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**WO 01/54563 A2**

(54) Title: METHOD AND APPARATUS FOR BIOPOTENTIAL SENSING AND STIMULATION

(57) Abstract: A biopotential sensor electrode (100) comprising at least one sensory component (104) coupled to a biopotential signal source (1208). The at least one sensory component comprises at least one layer of electrically conductive material (1202) and at least one dielectric layer (1204). At least one conditioning component (1110) is coupled to condition signals from the at least one sensory component. At least one interface (1104) is configured to transfer signals among the at least one conditioning component and external instrumentation. At least one power source (906) is coupled among the at least one sensory component, the at least one conditioning component and the at least one interface.

METHOD AND APPARATUS FOR BIOPOTENTIAL SENSING AND STIMULATION

This invention relates to the field of biopotential sensors. In particular, the invention relates to surface electrodes.

5 Typical biopotential sensing/stimulating systems are used to gather a growing variety of biopotential signal types or information from subjects or patients. These sensing/stimulating systems are also used to stimulate the patient with a known signal such that skin impedance and other information can be sensed from the subjects or patients. Typical biopotential sensing/stimulating systems include two types of subsystems, biopotential sensors and the associated external monitoring systems or instrumentation. While the medical  
10 information capable of being extracted from this biopotential information has increased significantly with advances in medical science and technology, the usefulness of these systems remains as a limiting factor in patient treatment because of deficiencies of the typical biopotential sensing/stimulating systems.

Regarding the biopotential sensor/stimulator subsystem, biopotential sensors/stimulators can generally be categorized as being invasive or non-invasive. Invasive sensors are implanted surgically, and are used for  
15 accurate isolation of potential sources during sensing and/or delivery of a stimulating signal in to a specific target location. The invasive sensors/stimulators can usually be applied to peripheral nervous systems (i.e., axons or muscles) or to intracerebral sites as in brain research.

Non-invasive sensors/stimulators, also referred to as surface, skin, or scalp electrodes and/or sensors, are applied to the skin surface. These electrodes are typically connected to the surface of the skin via an  
20 electrolyte or gel, hence they are also referred to as wet surface electrodes, or wet electrodes. Wet surface electrodes are commercially available and are routinely used in the clinics and research labs. The preference for wet surface electrodes is due in part to the relatively low manufacturing cost of wet electrodes, and historically proven technology. Furthermore, the wet surface electrodes are passive devices that can be used for both sensing and stimulating, since all the necessary electronics and intelligence resides in the external monitoring  
25 systems or instruments.

One class of surface electrodes does not use electrolytes. These electrodes, referred to as active electrodes, employ an impedance transformation at the sensing site via active electronics. The active electrodes are subdivided into two electrode types, dry electrodes and insulated electrodes. The dry electrode has a metal in direct contact with the skin which is followed by an impedance converting amplifier. The insulated electrode  
30 is capacitively coupled to the skin via a dielectric which is followed by an impedance converting amplifier.

Research results for active electrodes have demonstrated that both dry and insulated electrodes are comparable to wet electrodes for sensing or receiving electrocardiogram (ECG or EKG) signals. However, typical active dry and insulated electrodes do not exhibit the same consistency and signal to noise ratio (SNR) as the wet electrodes. In addition, the typical non-invasive active electrodes have been used for signal sensing  
35 purposes only and not stimulating. While the research has focused on ECG signals, there are numerous other biopotential signal types to which the application of active electrodes would be desirable but has yet to be demonstrated.

Efforts to realize active insulated electrodes have included significant research and development in the area of sensor dielectrics. A number of materials have been investigated for thin-film capacitor fabrication in  
40 sensors of the active hybrid electrodes. Some of the materials typically considered for use include silicon

monoxide (SiO), silicon dioxide (SiO<sub>2</sub>), silicon nitride (Si<sub>3</sub>N<sub>4</sub>), Diamond like Carbon (DLC), and tantalum pentoxide (Ta<sub>2</sub>O<sub>5</sub>). In practice, deposited dielectric films thinner than 500-700 Angstroms (Å) have a fairly high pinhole density and the yields are poor. Pinholes lead to resistive shorts between the electrodes (in the vicinity of each other) and increase the leakage current. Thick dielectric films, or films with a thickness greater than approximately 20,000 Å also may exhibit problems because of the high internal stress levels found in these films. High compressive forces cause the films to peel off; however, large tensile forces can be relieved by crazing, or the production of fine cracks in the film. These factors thus may limit the thickness of the dielectric material to between 800 Å and 10,000 Å.

While both silicon monoxide and silicon dioxide are good insulators for electrical isolation, their behavior as a barrier to sodium ions (Na<sup>+</sup>) is poor. In addition, these two materials require high temperatures in order to form high quality films with few pinholes. Tantalum pentoxide also can suffer from high-temperature deposition requirements and low breakdown voltage.

The insulated electrodes with dielectrics currently in use are not practical because of breakage, scratched surfaces, and inconsistency. Therefore, there is a need for an electrode dielectric material having a number of specific properties. The properties desired include: low reaction with sodium chloride (NaCl) for biocompatibility and sensor protection; low deposition temperature (approximately less than 500 degrees Celsius) to be compatible with electrode material; high dielectric constant for obtaining a large capacitance in a small area; high dielectric strength (resulting in high breakdown voltage) for electrostatic protection; moderate leakage resistance for impedance matching to the amplifier; and, oxidation rate 30 times slower than that of silicon.

Regarding electrode monitoring subsystems, a typical electrode monitoring system consists of the following components: (1) an array of wet electrodes attached to the monitoring environment; (2) electrode cables for coupling each of the wet electrodes to instrumentation; (3) a cable converter box for receiving the electrode cables; and, (4) a monitoring system connected to the cable converter box with a series of cables. The typical electrode signal path from the sensor to the monitoring system is through unshielded cables of approximately 3 to 6 feet in length. These cables typically degrade the signal-to-noise-ratio (SNR) of the recording system and increase motion artifacts. In addition, the cables confine the movement of the subject as well as impose a health hazard in monitoring systems. Consequently, there is a need for an electrode monitoring system that does not require the patient to be wired to the monitoring system, a system that eliminates the need for electrode cables, the cable converter box, and the monitoring cables.

Wireless telemetry systems in general are classified as active or passive. Active telemetry systems are used for telemetry over longer distances. Therefore, typical active telemetry systems require a power source in both transmitter and receiver sections. The power source is primarily used to operate active devices such as transistors that form the circuits for these systems. The factors that influence the distance of communications include the available power, frequency of operation, and antenna size.

Typical telemetry for monitoring systems use either infrared red (IR) or radio-frequency (RF) links. These systems consist of several wet electrodes mounted on a cap and connected via cables to a transmitter section. The transmitter section consists of transmitter circuitry, a power unit, IR light emitting diodes or a large antenna, voltage converters/multiplexers, and a microcontroller unit. The transmitter section requires very high bandwidth and additional signal processing circuitry in order to provide digitized and time multiplexed data for

transmission. As such, the size and weight of the transmitter section in these telemetry systems prevents them from being mounted on the cap with or in the electrodes. Therefore, the transmitter section is placed on a belt strap which is attached to the subject. Thus, the cables along with the size, weight, and power consumption of the transmitter section limit the application of these systems.

5 While a number of RF telemetry systems have been deployed, most have been discontinued for use in electrode monitoring applications because of these limitations. Furthermore, IR telemetry systems have also found limited applications due to the size and poor SNR resulting from signal attenuation due to light reflections, and the amount of light that couples into the detectors.

10 Recently, in the field of local area networking and telephony, wireless systems have been introduced that utilize RF and spread spectrum techniques. These systems in their current state are not suitable for use in electrode monitoring systems without major modification, for a number of reasons. As an example, since these systems provide only a single transmitter channel, they would require additional signal processing and multiplexing if used in an electrode monitoring system. Furthermore, an increase in the number of electrodes would increase the power consumption, and thus the size of the transmitters, inhibiting their use for high  
15 resolution electrode recording. Thus, there is a need for a micro-telemetry system that eliminates cables that connect a subject to a monitoring system and is small in size and weight for ease of attachment and carrying.

The descriptions provided herein are exemplary and explanatory and are provided as examples of the claimed invention.

The accompanying drawings illustrate embodiments of the claimed invention. In the drawings:

20 Figure 1 is a hybrid sensor electrode of an embodiment.

Figure 2 is the hybrid sensor electrode an alternate embodiment.

Figure 3 is a hybrid sensor electrode of another alternate embodiment.

Figure 4 is a wireless hybrid sensor electrode of an embodiment.

Figure 5 is a wireless hybrid sensor electrode of an alternate embodiment.

25 Figure 6 is a functional block diagram of a hybrid sensor electrode of an embodiment.

Figure 7 is a functional block diagram of an interface for a hybrid sensor electrode digital interface of an embodiment.

Figure 8 is a functional block diagram of a hybrid sensor electrode of an alternate embodiment.

Figure 9 is a block diagram of stimulation circuitry of a hybrid sensor electrode of an embodiment.

30 Figure 10 is a schematic diagram of stimulation circuitry of a hybrid sensor electrode of an embodiment.

Figure 11 is a block diagram of sensor pick-up circuitry of a hybrid sensor electrode of an embodiment.

Figure 12 is a sensory element of a hybrid sensor electrode of an embodiment.

Figure 13 is an alternate sensory element or component of a hybrid sensor electrode of an embodiment.

35 Figure 14 is a sensory element configuration of a hybrid sensor electrode of an embodiment.

Figure 15 is an alternate sensory element configuration of a hybrid sensor electrode of an embodiment.

Figure 16 is a functional block diagram of a hybrid sensor electrode array of an embodiment.

Figure 17 is a functional block diagram of an alternate hybrid sensor electrode array of an embodiment.

Figure 18 is a block diagram of a telemetry system of a hybrid sensor electrode of an embodiment.

40 Figure 19 is a functional block diagram of a hybrid sensor telemetry electrode of an embodiment.

Figure 20 is a functional block diagram of a hybrid sensor telemetry electrode of an alternate embodiment.

Figure 21 is a functional block diagram of a radio frequency (RF) powered or telemetry powered hybrid sensor telemetry electrode of an embodiment.

5 Figure 22 is a hybrid sensor electrode of an embodiment having a telemetry system and a coil antenna.

Figure 23 is a hybrid sensor electrode of an embodiment with a flat antenna.

Figure 24 is a block diagram of integrated circuitry (IC) of a hybrid sensor electrode transmitter section of an embodiment using telemetry powering.

10 Figure 25 is a block diagram of integrated circuitry (IC) of a hybrid sensor electrode transmitter section of an embodiment using internal battery power.

Figure 26 is a flowchart of a method for collecting biopotential signals of an embodiment.

Figure 1 is a hybrid sensor electrode 100 of an embodiment. The hybrid sensor electrode 100 is a hybrid between dry electrodes and insulated electrodes and, unlike any of the typical dry or insulated electrodes, the hybrid sensor electrode houses the power source within the same package. This configuration minimizes interference noise, provides plug compatibility to the current monitoring systems, and reduces the possibility of accidental shocks that could arise from the monitoring system. This configuration also provides an improved signal to noise ratio (SNR), and allows for programmable signal gains of greater than two orders of magnitude using the active electronics integrated into the sensor electrode. Furthermore, the hybrid sensor electrode is scalable, wherein multiple sensing sites can be integrated onto a single substrate for built-in redundancy and performance as described herein.

20 The hybrid sensor electrode 100 includes, but is not limited to, a hybrid sensor substrate 102, a metallic sensory component 104 coupled between the skin, or sensing environment, and one side of the hybrid sensor substrate 102, sensory components and electronics 106 coupled to another side of the hybrid sensor substrate 102, an electronic connector/connection 108 to a battery substrate 110 housing one or two battery holders 112, 25 and a package or housing 114. The housing 114 may be attached to a strap using mounting holes 116 or to the surface of the skin using adhesive tape. A wire or cable 118 transfers signals between the hybrid sensor electrode 100 and external instrumentation, but the embodiment is not so limited. While an embodiment uses batteries as a power source, solar cells or other power sources may be used.

30 Figure 2 is a hybrid sensor electrode 200 of an alternate embodiment. This hybrid sensor electrode includes, but is not limited to, a metallic sensory component 202 coupled between the sensing environment and one side of a hybrid sensor substrate 204, sensory components and electronics coupled to another side of the hybrid sensor substrate, an electronic connector/connection to a battery substrate housing battery holders 206, and a two-piece package 208. The metallic sensory component 202 includes a smooth flat surface for contact with the skin, but is not so limited. The package 208 includes a hybrid sensor housing and a housing cap, both 35 removeably coupled to the hybrid sensor substrate. The package 208 may be attached to a strap using mounting holes or to the surface of the skin using adhesive tape. A wire or cable coupled through the wire ports 212 transfers signals between the hybrid sensor electrode 200 and external instrumentation, but the embodiment is not so limited. While an embodiment uses batteries 210 as a power source, solar cells or other power sources may be used. Furthermore, while an embodiment uses a permanent metallic sensory component, a disposable 40 metallic sensory component may be used.

Figure 3 is a side view of a hybrid sensor electrode 300 of another alternate embodiment. This alternate hybrid sensor electrode 300 includes a metallic sensory component 302 having a rough or bumped surface 304. This rough surface 304 provides for contact with the skin over hair, for example on the scalp, and can be a disposable component.

5           Figure 4 is a wireless hybrid sensor electrode 400 of an embodiment. The wireless hybrid sensor electrode 400 includes, but is not limited to, a metallic sensory component 402 coupled to a hybrid sensor substrate 404 housing sensory electronics and components 406. Wireless technology is integrated into the sensor package using a transmitter substrate 408, transmitter electronics 410, and antenna components 412 to enable the telemetering of both data and power.

10           Figure 5 is a wireless hybrid sensor electrode 500 of an alternate embodiment. While the wireless hybrid sensor electrode 400 of Figure 4 includes a separate transmitter substrate 408 housing the transmitter electronics 410 and the antenna/reference signal connector 412, the alternate embodiment 500 has the components of the transmitter 502 on the electrode holder substrate 504 and eliminates the transmitter substrate 408. Further alternative embodiments of the wireless hybrid sensor electrode described herein utilize radio  
15 frequency (RF) powering to remotely provide power to the sensor electronics, thereby eliminating the batteries as a power source.

A hybrid sensor electrode package or housing of an embodiment comprises a main housing and a cover piece. The cover piece locks into the main housing, but is not so limited. A windowed hybrid sensor electrode package exposes a metallic sensory component on one side of the substrate to the environment, and isolates  
20 other components from the environment. The package integrates the conditioning circuitry and battery substrate with strap mounting holes. The power source of this embodiment includes batteries that are held in place by holders on a separate substrate and connected electrically to the sensor substrate.

An alternate embodiment of the hybrid sensor electrode package includes a package type comprising a single piece housing. The single piece housing allows for a disposable version of the hybrid sensor electrode by providing a housing that snap connects to a disposable sensor substrate. The disposable version eliminates  
25 battery or sensor replacement.

Figure 6 is a functional block diagram of a hybrid sensor electrode 600 of an embodiment. The hybrid sensor electrode 600 includes an interface 602 that receives signals from a sensor pick-up section 604 and provides signals to monitoring/controlling instruments 606. The interface 602 can be coupled to the  
30 monitoring/controlling instruments 606 using cables or using a wireless interface, but is not so limited. The interface 602 is coupled to sensory circuitry including stimulation circuitry 608, or sensor stimuli circuitry, sensory components 610, and conditioning circuitry 604, or sensor pick-up circuitry. The stimulation circuitry 608 and the conditioning circuitry 604 are coupled to a sensory component 610 that receives signals or data from the environment 612 that is being monitored. The monitored environment 612 includes but is not limited  
35 to human skin and animal skin. A power source 614 is coupled to each of the interface 602, stimulation circuitry 608, sensory component 610, and conditioning circuitry 604.

The interface 602 of an embodiment can be analog or digital. Using an analog interface, the interface block includes a conductive wire and amplifier. Using a digital interface, the interface block comprises several components including analog-to-digital (A/D) converters, memory, and a digital input/output interface.

Figure 7 is a functional block diagram of a hybrid sensor electrode digital interface 700 of an embodiment. The digital interface 700 includes at least one analog-to-digital (A/D) converter 708, memory 710, protocol input/output (I/O) interface units 702, and a state machine 706, but is not so limited. The interface 700 can be realized using low power circuitry comprising complementary metal-oxide semiconductor (CMOS) circuitry or SiGe/CMOS process circuitry, but is not so limited.

The I/O interface unit 702 communicates with the monitoring and controlling instrumentation 704 using a custom digital protocol. The state machine 706, as the controller for the digital interface 700, monitors and sequences the A/D converter 708, memory 710, and interface units 702. The state machine 706 can partially reside in the memory 710, but is not so limited.

The A/D converter 708 includes a 12-bit A/D realized in complementary metal-oxide semiconductor (CMOS) technology with a low power design using successive approximation or delta-sigma modulation techniques, but is not so limited. The A/D converter 708 receives input from the analog sensor section and converts the signal to a 12 bit or larger bit digital word.

The memory device or memory 710 is used to store manufacturing data, and as a data buffer to the interface 700 and the instrument. The memory device 710 includes memory selected from a group including electrically erasable programmable read only memory (EEPROM), flash memory, or other types of non volatile memory. The memory device 710 may be integrated with or separated from the A/D converter circuitry 708.

Figure 8 is a functional block diagram of a hybrid sensor electrode 800 of an alternate embodiment. In this alternate embodiment, the hybrid sensor electrode 800 includes an interface 802 that receives signals from and provides signals to monitoring/controlling instruments 804. The interface 802 is coupled to sensory circuitry including sensory components 806 and conditioning circuitry 808, or sensor pick-up circuitry. The interface 802 couples biopotential signals received from the monitored environment 812 by the sensory component 806 through the conditioning circuitry 808 to the monitoring/controlling instruments or external instrumentation 804. A power source 810 is coupled to each of the interface 802, sensory component 806, and conditioning circuitry 808.

Figure 9 is a block diagram of stimulation circuitry 900 of a hybrid sensor electrode of an embodiment. The stimulation circuitry 900 is coupled to transfer signals between the interface 902 and the sensory component 904. The stimulation circuitry 900 includes, but is not limited to, voltage/current (V/I) source circuitry 906, current-to-voltage converter or transresistance (TRA) amplifier 908, and programmable generator circuitry 910. The programmable generator 910 is coupled between the interface 902 and the current source 906. The current source 906 is coupled to the sensor 904 and the TRA 908. The current source output 914 can be dynamically monitored by the TRA 908 in order to operate in a closed-loop control fashion for accuracy and reliability. The TRA output is coupled as feedback 912 to the interface.

Figure 10 is a schematic diagram of stimulation circuitry 1000 of a hybrid sensor electrode of an embodiment. An embodiment of the circuitry uses CMOS technology, but is not so limited. The programmable current source includes transistors M5 and M6 as references and transistors M7 to M10 as current mirrors that establish a current threshold for transistors M1 to M4. The signal inputs to transistors M1 to M4 are labeled as A,B,C,and D respectively. These input signals are used to add or turn off the respective transistors for summing current at the node labeled Iout. The transistors M11, M12, and M13 form the TRA that converts the summed current to a voltage if a threshold (I<sub>th</sub>) is exceeded, feeding back to the interface to turn off one or several of the

M1 to M4 devices for lower current output. A portion of the I<sub>out</sub> current is delivered to the skin of a subject. The delivered current should not exceed 100 micro amps and it can be as low as 5 micro amps.

Figure 11 is a block diagram of sensor pick-up circuitry 1100 of a hybrid sensor electrode of an embodiment. The sensor pick-up circuitry 1100, or conditioning circuitry, is coupled to transfer signals between the sensory component 1102 and the interface 1104. The sensor pick-up circuitry 1100 includes, but is not limited to, impedance matching circuitry 1106, amplification/buffering circuitry 1108, and conditioning circuitry 1110. The impedance matching circuitry 1106 provides charge balancing for the sensing element, impedance matching to minimize loading with a feedback controlled amplifier that has low noise and low offset characteristics. The amplification and buffering circuitry 1108 provides programmable gain control, a programmable filter for frequency band selection, and feedback control for minimization of noise and drift. The conditioning circuitry 1110 provides signal level shifters, output electronic static discharge protection, and input/output matching.

Figure 12 is a sensory element 1200 of a hybrid sensor electrode of an embodiment. The sensory element 1200 includes a first metallic contact 1202 coupled to a first side of a dielectric 1204 and a second metallic contact 1206 coupled to a second side of the dielectric 1204. The first metallic contact 1202 is placed in the environment 1208 to be monitored. The second metallic contact 1206 is coupled to other sensory elements and circuitry 1210.

The hybrid sensory element of an embodiment is a hybrid between dry electrodes and insulated electrodes as it provides metallic contact at both ends and allows means of stimulating the sensor environment in addition to sensing the signals from the environment. Like the dry electrodes, the sensor has a metallic or conductive material (e.g., Gold, Stainless Steel) in contact with the skin. Similar to the insulated electrode, the coupling to the skin is capacitive. The capacitive coupling to the skin in an embodiment of the hybrid sensor electrode is via a metallic contact with the skin followed by a dielectric, a metallic material followed by a dissimilar metallic material, then transimpedance amplifiers and circuits for signal conditioning.

Figure 13 is an alternate sensory element or component 1300 of a hybrid sensor electrode of an embodiment. The sensory element 1300 includes a first metallic contact 1302 coupled to the environment to be sensed 1304. The first metallic contact 1302 is also coupled to a second metallic contact 1306 via a bond 1308. The bond 1308 includes, but is not limited to, a metallic bond, a metallic snap connector, and any other type of metallic contact that electrically couples the first metallic contact 1302 to the second metallic contact 1306 such that the first metallic contact 1302 is removable and disposable. The second metallic contact 1306 is coupled to one side of a dielectric 1310. Another side of the dielectric 1310 is coupled to a third metallic contact 1312. The third metallic contact 1312 is coupled to a fourth metallic contact 1314 via another bond 1316. The fourth metallic contact 1314 couples to the hybrid sensor electrode circuitry 1318 and other sensory elements.

Figure 14 is a sensory element configuration 1400 of a hybrid sensor electrode of an embodiment. This sensory element configuration 1400 can be used with any of the sensor elements described herein, but is not so limited. The sensory element 1400 includes a first metallic contact 1402 coupled to a first side of a dielectric 1404 and a second metallic contact 1406 coupled to a second side of the dielectric 1404. The first metallic contact 1402 is placed in the environment to be monitored 1408. The second metallic contact 1406 is coupled to protection circuitry 1410. The protection circuitry 1410 includes back-to-back diodes 1412 for high voltage protection, but is not so limited. The second metallic contact 1406 is coupled to a resistive element 1418 using a



third metallic contact 1414 and a metallic bond 1416. The resistive element 1418 is coupled to a low noise amplifier 1420 through a charge balancing current source/sink 1422. The low noise amplifier 1420 includes feedback, but is not so limited.

5 Regarding transduction/sensing mechanisms, the sensory element of an embodiment, when in contact with the surface of the body or the skin, or in close proximity to the environment of the surface of the body, forms a completed network that allows biopotentials (e.g., ionic) or fields to be picked up from the surface of the skin and transferred to instruments for analysis and recording. The functioning of the sensor can be described as a network of electrical circuit components such as amplifiers, resistors, capacitors and impedances. The sensor, when in contact with the skin, provides a means of converting the ionic potential at the skin  
10 boundary to electrical potentials. When in the vicinity of the skin, the sensor converts the electrical field near the skin to electrical potential. Consequently, the sensor serves as two integrated sensors that convert both ionic potentials and electric fields to electrical potential such that it can be monitored and recorded by instruments to which it is coupled. The sensor output provides the electrical interface for utilizing four types of biopotential signals and for connecting to the associated electrocardiogram (EKG), electroencephalogram (EEG),  
15 electromyogram (EMG), and electro-oculogram (EOG) instrumentation without additional conditioning.

In the design of the hybrid sensor electrode of an embodiment, the effects of changing skin impedance are minimized by introducing an electrode input impedance placed in series with the skin impedance that has a much larger magnitude (electrode-dominant impedance). This electrode input impedance includes a sensor impedance in series with the skin impedance coupled to the local amplifier input impedance and charge  
20 balancing circuitry. The local amplifier circuitry of an embodiment should have a very high input impedance (greater than 1 terra ohm), low offset voltage (less than 200 microvolts), low noise (less than 1 microvolt root mean square (rms) per root hertz (Hz) at 1 Hz) and operate at voltages less than 3 volts (V). The charge balancing circuitry should be able to leak or provide current to the amplifier and sensory element node currents as low as 10 nano amperes and as high as 1 micro amperes. The charge balancing circuitry minimizes direct  
25 current (DC) offset and motion artifacts caused by the motion of the subject and variation of low frequency components of the biopotential.

Figure 15 is an alternate sensory element configuration 1500 of a hybrid sensor electrode of an embodiment. This sensory element configuration 1500 can be used with any of the sensor elements described herein, but is not so limited. The sensory element 1500 includes a first metallic contact 1504, placed in the  
30 environment to be monitored 1502, coupled to a second metallic contact 1506 using a metallic bond 1508. The second metallic contact 1506 is coupled to protection circuitry 1510, for example back-to-back diodes. The second metallic contact 1506 is coupled to a third metallic contact 1512 using a metallic bond 1514. The third metallic contact 1512 is coupled to a side of a dielectric 1516. Another side of the dielectric 1516 is coupled to common cathode diode circuitry 1518 and the input of a low noise amplifier 1520 using a fourth metallic  
35 contact 1522 and a metallic bond 1524.

The effects of changing skin impedance are minimized in the hybrid sensor electrode by introducing an electrode input impedance placed in series with the skin impedance. The electrode input impedance includes a sensor impedance in series with the skin impedance coupled to the local amplifier input impedance and charge  
40 balancing circuitry. The local amplifier circuitry of an embodiment has a very high input impedance (equal to or greater than 1 terra ohm), low offset voltage (less than 200 microvolts), low noise (less than 1 microvolt rms

per root hertz at 1 Hz) and operates at voltages less than 3 volts. The charge balancing circuitry of an embodiment leaks or provides current to the amplifier and sensory element node approximately in the range 10 nano amperes to 1 micro amperes. The charge balancing minimizes DC offset and motion artifacts caused by the motion of the subject and variation of low frequency components of the biopotential at the skin. In this  
5 embodiment, the charge balancing circuitry comprises a common cathode diode that further serves as protection against high voltages, and provides large input impedance.

Regarding the selection of electrode materials, a number of materials have been investigated for thin-film capacitor fabrication, where some of the commonly used materials include silicon monoxide (SiO), silicon dioxide (SiO<sub>2</sub>), silicon nitride (Si<sub>3</sub>N<sub>4</sub>), Diamond like Carbon (DLC), and tantalum pentoxide (Ta<sub>2</sub>O<sub>5</sub>).

10 Tantalum pentoxide is used as the dielectric material of an electrode of an embodiment.

The properties of the dielectric material of an embodiment of the electrode include, but are not limited to: low reaction with sodium chloride (NaCl) for biocompatibility and sensor protection; low deposition temperature (less than 500 degrees Celsius) to be compatible with the electrode material (the melting point of aluminum is 660 degrees Celsius); high dielectric constant for obtaining a large capacitance in a small area; high  
15 dielectric strength (needing high breakdown voltage, or BV) for electrostatic protection; and, moderate leakage resistance for impedance matching to the amplifier. Considering these factors, silicon nitride (Si<sub>3</sub>N<sub>4</sub>) is used as the dielectric material of an embodiment. Silicon nitride is an extremely good barrier to the diffusion of water and ions, particularly sodium (Na<sup>+</sup>) ions. Furthermore, silicon nitride oxidizes 30 times slower than silicon, adheres well to aluminum, and has a high dielectric constant. Moreover, silicon nitride can be deposited by  
20 plasma-enhanced chemical vapor deposition (PECVD), atmospheric-pressure chemical vapor deposition (APCVD), and low pressure chemical vapor deposition (LPCVD), with each of these deposition techniques resulting in different nitride characteristics. Following selection of the dielectric, electrode, and substrate materials, dielectric film deposition conditions and thickness are optimized.

The hybrid sensor electrode of an embodiment is scalable, and this allows for the integration of  
25 multiple sensing sites onto a single substrate for built-in redundancy and performance. Figure 16 is a functional block diagram of a hybrid sensor electrode array 1600 of an embodiment. The array 1600 includes a number of hybrid sensor electrodes 1602 on a single substrate 1610, where the electrodes are coupled to the monitored environment 1604, but is not so limited. The monitored environment 1604 includes but is not limited to human skin and animal skin. The electrodes 1602 are coupled to a bidirectional multiplexer 1606 that provides for  
30 communications among the hybrid sensor electrodes 1602 and monitoring/controlling equipment or external instrumentation 1608.

The hybrid sensor electrode 1602 includes an interface 1620 that receives signals from and provides signals to monitoring/controlling instruments 1608 through the bidirectional multiplexer 1606. The bidirectional multiplexer 1606 can be coupled to the monitoring/controlling instruments 1608 using a wired  
35 interface, a wireless interface, or a combination wired/wireless interface, but is not so limited. The interface 1620 is coupled to sensory circuitry including stimulation circuitry 1622, or sensor stimuli circuitry, sensory components 1624, and conditioning circuitry 1626, or sensor pick-up circuitry. The interface 1620 of an embodiment couples signals from the interface 1620 through the stimulation circuitry 1622 and sensory component 1624 to the conditioning circuitry 1626 and back to the interface 1620. The stimulation circuitry  
40 1622 and the conditioning circuitry 1626 are coupled to a sensory component 1624 that receives signals or data

communications among the hybrid sensor electrodes 1602 and monitoring/controlling equipment or external instrumentation 1608.

The hybrid sensor electrode 1602 includes an interface 1620 that receives signals from and provides signals to monitoring/controlling instruments 1608 through the bidirectional multiplexer 1606. The  
5 bidirectional multiplexer 1606 can be coupled to the monitoring/controlling instruments 1608 using a wired interface, a wireless interface, or a combination wired/wireless interface, but is not so limited. The interface 1620 is coupled to sensory circuitry including stimulation circuitry 1622, or sensor stimuli circuitry, sensory components 1624, and conditioning circuitry 1626, or sensor pick-up circuitry. The interface 1620 of an  
10 embodiment couples signals from the interface 1620 through the stimulation circuitry 1622 and sensory component 1624 to the conditioning circuitry 1626 and back to the interface 1620. The stimulation circuitry 1622 and the conditioning circuitry 1626 are coupled to a sensory component 1624 that receives signals or data from the environment 1604 that is being monitored. A power source 1628 is coupled to each of the interface 1620, stimulation circuitry 1622, sensory component 1624, and conditioning circuitry 1626. In an alternate  
15 embodiment, a single power source 1630 can be used to provide power to all of the hybrid sensor electrodes 1602 of the hybrid sensor electrode array 1600.

Figure 17 is a functional block diagram of an alternate hybrid sensor electrode array 1700 of an embodiment. The alternate array 1700 includes a number of alternate hybrid sensor electrodes 1702 on a single substrate 1710, where the electrodes 1702 are coupled to the monitored environment 1704, but is not so limited. The electrodes 1702 are coupled to a bidirectional multiplexer 1706 that provides for communications among  
20 the hybrid sensor electrodes 1702 and monitoring/controlling equipment 1708. The alternate hybrid sensor electrode 1702 includes an interface 1720 that receives signals from and provides signals to monitoring/controlling instruments 1708 through the bidirectional multiplexer 1706. The interface 1720 is coupled to sensory circuitry including sensory components 1722 and conditioning circuitry 1724, or sensor pick-up circuitry. A power source 1726 is coupled to each of the interface 1720, sensory component 1722, and  
25 conditioning circuitry 1724. In an alternate embodiment, a single power source 1728 can be used to provide power to all of the hybrid sensor electrodes 1702 of the hybrid sensor electrode array 1700.

The hybrid sensor electrode system of an embodiment provides a micro-telemetry system that eliminates any cables or wires used to connect the electrodes of a subject to a monitoring system. As the micro-telemetry system is co-located with the electrode, and the electrode is attached to the subject, the size, weight,  
30 power consumption and bandwidth of the transmitter section are the key parameters in design of a telemetry system for electrode systems. The transmitter section of an embodiment provides, but is not limited to, long term monitoring, low bandwidth and improved SNR and power consumption, while not disturbing the normal physical processes of the subject.

Figure 18 is a block diagram of a telemetry system 1800 of a hybrid sensor electrode of an  
35 embodiment. Each electrode 1802 is configured with an embedded micro-transmitter 1804 and a power source 1806 that includes a battery, but is not so limited. In an alternate embodiment, the electrode 1802 and the transmitter 1804 can share the power source 1806. The transmitter 1804 is coupled to the electrode 1802 and converts the electrode signals to radio frequency signals for transmission. The transmitter 1804 has dimensions approximately in the range 5 to 20 millimeters (mm) long, 5 to 20 mm wide, and 1 to 5 mm high while weighing

less than 100 milligram (mg) and using less and 100 milliwatts (mW) of discrete power, but is not so limited. As each transmitter 1804 processes signals from a single electrode 1802, the bandwidth requirement for each channel is identical, allowing for repeatable and consistent SNR. In addition, a reference link 1808 between each electrode 1802 allows all electrodes to be synchronized and referenced to a single potential. This reference link can be provided by means of current injection to the surface of the skin by a master electrode that is received by all other electrodes (slave electrodes). The reference link 1808 can also be provided using telemetry from the receiver section. Furthermore, the reference link 1808 can be provided using a wired link among the electrodes.

The receiver section 1820 of an embodiment includes up to 8 antennas 1822 and receivers 1824, wherein each receiver 1824 processes telemetry signals from numerous electrodes 1802, but is not so limited. A receiver section 1820 of an embodiment comprising up to 8 channels is modularized and expandable to convert transmitted signals from up to 256 electrodes simultaneously. The modularization allows for an increase or decrease in the number of electrodes without affecting system performance. Furthermore, each channel has adequate bandwidth for distortion free telemetry plus appropriate filtering to maximize the SNR and to prevent aliasing in sampled-data monitoring systems.

The output signal 1826 from the receiver section 1820 is compatible with and interfaces with typical electrode monitoring systems 1828. This compatibility is provided by the use of a receiver output section that is compatible in the following areas: connector plug-in to fit in standard monitoring systems; signal levels and bandwidths not exceeding the current systems requirements; and, low output impedance to prevent signal attenuation. Thus, the telemetry system of an embodiment allows for retrofit of current monitoring systems without modification. Furthermore, the receiver section 1820 can be integrated with the monitoring system 1828.

The coupling among the electrodes 1802 and the monitoring system 1828 can include a network. In an embodiment, the monitoring system can be coupled 1826 to the receiver section 1820 using network connections including wired, wireless, and combined wired and wireless connections. In an alternate embodiment, the receivers 1824 of a receiver section can be located away from the controller 1830 and coupled to the controller 1830 using network connections including wired, wireless, and combined wired and wireless connections. The controller 1830 can then be coupled 1826 to the monitoring system 1828 using network connections including wired, wireless, and combined wired and wireless connections.

Figure 19 is a functional block diagram of a hybrid sensor telemetry electrode 1900 of an embodiment. The hybrid sensor telemetry electrode 1900 includes an interface 1902 that couples signals between circuitry of the sensor electrode and monitoring and controlling instruments 1904. The interface 1902 is coupled to the monitoring and controlling instruments 1904 using a wireless interface or network, but is not so limited. The interface 1902 is coupled to a data telemetry transmitter/receiver (transceiver) 1906 of the sensor electrode 1900, but is not so limited. In one alternate embodiment the interface 1902 can be coupled to a transmitter. In another alternate embodiment the interface can be coupled to a receiver. In yet another alternate embodiment, the interface can be separately coupled to a transmitter and a receiver.

The transceiver 1906 is coupled to sensory circuitry including stimulation circuitry 1908, or sensor stimuli circuitry, sensory components 1920, and conditioning circuitry 1912, or sensor pick-up circuitry. The

stimulation circuitry 1908 and the conditioning circuitry 1912 are coupled to a sensory component 1910 that receives signals or data from the environment 1916 that is being monitored. The monitored environment 1916 includes but is not limited to human skin and animal skin. A power source 1914 is coupled to each of the transceiver 1906, stimulation circuitry 1908, sensory component 1910, and conditioning circuitry 1912.

5 Figure 20 is a functional block diagram of a hybrid sensor telemetry electrode 2000 of an alternate embodiment. In this alternate embodiment, the transceiver 2002 is coupled to sensory circuitry including sensory components 2004 and conditioning circuitry 2006, or sensor pick-up circuitry. The transceiver 2002 couples signals from the sensory component 2004 through the conditioning circuitry 2006 to the interface 2008. A power source 2010 is coupled to each of the transceiver 2002, sensory component 2004, and conditioning  
10 circuitry 2006.

Further alternative embodiments of the hybrid sensor telemetry electrode use radio frequency (RF) powering to remotely provide power to the hybrid sensor circuitry, thereby eliminating the battery power source. Figure 21 is a functional block diagram of a RF powered or telemetry powered hybrid sensor telemetry electrode 2100 of an embodiment. The RF powered hybrid sensor telemetry electrode 2100 includes an interface 2102  
15 that couples signals between circuitry of the sensor electrode and monitoring and controlling instruments 2104. The interface 2102 is coupled to the monitoring and controlling instruments 2104 using a wireless interface or network, but is not so limited. The interface 2102 is coupled to a data telemetry transmitter/receiver (transceiver) 2106 of the sensor electrode, but is not so limited.

The transceiver 2106 is coupled to sensory circuitry including stimulation circuitry 2108, or sensor stimuli circuitry, sensory components 2110, and conditioning circuitry 2112, or sensor pick-up circuitry. The stimulation circuitry 2108 and the conditioning circuitry 2112 are coupled to a sensory component 2110 that receives signals or data from the environment 2114 that is being monitored. A telemetry power source 2116 is coupled to each of the transceiver 2106, stimulation circuitry 2108, sensory component 2110, and conditioning  
20 circuitry 2112.

25 Figure 22 is a hybrid sensor electrode 2200 of an embodiment having a telemetry system and a coil antenna 2202. The coil antenna 2202 is used to communicate with the electrode 2200 and to provide power to the electrode 2200, thereby eliminating batteries as an electrode power source.

The transceiver section of a RF powered hybrid sensor telemetry electrode of an embodiment is coupled to an antenna that optimizes the performance of the link while providing reduced size, weight, and cost.  
30 The antenna types are configured for use with frequencies in the range of 1 kHz to 6 GHz. The antenna types used in a hybrid sensor electrode of an embodiment can be either a flat antenna, a spiral antenna, or an array antenna.

Figure 23 is a hybrid sensor electrode 2300 of an embodiment with a flat antenna 2302. A flat antenna 2302 of an embodiment includes an air-core transmitter antenna used for transmitting and receiving in a 13.56  
35 MHz system. The dimensions of the flat antenna are approximately in the range 20 mm by 20 mm by 1 mm, but are not so limited. The range of a system link using this antenna is approximately in the range 0.5 to 1.5 meters.

Alternate embodiments of the hybrid sensor electrode may use a spiral antenna or an array antenna for transmitting and receiving at higher frequencies. A spiral antenna comprises a thick film spiral inductor embedded in a printed circuit board.

A typical sensor electrode application may impose dimensional limitations on the sensor electrode package. For example, bulky transmitter sizes may not be ideal for head mounts during sleep studies due to patient discomfort. Furthermore, heavy transmitters that often find use in high resolution electrode/EKG applications where tens of electrodes are placed on the subject could lead to patient discomfort. Moreover, the size and weight of the transmitter section limits the telemetry application area. In considering these transmitter section limitations, elimination of batteries as a sensor electrode power source would result in a reduction in the size and weight of the associated sensor electrode, with an associated increase in patient comfort. This reduction in size and weight arises from the elimination of a typical battery that has parameters including: a diameter of approximately 6 to 18 mm; a thickness of approximately 6 mm; a weight of approximately less than 100 mg; and, a life approximately in the range of one day to 6 months.

The hybrid sensor electrode of an embodiment eliminates the requirement for a local battery by using remote powering, also referred to as telemetry powering, infrared (IR) powering, or RF powering. The remote powering is provided over ranges in excess of one meter. Thus, each receiver section will not only be able to communicate with eight transmitters section, but also will have the capability to remotely power the transmitters via the transmitter antenna.

Figure 24 is a block diagram of integrated circuitry (IC) 2400 of a hybrid sensor electrode transmitter section of an embodiment using telemetry powering. Figure 25 is a block diagram of integrated circuitry (IC) 2500 of a hybrid sensor electrode transmitter section of an embodiment using internal battery power. These ICs 2400 and 2500 provide reduced size, weight, power, and cost with an associated benefit of higher levels of integrated functionality. Furthermore, these ICs 2400 and 2500 provide the ability to inject low current to measure skin impedance, and to allow intra-electrode communication for noise reduction and noise cancellation. The ICs of an embodiment use 0.8 micrometer complementary metal-oxide semiconductor (CMOS) technology, but are not so limited.

The ICs 2400 and 2500 are partitioned based on functionality, wherein the functional partitions include power management circuitry, power conditioning circuitry, transmitter circuitry, and sensor conditioning circuitry, but are not so limited. In an embodiment, each section of the IC can be tested separately and disabled from outside pins, allowing for full or partial utilization of the IC as needed. For example, the remote power detection circuitry is part of the power conditioning section. Provisions are made via additional bonding pads and power switching mechanisms wherein this circuitry can be disabled so that all other sections of the IC can be tested separately.

In operation, with reference to Figure 24, a large alternating current (AC) signal is received by the dual-purpose coil/antenna 2402. The AC signal is converted into a regulated direct current (DC) voltage, which supplies power to the local components. Initially, the controller state machine 2404 momentarily closes switches C1 and C2, while switches C3 and C4 remain open. This allows the incoming AC signal to be rectified and regulated into a DC voltage. In an embodiment, the rectifier and regulator 2406 converts an AC signal to a DC signal and regulates the voltages for the entire IC. The regulated DC voltage is stored for local DC distribution to the rest of the circuit.

Prior to DC power distribution, the DC power management circuitry 2408 optimizes power consumption by prioritizing power to the components. The power manager/controller 2408 supervises the

instantaneous power on the bus, and determines which section of the circuit has priority for utilizing the power. According to a round robin mechanism, the power manager/controller 2408 turns segments of the circuit on or off to optimize power consumption.

When the charge storage operation is completed, the controller state machine 2404 simultaneously  
5 opens C1 and C2, while closing C3 and C4 to allow electrode/EKG data to be transmitted. The high voltage isolator 2410 prevents large signals that may perturb the driver and transmitter circuitry 2412. The sensor output conditioning circuit 2414 generates programmable pulsed current of 1 microamp ( $\mu\text{A}$ ) to 100  $\mu\text{A}$  in amplitude and delivers it to the sensor 2416. The sensor output conditioning circuitry 2414 amplifies, filters and biases the electrode/EKG signal to be sent to the transmitter. The detection-controller circuitry 2418 determines  
10 whether the signal level is that of an electrode or EKG, and conditions the signal to prevent saturation of the transmitter circuitry. Upon completion of data transmission, the process of remote powering and data transmission is repeated.

As a result of advances made in the areas of micromachining, integrated circuit technology, and printed wiring board capabilities, the cost difference between active electrodes of an embodiment and wet surface  
15 electrodes is negligible. Furthermore, the superior performance of the active electrodes of an embodiment allow for their use in new application areas that demand higher performance and a higher number of electrodes than their wet counterparts. For example, long term (over 24 hours) recording and embedded telemetry are provided, and applications such as biofeedback (use of sensors and computers to improve or control deficiencies), sleep monitoring (analyzing sleep patterns and disorders), alertness monitoring (monitoring the mental awareness of a  
20 person), biocontrol games (input and output form the biology to computer and video games), and biocontrol of computers are enabled.

Figure 26 is a flowchart of a method for collecting biopotential signals of an embodiment. Operation begins at step 2602, where at least one sensory component or element is capacitively coupled to a biopotential signal source. Power is telemetered to and received by the sensory component, at step 2604. Biopotential  
25 signals and data are collected, at step 2606, and the collected signals and data are telemetered to external instrumentation, at step 2608.

As can be seen, a method and apparatus for biopotential sensing and stimulation has been provided that can include a sensory component, a biopotential sensor electrode and a biopotential sensory electrode system. In one embodiment, the sensory component includes a first layer of electrically conductive material coupled  
30 among a biopotential signal source and a dielectric layer. A second layer of electrically conductive material is coupled among the dielectric layer, resistive elements, a charge balancing current source and sink, and circuits of the associated biopotential electrode.

In one embodiment, the biopotential sensor electrode includes the sensory component, conditioning components, an interface, and a power source. The sensory component is coupled among the biopotential signal  
35 source and the conditioning components. The conditioning components couple conditioned signals to the interface, which is configured to transfer signals to external instrumentation. The signal transfer occurs over wireless or wired connections. Stimulation components may also be coupled among the sensory component and the interface to provide stimulation signals to the biopotential signal source. The power source is coupled

among the sensory component, the conditioning components, and the interface, and includes batteries, solar cells, and telemetry power sources.

In one embodiment, the biopotential sensory electrode system includes at least one electrode array. The electrode array includes the biopotential sensor electrodes and a receiver section that transfers biopotential signals among the biopotential signal source and external instrumentation and equipment. A reference link among the biopotential sensor electrodes of an array is provided by a coupling that includes current injection to a surface of the biopotential signal source, or via a common wire to all electrodes.

In another embodiment, a biopotential sensor electrode is provided that includes at least one sensory component coupled to a biopotential signal source, the at least one sensory component comprising at least one layer of electrically conductive material and at least one dielectric layer, at least one conditioning component coupled to condition signals from the at least one sensory component, at least one interface configured to transfer signals among the at least one conditioning component and external instrumentation, and at least one power source coupled among the at least one sensory component, the at least one conditioning component, and the at least one interface.

In such biopotential sensor electrode, the at least one sensory component can include a dielectric layer coupled between a first and a second layer of electrically conductive material, the first layer of electrically conductive material being coupled to the biopotential signal source and the second layer of electrically conductive material being coupled to the at least one conditioning component. Such second layer of electrically conductive material can be coupled to the at least one conditioning component using at least one component selected from a group consisting of high voltage protection circuitry, at least one bond, at least one metal layer, at least one resistive element, charge balancing circuitry, and a feedback amplifier. Such at least one bond can be selected from a group consisting of a permanent metallic bond and at least one mating spring snap connector button, the at least one mating spring snap connector button being disposable. Such first layer of electrically conductive material can be coupled to the dielectric layer through a third layer of electrically conductive material and a first bond and the second layer of electrically conductive material can be coupled to the dielectric layer through a fourth layer of electrically conductive material and a second bond. Such first bond and second bond can be selected from a group consisting of a permanent metallic bond and at least one mating spring snap connector button, such one side of the at least one mating spring snap connector button being disposable. Such first layer of electrically conductive material can be coupled to the biopotential signal source using at least one component selected from a group consisting of high voltage protection circuitry, at least one bond, and at least one metal layer and such second layer of electrically conductive material can be coupled to the at least one conditioning component using at least one component selected from a group consisting of charge balancing circuitry and at least one bond. Such at least one bond can be selected from a group consisting of a permanent metallic bond and at least one mating spring snap connector button, one side of the at least one mating spring snap connector button being disposable.

In such biopotential sensor electrode, the at least one sensory component can include a dielectric layer coupled between the biopotential signal source and an electrically conductive layer, the electrically conductive layer being coupled to the at least one conditioning component.



Such biopotential sensor electrode can include at least one stimulation component coupled among the at least one interface and the at least one sensory component, the at least one stimulation component providing stimulation signals to a skin. Such at least one stimulation component can include at least one component selected from a group consisting of at least one programmable current source, at least one programmable voltage source, at least one programmable generator, at least one current-to-voltage converter, and at least one transresistance amplifier.

In such biopotential sensor electrode, the at least one interface transfers a signal among the at least one conditioning component and the external instrumentation using at least one medium selected from a group consisting of wires, cables, and buses.

Such biopotential sensor electrode can include at least one telemetry component coupled among the at least one conditioning component, the at least one interface, and the at least one power source. Such at least one telemetry component can include a telemetry receiver and transmitter, the at least one telemetry component transferring information and power among the biopotential sensor electrode and the external instrumentation. At least one antenna can be coupled to the at least one telemetry component.

In such biopotential sensor electrode, the at least one power source includes a telemetry power component that produces power in response to telemetry signals received from the external instrumentation.

In such biopotential sensor electrode, the at least one power source includes at least one power source selected from a group consisting of at least one battery and at least one solar cell.

In such biopotential sensor electrode, the at least one layer of electrically conductive material can include at least one material selected from a group consisting of stainless steel, platinum, gold, and silver silver-chloride.

In such biopotential sensor electrode, the at least one dielectric layer can include at least one material selected from a group consisting of Diamond Like Carbon (DLC) material, tantalum pentoxide, nitride, silicon nitride, oxide, and aluminum dioxide.

In such biopotential sensor electrode, the at least one layer of electrically conductive material can have a surface texture selected from a group consisting of smooth, rough, and bumped.

In such biopotential sensor electrode, the at least one conditioning component can include at least one component selected from a group consisting of impedance matching circuitry, charge balancing circuitry, amplification and buffering circuitry, programmable gain control circuitry, programmable filter circuitry, feedback control circuitry, and conditioning circuitry.

Such biopotential sensor electrode can include at least one bidirectional multiplexer coupled to transfer signals among the at least one interface and the external instrumentation.

Such biopotential sensor electrode can include a housing selected from a group consisting of a single piece housing, a two-piece housing, and a disposable housing.

In such biopotential sensor electrode, the at least one interface can be selected from a group consisting of an analog interface and a digital interface.

In such biopotential sensor electrode, the at least one interface can be a digital interface comprising at least one analog-to-digital converter, at least one memory device, at least one input/output interface unit, and at least one state machine.

Such biopotential sensor electrode can comprise a substrate including at least one electrode array, the at least one electrode array including at least one other biopotential sensor electrode. Such at least one power source can be shared among the at least one other biopotential sensor electrode.

Such biopotential sensor electrode can include at least one reference link among at least one other  
5 biopotential sensor electrode, the at least one reference link allowing the biopotential sensor electrode to be synchronized and referenced to a single potential, the at least one reference link being provided by at least one coupling selected from a group consisting of a wired link, a telemetry link, and current injection to a skin surface.

In another embodiment, a biopotential sensor electrode is provided that includes at least one sensory  
10 component and at least one telemetry component, the at least one sensory component comprising at least one layer of electrically conductive material and at least one dielectric layer, the at least one sensory component being coupled among a biopotential signal source and the at least one telemetry component, the at least one telemetry component transferring signals and power among the biopotential sensor electrode and external instrumentation.

In another embodiment, a method for collecting biopotential signals is provided that comprising  
15 receiving telemetered power signals at a biopotential sensor electrode, generating power in response to the telemetered power signals, receiving the biopotential signals via a coupling with a skin surface and transferring the biopotential signals from the biopotential sensor electrode using at least one coupling comprising a wireless link.

In another embodiment, a computer readable medium containing executable instructions which, when  
20 executed in a processing system, causes the system to collect biopotential signals is provided. The collection comprises the steps of receiving telemetered power signals at a biopotential sensor electrode, generating power in response to the telemetered power signals, receiving the biopotential signals via a coupling with a skin surface and transferring the biopotential signals from the biopotential sensor electrode using at least one  
25 coupling comprising a wireless link.

In another embodiment, an electromagnetic medium containing executable instructions which, when  
executed in a processing system, causes the system to collect biopotential signals is provided. The collection comprises receiving telemetered power signals at a biopotential sensor electrode, generating power in response to the telemetered power signals, receiving the biopotential signals via a coupling with a skin surface and  
30 transferring the biopotential signals from the biopotential sensor electrode using at least one coupling comprising a wireless link.

In another embodiment, a biopotential sensor electrode is provided that includes at least one sensory  
means and at least one telemetry means, the at least one sensory means comprises at least one layer of  
35 electrically conductive material and at least one dielectric layer, the at least one sensory means is coupled among a biopotential signal source and the at least one telemetry means, the at least one telemetry means transfers signals and power among the biopotential sensor electrode and external instrumentation.

In another embodiment, a biopotential sensor electrode is provided that comprises means for receiving telemetered power signals at a biopotential sensor electrode, means for generating power in response to the telemetered power signals, means for receiving the biopotential signals via a coupling with a skin surface and

means for transferring the biopotential signals from the biopotential sensor electrode using at least one coupling comprising a wireless link.

In another embodiment, a biopotential electrode sensory component is provided that comprises a first layer of electrically conductive material coupled among a biopotential signal source and a dielectric layer, and a second layer of electrically conductive material coupled among the dielectric layer, at least one resistive element, at least one charge balancing current source and sink and at least one biopotential electrode circuit.

In such biopotential electrode sensory component, the biopotential signal source can be further coupled to the at least one biopotential electrode circuit using at least one component selected from a group consisting of high voltage protection circuitry, at least one bond, at least one metal layer, and a feedback amplifier. Such at least one bond can be selected from a group consisting of a permanent metallic bond and a snap connector.

In such biopotential electrode sensory component, the first layer of electrically conductive material can be coupled to the dielectric layer through a third layer of electrically conductive material and a first bond, the second layer of electrically conductive material can be coupled to the dielectric layer through a fourth layer of electrically conductive material and a second bond. Such first bond and such second bond can be selected from a group consisting of a permanent metallic bond and a snap connector.

In such biopotential electrode sensory component, the dielectric layer can comprise at least one material selected from a group consisting of Diamond Like Carbon (DLC) material, tantalum pentoxide, nitride, silicon nitride, oxide, and aluminum dioxide.

In such biopotential electrode sensory component, the first layer and second layer of electrically conductive material can comprise at least one material selected from a group consisting of stainless steel, platinum, gold, and silver silver-chloride.

In such biopotential electrode sensory component, the first layer of electrically conductive material has a surface texture selected from a group consisting of smooth, rough, and bumped.

Such biopotential electrode sensory component can further include an electrical coupling to at least one interface selected from a group consisting of an analog interface and a digital interface.

Such biopotential electrode sensory component can further comprise an electrical coupling to at least one telemetry component, the at least one telemetry component transferring biopotential signals and power among the biopotential electrode sensory component and external instrumentation.

Such biopotential electrode sensory component can further comprise an electrical coupling to at least one reference link that allows at least one biopotential sensor electrode associated with the biopotential electrode sensory component to be synchronized and referenced to a single potential, the at least one reference link being provided by at least one coupling selected from a group consisting of a wired link, a telemetry link, and current injection to a skin surface.

In another embodiment, a biopotential electrode sensory component is provided that comprises a first layer of electrically conductive material coupled among a biopotential signal source, a dielectric layer, and voltage protection circuitry, and a second layer of electrically conductive material coupled among the dielectric layer, at least one biopotential electrode circuit, and at least one charge balancing circuit.

Such biopotential electrode sensory component can include a third and fourth electrically conductive layer coupled between the first layer of electrically conductive material and the dielectric layer using at least one

bond. Such at least one bond can be selected from a group consisting of a permanent metallic bond and a snap connector. Such third layer and fourth layer of electrically conductive material comprise at least one material selected from a group consisting of stainless steel, platinum, gold, and silver silver-chloride.

5 In such biopotential electrode sensory component, the biopotential signal source can be coupled to the at least one biopotential electrode circuit using a feedback amplifier.

In such biopotential electrode sensory component, the dielectric layer comprises at least one material selected from a group consisting of Diamond Like Carbon (DLC) material, tantalum pentoxide, nitride, silicon nitride, oxide, and aluminum dioxide.

10 In such biopotential electrode sensory component, the first layer and second layer of electrically conductive material can comprise at least one material selected from a group consisting of stainless steel, platinum, gold, and silver silver-chloride.

In such biopotential electrode sensory component, the first layer of electrically conductive material can have a surface texture selected from a group consisting of smooth, rough, and bumped.

15 Such biopotential electrode sensory component can further comprise an electrical coupling to at least one interface selected from a group consisting of an analog interface and a digital interface.

Such biopotential electrode sensory component can further comprise an electrical coupling to at least one telemetry component, the at least one telemetry component transferring biopotential signals and power among the biopotential electrode sensory component and external instrumentation.

20 Such biopotential electrode sensory component can further comprise an electrical coupling to at least one reference link that allows at least one biopotential sensor electrode associated with the biopotential electrode sensory component to be synchronized and referenced to a single potential, the at least one reference link being provided by at least one coupling selected from a group consisting of a wired link, a telemetry link, and current injection to a skin surface.

25 In another embodiment, a method for collecting biopotential signals is provided that comprises coupling a sensory component to a skin surface, converting ionic potentials and electric fields received by the sensory component to electrical potentials, minimizing effects of changing skin impedance on the electrical potentials using a sensor impedance in series with a skin impedance, wherein a magnitude of the sensor impedance is greater than a magnitude of the skin impedance, minimizing direct current offset and motion artifacts of the electrical potentials using charge balancing and providing electrical potentials to external  
30 instrumentation.

In another embodiment, a computer readable medium containing executable instructions which, when executed in a processing system, causes the system to collect biopotential signals is provided. The collection comprises coupling a sensory component to a skin surface, converting ionic potentials and electric fields received by the sensory component to electrical potentials, minimizing effects of changing skin impedance on  
35 the electrical potentials using a sensor impedance in series with a skin impedance, wherein a magnitude of the sensor impedance is greater than a magnitude of the skin impedance, minimizing direct current offset and motion artifacts of the electrical potentials using charge balancing and providing electrical potentials to external instrumentation.

In another embodiment, an electromagnetic medium containing executable instructions which, when executed in a processing system, causes the system to collect biopotential signals is provided. The collection comprises coupling a sensory component to a skin surface, converting ionic potentials and electric fields received by the sensory component to electrical potentials, minimizing effects of changing skin impedance on the electrical potentials using a sensor impedance in series with a skin impedance, wherein a magnitude of the sensor impedance is greater than a magnitude of the skin impedance, minimizing direct current offset and motion artifacts of the electrical potentials using charge balancing and providing electrical potentials to external instrumentation.

In another embodiment, a biopotential electrode sensory component is provided that includes means for coupling a sensory means to a skin surface, means for converting ionic potentials and electric fields received by the sensory means to electrical potentials, means for minimizing effects of changing skin impedance on the electrical potentials using an impedance in series with a skin impedance, wherein a magnitude of the impedance is greater than a magnitude of the skin impedance, means for minimizing direct current offset and motion artifacts of the electrical potentials using charge balancing means and means for providing electrical potentials to external instrumentation.

In another embodiment, a biopotential sensor electrode system is provided that comprises at least one electrode array including at least one biopotential sensor electrode coupled to at least one telemetry component and at least one power source, the at least one biopotential sensor electrode including at least one sensory component coupled to a biopotential signal source, and at least one receiver section comprising at least one receiver, the at least one receiver section transferring biopotential signals among the biopotential signal source and external instrumentation using the at least one telemetry component.

In such biopotential sensor electrode system, the at least one sensory component can comprises at least one layer of electrically conductive material and at least one dielectric layer, the at least one biopotential sensor electrode further comprising at least one conditioning component coupled to condition signals from the at least one sensory component, at least one interface configured to transfer signals among the at least one conditioning component and external instrumentation and at least one power source coupled among the at least one sensory component, the at least one conditioning component, and the at least one interface. Such biopotential sensor electrode system can further comprise at least one stimulation component coupled among the at least one interface and the at least one sensory component, the at least one stimulation component providing stimulation signals to the biopotential signal source, the at least one stimulation component comprising at least one component selected from a group consisting of at least one programmable current source, at least one programmable voltage source, at least one programmable generator, at least one current-to-voltage converter, and at least one transresistance amplifier. Such biopotential sensor electrode system can further comprise at least one bidirectional multiplexer coupled to transfer signals among the at least one interface and the external instrumentation. Such at least one interface can be selected from a group consisting of an analog interface and a digital interface.

In such biopotential sensor electrode system, the at least one sensory component can comprise a dielectric layer coupled between a first and a second layer of electrically conductive material, the first layer of

electrically conductive material can be capacitively coupled to the biopotential signal source, and the second layer of electrically conductive material can be coupled to the at least one conditioning component. Such second layer of electrically conductive material can be coupled to the at least one conditioning component using at least one component selected from a group consisting of high voltage protection circuitry, at least one bond, at least one metal layer, at least one resistive element, charge balancing circuitry, and a feedback amplifier. Such at least one bond can be selected from a group consisting of a permanent metallic bond and a snap connector. Such first layer of electrically conductive material can be coupled to the dielectric layer through a third layer of electrically conductive material and a first bond, the second layer of electrically conductive material can be coupled to the dielectric layer through a fourth layer of electrically conductive material and a second bond. Such first bond and the second bond can be selected from a group consisting of a permanent metallic bond and a snap connector. Such first layer of electrically conductive material can be coupled to the biopotential signal source using at least one component selected from a group consisting of high voltage protection circuitry, at least one bond, and at least one metal layer, and such second layer of electrically conductive material can be coupled to the at least one conditioning component using at least one component selected from a group consisting of charge balancing circuitry and at least one bond. Such at least one bond can be selected from a group consisting of a permanent metallic bond and a snap connector.

In such biopotential sensor electrode system, the at least one telemetry component can comprise a telemetry receiver and transmitter and antenna, the at least one telemetry component transferring information and power among the biopotential sensor electrode and the external instrumentation.

In such biopotential sensor electrode system, the at least one power source can comprise at least one power source selected from a group consisting of at least one battery, at least one solar cell, and a telemetry power component, the telemetry power component generating power in response to telemetry signals received from the external instrumentation.

In such biopotential sensor electrode system, the at least one power source can be coupled among the at least one biopotential sensor electrode of the at least one electrode array.

In such biopotential sensor electrode system, the at least one power source can comprise a power source for each biopotential sensor electrode of the at least one electrode array.

Such biopotential sensor electrode system can further comprise at least one reference link among the at least one biopotential sensor electrode that allows the at least one biopotential sensor electrode to be synchronized and referenced to a single potential, the at least one reference link being provided by at least one coupling selected from a group consisting of a wired link, a telemetry link, and current injection to a skin surface.

In such biopotential sensor electrode system, the at least one biopotential sensor electrode can be on a single substrate.

Such biopotential sensor electrode system can further comprise a network coupled among the at least one electrode array and the external instrumentation, the network comprising at least one network coupling selected from a group consisting of wired, wireless, and a combination of wired and wireless.

In another embodiment, a biopotential sensor electrode system is provided that comprises at least one electrode array including at least one biopotential sensor electrode, the at least one biopotential sensor electrode

comprising at least one signal transfer component and at least one sensory component coupled to a biopotential signal source, the at least one sensory component comprising a first layer of electrically conductive material coupled among a biopotential signal source and a dielectric layer, a second layer of electrically conductive material coupled among the dielectric layer, at least one resistive element, at least one charge balancing current source and sink, and at least one biopotential electrode circuit, and at least one receiver section comprising at least one receiver, the at least one receiver section transferring biopotential signals among the signal transfer component and external instrumentation.

Such biopotential sensor electrode system can further comprise at least one reference link among the at least one biopotential sensor electrode that allows the at least one biopotential sensor electrode to be synchronized and referenced to a single potential, the at least one reference link being provided by at least one coupling selected from a group consisting of a wired link, a telemetry link, and current injection to a skin surface.

Such biopotential sensor electrode system can further comprise a network coupled among the at least one electrode array and the external instrumentation, the network comprising at least one network coupling selected from a group consisting of wired, wireless, and a combination of wired and wireless.

In another embodiment, a biopotential sensor electrode system can be provided that comprises at least one electrode array including at least one biopotential sensor electrode, the at least one biopotential sensor electrode comprising at least one signal transfer component and at least one sensory component coupled to a biopotential signal source, the at least one sensory component comprising a first layer of electrically conductive material coupled among a biopotential signal source, a dielectric layer, and voltage protection circuitry, a second layer of electrically conductive material coupled among the dielectric layer, at least one biopotential electrode circuit, and at least one charge balancing circuit, and at least one receiver section comprising at least one receiver, the at least one receiver section transferring biopotential signals among the signal transfer component and external instrumentation.

Such biopotential sensor electrode system can further comprise at least one reference link among the at least one biopotential sensor electrode that allows the at least one biopotential sensor electrode to be synchronized and referenced to a single potential, the at least one reference link being provided by at least one coupling selected from a group consisting of a wired link, a telemetry link, and current injection to a skin surface.

Such biopotential sensor electrode system can further comprise a network coupled among the at least one electrode array and the external instrumentation, the network comprising at least one network coupling selected from a group consisting of wired, wireless, and a combination of wired and wireless.

In another embodiment, a method for collecting biopotential signals is provided that comprises transferring telemetry signals among at least one sensor electrode and external instrumentation, the telemetry signals comprising power signals and biopotential signals, generating power for the sensor electrode in response to the power signals, receiving and conditioning biopotential signals from a skin surface at the sensor electrode, providing stimulation signals to the skin surface, and receiving telemetered conditioned biopotential signals at the external instrumentation.

In another embodiment, a computer readable medium containing executable instructions which, when executed in a processing system, causes the system to collect biopotential signals is provided. The collection comprises transferring telemetry signals among at least one sensor electrode and external instrumentation, the telemetry signals comprising power signals and biopotential signals, generating power for the sensor electrode  
5 in response to the power signals, receiving and conditioning biopotential signals from a skin surface at the sensor electrode, providing stimulation signals to the skin surface, and receiving telemetered conditioned biopotential signals at the external instrumentation.

In another embodiment, an electromagnetic medium containing executable instructions which, when executed in a processing system, causes the system to collect biopotential signals is provided. The collection  
10 comprises transferring telemetry signals among at least one sensor electrode and external instrumentation, the telemetry signals comprising power signals and biopotential signals, generating power for the sensor electrode in response to the power signals, receiving and conditioning biopotential signals from a skin surface at the sensor electrode, providing stimulation signals to the skin surface, and receiving telemetered conditioned biopotential signals at the external instrumentation.

In another embodiment, a biopotential sensor electrode system is provided that comprises  
15 means for transferring telemetry signals among at least one sensor means and external instrumentation, the telemetry signals comprising power signals and biopotential signals, means for generating power for the sensor electrode in response to the power signals, means for receiving and conditioning biopotential signals from a skin surface at the sensor electrode, means for providing stimulation signals to the skin surface, and means for  
20 receiving telemetered conditioned biopotential signals at the external instrumentation.

The foregoing description of various embodiments of the claimed invention is presented for purposes of illustration and description. It is not intended to limit the claimed invention to the precise forms disclosed. Many modifications and equivalent arrangements may be apparent.



What is claimed is:

1. A biopotential sensor electrode, comprising:
  - at least one sensory component coupled to a biopotential signal source, the at least one sensory component comprising at least one layer of electrically conductive material and at least one dielectric layer;
  - 5 at least one conditioning component coupled to condition signals from the at least one sensory component;
  - at least one interface configured to transfer signals among the at least one conditioning component and external instrumentation; and
  - at least one power source coupled among the at least one sensory component, the at least one
  - 10 conditioning component, and the at least one interface.
2. The biopotential sensor electrode of claim 1, wherein the at least one sensory component comprises a dielectric layer coupled between a first and a second layer of electrically conductive material, wherein the first layer of electrically conductive material is coupled to the biopotential signal source, and
- 15 wherein the second layer of electrically conductive material is coupled to the at least one conditioning component.
3. The biopotential sensor electrode of claim 2, wherein the second layer of electrically conductive material is coupled to the at least one conditioning component using at least one component selected
- 20 from a group consisting of high voltage protection circuitry, at least one bond, at least one metal layer, at least one resistive element, charge balancing circuitry, and a feedback amplifier.
4. The biopotential sensor electrode of claim 3, wherein the at least one bond is selected from a group consisting of a permanent metallic bond and at least one mating spring snap connector button, wherein one side of the at least one mating spring snap connector button is disposable.
- 25 5. The biopotential sensor electrode of claim 2, wherein the first layer of electrically conductive material is coupled to the dielectric layer through a third layer of electrically conductive material and a first bond, wherein the second layer of electrically conductive material is coupled to the dielectric layer through a fourth layer of electrically conductive material and a second bond.
6. The biopotential sensor electrode of claim 4, wherein the first bond and the second bond are
- 30 selected from a group consisting of a permanent metallic bond and at least one mating spring snap connector button, wherein one side of the at least one mating spring snap connector button is disposable.
7. The biopotential sensor electrode of claim 2, wherein the first layer of electrically conductive material is coupled to the biopotential signal source using at least one component selected from a group consisting of high voltage protection circuitry, at least one bond, and at least one metal layer, and wherein the

second layer of electrically conductive material is coupled to the at least one conditioning component using at least one component selected from a group consisting of charge balancing circuitry and at least one bond.

8. The biopotential sensor electrode of claim 5, wherein the at least one bond is selected from a group consisting of a permanent metallic bond and at least one mating spring snap connector button, wherein one side of the at least one mating spring snap connector button is disposable.

9. The biopotential sensor electrode of claim 1, wherein the at least one sensory component comprises a dielectric layer coupled between the biopotential signal source and an electrically conductive layer, wherein the electrically conductive layer is coupled to the at least one conditioning component.

10. The biopotential sensor electrode of claim 1, further comprising at least one stimulation component coupled among the at least one interface and the at least one sensory component, wherein the at least one stimulation component provides stimulation signals to a skin.

11. The biopotential sensor electrode of claim 10, wherein the at least one stimulation component comprises at least one component selected from a group consisting of at least one programmable current source, at least one programmable voltage source, at least one programmable generator, at least one current-to-voltage converter, and at least one transresistance amplifier.

12. The biopotential sensor electrode of claim 1, wherein the at least one interface transfers signals among the at least one conditioning component and the external instrumentation using at least one medium selected from a group consisting of wires, cables, and buses.

13. The biopotential sensor electrode of claim 1, further comprising at least one telemetry component coupled among the at least one conditioning component, the at least one interface, and the at least one power source.

14. The biopotential sensor electrode of claim 13, wherein the at least one telemetry component comprises a telemetry receiver and transmitter, wherein the at least one telemetry component transfers information and power among the biopotential sensor electrode and the external instrumentation.

15. The biopotential sensor electrode of claim 14, further comprising at least one antenna coupled to the at least one telemetry component.

16. The biopotential sensor electrode of claim 1, wherein the at least one power source comprises a telemetry power component that produces power in response to telemetry signals received from the external instrumentation.

17. The biopotential sensor electrode of claim 1, wherein the at least one power source comprises at least one power source selected from a group consisting of at least one battery and at least one solar cell.
18. The biopotential sensor electrode of claim 1, wherein the at least one layer of electrically conductive material comprises at least one material selected from a group consisting of stainless steel, platinum, gold, and silver silver-chloride.
19. The biopotential sensor electrode of claim 1, wherein the at least one dielectric layer comprises at least one material selected from a group consisting of Diamond Like Carbon (DLC) material, tantalum pentoxide, nitride, silicon nitride, oxide, and aluminum dioxide.
20. The biopotential sensor electrode of claim 1, wherein the at least one layer of electrically conductive material has a surface texture selected from a group consisting of smooth, rough, and bumped.
21. The biopotential sensor electrode of claim 1, wherein the at least one conditioning component comprises at least one component selected from a group consisting of impedance matching circuitry, charge balancing circuitry, amplification and buffering circuitry, programmable gain control circuitry, programmable filter circuitry, feedback control circuitry, and conditioning circuitry.
22. The biopotential sensor electrode of claim 1, further comprising at least one bidirectional multiplexer coupled to transfer signals among the at least one interface and the external instrumentation.
23. The biopotential sensor electrode of claim 1, further comprising a housing selected from a group consisting of a single piece housing, a two-piece housing, and a disposable housing.
24. The biopotential sensor electrode of claim 1, wherein the at least one interface is selected from a group consisting of an analog interface and a digital interface.
25. The biopotential sensor electrode of claim 1, wherein the at least one interface is a digital interface comprising at least one analog-to-digital converter, at least one memory device, at least one input/output interface unit, and at least one state machine.
26. The biopotential sensor electrode of claim 1, further comprising a substrate including at least one electrode array, wherein the at least one electrode array comprises at least one other biopotential sensor electrode.
27. The biopotential sensor electrode of claim 26, wherein the at least one power source is shared among the at least one other biopotential sensor electrode.
28. The biopotential sensor electrode of claim 1, further comprising at least one reference link among at least one other biopotential sensor electrode, wherein the at least one reference link allows the

biopotential sensor electrode to be synchronized and referenced to a single potential, wherein the at least one reference link is provided by at least one coupling selected from a group consisting of a wired link, a telemetry link, and current injection to a skin surface.

29. A biopotential sensor electrode, comprising at least one sensory component and at least one telemetry component, wherein the at least one sensory component comprises at least one layer of electrically conductive material and at least one dielectric layer, wherein the at least one sensory component is coupled among a biopotential signal source and the at least one telemetry component, wherein the at least one telemetry component transfers signals and power among the biopotential sensor electrode and external instrumentation.

30. A method for collecting biopotential signals, comprising:  
receiving telemetered power signals at a biopotential sensor electrode;  
generating power in response to the telemetered power signals;  
receiving the biopotential signals via a coupling with a skin surface; and transferring the biopotential signals from the biopotential sensor electrode using at least one coupling comprising a wireless link.

31. A computer readable medium containing executable instructions which, when executed in a processing system, causes the system to collect biopotential signals, the collection comprising:  
receiving telemetered power signals at a biopotential sensor electrode;  
generating power in response to the telemetered power signals;  
receiving the biopotential signals via a coupling with a skin surface; and  
transferring the biopotential signals from the biopotential sensor electrode using at least one coupling comprising a wireless link.

32. An electromagnetic medium containing executable instructions which, when executed in a processing system, causes the system to collect biopotential signals, the collection comprising:  
receiving telemetered power signals at a biopotential sensor electrode;  
generating power in response to the telemetered power signals;  
receiving the biopotential signals via a coupling with a skin surface; and  
transferring the biopotential signals from the biopotential sensor electrode using at least one coupling comprising a wireless link.

33. A biopotential sensor electrode, comprising at least one sensory means and at least one telemetry means, wherein the at least one sensory means comprises at least one layer of electrically conductive material and at least one dielectric layer, wherein the at least one sensory means is coupled among a biopotential signal source and the at least one telemetry means, wherein the at least one telemetry means transfers signals and power among the biopotential sensor electrode and external instrumentation.

34. A biopotential sensor electrode, comprising:  
means for receiving telemetered power signals at a biopotential sensor electrode;  
means for generating power in response to the telemetered power signals;  
means for receiving the biopotential signals via a coupling with a skin surface; and  
5 means for transferring the biopotential signals from the biopotential sensor electrode using at least one coupling comprising a wireless link.
35. A biopotential electrode sensory component, comprising:  
a first layer of electrically conductive material coupled among a biopotential signal source and a  
10 dielectric layer; and  
a second layer of electrically conductive material coupled among the dielectric layer, at least one resistive element, at least one charge balancing current source and sink, and at least one biopotential electrode circuit.
- 15 36. The biopotential electrode sensory component of claim 35, wherein the biopotential signal source is further coupled to the at least one biopotential electrode circuit using at least one component selected from a group consisting of high voltage protection circuitry, at least one bond, at least one metal layer, and a feedback amplifier.
- 20 37. The biopotential electrode sensory component of claim 36, wherein the at least one bond is selected from a group consisting of a permanent metallic bond and a snap connector.
- 25 38. The biopotential electrode sensory component of claim 35, wherein the first layer of electrically conductive material is coupled to the dielectric layer through a third layer of electrically conductive material and a first bond, wherein the second layer of electrically conductive material is coupled to the dielectric layer through a fourth layer of electrically conductive material and a second bond.
- 30 39. The biopotential electrode sensory component of claim 38, wherein the first bond and the second bond are selected from a group consisting of a permanent metallic bond and a snap connector.
40. The biopotential electrode sensory component of claim 35, wherein the dielectric layer comprises at least one material selected from a group consisting of Diamond Like Carbon (DLC) material, tantalum pentoxide, nitride, silicon nitride, oxide, and aluminum dioxide.
41. The biopotential electrode sensory component of claim 35, wherein the first layer and second layer of electrically conductive material comprise at least one material selected from a group consisting of stainless steel, platinum, gold, and silver silver-chloride.

42. The biopotential electrode sensory component of claim 35, wherein the first layer of electrically conductive material has a surface texture selected from a group consisting of smooth, rough, and bumped.
- 5 43. The biopotential electrode sensory component of claim 35, further comprising an electrical coupling to at least one interface selected from a group consisting of an analog interface and a digital interface.
44. The biopotential electrode sensory component of claim 35, further comprising an electrical coupling to at least one telemetry component, wherein the at least one telemetry component transfers biopotential signals and power among the biopotential electrode sensory component and external  
10 instrumentation.
45. The biopotential electrode sensory component of claim 35, further comprising an electrical coupling to at least one reference link that allows at least one biopotential sensor electrode associated with the biopotential electrode sensory component to be synchronized and referenced to a single potential, wherein the at least one reference link is provided by at least one coupling selected from a group consisting of a wired link, a  
15 telemetry link, and current injection to a skin surface.
46. A biopotential electrode sensory component, comprising:  
a first layer of electrically conductive material coupled among a biopotential signal source, a dielectric layer, and voltage protection circuitry;  
a second layer of electrically conductive material coupled among the dielectric layer, at least one  
20 biopotential electrode circuit, and at least one charge balancing circuit.
47. The biopotential electrode sensory component of claim 46, wherein a third and fourth electrically conductive layer are coupled between the first layer of electrically conductive material and the dielectric layer using at least one bond.
48. The biopotential electrode sensory component of claim 47, wherein the at least one bond is  
25 selected from a group consisting of a permanent metallic bond and a snap connector.
49. The biopotential electrode sensory component of claim 46, wherein the biopotential signal source is further coupled to the at least one biopotential electrode circuit using a feedback amplifier.
50. The biopotential electrode sensory component of claim 46, wherein the dielectric layer comprises at least one material selected from a group consisting of Diamond Like Carbon (DLC) material, tantalum pentoxide, nitride, silicon nitride, oxide, and aluminum dioxide.  
30

51. The biopotential electrode sensory component of claim 46, wherein the first layer and second layer of electrically conductive material comprise at least one material selected from a group consisting of stainless steel, platinum, gold, and silver silver-chloride.

5 52. The biopotential electrode sensory component of claim 47, wherein the third layer and fourth layer of electrically conductive material comprise at least one material selected from a group consisting of stainless steel, platinum, gold, and silver silver-chloride.

53. The biopotential electrode sensory component of claim 46, wherein the first layer of electrically conductive material has a surface texture selected from a group consisting of smooth, rough, and  
10 bumped.

54. The biopotential electrode sensory component of claim 46, further comprising an electrical coupling to at least one interface selected from a group consisting of an analog interface and a digital interface.

55. The biopotential electrode sensory component of claim 46, further comprising an electrical coupling to at least one telemetry component, wherein the at least one telemetry component transfers  
15 biopotential signals and power among the biopotential electrode sensory component and external instrumentation.

56. The biopotential electrode sensory component of claim 46, further comprising an electrical coupling to at least one reference link that allows at least one biopotential sensor electrode associated with the biopotential electrode sensory component to be synchronized and referenced to a single potential, wherein the at  
20 least one reference link is provided by at least one coupling selected from a group consisting of a wired link, a telemetry link, and current injection to a skin surface.

57. A method for collecting biopotential signals, comprising:  
coupling a sensory component to a skin surface;  
converting ionic potentials and electric fields received by the sensory component to electrical  
25 potentials;  
minimizing effects of changing skin impedance on the electrical potentials using a sensor impedance in series with a skin impedance, wherein a magnitude of the sensor impedance is greater than a magnitude of the skin impedance;  
minimizing direct current offset and motion artifacts of the electrical potentials using charge balancing;  
30 and  
providing electrical potentials to external instrumentation.

58. A computer readable medium containing executable instructions which, when executed in a processing system, causes the system to collect biopotential signals, the collection comprising:

coupling a sensory component to a skin surface;  
converting ionic potentials and electric fields received by the sensory component to electrical potentials;

5 minimizing effects of changing skin impedance on the electrical potentials using a sensor impedance in series with a skin impedance, wherein a magnitude of the sensor impedance is greater than a magnitude of the skin impedance;

minimizing direct current offset and motion artifacts of the electrical potentials using charge balancing;  
and

10 providing electrical potentials to external instrumentation.

59. An electromagnetic medium containing executable instructions which, when executed in a processing system, causes the system to collect biopotential signals, the collection comprising:

coupling a sensory component to a skin surface;

converting ionic potentials and electric fields received by the sensory component to electrical potentials;

15 minimizing effects of changing skin impedance on the electrical potentials using a sensor impedance in series with a skin impedance, wherein a magnitude of the sensor impedance is greater than a magnitude of the skin impedance;

minimizing direct current offset and motion artifacts of the electrical potentials using charge balancing;  
and

providing electrical potentials to external instrumentation.

20 60. A biopotential electrode sensory component, comprising:

means for coupling a sensory means to a skin surface;

means for converting ionic potentials and electric fields received by the sensory means to electrical potentials;

25 means for minimizing effects of changing skin impedance on the electrical potentials using an impedance in series with a skin impedance, wherein a magnitude of the impedance is greater than a magnitude of the skin impedance;

means for minimizing direct current offset and motion artifacts of the electrical potentials using charge balancing means; and

means for providing electrical potentials to external instrumentation.

30

61. A biopotential sensor electrode system, comprising:

at least one electrode array including at least one biopotential sensor electrode coupled to at least one telemetry component and at least one power source, wherein the at least one biopotential sensor electrode includes at least one sensory component coupled to a biopotential signal source; and



at least one receiver section comprising at least one receiver, the at least one receiver section transferring biopotential signals among the biopotential signal source and external instrumentation using the at least one telemetry component.

5 62. The biopotential sensor electrode system of claim 61, wherein the at least one sensory component comprises at least one layer of electrically conductive material and at least one dielectric layer, wherein the at least one biopotential sensor electrode further comprises:

at least one conditioning component coupled to condition signals from the at least one sensory component;

10 at least one interface configured to transfer signals among the at least one conditioning component and external instrumentation; and

at least one power source coupled among the at least one sensory component, the at least one conditioning component, and the at least one interface.

15 63. The biopotential sensor electrode system of claim 61, wherein the at least one sensory component comprises a dielectric layer coupled between a first and a second layer of electrically conductive material, wherein the first layer of electrically conductive material is capacitively coupled to the biopotential signal source, and wherein the second layer of electrically conductive material is coupled to the at least one conditioning component.

20 64. The biopotential sensor electrode system of claim 63, wherein the second layer of electrically conductive material is coupled to the at least one conditioning component using at least one component selected from a group consisting of high voltage protection circuitry, at least one bond, at least one metal layer, at least one resistive element, charge balancing circuitry, and a feedback amplifier.

25 65. The biopotential sensor electrode system of claim 64, wherein the at least one bond is selected from a group consisting of a permanent metallic bond and a snap connector.

30 66. The biopotential sensor electrode system of claim 63, wherein the first layer of electrically conductive material is coupled to the dielectric layer through a third layer of electrically conductive material and a first bond, wherein the second layer of electrically conductive material is coupled to the dielectric layer through a fourth layer of electrically conductive material and a second bond.

67. The biopotential sensor electrode system of claim 66, wherein the first bond and the second bond are selected from a group consisting of a permanent metallic bond and a snap connector.

35 68. The biopotential sensor electrode system of claim 66, wherein the first layer of electrically conductive material is coupled to the biopotential signal source using at least one component selected from a group consisting of high voltage protection circuitry, at least one bond, and at least one metal layer, and wherein

the second layer of electrically conductive material is coupled to the at least one conditioning component using at least one component selected from a group consisting of charge balancing circuitry and at least one bond.

69. The biopotential sensor electrode system of claim 68, wherein the at least one bond is selected from a group consisting of a permanent metallic bond and a snap connector.

5 70. The biopotential sensor electrode system of claim 62, further comprising at least one stimulation component coupled among the at least one interface and the at least one sensory component, wherein the at least one stimulation component provides stimulation signals to the biopotential signal source, wherein the at least one stimulation component comprises at least one component selected from a group consisting of at least one programmable current source, at least one programmable voltage source, at least one  
10 programmable generator, at least one current-to-voltage converter, and at least one transresistance amplifier.

71. The biopotential sensor electrode system of claim 61, wherein the at least one telemetry component comprises a telemetry receiver and transmitter and antenna, wherein the at least one telemetry component transfers information and power among the biopotential sensor electrode and the external instrumentation.

15 72. The biopotential sensor electrode system of claim 61, wherein the at least one power source comprises at least one power source selected from a group consisting of at least one battery, at least one solar cell, and a telemetry power component, wherein the telemetry power component generates power in response to telemetry signals received from the external instrumentation.

20 73. The biopotential sensor electrode system of claim 61, wherein the at least one power source is coupled among the at least one biopotential sensor electrode of the at least one electrode array.

74. The biopotential sensor electrode system of claim 61, wherein the at least one power source comprises a power source for each biopotential sensor electrode of the at least one electrode array.

25 75. The biopotential sensor electrode system of claim 62, further comprising at least one bidirectional multiplexer coupled to transfer signals among the at least one interface and the external instrumentation.

76. The biopotential sensor electrode system of claim 62, wherein the at least one interface is selected from a group consisting of an analog interface and a digital interface.

30 77. The biopotential sensor electrode system of claim 61, further comprising at least one reference link among the at least one biopotential sensor electrode that allows the at least one biopotential sensor electrode to be synchronized and referenced to a single potential, wherein the at least one reference link is provided by at

least one coupling selected from a group consisting of a wired link, a telemetry link, and current injection to a skin surface.

78. The biopotential sensor electrode system of claim 61, wherein the at least one biopotential sensor electrode is on a single substrate.

79. The biopotential sensor electrode system of claim 61, further comprising a network coupled among the at least one electrode array and the external instrumentation, wherein the network comprises at least one network coupling selected from a group consisting of wired, wireless, and a combination of wired and wireless.

80. A biopotential sensor electrode system, comprising:  
at least one electrode array including at least one biopotential sensor electrode, wherein the at least one biopotential sensor electrode comprises at least one signal transfer component and at least one sensory component coupled to a biopotential signal source, wherein the at least one sensory component comprises,  
a first layer of electrically conductive material coupled among a biopotential signal source and a dielectric layer;  
a second layer of electrically conductive material coupled among the dielectric layer, at least one resistive element, at least one charge balancing current source and sink, and at least one biopotential electrode circuit; and  
at least one receiver section comprising at least one receiver, the at least one receiver section transferring biopotential signals among the signal transfer component and external instrumentation.

81. The biopotential sensor electrode system of claim 80, further comprising at least one reference link among the at least one biopotential sensor electrode that allows the at least one biopotential sensor electrode to be synchronized and referenced to a single potential, wherein the at least one reference link is provided by at least one coupling selected from a group consisting of a wired link, a telemetry link, and current injection to a skin surface.

82. The biopotential sensor electrode system of claim 80, further comprising a network coupled among the at least one electrode array and the external instrumentation, wherein the network comprises at least one network coupling selected from a group consisting of wired, wireless, and a combination of wired and wireless.

83. A biopotential sensor electrode system, comprising:  
at least one electrode array including at least one biopotential sensor electrode, wherein the at least one biopotential sensor electrode comprises at least one signal transfer component and at least one sensory component coupled to a biopotential signal source, wherein the at least one sensory component comprises,

a first layer of electrically conductive material coupled among a biopotential signal source, a dielectric layer, and voltage protection circuitry;

a second layer of electrically conductive material coupled among the dielectric layer, at least one biopotential electrode circuit, and at least one charge balancing circuit; and

5 at least one receiver section comprising at least one receiver, the at least one receiver section transferring biopotential signals among the signal transfer component and external instrumentation.

84. The biopotential sensor electrode system of claim 83, further comprising at least one reference link among the at least one biopotential sensor electrode that allows the at least one biopotential sensor electrode to be synchronized and referenced to a single potential, wherein the at least one reference link is provided by at least one coupling selected from a group consisting of a wired link, a telemetry link, and current injection to a skin surface.

85. The biopotential sensor electrode system of claim 83, further comprising a network coupled among the at least one electrode array and the external instrumentation, wherein the network comprises at least one network coupling selected from a group consisting of wired, wireless, and a combination of wired and wireless.

86. A method for collecting biopotential signals, comprising:  
transferring telemetry signals among at least one sensor electrode and external instrumentation, wherein the telemetry signals comprise power signals and biopotential signals;  
20 generating power for the sensor electrode in response to the power signals;  
receiving and conditioning biopotential signals from a skin surface at the sensor electrode;  
providing stimulation signals to the skin surface; and  
receiving telemetered conditioned biopotential signals at the external instrumentation.

87. A computer readable medium containing executable instructions which, when executed in a processing system, causes the system to collect biopotential signals, the collection comprising:  
transferring telemetry signals among at least one sensor electrode and external instrumentation, wherein the telemetry signals comprise power signals and biopotential signals;  
generating power for the sensor electrode in response to the power signals;  
30 receiving and conditioning biopotential signals from a skin surface at the sensor electrode;  
providing stimulation signals to the skin surface; and  
receiving telemetered conditioned biopotential signals at the external instrumentation.

88. An electromagnetic medium containing executable instructions which, when executed in a processing system, causes the system to collect biopotential signals, the collection comprising:

transferring telemetry signals among at least one sensor electrode and external instrumentation, wherein the telemetry signals comprise power signals and biopotential signals;

generating power for the sensor electrode in response to the power signals;

receiving and conditioning biopotential signals from a skin surface at the sensor electrode;

5 providing stimulation signals to the skin surface; and

receiving telemetered conditioned biopotential signals at the external instrumentation.

89. A biopotential sensor electrode system, comprising:

10 means for transferring telemetry signals among at least one sensor means and external instrumentation, wherein the telemetry signals comprise power signals and biopotential signals;

means for generating power for the sensor electrode in response to the power signals;

means for receiving and conditioning biopotential signals from a skin surface at the sensor electrode;

means for providing stimulation signals to the skin surface; and

means for receiving telemetered conditioned biopotential signals at the external instrumentation.

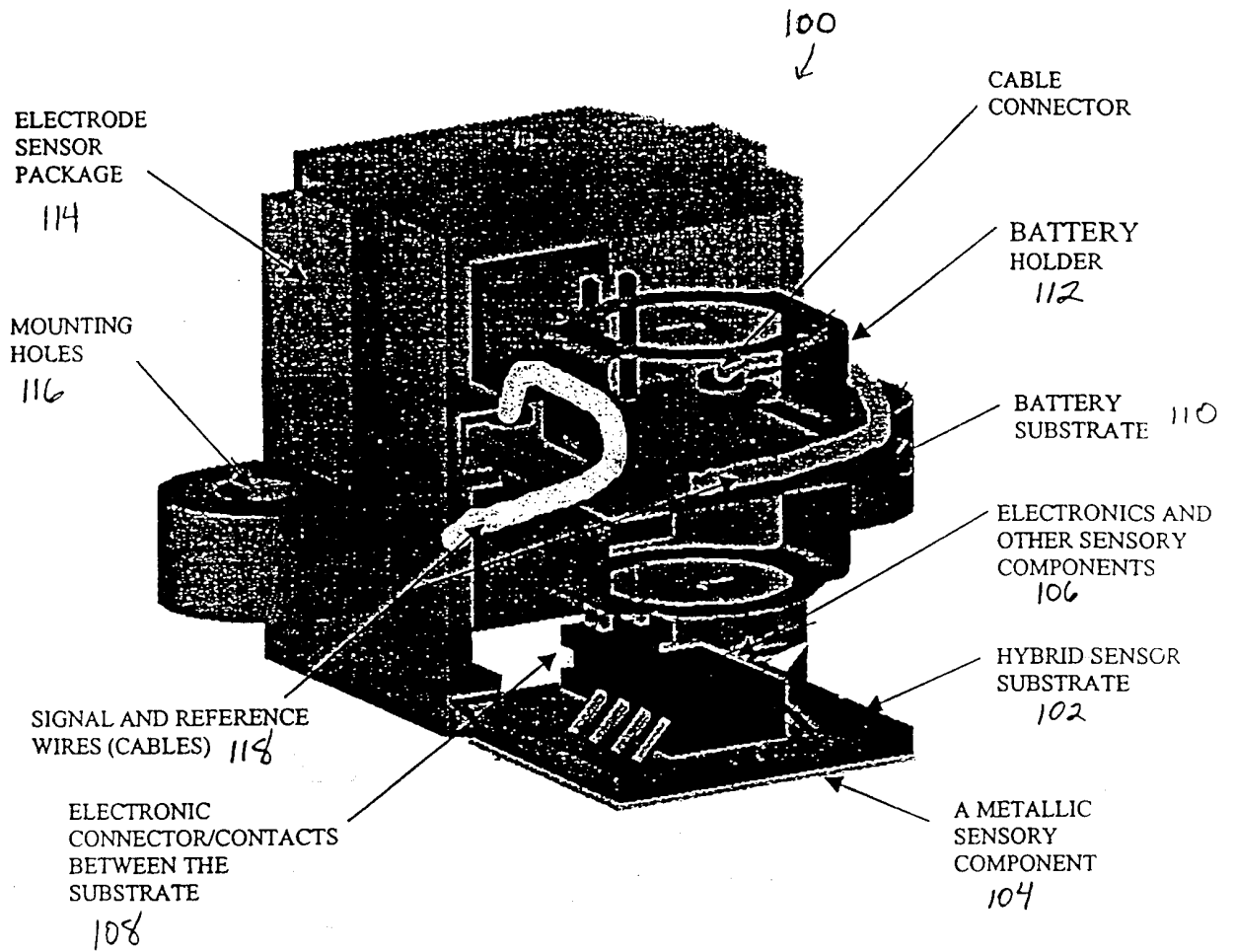


FIGURE 1

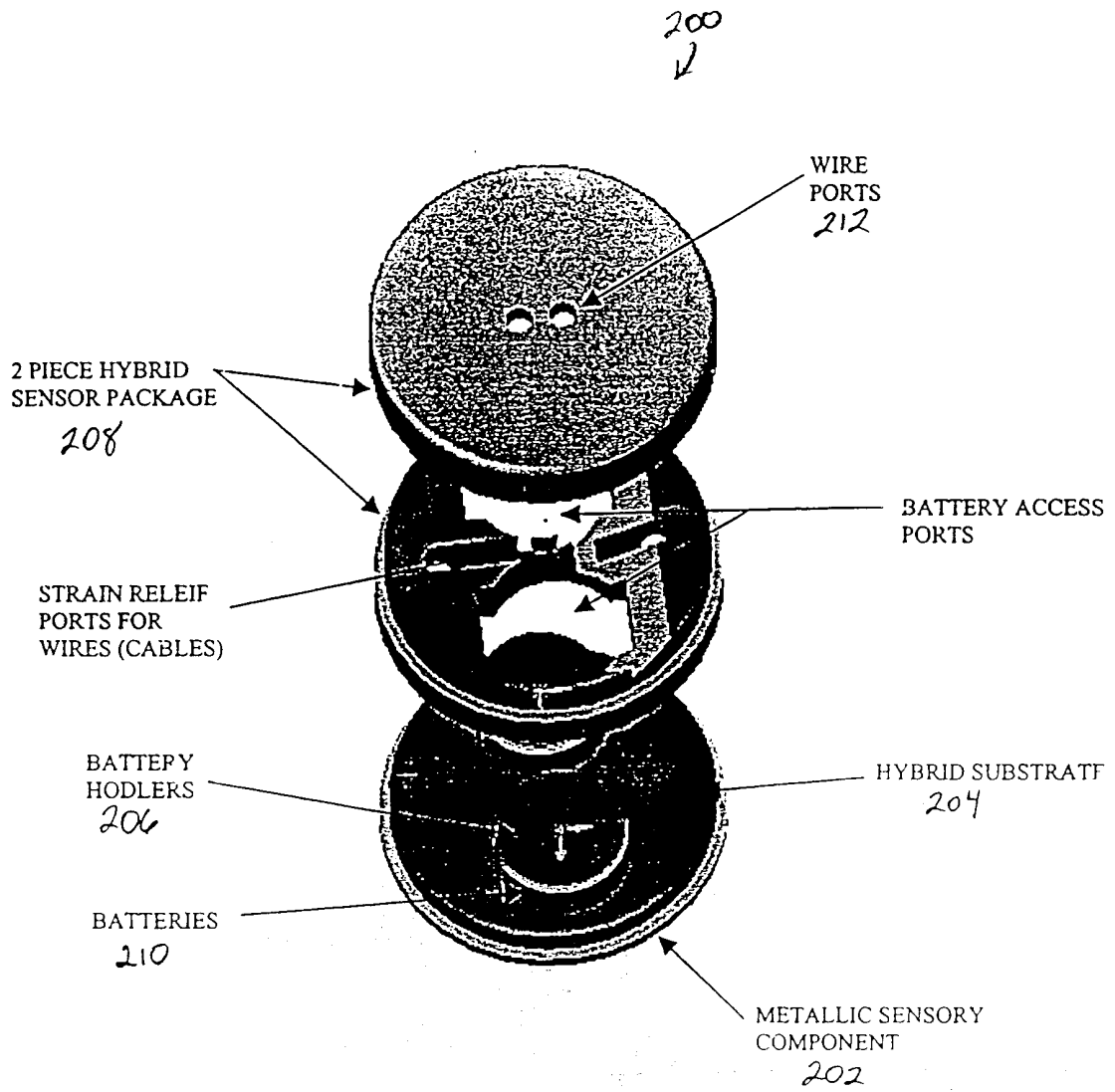


FIGURE 2

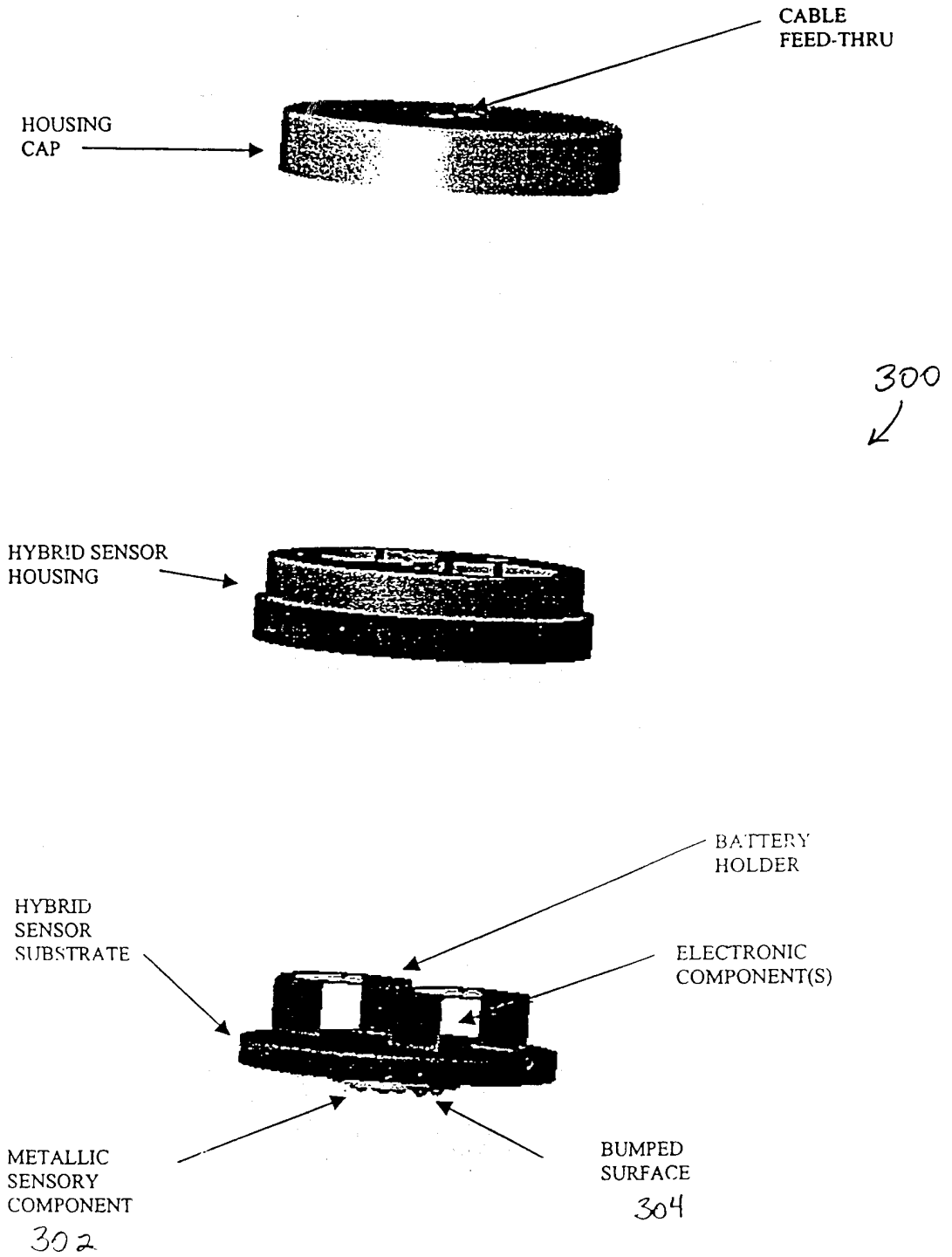


FIGURE 3



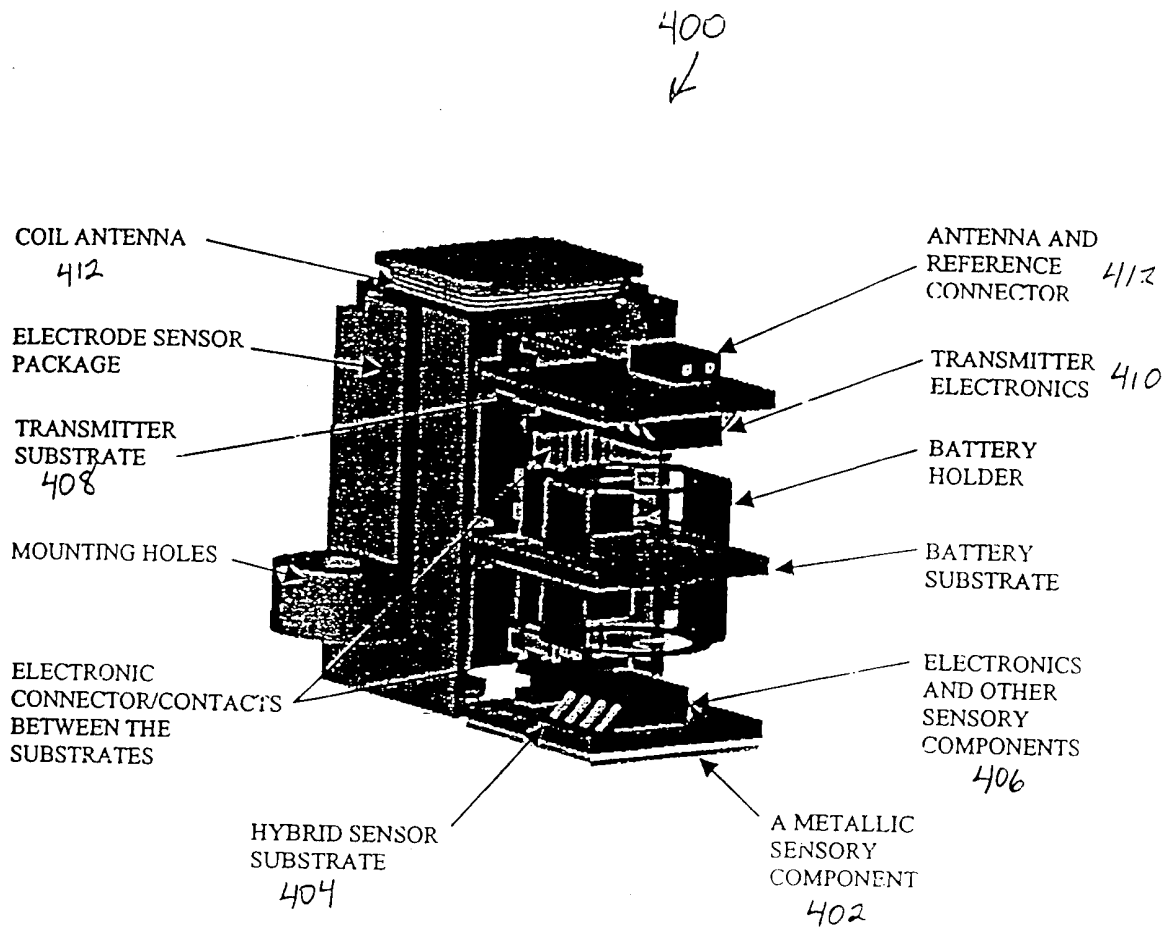


FIGURE 4

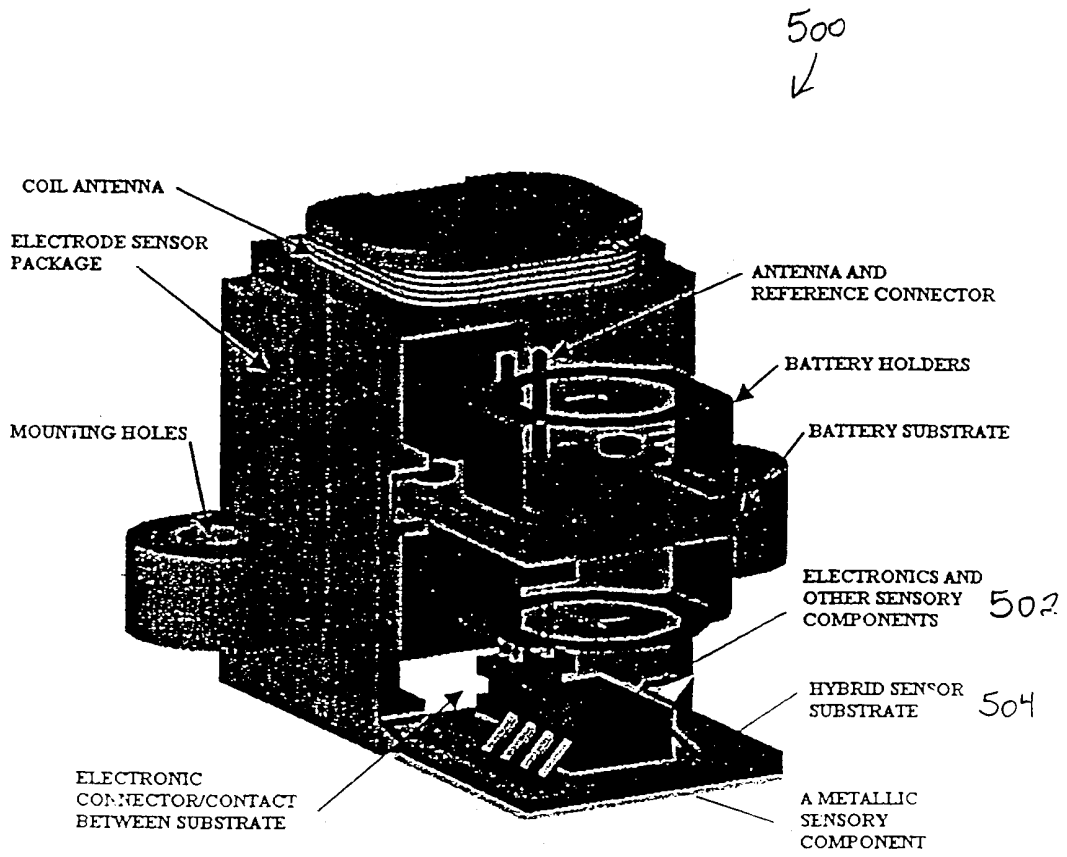


FIGURE 5

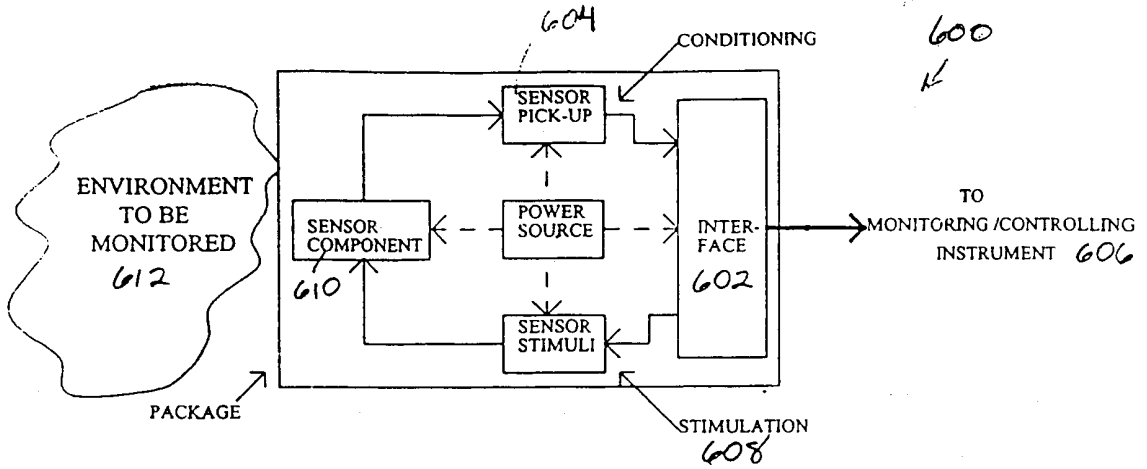


FIGURE 6

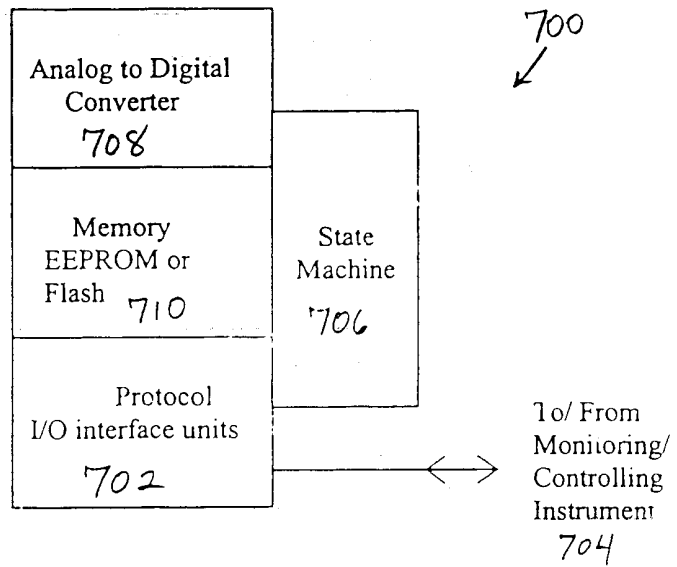


FIGURE 7

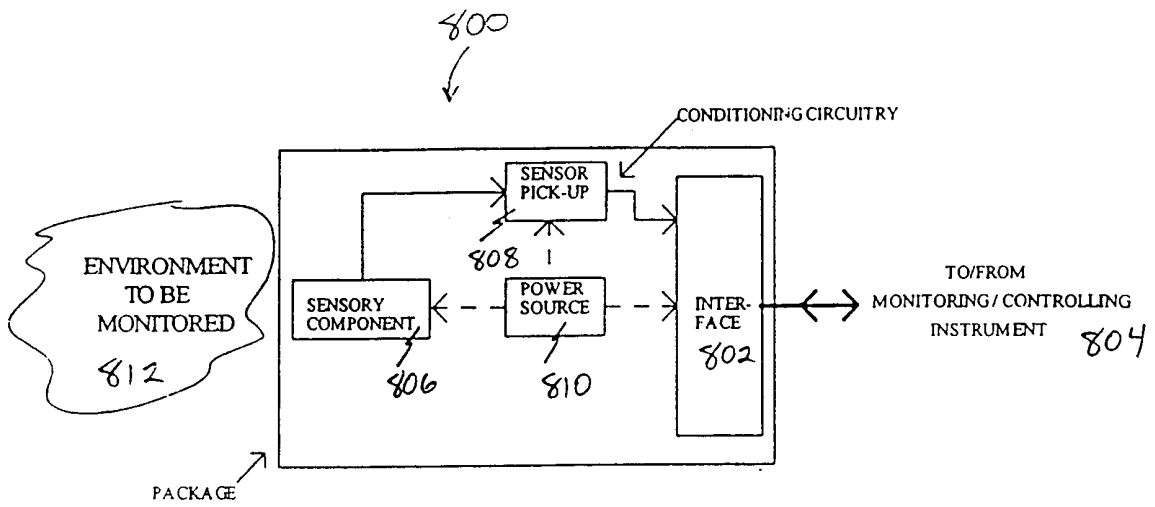


FIGURE 8

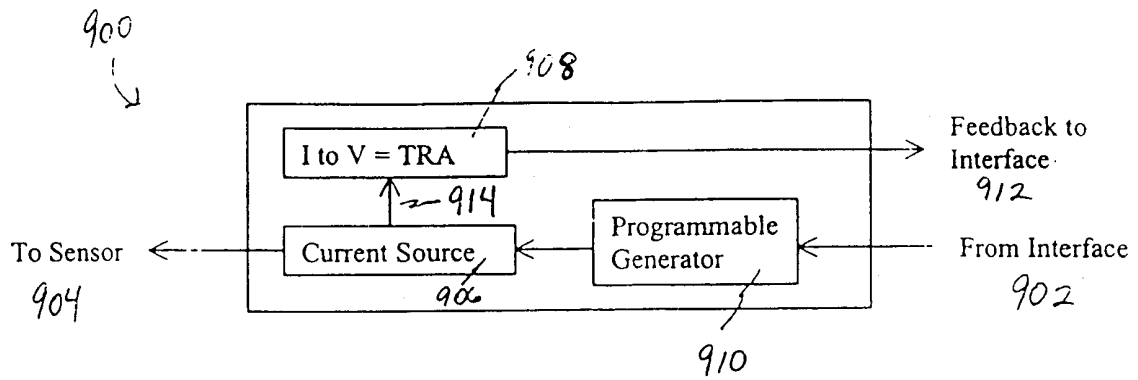


FIGURE 9

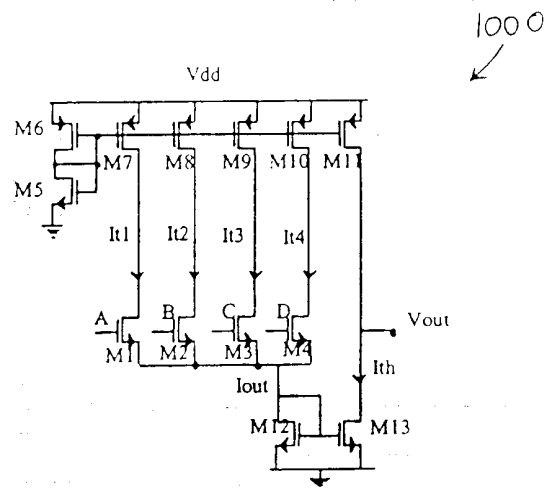


FIGURE 10

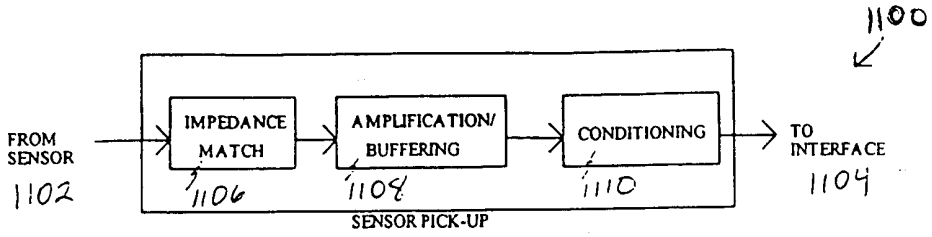


FIGURE 11

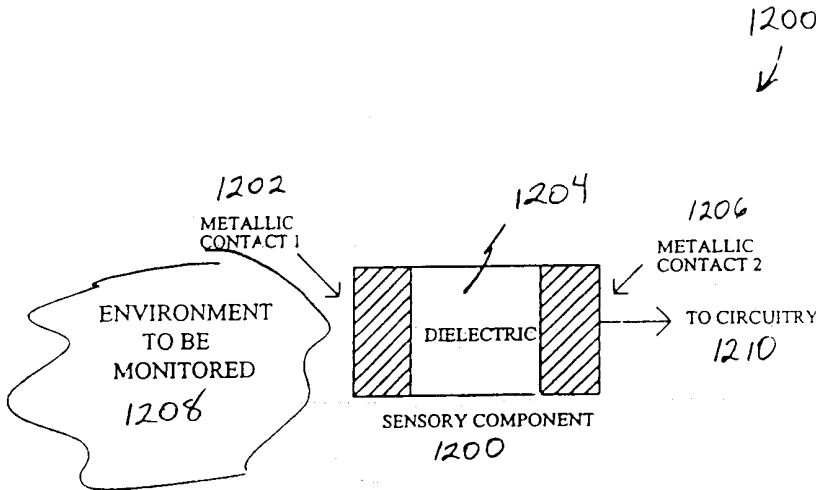
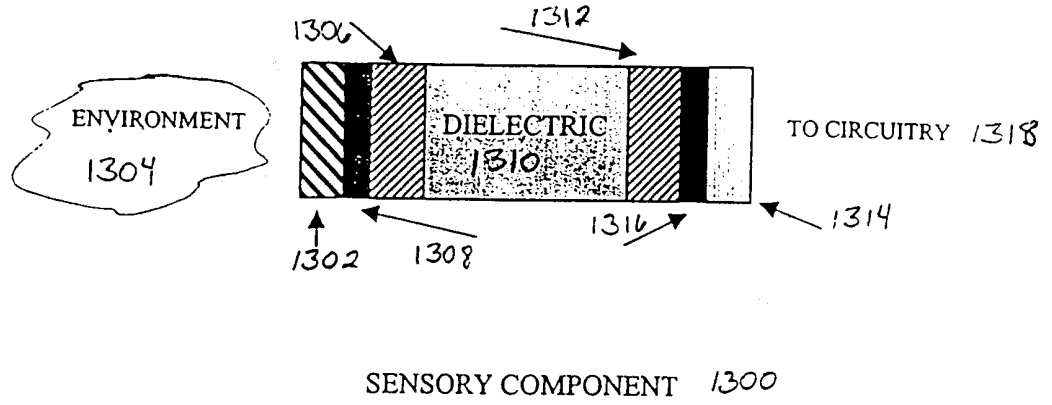


FIGURE 12



SENSORY COMPONENT 1300

FIGURE 13

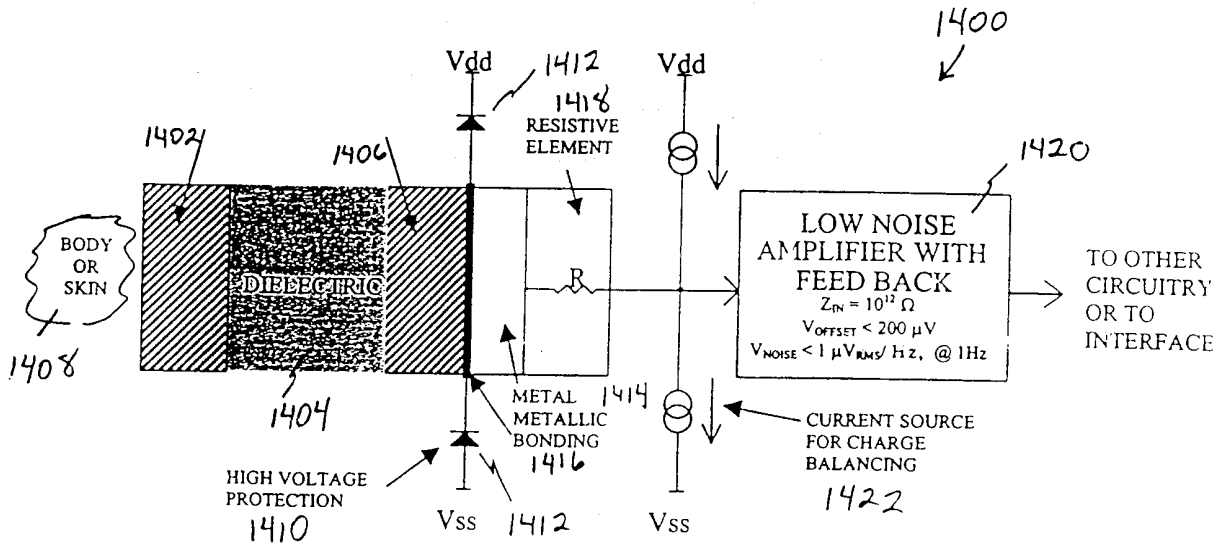


FIGURE 14

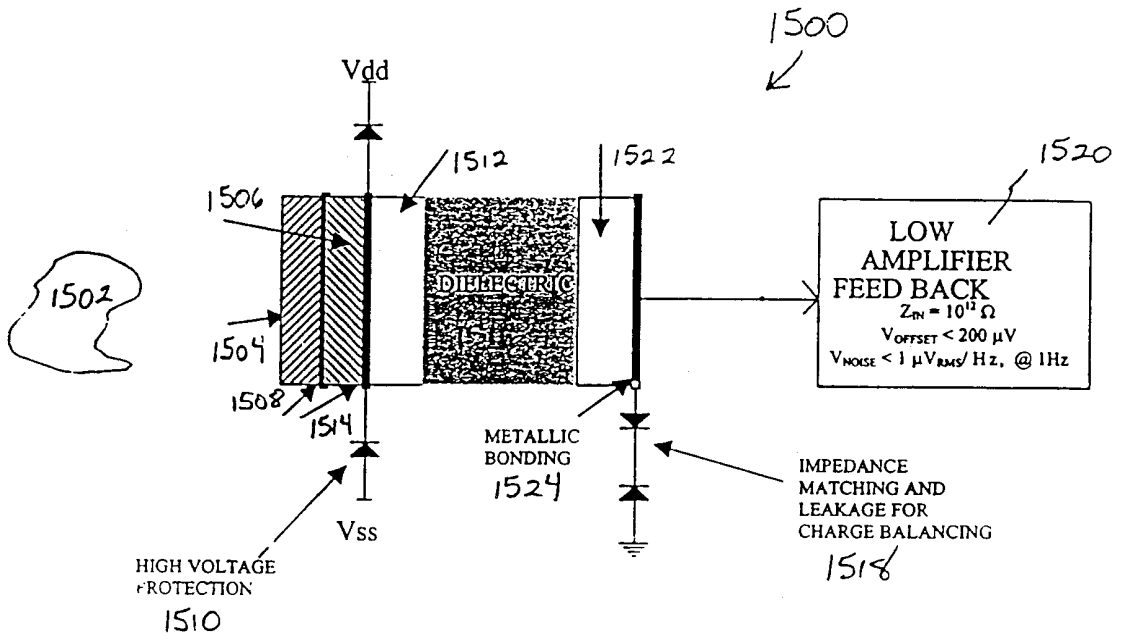


FIGURE 15



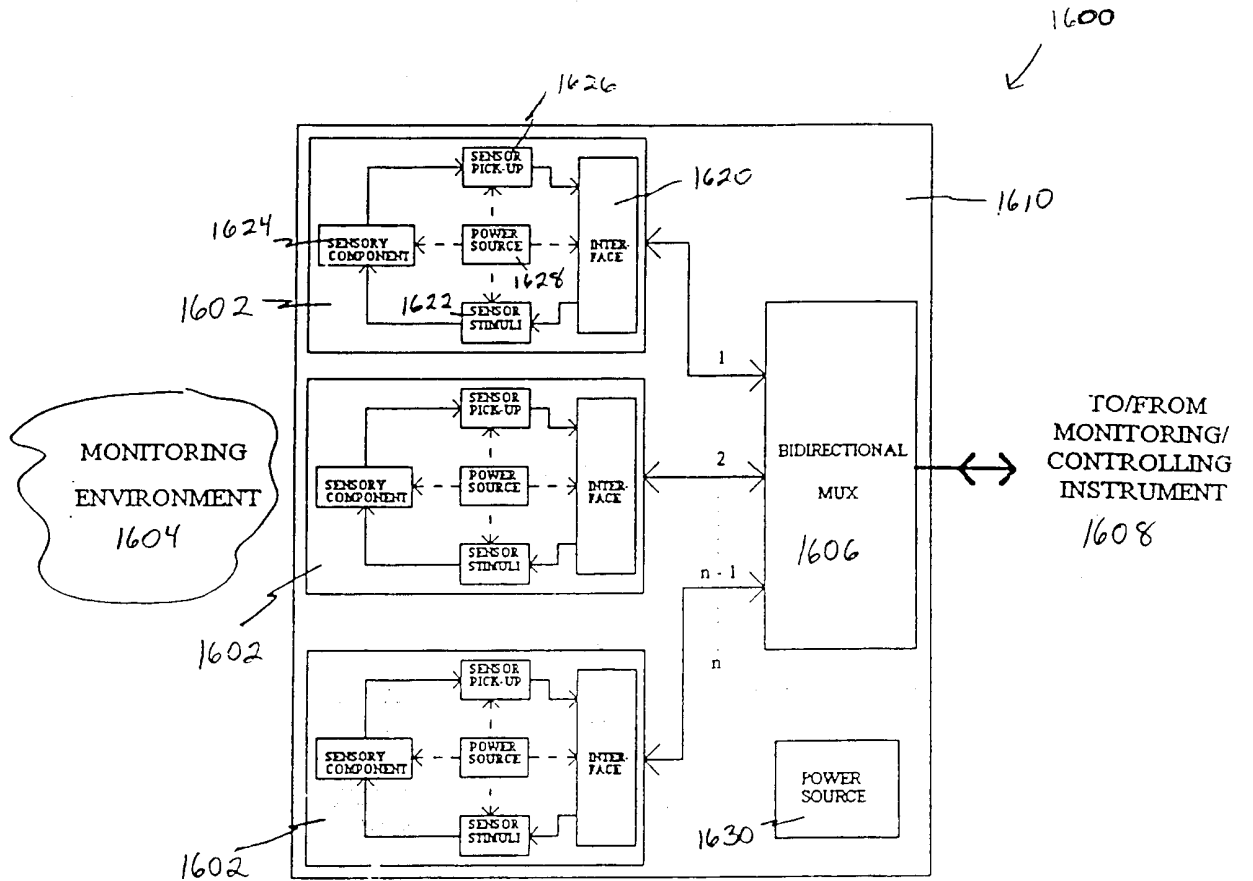


FIGURE 16

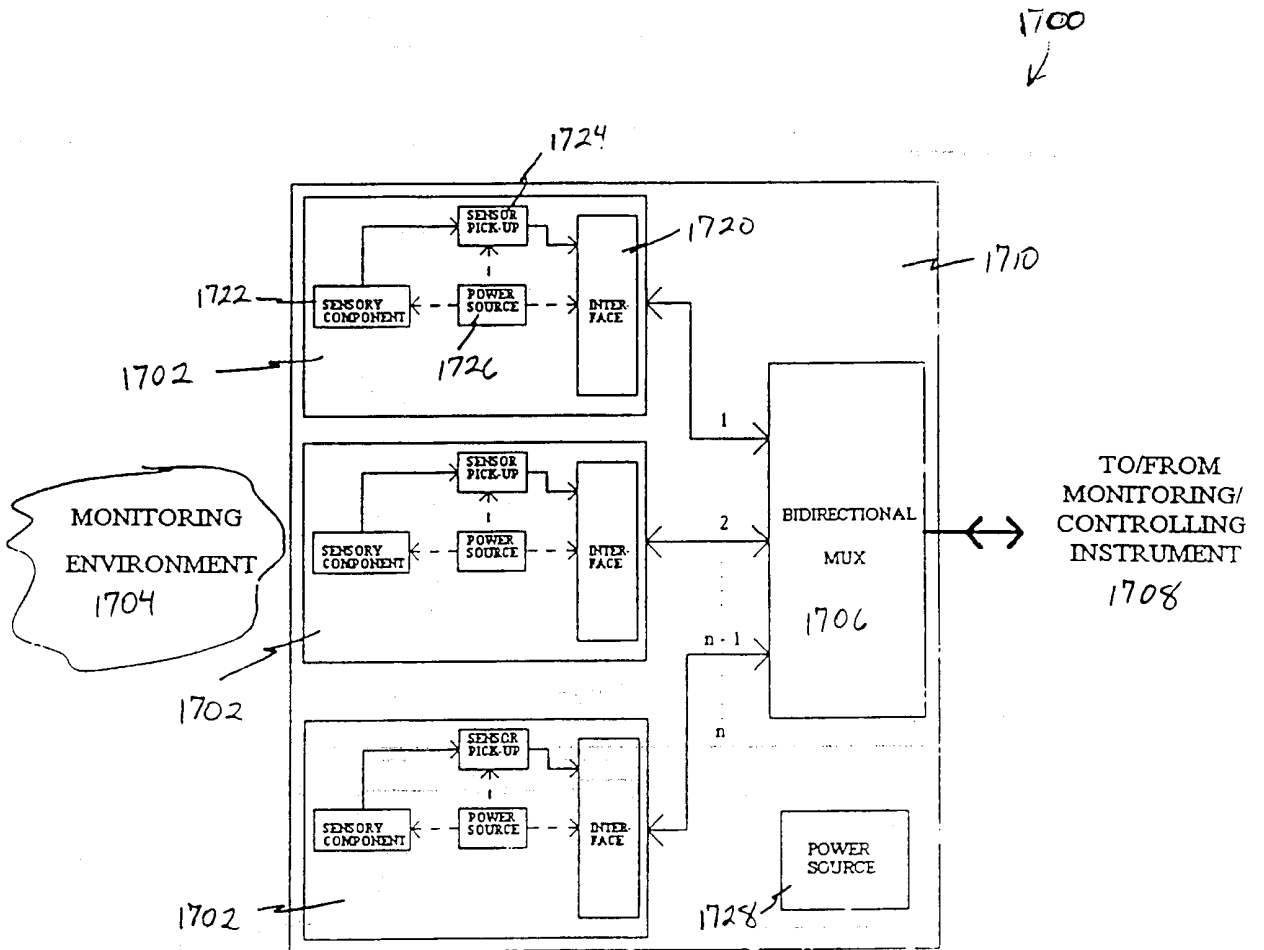


FIGURE 17

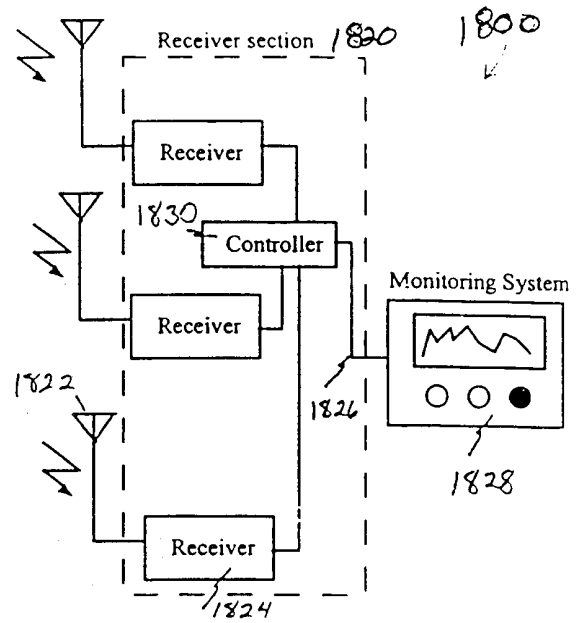
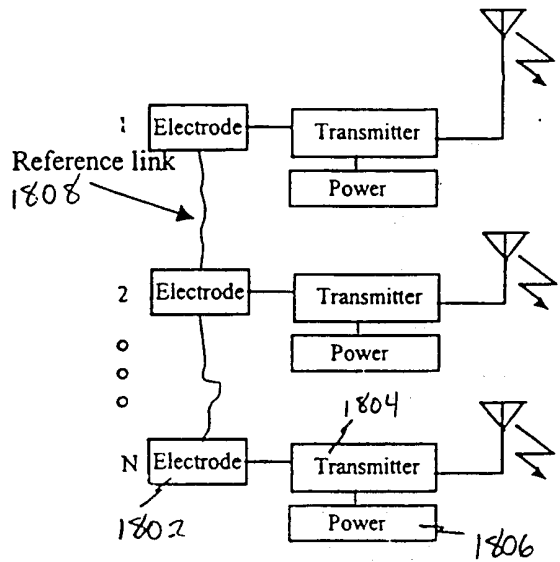


FIGURE 18

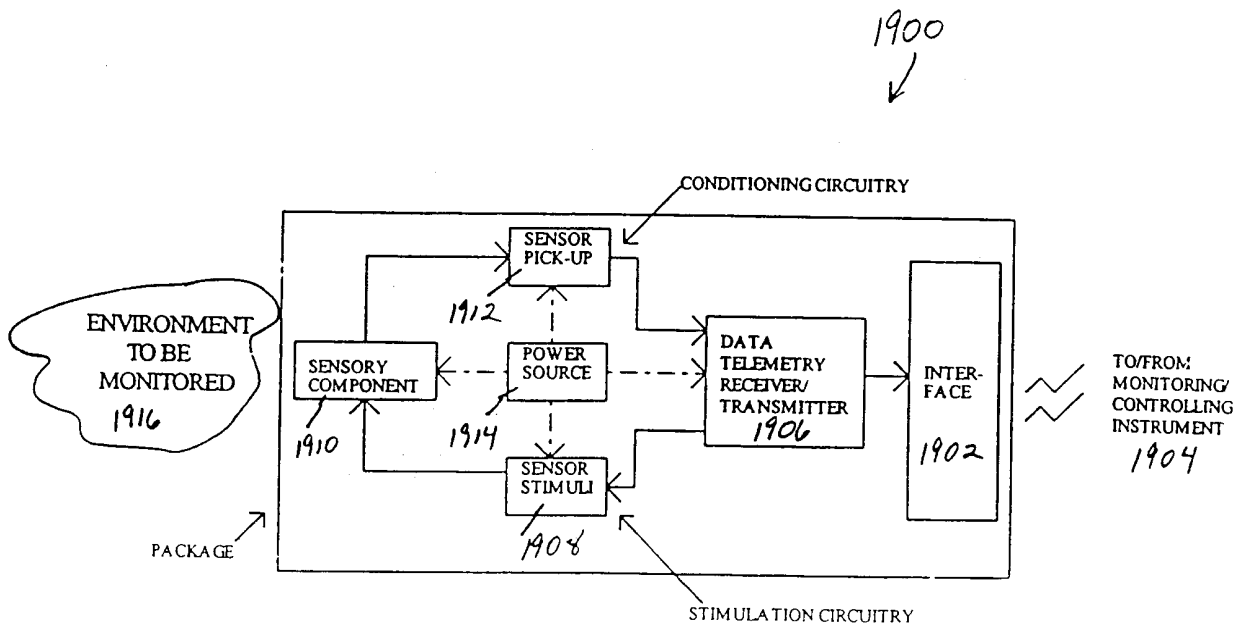


FIGURE 19

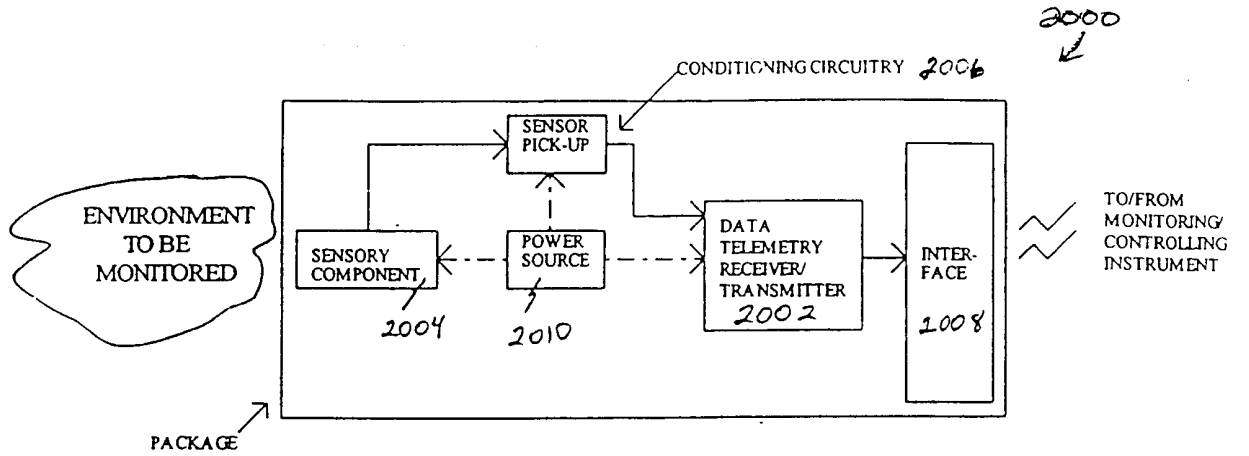


FIGURE 20

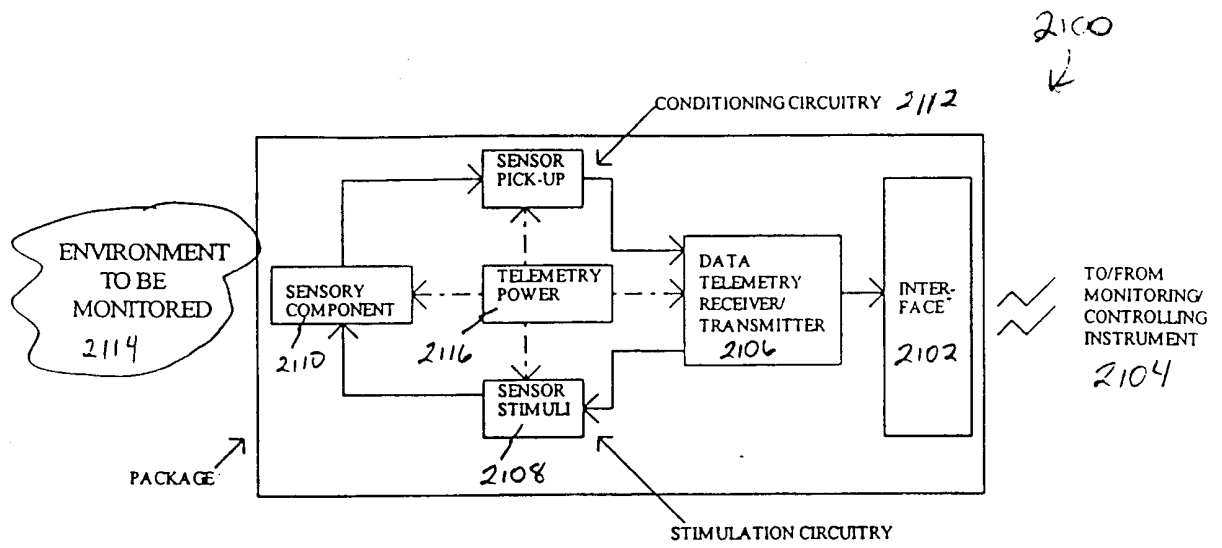


FIGURE 21

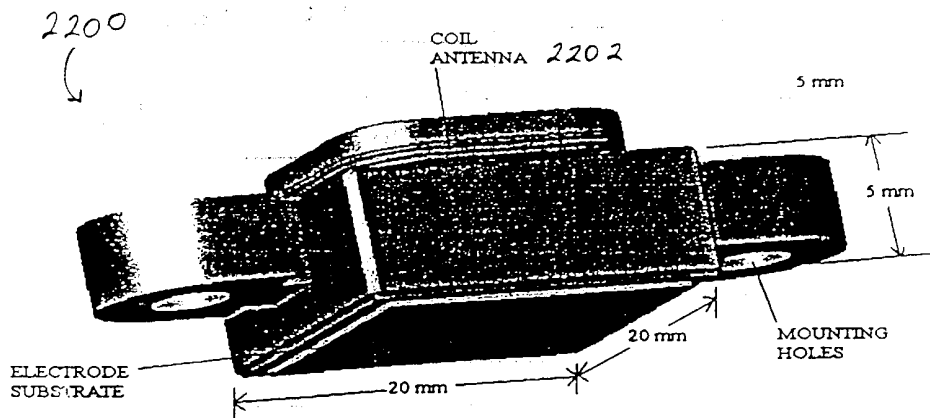


FIGURE 22

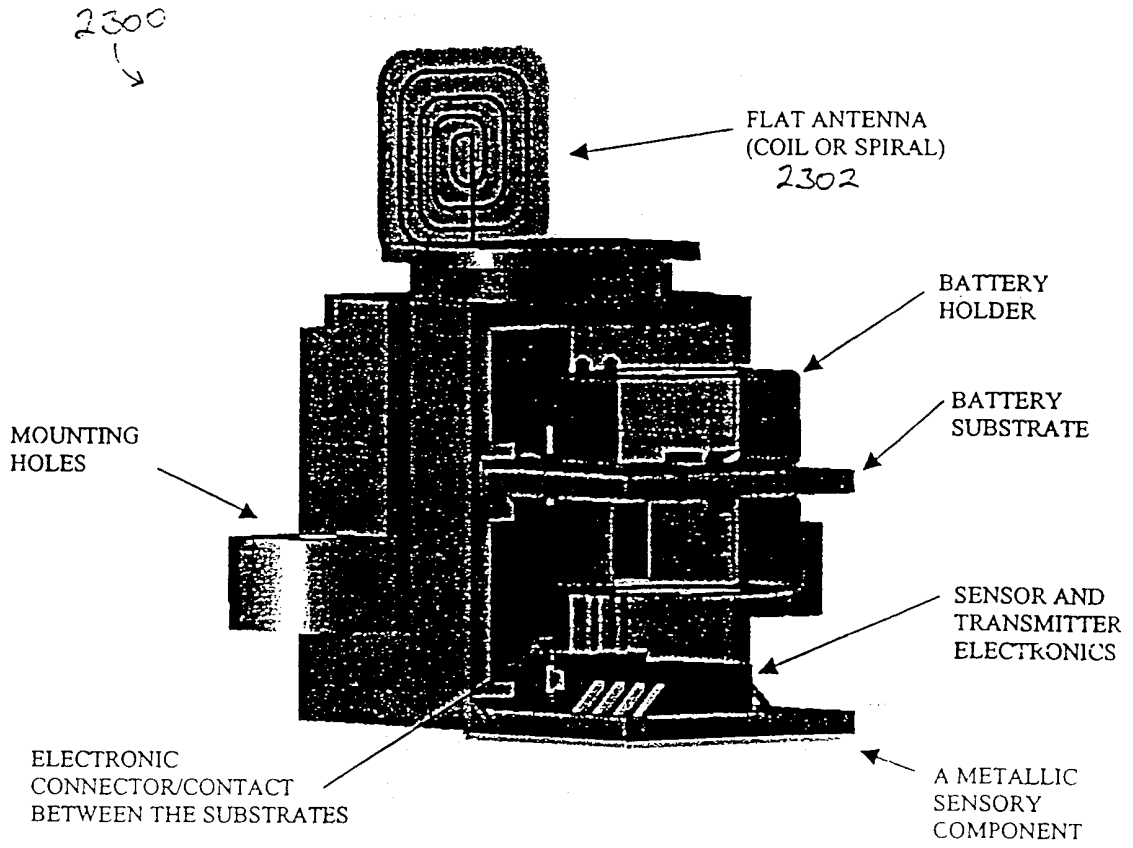


FIGURE 23

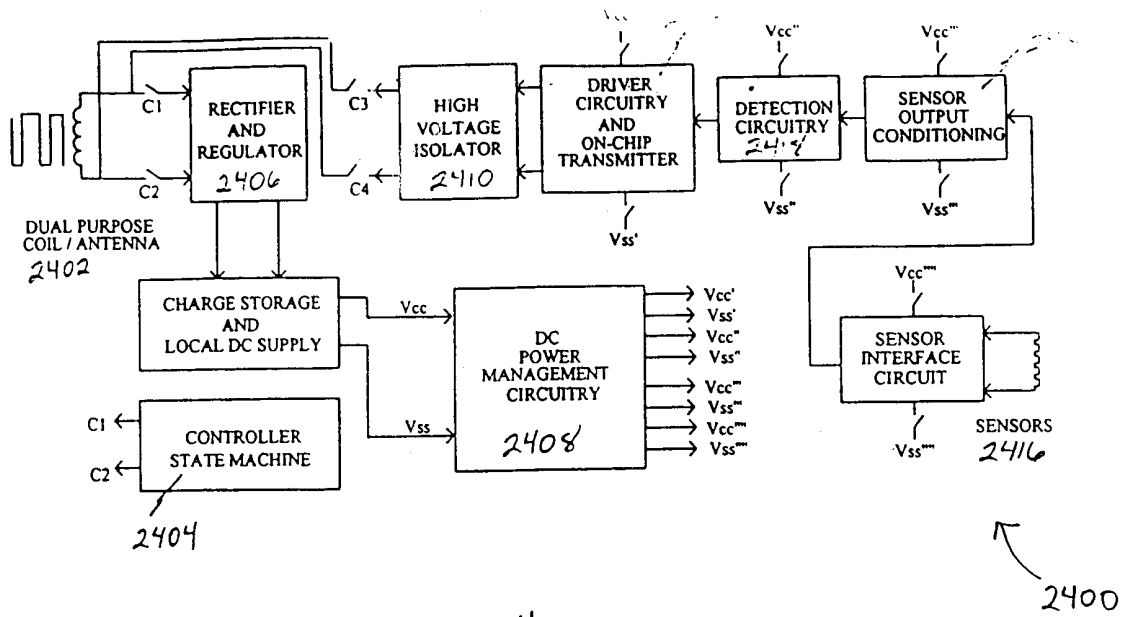


FIGURE 24

2500

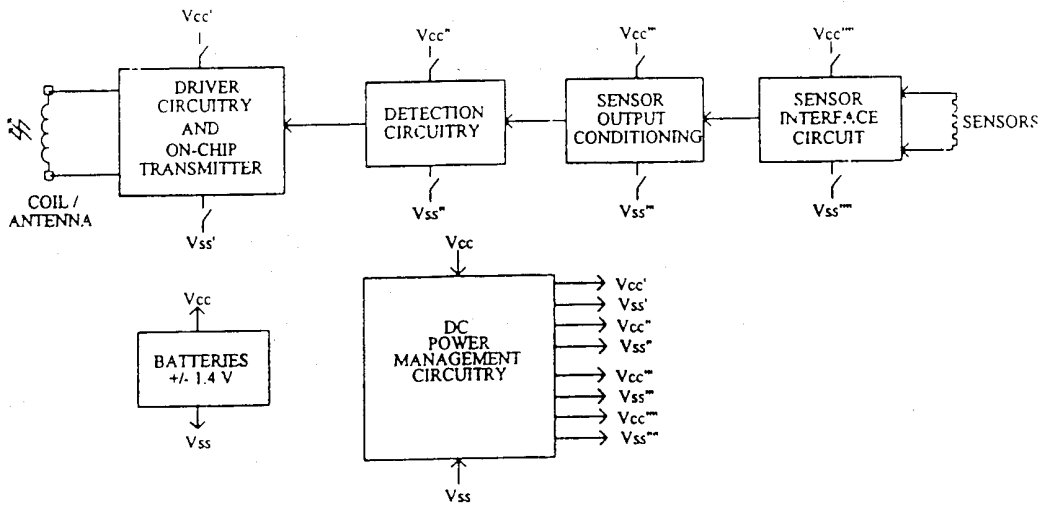


FIGURE 25



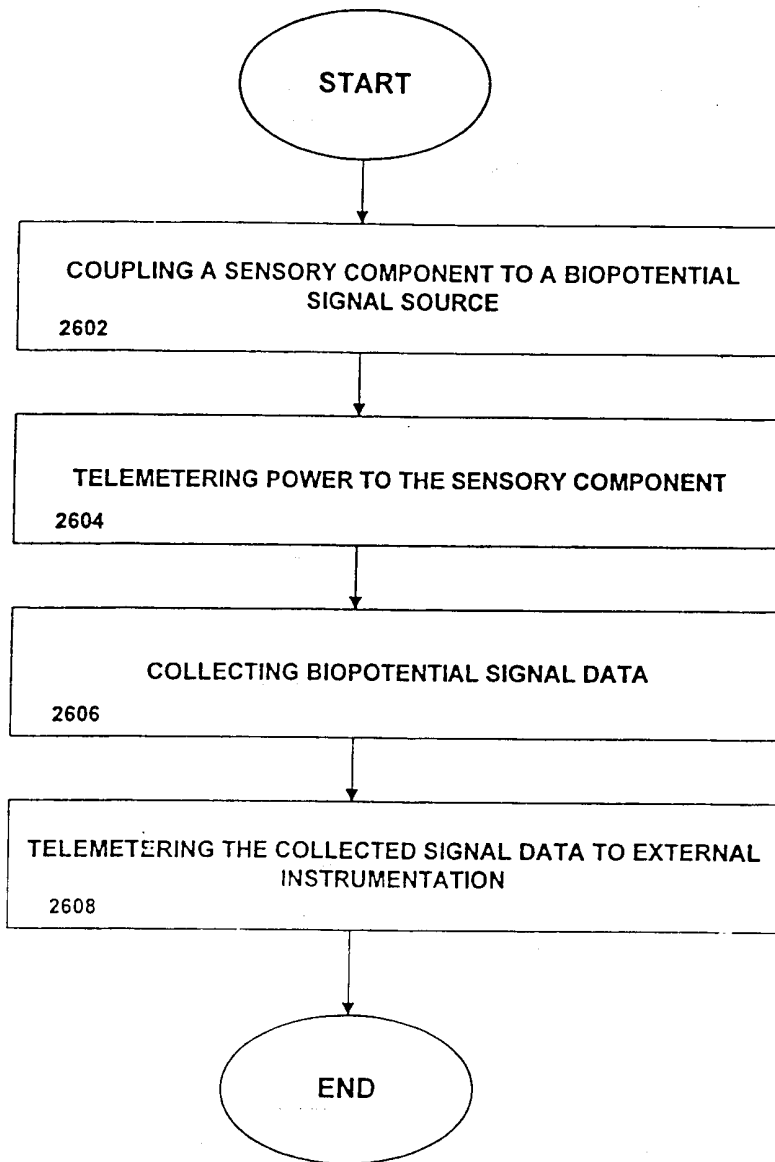


Figure 26