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(71) Applicant: **3M INNOVATIVE PROPERTIES COMPANY** [US/US]; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US).

(72) Inventors: **RUDEK, David M.**; Carl-Schurz-Strasse 1, D-41453 Neuss (DE). **SCHUMACHER, Knut**; Carl-Schurz-Strasse 1, D-41453 Neuss (DE). **HAHN, Joerg**; Carl-Schurz-Strasse 1, D-41453 Neuss (DE). **WISCHNEPOLSKI, Waleri**; Carl-Schurz-Strasse 1, D-41453 Neuss (DE). **STRICKER, Andrea**; Carl-Schurz-Strasse 1, D-41453 Neuss (DE). **TUMA, Phillip E.**; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US). **GOLLNICK, Hans Emanuel**; Carl-Schurz-Strasse 1, D-41453 Neuss (DE).

(74) Agent: **GROSS, Kathleen B.** et al.; 3M Center, Office of Intellectual Property Counsel, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US).

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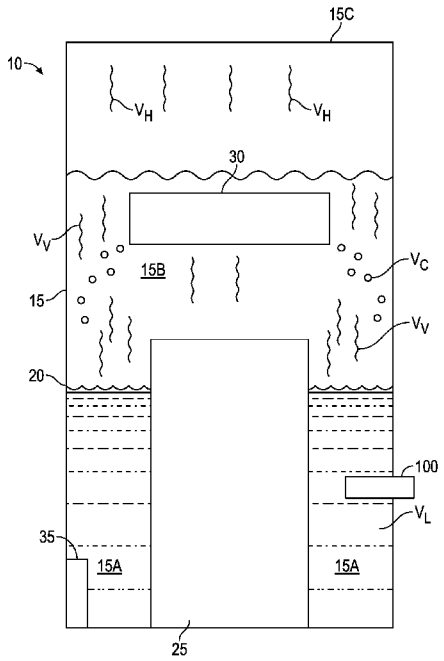

FIG. 1

(57) Abstract: A contamination detection system includes a sensor configured to be immersed in the fluid and configured to sense an electrical property value for the fluid when in direct contact with the fluid, an analyzer that receives the electrical property value and, based on the electrical property value, determines the amount of the contaminant in the fluid, and a communicator configured to communicate the amount of the contaminant in the fluid. The sensor includes a printed circuit board having a first surface and a second surface opposite the first surface, the first surface and the second surface separated by a thickness, and a first sensing area including a receiving electrode and a transmitting electrode each configured to directly contact the fluid. A method for detecting an amount of a contaminant in a fluid is also described.

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SYSTEMS AND METHODS FOR DETECTING CONTAMINATION IN A FLUID

BACKGROUND

Int. Appl. Pub. No. WO 2022/013786 (Münstermann et al.) 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. Int. Appl. Pub. No. WO 2022/058915 (Tuma et al.) discloses a thermal management system including a fluid and a sensing mechanism for sensing one or more organic contaminants in the working fluid. Int. Appl. Pub. No. WO 2020/126457 (Katzenmeier et al.) discloses a method for determining at least one parameter of a cooling lubricant emulsion for machine tools using at least one sensor.

SUMMARY OF THE DISCLOSURE

The present disclosure provides systems and methods for effectively measuring contamination in a fluid. The systems and methods utilize sensors that allow for direct contact between the sensor and a fluid, are cost effective to manufacture, and can be discarded after use. Systems and methods according to the present disclosure also allow for multiple sensor signals to be gathered in a fluid.

In one aspect, the present disclosure provides a contamination detection system that includes a sensor configured to be immersed in the fluid and configured to sense an electrical property value for the fluid when in direct contact with the fluid, an analyzer that receives the electrical property value and, based on the electrical property value, determines the amount of the contaminant in the fluid, and a communicator configured to communicate the amount of the contaminant in the fluid. The sensor includes a printed circuit board having a first surface and a second surface opposite the first surface, the first surface and the second surface separated by a thickness, and a first sensing area including a receiving electrode and a transmitting electrode each configured to directly contact the fluid.

In other words, the present disclosure provides a contamination detection system that includes a sensor configured to be immersed in the fluid and configured to sense an electrical property value for the fluid when in direct contact with the fluid and a controller including processing circuitry and a memory operably coupled to the sensor. The configured is to receive the electrical property value, determine, based on the sensed electrical property value, the amount of the contaminant in the fluid, and communicate the amount of the contaminant in the fluid. The sensor includes a first surface and a second surface opposite the first surface, the first surface and the second surface separated by a thickness, and a first sensing area comprising a receiving electrode and a transmitting electrode each configured to directly contact the fluid.

In another aspect, the present disclosure provides a method of detecting an amount of a contaminant in a fluid. The method includes immersing a sensor into a fluid, receiving a sensed electrical property value from the sensor using a signal receiver, determining the amount of the contaminant in the

fluid based on the sensed electrical property value using an analyzer, and communicating the amount of the contaminant in the fluid using a communicator. The sensor includes a printed circuit board having a first surface and a second surface opposite the first surface, the first surface and the second surface separated by a thickness, and a first sensing area including a receiving electrode and a transmitting electrode, each of which directly contacts the fluid.

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

FIG. 1 is a schematic illustration of a two-phase immersion cooling system according to some embodiments of the present disclosure.

FIG. 2 is a schematic illustration of a cooling lubricant system according to some embodiments of the present disclosure.

FIGS. 3A and 3B illustrate sensors useful for some embodiments of the present disclosure.

FIGS. 4A to 4D illustrate sensor systems useful for some embodiments of the present disclosure.

FIG. 5 illustrates a long sensor in accordance with embodiments herein.

FIGS. 6A to 6C illustrate a sensor with electrodes in a series configuration and a system according to some embodiments of the present disclosure.

FIGS. 7A to 7E illustrate a surface sensing sensor configuration useful for some embodiments of the present disclosure.

FIG. 8 illustrates a method for determining the concentration of a contaminant in a fluid according to some embodiments of the present disclosure.

FIG. 9 illustrates a quality control system according to some embodiments of the present disclosure.

FIGS. 10A to 10C illustrate conductivity measurement system in example network architectures.

FIGS. 11A to 11D illustrate a sensing system in accordance with embodiments herein.

FIGS. 12 to 14 illustrate example computing devices that can be used in embodiments of the present disclosure.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The present disclosure relates to systems and methods that include sensors that can 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 detect and reduce an amount of a contaminant before, or during, an operation.

Many industrial processes use liquid materials 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. Many industrial processes, however, rely on certain properties of a liquid being within a specified range or being unchanged compared to the property in an initial state. Troubleshooting changes in a liquid during a process can require detailed chemical knowledge, time, and elimination of other causes. For many operations, troubleshooting costs time that cannot be spared.

Described herein are sensors and sensor systems that are used to measure electrical properties of fluids. Broadly, sensors herein can 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. Sensors herein can also function by a transmitting electrode receiving a current. As a fluid flows between the transmitting electrode and a receiving electrode, it the receiving electrode receives a voltage. 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. However, it is expressly contemplated that other electrical properties may be calculated and relevant to embodiments herein. For example, conductivity and relative permittivity may be determined from impedance measurements. Any of these electrical properties may be relevant, as illustrated herein, for determining quality of fluids.

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.

In some embodiments, 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 to be applied to a transmitting electrode and for current to be transmitted from a receiving electrode or for current to be applied to a transmitting electrode and for 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.

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.

Sensors as described herein may be used to sense properties of input fluids for an industrial manufacturing process or to sense properties of fluids in use during a manufacturing process. Data from these property sensors measuring the input fluids can be processed along with data from a property sensor measuring the fluid in use, 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. For example, 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. A number of properties varied previously to establish a set of calibration data representing calibration impedance responses measured previously at the different property values can determine the number of properties that can later be determined by the sensor. A 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, purity in case of fluids that become contaminated during use, and mixing ratio in case of the fluid being a mixture, to name only some.

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 an amount of a contaminant in the fluid. In some of these embodiments, the fluid is coolant in a two-phase immersion cooling system, and a contaminant of the fluid is a plasticizer used in a cabling system inside the system. In other embodiments, the fluid is a cooling lubricant emulsion for machining tools, and a contaminant of the fluid is a microorganism or solid particles that result from abrading. In some embodiments, the fluid is a cooling lubricant emulsion, and a property of the fluid is an oil-to-water ratio.

In some 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. The fluid may be a static 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 paint, resin (e.g., for adhesive or other purposes), cure-in-place gaskets, adhesives, coating materials, dental impression material, void filler, sealant, an engineered fluid, a dielectric fluid, a thermally conductive interface material, a precursor material to any of these, emulsions, or any material that can lose stability over time or become contaminated over time.

In some embodiments, the system and method of the present disclosure, the fluid is a coolant in a two-phase immersion cooling system. Large scale computer server systems can perform significant workloads and generate a large amount of heat during their operation. A significant portion of the heat is generated by the operation of the server systems. Due in part to the large amount of heat generated, these servers have been rack-mounted and air-cooled via internal fans and/or fans attached to the back of the rack or elsewhere within the server ecosystem. As the need for access to greater and greater processing and storage resources continues to expand, the density of server systems (i.e., the amount of processing power and/or storage placed on a single server, the number of servers placed in a single rack, and/or the number of servers and or racks deployed on a single server farm), continue to increase. With the desire for increasing processing or storage density in these server systems, the thermal challenges that result remain a significant obstacle. Conventional cooling systems (e.g., fan based) require large amounts of power, and the cost of power required to drive such systems increases exponentially with the increase in server densities.

Two-phase immersion cooling is an emerging cooling technology for the high-performance server computing market which relies on the heat absorbed in the process of vaporizing a liquid (the cooling fluid) to a gas (i.e., the heat of vaporization). Unlike many other devices, computers cannot use water cooling, as water is electrically conductive and will break electronic components. Therefore, the fluids used in immersion cooling are dielectric liquids to ensure that they can safely come into contact with energized electronic components. The working fluids used in this application must meet certain requirements to be viable in the application. For example, the boiling temperature during operation can

usefully be in a range from 30°C to 75°C. Generally, this range accommodates maintaining the server components at a sufficiently cool temperature while allowing heat to be dissipated efficiently to an ultimate heat sink (e.g., outside air). The working fluid must be inert so that it is compatible with the materials of construction and the electrical components. Certain perfluorinated and partially fluorinated materials have been found useful to meet these requirements. Oils such as mineral oil and other hydrocarbon oils as well as silicone oils and other silicone fluids can also be useful.

In a typical two-phase immersion cooling system, servers are submerged in a bath of working fluid (having a boiling temperature Tb) that is sealed and maintained at or near atmospheric pressure. A vapor condenser integrated into the tank is cooled by water at temperature Tw. During operation, after steady reflux is established, the working fluid vapor generated by the boiling working fluid forms a discrete vapor level as it is condensed back into the liquid state. Above this layer is the "headspace," a mixture of a non-condensable gas (typically air), water vapor, and the working fluid vapor which is at a temperature somewhere between Tw and the temperature of ambient air outside the tank, Tamb. These three distinct phases (liquid, vapor, and headspace) occupy volumes within the tank.

During normal operation of immersion cooling systems, working fluids can extract, for example, organic contaminants from various components (e.g., cable cladding, seals, gaskets, and printed circuit boards) within the tank such as elastomeric polymers, adhesives, coatings, thermal compounds, PVC insulation, and plasticizers. Contaminants can also include water and solid particulate. Entrained water is found in nearly all permeable materials, including PCBs, polymers, seals, and gaskets. Solid particulate examples include zip ties, paper towel fibers, clothing fibers, dander, metal or plastic shavings, and thread sealants. The solubility of these contaminants varies. For example, dioctylpthalate (DOP), a common PVC plasticizer is soluble in perfluorocarbon (PFC) fluids at part per million (ppm) levels but is fully miscible in certain hydrofluoroethers. High molecular weight compounds may have lower solubility. Regardless of solubility, in real world applications, these contaminants are typically present only at very low concentrations on the order of 100 parts per million (ppm) or less.

Even at these very low concentrations, thermal performance of the system can be significantly impacted. For example, consider that a 200-Watt microprocessor can boil approximately 100 liters of thermal management fluid per day. If that fluid contains only 10 ppm of the contaminant DOP, then it contains 1 to 2 grams of DOP. As that 100 liters boils away, some of the nonvolatile DOP is left behind by distillation and will precipitate onto and coat the boiling surface of the electronic device (e.g., microprocessor), thereby impeding heat transfer. Performance of the electronic device (e.g., the operating junction temperature of the microprocessor) degrades immediately upon addition of even very low amounts of certain contaminants, including DOP.

Consequently, systems methods for measuring, in situ, the level of certain contaminants in the thermal management fluid so that preventive action (e.g., changing a filter) can be taken before performance is affected or hardware is damaged are desirable.

Referring now to FIG. 1, in some embodiments, a two-phase immersion cooling system 10 includes a housing 15 having an interior space. Within a lower volume 15A of the interior space, a liquid phase V_L of a working fluid having an upper liquid surface 20 (i.e., the topmost level of the liquid phase V_L) may be disposed. The interior space may also include an upper volume 15B extending from the liquid surface 20 to an upper wall 15C of the housing 15. During steady state operation of the system 10, the upper volume 15B may include a vapor phase V_V of the working liquid (generated by the boiling working fluid and forming a discrete phase as it is condensed back into the liquid state) and a headspace phase V_H including a mixture of non-condensable gas (e.g., air) and working fluid vapor, which is disposed above the vapor phase V_V.

In some embodiments, a heat generating component 25 is disposed within the interior space such that it is at least partially immersed in the liquid phase V_L of the working fluid. While heat generating component 25 is illustrated as being only partially submerged below the upper liquid surface 20, in some embodiments, the heat generating component 25 may be fully disposed below the liquid surface 20. In some embodiments, the heat generating components may include one or more electronic devices, such as computing servers.

In various embodiments, a heat exchanger 30 (e.g., a condenser) may be disposed within the upper volume 15B. Generally, the heat exchanger 30 may be configured such that it is able to condense the vapor phase V_V of the working fluid that is generated as a result of the heat that is produced by the heat generating element 25. For example, the heat exchanger 30 may have an external surface that is maintained at a temperature that is lower than the condensation temperature of the vapor phase V_V of the working fluid. In this regard, at the heat exchanger 30, a rising vapor phase V_V of the working fluid may be condensed back to liquid phase or condensate V_C by releasing latent heat to the heat exchanger 30 as the rising vapor phase V_V contacts the heat exchanger 30. The resulting condensate V_C may then be returned to the liquid phase V_L disposed in the lower volume of 15A. The heat exchanger may be a water condenser that allows the flow of water into and out of housing 15 using a manifold.

The system 10 includes a sensor 100 configured to detect the presence of certain organic contaminants (e.g., dioctylpthalate, polydimethylsiloxanes, aliphatic and aromatic hydrocarbons, esters, ethers, polyalkylene oxides and various other organic polymers, oligomers, plasticizers, and adjuvants commonly used in the electronics industry), water, or particles in the working fluids. One or more sensors 100 described below in any of their embodiments are included in the system 10. Sensor 100 may be positioned in the liquid phase VL of the working fluid (or otherwise in fluid communication with the liquid phase V_L of the working fluid) and may be located in the housing as shown in FIG. 1 or designed into an organic filtration element 35. In the sensor, the receiving electrode and the transmitting electrode each directly contacts the fluid. The sensor may include an edge connector that is not in contact with the fluid for coupling the sensor to a signal receiver or analyzer. The system 10 can include a channel or manifold of various configurations to allow receiving electrode and transmitting electrodes to contact the fluid and to prevent the edge connector from contacting the fluid.

In some embodiments, the system and method of the present disclosure, the fluid is a cooling lubricant for machining tools. In a machining process, a workpiece is given a specific shape by mechanical separation (e.g., turning, milling, or grinding) of excess material with a tool. Due to friction, the mechanical work introduced is almost completely converted into heat. Water-miscible cooling lubricants are widely used in the metal-working industry for metal-cutting machining. Such cooling lubricants often contain more than 90% water and can be in the form of emulsions or solutions. Cooling lubricant emulsions include oil and water and often include emulsifiers, buffers, and other additives (e.g., anti-corrosion additives and biologically stabilizing additives) to give the emulsion properties precisely tailored to their respective areas of application and to ensure stability. Cooling lubricant solutions, on the other hand, are usually free of mineral oil and are typically transparent. Water-miscible cooling lubricants are usually available as concentrates, which include oil, water, and the desired additives and are mixed with water in the correct order and in the correct ratio before use. The final cooling lubricant can contain ten percent concentrate or less.

Due to their high water content, water-miscible cooling lubricants generally possess the positive physical properties of water, including a very good cooling effect. The high water content of water-miscible cooling lubricants emulsions also has disadvantages: a low oil content of approximately five to eight percent gives these cooling lubricants a reduced lubricating effect, and cut surfaces cannot be wetted as well. The oil-to-water ratio needs to be controlled to achieve reliable and high quality machine results. The greatest risk associated with the use of water-mixed metalworking fluids is their susceptibility to microbial contamination. Fungi, bacteria, or yeasts frequently multiply if the cooling lubricant is not treated and cared for appropriately. Not only the finished emulsion in the machines but also the concentrate itself is at risk if stored incorrectly. Microbial contamination in cooling lubricants can cause severe health problems after skin contact and can pose problems for the workpiece, tool, and machine, including discoloration of the machined parts, shorter tool life, and corrosion.

Referring now to FIG. 2, a machining system 250 includes a machining center 260, which can include the workpiece and the tool for machining the workpiece. Drum 220 includes water for diluting the concentrate used to make the cooling lubricant emulsion 230. Water is transferred from the drum 220 to the cooling lubricant emulsion 230 using conduit 225. The cooling lubricant emulsion 230 is conveyed to the tool or the workpiece in the machining center 260. The cooling lubricant emulsion 230 is typically collected again and recycled.

Machining system 250 includes sensors 200a and 200b. Sensor 200a is immersed in the drum 220 including water, and sensor 200b is immersed in the cooling lubricant emulsion 230. Although sensors 200a, 200b are shown in both drum 220 and cooling lubricant emulsion 230, machining systems are contemplated which include sensor 200b in cooling lubricant emulsion 230 only or which include sensor 200a in the drum 220 of water for diluting the concentrate. Machining system 250 also includes sensor signal readers 202a and 202b, which connect to a sensor, for example, through an edge connector

on a connection end of a PCB-board (not shown in FIG. 2). In the embodiment illustrated in FIG. 2, concentrator 210 receives sensor signals, processes sensor signals, and provides an output.

Illustrated sensors 200a and 200b have electrodes in a series configuration as described further below in connection with FIS. 6A to 6C. Each slot including an electron pair has a different distance from the connection end. Although the slots are shown in a column, vertical alignment of the slots and their electron pairs is not required. A temperature sensor may be included on the PCB board as well as shown in FIG. 6A. Sensors 200a and 200b have an arrangement of electrode pairs (i.e., the transmitting electrode and the receiving electrode) in a vertical stack along a PCB, allowing for each electrode pair to be positioned at a different depth within drum 200 or cooling lubricant emulsion 230. Electrode pair 242 at a lowest depth measures a first electrical signal at depth 232. Electrode pair 244 at a second-to-lowest depth measures a second electrical signal at depth 234. Similarly, electrode pairs 246 and 248 measures electrical signals at depths 236 and 238, respectively. These depths and electrode pairs can also be envisioned in cooling lubricant emulsion 230 although they are not labeled. While FIG. 2 illustrates sensors 200a and 200b 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 one electrode pair, 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.

In addition to microbial contamination that can form as described above, a cooling lubricant emulsion can become unstable over time and/or become contaminated with particulate material from the machining process. Systems and methods of the present disclosure can be useful for detecting these problems. For example, an electrical signal measured at depth 236 may be different from an electrical signal measured at depth 234 if separation is occurring such that one material (e.g., oil) is separating to the top of the emulsion. For example, an electrical signal measured at depth 232 may be different from an electrical signal measured at depth 234 if the cooling lubricant emulsion is experiencing sedimentation, where particulates are settling at the bottom of a container. Such changes in a cooling lubricant emulsion may occur before or during use. Advantageously, sensor 202b can be immersed in cooling lubricant emulsion 230 before or during use. The purity of input water in drum 220 may also be evaluated with sensor 200a before or during use. Advantageously, sensors 200a and 200b may also be moved in the fluid such as to stir the fluid.

Furthermore, sensor 200b may be useful for detecting entrained air bubbles or excessive foaming or droplets in the fluid. Droplets may indicate that a phase separation is imminent in an emulsion. Slots 242, 244, and 246 are useful for detecting bubbles or droplets. Generally, a consistent fluid with no bubbles or droplets provides an insulation effect and maintains a consistent conductivity across all electrode pairs. When a droplet or air bubble reaches a width of one of the slots, the droplet or bubble will connect both sides of the electrodes, resulting in a detectable change in conductivity. Also, when a fluid level drops below slot 248, the electrodes are only in contact with air, and a change in conductivity

results. Sensors 200a and 200b can have electrode pairs as described for sensor 300 below. Furthermore, a two-phase immersion cooling system as shown in FIG. 1 and a machining system as shown in FIG. 2 can use any of the sensors described in connection with FIGS. 2, 3A, 3B, 4A to 4D, 5, 6A to 6C, and 7A to 7C, or any combination thereof of such sensors.

FIGS. 3A-3B illustrate material measurement sensors in accordance with embodiments herein. FIG. 3A illustrates a sensor 300. As illustrated in FIG. 3A, a sensor 300 includes a PCB board 302 with one or more grounds 330 and a TX contact 340. 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 sensor 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.

Each of the electrode pairs are decoupled from the adjacent pair such that four separate electrical signals are received, one from each electrode pair 310, 320. Sensor 300 is placed, in some embodiments, perpendicularly to the flow of fluid, such that a first slot 352 receives a first portion of fluid flow, a second slot 354 receives a second portion of fluid flow, a third slot 356 receives a third portion of fluid flow, and a fourth slot 358 receives a fourth portion of fluid flow. In other embodiments, the different slots 352, 354, 356, and 358 can measure different areas in a static fluid. Therefore, system 300 can simultaneously generate four different signals relative to a single fluid, providing a better picture of whether an oil-to-water ratio, a contaminant amount, or other measured parameter is consistent across an entire sensing area.

In previous sensing systems, including that described in Int. Appl. Pub. No. WO 2022/013786 (Münstermann et al.), conductivity measurements required both a positive and a negative pole, which required two PCBs per electrode pair. In contrast, sensor 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 useful 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 slots 352, 354, 356, 358, using copper for example. The metallization process may

cause electrodes 320 to be connected to electrodes 310. 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 fluids. PCB boards often have a maximum operating temperature less than 170 °C, which limits the temperature of fluids into which a sensor 300 can be immersed. Fluids may have a range of viscosities, for example up to around 10^5 Pa s. In some embodiments, increasing the width of slots 352 to 358 may be useful for higher viscosity fluids although increasing the slot width may make the sensor 300 less sensitive. Similarly, for fluids with particulates, such as suspensions for example, advantageously, the width of slots 352 to 358 can be selected to be larger than the particles' sizes. Additionally, systems herein may be limited to fluids that do not cause corrosion or otherwise damage the PCB 302 or electrodes 310, 320.

FIG. 3B illustrates another embodiment of a sensor 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 electrical signal 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 processes are at least partially temperature dependent, and temperature can be important for the two-phase immersion sensing system 10 shown in FIG. 1 and the machining system 250 shown in FIG. 2. 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.

FIGS. 3A-3B illustrate 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 fluid.

A method of forming sensors 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.

Sensors according to embodiments herein can be placed in direct contact with a fluid, providing a measurement of an electrical contact based on that direct contact. This provides a more accurate measure

of an amount of contaminant, for example, than other methods that do not allow for direct contact between a sensor and a material. In scenarios where the fluid of interest is corrosive or highly viscous, for example, it is beneficial to be able to discard the sensor after use.

FIGS. 4A to 4D illustrate an article 400 including a sensor within a conduit, such as conduit 225 illustrated in FIG. 2. Referring to FIG. 2, the conduit may run between cooling lubricant emulsion 230 and machining center 260 or between drum 220 and cooling lubricant emulsion 230. Article 400 can also be useful for placing sensor 100 within a manifold, such as described above in connection with FIG. 1.

FIG. 4A illustrates a sensor 410 within conduit 422. Sensor 410 has four electrode slots such that, as a fluid passes through conduit (into the field), it passes through the slots of sensor 410, and electrical signal measurements are passed to a control system, by edge connector 412, for example. Variation in the electrical signal measurements between one electrode slot and another electrode slot indicates may indicate a variation in quality consistency of the fluid. FIG. 4B illustrates a perspective view of article 400. Conduit 422 may couple to another part of a fluid transport system using threading 426, or another suitable fastening system. FIGS. 4C and 4D illustrate cutaway views of article 400. In FIG. 4C, an over-molded plastic 444 is used as a seal to hold sensor 410 in place. Such a seal may have an end stop 442 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. 4D, a different seal configuration is illustrated – an O-ring can be used. Corresponding recesses that can receive an O-ring 464 may be machined into the conduit to stabilize the sensor against the pressure of fluid flow.

The illustrated article 400 may be replaceable, such that a sensing assembly is a single-use assembly, in some embodiments. In other embodiments, the sensor 410 is removeable such that the sensor is a single-use sensor.

FIG. 5 illustrates a long sensor in accordance with some embodiments of the present disclosure. Sensor 500 is illustrated in FIG. 5 as having a length 530 of separation between an electrode portion 520 and edge connector 510. Edge connector 510 desirably does not come into contact with a mixture. Therefore, having a separation 530 in between edge connector 510 and electrode portion 520 increase the flexibility of use for a sensor, for example, allowing sensor 500 to be used in a deeper container. Sensor 500 can be dipped and used to stir the sensor in a fluid without the edge connector touching fluid (and short circuiting), allowing for material characterization data (e.g., electrical signal and temperature) to be monitored and visualized in real time.

FIG. 6A illustrates a sensor 600 with electrode in a series configuration similar to sensors 200a and 200b shown in FIG. 2. A temperature sensor 604 is included on the PCB board as well. A length 606 between edge connector 608 and the electrode slot 602 closest to edge connector 608 is also included to reduce the chance of edge connector 608 contacting fluid in a container.

FIGS. 6B and 6C illustrate example mixtures and resulting electrical signal measurements using a sensor 600. In the illustrated embodiment, the electrical signal measurement is conductivity “c” over time

"t". FIG. 6B illustrates a stable dispersion 650, which results in conductivity measurements from each electrode pair that are very similar. FIG. 6C illustrates a dispersion 660 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. 6A to 6C 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.

Slots in the sensors illustrated in FIGS. 2, 3A, 3B. 4A to 4D, 5, and 6A to 6C may have any desired width. In some embodiments, the width of the slits is up to 4 millimeters (mm), 3 mm, 2, mm, or 1mm. 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 micrometers (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. In addition to the change in width, the slots may also change in length to suit a particular application. For example, in checking the shelf-life of a fluid in 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 contact. 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.

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. 3A, 3B, 4A to 4D, and 5, or a vertical configuration such as FIGS. 2 and 6A to 6C). 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 electrical signals at multiple depths 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. Furthermore, only one aperture with only one electrode pair may be useful.

In some embodiments, a sensitivity of sensing systems herein can be increased by using surface sensing instead of bulk sensing. FIG. 7A illustrates a schematic of a bulk electrical signal sensing system in accordance with embodiments herein. Bulk sensing involves fluid passing between a first electrode 702 and a second electrode 704, as indicated by material flow direction 708. The fluid may also be static instead of flowing. An electric field 706 is generated by the first and second electrodes, 702 and 704 respectively. A housing or support structure 710 may provide structure and support for electrodes 702, 704, such as the PCB and slots described above in any of their embodiments.

FIG. 7B illustrates a top-down view 720 of a surface-sensing sensor configuration in accordance with some embodiments of the present disclosure. A housing or support structure 726 may have a first set of electrodes 722 and a second set of electrodes 724 machined into or printed thereon. For example,

transmitting electrodes 722 and receiving electrodes 724 may be machined into, or printed onto, a printed circuit board.

FIG. 7C illustrates a close-up view of portion 730, illustrating a cutaway view of a sensor configuration. A first electrode 722 and second electrode 724, supported by structure 726 generate an electric field 732. An electrical property of a fluid in contact with electrodes 722, 724 can be measured.

In contrast with configuration 700, sensor configuration 720 does not rely on fluid passing through gaps, slots or apertures of a sensor. Instead, sensor signals are generated based on contact with a fluid.

FIG. 7D and 7E illustrate a sensor in accordance with some embodiments of the present disclosure. A sensor 750 is illustrated with a sensing area 760 spaced apart from an edge connector 752 by a space 754. Edge connector 752 may couple to a processing system for sensor signals received from sensing area 760. Sensing area 760 is a surface-sensing sensor that can provide significantly higher sensitivity than a similarly sized bulk sensor.

FIG. 7E illustrates a close-up view of sensing area 760. Two channels 762 are outlined on surface 760. It is expressly contemplated that an additional two channels 762 may be present on a surface opposite surface 760, so that four channels are present on a single sensor 750. Channels 762 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. 7D and 7E 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 760 as well as bulk-sensing electrode slots along space 754.

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

Using systems and methods described herein, it is possible to monitor a number of parameters relevant to the quality of a fluid before and during use of the fluid in addition to the amounts of contaminants in the fluid. Monitoring fluid quality may refer to any of consistency, composition, or other relevant quality indication. Systems and methods of use herein may provide indications of mix ratio (e.g., oil-to-water mix ratio) and may provide in-situ process indications such as amount of contaminants, aging, air bubble detection, lot-to-lot variation, raw material quality, phase separation, and fluid level. Using sensor systems herein, it is possible to automatically detect a quality concern (e.g., contamination,

particulates, oil-to-water mix ratio, excessive foaming, and fluid level) 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 process: at intake, during or after mixing, and within a container.

FIG. 8 illustrates a method of detecting an amount of a contaminant in accordance with embodiments herein. In block 810, a sensor is immersed in a fluid. The fluid may be static or flowing and may be a liquid or a foam. The fluid may be a dielectric fluid. The fluid may be an emulsion such as a cooling lubricant emulsion. The fluid may be located in a housing of a conduit, in a housing of a two-phase immersion cooling system, or in a container, for example, useful in a machining system. The sensor has a first sensing area comprising a receiving electrode and a transmitting electrode, each of directly contacts the fluid. Direct contact between a fluid and an electrode pair ensures accurate measurements. The sensing system may be a bulk sensing system or a surface sensing system. The sensor may have one, two, three, four or more discrete electrode pairs.

In block 820, an electrical signal is received from the sensor. Multiple electrode pairs may, when a sufficient voltage is passed through them, for example, detect one or more electrical properties of the material. Based on the sensor signals, a number of things may be determined for the fluid including an amount of a contaminant. For an emulsion, an oil-to-water ratio may be determined. Aging may also be detectable, as well as differences between batches of materials. Instability indications such as excessive foaming, impending phase separation, and particulate material may also be detectable. Measurements may be taken serially, for example one signal received every second, or more frequently. 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 840, a result is communicated based on the measurements. The communication may include characterization of the material, including an amount of the contaminant in the material, as indicated in block 832. Also, an oil-to-water ratio may be detected, an amount of foaming, an age indication, a fluid level, or other parameter of interest may be calculated and provided. A prediction may also be provided, as indicated in block 834. For example, based on a trend of previous sensor readings, it may be possible to predict future behavior of the fluid being measured. Other characterization information 838 may also be provided. For example, a conductivity reading trending in one direction may indicate that an amount of a contaminant is moving toward an edge of an acceptable range or that an increase in instability is trending toward phase separation of an emulsion.

In some embodiments, the communicating comprises generating a command to remove the contaminant or otherwise indicate that corrective action is needed. For example, when an amount of a contaminant in the fluid becomes high enough, communicating may include a command to replace a filter (e.g., filter 35 in FIG. 1) as indicated in block 842. An indication that the fluid level has become too low may result in a command to add fluid. In embodiments where a fluid has corrosive effects predictive

feedback may provide an indication that the sensor needs to be replaced, as indicated in block 846. Other predictive information may also be provided, as indicated in block 834, that may trigger other actions, as indicated in block 848. For example, an emulsion experiencing separation may need stabilizing, e.g. remixing or heating, or a fluid experiencing excessive foaming may benefit from the addition of a defoamer. Feedback may also indicate exchange of the fluid is needed.

In some embodiments, as illustrated herein, providing feedback may also include providing conductivity readings, fluid characterizations, or predictions to a user. Other information such as material source, batch number, material name, temperature, and pressure may also be provided.

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 an electrical signal using a suitable sensing system, such as that described herein.

In some embodiments, when running an actual measurement of quality control parameters of a fluid, measured impedance responses (MIR), for example, each measured at certain measurement sensing frequencies (MSF), can be recorded in the control system. In order to derive a value for an amount of contaminant, 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) contaminant amount in the actual measurement.

The same sensing frequencies used for calibration will often be used also for the measurement. There may, however, occur an amount of contaminant 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 amount of contaminant which can then be considered the contaminant amount in the measurement. The interpolation is performed by software on the control system, using the parametrized multi-dimensional polynomials. The result of the interpolation and derivation is a value of the contaminant amount as the fluid contacts the sensor during the measurement.

In some embodiments, the calibration impedance responses can be measured in their dependence on two parameters, namely on the sensing frequency and on the amount of contaminant. 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 fluid 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 fluid. 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 an amount of a contaminant, with a time stamp, for quality assurance. The amount of the contaminant 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.

In some embodiments of the system and method disclosed herein, relative thresholds instead of absolute thresholds may be useful. Base levels may be important to measure to have a more accurate relative threshold. For example, if a conductivity measurement changes in a proportionate factor to the base level (e.g., to 50% of the base level) then it can be determined that a contaminant is present, a fluid level has dropped, or too much entrained air is present. Relative thresholds may be helpful to reduce waste of material on accidental purges and wasted time in attempting to correct an inconsistency that may not be present or that may not be at a level that requires correction.

Sensing systems herein may operate using a single voltage and frequency. However, it is expressly contemplated that voltage, frequency or both may be varied. 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.

FIG. 9 illustrates a contamination detection system in accordance with some embodiments of the present disclosure. The contamination detection system may be used to identify and correct a detected contaminant in a fluid. The contamination detection system may be implemented in a static environment – e.g. as a dip sensor 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.

The contamination detection system may be implemented by a suitable processor 950 in communication with a sensing system 930. Sensing system 930 may include one or more electrode pairs 932 in direct contact with a fluid. Sensing system 930 may also include a temperature sensor 934. Electrode pairs 932 may be, for example, formed within apertures machined or built into the printed circuit board or on a surface of a printed board as described above in any of their embodiments. Temperature sensor 934 may be shielded from direct contact with a fluid, as described above in some embodiments. Sensing system 930 may include other features 938.

In the embodiment illustrated in FIG. 9, sensor signals from sensing system 930 are received by processor 950 using an active signal receiver 952. Active signal receiver 952 may receive signals from sensing system 930 periodically or continuously during an operation. Received sensor signals may be

impedance signals, conductivity signals, relative permittivity (i.e., dielectric constant) signals, or a combination thereof. In embodiments where a conductivity value is used to detect an inconsistency, a conductivity signal generator 954 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 956.

A historic signal retriever 958 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 960, 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 undesired amount of contaminant. 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 962 compares the received signal, or calculated conductivity, to the threshold and, if a deviation outside the allowed threshold is detected, command generator 964 generates a command, which is communicated, using command communicator 966, to a device 980.

Device 980 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 980 may, in some embodiments, include a feedback component, such as audio, visual or haptic feedback that indicates to a controller that an undesirable amount of a contaminant is detected. Device 980 may also be a correction mechanism, and command generator 964 may generate a command to conduct a correction mechanism selected based on the detected inconsistency, e.g. a purge valve, a fluid inlet valve, a command to change a filer, etc. Processor 950 may include other features 968.

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 962 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., 10 ms, 100 ms, etc.), threshold generator generates a prediction for the conductivity value, with confidence bands based on the historic signals retrieved by historic signal retriever 958. If the actual value measured drops below a lower confidence band, or goes above a higher confidence band, signal analyzer 962 detects an undesired level of a contaminant. If the conductivity measurement is within the confidence bands, signal analyzer 962 provides an output that no

contamination, or no contamination requiring correction has been detected. Command generator 964 may provide an indication that a GUI of device 980 does not require updating.

A relative threshold is an important component in case of 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 contamination 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 electrical properties, such as the amount of electrical current the relative permittivity (i.e., dielectric constant) could be used instead or as well for the detections algorithm.

Measuring conductivity can provide valuable information regarding an amount of a contaminant in a fluid. For example, as shown in the Examples, below, conductivity measurements may be used for determining the presence of a variety of contaminants that may be present in a fluid.

FIGS. 10A-C illustrate a conductivity measurement system in a network of systems in accordance with embodiments herein. In the example shown in FIG. 10A, some items are similar to those shown in earlier figures. FIG. 10A specifically shows that an electrical property sensing system 1010 can be located at a remote server location 1002. Therefore, computing device 1020 accesses those systems through remote server location 1002. User 1050 can use computing device 1020 to access user interfaces 1022 as well. For example, a user 1050 may interact with an application on the user interface 1022 of their smartphone 1020, or laptop, or other computing device to receive information from a two-phase immersion coolant system, a machining system, or a quality control system.

FIG. 10A shows that it is also contemplated that some elements of systems described herein are disposed at remote server location 1002 while others are not. By way of example, data stores of historic sensor signals 1030, thresholds 1040 and / or component information 1060 can be disposed at a location separate from location 1002 and accessed through the remote server at location 1002. Regardless of where they are located, they can be accessed directly by computing device 1020, 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 1050 to interact with system 1010 through their computing device 1020, to initiate a fluid 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, and personal digital assistants.

An electrical property 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 1010 receives electrical property measurements from one or more sensors 1070. Each sensor may include one or more pairs of electrodes on a PCB. Electrode pairs 932 may be, for example, formed within apertures machined or built into the printed circuit board or on a surface of a printed board as described above in any of their embodiments.

Electrical property measurement systems 1010 may receive a sensor signal as a conductivity signal, a relative permittivity (i.e., dielectric constant) signal, or 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 relative permittivity 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. 10, for example. An amount of a contaminant may be calculated based on calibration data, stored in a datastore 1060, 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 1010 may receive sensor signals from all sensors associated with a system such as two-phase immersion cooling system or a machining system. System 1010 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 useful 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 an amount of a contaminant in real time. With machine learning techniques, an amount of a contaminant could be predicted ahead of time. This allows for quicker adjustments.

Similarly, machine learning models, as described herein, may receive information from multiple systems, such as multiple sensors within a system including conductivity sensors, temperature sensors, motor speed signals, and material information. In some embodiments, 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 1010 can receive and communicate with pump controllers, inlet and purge valves, temperature sensors, heating elements, datastores having information for any of the fluids being used and their potential contaminants.

In embodiments where machine learning models are used, datastore may also include an analyzer that learns usage behavior of a particular system (e.g., a two-phase immersion cooling system or machining system) in order to improve operation and predictions. Usage data such as frequencies of purging fluid, adding fluid, changing out of the filter, and changing out of the sensor can be collected and used to train a model to more accurately predict trends and provide corrective action.

Similarly, as described herein, computing device may display a GUI created by generator 1022 that is updated periodically with information collected by system 1010 and / or any of datastores 1030, 1040, 1060. 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 an amount of a contaminant 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 system (e.g., a two-phase immersion cooling system or machining system). Alternatively, either encoder or regressor, or both, may be deployed in a cloud-based storage system. 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 fluids and contaminants in varying concentrations. 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 concentrations 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 fluid or contaminated fluid, this novel approach allows adaption for lot-to-lot variation of the fluid. This may be particular useful for a

cooling lubricant emulsion where a change in one of the parts can lead to a change in the mixed signal for the same oil to water ratio. It also enables tracking the mixing of the new materials of the same family by 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 fluid addition has completed, when phase separation is reversed, or when an emulsion has again reached stability.

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. 10A illustrates a concentration profile simulation system architecture 1000. Architecture 1000, however illustrates one embodiment of an implementation of a conductivity sensing system 1010. As an example, architecture 1000 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. 1-9 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. 10B illustrates an example system architecture. In the embodiment of FIG. 10B, the system is connected through wires, such that it is not a wireless or open distributing solution. Wired communication may also be useful in embodiments where a wireless connection would have slower transfer rates or potentially unreliability. However, as discussed with respect to FIG. 10A, it is contemplated that wireless systems may also be possible.

An electrical property sensor 1070 may capture a conductivity signal, for example, from one or more PCB sensors described herein, and provide that sensor signal to a signal converter 1082 where, if needed, signal conversion occurs. However, it is expressly contemplated that in some embodiments, electrical property sensor 1070 may provide a sensor signal directly to processor 1084. Signal converter 1082 may convert, for example, impedance to conductivity, an analog to a digital signal, or may do another suitable conversion.

Processor 1084 receives an electrical property indication, and generates an electrical property output, which may be provided to one or more devices 1086. Devices 1086 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 1084 may also consult one or more data stores 1088 in order to generate additional indications. For example, data store 1088 may include past conductivity sensor signals, conductivity sensor signal thresholds, and commands to adjust a system based on conductivity signal thresholds. Processor 1084 may act accordingly.

In accordance with embodiments herein, system may also have a pressure sensor 1090 that generates another signal. If needed, a signal converter 1092 may convert the additional signal from one form to another, from ampere to voltage, analog-to-digital, etc.

Processor 1084 may receive signals from electrical property sensor 1070 and another sensor 1090 continuously throughout a process, and may be able to generate outputs continuously as well, providing substantially real time information about a system. Processor 1084 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 1084 may communicate with sensors 1070, 1090 wirelessly, using a wired connection, or through any other suitable network. Processor 1084 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 1090 directly to processor 1084, from sensor 1070 through signal converter 1082, and directly to datastore 1088, where it may be retrieved by processor 1084. Similarly, a request for information from devices 1086 may be sent directly to sensors 1070, 1090, to datastore 1088 or to processor 1084.

In some embodiments, an MQTT broker is used to allow, for example, devices 1086 to subscribe to a subset of data from electrical property sensor 1070 or processor 1084, for example.

In some embodiments, processor 1084 also communicates with data store 1088, such that conductivity and other 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 undesired amount of a contaminant 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. 10B illustrates a single processor that receives information from a single set of sensors for a process. However, it is expressly contemplated that a production environment may have multiple machining systems running with multiple conductivity 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. 10C illustrates one configuration of a system that may be able to provide such functionality.

FIG. 10C illustrates a signal analysis system that communicates with a number of devices using a cloud-based network. As illustrated in FIG. 10C signal analysis system 2100 may communicate with a local analysis system 2140, such as that described with respect to FIG. 10B. Signal analysis system 2100 may receive a number of sensor signal data 2110 from a number of operations, such as a pilot line 2104, any of an operational line 2102, and/or a laboratory set up 2106. As described with respect to FIG. 10B, sensor signals 2100 may be digital signals, analog signals, conductivity measurement 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 2102 – 2106 may be received.

Signal analysis system 2100 may conduct analysis on receive sensor signal information 2100, 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, changing a filer, or any of those described above.

Signal analysis of 2100 may provide output indicia 2120 a number of suitable devices 2150. Signal analysis system 2100 may provide output information 2120 continuously, or in response to a request 2134 information. Request 2130 may be a one-time request for current status information, or a request to receive continuous updates going forward.

FIG. 11A-11D illustrate a sensing system in according with embodiments herein. Current sensing setups include components from different manufacturers, and data preparation and processing are 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. 11A illustrates a schematic of a sensing system in accordance with embodiments herein. Sensing system 1100 may be used with sensor described in embodiments herein, for example, or with another suitable sensor. A sensor signal reader 1102 connects to a sensor, for example an edge connector of a PCB-board that includes one or more electrode pairs. In some embodiments, a trans-impedance amplifier is present to convert current measurements to voltage. A concentrator 1110 receives sensor signals, processes said sensor signals, and provides an output. An output may be provided using an I/O device 1106 and / or another wired or wireless communication protocol 1108. A power source 1112 may provide power to concentrator 1110. While a wired power source 1112 is illustrated, it is possible that power may be provided wirelessly, or concentrator 1110 may be integrated into a two-phase immersion cooling system, or in a container, for example, useful in a machining system from which it draws power.

FIG. 11B illustrates one example interface 1120 of a concentrator, that may receive sensor signals using one or more sensor signal receiving ports 1124. Other data or inputs may be received through another receiver 1122, in some embodiments.

FIG. 11C illustrates another interface 1130, which may receive a coupling to an input/output device. Power may be provided, for example using port 1134. Data may be communicated from a concentrator using a computer link 1136.

FIG. 11D illustrates a component diagram of a sensing system 1140 in accordance with embodiments herein. One or more sensors 1142 provide sensor signals, received by one or more receivers 1144 coupled to, or included within, a housing 1165. In some embodiments, system 1140

includes an analog front-end which may include a filter 1148 and / or an analog multiplexor 1146. A converter, e.g. a DA- or DC-converter 1149 may be present. Concentrator 1150 may include non-volatile memory 1152, flash memory 1154, or another suitable information storage. A temperature sensor 1156 may be incorporated into concentrator 1150, or receive a temperature signal from a temperature sensor. Concentrator 1150 may include a clock 1158. Concentrator 1162 may also include reset functionality 1162.

A sensor analyzer 1170 may include calibration data and / or functionality 1172. A real-time operating system 1173 may manage functionality. Sensor analyzer 1170 may include Fourier transformer 1176. Sensor analyzer 1170 may include a waveform generator 1176. Sensor analyzer may include other applications 1175 that provide other functionality, such as detecting of material characteristics like mix ratio, material age, curing progress, etc. Sensor analyzer 1170 may also include an identifier 1174 that identifies a type of sensor.

Concentrator 1150 may include a power management system 1160 that includes, or accesses, a power supply 1166. A power quality 1168 may be monitored. Energy consumption 1169 may be tracked. Conversion input and output ranges 1164 may be stored. A symmetric voltage 1167 may be used.

FIGS. 12 to 14 illustrate example devices that can be used in the embodiments shown in previous Figures. FIG. 12 illustrates an example mobile device that can be used in the embodiments shown in previous Figures. FIG. 12 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. 12 provides a general block diagram of the components of a mobile cellular device 1216 that can run some components shown and described herein. Mobile cellular device 1216 interacts with them or runs some and interacts with some. In the device 1216, a communications link 1213 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 1213 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 1215. Interface 1215 and communication links 1213 communicate with a processor 1217 (which can also embody a processor) along a bus 1219 that is also connected to memory 1221 and input/output (I/O) components 1223, as well as clock 1225 and location system 1227.

I/O components 1223, in one embodiment, are provided to facilitate input and output operations and the device 1216 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 1223 can be used as well.

Clock 1225 illustratively comprises a real time clock component that outputs a time and date. It can also provide timing functions for processor 1217.

Illustratively, location system 1227 includes a component that outputs a current geographical location of device 1216. 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 1221 stores operating system 1229, network settings 1231, applications 1233, application configuration settings 1235, data store 1237, communication drivers 1239, and communication configuration settings 1241. Memory 1221 can include all types of tangible volatile and non-volatile computer-readable memory devices. It can also include computer storage media (described below). Memory 1221 stores computer readable instructions that, when executed by processor 1217, cause the processor to perform computer-implemented steps or functions according to the instructions. Processor 1217 can be activated by other components to facilitate their functionality as well. It is expressly contemplated that, while a physical memory store 1221 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. 13 shows that the device can also be a smart phone 1371. Smart phone 1371 has a touch sensitive display 1373 that displays icons or tiles or other user input mechanisms 1375. Mechanisms 1375 can be used by a user to run applications, make calls, perform data transfer operations, etc. In general, smart phone 1371 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. 13 illustrates an embodiment where a device 1300 is a smart phone 1371, it is expressly contemplated that a display may be presented on another computing device.

FIG. 14 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. 14, an example system for implementing some embodiments includes a general-purpose computing device in the form of a computer 2210. Components of computer 2210 may include, but are not limited to, a processing unit 2220 (which can comprise a processor, also known as processing circuitry), a system memory 2230, and a system bus 2221 that couples various system components including the system memory to the processing unit 2220. The system bus 2221 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. 14.

Computer 2210 typically includes a variety of computer readable media. Computer readable media can be any available media that can be accessed by computer 2210 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 2210. 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 2230 includes computer storage media in the form of volatile and/or nonvolatile memory such as read only memory (ROM) 2231 and random-access memory (RAM) 2232. A basic input/output system 2233 (BIOS) containing the basic routines that help to transfer information between elements within computer 2210, such as during start-up, is typically stored in ROM 2231. RAM 2232 typically contains data and/or program modules that are immediately accessible to and/or presently being operated on by processing unit 2220. By way of example, and not limitation, FIG. 14 illustrates operating system 2234, application programs 2235, other program modules 2236, and program data 2237.

The computer 2210 may also include other removable/non-removable and volatile/nonvolatile computer storage media. By way of example only, FIG. 14 illustrates a hard disk drive 2241 that reads from or writes to non-removable, nonvolatile magnetic media, nonvolatile magnetic disk 2252, an optical disk drive 2255, and nonvolatile optical disk 2256. The hard disk drive 2241 is typically connected to the system bus 2221 through a non-removable memory interface such as interface 2240, and optical disk drive 2255 are typically connected to the system bus 2221 by a removable memory interface, such as interface 2250.

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. 14, provide storage of computer readable instructions, data structures, program modules and other data for the computer 2210. In FIG. 14, for example, hard disk drive 2241 is illustrated as storing operating

system 2244, application programs 2245, other program modules 2246, and program data 2247. Note that these components can either be the same as or different from operating system 2234, application programs 2235, other program modules 2236, and program data 2237.

A user may enter commands and information into the computer 2210 through input devices such as a keyboard 2262, a microphone 2263, and a pointing device 2261, 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 2220 through a user input interface 2260 that is coupled to the system bus but may be connected by other interface and bus structures. A visual display 2291 or other type of display device is also connected to the system bus 2221 via an interface, such as a video interface 2290. In addition to the monitor, computers may also include other peripheral output devices such as speakers 2297 and printer 2296, which may be connected through an output peripheral interface 2295.

The computer 2210 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 2280.

When used in a LAN networking environment, the computer 2210 is connected to the LAN 2271 through a network interface or adapter 2270. When used in a WAN networking environment, the computer 2210 typically includes a modem 2272 or other means for establishing communications over the WAN 2273, such as the Internet. In a networked environment, program modules may be stored in a remote memory storage device. FIG. 14 illustrates, for example, that remote application programs 2285 can reside on remote computer 2280.

In the present detailed description, 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.

EXAMPLES

These examples are merely for illustrative purposes and are not meant to be overly limiting on the scope of the appended claims. Notwithstanding that the numerical ranges and parameters setting forth the broad scope of the present disclosure are approximations, the numerical values set forth in the specific examples are reported as precisely as possible. Any numerical value, however, inherently contains certain errors necessarily resulting from the standard deviation found in their respective testing measurements. At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, each numerical parameter should at least be construed considering the number of reported significant digits and by applying ordinary rounding. Unless otherwise noted, all chemicals used in the examples can be obtained from the noted suppliers.

Example

A sensor as illustrated in FIG. 5 was designed. First the holes for the electrodes and the temperature sensor were milled out. After drilling holes or milling slots in the PCB, the PCB was chemically coated with copper. This coating happened in tanks filled with liquid chemicals. After this process, a 1-μm thin layer of copper covered the inside of the milled apertures. To increase the thickness of this layer, additional copper was added by galvanic copper deposition. After this step, a 20-μm thick layer of copper covered the inside of the holes and slots. There were two electrically conductive surfaces facing to each other, but they were electrically connected together at both ends of the slots.

To get two electrically separate electrodes, the connections at the ends of the slots were removed by drilling or milling holes or slots at the end of the plated slots. The copper plating of the plated slots was thus removed in the curved area at the ends.

Four glass jars were each charged with 300 milliliters (mL) of ethoxy nonafluorobutane obtained under the trade designation "3M NOVEC 7200 ENGINEERING FLUID" from 3M Company, St. Paul, MN. Nothing was added to jar 1. Into glass jars 2 to 4, a small piece of plastic was added from three different cables measuring approximately 5 mm long. The cables were typical of that found in a two-

phase immersion cooling system. The material was that indicated in Table 1, below. The glass jars were allowed to stand for 48 hours at room temperature. The sensor described above was dipped into the fluid and was allowed to retrieve conductivity signals through a reader connected to a connector box where a software program took the signals and created data that was graphed over time for conductivity measurements. The results are provided in Table 1, below.

Table 1.

Jar	Plastic	Conductivity (Siemens/meter)
1	none	0
2	Thermoplastic Elastomer (TPE)	$5.6\text{-}5.3 \times 10^{-7}$
3	Fluorinated Ethylene Propylene (FEP)	2.15×10^{-7}
4	"HF365" Ribbon Cable obtained from 3M Company	0.85×10^{-8}

The preceding description, given in order to enable one of ordinary skill in the art to practice the claimed disclosure, is not to be construed as limiting the scope of the disclosure, which is defined by the claims and all equivalents thereto.

What Is Claimed Is:

1. A method of detecting an amount of a contaminant in a fluid, the method comprising:

immersing a sensor into a fluid, wherein the sensor comprises a printed circuit board comprising:

a first surface and a second surface opposite the first surface, the first surface and the second surface separated by a thickness; and

a first sensing area comprising a receiving electrode and a transmitting electrode, each of which directly contacts the fluid;

receiving using a signal receiver a sensed electrical property value from the sensor;

determining using an analyzer the amount of the contaminant in the fluid based on the sensed electrical property value; and

communicating the amount of the contaminant in the fluid using a communicator.

2. The method of claim 1, wherein the first sensing area further comprises an aperture extending from the first surface of the printed circuit board to the second surface of the printed circuit board, wherein the aperture comprises the receiving electrode and the transmitting electrode.

3. The method of claim 2, wherein the aperture is one of a plurality of apertures providing a plurality of sensing areas.

4. The method of claim 1, wherein the first sensing area is on the first surface of the printed circuit board, 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 is interleaved between the plurality of receiving branches.

5. The method of claim 4, further comprising a second sensing area comprising a second receiving electrode and a second transmitting electrode, wherein the second sensing area is on the first surface of the printed circuit board or on the second surface of the printed circuit board.

6. The method of any one of claims 1 to 5, wherein the sensor is configured to be located in a housing in a conduit as the fluid flows through the housing in the conduit.

7. The method of any one of claims 1 to 5, wherein the sensor is configured to be immersed in the fluid while the fluid is static.

8. The method of any one of claims 1 to 7, wherein the electrical property value comprises an impedance, a conductivity, or a relative permittivity.

9. The method of any one of claims 1 to 8, wherein the fluid is a liquid or a foam.

10. The method of any one of claims 1 to 9, wherein the fluid is a dielectric fluid.

11. The method of any one of claims 1 to 10, wherein the fluid is located in a housing of a two-phase immersion cooling system.

12. The method of any one of claims 1 to 11, wherein the contaminant is a plasticizer in a polymeric material.

13. The method of any one of claims 1 to 9, wherein the fluid is a cooling lubricant.

14. The method of claim 13, wherein the fluid comprises water, and wherein the contaminant is a microorganism.

15. The method of claim 13 or 14, wherein the contaminant comprises particles dispersed in the fluid.

16. The method of any one of claims 1 to 15, wherein the sensing area comprises a sensing length and a sensing width, and wherein the printed circuit board has a length that is more than twice the sensing length.

17. The method of any one of claims 1 to 16, wherein the printed circuit board further comprises an edge connector configured to communicably couple to the signal receiver.

18. The method of claim 17, wherein the edge connector is configured to communicate signals from the sensing area to the analyzer.

19. The method of any one of claims 1 to 18, wherein the printed circuit board further comprises a temperature sensor on at least one of the first surface or the second surface.

20. The method of any one of claims 1 to 19, wherein at the transmitting electrode, a voltage is controlled, and wherein the receiving electrode receives a conducted electrical current.

21. The method of any one of claims 1 to 19, wherein at the transmitting electrode an electrical current is controlled, and wherein the receiving electrode receives a voltage.

22. The method of any one of claims 1 to 19, wherein the transmitting electrode transmits an electrical signal.

23. The method of any one of claims 1 to 22, further comprising comparing the sensed electrical property value to a threshold value for the fluid.

24. The method of any one of claims 1 to 23, wherein the communicating comprises generating a command to remove the contaminant.

25. The method of any one of claims 1 to 24, wherein the communicating comprises communicating a value to a display.

26. A contamination detection system comprising:

a sensor configured to be immersed in the fluid and configured to sense an electrical property value for the fluid when in direct contact with the fluid, the sensor comprising:

a first surface and a second surface opposite the first surface, the first surface and the second surface separated by a thickness; and

a first sensing area comprising a receiving electrode and a transmitting electrode each configured to directly contact the fluid;

an analyzer that receives the electrical property value and, based on the sensed electrical property value, determines the amount of the contaminant in the fluid; and

a communicator configured to communicate the amount of the contaminant in the fluid.

27. A contamination detection system comprising:

a sensor configured to be immersed in the fluid and configured to sense an electrical property value for the fluid when in direct contact with the fluid, the sensor comprising:

a first surface and a second surface opposite the first surface, the first surface and the second surface separated by a thickness; and

a first sensing area comprising a receiving electrode and a transmitting electrode each configured to directly contact the fluid;

a controller comprising processing circuitry and a memory, the controller operably coupled to the sensor and configured to:

receive the electrical property value;

determine, based on the sensed electrical property value, the amount of the contaminant in the fluid; and

communicate the amount of the contaminant in the fluid.

28. The contamination detection system of claim 26 or 27, wherein the first sensing area further comprises an aperture extending from the first surface of the printed circuit board to the second surface of the printed circuit board, wherein the aperture comprises the receiving electrode and the transmitting electrode.

29. The contamination detection system of claim 28, wherein the aperture is one of a plurality of apertures providing a plurality of sensing areas.

30. The contamination detection system of claim 26 or 27, wherein the first sensing area is on the first surface of the printed circuit board, 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 is interleaved between the plurality of receiving branches.

31. The contamination detection system of claim 30, further comprising a second sensing area comprising a second receiving electrode and a second transmitting electrode, wherein the second sensing area is on the first surface of the printed circuit board or on the second surface of the printed circuit board.

32. The contamination detection system of any one of claims 26 to 31, wherein the sensor is configured to be located in a housing in a conduit as the fluid flows through the housing in the conduit.

33. The contamination detection system of any one of claims 26 to 31, wherein the sensor is configured to be immersed in the fluid while the fluid is static.

34. The contamination detection system of any one of claims 26 to 33, wherein the electrical property value comprises an impedance, a conductivity, or a relative permittivity.

35. The contamination detection system of any one of claims 26 to 34, wherein the sensor is configured to be located in a housing of a two-phase immersion cooling system.

36. The contamination detection system of any one of claims 26 to 35, wherein the contaminant is a plasticizer in a polymeric material.

37. The contamination detection system of any one of claims 26 to 34, wherein the sensor is configured to be located in a container of cooling lubricant.

38. The contamination detection system of claim 37, wherein the contaminant is a microorganism.

39. The contamination detection system of claim 37 or 38, wherein the contaminant comprises metallic particles.

40. The contamination detection system of any one of claims 26 to 39, wherein the sensing area comprises a sensing length and a sensing width, and wherein the printed circuit board has a length that is more than twice the sensing length.

41. The contamination detection system of any one of claims 26 to 40, wherein the printed circuit board further comprises an edge connector configured to communicably couple to a sensor signal receiver.

42. The contamination detection system of claim 41, wherein the edge connector is configured to communicate signals from the sensing area to a signal processor.

43. The contamination detection system of any one of claims 26 to 42, wherein the printed circuit board further comprises a temperature sensor on at least one of the first surface or the second surface.

44. The contamination detection system of any one of claims 26 to 43, wherein the sensor is configured to sense the electrical property value when a voltage is controlled at the transmitting electrode, and wherein the receiving electrode is configured to receive a conducted electrical current.

45. The contamination detection system of any one of claims 26 to 43, wherein the sensor is configured to sense the electrical property value when an electrical current is controlled at the transmitting electrode, and wherein the receiving electrode is configured to receive a voltage.

46. The contamination detection system of any one of claims 26 to 43, wherein the sensor is configured to sense the electrical property value when the transmitting electrode transmits an electrical signal.

47. The contamination detection system of any one of claims 26 to 46, wherein the analyzer or controller compares the sensed electrical property value to a threshold value for the fluid, and if the sensed electrical property value is outside the threshold, generates a contamination detection indication.

48. The contamination detection system of any one of claims 26 to 47, wherein the communicator or controller generates a command to remove the contaminant.

49. The contamination detection system of any one of claims 26 to 48, wherein the communicator or controller is configured to communicate the amount of the contaminant in the fluid to a display.

50. The contamination detection system of any one of claims 26 to 49, wherein the sensor further comprises at least one further sensing area comprising a further receiving electrode and a further transmitting electrode each configured to directly contact the fluid, wherein the controller or analyzer is configured to:

receive at least one further electrical property value;

determine, based on the at least one further sensed electrical property value, at least one of a level of the fluid, an oil-to-water ratio of the fluid, or an amount of air bubbles in the fluid; and

communicate at least one of the level of the fluid, the oil-to-water ratio of the fluid, or the amount of air bubbles in the fluid.

51. The method of any one of claims 1 to 25, wherein the sensor further comprises at least one further sensing area comprising a further receiving electrode and a further transmitting electrode each configured to directly contact the fluid, the method further comprising:

receiving at least one further electrical property value;

determining, based on the at least one further sensed electrical property value, at least one of a level of the fluid, an oil-to-water ratio of the fluid, or an amount of air bubbles in the fluid; and

communicating at least one of the level of the fluid, the oil-to-water ratio of the fluid, or the amount of air bubbles in the fluid.

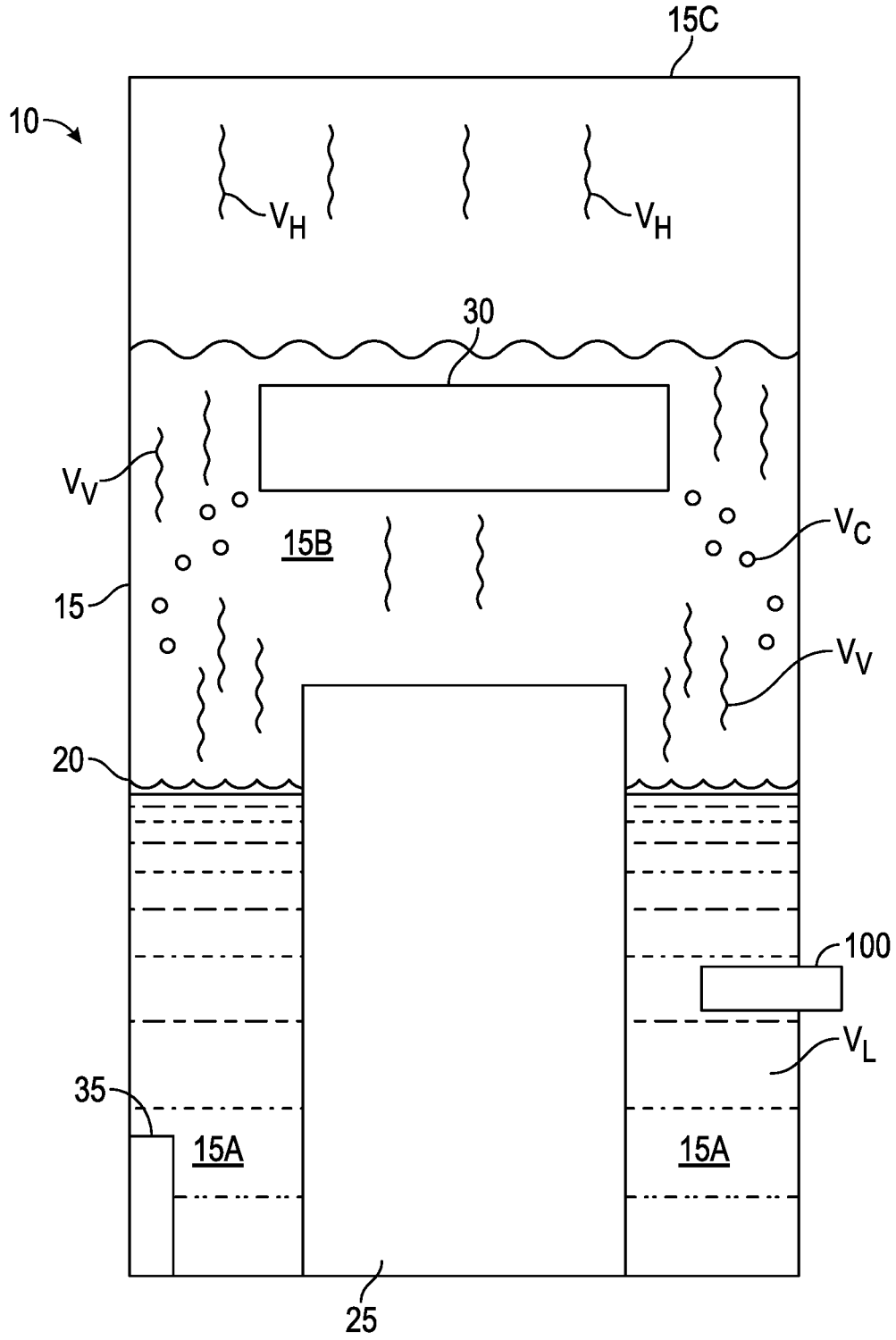

FIG. 1

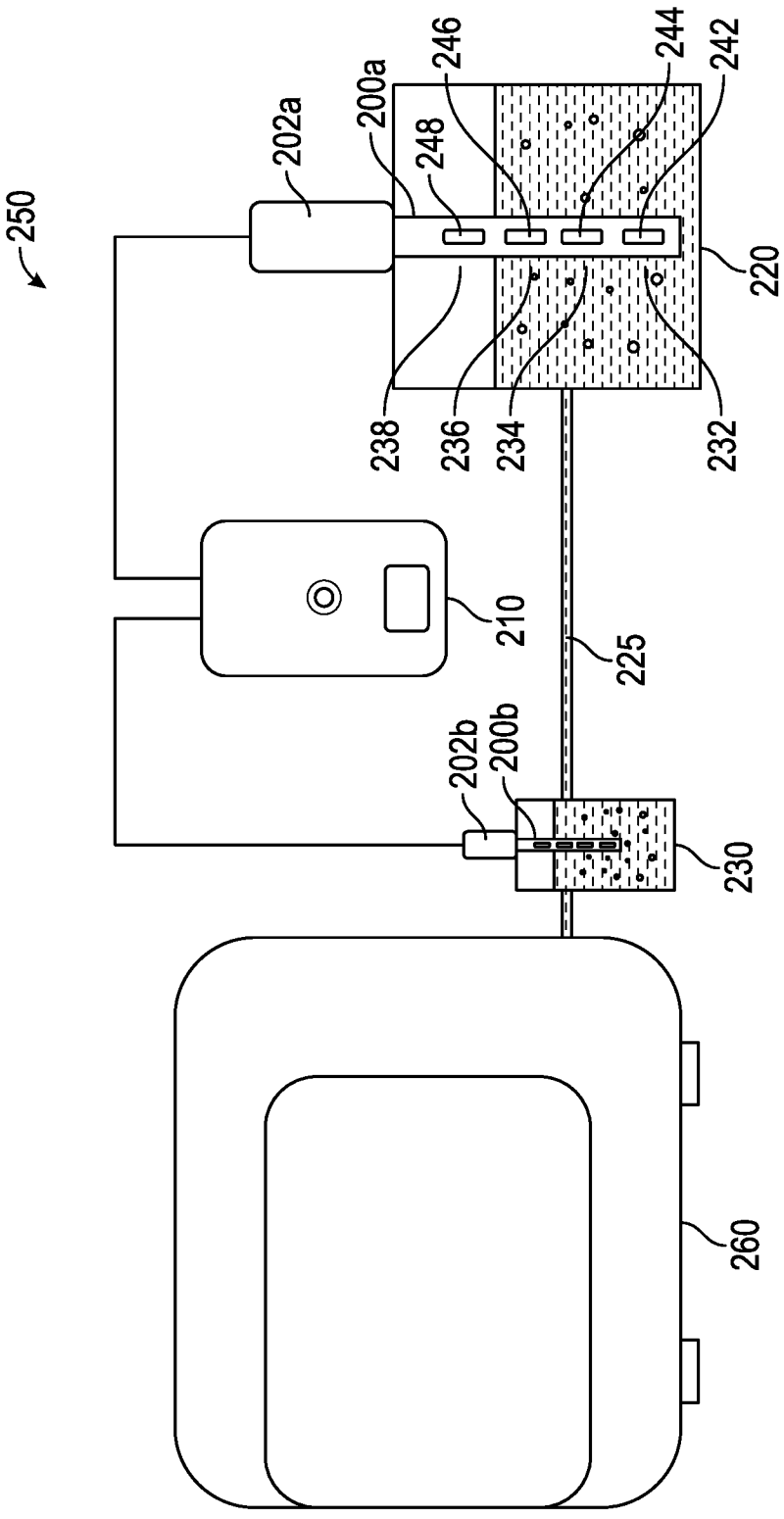
250
202a
200a
246
244
242
248
220
238
236
234
232
210
225
202b
200b
230
260

FIG. 2

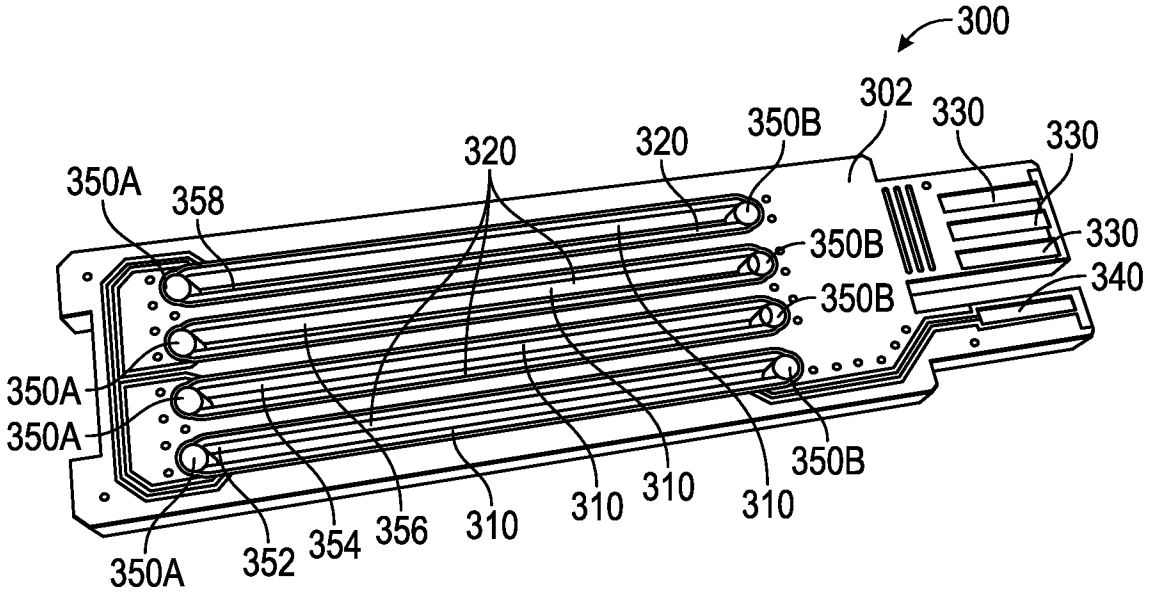
300
302
330
330
350B
320
320
350A
358
350B
330
340
350B
350A
350A
350B
350A
352
354
356
310
310
310
310

FIG. 3A

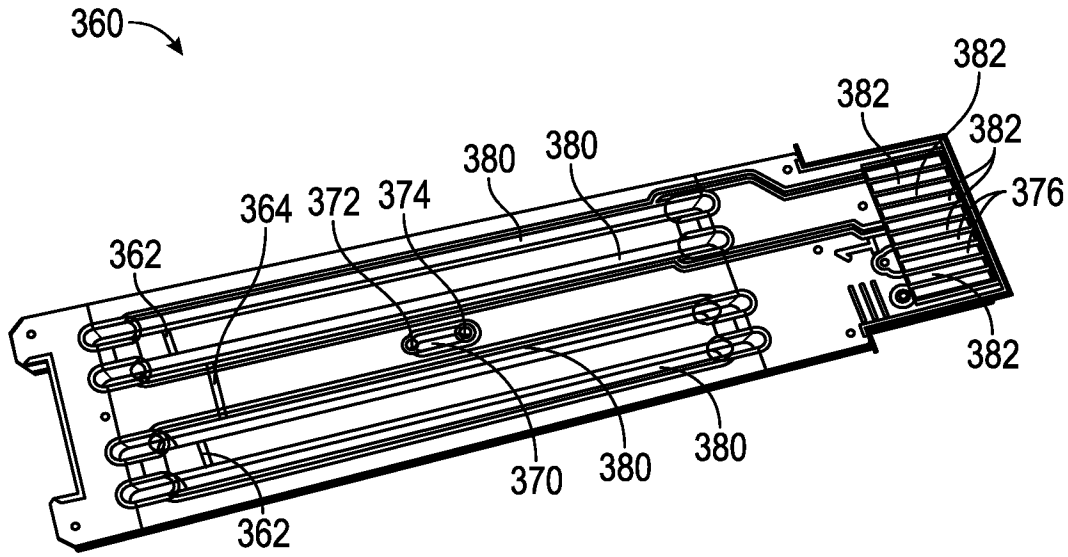
360
382
382
382
376
380
380
364
372
374
362
382
370
380
380
362

FIG. 3B

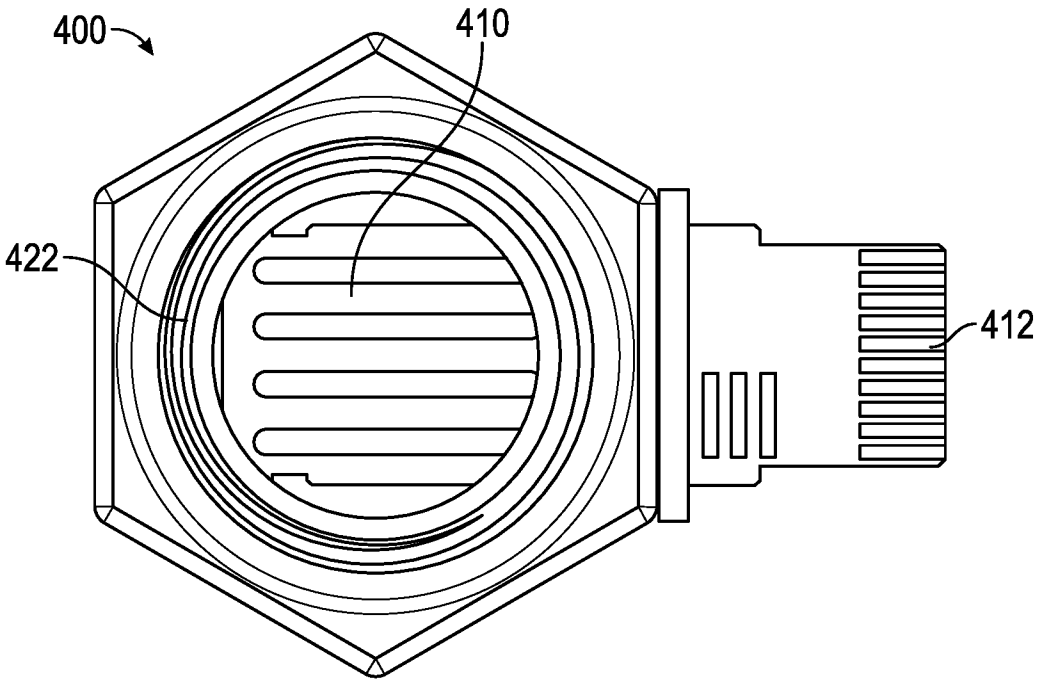

FIG. 4A

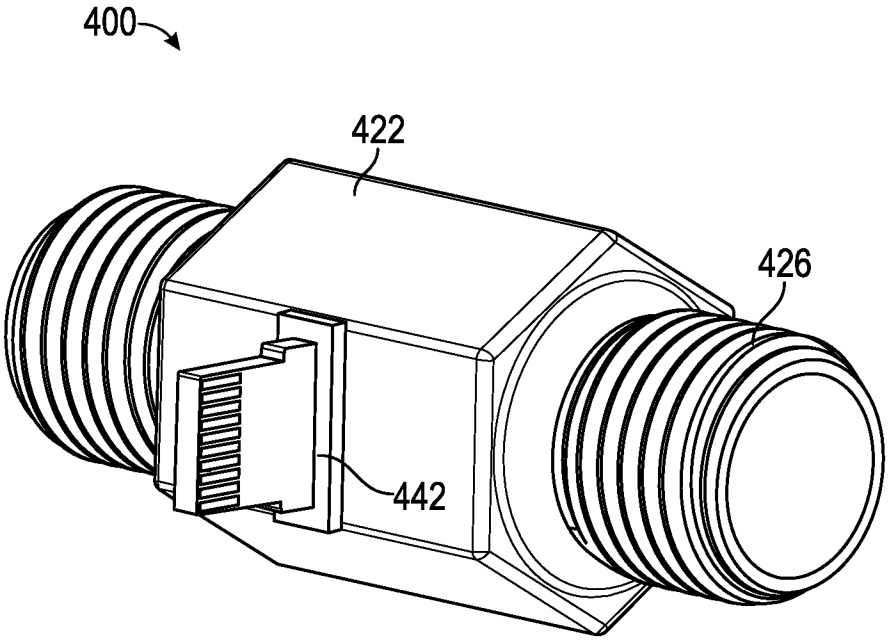

FIG. 4B

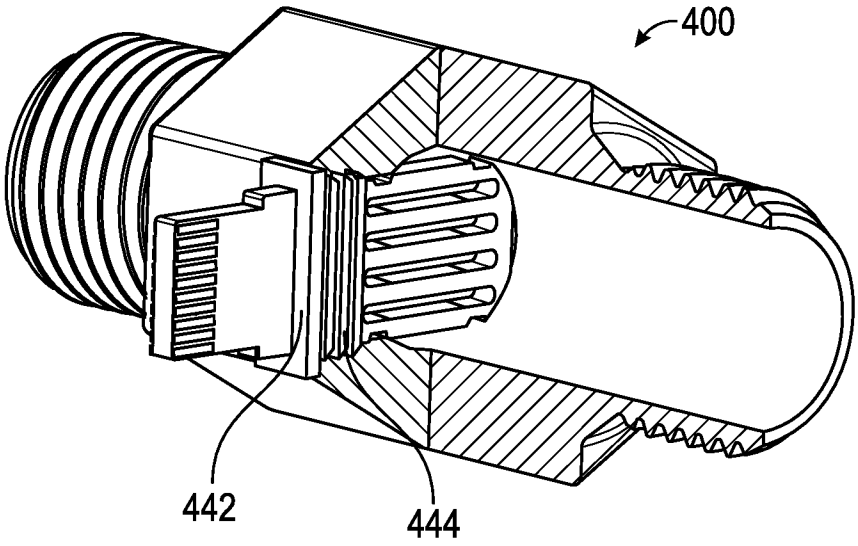

FIG. 4C

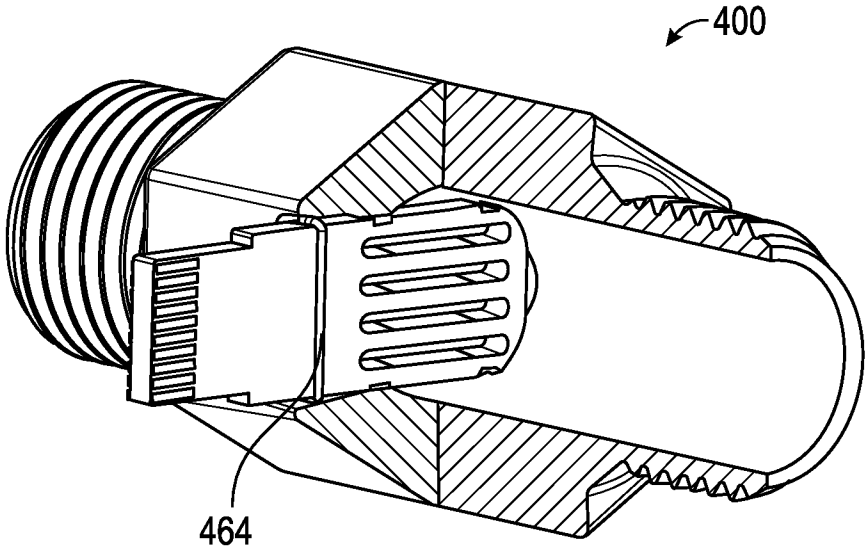

FIG. 4D

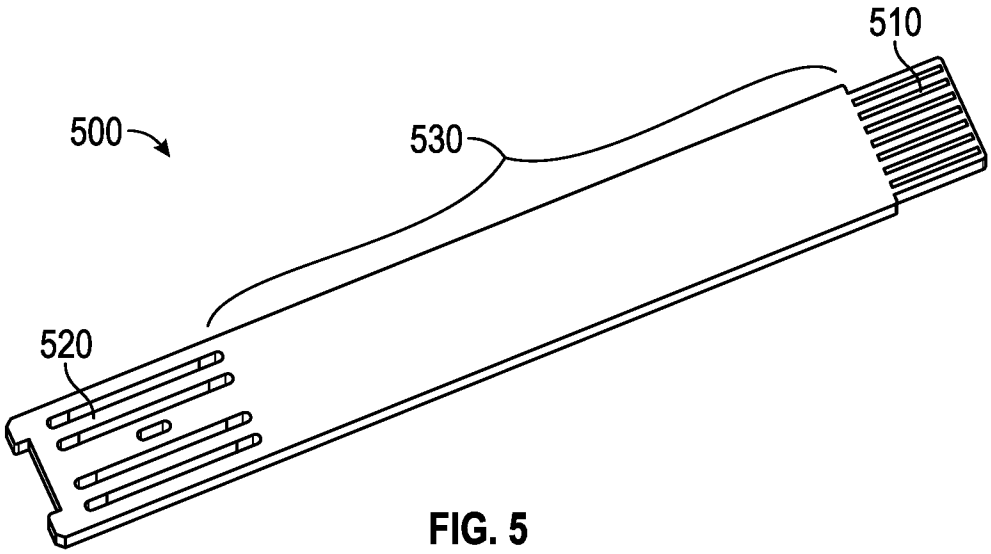

FIG. 5

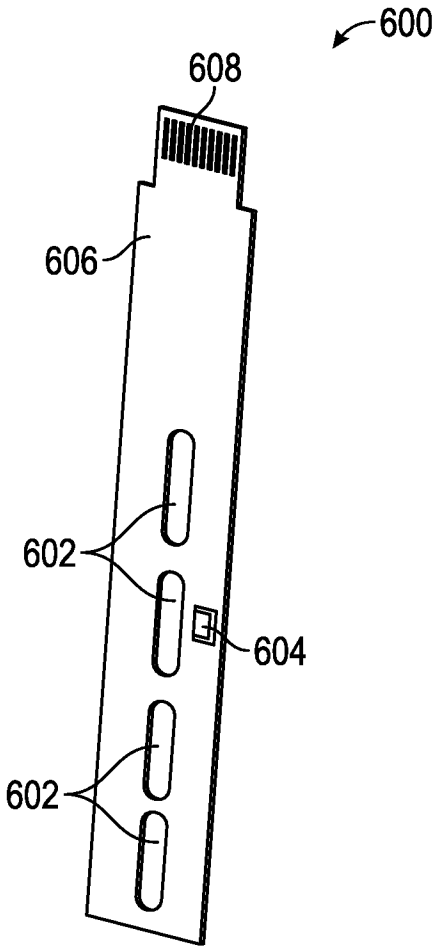

FIG. 6A

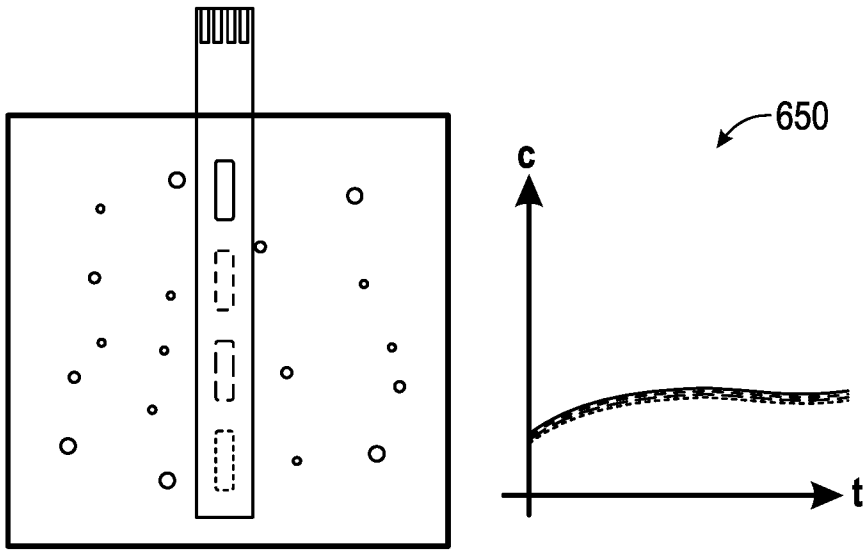

FIG. 6B

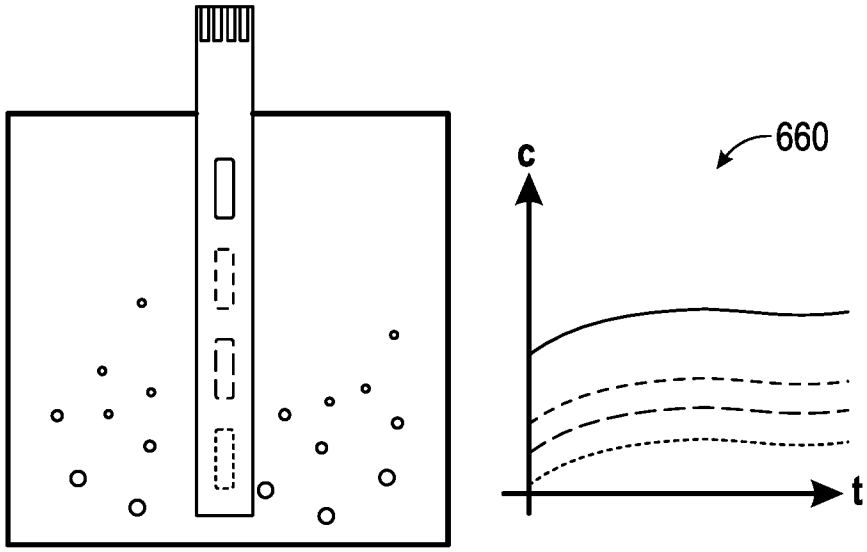

FIG. 6C

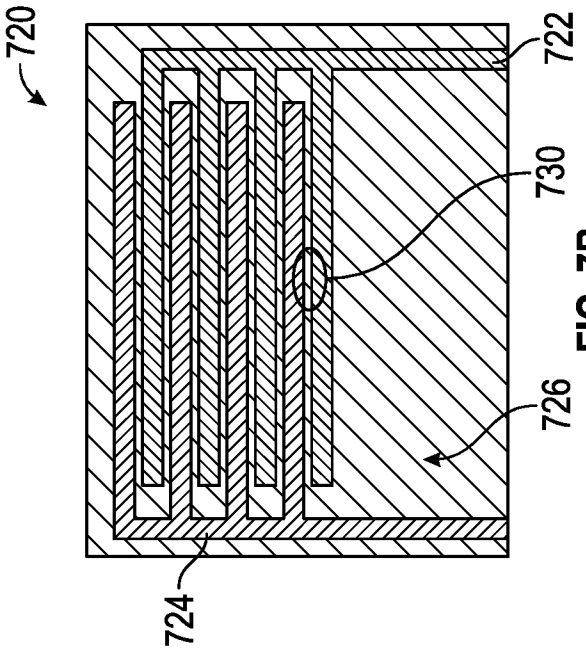

FIG. 7B

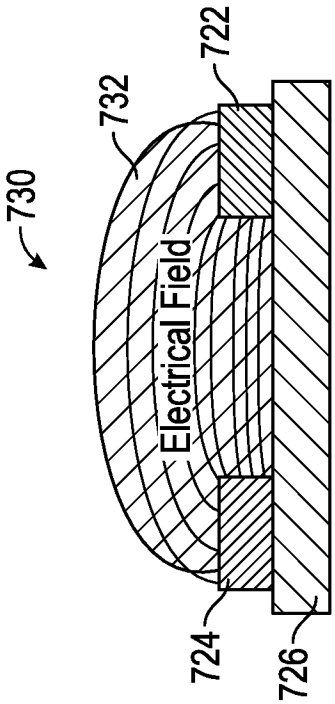

FIG. 7C

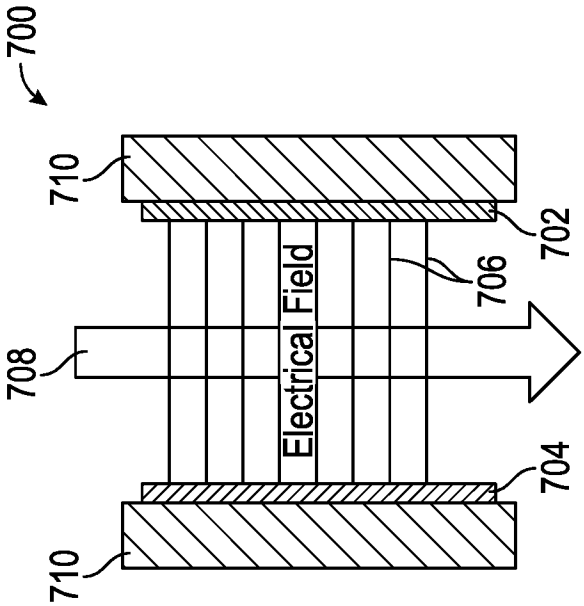

FIG. 7A

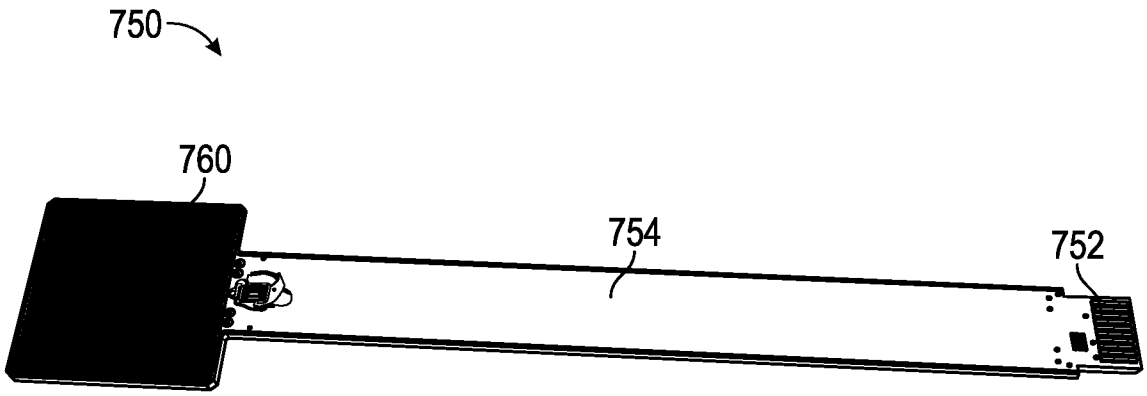

FIG. 7D

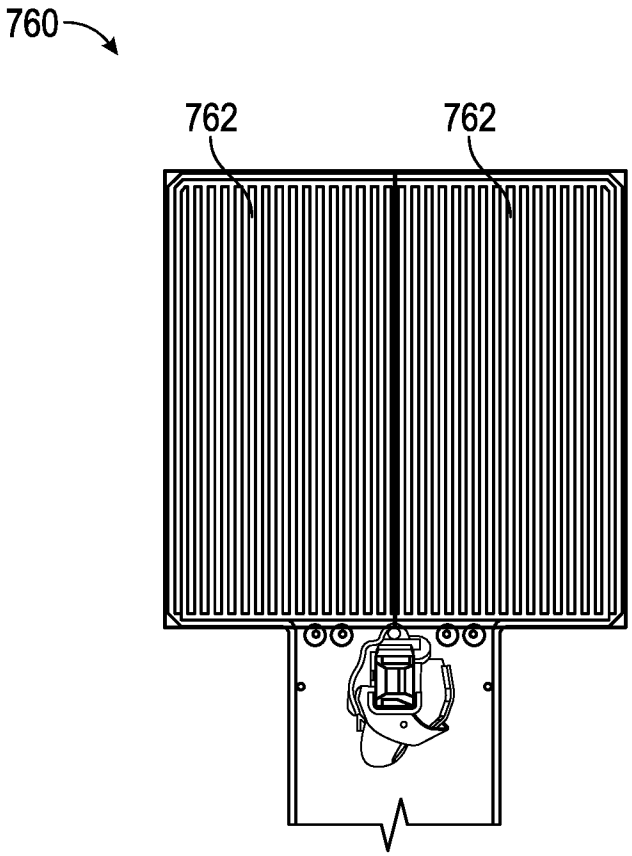

FIG. 7E

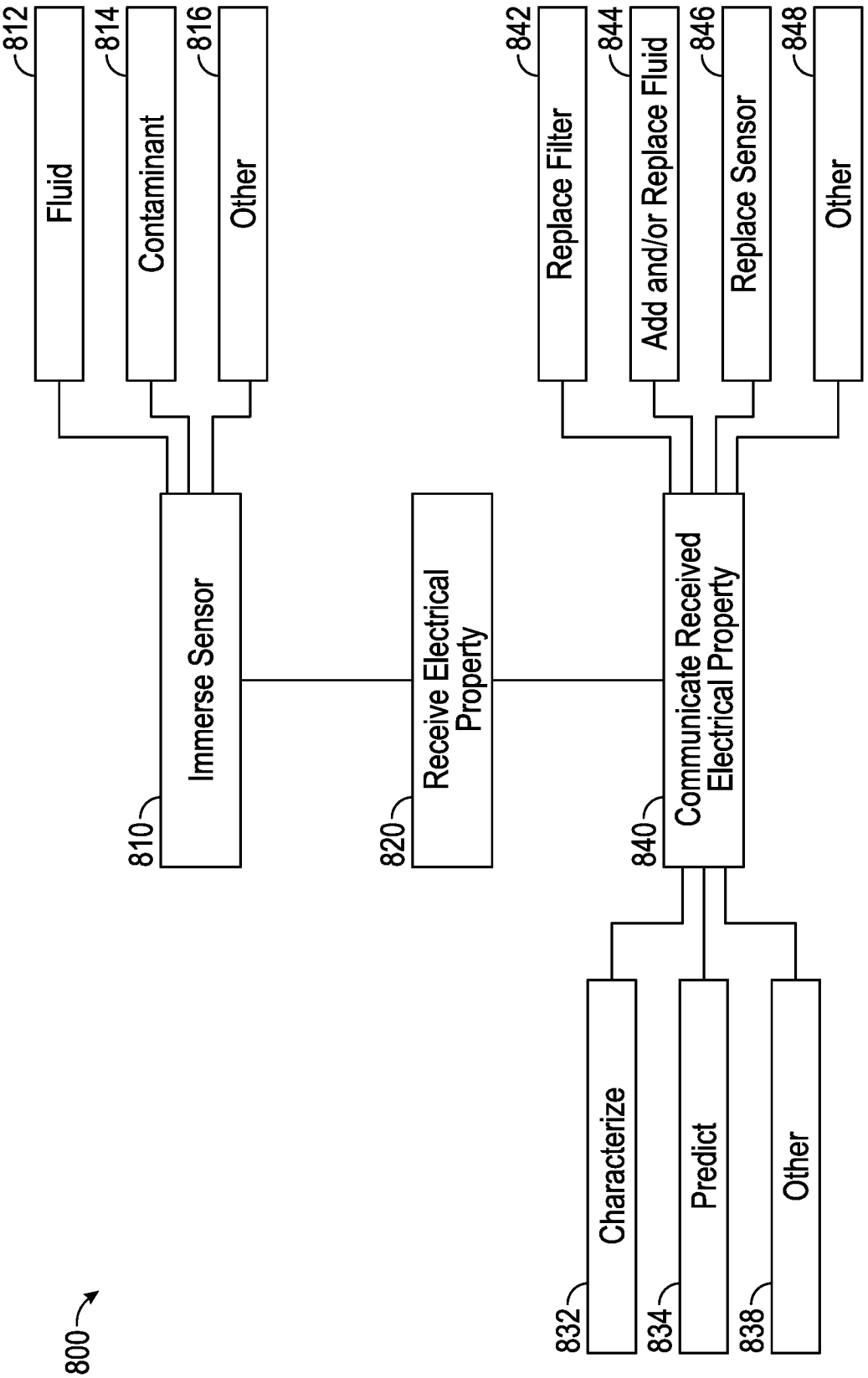
800
810
Immerse Sensor
812
Fluid
814
Contaminant
816
Other
820
Receive Electrical Property
840
Communicate Received Electrical Property
842
Replace Filter
844
Add and/or Replace Fluid
846
Replace Sensor
848
Other
832
Characterize
834
Predict
838
Other

FIG. 8

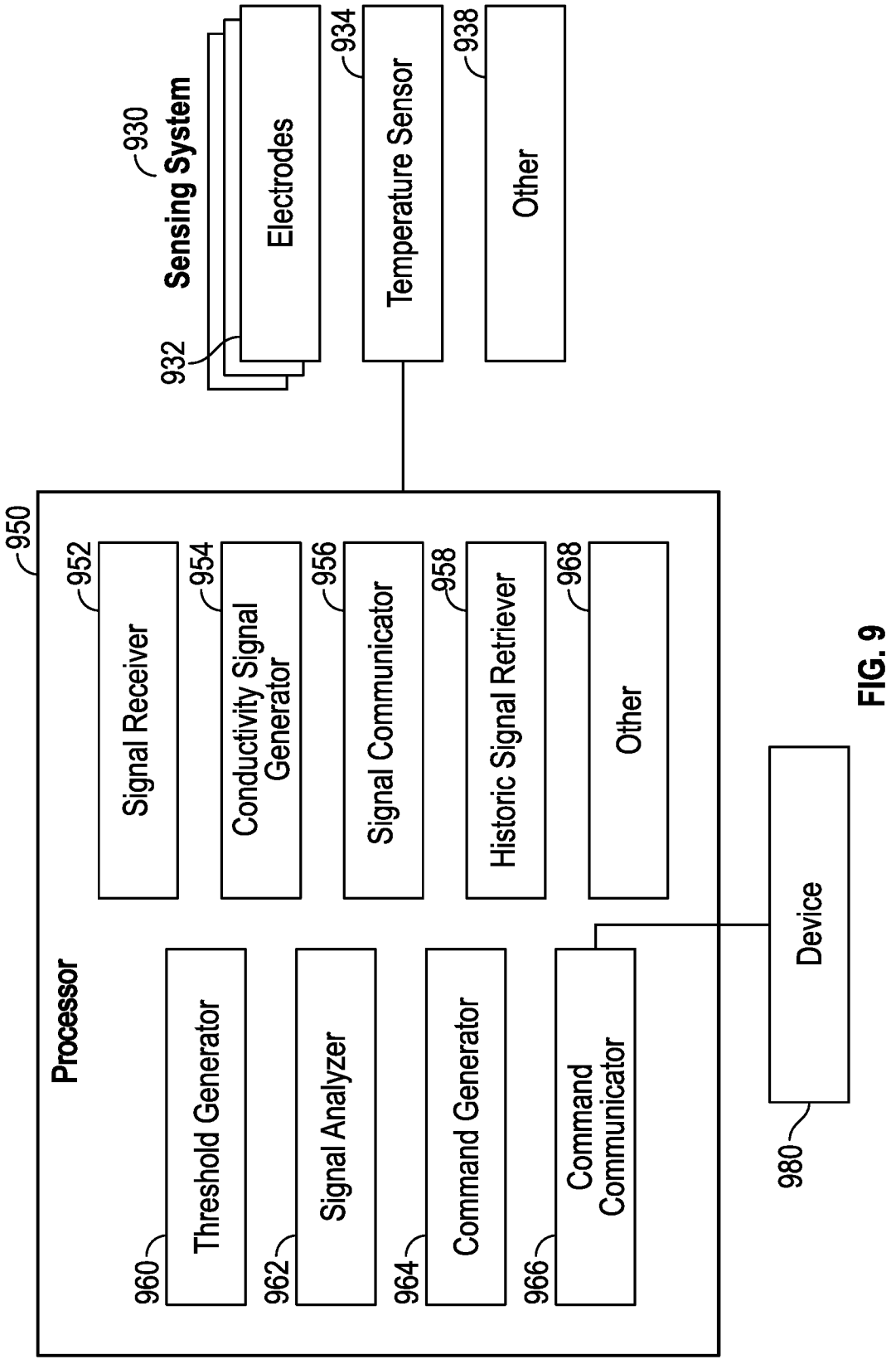
930
Sensing System
932
Electrodes
934
Temperature Sensor
938
Other
950
Processor
952
Signal Receiver
954
Conductivity Signal Generator
956
Signal Communicator
958
Historic Signal Retriever
968
Other
960
Threshold Generator
962
Signal Analyzer
964
Command Generator
966
Command Communicator
980
Device

FIG. 9

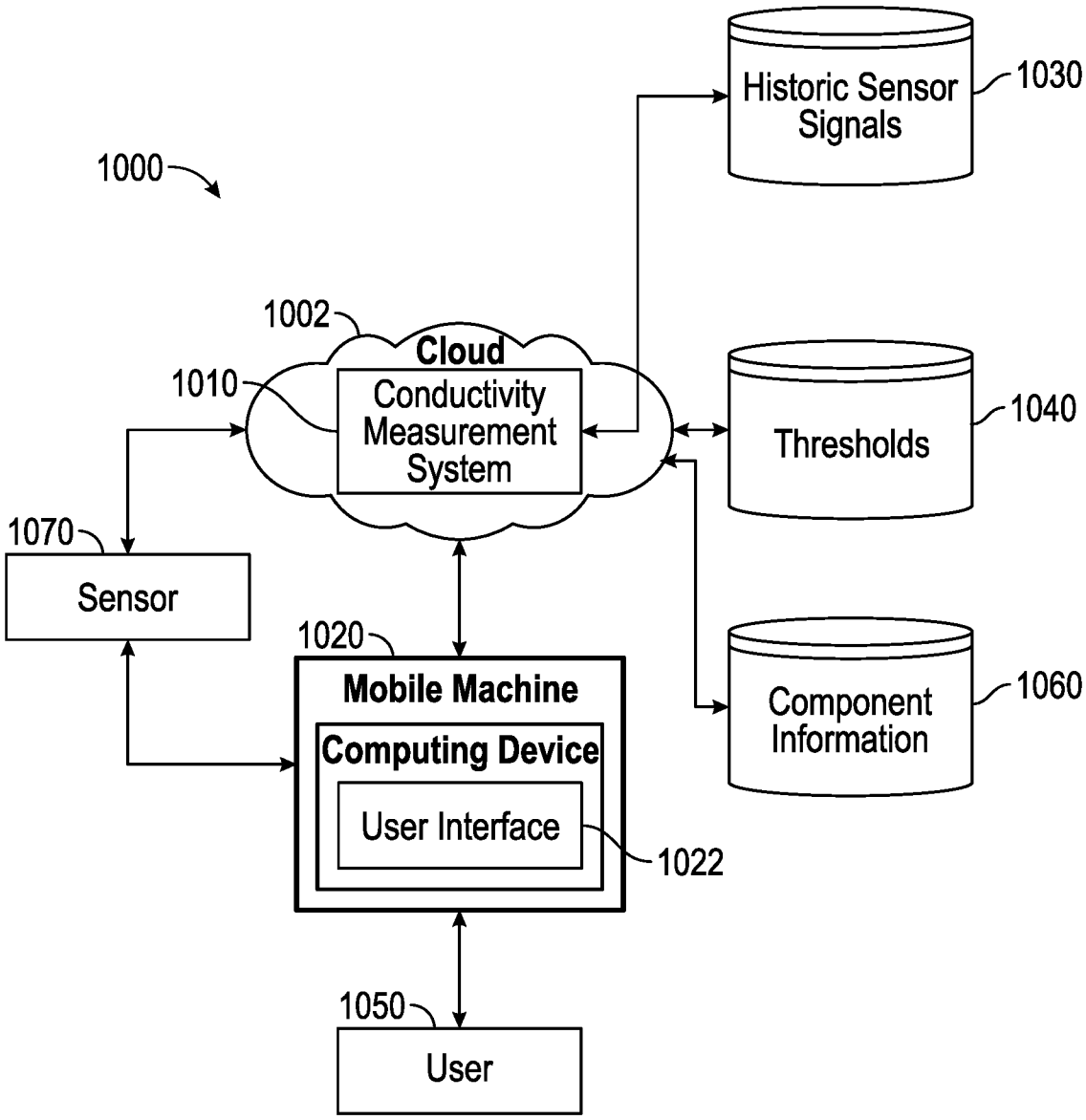
1000
Historic Sensor Signals
1030
1002
Cloud
1010
Conductivity Measurement System
Thresholds
1040
1070
Sensor
1020
Mobile Machine
Computing Device
User Interface
1022
Component Information
1060
1050
User

FIG. 10A

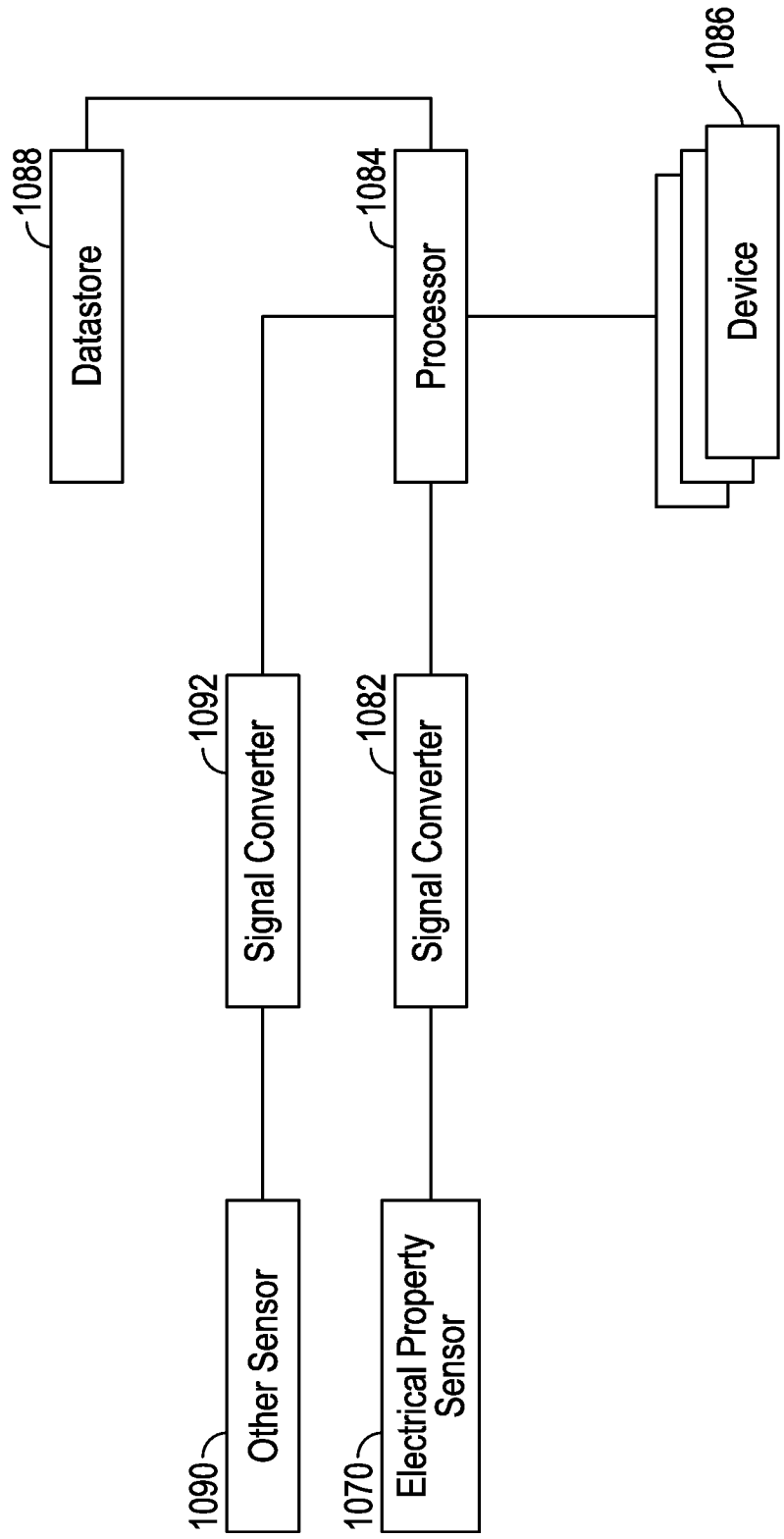
1086
1088
Datastore
1084
Processor
Device
1092
Signal Converter
1082
Signal Converter
1090
Other Sensor
1070
Electrical Property Sensor

FIG. 10B

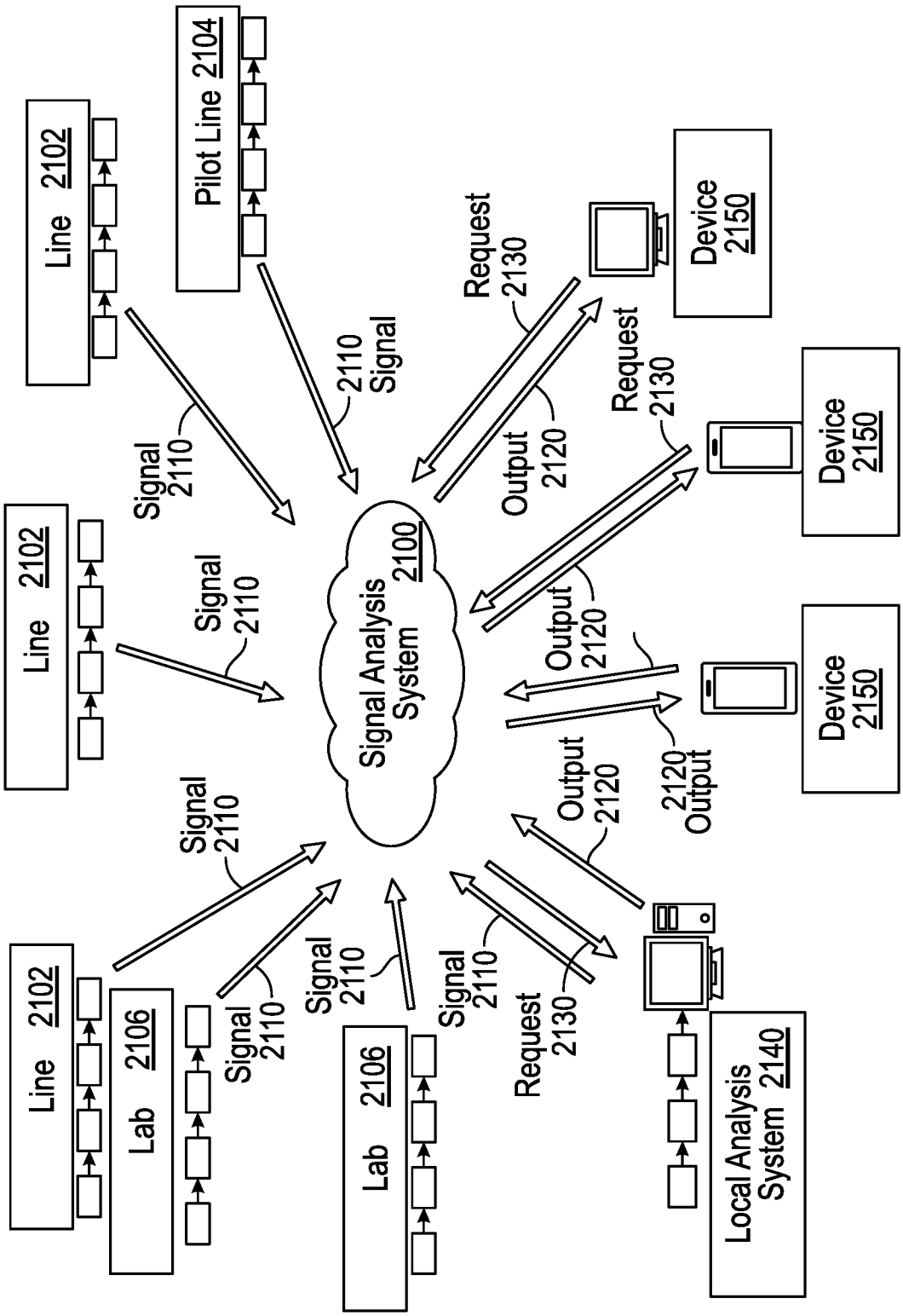
Line 2102
Pilot Line 2104
Signal 2110
2110 Signal
Request 2130
Output 2120
Device 2150
Signal Analysis System 2100
Lab 2106
Local Analysis System 2140

FIG. 10C

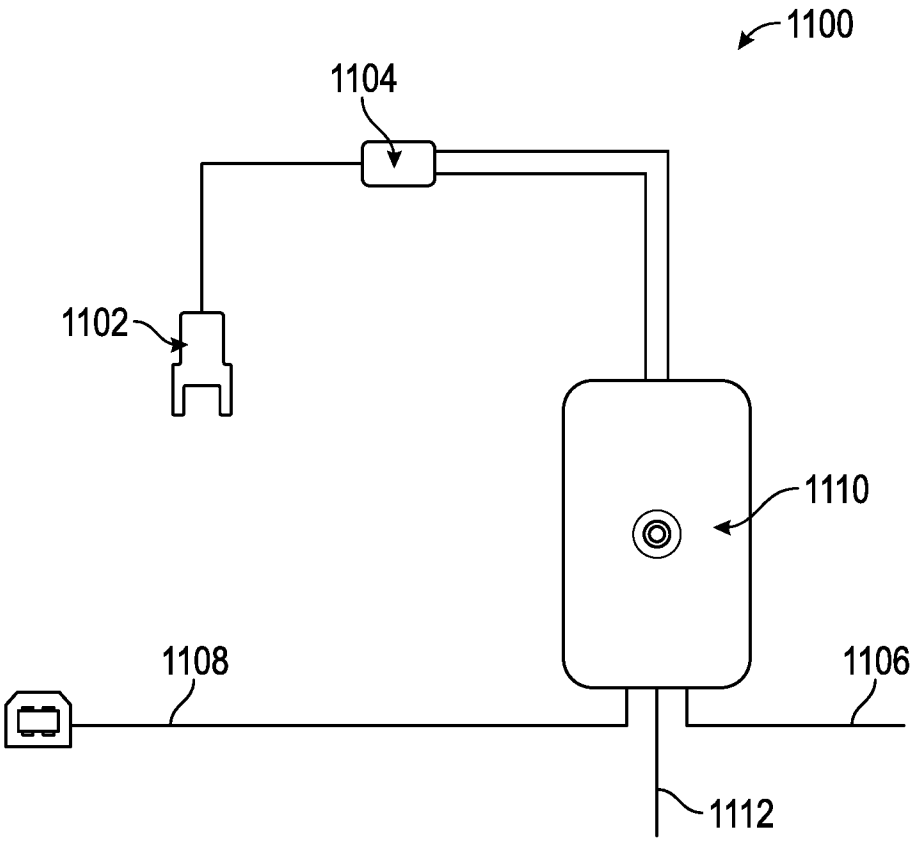

FIG. 11A

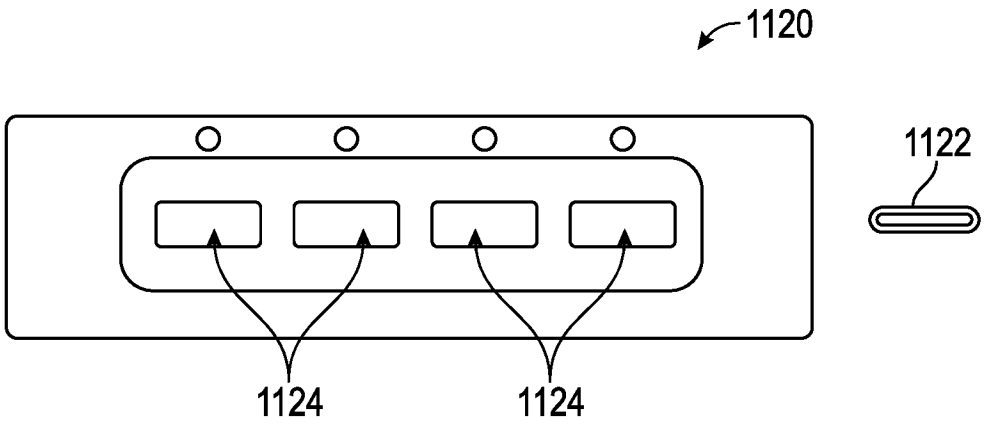

FIG. 11B

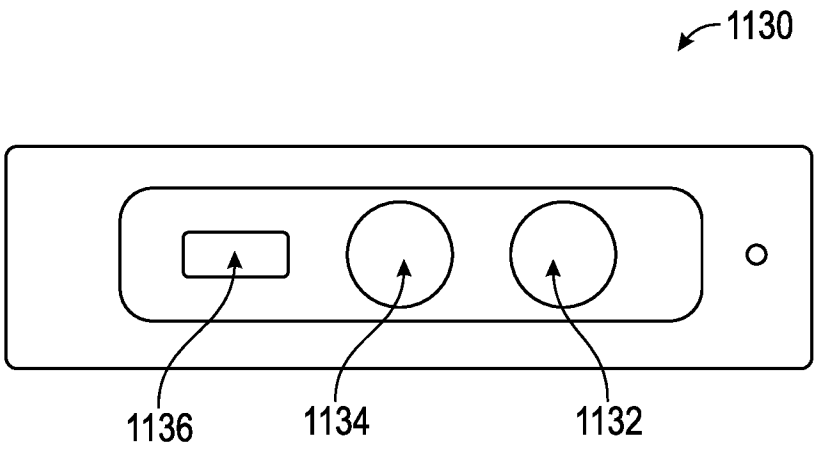

FIG. 11C

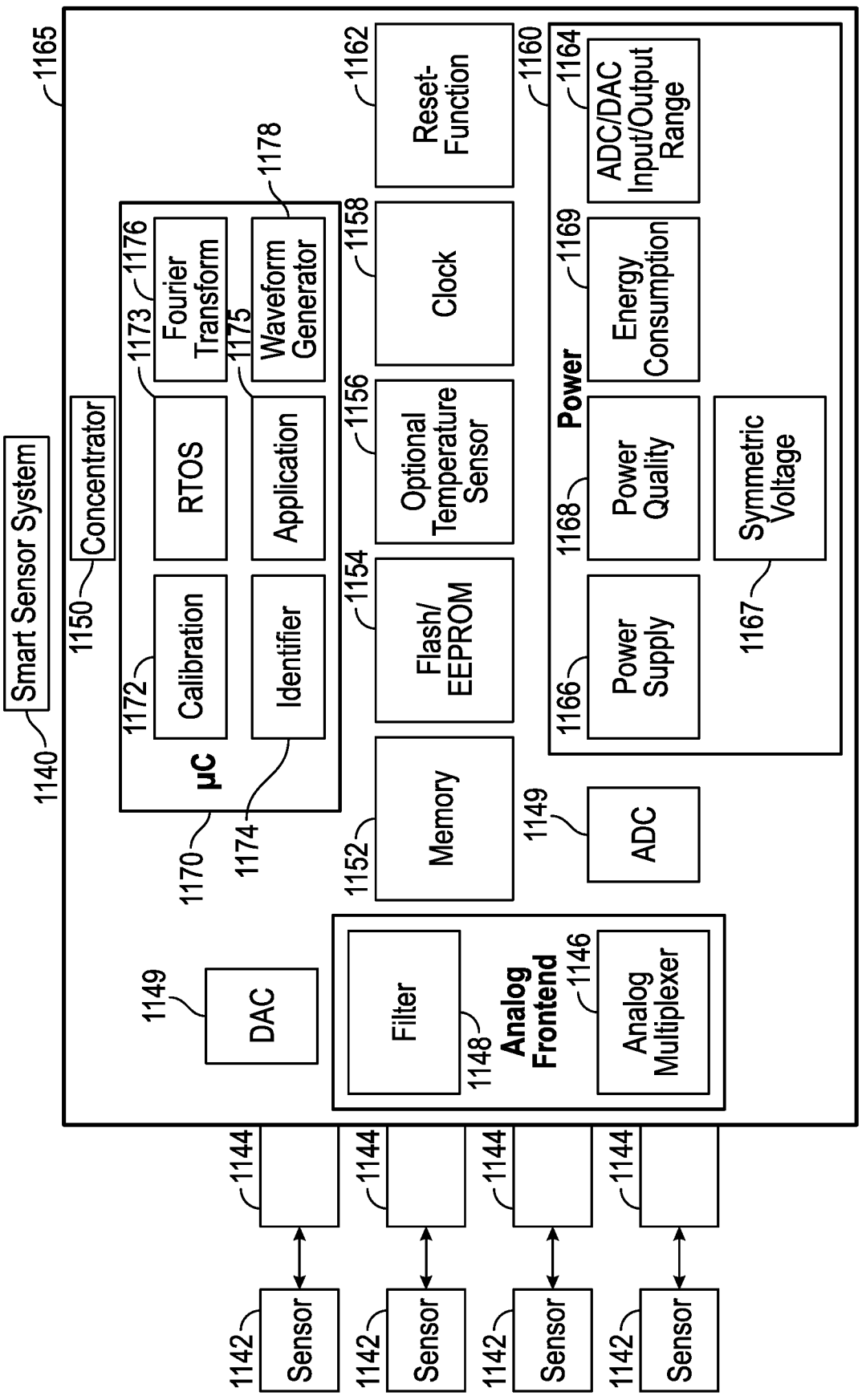
Smart Sensor System
1140
1165
Concentrator
1150
µC
1170
RTOS
1173
Fourier Transform
1176
Application
1175
Waveform Generator
1178
Calibration
1172
Identifier
1174
Reset-Function
1162
Clock
1158
Optional Temperature Sensor
1156
Flash/ EEPROM
1154
Memory
1152
ADC
1149
Power
1160
ADC/DAC Input/Output Range
1164
Energy Consumption
1169
Power Quality
1168
Symmetric Voltage
1167
Power Supply
1166
DAC
1149
Analog Frontend
1146
Filter
1148
Analog Multiplexer
1144
Sensor
1142

FIG. 11D

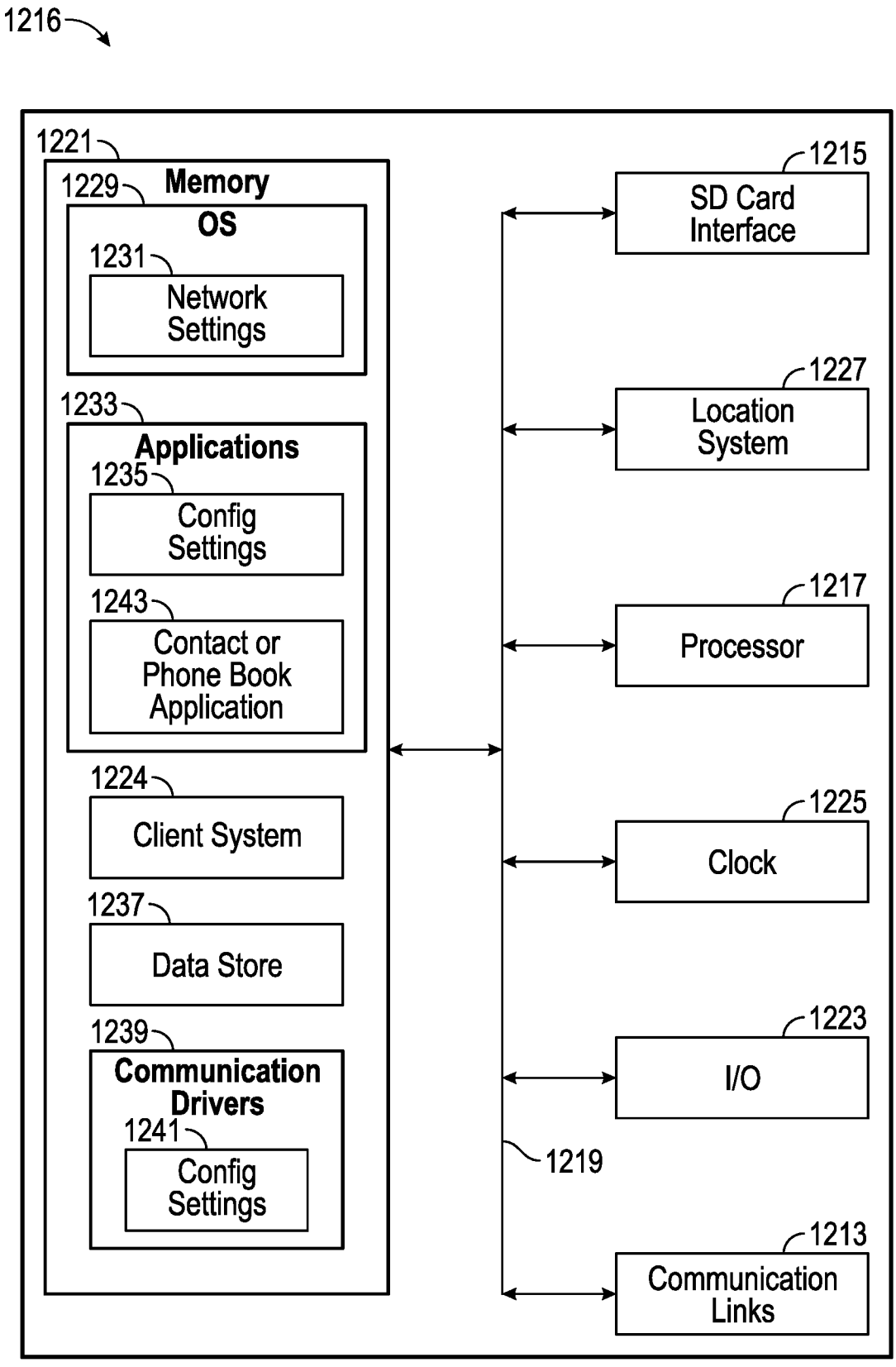
1216
1221
Memory
1229
OS
1231
Network Settings
1233
Applications
1235
Config Settings
1243
Contact or Phone Book Application
1224
Client System
1237
Data Store
1239
Communication Drivers
1241
Config Settings
1219
1215
SD Card Interface
1227
Location System
1217
Processor
1225
Clock
1223
I/O
1213
Communication Links

FIG. 12

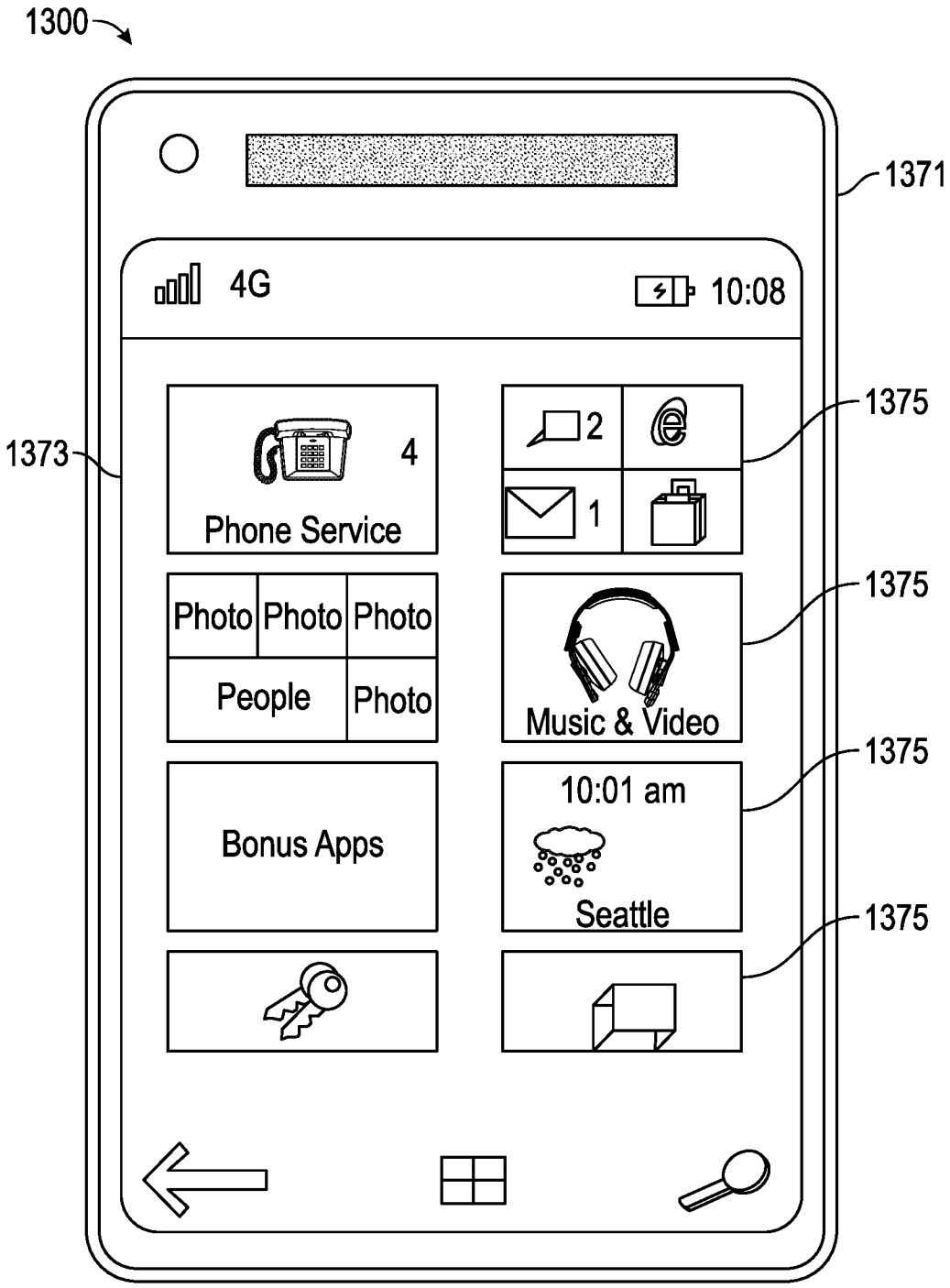
1300
1371
4G
10:08
1373
4
Phone Service
2
1
1375
Photo
Photo
Photo
People
Photo
Music & Video
1375
Bonus Apps
10:01 am
Seattle
1375
1375

FIG. 13

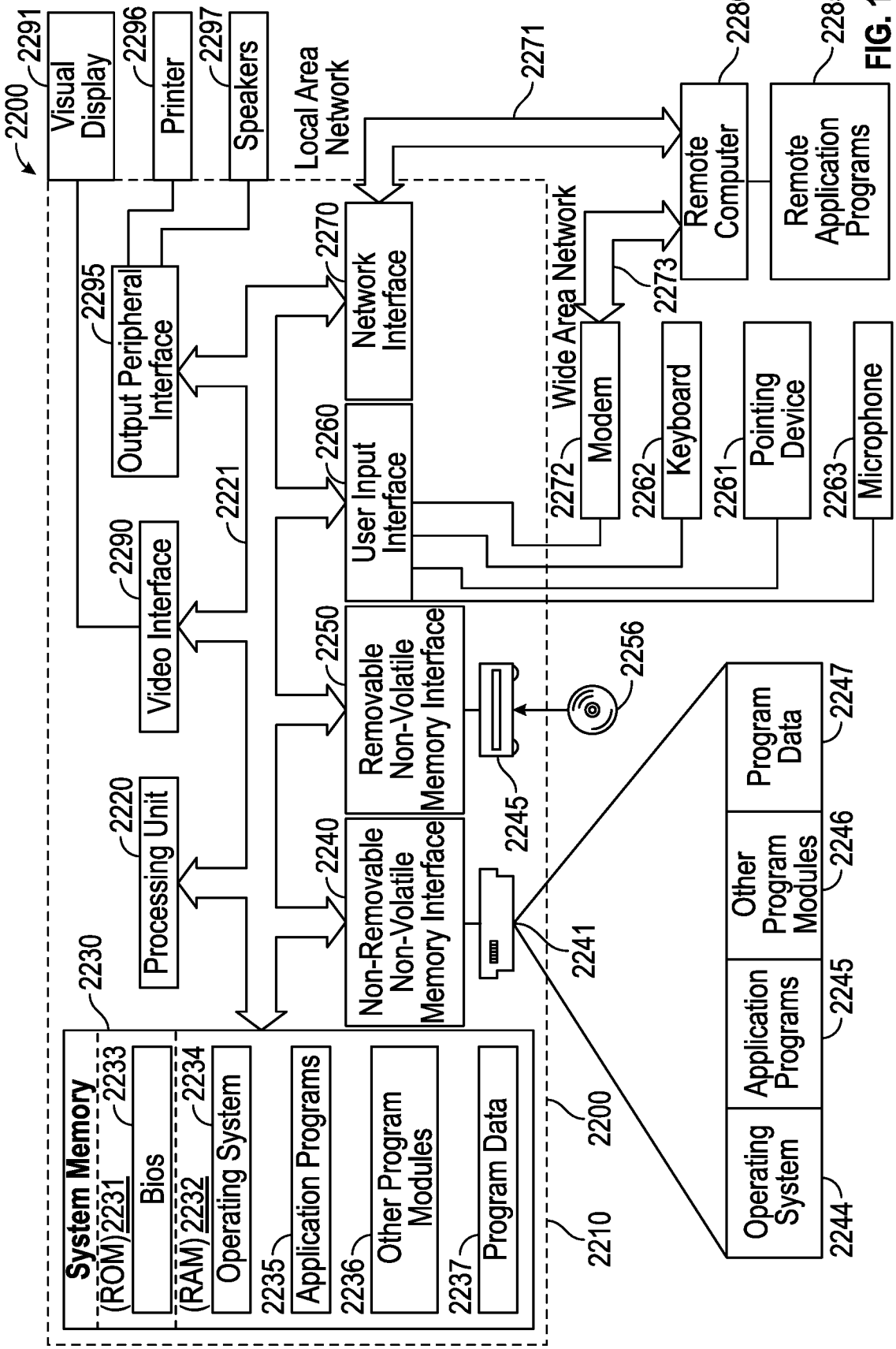
2200
2291
Visual Display
2296
Printer
2297
Speakers
Local Area Network
2271
2280
Remote Computer
2285
Remote Application Programs
2270
Network Interface
2295
Output Peripheral Interface
2260
User Input Interface
Wide Area Network
2272
Modem
2262
Keyboard
2261
Pointing Device
2263
Microphone
2273
2221
2290
Video Interface
2250
Removable Non-Volatile Memory Interface
2256
2220
Processing Unit
2240
Non-Removable Non-Volatile Memory Interface
2245
2241
2230
System Memory
(ROM) 2231
2233
Bios
(RAM) 2232
2234
Operating System
2235
Application Programs
2236
Other Program Modules
2237
Program Data
2210
2200
Program Data
2247
Other Program Modules
2246
Application Programs
2245
Operating System
2244

FIG. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2024/055723

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01N27/02 G01N27/06 G01N27/22 G01N33/18 G01N33/28
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)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

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[x] Further documents are listed in the continuation of Box C.

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Date of the actual completion of the international search	Date of mailing of the international search report
16 September 2024	26/09/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Gomez, Adriana

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