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(54) Title: SYSTEMS AND METHODS FOR QUALITY VERIFICATION FOR A MIXTURE

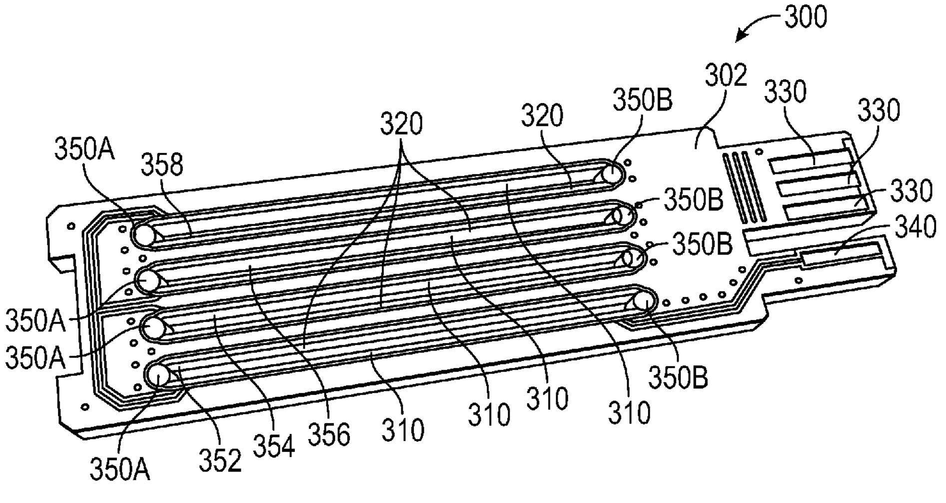

FIG. 3A

(57) Abstract: An electrical property sensor is presented that includes a printed circuit board with a first face separated from a second face by a thickness, the first face having a length and a 5 width. The sensor also includes a first sensing area on the first face, the first sensing area comprising a receiving electrode and a transmitting electrode. When a fluid contacts the first or second sensing area, and the transmitting electrode is actuated, a sensed electrical property value is measured at the receiving electrode.

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SYSTEMS AND METHODS FOR QUALITY VERIFICATION FOR A MIXTURE

BACKGROUND

Many products require mixtures in manufacture – e.g. paint for commercial or industrial use, adhesives, resins, etc. Many mixtures include different materials that, over time, may settle or separate. It may not be easily recognized by a user of the mixture that the composition is no longer consistent.

SUMMARY OF THE DISCLOSURE

An electrical property sensor is presented that includes a printed circuit board with a first face separated from a second face by a thickness, the first face having a length and a width. The sensor also includes a first sensing area on the first face, the first sensing area comprising a receiving electrode and a transmitting electrode. When a fluid contacts the first or second sensing area, and the transmitting electrode is actuated, a sensed electrical property value is measured at the receiving electrode.

Systems and methods including such sensors allow for direct contact between the sensor and a fluid flowing through a dispenser as sensors herein are cost effective to manufacture and can be discarded after use. Systems and methods herein also allow for multiple sensor signals to be gathered across a fluid flow, providing real-time information about materials going into, and out of, a mixing area. Systems and methods herein also allow for bubble detection and removal. Systems and methods herein allow for dispensing systems and their operators to change operational parameters during an operation to address issues as they are occurring, or potentially before the occur, such that less material is wasted and more accurate dispensing is possible.

The above summary of the present disclosure is not intended to describe each disclosed embodiment or every implementation of the present disclosure. The description that follows more particularly exemplifies illustrative embodiments. In several places throughout the application, guidance is provided through lists of examples, which examples may be used in various combinations. In each instance, the recited list serves only as a representative group and should not be interpreted as an exclusive list. Thus, the scope of the present disclosure should not be limited to the specific illustrative structures described herein, but rather extends at least to the structures described by the language of the claims,

and the equivalents of those structures. Any of the elements that are positively recited in this specification as alternatives may be explicitly included in the claims or excluded from the claims, in any combination as desired. Although various theories and possible mechanisms may have been discussed herein, in no event should such discussions serve to limit the claimable subject matter.

BRIEF DESCRIPTION OF FIGURES

FIGS. 1A-1C illustrate systems for dispensing an atomized fluid that may benefit from systems and methods herein.

FIG. 2 illustrates an exploded view of a spray gun, in which embodiments described herein may be implemented.

FIGS. 3A-3D illustrate material measurement flow sensors in accordance with embodiments herein.

FIGS. 4A-4B illustrate spray guns in accordance with embodiments herein.

FIGS. 5A & 5B illustrate material measurement flow sensors as used in accordance with embodiments herein.

FIGS. 6A, 6B, and 7A-D illustrate example dispensing systems having sensor systems installed in accordance with embodiments herein.

FIGS. 8A-8C illustrate dispersion states that may be experienced using sensor systems and methods described herein.

FIG. 9 illustrates an embodiment of a stir stick configured to provide in-situ conductivity measurements for a mixture.

FIGS. 10 illustrates a long sensor in accordance with embodiments herein.

FIGS. 11A-11D illustrates a sensor with electrodes in a series configuration in accordance with embodiments herein.

FIGS. 12 illustrates another embodiment of a system in which embodiments herein may be useful.

FIGS. 13A-13C illustrate a sensor configuration for bubble detection in accordance with embodiments herein.

FIG. 14 illustrates a method for detecting and correcting quality concerns in a mixture in accordance with embodiments herein.

FIG. 15 illustrates a quality control system, in accordance with embodiments herein.

FIG. 16A-B illustrate a stacked PCB sensor in accordance with embodiments herein.

FIGS. 17A-17D illustrate a sensor in accordance with embodiments herein.

FIGS. 18A-18E illustrate a surface sensing sensor configuration in accordance with embodiments herein.

19A-19E illustrate flexible sensor systems in accordance with embodiments herein.

FIG. 20 illustrates a method of quality controlling a material dispensing system in accordance with embodiments herein.

FIGS. 21A-21C illustrates conductivity measurement system in example network architectures.

FIGS. 22A-22D illustrate a sensing system in accordance with embodiments herein.

FIG. 23 illustrates a dispensing system in accordance with embodiments herein.

FIGS. 24-26 illustrates example computing devices that can be used in embodiments herein.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The present disclosure relates to systems and methods that include sensors that determine properties of fluids in-situ. The disclosure also relates to data sets received by such sensors and methods of using said data for analyzing said fluid properties. Using systems and methods described herein, it may be possible to adjust use conditions of a mixture (e.g. change pressure, temperature, mix ratio, etc.) or to improve composition consistence (e.g. re-mix, off-gas, etc.) before, or during, an operation.

Many industrial processes use mixtures such as liquid adhesives, liquid food ingredients, liquid coolants, or liquid reaction products, to name a few examples. Certain properties of such liquids vary over time: a dispersion or emulsion may separate, an oil may become less viscous as temperature rises, a coolant may age and have a lower heat capacity than initially. Performance of the product as used may suffer. For example, paint may have a soft cure (or no cure at all), may be brittle, crack, experience delamination or poor adhesion. If a paint mixture is not consistent before application, corrective action may take considerable time – energy-intensive sanding and surface preparation may be required before the painting operation is attempted a second time. Troubleshooting these issues require detailed chemical knowledge, time and elimination of other causes. For many operations, troubleshooting costs time that cannot be spared.

Co-pending international application IB2021/056362, filed on July 14, 2021, discloses a property sensor for determining a property value of a liquid that includes two PCB boards that define a channel through which the liquid flows. While this allows for direct contact between the sensor and the fluid, there exists a need for cost-effective sensors that can provide more contextual information about material mixing. Embodiments herein provide systems and methods for effectively and accurately measuring material information for mixture quality control.

Described herein are sensors and sensor systems that are used to measure electrical properties of fluids. Broadly sensors herein function by a transmitting electrode receiving a voltage, which creates an electrical field. As a fluid flows between the transmitting electrode and a receiving electrode, it conducts a current to the receiving electrode. The term "sensor" as used herein may refer both to the physical sensor that provides a sensor signal indicative of conducted current, as well as to a "sensor system" that includes a processor that calculates an electrical property of the fluid based on the sensor signal.

The term "electrical property" is intended to broadly refer to any electrical property of a fluid that can be derived based on impedance measurements of a sensor. Used herein, for ease of understanding the embodiments, are the example of impedance measurements. However, it is expressly contemplated that other electrical properties may be calculated and relevant to embodiments herein. For example, conductivity measurements or dielectric constants may also be determined from impedance measurements. Either conductivity or dielectric constant may be relevant, as illustrated herein, for determining relevant functionality of a dispensing system or quality of fluids flowing therein.

As described herein, sensors are described as measuring electrical properties of "fluids." The term "fluid" is intended to be interpreted broadly and is intended to cover liquids with low viscosities, liquids with high viscosities, semi-solid materials, suspensions, melted materials, or other flowable materials.

Electrical parameters, as used herein, may be detected by an electrode pair. Fluid may flow between or past the electrode pair. A transmitting electrode may generate an electric field when a voltage or a current is applied, while a receiving electrode receives a current or voltage. The sensed electrical parameter may be a conductivity, relative permittivity or an impedance. The terms relative permittivity and dielectric constant are used herein interchangeably.

Sensors are described herein as having one or more “apertures” within a “printed circuit board.” These terms are intended to be interpreted broadly. For example, an aperture may fully extend through a thickness of a sensor along part of, or the entirety of its length. Apertures may have beveling along part or all of a perimeter. An aperture may be elongated, such as a slot, or may be shaped, such as a circular or ovular hole. An aperture may have one or more corners or edges, or may have curvature along part or all of its perimeter. As used herein, a “printed circuit board” refers to a laminated sandwich structure of conductive and insulating layers. Printed circuit boards (PCBs) herein may include any number of terminals and conductors that allow for voltage (or current) to be applied to a transmitting electrode and for current (or voltage) to be transmitted from a receiving electrode. PCBs may be manufactured using traditional PCB manufacturing technology or additive manufacturing technology. As used herein, PCB is intended to cover any number of layers, with or without an edge connector. Any suitable conductive metal may be used to form conductive layers. Any suitable insulating material may be used to form insulating layers. While an edge connector is described and illustrated as one way to communicate a signal from the receiving electrode to an analysis system. A signal reader may receive an edge connector, for example. However, other suitable connection mechanisms are possible.

Any suitable technique may be used to form sensors of the present disclosure, including those known to one skilled in the art having the benefit of the present disclosure. In some embodiments, the sensors may be formed using 3D electronics printing techniques, such as electronics printing on 3D substrates or fully additive manufacturing. Non-limiting examples of fully additive manufacturing include fused filament fabrication, stereolithography, or inkjet printing. In the fully additive manufacturing approach, both electronic and structural elements of the sensor may be made using one or more additive manufacturing techniques and this approach may also be described as a fully integrated manufacturing approach. In general, the structural elements of the sensor may be described as substrate material, and the electronics elements of the sensor may be described as functional material.

Suitable substrate materials usable in 3D electronics printing techniques may include polymers or ceramics. Substrates may include flexible materials, such as polyimide or polyethylene terephthalate (PET). The substrate material may be selected to have good adhesion properties to the functional materials used, to withstand curing or sintering used in the printing process, and to be sufficiently durable for the intended application of the sensor. The substrate materials may be used to form structural elements of the sensor (e.g., dielectric substrate of the printed circuit board) using any suitable technique, including additive manufacturing techniques.

Suitable functional materials usable in 3D electronics printing techniques may include conductive inks, dielectric inks, hybrid inks, or other functional inks. In some embodiments, conductive inks may be used to print conductive traces, electrodes, and interconnects. Conductive inks generally include conductive materials, such as silver nanoparticles, graphene, or nanotubes, dispersed in a liquid medium. Dielectric inks may be used to print electrically insulating structures. Dielectric inks may include polymers or ceramics, dispersed in a liquid medium. Hybrid inks may combine more than one functionality into a single ink formulation.

Property sensors as described herein may be used to sense properties of a fluid resulting from a mixing process. They may also be used to sense properties of input fluids for a mixing process or for an industrial manufacturing process. Advantageously, separate property sensors for respective input fluids are placed just in front of the mixer. Data from these property sensors measuring the input fluids can be processed along with data from a property sensor measuring the mixed fluid, e.g. in an integrated materials property monitoring system. Where, for example, a fluid composition is mixed from three input fluids, a property of each of the three fluids before mixing can be determined using three property sensors at the respective outlets of the three containers containing the three input fluids. This may help in quality control and reduce waste that might otherwise occur due to one of the input fluids being outside a specification for the property.

As used herein, the term “real-time” refers to data is processed within milliseconds so that it is available virtually immediately as feedback. While some delay due to processing are inevitable, “real-time” is intended to cover systems and methods where data can be collected or entered and a user can then interact with it without noticeable delay. E.g. a user may make a data entry into a system, and the data entry is then substantially immediately available for viewing or editing.

Sensors described herein may determine various properties of a fluid, like, for example, mixing ratio of a two-component adhesive or curing status of a curable composition or ageing status. The number of properties which were varied previously to establish the set of calibration data representing calibration impedance responses measured previously at the different property values determines the number of properties that can later be determined by the property sensor. The pre-stored set of calibration data representing calibration impedance responses measured previously at the one or more sensing frequencies and at different property values of a property of the fluid forms, or represents, a multi-dimensional data field which is specific for the fluid. This data field allows the property value deriver to determine, from a response impedance actually measured, a value of the property of the fluid.

A fluid has many properties: for example, viscosity, density, color, content of volatile components, water content, chemical composition, boiling point, but also ageing status, curing status in case of fluid curable compositions, or mixing ratio in case of the fluid being a mixture, to name only some.

The term “curing” as used herein is intended to broadly cover a changing of a material from a first state to a second state. For example, some liquids cure into solids. Some mixtures may experience crosslinking. Some mixtures may experience pre-polymerization. Some mixtures may experience conversion.

Detecting these and other similar state changes are expressly contemplated for embodiments herein. Further, certain properties of certain fluids, however, vary with time and/or with other parameters such that the response impedance in a property sensor described herein varies with time and/or with the other parameters, too. Values of these properties may be derived via sensors and systems described herein. Additionally, variation with time includes variation of the property between different production lots of the fluid. The property sensor described herein can thus be used to detect differences in a certain property (e.g. chemical composition) of a suitable fluid between a later production lot and an earlier production lot of the fluid.

The term “property” of the fluid, according to the present disclosure, is not particularly limited. For example, as described in embodiments herein, one property of interest is a mixing ratio of two or more components of the fluid. In certain of these embodiments, the fluid is a two-component adhesive, and a property of the fluid is a mixing ratio of the components. In other embodiments, a property of interest is a curing degree or a curing status. In certain of these embodiments the fluid is a curable composition, and a property of the fluid is the degree of curing of the composition.

In other embodiments, a property of interest is an ageing degree or an ageing status. In certain of these embodiments the fluid is an ageing fluid, i.e. a fluid in which certain characteristics change over time once the ageing fluid has been created. The property sensor may determine a change in the response impedance of the ageing fluid after some ageing, compared to response impedances of an identical fluid recorded before ageing and at certain times after ageing. The property sensor may thereby determine an ageing degree or an ageing status of the fluid.

A property of the fluid may take different values, such as, for example, a property “dynamic viscosity” of the fluid “water” can take values like 1.30 mPa.s or 0.31 mPa.s. Such values are referred to herein as property values. Certain properties may not be related to only numerical property values. A property “curing degree”, for example, may have property values like, for example, “uncured”, “partially cured” or “fully cured”. A property “curing status”, for example, may have property values like, for example, “uncured” or “fully cured”. A fluid according to the present disclosure may be a viscous fluid. Independent of its viscosity, the fluid may be a flowing fluid. The fluid may be a continuously flowing fluid.

“Fluid” or “fluid mixture” are used broadly herein to refer to a composition comprising two or more components. The components may both be liquids, or it may be particulates in a liquid, etc. Generally, a “fluid” or “fluid mixture” refers to a flowable substance. Systems and methods herein may be useful for a range of fluid applications including, but not limited to: paint, resin – for adhesive or other purposes, cure-in-place gaskets, adhesives or other coating materials, dental impression material, void filler, sealant, an engineered fluid, a thermally conductive interface material, a precursor material to any of these, or emulsions or any material that can lose stability over time.

FIGS. 1A-1C illustrate systems for dispensing an atomized fluid that may benefit from systems and methods herein. FIG. 1A illustrates a painting operation 100 where a spray gun 114 atomizes paint from a paint cup 110 using air from air supply 112. However, while a painting operation is illustrated, container 110 could provide other material for dispensing. FIG. 1B illustrates another configuration of a spray gun 130, that receives two materials and provides an atomized mixture. Spray gun 130 may be coupled to a system 150, illustrated in FIG. 1C. System 150 may include pumping systems for one or both components 132, and / or a pressurized air source.

FIG. 2 illustrates an exploded view of a spray gun, in which embodiments described herein may be implemented. Spray gun 200 includes, among other features, includes a container 202 that holds fluid to be dispensed. However, while a container 202 is illustrated that couples to a nozzle using fastener 204, it is expressly contemplated that a larger container, may feed fluid to spray gun 200, for example using a pump. Spray gun may actuate when trigger 208 is pulled, for example.

FIGS. 3A-3B illustrate material measurement flow sensors in accordance with embodiments herein. FIG. 3A illustrates a PCB material measurement flow sensor 300. As illustrated in FIG. 3A, a sensing system 300 includes a PCB board 302 with one or more grounds 330 and a TX contact 440. The TX contact provides a transmitting signal to each transmitting electrode 310. Four RX contacts (not shown), located on the reverse side of the PCB, receive the indication of a sensed impedance from each of the electrode pairs. The electrical potential of each receiving electrode 320 is electronically regulated to ground potential separately. The regulator action for each receiving electrode, in some embodiments, is interpreted as an impedance signal for each electrode pair. In the illustrated embodiment, four separate measurements channels can provide information, each through its own TX contact 340 and RX contact (not shown).

In the illustrated embodiment, a sensing system 300 has four electrode pairs, with four transmitting electrodes 310, each paired with one of four receiving electrodes 320. However, it is expressly contemplated that more, or fewer, electrode pairs may be present, depending on available area on a PCB board and sensing needs. For example, for some applications, only a single electrode pair is present. For some applications, two electrode pairs are present, or three electrode pairs. For some embodiments, six or more electrode pairs are present, or eight or more electrode pairs, or more than eight pairs.

Each of the electrode pairs are decoupled from the adjacent pair such that four separate conductivity measurements are received, one from each electrode pair 310, 320. Sensing system 300 is placed, in some embodiments, perpendicularly to the flow of material, such that a first sensing area 352 receives a first portion of material flow, a second sensing area 354 receives a second portion of material flow, a third sensing area 356 receives a third portion of material flow, and a fourth sensing area 358 receives a fourth portion of material flow. Therefore, system 300 can simultaneously generate four different signals relative to a single material flow, providing a better picture of whether a mixing ratio (or other measured parameter) is consistent across an entire sensing area.

In comparison to previous sensing systems, conductivity measurements required both a positive and a negative pole, which would require two PCBs per electrode pair. In contrast, system 300 allows for four measurements to be taken simultaneously with a single

PCB. It also provides a larger surface area for material flow, through a shorter sensor distance.

FIG. 3A illustrates an embodiment where each electrode pair is part of a slot 352, 354, 356, 358. However, it is also contemplated that, instead of being closed on both sides, a sensing area may include a pair of electrodes on a protrusion, or within an aperture, in a "comb"-like structure. However, it may be preferred for both ends to be closed from a structural standpoint, especially with viscous fluids.

As described further herein, the electrodes 310, 320 may be formed by metallization on the interior surface of slides 352, 354, 356, 358, using copper for example. The metallization process may cause electrodes 320 to be connected to electrodes 410. Therefore, a decoupling or disconnecting step is needed. This can be done by breaking the connection, for example by drilling a hole in the positions 350A and 350B as illustrated, by punching out a perforated component, milling, nibbling, etching, laser cutting or another suitable method.

Systems and methods herein may be used for a variety of materials being dispensed. PCB boards often have a maximum operating temperature less than 170° C, which limits the temperature of materials that can be dispensed through a sensor system 300. Materials may have a range of viscosities, for example up to around 10^5 Pa s. Higher viscosity might result in a dispensing pressure being insufficient to force the material through slots 352-358 without breaking the sensor. However, higher viscosity materials may be accommodated by increasing the width of slots 352-358. However, sensing system 300 may be less sensitive. Similarly, for materials with particulates, such as suspensions for example, particle sizes have to be smaller than the width of slots 352-358. Additionally, systems herein may be limited to solvents that do not cause corrosion or otherwise damage the PCB 302 or electrodes 310, 320.

FIG. 3B illustrates another embodiment of a sensing system 360, which includes a built-in temperature sensor 370. Temperature sensor 370 sits within a slot with a connection point 372 for a ground signal and a connection point 374 for a temperature signal. Ground signal connection point 372 connects to a ground signal communicator 382. Temperature signal communication point 374 connects to a temperature signal communicator 376. Similar to the embodiment of FIG. 3A, four impedance or conductivity sensor slots 380 are also present, each connected to a ground signal 382. However, it is noted that two different spacings between slots are present in the embodiment of FIG. 3B. A first spacing, 362 is present between a first and second slot 380, and between a third and fourth slot 380, while a second spacing 364 is present between second and third slots 380. Increased spacing 364 may provide improved shielding against interference between electromagnetic fields generated by each electrode pair.

Many mixing processes are at least partially temperature dependent, with material properties like viscosity changing with temperature. Temperature sensors inserted from an external point are often fragile and need to be in the middle of the flow of the material being tested. In the embodiment of FIG. 3B, a temperature sensor is sealed within a housing, which keeps it isolated from the material. The seal layer may be a layer of varnish, for example, which may allow for the thermal contact to be improved relative to other housing materials. As illustrated, the temperature sensor connects via contacts 382 on the edge connector. However, while an edge connector is illustrated, it is expressly contemplated that other connection mechanisms are suitable.

FIGS. 3A-3B illustrates an embodiment where slots 352-358, 370 and 380 are ovular in shape, with a generally straight body and rounded ends. However, other configurations are possible. Electrodes 310, 320 may be curved, for example, or otherwise shaped to accommodate an available volume of a dispensing system.

FIGS. 3C-3D illustrate a housing for a sensor in accordance with some embodiments herein. A sensor, such as sensor 300 or 360 may be directly received by a material dispensing system in some embodiments. However, it is also contemplated that, in some embodiments, a housing 390 may receive a sensor 396 directly. Housing 390 includes a receiving slot 392 that receives a sensor, as illustrated in configuration 394.

In some embodiments, housing 390 is built into a dispensing system such that a sensor 396 is received by the dispensing system. In some embodiments, a dispensing system receives housing 390, with sensor 396 already installed therein. Sensor 396 may be sealed into housing 390, in some embodiments, such that a dispensing system receives housing 390.

FIGS. 4A-4B illustrate spray guns in accordance with embodiments herein. FIG. 4A illustrates the exploded view of FIG. 2, with potential placement options for a conductivity sensor, such as the one described in FIGS. 3A-3B, or any other sensor configurations described herein.

As illustrated in FIG. 4A, one potential placement option is in the container 420, such as in a mixing impeller, in the cup itself, or in the lid.

Additionally, or alternatively, another potential placement option is to place a sensor at a feeding point of the spray gun. In this illustrated embodiment of FIG. 4A, this would provide a quality indication of a mixture as it enters a gun. In a two-part spray gun (as illustrated in FIG. 4B, there could be two sensors at a feed point – one for each incoming material prior to mixing. This may be particularly helpful for troubleshooting if one or both incoming materials are mixtures themselves. Some dispensers described herein benefit from a needle valve 440, which allows for flow regulation.

Additionally, or alternatively, another placement option would be in the atomizing head 460.

FIG. 4B illustrates a 2-part spray gun in accordance with embodiments herein. An additional placement option for a 2-part spray gun would be behind a spray nozzle 480, to ensure that the mixture of the two (or more) incoming components are mixed correctly prior to spraying.

Using systems and methods described herein, it is possible to monitor a number of parameters relevant to the quality of a mixture prior to, or during use of said mixture. Monitoring mixture quality may refer to any of consistency, texture, composition or other relevant quality indication. Sensor systems and methods of use herein may provide indications of mix ratio, curing (e.g. open time, curing speed, temperature changes) and may provide in-situ process indications such as aging, air bubble detection or concentration, lot-to-lot variation, raw material quality, and phase separation. Using sensor systems herein, it is possible to automatically detect a quality concern (mix ratio imbalance, phase separation, etc.) and provide indications for correcting the quality concern, so that a correction can occur in-situ.

Early detection of quality concerns can help reduce correction time and will, therefore, reduce operation time, corrective supply cost, and corrective operation time and cost. Sensors described herein can be implemented in many parts of a dispensing operation – at intake, during or after mixing, within a dispenser, within a container, etc.

Sensors described herein are communicable with a computerized control system which may provide an AC voltage to generate a required electric field needed for measuring conductivity using a suitable sensing system, such as that described herein.

When running an actual measurement of quality control parameters of a mixture, the measured impedance responses (MIR), each measured at certain measurement sensing frequencies (MSF), can be recorded in the control system.

In order to derive a value for the mixing ratio, for example, from the measured impedance responses at the measurement sensing frequencies, software running on the control system identifies, within the set of calibration impedance response triples, those triples having the closest calibration response impedances, closest to the measured impedance responses, and the closest calibration sensing frequencies, closest to the measurement sensing frequencies. This identification and a potential interpolation can be performed easily by using the parametrized multi-dimensional polynomials modelling the plurality of data sets, i.e. the plurality of triples of (CMR, CSF, CIR). From those calibration data, the software derives a value for the (sofar unknown) mixing ratio in the actual measurement.

The same sensing frequencies used for calibration will often be used also for the measurement. There may, however, occur a mixing ratio in the measurement for which no calibration impedance response had been determined in calibration. So there may be not an exact match in both sensing frequency and response impedance between a triple in the calibration data set. In such a case, an interpolation between two suitably chosen calibration triples, containing two calibration impedance responses close to the measured response impedance, yields an interpolated calibration mixing ratio which can then be considered the mixing ratio in the measurement. The interpolation is performed by software on the control system 220, using the parametrized multi-dimensional polynomials.

The result of the interpolation and derivation is a value of the mixing ratio of components A and B as the mixture passes through the PCB sensor during the measurement.

In the present embodiment, the calibration impedance responses were measured in their dependence on two parameters, namely on the sensing frequency and on the mixing ratio. In other embodiments, dependence of impedance responses on further parameters may be taken into account, such as, for example, dependence on the temperature of the adhesive in the sensing zone. A data set of the calibration impedance responses would then be a quadruple of values, such as (CMR, CSF, CIR, Temperature), and the pre-stored set of calibration impedance responses would be a set of quadruples forming a four-dimensional data field, which is specific for the mixture. Taking further parameters into account could make a data set be a quintuple of values, or high-order tuples of values, so that the data sets of calibration impedance responses is a multi-dimensional data field of more dimensions and can be represented by different parametrized multi-dimensional polynomials.

A control system may record the values for mixing ratio, with a time stamp, for quality assurance. The mixing ratio derived during the actual measurement can be checked continuously against a desired mixing ratio. If its deviation from the desired mixing ratio is larger than acceptable, the control system may change the flow rate of either components suitably to adjust the measured mixing ratio towards the desired mixing ratio.

A method of forming sensor systems like those illustrated herein may be similar to that described in PCT/US22/52343, for example FIG. 5 and the associated description, which is incorporated herein by reference.

FIGS. 5A-5B illustrate material measurement flow sensors as used in accordance with embodiments herein. As illustrated in both images, sensors according to embodiments herein can be placed in direct contact with a material or fluid, providing a conductivity measurement based on that direct contact. This provides a more accurate measure of mixing ratio than other methods that do not allow for direct contact between a sensor and a material. However, as illustrated in FIGS. 5A and 5B, a sensor is coated with material after use. In scenarios where the material of interest is corrosive, highly viscous or is curable, it is beneficial to be able to discard the sensor after use.

FIGS. 6-7 illustrate example implementations of dispensing systems with sensor systems installed in accordance with embodiments herein. FIGS. 6A-6B illustrate a PCB sensor 620 incorporated into a nozzle such that fluid flow from a container (not shown) passes from adapter 630, through sensor 620, and then is dispensed by atomizing nozzle 610.

FIGS. 7A-7D illustrate placement of a sensor within a conduit. FIG. 7A illustrates a sensor 710 within conduit 700. Sensor 710 has four electrode slots such that, as a mixture passes through conduit (into the field), it is forced through the slots of sensor 710, and conductivity measurements are passed to a control system, by edge connector 712, for example. However, while an edge connector is illustrated, it is expressly contemplated that other connection mechanisms are suitable.

Variation in the conductivity measurements between one electrode slot and another electrode slot indicates may indicate a variation in quality consistency of the mixture.

FIG. 7B illustrates a perspective view 700 of a conduit 722. Conduit 722 may couple to another part of a dispensing system or a fluid transport system. Conduit 722 may couple to another part of a fluid flow system using threading 726, or another suitable fastening system.

FIGS. 7C and 7D illustrate cutaway views of a conduit. In FIG. 7C, an over-molded plastic 744, 740, 760 is used as a seal to hold a PCB sensor in face. Such a seal may have an end stop to confirm the sensor is in place. However, other seal options, and position confirmation options (e.g. a snap or clip) may also be possible. The illustrated seal may include barbs to maintain a connection.

In FIG. 7D, a different seal configuration is illustrated – an O-ring can be used. Corresponding recesses that can receive an O-ring 764 may be machined into the conduit to stabilize the sensor against the pressure of fluid flow.

The illustrated conduit may be replaceable, such that a sensing assembly is a single-use assembly, in some embodiments. In other embodiments, the sensor is removeable such that the PCB sensor is a single-use sensor.

The exemplary embodiments illustrated in FIGS. 7A-7D concern a PCB-based impedance sensor that can be attached to a static mixer, using an adapter or other connection mechanism, providing mix ratio information in real time. The use of an adapter that can receive a PCB unit allows for compatibility of the PCB sensor with a number of dispensing systems.

FIGS. 8A-8C illustrate three dispersion states that may be experienced using sensor systems and methods described herein. FIG. 8A illustrates a stable dispersion 810 where particles (or another fluid) are dispersed evenly throughout the mixture. From a colloidal point of view, a dispersion is stable when flocculation of separated particles is prevented because the particles repel each other. FIG. 8B illustrates an example of a dispersion 820 experiencing creaming, where separation is occurring such that one material is separating to the top of the mixture. A dispersion 830 is illustrated in FIG. 8C that is experimenting sedimentation, where particulates are settling at the bottom of a container.

Described thus far is a sensor system that can be used for evaluating the quality of a mixture during a dispensing operation. However, it is expressly contemplated that the same, or similar sensors, may be used to evaluate a mixture in a container. For example, a painting operation often involves mixing different fluids, or mixtures, into a container prior to coupling that container to a dispenser.

Additionally, many materials may be stored in large containers prior to use, and those containers may not be clear or otherwise allow for easy visual inspection. For example, many materials are stored in 55-gallon drums prior to use, which are not transparent. It is difficult to visually confirm settling, or whether a mixture is close to a phase separation.

FIG. 9 illustrates an embodiment of a stir stick configured to provide in-situ conductivity measurements for a mixture. Schematic 900 illustrates a stir stick 910 that may be used with a container, such as paint mixing cup 920. However, stir stick 910 may be suitable for other containers, and other mixtures as well.

Stir stick 910 provides a sensor 916 that can be moved through a mixture (or placed in a flowing mixture). A window 914 is included in stir stick 910 to allow for connection of an edge connector to wire leads. However, in some embodiments a wire lead may connect to edge connector in another suitable manner. In some embodiments, stir stick 910 includes one or more retention clips 912, or other suitable wire retention features that assist in coupling an edge connector of sensor 916 to wire leads. However, while an edge connector is illustrated, it is expressly contemplated that other connection mechanisms are suitable.

Sensor 916 is illustrated as coplanar to stir stick 910. This may allow for sensor 916 to be more easily cleaned after a stirring operation (e.g. by wiping down stir stick 910). However, it is expressly contemplated that sensor 916 and / or stir stick 910 may be single-use products such that they are discarded in between uses.

Sensor 916, in other embodiments is offset from stir stick 910 (e.g. mounted to a first side or the other side) such that wire leads may be connected without a window 914.

Stir stick 910 is configured such that, as it is moved relative to a mixture, the mixture is forced to flow through slots in sensor 916.

FIG. 10 illustrates a long sensor in accordance with embodiments herein. Sensor 1000 is illustrated in FIG. 10 as having a length 1030 of separation between an electrode portion 1020 and edge connector 1010. Edge connector 1010 should not come into contact with a mixture. Therefore, having a separation 1030 in between edge connector 1010 and electrode portion 1020 increase the flexibility of use for a conductivity sensor – for example allowing sensor 1000 to be used in a deeper container to ensure consistency throughout the depth of the container. Sensor 1000 can be dipped and used to stir the sensor inside a mixture without the edge connector to touch fluid (and short circuit), allowing for material characterization data (conductivity, temperature and dielectric constant) to be monitored and visualized in real time. However, while an edge connector is illustrated, it is expressly contemplated that other connection mechanisms are suitable.

FIGS. 11A-11D illustrates a sensor with electrode in a series configuration in accordance with embodiments herein. Discussed thus far have been sensor configurations where electrode slots 1102 are coplanar along an edge of the sensor opposite edge connector 1108. A temperature sensor 1104 is included on the PCB board as well. A length 1106 between edge connector 1108 and the electrode slot 1102 closest to edge connector 1108 is also included to reduce the chance of edge connector 1108 contacting fluid in a container. However, while an edge connector is illustrated, it is expressly contemplated that other connection mechanisms are suitable.

FIG. 11B illustrates a scenario 1130 showing the use of sensor 1100 in an incomplete mixture in a container 1140. The arrangement of sensors in a vertical stack along a PCB allows for each electrode slot to be positioned at a different depth within container 1140. Electrode pair 1142, at a lowest depth measures a first conductivity at depth 1132. Electrode pair 1144, at a second-to-lowest depth measures a second conductivity at depth 1134. The conductivity at depth 1132 will differ from the conductivity at depth 1134 because the composition is different. Similarly, a conductivity measured by electrode pair 1146, at depth 1136, will be different than a conductivity measured by electrode pair 1148, at depth 1138, because the concentrations differ.

While FIGS. 11A and 11B illustrate a sensor 1100 with four electric pairs arranged in a vertical stack on a PCB, it is expressly contemplated that a different number of electrode pairs may be present, for example only 2 electrode pairs, only 3 electrode pairs, or more than 4 electrode pairs, such as five electrode pairs, six electrode pairs, or more than six electrode pairs. Additionally, a spacing is present between electrodes, which may be longer or shorter than that illustrated.

A sensor such as sensor 1100 may be particularly useful for containers housing dispersions or emulsions that, currently, need to be continuously rotated, or constantly in motion, to prevent sedimentation or creaming. However, the resulting mixing quality is unproven. Sensor 1100 may be used to measure current dispersion / emulsion consistency or built into a stir stick or other stirring implement such that in-situ mixing indicia can be provided to ensure that a mixture is sufficiently mixed, but that time is not wasted over-mixing.

FIGS. 11C-11D illustrate example mixtures and resulting conductivity measurements using a sensor 1100. FIG. 11C illustrates a stable dispersion 1150, which results in conductivity measurements from each electrode pair that are very similar. FIG. 11C illustrates a dispersion 1160 experiencing sedimentation, which causes conductivity measures to differ between the different electrode pairs as the concentration varies with the depth of electrode pairs in a mixture.

Sensors like those illustrated in FIGS. 11A-11D may be particularly useful for measuring flocculation or aggregation in-situ, potentially before significant sedimentation or phase separation has occurred. This may help ensure that corrective action is taken sooner.

FIG. 12 illustrates another embodiment of a system in which embodiments herein may be useful. System 1200 illustrates an exemplary dispensing system 1200 with a controller 1202, which may include a motor that provides pressure for dispensing a mixture through dispenser 1210. The mixture being dispensed may have a quality control issue not readily apparent to an operator. Systems and methods herein may be useful for detecting and correcting a quality control issue. As described above FIGS. 7A-7D, sensors described herein may be placed within a conduit, e.g. sensing area 1210 where a material is first provided. As a material flows through, or exits, sensing area 1210, it may have entrained air bubbles or droplets formed of only one component (or a subset of components) of the mixture. If the material coming from sensing area 1210 is provided for combination into a mixture downstream, air bubbles also will affect the resulting mix ratio. For a dispensed mixture, this can result in an incorrect mixing ratio being dispensed. For viscous fluids, this may result in an area of a worksurface not receiving dispensed fluid. Air bubbles are a problem for various dispensing applications, potentially causing an interrupted seal during sealing dispensing, an interrupted adhesive bond during adhesive dispensing, etc.

Similarly, an improperly mixed mixture also present quality control concerns. Droplets may indicate that a phase separation is imminent in a mixture. For example, a droplet size of a first mixture or a second mixture may indicate an instability of an emulsion prior to phase separation. Such detection may allow for proactive treatment to maintain an emulsion before separation occurs.

It is important to detect, and potentially remove, air and / or droplets from a dispensing system. Therefore, in some embodiments, before reaching a dispenser 1240, material passes through sensing area 1210, which includes any of the PCB-based sensors described herein. The sensor detects an inconsistent mixture (e.g. air bubbles or droplets) such that a corrective action mechanism 1220 may be activated before the material reaches dispenser 1240.

For entrained air bubbles, a valve 1230 can be opened, allowing for the air bubble containing portion to leave through stream 1250. When the air bubble has passed, valve 1230 closes, and the material continues on to dispensing system 1240.

Similarly, if phase separation, or other quality issue is detected in a mixture passing through sensing area 1210, valve 1230 may divert the mixture in flow 1250 for corrective action – e.g. re-mixing, degassing, excess purge, etc. Phase separation may be detectable as droplets of a first material begin to form from aggregation.

Controller 1202 may also cause dispenser 1240 to stop dispensing until the mixture is deemed sufficiently mixed. In the illustrated embodiment, the material from flow 1250 may be returned through controller 1202 to sensing area 1210 to confirm quality is sufficient to resume dispensing. Controller 1202 may provide a notification to other systems that are connected to dispensing system 1240 (e.g. a motion controller that moves 1240 relative to a surface receiving dispensed material) and / or to an operator through a user interface on a display, an audible indicia, etc.

Valve 1230 automatically opens and closes, in some embodiments, based on an indication from either sensing system 1220 directly, controller 1202, or another controlling system that, based on a conductivity measurement received from system 1220, sends a command to implement a corrective action.

FIG. 12 is a schematic of a system 1200 with components for one material line clearly illustrated. However, it is expressly contemplated that, as illustrated, a dispensed mixture may be formed from two components, and a similar system may be provided for the second component.

FIGS. 13A-13C illustrate a sensor configuration that may be particularly useful to detecting bubbles or aggregation of droplets of a second phase forming prior to a phase separation.

FIG. 13A illustrates a dip sensor that may be particularly useful for detecting air bubbles or droplets in a mixture. Sensor includes four electrode pairs in four slots, 1302, 1304, 1306 and 1308, that are different sizes. Slot 1302 is wider than slot 1304, which is wider than slot 1306, which is wider than 1308. Slots 1302-1308 are illustrated in an arrangement from thickest to thinnest, however it is expressly contemplated that other arrangements are possible. Similarly, while four coplanar electrode pairs are illustrated, all substantially the same distance from edge connector 1314. However, while an edge connector is illustrated, it is expressly contemplated that other connection mechanisms are suitable.

Slots 1302-1308 are designed to both detect bubbles or droplets and provide an indication of size. Generally, a consistent mixture with no bubbles or droplets provides an insulation effect, and maintain a consistent conductivity across all electrode pairs. When a droplet reaches a width of one of the slots, the droplet will connect both sides of the electrodes, resulting in a detectable change in conductivity.

The design illustrated in FIG. 13A is illustrated as having slot widths that linearly increase – e.g. 1mm, 2mm, 3mm and 4mm. A linear increase in diameter corresponds to a cubic increase in volumetric flow through the apertures. Such a configuration provides a good understanding of how quickly phase separation will occur and / or how stable a mixture is. For example, if phase separation is more than a hour away, it may still be possible to dispense a mixture without corrective action.

However, it is explicitly contemplated that some embodiments may require smaller or larger slot sizes. For example, a thinnest slot may be as thin as 100 μm, or thinner than 150 μm, or thinner than 200 μm, or thinner than 300 μm, or thinner than 400 μm. One or more slots may be thinner than 500 μm. One or more slots may be thinner than 1 mm. For other applications, for example a stir stick being used in a larger measurement operation, such as checking a mixture quality of a 50 gallon drum.

In addition to the change in width, the slots may also change in length to suite a particular application. For example, in checking the shelf-life of a larger container, the overall sensor may need to be much longer – for example up to, or over, 1 meter in length.

In such instances, apertures must be larger – both to increase signal strength and to allow for significant flowthrough. A length may be increased to increase signal strength, balanced with a width selected to allow flowthrough without sacrificing signal strength. For example, for a meter-long sensor, the dimensions may be 10 centimeters long and 1 cm wide.

E.g. when a droplet (or bubble) reaches a diameter as wide or wider than slot 1308 (the narrowest slot), it connects the two electrodes within slot 1308, resulting in a conductivity spike only for electrode pair 1308, as, until the droplet (or bubble) diameter grows to a width as wide or wider than slot 1306, it will not connect the two sides of slot 1306. The conductivity will return to a baseline for the mixture once the bubble (or droplet) passes through slot 1308. Depending on the number of droplets (bubbles) in the mixture, the conductivity spike frequency changes.

Sensor 1300 also includes a temperature sensor 1310, illustrated as in-line with electrode pairs 1302-1308, it is expressly contemplated that temperature sensor 1310 may be positioned in another suitable position. Additionally, it is contemplated that, for some embodiments, a temperature sensor 1310 is not needed, e.g. for a mixture that does not change viscosity significantly over a temperature range of use.

Sensor 1300 is also illustrated as having a length 1312 that separates edge connector 1314 from electrode pairs 1302-1308. However, length 1312 may not be necessary if sensor 1300 is used as an in-line flow sensor, for example mounted within a conduit as illustrated in FIGS. 7A-7D. However, while an edge connector is illustrated, it is expressly contemplated that other connection mechanisms are suitable.

FIG. 13B and 13C illustrates a sensor connected to lead wires 1340, illustrating how a length 1312 provides additional separation from electrode pairs 1302-1308 when in use in a container 1350.

Described herein thus far have been a number of sensor configurations where a single line of parallel electrodes is illustrated (e.g. in the horizontal configuration of FIGS. 3-7 and 13, or a vertical configuration such as FIG. 11). However, it is expressly contemplated that an arrangement that combines the features of both configurations is possible. For example, a grid of electrode pairs may be useful to detect consistency at multiple depths as well as mixing quality (or the presence of droplets / bubbles) simultaneously. Additionally, while embodiments herein illustrate sets of four electrode pairs in different configurations, it is expressly contemplated that more, or fewer, electrode pairs may be present in any vertical or horizontal arrangement.

FIG. 14 illustrates a method for detecting and correcting quality concerns in a mixture in accordance with embodiments herein. Method 1400 may be practiced using sensor systems such as those described herein, combinations thereof, or other suitable sensors.

In block 1410, an inconsistency in a mixture is directed. The inconsistency may be entrained air, or inconsistent mixing – droplet formation, sedimentation, creaming, etc. Detection may be accomplished by detecting a conductivity spike by one or more electrode pairs on a PCB sensor. Detection may also be accomplished by detecting a difference in conductivity 1404- 1402 measured between a first electrode pair and a second electrode pair of a sensor system. Other detection methods 1408 described herein may be used. Detection occurs as a mixture flows through the electrode pairs in a conductivity sensors.

The conductivity sensor may be a disposable sensor intended to be thrown out after use, in some embodiments. The conductivity sensor may include one or more pairs of electrodes in a coplanar arrangement such that the dispensed material flows through different electrode pairs. The inclusion of multiple electrode pairs of electrodes of varying sides may help to detect air bubbles or droplets of varying sizes as they flow through a sensing area.

In block 1420, the detected inconsistency is corrected. Correction may include further mixing 1422 the mixture, for example to ensure a consistent concentration, reduce the risk of phase separation, and / or stabilize a dispersion or emulsion. Correction may also include degassing the mixture 1428, either to remove a detected air bubble or to remove entrained air introduced during a remixing step. Degassing may be accomplished using a vacuum, for example, or by purging a portion of the mixture containing the entrained air. Other suitable correction measures 1428, such as correcting a mixture composition, may also be used, such as a purge.

In some embodiments, it may be possible to mitigate a detected air bubble without purging, for example by instead sending a signal to the motor controlling fluid flow to increase speed and dispense an amount of material needed to replace the volume of air occupied by the bubble. In some embodiments, an applied pressure may increase, or a volumetric flow rate increased, in order to provide a similar volume of material if the bubble was not present.

In block 1440, consistency of the mixture may be confirmed prior to dispensing the mixture, in block 1430. For example, using sensors described herein, the consistency of the mixture may be confirmed by conductivity spikes stabilizing, e.g. reducing in severity and / or number, or by confirming that conductivity differences in electrode pairs have narrowed to an acceptable level. If consistency is not confirmed, the process may proceed back to block 1420 so that correction can be continued, or a new correction strategy may be selected.

FIG. 15 illustrates a quality control system, in accordance with embodiments herein. Quality control system 1550 may be used to identify and correct a detected inconsistency in a mixture. Quality control system 1550 may be implemented in a static environment – e.g. as a dip stick or other analysis tool for a contained fluid – or a dynamic environment – e.g. in a fluid flow conduit where fluid moves through electrode pairs in a PCB board.

Some systems and methods herein may benefit from using relative thresholds instead of absolute thresholds. Base levels may be important to measure to have a more accurate relative threshold. For example, if a conductivity measurement drops below a proportionate factor to the base level (e.g. to 50% of the base level) then it can be determined that an inconsistency is present – e.g. a concentration gradient indicative of poor mixing, droplets indicative of phase separation, or entrained air. Relative thresholds may be helpful to reduce waste of material on accidental purges, or wasted time in attempting to correct an inconsistency that may not be present, or may not be at a level that requires correction.

Inconsistency detection system 1550 may be implemented by a suitable computing device in communication with a sensing system 1530. Sensing system 1530 may include one or more electrode pairs 1532 in direct contact with a material flow. Sensing system 1530 may also include a temperature sensor 1534. Electrode pairs 1532 may be part of a printed circuit board, for example, formed within apertures machined or built into the printed circuit board. The apertures may be closed on both ends, or open on one end, in a comb-like structure, for example. Temperature sensor 1534 may be shielded from direct contact with a material flow, in some embodiments. Sensing system 1532 may include other features 1538.

Sensor signals from sensing system 1530 are received by quality control system 1550 using an active signal retriever 1552. Active signal retriever 1552 may receive signals from sensing system 1530 periodically or continuously during an operation. Received sensor signals may be impedance signals, conductivity signals, dielectric constant signals, or a combination thereof. In embodiments where a conductivity value is used to detect an inconsistency, a conductivity signal generator 1554 may convert a received signal to a conductivity value. The signal value, and / or the conductivity value, may be provided to a data store, for example using signal communicator 1556.

A historic signal retriever 1558 may communicate with a data store to retrieve previously captured signal values. Historic signal values of interest may include signal values retrieved in a recent period of time, from the same batch or mixture of materials. For example, values retrieved over a previous number of seconds or minutes may be important. In some embodiments, signal values may drift over longer periods of time due to changes in temperature, material aging, mixture ratio fluctuations, etc. But inconsistencies may be detectable as a rapid change in conductivity or a divergence of conductivity measurements in a sensing system from each other. Threshold generator 1560, in some embodiments, generates a relative threshold either periodically or continuously, based on historic signals. The relative threshold may be an absolute value, for example specifying that an increase or decrease of X% over Y time indicates an inconsistency. If conductivity values have fluctuated more significantly, the threshold change value may be larger, while if conductivity values have not fluctuated significantly, the threshold change value may be smaller.

Signal analyzer 1562 compares the received signal, or calculated conductivity, to the threshold and, if a deviation outside the allowed threshold is detected, command generator 1564 generates a command, which is communicated, using command communicator 1566, to a device 1580.

Device 1580 may, in some embodiments, include a display component, and the generated command may be an update to a graphical user interface, presented on the display component, indicating the detected inconsistency. Device 1580 may, in some embodiments, include a feedback component, such as audio, visual or haptic feedback that indicates to a controller that an air bubble is detected. Device 1580 may also be a correction mechanism, and command generator 1564 may generate a command to conduct a correction mechanism selected based on the detected inconsistency, e.g. a purge valve, a re-mixing command, a degassing command, etc.

System 1550 may include other features 1568.

In some embodiments, threshold generator includes a machine learning model to forecast the conductivity time series data into the future from historical data. This forecast may include a so-called confidence intervals. The training may be done upfront on a reference data set with no detected quality control concerns, or with quantified quality control concerns. Signal analyzer 1562 then compares a received signal to determine whether it falls within, or outside of, the confidence interval.

In some embodiments, at regular intervals (e.g., 10ms, 100ms, etc.), threshold generator generates a prediction for the conductivity value, with confidence bands based on the historic signals retrieved by historic signal retriever. If the actual value measured drops below a lower confidence band, or goes above a higher confidence band, signal analyzer detects an inconsistency. If the conductivity measurement is within the confidence bands, signal analyzer 1562 provides an output that no inconsistency, or no inconsistency requiring correction has been detected. Command generator 1564 may provide an indication that a GUI of device 1580 does not require updating.

A relative threshold is an important component of an air detection system because of the noise present in the data. The statistical concept of confidence bands can account for this - if data have more noise, the confidence bands are further away from the current value and the inconsistency detection algorithm will not yield wrong detections just because of noisy data, where a simple thresholding approach can suffer from this in this case.

While conductivity is discussed herein as the value of interest, it is expressly contemplated that other material parameters, such as the amount of electrical current and the relative permittivity (er), could be used instead or as well for the detections algorithm.

Measuring conductivity can provide valuable information regarding quality of a mixture. For example, as described herein, and in the Examples Section of PCT/US22/52343, conductivity measurements may be used for determining consistency issues due to lot-to-lot variation, entrained air, droplet formation, aging, concentration gradients, dispersion separation or emulsion separation.

Described herein thus far are sensor systems that are based on a single PCB board. Such systems are relatively inexpensive and, therefore, cost effective to use and replace. However, one disadvantage of designs described thus far is the large stray field compared to the main field present between each electrode pairs. The stray field effect is caused by the short distance between material flow input and output, e.g. the thickness of the PCB. One way to reduce the stray field effect is to solder multiple PCBs, each with electrode-containing apertures, into a PCB stack.

FIG. 16A-16B illustrate a stacked PCB sensor in accordance with embodiments herein. FIG. 16A illustrates a stacked PCB sensor of PCB boards similar to FIGS. 11A-11B, which FIG. 16B illustrates a stacked PCB sensor of PCB boards similar to FIGS. 13A-13C. As illustrated, in one embodiment, sensor stack 1600 may include four PCB sensors, with one 4-layer PCB 1610, two stacking PCBs 1620, which are provided to get the required sensitivity by increasing the electrode surface area, and a top PCB 1630. In some embodiments, flow through sensor stack 1600 is indicated by arrow 1650. While the embodiment of FIGS. 16A-16B both illustrate a four-layer sensor stack, it is expressly contemplated that fewer, or more PCB sensors, may be coupled together. For example, as few as two PCBs or as many as five, six, seven, eight, nine, ten or more PCBs.

Stacked sensor 1600 provides the benefits of a single PCB sensor with reduced stray field effects. The compact design also improves the shielding of the sensitive electrodes and may also be used as an electrode cartridge without needing additional housing as the sensitive area can be internally sealed. In some embodiments, the sensitive area is internally sealed by soldering, and can withstand applied pressure from a material sensor without requiring an additional housing.

Further, stacked sensor 1600 can utilize smaller electrodes, allowing for sensor stack 1600 to be integrated into an active or passive mixing nozzle at the material inputs as well as the material output. In a sensor stack, only one electrode 1610 with an edge connector configured to connect to lead wires. As illustrated in FIGS. 16A-16B, stacked sensors may include a temperature sensor and may include an elongated portion for embodiments where a stir stick is an appropriate vehicle for detecting conductivity. However, it is expressly contemplated that a stacked sensor of either configuration can, without the elongated portion, be suitable for placement in a conduit, such as that illustrated in FIG. 7.

FIGS. 17A-17D illustrate a sensor in accordance with embodiments herein. It is illustrated herein that a number of electrode slots may be organized in a row, such that each slot is roughly the same distance from an edge connector. It is also illustrated herein that a number of electrode slots may be organized in a column, such that each slot has a different distance from an edge connector. It is also expressly contemplated that, in some embodiments, electrode slots may be organized in both rows and columns. However, while an edge connector is illustrated, it is expressly contemplated that other connection mechanisms are suitable.

FIG. 17A illustrates a sensing setup 1700, with a sensor 1710 partially submerged in a solution 1720. Sensor 1710 includes electrode slots of a first size 1702 and a second size 1704. Electrode slots are arranged in both rows 1708 and columns 1708. Arranging electrode slots in both rows and columns provides additional insight into a material.

FIG. 17A illustrates a solution 1720 that is homogeneous, while FIG. 17B illustrates a solution 1750 that has experienced settling, which may be a sign of material age. Sensor 1740 may provide twelve different sensor signals for analysis, one from each electrode pair through which material can flow. A difference between signals from electrode slots 1742 and 1744 may indicate aging. A difference between a signals from electrode slots 1744 and 1746 may indicate a viscosity of solution 1750.

Many production sites store raw material in large containers, such as drums. Material separation results in a lighter phase on top and a heavier phase on the bottom. Quality may decrease as separation increases.

Additionally, it is desired to have a sensor that can handle a wider viscosity range of materials. Electrode slots with smaller widths may not handle higher viscosity materials well, while electrode slots with wider widths may not be as precise for low-viscosity materials. Sensors 1710, 1740 may handle a wider range of viscosities while also providing signals along a depth of a material container. While only four rows of electrode pairs are illustrated, it is expressly contemplated that more rows may be present in other embodiments, to suit a container depth. Additionally, while only three columns are illustrated, it is expressly contemplated that additional columns with wider or narrower electrode slots are also possible.

FIGS. 17C and 17D illustrate example signal profiles that may be received from a sensor 1710 or 1740. Profile 1760 indicates a low viscosity material while sensor 1770 indicates a high viscosity material.

Sensor systems herein may be used to detect a viscosity of a material, as illustrated in the comparison between profile 1760 and 1770. The viscosity of a material impacts the exchange rate of material within a gap between electrodes. The delay between the signals of the large gaps and the signals of the smaller gaps indicates the viscosity of the material. A lower viscosity results in a shorter delay while a higher viscosity results in a longer delay.

FIGS. 18A-18E illustrate a surface sensing sensor configuration in accordance with embodiments herein. While some adhesives and other materials are dispensed onto a surface, others are applied through a coating process. Adhesive coatings are an example of a non-conductive coating. Non-conductive coatings can result in buildup of static electricity, resulting in electrical discharge during the coating process. For safety, a target conductivity of adhesive coatings may be higher than 10,000 pSiemens/m. A sensitivity of sensing systems herein can be increased by using surface sensing instead of bulk sensing.

FIG. 18A illustrates a schematic of a bulk electrical signal sensing system in accordance with embodiments herein. Bulk sensing involves fluid passing between a first electrode 1802 and a second electrode 1804, as indicated by material flow direction 1808. An electric field 1806 is generated by the first and second electrodes, 1802 and 1804 respectively. A housing or support structure 1810 may provide structure and support for electrodes 1802, 1804.

FIG. 18B illustrates a top-down view 1820 of a surface-sensing impedance sensor configuration in accordance with embodiments herein. A housing or support structure 1826 may have a first set of electrodes 1822 and a second set of electrodes 1826 machined into or printed thereon. For example, transmitting electrodes 1822 and receiving electrodes 1826 may be machined into, or printed onto, a printed circuit board.

FIG. 18C illustrates a close-up view of portion 1830, illustrating a cutaway view of an impedance sensor configuration. A first electrode 1822 and second electrode 1826, supported by structure 1826 generate an electric field 1832. An electrical property of a fluid in contact with electrodes 1822, 1824 can be measured.

In contrast with configuration 1800, sensor configuration 1820 does not rely on fluid passing through gaps, slots or apertures of a sensor. Instead, sensor signals are generated based on contact with a material.

FIG. 18D and 18E illustrate an impedance sensor in accordance with embodiments herein. A sensor 1850 is illustrated with a sensing area 1860 spaced apart from an edge connector 1852 by a space 1854. Edge connector 1852 may couple to a processing system for sensor signals received from sensing area 1860. Sensing area 1860 is a surface-sensing sensor that can provide significantly higher sensitivity than a similarly sized bulk sensor.

However, while an edge connector is illustrated, it is expressly contemplated that other connection mechanisms are suitable.

FIG. 18E illustrates a close-up view of sensing area 1860. Two channels 1862 are outlined on surface 1860. It is expressly contemplated that an additional two channels 1862 may be present on a surface opposite surface 1860, so that four channels are present on a single sensor 1850. Channels 1862 are decoupled from one another, such that each channel provides a separate signal relative to an electrical property of a material. The presence of multiple channels reduces the number of measured artifacts.

While FIGS. 18D-18E illustrate a sensor as having two channels per sensing area, it is expressly contemplated that more channels, or only a single channel are present. For example, three channels may be present on a single surface, or four channels, or six channels, or 8 channels or even more. A sensor may have the same, or different, number of channels on each side.

Discussed herein are sensing systems that can use either bulk sensing techniques or surface sensing techniques. However, it is expressly contemplated that both bulk and surface sensing techniques can be used in a single sensing system. For example, a sensing system could have both a surface 1860 as well as bulk-sensing electrode slots along space 1854.

Bulk sensing sensors may be useful for screening a material for quality conditions – e.g. tracking air bubbles, or other defects. Surface sensing sensors may be useful for precise measurements in applications where high resolution is needed.

Sensing systems herein may operate using a single voltage and frequency. However, it is expressly contemplated that voltage, frequency or both may be varied. Additionally, current could be used instead of voltage. For example, a sensing system may conduct a frequency sweep, from a first frequency to a second frequency. The sweep may occur at a specific sweep rate, which may be linear or logarithmically spaced. Sweeps may be triggered automatically or manually.

FIGS. 19A-19D illustrate a sensor in accordance with embodiments herein. It is illustrated herein that a number of electrode slots may be organized in a row, such that each slot is roughly the same distance from an edge connector. It is also illustrated herein that a number of electrode slots may be organized in a column, such that each slot has a different distance from an edge connector. It is also expressly contemplated that, in some embodiments, electrode slots may be organized in both rows and columns. However, while an edge connector is illustrated, it is expressly contemplated that other connection mechanisms are suitable.

FIG. 19A illustrates a sensing setup 1900, with a sensor 1910 partially submerged in a solution 1920. Sensor 1910 includes electrode slots of a first size 1902 and a second size 1904. Electrode slots are arranged in both rows 1908 and columns 1908. Arranging electrode slots in both rows and columns provides additional insight into a material.

FIG. 19A illustrates a solution 1920 that is homogeneous, while FIG. 19B illustrates a solution 1950 that has experienced settling, which may be a sign of material age. Sensor 1940 may provide twelve different sensor signals for analysis, one from each electrode pair through which material can flow. A difference between signals from electrode slots 1942 and 1944 may indicate aging. A difference between a signals from electrode slots 1944 and 1946 may indicate a viscosity of solution 1950.

Many production sites store raw material in large containers, such as drums. Material separation results in a lighter phase on top and a heavier phase on the bottom. Quality may decrease as separation increases.

Additionally, it is desired to have a sensor that can handle a wider viscosity range of materials. Electrode slots with smaller widths may not handle higher viscosity materials well, while electrode slots with wider widths may not be as precise for low-viscosity materials. Sensors 1910, 1940 may handle a wider range of viscosities while also providing signals along a depth of a material container. While only four rows of electrode pairs are illustrated, it is expressly contemplated that more rows may be present in other embodiments, to suit a container depth. Additionally, while only three columns are illustrated, it is expressly contemplated that additional columns with wider or narrower electrode slots are also possible.

FIGS. 19C and 19D illustrate example signal profiles that may be received from a sensor 1910 or 1940. Profile 1960 indicates a low viscosity material while sensor 1970 indicates a high viscosity material.

Sensor systems herein may be used to detect a viscosity of a material, as illustrated in the comparison between profile 1960 and 1970. The viscosity of a material impacts the exchange rate of material within a gap between electrodes. The delay between the signals of the large gaps and the signals of the smaller gaps indicates the viscosity of the material. A lower viscosity results in a shorter delay while a higher viscosity results in a longer delay.

FIG. 20 illustrates a method of quality controlling a material dispensing system in accordance with embodiments herein. Method 2000 may be used with the dispensers described herein, or another suitable sensing system.

In block 2010, one or more components to be dispensed are provided to a sensing area. The sensing area may be a material dispenser, a transport line to a material dispenser, before a nozzle, atomizer, or other transportation mechanism or container within a fluid system. For example, a material dispenser may dispense a liquid 2012, particles 2014 either in suspension or otherwise. The material may also be a mixture 2016 of materials, for example an emulsion or another A and B component mixture. An emulsion must be dispensed as a stable emulsion, and reactive A:B components should be provided at a desired mix ratio. Other components 2018 may also be provided to a sensing area prior to dispensing.

In block 2020, the mixture contacts a sensing system. Contacting a sensing system may include passing through a sensing system, e.g. through one or more apertures on a PCB, before being dispensed, stored, removed from storage. Contacting a sensing system may also include the mixture contacting a surface of a sensor, the surface being part of a PCB. For conductivity sensors, direct contact between a material and an electrode pair ensures accurate measurements. The sensing system may be a bulk sensing system or a surface sensing system. The sensing system may receive two, three, four or more discrete electrode pairs.

In block 2030, conductivity measurements are received from the sensing system. The sensing system may have multiple sensors, for example a plurality of electrode pairs that, when a sufficient voltage (or current) is passed through them, detects an electrical parameter of the material. Based on the sensor signals, a number of things may be determined for the material. For a mixture, a mixing ratio may be determined. For a curable material, a curing progressing may be detected. Aging may also be detectable, as well as differences between batches of materials. Instability indications – such as entrained air, impending phase separation, contamination, etc. may also be detectable. Conductivity measurements may be taken serially, for example one signal received every second, or more frequently. Conductivity measurements may also be taken in parallel, for example from each of a plurality of electrode pairs. The electrode pairs may be coplanar with each other, in some embodiments.

In block 2040, feedback is provided based on the conductivity measurements. Feedback may include characterization of the material, as indicated in block 2032. For example, a mix ratio may be detected, entrained air or single component fluid pockets, an age indication or other parameter of interest may be calculated and provided. A prediction may also be provided, as indicated in block 2034. For example, based on a trend of previous conductivity sensor readings, it may be possible to predict future behavior of the material being measured. Other characterization information 2038 may also be provided. For example, a conductivity reading trending in one direction may indicate that a mix ratio is moving toward an edge of an acceptable range and, therefore, that a mix rate should be changed, or that an increase in instability is trending toward phase separation. Similarly, a conductivity reading may indicate that a curable component is curing.

Feedback may also indicate corrective action is needed. For example, an emulsion or dispersion experiencing separation may need stabilizing 2042 – e.g. remixing, heating, etc. Feedback may also indicate that a purge of one component, multiple components, or a mixture, is needed, as indicated in block 2044. In embodiments where a material has corrosive effects, or cures over time, predictive feedback may provide an indication that the sensor needs to be replaced, as indicated in block 2046. Other predictive information may also be provided, as indicated in block 2038, that may trigger other actions, as indicated in block 2048.

In some embodiments, as illustrated herein, providing feedback may also include providing conductivity readings, material characterizations or predictions to a customer, controller of a dispenser, or other useful information such as material source, batch number, material name, dispensing temperature, dispensing pressure, material concentration(s), mix ratio, or any other information. FIGS. 21A-C illustrate a conductivity measurement system in a network of systems in accordance with embodiments herein.

In the example shown in FIG. 21A, some items are similar to those shown in earlier figures. FIG. 21A specifically shows that a conductivity sensing system 2110 can be located at a remote server location 2102. Therefore, computing device 2120 accesses those systems through remote server location 2102. User 2150 can use computing device 2120 to access user interfaces 2122 as well. For example, a user 2150 may interact with an application on the user interface 2122 of their smartphone 2120, or laptop 2120, or other computing device 2120 to receive information from a dispensing system or a quality control system.

FIG. 21A shows that it is also contemplated that some elements of systems described herein are disposed at remote server location 2102 while others are not. By way of example, data stores 2130, 2140 and / or 2160 can be disposed at a location separate from location 2102 and accessed through the remote server at location 2102. Regardless of where they are located, they can be accessed directly by computing device 2120, through a network (either a wide area network or a local area network), hosted at a remote site by a service, provided as a service, or accessed by a connection service that resides in a remote location. Also, the data can be stored in substantially any location and intermittently accessed by, or forwarded to, interested parties. For instance, physical carriers can be used instead of, or in addition to, electromagnetic wave carriers. This may allow a user 2150 to interact with system 2110 through their computing device 2160, to initiate a seal check process.

It will also be noted that the elements of systems described herein, or portions of them, can be disposed on a wide variety of different devices. Some of those devices include servers, desktop computers, laptop computers, imbedded computer, industrial controllers, tablet computers, or other mobile devices, such as palm top computers, cell phones, smart phones, multimedia players, personal digital assistants, etc.

A conductivity measurement system may be any suitable system configured to, using systems and methods herein, collect conductivity measurements, conduct analysis and provide the analysis to a receiving device, storage or graphical user interface generator. FIG. 16 of PCT/US22/52343, describes operation of such a system and is hereby incorporated by reference.

System 2110 receives conductivity measurements from one or more sensors 2170. Each sensor may include one or more pairs of electrodes on a PBC. The electrodes may be coplanar and spaced similarly away from one end of the PCB, in some embodiments, or may be coplanar and in line with a length of the PCB. Sensors may be formed either by metallization or another process. Sensors 2170 are decoupled from each other such that independent conductivity signals are received from each sensor. Sensors 2170 may each include a positive and negative electrode, decoupled from one another.

Conductivity measurement systems 2110 may receive a sensor signal as a conductivity signal or a dielectric constant signal, but may also be received as an impedance signal. In embodiments where a received signal is an impedance signal, a conductivity value may be calculated based on the impedance signal. Similarly, a dielectric constant may be calculated based on a received impedance signal. Based on received sensor signals, calculations and / or predictions may be undertaken, as described in FIG. 21, for example. A mixing ratio may be calculated based on calibration data, stored in a datastore 2160, which may be indicative of conductivity data from pure components and / or known mixtures of components. As described above, sensors may be placed at both the inlets and outlet of a sensing zone and, therefore, system 2110 may receive sensor signals from all sensors associated with a material dispensing system. System 2110 may be configured to correct for the time delay between sensor signal capture and analysis, in some embodiments. In other embodiments, where trend information is particularly relevant, correction may not be needed.

Systems and methods are described herein that take advantage of machine learning algorithms. Machine learning models may be preferred because they can better handle noisy data, make predictions about future signal trends, and make adjustments before mix quality significantly shifts. Systems and methods described herein can calculate the mix ratio real time. With machine learning techniques, the mix ratio could be predicted ahead of time. This allows quicker adjustments which keeps the mix ratio closer to the target value more of the time. With some current dispensers, a lot of material is entrained in the static mixer, such that, by the time a shift in mix ratio is detected, the material already in the mixer will continue to have the wrong mix ratio for at least a mixer's worth of adhesive, so identifying mix ratio issues earlier can save material and a potential purge.

Similarly, machine learning models, as described herein, may receive information from multiple systems, such as multiple sensors within a dispensing system including conductivity sensors, temperature sensors, motor speed signals, material information, etc. In some embodiment, multiple machine learning models are used simultaneously, each by an individual system such that each system's model can learn and the overall model can be improved. However, it is also expressly contemplated that non-machine learning models may also be used.

Sensing systems herein are described as having the functionality of receiving and sending communicable information to and from other devices. This may be done through an application program interface, for example, such that system 2110 can receive and communicate with pump controllers, line pressure sensors, movement controllers for portions of dispensing system, temperature sensors, heating elements, datastores having information for any of the materials being dispensed or the mixture being generated, etc.

In embodiments where machine learning models are used, datastore may also include an analyzer that learns usage behavior of a particular dispensing system in order to improve operation and predictions. Similarly, frequency and patterns of dispensing may provide information about curing and improve mixing models. For example, usage data such as frequency of dispense, purging frequency, pattern of dispense, change out of the sensor, etc., can be collected and used to train a model to more accurately predict trends and provide corrective action.

Similarly, as described herein, display 2160 may display a GUI created by generator 2120 that is updated periodically with information collected by system 2110 and / or any of datastores 2130-2160. Information may be passively updated or provided with an alert or notification as it is updated, for example current status information may be presented and an alert (visual, audio, or haptic) may be provided if the mixing ratio is drifting toward an unacceptable range. Additionally, or alternatively, notifications may be provided when a device command is generated, or when operator intervention is needed.

In some embodiments, a signal encoder and regressor may operate locally, for example using a computer processing device associated with a material dispensing system. Alternatively, either encoder or regressor, or both, may be deployed in a cloud-based storage system.

The output of encoder may be directly used to apply pressure changes on the cartridges associated with one or more material components to ensure that the mixture meets a predefined mixing ratio. E.g., if the mixed material contains too much of part A, the pressure on the cartridge containing part A is reduced and the pressure on the cartridge that contains part B increased.

A regressor may then take the encoded signals and produce a mixing ratio signal. The regressor may be a machine learning based algorithm that can be trained in any suitable way.

A first training option is a separate training option where the Encoder-Decoder model is trained on a set of signals of a variety of parts for part A, part B, and diverse mixtures. The Machine Learning Regressor is trained in a second step afterwards on the encoded signals and the corresponding mixing ratios.

A second training option is an alternating training option, where one batch of signals is used for one training step in the Encoder-Decoder and then used for one training step in the Encoder-Machine Learning Regressor part. A training step consists of a forward pass of the data in a batch, the calculation of the gradient, and an application of the gradient to optimize the weights in the model.

A third training option is a combined training option where the triplet of Encoder-Decoder pair and Machine Learning model are optimized simultaneously. This means that a batch is forward through the Encoder, and the representation obtained is forwarded through the Decoder and the Machine Learning Regressor. Then the gradients calculated with both outputs are applied in a weighted combination in the backwards pass.

Alternating or combined training may provide a benefit in that the representation of the signals is learned in a way that it has a positive effect on the performance of the Regressor which can lead to a lower error when estimating the mixing ratio. Learning a representation of signals on a variety of materials and mixing ratios also allows the models to be used on previously unseen materials of the same chemical family.

In difference to a system which only uses a single signal from the mixed material, this novel approach allows adaption for lot-to-lot variation of the raw material, where a change in one of the parts can lead to a change in the mixed signal for the same mixing ratio. It also enables tracking the mixing of the new materials of the same family be learning to fuse the signals of two parts into a mixed signal.

Data traces collected from a sensor system can be processed to provide other information as described herein. For example, sensors may provide signals that can be processed to indicate that corrective action is needed.

As described herein, in some embodiments, a sensor includes four electrode pairs. A time series of conductivity can be analyzed from the four sensor capacitors to determine when corrective action has been successful – e.g. when remixing has completed, when phase separation is reversed or a mixture has again reached stability.

For example, mixing (or remixing) may take time to reach a steady state. For example, when starting a mixing operation, backpressure and different viscosities of components can cause mixing to start off poorly and gradually stabilize. The same variance can be used to track the stabilization and indicate when the dispenser can dispense material on a workpiece or to a receiving container. The trend of the variance can be analyzed against a threshold. The threshold is specific for each material. However, instead of determining a threshold, the signal can be tested for stationarity using the Augmented Dickey-Fuller test. The advantage with this is that manual thresholds often need to be tuned for a new batch, but the ADF test is adaptable.

Inhomogeneity can also be detected using sensors described herein. The four electrode pairs should also record similar readings. Some constant offset is possible due to manufacturing tolerances, but in a stable mixing process, the variations of the four signals should be synchronous.

Once each signal has stabilized, the four sensors should have a high covariance. Negative covariance indicates a persisting anti-correlated behavior and signifies spatial inhomogeneity.

Similarly, a single component of a mixture can also be inhomogeneous, e.g., because of settling in the barrel or insufficient mixing during manufacturing. An augmented Dickey-Fuller test can again be used to confirm stationarity over a longer time. The relevant time frame would be determined by the time it takes to empty the container.

FIG. 21A illustrates a concentration profile simulation system architecture 2100. Architecture 2100, however illustrates one embodiment of an implementation of a conductivity sensing system 2110. As an example, architecture 2100 can provide computation, software, data access, and storage services that do not require end-user knowledge of the physical location or configuration of the system that delivers the services. In various embodiments, remote servers can deliver the services over a wide area network, such as the internet, using appropriate protocols. For instance, remote servers can deliver applications over a wide area network and they can be accessed through a web browser or any other computing component. Software or components shown or described in FIGS. 1-20 as well as the corresponding data, can be stored on servers at a remote location. The computing resources in a remote server environment can be consolidated at a remote data center location or they can be dispersed. Remote server infrastructures can deliver services through shared data centers, even though they appear as a single point of access for the user. Thus, the components and functions described herein can be provided from a remote server at a remote location using a remote server architecture. Alternatively, they can be provided by a conventional server, installed on client devices directly, or in other ways.

FIG. 21B illustrates an example system architecture. In the embodiment of FIG. 21B, the system is connected through wires, such that it is not a wireless or open distributing solution. Wired communication may also be preferred in embodiments where a wireless connection would have slower transfer rates or potentially unreliability. However, as discussed with respect to FIG. 21A, it is contemplated that wireless systems may also be possible.

A conductivity sensor 2180 may capture a conductivity signal, for example from one or more PCB sensors described herein, provide that sensor signal to a signal converter 2182 where, if needed, signal conversion occurs. However, it is expressly contemplated that in some embodiments conductivity sensor 2180 may provide a sensor signal directly to processor 2184. Signal converter 2182 may convert, for example, impedance to conductivity, an analog to a digital signal, or may do another suitable conversion.

Processor 2184 receives a conductivity indication, and generates a conductivity output, which may be provided to one or more devices 2186. Devices 2186 may include a computing device with display, a smart phone with display, a laptop with display, or to another device, for example a storage medium which stores the conductivity sensor signal for future reference. Processor 2184 may also consult one or more data stores 2188 in order to generate additional indications. For example, data store 2188 may include past conductivity sensor signals, conductivity sensor signal thresholds, commands to adjust dispensing parameters based on conductivity signal thresholds, etc. Processor 2184 may act accordingly.

In accordance with embodiments herein, system may also have a pressure sensor 2190 that generates a pressure signal, indicative of a detected pressure at a point within the dispensing system. If needed, a signal converter 2192 may convert the pressure signal from one form to another, from ampere to voltage, analog-to-digital, etc.

Processor 2184, or another suitable processor, may generate a pressure output, which may be provided to one or more devices 2186. Processor 2184 may receive signals from pressure sensor 2190 and conductivity sensor 2180 continuously throughout a process, and may be able to generate outputs continuously as well, providing substantially real time information about a dispensing system. Processor 2184 may include one or more suitable machine learning techniques, may consult a lookup table, or perform another suitable data analysis technique on a received conductivity signal or pressure signal.

Processor 2184 may communicate with sensors 2180, 2190 wirelessly, using a wired connection, or through any other suitable network. Processor 2184 may receive signals as encrypted signals, may provide output as an encrypted output, or may operate without encryption protocols in place.

Any number of suitable communication routes are envisioned, e.g. from sensor 2190 directly to processor 2184, from sensor 2180 through signal converter 2182, and directly to datastore 2188, where it may be retrieved by processor 2184. Similarly, a request for information from devices 2186 may be sent directly to conductivity sensors 2180, 2190, to datastore 2188 or to processor 2184.

In some embodiments, an MQTT broker is used to allow, for example, devices 2186 to subscribe to a subset of data from sensor 2190 or processor 2184, for example.

In some embodiments, processor 2184 also communicates with data store 2188, such that conductivity and pressure signals are also stored for later analysis. – For example, a data set including conductivity and pressure signals over time may be used to train a machine learning algorithm, or may be used for troubleshooting purposes. For example, a machine learning algorithm may be able to detect patterns in the data set, such as an off mix ratio and need to purge, and provide indications and or thresholds about how to detect when mix ratio deviation occurs before the deviation become severe.

FIG. 21B illustrates a single processor that receives information from a single set of sensors for a dispensing operation. However, it is expressly contemplated that a production environment may have multiple dispensers running with multiple conductivity sensors and pressure sensors providing status information continuously. It is anticipated, therefore, that multiple users may want to view information about multiple production lines at the same time. FIG. 21C illustrates one configuration of a system that may be able to provide such functionality.

FIG. 21C illustrates a signal analysis system that communicates with a number of devices using a cloud-based network. As illustrated in FIG. 21C signal analysis system 2200 may communicate with a local analysis system 2240, such as that described with respect to FIG. 21B. Signal analysis system 2200 may receive a number of sensor signal data 2210 from a number of dispensing operations, such as a pilot line 2204, any of an operational line

2202, and/or a laboratory set up 2206. As described with respect to FIG. 21B, sensor signals 2200 may be digital signals, analog signals, conductivity measurement signals, pressure signals, or other signal information. For example, a low reservoir detected signal, a valve switch indication, or any other detectable indication from any of systems 2202 – 2206.

Signal analysis system 2200 may conduct analysis on receive sensor signal information 2200, for example using any suitable analysis tool such as lookup table, comparison thresholds, and/or machine learning algorithms to detect parameter trend information that may indicate a problem, or an action that needs to be taken, such as purging, adjusting mix ratio, etc.

Signal analysis of 2200 may provide output indicia 2220 a number of suitable devices 2250. Signal analysis system 2200 may provide output information 2220 continuously, or in response to a request 2234 information. Our request 2130 may be a one-time request for current status information, or a request to receive continuous updates going forward.

FIG. 22A-22D illustrate a sensing system in according with embodiments herein. Current sensing setups include components from different manufacturers, and data preparation and processing is done using a separate computing device. However, it is desired to have a robust and compact system that processes data quickly with limited downtime or booting time, such that quality concerns with a material are detected quickly.

In some embodiments herein a sensor contains signal preparation and processing within a single housing, e.g. a “smart” sensor. Such smart sensors contain a processing component – e.g. a microprocessor, a microcontroller, a digital signal processor or other processing circuitry. In some embodiments, a sensor also includes one or more standardized interfaces for interfacing with other systems – e.g. fieldbus systems, sensor networks, input/output links, etc. In some embodiments herein, sensor signal processing is completed without an external computer. Sensing systems herein provide decentralization, increased reliability, reduced cost, increased flexibility and simplification.

In some embodiments, a sensor system herein includes a concentrator which integrates electronic parts in a single housing. In some embodiments, all electronic components are on one PCB. In some embodiments, an analog frontend with signal conversion (e.g. AD-Converters, DA-Converters or both) are connected to a microcontroller that performs signal converting, processing and provide an output signal. Sensing systems herein may also incorporate operational circuitry, including power-supply, I/O protection circuitry, signal conditioning, reset management and / or debugging circuitry and interfaces. In some embodiments herein, the concentrator includes user-interface components such as LED signaling, UART, USB, wireless interfaces (e.g. Bluetooth®, WiFi, Zigbee®, cellular network), dot-matrix or alphanumeric display, industrial bus systems and / or tactile interface components such as push-buttons, switches, touchscreens, etc.

Systems herein may include user accessible data – e.g. a signal value, a pass/fail (e.g. "yes" or "no," "go" or "stop," etc.). Systems herein may provide a quality or quantity indication. Systems herein may provide a data stream with time and / or frequency-dependent data for storage and / or further processing. Systems herein may include algorithms and / or calibrations needed for data manipulation.

FIG. 22A illustrates a schematic of a sensing system in accordance with embodiments herein. Sensing system 2300 may be used with sensor described in embodiments herein, for example, or with another suitable sensor. A sensor signal reader 2302 connects to a sensor, for example an edge connector of a PCB-board that includes one or more electrode pairs. However, while an edge connector is illustrated, it is expressly contemplated that other connection mechanisms are suitable.

In some embodiments, a trans-impedance amplifier is present to convert current measurements to voltage, or vice versa. A concentrator 2310 receives sensor signals, processes said sensor signals, and provides an output. An output may be provided using an I/O device 2306 and / or another wired or wireless communication protocol 2308. A power source 2312 may provide power to concentrator 2310. While a wired power source 2312 is illustrated, it is possible that power may be provided wirelessly, or concentrator 2310 may be integrated into a material dispensing system from which it draws power.

FIG. 22B illustrates one example interface 2320 of a concentrator, that may receive sensor signals using one or more sensor signal receiving ports 2324. Other data or inputs may be received through another receiver 2322, in some embodiments.

FIG. 22C illustrates another interface 2330, which may receive a coupling to an input/output device. Power may be provided, for example using port 2334. Data may be communicated from a concentrator using a computer link 2336.

FIG. 22D illustrates a component diagram of a sensing system 2340 in accordance with embodiments herein. One or more sensors 2342 provide sensor signals, received by one or more receivers 2344 coupled to, or included within, a housing 2370. In some embodiments, system 2340 includes an analog front-end which may include a filter 2348 and / or an analog multiplexor 2346. A converter, e.g. a DA- or DC-converter 2349 may be present. Concentrator 2350 may include non-volatile memory 2352, flash memory 2354, or another suitable information storage. A temperature sensor 2356 may be incorporated into concentrator 2350, or receive a temperature signal from a temperature sensor. Concentrator 2350 may include a clock 2358. Concentrator 2362 may also include reset functionality 2362.

A sensor analyzer 2370 may include calibration data and / or functionality 2372. A real-time operating system 2373 may manage functionality. Sensor analyzer 2370 my include Fourier transformer 2376. Sensor analyzer 2370 may include a waveform generator 2376. Sensor analyzer may include other applications 2375 that provide other functionality, such as detecting of material characteristics like mix ratio, material age, curing progress, etc. Sensor analyzer 2370 may also include an identifier 2374 that identifies a type of sensor.

Concentrator 2350 may include a power management system 2360 that includes, or accesses, a power supply 2466. A power quality 2368 may be monitored. Energy consumption 2369 may be tracked. Conversion input and output ranges 2364 may be stored. A symmetric voltage 2367 may be used.

FIG. 23 illustrates a dispensing system in accordance with embodiments herein. Many dispensing operations are done with a portable, handheld system. Errors in dispensing or adhesive failure can result if material quality or machine settings are not correct. For example, an incorrect mix ratio or an incorrect pressure setting may result in an unacceptable product. It is desired to have a handheld dispensing system that can provide real-time sensing and feedback to a user. Described in FIG. 23 is one example of a system that can receive and process sensor signals without a separate computing device. Described herein are many embodiments of sensors that may be used with a dispenser. Described herein are systems for measuring pressure in a dispensing system. System 2400 includes a dispenser 2410. Dispenser 2410 is illustrated as an adhesive dispenser 2410, however other dispensers may also benefit from systems described herein. Dispenser 2410 includes an in-line sensor 2430 that senses electrical properties of a material being dispensed. A pressure sensor 2240 is incorporated into dispenser 2210 and monitors the pressure within the dispenser.

Dispenser 2410 also includes a signal processing system 2420. A signal receiver receives a sensed parameter signal from sensor 2430. A processing unit, which may include any suitable processor or processing circuitry, processes the sensed signal. A memory may store calibration data, historic signals, etc. A display 2450 may present processed information to a user, the information received from signal processing system 2420, for example using a communication module. Display 2450 may be integrated into dispenser 2410, or another display visible to a dispenser operator, such as a mobile computer, a worksite display, etc. However, while a display 2450 is illustrated as conveying processed information to an operator, it is expressly contemplated that output from signal processing system 2420 can be presented as audio or haptic feedback in some embodiments herein.

Based on sensed signals, signal processing system 2420 may also actuate a change in dispensing parameters. For example, a mix ratio may be sensed that as drifted away from a specified mix ratio. Signal processing system 2420 may, based on the sensed mix ratio drift, adjust a mix ratio by changing a pump speed for one component. Signal processing system 2420 may control pump speed directly, or indirectly, such that an instruction to change the pump speed is sent to a pump controller. Signal processing system 2420 may also communicate the mix ratio drift, e.g. through display 2450. In some embodiments, signal processing system 2420 may only communicate a detected material issue – e.g. mix ratio, aging, curing, pressure, etc. – and an operator may need to take steps to address the issue manually. However, it is expressly contemplated that, in some embodiments, dispenser parameters are adjusted automatically, in real-time, based on signals from sensors 2430, 2440.

In some embodiments, dispensing system 2400 includes a material inventory system 2260. Material inventory system 2460 may store physical materials 2462 and dispensers 2464 (e.g. different static mixer types for placement in dispensing system 2410) available for operator use. However, it is expressly contemplated that, in some embodiments, material inventory system 2260 stores only information about materials 2462 and dispensers 2464.

Materials 2462 may include information relevant to a dispensing operation that utilize them. For example, a dispensing cartridge may include an RFID tag, NFC tag, or other wirelessly accessible data storage. Information may also be transferred using a printed code – such as a bar code or QR code. In some embodiments, a printed RFID label is applied to dispensing cartridges.

When a cartridge of a material 2462 comes within a data transfer range (RFID range, NFC range, etc.) dispensing information can be retrieved by dispensing system 2410, or from material inventory system 2460. Dispensing information may include dispensing parameters 2466, such as an operating pressure for one or both components, and / or a preferred 2468 for use with material 2462. Other information may also be provided.

Based on the received information, system 2410 may display operating guidance on a display, e.g. 2450, for an operator. For example, in some embodiments, a dispenser receives expected process parameters from material information system 2460 based on an identification of material 2462 from an NFC tag, RFID tag, or other information storage system on a material to be dispensed.

Using sensors such that those described herein, or other suitable sensors, it may then also be possible for dispensing system 2410 to receive sensed electrical parameter values, from which ongoing process conditions may be determined – mix ratio, material age, curing, etc. Based on sensed process values, guidance may be provided or action automatically taken by system 2410 to correct an inconsistency.

FIGS. 24-26 illustrate example devices that can be used in the embodiments shown in previous Figures. FIG. 24 illustrates an example mobile device that can be used in the embodiments shown in previous Figures. FIG. 24 is a simplified block diagram of one illustrative example of a handheld or mobile computing device that can be used as either a worker's device or a supervisor / safety officer device, for example, in which the present system (or parts of it) can be deployed. For instance, a mobile device can be deployed in the operator compartment of computing device for use in generating, processing, or displaying the data.

FIG. 24 provides a general block diagram of the components of a mobile cellular device 2516 that can run some components shown and described herein. Mobile cellular device 2516 interacts with them or runs some and interacts with some. In the device 2516, a communications link 2513 is provided that allows the handheld device to communicate with other computing devices and under some embodiments provides a channel for receiving information automatically, such as by scanning. Examples of communications link 2513 include allowing communication though one or more communication protocols, such as wireless services used to provide cellular access to a network, as well as protocols that provide local wireless connections to networks.

In other examples, applications can be received on a removable Secure Digital (SD) card that is connected to an interface 2515. Interface 2515 and communication links 2513 communicate with a processor 2517 (which can also embody a processor) along a bus 2519 that is also connected to memory 2521 and input/output (I/O) components 2523, as well as clock 2525 and location system 2527.

I/O components 2523, in one embodiment, are provided to facilitate input and output operations and the device 2516 can include input components such as buttons, touch sensors, optical sensors, microphones, touch screens, proximity sensors, accelerometers, orientation sensors and output components such as a display device, a speaker, and or a printer port. Other I/O components 2523 can be used as well.

Clock 2525 illustratively comprises a real time clock component that outputs a time and date. It can also provide timing functions for processor 2517.

Illustratively, location system 2527 includes a component that outputs a current geographical location of device 2516. This can include, for instance, a global positioning system (GPS) receiver, a LORAN system, a dead reckoning system, a cellular triangulation system, or other positioning system. It can also include, for example, mapping software or navigation software that generates desired maps, navigation routes and other geographic functions.

Memory 2521 stores operating system 2529, network settings 2531, applications 2533, application configuration settings 2535, data store 2537, communication drivers 2539, and communication configuration settings 2541. Memory 2521 can include all types of tangible volatile and non-volatile computer-readable memory devices. It can also include computer storage media (described below). Memory 2521 stores computer readable instructions that, when executed by processor 2517, cause the processor to perform computer-implemented steps or functions according to the instructions. Processor 2517 can be activated by other components to facilitate their functionality as well. It is expressly contemplated that, while a physical memory store 2521 is illustrated as part of a device, that cloud computing options, where some data and / or processing is done using a remote service, are available.

FIG. 25 shows that the device can also be a smart phone 2671. Smart phone 2671 has a touch sensitive display 2673 that displays icons or tiles or other user input mechanisms 2675. Mechanisms 2675 can be used by a user to run applications, make calls, perform data transfer operations, etc. In general, smart phone 2671 is built on a mobile operating system and offers more advanced computing capability and connectivity than a feature phone. Note that other forms of the devices are possible.

However, while FIG. 25 illustrates an embodiment where a device 2600 is a smart phone 2671, it is expressly contemplated that a display may be presented on another comping device.

FIG. 26 is one example of a computing environment in which elements of systems and methods described herein, or parts of them (for example), can be deployed. With reference to FIG. 26, an example system for implementing some embodiments includes a general-purpose computing device in the form of a computer 2710. Components of computer 2710 may include, but are not limited to, a processing unit 2720 (which can comprise a processor), a system memory 2730, and a system bus 2721 that couples various system components including the system memory to the processing unit 2720. The system bus 2721 may be any of several types of bus structures including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures. Memory and programs described with respect to systems and methods described herein can be deployed in corresponding portions of FIG. 22.

Computer 2710 typically includes a variety of computer readable media. Computer readable media can be any available media that can be accessed by computer 2710 and includes both volatile/nonvolatile media and removable/non-removable media. By way of example, and not limitation, computer readable media may comprise computer storage media and communication media. Computer storage media is different from, and does not include, a modulated data signal or carrier wave. It includes hardware storage media including both volatile/nonvolatile and removable/non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules or other data. Computer storage media includes, but is not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical disk storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by computer 2710. Communication media may embody computer readable instructions, data structures, program modules or other data in a transport mechanism and includes any information delivery media. The term “modulated data signal” means a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal.

The system memory 2730 includes computer storage media in the form of volatile and/or nonvolatile memory such as read only memory (ROM) 2731 and random-access memory (RAM) 2732. A basic input/output system 2733 (BIOS) containing the basic routines that help to transfer information between elements within computer 2710, such as during start-up, is typically stored in ROM 2731. RAM 2732 typically contains data and/or program modules that are immediately accessible to and/or presently being operated on by processing unit 2720. By way of example, and not limitation, FIG. 26 illustrates operating system 2734, application programs 2735, other program modules 2736, and program data 2737.

The computer 2710 may also include other removable/non-removable and volatile/nonvolatile computer storage media. By way of example only, FIG. 26 illustrates a hard disk drive 2741 that reads from or writes to non-removable, nonvolatile magnetic media, nonvolatile magnetic disk 2752, an optical disk drive 2755, and nonvolatile optical disk 2756. The hard disk drive 2741 is typically connected to the system bus 2721 through a non-removable memory interface such as interface 2740, and optical disk drive 2755 are typically connected to the system bus 2721 by a removable memory interface, such as interface 2750.

Alternatively, or in addition, the functionality described herein can be performed, at least in part, by one or more hardware logic components. For example, and without limitation, illustrative types of hardware logic components that can be used include Field-programmable Gate Arrays (FPGAs), Application-specific Integrated Circuits (e.g., ASICs), Application-specific Standard Products (e.g., ASSPs), System-on-a-chip systems (SOCs), Complex Programmable Logic Devices (CPLDs), etc.

The drives and their associated computer storage media discussed above and illustrated in FIG. 26, provide storage of computer readable instructions, data structures, program modules and other data for the computer 2710. In FIG. 26, for example, hard disk drive 2741 is illustrated as storing operating system 2744, application programs 2745, other program modules 2746, and program data 2747. Note that these components can either be the same as or different from operating system 2734, application programs 2735, other program modules 2736, and program data 2737.

A user may enter commands and information into the computer 2710 through input devices such as a keyboard 2762, a microphone 2763, and a pointing device 2761, such as a mouse, trackball or touch pad. Other input devices (not shown) may include a joystick, game pad, satellite receiver, scanner, or the like. These and other input devices are often connected to the processing unit 2720 through a user input interface 2760 that is coupled to the system bus but may be connected by other interface and bus structures. A visual display 2791 or other type of display device is also connected to the system bus 2721 via an interface, such as a video interface 2790. In addition to the monitor, computers may also include other peripheral output devices such as speakers 2797 and printer 2796, which may be connected through an output peripheral interface 2795.

The computer 2710 is operated in a networked environment using logical connections, such as a Local Area Network (LAN) or Wide Area Network (WAN) to one or more remote computers, such as a remote computer 2780.

When used in a LAN networking environment, the computer 2710 is connected to the LAN 2771 through a network interface or adapter 2770. When used in a WAN networking environment, the computer 2710 typically includes a modem 2772 or other means for establishing communications over the WAN 2773, such as the Internet. In a networked environment, program modules may be stored in a remote memory storage device. FIG. 26 illustrates, for example, that remote application programs 2785 can reside on remote computer 2780.

In the present detailed description of the preferred embodiments, reference is made to the accompanying drawings, which illustrate specific embodiments in which the invention may be practiced. The illustrated embodiments are not intended to be exhaustive of all embodiments according to the invention. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the present invention. The following detailed description, therefore, is not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims.

Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties used in the specification and claims are to be understood as being modified in all instances by the term “about.” Accordingly, unless indicated to the contrary, the numerical parameters set forth in the foregoing specification and attached claims are approximations that can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings disclosed herein.

As used in this specification and the appended claims, the singular forms “a,” “an,” and “the” encompass embodiments having plural referents, unless the content clearly dictates otherwise. As used in this specification and the appended claims, the term “or” is generally employed In its sense including “and/or” unless the content clearly dictates otherwise.

Spatially related terms, including but not limited to, “proximate,” “distal,” “lower,” “upper,” “beneath,” “below,” “above,” and “on top,” if used herein, are utilized for ease of description to describe spatial relationships of an element(s) to another. Such spatially related terms encompass different orientations of the device in use or operation in addition to the particular orientations depicted in the figures and described herein. For example, if an object depicted in the figures is turned over or flipped over, portions previously described as below or beneath other elements would then be above or on top of those other elements.

As used herein, when an element, component, or layer for example is described as forming a “coincident interface” with, or being “on,” “connected to,” “coupled with,” “stacked on” or “in contact with” another element, component, or layer, it can be directly on, directly connected to, directly coupled with, directly stacked on, in direct contact with, or intervening elements, components or layers may be on, connected, coupled or in contact with the particular element, component, or layer, for example. When an element, component, or layer for example is referred to as being “directly on,” “directly connected to,” “directly coupled with,” or “directly in contact with” another element, there are no intervening elements, components or layers for example. The techniques of this disclosure may be implemented in a wide variety of computer devices, such as servers, laptop computers, desktop computers, notebook computers, tablet computers, hand-held computers, smart phones, and the like. Any components, modules or units have been described to emphasize functional aspects and do not necessarily require realization by different hardware units. The techniques described herein may also be implemented in hardware, software, firmware, or any combination thereof. Any features described as modules, units or components may be implemented together in an integrated logic device or separately as discrete but interoperable logic devices. In some cases, various features may be implemented as an integrated circuit device, such as an integrated circuit chip or chipset. Additionally, although a number of distinct modules have been described throughout this description, many of which perform unique functions, all the functions of all of the modules may be combined into a single module, or even split into further additional modules. The modules described herein are only exemplary and have been described as such for better ease of understanding.

If implemented in software, the techniques may be realized at least in part by a computer-readable medium comprising instructions that, when executed in a processor, performs one or more of the methods described above. The computer-readable medium may comprise a tangible computer-readable storage medium and may form part of a computer program product, which may include packaging materials. The computer-readable storage medium may comprise random access memory (RAM) such as synchronous dynamic random access memory (SDRAM), read-only memory (ROM), non-volatile random access memory (NVRAM), electrically erasable programmable read-only memory (EEPROM), FLASH memory, magnetic or optical data storage media, and the like. The computer-readable storage medium may also comprise a non-volatile storage device, such as a hard-disk, magnetic tape, a compact disk (CD), digital versatile disk (DVD), Blu-ray disk, holographic data storage media, or other non-volatile storage device.

The term “processor,” as used herein may refer to any of the foregoing structure or any other structure suitable for implementation of the techniques described herein. In addition, in some aspects, the functionality described herein may be provided within dedicated software modules or hardware modules configured for performing the techniques of this disclosure. Even if implemented in software, the techniques may use hardware such as a processor to execute the software, and a memory to store the software. In any such cases, the computers described herein may define a specific machine that is capable of executing the specific functions described herein. Also, the techniques could be fully implemented in one or more circuits or logic elements, which could also be considered a processor.

An electrical property sensor is presented that includes a printed circuit board with a first face separated from a second face by a thickness, the first face having a length and a width. The sensor also includes a first sensing area on the first face, the first sensing area including a receiving electrode and a transmitting electrode. When a fluid contacts the first or second sensing area, and the transmitting electrode is actuated, a sensed electrical property value is measured at the receiving electrode.

The sensor may be configured such that the sensed electrical property value is a current flow measurement.

The sensor may be configured such that the sensed electrical property value is an impedance.

The sensor may be configured such that the sensed electrical property value is a relative permittivity.

The sensor may be configured such that the transmitting electrode includes a plurality of transmitting branches, the receiving electrode includes a plurality of receiving branches, and the plurality of transmitting branches are interleaved between the plurality of receiving branches.

The sensor may be configured such that it includes a second sensing area, the second sensing area including a second receiving electrode and a second transmitting electrode.

The sensor may be configured such that the first sensing area is on the first face and the second sensing area is on the second face.

The sensor may be configured such that the both the first and second sensing areas are on the first face.

The sensor may be configured such that the first and second sensing areas are decoupled such that the sensed electrical property value from the first sensing area differs from the sensed electrical property value from the second sensing area.

The sensor may be configured to include a third sensing area decoupled from both the first and second sensing areas.

The sensor may be configured such that it has a temperature sensor.

The sensor may be configured such that the temperature sensor is electrically isolated from the fluid flow.

The sensor may be configured such that the sensing area includes a sensing length and a sensing width, and the length of the PCB is more than twice the sensing length.

The sensor may be configured such that it includes an edge connector configured to communicably couple to a sensor signal receiver.

The sensor may be configured to include an aperture along the PCB, between the edge connector and the sensing area.

The sensor may be configured such that a length of the PCB is more than three times the length of the first aperture.

The sensor may be configured such that a length of the PCB is more than four times the length of the first aperture.

A sensing system for a mixture that includes a sensing zone containing a mixture and a sensor within the sensing zone. The sensor includes a printed circuit board (PCB). The sensor also includes a first and a second area of the PCB, each of the first and second areas including a receiving electrode spaced apart from a transmitting electrode, the first area is decoupled from the second area such that a first electrical parameter value, sensed by the first area, differs from the second electrical parameter, sensed by the second area. The mixture is in direct contact with the transmitting electrode and the receiving electrode of each of the first and second areas. The system also includes a communication component that communicates the first and second electrical parameter values.

The system may be configured such that the sensing zone is a container housing the mixture.

The system may be configured such that sensing system detects a difference between the first and second electrical parameter values and, based on the difference, indicates an instability in the mixture.

The system may be configured such that detected instability indicates a contaminant.

The system may be configured such that, based on the instability, a controller generates an indication.

The system may be configured such that the indication is communicated to a controller of a container housing the material.

The system may be configured such that, to detect the instability, the system is configured to, in situ, detect a difference between the first and second current signals, compare that difference to an acceptable threshold difference, and generate the instability indication if the difference exceeds the threshold difference.

The system may be configured such that, based on a detection that the difference between the first and second current signals has decreased below the threshold difference, generating an indication that the instability is resolved.

The system may be configured such that, the transmitting electrode is parallel to a surface of the PCB.

The sensor may be configured such that the sensed electrical property value is a current flow measurement.

The sensor may be configured such that the sensed electrical property value is an impedance.

The sensor may be configured such that the sensed electrical property value is a sdielectric constant.

The sensor may be configured such that the transmitting electrode includes a plurality of transmitting branches, the receiving electrode includes a plurality of receiving branches, and the plurality of transmitting branches are interleaved between the plurality of receiving branches.

The sensor may be configured such that it includes a second sensing area, the second sensing area including a second receiving electrode and a second transmitting electrode.

The sensor may be configured such that the first sensing area is on the first face and the second sensing area is on the second face.

The sensor may be configured such that both the first and second sensing areas are on the first face.

The sensor may be configured such that the first and second sensing areas are decoupled such that the sensed electrical property value from the first sensing area differs from the sensed electrical property value from the second sensing area.

The sensor may be configured such that it includes a third sensing area decoupled from both the first and second sensing areas.

The sensor may be configured such that it includes a temperature sensor.

The sensor may be configured such that the temperature sensor is electrically isolated from the fluid flow.

The sensor may be configured such that the sensing area includes a sensing length and a sensing width, and the length of the PCB is more than twice the sensing length.

The sensor may be configured such that an edge connector configured to communicably couple to a sensor signal receiver.

The sensor may be configured such that an aperture along the PCB, between the edge connector and the sensing area.

A method of sensing a material status of a material includes contacting the material to a sensor, the contact includes direct contact of the sensor to the material. The sensor includes a PCB including a first surface and a second surface, the first and second surfaces separated by a thickness. The sensor includes a sensing area on the first surface, the sensing area configured to detect an electrical parameter value. The sensor also includes an edge connector configured to communicate signals from the sensing area to a signal processor. The method also includes receiving an electrical signal from the sensor, the electrical signal communicated by the edge connector. The method also includes detecting, based on the received signal, the material status, the detecting is done in real-time by the signal processor. The method also includes communicating the detected material status.

The method may be configured such that signal processor receives the sensed electrical parameter value, detects the material status and communicates the detected material status.

The method may be configured such that communicating includes the signal processor communicating the detected material status to a graphical user interface generator, which generates a graphical user interface for a device with a screen.

The method may be configured such that the device includes the signal processor.

The method may be configured such that the sensed electrical property value is a current flow measurement.

The method may be configured such that the sensed electrical property value is an impedance.

The method may be configured such that the sensed electrical property value is a dielectric constant.

The method may be configured such that the sensing area includes a transmitting electrode and a receiving electrode, the transmitting electrode includes a plurality of transmitting branches, the receiving electrode includes a plurality of receiving branches, and the plurality of transmitting branches are interleaved between the plurality of receiving branches.

The method may be configured such that it includes a second sensing area, the second sensing area including a second receiving electrode and a second transmitting electrode.

The method may be configured such that the first sensing area is on the first face and the second sensing area is on the second face.

The method may be configured such that both the first and second sensing areas are on the first face.

The method may be configured such that the first and second sensing areas are decoupled such that the sensed electrical property value from the first sensing area differs from the sensed electrical property value from the second sensing area.

The method may be configured such that it includes a third sensing area decoupled from both the first and second sensing areas.

The method may be configured such that it includes a temperature sensor.

The method may be configured such that the temperature sensor is electrically isolated from the fluid flow.

The method may be configured such that the sensing area includes a sensing length and a sensing width, and the length of the PCB is more than twice the sensing length.

The method may be configured such that it includes an edge connector configured to communicably couple to a sensor signal receiver.

The method may be configured such that it includes an aperture along the PCB, between the edge connector and the sensing area.

What Is Claimed Is:

1. An electrical property sensor comprising:

   a printed circuit board with a first face separated from a second face by a thickness, the first face having a length and a width;

   a first sensing area on the first face, the first sensing area comprising a receiving electrode and a transmitting electrode; and

   wherein, when a fluid contacts the first or second sensing area, and the transmitting electrode is actuated, a sensed electrical property value is measured at the receiving electrode.

2. The sensor of claim 1, wherein the sensed electrical property value is a current flow measurement.
3. The sensor of claim 1 or 2, wherein the sensed electrical property value is an impedance.
4. The sensor of any of claims 1-3, wherein the sensed electrical property value is a relative permittivity.
5. The sensor of any of claims 1-4, wherein the transmitting electrode comprises a plurality of transmitting branches, the receiving electrode comprises a plurality of receiving branches, and wherein the plurality of transmitting branches are interleaved between the plurality of receiving branches.
6. The sensor of any of claims 1-5, and further comprising a second sensing area, the second sensing area comprising a second receiving electrode and a second transmitting electrode.
7. The sensor of claim 6, wherein the first sensing area is on the first face and the second sensing area is on the second face.
8. The sensor of claim 6, wherein both the first and second sensing areas are on the first face.
9. The sensor of claim 6, wherein the first and second sensing areas are decoupled such that the sensed electrical property value from the first sensing area differs from the sensed electrical property value from the second sensing area.
10. The sensor of claim 6, and further comprising a third sensing area decoupled from both the first and second sensing areas.
11. The sensor of any of claims 1-10, and further comprising a temperature sensor.

12. The sensor of claim 11, wherein the temperature sensor is electrically isolated from the fluid flow.
13. The sensor of any of claims 1-12, wherein the sensing area comprises a sensing length and a sensing width, and wherein the length of the PCB is more than twice the sensing length.
14. The sensor of any of claims 1-13, and further comprising an edge connector configured to communicably couple to a sensor signal receiver.
15. The sensor of claim 14, and further comprising an aperture along the PCB, between the edge connector and the sensing area.
16. The sensor of any of claims 1-15, wherein a length of the PCB is more than three times the length of the first aperture.
17. The sensor of any of claims 1-16, wherein a length of the PCB is more than four times the length of the first aperture.
18. A sensing system for a mixture comprising:

    a sensing zone containing a mixture;

    a sensor within the sensing zone, the sensor comprising:

        a printed circuit board (PCB);

        a first and a second area of the PCB, each of the first and second areas comprising a receiving electrode spaced apart from a transmitting electrode, wherein the first area is decoupled from the second area such that a first electrical parameter value, sensed by the first area, differs from the second electrical parameter, sensed by the second area; and

        wherein the mixture is in direct contact with the transmitting electrode and the receiving electrode of each of the first and second areas; and

    a communication component that communicates the first and second electrical parameter values.
19. The system of claim 18, wherein the sensing zone is a container housing the mixture.
20. The system of claim 18 or 19, wherein the sensing system detects a difference between the first and second electrical parameter values and, based on the difference, indicates an instability in the mixture.

21. The system of claim 20, wherein the detected instability indicates a contaminant.
22. The system of any of claims 18-22, wherein, based on the instability, a controller generates an indication.
23. The system of claim 22, wherein the indication is communicated to a controller of a container housing the material.
24. The system of claim 23, wherein, to detect the instability, the system is configured to, in situ, detect a difference between the first and second current signals, compare that difference to an acceptable threshold difference, and generate the instability indication if the difference exceeds the threshold difference.
25. The system of claim 24, and wherein, based on a detection that the difference between the first and second current signals has decreased below the threshold difference, generating an indication that the instability is resolved.
26. The system of any of claims 18-25, wherein the transmitting electrode is parallel to a surface of the PCB.
27. The sensor of any of claims 18-26, wherein the sensed electrical property value is a current flow measurement.
28. The sensor 18-27, wherein the sensed electrical property value is an impedance.
29. The sensor of any of claims 18-28, wherein the sensed electrical property value is a dielectric constant.
30. The sensor of any of claims 18-29, wherein the transmitting electrode comprises a plurality of transmitting branches, the receiving electrode comprises a plurality of receiving branches, and wherein the plurality of transmitting branches are interleaved between the plurality of receiving branches.
31. The sensor of any of claims 18-30, and further comprising a second sensing area, the second sensing area comprising a second receiving electrode and a second transmitting electrode.
32. The sensor of claim 32, wherein the first sensing area is on the first face and the second sensing area is on the second face.
33. The sensor of claim 32, wherein both the first and second sensing areas are on the first face.

34. The sensor of claim 32, wherein the first and second sensing areas are decoupled such that the sensed electrical property value from the first sensing area differs from the sensed electrical property value from the second sensing area.
35. The sensor of claim 32, and further comprising a third sensing area decoupled from both the first and second sensing areas.
36. The sensor of any of claims 18-35, and further comprising a temperature sensor.
37. The sensor of claim 36, wherein the temperature sensor is electrically isolated from the fluid flow.
38. The sensor of any of claims 18-37, wherein the sensing area comprises a sensing length and a sensing width, and wherein the length of the PCB is more than twice the sensing length.
39. The sensor of any of claims 18-39, and further comprising an edge connector configured to communicably couple to a sensor signal receiver.
40. The sensor of claim 39, and further comprising an aperture along the PCB, between the edge connector and the sensing area.
41. A method of sensing a material status of a material, the method comprising: contacting the material to a sensor, wherein the contact comprises direct contact of the sensor to the material, the sensor comprising:
    a PCB comprising a first surface and a second surface, the first and second surfaces separated by a thickness;
    a sensing area on the first surface, the sensing area configured to detect an electrical parameter value; and
    an edge connector configured to communicate signals from the sensing area to a signal processor;

    receiving an electrical signal from the sensor, the electrical signal communicated by the edge connector;

    detecting, based on the received signal, the material status, wherein the detecting is done in real-time by the signal processor; and

    communicating the detected material status.
42. The method of claim 41, wherein the signal processor receives the sensed electrical parameter value, detects the material status and communicates the detected material status.

43. The method of claim 42, wherein communicating comprises the signal processor communicating the detected material status to a graphical user interface generator, which generates a graphical user interface for a device with a screen.
44. The method of claim 43, wherein the device comprises the signal processor.
45. The method of any of claims 40-44, wherein the sensed electrical property value is a current flow measurement.
46. The method of any of claims 40-45, wherein the sensed electrical property value is an impedance.
47. The method of any of claims 40-46, wherein the sensed electrical property value is a dielectric constant.
48. The method of any of claims 40-47, wherein the sensing area comprises a transmitting electrode and a receiving electrode, the transmitting electrode comprises a plurality of transmitting branches, the receiving electrode comprises a plurality of receiving branches, and wherein the plurality of transmitting branches are interleaved between the plurality of receiving branches.
49. The method of any of claims 40-48, and further comprising a second sensing area, the second sensing area comprising a second receiving electrode and a second transmitting electrode.
50. The method of claim 49, wherein the first sensing area is on the first face and the second sensing area is on the second face.
51. The method of claim 50, wherein both the first and second sensing areas are on the first face.
52. The method of claim 50, wherein the first and second sensing areas are decoupled such that the sensed electrical property value from the first sensing area differs from the sensed electrical property value from the second sensing area.
53. The method of claim 50, and further comprising a third sensing area decoupled from both the first and second sensing areas.
54. The method of any of claims 40-53, and further comprising a temperature sensor.
55. The method of claim 54, wherein the temperature sensor is electrically isolated from the fluid flow.

56. The method of any of claims 40-55, wherein the sensing area comprises a sensing length and a sensing width, and wherein the length of the PCB is more than twice the sensing length.
57. The method of any of claims 40-56, and further comprising an edge connector configured to communicably couple to a sensor signal receiver.
58. The method of claim 57, and further comprising an aperture along the PCB, between the edge connector and the sensing area.

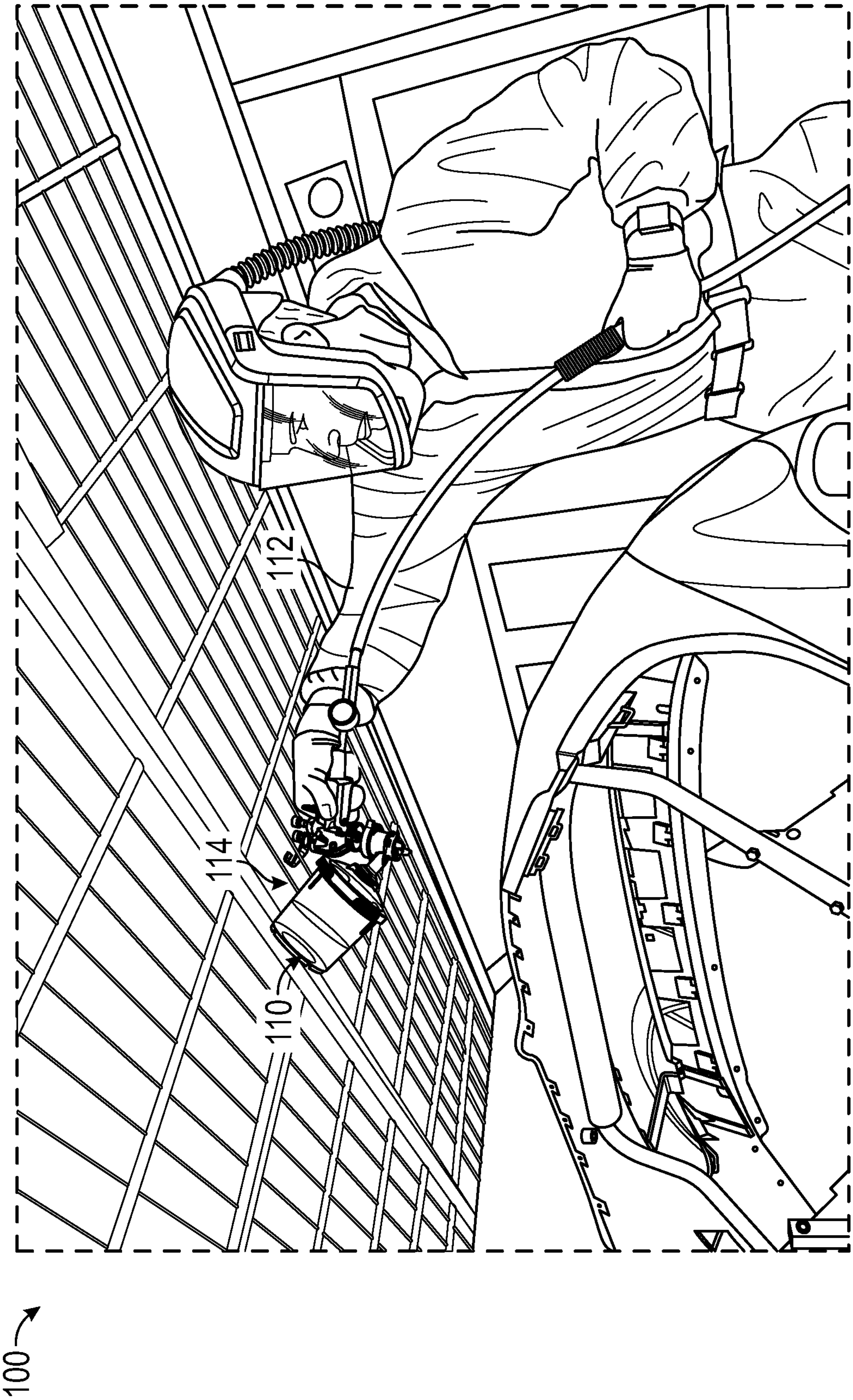


FIG. 1A

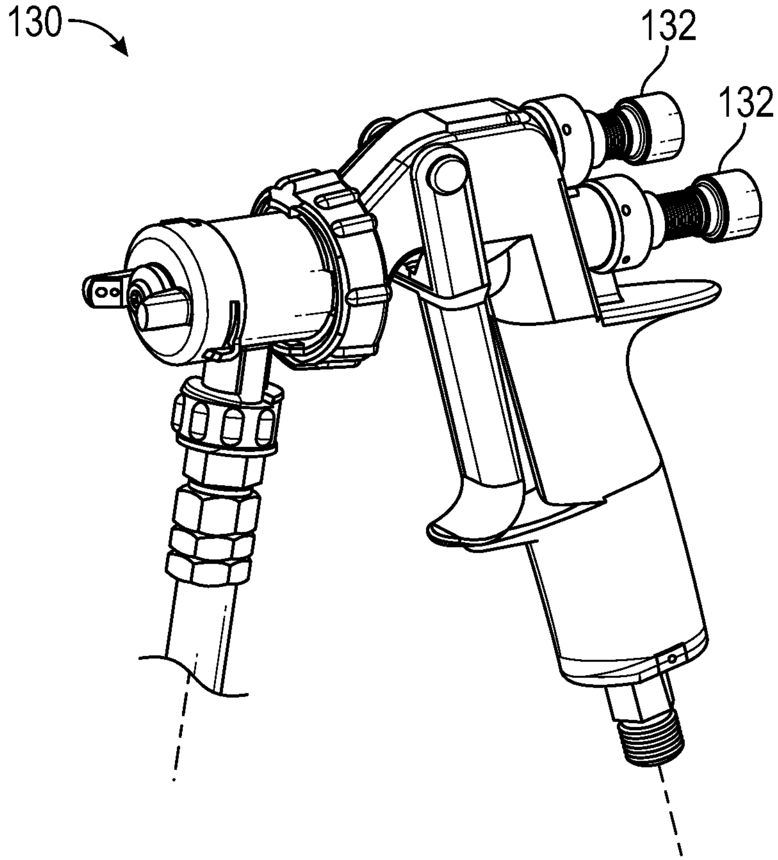


FIG. 1B

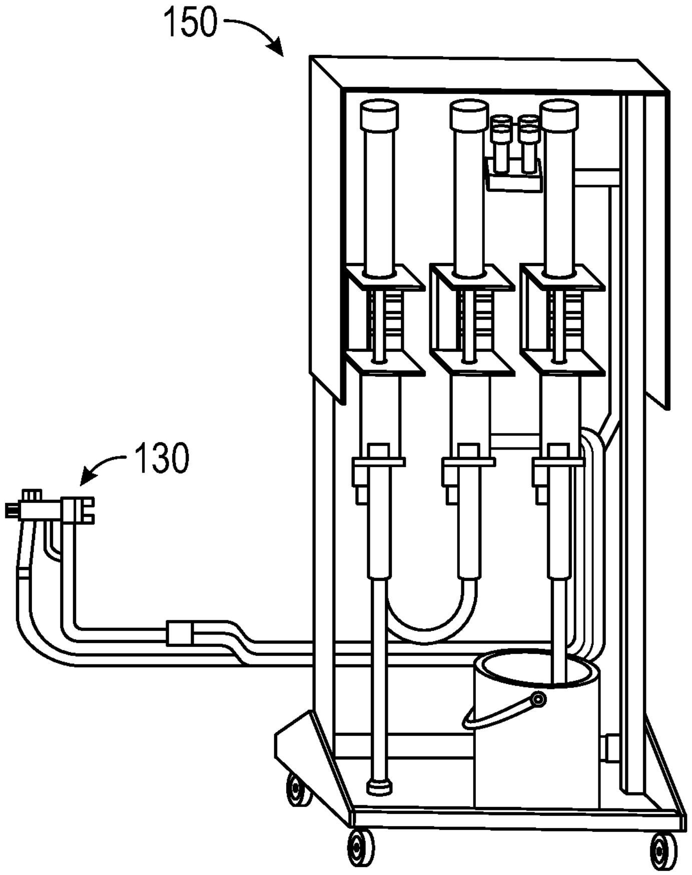


FIG. 1C

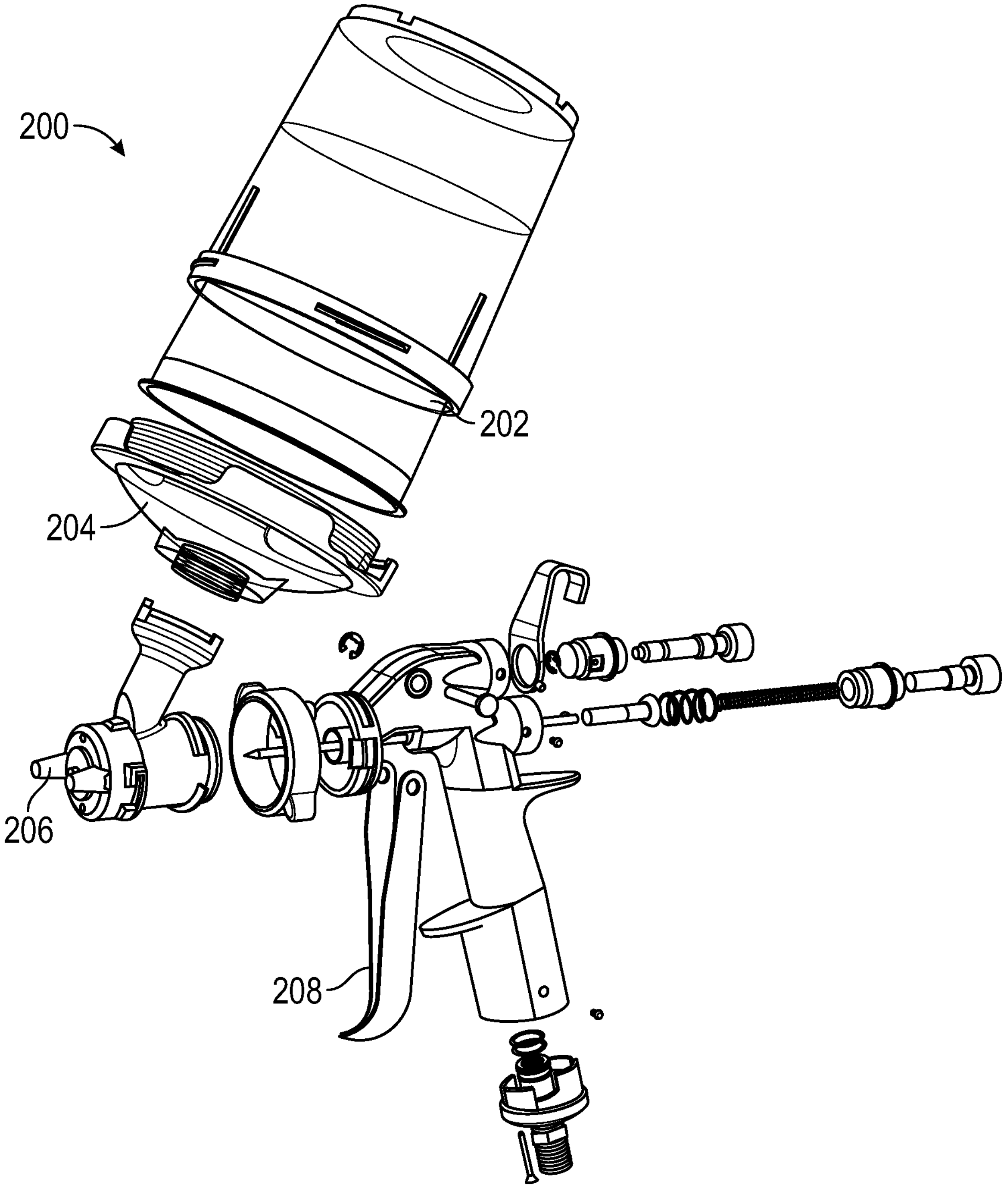
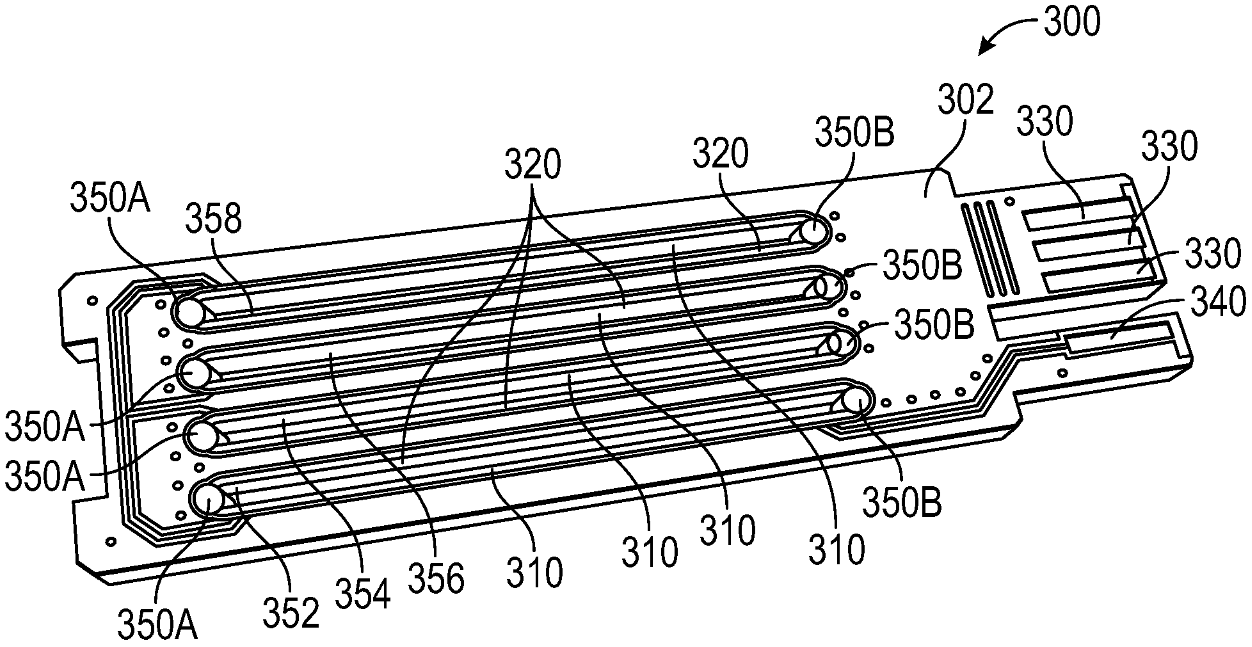


FIG. 2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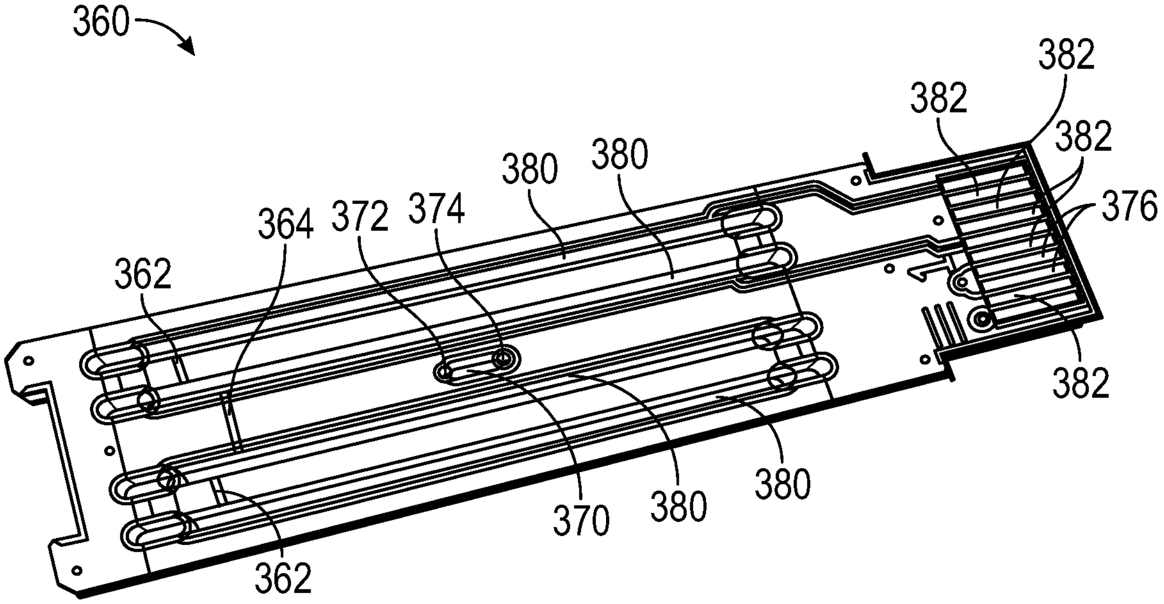
310

FIG. 3A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362
370
380
380

FIG. 3B

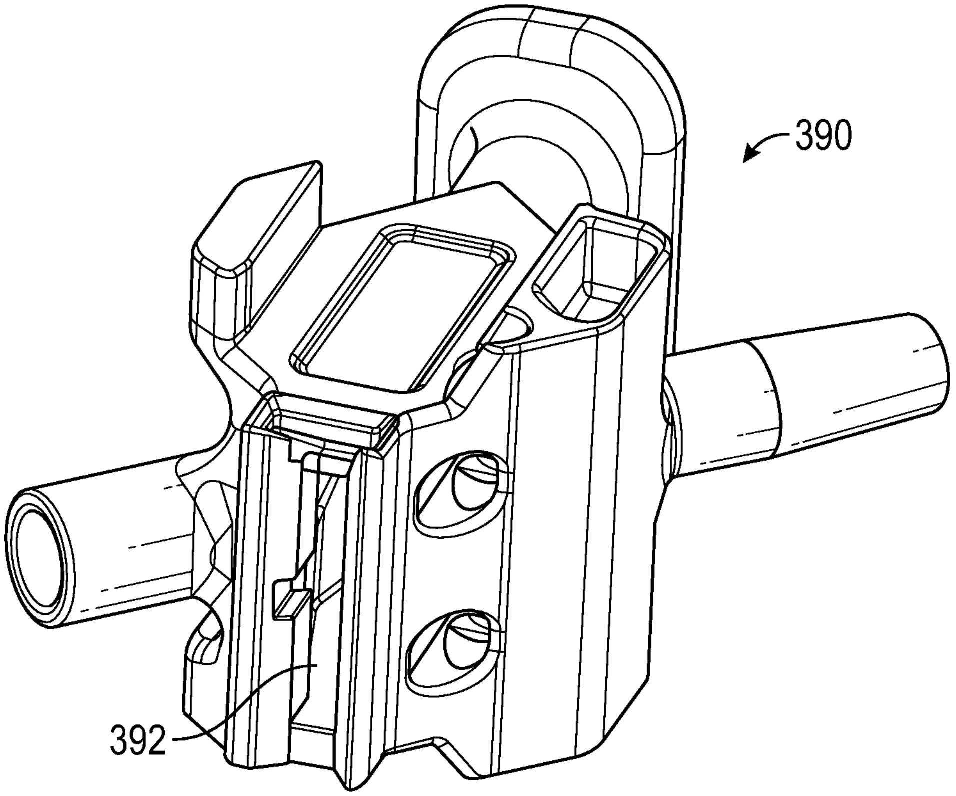


FIG. 3C

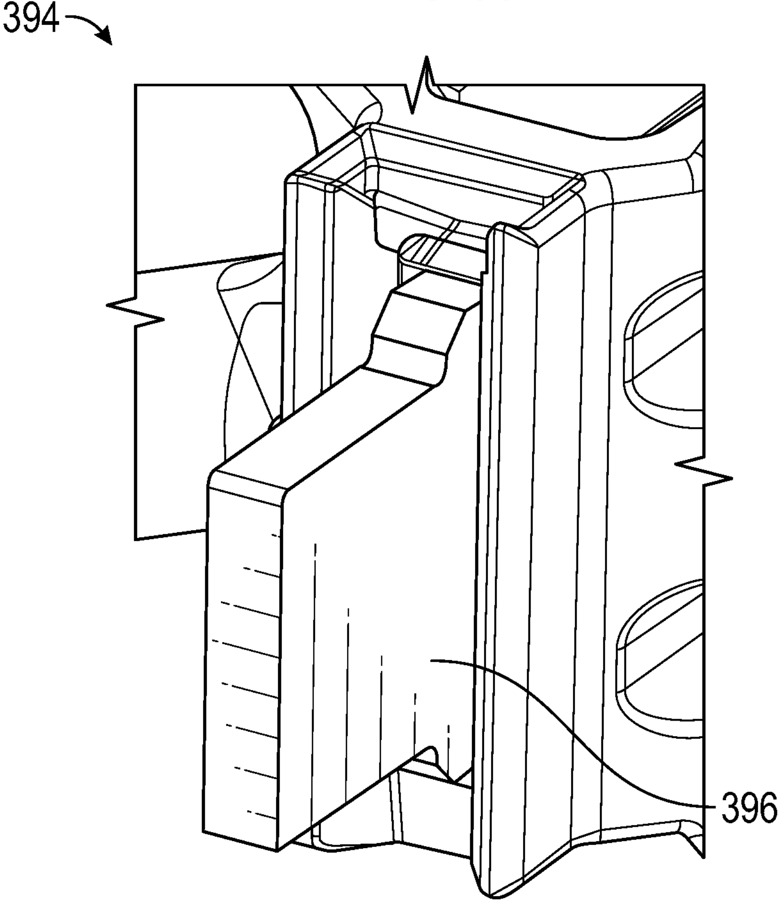


FIG. 3D

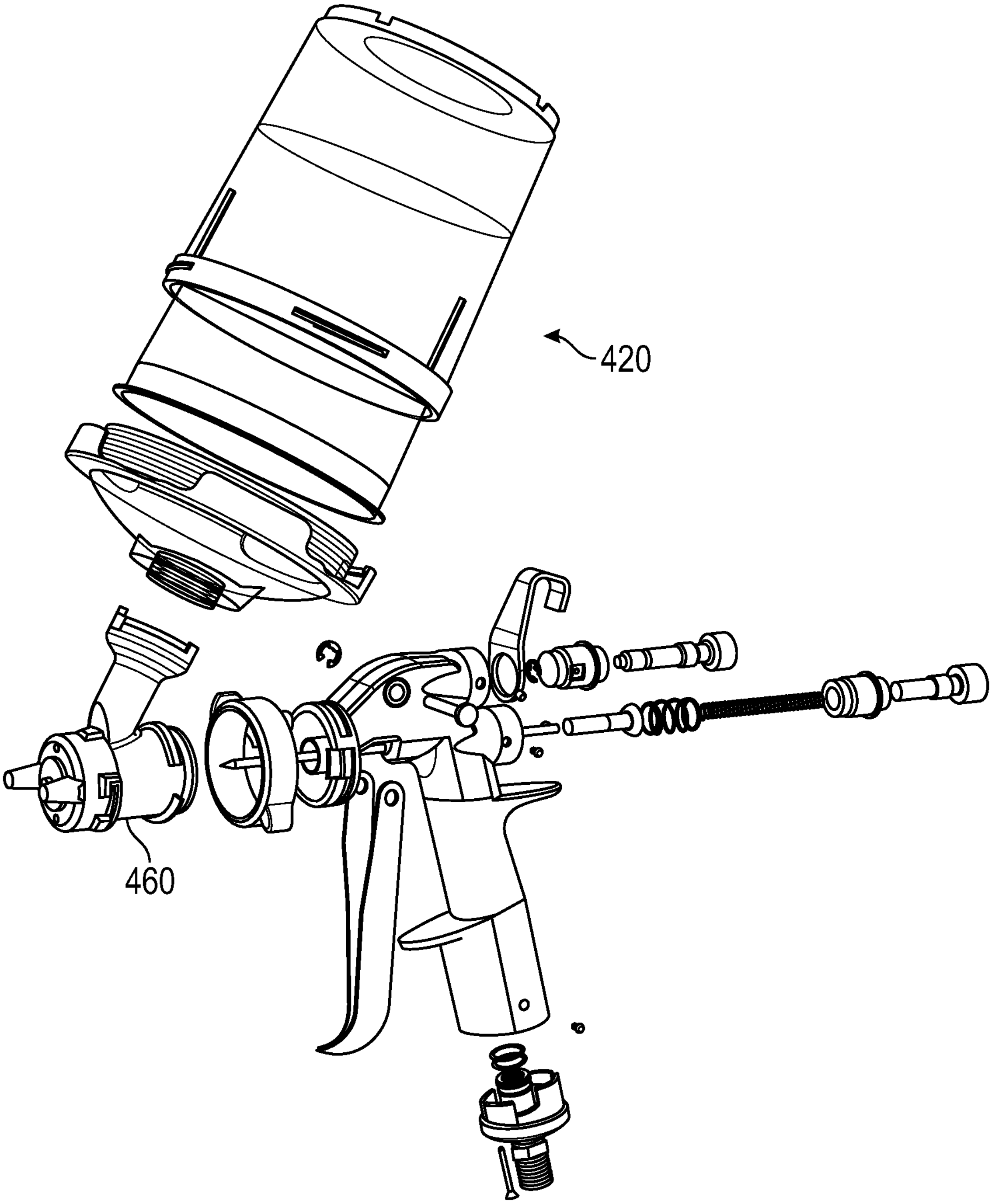


FIG. 4A

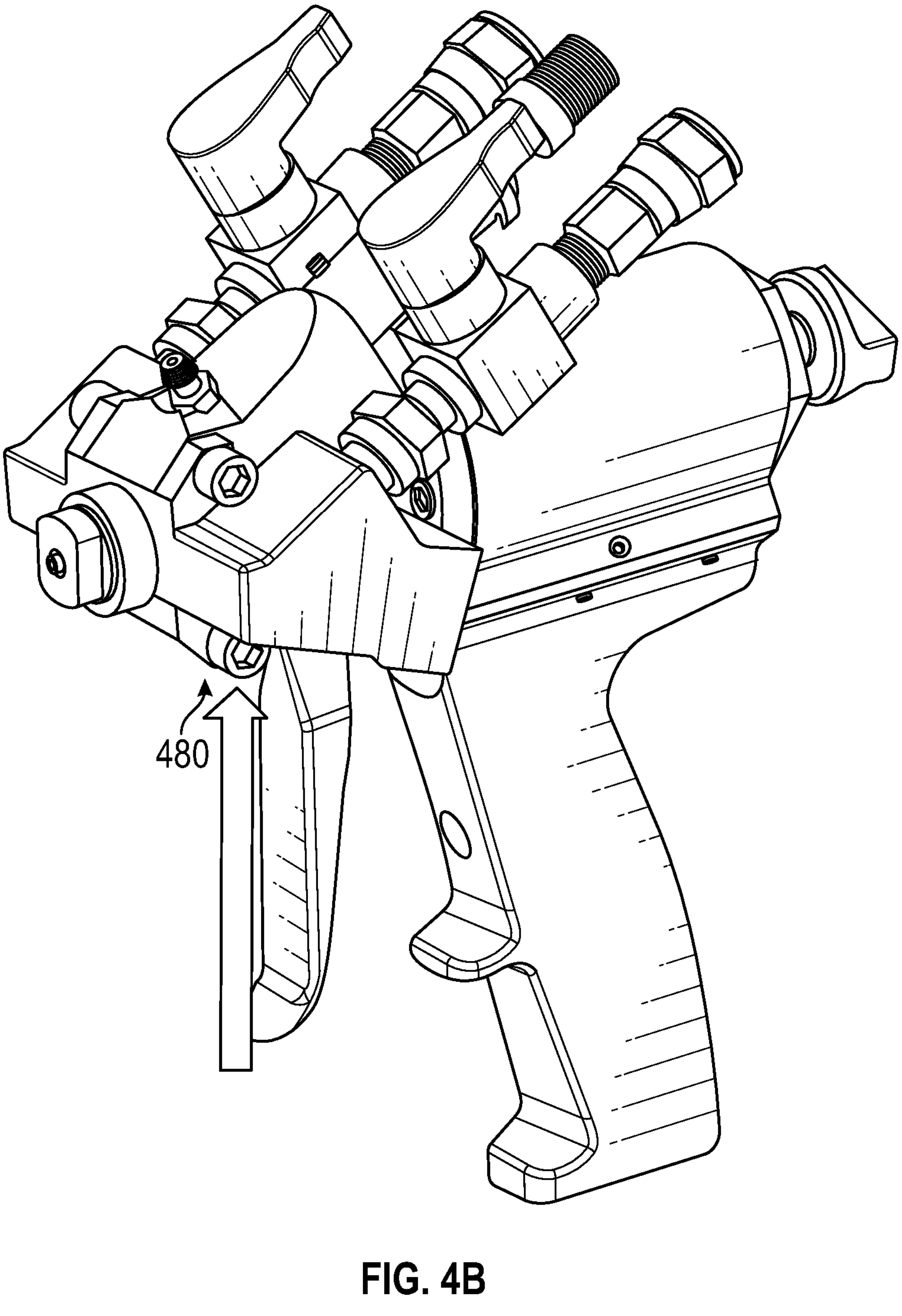


FIG. 4B

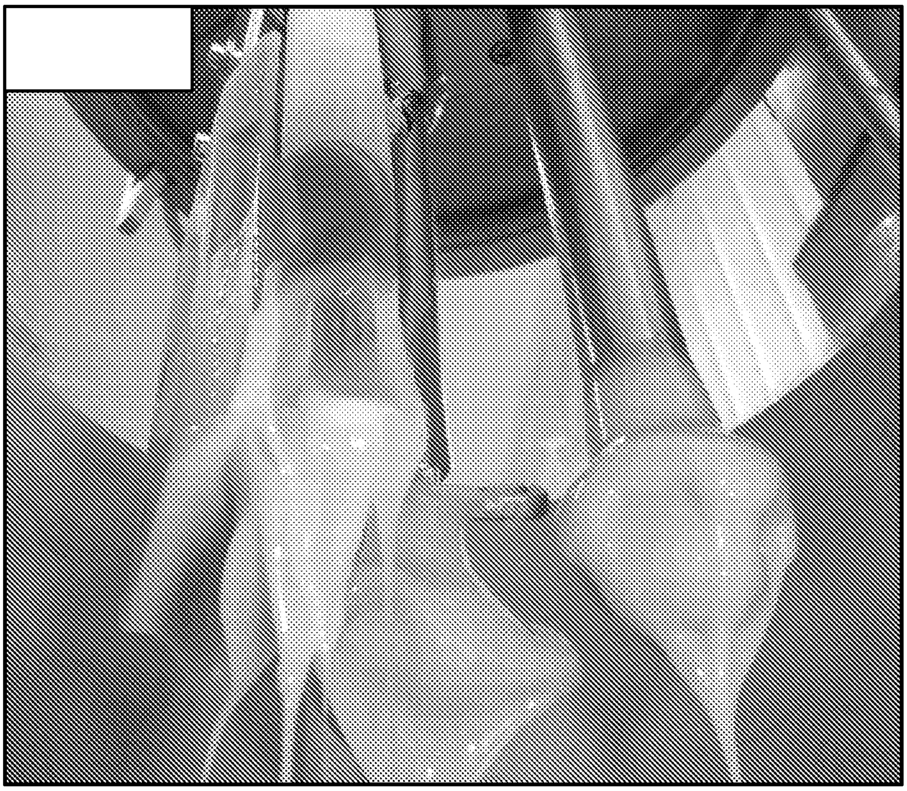


FIG. 5A

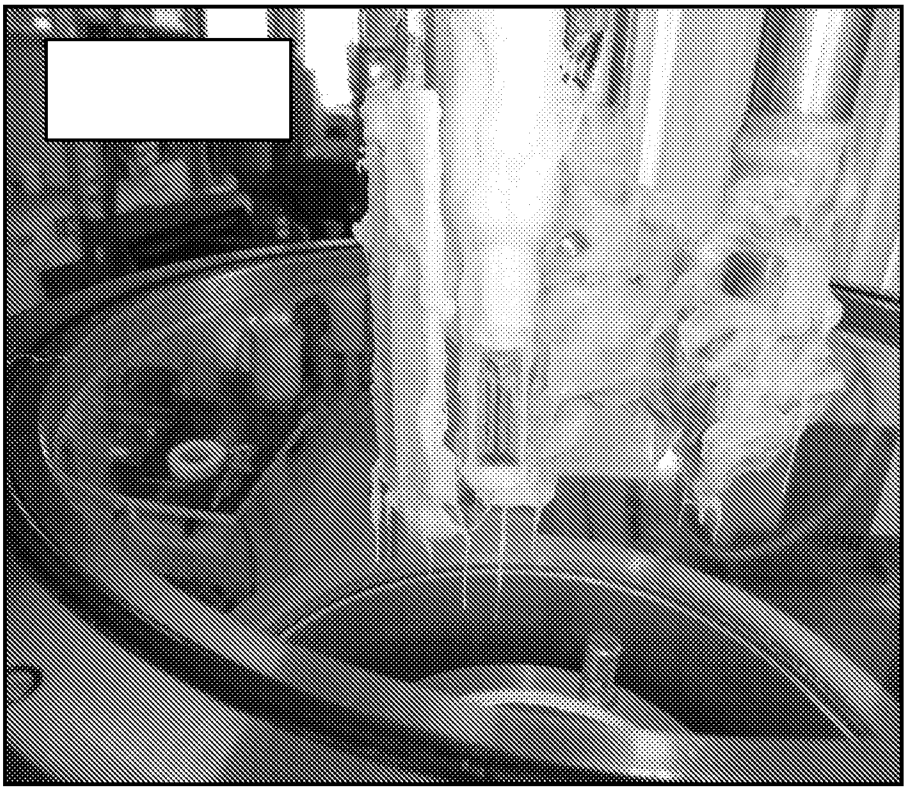


FIG. 5B

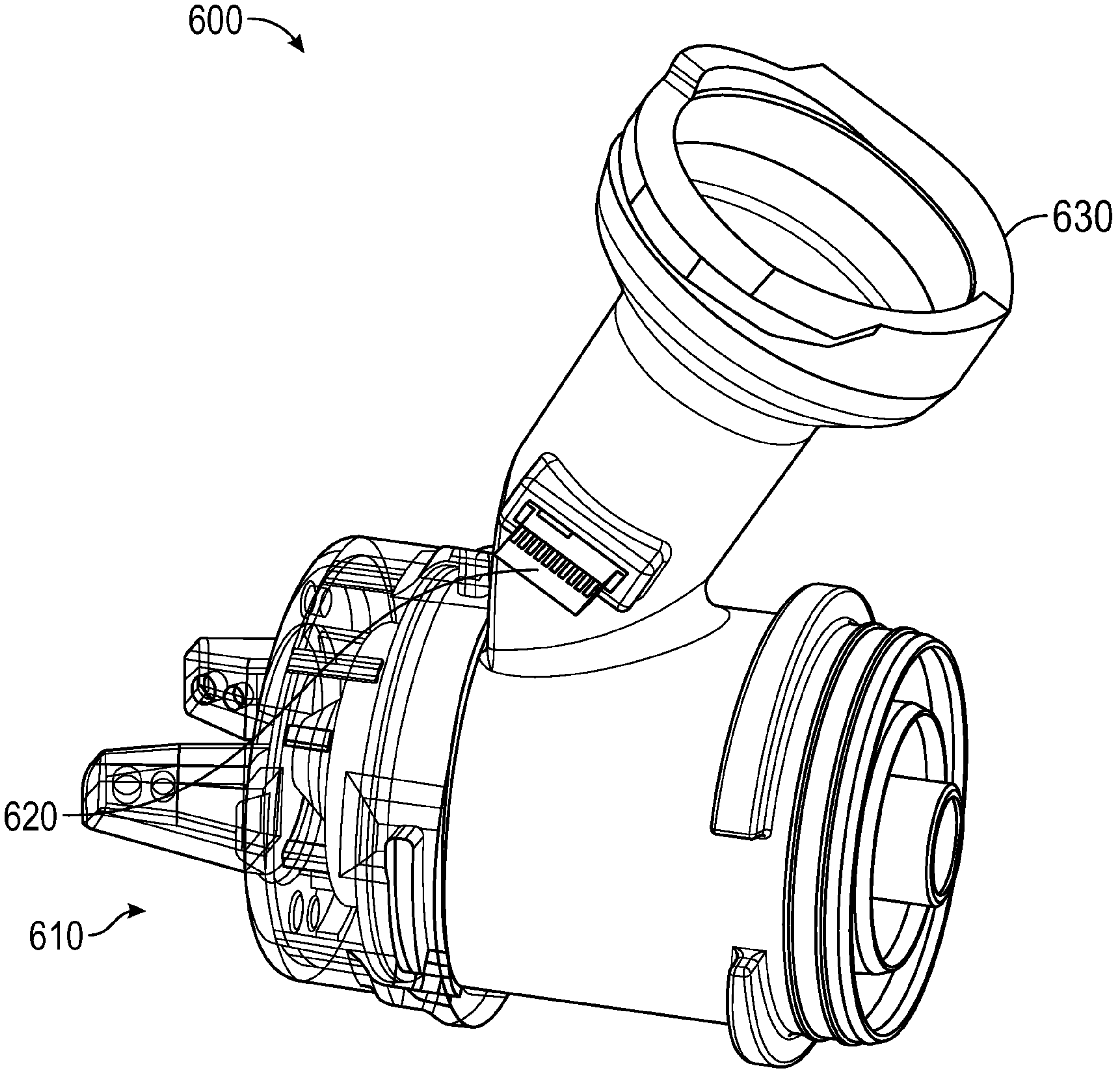


FIG. 6A

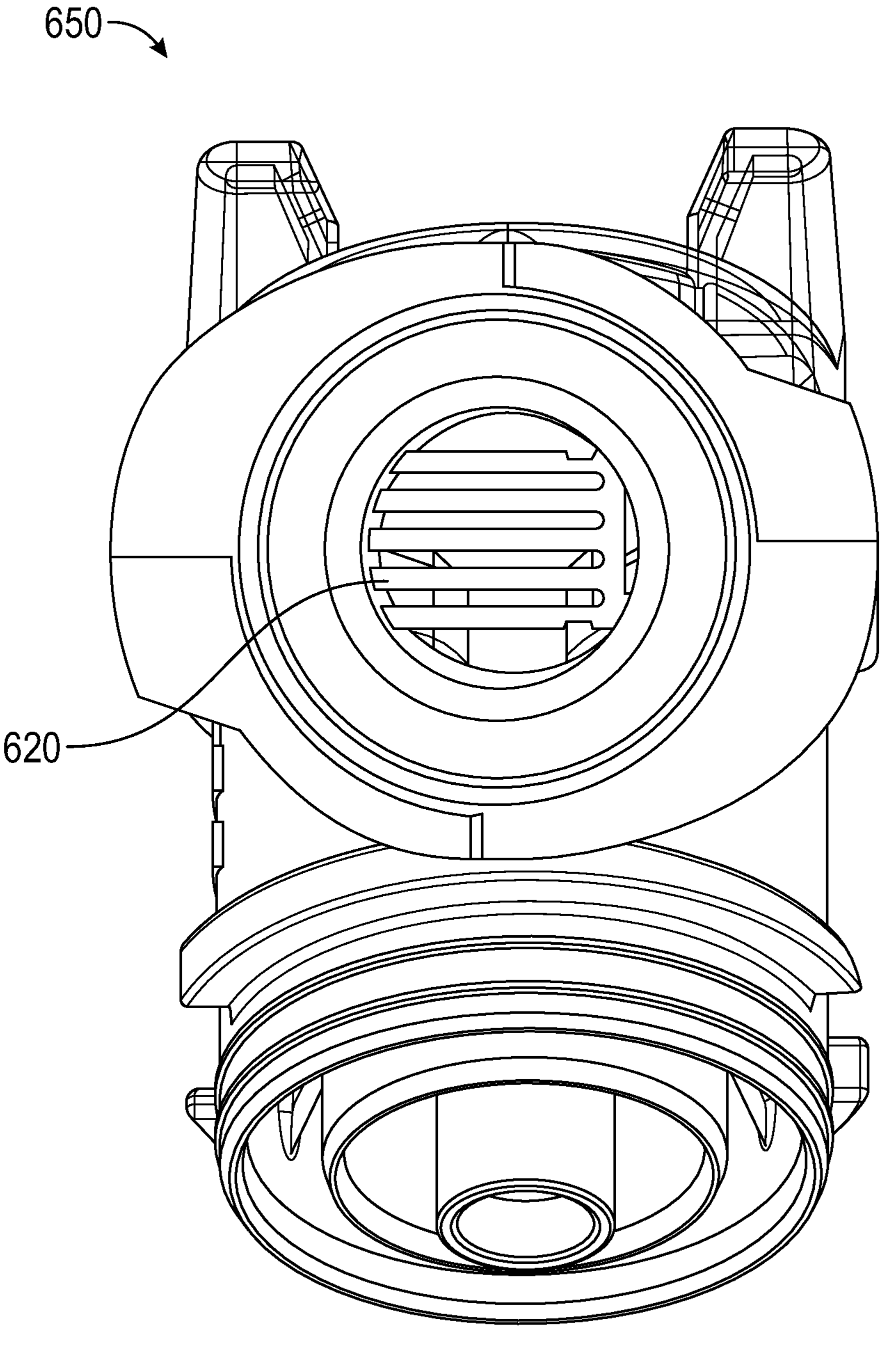


FIG. 6B

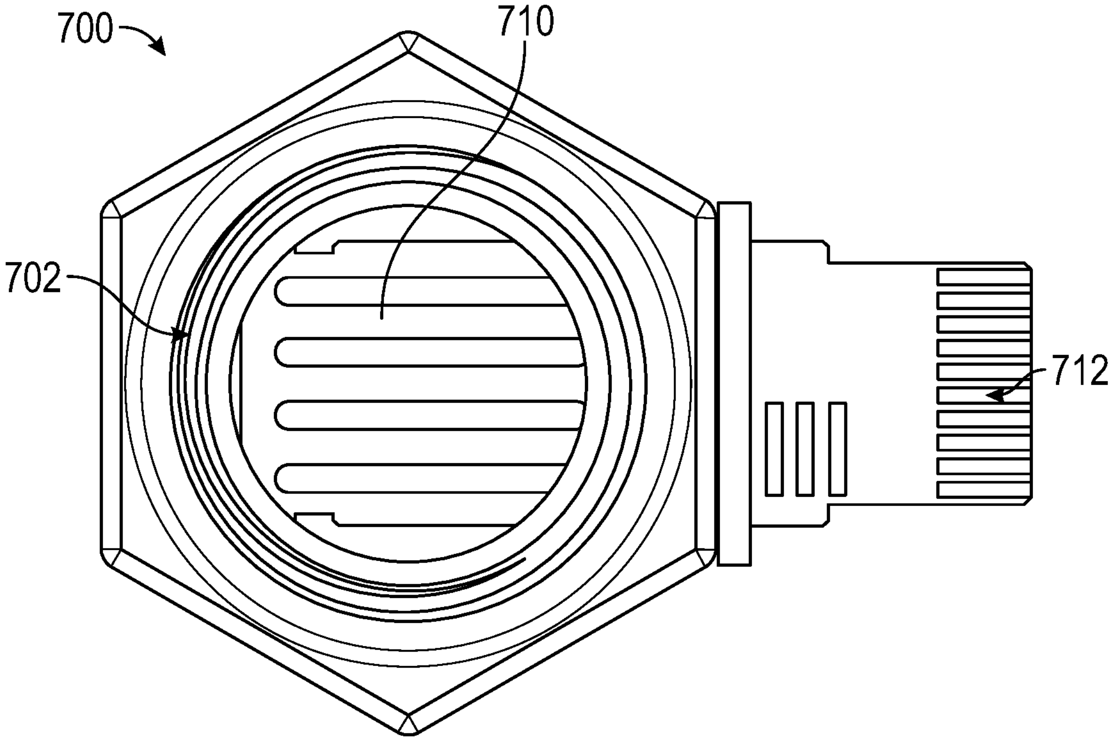


FIG. 7A

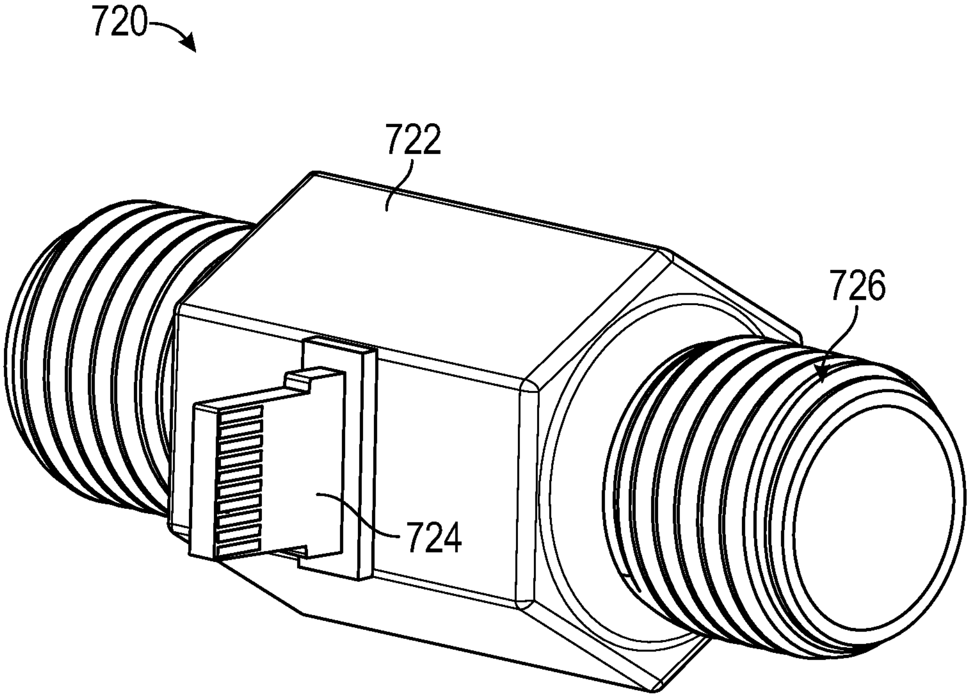


FIG. 7B

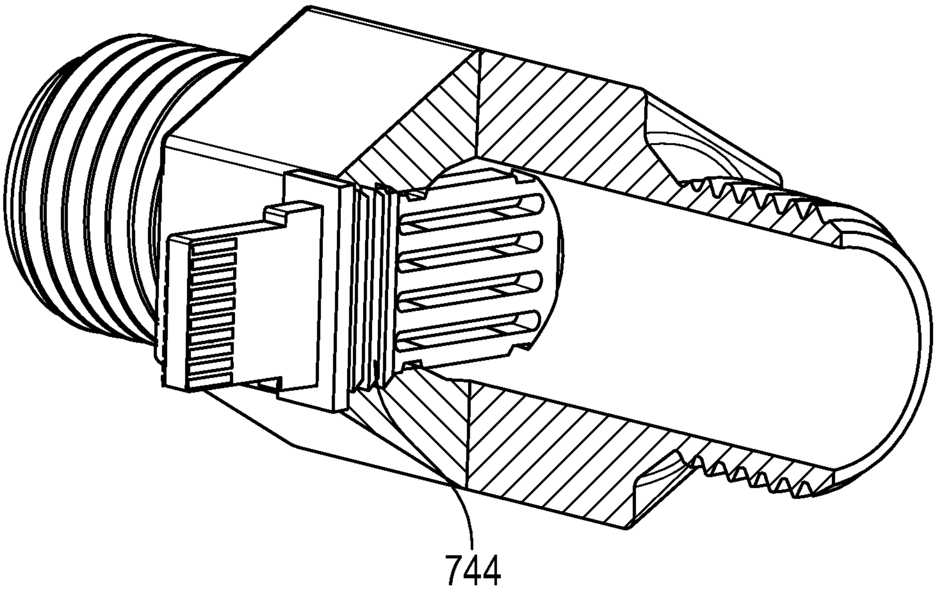


FIG. 7C

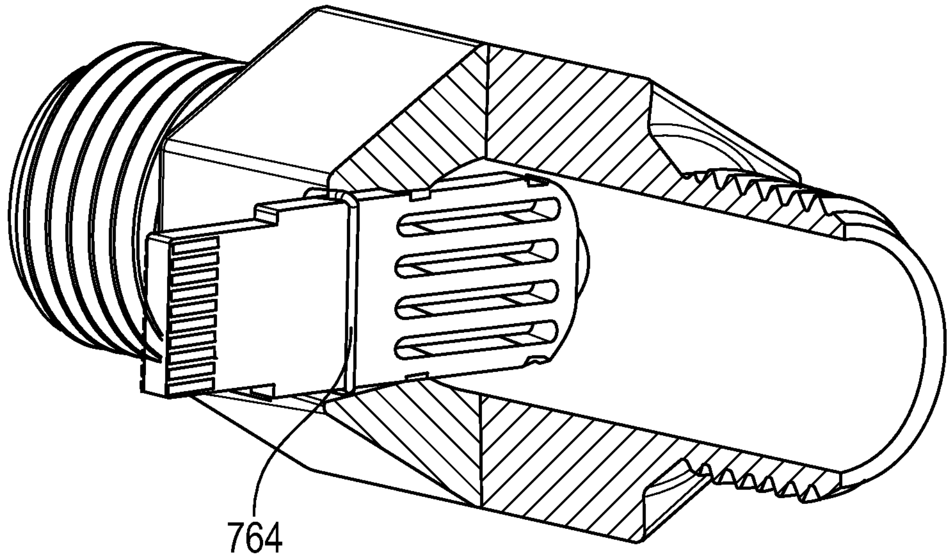
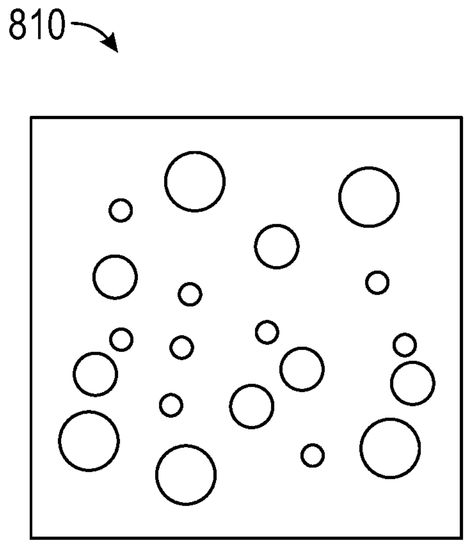
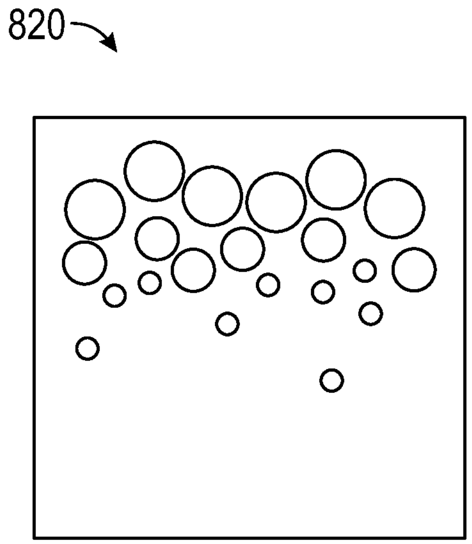


FIG. 7D



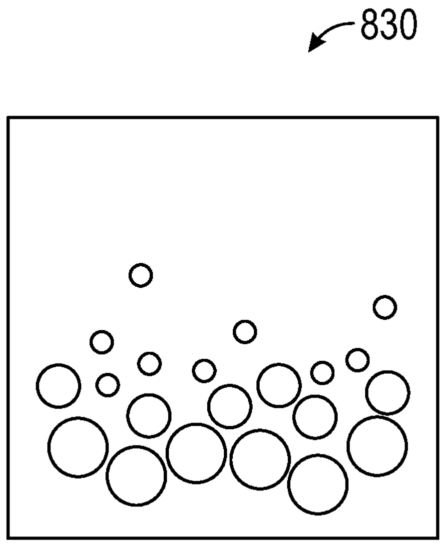
Stable Dispersion

FIG. 8A



Creaming

FIG. 8B



Sedimentation

FIG. 8C

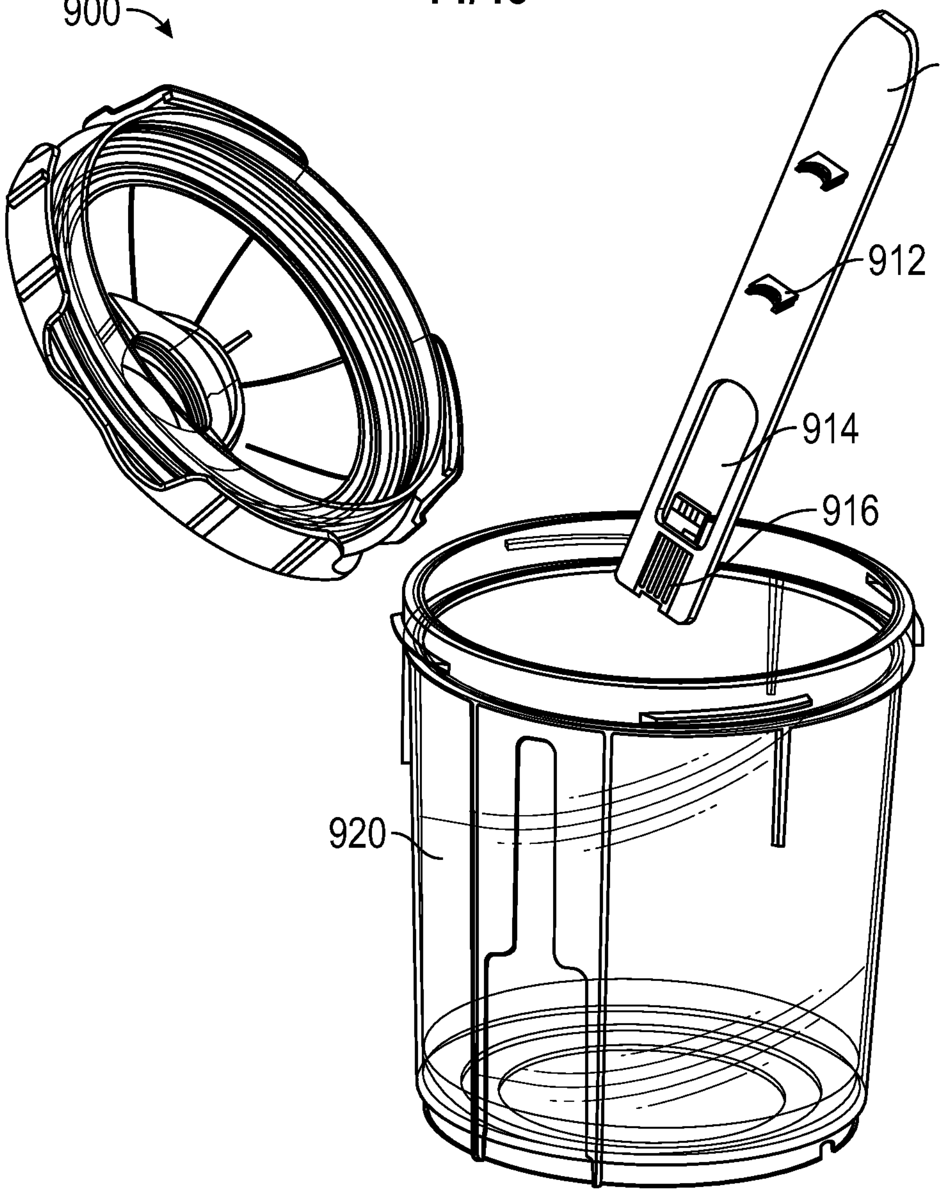


FIG. 9

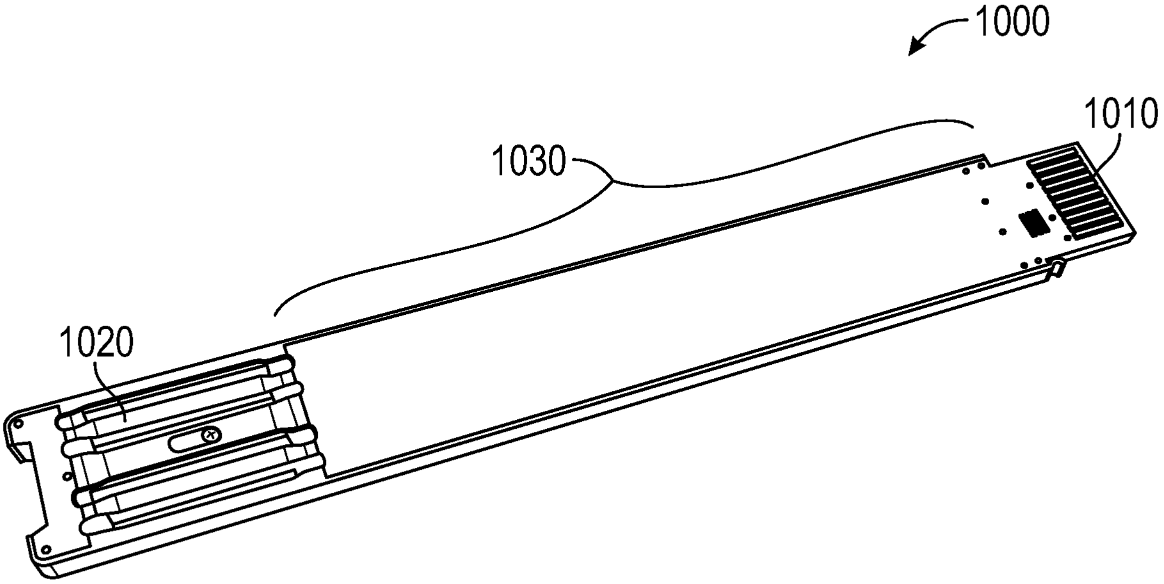


FIG. 10

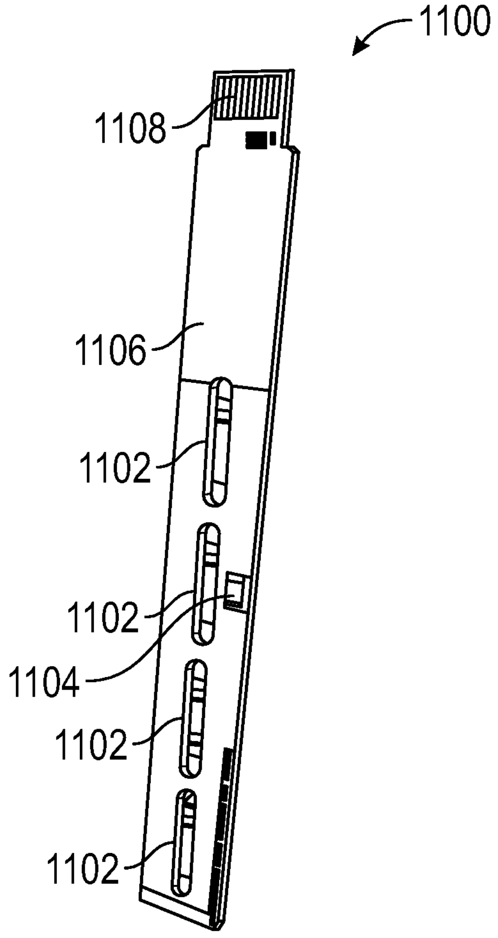


FIG. 11A

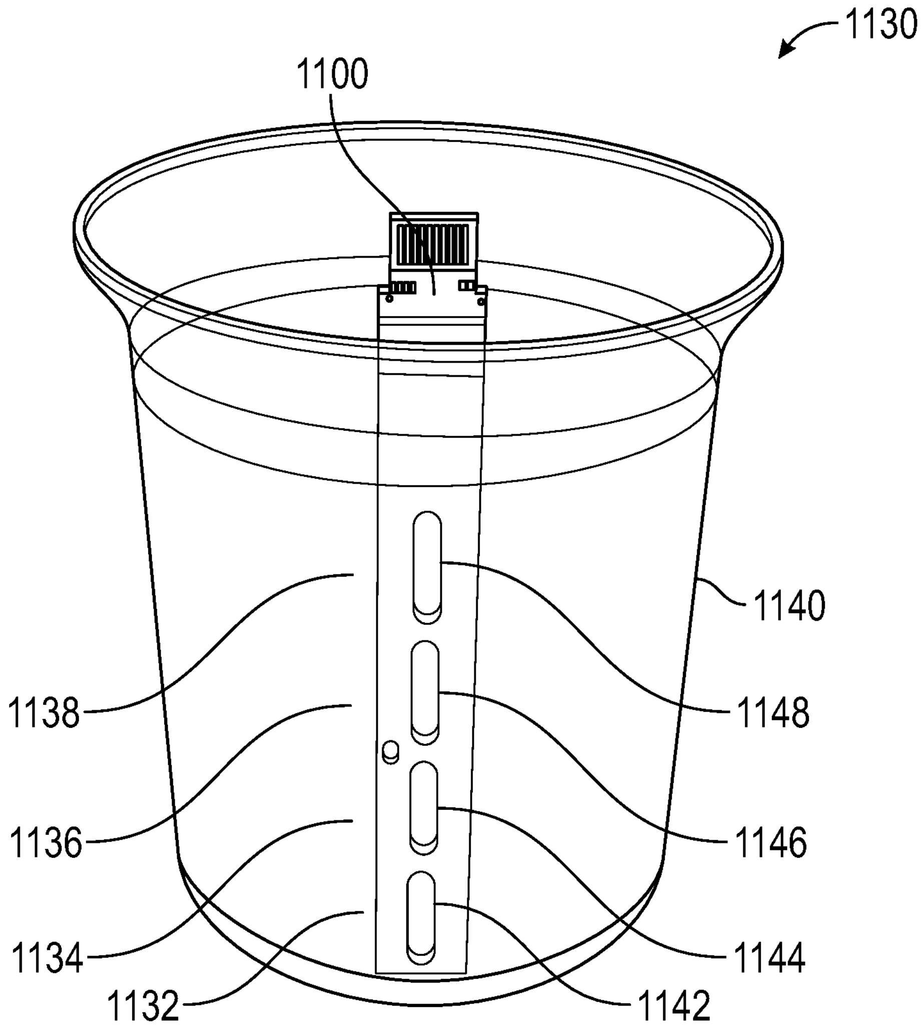


FIG. 11B

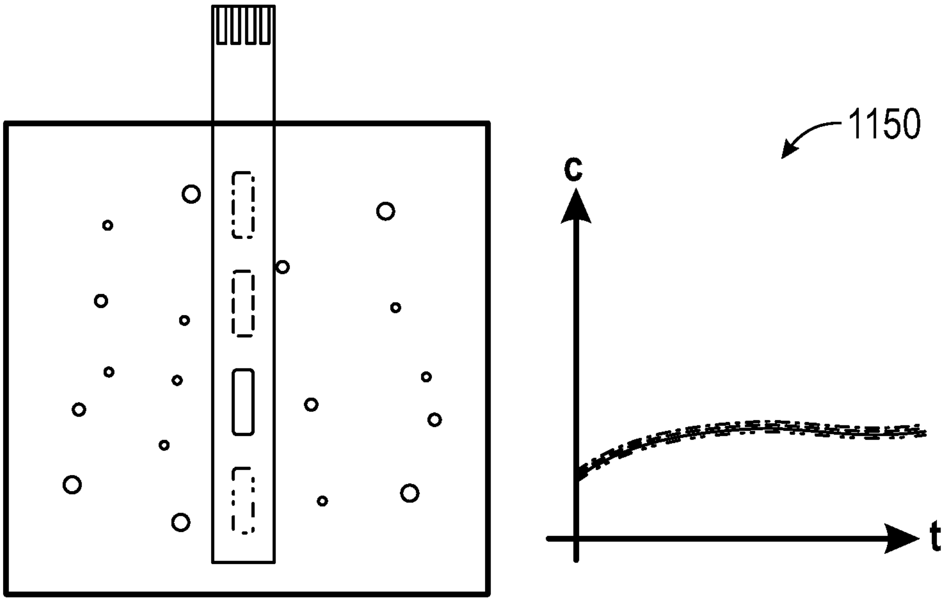


FIG. 11C

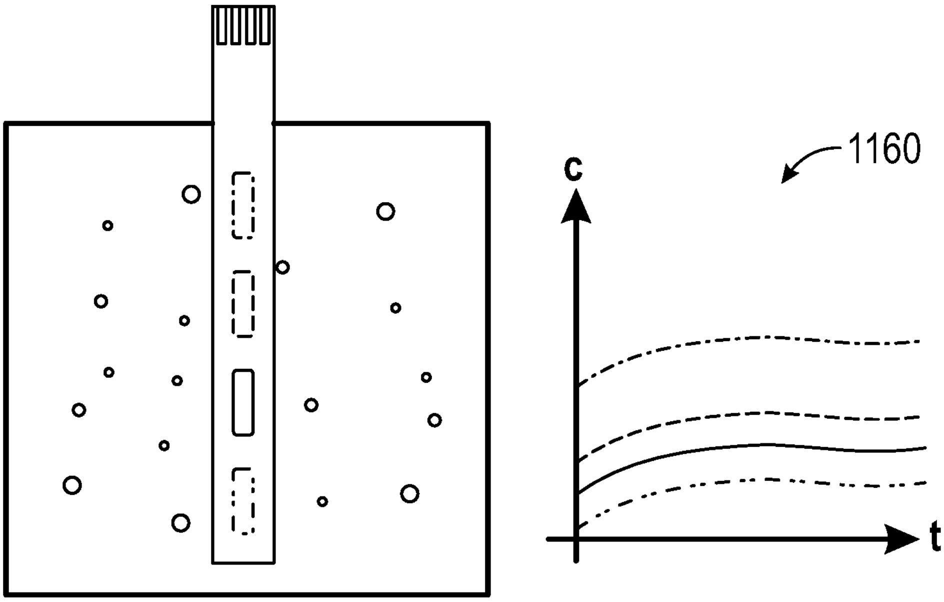


FIG. 11D

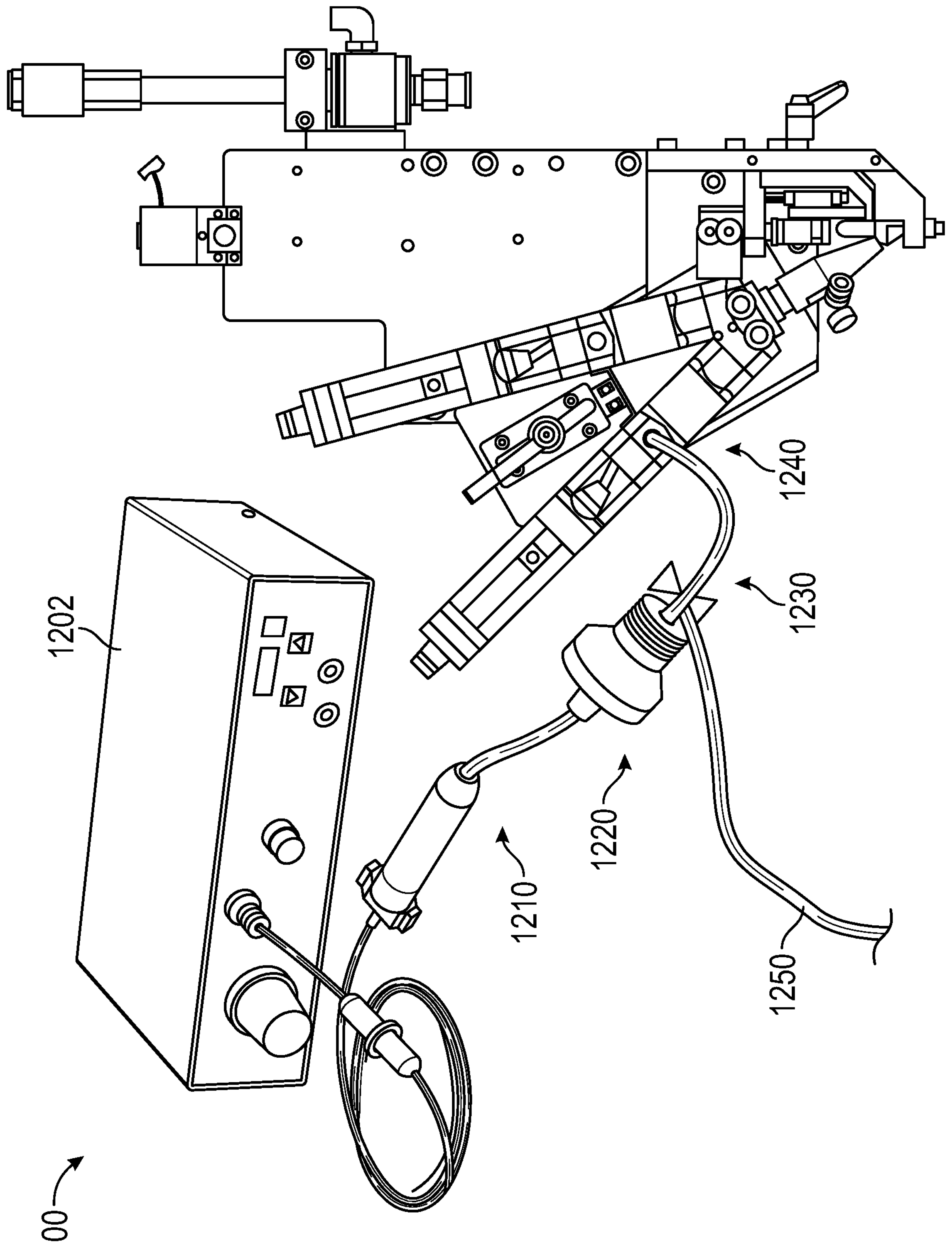


FIG. 12

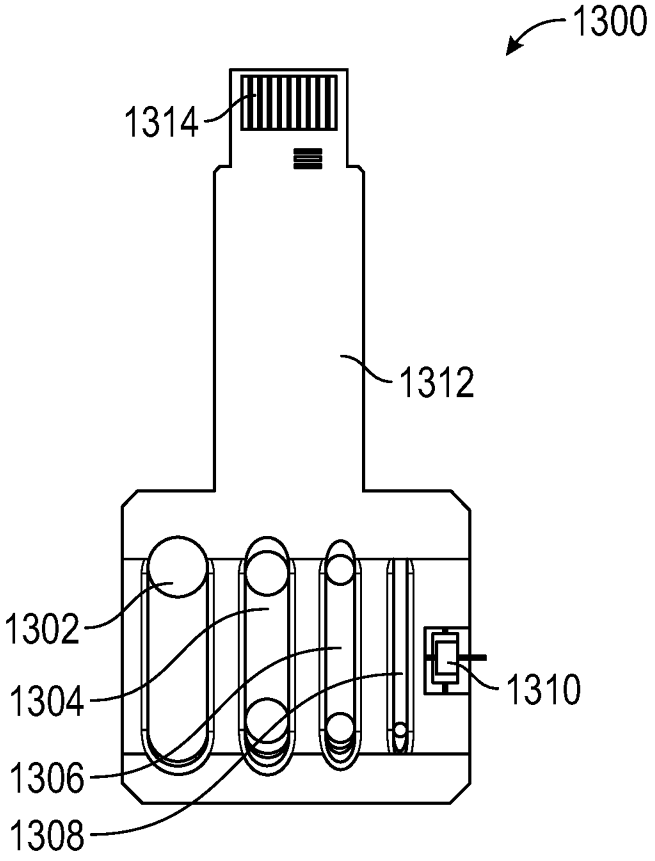


FIG. 13A

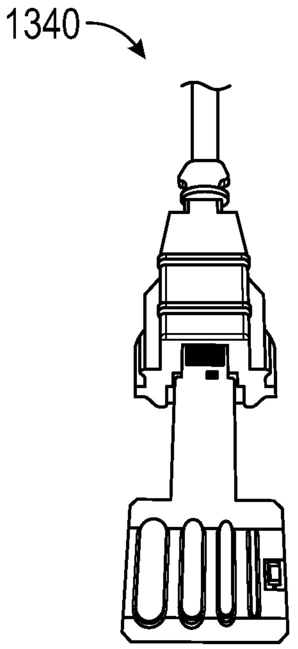


FIG. 13B

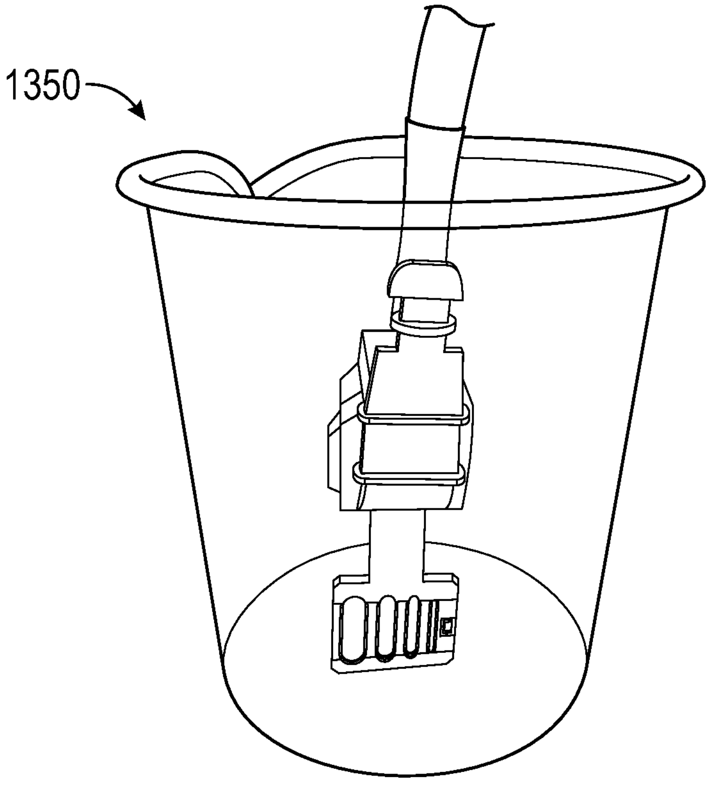


FIG. 13C

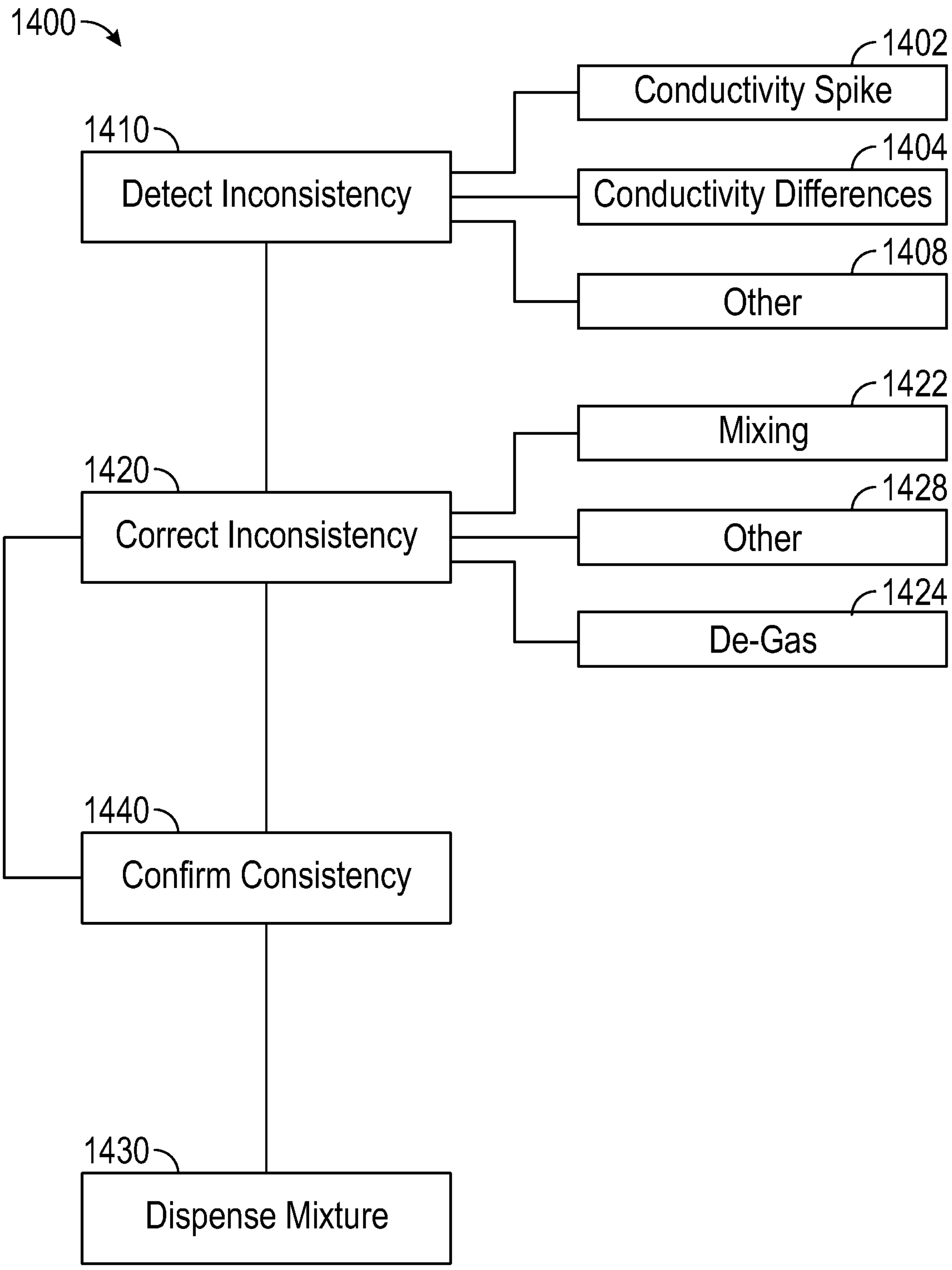

1400
1410
Detect Inconsistency
1402
Conductivity Spike
1404
Conductivity Differences
1408
Other
1422
Mixing
1420
Correct Inconsistency
1428
Other
1424
De-Gas
1440
Confirm Consistency
1430
Dispense Mixture

FIG. 14

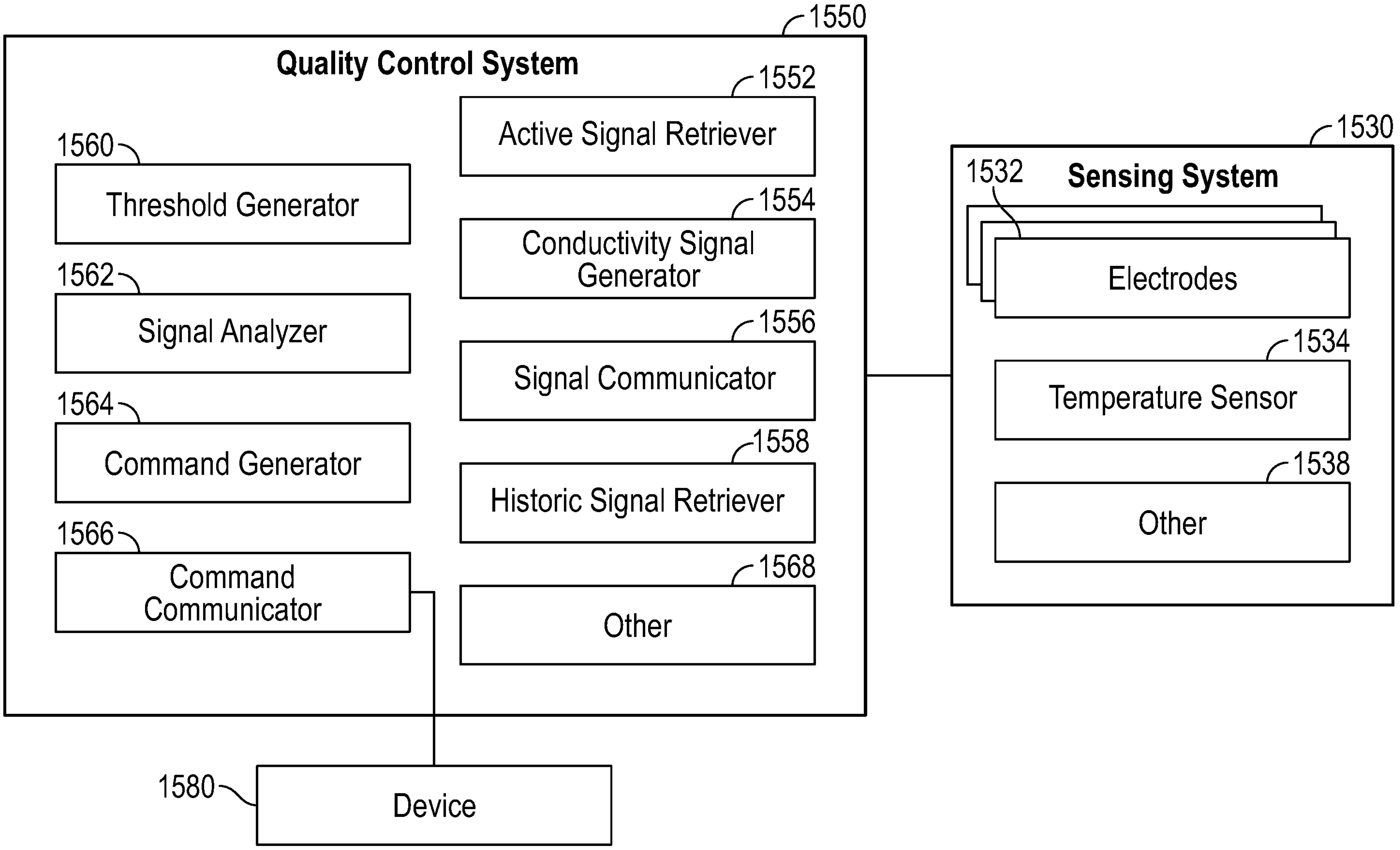

1550
Quality Control System
1552
Active Signal Retriever
1554
Conductivity Signal Generator
1556
Signal Communicator
1558
Historic Signal Retriever
1568
Other
1560
Threshold Generator
1562
Signal Analyzer
1564
Command Generator
1566
Command Communicator
1580
Device
1530
Sensing System
1532
Electrodes
1534
Temperature Sensor
1538
Other

FIG. 15

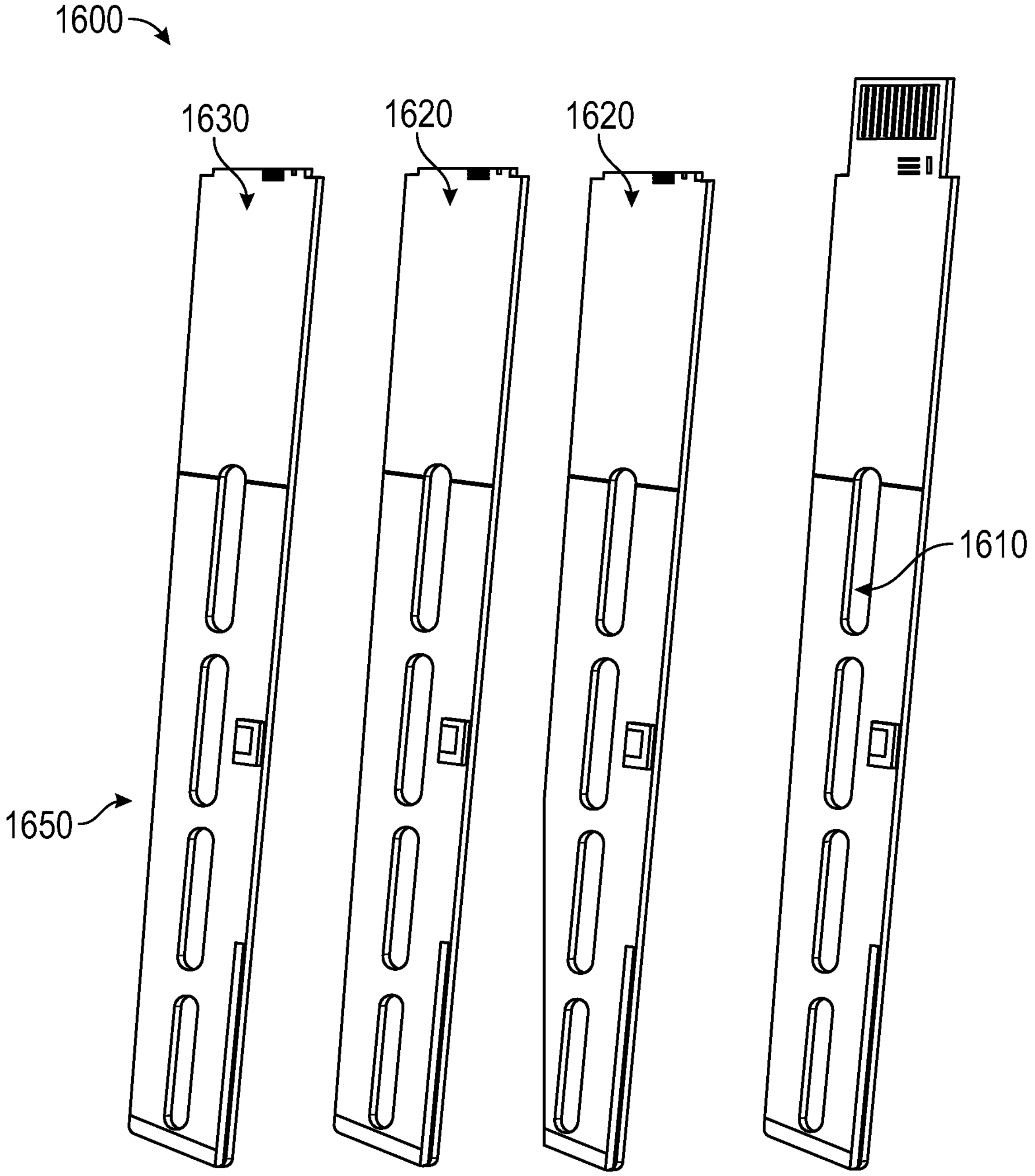


FIG. 16A

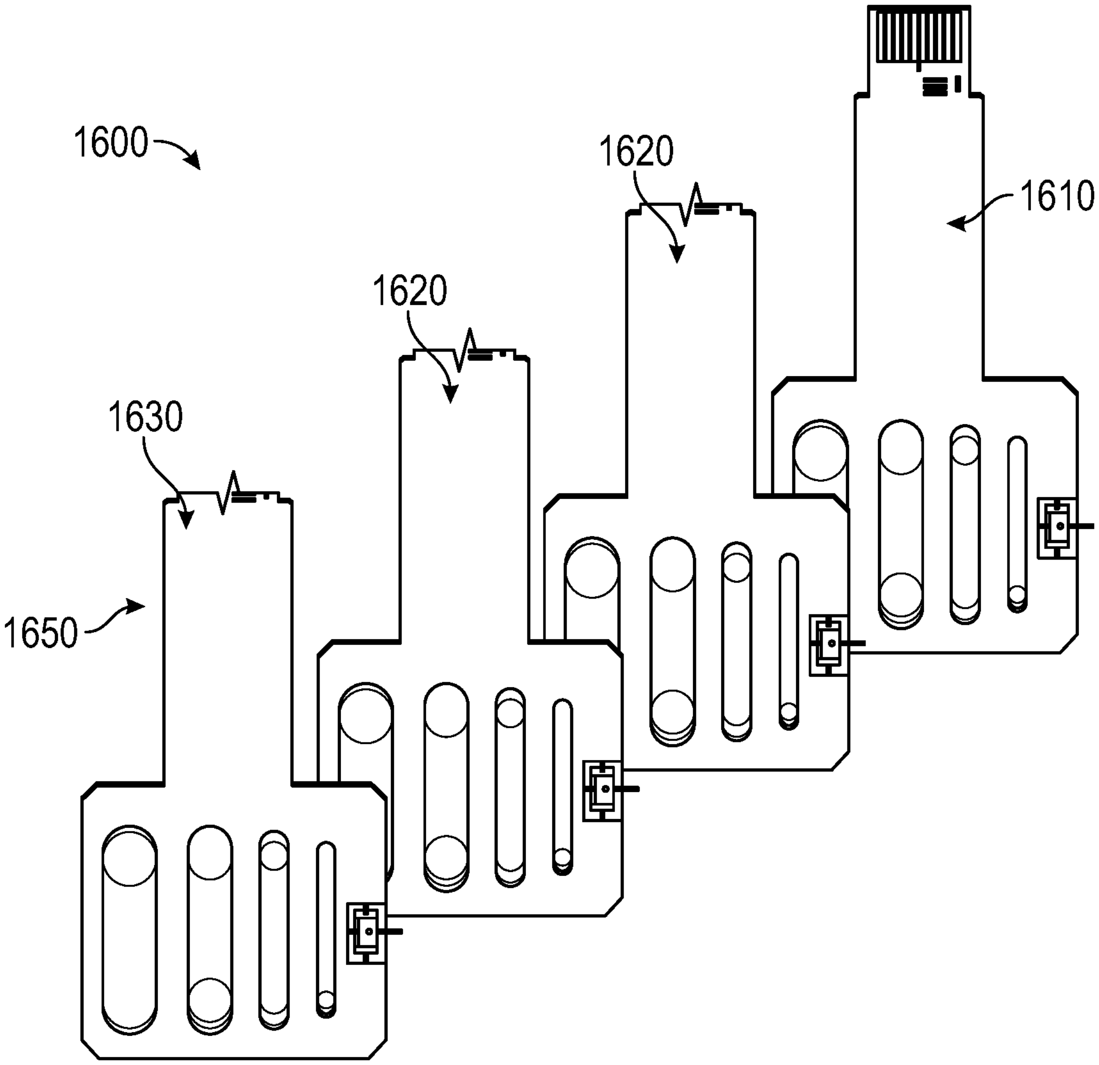


FIG. 16B

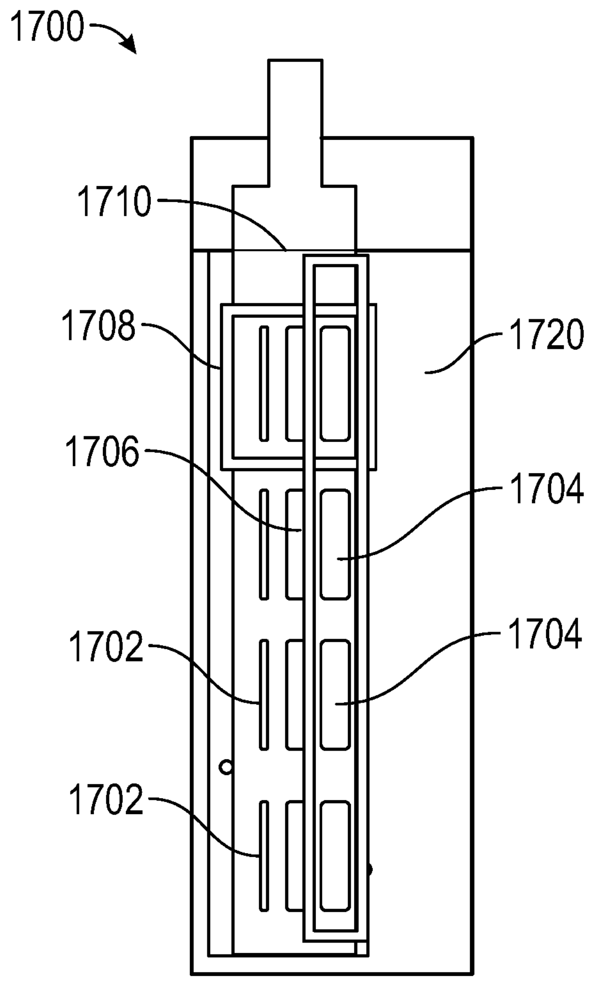


FIG. 17A

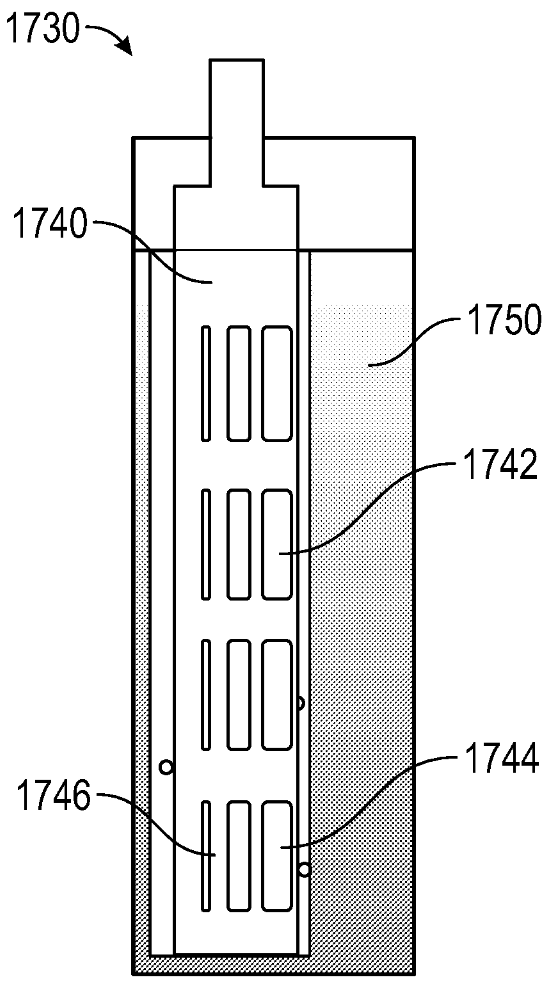


FIG. 17B

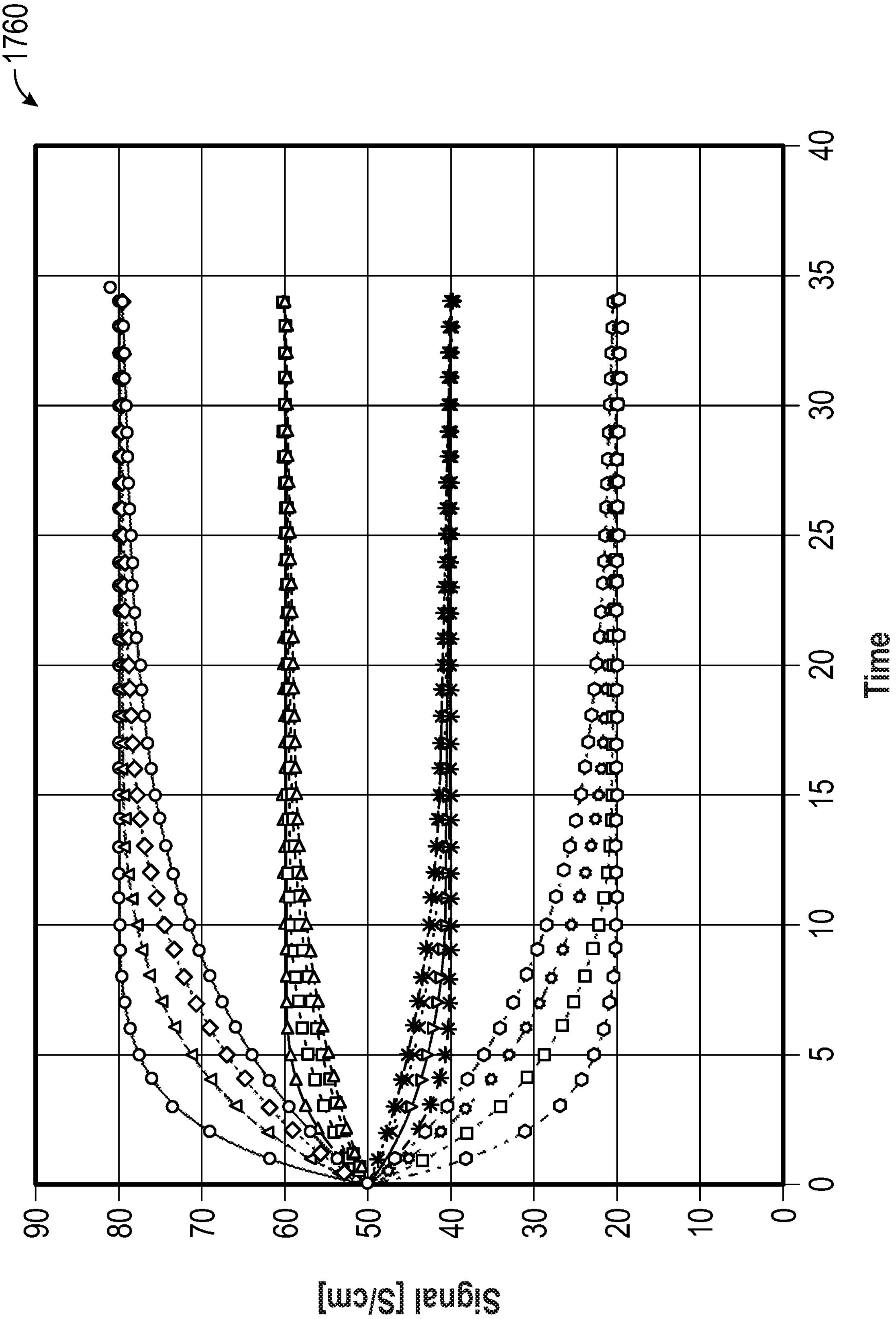

1760
Signal [S/cm]
90
80
70
60
50
40
30
20
10
0
Time
0
5
10
15
20
25
30
35
40

FIG. 17C

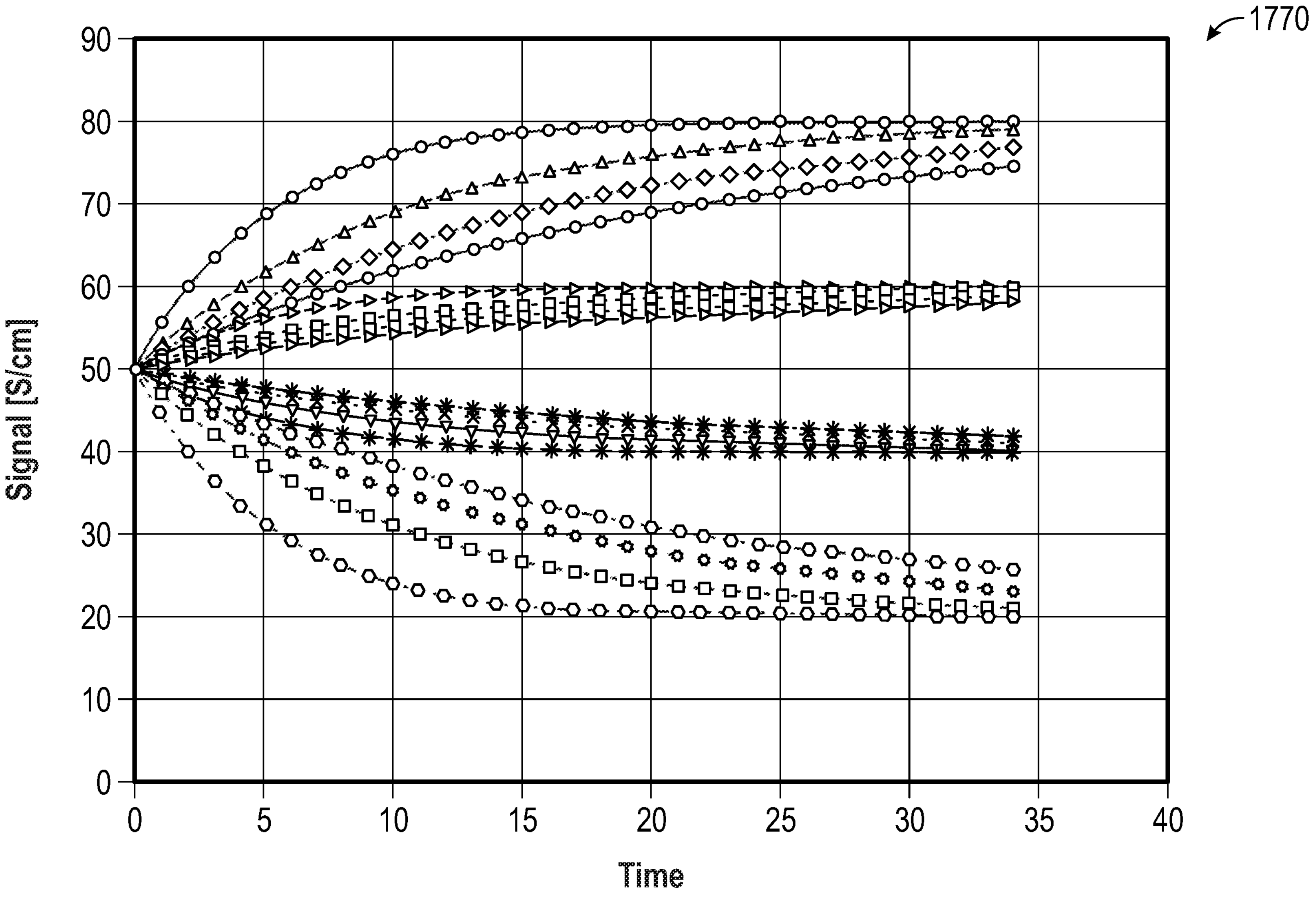

1770
Signal [S/cm]
90
80
70
60
50
40
30
20
10
0
Time
0
5
10
15
20
25
30
35
40

FIG. 17D

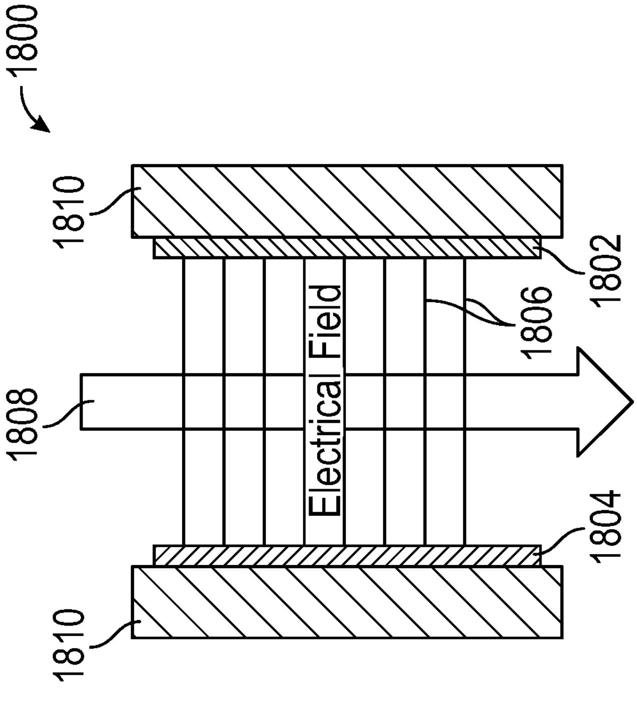


FIG. 18A

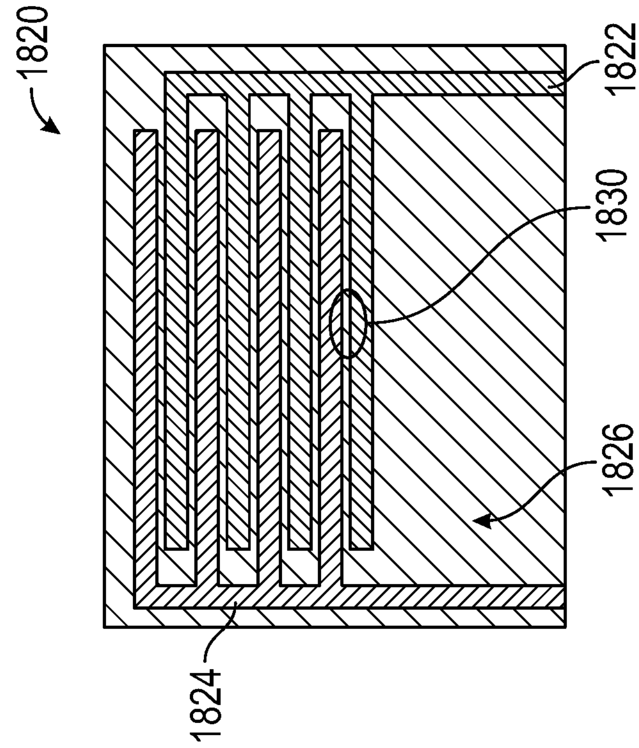


FIG. 18B

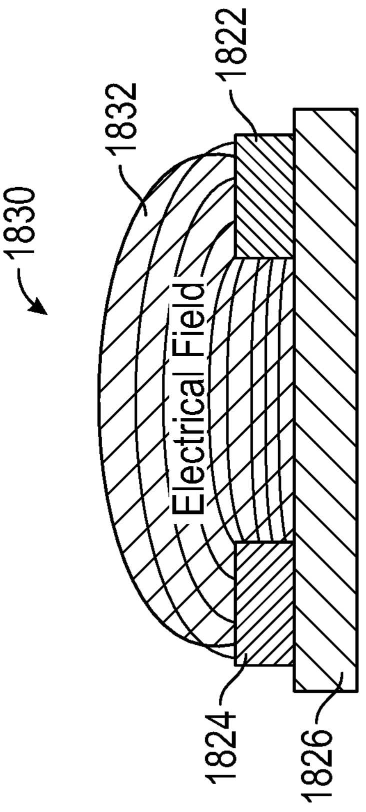


FIG. 18C

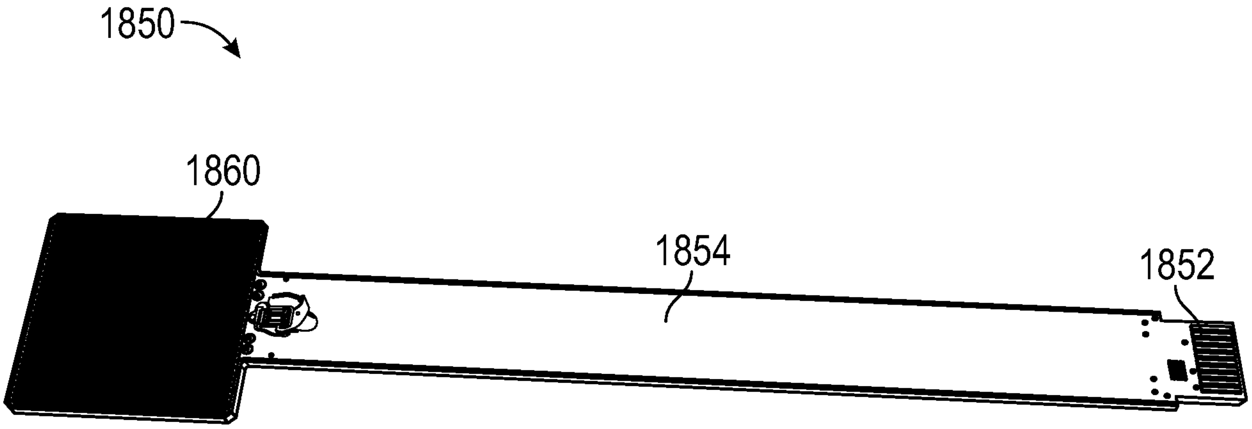


FIG. 18D

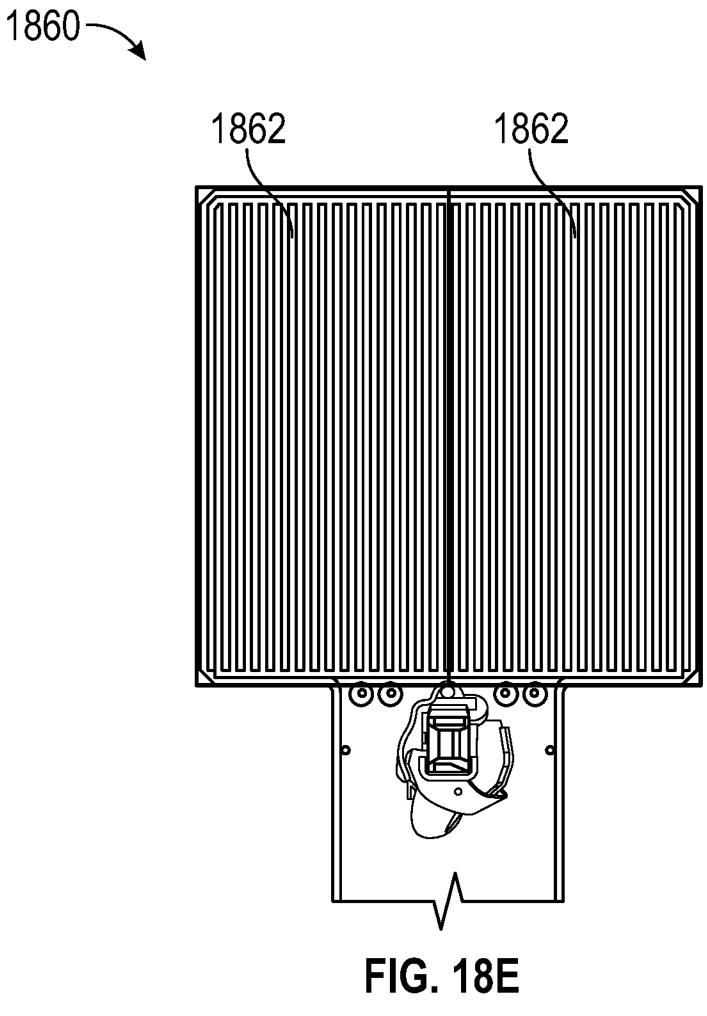


FIG. 18E

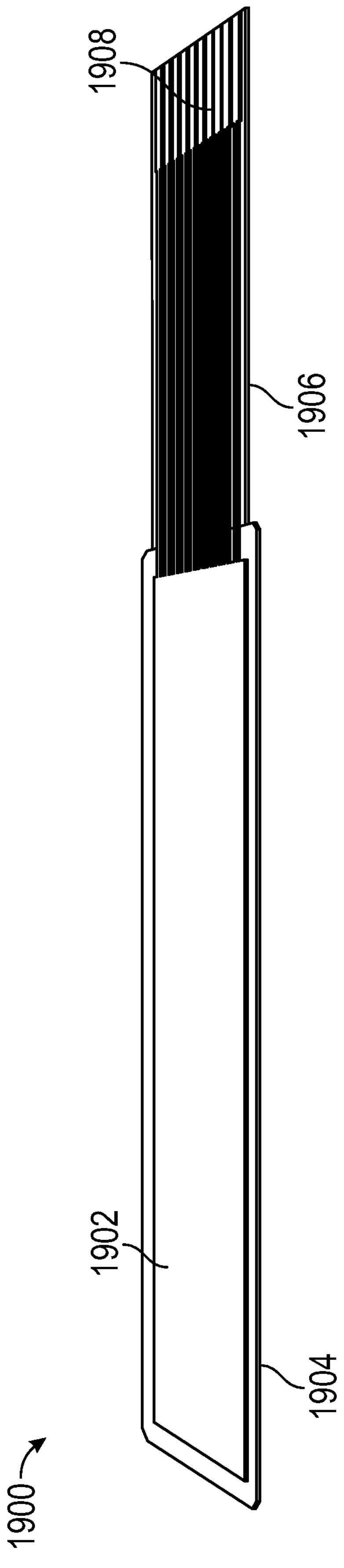


FIG. 19A

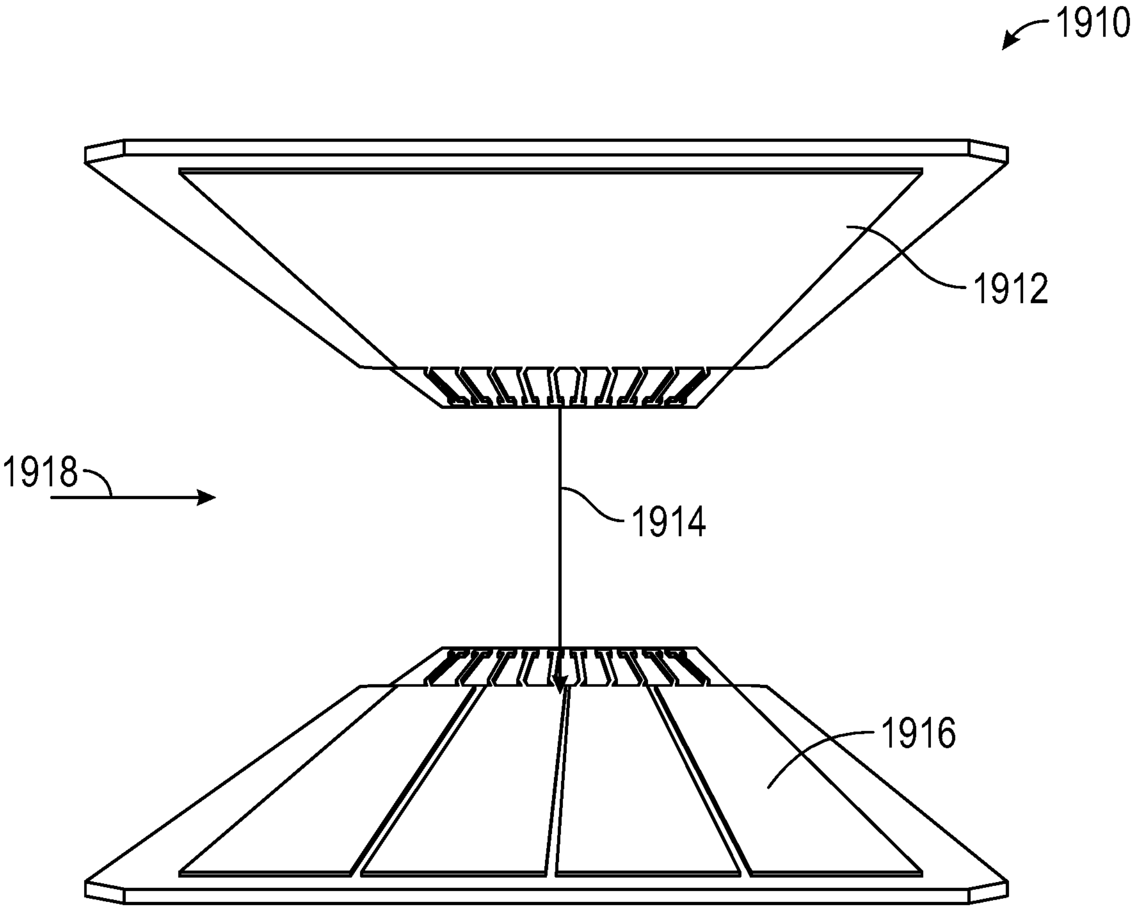


FIG. 19B

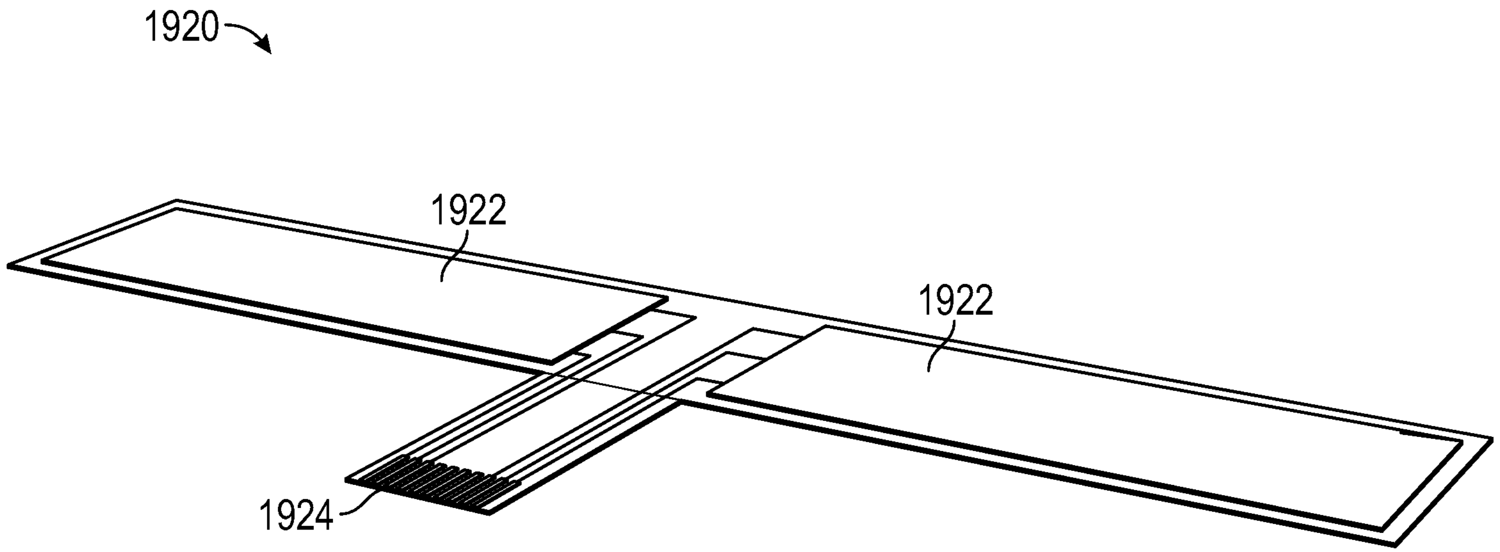


FIG. 19C

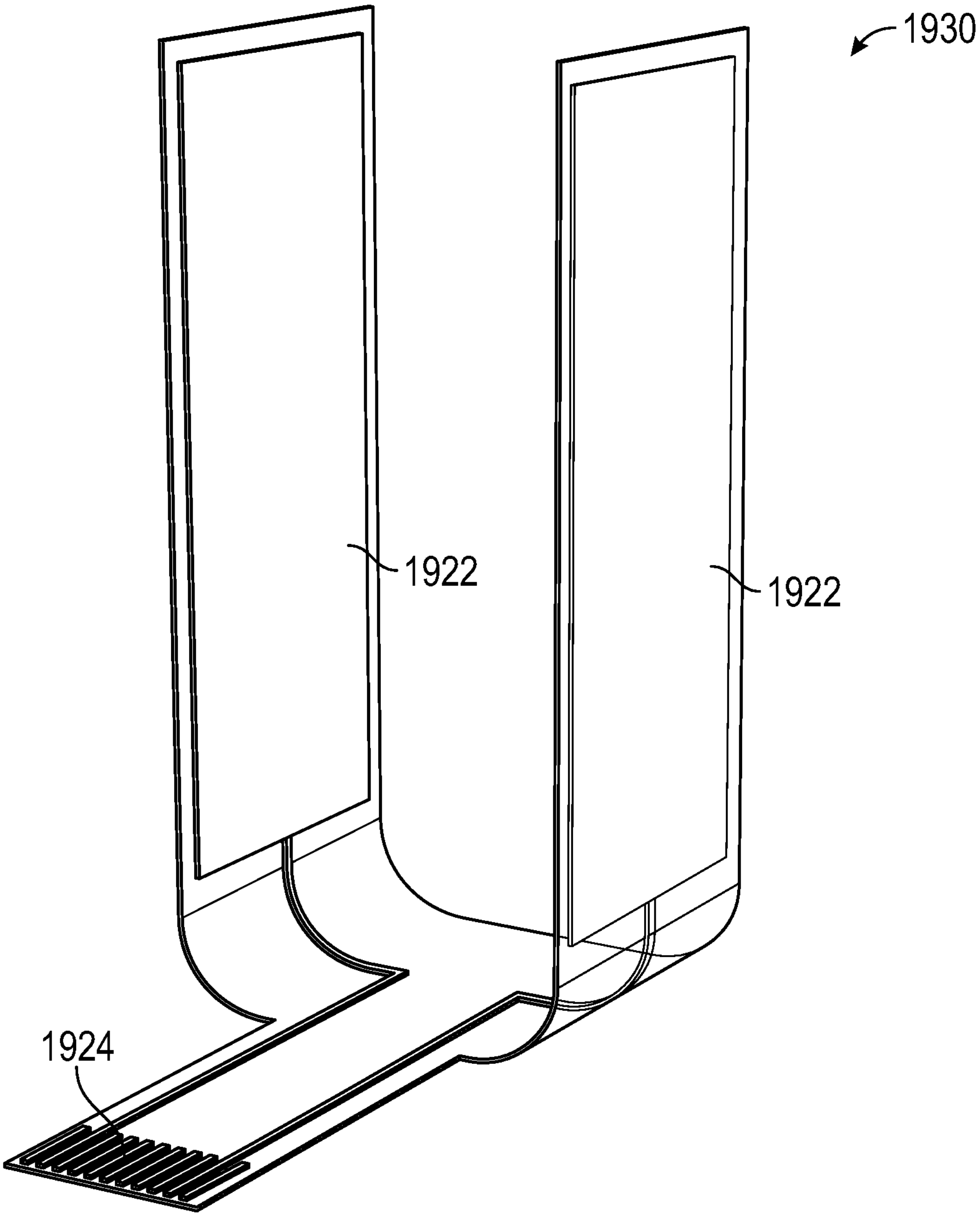


FIG. 19D

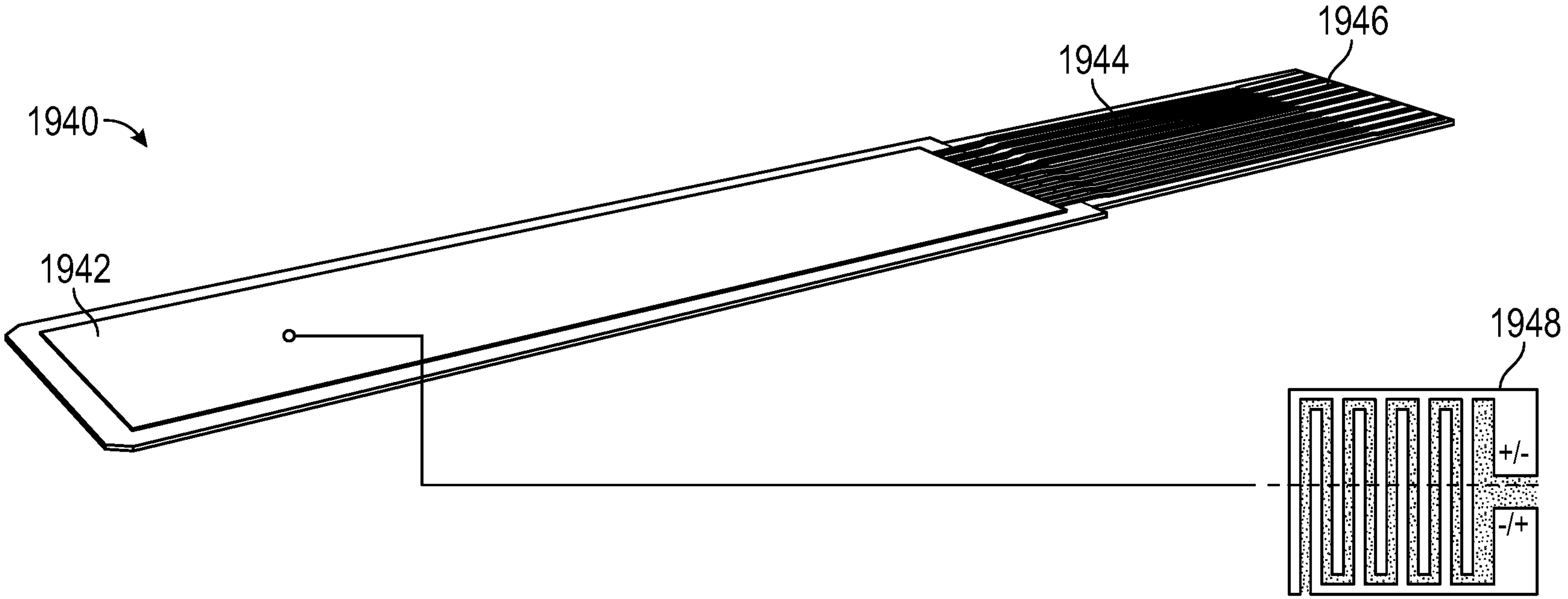


FIG. 19E

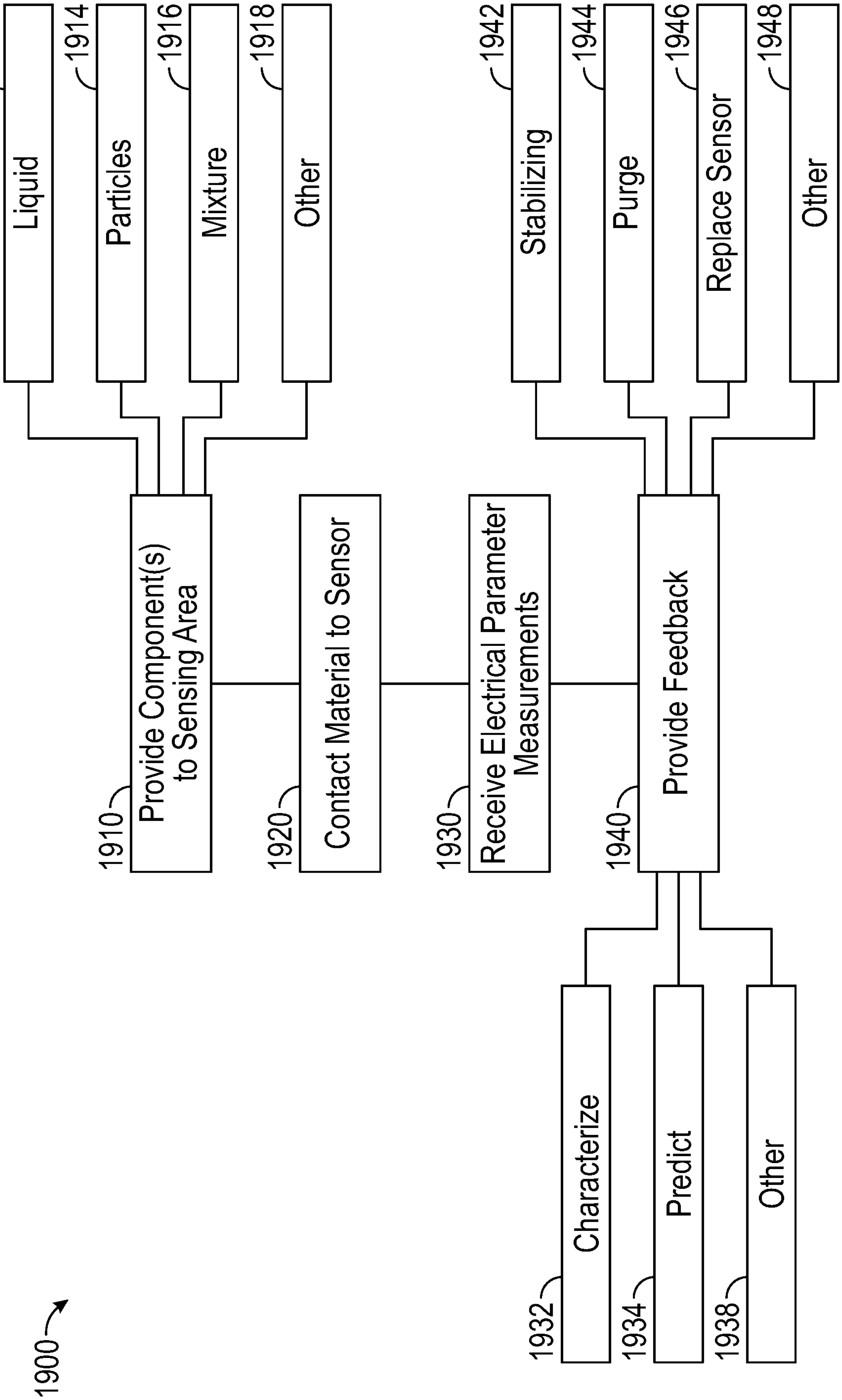

1900
1910
Provide Component(s) to Sensing Area
1912
Liquid
1914
Particles
1916
Mixture
1918
Other
1920
Contact Material to Sensor
1930
Receive Electrical Parameter Measurements
1940
Provide Feedback
1932
Characterize
1934
Predict
1938
Other
1942
Stabilizing
1944
Purge
1946
Replace Sensor
1948
Other

FIG. 20

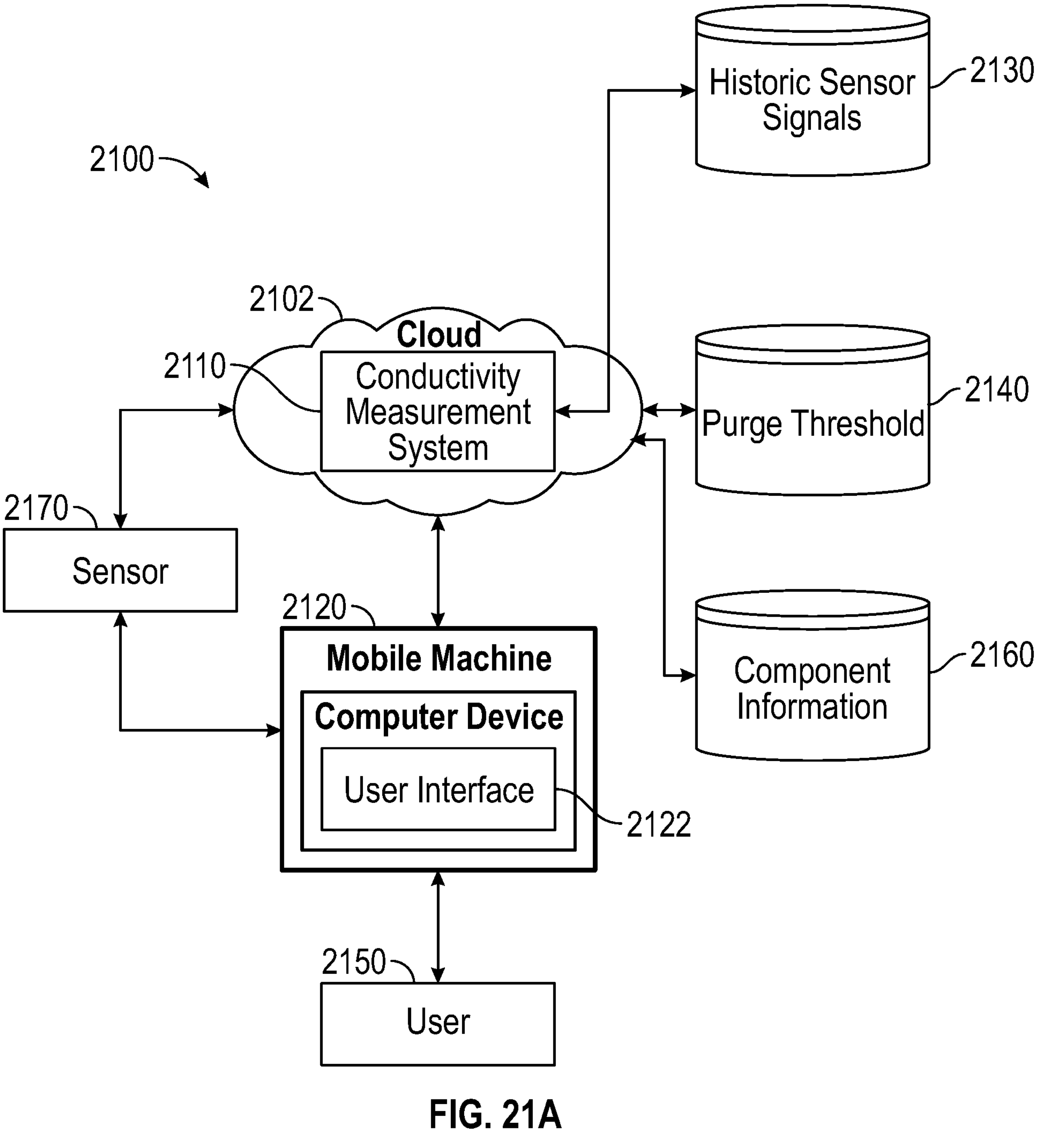

2100
2102
Cloud
2110
Conductivity Measurement System
Historic Sensor Signals
2130
Purge Threshold
2140
Component Information
2160
2170
Sensor
2120
Mobile Machine
Computer Device
User Interface
2122
2150
User

FIG. 21A

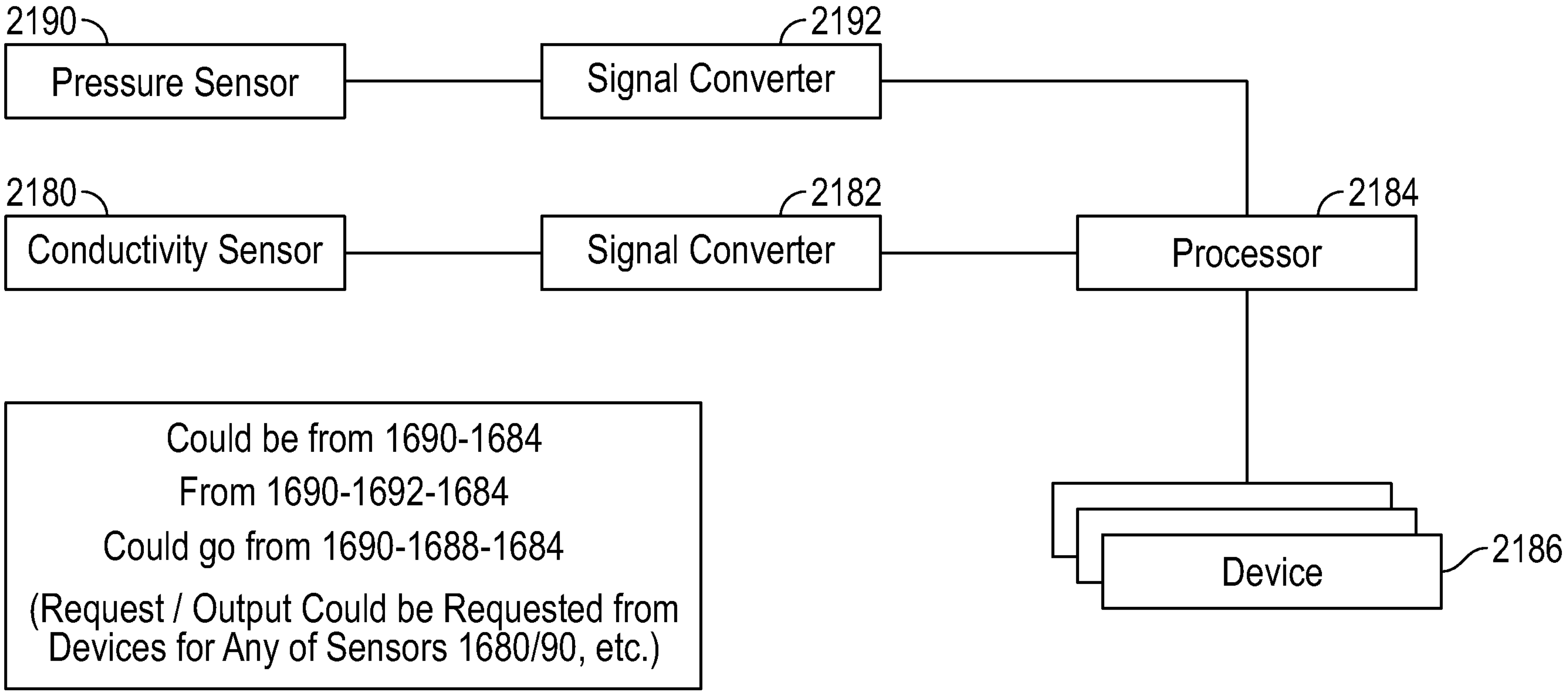

2190
Pressure Sensor
2192
Signal Converter
2180
Conductivity Sensor
2182
Signal Converter
2184
Processor
Device
2186
Could be from 1690-1684
From 1690-1692-1684
Could go from 1690-1688-1684
(Request / Output Could be Requested from Devices for Any of Sensors 1680/90, etc.)

FIG. 21B

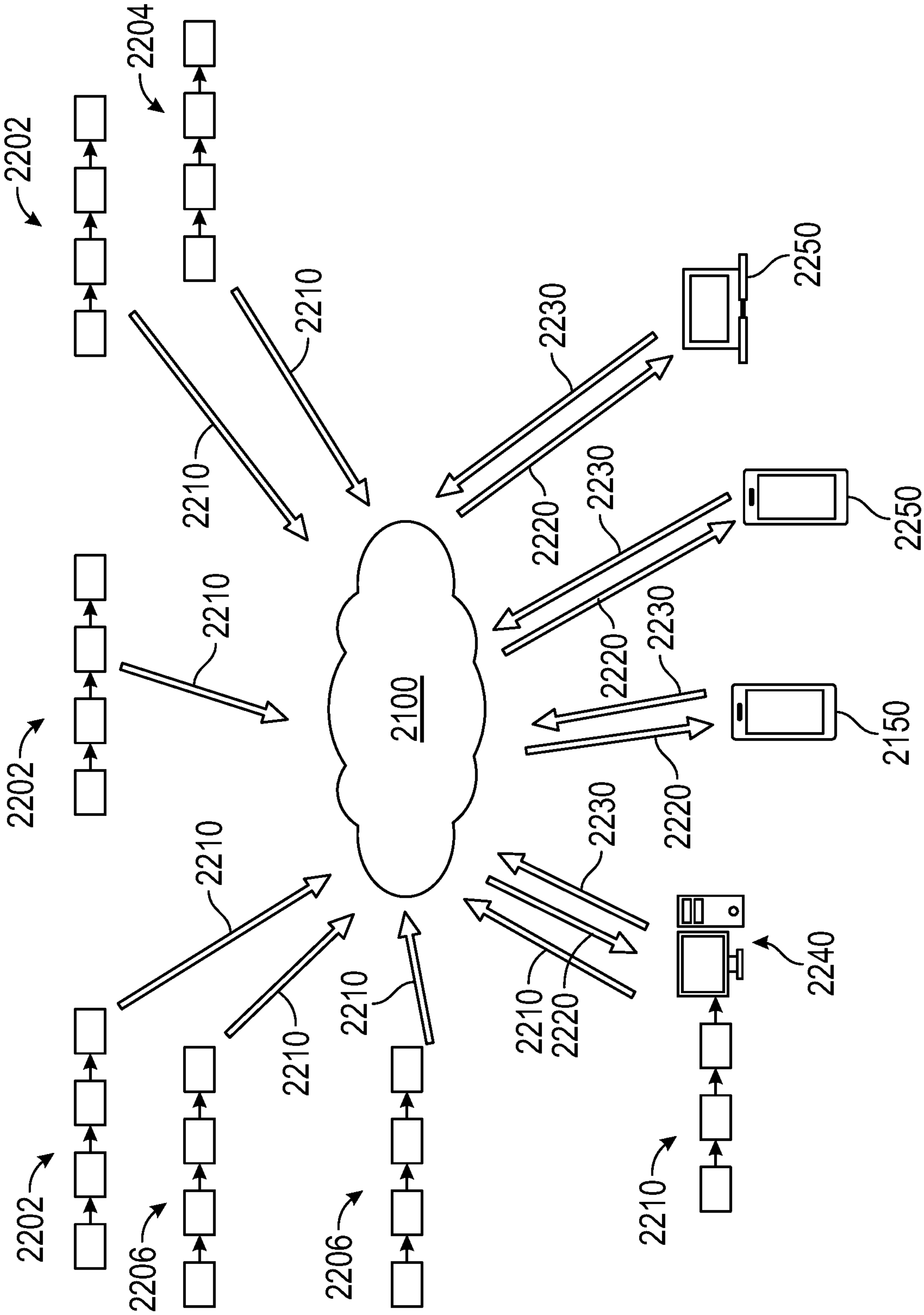

2204
2202
2210
2210
2230
2250
2210
2220
2230
2250
2202
2210
2100
2220
2230
2150
2220
2230
2210
2210
2220
2240
2202
2210
2210
2206
2206
2210

FIG. 21C

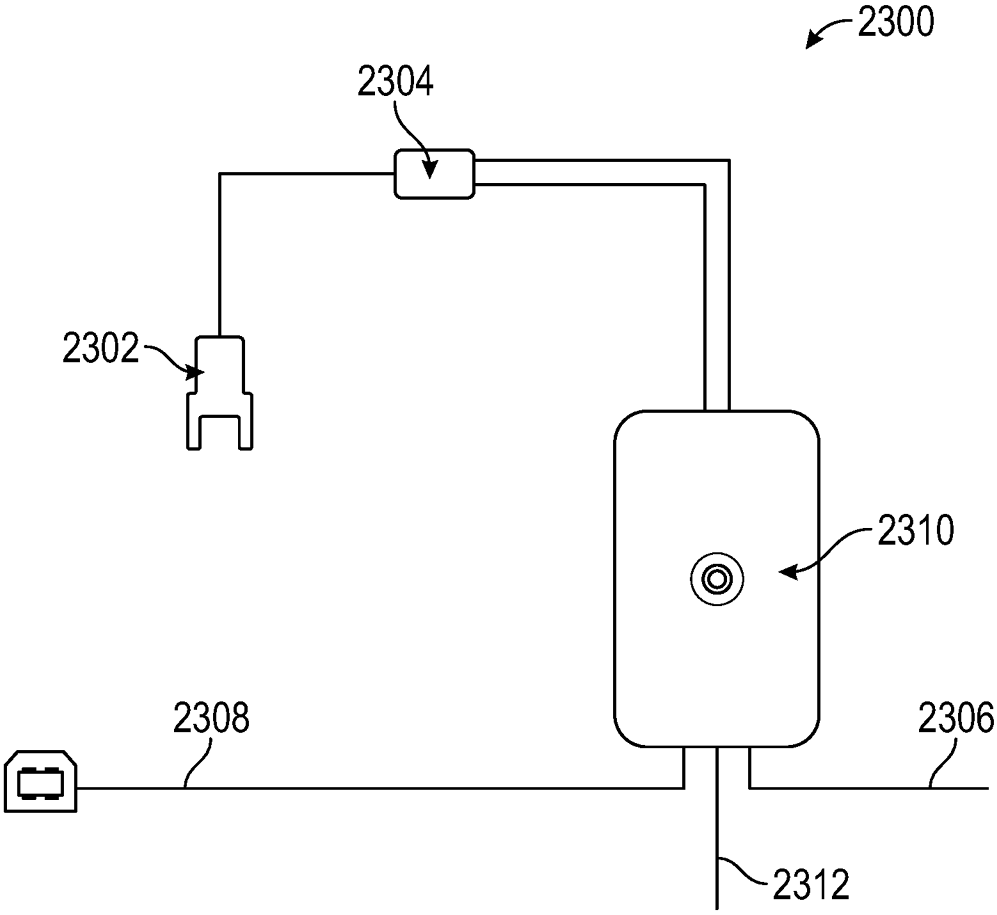


FIG. 22A

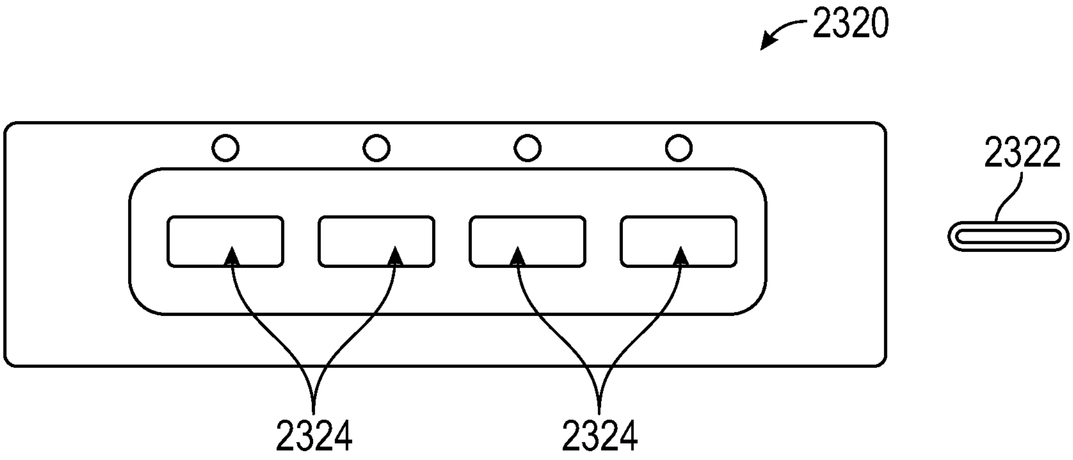


FIG. 22B

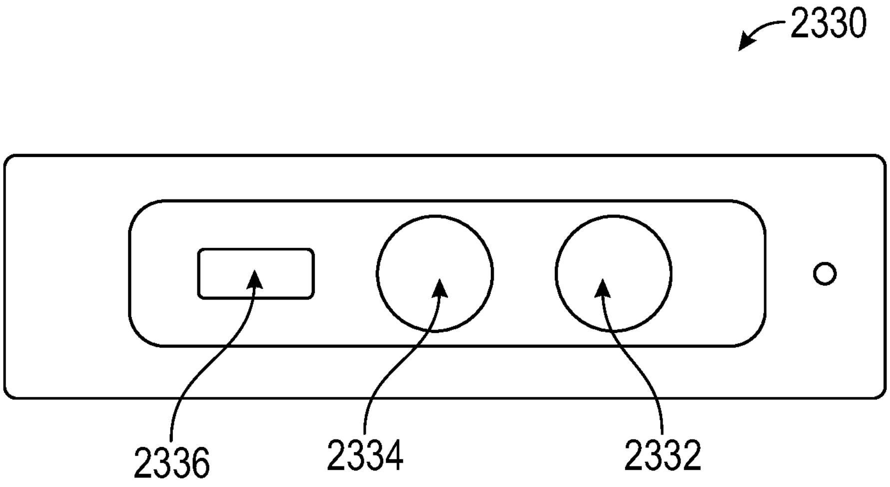


FIG. 22C

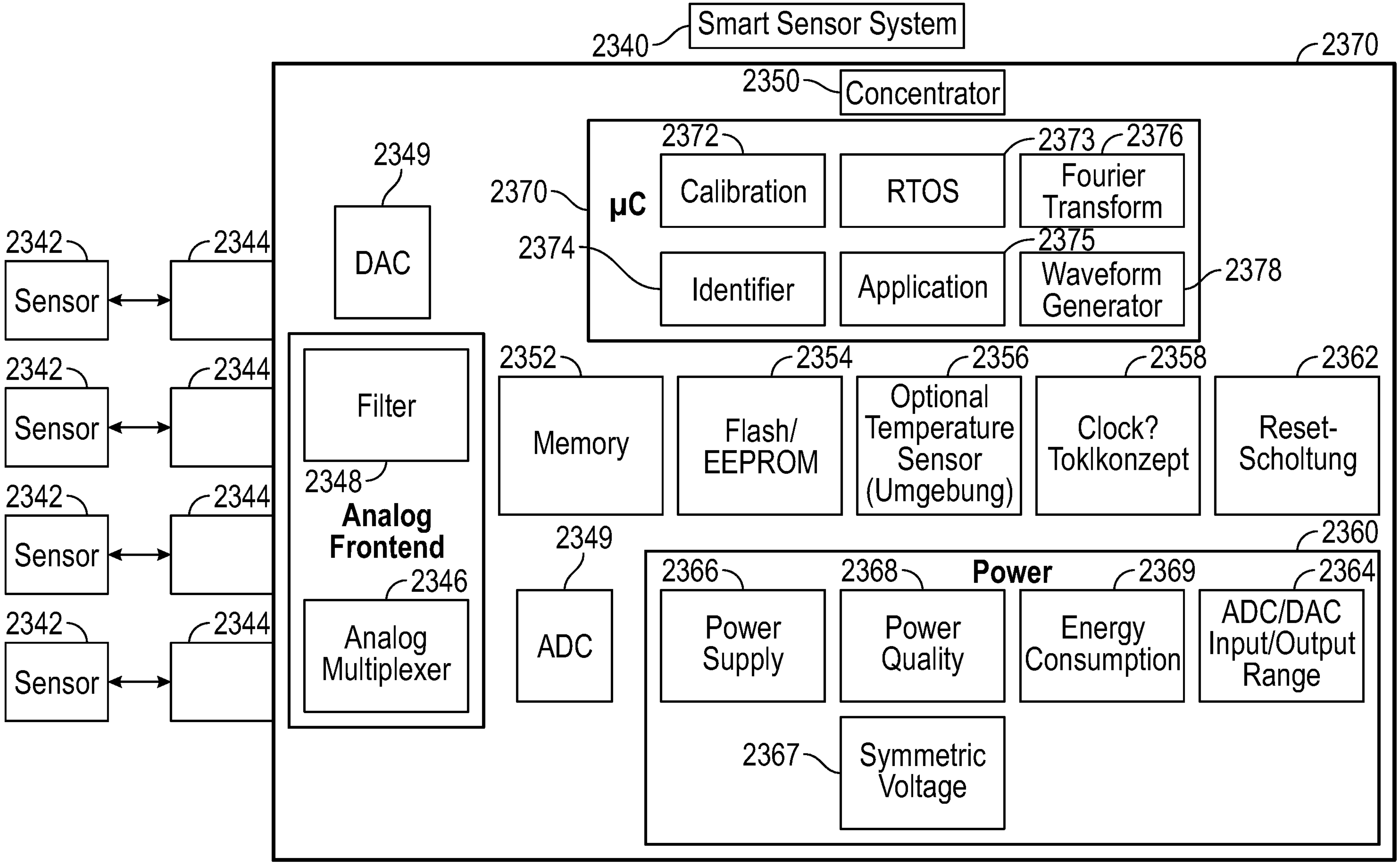

2340
Smart Sensor System
2370
2350
Concentrator
2349
DAC
2370
µC
2372
Calibration
RTOS
2373
2376
Fourier Transform
2374
Identifier
Application
2375
Waveform Generator
2378
2342
Sensor
2344
2342
Sensor
2344
2342
Sensor
2344
2342
Sensor
2344
Filter
2348
Analog Frontend
2346
Analog Multiplexer
2352
Memory
2354
Flash/ EEPROM
2356
Optional Temperature Sensor (Umgebung)
2358
Clock? Toklkonzept
2362
Reset- Scholtung
2349
ADC
2360
Power
2366
Power Supply
2368
Power Quality
2369
Energy Consumption
2364
ADC/DAC Input/Output Range
2367
Symmetric Voltage

FIG. 22D

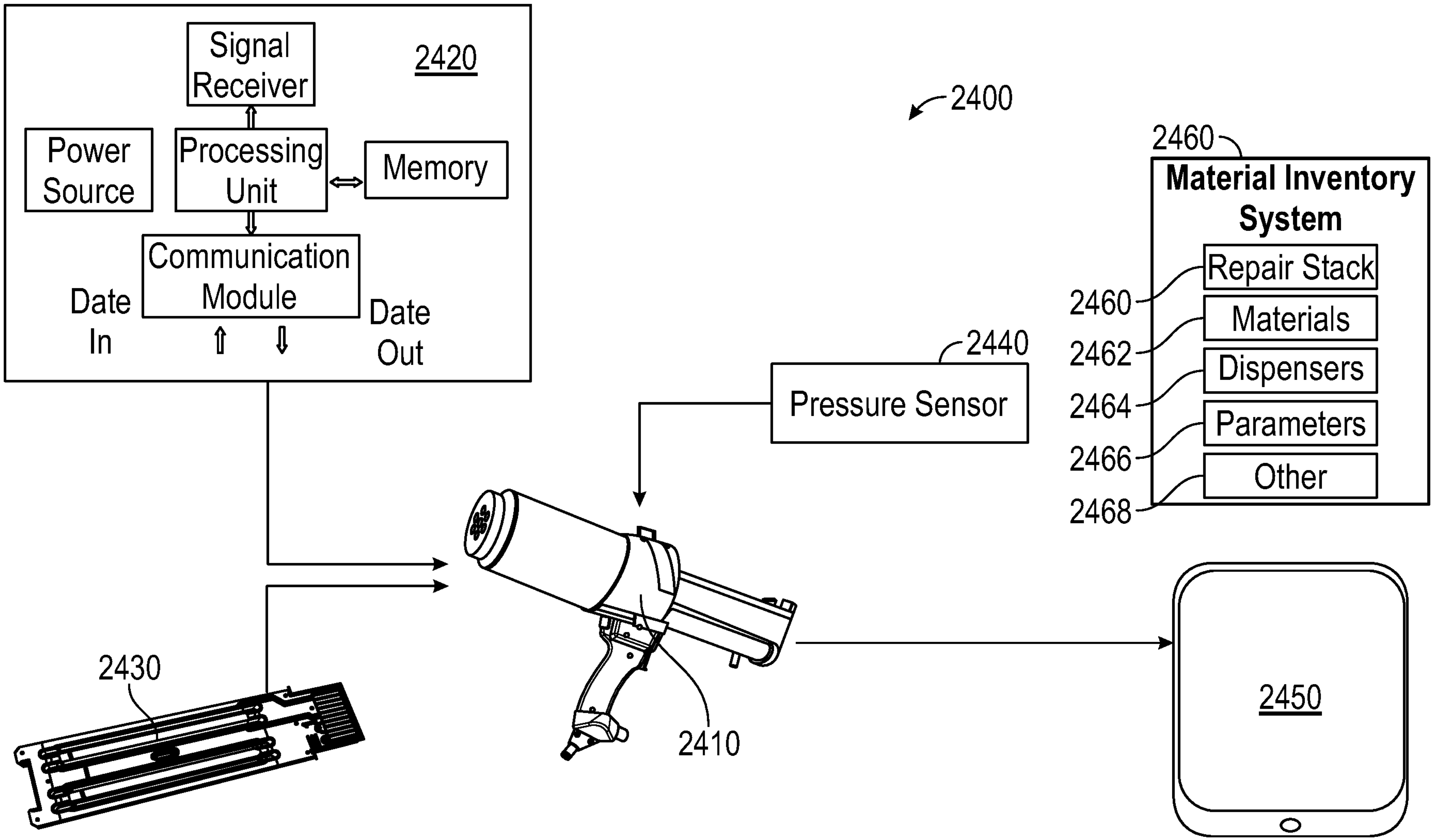

Signal Receiver
2420
Power Source
Processing Unit
Memory
Communication Module
Date In
Date Out
2400
2460
Material Inventory System
Repair Stack
Materials
Dispensers
Parameters
Other
2460
2462
2464
2466
2468
2440
Pressure Sensor
2430
2410
2450

FIG. 23

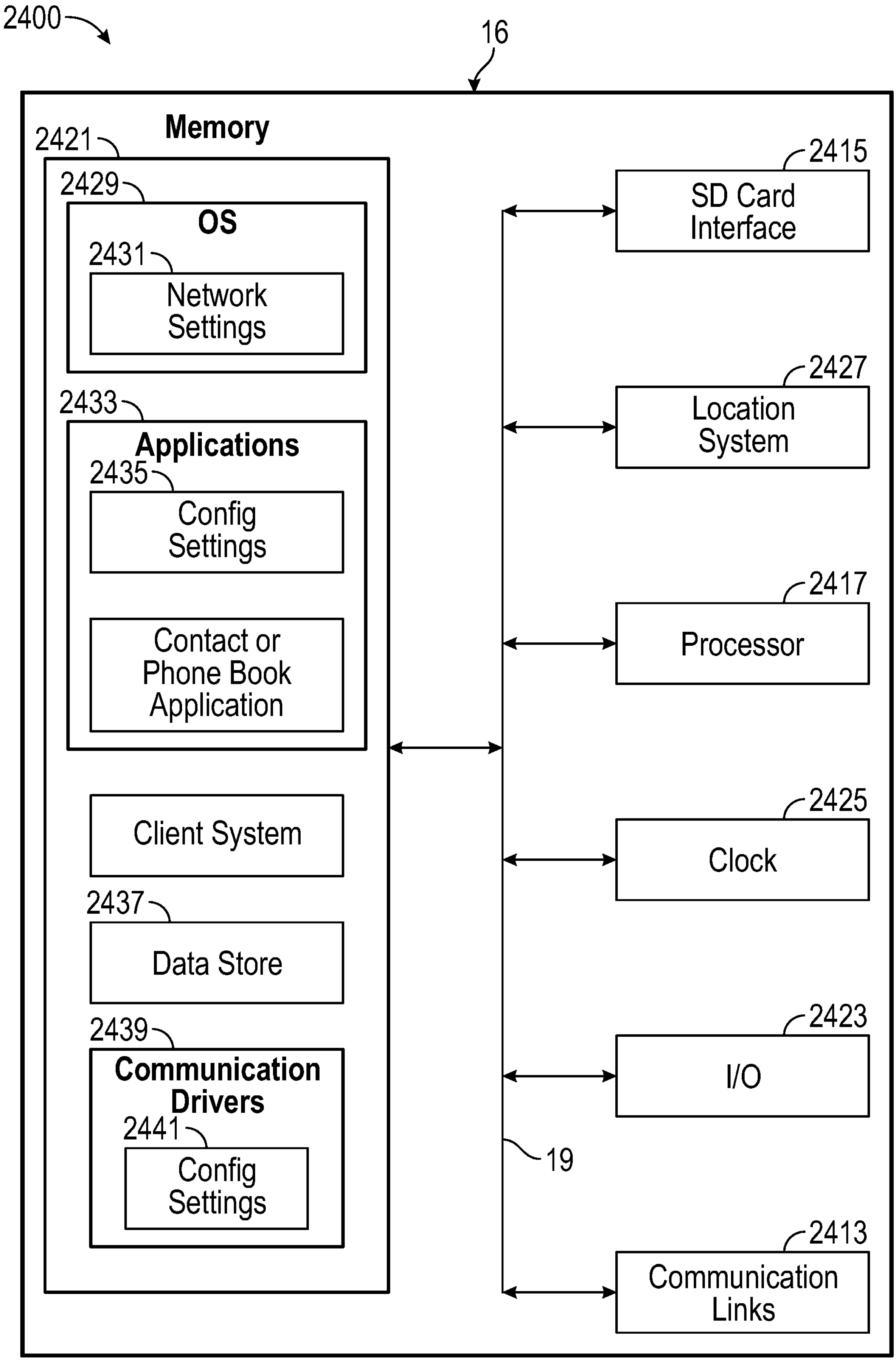

2400
16
2421
Memory
2429
OS
2431
Network Settings
2433
Applications
2435
Config Settings
Contact or Phone Book Application
Client System
2437
Data Store
2439
Communication Drivers
2441
Config Settings
2415
SD Card Interface
2427
Location System
2417
Processor
2425
Clock
2423
I/O
19
2413
Communication Links

FIG. 24

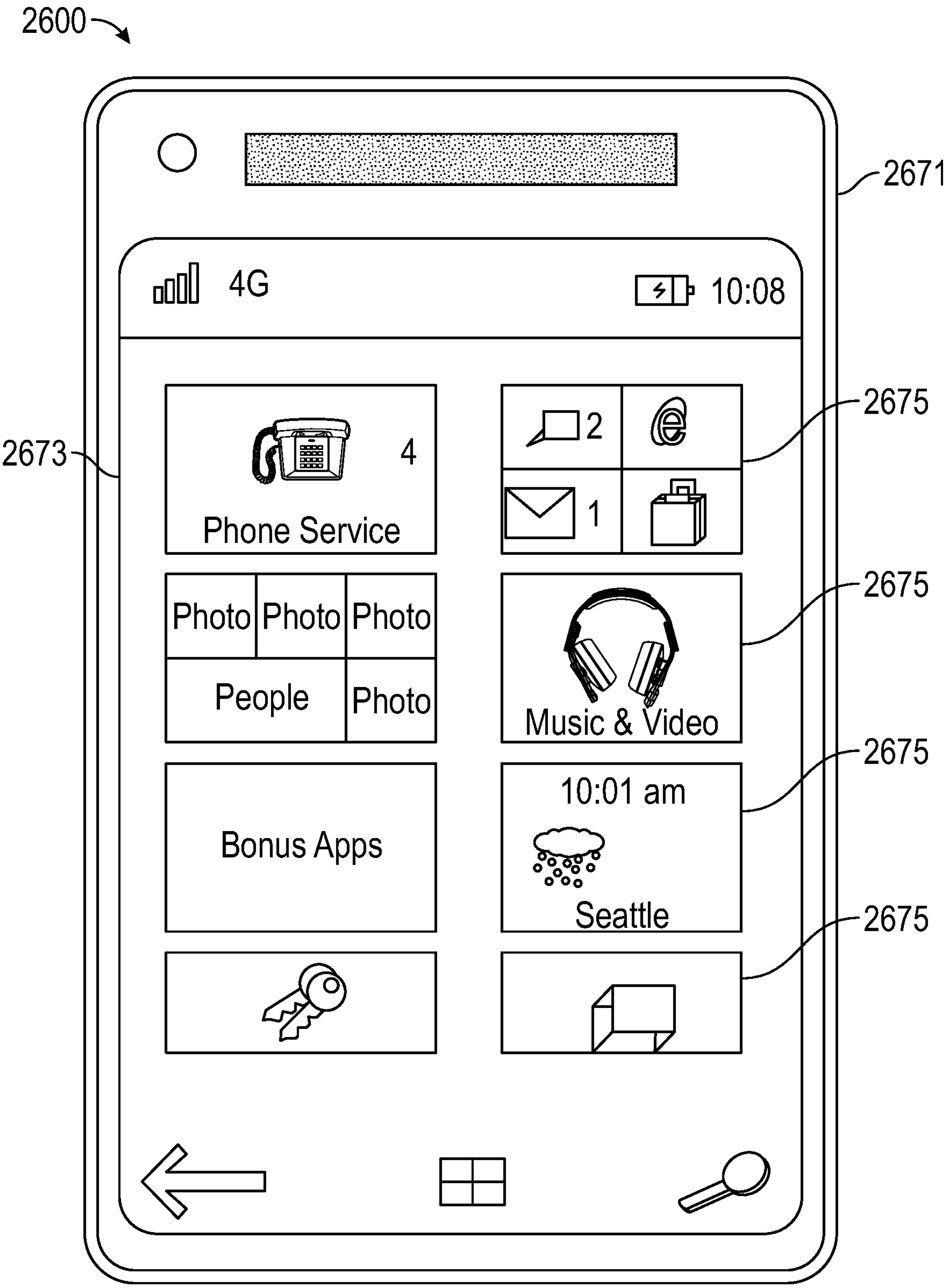

2600
2671
2673
2675
2675
2675
2675
4G
10:08
4
Phone Service
2
1
Photo
Photo
Photo
People
Photo
Music & Video
Bonus Apps
10:01 am
Seattle

FIG. 25

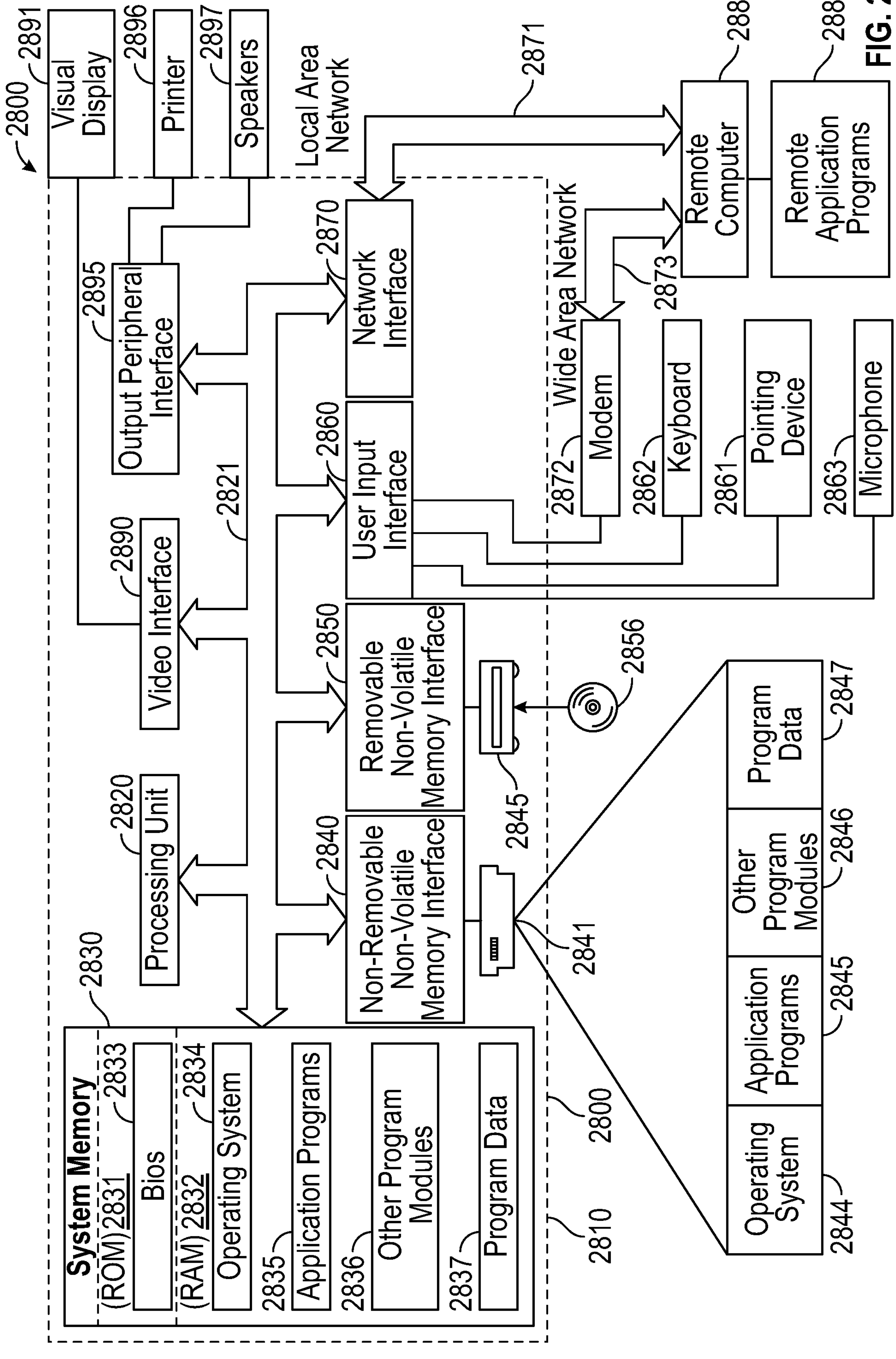

2800
Visual Display
2891
Printer
2896
Speakers
2897
Local Area Network
2871
Remote Computer
2880
Remote Application Programs
2885
Output Peripheral Interface
2895
Network Interface
2870
Wide Area Network
2873
Modem
2872
Keyboard
2862
Pointing Device
2861
Microphone
2863
User Input Interface
2860
Video Interface
2890
2821
Removable Non-Volatile Memory Interface
2850
2856
2845
Processing Unit
2820
Non-Removable Non-Volatile Memory Interface
2840
2841
Program Data
2847
Other Program Modules
2846
Application Programs
2845
Operating System
2844
2830
System Memory
(ROM) 2831
Bios
2833
(RAM) 2832
Operating System
2834
Application Programs
2835
Other Program Modules
2836
Program Data
2837
2800
2810

FIG. 26

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2024/055668

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N27/02 G01N27/06 G01N27/22 G01N33/26
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)
G01N

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 3 940 377 A1 (3M INNOVATIVE PROPERTIES CO [US]) 19 January 2022 (2022-01-19) paragraph [0143] - paragraph [0152]; figure 3 -----	1-3,11, 27,45
X	US 2006/105467 A1 (NIKSA ANDREW J [US] ET AL) 18 May 2006 (2006-05-18)	1,3, 5-11,13, 18, 20-28, 30-36, 38, 49-53,56
	paragraph [0046] - paragraph [0051]; figures 1A,10 paragraph [0081] - paragraph [0088]; figure 14 ----- -/--	

☒ 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

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