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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 December 2024 (12.12.2024)

WIPO | PCT

(10) International Publication Number
WO 2024/254086 A2

(51) International Patent Classification:
Not classified

(21) International Application Number:
PCT/US2024/032439

(22) International Filing Date:
04 June 2024 (04.06.2024)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/471,110 05 June 2023 (05.06.2023) US

(71) Applicant: **NEW YORK UNIVERSITY** [US/US]; 70 Washington Square South, New York, New York 10012 (US).

(72) Inventors: **HORNSTEIN, Alexis Nathan**; 232 Fourth Street, Providence, Rhode Island 02906 (US). **FENTON, André Antonio**; 70 Washington Square South, New York, New York 10012 (US).

(74) Agent: **MARTIN, Matthew E.** et al.; c/o Foley & Lardner LLP, 3000 K Street N.W., Suite 600, Washington, District of Columbia 20007-5109 (US).

(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, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, 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,

(54) Title: A DISTRIBUTED SYSTEM FOR BIOSENSING

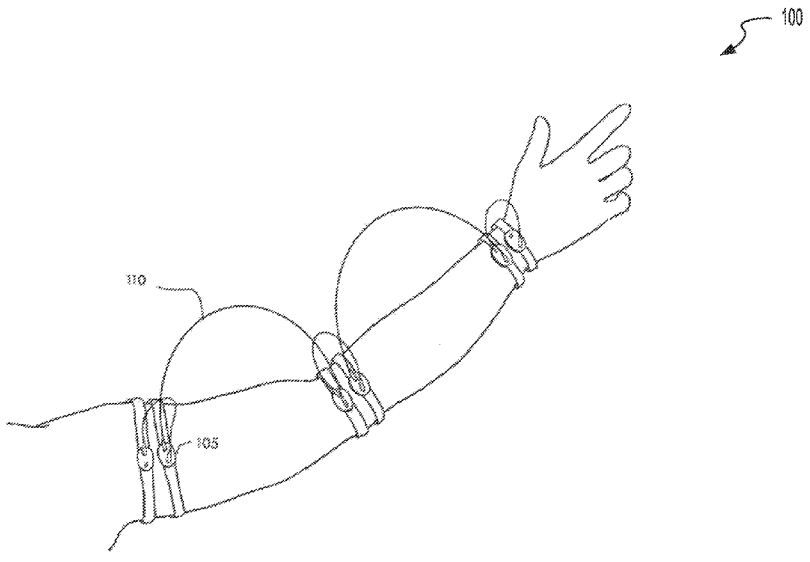

FIG. 1

(57) Abstract: A system can include an array holder. The system can include a plurality of sensing cells. Each of the plurality of sensing cells can include a housing configured to mechanically couple with the array holder, at least one processor disposed in the housing, a first hydrogel disposed in the housing and configured to mechanically and electrically couple with a patient, and a second hydrogel disposed in the housing and configured to electrically couple with the array holder.

WO 2024/254086 A2

[Continued on next page]

LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, 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))*

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

A DISTRIBUTED SYSTEM FOR BIOSENSING

A DISTRIBUTED SYSTEM FOR BIOSENSING

CROSS-REFERENCE TO RELATED PATENT APPLICATION

[0001] This application claims the benefit and priority of U.S. Provisional Patent Application No. 63/471,110, filed on June 5, 2023, the entirety of which is incorporated by reference herein.

TECHNICAL FIELD

[0002] The present disclosure relates generally to a system for biosensing.

BACKGROUND

[0003] Bio-electrical tests can include electroencephalograms, electrocardiograms, or electromyography.

SUMMARY

[0004] At least one aspect of the present disclosure is directed to a system. The system can include an array holder. The system can include a plurality of sensing cells. Each of the plurality of sensing cells can include a housing configured to mechanically couple with the array holder, at least one processor disposed in the housing, a first hydrogel disposed in the housing and configured to mechanically and electrically couple with a patient, and a second hydrogel disposed in the housing and configured to electrically couple with the array holder.

[0005] Another aspect of the present disclosure is directed to a method. The method can include providing an array holder. The method can include providing a plurality of sensing cells. Each of the plurality of sensing cells can include a housing configured to mechanically couple with the array holder, at least one processor disposed in the housing, a first hydrogel disposed in the housing and configured to mechanically and electrically couple with a patient, and a second hydrogel disposed in the housing and configured to electrically couple with the array holder.

[0006] Those skilled in the art will appreciate that the summary is illustrative only and is not intended to be in any way limiting. Other aspects, inventive features, and advantages of the devices and/or processes described herein, as defined solely by the claims, will become apparent in the detailed description set forth herein and taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The details of one or more implementations of the subject matter described in this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages of the subject matter will become apparent from the description, the drawings, and the claims.

[0008] FIG. 1 illustrates a system for distributed biosensing, according to an example implementation.

[0009] FIG. 2 illustrates a system for distributed biosensing, according to an example implementation.

[0010] FIG. 3 illustrates a sensing cell, according to an example implementation.

[0011] FIG. 4 illustrates a divider, according to an example implementation.

[0012] FIG. 5 illustrates a crossover network, according to an example implementation.

[0013] FIG. 6 illustrates a frequency plot of the crossover network shown in FIG. 5, according to an example implementation.

[0014] FIG. 7 illustrates a sensing cell, according to an example implementation.

[0015] FIG. 8 illustrates a power source, according to an example implementation.

[0016] FIG. 9 illustrates a power source, according to an example implementation.

[0017] FIG. 10 illustrates a carrier wave detector, according to an example implementation.

[0018] FIG. 11 illustrates a carrier wave detector, according to an example implementation.

[0019] FIG. 12 illustrates nine parallel carrier waves, according to an example implementation.

[0020] FIG. 13 illustrates data validation, according to an example implementation.

[0021] FIG. 14 illustrates a schematic of an impedance-modulation communication system, according to an example implementation.

[0022] FIG. 15 illustrates a simulation of the voltage in the LC tank and the voltage of the peak detector, according to an example implementation.

[0023] FIG. 16 illustrates schematic of a CMOS inverter driven by the carrier wave, according to an example implementation.

[0024] FIG. 17 illustrates an array holder, according to an example implementation.

[0025] FIG. 18 illustrates an array holder, according to an example implementation.

[0026] FIG. 19 illustrates a system for distributed biosensing, according to an example implementation.

[0027] FIG. 20 illustrates a method for distributed biosensing, according to an example implementation.

[0028] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0029] Following below are more detailed descriptions of various concepts related to, and implementations of, methods, apparatuses, and systems for distributed biosensing. The various concepts introduced above and discussed in greater detail below may be implemented in any of a number of ways, as the described concepts are not limited to any particular manner of implementation. Examples of specific implementations and applications are provided primarily for illustrative purposes.

[0030] The systems and methods of the present disclosure can include a collection of instruments to perform synchronous measurements of electrical potential on skin for a variety of bio-electrical tests, such as electroencephalograms (EEG), electrocardiograms (EKG), or electromyography (EMG). The systems and methods of the present disclosure can use a distributed architecture to make a low-cost and flexible sensing device. The device can be designed to sense and store a collection of synchronized data streams on a plurality of individual sensing cells, as commanded and synchronized by a centralized coordinator module. After collecting data for a sensing period, each sensing cell can then transfer its recorded data to the coordinator module where it is combined with the data from the other sensing cells, before being transferred to a computer system for analysis by health care practitioners.

[0031] FIG. 1 illustrates a schematic of a system 100 (e.g., system for distributed biosensing). The system 100 can include a point-of-care system. The system 100 can include an at-home system. The system 100 can include one or more sensing cells 105 (e.g., sensor

cell). The system 100 can include an array of sensing cells 105 (e.g., sensing cell array). The system 100 can include a plurality of sensing cells 105. The plurality of sensing cell 105 can couple with a patient (e.g., user). Sensing capabilities can be distributed to each of the sensing cells 105 in the array.

[0032] The system can include an array holder 110. The array holder 110 can couple with each of the plurality of sensing cells 105. The array holder 110 can include a rivet, bus strip, locking ridge, metal connector, and/or insulating plastic housing. The array holder 110 can be mechanically hinged. The array holder 110 can be mechanically flexible.

[0033] FIG. 2 illustrates the system 100. The system 100 can include the array holder 110. The array holder 110 (e.g., holder) can include a metal bus (e.g., bus bar, array holder's bus, holder's bus). The array holder 110 can couple with each of the plurality of sensing cell 105. The array holder 110 can include a formed conductive attachment.

[0034] The system 100 can include the plurality of sensing cells 105. Each of the plurality of sensing cells 105 can include one or more housings 115 (e.g., cell housings, sensing cell housing). The housing 115 can couple with the array holder 110. For example, the housing 115 can mechanically couple with the array holder 110. The housing 115 can include a plastic component that holds all the components inside. The housing 115 can snap into a specific location on the array holder 110. The housing 115 can include one or more protrusions configured to couple the housing 115 with the array holder 110. The housing 115 can couple with the array holder 110 via a lip protruding outward on the conductive material of the array holder 110 and a mating feature protruding inward on the housing 115. The array holder 110 can include a protrusion. The housing 115 can include a lip. As the sensing cell 105 is pushed onto the array holder 110, the housing 115 can expand slightly to allow the mating feature to pass the array holder lip, and then the housing 115 can lock into place. The housing 115 can couple with the array holder 110 via a button snap. The housing 115 can couple with the array holder 110 via an electrical connection. The housing 115 can couple with the array holder 110 via a snap-fit connection.

[0035] Each of the plurality of sensing cells 105 can include at least one processor 120 (e.g., coordinator, coordinator module, centralized coordinator module). The processor 120 can be disposed in the housing 115. The processor 120 can include a chip-scale silicon die that holds the entire electrical functionality of the sensing cell 105. For example, the processor 120 can include signal processing, data storage, and bi-directional communication

capability. The processor 120 can be made of silicon. The processor 120 can include a silicon die. The processor 120 of each of the plurality of sensing cells 105 can perform synchronous measurements. For example, the processor 120 of each of the plurality of sensing cells 105 can perform synchronous measurements of electrical potentials on skin of the patient.

[0036] Each of the plurality of sensing cells 105 can include a first hydrogel 125 (e.g., patient hydrogel). The first hydrogel 125 can be disposed in the housing 115. The first hydrogel 125 can mechanically couple with the patient. For example, the first hydrogel 125 can mechanically couple with the patient's skin (e.g., skin of the patient). The first hydrogel 125 can electrically couple with the patient. For example, the first hydrogel 125 can electrically couple with the patient's skin. The first hydrogel 125 can include a bio-compatible hydrogel. The first hydrogel 125 can make an electrical contact between the processor 120 and the patient's skin. The first hydrogel 125 can be disposed on a first side of the processor 120. Surface tension can keep the first hydrogel 125 from exiting the housing 115. The first hydrogel 125 can be contained in the housing 115 by a mesh retaining cover. A thin thread of the first hydrogel 125 can couple with or make contact with the patient's skin (e.g., patient's scalp). A peelable cover can be coupled with the housing 115 to contain the first hydrogel 125. The peelable cover can be heat-sealed over the first hydrogel 125. The peelable cover can keep the moisture in the first hydrogel 125. The first hydrogel 125 can be formed from a powder that be poured into the housing 115. Water (e.g., distilled water) can be mixed with the powder to form the first hydrogel 125. The hydrogel 125 can allow for some positional inaccuracies.

[0037] Each of the plurality of sensing cells 105 can include a second hydrogel 130 (e.g., array bus hydrogel). The second hydrogel 130 can be disposed in the housing 115. The second hydrogel 130 can couple with the array holder 110. For example, the second hydrogel 130 can electrically couple with the array holder 110. The second hydrogel 130 can mechanically couple with the array holder 110. The second hydrogel 130 can include a general-purpose hydrogel that makes electrical contact between the processor 120 and the array holder 110. For example, the second hydrogel 130 can make electrical contact between the processor 120 and the bus of the array holder 110. The second hydrogel 130 can be disposed on a second side of the processor 120. The second side of the processor 120 can be opposite the first side of the processor 120. The second hydrogel 130 can include a general-purpose hydrogel.

[0038] Each of the plurality of sensing cells 105 can include a divider 135. The divider 135 is nonconductive in one embodiment. It may be made of the same material of the housing, for example it may be a plastic divider. The divider 135 can couple with the housing 115. The divider 135 can couple with the processor 120. For example, the processor 120 can be supported by the divider 135. The divider 135 can separate the first hydrogel 125 and the second hydrogel 130, while providing exposure of the first hydrogel 125 to the processor 120 and the second hydrogel 130 to the processor 120. The processor 120 can couple with the divider 135.

[0039] Mechanically, the sensing cell 105 can be shaped like a plastic barrel, with a horizontal divider (e.g., divider 135) in the middle. The sensing cell 105 can have a diameter. The diameter can be between 4 mm and 8 mm (e.g., 4 mm, 5 mm, 6 mm, 7 mm, or 8 mm). The sensing cell 105 can have a height. The height can be between 4 mm and 8 mm (e.g., 4 mm, 5 mm, 6 mm, 7 mm, or 8 mm). The sensing cell 105 can be rigid. The sensing cell 105 can be more rigid than the array holder 110. The horizontal divider can include a mounting point for a silicon die, and accommodations for a power source. Electrical contact can be provided to the patient and a holder's bus by two electrically conductive hydrogels, which can make electrical contact with the silicon die and the bus or patient. The silicon in the sensing cell 105 can have two primary electrical contacts. These primary electrical contacts can include the bus bar (e.g., common ground) and the patient's skin. The silicon in the sensing cell 105 can have additional contacts. The additional contacts can include a power source, a high-pass filtered signal, or a low-pass filtered signal.

[0040] The sensing cell 105 can include a mating feature slightly inset from the end on the holder side of the sensing cell 105. The mating feature can be designed to be slightly smaller than a mating contact surface on the array holder 110, allowing the sensing cell 105 to snap into the array holder 110 and remain in place. The mating feature can include a protrusion. The sensing cell 105 can have a diameter between 5 mm and 10 mm. The sensing cell 105 can have a width between 5 mm and 10 mm. The sensing cell 105 can have a height between 5 mm and 10 mm.

[0041] FIG. 3 illustrates the sensing cell 105. The sensing cell 105 can include one or more power sources 305. The power source 305 can include an ultracapacitor. The sensing cell 105 can include the housing 115. The sensing cell 105 can include the first hydrogel 125. The sensing cell 105 can include the second hydrogel 130. The sensing cell 105 can include the processor 120. The processor 120 can use power on the order of microwatts. The

operating time for the system 100 can be less than an hour or 30 minutes for the test, and a few additional minutes for data retrieval. The total energy used by the sensing cell 105 over the course of a test in the tens of microjoules. The power source 305 can supply power to each of the plurality of sensing cells 105. The power source 305 may be electrically connected to the processor 120 such as by conductive glue. A non-conductive filler component may be disposed between the first hydrogel 125 and the divider 135 or the second hydrogel and the divider 135. The ultracapacitor can supply power to each of the plurality of sensing cells 105.

[0042] The power source 305 can include a discrete ultracapacitor. A small, discrete power source can be used. Ultracapacitors can provide the power for the system 100. Ultracapacitors can fit within the available footprint. An example, the power source 305 can include a chip capacitor, which can provide 11 mF of capacitance at a maximum of 3.3 V, or roughly 60 mJ of energy storage.

[0043] The power source 305 can include a battery. The power source 305 can include a disposable battery. The system 100 can include alkaline button cells such as those used for hearing aid or watches. As an example, an AG1-size alkaline battery is 6.8 mm in diameter and 2.1 mm high, and can store 20 mJ of energy at 1.5V, sufficient for a microwatt-scale load. The battery can be integrated into the horizontal plate in a manner similar to the ultracapacitor.

[0044] Sensing in the sensing cell 105 can be done by measuring AC voltage signals from human skin, conducted through the first hydrogel 125, and comparing them to a standard 0.6 V voltage reference formed by a silicon diode built into a controller. The target frequency for relevant bio-signals in the skin can be up to 100 Hz, so the voltage can be sampled at a Nyquist frequency of 200 Hz. The AC voltage can be buffered with an op-amp and biased to 0.3 V. The analog-digital accuracy can be greater than or equal to 12-bit accuracy.

[0045] To convert the analog signal to a digital value, an ADC can be integrated into the design of the controller. An R-2R ladder with temperature compensation can form a simple, low-cost, high-precision ADC.

[0046] To operate an array of sensing cells 105 and to record and retrieve high-quality information from the sensing cells 105, the system 100 can have a method of communicating simultaneously with all of the sensing cells 105. The system 100 can have a

method of communicating with just one specific sensing cell 105 at a time. The system 100 can have various requirements for a communication call for a communication scheme that can send multiple types of commands over a common transmission medium. The transmission medium can include radio through free space, a shared conductive bus, or use of the patient's skin as a conductor. Because this system 100 (e.g., distributed system) can use a common bus shared by all the sensing cells 105 and the coordinator, a way to represent a large number of individual commands that can be sent out over the bus, as well as an addressing system to communicate with any single sensing cell 105 in the array, can be useful.

[0047] The set of commands can include WAKE, SYNCHRONIZE CLOCKS, RECORD SAMPLE, BEGIN RECORDING, ADDRESS (e.g., one command for each sensing cell 105 in the array), TRANSMIT DATA, CHECKSUM, ACKNOWLEDGE, ERROR, or REPEAT LAST CHUNK. All of these commands can be represented by a single 8-bit value, and that value can be transmitted from the coordinator to the transmission medium. The transmission medium can serve as a bus to connect the coordinator to all the sensing cells 105. Commands may be sent along the medium as asynchronous data similar to a modem (e.g., synchronous serial communication), or in parallel by using eight carrier waves at eight distinct frequencies (e.g., parallel communication).

[0048] The synchronous serial communication method can use a single frequency channel to convey data from the coordinator to the sensing cell array (e.g., data carrier wave), and a separate frequency channel can serve as a clock signal that the coordinator and sensing cells 105 can all access equally. The separate frequency channel can be the power frequency channel in a remote power embodiment. In the simplest embodiment, a bit of data on the data carrier wave can be represented as the presence or absence of a carrier wave at a given clock period. In this case, the bandwidth of the system 100 can be set by the frequency of the data carrier wave, and each bit of data can be detected on the sensing cell 105 by a carrier wave detector. If this method of communication is used in conjunction with the remote power method technique, the data carrier frequency can be separated from the remote power frequency by use of a crossover network (e.g., crossover filter).

[0049] FIG. 4 illustrates a top view of the divider 135 (e.g., a top view of a horizontal divider in the sensing cell 105). The divider 135 can couple with the processor 120. For example, the processor 120 can be supported by the divider 135. This illustration shows a detailed view of the layout of electrical contacts on the silicon die in the variant using a

discrete power source (e.g., power source 305). The power source 305 can include an ultracapacitor. The illustration shows the layout of the horizontal divider and an ultracapacitor serving as a power source, as well as detailing insulating potting which serves to anchor the silicon die and ultracapacitor in place and to insulate the power connections from the hydrogel. The divider 135 can include a hole 405 (e.g., hole through the divider). The divider 135 can include one or more conductive inserts 410. The divider 135 can include a depression 415 (e.g., depression for an ultracapacitor).

[0050] The sensing cell 105 can receive AC power from the coordinator module (e.g., coordinator, centralized coordinator module) transmitted over the patient's skin (e.g., remote power). The sensing cell 105 can rectify the power into DC for use in the circuitry of the sensing cell 105. This can allow the sensing cell 105 to be used indefinitely, without recharging or replacing the power source 305. This can reduce the discrete component count (and complexity and cost) of the sensing cell 105.

[0051] The remote power technique can be a way to transmit and extract energy from AC waves generated by the coordinator module and transmitted through the patient's skin to the array of sensing cells 105. With this approach, AC energy used for power transmission can be filtered out from the energy used for communication. Otherwise, the communication signals can be greatly attenuated. This can be accomplished using a crossover network to separate out the frequency ranges of the signal. Sensing signals are in the low frequency range (e.g., under 100 Hz). Communication can be in a range of 10 kHz to 5 mHz. Power transmission can be comfortably above that frequency range (e.g., above 10 mHz).

[0052] FIG. 5 illustrates a crossover network 500. The crossover network 500 can include a second-order passive crossover. This crossover network 500 can be achieved with a few passive components that can be built into the design of the sensing cell 105. The crossover network 500 can include a passive filter. Both the inductor and capacitor can be too high-value (and high-footprint) to be cost-effectively built into the cell processor's silicon, but they can be designed into the housing 115 of the sensing cell 105, or embedded into the housing 115 as discrete, surface-mount components.

[0053] FIG. 6 illustrates a frequency plot 600 of the crossover network shown in FIG. 5. For the low pass filtered signal, the gain drops down above the cutoff frequency. For the high pass filtered signal, the gain is reduced below the cutoff frequency. By selecting

communications frequencies above the cutoff frequency, a passive filter can be designed that separates the two components of the signal, with minimal interference.

[0054] FIG. 7 illustrates the sensing cell 105. For extreme integration and cost reduction, the components can be built into the housing 115 of the sensing cell 105. Capacitors can be created by a single layer of thin plastic film, metallized on both sides, encircling the housing 115 of the sensing cell 105. The capacitors can include metalized film capacitors 705. Inductors can similarly be created by winding enameled wire 710 (e.g., inductors, windings of enameled wire) around the outside of the sensing cell 105. The inductor and the capacitor for the crossover network can be the only physically large components in the system 100. Capacitance value can increase with greater surface area or a smaller distance between the plates of the capacitor. For a material like a silicon die or a metallized plastic film, the thickness can only be shrunk to a certain limit before the material fails. Therefore, to achieve a certain capacitance, the surface area can be increased. Increasing the surface area of a silicon die can be expensive.

[0055] The system 100 can include a film dipped into the hydrogel. Conductive glue can be used to attach the inductor wire to the capacitor, which can simplify the design of the inductor and the capacitor. The inductor can include wrapping wire in loops. Increasing the number of loops can increase inductance. To form the inductor in the crossover network, a low-cost, 32-gauge magnet wire can be used to wrap a plurality of loops around the circumference of the sensing cell 105. Magnet wire can have enameled insulation, so it does not short against the capacitor unless the enamel insulation is removed and a conductive glue is added to form an electrical connection.

[0056] FIG. 8 illustrates the power source 305. The power source 305 can include an integrated film capacitor. The film capacitor can be made of a metallized plastic film wrapped around the housing 115 of the sensing cell 105 (e.g., sensing cell housing). The film capacitor can be built into the housing 115. As an example, 76 wraps of 0.7 μm thick metallized PET film can be sufficient to create a 1 μF capacitor while adding less than 1 mm of thickness to the housing 115. The power source 305 can include a wrapped metallized foil sheet 805. The power source 305 can include the housing 115. An electrical contact 810 can be formed by bending a plastic sheet over the edge of the housing 115 and securing it to the divider 135.

[0057] FIG. 9 illustrates the power source 305. The power source 305 can include a metallized plate capacitor. The metallized plate capacitor can include an integrated metallized plate capacitor. The integrated metallized plate capacitor can include the power source 305 in the housing. The integrated metallized plate capacitor can be directly built onto the outside of the plastic housing of the sensing cell 105 using known deposition techniques, such as CVD, ALD, and sputter coating techniques. For example, aluminum can be sputter-coated evenly onto the plastic housing in an inert environment. Following sputter coating, the housing 115 can be moved to an oxygen-rich environment for a fixed amount of time, during which the aluminum coating grows an oxide layer (e.g., Al_2O_3). After such time as the oxide layer has grown to 10 nm thickness, a second layer of aluminum can be sputtered around the housing 115, forming a second conductive cylinder spaced 10 nm away from the first cylinder. These two layers can form a capacitor, with the aluminum oxide layer acting as the insulation between them. In a sensing cell 105 with a diameter of 10 mm and a height of 10 mm, such a capacitor can be on the order of microfarads, and could store energy on the order of ~100 microjoules. This can be sufficient for an extremely low-power nanowatt-scale load. The power source 305 can include a coating 905 (e.g., sputter coating). The power source 305 can include an Al_2O_3 layer. For example, the coating 905 can include a layer of Al_2O_3. The power source 305 can include sputtered electrical contact traces 910.

[0058] FIG. 10 illustrates a carrier wave detector 1000. Each carrier wave detector 100 can include analog circuitry designed to give a binary representation of whether or not a carrier wave of a particular frequency is present. The carrier wave detector 100 can be made up of a buffer, band-pass filter, peak detector, and/or comparator.

[0059] FIG. 11 illustrates the carrier wave detector 1000. The implementation of the carrier wave detector may vary depending on the frequency and precision required. An analog implementation is shown in FIG. 10. The carrier wave detector 100 can be made up of a buffer, low pass filter, high pass filter, peak detector, and/or comparator.

[0060] In some embodiments, more than one carrier wave detector 1000 may be utilized. FIG. 12 illustrates nine parallel carrier waves 1200. Parallel communication can offer a high-bandwidth way to send data from the coordinator to the sensing cells 105. In this method, the design uses nine parallel carrier waves, evenly spaced from 20 Hz to 100 kHz, which can be transmitted across the patient's skin. Each frequency channel can serve as a bit of data. For example, 20 kHz can serve as the 2^0 bit, 40 kHz can serve as the 2^1 bit, and so on up to 90 kHz as the 2^7 bit. The final 100 kHz channel can serve as the "data ready"

channel, which can indicate when the data on each of the command bits have settled into their correct data state and the data may be read by each sensing cell 105.

[0061] A parallel architecture can provide bandwidth and simplicity. On each channel, a binary "1'" can be simply represented as the presence of a carrier wave on that channel, and a binary "0" can be represented as the absence. On the coordinator, the hardware for transmission of the command bytes can include nine oscillators, one at each carrier frequency, capacitively coupled to the transmission medium. On the sensing cell 105, the data can be received with an array of carrier wave detectors 1000.

[0062] The processor 120 can have an array of nine carrier wave detectors 1000, each tuned to the frequency of a carrier wave. The output of this array can include an 8-bit digital data bus and a single "data ready" bit that indicates to the processor 120 that the data on the bus is ready to be read and processed.

[0063] FIG. 13 illustrates data validation 1300. Because these can be analog processes, data transitions may not take place instantaneously. It can take time to charge or discharge the capacitors in the peak-detector portion of the carrier wave detector, and each component in the pipeline can add a slight delay. To ensure that the processor 120 only acts on valid data, the data ready pin can be brought high after a transition time has passed and the data on the bus can be assured to be valid. Once the DATA READY pin goes high, the processor 120 can read the data on the bus and can continue to the next point in its workflow. Data may not be sent at any fixed interval, and when no data has been sent, the DATA READY pin can remain low.

[0064] All of the sensing cells 105 may record their value at the same time, with a small margin of error, for the data from the array to be ultimately accurate. This can be accomplished by sending a RECORD SAMPLE command to all the sensing cells 105 at every sample interval. The coordinator may have an accurate clock to ensure reliable, repeatable measurements, which can be accomplished with a temperature-controlled oscillator or a real-time clock module.

[0065] Each sensing cell 105 may be able to communicate with a coordinator during startup/synchronization and data retrieval. Receiving data from the coordinator can be straightforward. The start signal can offer a low bandwidth means of asynchronous communication. However, the sensing cells 105 may need to each send back at least 720,000 bytes to the coordinator. It can be common to have 32 or more sensing cells 105 in one array.

This can require a high-speed, addressable way for the coordinator to query an individual sensing cell 105, retrieve its data, error-check the data, and request any corrections if necessary. There can be two principal ways for the sensing cells 105 to transmit data back to the coordinator. The highest-bandwidth and most straightforward way, but also the solution with the highest power usage, can include the sensing cell 105 having its own array of oscillators, and the coordinator to have its own array of frequency detectors (e.g., parallel transmission). A simpler, lower-power, but lower-bandwidth approach can work using a single carrier frequency (e.g., impedance modulation communication).

[0066] In parallel transmission, each sensing cell 105 can have an array of nine oscillators, and the coordinator can have a matching array of nine carrier wave detectors 1000. In the parallel transmission approach, all sensing cells 105 can have their oscillators disabled unless they are specifically addressed and queried by the coordinator. If they are, the coordinator can provide the clock signal by clocking the DATA READY carrier wave.

[0067] FIG. 14 illustrates a schematic 1400 of an impedance-modulation communication system. The impedance-modulation communication system can include a way of creating a low-power simplex communications link between the coordinator (e.g., processor 120) and the array of sensing cells 105. The impedance modulation communication system can include a resonant LC tank in the coordinator, driven by an oscillator of frequency F, which is connected through a contact pad to the patient's skin. The impedance-modulation communication system can include the coordinator and the sensing cell 105.

[0068] Each sensing cell 105 can include a high-speed digital switch capable of switching AC, either a triac or a gate turn-off thyristor. When the switch is disconnected, the LC tank can be undamped and the signal amplitude measured at A1 can be high due to the resonance of the LC tank, indicating a binary "1". When that switch is connected, the resonant tank can be damped and the signal amplitude at A1 can drop measurably, indicating a binary "0".

[0069] The resonant nature of an LC tank can mean that a voltage change at A1 is not instantaneous, but may take 1-2 cycles of the sine wave to get a reliably measurable result. The cell processor can be configured to wait a certain number of sine cycles before continuing to the next bit of data, and the coordinator may also wait a minimum time before reading the data to ensure the data at A1 is valid. In practice, with a high-Q oscillator, a delay of one cycle can be sufficient to ensure valid data.

[0070] FIG. 15 illustrates a simulation 1500 of the voltage in the LC tank 1505 and the voltage of the peak detector 1510. The voltage in the peak detector can increase over two cycles.

[0071] FIG. 16 illustrates a schematic 1600 of a CMOS inverter driven by the carrier wave. To ensure that both the coordinator (e.g., processor 120) waits for a sufficient time for the data to become valid before it reads the bit, and that the cell processor waits for a sufficient time before advancing to the next bit, a simple delay can be built that can wait for an integer number of cycles before advancing to the next step in the workflow. A way of doing that is with a CMOS inverter driven by the carrier wave. That can provide a digital square wave at the frequency of the carrier wave, and that wave can be fed into a CMOS D flip-flop to divide that frequency by two, providing the correct sampling frequency.

[0072] For the sensing cells 105 to function together on a shared bus, each sensing cell 105 in an array may have a unique address. This address can be set arranging a series of address contacts into the binary value of each address, and integrating that design as part of the wafer construction, or by using a wafer design for any number of sensing cells 105 and laser-trimming fuses in post-processing to set the addresses. There is no theoretical limit to the size of the address space. All addresses can be represented with a 7-bit address register.

[0073] Data can be stored in an array of SRAM memory storage built into the processor 120. SRAM is a storage technology built using the same CMOS technology used to manufacture the other elements on the cell processor die, and can be integrated into the same silicon. Storage may be sufficient to store all data collected during the sensing period. Each data point can be 16-bits and sampled at 200 Hz for 30 minutes, for a total of 720,000 bytes of storage. This array can include a multiplexer to address data being stored or retrieved from the array, and a block of SR flip-flops that actually stores the data.

[0074] FIG. 17 illustrates the array holder 110. The array holder 110 can include the plurality of sensing cells 105. The array holder 110 can include an electro-mechanical device that arranges all of the sensing cells 105 spatially and holds them in contact with the patient's body. The array holder 110 can provide a common bus to electrically connect all of the sensing cells 105 and the coordinator. The array holder 110 can include the first hydrogel 125 and the second hydrogel 130. Each of the sensing cells 105 can be disposed at different locations of the patient's body.

[0075] The array holder 110 may take different forms, depending on the part of the body that it attaches to. The array holder 110 can include a rivet, bus strip 1710 (e.g., metal bus strip), locking ridge 1725, metal connector 1715 (e.g., bus strip connectors), plastic housing 1705 (e.g., insulating plastic housing), and/or a mating feature 1720. The array holder 110 can include one or more electrodes. The metal connector 1715 can include the one or more electrodes.

[0076] The insulating plastic housing 1705 can include a plastic housing that is closest to the patient's skin. The insulating plastic housing 1705 can insulate the patient's skin from touching the metal bus strip 1710. The insulating plastic housing 1705 can provide structure to position the sensing cells 105 in the relevant locations on the patient's body. The insulating plastic housing 1705 can include holes. The holes can allow the sensing cells 105 to mate with the metal connectors 1715 on the bus strip 1710.

[0077] The metal bus strip 1710 can be a single component of material cut from a large sheet, or it may be formed by riveting or spot-welding individual metal strips together into the correct form. The bus strip 1710 can be attached to the plastic housing 1705 so that the housing is between the patient and the bus strip 1710. The bus strip connectors 1715 can include metal connectors that form a mechanical and electrical connection between the bus strip 1710 and the sensing cells 105.

[0078] FIG. 18 illustrates the array holder 110. The array holder 110 can include a body tensioning system. The body tensioning system can include a series of straps that are able to hold the plastic housing against the patient. The straps may be adjusted, either by an elastic strap or an adjustable or Velcro buckle (e.g., hook and loop fasteners), so that the array holder 110 is held securely against the patient and the sensing hydrogels are compressed against the patient's skin, making a secure electrical contact with the patient's skin at each sensing cell 105.

[0079] The data bus can include an electrically conductive bus that provides electrical contact to all of the sensing cells 105 in the array. Each sensing cell 105 can make electrical contact with the bus when it snaps into the array holder 110. There can be a contact where the coordinator can also connect electrically to the bus.

[0080] The array holder 110 can include an array holder headset 1805. The array holder 110 can conform to the patient's head. The array holder 110 can conform within a predetermined number of degrees to the patient's head. The array holder 110 can include a

neck bracket 1810 (e.g., neck brace) for stabilization. The array holder 110 can include an electrical contact point 1815 for one or more sensing cells 105. The array holder 110 can include an electrically insulated material where the headset touches the patient's skin. For example, the neck bracket 1810 can be made of electrically insulated material.

[0081] The sensing cell 105 can connect to the metal strip 1710 that comprises the data bus by a snap connection. A metal connector 1715 can be electrically and mechanically connected to the metal bus strip 1710. The metal connector 1715 can have a dimensions locking ridge that is designed to interface with the mating surface on the sensing cell's plastic housing. The sensing cell 105 can push onto the metal connector 1715 like a pen cap onto a pen, and the force of the push can cause the sensing cell's housing to deform slightly as the locking ridge is forced past the mating surface. Once the two surfaces have moved past each other, the sensing cell's housing can snap back to its original shape, and the mating surface holds the sensing cell's housing against the metal connector 1715 unless sufficient force is provided to dislodge it.

[0082] The sensing cell 105 can connect electrically to the bus strip 1710 by causing the hydrogel (e.g., second hydrogel 130) in the sensing cell 105 to make contact with the metal contact attached to the bus strip 1710. The hydrogel can compress as the sensing cell 105 locks onto the metal connector 1715 and deforms itself around the connector 1715, making a robust electrical connection.

[0083] The array holder design may be adjusted for different numbers and placements of sensing cells 105. For example, an electrocardiogram (EKG) can have twelve sensing locations across the torso and limbs. An electroencephalogram (EEG) can have upwards of thirty-two sensing locations across the scalp. An electromyogram (EMG) can have anywhere from three to dozens of sensing locations across various muscle groups on the body.

[0084] FIG. 19 illustrates the system 100. The system 100 can include an ad-hoc array made out of modular, single-cell units. Single cell units can include one sensing cell 105 and a bus fragment 1905. The bus fragment 1905 can include the array holder 110 with capacity only for a single cell, two snap connections to electrically connect two insulated bus wires 1910, and two adjustable straps 1915 to attach the unit to the patient. The adjustable straps 1915 can include a first portion with hooks 1920 and a second portion with loops 1925. The two bus wires 1910 can allow an arbitrary number of single-cell units to be connected to one another, and a coordinator is attached to a unit at one end of the array. The system 100

can include a bracelet (e.g., snap bracelet). The array holder 110 can be in the form of a bracelet. The bracelet can be conductive. The bracelet can be shape-changing. The array holder 110 can conform to the patient's head or other part of the body as described herein. The system 100 can include one or more conductive snaps 1930. The array holder 110 can include one or more bus fragments 1905. The array holder 110 can include one or more bus wires 1910.

[0085] The ad-hoc array can be a flexible way to support less common sensing arrays and geometries without needing a specialized array holder 110. Because of the distributed nature of sensing cells 105, the functionality of the entire system may not be affected by different numbers or arrangements of cells. This is a fundamentally different, modular approach to sensing bio-electrical signals from the body. As an example, the system of FIG. 1 illustrates an ad-hoc array made up of six single-cell units to measure an EMG of the muscle movements in a patient's arm.

[0086] Whether the array is a fabricated array holder 110 or an ad-hoc array of single-cell units, every sensing cell 105 can be tensioned against the body. This tensioning can compress the hydrogel (e.g., first hydrogel 125) in the sensing cell 105 against the patient's skin, allowing it to penetrate through body hair and make solid, constant electrical contact with the patient's skin. Tensioning can be done on a cell-by-cell basis or by tightening a larger array holder 110 against the patient, such as the strap system shown in FIG. 18 to tighten an EEG-style array holder against the patient's head.

[0087] Before the array can be used, a sensing cell 105 may be installed at various (e.g., appropriate) locations on the array holder 110. Each holder location can correspond with a particular address of a sensing cell 105, and a sensing cell 105 with that particular address may be installed at the corresponding location. This step could be done in advance, at a manufacturing facility, or a practitioner could prepare the array before performing a test on a patient.

[0088] The practitioner may then place the array holder 110 onto the patient, and securely tighten the array holder 110 against the patient's skin. The practitioner may then place the coordinator onto the patient and connect the coordinator to the array holder's bus.

[0089] To ensure that every sensing cell 105 is functioning properly and making electrical contact with the sensing cell 105, a series of checks can be performed on each sensing cell. For cell presence, the practitioner can set the coordinator into "validation mode,"

and the coordinator can then begin the validation by querying each sensing cell 105 up to a maximum address number (e.g., 128) to ascertain if that sensing cell 105 is present on the patient's body. The coordinator can then display a list of detected sensing cells 105 to the practitioner. If a sensing cell 105 is attached but is listed as "not present" on the list of detected cells, the practitioner may adjust that sensing cell 105 and re-start the validation.

[0090] The next step can include testing each sensing cell's recording capability. To do this, the coordinator can generate a 100 Hz test signal that it applies to the patient's skin. The coordinator can then command each sensing cell 105 to record data for a validation period (e.g., at least 1 minute), and then retrieves the data from each sensing cell 105. If a sensing cell 105 does not have a faithful recording of the test signal, the coordinator can alert the practitioner that that cell is not functioning correctly and may be adjusted until it is accurately sensing the signal.

[0091] Once the cell presence test and recording tests have been passed for every sensing cell 105 in the array, the array has been validated and is ready to record the patient. Once the array has been validated and the patient prepared for the test, the practitioner can begin the test by commanding the coordinator to start recording. The coordinator can send out regular signals at 200 Hz to all sensing cells 105 connected to the patient's body. The coordinator can command them to record a measurement of the electrical potential at that instant. The coordinator can continue sending these recording signals for the recording period specified by the practitioner. Once the recording is complete, the coordinator can shift into data retrieval mode, and can send a DATA RETRIEVAL command to the sensing cells 105.

[0092] In data retrieval mode, the sensing array can remain connected to the patient's body. The coordinator can send out the command "TRANSMIT DATA," followed by the address of the first sensing cell in the array, the first address of data memory that it is querying, and a number of bytes of data that it is requesting (e.g., block size). It can pulse the "DATA_READY" pin, serving as a clock, and clocks in data at every clock pulse. Once the full block of data has been received, the coordinator can send out the command "TRANSMIT CHECKSUM," with the initial address of data memory and the block size, and the sensing cell 105 can respond with a calculated checksum of that data block. If the checksum matches the Coordinator's calculated checksum, it can then send out a "TRANSMIT DATA" command for the next block of the data, if not, it can repeat the "TRANSMIT DATA" command for the current block and overwrites the previously received data until the checksum matches or the coordinator declares a communications failure. Once the entirety of

the sensing cell's data has been transmitted, the coordinator can then query the address of the next sensing cell, and continues to retrieve data from each of the sensing cells 105 until it has received and stored all of their data in the coordinator's memory.

[0093] The data can be retrieved from the coordinator for analysis. The data may be taken from the coordinator and moved to a computer system where a health care practitioner or automated analysis software can access it for processing (e.g., through machine learning), analysis, and/or interpretation. The coordinator can move the data to a computer system in a number of ways. For example, the coordinator can transmit the data to a nearby mobile device or computer by a Wi-Fi or Bluetooth connection, paired with a receiving app on that computer. The coordinator can transmit the data directly to a cloud service by a cellular modem built into the coordinator. The coordinator can save the data onto an onboard memory where it can be retrieved via a USB connection The coordinator can save the data onto a memory card, which can then be removed and returned to a health care practitioner or service for analysis.

[0094] Detection of one or more signals in the electrocardiogram can be used to determine whether the user has a concussion. The one or more signals in the EEG can be indicative of a concussion or other brain injury. The one or more signals in the EEG can be used to diagnose a concussion. A brain injury can affect brain function, which can appear as the one or more signals in the EEG.

[0095] Annotations ordinarily performed by an EEG/EKG technician (e.g., technician) can be performed by software (e.g., phone software, smart phone software). An application (e.g., app, mobile app, mobile application, phone app, phone application) can be used to provide stimuli, such as images, while a user (e.g., patient) is undergoing an EEG. The one or more stimuli can be shown or presented to the user. The phone application can present one or more stimuli to the user. For example, the different visual stimuli (e.g., visuals) can be used to determine whether the user has a concussion. The different visuals can be presented to the user to determine which visuals the user recognizes and which visuals the user does not recognize. Data from this test can be used to determine whether the user has a concussion. The user can wear the array holder 110 while receiving the stimuli from the phone application. For example, the user can wear one or more of the array holder headset or bracelet while receiving the stimuli from the phone application.

[0096] While undergoing the EEG, the user can be presented with one or more stimuli. The one or more stimuli can originate from the phone application. A cellphone (e.g., phone) can present or give the one or more stimuli to the user while the user is undergoing the EEG. A user-facing camera in the phone can be used to autogenerate actions that user performs. For example, the actions can include tics (e.g., blinking, clicking, grunting). The phone camera can detect other data relevant to EEG tests, such as face-tracking to detect when the user is looking at the phone screen, gaze-tracking to determine where the user is looking on the phone screen, and pupil diameter changes to indicate states of focus. The cellphone can be used to record the actions that the user performs as annotations (e.g., timestamped notations that are saved to an annotation file that is synchronized with the EEG data). The annotations can be recorded in an annotation file. The annotation file can be synchronized with the EEG setup.

[0097] For example, the EEG setup can be synchronized to time-stamped data file. A clinical EEG can be used with the cellphone. The cellphone can be synchronized to track the EEG. The array holder 110 can include a clock that synchronizes with a clock on the cellphone. The cellphone can show an image and play a sound (e.g., 20 kHz). An ultrasonic transducer can be used as a wireless connection. Information can be encoded in ultrasonic audio information.

[0098] Other EEGs (e.g., commercial or research EEGs) can be used with a cellphone in this manner. The data being displayed and the annotations being recorded on the cellphone can be synchronized to the EEG data without modification to the EEG, e.g., by using one channel on the EEG to record audio data from a common ultrasonic transducer, or microphone. Upon displaying an image, the cellphone can play an ultrasonic sound (e.g., 20 kHz) that cannot be heard by the user, but can be detected by the EEG. By using a combination of ultrasonic tones, similar to the DTMF system used to convey data in a touchtone phone system, the cellphone can indicate a large number of different states to the EEG, such as when it starts and finishes displaying a particular visual stimulus. This way of transporting data from a phone's speaker to an ultrasonic microphone on an unused EEG channel can allow for a way to wirelessly transmit synchronous data from any commercial phone, computer, or mobile device to any commercial EEG, without the need to modify the hardware.

[0099] FIG. 20 illustrates a method 2000 for distributed biosensing. In brief summary, the method 2000 can include providing an array holder (BLOCK 2005). The method 2000 can include providing a sensing cell (BLOCK 2010).

[0100] The method 2000 can include providing an array holder (BLOCK 2005). The array holder can include a rivet, bus strip, locking ridge, metal connector, and/or insulating plastic housing. The array holder can be mechanically hinged. The array holder can be mechanically flexible.

[0101] The method 2000 can include providing a sensing cell (BLOCK 2010). For example, the method 2000 can include providing a plurality of sensing cells. Each of the plurality of sensing cells can include a housing configured to mechanically couple with the array holder. Each of the plurality of sensing cells can include at least one processor disposed in the housing. The at least one processor can include a silicon die. The at least one processor of each of the plurality of sensing cells can be configured to perform synchronous measurements. The at least one processor of each of the plurality of sensing cells can be configured to perform synchronous measurements of electrical potentials on the skin of the patient. Each of the plurality of sensing cells can include a first hydrogel disposed in the housing and configured to mechanically and electrically couple with a patient. Each of the plurality of sensing cells can include a second hydrogel disposed in the housing and configured to electrically couple with the array holder.

[0102] The method 2000 can include disposing the first hydrogel on a first side of the at least one processor. The method 2000 can include disposing the second hydrogel on a second side of the at least one processor. The second side of the at least one processor can be opposite the first side of the at least one processor. The second side of the at least one processor can be on the same side as the first side of the at least one processor.

[0103] The method 2000 can include separating, by a divider, the first hydrogel and the second hydrogel. The method 2000 can include coupling the at least one processor with the divider. For example, coupling the at least one processor with the divider can include mechanically contacting the processor with the divider. Coupling the at least one processor with the divider can include electrically coupling the processor with the divider.

[0104] The method 2000 can include supplying, by a power source, power to each of the plurality of sensing cells. The method 2000 can include supplying, by an ultracapacitor,

power to each of the plurality of sensing cells. The method 2000 can include presenting, by a mobile application, one or more stimuli to the patient.

[0105] Embodiments of the subject matter and the operations described in this specification can be implemented in digital electronic circuitry, or in computer software, firmware, or hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. The subject matter described in this specification can be implemented as one or more computer programs, e.g., one or more circuits of computer program instructions, encoded on one or more computer storage media for execution by, or to control the operation of, data processing apparatus. Alternatively or in addition, the program instructions can be encoded on an artificially generated propagated signal, e.g., a machine-generated electrical, optical, or electromagnetic signal that is generated to encode information for transmission to suitable receiver apparatus for execution by a data processing apparatus. A computer storage medium can be, or be included in, a computer-readable storage device, a computer-readable storage substrate, a random or serial access memory array or device, or a combination of one or more of them. Moreover, while a computer storage medium is not a propagated signal, a computer storage medium can be a source or destination of computer program instructions encoded in an artificially generated propagated signal. The computer storage medium can also be, or be included in, one or more separate components or media (e.g., multiple CDs, disks, or other storage devices).

[0106] The operations described in this specification can be performed by a data processing apparatus on data stored on one or more computer-readable storage devices or received from other sources. The term “data processing apparatus” or “computing device” encompasses various apparatuses, devices, and machines for processing data, including by way of example a programmable processor, a computer, a system on a chip, or multiple ones, or combinations of the foregoing. The apparatus can include special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application specific integrated circuit). The apparatus can also include, in addition to hardware, code that creates an execution environment for the computer program in question, e.g., code that constitutes processor firmware, a protocol stack, a database management system, an operating system, a cross-platform runtime environment, a virtual machine, or a combination of one or more of them. The apparatus and execution environment can realize various different computing

model infrastructures, such as web services, distributed computing and grid computing infrastructures.

[0107] A computer program (also known as a program, software, software application, script, or code) can be written in any form of programming language, including compiled or interpreted languages, declarative or procedural languages, and it can be deployed in any form, including as a stand-alone program or as a circuit, component, subroutine, object, or other unit suitable for use in a computing environment. A computer program may, but need not, correspond to a file in a file system. A program can be stored in a portion of a file that holds other programs or data (e.g., one or more scripts stored in a markup language document), in a single file dedicated to the program in question, or in multiple coordinated files (e.g., files that store one or more circuits, subprograms, or portions of code). A computer program can be deployed to be executed on one computer or on multiple computers that are located at one site or distributed across multiple sites and interconnected by a communication network.

[0108] Processors suitable for the execution of a computer program include, by way of example, microprocessors, and any one or more processors of a digital computer. A processor can receive instructions and data from a read only memory or a random-access memory or both. The elements of a computer are a processor for performing actions in accordance with instructions and one or more memory devices for storing instructions and data. A computer can include, or be operatively coupled to receive data from or transfer data to, or both, one or more mass storage devices for storing data, e.g., magnetic, magneto optical disks, or optical disks. A computer need not have such devices. Moreover, a computer can be embedded in another device, e.g., a personal digital assistant (PDA), a Global Positioning System (GPS) receiver, or a portable storage device (e.g., a universal serial bus (USB) flash drive), to name just a few. Devices suitable for storing computer program instructions and data include all forms of non-volatile memory, media and memory devices, including by way of example semiconductor memory devices, e.g., EPROM, EEPROM, and flash memory devices; magnetic disks, e.g., internal hard disks or removable disks; magneto optical disks; and CD ROM and DVD-ROM disks. The processor and the memory can be supplemented by, or incorporated in, special purpose logic circuitry.

[0109] To provide for interaction with a user, implementations of the subject matter described in this specification can be implemented on a computer having a display device, e.g., a CRT (cathode ray tube) or LCD (liquid crystal display) monitor, for displaying

information to the user and a keyboard and a pointing device, e.g., a mouse or a trackball, by which the user can provide input to the computer. Other kinds of devices can be used to provide for interaction with a user as well; for example, feedback provided to the user can be any form of sensory feedback, e.g., visual feedback, auditory feedback, or tactile feedback; and input from the user can be received in any form, including acoustic, speech, or tactile input.

[0110] The implementations described herein can be implemented in any of numerous ways including, for example, using hardware, software or a combination thereof. When implemented in software, the software code can be executed on any suitable processor or collection of processors, whether provided in a single computer or distributed among multiple computers.

[0111] Also, a computer may have one or more input and output devices. These devices can be used, among other things, to present a user interface. Examples of output devices that can be used to provide a user interface include printers or display screens for visual presentation of output and speakers or other sound generating devices for audible presentation of output. Examples of input devices that can be used for a user interface include keyboards, and pointing devices, such as mice, touch pads, and digitizing tablets. As another example, a computer may receive input information through speech recognition or in other audible format.

[0112] Such computers may be interconnected by one or more networks in any suitable form, including a local area network or a wide area network, such as an enterprise network, and intelligent network (IN) or the Internet. Such networks may be based on any suitable technology and may operate according to any suitable protocol and may include wireless networks, wired networks or fiber optic networks.

[0113] A computer employed to implement at least a portion of the functionality described herein may comprise a memory, one or more processing units (also referred to herein simply as "processors"), one or more communication interfaces, one or more display units, and one or more user input devices. The memory may comprise any computer-readable media, and may store computer instructions (also referred to herein as "processor-executable instructions") for implementing the various functionalities described herein. The processing unit(s) may be used to execute the instructions. The communication interface(s) may be coupled to a wired or wireless network, bus, or other communication means and may

therefore allow the computer to transmit communications to or receive communications from other devices. The display unit(s) may be provided, for example, to allow a user to view various information in connection with execution of the instructions. The user input device(s) may be provided, for example, to allow the user to make manual adjustments, make selections, enter data or various other information, or interact in any of a variety of manners with the processor during execution of the instructions.

[0114] The various methods or processes outlined herein may be coded as software that is executable on one or more processors that employ any one of a variety of operating systems or platforms. Additionally, such software may be written using any of a number of suitable programming languages or programming or scripting tools, and also may be compiled as executable machine language code or intermediate code that is executed on a framework or virtual machine.

[0115] In this respect, various inventive concepts may be embodied as a computer readable storage medium (or multiple computer readable storage media) (e.g., a computer memory, one or more floppy discs, compact discs, optical discs, magnetic tapes, flash memories, circuit configurations in Field Programmable Gate Arrays or other semiconductor devices, or other non-transitory medium or tangible computer storage medium) encoded with one or more programs that, when executed on one or more computers or other processors, perform methods that implement the various embodiments of the solution discussed above. The computer readable medium or media can be transportable, such that the program or programs stored thereon can be loaded onto one or more different computers or other processors to implement various aspects of the present solution as discussed above.

[0116] The terms “program” or “software” are used herein to refer to any type of computer code or set of computer-executable instructions that can be employed to program a computer or other processor to implement various aspects of embodiments as discussed above. One or more computer programs that when executed perform methods of the present solution need not reside on a single computer or processor, but may be distributed in a modular fashion amongst a number of different computers or processors to implement various aspects of the present solution.

[0117] Computer-executable instructions may be in many forms, such as program modules, executed by one or more computers or other devices. Program modules can include routines, programs, objects, components, data structures, or other components that perform

particular tasks or implement particular abstract data types. The functionality of the program modules can be combined or distributed as desired in various embodiments.

[0118] Also, data structures may be stored in computer-readable media in any suitable form. For simplicity of illustration, data structures may be shown to have fields that are related through location in the data structure. Such relationships may likewise be achieved by assigning storage for the fields with locations in a computer-readable medium that convey relationship between the fields. However, any suitable mechanism may be used to establish a relationship between information in fields of a data structure, including through the use of pointers, tags or other mechanisms that establish relationship between data elements.

[0119] Any references to implementations or elements or acts of the systems and methods herein referred to in the singular can include implementations including a plurality of these elements, and any references in plural to any implementation or element or act herein can include implementations including only a single element. References in the singular or plural form are not intended to limit the presently disclosed systems or methods, their components, acts, or elements to single or plural configurations. References to any act or element being based on any information, act or element may include implementations where the act or element is based at least in part on any information, act, or element.

[0120] Any implementation disclosed herein may be combined with any other implementation, and references to "an implementation," "some implementations," "an alternate implementation," "various implementations," "one implementation" or the like are not necessarily mutually exclusive and are intended to indicate that a particular feature, structure, or characteristic described in connection with the implementation may be included in at least one implementation. Such terms as used herein are not necessarily all referring to the same implementation. Any implementation may be combined with any other implementation, inclusively or exclusively, in any manner consistent with the aspects and implementations disclosed herein.

[0121] References to "or" may be construed as inclusive so that any terms described using "or" may indicate any of a single, more than one, and all of the described terms. References to at least one of a conjunctive list of terms may be construed as an inclusive OR to indicate any of a single, more than one, and all of the described terms. For example, a reference to "at least one of 'A' and 'B'" can include only 'A', only 'B', as well as both 'A' and 'B'. Elements other than 'A' and 'B' can also be included.

[0122] The systems and methods described herein may be embodied in other specific forms without departing from the characteristics thereof. The foregoing implementations are illustrative rather than limiting of the described systems and methods.

[0123] Where technical features in the drawings, detailed description or any claim are followed by reference signs, the reference signs have been included to increase the intelligibility of the drawings, detailed description, and claims. Accordingly, neither the reference signs nor their absence have any limiting effect on the scope of any claim elements.

[0124] The systems and methods described herein may be embodied in other specific forms without departing from the characteristics thereof. The foregoing implementations are illustrative rather than limiting of the described systems and methods. Scope of the systems and methods described herein is thus indicated by the appended claims, rather than the foregoing description, and changes that come within the meaning and range of equivalency of the claims are embraced therein.

WHAT IS CLAIMED IS:

1. A system, comprising:

an array holder; and

a plurality of sensing cells, each of the plurality of sensing cells comprising:

a housing configured to mechanically couple with the array holder;

at least one processor disposed in the housing;

a first hydrogel disposed in the housing and configured to mechanically and electrically couple with a patient; and

a second hydrogel disposed in the housing and configured to electrically couple with the array holder.

2. The system of claim 1, wherein:

the first hydrogel is disposed on a first side of the processor; and

the second hydrogel is disposed on a second side of the processor opposite the first side of the processor.

3. The system of claim 1, further comprising:

a divider configured to separate the first hydrogel and the second hydrogel; and

the processor configured to couple with the divider.

4. The system of claim 1, further comprising:

a power source configured to supply power to each of the plurality of sensing cells.

5. The system of claim 1, wherein the processor comprises a silicon die.

6. The system of claim 1, wherein the processor of each of the plurality of sensing cells is configured to perform synchronous measurements.

7. The system of claim 1, wherein the processor of each of the plurality of sensing cells is configured to perform synchronous measurements of electrical potentials on skin of the patient.

8. The system of claim 1, wherein the array holder comprises bus fragments and bus wires.

9. The system of claim 1, further comprising an ultracapacitor configured to supply power to each of the plurality of sensing cells.

10. The system of claim 1, wherein the housing comprises one or more protrusions configured to couple the housing with the array holder.

11. The system of claim 1, further comprising:

a mobile application configured to present one or more stimuli to the patient.

12. A method, comprising:

providing an array holder; and

providing a plurality of sensing cells, each of the plurality of sensing cells comprising:

a housing configured to mechanically couple with the array holder;

at least one processor disposed in the housing;

a first hydrogel disposed in the housing and configured to mechanically and electrically couple with a patient; and

a second hydrogel disposed in the housing and configured to electrically couple with the array holder.

13. The method of claim 12, comprising:

disposing the first hydrogel on a first side of the at least one processor; and

disposing the second hydrogel on a second side of the at least one processor opposite the first side of the at least one processor.

14. The method of claim 12, comprising:

separating, by a divider, the first hydrogel and the second hydrogel; and

coupling the at least one processor with the divider.

15. The method of claim 12, comprising:

supplying, by a power source, power to each of the plurality of sensing cells.

16. The method of claim 12, wherein the at least one processor comprises a silicon die.

17. The method of claim 12, wherein the at least one processor of each of the plurality of sensing cells is configured to perform synchronous measurements.

18. The method of claim 12, wherein the at least one processor of each of the plurality of sensing cells is configured to perform synchronous measurements of electrical potentials on skin of the patient.

19. The method of claim 12, comprising:

supplying, by an ultracapacitor, power to each of the plurality of sensing cells.

20. The method of claim 12, comprising:

presenting, by a mobile application, one or more stimuli to the patient.

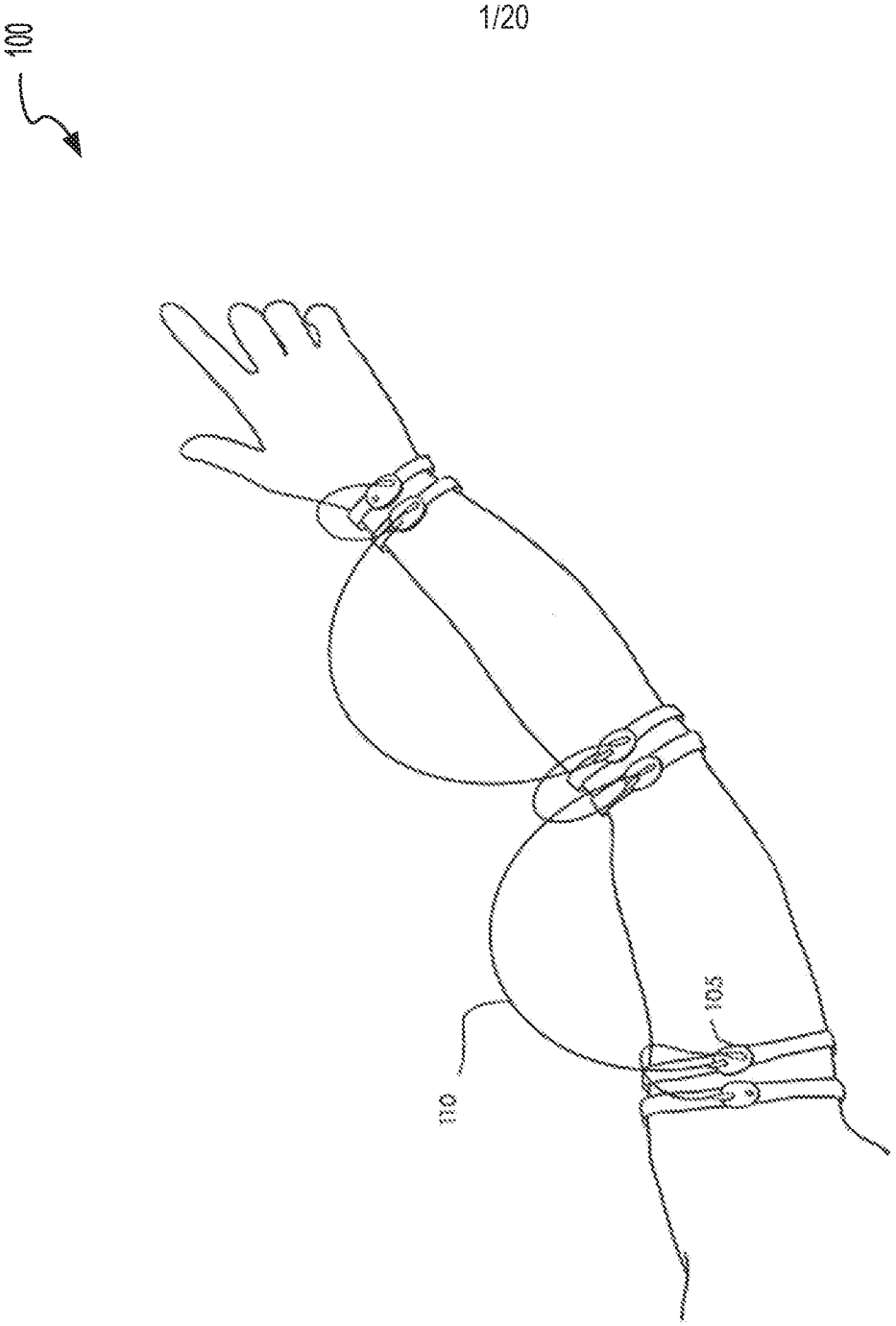

FIG. 1

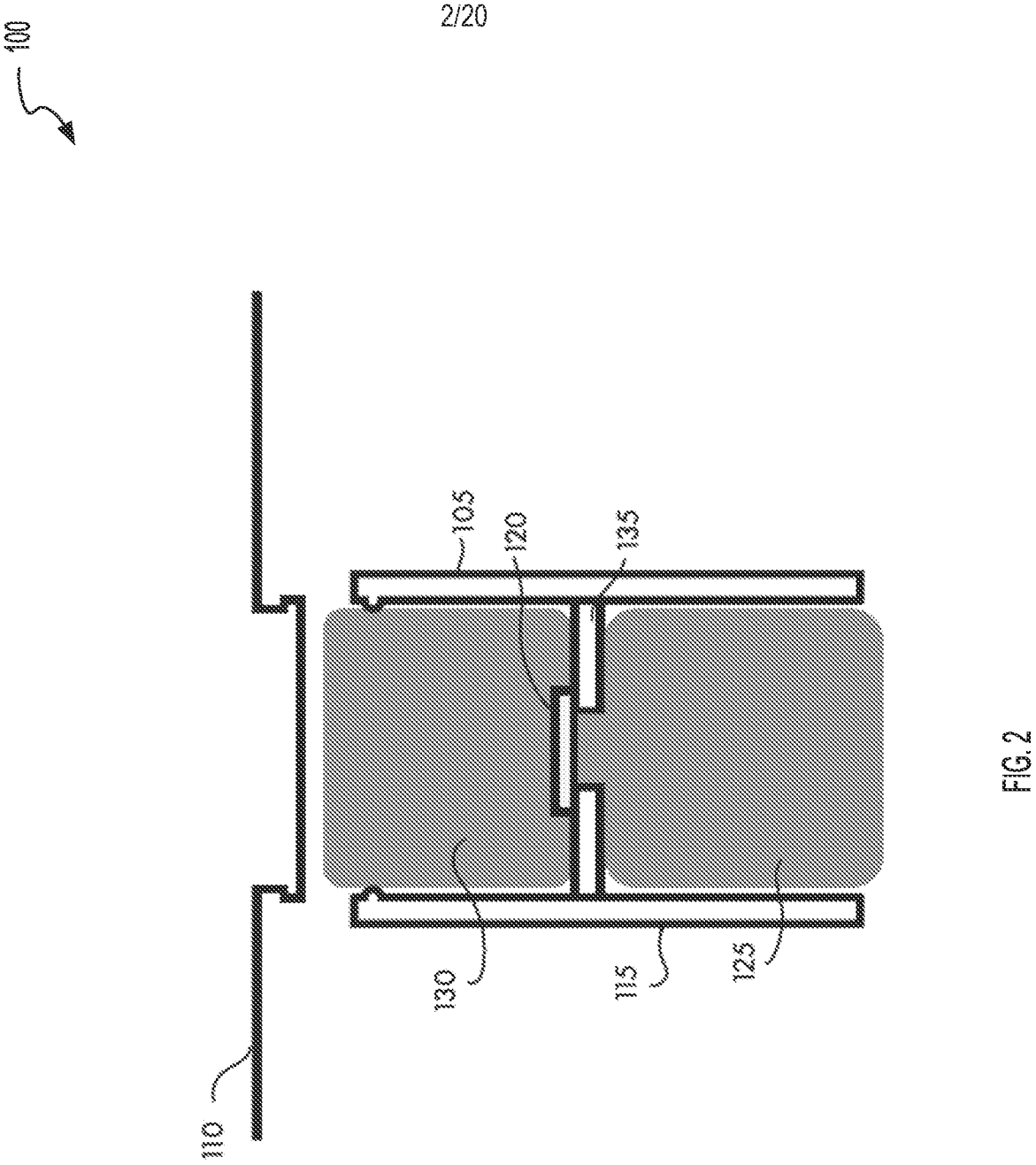

FIG. 2

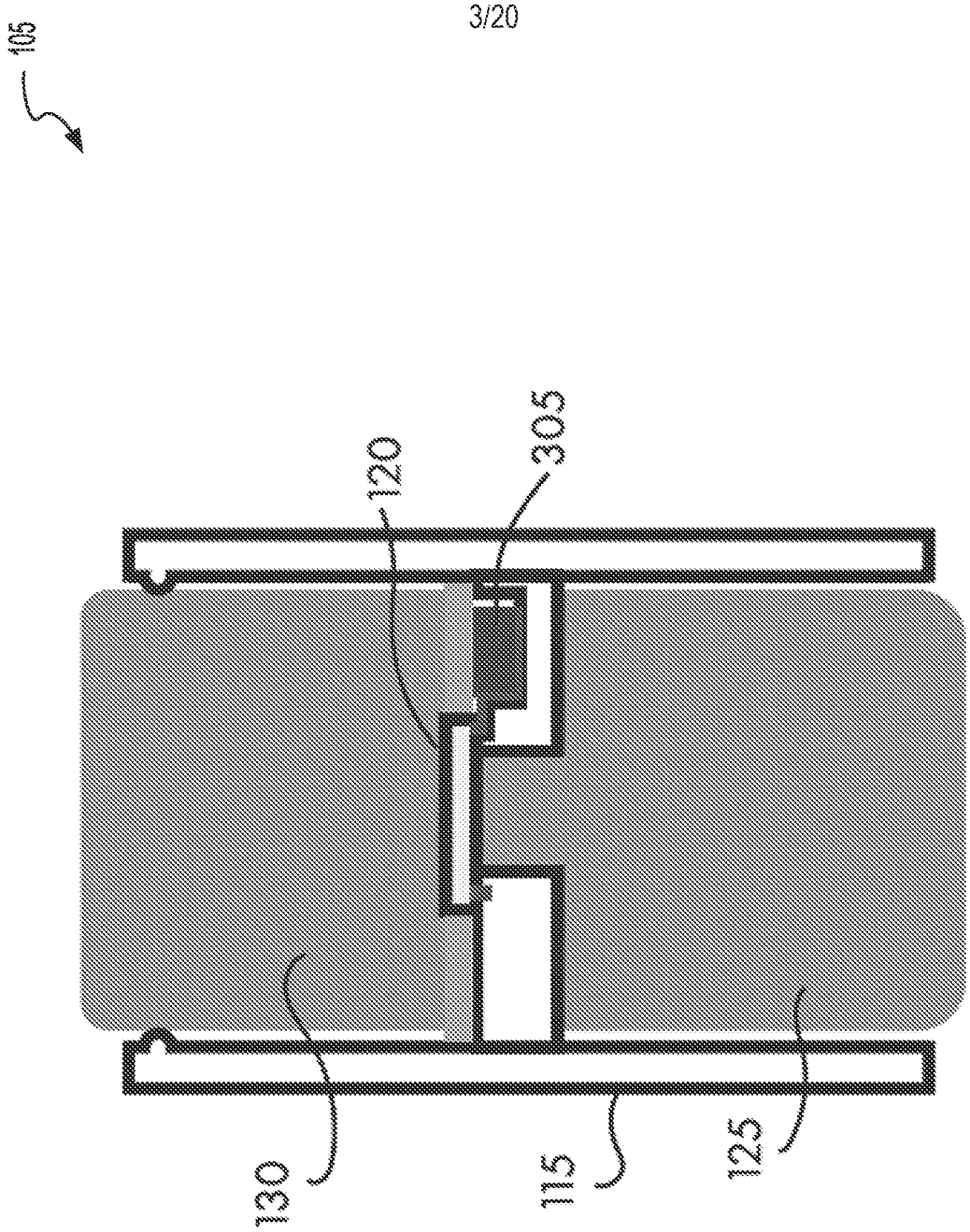

FIG. 3

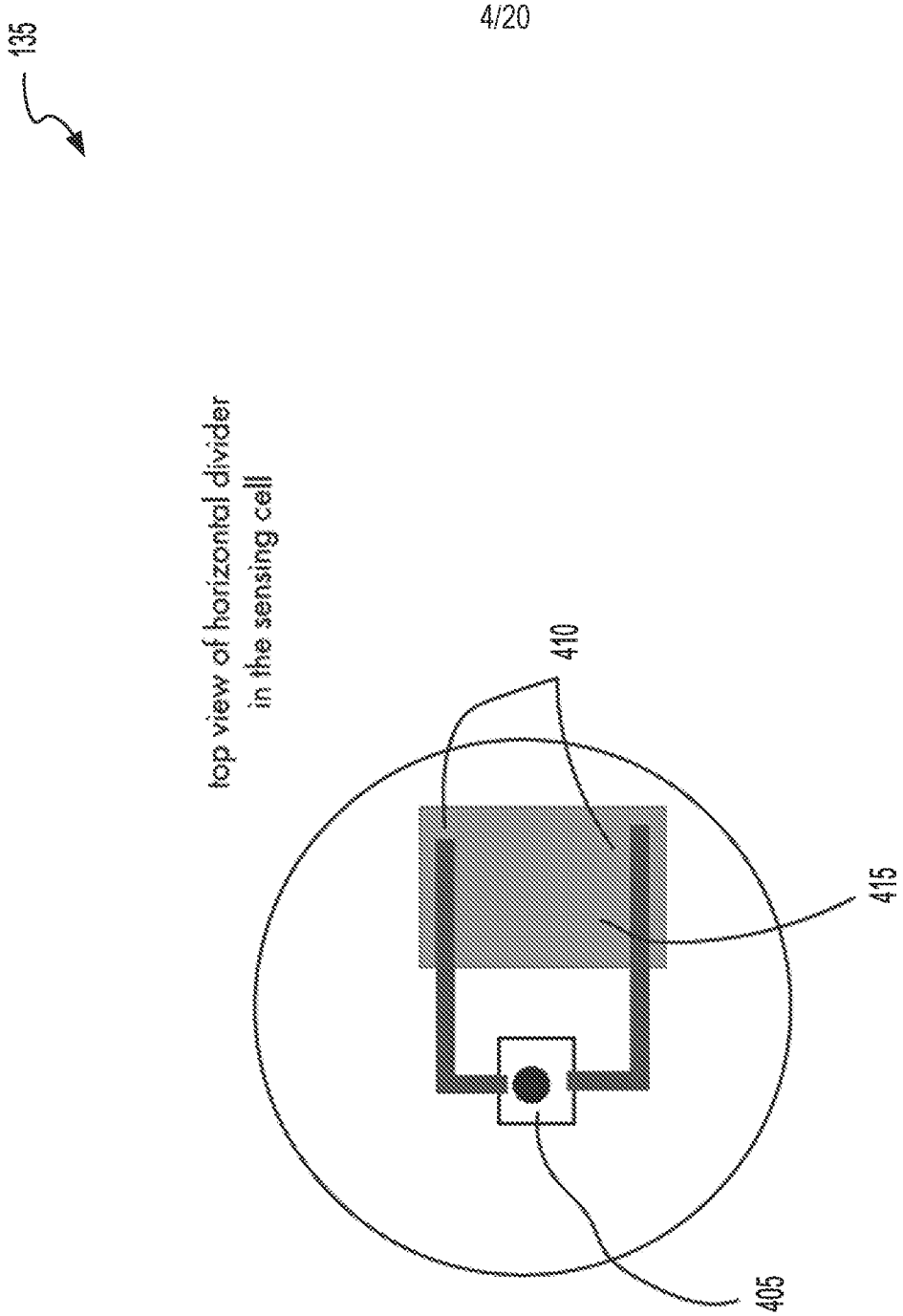
135
top view of horizontal divider
in the sensing cell
410
415
405

FIG. 4

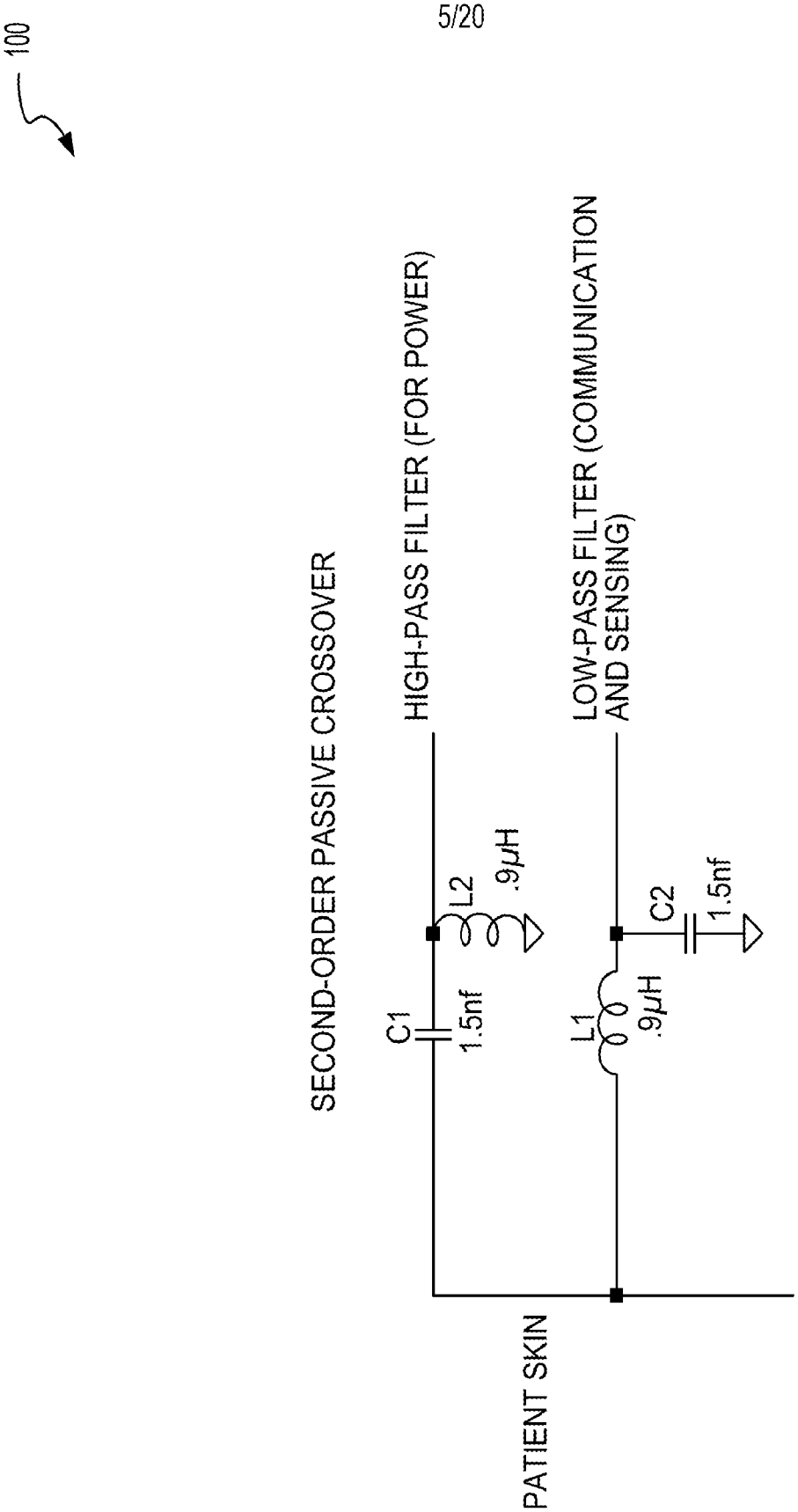
100
SECOND-ORDER PASSIVE CROSSOVER
HIGH-PASS FILTER (FOR POWER)
LOW-PASS FILTER (COMMUNICATION AND SENSING)
C1
1.5nf
L2
.9μH
L1
.9μH
C2
1.5nf
PATIENT SKIN

FIG. 5

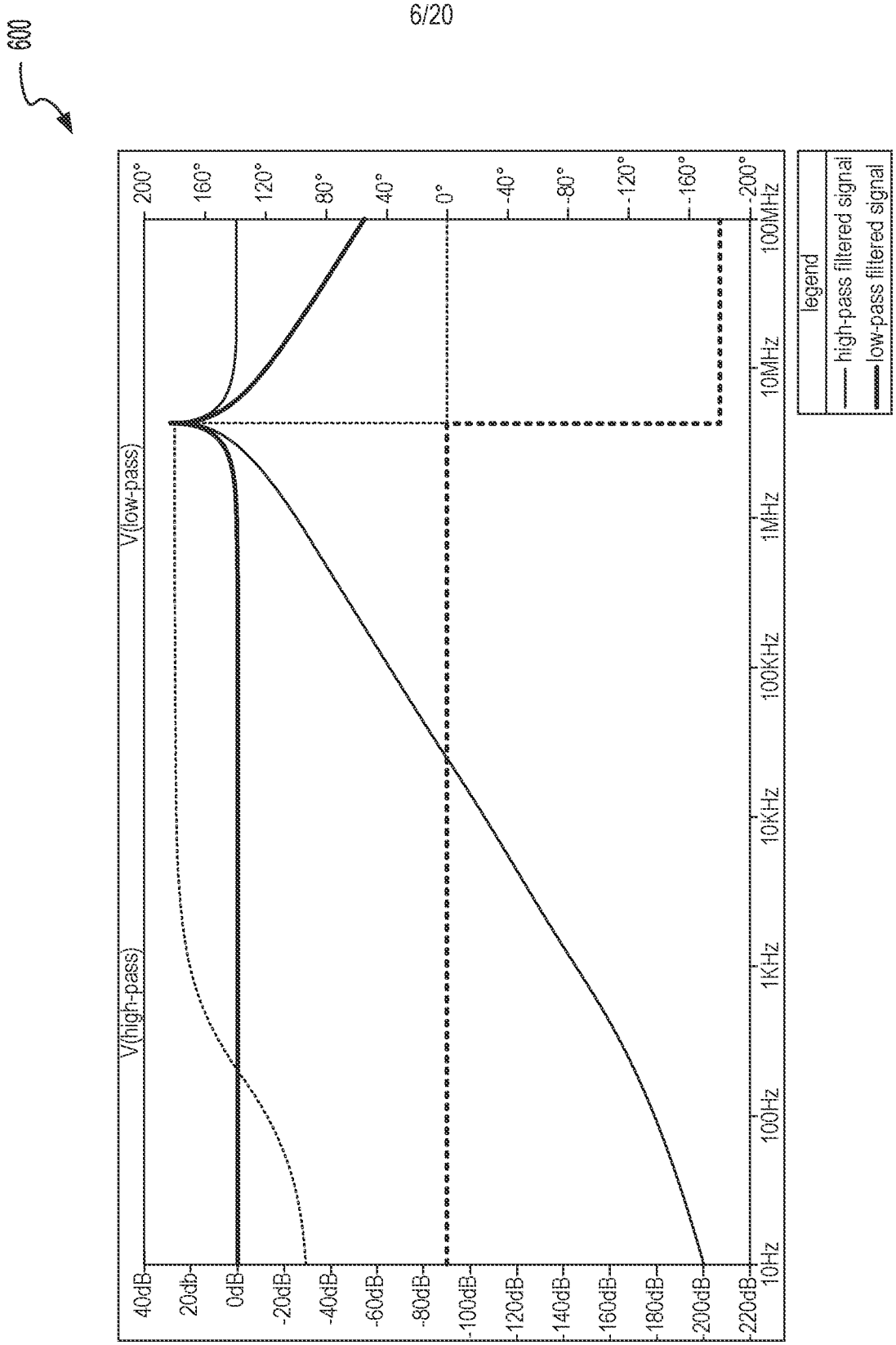
600
V(high-pass)
V(low-pass)
40dB
20db
0dB
-20dB
-40dB
-60dB
-80dB
-100dB
-120dB
-140dB
-160dB
-180dB
-200dB
-220dB
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
200°
160°
120°
80°
40°
0°
-40°
-80°
-120°
-160°
-200°
legend
high-pass filtered signal
low-pass filtered signal

FIG. 6

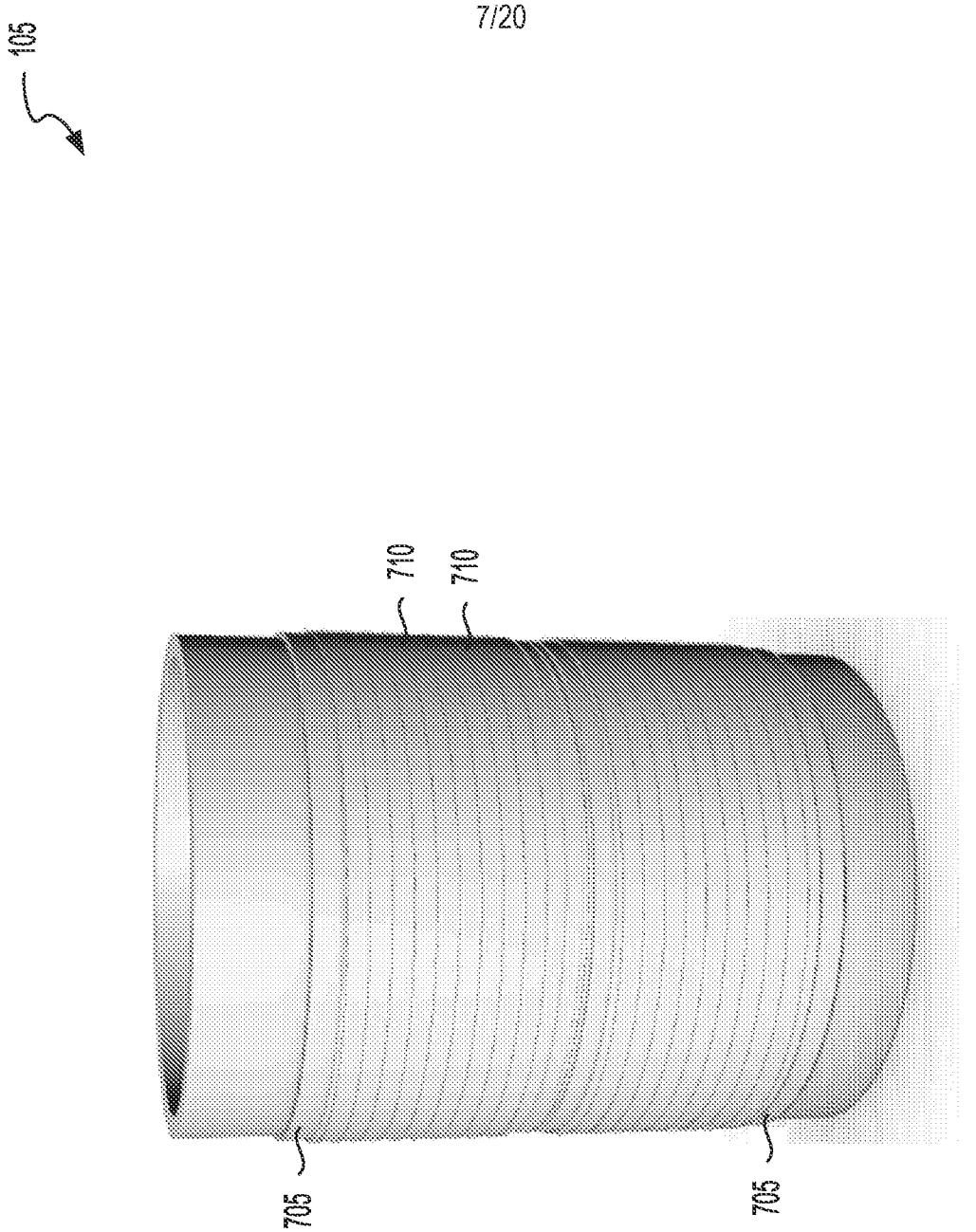

FIG. 7

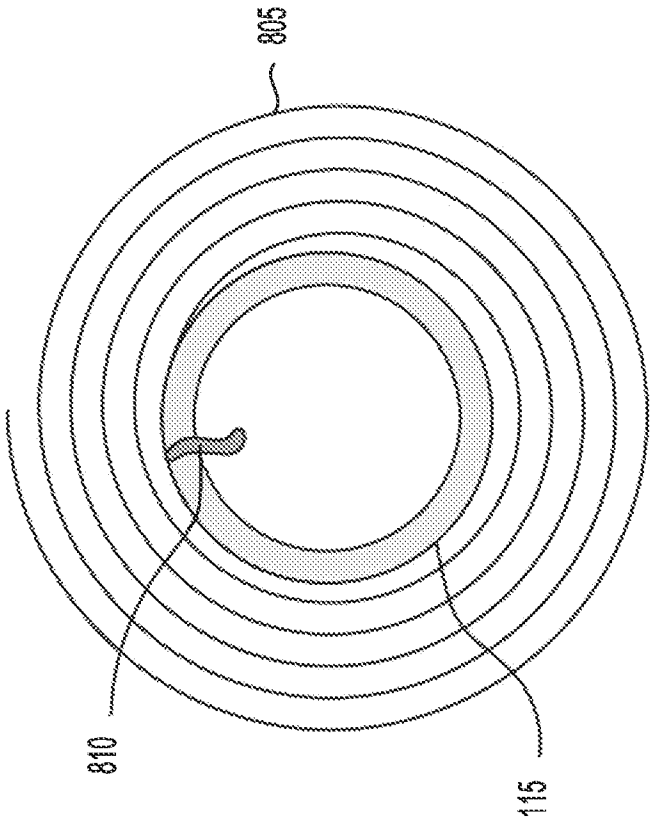

FIG. 8

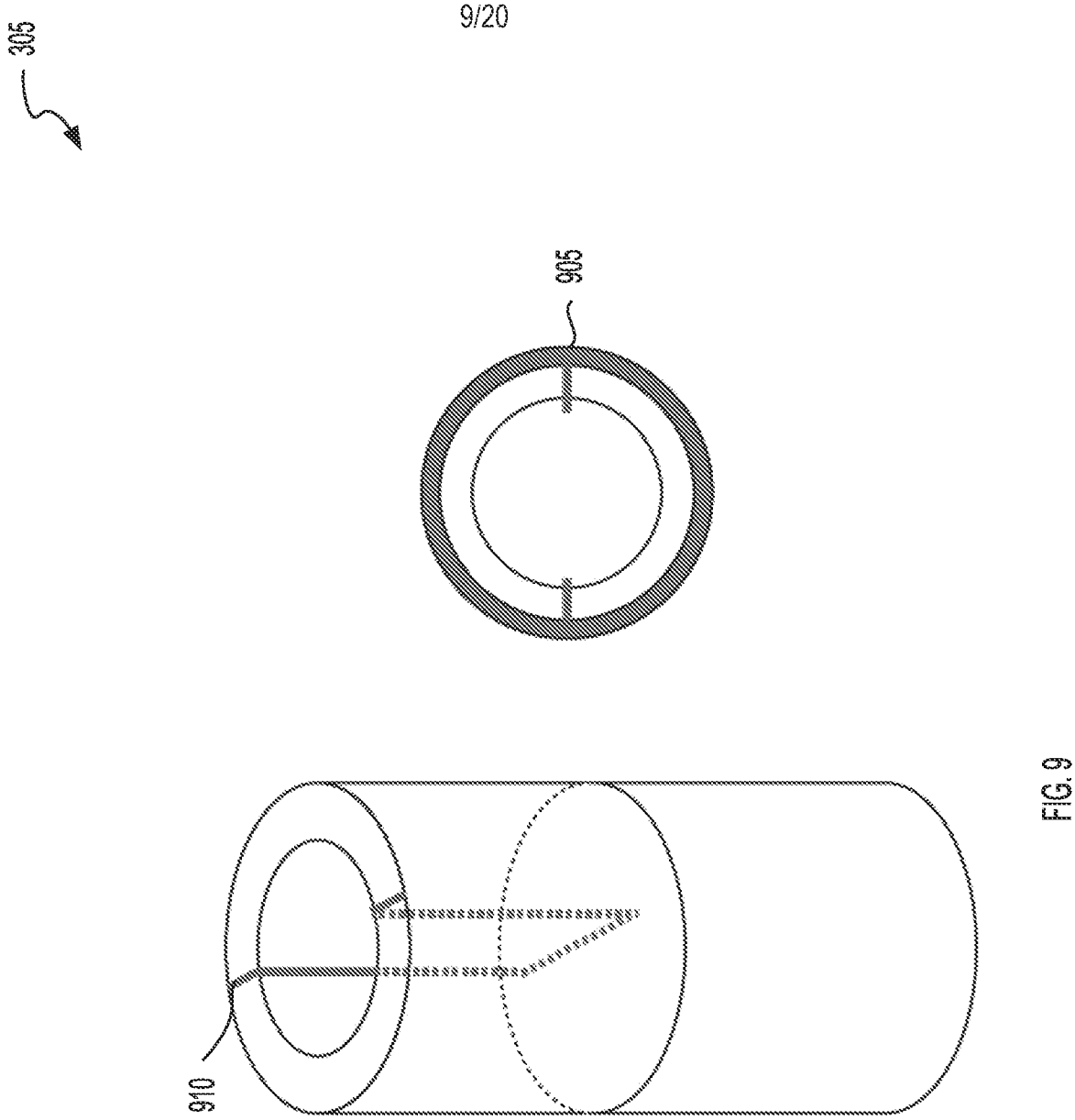

FIG. 9

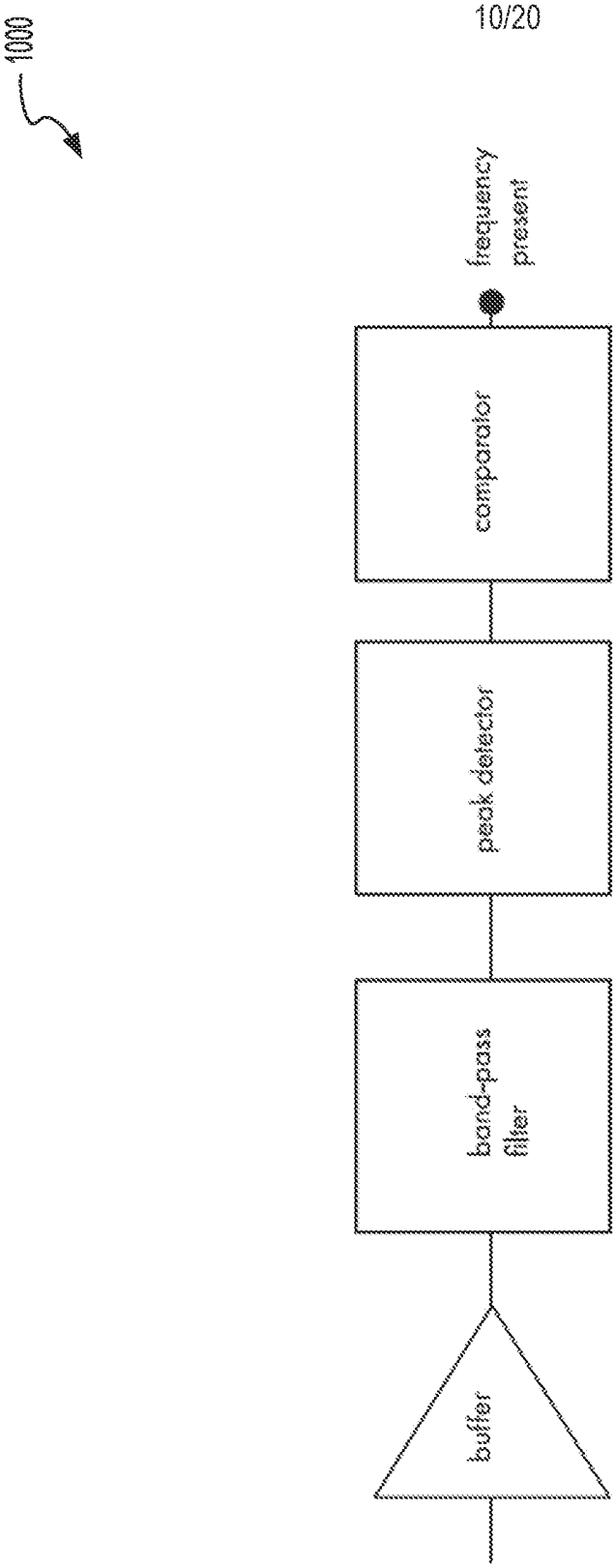
1000
frequency present
comparator
peak detector
band-pass filter
buffer

FIG. 10

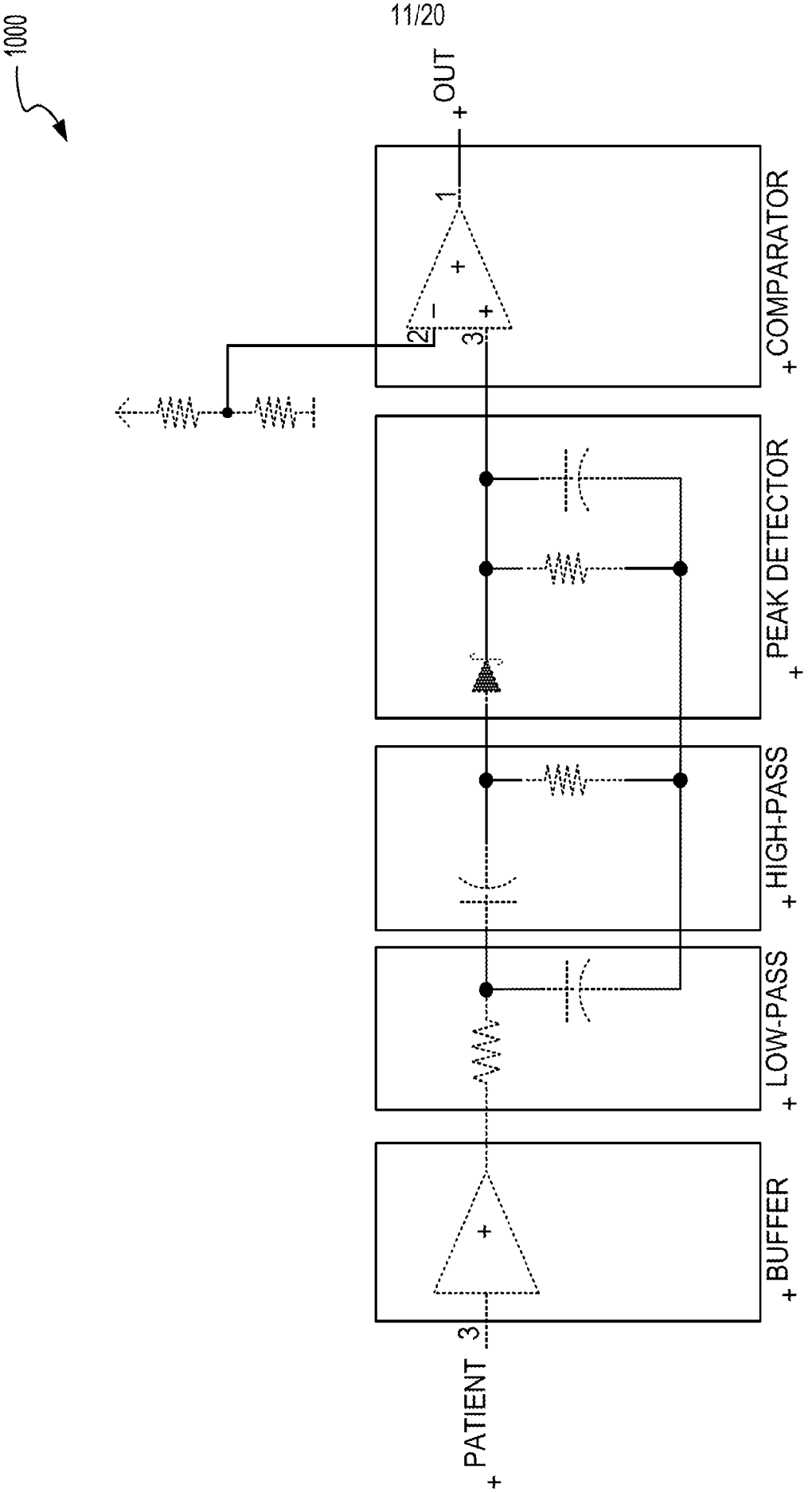
1000
OUT
1
2
3
COMPARATOR
PEAK DETECTOR
HIGH-PASS
LOW-PASS
BUFFER
3
PATIENT

FIG. 11

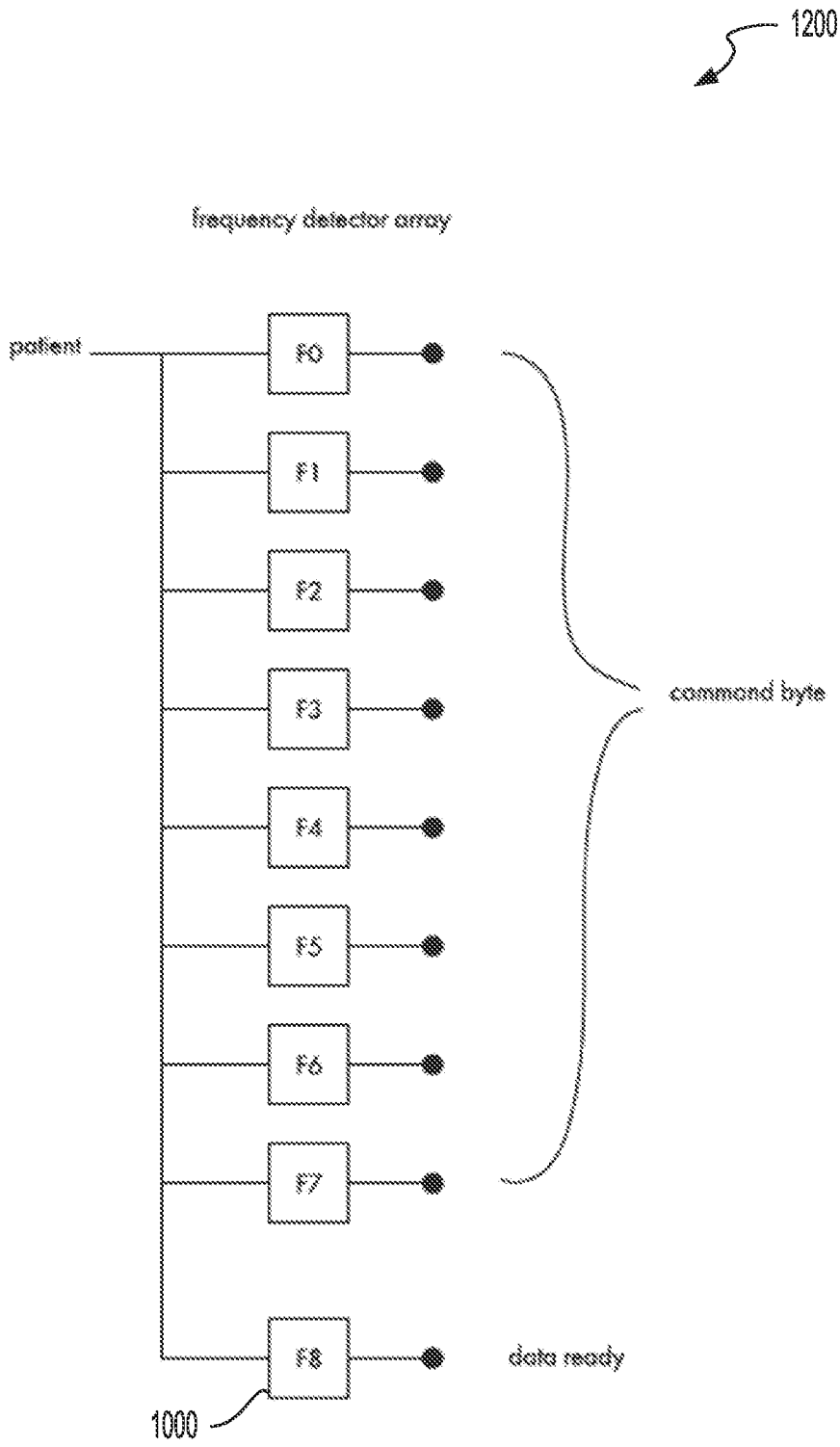
1200
frequency detector array
patient
F0
F1
F2
F3
F4
F5
F6
F7
F8
command byte
data ready
1000

FIG. 12

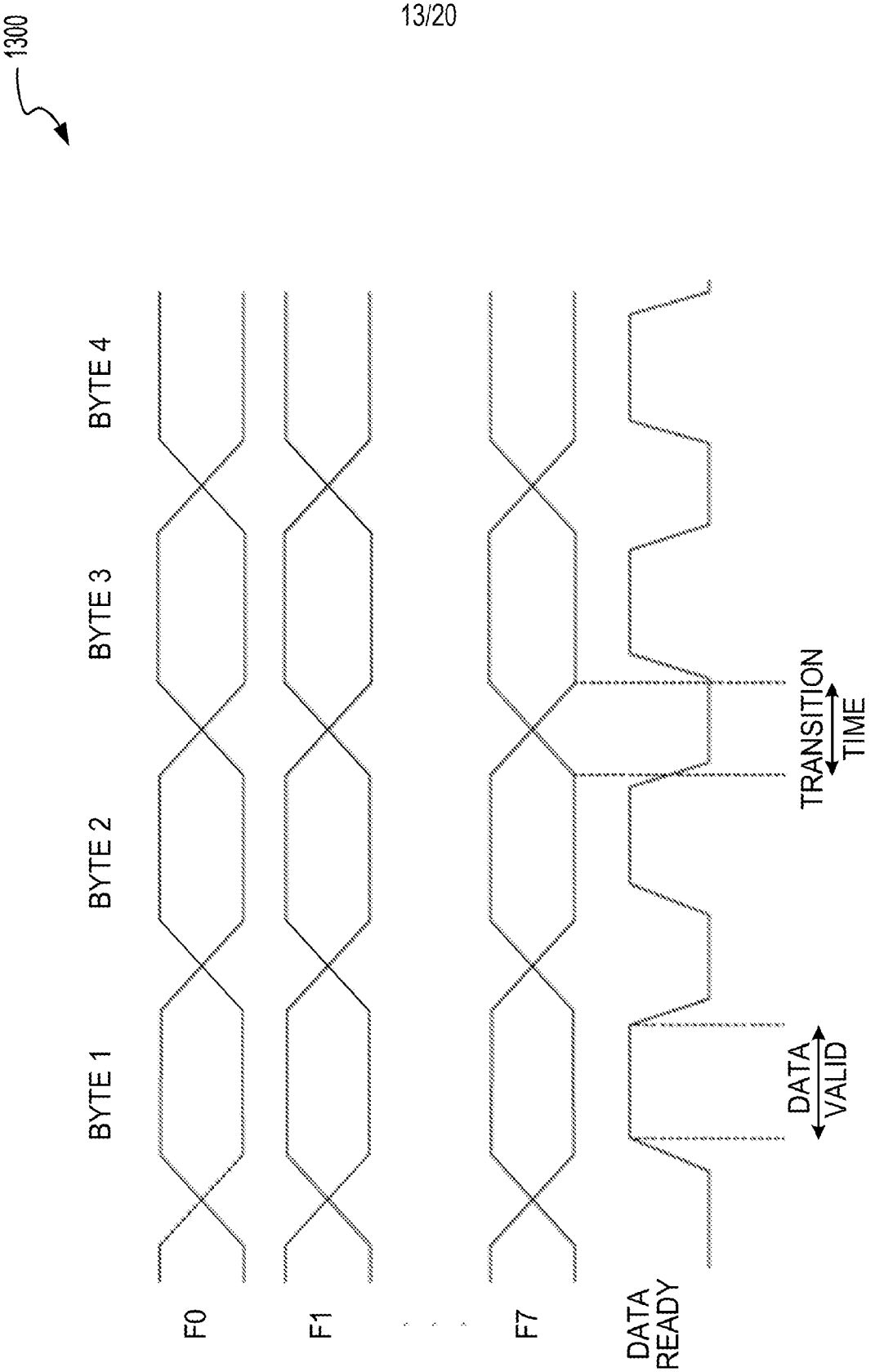
1300
BYTE 1
BYTE 2
BYTE 3
BYTE 4
F0
F1
F7
DATA READY
DATA VALID
TRANSITION TIME

FIG. 13

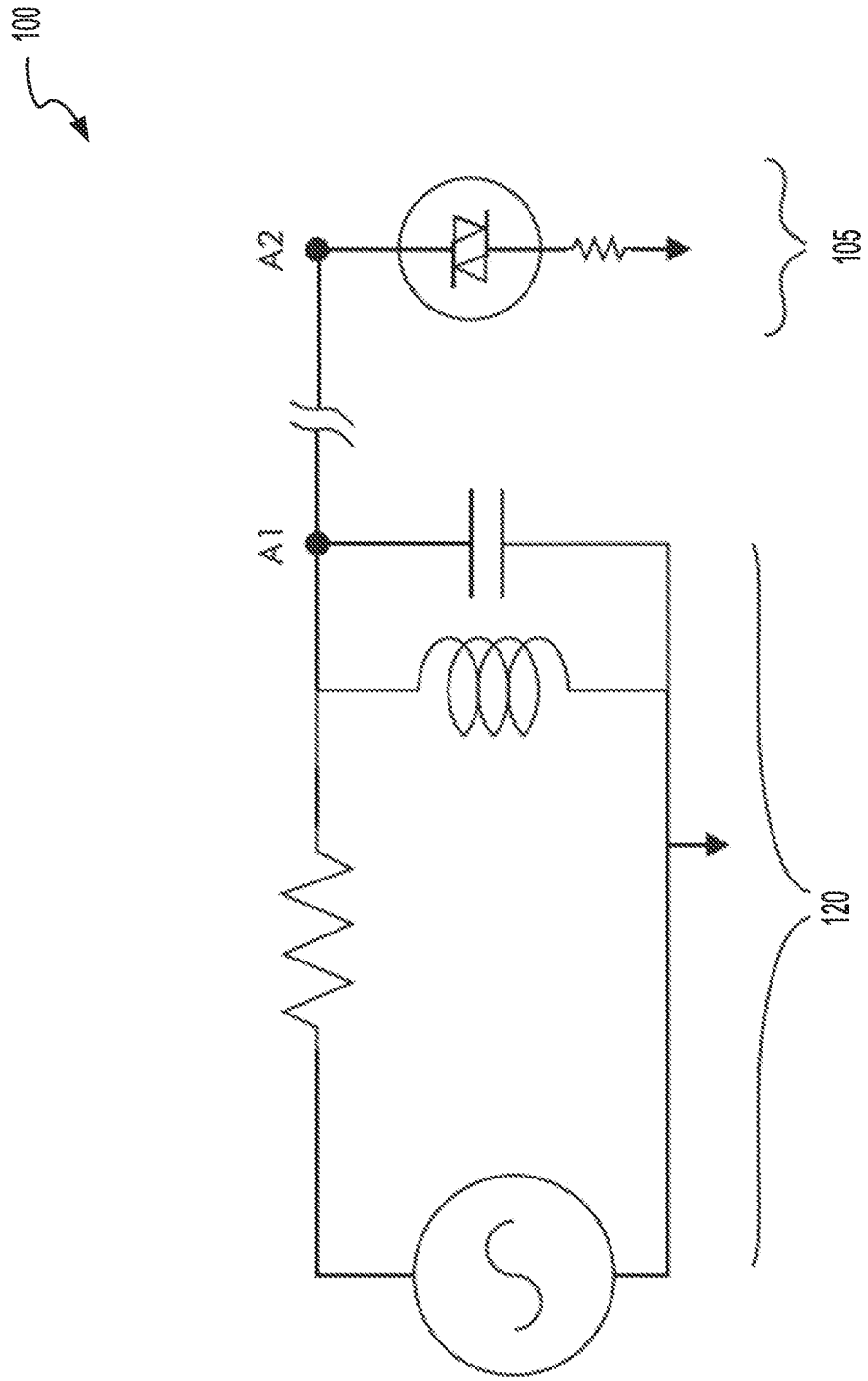

FIG. 14

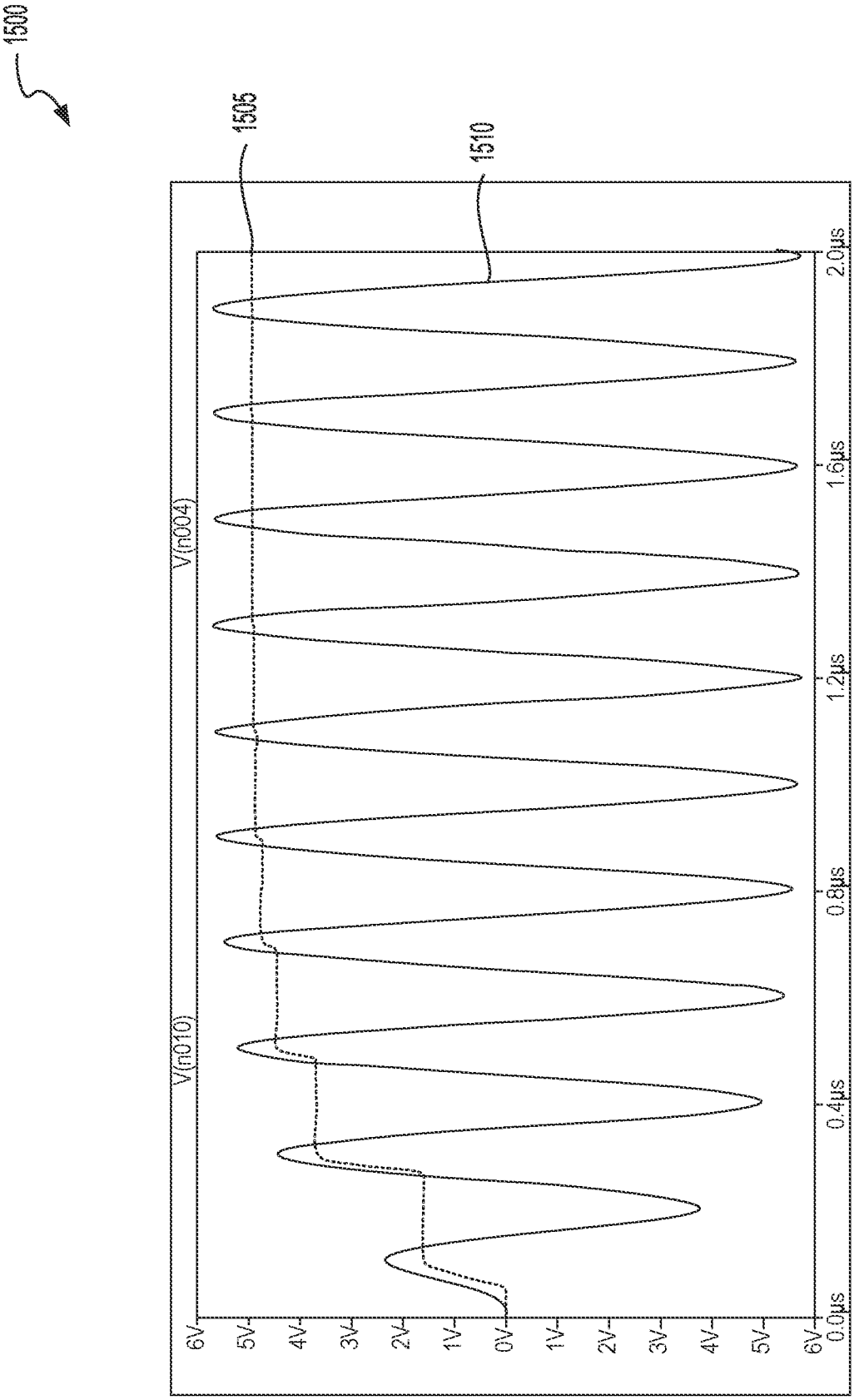
1500
1505
1510
V(n004)
V(n010)
6V
5V
4V
3V
2V
1V
0V
1V
2V
3V
4V
5V
6V
0.0µs
0.4µs
0.8µs
1.2µs
1.6µs
2.0µs

FIG. 15

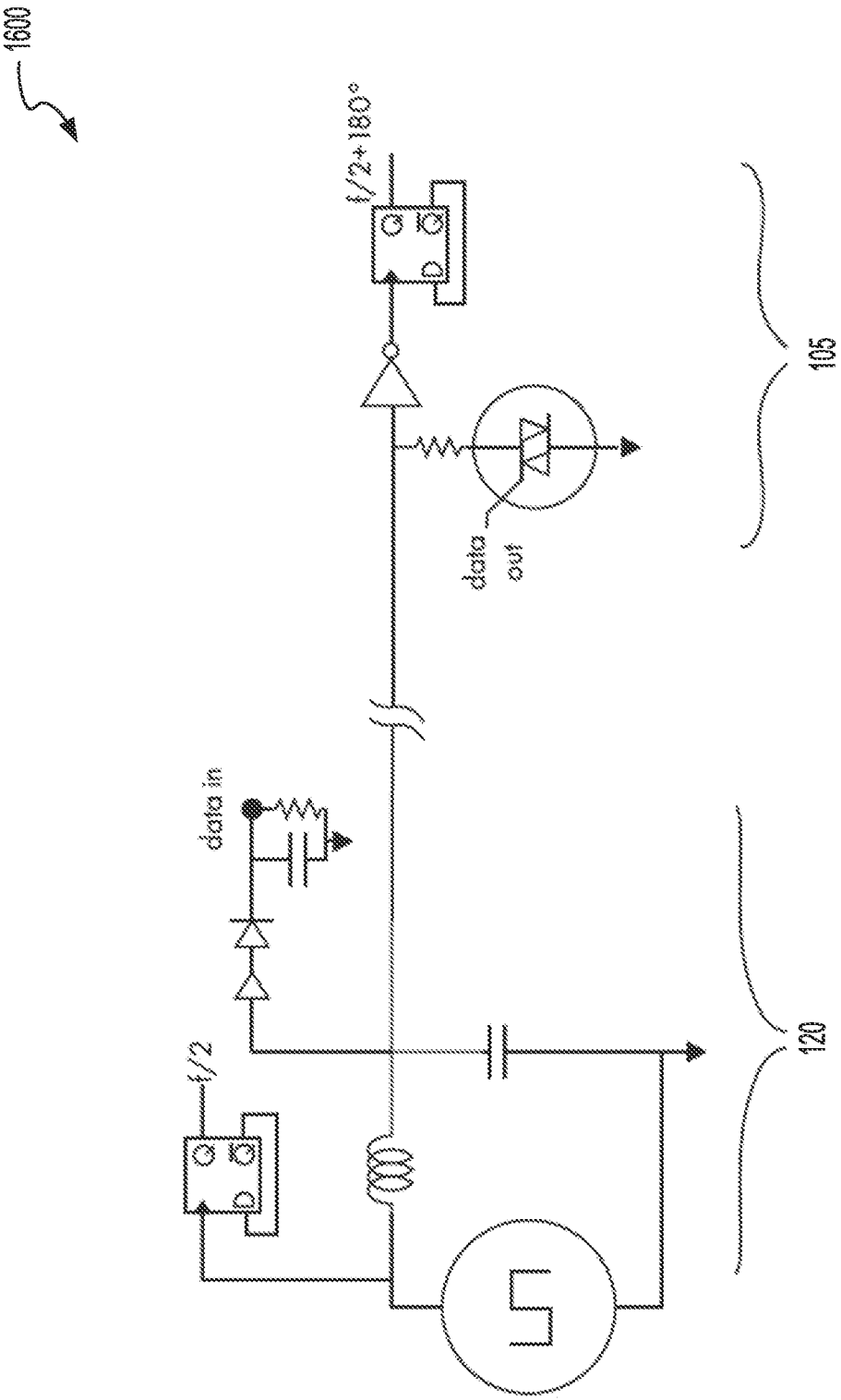

FIG. 16

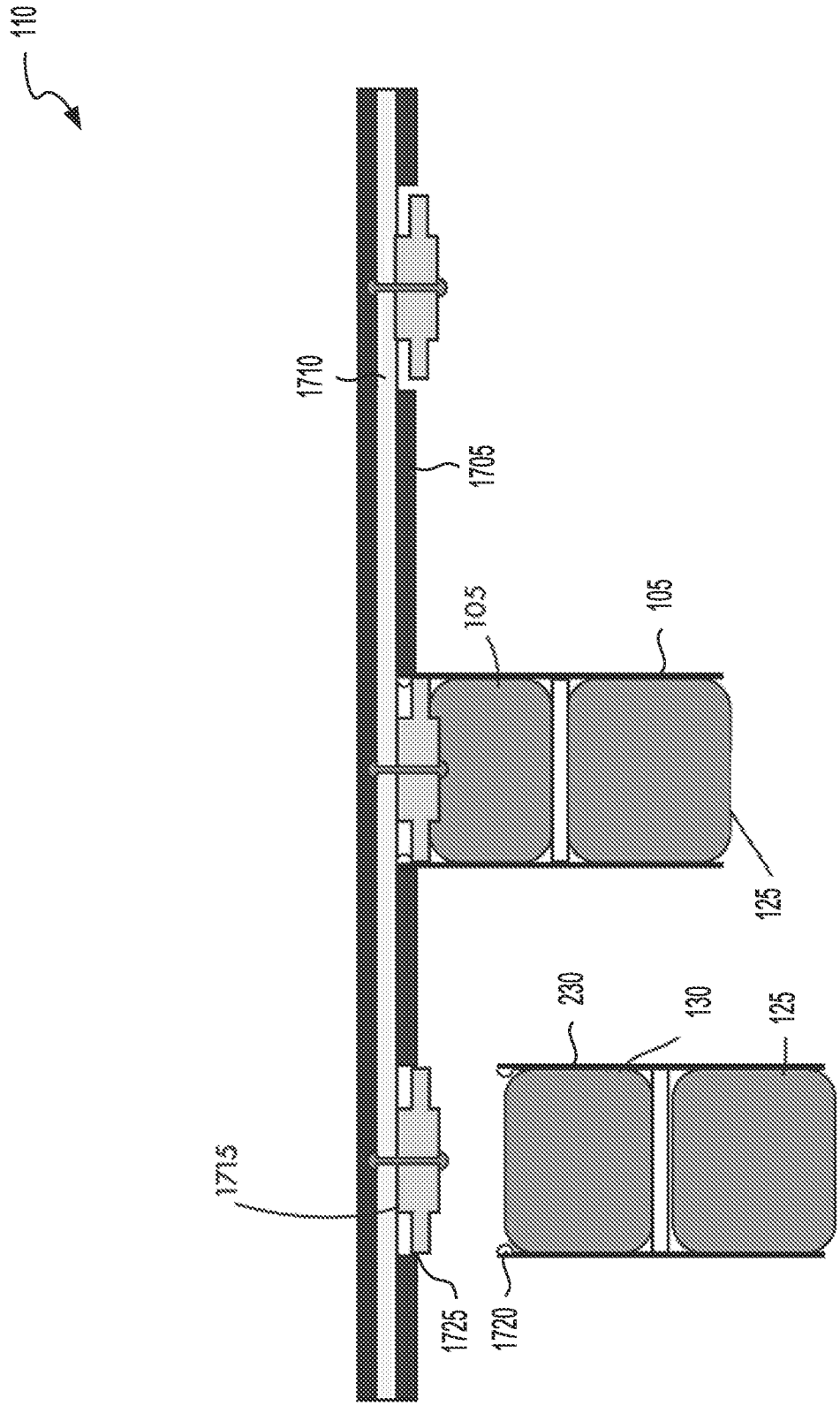

FIG. 17

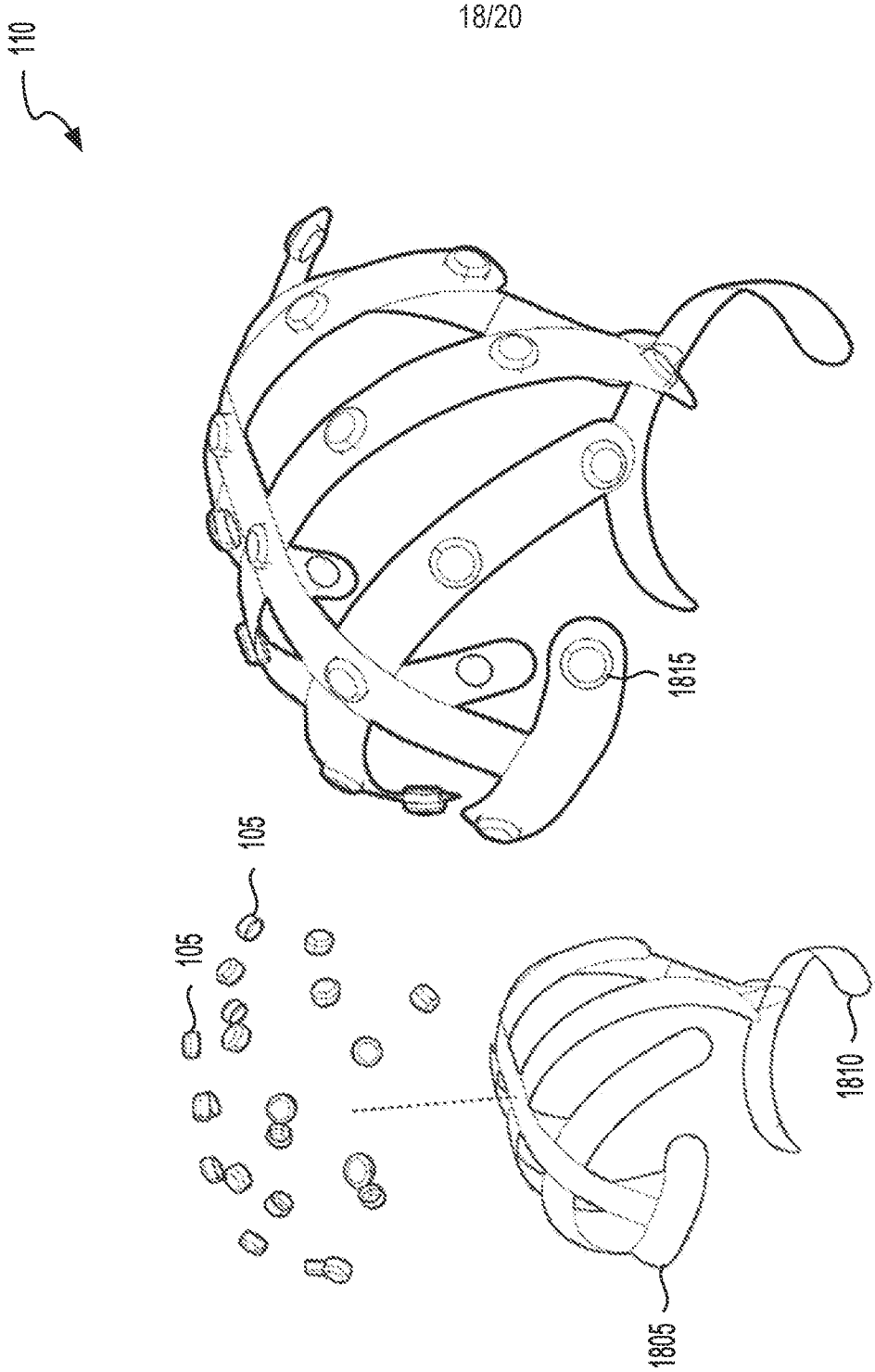

FIG. 18

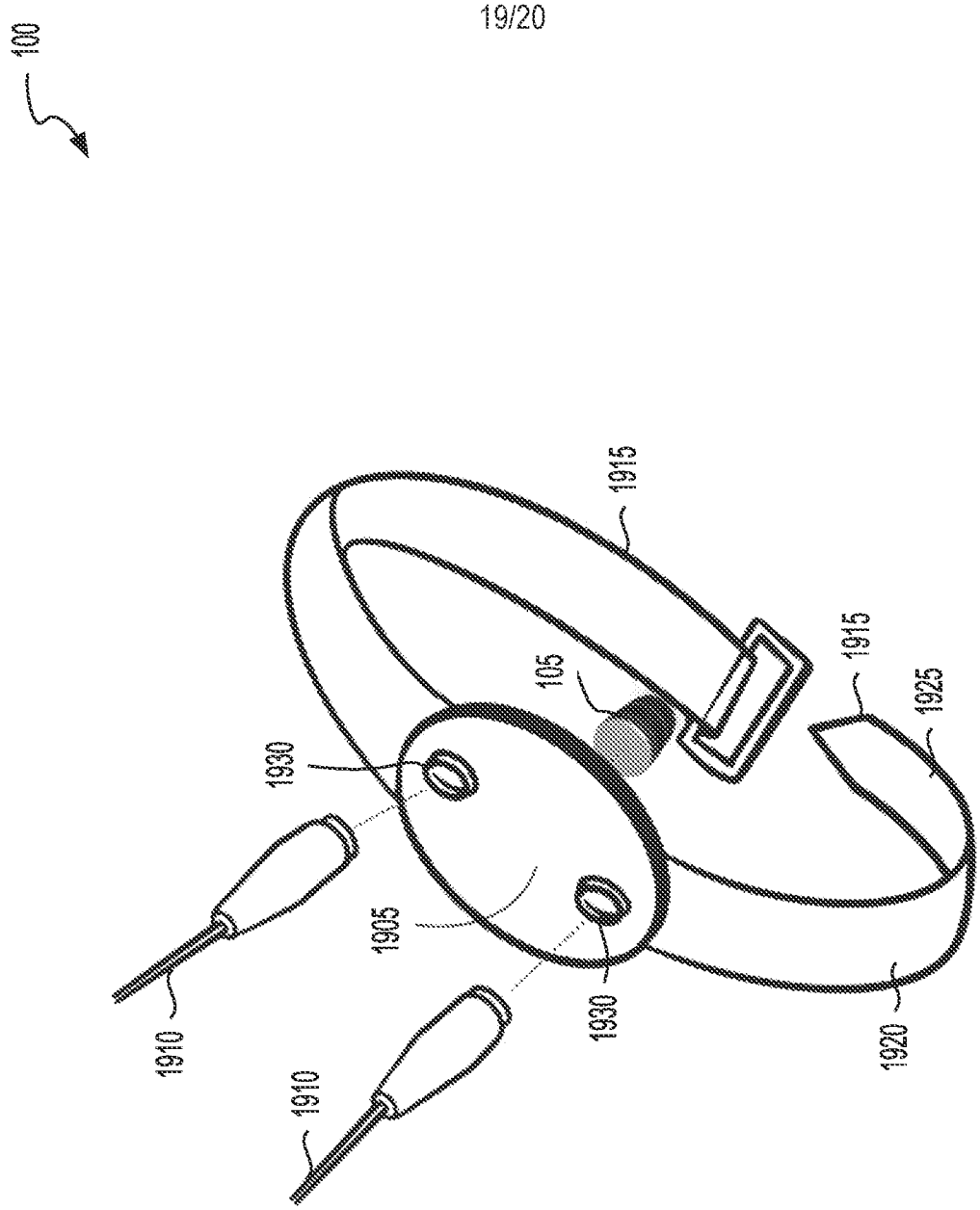

FIG. 19

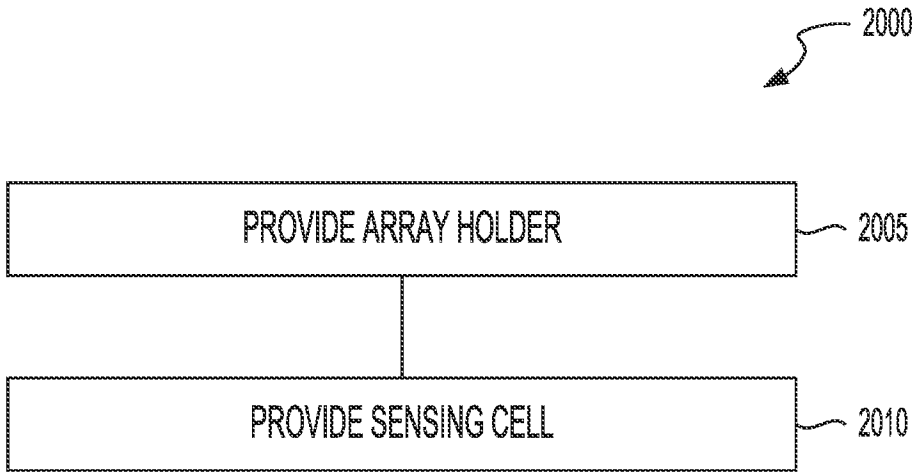

FIG. 20