(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
21 March 2013 (21.03.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/038285 A1

(51) International Patent Classification:
A61B 5/0476 (2006.01)

(21) International Application Number:
PCT/IB2012/054369

(22) International Filing Date:
27 August 2012 (27.08.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/534,918 15 September 2011 (15.09.2011) US

(71) Applicant *(for all designated States except US)*: **KONINKLIJKE PHILIPS ELECTRONICS N.V.** [NL/NL]; High Tech Campus 5, NL-5621 BA Eindhoven (NL).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **MIHAJLOVIC, Vojkan** [RS/NL]; Philips Ip & S, High Tech Campus 44, NL-5656AE Eindhoven (NL). **JAEGER, Mark Christoph** [DE/NL]; Philips Ip & S, High Tech Campus 44, NL-5656AE Eindhoven (NL). **VOSSEN, Franciscus Jacobus** [NL/NL]; Philips Ip & S, High Tech Campus 44, NL-5656AE Eindhoven (NL). **GILLIES, Murray Fulton** [GB/NL]; Philips Ip & S, High Tech Campus 44, NL-5656AE Eindhoven (NL).

(74) Agents: COOPS, Peter et al.; Philips Ip&s - Nl, High Tech Campus 44, NL-5656 AE Eindhoven (NL).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

[Continued on next page]

(54) Title: EEG SYSTEM AND ELECTRODE PRESSURE CONTROL SYSTEM

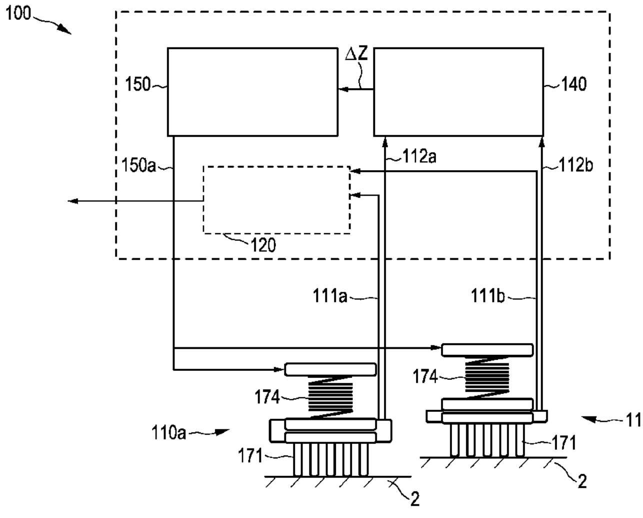


FIG. 2

(57) Abstract: The invention relates to an EEG system (100) comprising a first EEG electrode (110a), providing a first EEG signal (111a) and a first impedance signal (112a), and a second EEG electrode (110b), providing a second EEG signal (111b) and a second impedance signal (112b). The system further comprises a determination unit (140) for determining an impedance difference value (ΔZ) indicating the impedance difference between the electrodes, and a control unit (150) for controlling the first and/or the second electrode depending on the impedance difference value, e.g. by controlling actuators (174) for increasing and/or decreasing the pressure on the respective electrode, or by producing a vibration in some electrodes. The invention further relates to a respective method of operating an EEG system and to a computer program. An electrode pressure control system and method may also be used with other types of electrodes, such as ECG or EMG electrodes.

WO 2013/038285 A1

- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

- *with international search report (Art. 21(3))*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

EEG SYSTEM AND ELECTRODE PRESSURE CONTROL SYSTEM

FIELD OF THE INVENTION

The present invention relates to an electroencephalography (EEG) system comprising EEG electrodes for contacting skin of a user. The present invention further relates to a method of operating such EEG system and a computer program for implementing such method. Furthermore, the present invention relates to an electrode pressure control system for controlling pressure in an axial direction on an electrode, in particular an EEG electrode, and a computer program for implementing such method.

BACKGROUND OF THE INVENTION

The present invention in particular relates to measuring electrical brain activity, also known as electroencephalography (EEG) or the measurement of an electroencephalogram. Electrical brain activity or EEG is measured by means of EEG electrodes contacting skin of the user, in particular the scalp of the user. One type of known electrodes are wet or gel electrodes. And another type of known electrodes are dry electrodes (not using gel). The main challenge when applying EEG wet or gel electrodes is to get a good, thus low, contact impedance to the skin. In clinical measurements this is normally done with a (shower-cap like) rubber cap with integrated metal electrodes (e.g. Ag/AgCl coated). The skin underneath these electrodes usually needs to be prepared by decreasing and often additional abrasion (e.g. removal of the dry top layer of the skin, the stratum corneum). The conductive gel is then applied between each electrode and the scalp (typically through a hole in the electrode or cap). This assures a low ohmic contact to the deeper skin layer (the epidermis) and "conversion" from ion current in the body to electron current in the measuring system. Using conductive gel also solves (partly) the problem of the varying distance between the electrode and the skin due to the variation from person to person with respect to the hair layer thickness and the amount of hair, as well as temporal changes of the distance that might occur due to the head and/or body motion.

However, in a lot of other cases not involving clinical measurements, for example for lifestyle consumer products or for disabled patients or remote monitoring purposes, these kinds of wet or gel electrodes are not practical. In these cases dry electrodes can be used. When these solutions are applied to a larger population, there might still be difficulties getting sufficient signal quality when coping with thick and/or long hair. A problem with these solutions can be a poor contact to the skin (or the scalp) and insufficient signal quality.

US 2011/0015503 A1 discloses an EEG processing unit comprising a semi-rigid framework which substantially conforms to the patient's head and supports a set of electrodes in predetermined loci on the patient's head to ensure proper electrode placement. The EEG processing unit includes automated connectivity determination apparatus which can use pressure-sensitive electrode placement ensuring proper contact with patient's scalp and also automatically verifies electrode placement via measurements of electrode impedance through automated impedance shaking. There is a need to further improve such unit or system.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an improved EEG system and method for operating the same. It is a further object of the present invention to provide an improved electrode pressure control system and method. It is a further object of the present invention to provide computer program for implementing such methods.

In a first aspect of the present invention an EEG system is presented comprising a first EEG electrode for contacting skin of a user, the first EEG electrode providing a first EEG signal of the user and providing a first impedance signal comprising at least one impedance value of the first electrode with respect to the skin, and a second EEG electrode for contacting skin of the user, the second EEG electrode providing a second EEG signal of the user and providing a second impedance signal comprising at least one impedance value of the first electrode with respect to the skin. The system further comprises a determination unit for determining, based on the first impedance signal and the second impedance signal, an impedance difference value indicating a difference between an impedance value of the first electrode with respect to the skin and an impedance value of the second electrode with respect to the skin.

In a further aspect of the present invention a method of operating an EEG system is presented, the method comprising receiving a first EEG signal provided by a first EEG electrode for contacting skin of a user, receiving a second EEG signal provided by a second EEG electrode for contacting skin of a user, receiving a first impedance signal provided by the first EEG electrode, the first impedance signal comprising at least one impedance value of the first electrode with respect to the skin, receiving a second impedance signal provided by the second EEG electrode, the second impedance signal comprising at least one impedance value of the second electrode with respect to the skin, and determining, based on the first impedance signal and the second impedance signal, an impedance difference value indicating a difference between an impedance value of the first electrode with respect to the skin and an impedance value of the second electrode with respect to the skin.

In a further aspect of the present invention a computer program is presented comprising program code means for causing a computer to carry out the steps of the method according to the invention when said computer program is carried out on the computer.

The present invention is based on the idea to provide an EEG system and corresponding method for achieving equal or nearly equal electrode-skin contact impedance for the EEG electrodes, in particular for all EEG electrodes. In this way the impedances of the electrodes are balanced. The impedance of the electrode (contacting the skin) with respect to the skin (or impedance between the electrode and the skin) is also called electrode-skin contact impedance. By determining an impedance difference value the relative impedance or impedance difference of the first and second electrodes can be determined, not an absolute value. It can thus be ensured that the electrode-skin contact impedance does not substantially differ for different electrodes. It was found that due to the very low strength of the electrical brain activity signal (EEG signal) that balancing the electrode-skin contact impedance among a set of EEG electrodes is one of the crucial aspects for providing sufficient EEG signal quality and diminishing the impact of artifacts. If the electrode-skin contact impedances are not the same across the set of EEG electrodes, this can cause huge DC offsets which require amplifiers with large dynamic ranges and increases the artifacts stemming from environmental noise and motion and facial muscle tension. As the present invention provides equal or nearly equal electrode-skin contact impedances between the different electrodes, the use of an EEG amplifier with a very large dynamic range can be avoided, which in turn decreases cost and power consumption.

In one embodiment the system further comprises a current source, and wherein each impedance signal is an electrical signal measured when the current source is active. This provides an easy way of determining the electrode-skin contact impedance. In this way a direct measurement of contact impedance of the respective electrode can be provided, or in other words, an indirect measurement of the pressure on the respective electrode can be provided. The current source can for example be a DC current source or an AC current source.

In a variant of this embodiment the system further comprises at least one switch for determining, for each electrode, an open circuit voltage when the switch is open and for determining a short circuit current when the switch is closed, wherein each impedance signal is based on the open circuit voltage and the short circuit current.

In another embodiment each electrode comprises a pressure sensor, and wherein each impedance signal is a pressure sensor signal provided by the respective pressure sensor. In this way an indirect measurement of the contact impedance can be provided, or in other words a direct measurement of the pressure on the respective electrode can be provided.

In another embodiment the system further comprises more than two electrodes, the determination unit configured to determine, based on the impedance signals provided by the electrodes, impedance difference values for pairs of electrodes. In this way the impedance cannot only be balanced between two electrodes, but also between a set of electrodes as well. In particular the impedance can be balanced between all electrodes.

In another embodiment, the system further comprises a control unit for controlling the first electrode and/or the second electrode depending on the impedance difference value. The control unit can in particular be configured control the electrodes such that the impedance difference value is minimized.

In another embodiment, or variant of the previous embodiment, the system further comprises a control unit for controlling in an axial direction pressure on the first electrode and/or pressure on the second electrode depending on the impedance difference value. In this way the impedance difference between the electrodes can be automatically corrected, as the amount of pressure applied on an electrode is inversely-proportional to the electrode-skin contact impedance. The control unit can in particular be configured to control the pressure such that the pressure on the first electrode and the pressure on the second electrode is balanced.

In a variant of this embodiment each electrode comprises an actuator for increasing and/or decreasing the pressure on the respective electrode. In particular, the control unit can then be configured to provide at least one control signal to the actuators depending on the impedance difference value.

In a further variant the control signal is provided, if the absolute value of the determined impedance difference value is above a predefined threshold. In particular, if the predefined threshold is small, the impedance difference value can be automatically corrected to get to zero or close to zero. In this way, the control unit can be configured to control such as to minimize the impedance difference value (e.g. through continuous or repeated control). The minimization of the impedance difference value can for example result in increasing the pressure on one (or more) electrodes, or in decreasing the pressure on one (or more) electrodes.

In a further variant of this embodiment the control unit is further configured to control motion of the electrode in a plane perpendicular to the axial direction. In this way contact of the electrode, in particular through hair, can be further improved. The motion in the plane perpendicular to the axial direction can in particular be a rotational motion.

In another variant the control unit can be configured to control the electrodes subsequently in time or simultaneously in time. Thus, the control unit can control only the first electrode or the second electrode. For example, the control unit can be configured to determine if the contact impedance value of the first electrode is higher than the contact impedance value of the second electrode. If this is the case, the control unit can be configured to only control the pressure on the first electrode (not the second electrode). If this is not the case, the control unit can be configured to only control the pressure on the second electrode (not the first electrode). Alternatively, the control unit can be configured to control the first electrode and the second electrode simultaneously in time, thus both the first electrode and the second electrode.

In another embodiment the determination unit is configured to determine the impedance difference value continuously or repeatedly. In a variant, also the control unit can be configured to control the pressure on the electrode continuously or repeatedly. For example, the determination can be in real-time or at predefined time intervals. In this way it can be ensured that the impedances or the equality relation of the impedances is preserved over time. This can in particular be achieved by continuous or repeated readjustment of the pressures on all electrodes, while the system is in use. The readjustment can keep the impedances within the desired boundaries.

In a further embodiment each electrode comprises a plurality of pins for contacting the skin of the user. In this way the comfort level of the EEG system and the convenience for the user can be improved. The pins can in particular be adapted to extend through the hair of the user. The convenience and the comfort can be improved by designing the electrode in such a way that it has many degrees of freedom with respect to positioning the electrode and mounting it on the user's head. In a variant, the plurality of pins can for example have rounded tips for contacting the skin. This further increases user comfort. In another variant, the pins can be arranged in a flexible substrate. In this way they are able to flex and bend such as to ensure equal distribution of pressure among all pins of an electrode and/or to ensure that the large number of pins make galvanic contact to the skin.

In a further embodiment the electrodes are attached to a flexible or deformable material. For example, the flexible or deformable material can be a textile-like material.

In a further embodiment each electrode can comprise a ball-and-socket join. This introduces another layer of flexibility that can further improve the pressure distribution, therefore better balance of the electrode-skin contact impedances.

In another embodiment the system further comprises a wearable device configured to be put at least partly around the head of a user, the wearable device comprising a support structure for supporting the electrodes. In this way, the system or electrodes can be positioned on the user's head, in particular the electrodes can be positioned at different locations on the user's head or scalp. The wearable device or support structure can for example be or comprise a patch configured to be put at least partly around the head of the user. The wearable device can be integrated in or can be a head band, head cap, headset, helmet, or the like.

In a further embodiment the system further comprise an EEG processing unit comprises for processing the first EEG signal and the second EEG signal. Such an EEG processing unit can be used for providing EEG data, which can then, for example, be displayed or further processed.

In a further aspect of the present invention an electrode pressure control system for controlling pressure in an axial direction on an electrode is presented, the system comprising a first electrode for contacting skin of a user, the first electrode providing a first physiological signal of the user and providing a first impedance signal comprising at least one impedance value of the first electrode with respect to the skin, and a second electrode for contacting skin of the user, the second electrode providing a second physiological signal of the user and providing a second impedance signal comprising at least one impedance value of the second electrode with respect to the skin. The system further comprises a determination unit for determining, based on the first impedance signal and the second impedance signal, an impedance difference value indicating a difference between an impedance value of the first electrode with respect to the skin and an impedance value of the second electrode with respect to the skin, and a control unit for controlling the pressure on the first electrode and/or the pressure on the second electrode depending on the impedance difference value.

In a further aspect of the present invention an electrode pressure control method for controlling pressure in an axial direction on an electrode is presented, the method comprising receiving a first physiological signal of the user provided by a first electrode, receiving a second physiological signal of the user provided by a second electrode, receiving a first impedance signal provided by the first electrode, the first impedance signal comprising at least one impedance value of the first electrode with respect to the skin, receiving a second impedance signal provided by the second electrode, the second impedance signal comprising at least one impedance value of the second electrode with respect to the skin, determining, based on the first impedance signal and the second impedance signal, an impedance difference value indicating a difference between an impedance value of the first electrode with respect to the skin and an impedance value of the second electrode with respect to the skin, and controlling the pressure on the first electrode and/or the pressure on the second electrode depending on the impedance difference value.

In a further aspect of the present invention a computer program is presented comprising program code means for causing a computer to carry out the steps of the electrode pressure control method according to the invention when said computer program is carried out on the computer is presented.

It is a further basic idea of the present invention to provide an electrode pressure control system and method for controlling pressure in an axial direction on an electrode capable of balancing the impedances as described before. It has been found that the amount of pressure applied to an electrode is inversely-proportional to the electrode-skin contact impedance. Equal or nearly equal pressure or pressure distribution on the electrodes, in particular on all electrodes, can be achieved by controlling the pressure on the electrodes depending on the determined impedance difference value or values. The control unit can in particular be configured to minimize the impedance difference value (e.g. through continuous or repeated control). The electrode on which pressure is applied and controlled can in particular be an EEG electrode. However, in general, the electrode can also be another type of electrode, such as for example an ECG (electrocardiography) electrode, and EMG (electromyogram) electrode, an EOG (electrooculogram) electrode, or a GSR (galvanic skin response or skin conductance) electrode.

In a further aspect of the present invention an electrode pressure control system for controlling pressure in an axial direction on an electrode, the system comprising: a first electrode for contacting skin of a user, the first electrode providing a first physiological signal of the user, a first pressure sensor for providing a first pressure sensor signal indicating the pressure on the first electrode, and a control unit for controlling the pressure on the first electrode depending on the first pressure sensor signal.

In an advantageous embodiment of this electrode pressure control system, the system further comprises a second electrode for contacting the skin of a user, the second electrode providing a second physiological signal of the user, and a second pressure sensor for providing a second pressure sensor signal indicating the pressure on the second electrode, wherein the control unit is configured to control the pressure on the first electrode and/or the pressure on the second electrode based on the first pressure sensor signal and the second pressure sensor signal such that the pressure on the first electrode and the pressure on the second electrode is balanced.

In a further aspect of the present invention an electrode pressure control method for controlling pressure in an axial direction on an electrode is presented, the method comprising receiving a first physiological signal of the user provided by a first electrode, receiving a first pressure sensor signal indicating the pressure on the first electrode and provided by a first pressure sensor, controlling the pressure on the first electrode depending on the first pressure sensor signal.

In a further aspect of the present invention a computer program is presented comprising program code means for causing a computer to carry out the steps of the electrode pressure control method according to the invention when said computer program is carried out on the computer is presented.

It is a further basic idea of the present invention to provide an electrode pressure control system and method for controlling pressure in an axial direction on an electrode using the measurement of a pressure sensor, in particular integrated into the respective electrode(in particular EEG electrode). By using a pressure sensor the electronics (in particular EEG electronics) do not need to be substantially changed. By using the pressure sensor a separate feedback loop can easily be provided.

In an advantageous embodiment of this electrode pressure control system or method, the system further comprises receiving a second physiological signal of the user provided by a second electrode, receiving a second pressure sensor signal indicating the pressure on the second electrode and provided by a second pressure sensor, and controlling the pressure on the first electrode and/or the pressure on the second electrode based on the first pressure sensor signal and the second pressure sensor signal such that the pressure on the first electrode and the pressure on the second electrode is balanced.

In a variant of this embodiment the control unit is configured to select a desired pressure value based on the first pressure sensor signal and the second pressure sensor signal, and to control the pressure on the first electrode and the pressure on the second electrode such that this desired pressure value is achieved for the first electrode and the second electrode. For example, the specific value can be a mean value of the pressure on the first electrode and the pressure on the second electrode.

Preferred embodiments of the invention are defined in the dependent claims. It shall be understood that the claimed method of operating an EEG system, the claimed computer program, the claimed electrode pressure control system, or the claimed electrode pressure control method has similar and/or identical preferred embodiments as the claimed EEG system and as defined in the dependent claims.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiment(s) described hereinafter. In the following drawings:

Fig. 1a shows a first example of a diagram showing impedance as a function of pressure,

Fig. 1b shows a second example of a diagram sowing impedance as a function of pressure,

Fig. 2 shows a schematic diagram of a system according to a first embodiment of the invention,

Fig. 3 shows a schematic diagram of system according to a second embodiment,

Fig. 3a shows a schematic diagram of a system according to a variant of the second embodiment of Fig. 3,

Fig. 3b shows a schematic view of an electrode of the system of Fig. 3 or Fig. 3a,

Fig. 4 shows a schematic view of electrodes of a system according to another embodiment,

Fig. 5a shows a simplified drawing an EEG system according to a basic example,

Fig. 5b shows a simplified circuit diagram of the basic example of Fig. 5a,

Fig. 6a shows a simplified drawing an EEG system according to a first example,

Fig. 6b shows a simplified circuit diagram of the first example of Fig. 6a,

Fig. 7a shows a simplified drawing an EEG system according to a second example,

Fig. 7b shows a simplified circuit diagram of the second example of Fig. 7a,

Fig. 8a shows a simplified drawing an EEG system according to a third example,

Fig. 8b shows a simplified circuit diagram of the third example of Fig. 8a,

Fig. 9a shows a simplified drawing an EEG system according to a fourth example,

Fig. 9b shows a simplified circuit diagram of the fourth example of Fig. 9a,

Fig. 10 shows a schematic diagram of an electrode having a ball-socket-join in two different positions,

Fig. 11 shows a schematic diagram of an electrode contacting the scalp of a user,

Fig. 12 shows a schematic diagram of a patch,

Fig. 13a shows a perspective view of a wearable device in form of a head band,

Fig. 13b shows a perspective view of the wearable device of Fig. 13 put around the head of a user, and

Fig. 14 shows two schematic diagrams of a patch with an electrode with two different amounts of pressure applied.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1a shows a first example of a diagram showing impedance as a function of pressure, and Fig. 1b shows a second example of a diagram sowing impedance as a function of pressure. Fig. 1a shows the measured electrode-skin contact impedance as a function of the pressure on the electrode for a Gold-plated electrode (contacting scalp of a user at the Cz position). Fig. 1b shows the measured electrode-skin contact impedance of a function of the pressure on the electrode for an AgCl electrode (contacting scalp of a user at the Cz position). In each of Fig. 1a and Fig. 1b the pressure has three different ranges, which are low pressure (in these examples about 75g or 1.5kPa), medium pressure (in these examples about 200g or 4kPa), and high pressure (in these examples about 350g or 7kPa). As can be seen in Fig. 1a or Fig. 1b, the amount of pressure applied to the electrode is inversely-proportional to the electrode-skin contact impedance.

Fig. 2 shows a schematic diagram of a system 100 according to a first embodiment of the invention. The system of Fig. 2 is an EEG system, and can in particular also be an electrode pressure control system. The system 100 comprises a first EEG electrode 110a for contacting skin 2 of a user and a second EEG electrode 110b for contacting the skin 2 of the user. The first EEG electrode 110a provides a first EEG signal 111a of the user and the second EEG electrode 110b provides a second EEG signal 111b of the user. The system 100 can optionally (indicated by the dashed line in Fig. 2) further comprise a EEG processing unit 120 for processing the first EEG signal 111a and the second EEG signal 111b. Alternatively, the system 100 can further comprise a transmission link for transmitting the EEG signals 111a, 111b to an external device or system.

Further, the first EEG electrode 110a provides a first impedance signal 112a comprising at least one impedance value of the first electrode 110a, and the second EEG electrode 110b provides a second impedance signal 112b comprising at least one impedance values of the second electrode 110b. The impedance signal 111a, 111b can in particular comprise the respective impedance values over time.

The system 100 further comprises a determination unit 140 for determining, based on the first impedance signal 112a and the second impedance signal 112b, an impedance difference value ΔZ indicating a difference between an impedance value of the first electrode 110a with respect to the skin and an impedance value of the second electrode 110b with respect to the skin. The determination unit 140 can in particular be configured to determine the impedance difference value ΔZ continuously or repeatedly.

The system 100 further comprises a control unit 150 for controlling the first electrode 110a and/or the second electrode 110b depending on the impedance difference value ΔZ. In particular, if the system 100 is an electrode pressure control system for controlling pressure in an axial direction on an electrode 110a, 110b, the system 100 comprises a control unit 150 that is configured to control in an axial direction A pressure on the first electrode 110a and/or pressure on the second electrode 110b depending on the impedance difference value ΔZ. In another example, the control unit 150 can be configured to control the position of at least one of the electrodes, to control the position of pins of at least one electrode, or to control the length of the electrodes.

Each of the electrodes 110a, 110b can comprise an actuator 174. The control unit 150 is configured to provide at least one control signal 150a to the actuators 174 depending on the impedance difference value. If the control unit 150 is configured for controlling in the axial direction A pressure on the first electrode 110a and/or pressure on the second electrode 110b, each electrode 110a, 110b can comprise an actuator 174 for increasing and/or decreasing the pressure on the respective electrode 110a, 110b. In this case, the pressure actuator 174 is used to modify the pressure that the electrode 110a, 110b exerts to the skin (or scalp). The actuator 174 can for example be realized as a pneumatic actuator or micro-machined actuator. The actuator 174 modifies the pressure based on the at least one control signal 150a from the control unit 150. Another option is the usage of a vibration motor that can help the pins 171 to penetrate through hair and exert the required pressure.

The control unit 150 fuses the information received from different electrodes 110a, 110b (impedance signal or pressure sensor signal) and uses it for automatically adjusting the pressure in each electrode 110a, 110b.

The differences in the impedances are translated into the control signals (commands) to the actuators. In other words, the control signals are provided to the actuators depending on the impedance difference value. The control signals can be used to increase and/or decrease pressure on some of the electrodes, or to produce a vibration in some electrodes in order to decrease the electrode-skin contact impedance.

In one example, the control of the electrodes 110a, 110b can be subsequently in time (e.g. oscillating). For example, if it is determined that the contact impedance value of the first electrode 110a is higher than the contact impedance value of the second electrode 110b, then only the pressure on the first electrode can be controlled (not the second electrode). Then, after controlling the pressure, if the first electrode 110a has a contact impedance value lower than the contact impedance value of the second electrode 110b, the system can switch to controlling pressure on the second electrode 110b. In an alternative example, both the first electrode 110a and the second electrode 110b can be controlled simultaneously in time.

It will be understood that one or more of the above mentioned determination unit 140, control unit 150, and EEG processing unit 120 can be implemented in the same processing unit (e.g. processor or microprocessor), or can be implemented in separate processing units.

In one example, the system further comprising a current source 180 (not shown in Fig. 2), and each impedance signal 112a, 112b is an electrical signal measured when the current source 180 is active. This example is described in more detail with reference to Fig. 6 to Fig. 9. In particular, the system can further comprise at least one switch S_1, S_2 for determining, for each electrode 110a, 110b, an open circuit voltage Voc_1, Voc_2 when the switch S_1, S_2 is open and for determining a short circuit current Isc_1, Isc_2 when the switch S_1, S_2 is closed, wherein each impedance signal 112a, 112b is based on the open circuit voltage Voc_1, Voc_2 and the short circuit current Isc_1, Isc_2.

In an alternative example, each electrode 110a, 110b comprising a pressure sensor 173, and each impedance signal 112a, 112b is a pressure sensor signal provided by the respective pressure sensor 173. This will be explained in more detail with reference to Fig. 3, Fig. 3a, and Fig. 3b.

In the shown embodiments, in particular referring to Fig. 2 to 4, it will be understood that like reference numerals indicate like elements. In the shown embodiments, in particular referring to Figs. 2 to 4, each electrode comprises a plurality of pins 171 for contacting the skin of the user 1, in particular the scalp of the user. In this way the comfort level of the EEG system and the convenience for the user can be improved. The pins 171 can in particular be adapted to extend through the hair of the user. The pins 171 each have a rounded tip for contacting the skin. This further increases user comfort. Further, the pins 171 are arranged in a flexible substrate170. In this way they are able to flex and bend such as to ensure equal distribution of pressure among all pins of an electrode and/or to ensure that the large number of pins make galvanic contact to the skin. The electrode or pins can be made of conductive metal or metal-alloy (e.g., silver, silver-chloride, or gold).

Fig. 3 shows a schematic diagram of system according to a second embodiment. The system of Fig. 3 is an electrode pressure control system, and can in particular also be an EEG system. The electrode pressure control system 100 of Fig. 3 is configured for controlling pressure in an axial direction A on an electrode 110a, 110b. The system 100 comprises a first electrode 110a for contacting skin 2 of a user 1, the first electrode 110a providing a first physiological signal 111a of the user 1. In particular, the physiological signal 111a can be an EEG signal. Alternatively, the physiological signal could also be an ECG, EMG, EOG or GSR signal. The system 100 further comprises a first pressure sensor 173 for providing a first pressure sensor signal 112a indicating the pressure on the first electrode 110a. In the embodiment of Fig. 3, the pressure sensor is part of or integrated into the first electrode 110a. The system further comprises a control unit 150 for controlling the pressure on the first electrode 110a depending on the first pressure sensor signal 112a. The pressure sensor 173 can be used to monitor the exact pressure applied to the electrode 110a. The pressure sensor signal 112a is then used as an input to the control unit 150. The control unit 150 is configured to provide a control signal 150a to the actuator 174 depending on the pressure sensor signal 112a. The pressure sensor 173 can for example easily be realized with a simple piezoelectric element and a corresponding readout device.

The system 100 can optionally further comprise a visualization element (not shown in Fig. 3), such as a display, for visualizing the pressure sensed by the pressure sensor 173.

Fig. 3a shows a schematic diagram of a system according to a variant of the second embodiment of Fig. 3. Compared to the embodiment of Fig. 3, the electrode pressure control system 100 of Fig. 3a further comprises a second electrode 110b for contacting the skin 2 of a user 1, the second electrode 110b providing a second physiological signal 111b of the user 1, as explained with reference to Fig. 3. The system 100 further comprises a second pressure sensor 173 for providing a second pressure sensor signal 112b indicating the pressure on the second electrode 110a, 110b. The control unit 150 is configured to control the pressure on the first electrode 110a and/or the pressure on the second electrode 110b based on the first pressure sensor signal and the second pressure sensor signal such that the pressure on the first electrode 110a and the pressure on the second electrode 110b is balanced. This can in particular be achieved by providing a determination unit 140 (not shown in Fig. 3a) for determining, based on the first impedance signal 112a and the second impedance signal 112b, an impedance difference value ΔZ, as explained with reference to Fig. 2.

Alternatively, the equilibrium or balancing can for example also be achieved by leading all the actuators 174 to a predefined pressure value. Thus, the control unit 150 (or determination unit) can be configured to select a desired pressure value based on the first pressure sensor signal 112a and the second pressure sensor signal 112b, and the control unit 150 can be configured to control the pressure on the first electrode 110a and the pressure on the second electrode 110b such that this desired pressure value is achieved for the first electrode 110a and the second electrode 110b.

In particular, the specific value can be a mean value of the pressure on the first electrode 110a and the pressure on the second electrode 110b (in particular a mean value of all used electrodes). Thus, if the pressure on the first electrode 110a is a first pressure (e.g. 3Pa) and the pressure on the second electrode 110b is a second pressure (e.g. 9kPa), the control unit 150 can be configured to control the pressure on the first electrode 110a and the pressure on the second electrode 110b to a mean value (e.g. (3kPa+9kPa)/2 = 4.5 kPa) of the first pressure and the second pressure.

Fig. 3b shows a schematic view of an electrode 110a, 110b of the system of Fig. 3 or Fig. 3a. The electrode 110a, 110b comprises a plurality of pins 171, a pressure sensor 173 and an actuator 174, as explained above. The pins 171 are arranged in a flexible substrate 170. The substrate 170 with the pins 171 is attached to a rigid electrode support 172. Through the electrode pins 171 the physiological signal 111a, 111b (in particular EEG signal) is provided. The pressure sensor 173 is arranged on the electrode support 172. The pressure sensor 173 provides the pressure sensor signal 112a, 112b. In this example, the actuator 174 is arranged on the pressure sensor 174. However, it will be understood that the actuator 174 can also be arranged at any other suitable position for increasing and/or decreasing pressure on the electrode (or pins). For example, the actuator and the pressure sensor can be a single unit (e.g. a piezoelectric element), or can be separate units.

As can be seen in Fig. 3b, the electrode 110a, 110b can be attached to a patch 175 configured to be put at least partly around the head of the user.

It will be understood that the electrode 110a, 110b of the system according to the first embodiment of Fig. 2 can correspond to the electrode shown in Fig. 3b. However, the pressure sensor 173 does not necessarily need to be provided in the electrode of the system of the first embodiment of Fig. 2.

Fig. 4 shows a schematic view of electrodes of a system according to another embodiment. The embodiment of Fig. 4 is in particular a variant of the embodiment of Fig. 2 or the embodiment of Fig. 3 or Fig. 3a. In Fig. 4 the system 100 comprises more than two electrodes 110a-d. In Fig. 4 four electrodes 110a-d are illustrated. However, it will be understood that any suitable number of electrodes can be used. The electrodes 110a-d are attached to a patch 175. The first electrode 110a provides a first physiological (EEG) signal 111a, the second electrode provides a second physiological signal (EEG) signal 111b, the third electrode 110c provides a third physiological (EEG) signal 111c, and the fourth electrode 110d provides a fourth physiological (EEG) signal 110d. Furthermore, each electrode 110a-d can provide an impedance signal 112a-d. The determination unit 140 can then be configured to determine, based on the impedance signals 112a-d provided by the electrodes 110a-d, impedance difference values for pairs of electrodes 110a-d. The control unit 150 can then be configured to control the pressure on the electrodes depending on the impedance difference values. For example, one of the electrodes 110a-d can be selected to be a reference electrode. Impedance difference values of pairs having this reference electrode and one of the remaining electrodes can then be determined. The control unit 150 can then control the pressure on each of these remaining electrodes, but not on the reference electrode.

The basic operation of an EEG system will now be explained with reference to Fig. 5a and Fig. 5b. Fig. 5a shows a simplified drawing an EEG system according to a basic example, and Fig. 5b shows a simplified circuit diagram of the basic example of Fig. 5a. Brain waves are typically sensed by means of two, or more, EEG electrodes 110a, 110b making contact to the scalp of a user (e.g. person). Both EEG electrodes 110a, 110b of Fig.

5a are wired to an EEG-type of electronic circuitry shown in Fig. 5b. This electronic circuitry comprises the EEG processing unit 120 mentioned above, which is a microprocessor (μP) in this case. The first stage of the electronic circuitry is a so called differential stage with input resistances as high as possible. With R_in approaching infinity, the output signal of the first stage is solely determined by the person's brain signals. To obtain sufficient EEG signal quality using dry electrodes for real life applications, the contact impedance between electrode and the person's scalp should stay below a certain value (e.g. 1 MΩ to 10MΩ), depending on the EEG phenomena used in an application. For higher contact impedances (in the order of 100MΩ), the picked up brain signals are often dominated by noise and can no longer be filtered out. What is even more important for the proper signal amplification is that the contact impedance is balanced between the electrodes. In a typical EEG instrumentation, the actual contact impedance between the dry electrode and person's scalp cannot be measured precisely. As long as 'sensible' signals are measured (voltage amplitude of a signal is in a certain range) it is said to be acceptable, otherwise the complete electrode mounting system or individual electrodes are moved back and forth to get a better contact between electrodes and the scalp.

In Fig. 5a and Fig. 5b the current source I_brain between the electrodes 110a and 110b is just a model for brain activity. In Fig. 5b the first stage in a typical EEG electronic circuitry is a so called differential stage. With its input resistance approaching infinity, the stage is not sensitive to Zcontact_1 and Zcontact_2 and only brain waves contribute to the output signal. Subsequently, the frequency band of interest is filtered out, amplified and digitized. In the digital domain the signal is analyzed and properly dealt with. This is done through a number of stages depicted in Fig. 5b (from left to right): a differential stage that amplifies the signal difference between the two inputs (+ and -), a high pass filter that removes the DC offsets (low frequency components), a first gain stage that amplifies the signal, a low pass filter that removes high frequency components, a second gain stage that amplifies the signal, and an analog to digital (A/D) converter.

A basic measurement principle will now be explained. Fig. 6a shows a simplified drawing an EEG system according to a first example, and Fig. 6b shows a simplified circuit diagram of the first example of Fig. 6a. As can be seen in Fig. 6a electrodes 110a-d are integrated in a wearable device in form of a headphone. One electrode is touching the left ear and another one touching the right ear of the person. The system further comprises a current source 180. In Fig. 6b the current source 180 is touching and driving the left ear. However, it will be understood that it could also be touching and driving the right ear. In the example of Fig. 6a and Fig. 6b current from the current source 180 is driven through the head (Idrive = I) from left to right by electrodes 110c, 110d which make contact with the subject's ears. The current is driven through the head from left to right, by which a small fraction of this drive signal is picked up via the first electrode 110a or the second electrode 110b. The signal picked up by a first electrode 110a or the second electrode 110b and is directed to a switch S_1, S_2, to measure the so called open circuit voltage Voc and subsequently short circuit current Isc. Thus, the system comprises a switch S_1, S_2 for determining, for each electrode 110a, 110b, an open circuit voltage Voc_1, Voc_2 when the switch S_1, S_2 is open and for determining a short circuit current Isc_1, Isc_2 when the switch S_1, S_2 is closed, wherein each impedance signal 112a, 112b is based on the open circuit voltage Voc_1, Voc_2 and the short circuit current Isc_1, Isc_2. Via the switch open circuit voltage Voc and subsequently short circuit current Isc is measured. With these two measured signals the contact impedance Z of the pin electrodes can be calculated.

The current source 180 can be a DC current source or an AC current source. If the current source is a DC current source, presence of this current source does not interfere with the actual EEG measurement. In fact, the DC voltage can be adjusted to a value to compensate for a common mode difference voltage between the user and the electronic circuitry. For an actual impedance measurement the switches S_1 and S_2 are driven. Although the DC current source does not interfere with the EEG measurement, closing one of the switches S_1, S_2 does interfere with the actual EEG measurement. Thus, when determining the impedances, no EEG signal can be measured.

As explained above, a small amount of electrical current from the current source 180 is driven through the person's head, and a fraction is 'tapped off' via the electrodes 110a, 110b making contact to the person's skin or scalp. This 'tapped off' current is related to the electrode-skin (or scalp) contact impedance Z and is used to determine or estimate the value of electrode-skin contact impedance Z and/or to balance the electrode-skin contact impedance Z.

The pins of the first electrode 110a and the second electrode 110b can have rounded tips, but they are hampered by hair and for comfort reasons a relatively low force is applied. This combination of issues makes it virtually impossible to reach contact impedance below 100 kΩ. However, the ear electrodes provide better contact to skin, which is also more balanced. Provided that the larger contact surface is used to make the contact, the contact impedance can be less than 100 kΩ. It can be assumed that impedance of pin electrodes (Zcontact_1 and Zcontact_2) is higher compared to the ear electrodes, and several orders of magnitudes higher than the impedance of the brain. This allows certain model simplifications. With switch S put in its top position, Voc is calculated. After that, switch S is put in its bottom position to calculate Isc. With these two measured signals, only some basic math is needed to calculate the output impedance of the Thevenins equivalent model.

S in top position:

$$V_{oc1} = I \cdot (Z_{brain1} + Z_{brain2} + Z_{contactR})$$

S in bottom position:

$$I_{sc1} = I \cdot \left(\frac{Z_{brain1} + Z_{brain2} + Z_{contactR}}{Z_{contact1} + Z_{brain1} + Z_{brain2} + Z_{contactR}}\right)$$

$$\frac{V_{oc1}}{I_{sc1}} = Z_{contact1} + Z_{brain1} + Z_{brain2} + Z_{contactR}$$

In the same way the contact impedance of the second electrode 110b can be calculated.

S in top position:

$$V_{oc2} = I \cdot (Z_{brain2} + Z_{contactR})$$

S in bottom position:

$$I_{sc2} = I \cdot \left(\frac{Z_{brain2} + Z_{contactR}}{Z_{contact2} + Z_{brain2} + Z_{contactR}}\right)$$

$$\frac{V_{oc2}}{I_{sc2}} = Z_{contact2} + Z_{brain2} + Z_{contactR}$$

To estimate whether the impedance is balanced between two pin electrodes we subtract the obtained combined contact impedance values.

$$\frac{V_{oc2}}{I_{sc2}} - \frac{V_{oc1}}{I_{sc1}} = Z_{contact2} - Z_{brain1} - Z_{contact1}$$

The fact that the impedance values of the first electrode 110a and the second electrode 110b (Zcontact_1 and Zcontact_2) are much larger than the Zbrain_2, allows us to simplify the last equation.

$$\frac{V_{oc2}}{I_{sc2}} - \frac{V_{oc1}}{I_{sc1}} = Z_{contact2} - Z_{contact1}$$

This suggests that we can estimate that we have achieved balanced skin-electrode impedance if the outcome of the equation is (close to) zero.

To have a more precise estimation of contact impedance, in cases where all electrodes are of pin structure, the circuitry presented in Fig. 6a and Fig. 6b can be extended. This involves a similar circuit but with the current being driven through the head from right to left via the electrodes, Z_1 and Z_2 situated above the ears rather than the ear electrodes themselves. This circuitry can be activated sequentially after the previous one. Following the same calculation process as above, we can come-up with the system of four equations.

$$\frac{V'_{oc1}}{I'_{sc1}} = Z_{contact1} + Z_{brain2} + Z_{brain3} + Z_{contactR}$$

$$\frac{V'_{oc2}}{I'_{sc2}} = Z_{contact2} + Z_{brain3} + Z_{contactR}$$

$$\frac{V''_{oc2}}{I''_{sc2}} = Z_{contact1} + Z_{brain1} + Z_{contactL}$$

$$\frac{V''_{oc1}}{I''_{sc1}} = Z_{contact2} + Z_{brain1} + Z_{brain2} + Z_{contactL}$$

After removing the impact of brain impedances, the system will look like.

$$\frac{V'_{oc1}}{I'_{sc1}} = Z_{contact1} + Z_{contactR}$$

$$\frac{V'_{oc2}}{I'_{sc2}} = Z_{contact2} + Z_{contactR}$$

$$\frac{V''_{oc2}}{I''_{sc2}} = Z_{contact1} + Z_{contactL}$$

$$\frac{V''_{oc1}}{I''_{sc1}} = Z_{contact2} + Z_{contactL}$$

If we sum these values and assume that the contact impedances are balanced we can have an estimation of the impedance for all electrodes.

$$\frac{V'_{oc1}}{I'_{sc1}} + \frac{V'_{oc2}}{I'_{sc2}} + \frac{V''_{oc2}}{I''_{sc2}} + \frac{V''_{oc1}}{I''_{sc1}} = [2(Z]_{contact1} + Z_{contact2} + Z_{contactL} + Z_{contactR})$$

$$[(Z]_{all} =) Z_{contact1} \sim Z_{contact2} \sim Z_{contactL} \sim Z_{contactR}$$

$$Z_{all} = \frac{1}{8}\left(\frac{V'_{oc1}}{I'_{sc1}} + \frac{V'_{oc2}}{I'_{sc2}} + \frac{V''_{oc2}}{I''_{sc2}} + \frac{V''_{oc1}}{I''_{sc1}}\right)$$

In case this value is not in the expected range we should follow the skin-electrode contact impedance balancing steps. They consist of estimating the values of contact impedance differences between pairs of electrodes, based on the system of equations above.

$$\frac{V'_{oc2}}{I'_{sc2}} - \frac{V'_{oc1}}{I'_{sc1}} = Z_{contact2} - Z_{contact1}$$

$$\frac{V''_{oc2}}{I''_{sc2}} - \frac{V'_{oc1}}{I'_{sc1}} = Z_{contactL} - Z_{contactR}$$

$$\frac{V''_{oc1}}{I''_{sc1}} - \frac{V'_{oc2}}{I'_{sc2}} = Z_{contactL} - Z_{contactR}$$

$$\frac{V''_{oc1}}{I''_{sc1}} - \frac{V''_{oc2}}{I''_{sc2}} = Z_{contact2} - Z_{contact1}$$

If the outcome of these equations is close to zero and the outcome of the previous set of equations gives results which are close to each other (e.g., in the range of 100kΩ) that means that the impedance is balanced between electrodes. Although the system of equations does not give the unique solution the former one indicate the pair of electrodes that have the worst balance. By modifying the position and/or contact of one of the electrodes (e.g., by increasing the pressure exerted on the electrode) such as to decrease the impedance we can infer whether this particular electrode is causing misbalance or nor and act accordingly.

In the following an AC measurement will be described. The measuring for the ‘short circuit current’ Isc can be done via a so called transimpedance stage. For measuring the ‘open circuit voltage’ Voc, the existing circuitry for sensing brain signals can be used. Applying a drive current with approximately the same frequency as brain waves, will be filtered out and amplified by the EEG like electronics. A possible embodiment of integrating our new electrode impedance measurement in the EEG like system is shown in Fig. 7a and Fig. 7b.

Fig. 7a shows a simplified drawing an EEG system according to a second example, and Fig. 7b shows a simplified circuit diagram of the second example of Fig. 7a. A low frequent AC current is driven through the head of which a fraction is ‘tapped of’ by the first electrodes 110a and the second electrode 110b. The open circuit voltages Voc are measured by the same circuitry as for measuring brain waves. The short circuit currents Isc are measured via so called transimpedance stages. Timing of the switches and calculating the actual impedance values for the first electrode 110a and the second electrode 110b is done by the microprocessor. An AC current, with approximately the same frequency as the brain waves of interest, is driven from left to right through the human head. By simultaneously closing switch S_1, the negative input node of the differential stage is pulled to ‘ground’ potential. As a consequence, the open circuit voltage of the second electrode 110b will be amplified, filtered and digitized to interface to the microprocessor. At the same time, the short circuit current of the first electrode 110a is measured via the transimpedance stage, digitized and also interfaced to the microprocessor.

$I_{driveAC}$

S_1 is closed, S_2 is open:

$$V_{oc2} = I_{driveAC} \cdot (Z_{brain3} + Z_{contactR})$$

$$V_{oc12(2)} = V_{oc2} \cdot G_1 \cdot G_2 \cdot G_3 = I_{driveAC} \cdot (Z_{brain3} + Z_{contactR}) \cdot G_1 \cdot G_2 \cdot G_3$$

$$I_{sc1} = I_{driveAC} \cdot \left(\frac{Z_{brain2} + Z_{brain3} + Z_{contactR}}{Z_{brain2} + Z_{brain3} + Z_{contactR} + Z_{contact1}} \right)$$

$$V_{sc1} = I_{sc1} \cdot R_{FS} = I_{driveAC} \cdot \left(\frac{Z_{brain2} + Z_{brain3} + Z_{contactR}}{Z_{brain2} + Z_{brain3} + Z_{contactR} + Z_{contact1}} \right) \cdot R_{FS}$$

The microprocessor stores the digitized values for the measured V_oc12 (= V_oc2) and V_sc1 (= Isc1), for future use. The driving of the switches is reversed and an identical measurement is carried out.

$I_{driveAC}$

S_1 is open, S_2 is closed:

$$V_{oc1} = I_{driveAC} \cdot (Z_{brain1} + Z_{brain3} + Z_{contactR})$$

$$V_{oc12(1)} = -V_{oc1} \cdot G_1 \cdot G_2 \cdot G_3 = -I_{driveAC} \cdot (Z_{brain1} + Z_{brain3} + Z_{contactR}) \cdot G_1 \cdot G_2 \cdot G_3$$

$$I_{sc2} = I_{driveAC} \cdot \left(\frac{Z_{brain3} + Z_{contactR}}{Z_{brain3} + Z_{contactR} + Z_{contact2}} \right)$$

$$V_{sc2} = I_{sc2} \cdot R_{FB} = I_{driveAC} \cdot \left(\frac{Z_{brain3} + Z_{contactR}}{Z_{brain3} + Z_{contactR} + Z_{contact2}} \right) \cdot R_{FB}$$

By now, the microprocessor has all the information required to calculate the contact impedance balance of the first electrode 110a and the second electrode110b. Given the fact that the contact impedances of the electrodes are dominant, the calculations are simplified as follows.

$$\frac{V_{oc12(2)}}{V_{sc2}} = (Z_{brain3} + Z_{contactR} + Z_{contact2}) \cdot \frac{G_1 \cdot G_2 \cdot G_3}{R_{FB}}$$

$$\frac{|V_{oc12(1)}|}{V_{sc1}} = (Z_{brain1} + Z_{brain3} + Z_{contactR} + Z_{contact1}) \cdot \frac{G_1 \cdot G_2 \cdot G_3}{R_{FB}}$$

$$\frac{V_{oc12(2)}}{V_{sc2}} - \frac{|V_{oc12(1)}|}{V_{sc1}} \sim [(Z]_{contact2} - Z_{contact1}) \cdot \frac{G_1 \cdot G_2 \cdot G_3}{R_{FB}}$$

If the voltage ratio indicates that the impedance difference is higher than, e.g., 100kΩ then the microprocessor can trigger additional circuitry to improve the contact between the electrode with the higher impedance and the person's scalp.

In the following a DC-current measurement will be described. Instead of applying an AC current, it can also be done by means of DC current drive. Fig. 8a shows a simplified drawing an EEG system according to a third example, and Fig. 8b shows a simplified circuit diagram of the third example of Fig. 8a. Compared to Fig. 7a and Fig. 7b, in the block schematic of Fig. 8a and Fig. 8b, the AC current source is replaced by a DC equivalent source. The DC current source is applied to drive current through a human head. The differential stage in the EEG-type circuitry is followed by a high pass filter (HPF) to block any DC component, including our DC measurement signal. Therefore, the signal is tapped of and amplified via an added stage after which it is digitized and interfaced to the microprocessor. Since the HPF in the EEG kind of circuitry blocks any dc component, our dc measurement signal is tapped off and amplified by stage Gain 4.

The switches are driven in a sequential order, and the open circuit voltages and short circuit currents of the two electrodes are measured and stored in the microprocessor.

$I_{driveDC}$

S_1 is closed, S_2 is open:

$$V_{oc2} = I_{driveDC} \cdot (Z_{brain3} + Z_{contactR})$$

$$V_{oc12(2)} = V_{oc2} \cdot G_4 = I_{driveDC} \cdot (Z_{brain3} + Z_{contactR}) \cdot G_4$$

$$I_{sc1} = I_{drivDC} \cdot \left(\frac{Z_{brain2} + Z_{brain3} + Z_{contactR}}{Z_{brain2} + Z_{brain3} + Z_{contactR} + Z_{contact1}}\right)$$

$$V_{sc1} = I_{sc1} \cdot R_{FB} = I_{driveDC} \cdot \left(\frac{Z_{brain2} + Z_{brain3} + Z_{contactR}}{Z_{brain2} + Z_{brain3} + Z_{contactR} + Z_{contact1}}\right) \cdot R_{FB}$$

With V_oc12 (=V_oc2) and V_sc1 (=I_sc1) being measured and stored in the microprocessor, the driving of the switches is reversed.

$I_{driveDC}$

S_1 is open, S_2 is closed:

$$V_{oc1} = I_{driveDC} \cdot (Z_{brain2} + Z_{brain3} + Z_{contactR})$$

$$V_{oc12(1)} = -V_{oc1} \cdot G_1 \cdot G_2 \cdot G_3 = -I_{driveDC} \cdot (Z_{brain2} + Z_{brain3} + Z_{contactR}) \cdot G_4$$

$$I_{sc2} = I_{drivDC} \cdot \left(\frac{Z_{brain3} + Z_{contactR}}{Z_{brain3} + Z_{contactR} + Z_{contact2}}\right)$$

$$V_{sc2} = I_{sc2} \cdot R_{FB} = I_{driveDC} \cdot \left(\frac{Z_{brain3} + Z_{contactR}}{Z_{brain3} + Z_{contactR} + Z_{contact2}}\right) \cdot R_{FB}$$

At this moment in time, the microprocessor has all the information on board to calculate the contact impedance balance. Given the fact that the contact impedances of the electrodes are dominant, the calculations are simplified as follows.

$$\frac{V_{oc12(2)}}{V_{sc2}} = (Z_{brain2} + Z_{contactR} + Z_{contact2}) \cdot \frac{G_4}{R_{FB}}$$

$$\frac{|V_{oc12(1)}|}{V_{sc1}} = (Z_{brain1} + Z_{brain2} + Z_{contactR} + Z_{contact1}) \cdot \frac{G_4}{R_{FB}}$$

$$\frac{V_{oc12(2)}}{V_{sc2}} - \frac{|V_{oc12(1)}|}{V_{sc1}} \sim [(Z]_{contact2} - Z_{contact1}) \cdot \frac{G_4}{R_{FB}}$$

Based on this value the microprocessor can give a trigger to additional circuitry. In turn this circuitry takes measures to improve the contact impedance of a particular electrode. Similar reasoning can be applied to the more elaborate case where we combine the current driven through the head from right to left with the current driven through the head from left to right.

In the following an alternative for a typical so-called “Driven Right Leg” will be explained. In the world we live in nowadays, we are surrounded by magnetic and electrical sources. Each one is a potential source of interfering with brain wave measurements. From an electronic point of view, all these sources may be lumped into one source and connected to the user or person, which is illustrated by V_interference in Fig. 9a and Fig. 9b.

Fig. 9a shows a simplified drawing an EEG system according to a fourth example, and Fig. 9b shows a simplified circuit diagram of the fourth example of Fig. 9a. The surrounding interfering sources are lumped into one voltage source V_interference and connected to the head of the user or person (human). In the electronic schematic or circuit diagram of Fig. 9b, this voltage source V_interference lifts both input nodes of the first stage in the EEG instrumentation. Due to the limited Common Mode Rejection Rate (CMRR) of this stage, the output will suffer from an unwanted DC level. Related to the ground of the electronic circuitry, the person is at a certain DC level. Both input nodes of the differential stage in the EEG instrumentation are lifted to the level defined by V_interference. Next to the wanted difference signal ‘Vpos - Vneg’ also ‘Vpos + Vneg’ contributes to the output signal of this stage.

$$V_{out} = G_{diff} \cdot (V_{pos} - V_{neg}) + \frac{G_{com}}{2} \cdot (V_{pos} + V_{neg})$$

$$G_{diff} \gg G_{com}$$

Even though the gain for common mode signals is much smaller than for differential mode signals, for a high enough interference signal should not be neglected. To minimize the contribution of ‘Vpos + Vneg’ in the output signal, the current source touching the left ear may be driven to counter react on V_interference. In turn, ‘Vpos + Vneg’ at the input nodes is adjusted to zero. In a typical EEG measurement system then this problem is dealt with it in a slightly different way. The right leg of a person is connected to a feed-back controlled voltage / current source, which is regulated to counter the induced interference voltage level. With the present current sources in our proposed system, the use of a so-called Driven Right Leg (DRL) circuitry is no longer needed.

The electrode or pins can be made of conductive metal or metal-alloy (e.g., silver, silver-chloride, or gold). The pin-structured, dry electrodes can provide flexibility. In a first example, the flexibility is achieved by allowing the free end of the pin (the one that penetrates the hair) to move to a certain degree in the plane orthogonal to the pin’s. The pins can for example be arranged in a flexible substrate. In a second example, the flexibility can be achieved using spring loaded pins that have a rigid support to increase the efficiency of the springs and a layer with conductive material. In a third example, the aforementioned examples can be combined into a single solution with spring loaded pins that can move to a certain degree in the plane orthogonal to the pin’s axis.

Fig. 10 shows a schematic diagram of an electrode 110a, 110b having a ball-socket-join 177 in two different positions. The pin-structured electrode 110a, 110b has a rigid support 172 used as a base for providing better pressure distribution to all the pins 171 in one electrode 110a, 110b. The support 172 can be a simple rectangular or round surface, or can comprise of a ball-and-socket join 177 as shown in Fig. 10. The latter embodiment shown in Fig. 10 introduces another layer of flexibility that can further improve the pressure distribution, hence better balance the electrode-skin contact impedance.

Fig. 11 shows a schematic diagram of an electrode 110a, 110b contacting the scalp of a user 1. In this example the control unit 150 is further configured to control motion of the electrode 110a, 110b in a plane perpendicular to the axial direction A. This motion is indicated by a two-sided arrow in Fig. 11. This motion can in particular be a rotational motion. The pin structured electrode 100a, 110b of Fig. 11 is driven by an actuator 174 in form of an electrode motor, clock wise and/or anti clock wise. By doing so, the pins are more likely to penetrate through the hair to make proper contact to the person his scalp. Fig. 11 illustrates an example using an vibration motor that can help the pins to penetrate through hair and exert the required pressure (e.g. obtain the desired balance of skin-electrode contact impedance). The electrode support structure can be driven clock wise or anti clock wise by means of a small electro motor. If we assume that a particular electrode is identified as the one that is not in proper contact to the skin, by means of the electrode motor 174, the pins 171 are driven clock wise and/or anti clock wise for a short period of time. Due to the flexibility of the pins 171, no risk of pulling the hair exists and the pins 171 are likely to penetrate through the layer of hair to make proper contact to the scalp of the user or person 1. In the case of baldness, the same mechanism can be used to slightly rub the skin to improve the contact. The impedance-vibration step may be repeated multiple times to ensure a low ohmic contact. In the example of Fig. 11 each pin further comprises a spring 176, as explained above.

The system 100 described herein can further comprise a wearable device 200 configured to be put at least partly around the head of a user 1, the wearable device 200 comprising a support structure 175 for supporting the electrodes. The wearable device 200 can be integrated in or be a head band, head cap, headset, helmet, or the like. The support structure 175 can for example be in the form of a patch. Fig. 12 shows a schematic diagram of a patch 175. In Fig. 12 eight dry electrodes 110a-h with pins are arranged on the (EEG) patch 175. The patch 175 is a deformable or a textile-like material. The patch 175 can be used to integrate the pin-structured electrodes 110a-h and their support system in the wearable device 200 that can be placed on a person's head, such that it covers the area of the brain from which the electrical signals should be obtained. The (EEG) patch 175 enables the electrode support system to follow the curvature of the head. While a textile-like material will adapt its structure to the curvature of a person's head, a deformable material might be used instead that can be modeled by the person using the EEG system such that it fits to his/her head. The patch 175 can be positioned on or around the head of the user using the wearable device 200 (e.g. a head band, head cap, headset, helmet or the like).

Fig. 13a shows a perspective view of a wearable device 200 in form of a head band. Fig. 13b shows a perspective view of the wearable device 200 of Fig. 13a put around the head of a user 1. The wearable device 200 comprises a (EEG) patch 175 as described with reference to Fig. 12. For example an elastic Velcro strap 220 can be used to increase the pressure on the electrodes and consequently electrode-skin contact impedance. Depending on the exact usage case of the system or wearable device, the (EEG) patch 175 might be positioned at different locations on a person's head. The wearable device 200 can comprise a stretchable band 210 which loops around the circumference of the head of the user 1. The patch 175 and the Velcro strap 220 can be arranged on the stretchable band 210, as shown in Fig. 13a and Fig. 13b.

The connection between the positioning element and the (EEG) patch can be achieved using a rigid element or an elastic one. In both cases, each electrode support system must be paired with a single positioning element to provide independent pressure adjustments for each electrode and allow for maximum flexibility of each pin-structured electrode. Many embodiments can be realized, ranging from the simple one where elastic Velcro straps are used as a positioning element connected to a headband with an elastic Velcro strap, as shown in Fig. 13a and Fig. 13b, to a rigid helmet or headphones with e.g., plastic elements that hold each electrode in place. Such wearable device is for example disclosed in WO2011/055291 A1, which is incorporated by reference herein.

Fig. 14 shows two schematic diagrams of a patch with an electrode with two different amounts of pressure applied. In the upper diagram of Fig. 14 a first lower pressure is applied in an axial direction A and in the lower diagram of Fig. 14b a second higher pressure compared to the first pressure is applied in the axial direction A. As can be seen in Fig. 14, increasing the pressure by the actuator corresponds to tightening (manually) the elastic strap connection between the electrode and the headband which will exert more pressure to the (EEG) electrode 110a, 110b through the pressure component orthogonal to the electrode surface.

The present invention can be applied in the area of brain signal acquisition systems used in the clinical and consumer domain. They range from practical headset designs for EEG measurements, to clinically designed headsets for EEG patient monitoring at home. The clinical relevance can be seen in the areas of post-surgical recovery monitoring and rehabilitation and in providing alternative or complementary communication and/or control channels. The commercial value of the applications in the consumer arena is in the area of Neurofeedback for improving cognition and enhancing relaxation, in the area of prevention and monitoring of mental health, and in gaming market, especially in games that include BCI technology.

An important application for convenient brain wave sensing technology is Alpha Neurofeedback. Alpha Neurofeedback (NF) is a novel method which may find application areas both in consumer and professional healthcare products. NF induces a feeling of ease in a person without the person feeling the burden of responsibility for his own mental state. This is particularly relevant for a hospital setting, where the user, or patient, is put at ease in a very subtle way without requiring them to be aware of the effect of NF. This is important for a hospital setting as it means the patient is not burdened with the feeling of being responsibly of having to relax. Any such burden, especially when coupled to the quality of for example a MR or PET scan, can be counterproductive and often induces stress rather than reducing it.

In the clinical domain the usage of Alpha Neurofeedback can provide natural and relaxing experience, e.g., to patients in the uptake procedure for PET scans. As the NF setup requires the usage of electrodes the proposed invention can help in developing a convenient setup that would not impose additional burden to the patients. The solution can be realized either as a specially designed headset or be integrated in the chair (armchair) where the patient sits or lays down before the clinical procedure. In the later the complete setup should be integrate in the chair where a person positions the back of his head.

While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single element or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems.

Any reference signs in the claims should not be construed as limiting the scope.

CLAIMS:

1. An EEG system comprising:

- a first EEG electrode (110a) for contacting skin (2) of a user (1), the first EEG electrode (110a) providing a first EEG signal (111a) of the user (1) and providing a first impedance signal (112a) comprising at least one impedance value of the first electrode (110a) with respect to the skin (2),
- a second EEG electrode (110b) for contacting skin (2) of the user (1), the second EEG electrode (110b) providing a second EEG signal (111b) of the user (1) and providing a second impedance signal (112b) comprising at least one impedance value of the second electrode (110b) with respect to the skin (2), and
- a determination unit (140) for determining, based on the first impedance signal (112a) and the second impedance signal (112b), an impedance difference value (ΔZ) indicating a difference between an impedance value of the first electrode (110a) with respect to the skin (2) and an impedance value of the second electrode (110b) with respect to the skin (2).

2. The system of claim 1, further comprising a current source (180), and wherein each impedance signal (112a, 112b) is an electrical signal measured when the current source (180) is active.

3. The system of claim 2, further comprising at least one switch (S_1, S_2) for determining, for each electrode (110a, 110b), an open circuit voltage (Voc_1, Voc_2) when the switch (S_1, S_2) is open and for determining a short circuit current (Isc_1, Isc_2) when the switch (S_1, S_2) is closed, wherein each impedance signal (112a, 112b) is based on the open circuit voltage (Voc_1, Voc_2) and the short circuit current (Isc_1, Isc_2).

4. The system of claim 1, each electrode (110a, 110b) comprising a pressure sensor (173), and wherein each impedance signal (112a, 112b) is a pressure sensor signal provided by the respective pressure sensor (173).

5. The system of claim 1, further comprising more than two electrodes (110a-d), the determination unit (140) configured to determine, based on the impedance signals provided by the electrodes, impedance difference values for pairs of electrodes.

6. The system of claim 1, further comprising a control unit (150) for controlling in an axial direction (A) pressure on the first electrode (110a) and/or pressure on the second electrode (110b) depending on the impedance difference value (ΔZ).

7. The system of claim 6, wherein each electrode (110a, 110b) comprises an actuator (174) for increasing and/or decreasing the pressure on the respective electrode (110a, 110b).

8. The system of claim 6, the control unit (150) further configured to control motion of the electrode (110a, 110b) in a plane perpendicular to the axial direction (A).

9. The system of claim 6, wherein the determination unit (140) is configured to determine the impedance difference value (ΔZ) continuously or repeatedly.

10. The system of claim 1, each electrode (110a, 110b) comprising a plurality of pins (171) for contacting the skin of the user (1).

11. The system of claim 1, further comprising a wearable device (200) configured to be put at least partly around the head of a user (1), the wearable device (200) comprising a support structure (175) for supporting the electrodes (110a, 110b).

12. The system of claim 1, further comprising an EEG processing unit (120) for processing the first EEG signal (111a) and the second EEG signal (112a).

13. A method of operating an EEG system, the method comprising:

- receiving a first EEG signal (111a) provided by a first EEG electrode (110a) for contacting skin (2) of a user (1),
- receiving a second EEG signal (111b) provided by a second EEG electrode (110b) for contacting skin (2) of a user (1),
- receiving a first impedance signal (112a) provided by the first EEG electrode

(110a), the first impedance signal (112a) comprising at least one impedance value of the first electrode (110a) with respect to the skin,

- receiving a second impedance signal (112b) provided by the second EEG electrode (110b), the second impedance signal (112b) comprising at least one impedance value of the second electrode (110b) with respect to the skin, and
- determining, based on the first impedance signal (112a) and the second impedance signal (112b), an impedance difference value (ΔZ) indicating a difference between an impedance value of the first electrode (110a) with respect to the skin (2) and an impedance value of the second electrode (110b) with respect to the skin (2).

14. A computer program comprising program code means for causing a computer to carry out the steps of the method as claimed in claim 13 when said computer program is carried out on the computer.

15. An electrode pressure control system for controlling pressure in an axial direction on an electrode (110a, 110b), the system (100) comprising:

- a first electrode (110a) for contacting skin of a user (1), the first electrode (110a) providing a first physiological signal (111a) of the user (1) and providing a first impedance signal (112a) comprising at least one impedance value of the first electrode (110a) with respect to the skin,
- a second electrode (110b) for contacting skin (2) of the user (1), the second electrode (110b) providing a second physiological signal (111b) of the user (1) and providing a second impedance signal (112b) comprising at least one impedance value of the second electrode (110b) with respect to the skin,
- a determination unit (140) for determining, based on the first impedance signal (112a) and the second impedance signal (112b), an impedance difference value (ΔZ) indicating a difference between an impedance value of the first electrode (110a) with respect to the skin and an impedance value of the second electrode (110b) with respect to the skin, and
- a control unit (150) for controlling the pressure on the first electrode (110a) and/or the pressure on the second electrode (110b) depending on the impedance difference value.

16. An electrode pressure control system for controlling pressure in an axial direction on an electrode (110a, 110b), the system (100) comprising:

- a first electrode (110a) for contacting skin of a user (1), the first electrode (110a) providing a first physiological signal (111a) of the user (1),
- a first pressure sensor (173) for providing a first pressure sensor signal (112a) indicating the pressure on the first electrode (110a, 110b), and
- a control unit (150) for controlling the pressure on the first electrode (110a) depending on the first pressure sensor signal.

17. The system of claim 16, further comprising:

- a second electrode (110b) for contacting the skin of a user (1), the second electrode (110b) providing a second physiological signal (111b) of the user (1), and
- a second pressure sensor (173) for providing a second pressure sensor signal (112b) indicating the pressure on the second electrode (110a, 110b),
- the control unit (150) configured to control the pressure on the first electrode (110a) and/or the pressure on the second electrode (110b) based on the first pressure sensor signal and the second pressure sensor signal such that the pressure on the first electrode (110a) and the pressure on the second electrode (110b) is balanced.

18. The system of claim 17, the control unit (150) configured to select a desired pressure value based on the first pressure sensor signal (112a) and the second pressure sensor signal (112b), and to control the pressure on the first electrode (110a) and the pressure on the second electrode (110b) such that this desired pressure value is achieved for the first electrode (110a) and the second electrode (110b).

19. The system of claim 18, wherein the specific value is a mean value of the pressure on the first electrode (100a) and the pressure on the second electrode (110b).

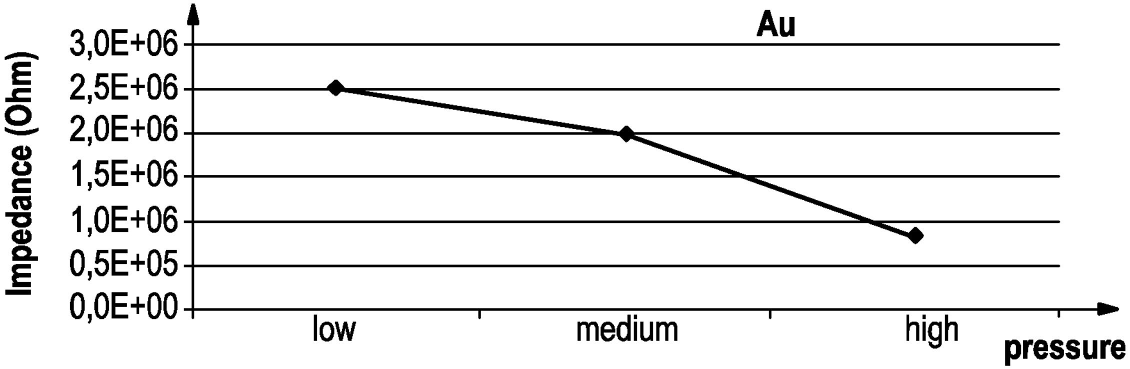

Au
Impedance (Ohm)
3,0E+06
2,5E+06
2,0E+06
1,5E+06
1,0E+06
0,5E+05
0,0E+00
low
medium
high
pressure

FIG. 1a

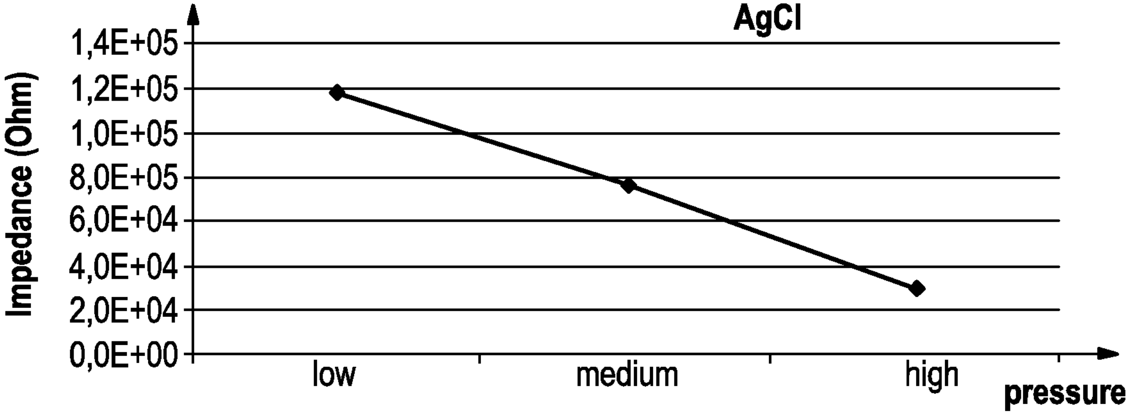

AgCl
Impedance (Ohm)
1,4E+05
1,2E+05
1,0E+05
8,0E+05
6,0E+04
4,0E+04
2,0E+04
0,0E+00
low
medium
high
pressure

FIG. 1b

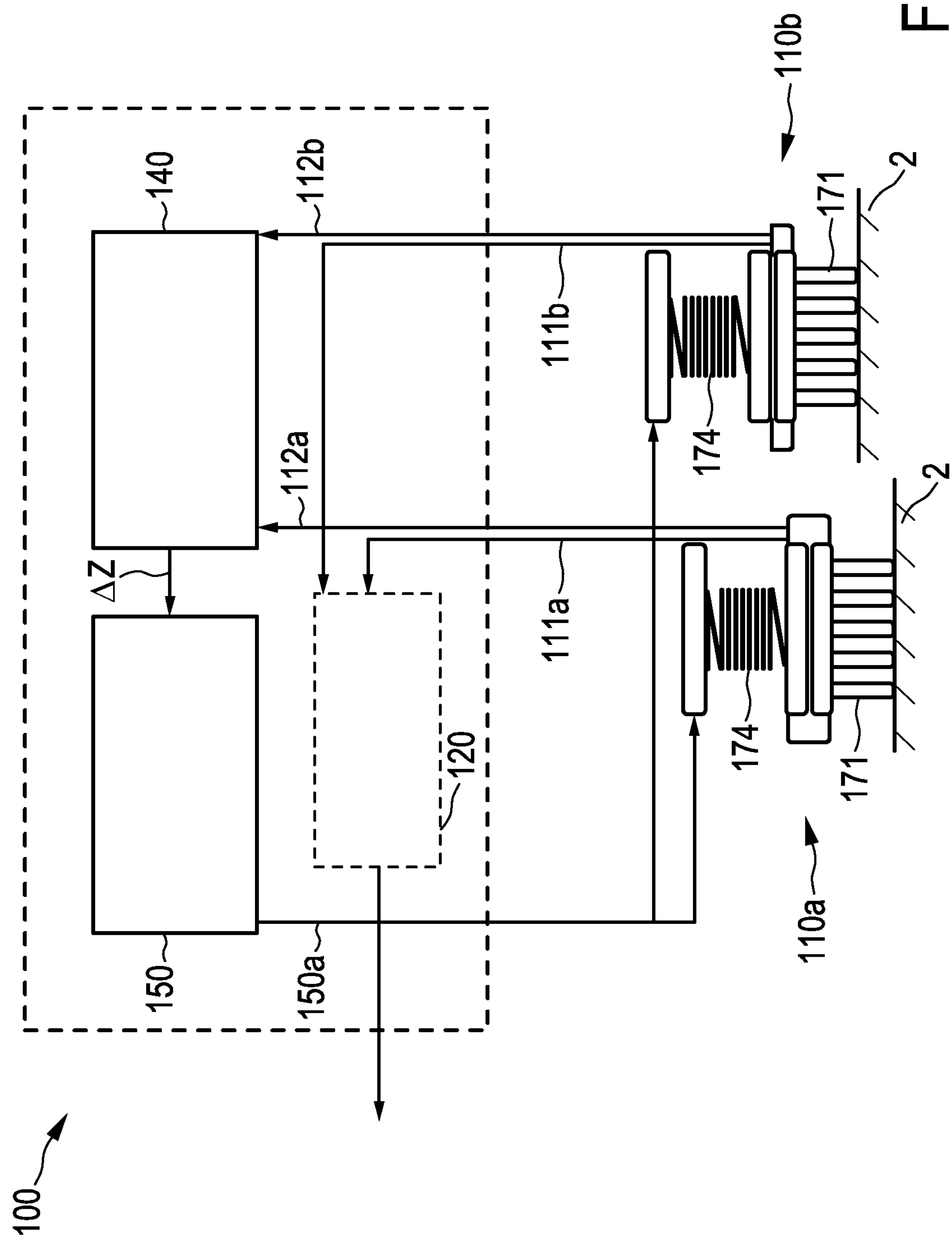

100
140
150
112b
112a
ΔZ
150a
120
111b
111a
174
174
171
171
2
2
110a
110b

FIG. 2

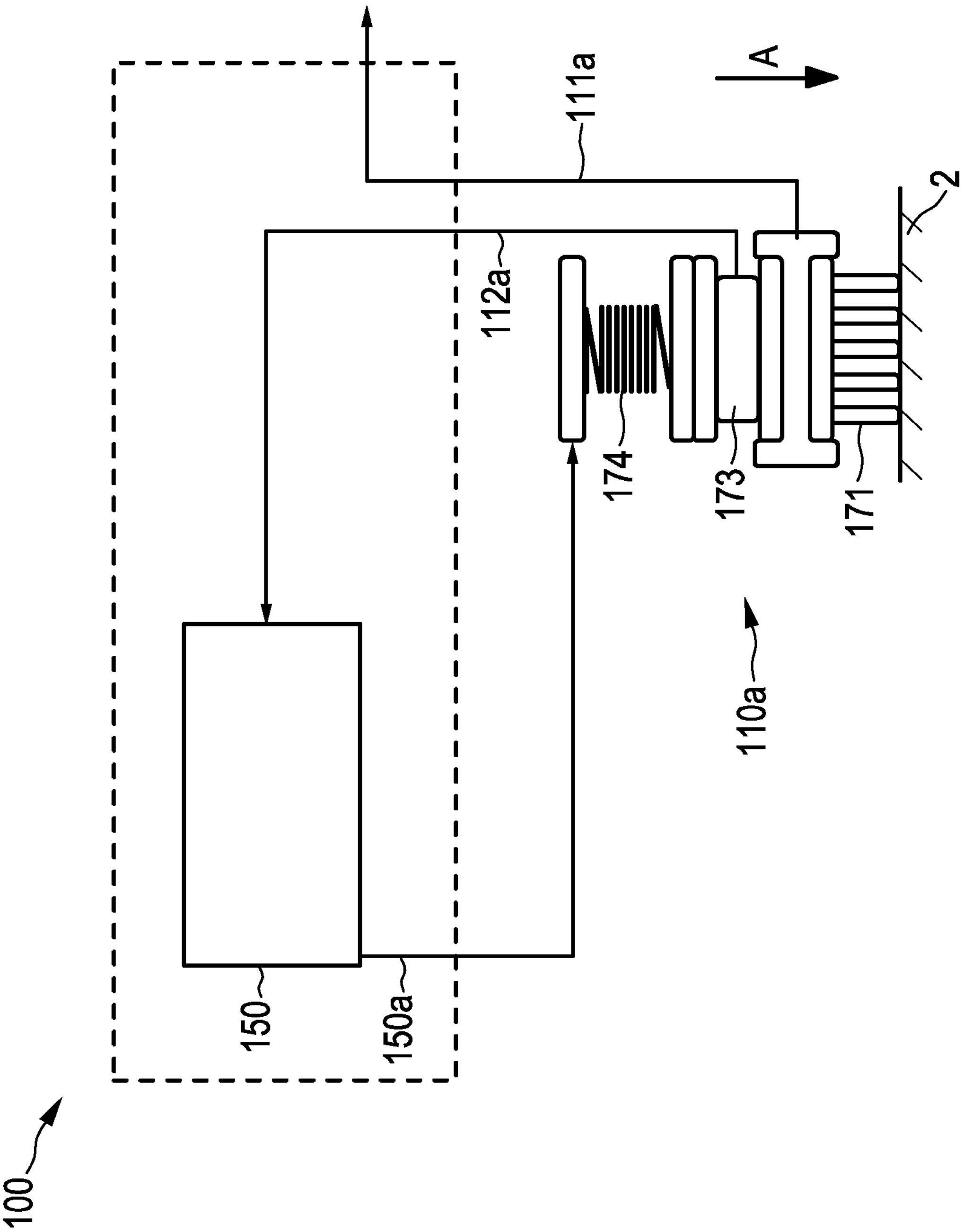


FIG. 3

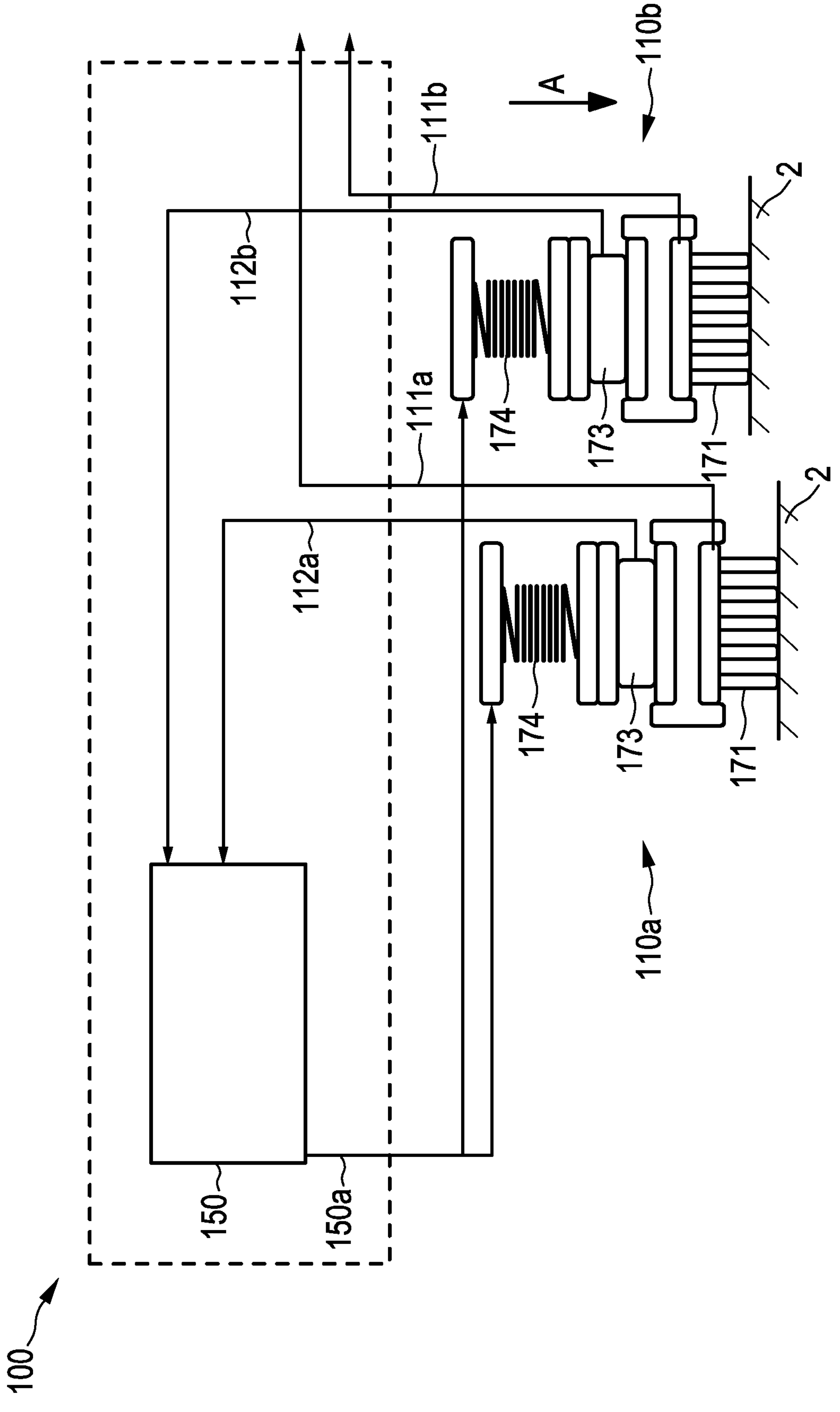

100
150
150a
112a
112b
111a
111b
A
110a
110b
174
173
171
2
174
173
171
2

FIG. 3a

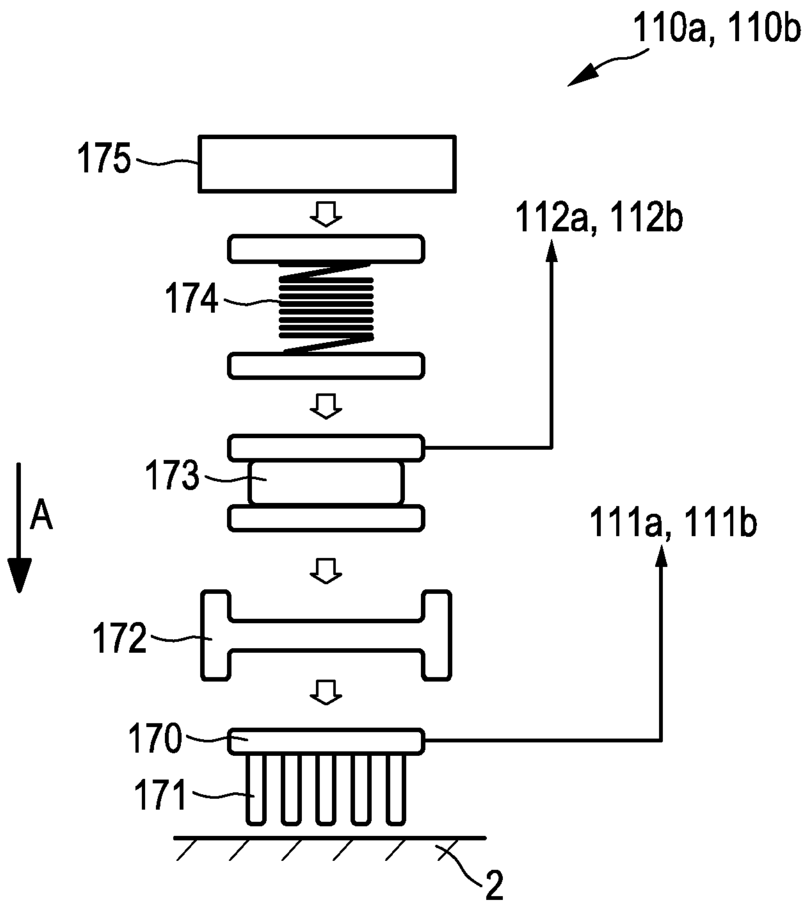


FIG. 3b

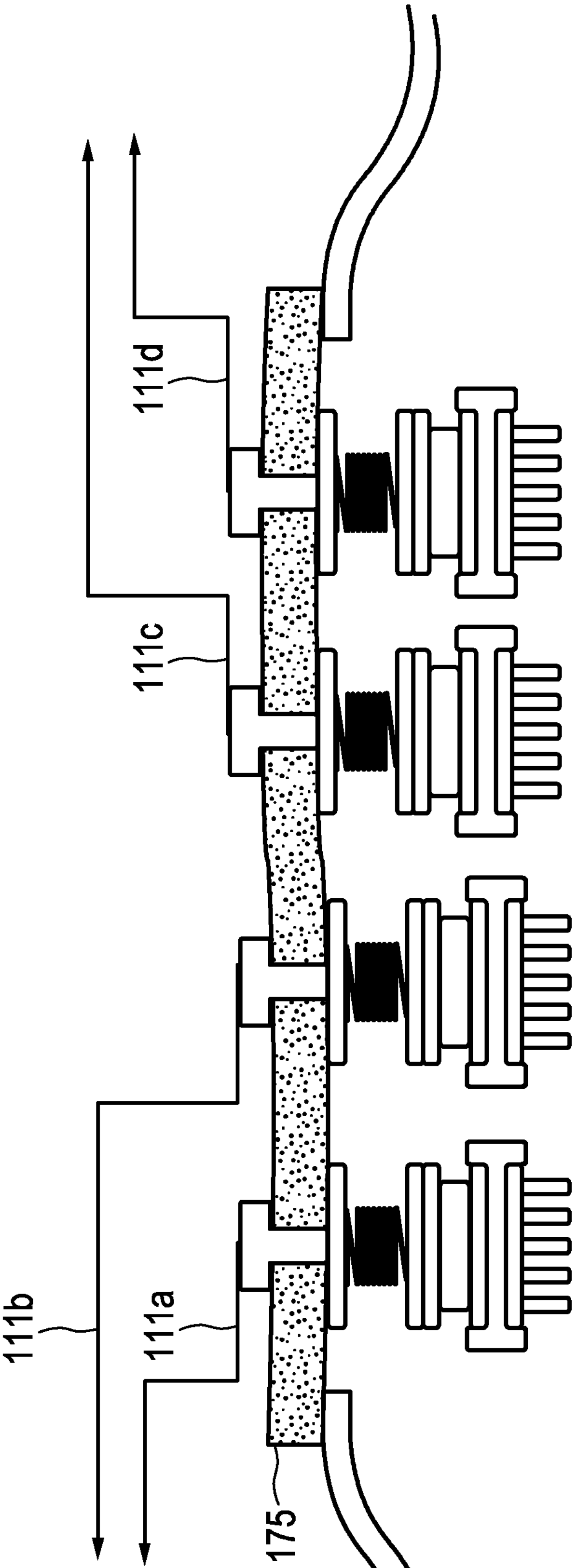


FIG. 4

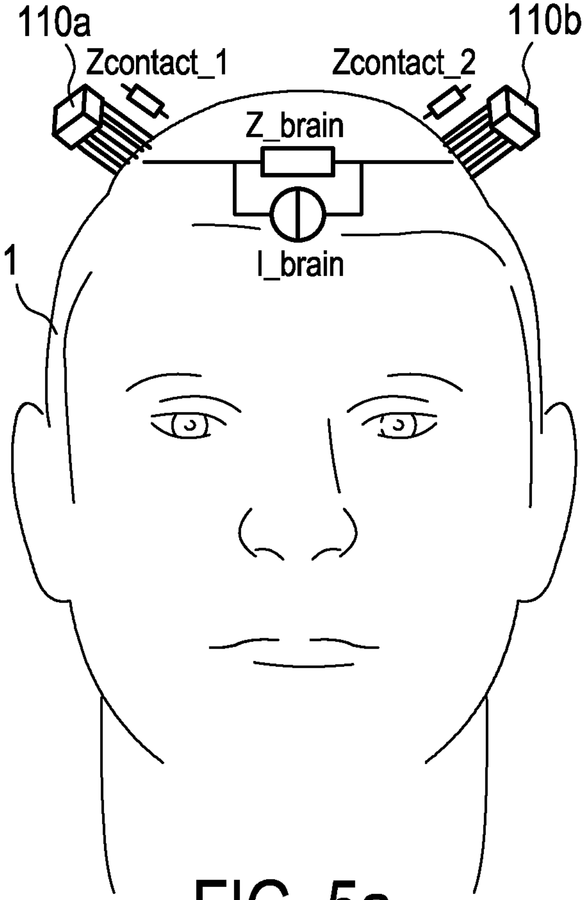

110a
Zcontact_1
Zcontact_2
110b
Z_brain
I_brain
1

FIG. 5a

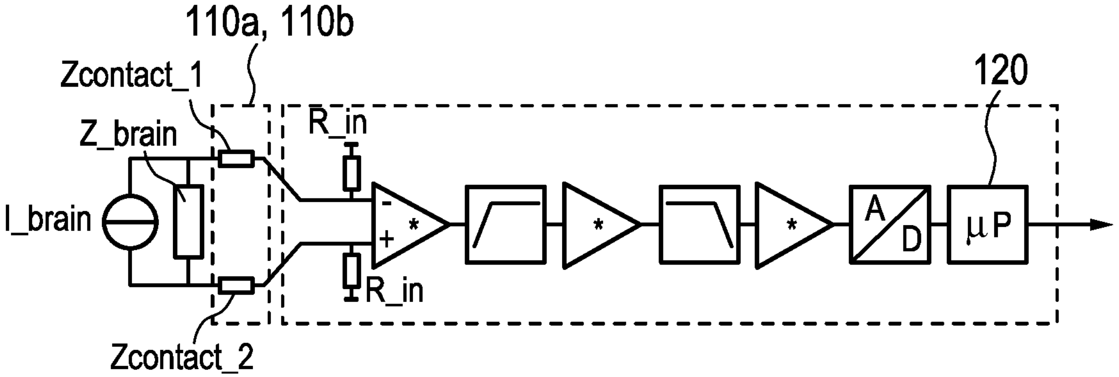

110a, 110b
Zcontact_1
Z_brain
I_brain
Zcontact_2
R_in
R_in
-
+
*
*
*
A
D
μP
120

FIG. 5b

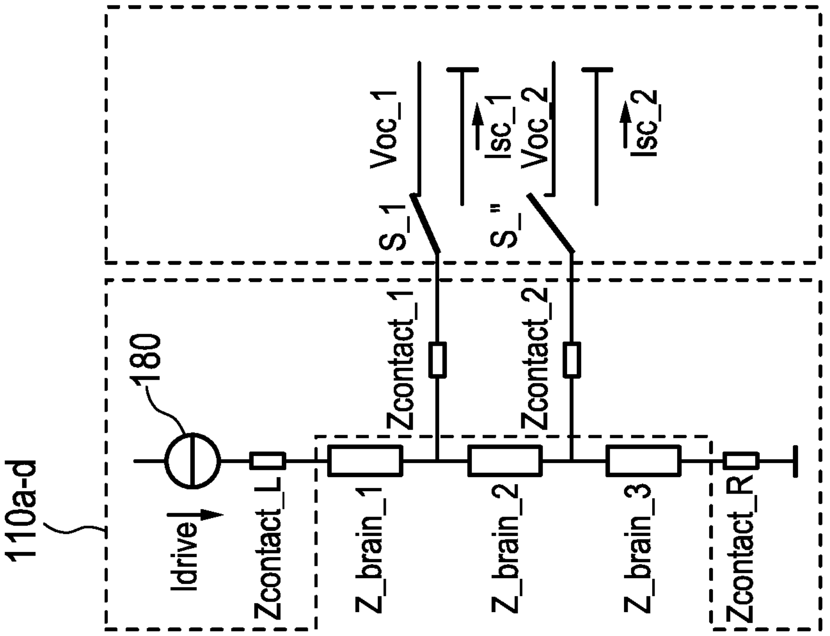

110a-d
180
Idrive
Zcontact_L
Z_brain_1
Z_brain_2
Z_brain_3
Zcontact_R
Zcontact_1
Zcontact_2
S_1
S_"
Voc_1
Isc_1
Voc_2
Isc_2

FIG. 6B

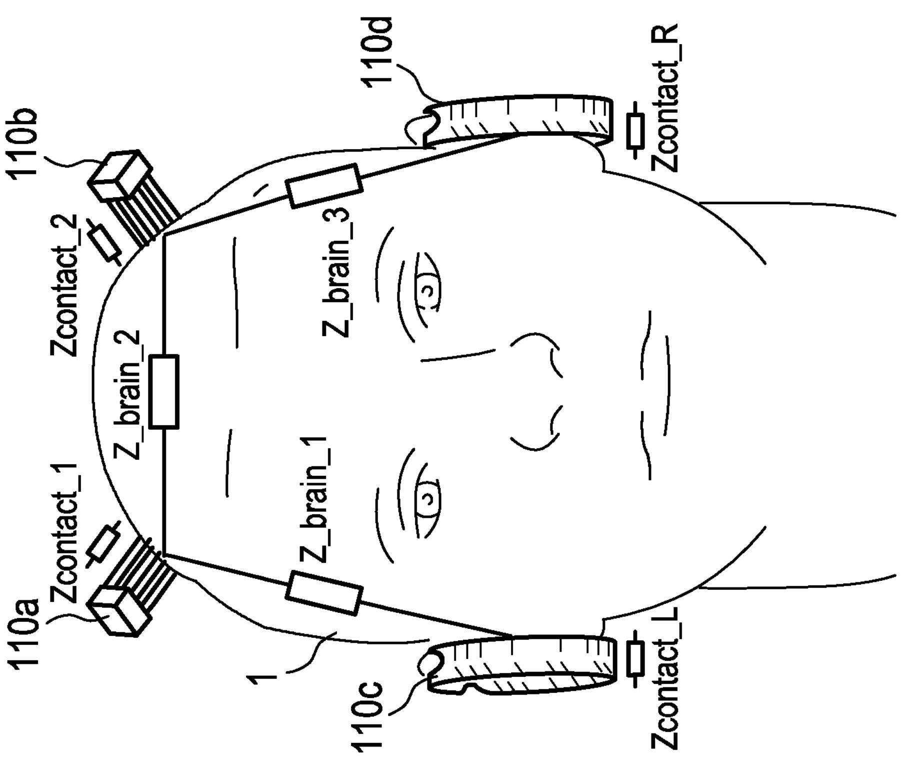

110a
110b
110c
110d
1
Zcontact_1
Zcontact_2
Z_brain_1
Z_brain_2
Z_brain_3
Zcontact_L
Zcontact_R

FIG. 6a

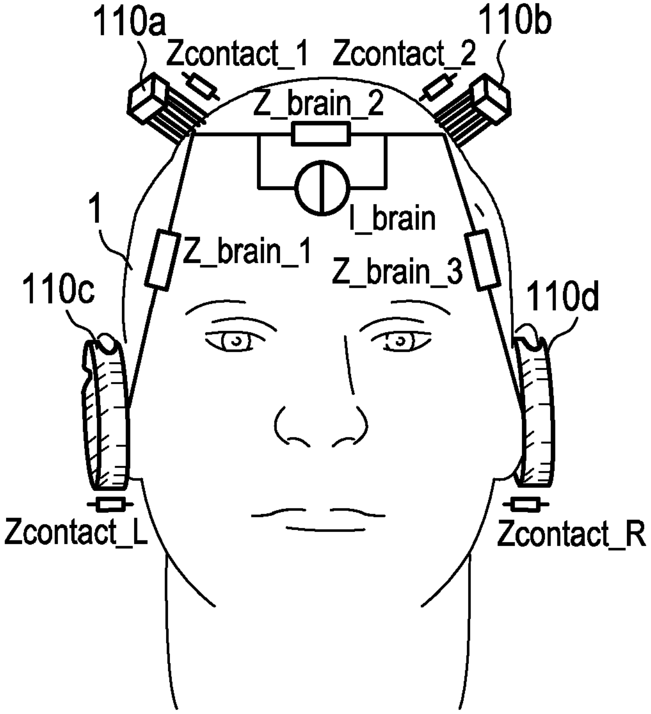

110a
Zcontact_1
Zcontact_2
110b
Z_brain_2
1
I_brain
Z_brain_1
Z_brain_3
110c
110d
Zcontact_L
Zcontact_R

FIG. 7a

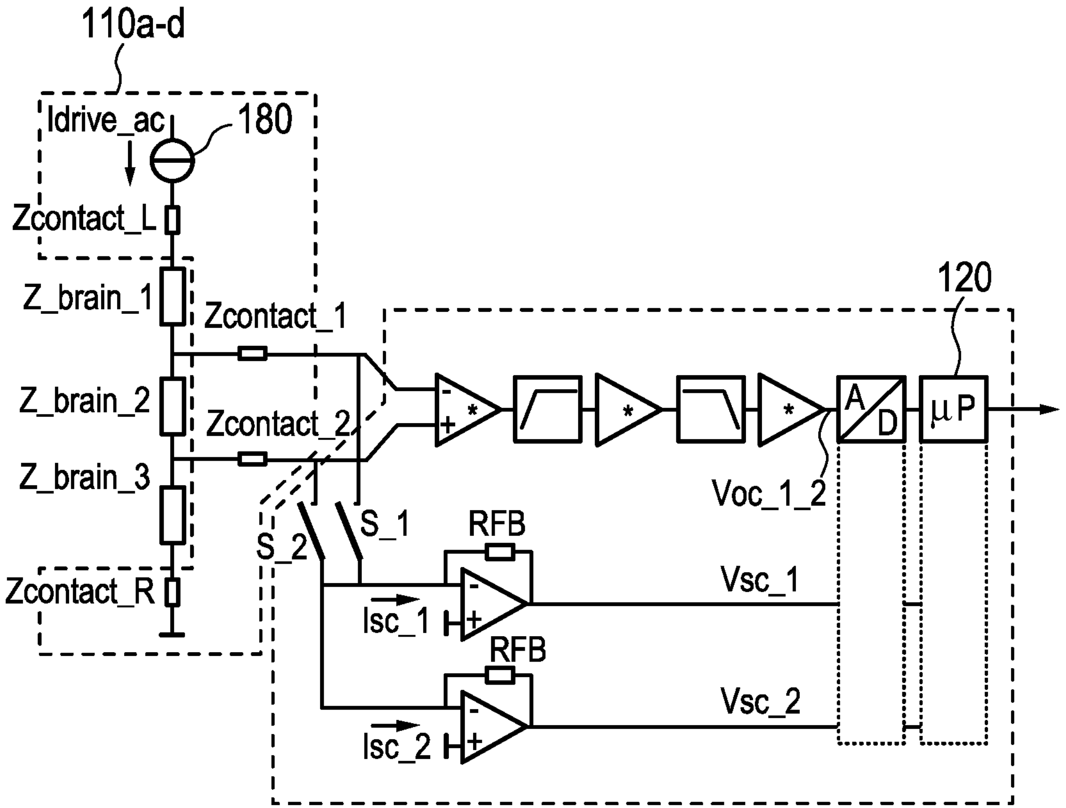

110a-d
Idrive_ac
180
Zcontact_L
Z_brain_1
Zcontact_1
Z_brain_2
Zcontact_2
Z_brain_3
Zcontact_R
S_2
S_1
RFB
RFB
Isc_1
Isc_2
Vsc_1
Vsc_2
Voc_1_2
A
D
µP
120
-
+
*

FIG. 7b

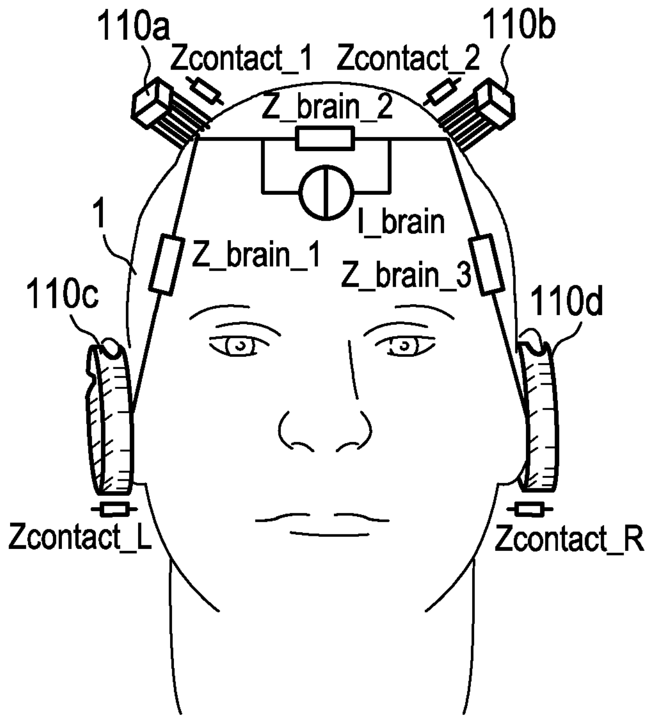

110a
Zcontact_1
Zcontact_2
110b
Z_brain_2
I_brain
1
Z_brain_1
Z_brain_3
110c
110d
Zcontact_L
Zcontact_R

FIG. 8a

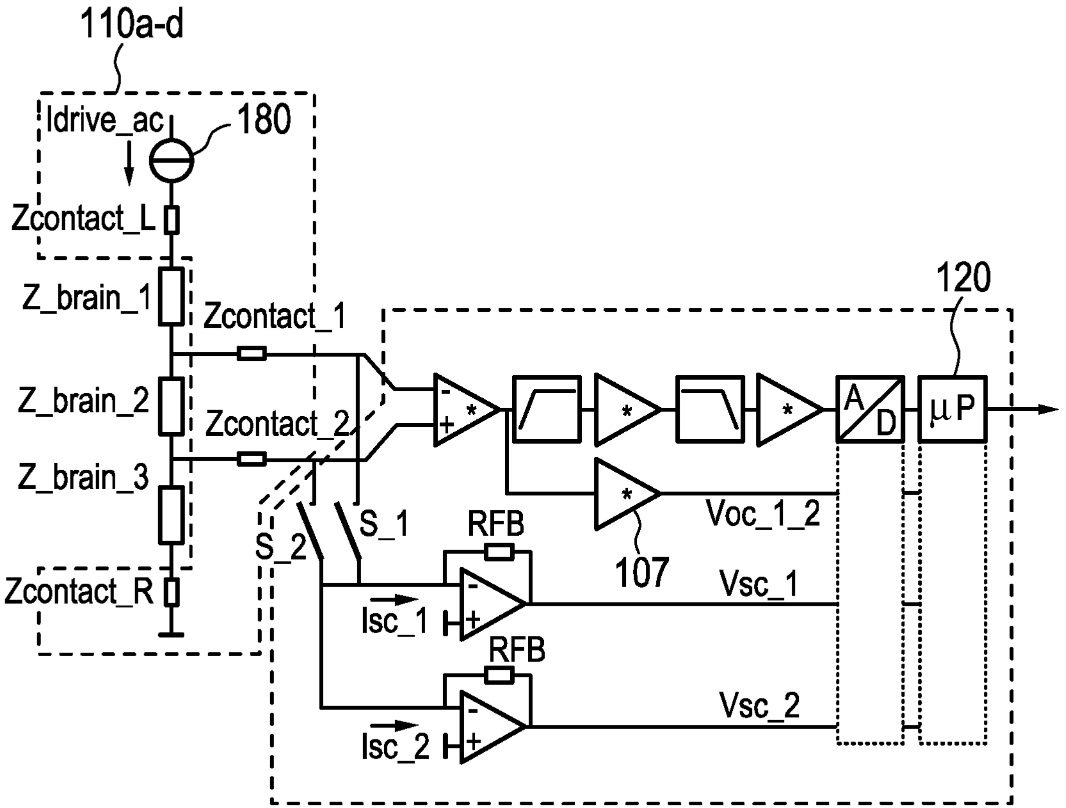

110a-d
Idrive_ac
180
Zcontact_L
Z_brain_1
Zcontact_1
Z_brain_2
Zcontact_2
Z_brain_3
Zcontact_R
S_1
S_2
RFB
Isc_1
RFB
Isc_2
120
A
D
µP
Voc_1_2
107
Vsc_1
Vsc_2

FIG. 8b

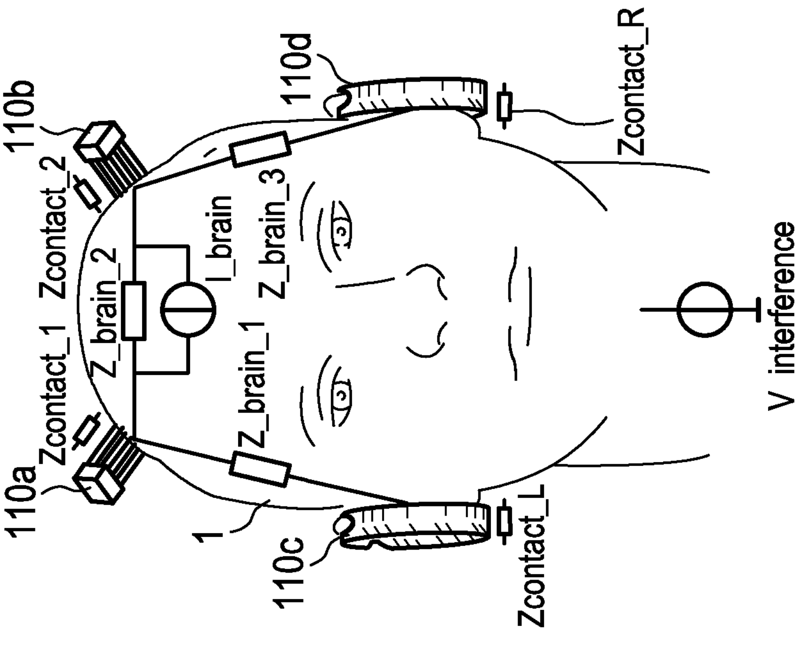

110a
110b
110c
110d
1
Zcontact_1
Zcontact_2
Z_brain_1
Z_brain_2
Z_brain_3
I_brain
Zcontact_L
Zcontact_R
V_interference

FIG. 9a

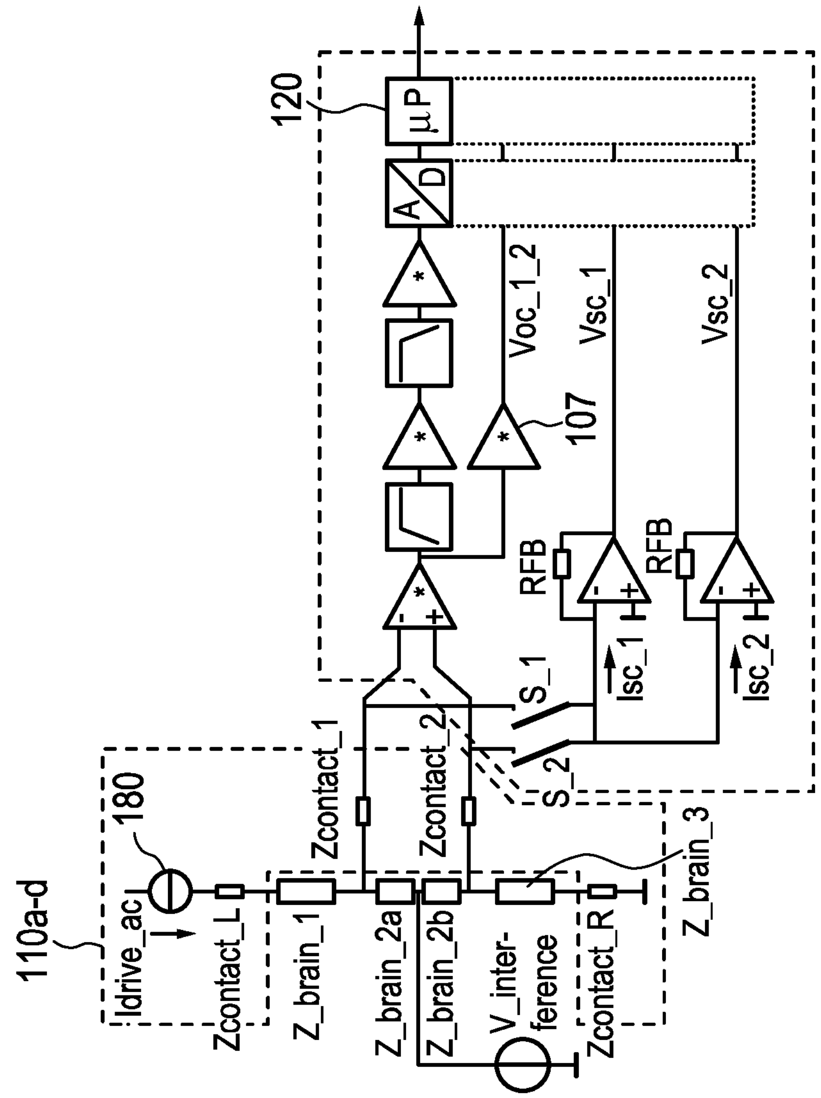

110a-d
180
Idrive_ac
Zcontact_L
Z_brain_1
Z_brain_2a
Z_brain_2b
V_inter-ference
Zcontact_R
Z_brain_3
Zcontact_1
Zcontact_2
S_1
S_2
Isc_1
Isc_2
RFB
RFB
107
Voc_1_2
Vsc_1
Vsc_2
A
D
μP
120

FIG. 9b

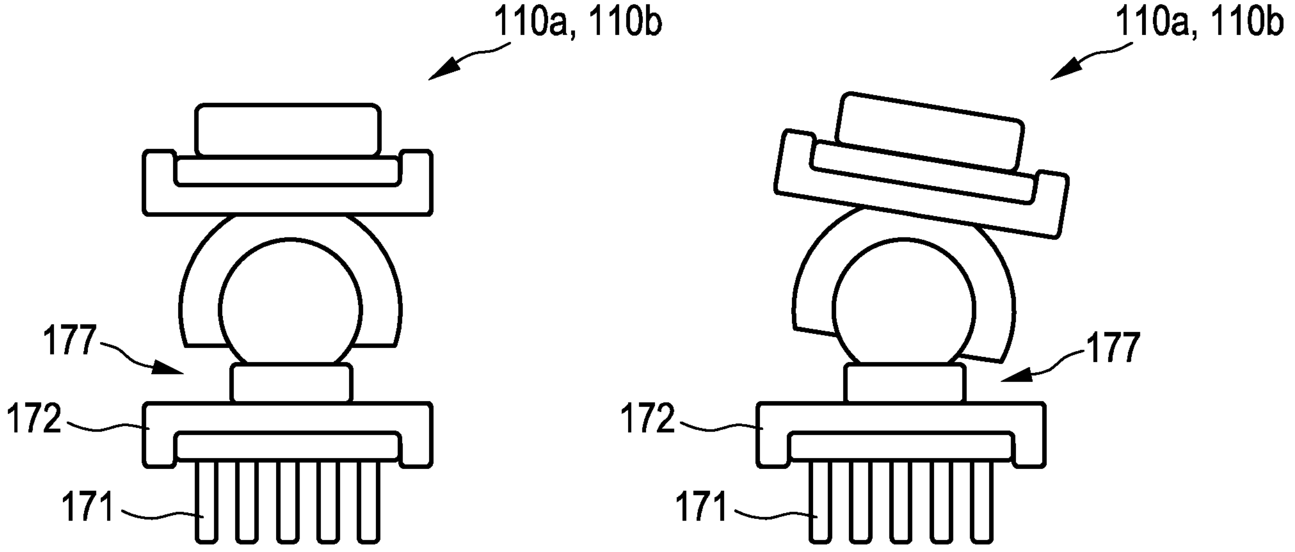


FIG. 10

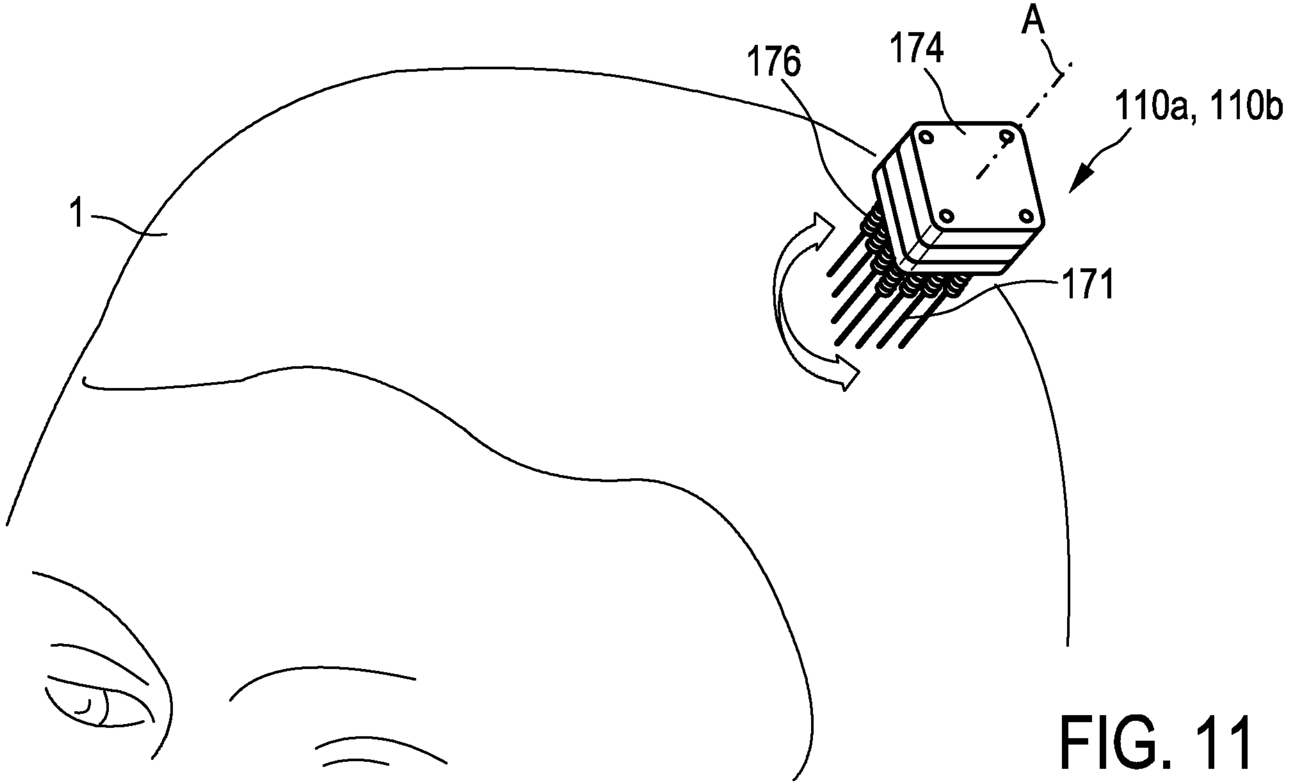


FIG. 11

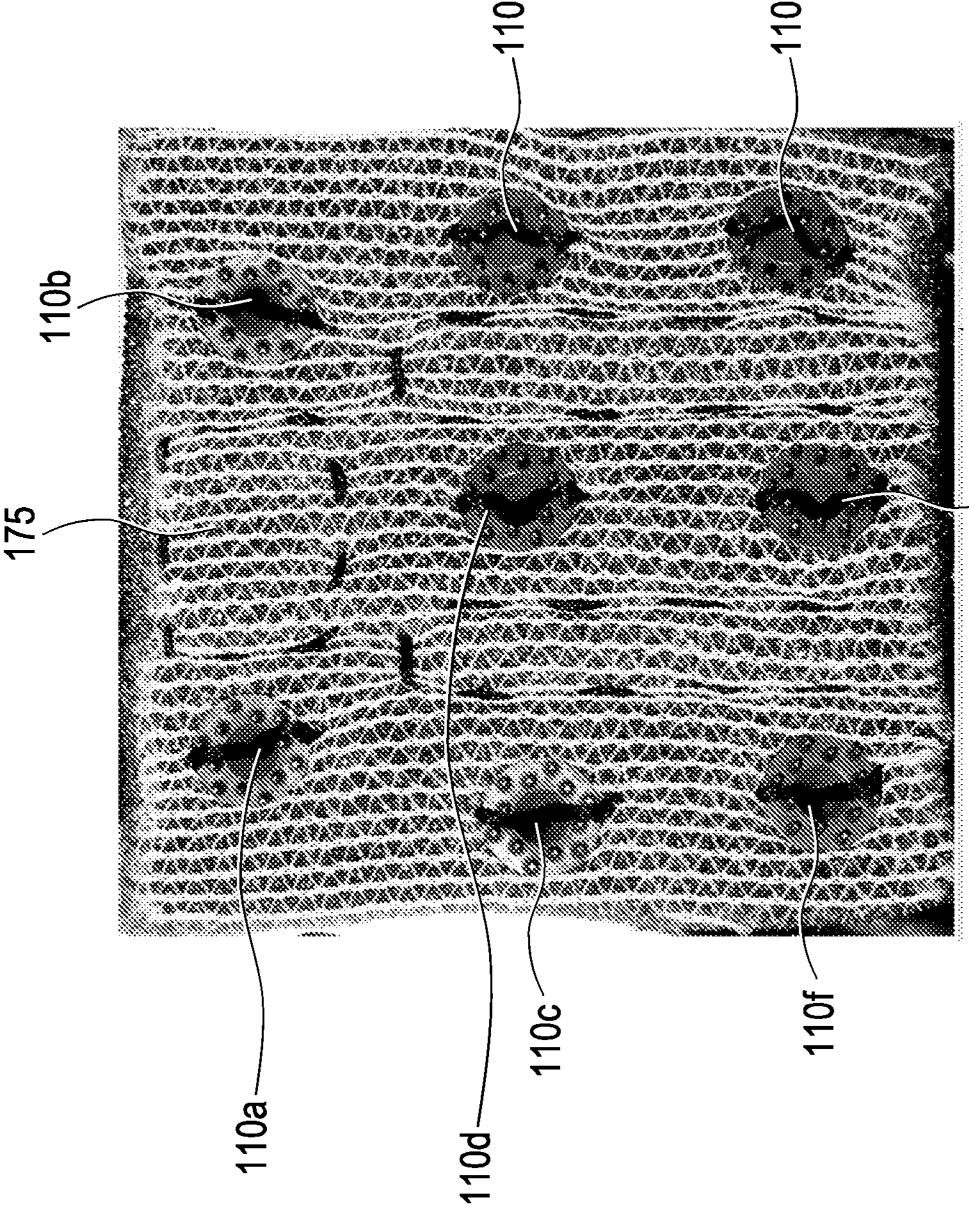


FIG. 12

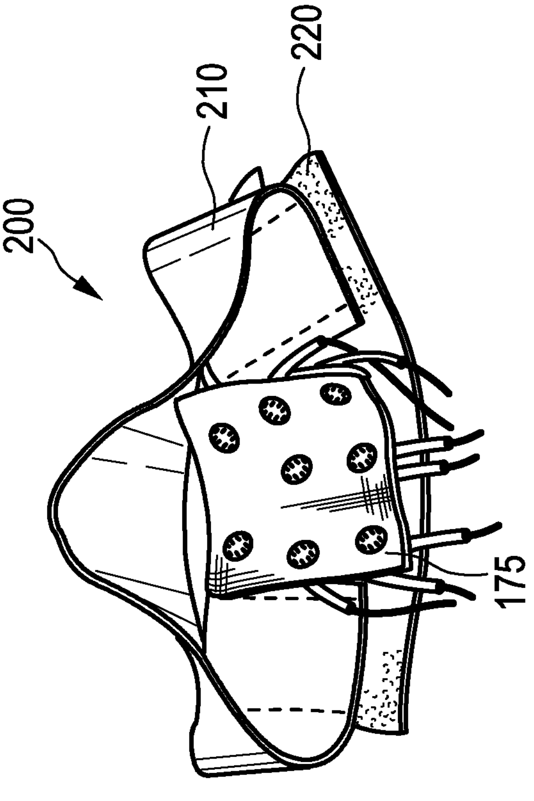


FIG. 13a

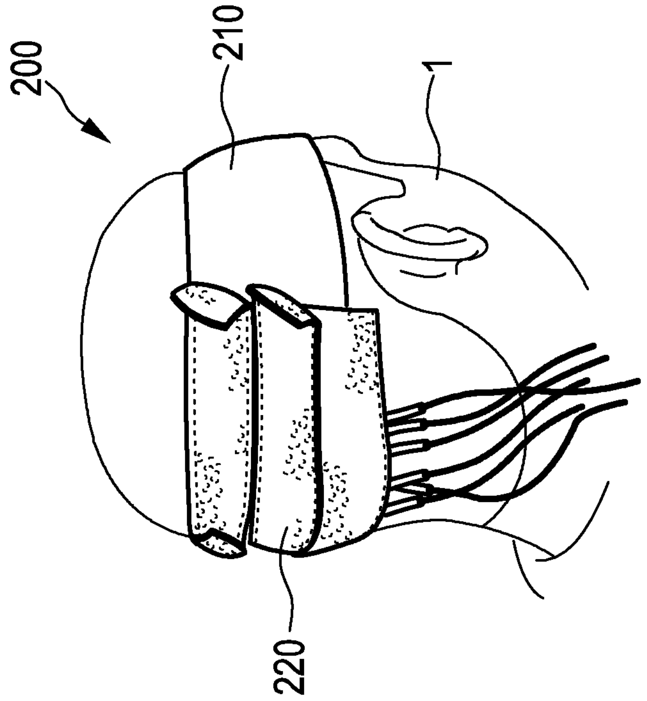
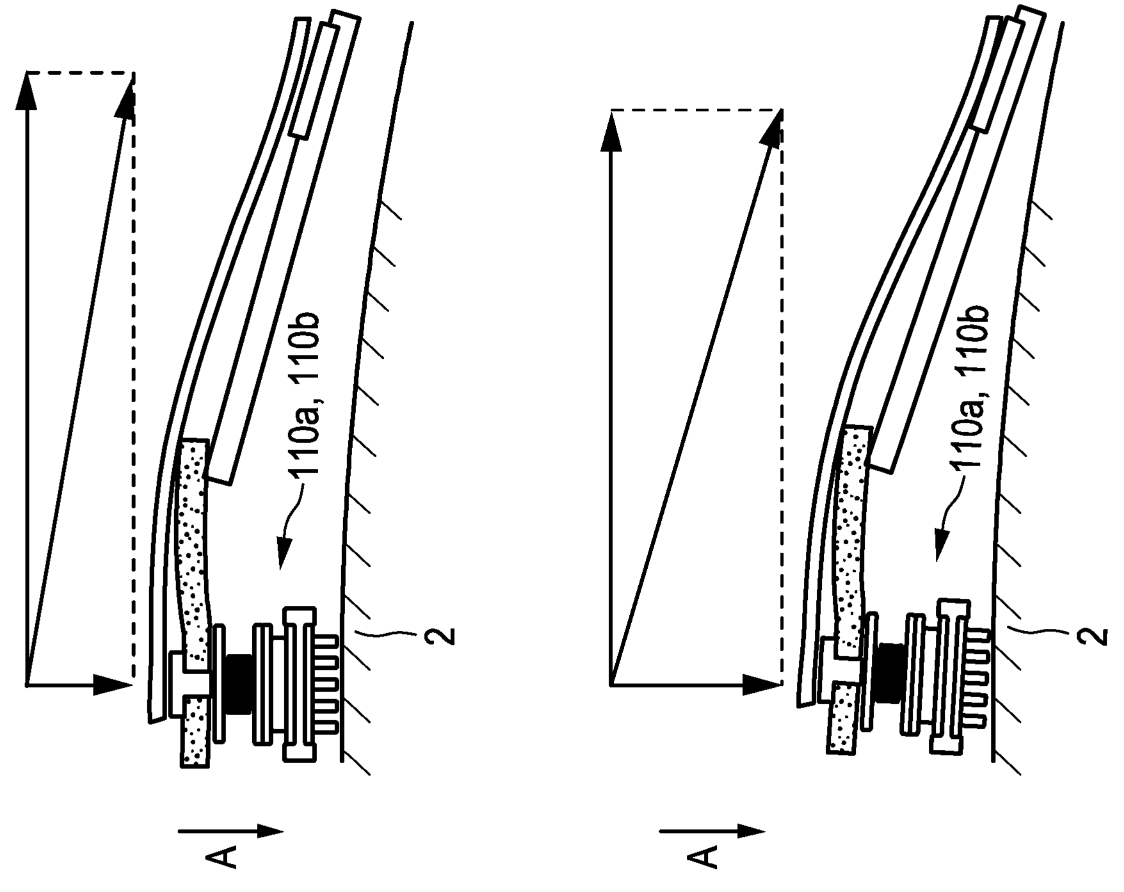


FIG. 13b

FIG. 14



INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/054369

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/0476
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011/015503 A1 (JOFFE DAVID [US] ET AL) 20 January 2011 (2011-01-20) cited in the application paragraphs [0071] - [0074], [0077] - [0082]; figures ----- -/--	1-15

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 10 December 2012	Date of mailing of the international search report 26/02/2013
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Küster, Gunilla

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/054369

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	ENNO FREYE: "Cerebral Monitoring in the Operating Room and the Intensive Care Unit - An Introductory for the Clinician and a Guide for the Novice Wanting to Open a Window to the Brain", JOURNAL OF CLINICAL MONITORING AND COMPUTING, vol. 19, no. 1-2, 1 April 2005 (2005-04-01), pages 77-168, XP055047093, ISSN: 1387-1307, DOI: 10.1007/s10877-005-0713-y page 81 - page 82 -----	1-15
A	US 2009/043221 A1 (KAPLAN RICHARD [US] ET AL) 12 February 2009 (2009-02-12) paragraphs [0007], [0066] - [0068] -----	1,13-15
Y	US 6 493 576 B1 (DANKWART-EDER FRANZ [DE]) 10 December 2002 (2002-12-10) column 6, lines 63-67 column 8, line 53 - column 10, line 10; figure 8 -----	2,3
A	US 2011/066020 A1 (SVOJANOVSKY ALEXANDER [DE]) 17 March 2011 (2011-03-17) the whole document -----	1,13-15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2012/054369

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-15

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-15

Determining an impedance difference between two electrodes, in particular EEG electrodes

---

2. claims: 16-19

Pressure control system for controlling pressure in an axial direction on an electrode, based on a pressure sensor signal indicating the pressure on the electrode

---

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2012/054369

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 2011015503	A1	20-01-2011	NONE		
US 2009043221	A1	12-02-2009	US 2009043221	A1	12-02-2009
			WO 2009023488	A1	19-02-2009
US 6493576	B1	10-12-2002	NONE		
US 2011066020	A1	17-03-2011	NONE		