** may be considered to be a suitable electrical contact to signal processing components **406** of electrode assembly **404**—see FIG. 4D.

Where electrode units **104** of ECG systems **100**, **200**, **300**, **400** are provided by multi-mode electrode units **600**, an ECG system **100**, **200**, **300**, **400** may be operated with its electrode units **600** operating in different modes. By way of non-limiting example, electrode units **104A**, **104B** may operate in any desired combination or permutation of: field-sensing non-contact mode (e.g. over clothing), field-sensing contact mode (i.e. directly against the individual's skin) and current-sensing mode. Similarly, each of electrode unit **104C** and any additional electrode units connected to connectors **108** may operate in any desired one of: field-sensing non-contact mode, field-sensing contact mode and current-sensing mode.

The operation of electrode units **104** in different operational modes within a particular ECG system **100**, **200**, **300**, **400** may yield corresponding electrical signals **502** (see FIGS. 5A, 5B) having different amplitudes. For example, an electrode unit **104** operating in current-sensing mode typically provides a signal **502** which is several orders of magnitude larger than an electrode unit **104** operating in field-sensing mode. Similarly, an electrode unit **104** operating in a field-sensing contact mode may yield a slightly stronger (e.g. 10%-50% stronger) signal **502** than an electrode unit **104** operating in field-sensing non-contact mode. Signals **502** having different amplitudes can be scaled or the like (e.g. by signal processing hardware **114**) to normalize the signals prior to determining ECG leads (or other combined or differential signals). Suitable scaling factors can be pre-determined parameters, user-configurable parameters, system-configurable parameters or determined on an ad hoc basis. In one non-limiting example, digital signal processor **510** (FIG. 5A) may be configured to determine the amplitude (e.g. the maximum and minimum level) of each signal from each electrode unit **104** and to use this information to scale the signals from the various electrodes to normalize the signals to have at least approximately the same amplitude. In another non-limiting example, an amplifier or automatic gain control circuit (AGC) in analog signal conditioning circuitry **512** (FIG. 5B) may scale signals from electrode units operating in different modes by suitable pre-determined and/or configurable factor(s) in effort to normalize the signals from electrode units operating in different modes. In some embodiments, scaling may be non-linear.

In some circumstances, it may be desirable to determine the operational modes of electrode units **104** so that appropriate adjustments can be made to their corresponding

signals before generating ECG leads (or other combined or differential signals). For example, where one electrode unit **104** is being operated in a field-sensing mode and another electrode unit **104** is being operated in a current-sensing mode, it may be desirable to scale the signals to have the same order of magnitude.

As discussed above with reference to FIGS. 6A and 6B, in some embodiments, signals from different operational modes of electrode unit **600** can be conveyed on different conductors of cable **624** and conveyed to the base unit of an ECG system through a different pin of connector **108**. In this manner, the ECG system may be able to tell the operational mode of each of its electrode units **104**. In some embodiments, an operator may additionally or alternatively provide information to the ECG system (e.g. via user inputs **132**) to allow the ECG system to determine which electrode unit **104** is operating in which operational mode. In some embodiments, the strength of the signal from each electrode unit **104** may additionally or alternatively be used by the ECG system to determine the operational mode of each electrode unit **104**. For example, a signal having an amplitude above a certain threshold may be indicative of a current-sending mode of operation.

In some embodiments, one or more additional sensors (not expressly shown) can additionally or alternatively be incorporated into electrode units **104** to assist with determining the mode of operation. For example, one or more first proximity sensors can be located in electrode unit **104** to detect a presence of a resistive sensor element (e.g. a resistive sensor element **608** connected to snap-mechanism **622** or a resistive sensor element **630** clamped between arms **610A**, **610B** of clamp **610**). If the one or more first proximity sensors detect a resistive sensor element, then ECG system may conclude that electrode unit **104** is operating in current-sensing mode. One or more second proximity sensors can be located in electrode unit **104** to detect the proximity of the individual's skin. If the one or more second proximity sensors detect that the individual's skin is within a certain threshold distance and the one or more first proximity sensors do not detect a resistive sensor element, then ECG system may conclude that electrode unit **104** is operating in field-sensing contact mode. On the other hand, if the one or more second proximity sensors detect that the individual's skin is outside of the threshold distance and the one or more first proximity sensors do not detect the resistive sensor element, then it may be assumed that the electrode unit **104** is operating in a field-sensing non-contact mode. In some embodiments, the one or more second proximity sensors may be configured to detect the presence of a clamp portion of the electrode unit (explained in more detail below) and may conclude that electrode unit **104** is operating in a field-sensing non-contact mode when the clamp portion is sufficiently proximate or a field-sensing contact mode when the clamp portion is sufficiently far away.

It will be appreciated that the use of proximity sensors represent just one sensor-based technique for determining the operational mode of an electrode unit **104**. Sensors other than proximity sensors may additionally or alternatively be used to help with the determination of the operational mode of an electrode unit **104**. For example, suitable electrical contact sensors (e.g. micro-switches) and/or the like could be used to detect the presence of resistive sensor elements and/or clothing. For example, suitable proximity sensor, micro-switches, electrical contact sensors or the like could be used to detect whether or not clamp **610** is closed and could thereby be used to determine if a resistive sensor element or clothing was being held in clamp **610**.

As discussed above, electrode unit **600** comprises a capacitive sensor element **606** which enables electrode unit **600** to operate in a field-sensing mode. FIG. **8** is an exploded cross-sectional view of a capacitive sensor element **606** that may be used with the FIG. **6A**, **6B** electrode unit **600** or an electrode unit **104** according to a particular embodiment. Capacitive sensor element **606** comprises proximate and distal surfaces **614**, **620** corresponding to proximate and distal surfaces **614**, **620** shown in FIG. **6B**. The main sensor of capacitive sensor element **606** comprises an electrodynamic sensor **650** which is sensitive to local electric field. A non-limiting example of a suitable electrodynamic sensor **650** is described, for example, in U.S. Pat. No. 7,885,700. Another non-limiting example of a suitable electrodynamic sensor **650** is the sensor No. PS25205B marketed by Plessey Semiconductors Ltd. of the UK.

Capacitive sensor element **606** of the FIG. **8** embodiment comprises a number of components and layers:

An antenna component **652** which serves as an antenna to increase electromagnetic signal sensitivity of electrodynamic sensor **650** and to improve the signal resolution of electrodynamic sensor **650**. Antenna component **652** of the illustrated embodiment comprises a PCB core **654**. On an inner side of PCB core **654**, antenna component **652** comprise a layer of metallization (e.g. solder plated conductor) **656** which is in direct electrical contact with electrodynamic sensor **650** (described below). On an outer side of PCB core **654**, antenna component **652** comprises a layer of metallization (e.g. solder plated conductor) **658**, which is in turn coated with a thin non-conductive protective (e.g. solder mask) layer **660**. Inner and outer metallization layers **656**, **658** are electrically connected to one another by conductive vias **662** provided at suitable locations. Outer metallization layer **658** may be transversely recessed (e.g. by 1-5 mm) at its transverse edges **568A** to insulate outer metallization layer **658** from sensor housing **659**. Metallization layer **658** (and, possibly metallization layer **656**) may serve as the radiating element of an antenna which is in electrical contact with the sensing surface of electrodynamic sensor **650**. Metallization layer **658** and, possibly metallization layer **656** (i.e. the radiating element of antenna component **652**) may have a surface area that is greater than a surface area of the sensing surface of electrodynamic sensor **650**. In some embodiments, an outer peripheral rim of antenna component **652** could be provided with a stepped profile (e.g. an outer peripheral rim having less thickness in the left-to-right dimension of FIG. **8**) to accommodate the thickness of rim **618A** (see FIG. **6B**).

A sensor-positioning layer **664** may be used on an inside of antenna layer **652** and may provide a cut-out **666** as shown to ensure the proper placement and/or orientation of electrodynamic sensor **650**. Sensor-positioning layer **664** may comprise a suitable non-conductive PCB material or a single-layer PCB substrate with etched out copper layer.

A sensor-holding layer **668** which holds electrodynamic sensor **650**. Sensor-holding layer **668** may comprise a sensor-holding PCB. Sensor-holding layer **668** may provide suitable solderable contacts to solder electrodynamic sensor **650** and suitable electrical connections to main PCB layer **672** described below. In some embodiments, sensor-holding layer **668** and main PCB layer **672** may comprise complementary (e.g. male and

female) electrical contacts and/or connector components (not shown) that mate when sensor element **606** is assembled.

An insulator layer **670**, which provides compressive force and facilitates proper electrical contact between the inner metallization layer **656** of antenna layer **652** and electrodynamic sensor **650**. Insulation layer **670** may comprise Ethafoam™ material, for example. Insulator layer **670** may comprise a cut-out section (not shown) which permits electrical connections between sensor-holding layer **668** and main PCB layer **672** (as discussed above).

A main PCB layer **672** which houses the electronic circuitry (e.g. amplifiers, other signal conditioning components and/or the like) for operation of capacitive sensing element **606**. Main PCB layer may provide electrical contact to cable **624** described with reference to FIGS. **6A** and **6B** above.

A distal component **674** serving as distal surface **620**. Distal component **674** may comprise a metalized layer **676** which may provide electrical noise shielding. In the illustrated embodiment, metallization layer **676** is provided on the outside of distal component **674**. Distal component **674** may provide suitable conduits (not shown) for electrical connection to snap mechanism **622**.

A snap-mechanism **622** for connecting to complementary snap mechanism **626** of resistive sensor elements **608**. In the illustrated embodiment, snap-mechanism **622** comprises a female snap mechanism. In other embodiments, however, snap-mechanism **622** could comprise a male snap mechanism. As discussed above, snap-mechanism **622** may be electrically connected to a conductor in cable **624**. Snap-mechanism **622** may be electrically insulated from metallization layer **676** by suitable etching of metallization layer **676** or some other suitable insulating technique.

In some embodiments, electrode unit **104** comprises capacitive sensor element **606** as described herein to enable electrode unit **104** to operate in a field-sensing mode and may be provided with or without components that permit operation in current sensing mode. In some embodiments, electrode assembly **404** comprises one or more electrode units **104** that operate in field-sensing mode and comprises capacitive sensor element **606**. In some embodiments, capacitive sensor elements **606**, individually, or as part of electrode unit **104**, multimode electrode unit **600** or electrode assembly **404** may be incorporated into clothing, such as shirts, pants, shoes, clothing accessories, including watches, hats, belts, headbands, helmets, fitness bands, sports equipment, including, pads (e.g. shoulder, knee, elbow pads, and/or the like), guards, gloves, and the like. In some embodiments, capacitive sensor elements **606** may be embedded (e.g. sewn into, attached to, and/or the like) within clothing, clothing accessories, sports equipment, and the like. Capacitive sensor elements **606**, electrode unit **600**, and/or electrode assembly **404** may also be embedded or incorporated into or contained within seats (e.g. seats (operator seat(s) and/or other seat(s)) in a vehicle such as a car, plane, motorcycle, truck, boat, or the like, car seats, strollers, and/or the like), chairs (e.g. wheelchairs and/or the like), restraints for the seats and/or chairs (e.g. seat belts, safety belts, and/or the like), the controls of a vehicle (e.g., in the handle bars of a motorcycle, in the steering wheel of a car, and/or the like), beds (e.g. a hospital bed, crib, bed frame, and/or the like), couches, and/or the like, furniture (e.g. tables, sofas, recliners, and/or the like), decorations, furnish-

ings (e.g. cushions, pillows, and/or the like), and other fixtures (e.g. toilet seats, sinks, bath tub, and/or the like). In some embodiments, capacitive sensor elements 606, electrode unit 600, and/or electrode assembly 404 may be embedded or incorporated into or contained within emergency response vehicles, such as police cars, ambulance, fire engines, and/or the like, and military vehicles, such as tanks, armored vehicles, infantry vehicles, amphibious vehicles, trooper carriers, engineering vehicles, military aircraft and/or the like. These implementations allow capacitive sensor elements 606, electrode unit 600, and/or electrode assembly 404 to operate in field sensing mode and to detect electrical signals from the heart muscle of an individual or other when the individual is wearing clothing and clothing accessories or when the individual is in close proximity to the chairs, beds, couches, furniture, decorations, furnishings, and fixtures. In some embodiments, capacitive sensor elements 606, electrode unit 600, and/or electrode assembly 404 may be used to sense other types of electrically-based physiological phenomena (physiological electrical activity), such as electrical activity of the brain (e.g. EEG data), electrical activity associated with skeletal muscles (e.g. EMG data), electrical activity of the eye (e.g. EOG data) and/or the like. In some embodiments, electrode assembly 404 is powered by batteries, including removable or non-removable batteries. In some embodiments, these batteries are charged using a physical connection to a source of electricity. In other embodiments, these batteries are charged wirelessly. In some embodiments, these batteries may be charged by body movement. In some embodiments, these batteries may be charged by body heat. In other embodiments, electrode assemblies 404 may be charged by a combination of any of the foregoing methods.

ECG systems (e.g. systems 100, 200, 300, 400) according to particular embodiments may include mechanisms for reducing the effects of ambient electrical noise. More particular, ECG systems according to particular embodiments may comprise one or both of a grounding strap (not shown) or a right leg electrode (not shown). Such a grounding strap or right leg electrode may be used in addition to the grounding techniques implemented in electrode units 104 and/or in addition to filtering techniques provided by signal processing components described above to reduce the ambient electrical noise's impact on received electrical heart activity signals. Some sources of ambient noise (e.g. power line hum that could be either 60 Hz or 50 Hz) may be too strong to be effectively filtered by using the signal processing circuitry of the ECG systems. Accordingly, in some embodiments, one or both of a grounding strap or a right leg electrode may be used to increase the signal-to-noise ratio for subsequent signal processing.

A grounding strap may be provided to link the negative side of the power source (e.g. battery (not shown)) of base unit 102 to the individual's skin while limiting the current flow for safety of the individual. Such a grounding strap may be similar to the grounding straps used in electronics laboratories and/or electronic fabrication facilities and may be worn so as to touch the individual's skin to be effective for ambient electrical noise rejection (e.g. common mode rejection of the amplifiers associated with electrode units 104).

A Right Leg Drive (RLD) electrode may be implemented to inject the "inverted" polarity noise of same amplitude as an ambient electrical noise onto an individual's skin in order to compensate for the common mode noise. The RLD circuitry may comprise an inverting amplifier, a filter and a safety limiting resistor to prevent exceeding the safety limit of the noise signal injected onto the skin. This RLD elec-

trode may or may not touch the skin in order to inject inverted ambient noise into the system. The DSP may use the inverted ambient noise signal from the RLD electrode to at least partially cancel ambient noise and to thereby increase the signal-to-noise ratio. A RLD electrode may be provided with similar physical characteristics as electrode unit 600 described above and may comprise a clamp portion similar to clamp portion 602 for attaching to an individual's clothing or the like.

In some embodiments, ECG systems 100, 200, 300, 400 (FIGS. 4A-4D) are portable and lightweight systems that are convenient to use and transport. For example, they may be compact enough to be carried by hand so that they are easy to transport to an individual's current location, which may be in the individual's home or in some other location. In some embodiments, ECG systems 100, 200, 300, 400 may be designed to be small enough to fit within a carrying bag or pocket.

FIG. 9 illustrates an ECG system 900 incorporating a harness 901 and a plurality of electrode units 104 according to a particular embodiment. In many respects, ECG system 900 is similar to ECG systems 100, 200, 300, 400 (FIGS. 4A-4D) described above. In the illustrated embodiment of system 900, harness 901 comprises a rigid portion 903 one or more straps 910 that wrap around the body of an individual or are otherwise shaped to fit on or to be worn around the individual's body. In some embodiments, straps 910 are configured to extend from and recoil into rigid components 903, which may be located at the front of the individual's body (as illustrated in FIG. 9) and/or located at the back and/or to the side of the individual's body. Harness 901 and/or straps 910 may comprise components that are connected to each other by fasteners, such as hook and loop, clips, buttons, and/or the like. Electrode units 104 may be similar to electrode units 104 described elsewhere herein and may comprise any feature(s) of and/or modification(s) to electrode units 104. In some embodiments, electrode units 104 may comprise capacitive sensor elements, each having an electrodynamic sensor sensitive to electromagnetic waves and an antenna comprising an electrically conducting radiating element for receiving electromagnetic waves as described elsewhere herein. In some embodiments, electrode units may comprise multi-mode electrode units 600 of the type described herein. In the FIG. 9 embodiment, electrode units 104 are provided as part of electrode assemblies 404 which may be substantially similar to electrode assemblies 404 described elsewhere herein and may comprise any feature(s) of or modification(s) to electrode assemblies 404. Electrode assemblies 404 may be located at locations (e.g. adjustable locations) on harness 901 and/or straps 910 so that when harness 901 is worn by an individual, electrode assemblies 404 will be located in desirable positions relative to the heart—e.g. for detection of suitable ECG data. Electrode assemblies 404 may be integrated into or embedded within harness 901 and/or straps 910 or attached to harness 901 and/or straps 910 by hooks, clips, compression clips, hook and loop systems, and the like. In some embodiments, harness 901 comprises tracks such that electrode assemblies 404 are movable along the tracks to different locations of the person's body. In some embodiments, harness 901 comprises location indicators, such as a coloured indicator, an identification spot, and/or the like, to allow the wearer to position electrode assemblies 404 to the applicable location on the wearer's body. In other embodiments, harness 901 comprises measurement lines, a ruler, and/or the like to allow the wearer to measure distances between locations on harness 901. The location indicators and/or measurement

lines may also allow different wearers to adjust the locations of electrode assemblies **404** on harness **901** depending on the wearer's body type and/or body traits. System **900** may comprise controls for operating electrode assemblies **404**, such as controls for switching individual electrode units **104** between field-sensing and current-sensing modes (e.g. where electrode units **104** comprise multi-mode electrode units, such as electrode units **600**), on-off switches, and the like. In some embodiments, harness **901** comprises compression clamps, and the compression clamps hold electrode assemblies **404** at appropriate locations on an individual's body. In some embodiments, electrode assembly **404** or electrode unit **104** comprises capacitive sensor element having an electrodynamic sensor sensitive to electromagnetic waves and an antenna comprising an electrically conducting radiating element for receiving electromagnetic waves as described elsewhere herein.

System **900** may also comprise a base unit **920** which may be similar to base unit **402** of ECG system **400** described above. Base unit **920** may comprise suitable communication hardware (not shown) similar to communication hardware **430** described above, which may facilitate communication between electrode assemblies **404** and external ECG systems or to other devices (not shown) such as a smartphone, tablet, laptop, computers, and/or the like. Communication between electrode units **104** and base unit **920** may be by wire or cable embedded within or attached to harness **901**, straps **910**, tracks, and/or the like. Communication between electrode units **104** and base unit **920** may additionally or alternatively be wireless according to any suitable wireless communication protocol. Communication between base unit **920** and the external ECG system and/or other devices may be wireless according to any suitable wireless communication protocol. Base unit **920** may comprise connectivity indicators **922** to allow the harness wearer to determine whether reliable communication is established between base unit **920** and the external ECG system and/or other devices. System **900** may also incorporate other sensors or medical devices such as blood pressure cuff, pulse oximeters, glucose monitors, and/or the like, although this is not necessary.

Electrode units **104** described herein (including electrode units **204**, **304**, **600** and electrode assemblies **404**) are sensitive to electrical characteristics of the body (physiological electrical activity), whether they are current-sensing electrode units, field-sensing electrode units, multi-mode electrode units operating in current-sensing mode or multi-mode electrode units operating in contact or non-contact field-sensing mode. Because of this sensitivity to physiological electrical activity, electrode units **104** may be used to sense physiological electrical activity other than the electrical activity of the heart muscle and can be used as a part of corresponding systems used to generate other types of data based on such physiological electrical activity (e.g. electrical characteristics of other cell(s), tissue(s), organ(s) and/or system(s) in the person's body). By way of non-limiting example, electrode units similar in many respects to electrode units **104** described herein could be used to sense other types of electrically-based physiological phenomena (physiological electrical activity), such as electrical activity of the brain (e.g. as part of an EEG system for generating EEG data), electrical activity associated with skeletal muscles (e.g. as part of an EMG system for generating EMG data), electrical activity of the eye (e.g. as part of an EOG system for generating EOG data) and/or the like. Using such electrode units, ECG systems **100**, **200**, **300**, **400**, and/or **900** described herein could be used or suitably modified for use as EEG, EMG and/or EOG systems. Similarly, signal pro-

cessing systems **500A**, **500B** could be used or suitably modified for use in EEG, EMG and/or EOG systems.

FIG. **10** schematically illustrates an EEG system **1000** according to a particular embodiment. EEG system **1000** of the FIG. **10** embodiment is shown having a general architecture that is similar to ECG system **400** (FIG. **4D**) and similar reference numerals are used to refer to features of EEG system **1000** that are similar to corresponding features of ECG system **400**. It will be appreciated by those skilled in the art (given the description of ECG systems **100**, **200**, **300**, **400** above and the description of EEG system **1000** below) that EEG system **1000** could be modified to have the general architecture of any of ECG systems **100**, **200**, **300**, and **400**. EEG system **1000** comprises a base unit **1002** and two or more electrode assemblies **1004A**, **1004B**, **1004C** (collectively and individually electrode assemblies **1004**). Consistent with the architecture of ECG system **400** (FIG. **4D**), each electrode assembly **1004** of the illustrated embodiment of EEG system **1000** comprises a corresponding electrode unit **104A**, **104B**, **104C** which may be similar to electrode units **104** described herein, but which may be configured for detection of brain activity and corresponding EEG data. By way of non-limiting example, electrode units **104** may comprise multi-mode electrode units similar to multi-mode electrode units **600** described herein. In some embodiments, electrode units **600** comprise capacitive sensor element **606** and the capacitive sensor element **606** comprises antenna component **652** and electrodynamic sensor **650** as described herein. In some embodiments, electrode units **104** may comprise one or more capacitive sensor elements, each having an electrodynamic sensor sensitive to electromagnetic waves and an antenna comprising an electrically conducting radiating element for receiving electromagnetic waves as described elsewhere herein.

Consistent with the architecture of ECG system **400** (FIG. **4D**), each electrode assembly **1004** of the illustrated embodiment of EEG system **1000** comprises corresponding signal processing components **1006A**, **1006B**, **1006C** (collectively and individually signal processing components **1006**) and communications components **1008A**, **1008B**, **1008C** (collectively and individually communications components **1008**). Signal processing components **1006** and communications components **1008** may be similar to signal processing components **406** and communications components **408** described herein, but may be configured for detection of brain activity and corresponding EEG data. In some embodiments, signal processing components **1006** (and/or signal processing components **114** of base unit **1002**) comprise signal amplifiers with very low noise. The input signals being measured by electrode units **104** in electrode assemblies **1004** of EEG system **1000** may be as low as tens of microvolts peak-to-peak; accordingly, amplifiers having noise levels below this may be desirable. Electrode units **104** and/or electrode assemblies **1004** may detect electrical signals from the brain in current-sensing mode, field-sensing contact mode and/or field sensing non-contact mode. In one embodiment, one electrode unit **104** and/or electrode assembly **1004** detects electrical signals from the brain in current-sensing mode with the other electrode unit **104** and/or electrode assembly **1004** in field-sensing contact mode or field sensing non-contact mode. In other embodiments, electrode units **104** and/or electrode assemblies **1004** may all operate in field-sensing non-contact mode to detect electrical signals from the brain. In some embodiments, electrode units **104** and/or electrode assemblies **1004** may operate in a combination of field-sensing contact mode and field-sensing non-contact mode. In some embodiments, electrode

units **104** and/or electrode assemblies **1004** may comprise one or more capacitive electrode sensor elements, each having an electrodynamic sensor sensitive to electromagnetic waves and an antenna comprising an electrically conducting radiating element for receiving electromagnetic waves as described elsewhere herein.

Base unit **1002** may be positioned at a location **105** away from an individual's body **101** and electrode assemblies **1004** may communicate measured signals or data back to base unit **1002**. In some embodiments, electrode assemblies **1004** may be electrically connected to one another (e.g. to provide a common ground or reference potential). In some embodiments, electrode assemblies **1004** may share some of signal processing components **1006** and/or communications components **1008**. In some embodiments, electrode assemblies **1004** may comprise suitably configured controllers (not shown) which may control signal processing components **1006** and/or communications components **1008**. In the embodiment illustrated in FIG. 10, electrode assemblies **1004** communicate wirelessly to base unit **1002**. In some embodiments, one or more than one of electrode assemblies **1004** may be physically connected to base unit **1002** by corresponding cables and may communicate to base unit **1002** through such cables. In some embodiments, electrode assemblies **1004** may be physically connected to a signal transmitter by a wire harness, and the signal transmitter communicates signals from electrode assemblies **1004** to base unit **1002** wirelessly. In some embodiments, electrode assemblies **1004** are similar to electrode units **104** in FIG. 4A whereby electrode assemblies **1004** may be removably connected to base unit **1002** using suitable electrical, signal transmission connectors, which may comprise slidable locking electric connectors, spring-biased electric connectors, magnetic connectors and/or the like.

Electrode assemblies **1004** may be located relative to a subject's body **101** (e.g. around a person's head in a hat, a net and/or the like, embedded within, or attached to the inside of, a hat, cap, helmet, and/or the like (including the pad material, if any, inside any of the foregoing)) to generate signals indicative of electrical activity of the subject's brain at their corresponding locations and may wirelessly communicate these signals back to base unit **1002** at a location **105** away from the subject's body **101**. While electrical potentials of individual neurons in the brain may be too small to detect reliably, electrode assemblies **1004** and EEG system **1000** may detect activity of groups of neurons having similar spatial orientations. In the illustrated embodiment of FIG. 10, EEG system **1000** is shown as having three electrode assemblies **1004A**, **1004B**, **1004C** which may be used in a suitable configuration for generating EEG data. In some embodiments, third electrode assembly **1004C** is not necessary and system **1000** may use as few as two electrode assemblies **1004**. In some embodiments, system **1000** may be provided with more than three electrode assemblies **1004** (e.g. tens or even hundreds of electrode assemblies **1004**) to provide additional views of brain electrical activity

Base unit **1002** of EEG system **1000** and display **120** may be similar in many respects to base unit **402** of ECG system **400** and display **120** of ECG system **400** described herein. EEG waveforms **1010** generated by EEG system **1000** based on signals received from electrode assemblies **1004** may be shown on display **120** and display **120** may be mounted in cradle **122** or removed from base unit **1002**. Base unit **1002** may comprise suitably configured hardware and/or software components for processing signals from electrode assemblies **1004** and for generating corresponding EEG waveforms. In the illustrated embodiment of FIG. 10, base unit

1002 of EEG system **1000** comprises: controller **112**, signal processing hardware **114**, data storage **116**, communications hardware **130** and user interface components **132**. These components may be configured to provide particular functionality using suitably coded software (not explicitly shown). In some embodiments, communications hardware **130** may facilitate communication of EEG data (e.g. data stored in data storage **116**, real time EEG waveforms **1010** and/or the like) from base unit **102** to an external EEG system **1024**. Other than for dealing with EEG data (in addition to or in the alternative to ECG data) and possibly for dealing with external EEG system(s) **1024**, these components of EEG system **1000** may be similar to the corresponding components of ECG system **400** described above. Base unit **1002** may comprise additional connectors **108** for optional connection to additional or alternative electrode units (not shown); and/or connections **134** for connecting to other medical equipment. Connectors **108** and connections **134** may be similar to those described above for ECG system **400**.

In some embodiments, electrode units **104** and/or electrode assemblies **1004** are embedded into, contained within, or attached to the inside of helmets, such as firefighter helmets, athlete helmets, soldier helmets, and the like (including the padding, such as foam, contained therewithin). In these embodiments, EEG system **1000** may be used to monitor the electrical activity of the brain of the individual wearing the helmets, such as firefighters, athletes, soldiers, and the like. The brain activity as shown in the form of EEG waveforms **1010** may be used to assess the condition of the helmet-wearing individual to determine whether the individual is in the proper condition for performing the specific tasks.

In some embodiments, electrode units **104** and/or electrode assemblies **1004** are fixed on the head of an individual corresponding to the locations known as the 10-20 international system of EEG electrode placement. In some embodiments, electrode units **104** and/or electrode assemblies **1004** are held to the skin of the individual through fasteners such as tape, adhesives, clips, elastic strap(s) and/or the like. In some embodiments, electrode assemblies **1004** are held in place on or around a subject's head through the use of compression clamps. In some embodiments, electrode units **104** and/or electrode assemblies are not in contact with the skin of the individual. Electrode units **104** and/or electrode assemblies **1004** may additionally or alternatively be held using a holder arm firmly fixed to an individual's bed, chair, seat or other furniture around the individual. Electrode units **104** and/or electrode assemblies **1004** may additionally or alternatively be held in pockets of hats or in suitable netting. Such hats or netting may be elastically deformable to deform when a person's head is inserted therein, such that restorative forces associated with such deformation tend to hold the hat (and the corresponding electrode units **104** and/or electrode assemblies **1004**) to the person's head in the correct locations desired for monitoring. In some embodiments, snap connectors may be used to hold such hats or netting in place.

Electrode units **104** or electrode assemblies **1004**, may also be used, whether as part of a helmet, hat, headband, or other types of headgear on individuals, to allow doctors to monitor whether the individual is suffering from brain conditions, such as strokes, seizures, hemorrhages, and the like. In some embodiments, EEG system **1000** comprises alarms which are sounded when EEG system **1000**, after analyzing EEG waveforms **1010**, determines that the individual is having trauma or some other detectable condition

in the brain. In some embodiments, EEG system **1000** communicates EEG waveforms **1010** to a computing device (e.g. device **126A**) that is operated by, or a display shown to, a doctor, technician, or the like, both of which allow the doctor, the technician, or the like to remotely monitor the brain activities of an individual. EEG system **1000** may be incorporated into medical diagnostic equipment, neuroprostheses or systems for use in detecting biofeedback, neuroimaging, brain-computer interfaces, interactive computer games, and the like. In some embodiments, EEG system **1000** can also be used to detect hearing in infants.

In some embodiments, EEG system **1000** may be installed in vehicles, such as cars, trucks, buses, planes, trains, and the like. Electrode units **104** and/or electrode assemblies **1004** may be installed or embedded into or contained within the interior of the vehicle, such as the steering wheel, seats (e.g. operator seat(s) and/or other seat(s)), headrests, dashboard, seat restraints (such as seat belts, safety belts, and/or the like), ceiling panel, ground panel, side panel, and/or the like. Base unit **1002** may be installed as part of the dashboard and/or control panel of the vehicle or be located in any other locations in the vehicle, such as the trunk or other storage space of the vehicle. In such installations, EEG system **1000** may or may not comprise display **120** or display **102** may comprise a part of the dashboard of the vehicle, the control panel of the vehicle, the entertainment system of the vehicle, heads-up display of the vehicle, or pop-up display in the vehicle.

In some embodiments, EEG waveforms **1010** may be analyzed by EEG system **1000** to assess the brain of a vehicle operator to determine whether the operator is suffering from a medical condition, is falling asleep, is drowsy, is driving under the influence of drugs, alcohol, or the like, or is otherwise impaired or unable to operate the vehicle appropriately. In some embodiments, EEG system **1000** is configured to send a distress signal, distress call, or warning signal to emergency responders, such as firefighters, police, and the like, emergency dispatch centers, or in-vehicle telematics service providers, when the brain of a vehicle operator is being affected by adverse medical conditions, trauma, or the like or when an accident has occurred, including accidents where one or more airbags have been activated. EEG system **1000** may contact emergency responders and emergency dispatch center through communication hardware **130**, including through wireless communication modules. EEG system **1000** may also communicate EEG waveforms **1010** to emergency responders and medical personnel or allow data containing information about the EEG waveforms **1010** to be accessed and/or downloaded by emergency responders or medical personnel to assist the responders and medical personnel in diagnosing and treating the vehicle operator. In some embodiments, EEG system **1000** may interface or communicate with a vehicle's safety systems, such as active cruise control system, lane departure warning system, frontal collision warning system, precrash system, collision mitigating system, collision avoidance system, and/or the like to reduce the likelihood of an accident occurring while the vehicle operator is incapacitated or otherwise unable to operate the vehicle.

In one embodiment, EEG system **1000** is operatively connected to the vehicle's embedded software system such that EEG system **1000** can communicate with the vehicle's systems to effect changes in the vehicle's physical parts, such as the brakes, engine, and the like. When a vehicle operator steps into the vehicle (e.g. possibly, but not necessarily before starting the vehicle), a vehicle operator may be asked to place one electrode unit **104** and/or one electrode

assembly **1004** onto the vehicle operator's head (operating in a current sensing mode or a contact field-sensing mode, in some embodiments) and one or more electrode units **104** and/or electrode assemblies **1004** embedded in the head rest of the vehicle operator's seat (operating in a non-contact field sensing mode, in some embodiments). It will be appreciated that, in some embodiments, additional or alternative locations of electrode units **104** and/or electrode assemblies **1004** could be used and that such electrode units (depending on their locations) could operate in current-sensing mode, field-sensing contact mode or field sensing non-contact mode. Signals detected by electrode units **104** and/or electrode assemblies **1004** may be used to generate corresponding EEG signals (e.g. EEG waveforms **1010**), which may be analyzed (e.g. by controller **112**, other controllers in EEG system **1000**, or external EEG systems **1024** (communicating with EEG system **1000** through communications component **1024A**)) to determine the state of the vehicle operator's brain. The analysis may be done through the use of software algorithms and may include comparison to other data sets. Where the EEG waveforms **1010** indicate the individual is incapacitated or is not in the proper condition to operate the vehicle, controller **112** communicates with the vehicle's on board system, which may act in accordance with instructions from controller **112**. In some embodiment, if the EEG waveform **1010** indicates that the vehicle operator is going to fall asleep, is drowsy, or is already asleep, controller **112** communicates an alarm instruction to the vehicle system, and the vehicle system, upon receiving the instruction, will sound an alarm insider the vehicle or increase the volume of the radio and/or music playing in the entertainment system to wake the vehicle operator. In some embodiments, the alarm may be a vibration of the operator's seat to wake the vehicle operator. In further embodiments, the vehicle's infotainment system may ask the vehicle operator questions or require the vehicle operator to issue commands in order to wake, keep awake or otherwise maintain the alertness of the vehicle operator. In another embodiment, if the EEG waveform **1010** indicates that the vehicle operator is incapacitated, controller **112** will not permit the vehicle to start or will communicate a stop instruction to the vehicle's system, and the vehicle's system will turn on the vehicle's emergency stop lights and slowly brake the vehicle to a stop. EEG system **1000** may also communicate the vehicle operator's location and condition to emergency dispatchers such that emergency personnel can attend to the vehicle's vehicle operator quickly. Data from such vehicular EEG systems may be recorded—e.g. for forensic analysis, data analytics and/or the like.

FIG. **11** schematically illustrates an EMG system **1100** according to a particular embodiment. EMG system **1100** of the FIG. **11** embodiment is shown having a general architecture that is similar to ECG system **400** (FIG. **4D**) and similar reference numerals are used to refer to features of EMG system **1100** that are similar to corresponding features of ECG system **400**. It will be appreciated by those skilled in the art (given the description of ECG systems **100**, **200**, **300**, **400** above and the description of EMG system **1100** below) that EMG system **1100** could be modified to have the general architecture of any of ECG systems **100**, **200**, **300**, and **400**. EMG system **1100** comprises a base unit **1102** and two or more electrode assemblies **1104A**, **1104B**, **1104C** (collectively and individually electrode assemblies **1104**). Consistent with the architecture of ECG system **400** (FIG. **4D**), each electrode assembly **1104** of the illustrated embodiment of EMG system **1100** comprises a corresponding electrode unit **104A**, **104B**, **104C** which may be similar to

electrode units **104** described herein, but which may be configured for detection of skeletal muscle activity and corresponding EMG data. In some embodiments, electrode units **104** or electrode assemblies **1104** may comprise one or more capacitive sensor elements, each having an electrodynamic sensor sensitive to electromagnetic waves and an antenna comprising an electrically conducting radiating element for receiving electromagnetic waves as described elsewhere herein. By way of non-limiting example, electrode units **104** may comprise multi-mode electrode units similar to multi-mode electrode units **600** described herein. In some embodiments, electrode units **600** comprise capacitive sensor element **606** and the capacitive sensor element **606** comprises antenna component **652** and electrodynamic sensor **650** as described herein.

Consistent with the architecture of ECG system **400** (FIG. 4D), each electrode assembly **1104** of the illustrated embodiment of EMG system **1100** comprises corresponding signal processing components **1106A**, **1106B**, **1106C** (collectively and individually signal processing components **1106**) and communications components **1108A**, **1108B**, **1108C** (collectively and individually communications components **1108**). Signal processing components **1106** and communications components **1108** may be similar to signal processing components **406** and communications components **408** described herein, but may be configured for detection of skeletal muscle activity and corresponding EMG data.

Base unit **1102** may be positioned at a location **105** away from the individual's body **101** and electrode assemblies **1104** may communicate measured signals or data back to base unit **1102**. In some embodiments, electrode assemblies **1104** may be electrically connected to one another (e.g. to provide a common ground or reference potential). In some embodiments, electrode assemblies **1104** may share some of signal processing components **1106** and/or communications components **1108**. In some embodiments, electrode assemblies **1104** may comprise suitably configured controllers (not shown) which may control signal processing components **1106** and/or communications components **1108**.

Electrode assemblies **1104** may be located relative to an individual's body **101** (e.g. in suitable locations relative to specific muscles and/or the like) to generate signals indicative of electrical activity of an individual's skeletal muscle at their corresponding locations and may wirelessly communicate these signals back to base unit **1102** at a location **105** away from the individual's body **101**. In the illustrated embodiment of FIG. 11, EMG system **1100** is shown as having three electrode assemblies **1104A**, **1104B**, **1104C** which may be used in a suitable configuration for generating EMG data. In some embodiments, third electrode assembly **1104C** is not necessary and system **1100** may use as few as two electrode assemblies **1104**. In some embodiments, system **1100** may be provided with more than three electrode assemblies **1104** to provide additional views of skeletal muscle electrical activity. Electrode units **104** and/or electrode assemblies **1104** may detect electrical signals from the skeletal muscles in current-sensing mode, field-sensing contact mode and/or field sensing non-contact mode. In one embodiment, one electrode unit **104** and/or electrode assembly **1104** detects electrical signals from a skeletal muscle in current-sensing mode with the other electrode unit **104** and/or electrode assembly **1104** in field-sensing contact mode or field sensing non-contact mode. In other embodiments, electrode units **104** and/or electrode assemblies **1104** may all operate in field-sensing non-contact mode to detect electrical signals from the skeletal muscle. In some embodiments, electrode units **104** and/or electrode assemblies **1104**

may operate in a combination of field-sensing contact mode and field-sensing non-contact mode.

Base unit **1102** of EMG system **1100** and display **120** may be similar in many respects to base unit **402** of ECG system **400** and display **120** of ECG system **400** described herein. EMG waveforms **1110** generated by EMG system **1100** based on signals received from electrode assemblies **1104** may be shown on display **120** and display **120** may be mounted in cradle **122** or removed from base unit **1102**. Base unit **1102** may comprise suitably configured hardware and/or software components for processing signals from electrode assemblies **1104** and for generating corresponding EMG waveforms. In the illustrated embodiment of the FIG. 11 EMG system **1100**, base unit **1102** comprises: controller **112**, signal processing hardware **114**, data storage **116**, communications hardware **130** and user interface components **132**. These components may be configured to provide particular functionality using suitably coded software (not explicitly shown). In some embodiments, communications hardware **130** may facilitate communication of EMG data (e.g. data stored in data storage **116**, real time EMG waveforms **1110** and/or the like) from base unit **102** to an external EMG system **1124**. Other than for dealing with EMG data (in addition to or in the alternative to ECG data) and possibly for dealing with external EMG system(s) **1124**, these components of EMG system **1100** may be similar to the corresponding components of ECG system **400** described above. Base unit **1102** may comprise additional connectors **108** for optional connection to additional or alternative electrode units (not shown); and/or connections **134** for connecting to other medical equipment. Connectors **108** and connections **134** may be similar to those described above for ECG system **400**. In the embodiment illustrated in FIG. 11, electrode assemblies **1104** communicate wirelessly to base unit **1102**. In some embodiments, one or more than one of electrode assemblies **1104** may be physically connected to base unit **1102** by corresponding cables and may communicate to base unit **102** through such cables. In some embodiments, electrode assemblies **1104** may be physically connected to a signal transmitter by a wire harness, and the signal transmitter communicates signals from electrode assemblies **1104** to base unit **1102** wirelessly. In some embodiments, electrode assemblies **1104** are similar to electrode units **104** in FIG. 4A whereby electrode assemblies **1104** may be removably connected to base unit **1102** using suitable electrical, signal transmission connectors, which may comprise slidable locking electric connectors, spring-biased electric connectors, magnetic connectors and/or the like.

In some embodiments, electrode assemblies **1104** are in direct contact with the skin of an individual. In other embodiments, electrode assemblies **1104** are not in contact with the skin of an individual. In one embodiment, electrode assemblies **1104** are mounted on an individual's body using a stretch band stretching around a limb with the band either endless or with the ends of the band fixed together by fasteners such as hook and loop fasteners, pins, buckles, and the like. In some embodiment, electrode assemblies **1104** are embedded into, contained within, incorporated into, or attached to sports equipment, such as fitness bands, shin pad, shin guard, knee pad, elbow pad, arm pad, shoulder pad, leg guard, chest protector, body pad, wrist pad, glove, and/or the like. In some embodiments, electrode assemblies **1104** are held in place on or around specific muscles through the use of compression clamps.

EMG system **1100** may also be used to monitor the activity of specific skeletal muscles of individuals, such as patients, athletes, soldiers, and the like. EMG waveforms

1110 may further be used to diagnose and/or assessing neuromuscular disease, back pain, motor control disorder, neuropathies, neuromuscular junction diseases, myopathies and/or the like. EMG signals detected by EMG system 1100 may also be used as control signals for prosthetic devices such as prosthetic hands, arms, lower limbs, and the like. EMG signals may further be used to assess strength, condition, and fatigue levels of specific muscles.

In one embodiment, an athlete wears a pad (e.g. a shin guard and/or the like) that incorporates two or more electrode assemblies 1104. One electrode assembly 1104 directly contacts the skin of the individual and operates in current sensing mode and/or field sensing contact mode. The other electrode assembly 1104 is not in direct contact with the skin and operates in field sensing non-contact mode. In some embodiments, both electrode assemblies 1104 operate in field sensing non-contact mode. It will be appreciated that, in some embodiments, additional or alternative locations of electrode units 104 and/or electrode assemblies 1104 could be used and that such electrode units (depending on their locations) could operate in current-sensing mode, field-sensing contact mode or field sensing non-contact mode. EMG waveforms 1110 are then analyzed by controller 112, other controllers in EMG system 1100, or external EMG system 1124 (which may be in communication with base unit 1102 through external EMG communication component 1124A) through the use of software algorithms. EMG waveforms 1110 may also be shown on display 120 in EMG system 1100 and analyzed by technicians, physicians, coaches, the athlete himself or herself, and the like. EMG waveforms 1100 may be used to determine the state of an individual's skeletal muscle (e.g. the muscle(s) under the athlete's pad), such as the tibialis anterior muscle. Such analysis of skeletal muscle activity can be used to ascertain muscle fatigue, muscle damage, muscle strength, muscle condition and/or the like.

In some embodiments, EMG system 1100 may be installed in vehicles, such as cars, trucks, busses, planes, trains, and the like. Electrode units 104 and/or electrode assemblies 1104 may be installed or embedded into or contained within the interior of the vehicle, such as the seats, arm rests, seat restraints, and/or the like. In some embodiments EMG system 1100 is used with adjustable seat systems, such as adjustable seats in vehicles, office chairs, massage chairs, and/or the like. EMG system 1100 uses EMG waveforms 1110 to determine the strain in of skeletal muscles of an individual sitting in the seats. EMG system 1100 may then communicate with the controller of the adjustable seat systems to adjust the characteristics of the seats, such as curvature, height, tilt, and/or the like, to reduce the strain in the individual's skeletal muscles. In some embodiments, EMG system 1100 may interface or communicate with a vehicle's safety systems, such as active cruise control system, lane departure warning system, frontal collision warning system, precrash system, collision mitigating system, collision avoidance system, and/or the like to reduce the likelihood of an accident occurring while the vehicle operator is incapacitated or otherwise unable to operate the vehicle.

In some embodiments, EMG system 1100 is used as part of a human-machine interface in which EMG signals and EMG waveforms 1110 are used for detecting the motion of an individual. Such detection can then be used for interpreting gestures performed by the individual. In some embodiments, EMG system 1100 is incorporated into medical diagnostic equipment or neuroprostheses.

FIG. 12 schematically illustrates an EOG system 1200 according to a particular embodiment. EOG system 1200 of the FIG. 12 embodiment is shown having a general architecture that is similar to ECG system 400 (FIG. 4D) and similar reference numerals are used to refer to features of EOG system 1200 that are similar to corresponding features of ECG system 400. It will be appreciated by those skilled in the art (given the description of ECG systems 100, 200, 300, 400 above and the description of EOG system 1200 below) that EOG system 1200 could be modified to have the general architecture of any of ECG systems 100, 200, 300, and 400. EOG system 1200 comprises a base unit 1202 and two or more electrode assemblies 1204A, 1204B, 1204C (collectively and individually electrode assemblies 1204). Consistent with the architecture of ECG system 400 (FIG. 4D), each electrode assembly 1204 of the illustrated embodiment of EOG system 1200 comprises a corresponding electrode unit 104A, 104B, 104C which may be similar to electrode units 104 described herein, but which may be configured for detection of corneo-retinal potential and corresponding EOG data. In some embodiments, electrode units 104 or electrode assemblies 1204 may comprise one or more capacitive sensor elements, each having an electrodynamic sensor sensitive to electromagnetic waves and an antenna comprising an electrically conducting radiating element for receiving electromagnetic waves as described elsewhere herein. By way of non-limiting example, electrode units 104 may comprise multi-mode electrode units similar to multi-mode electrode units 600 described herein. In some embodiments, electrode units 600 comprise capacitive sensor element 606 and the capacitive sensor element 606 comprises antenna component 652 and electrodynamic sensor 650 as described herein.

Consistent with the architecture of ECG system 400 (FIG. 4D), each electrode assembly 1204 of the illustrated embodiment of EOG system 1200 comprises corresponding signal processing components 1206A, 1206B, 1206C (collectively and individually signal processing components 1206) and communications components 1208A, 1208B, 1208C (collectively and individually communications components 1208). Signal processing components 1206 and communications components 1208 may be similar to signal processing components 406 and communications components 408 described herein, but may be configured for detection of electrical activity of the eye and corresponding EOG data.

Base unit 1202 may be positioned at a location 105 away from the individual's body 101 and electrode assemblies 1204 may communicate measured signals or data back to base unit 1202. In some embodiments, electrode assemblies 1204 may be electrically connected to one another (e.g. to provide a common ground or reference potential). In some embodiments, electrode assemblies 1204 may share some of signal processing components 1206 and/or communications components 1208. In some embodiments, electrode assemblies 1204 may comprise suitably configured controllers (not shown) which may control signal processing components 1206 and/or communications components 1208.

Electrode assemblies 1204 may be located relative to an individual's body 101 (e.g. in suitable locations relative to the individual's eye) to generate signals indicative of electrical activity of the individual's eye at their corresponding locations and may wirelessly communicate these signals back to base unit 1202 at a location 105 away from the individual's body 101. In the illustrated embodiment of FIG. 12, EOG system 1200 is shown as having three electrode assemblies 1204A, 1204B, 1204C which may be used in a

suitable configuration for generating EOG data. In some embodiments, third electrode assembly **1204C** is not necessary and system **1200** may use as few as two electrode assemblies **1204**. In some embodiments, system **1200** may be provided with more than three electrode assemblies **1204** to provide additional views of corneo-retinal electrical activity. Electrode assemblies **1204** may detect corneo-retinal electrical activity in current-sensing mode, field-sensing contact mode and/or field sensing non-contact mode. In one embodiment, electrode assembly **1204A** detects electrical signals from the brain in current-sensing mode with the other electrode assembly **1204** in field-sensing contact mode or field sensing non-contact mode. In other embodiments, electrode assemblies **1204** may all operate in field-sensing non-contact mode to detect electrical signals from the brain. In some embodiments, electrode assemblies **1204** may operate in a combination of field-sensing contact mode and field-sensing non-contact mode.

Base unit **1202** of EOG system **1200** and display **120** may be similar in many respects to base unit **402** of ECG system **400** and display **120** of ECG system **400** described herein. EOG waveforms **1210** generated by EOG system **1200** based on signals received from electrode assemblies **1204** may be shown on display **120** and display **120** may be mounted in cradle **122** or removed from base unit **1202**. Base unit **1202** may comprise suitably configured hardware and/or software components for processing signals from electrode assemblies **1204** and for generating corresponding EOG waveforms. In the illustrated embodiment of the FIG. **12**, EOG system **1200**, base unit **1202** comprises: controller **112**, signal processing hardware **114**, data storage **116**, communications hardware **130** and user interface components **132**. These components may be configured to provide particular functionality using suitably coded software (not explicitly shown). In some embodiments, communications hardware **130** may facilitate communication of EOG data (e.g. data stored in data storage **116**, real time EOG waveforms **1210** and/or the like) from base unit **102** to an external EOG system **1224**. Other than for dealing with EOG data (in addition to or in the alternative to ECG data) and possibly for dealing with external EOG system(s) **1224**, these components of EOG system **1200** may be similar to the corresponding components of ECG system **400** described above. Base unit **1202** may comprise additional connectors **108** for optional connection to additional or alternative electrode units (not shown); and/or connections **134** for connecting to other medical equipment. Connectors **108** and connections **134** may be similar to those described above for ECG system **400**. In the embodiment illustrated in FIG. **12**, electrode assemblies **1204** communicate wirelessly to base unit **1202**. In some embodiments, one or more than one of electrode assemblies **1004** may be physically connected to base unit **1202** by corresponding cables and may communicate to base unit **1202** through such cables. In some embodiments, electrode assemblies **1204** may be physically connected to a signal transmitter by a wire harness, and the signal transmitter communicates signals from electrode assemblies **1204** to base unit **1202** wirelessly. In some embodiments, electrode assemblies **1204** are similar to electrode units **104** in FIG. **4A** whereby electrode assemblies **1204** may be removably connected to base unit **1202** using suitable electrical, signal transmission connectors, which may comprise slidable locking electric connectors, spring-biased electric connectors, magnetic connectors and/or the like.

In some embodiments, a pair of electrode assemblies **1204** is placed above and below the eye. In other embodiments, the pair of electrode assemblies **1204** is placed to the

left and right of the eye. In some embodiments, electrode assemblies **1204** are embedded into, contained within, incorporated into, or attached to a frame, glasses, goggles, and the like. Signals detected by EOG system **1200** and/or EOG waveforms **1210** may be used to diagnose ophthalmological conditions such as Best's disease, macular dystrophy, retinitis pigmentosa, other retinal conditions and/or the like. In one embodiment, one of the electrode assemblies **1204** is in direct contact with the skin around the eye and the other electrode assembly **1204** is not in direct contact with the skin. In other embodiments, the electrode assemblies **1204** are both not in direct contact with the skin. In some embodiments, electrode assemblies **1204** are held in place on or around a subject's eyes through the use of compression clamps.

In some embodiments, EOG system **1200** is used to track eye movement of the individual. In some embodiments, EOG system **1200** is used to track the eye movement for actors who are performing motion capture for animated films. In some embodiments, EOG system **1200** may be used by individuals giving presentations. In some embodiments, EOG system **1200** may be used with entertainment systems, such as televisions, movie theatres, game consoles, and/or the like to track eye movement of the individual.

In some embodiments, EOG system **1200** may be used as part of a vehicle safety system. As an example, before operating a vehicle, the vehicle operator may be to first wear a frame around the operator's face with electrode assemblies **1204** mounted on the frame such that one of the electrode assemblies **1204** will be in contact with the skin of the vehicle operator near one of the eyes. The electrode assembly **1204** in contact with the skin may operate in current sensing mode and/or field-sensing contact mode and the other electrode unit **1204** on the frame may operate in field sensing non-contact mode. In other embodiments, electrode assemblies **1204** are located near the eye but not in contact with the skin of the vehicle operator. It will be appreciated that, in some embodiments, additional or alternative locations of electrode units **104** and/or electrode assemblies **1204** could be used and that such electrode units (depending on their locations) could operate in current-sensing mode, field-sensing contact mode or field sensing non-contact mode. Signals detected from electrode assemblies **1204** are sent to signal processing system **114** in base unit **1202** by wireless communications. Signals are then processed by signal processing system **114** to generate corresponding EOG signals (e.g. EOG waveforms **1210**). EOG waveforms **1210** are then analyzed by controller **112**, other controllers in EOG system **1200**, or external EOG system **1224** through the use of software algorithms to determine the eye movement of the vehicle operator. In one embodiment, when the EOG waveforms **1210** indicate that the individual is impaired, such as by alcohol, drugs, tiredness and/or the like, controller **112** communicates with the vehicle's on board system, which may act in accordance with instructions from controller **112**. In some embodiment, if the EOG waveform **1210** indicates that the vehicle operator is going to fall asleep, is drowsy, or is already asleep, controller **112** communicates an alarm instruction to the vehicle system, and the vehicle system, upon receiving the instruction, will sound an alarm insides the vehicle or increase the volume of the radio and/or music playing in the entertainment system to wake the vehicle operator. In some embodiments, the alarm may be a vibration of the operator's seat to wake the vehicle operator. In further embodiments, the vehicle's infotainment system may ask the vehicle operator questions or require the vehicle operator to issue commands in order

to wake or keep awake the vehicle operator. In another embodiment, if the EOG waveform **1210** indicates that the vehicle operator is incapacitated, controller **112** will not permit the vehicle to start or will communicate a stop instruction to the vehicle's system, and the vehicle's system will turn on the vehicle's emergency stop lights and slowly brake the vehicle to a stop. EOG system **1200** may also communicate the vehicle operator's location and condition to emergency dispatchers such that emergency personnel can attend to the vehicle's vehicle operator quickly. Data from such vehicular EOG systems may be recorded—e.g. for forensic analysis, data analytics and/or the like. In some embodiments, EOG system **1200** may be incorporated into military vehicles for use in adjusting weapon targeting systems and/or determining the state of the vehicle and/or weapon system operator. In some embodiments, EOG system **1200** may interface or communicate with autonomous driving systems in a vehicle. In some embodiments, the autonomous driving system may take over operation of the vehicle where the EOG system **1200** indicates that the vehicle operator incapacitated or otherwise unable to operate the vehicle. In some embodiments, EOG system **1200** may interface or communicate with a vehicle's safety systems, such as active cruise control system, lane departure warning system, frontal collision warning system, precrash system, collision mitigating system, collision avoidance system, and/or the like to reduce the likelihood of an accident occurring while the vehicle operator is incapacitated or otherwise unable to operate the vehicle.

In one embodiment, a vehicle, such as a car, truck, bus, plane, train, ship, and the like, comprises ECG systems **100**, **200**, **300**, **400**, **900**, EEG system **1000**, EMG system **1100**, or EOG systems **1200**, or a combination of all or some of the foregoing systems. The state of drowsiness of a vehicle operator may be determined solely by ECG data (e.g. ECG waveform **110**), EEG data (e.g. EEG waveforms **1010**), EMG data (e.g. EMG waveform **1110**), or EOG data (e.g. EOG waveform **1210**) or a combination of all or some of foregoing data. The use of sensors to provide ECG signals, EEG signals, EMG signals, and EOG signals for determining drowsiness of a vehicle operator is discussed in Sahayadhas, Arun et al., "Detective Driver Drowsiness Based on Sensors: A Review", *Sensors* 2012, 12, 16937-16953, and the content of the publication is hereby incorporated by reference in its entirety. In these embodiments, ECG data, EEG data, EMG data, or EOG data may be generated from signals received by electrode assemblies, and these electrode assemblies may comprise multi-mode electrode units similar to multi-mode electrode units **600** described herein. These multi-mode electrode units may operate in contact mode (current-sensing) or non-contact mode (current sensing or field sensing), depending on the location or position of the vehicle operator. In some embodiments, electrode units **600** comprise capacitive sensor element **606** and the capacitive sensor element **606** comprises antenna component **652** and electrodynamic sensor **650** as described herein. In some embodiments, the same electrode assemblies are used to detect different signals from the vehicle operator. In other embodiments, different electrode assemblies are used to detect signals from different physiological electrical activities of the vehicle operator (e.g. electrical activity of an organ, such as the heart (e.g. the heart muscle), brain, eye, or skeletal and/or other muscle).

In one embodiment, ECG systems **100**, **200**, **300**, **400**, **900**, EEG system **1000**, EMG system **1100**, or EOG systems **1200**, or a combination of all or some of the foregoing systems, are used to monitor infants, babies, toddlers, or

young children. Electrode assemblies, which may comprise multi-mode electrode units similar to multi-mode electrode units **600** described herein embedded within car seats, cribs, strollers, and/or the like and/or in seat restraints, such as a seat belt, safety belt, and/or the like, may detect electrical activity from different physiological electrical activities ((e.g. electrical activity of an organ, such as the heart (e.g. the heart muscle), brain, eye, or skeletal and/or other muscle)) of the infants, babies, toddlers, or young children by operating in current-sensing mode, field-sensing contact mode or field sensing non-contact mode (depending on the location or position of the infant, baby, toddler, or young child). ECG data (e.g. ECG waveform **110**), EEG data (e.g. EEG waveforms **1010**), EMG data (e.g. EMG waveform **1110**), or EOG data (e.g. EOG waveform **1210**) may then be generated from the signals received by the electrode assemblies and analyzed as described herein. ECG data, EEG data, EMG data, or EOG data may then be transmitted to a phone, tablet, computer, laptop, website, and/or the like, and displayed to a parent, guardian, babysitter, teacher, and/or the like to monitor the state of the infant, baby, toddler, or young child. In some embodiments, temperature sensor may also be added to provide temperature information of the infant, baby, toddler, or young child with the ECG data, EEG data, EMG data, or EOG data or a combination of some or all such data.

While a number of exemplary aspects and embodiments have been discussed above, those of skill in the art will recognize certain modifications, permutations, additions and sub-combinations thereof. For example:

In the illustrated embodiment of FIGS. **6A** and **6B**, cable **624** is shown as being permanently attached to sensor portion **604**. This is not necessary. In some embodiments, cable **624** may be attached to clamp portion **602** and the outputs of sensor portion **604** (e.g. sensed signals) may be connected to cable **624** by suitable electrical contact(s) between clamp portion **602** and sensor portion **604**. In some embodiments, connections to resistive sensor elements (e.g. snap mechanism **622** and/or clamp contacts **636**) can be routed through clamp portion **602** without the need for sensor portion **602**.

In some embodiments, clamp portion **602** of electrode unit **600** may be fabricated from bacteria resistant material (e.g. suitable plastic and/or the like).

In some embodiments, ECG systems **100**, **200**, **300**, **400** may be configured to provide a heart-shaped graphic on display **120** and to interpret the ECG data to cause the heart-shaped graphic to simulate actual heart-muscle activity as detected in the ECG data.

In some embodiments, multi-mode electrode units **600** (or any variations of multi-mode electrodes **600** described herein) may be connected to prior art ECG, EEG, EMG, or EOG systems—e.g. in the place of conventional electrode units. When connected in this manner, suitable adapters may be used to provide output signals from electrode units **600** in a format useable by the prior art ECG, EEG, EMG, or EOG system.

In some embodiments, cables (e.g. cables **106**, cables **624**) associated with the various electrode units or electrode assemblies described herein may be retractable and may be housed, for example, in the base unit or in the housing of the electrode unit or electrode assemblies, as applicable.

In some embodiments, an electrode unit comprising a capacitive sensor element **606** (see FIGS. **6A**, **6B**) could be incorporated into a blood pressure cuff and

attached to the body of an individual via the blood pressure cuff to sense heart muscle electrical activity in a field-sensing contact or field-sensing non-contact mode.

In some embodiments, electrode units (e.g. electrode units **104**) and/or electrode assemblies (e.g. electrode assemblies **404**) of the type described herein may be used in non-contact field-sensing mode for locating individuals (e.g. by their heart activity or similar electrical activity) in a nonvisible environment—e.g. as part of search and rescue operation in rubble, avalanche, smoky rooms and/or the like. In some embodiments, electrode units (e.g. electrode units **104**) and/or electrode assemblies (e.g. electrode assemblies) **404** of the type described herein may be used in non-contact field-sensing mode for motion detection systems. In some embodiments, electrode units and/or electrode assemblies may be used at sporting events or in public or private areas.

In some embodiments, electrode units (e.g. electrode units **104**) and/or electrode assemblies (e.g. electrode assemblies **404**) of the type described herein may comprise capacitive sensor elements having an electrodynamic sensor sensitive to electromagnetic waves and an antenna comprising an electrically conducting radiating element for receiving electromagnetic waves as described elsewhere herein.

Embodiments are described above wherein EEG system **1000** and EOG system **1200** are implemented in a vehicle. In some embodiments, any of the ECG systems described herein and/or EMG system **1100** may be implemented in a vehicular setting. Such embodiments may comprise embedding electrode units and/or electrode assemblies into components of the vehicle, such as (without limitation): the steering wheel, the dashboard, the vehicle ceiling, the vehicle floor, the vehicle seat(s), seat restraints, and/or the like. Such ECG and EMG systems can be used to determine the state of the heart muscle and/or the skeletal and/or other muscle of the vehicle operator. Such information may be communicated to first responders or suitable authorities in the event of an accident or during normal vehicular operation periods. Such embodiments can also alert the vehicle operator (using suitable alarms and/or the like) that the vehicle operator is having a heart attack or similar heart condition. Data from such vehicular ECG systems and/or EMG systems may be recorded—e.g. for forensic analysis, data analytics and/or the like.

In some embodiments, a plurality of ECG systems **100**, **200**, **300**, **400**, **900**, EEG systems **1000**, EMG system **1100** and EOG systems **1200** may be implemented together in a vehicle for the purpose of having redundant systems. Such systems may share a number of common hardware components. The results from one system may be used to confirm or augment the results from the other system.

ECG systems **100**, **200**, **300**, **400**, **900**, EEG system **1000**, EMG system **1100**, and/or EOG systems **1200** may communicate ECG, EEG, EMG, and/or EOG waveforms, as applicable, to a mobile device such as a phone, tablet, and/or the like. In some embodiments, these waveforms may be communicated to a website, cloud storage, or other online databases.

Signals received by electrode units (e.g. electrode units **104**) and/or electrode assemblies (e.g. electrode assemblies **404**) for ECG systems such as ECG systems **100**, **200**, **300**, **400**, and **900** may be analyzed to determine respiration patterns of an individual, and the respiration

information may be used alone or in conjunction with ECG data (e.g. ECG waveforms) or other data (such as EEG data, EMG data, or EOG data) to determine the state of the individual, such as whether the individual is asleep, drowsy, impaired, or is suffering from medical conditions

Signals received by electrode units and/or electrode assemblies for ECG systems such as ECG systems **100**, **200**, **300**, **400**, **900**, EEG systems such as EEG system **1000**, EMG systems such as EMG system **1100**, and/or EOG systems such as EOG system **1200** may be analyzed alone or in combination with other signals to determine the medical state of an individual such as drowsiness, unconsciousness, incapacity, brain injury, stroke, arrhythmias, compensated shock, decompensated shock, sepsis, heart attack, sleep, stress, attentiveness, cognition, respirations, internal bleeding, and/or the like.

Software may be used to interpret ECG waveforms, EEG waveforms, EMG waveforms, and/or EOG waveforms together to provide detailed information about the state of an individual.

The electrode units (e.g. electrode units **104**) and/or electrode assemblies (e.g. electrode assemblies **404**) of the type described herein may be used to measure ECG, EEG, EMG, and/or EOG signals based on instructions from software from the applicable system.

The electrode units (e.g. electrode units **104**) and/or electrode assemblies (e.g. electrode assemblies **404**) of the type described herein may also be incorporated or embedded into electronic devices, such as phones, tablets, laptop computers, desktop computers, smart watches, activity trackers, and the like, and/or casing or other protective gear for such devices.

The systems and methods described herein are not limited to humans and may be used for monitoring of animals, such as pet animals or animals at zoos.

Display **120** of ECG systems **100**, **200**, **300**, **400**, **900**, EEG systems **1000**, EMG system **1100** and EOG systems **1200** may be the displays of electronic devices, such as phones, tablets, laptop computers, desktop computers, smart watches, and/or the like.

ECG systems **100**, **200**, **300**, **400**, **900**, EEG systems **1000**, EMG system **1100** and EOG systems **1200** may be used for detection of signals from individuals located in or travelling with public areas, such as streets, malls, airports, ports, and/or the like.

Where the electrode units described herein capture signals related to the operation of cell(s), tissue(s), organ(s) and/or system(s), the controllers of the systems described herein may be configured to use these signals (individually and/or together) to create and display an animation on a suitable display. The animation may be based on the one or more signals and may show the operation of the cell(s), tissue(s), organ(s) and/or system(s).

EMG systems described elsewhere herein are described in connection with skeletal muscle. This is not necessary. In general, the EMG systems described herein may be used in connection with the electrical activity of other (non-skeletal) muscles and/or a combination of skeletal and other muscles.

It is therefore intended that the scope of the following appended claims and claims hereafter introduced should not be limited by the embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

What is claimed is:

1. A system for sensing physiological electrical activity in an individual comprising:

a first electrode unit for generating a first signal indicative of the physiological electrical activity at a first location on a body of the individual; and

a second electrode unit for generating a second signal indicative of the physiological electrical activity at a second location on the body of the individual;

wherein each of the first and second electrode units is configurable to operate in:

a field-sensing mode wherein the electrode unit is configured to generate its corresponding signal based on a detected electric field at a location on or in proximity to the individual's skin; and,

wherein each of the first and second electrode units comprises a capacitive sensor element, the capacitive sensor element of each of the electrode units comprising:

an electrodynamic sensor which is sensitive to electromagnetic waves; and

an antenna comprising an electrically conductive radiating element for receiving electromagnetic waves, the radiating element in electrical contact with a sensing surface of the electrodynamic sensor and having a surface area which is larger than a surface area of the sensing surface of the electrodynamic sensor, the antenna located relatively more proximate than the electrodynamic sensor to the individual's skin during operation of the electrode unit in the field-sensing mode.

2. The system according to claim 1 wherein the physiological electrical activity comprises electrical activity of an organ, the organ comprising a heart, a brain, an eye, or a skeletal muscle.

3. The system according to claim 2 wherein the organ comprises the heart and system is configured to combine the first and second signals to generate an ECG waveform.

4. The system according to claim 2 wherein the organ comprises the brain and the system is configured to combine the first and second signals to generate an EEG waveform.

5. The system according to claim 2 wherein the organ comprises the eye and the system is configured to combine the first and second signals to generate an EOG waveform.

6. The system according to claim 2 wherein the organ comprises the skeletal muscle and the system is configured to combine the first and second signals to generate an EMG waveform.

7. The system according to claim 1 wherein the capacitive sensor element of each of the electrode units comprises an electrically non-conductive layer disposed on the radiating element, wherein the non-conductive layer is on an outside face of the electrode unit which is located relatively more proximate than the radiating element to the individual's skin during operation of the electrode unit in the field-sensing mode.

8. The system according to claim 7 wherein the antenna comprises a metallization layer electrically connected to an inner metallization layer in direct electrical contact with the electrodynamic sensor.

9. The system according to claim 8 comprising an insulator layer to provide a compressive force for facilitating the direct electrical contact.

10. The system according to claim 1 comprising a distal component to provide electrical noise shielding.

11. The system according to claim 1 wherein at least one of the electrode units comprises a clamp.

12. The system according to claim 11 wherein the clamp is provided in a clamp portion of the electrode unit, the capacitive sensor element is provided in a sensor portion of the electrode unit and the clamp portion and sensor portion are attachable to, and detachable from, one another.

13. The system according to claim 11 wherein the clamp comprises a pair of clamp teeth for clamping objects therebetween and the clamp is shaped to clamp the individual's clothing between the clamp teeth and to thereby affix the at least one electrode unit to the individual's clothing.

14. The system according to claim 11 wherein the clamp comprises a pair of clamp teeth for clamping objects therebetween and one or more electrically conducting clamp contacts located in one or both of the teeth for clamping a portion of a resistive sensor element between the clamp teeth and corresponding electrical attachment of the resistive sensor element to the one or more clamp contacts, and wherein the at least one of the electrode units is configurable to operate in a current-sensing mode wherein the electrode unit is configured to generate its corresponding signal based on current flow through the resistive sensor element placed directly on the individual's skin.

15. The system according to claim 1 wherein at least one of electrode units comprises a first connector component for receiving a second complementary connector component of a resistive sensor element for removably electrically connecting the resistive sensor element to the electrode unit by connecting the first and second connector components, and wherein the at least one of the electrode units is configurable to operate in a current-sensing mode wherein the electrode unit is configured to generate its corresponding signal based on current flow through the resistive sensor element placed directly on the individual's skin.

16. The system according to claim 15 wherein the first and second connector components are shaped such that connecting the first and second connector components causes deformation of at least one of the first and second connector components and corresponding restorative forces which tend to maintain the connection between the first and second connector components.

17. The system according to claim 1 wherein the capacitive sensor element of each electrode unit comprises a first connector component for receiving a second complementary connector component of a resistive sensor element for removably electrically connecting the resistive sensor element to the electrode unit by connecting the first and second connector components, the first connector component located on a side of the electrodynamic sensor opposite that of the antenna, and wherein the at least one of the electrode units is configurable to operate in a current-sensing mode wherein the electrode unit is configured to generate its corresponding signal based on current flow through the resistive sensor element placed directly on the individual's skin.

18. A system for sensing physiological electrical activity in an individual comprising:

a first electrode unit for generating a first signal indicative of the physiological electrical activity at a first location on a body of the individual; and

a second electrode unit for generating a second signal indicative of the physiological electrical activity at a second location on the body of the individual;

wherein each of the first and second electrode units is configurable to operate in:

a field-sensing mode wherein the electrode unit is configured to generate its corresponding signal based on a detected electric field at a location on or in proximity to the individual's skin; and,

wherein each of the first and second electrode units comprises a capacitive sensor element, the capacitive sensor element of each of the electrode units comprising:

an electrodynamic sensor which is sensitive to electromagnetic waves; and

an antenna comprising an electrically conductive radiating element for receiving electromagnetic waves, the radiating element in electrical contact with a sensing surface of the electrodynamic sensor and having a surface area which is larger than a surface area of the sensing surface of the electrodynamic sensor, the antenna located relatively more proximate than the electrodynamic sensor to the individual's skin during operation of the electrode unit in the field-sensing mode;

wherein at least one of the electrode units comprises a first sensor configured to detect a presence of a resistive sensor element electrically connected to the at least one of the electrode units.

19. The system according to claim 18 wherein the at least one of the electrode units comprises a second sensor configured to detect proximity of the individual's skin and to thereby permit determination of whether the electrode unit is operating in a non-contact field-sensing mode wherein the at least one of the electrode units is not in contact with the individual's skin or a contact field-sensing mode wherein the at least one of the electrode units is in contact with the individual's skin.

20. The system according to claim 1 wherein the first electrode unit is operating in a non-contact field-sensing mode wherein the first electrode unit is not in contact with the individual's skin simultaneously with the second electrode unit operating in a contact field-sensing mode wherein the second electrode unit is in contact with the individual's skin and wherein the system is configured to combine the first signal and the second signal to generate a waveform.

21. The system according to claim 1 wherein the system is configured to combine the first signal and the second signal to generate one or more waveforms and to use the waveforms to determine a medical state of the individual.

22. The system according to claim 1 wherein the second electrode is configurable to operate in a current sensing mode wherein the second electrode unit is configured to generate its corresponding signal based on current flow through a resistive sensor element placed directly in contact with the individual's skin and wherein the first electrode unit is operating in the field-sensing mode simultaneously with the second electrode unit operating in the current-sensing mode and wherein the system is configured to combine the first signal and the second signal to generate a waveform.

23. The system according to claim 1 comprising a base unit connected to the electrode units to receive the first and second signals, the base unit comprising a digital signal processor configured to generate one or more waveforms based on a combination of the first and second signals.

24. The system according to claim 23 wherein the system is incorporated into a vehicle and at least one of the electrode units and the base unit are located in the interior of the vehicle.

25. The system according to claim 24 wherein the electrode unit is embedded into a seat in the vehicle and the base unit is incorporated into a head unit of the vehicle.

26. The system according to claim 25 wherein at least one of the electrode units is wirelessly connected to the base unit.

27. The system according to claim 23 wherein the base unit is configured to display the one or more waveforms on a display.

28. The system according to claim 24 wherein at least one of the electrode units is incorporated into a steering control of the vehicle.

29. The system according to claim 24 wherein the system is configured to use the waveforms to determine a medical state of an operator of the vehicle.

30. The system according to claim 29 wherein the medical state is drowsiness, unconsciousness, incapacity, brain injury, stroke, arrhythmias, compensated shock, decompensated shock, sepsis, heart attack, sleep, stress, attentiveness, cognition, respirations, or internal bleeding.

31. An electrode unit for use in sensing physiological electrical activity in an electrical activity monitoring system, the electrode unit comprising:

a capacitive sensor element for detecting electric field, the capacitive sensor element comprising:

an electrodynamic sensor sensitive to electromagnetic waves;

an antenna comprising an electrically conductive radiating element for receiving electromagnetic waves, the radiating element in electrical contact with a sensing surface of the electrodynamic sensor and having a surface area which is larger than a surface area of the sensing surface of the electrodynamic sensor, the antenna located relatively more proximate than the electrodynamic sensor to the individual's skin during operation of the electrode unit a field-sensing mode.

32. The electrode unit according to claim 31 comprising: a spring-biased clamp for attachment of the electrode unit to an individual's clothing when operating in a non-contact field-sensing mode.

33. The electrode unit according to claim 31 comprising an attachment means for physical and electrical attachment of the electrode unit to a resistive sensor element when operating in a resistive mode.

34. The electrode unit according to claim 31 wherein the electrical activity monitoring system comprises an ECG system, EEG system, EOG system, or EMG system.

35. The electrode unit according to claim 31 wherein the capacitive sensor element comprises an electrically non-conductive layer disposed on the radiating element, wherein the non-conductive layer is on an outside face of the electrode unit which is located relatively more proximate than the radiating element to the individual's skin during operation of the electrode unit in the field-sensing mode.

36. The electrode unit according to claim 35 wherein the antenna comprises a metallization layer electrically connected to an inner metallization layer in direct electrical contact with the electrodynamic sensor.

37. The electrode unit according to claim 36 comprising an insulator layer to provide compressive force and facilitate direct electrical contact between the metallization layer and the inner metallization layer.

38. The electrode unit according to claim 31 comprising a distal component to provide electrical noise shielding.

39. The electrode unit according to claim 33 wherein the attachment means comprises a first connector component for receiving a second complementary connector component of the resistive sensor element for physical and electrical

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attachment of the electrode unit to the resistive sensor element by connecting the first and second connector components.

40. The electrode unit according to claim 39 wherein the first and second connector components are shaped such that connecting the first and second connector components causes deformation of at least one of the first and second connector components and corresponding restorative forces which tend to maintain the connection between the first and second connector components.

41. The electrode unit according to claim 33 wherein the attachment means comprises a first connector component for receiving a second complementary connector component of the resistive sensor element for physical and electrical attachment of the electrode unit to the resistive sensor element by connecting the first and second connector components and wherein the first connector component is located on a side of the electrodynamic sensor opposite that of the antenna.

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42. The electrode unit according to claim 33 wherein the attachment means comprises a clamp, the clamp comprising a pair of clamp teeth configured to hold a portion of a resistive sensor element therebetween.

43. The electrode unit according to claim 32 wherein the clamp comprises one or more electrically conducting clamp contacts located in one or both of the teeth for providing electrical contact to the resistive sensor element.

44. The electrode unit according to claim 31 wherein the electrode unit is incorporated into a vehicle.

45. The electrode unit according to claim 44 wherein the electrode unit is in wireless communication with a head unit of the vehicle and communicates information about the electric field to the head unit.

46. The electrode unit according to claim 44 wherein the electrode unit is incorporated into a seat or a steering control of the vehicle.

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专利名称(译)	用于感测生理电活动的电极单元		
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申请(专利权)人(译)	EASYG LLC		
当前申请(专利权)人(译)	EASYG LLC		
[标]发明人	EVANS THOMAS CRANNELL GAVRILOVICH EFRAIM MIHAI RASVAN CATALIN ISBASESCU ION		
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摘要(译)

用于监测个体的生理电活动的系统和装置包括：第一电极单元，用于接收指示个体身体上的第一位置处的电活动的第一信号；以及第二电极单元，用于接收指示电活动的第二信号。个人身体上的第二个位置。第一和第二电极单元中的每一个可以以场感测模式操作，其中电极单元放置在个体皮肤上或附近。第一和第二电极单元包括电容传感器元件，并且每个电极单元的电容传感器元件包括对电磁波敏感的电动传感器；天线包括用于接收电磁波的导电辐射元件。场感测模式可以是非接触场感测模式，其中电极单元放置在个人的衣服上，或者是接触场感测模式，其中电极单元直接放置在个人的皮肤上。

