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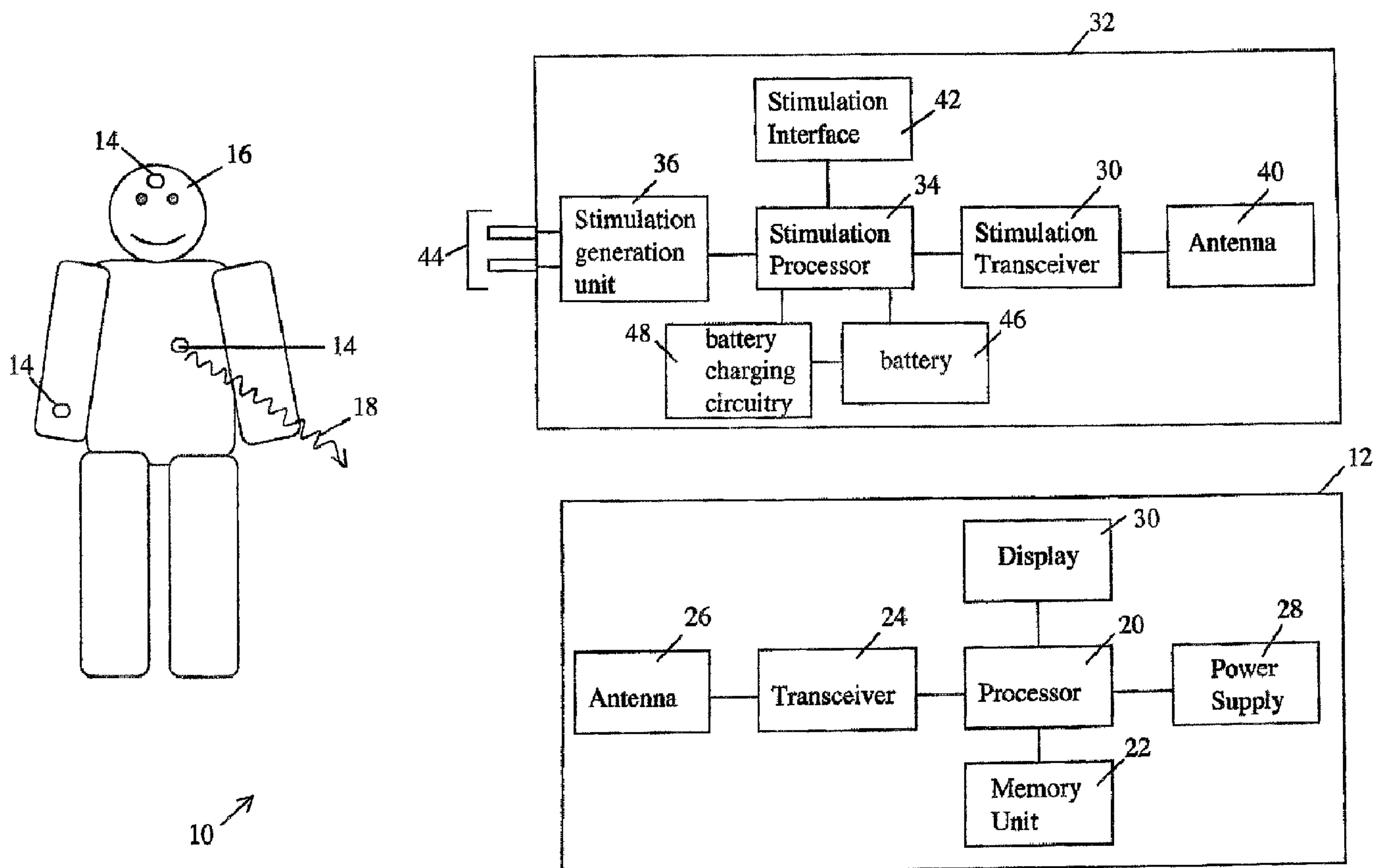
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(54) Titre : SYSTEME DE MONITORAGE PHYSIOLOGIQUE SANS FIL

(54) Title: WIRELESS PHYSIOLOGICAL MONITORING SYSTEM



(57) **Abrégé/Abstract:**

Embodiments of the invention relate to a wireless physiological monitoring system. The system includes at least one wireless sensor and a monitoring device which are linked to one another of a wireless fashion for measuring physiological signals of a patient. The at least one wireless sensor is located on the patient and may comprise a wireless surface electrode assembly or a wireless needle assembly. The system may also comprise a wireless stimulator synchronized with the wireless sensor for performing

(57) **Abrégé(suite)/Abstract(continued):**

certain diagnostic tests, such as nerve conduction velocity tests, for example. The wireless sensor preferably includes active, reference and common conductors. The common conductor can be used to measure the common mode voltage of the patient in the vicinity of the testing, and this voltage can then be subtracted from the measured active and reference voltages.

ABSTRACT OF THE DISCLOSURE

Embodiments of the invention relate to a wireless physiological monitoring system. The system includes at least one wireless sensor and a monitoring device which are linked to one another of a wireless fashion for
5 measuring physiological signals of a patient. The at least one wireless sensor is located on the patient and may comprise a wireless surface electrode assembly or a wireless needle assembly. The system may also comprise a wireless stimulator synchronized with the wireless sensor for performing certain diagnostic tests, such as nerve conduction velocity tests, for example. The
10 wireless sensor preferably includes active, reference and common conductors. The common conductor can be used to measure the common mode voltage of the patient in the vicinity of the testing, and this voltage can then be subtracted from the measured active and reference voltages.

Title: WIRELESS PHYSIOLOGICAL MONITORING SYSTEM**Field Of The Invention**

[0001] The invention relates to a wireless physiological monitoring system that can be used to measure a wide variety of physiological signals from a patient for monitoring the patient and/or diagnosing certain medical
5 conditions.

Background Of The Invention

[0002] The measurement of physiological signals from a patient for monitoring the patient and/or diagnosing a particular medical condition conventionally requires medical instrumentation to be physically attached to
10 the patient. This includes attaching electrodes to the patient at the measurement site and then transmitting the measured signals to the medical instrumentation via cables. In some cases, this can result in many cables being connected between the patient and the medical instrumentation. For instance, for multimodality intraoperative monitoring measurements, there
15 may be anywhere from 4 to 32 measurement channels, for electromyography (EMG) measurements there may be 1 to 4 measurement channels, for electrocardiogram (ECG) measurements, there may be ten measurement channels and for measuring brain potentials, there may be more than 128 channels in cases where signals are measured from the cortex.

[0003] The plurality of cables connecting the patient to the medical instrumentation provides many disadvantages. The cables are uncomfortable for the patient and limit the mobility of the patient. It is important for the patient to remain mobile so that the patient does not develop any blood clots. The cables also make it difficult to perform any tests on the patient which require
25 the patient to move. Further, in some cases, the cables may be stiff and can easily become detached from the patient especially when the patient moves.

[0004] The plurality of cables connecting the patient to the medical instrumentation are also cumbersome for the medical personnel that interact with the patient. In particular, the entire set-up can be confusing and in some
30 cases requires expertise for arranging all of the different electrodes and

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cables. Accordingly, the time required for attaching or removing the electrodes and cables to or from the patient can be quite long. This can be detrimental in situations in which speed is of the essence. In addition, the medical personnel may accidentally trip or become entangled in the cables. Further, in the
5 operating room, the cables to the patient are not accessible during surgery since the cables are in the "sterile field". This is a problem when troubleshooting faulty cables since cables in the operating room are routinely run over by people and heavy equipment and therefore subject to a high failure rate.

10 **Summary Of The Invention**

[0005] The inventors have developed a wireless physiological monitoring system that includes, at a minimum, at least one wireless sensor and a monitoring device which are linked to one another in a wireless fashion for measuring physiological signals from a patient for monitoring the patient.
15 The wireless physiological monitoring system may also be used to perform diagnostic tests on the patient. To perform certain diagnostic tests, the wireless physiological monitoring system may further include a wireless stimulator that is synchronized with the wireless sensor for performing certain diagnostic tests such as nerve conduction velocity tests, for example.

20 [0006] In one instance, the wireless sensor may be a wireless surface electrode assembly. In another instance, the wireless sensor may be a wireless needle assembly. In both cases, the sensors preferably include electrical leads for obtaining active, reference and common voltage measurements. This results in better signal quality for the measured
25 physiological signals since the common mode voltage can be measured and removed from both the measured active and reference voltages. The wireless needle assembly is also advantageous in that it requires no external surface electrodes to operate.

[0007] For both the wireless surface electrode assembly and the
30 wireless needle assembly, the sensors include a releasably attachable wireless adapter that provides a wireless connection between the sensor and

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the monitoring device, and a measurement module, for measuring physiological signals from the patient. The measurement module is disposable and the wireless adapter may be reused with another measurement module to form another wireless sensor.

5 **[0008]** In one instance, the wireless adapter may communicate according to the Bluetooth communication protocol.

[0009] Further, in one embodiment, the wireless adapter includes a processor and a pre-processing stage for processing the measured physiological signals prior to transmitting corresponding wireless signals to
10 the monitoring device. The wireless adapter may also include a memory unit for storing the raw measured or processed physiological signals.

[0010] The wireless physiological monitoring system of the invention advantageously allows for faster application and removal of the sensors to a patient since there are no cables that need to be attached. When the wireless
15 needle assembly is used as the wireless sensor, the medical practitioner simply places the needle assembly into the recording site and receives high quality signals through the wireless connection without the need to prepare and "wire-up" the patient. The wireless physiological monitoring system provides better signal quality for the measured physiological signals since
20 there are no cables which can pick up electromagnetic interference; this is a common problem with conventional equipment. There is also no leakage current once the measured physiological signals have been converted to wireless signals. Furthermore, since all of the components of the wireless physiological monitoring system are totally wireless, the mobility of the patient
25 is not compromised.

[0011] In a first aspect, the invention provides a wireless physiological monitoring system for measuring physiological signals from a patient. The system comprises a monitoring device having a first transceiver; at least one wireless sensor disposed on a measurement site on the patient for measuring
30 a physiological signal, the at least one wireless sensor having a second transceiver for transmitting a corresponding wireless physiological signal to

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the first transceiver; and, at least one wireless stimulator having a third transceiver, the at least one wireless stimulator being adapted to provide a stimulation current to the patient in response to at least one of a command signal transmitted by the first transceiver of the monitoring device and manual
5 actuation.

[0012] In one embodiment, the at least one wireless sensor includes a wireless adapter having the second transceiver; and, a measurement module having an active conductor and a reference conductor for receiving voltages used to produce a differential voltage measurement indicative of the
10 physiological signal, the measurement module further including a common conductor for receiving another voltage for removing common mode voltage from the differential measurement. The second transceiver transmits the differential measurement as the wireless physiological signal.

[0013] In another embodiment, a wireless surface electrode assembly
15 is used for the at least one wireless sensor. The measurement module of the wireless electrode assembly comprises: a base having an electrical interface connected to the active, reference and common conductors, the base having a shape complementary to that of the wireless adapter for releasable attachment to the wireless adapter; an active electrode for placement on the
20 patient, the active electrode being connected to the active conductor; a reference electrode for placement on the patient, the reference electrode being connected to the reference conductor; and, a common electrode for placement on the patient, the common electrode being connected to the common conductor.

25 **[0014]** The active and reference electrodes are located approximately equidistantly from the common electrode.

[0015] In another embodiment, a wireless needle assembly is used for the at least one wireless sensor. The measurement module of the wireless
30 needle assembly comprises: a base having an electrical interface connected to the active, reference and common conductors, the base having a shape complementary to that of the wireless adapter for releasable attachment to the

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wireless adapter; and, a shaft which houses the active, reference and common conductors, wherein a first conductor is disposed centrally along the longitudinal axis of the shaft, a second conductor is disposed concentrically about the first conductor, a first insulator is disposed in between the first and
5 second conductors, a third conductor is disposed concentrically about the second conductor, and a second insulator is disposed in between the second and third conductors.

[0016] In a second aspect, the invention provides a wireless physiological monitoring system for measuring physiological signals from a
10 patient. The system comprises a monitoring device having a first transceiver; and, at least one wireless sensor disposed on a measurement site on the patient for measuring a physiological signal. The at least one wireless sensor includes a wireless adapter having a second transceiver; and, a measurement
15 module having an active conductor and a reference conductor for receiving voltages used to produce a differential voltage measurement indicative of the physiological signal, the measurement module further including a common conductor for receiving another voltage for removing common mode voltage from the differential measurement. The second transceiver transmits a
20 wireless physiological signal corresponding to the differential voltage measurement to the first transceiver of the monitoring device.

[0017] In one embodiment, the system further comprises at least one wireless stimulator having a third transceiver, the at least one wireless stimulator being adapted to provide a stimulation current to the patient in response to at least one of a command signal transmitted by the first
25 transceiver of the monitoring device and manual actuation.

[0018] In a third aspect, the invention provides a wireless sensor for measuring a physiological signal from a patient, the wireless sensor being disposed on a measurement site on the patient. The wireless sensor comprises: a wireless adapter having a transceiver; and, a measurement
30 module having an active conductor and a reference conductor for receiving voltages used to produce a differential voltage measurement indicative of the

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physiological signal, the measurement module further including a common conductor for receiving another voltage for removing common mode voltage from the differential measurement. The transceiver transmits a wireless physiological signal corresponding to the differential voltage measurement.

5 **Brief Description Of The Drawings**

[0019] For a better understanding of the invention and to show more clearly how it may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings which show exemplary embodiments of the invention and in which:

10 Figure 1 shows an exemplary embodiment of a wireless physiological monitoring system in accordance with the invention;

Figure 2a shows a top view of an exemplary embodiment of a wireless surface electrode assembly for use as a wireless sensor in the system of Figure 1 in accordance with the invention;

15 Figures 2b shows an exploded side view of an exemplary embodiment of a wireless surface electrode assembly for use as a wireless sensor in the system of Figure 1 in accordance with the invention;

Figure 3a shows an exploded side view of an exemplary embodiment of a wireless needle assembly for use as a wireless sensor in the
20 system of Figure 1 in accordance with the invention;

Figure 3b shows a magnified view of an exemplary embodiment of the tip of the wireless needle assembly of Figure 3a; and,

Figure 4 shows an exemplary embodiment of a wireless adapter for use with either the wireless surface electrode assembly of Figures 2a and
25 2b or the wireless needle assembly of Figures 3a and 3b.

Detailed Description Of The Embodiments Of The Invention

[0020] It will be appreciated that for simplicity and clarity of illustration, elements shown in the figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements may be exaggerated

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relative to other elements for clarity. Further, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous elements. In addition, numerous specific details are set forth in order to provide a thorough understanding of the invention.

5 However, it will be understood by those of ordinary skill in the art that the invention may be practiced without these specific details. In other instances, well-known methods, procedures and components have not been described in detail so as not to obscure the invention.

[0021] Referring first to Figure 1, shown therein is an exemplary
10 embodiment of a wireless physiological monitoring system **10**. The wireless physiological monitoring system **10** comprises a monitoring device **12** and at least one wireless sensor **14**. Typically there are a plurality of wireless sensors **14**, three of which are shown for exemplary purposes. The wireless sensors **14** are attached to a patient **16** and each measures a desired
15 physiological signal from the patient **16**. Examples of physiological signals include an electroencephalographic (EEG) signal, an electrooculographic (EOG) signal, an electromyographic (EMG) signal or an electrocardiographic (ECG) signal. The measured physiological signal may be pre-processed by the wireless sensor **14**. The wireless sensors **14** then transmit corresponding
20 wireless physiological signals **18** to the monitoring device **12**. The transmission frequency may be in the Wireless Medical Telemetry Services (WMTS) band or the Industry Scientific and Medical (ISM) band or any other band approved for this activity. The WMTS band includes frequency ranges of 608 to 614 MHz, 1395 to 1400 MHz and 1429 to 1432 MHz. The ISM band
25 includes the frequency range of 2.4 to 2.4835 GHz. The structure of the wireless sensor **14** is discussed in more detail below.

[0022] The monitoring device **12** may perform a number of functions on the wireless physiological signals **18**. For instance, the monitoring device **12** may simply store the wireless physiological signals **18** for later downloading to
30 a computing device which processes the wireless physiological signals **18**. In this case, the monitoring device **12** may simply be a storage device.

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Alternatively, the monitoring device **12** may itself process the wireless physiological signals **18** as well as possibly display the wireless physiological signals **18** of the processed version. Accordingly, the monitoring device **12** may be a suitable computing device such as a laptop computer, a personal
5 computer (PC) or an application specific hardware device.

[0023] In one exemplary embodiment, the monitoring device **12** comprises a processor **20**, a memory unit **22**, a transceiver **24** with an antenna **26**, a power supply **28** and a display **30** connected as shown in Figure 1. The processor **20** controls the operation of the monitoring device **12**
10 and initiates monitoring and/or diagnostic tests on the patient **16** via the wireless sensors **14**. In particular, the processor **20** sends commands via the transceiver **24** to the wireless sensors **14** to initiate monitoring or diagnostic tests and also to synchronize with the wireless sensors **14**. The processor **20** may be any suitable processing element, such as a PC central processing
15 unit (CPU) chip, and in some instances may be a digital signal processor (DSP). The transceiver **24** operates according to a suitable wireless communication protocol. In one instance, the communication protocol may be the Bluetooth communication protocol as discussed in more detail below.

[0024] The processor **20** receives the wireless physiological signals **18**
20 and stores the wireless physiological signals **18** in the memory unit **22**. The memory unit **22** may be any suitable memory device such as a hard drive or flash memory or the like. The wireless physiological signals **18** can then be downloaded, via the transceiver **24**, or another suitable communications device (not shown), to another computing device for processing. Alternatively,
25 prior to storage or after storage, the processor **20** may then process the wireless physiological signals **18** according to a processing algorithm that is suitable for the type of monitoring or diagnostic test that is being performed. For instance, noise reduction algorithms may be applied to the signals **18** to improve the signal to noise ratio. In addition, pattern recognition or other
30 detection algorithms may be applied to the signals **18** to detect certain events in the signals **18**. These noise reduction and pattern recognition algorithms

are commonly known to those skilled in the art and will not be discussed further.

[0025] The processor **20** may display the wireless physiological signals **18** or the processed version of the signals **18** on the display unit **30**. The display **30** may be a monitor, an LCD, and the like. The power supply **28** provides power to the various components of the monitoring device **12**. The power supply **28** may be a rechargeable battery or may be a computer power supply unit that is connected to mains power.

[0026] The wireless physiological monitoring system **10** may further comprise at least one wireless stimulator **32** for performing certain diagnostic tests on the patient **16** such as nerve conduction velocity tests. In particular, the wireless stimulator **32** is used to generate a stimulation current to create an action potential in a nerve of the patient **16**.

[0027] The wireless stimulator **32** includes a stimulation processor **34**, a stimulation generation unit **36**, a stimulation transceiver **38** with an antenna **40**, a stimulation interface **42**, two prongs **44** and a battery **46** connected as shown in Figure 1. The wireless stimulator **32** may optionally include battery charging circuitry **48**. The stimulation processor **34** controls the operation of the wireless stimulator **32** and may be a DSP or a microcontroller. The stimulation processor **34** instructs the stimulation generation unit **36** to generate a stimulation current when the stimulation transceiver **38** receives an appropriate command signal from the monitoring device **12** or when it is manually actuated.

[0028] The stimulation generation unit **36** includes circuitry to create the stimulation current having different characteristics depending on the part of the patient **16** to which the stimulation current is being applied. In general, the stimulation current is preferably a controlled constant amplitude current and may include a single pulse or multiple pulses where each pulse may be monophasic or biphasic. For example, when the stimulation current is applied to the hand of the patient **16**, the amplitude may be up to 100 milliamps, the duration of up to 1 millisecond and the maximum voltage is limited to 400

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volts. However, when the wireless stimulator **32** is applied to the head of the patient **16**, it is used to generate motor-evoked potentials and requires higher amplitude voltages and current. In such an instance, the maximum voltage amplitude is limited to 1000 V, the maximum current amplitude is limited to 1.5
5 A and the maximum pulse duration is less than 1 ms.

[0029] The stimulation interface **42** allows a medical practitioner to control the wireless stimulator **32**. In one embodiment, the stimulation interface **42** includes a button, a dial and a small display (all not shown). The button may be manually actuated to start and stop the stimulation current, and
10 the dial may be used to change the intensity of the stimulation current. The display shows the intensity of the stimulation current and the remaining charge on the battery. Alternatively, as previously mentioned, the wireless stimulator **32** may be controlled from the monitoring device **12** over the wireless link. In both cases, the same level of synchronization is needed
15 between the wireless stimulator **32** and the corresponding wireless sensors **14** that are used to measure the response to the stimulation current.

[0030] During a diagnostic test, the two prongs **44** of the wireless stimulator **32** are applied to a test site on the skin of the patient **16** to stimulate the desired nerve. One of the prongs is a cathode terminal and the other
20 prong is an anode terminal. The wireless stimulator **32** also has touch-proof adapter connections (not shown) to stimulate through smaller external electrodes or needles for cases in which the prongs **44** are not appropriate.

[0031] The wireless stimulator **32** is powered by the battery **46**. In one embodiment, the battery **46** is a rechargeable battery. Accordingly, when the
25 wireless stimulator **32** is not in use, the wireless stimulator **32** is placed in a charging stand (not shown) for recharging the battery **46**. In this case, the stimulation processor **34** engages the battery charging circuitry **48** to recharge the battery **46**.

[0032] There are some diagnostic tests in which it is beneficial to have
30 two wireless stimulators. One example of such a diagnostic test is a collision study. One of the wireless stimulators is used to generate multiple action

potentials resulting in a muscle or nerve response from the patient **16** and the other wireless stimulator is used to generate a second action potential in a different nerve that cancels out an undesirable response detected at the recording site. For this diagnostic test, the timing between the delivery of the stimulation currents provided by the two wireless stimulators must be controlled to an accuracy of a few hundred microseconds.

[0033] Referring now to Figures 2a and 2b, shown therein is an exemplary wireless surface electrode assembly **50** for use as at least one of the wireless sensors **14** in the wireless physiological monitoring system **10**. The wireless surface electrode assembly **50** includes a measurement module **52** and a wireless adapter **54**. The measurement module **52** includes three conductive electrodes: an active electrode **56**, a reference electrode **58** and a common electrode **60**. The three electrodes **56**, **58** and **60** are used so that a differential measurement is made for the desired physiological signal and so that the common mode of the differential measurement can be removed. The common electrode **60** is preferably equidistant to both the active and reference electrodes **56** and **58** so that the voltage measured by the common electrode **60** is common to both the active and reference electrodes **56** and **58**. The signal provided by the common electrode **60** also allows for removing muscle artifacts from the physiological signals measured by the active and reference electrodes **56** and **58**. The electrodes can be made of any biocompatible conductive material with suitable mechanical properties, such as silver-silver chloride, gold, silver, tin, platinum or alloys thereof, or carbon.

[0034] Each of the electrodes **56**, **58** and **60** are wired to a base **62** of the measurement module **52** and are electrically insulated from one another. The base may be made of any biocompatible material with suitable mechanical properties, such as Nylon, Teflon or PVC. The base **62** further includes three electrical contacts (not shown) on a top portion thereof that interface with corresponding electrical contacts (not shown) on the bottom of the wireless adapter **54**. The wireless adapter **54** includes components for transmitting the wireless physiological signal **18** that corresponds to the

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physiological signal measured by the electrode assembly **50** to the monitoring device **12**. An exemplary implementation of the wireless adapter **54** is described below.

[0035] The wireless adapter **54** has a shape that is complementary to that of the measurement module **52** so that the wireless adapter **54** makes a snap-fit or friction-fit connection with the measurement module **52**. The connection is also such that the wireless adapter **54** is releasably attachable to the measurement module **52**. Accordingly, the wireless adapter **54** can be attached to a measurement module **52**, used for physiological monitoring or diagnostic testing on the patient **16**, and then detached from the measurement module **52** once monitoring/testing is completed so that the wireless adapter **54** can be reused and the measurement module **52** can be discarded.

[0036] The wireless surface electrode assembly **50** further includes an adhesive portion preferably applied to a section of each of the electrodes **56**, **58** and **60** to hold the wireless surface electrode assembly **50** in place once the assembly **50** has been attached to the patient **16**. Alternatively, or in addition, a piece of tape, or other adhesive means, may be applied to the electrodes **56**, **58** and **60** of the wireless surface electrode assembly **50** to hold it in place. The electrodes may also be glued on with a suitable glue such as collodion. Alternatively, the wireless surface electrode assembly **50** may be built into gloves that are worn and held in place by a medical practitioner that is obtaining physiological signals from the patient **16**.

[0037] Referring now to Figures 3a and 3b, shown therein are an exploded side view, and a magnified view of the tip, respectively, of an exemplary embodiment of a wireless needle assembly **70**, for use as at least one of the wireless sensors **14** in the wireless physiological monitoring system **10**.

[0038] The wireless needle assembly **70** includes a measurement module **72** and the wireless adapter **54**. The measurement module **72** includes a shaft with a needle tip **74** disposed at the end; the shaft and needle

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tip having three concentric conductors: an active conductor **76**, a reference conductor **78** and a common conductor **80**. The active and reference conductors **76** and **78** are separated by an insulator **82**. The reference and common conductors **78** and **80** are separated by an insulator **84**. The three
5 conductors **76**, **78** and **80** are used, in a similar manner to wireless sensor **50**, so that a differential measurement may be made for the desired physiological signal and so that the common mode component of the differential measurement may be removed.

[0039] The common conductor **80** is advantageously in close proximity
10 to both of the active conductor **76** and the reference conductor **78** so that it provides a close approximation to the common mode voltage of the active and reference conductors **76** and **78**. It should be noted that the location of the reference, common and active conductors **76**, **78** and **80** are interchangeable. For instance, the center conductor **76** may instead be the common conductor
15 and the outer electrode **80** may be the active conductor. However, it is preferable for the active and reference conductors **76** and **78** to remain close to one another to eliminate any far field effects in the measured voltages. Accordingly, the common conductor **80** is preferably the outer conductor.

[0040] Each of the conductors **76**, **78** and **80** are wired to a base **86** of
20 the measurement module **72**. The base **86** further includes three electrical contacts on a top portion thereof that interface with corresponding electrical contacts on the bottom of the wireless adapter **54**. Similar to the wireless surface electrode assembly **50**, the wireless adapter **54** has a shape that is complementary to that of the measurement module **72** so that the wireless
25 adapter **54** is releasably attachable to the measurement module **72**. Accordingly, the wireless adapter **52** is reusable and the measurement module **72** is disposable. The entire wireless needle assembly **70** is small enough to facilitate clinical use. Further, the tip **74** of the wireless needle assembly **70** may come in different lengths and diameters to facilitate
30 measurement at muscles or nerves of different sizes and depths.

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[0041] In use, the wireless needle assembly **70** is inserted into a desired measurement site on the patient. To hold the wireless needle assembly **70** in place, a piece of tape, or other adhesive means, may be applied to the wireless needle assembly **70**. The wireless needle assembly **70** may also be held in place by the hand of the medical practitioner who is measuring physiological signals from the patient **16**. Alternatively, the wireless needle assembly **70** may not need any tape or adhesive if it is inserted to an adequate depth. In another alternative, the tip of the wireless needle assembly **70** may have a hook or corkscrew shape to hold it in place.

[0042] It should also be noted that the wireless adapter **54** may be used with other needles having a different number of conductors. For instance, the wireless adapter **54** may be combined with a measurement module that has a standard monopolar conductor configuration or with a measurement module that has a standard bipolar conductor configuration. In these cases, if a differential voltage measurement is to be made while removing common-mode voltage, extra surface electrodes can be attached to the measurement module. For instance, in the case of a needle measurement module having a standard monopolar (single active electrode) conductor configuration, a common surface electrode and a reference surface electrode may be added. In the case of a needle measurement module having a standard bipolar conductor configuration (having active and reference electrodes), only a common surface electrode need be added.

[0043] Referring now to Figure 4, shown therein is an exemplary embodiment of the wireless adapter **54** for use with either the wireless surface electrode assembly **50** or the wireless needle assembly **70**. The wireless adapter **54** includes a processing unit **90**, a signal interface **92**, a pre-processing stage **94**, an analog-to-digital converter (ADC) **96**, a memory unit **98**, a battery **100**, a transceiver **102** and an antenna **104** connected as shown in Figure 4. The processing unit **90** controls the operation of the wireless adapter **54** and may be a DSP or the like.

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[0044] The electrical interface **92** provides an electrical connection to the active, common and reference leads of the measurement modules **52** or **72** to receive measurement signals **106**. The measurement signals **106** are then processed by the pre-processing stage **94** which includes a filtering stage followed by an amplification stage (both not shown). The filtering stage includes high pass filters (i.e. one for each of the active and reference measurement signals) to remove the contact potential component from the measurement signals **106** and provide filtered signals. It may also have a sine wave generator used for measuring impedance of the electrodes. The cutoff-frequency of the high pass filters is approximately 0.1 Hz to 20 Hz.

[0045] The amplification stage includes a differential amplifier for amplifying the filtered signals thereby providing pre-processed physiological signal **108**. The gain factor of the amplifiers is selected so that the pre-processed physiological signal **108** does not saturate the input stage of the ADC **96**. This depends on the type of physiological signals that are measured by the corresponding measurement module **52** or **72** (i.e. since different physiological signals have different amplitudes). The particular type of physiological signal that is being measured may be transmitted by the monitoring device **12** to the wireless adapter **54** so that the processing unit **90** can vary the gain of the amplification stage in the pre-processing stage **94**.

[0046] The ADC **96** digitizes the pre-processed physiological signal **108** to provide a digitized physiological signal **110**. The processing unit **90** sends the digitized physiological signal **110** to the transceiver **102** for transmitting the corresponding physiological wireless signal **18** via the antenna **104**. The wireless physiological signal **18** may be transmitted at different rates depending on the type of physiological measurement that is made.

[0047] Prior to sending the digitized physiological signals **110** to the transceiver **102**, the processing unit **90** may store the digitized physiological signals **110** in the memory unit **98**. In an alternative, the digitized signals **110** may not be transmitted and may instead simply be stored in the memory unit **98** for downloading at a later time.

[0048] In another alternative, the processing unit **90** may perform further processing on the digitized physiological signals **110** according to the type of physiological signal that is being recorded so that the transceiver **102** sends processed data that corresponds to the measured physiological signal rather than the actual measured physiological signals. The processed data may be readily displayed on the display **30** of the monitoring device **12**. In another alternative, the processing unit **90** may perform further processing on the digitized physiological signal **110** according to the type of physiological signal that is being recorded so that the transceiver **102** sends averaged data collected over multiple stimulation sweeps.

[0049] The battery **100** of the wireless adapter **54** is a low voltage battery and the other components of the wireless adapter **54** are also adapted for low voltage operation. This reduces the possibility of electrical shock to the patient **16**. In addition, this ensures that the battery **100** can operate for a long time before requiring replacement. In an alternative, the battery **100** may be rechargeable and the wireless adapter **54** may have an interface (not shown) to the battery **100** so that the battery **100** can be plugged into a battery charger and recharged.

[0050] Any suitable wireless communication protocol may be used for the monitoring device **12**, the wireless sensor **14** and the wireless stimulator **32**. In one embodiment, the Bluetooth standard is used as the wireless communication protocol. The Bluetooth standard provides a universal radio interface in the 2.4 GHz frequency band that enables low power electronic devices to wirelessly communicate with each other. In accordance with the Bluetooth standard, the monitoring device **12**, the wireless sensors **14** and the wireless stimulator **32** behave as nodes grouped in an ad-hoc network referred to as a piconet. The monitoring device **12** behaves as a master node and the wireless sensors **14** and the wireless stimulator **32** behave as slave nodes. The monitoring device **12** and each of the wireless sensors **14** and the wireless stimulator **32** is provided with a unique address so that the wireless

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physiological signals 18 from various wireless sensors 14 can be distinguished from one another.

[0051] Each node in the Bluetooth network has an internal "native" clock that determines the timing of the corresponding transceiver. The communication channel between the master nodes and the slave nodes is defined by a frequency hopping sequence derived from the address of the master node. The master node provides its native clock as a time slot reference. Each time slot supports full-duplex communication initiated by the master node: during the first part of the time slot the master node polls a slave node and during the second part of the time slot the corresponding slave node responds.

[0052] During operation, the wireless sensors 14 are instructed by the monitoring device 12 to start and stop data transmission so that power and bandwidth is not wasted. Accordingly, the wireless sensors 14 are usually in a "listening mode" to wait for commands from the monitoring device 12. In particular, when the wireless adapter 54 is attached to one of the measurement modules 50 or 70, the wireless adapter 54 turns on, joins the piconet, identifies itself to monitoring device 12 and listens for commands. The wireless adapter 54 turns off when it is disconnected from the measurement module 50 or 70.

[0053] Some of the physiological monitoring and diagnostic tests performed by the physiological wireless monitoring system 10 require stringent timing requirements for the wireless sensors 14 and/or the wireless stimulator 32. One example is nerve conduction diagnostic tests and evoked potential monitoring in which synchronization is preferably done to within approximately +/- 50 microseconds.

[0054] With the Bluetooth communication standard, the modulation rate of the master node is approximately 1 Mbit/sec which allows for synchronization down to 1 microsecond. This synchronization can be accomplished by adding extra hardware counting circuitry to the slave nodes, or by using the processors of the slave nodes, to keep track of the modulation

rate of the master node. Each slave node will count at the same rate, but will have different zero points based on the time at which they started counting.

[0055] The method of aligning the respective zero points is to have the slave node transmit a timing message to the master node and have the master node immediately respond. The slave node then measures the number of counts of the master modulation rate taken for the round trip and divides by two to get the transit time. This is done many times, 50 times for example, to get an average transit time and the average clock offset (this is more accurate than individual measurements). The slave node then adjusts its native clock based on the average clock offset less the transit time to achieve the stated accuracy. This synchronization procedure is done each time a connection is established between a slave node and the master node.

[0056] An example of a diagnostic test that can be performed with the wireless physiological monitoring system **10** is the Palmar nerve response, in which the prongs **44** of the wireless stimulator **32** are placed in contact with the skin above the desired nerve to inject a stimulation current. One of the wireless sensors **14** is placed on a finger in close proximity to the desired nerve to measure the resulting action potential of the desired nerve. The Palmar nerve response usually occurs in about 1 millisecond. Measuring the latency of this response involves finding the take-off point or peak amplitude of the action potential. An error of 50 microseconds in synchronization results in a 5% error in the response, which is at the limit of what is diagnostically acceptable.

[0057] Some other examples of diagnostic tests and physiological monitoring that can be done with the wireless physiological monitoring system **10** include the blink reflex and recording somatosensory evoked potentials. These tests are demanding in that multiple action potentials are averaged together. This is done since the amplitude of the response is similar to the noise level in the measured signal, which is typically about 1 microvolt. Any errors in timing between stimulus delivery and data acquisition results in a flattened peak in the averaged response making it difficult to determine the

latency of the response. If the synchronization errors exceed 50 microseconds then the quality of the responses is considered to be poor. Another example of physiological monitoring is the ECG which is typically recorded at a sampling rate of 200 Hz and requires 5 milliseconds of synchronization
5 accuracy.

[0058] Bandwidth may be a factor in some of the monitoring/diagnostic tests that require multiple recording electrodes, such as multimodality monitoring during surgery in which somatosensory evoked potentials, motor evoked potentials, brainstem auditory evoked responses (BAERs), EMG and
10 EEG are simultaneously recorded using up to 16 data channels that each acquire data at a sampling rate of 60 KHz or higher. Actually EEG and ECG signals require a sampling rate of 200 Hz, BAERs require a sampling rate of 60 kHz while most other evoked potentials require a sampling rate of 20 kHz. In addition, 16 bits are preferably used per sample. This results in a maximum
15 possible data rate of approximately 15 Mbits/sec, which exceeds the capability of the Bluetooth standard, but is still within the range of 802.11g wireless communication standards.

[0059] Unfortunately, the power consumption of devices that operate under the 802.11g wireless standard is 3 times higher than devices that
20 operate under the Bluetooth communication standard. This may be overcome by recording at a high speed triggered by the stimulus and storing the recorded and optionally processed physiological signals in the memory unit 98 of the wireless sensors 14 and then transmitting the recorded physiological signals from the wireless sensors 14 to the monitoring device 12 at lower
25 speeds after the physiological response has occurred. This technique is applicable whenever continuous monitoring of the unprocessed waveform data is not required, such as for channels related to evoked potentials where only the averaged signals over multiple recording sweeps need be transmitted.

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[0060] However, this technique does not work for channels related to EMG data which require continuous data transmission, but the EMG data can be sampled at lower frequencies.

[0061] It should further be noted that by storing and transmitting the data periodically, the transceiver **102** of the wireless adapter **54** can be turned off when not being used thereby saving power and extending the life of the battery **100**. In addition, to save power consumption, data bandwidth can be reduced by employing at least one of decimation, averaging and compression. However, the power consumption due to the added processing must be smaller than the savings in power consumption due to transmitting a reduced amount of data.

[0062] The wireless physiological monitoring system of the invention is particularly well suited for wireless monitoring of ECG, EMG and EEG monitoring and can be used clinically, intra-operatively and in an Intensive Care Unit (ICU). In use, the wireless sensors **14** may be color-coded and/or numbered according to the corresponding placement location on the patient **16**. Accordingly, a medical practitioner simply needs to refer only to the color-coding and/or numbering when attaching the wireless sensors **14** to the patient **16**.

[0063] In order to conduct auditory or visual evoked potential testing, the wireless physiological monitoring system **10** may further include at least one of a wireless auditory stimulator and a wireless visual stimulator (both not shown). The wireless auditory stimulator may be a set of wireless headphones or at least one wireless insert earphone that may be used to present an auditory stimulus to the patient **16**. The auditory stimulus may be a steady state waveform such as a tone, or a transient waveform such as a click, or some form of noise or a combination thereof in which the waveforms have a selectable phase, frequency and intensity. The wireless visual stimulator may be a set of goggles with a wireless link. The goggles may be used to provide steady state or transient visual stimuli such as a flash of light to at least one eye of the patient **16**. In both the auditory and visual cases, the

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wireless sensors **14** are placed at the appropriate location on the patient **16** to record the resulting evoked potential.

[0064] It should be understood that various modifications can be made to the embodiments described and illustrated herein, without departing from
5 the invention.

CLAIMS:

1. A wireless physiological monitoring system for measuring physiological signals from a patient, comprising:

a monitoring device having a first transceiver;

5 at least one wireless sensor disposed on a measurement site on the patient for measuring a physiological signal, the at least one wireless sensor having a second transceiver for transmitting a corresponding wireless physiological signal to the first transceiver; and

10 at least one wireless stimulator having a third transceiver, the at least one wireless stimulator being adapted to provide a stimulation current to the patient in response to at least one of a command signal transmitted by the first transceiver of the monitoring device and manual actuation.

2. The system of claim 1, wherein the at least one wireless sensor includes a wireless adapter comprising:

15 the second transceiver; and

a measurement module having an active conductor and a reference conductor for receiving voltages used to produce a differential voltage measurement indicative of the physiological signal, the measurement module further including a common conductor for receiving another voltage for removing common mode voltage from the differential
20 measurement.

3. The system of claim 2, wherein the second transceiver transmits the differential measurement as the wireless physiological signal.

4. The system of claim 3, wherein the at least one wireless sensor comprises a wireless surface electrode assembly comprising the measurement module.

25 5. The system of claim 4, wherein the measurement module of the wireless electrode assembly comprises:

a base having an electrical interface connected to the active, reference and common conductors, the base having a shape complementary to that of the wireless adapter for releasable attachment to the wireless adapter;

5 an active electrode for placement on the patient, the active electrode being connected to the active conductor;

a reference electrode for placement on the patient, the reference electrode being connected to the reference conductor; and

a common electrode for placement on the patient, the common electrode being connected to the common conductor.

10 6. The system of claim 5, wherein the active and reference electrodes are located approximately equidistantly from the common electrode.

7. The system of claim 3, wherein the at least one wireless sensor comprises a wireless needle assembly comprising the measurement module.

15 8. The system of claim 7, wherein the measurement module of the wireless needle assembly comprises:

a base having an electrical interface connected to the active, reference and common conductors, the base having a shape complementary to that of the wireless adapter for releasable attachment to the wireless adapter; and

20 a shaft which houses the active, reference and common conductors, wherein a first conductor is disposed centrally along the longitudinal axis of the shaft, a second conductor is disposed concentrically about the first conductor, a first insulator is disposed in between the first and second conductors, a third conductor is disposed concentrically about the second conductor, and a second insulator is disposed in between the second and third conductors.

25 9. The system of claim 7, wherein the measurement module of the wireless needle assembly comprises:

a base having an electrical interface connected to the active, reference and common conductors, the base having a shape complementary to that of the wireless adapter for releasable attachment to the wireless adapter;

a needle shaft comprising the active and reference conductors; and

5 a surface electrode comprising the common conductor.

10. The system of claim 7, wherein the measurement module of the wireless needle assembly comprises:

10 a base having an electrical interface connected to the active, reference and common conductors, the base having a shape complementary to that of the wireless adapter for releasable attachment to the wireless adapter;

a needle shaft comprising the active conductor; and surface electrodes comprising the reference and common conductors, respectively.

11. The wireless physiological monitoring system of claim 1 wherein said physiological signal is an electroencephalographic (EEG) signal.

15 12. The wireless physiological monitoring system of claim 1 wherein said physiological signal is an electrocardiographic (ECG) signal.

13. The wireless physiological monitoring system of claim 1 wherein said physiological signal is an electromyographic (EMG) signal.

20 14. The wireless physiological monitoring system of claim 1 further comprising a plurality of wireless sensors for measuring a plurality of physiological signals.

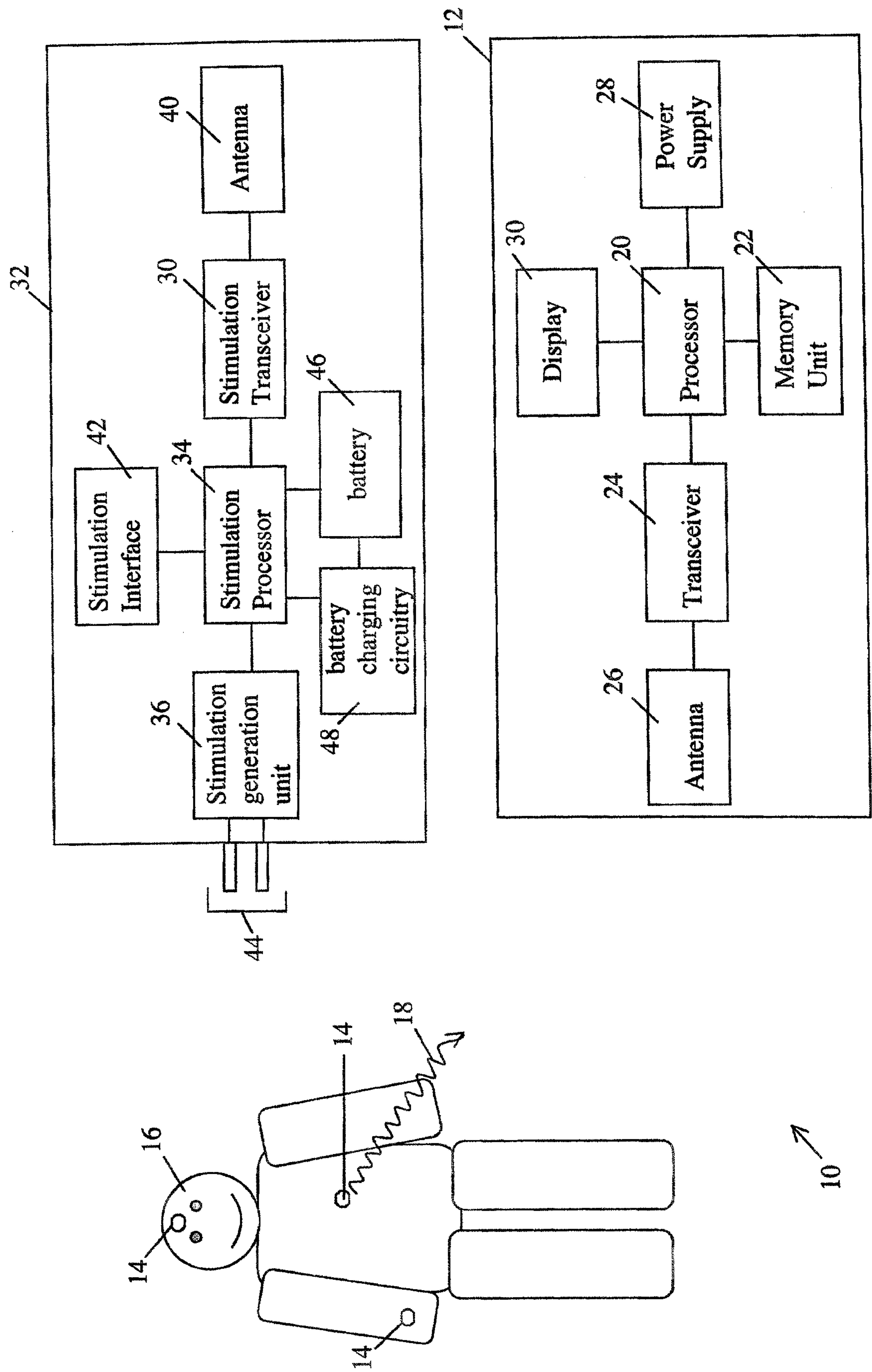


FIGURE 1

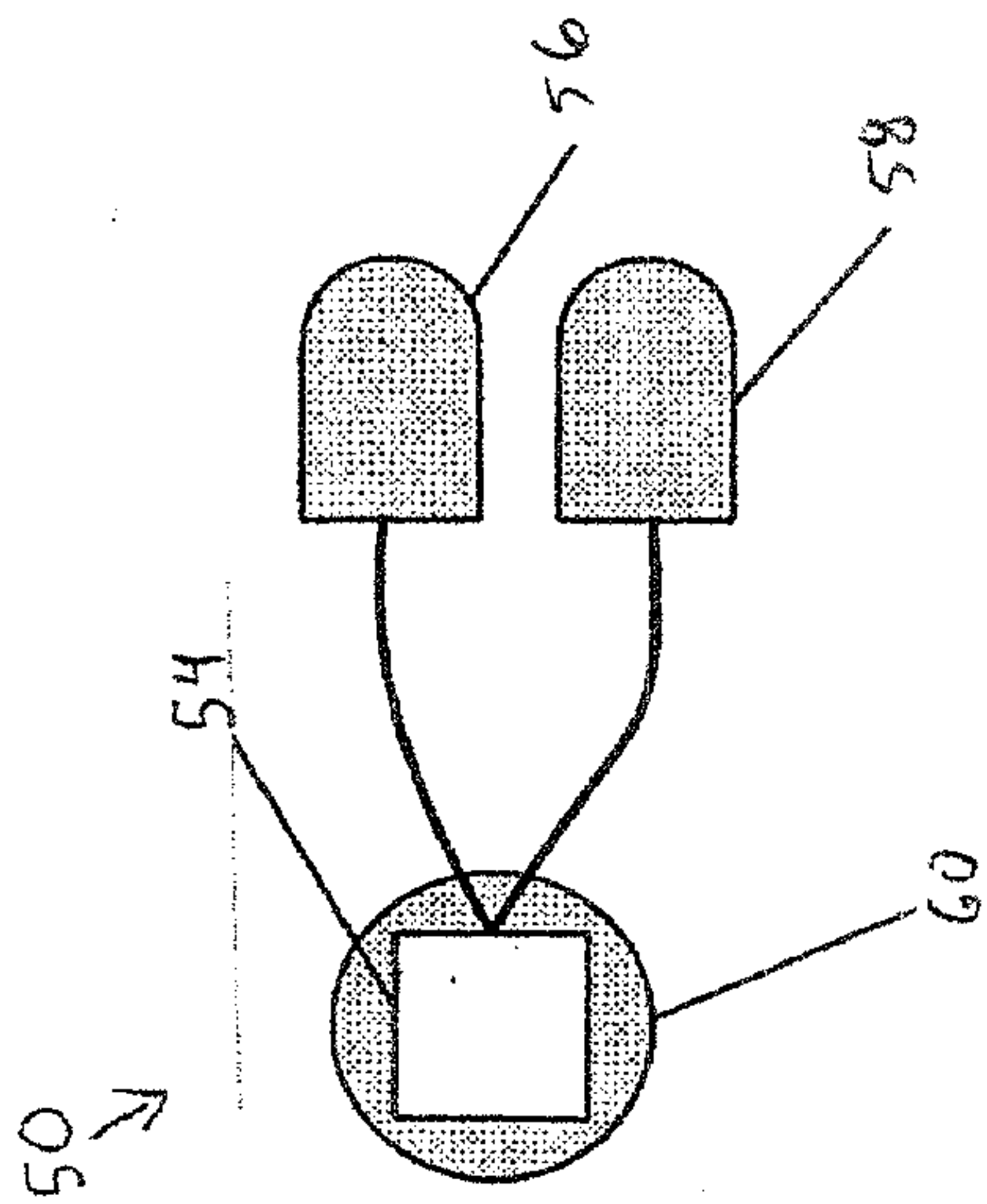


FIGURE 2a

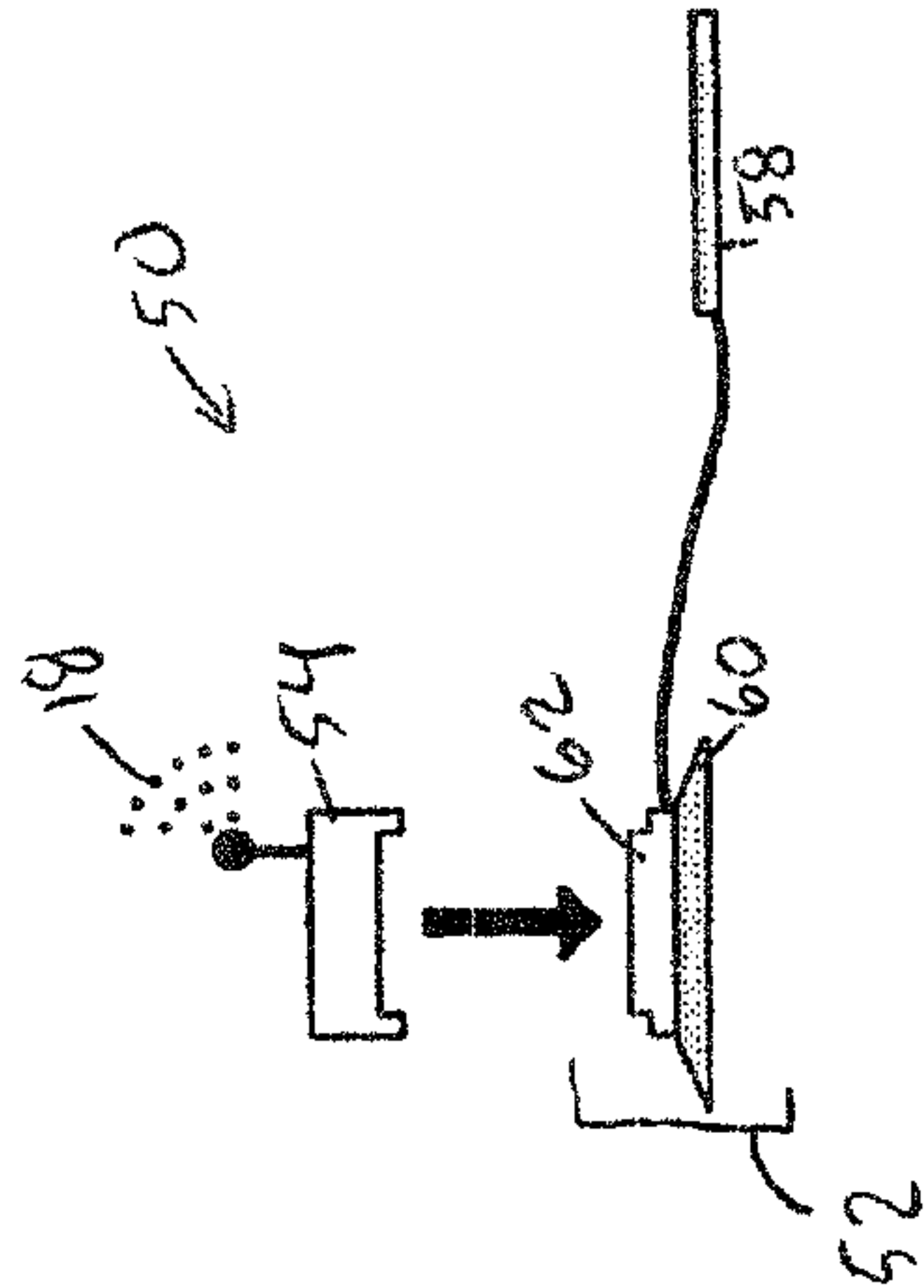


FIGURE 2b

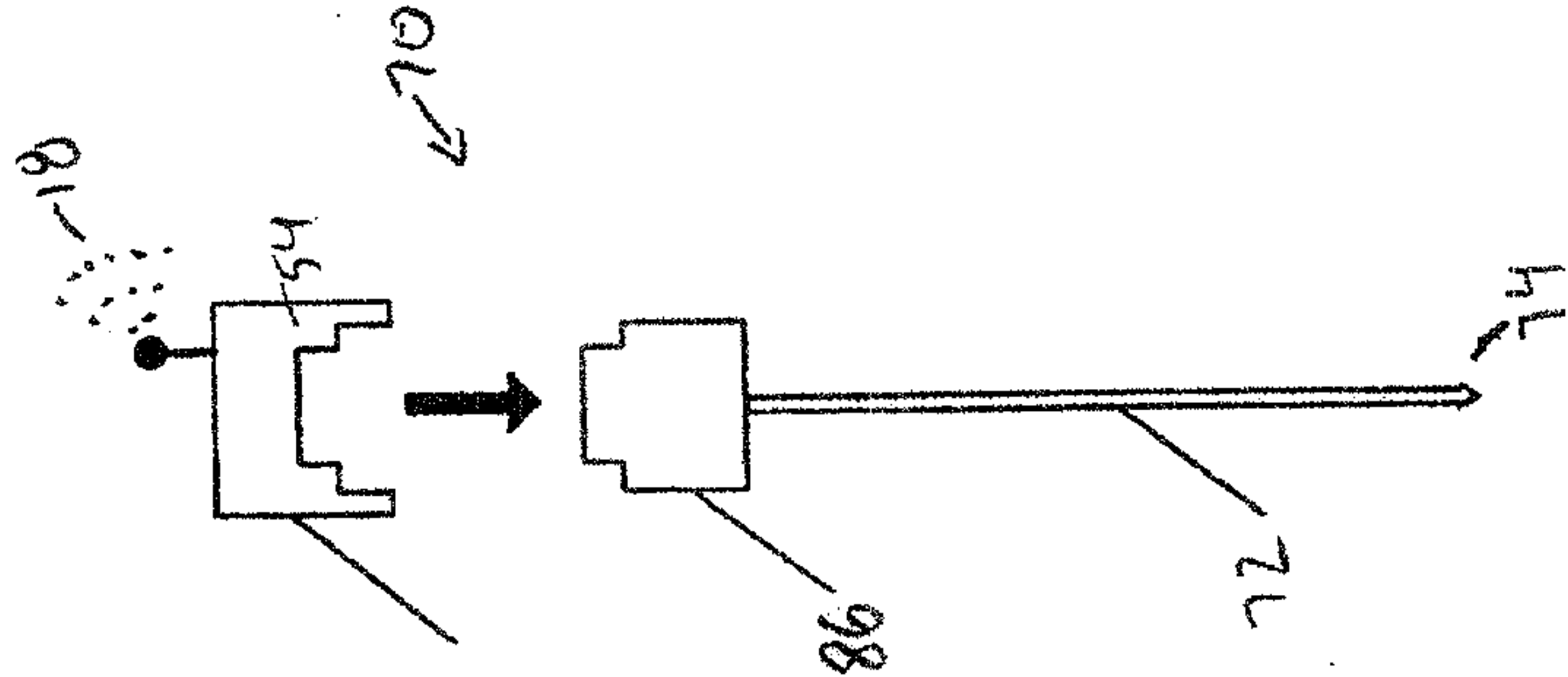


FIGURE 3a

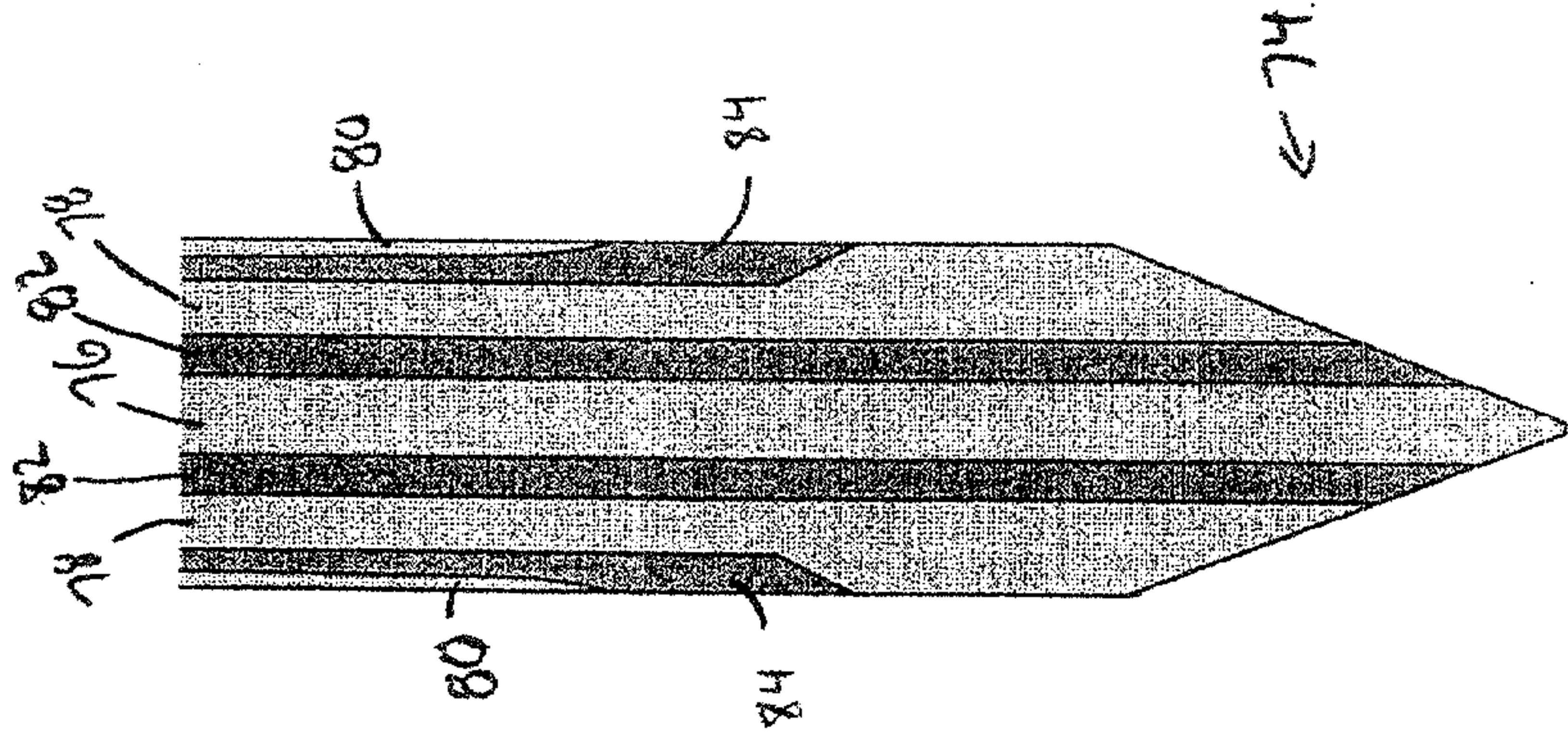


FIGURE 3b

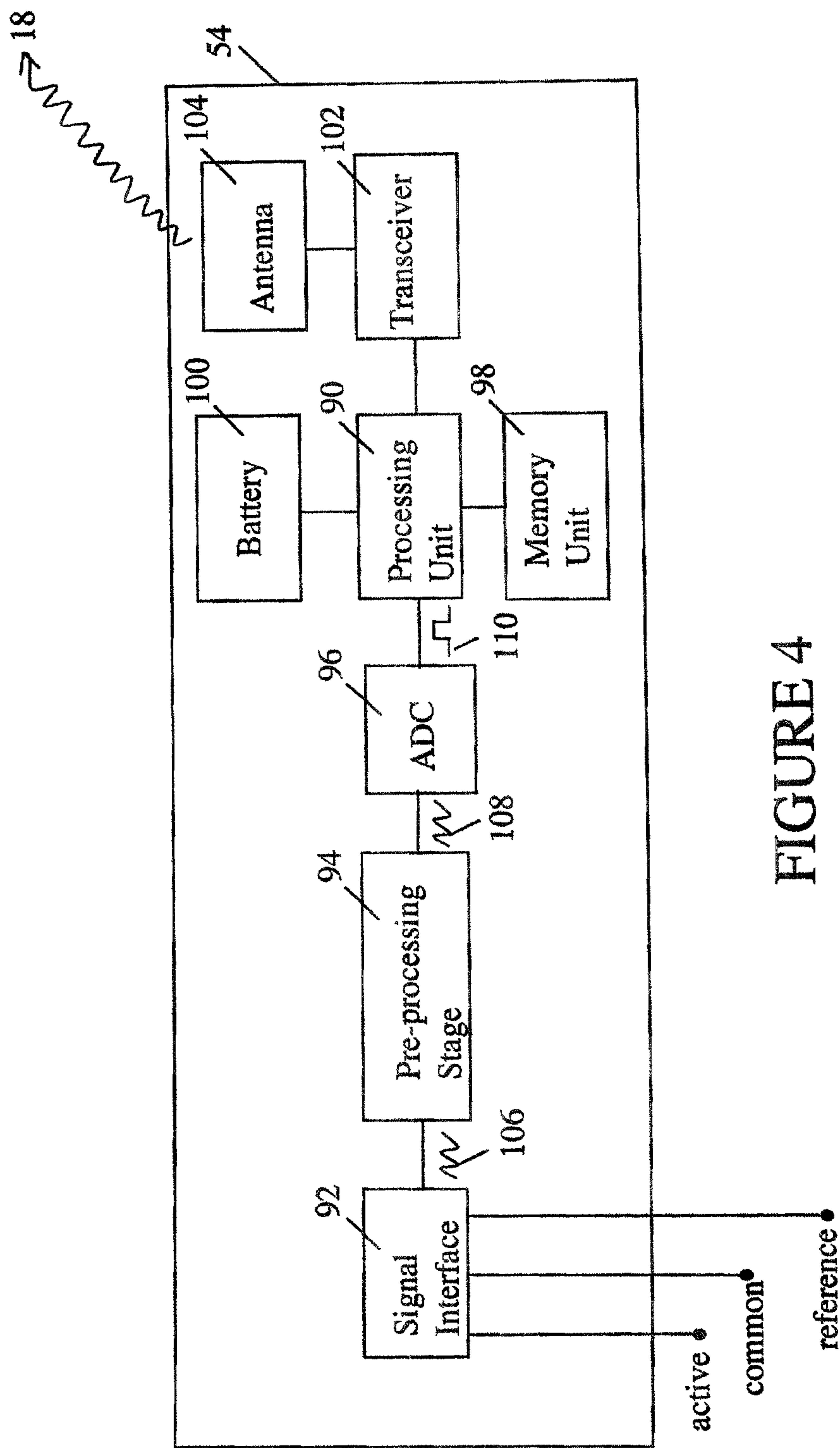


FIGURE 4

