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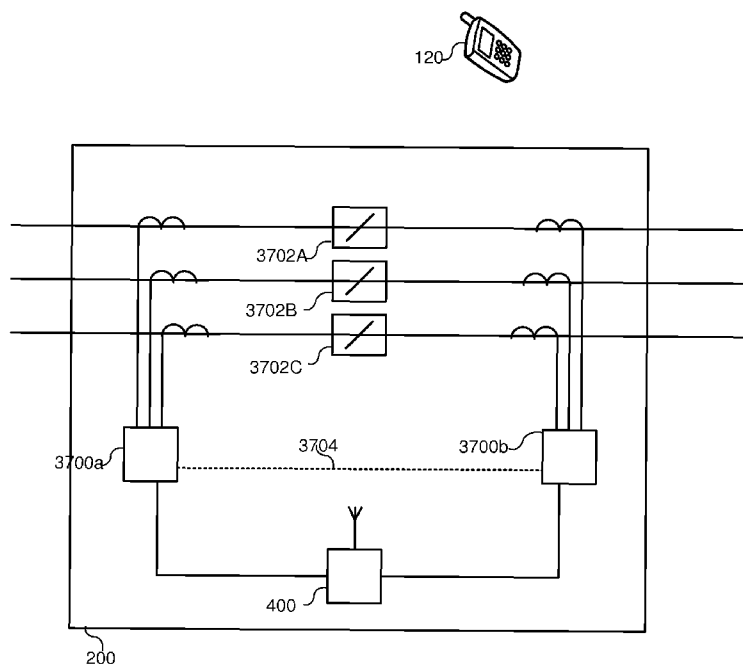


FIG. 16

(57) Abstract: A system for communicating information between a detection device and a wireless device is provided. The system generally includes a detection device adapted to monitor a condition related to a power system. A radio interface unit is in communication with the detection device via a communication member. A wireless device is further provided which is in radio communication with the radio interface unit such that the detection device communicates information to the wireless device through a radio interface unit. The system's components are further adapted to endure harsh conditions (e.g., prolonged exposure to water).



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FAULT DETECTION USING PHASE COMPARISON

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Field of the Invention

[001] The present invention relates generally to a system and method for communicating power system information, and more particularly to a system and method for communicating power system information through a radio frequency device. The present invention system further relates to an apparatus and method for locating a fault on an electric power conductor, and more particularly to an apparatus and method for locating a fault on an electric power conductor using phase comparison.

Description of the Prior Art

[002] Power transmission and distribution systems may include power system protection, monitoring, and control devices such as sensors, protective relays, faulted circuit indicators, and the like. Throughout, the term “power system device” will include any power system protection, monitoring, or control device. Detection devices are used in the power system industry to monitor certain areas and conditions in the power system. Some examples of detection devices include: faulted circuit indicators (FCIs); electrical sensors such as under voltage sensors, over voltage sensors, under current sensors, over current sensors, frequency sensors and the like; and the like.

[003] Faulted circuit indicators (FCIs) play a vital role in detecting and indicating faults and locations of faulted conductors to decrease the duration of power outages and improve the reliability of power systems throughout the world. Electrical utilities depend on faulted circuit indicators to help their employees quickly locate faulted conductors. Most conventional faulted circuit indicators utilize a mechanical target or a light emitting diode (LED) to provide a visual indication of a faulted conductor. By visually scanning faulted circuit indicators located at a site, an electrical utility crew can quickly locate a fault. Industry statistics indicate that faulted circuit indicators reduce fault location time by 50% – 60% versus the use of manual techniques, such as the “refuse and sectionalize” method. Nonetheless, electrical utilities still spend substantial amounts of time and money determining the locations of faults on their networks.

[004] A recent advancement is the use of Radio Frequency (“RF”) technology within fault circuit indication systems. In one prior art system, each faulted circuit indicator communicates with a radio interface unit which communicates the occurrence of a fault to an external receiver. The radio interface unit is often located in proximity to an FCI

within an underground vault, which is susceptible to external elements. For example, vaults may often be filled with water thereby exposing the radio interface unit located therein to also be exposed to such. In another example, for overhead FCI systems, radio interface units are also exposed to the external elements as they are situated in proximity to the overhead FCI device.

[005] As such, it is an object of the present invention to provide a system for communicating power system information through a radio frequency device which may endure harsh external elements.

[006] In one application, solid dielectric cables such as cross-linked polyethylene (XLPE) cables are often used as electrical power conductors or underground electric power transmission lines. Installation of these cables often requires splicing vaults or manholes to be installed. Splice failures is often regarded as the leading source of cable failures. Nevertheless, power system devices are generally not installed in splice vaults. Accordingly, when faults occur at a splice vault, sustained power outages occur until the exact location of the fault is determined. Traditionally, determining the location of a fault is generally performed by a visible inspection of cables in each splice vault. This inspection process can be rather extensive especially if the vault is located in a hard to reach location such as a busy intersection.

[007] Accordingly, it is generally an object of the present invention to provide a system for determining the location of a fault. It is specifically an object of the present invention to determine the location of a fault using a phase comparison. The present invention apparatus and method may utilize RF technology such that a fault location may be determined in hard to reach locations such as a splice vault.

Brief Description of the Drawings

[008] Although the characteristic features of this invention will be particularly pointed out in the claims, the invention itself, and the manner in which it can be made and used, can be better understood by referring to the following description taken in connection with the accompanying drawings forming a part hereof, wherein like reference numerals refer to like parts throughout the several views and in which:

[009] FIG. 1 illustrates a system view of a faulted circuit indicator monitoring system in accordance with an aspect of the present invention.

[0010] FIG. 2A illustrates a wireless device communicating with eight radio interface units, each of which is connected to four groups of faulted circuit indicators in accordance with an aspect of the present invention.

[0011] FIG. 2B illustrates the underground vault 200e of FIG. 2A.

[0012] FIG. 3 illustrates a circuit diagram of the radio interface unit of FIG. 1 in accordance with an aspect of the present invention.

[0013] FIG. 4 is a circuit diagram of an embodiment of the present invention system showing the compensation for magnetic field interference implementing a differential inductor coil configuration.

[0014] FIG. 5 illustrates an example of the housing of a radio interface unit in accordance with an aspect of the present invention.

[0015] FIGS. 6A and 6B illustrate a cross-sectional view of an embodiment of the present invention system showing the engagement of the communication member and interface implementing a differential inductor coil configuration.

[0016] FIG. 6C and 6D illustrate a cross-sectional view of another embodiment of the present invention system showing the engagement of the communication member and interface implementing a differential inductor coil configuration.

[0017] FIG. 7 is a circuit diagram of an embodiment of the present invention system illustrating the interaction between the communication member and the interface implementing a parallel inductor coil configuration.

[0018] FIG. 8 is a circuit diagram of an embodiment of the present invention system illustrating the interaction between the communication member and the interface implementing a serial inductor coil configuration.

[0019] FIG. 9 is a circuit diagram of an embodiment of the present invention system illustrating the interaction between the communication member and the interface implementing a circuit for preventing false latching from ringing currents.

[0020] FIGS. 10A-10C are graphical representations depicting the progression of a ringing pulse exiting the detection circuit of FIG. 8 and the suppression of false latching caused by ringing.

[0021] FIG. 11A illustrates the user interface of a wireless device of FIGS. 2A and 2B used to scan a number of groups of faulted circuit indicators connected to separate radio interface units for their status.

[0022] FIG. 11B illustrates the same wireless device user interface of FIG. 11A after a scan operation has been completed.

[0023] FIG. 11C illustrates the same wireless device user interface FIG. 1A where a number of faulted circuit indicators attached to the selected radio interface unit are asserting a fault condition.

[0024] FIG. 11D illustrates the same wireless device user interface FIG. 11A where, in addition to the selected radio interface unit, two other radio interface units are coupled to one or more faulted circuit indicators asserting a fault condition.

[0025] FIG. 11E illustrates a schematic for a circuit diagram for a wireless device according to an embodiment of the present invention.

[0026] FIG. 12 illustrates a system diagram of a fault communication system having detection devices in communication with a wireless device for detection and communication of a fault using a phase comparison method.

[0027] FIG. 13 illustrates an embodiment of the system of FIG. 12 in accordance with one aspect of the present invention.

[0028] FIG. 14 illustrates another embodiment of the system of FIG. 12 in accordance with one aspect of the present invention.

[0029] FIG. 15 illustrates a system diagram of a fault communication system having detection devices in communication with a wireless device for detection and communication of a fault between underground vaults using a phase comparison method.

[0030] FIG. 16 illustrates a system diagram of a fault communication system having detection devices in communication with a wireless device for detection and communication of a fault within an underground vault using a phase comparison method.

[0031] FIGs. 17A and 17B illustrate logic diagrams for the circuitry of one of the detection devices of FIG. 12.

[0032] FIG. 18 illustrates a timing diagram of the signals shared between the detection devices of FIGs. 17A and 17B.

[0033] FIG. 19 illustrates a logic diagram for the circuitry of one of the detection devices of FIG. 12-16.

[0034] FIG. 20 illustrates a diagram of data packet which may be used for transmitting current information in the system of FIG. 19.

Detailed Description of the Illustrated Embodiment

[0035] FIG. 1 illustrates a faulted circuit indicator monitoring system in accordance with an aspect of the present invention. A number of overhead faulted circuit indicators 207 each contain a two-way radio that communicates the occurrence of a fault via a short range antenna 203 to a local site 110 having an intelligent module 106 installed

within radio range of the faulted circuit indicators 207. The intelligent module then uses the existing wired telephone network (not shown) to communicate the fault occurrence to a remote site 112. Alternatively, the intelligent module may include a radio interface unit associated therewith for communication with an antenna 114b to communicate the fault occurrence to a remote site 112 having another long range RF antenna 114a. The remote site 112 includes a remote intelligent module 107, which may be connected to another site (not shown) via a wired connection 116. When a fault is detected by a faulted circuit indicator, the occurrence is relayed in the manner described above to the remote site 112, triggering the dispatch of a team to the fault site. The user then uses a wireless device 102 (e.g., a wireless handheld device). In another embodiment, the wireless device may be located in a vehicle 104 to determine which conductor 205 is faulted.

[0036] Note that the conductors could also be located in an underground vault 200, which may be accessible through a manhole 118. Faulted circuit indicators 206 attached to the underground conductors 210 are wired to a radio interface unit 400 with a short range antenna 202 to communicate with the wireless device 102 or wireless device installed in a vehicle 104. In one embodiment, the short range antenna 202 may be part of or separate from the radio interface unit.

[0037] Referring to the drawings and to FIGS. 2A and 2B in particular, a wireless device 102 communicates 904 with eight installations of faulted circuit indicators 200a-200h. As illustrated, each installation of faulted circuit indicators consists of a radio interface unit, and four separate groups ("ways") of faulted circuit indicators, wherein each group has three faulted circuit indicators, one for each phase. For example, the installation shown at 200e, as shown in FIGS 2A and 2B includes four separate groups 206a-d of faulted circuit indicators connected to a radio interface unit 400e through cables 220e with a separate short range antenna 202e connected through cable 208e. This radio interface unit 400e may include a particular setting such that it may be differentiated from the other radio interface units. For example, this identification setting may be in the form of a designation setting (e.g., serial number), whereupon each particular radio interface unit has a particular designation (e.g., a particular serial number). In another embodiment, the identification setting may be in the form of an address setting (e.g., a media access control (MAC) address). In yet another embodiment, in order to ensure proper differentiation among a plurality of units, each radio interface unit may include both a designation setting and an address setting. For

example, both the radio interface unit 400b and radio interface unit 400e may be associated with a particular address (e.g., address 5). In order to differentiate between these radio interface units 400b and 400e, each radio interface unit 400b and 400e is given a particular designation setting (e.g., particular serial numbers). In this way, radio interface units may be differentiated.

[0038] Each faulted circuit indicator within these separate groups 206a-d may be used to monitor the various phases (e.g., commonly referred to as the A, B, C phases) associated therewith. For example, each of the faulted circuit indicators associated with way 206a may be used to monitor the three phases associated therewith. Through this system, the installation 200e of faulted circuit indicators 206a, 206b, 206c, 206d may communicate with wireless device 102.

[0039] Additionally, the wireless device 102 may alternatively be adapted to communicate with radio interface units associated with overhead fault circuit indicators as illustrated in FIG. 1. In yet another embodiment, the wireless device may be in the form of a personal digital assistant (PDA) with a wireless interface, a laptop computer or a handheld computer with a wireless interface, etc. and may optionally be mounted in a service vehicle.

[0040] Referring back to FIG. 1, various components of the faulted circuit indicator monitoring system may be located in an underground vault 200 and only accessible through a manhole 118. As discussed above, the underground vault 200 is often susceptible to external elements and even flooding. Accordingly, its contents are also susceptible to external elements such as water. Likewise, overhead FCI systems also include electronic devices which are exposed to external elements. Accordingly, it is also desirable that any connections between the electronic devices be wireless and/or waterproof. Moreover, it is also desirable that the communication members (e.g., probes or other wireless connection means) and corresponding detection devices be substantially self-contained.

[0041] For example, it is desirable that any connection between each FCI 206 and the radio interface unit 400 of the previous figures be wireless and waterproof. Also, it is desirable that both the communication members (not shown) from the FCI 206 and the radio interface unit 400 each be substantially self-contained.

[0042]

[0043] As illustrated in FIG. 4, the interfering magnetic field 532 may be cancelled using a differential inductor coil configuration. In this arrangement, the communication

member includes two inductor coils 420f and 420g which are connected in opposite directions. The interfering magnetic field 532 induces a current I_1 in inductor coil 420f and a current I_2 in inductor coil 420g of the radio interface unit. The currents I_1 and I_2 are induced in opposite directions and each induce a voltage V_1 in opposite polarity to each other across load 538f. Accordingly, this arrangement provides for a net induced voltage of 0, thereby compensating for interference from a magnetic field and thereby negating false signals.

[0044] Referring to FIG. 5, a radio interface unit 400h is provided for accommodating a differential inductor coil probe for cancelling interfering magnetic fields. The housing 400h may be substantially self-contained, with the electronic components (not shown) contained therein. The electronic components contained within the housing 400h may further be encapsulated using an encapsulate material such as potting material. One such encapsulate material is referred to as potting material. Potting material may include epoxy based materials, urethane based materials, silicone based materials, acrylic based materials, polyester based materials, and others. Urethane and silicone based materials are the types used most often in the electronics industry. Accordingly, the housing 402h further defines cavities (e.g., at 304h) for receiving differential inductor coil probes (e.g., at 609) having dual prongs in a manner in which they do not expose the electronic components contained within the housing 402h to the external environment.

[0045] In another embodiment, the radio interface unit 400h may be provided for accommodating a differential inductor coil for cancelling interfering magnetic fields. The differential inductor coil probes (e.g., at 609) which interface the cavities (e.g., at 304h) within sockets 408h, which are coupled to a detection device such as an FCI as described with regards to FIG. 1. The differential inductor coil probe 609 is also substantially self-contained. The differential inductor coil probes (e.g., at 609) wirelessly communicate with the radio interface unit 400h via cavities (e.g., 304h) in the manner described below.

[0046] FIGS. 6A and 6B illustrate one embodiment of the hardware arrangement for the circuitry described with respect to FIG. 4 having an interface between the differential inductor coil probe and the cavity. Contained within the housing 402i are various electronic components of the radio interface unit 400i. The electronic components are further encapsulated by an encapsulate material 514i such as a potting material. The housing 402i further defines a plurality of cavities (e.g., at 304i) for

receiving differential inductor coil probes (e.g., at 609i) in a manner in which they do not expose the electronic components contained within the housing 402i to the external environment. Further provided is a printed circuit board 502i which includes a plurality of magnetic field sensors such as hall-effect sensors (e.g., at 302i) and a plurality of inductors (e.g., at 420i) implemented thereon. FIGS. 6C and 6D are similar to FIGS. 6A and 6B with the exception that the inductors 506k of FIG. 6C and 6D are in the form of coiled inductors.

[0047] During operation of each to the embodiments illustrated in FIGS. 6A-D, the interface between the differential inductor coil probes 609 i, k and the radio interface unit 400 i, k is as follows. The differential inductor coil probes 609 i, k may be inserted into the cavities 304i, k. For example, as shown in FIGS. 5B and 5D, a magnet 902 i, k is situated between the prongs of differential inductor coil probe 609 i, k. A corresponding magnetic field sensor (e.g., hall-effect sensor 302 i, k) situated on printed circuit board 502 i, k detects the presence of a magnetic field from magnet 902 i, k upon insertion of the differential inductor coil probe 609 i, k into the cavity 304 i, k. The hall-effect sensor 302 i, k produces a signal to the microprocessor, thereby signaling the presence of a differential inductor coil probe 609 i, k. Although a hall-effect sensor is described herein, other suitable elements may be implemented (e.g., a Reed switch).

[0048] The differential inductor coil probes 609 i, k which interface the cavities 304 i, k are coupled to a detection device such as an FCI as described with regards to FIG. 1. The differential inductor coil probe 609 i, k includes an inductor coil 604 i, k in each prong and is also substantially self-contained. The differential inductor coil probes 609 i, k wirelessly communicate with the radio interface unit 400 i, k via cavities (e.g., 304 i, k) by magnetic field induction in the manner described below.

[0049] FIG. 7 illustrates one embodiment which implements the differential coil configuration of FIG. 4. In this arrangement, the differential inductor coil probe 609a is in a parallel inductor coil configuration. During operation, two inductor coils 420a and 420b are connected in parallel in opposite directions. The interfering magnetic field (not shown) induces a current I_1 in inductor coil 420a and a current I_2 in inductor coil 420b of the radio interface unit. The currents I_1 and I_2 are induced in opposite directions and each induce a voltage V_1 in opposite polarity to each other across load 538, thereby canceling the respective voltages. Accordingly, this arrangement provides for a net

induced voltage of 0, thereby compensating for interference from a magnetic field and negating false signals.

[0050] The arrangement of FIG. 7, in effect, forms a differential pulse transformer configuration 558a, whereupon high-energy, short-lasting pulses are transmitted with low distortions. During operation, a trip current signal I_T is sent from a detection device such as an FCI 206 when a conductor (e.g., 210 of FIG. 1) related thereto exceeds a select current threshold (e.g., upon an occurrence of a ground fault) via cable 220 into differential inductor coil probe 609a with series load resistors R. The inductor coils L1 and L2 are connected in parallel to generate magnetic fields 540a and 540b in opposite directions. The trip current signal I_T induces magnetic fields 540a and 540b in opposite directions. The magnetic fields 540a and 540b from the trip current I_T induces currents I_1 and I_2 in inductor coils 420a and 420b of the radio interface unit. The induced currents I_1 and I_2 further induce a differential voltage ΔV across load 538. Information regarding a positive differential voltage ΔV across load 538 may be transmitted from the radio interface unit to the wireless handheld unit to signal a trip signal by an FCI.

[0051] Alternatively, a reset current signal I_R may be sent from a detection device such as an FCI 206 after the current in a conductor (e.g., 210 of FIG. 1) is restored from a previously tripped condition. In order to distinguish between the reset current signal I_R and the trip current signal I_T , these signals may be sent or established in opposite directions. The reset current signal I_R induces magnetic fields 540a and 540b in opposite directions. The magnetic fields 540a and 540b from the reset current I_R induces currents I_1 and I_2 in inductor coils 420a and 420b of the radio interface unit. The induced currents I_1 and I_2 further induce a differential voltage ΔV across load 538. Information regarding a negative differential voltage ΔV across load 538 may be transmitted from the radio interface unit to the wireless handheld unit to signal a reset signal by an FCI.

[0052] In yet another embodiment, FIG. 8 illustrates another embodiment which implements the differential coil configuration of FIG. 4. In this arrangement, the differential inductor coil probe 609c is in a serial inductor coil configuration. During operation, two inductor coils 420a and 420b are connected in series in opposite directions. The interfering magnetic field (not shown) induces a current I_1 in inductor coil 420a and a current I_2 in inductor coil 420b of the radio interface unit. The currents I_1 and I_2 are induced in opposite directions and each induce a voltage V_1 in opposite polarity to each other across load 538, thereby canceling the respective voltages.

Accordingly, this arrangement provides for a net induced voltage of 0, thereby compensating for interference from a magnetic field and negating false signals.

[0053] The arrangement of FIG. 8, in effect, forms a differential pulse transformer configuration 558a, whereupon high-energy, short-lasting pulses are transmitted with low distortions. Because the inductor coils L1 and L2 are connected in series, the design values thereof are generally lower than the parallel arrangement of FIG. 7 due to the additive or period inductance. During operation, a trip current signal I_T is sent from a detection device such as an FCI 206 when a conductor (e.g., 210 of FIG. 1) related thereto exceeds a select current threshold (e.g., upon an occurrence of a ground fault) via cable 220 into differential inductor coil probe 609a with series damping ringing pulse resistors R. The inductor coils L1 and L2 are connected in series to generate magnetic fields 540a and 540b in opposite directions. The trip current signal I_T induces magnetic fields 540a and 540b in opposite directions. The magnetic fields 540a and 540b from the trip current I_T induces currents I_1 and I_2 in inductor coils 420a and 420b of the radio interface unit. The induced currents I_1 and I_2 further induce a differential voltage ΔV across load 538. Information regarding a positive differential voltage ΔV across load 538 may be transmitted from the radio interface unit to the wireless handheld unit to signal a trip signal by an FCI.

[0054] Alternatively, a reset current signal I_R may be sent from a detection device such as an FCI 206 after the current in a conductor (e.g., 210 of FIG. 1) is restored from a previously tripped condition. In order to distinguish between the reset current signal I_R and the trip current signal I_T , these signals may be sent or established in opposite directions. The reset current signal I_R induces magnetic fields 540a and 540b in opposite directions. The magnetic fields 540a and 540b from the reset current I_R induces currents I_1 and I_2 in inductor coils 420a and 420b of the radio interface unit. The induced currents I_1 and I_2 further induce a differential voltage ΔV across load 538. Information regarding a negative differential voltage ΔV across load 538 may be transmitted from the radio interface unit to the wireless handheld unit to signal a reset signal by an FCI.

[0055] FIG. 9 illustrates another embodiment which implements the differential coil configuration of FIG. 4. In this arrangement, a trip current I_T or a reset current I_R signal from the differential inductor coil probe 609a generates equal and opposite magnetic fields 540a and 540b. The magnetic fields 540a and 540b induce currents I_1 and I_2 in the radio interface unit. A detection circuit 559a is further provided with symmetrical

network branches having inputs 580a and 580b coupled to inductor coils 420a and 420b. Symmetrical ends 582a and 582b are further coupled to a latching flip-flop G1/G2 and a microcontroller 310. Each symmetric network branch includes a series diode; an amplitude control element such as a shunt diode or a shunt resistor; a low pass filter; and a charging circuit (or charge holding circuit). In an embodiment of the detection circuit 559a, shunt diodes D1 and D3 are the amplitude control elements for the incoming pulse, whereas the low pass filter and charging circuit is formed by a network of resistors and capacitor.

[0056] More specifically, the direction of the voltage/current peak from an induced pulse is detected with four diodes (D1, D2, D3 and D4) at inputs 580a and 580b, respectively. A positive pulse U3 FIG.10Aii (at D3 and D4) is directed through resistor R4 into capacitor C2, storing the charge. Resistor R5 or R2 allows capacitor discharging of positive pulse U3 in a controlled manner, preventing false latching from ringing currents from the FCI and probe circuits (e.g., L1, L2 and R). A negative pulse U1 FIG.10Ai is conducted through diode D1, with diode D2 blocking any residual voltage from getting into capacitor C1 through clamping in diode D1 and reverse bias rectification in diode D2. Diode D1 clamps the negative pulse at about -0.5 V to -0.8 V, depending on the diode type.

[0057] The R4/C2 (and R1/C1) components create a low-pass filter, preventing high frequency spikes changing the logic state of the flip-flop gates G1/G2 (NOR gate flip flops). The positive pulse U3 generates a current, through R4, which charges capacitor C2. Resistors R6 and R3 each prevent latch-up of respective CMOS gates G2 and G1, and allow charging capacitors C1 and C3 to reach a higher voltage above the internal CMOS gates clamping voltage. Charging and retaining charge is important in preventing undesired flip-flop action due to ringing in the Trip/Reset pulses. In this arrangement, NOR gates G1 and G2 are further connected in an R-S flip-flop configuration, with active-high inputs.

[0058] Pulse U4 FIG.10 Bii is applied to gate G2 input 587 of the flop-flop. If the flip-flop outputs logic 0 on G1 at output 587, prior to the trip pulse, the pulse changes the logic state of line 550 from logic 0 to logic 1. The status of the flip-flop is evaluated with a microprocessor 310 at I/O interface 552. The microprocessor 310 such as a Texas Instruments MSP430 family is suitable for this application where a standard program can be written.

[0059] On a power-up, flip-flop G1/G2 sets a random output logic level on line 550. Resistor R7, serial with the G1 output, allows for resetting of the flip-flop G1/G2 with the microprocessor 310. A program may further be provided for driving the microprocessor 310, changing the I/O interface 552 from input to output, and setting line input 550 with a logic 0. If, at the same time, the gate G1 outputs logic 1, the resistor R7 allows voltage at gate G2 input 587 to drop below the threshold level of logic 0, causing flip-flop G1/G2 to change the G1 output to logic 0. This circuit arrangement allows reusing the same line 550 to read logic data from flip-flop G1/G2 and resetting the flip-flop G1/G2, with a single copper trace line input 550 and a single reset resistor R7.

[0060] The flip-flop NOR gates G1/G2 may further create a CMOS memory location, thereby allowing for latching and storage of logic values for month and years. CMOS inherently uses a relatively small supply current, thereby allowing for extension of the lifetime of a supply battery.

[0061] A ringing pulse from a trip pulse or a reset pulse can often cause false latching. The arrangement of FIG. 9 provides for an embodiment which suppresses such false latching. FIGS. 10A-10C depict the progression of a ringing pulse exiting the detection circuit of FIG. 9 and the suppression of false latching caused by ringing.

[0062] The arrangement of FIG. 9 is designed to accept a trip/reset pulse from a various FCI sensors and differential inductor coil probes. Such hardware diversification may result in a trip or reset pulse with multiple ringing portions such as 560b, 564a and 566b in induced pulse U1, and 560c, 564c and 566c in induced pulse U3 shown in FIGS. 10Ai and 10Aii. In effect, induced pulses U1 and U3 generated by differential pulse transformer 558a at both ends of the coil pair (e.g., inductor coils 420a and 420b) will be of similar amplitude and reversed polarity in the absence of shunt diodes D1 and D3 and series diodes D2 and D4 (shown as dotted lines).

[0063] Shunt diodes D1 and D3 may be used to clamp a negative pulse, whereas series diodes D2 and D4 may be used to rectify and pass a positive pulse in forward bias. Diode pairs D1 and D2 clamp and rectify negative and positive pulse portions 560a, 564a and 566a in a reversed polarity induced pulse U1. Diode pairs D3 and D4 rectify and clamp positive and negative pulse portions 560c, 564b and 566c, respectively, in a positive polarity induced pulse U3.

[0064] FIG. 10Bi depicts the voltage of pulse U2 across capacitor C1, induced by a ringing pulse U1. An erred latching of the flip-flop G1/G2 may result if the voltage of pulse U2 reaches above the logic 1 threshold 570. The desired positive polarity induced

pulse U3 depicted in FIG. 10Aii with a higher amplitude generates filtered pulse U4 across capacitor C2 as shown in FIG. 10Bii, that in turn generates logic 1 for gate G2. The charge of pulse U4 across capacitor C2 holds longer than the later charging of ringing pulse U2 across C1 as shown in FIG. 10Bi.

5 **[0065]** FIG. 10c superimposes pulses U2 and U4 presented to the flip-flop G1/G2 to illustrate the concept that an extended logic 1 level of pulse U4 presented to gate G2 outlasts a false logic 1 caused by ringing pulse U2 presented to gate G1, thus preserving a proper logic latch by the flip-flop G1/G2. The time constant of the C2/R5/R6 (or C1/R2/R3) allows for rejection of most false ringing voltage of pulse U2
10 by a voltage margin 572, and a time margin 574 depending on the amplitude differences of pulses U4 and U2 set at the logic level in G1/G2. The diode pair and RC network in differential arrangement allows for error-free detection of the desired induced pulse U4 under the presence of a "ringing" signal U2 on the opposite side of the differential pulse transformer 558. The same principle of operation applies if the
15 induced pulses U1 and U3 are of reverse polarity, except that the pulses in FIGS 10a to 10c will be interposed between U1 and U3, and between U2 and U4. The teachings described in relation to FIGS. 9 and 10 may further be implemented for a single probe differential coil configuration without deviating from the spirit of the present invention.

[0066] The detection device communicates with the radio interface unit 400
20 according to any of the embodiments herein described. Thus, the monitoring system of the present invention may be used to monitor states or conditions that are detected with any of the detection devices (e.g., FCIs or other sensors) mentioned above.

[0067] It is a further aspect of this invention that the faulted circuit indicator monitoring system differentiate between the different types of detection devices that
25 may be in communication with the radio interface unit 400. The differentiation may be performed between two different types of detection devices using the permanent magnet (e.g., at 902i, or 902k) of the inductor coil probes (e.g., at 609i, or 609k) and the magnetic field sensor (e.g., 302i, or 302k). The polarity of the permanent magnet (e.g., at 902i, or 902k) for a particular type of detection device may be a polar opposite from
30 the permanent magnet (e.g., at 902i, or 902k) for another particular type of detection device. The radio interface unit 400 may then be configured to transmit the status of only one particular type of detection device when interrogated by a specific wireless device 102 (or when the wireless device 102 interrogates using a specific algorithm), and transmit the status of another particular type of detection device when interrogated

by another specific wireless device 102 (or when the wireless device 102 interrogates using another algorithm).

[0068] For example, the radio interface unit 400 may be mounted in a vault 200 containing electrical conductors for an electrical power utility, and access to water lines for a water utility. Faulted circuit indicators may be used to monitor faulted circuits on the electrical conductors, and may be in communication with the radio interface unit 400 using the various probe systems described herein. However, the inductor coil probes (e.g., at 609i, or 609k) for the faulted circuit indicators would be configured such that the permanent magnets (e.g., at 902i, or 902k) have a common pole (north) facing the magnetic field sensor (e.g., 302i, or 302k). If the radio interface unit 400 has twelve connector sockets (e.g., 408h), less than all of them may be used by the faulted circuit indicators. The magnetic field sensors (e.g., 302i, or 302k) would sense that all of these inductor coil probes (e.g., at 609i, or 609k) have permanent magnets (e.g., at 902i, or 902k) with a common polarity.

[0069] The radio interface unit 400 may also be in communication with inductor coil probes (e.g., at 609i, or 609k) from detection devices for the water utility. For example, the water utility may want to monitor whether the pressure in the water lines exceeds a threshold. The water utility could install such detection devices on the water lines, and have these water pressure detection devices communicate with inductor coil probes (e.g., at 609i, or 609k) in communication with the remaining connector sockets (e.g., , 408h) of the radio interface unit 400. The inductor coil probes (e.g., at 609i, or 609k) from the water utility would include permanent magnets (e.g., at 902i, or 902k) having a common pole (south) facing the magnetic field sensor (e.g., 302i, or 302k). The pole of the permanent magnets (e.g., at 902i, or 902k) facing the inductor coil probes (e.g., at 609i, or 609k) of the water utility would be opposite the pole of the permanent magnets (e.g., at 902i, or 902k) facing the inductor coil probes (e.g., at 609i, or 609k) of the electric utility. In this way, the radio interface unit 400 could differentiate between detection devices of different utilities, and transmit information relating only to the utility that interrogates the radio interface unit 400.

[0070] The radio interface unit 400e may include a particular identification setting such that it may be differentiated from the other radio interface units. For example, this identification setting may be in the form of a designation setting (e.g., serial number), whereupon each particular radio interface unit has a particular designation (e.g., a particular serial number). In another embodiment, the identification setting may be in

the form of an address setting (e.g., a media access control (MAC) address). In yet another embodiment, in order to ensure proper differentiation among a plurality of units, each radio interface unit may include both a designation setting and an address setting. For example, radio interface unit 400e may be associated with particular address (e.g., address 5). In order to differentiate between these radio interface units 400e and 400h, each radio interface unit is given a particular designation setting (e.g., particular serial numbers). In this way, radio interface units may be differentiated.

[0071] Referring back to the drawings and to FIGS. 2A and 2B in particular, a wireless device 102 communicates 904 with eight installations of faulted circuit indicators 200a-200h. As illustrated, each installation of faulted circuit indicators consists of a radio interface unit, and four separate groups ("ways") of faulted circuit indicators, wherein each group has three faulted circuit indicators, one for each phase. For example, the installation shown at 200e, as shown in FIGS 2A and 2B includes four separate groups 206a-d of faulted circuit indicators connected to a radio interface unit 400e through cables 220e with a separate short range antenna 202e connected through cable 208e. This radio interface unit 400e may include a particular setting such that it may be differentiated from the other radio interface units. For example, this identification setting may be in the form of a designation setting (e.g., serial number), whereupon each particular radio interface unit has a particular designation (e.g., a particular serial number). In another embodiment, the identification setting may be in the form of an address setting (e.g., a media access control (MAC) address). In yet another embodiment, in order to ensure proper differentiation among a plurality of units, each radio interface unit may include both a designation setting and an address setting. For example, both the radio interface unit 400h and radio interface unit 400e may be associated with a particular address (e.g., address 5). In order to differentiate between these radio interface units 400h and 400e, each radio interface unit 400h and 400e is given a particular designation setting (e.g., particular serial numbers). In this way, radio interface units may be differentiated.

[0072] Each faulted circuit indicator within these separate groups 206a-d may be used to monitor the various phases (e.g., commonly referred to as the A, B, C phases) associated therewith. For example, each of the faulted circuit indicators associated with way 206a may be used to monitor the three phases associated therewith. Through this system, the installation 200e of faulted circuit indicators 206a, 206b, 206c, 206d may communicate with wireless device 102.

[0073] In one embodiment in which the identification setting of each radio interface unit is an address setting, the address setting of a radio interface unit 400 may be adjusted by simply turning the address dial 414h. Although this embodiment specifically describes the setting in the form of an identification setting and, more particularly an address setting, the setting to be adjusted may be any setting, (e.g., a designation setting, power setting, communication setting, etc.). Moreover, although a dial is specifically shown, any actuator is suitable (e.g., a linear multi-position switch instead of a dial).

[0074] FIG. 11A illustrates an example of a user interface of the wireless device 102 that may be used in the systems illustrated in FIGS. 2A and 2B. The user interface includes a power indicator 1001, such as a green LED, which is illuminated when the wireless device 102 is turned on via power button 1024. In addition, the user interface includes two controls, an information acquisition control which is implemented as a “scan” button 1012, and an identification setting increment control which is implemented as a “next” button 1010. The “scan” button 1012 causes the wireless device 102 to scan the nearby area for any radio interface units (e.g., those associated with the installation of faulted circuit indicators of FIGS. 2A and 2B) that may be present. During the scan, each radio interface unit may be adapted to communicate its identification setting (e.g., address), its status, and the status of any faulted circuit indicators that are connected to it.

[0075] Once a scan is completed, a summary of the scan is displayed on a radio address indicator 1006. The radio address indicator 1006 comprises a plurality of radio interface unit status indicators. Each LED of the radio address indicator 1006 may correspond to each radio interface unit associated with each one of the installations of faulted circuit indicators 200a-h of FIGS. 2A and 2B. The radio interface unit status indicators may be implemented using eight tri-color LEDs. Depending on the result of the scan operation, the LEDs within the radio address indicator 1006 will be illuminated in different ways. If a radio interface unit with a particular address is not detected, then the radio address indicator 1006 LED with the corresponding address will not be illuminated. Conversely, for each radio interface unit detected, a corresponding LED within the radio address indicator 1006 will display amber, green or red. A particular LED within the radio address indicator 1006 displays green if none of the faulted circuit indicators connected to the particular radio interface unit have detected a fault. Conversely, a particular LED within the radio address indicator 1006 displays red if any

of the faulted circuit indicators connected to the corresponding radio interface unit have detected a fault. As discussed later, a particular LED may be illuminated as amber if the corresponding radio interface unit is presently selected as discussed below.

[0076] The “next” button 1010 allows a user of the wireless device 102 to sequentially step through each of the radio interface units that the wireless device 102 detected during its last scan operation. The user interface of the wireless device 102 also includes a group (way) indicator 1022, which displays the status of any group of faulted circuit indicators connected to the radio interface unit presently monitored by the wireless device 102. The group (way) indicator 1022 includes a plurality of faulted circuit indicator status indicators, which as shown, are twelve LEDs 1008. The twelve LEDs are organized in four rows, each corresponding to one of four separate groups (ways) of faulted circuit indicators, and three columns, each corresponding to a separate phase 1014. For example, if the user were to select the display for radio interface 400e of FIGS. 2A and 2B, the group (way) indicators 1022 will correspond to each group of faulted circuit indicators 206a-d, whereas if the user were to select the display for radio interface 400h of FIGS. 2A and 2B, the group (way) indicators 1022 will correspond to each group of faulted circuit indicators 206e-h. As discussed above, each of the faulted circuit indicators associated with the particular group (or way) are generally associated with different phases (e.g., A, B, C phases) and accordingly will correspond to the LEDs 1008.

[0077] During operation, if a particular faulted circuit indicator is not faulted, the corresponding LED will display green. Conversely, if a particular faulted circuit indicator is faulted, the corresponding LED will display red. And if the particular faulted circuit indicator is not connected, the corresponding LED will not be illuminated.

[0078] The user interface of the wireless device 102 also includes a system health indicator 1018, which displays information about the health of the presently selected radio interface unit. One implementation of the system health indicator 1018 is a bi-color LED, which displays green when there are no issues with the selected radio interface unit, and red when the selected radio interface unit has an issue that requires maintenance. In another embodiment, a tri-color LED may be used to indicate the system life of the radio interface unit. For example, a green color may indicate that greater than one year of system life remains. An amber color may indicate that less than one year of system life remains. A red color may indicate that complete depletion

of system life is imminent. In one embodiment, the system life of the radio interface unit may equate to the battery life associated therewith.

[0079] FIG. 11B illustrates an embodiment of the disclosed user interface 102 after a scan operation has been completed, and the “next” button has been pushed to display the status of the faulted circuit indicators attached to the radio interface unit with address 5 (e.g., 400e of FIG 2). Among others, the radio interface unit with address 8 has reported as problem free as indicated by the LED 1020 being illuminated as green. Also, the radio interface unit with address 4 indicates that that unit is either not installed, or the radio within the radio interface unit has malfunctioned, as indicated by the unlit LED 1003.

[0080] For illustration purposes, the status of the faulted circuit indicators attached to the radio interface unit with address 5 (e.g., 400e of FIG 2), are being displayed in the group (way) indicator 1022. This is indicated by LED 1007, which is displayed as amber in the illustrated embodiment. All faulted circuit indicators in group or way 1 (e.g., 206a of FIGS. 2A and 2B), group or way 2 (e.g., 206b of FIGS. 2A and 2B), and group or way 3 (e.g., 206c of FIG. 2) are installed, and none have detected faults. Therefore, the particular LEDs corresponding to those faulted circuit indicators are illuminated green. For instance, the LED 1016 corresponding to way 2 (e.g., 206b of FIGS. 2A and 2B), phase C is illuminated green. In addition, the group (way) indicator 1022 indicates that none of the faulted circuit indicators corresponding to group or way 4 (e.g., 206d of FIGS. 2A and 2B) are installed. In the illustrated embodiment, this is indicated with an unlit LED, such as the LED 1015 corresponding to group or way 4, phase C. Because, the faulted circuit indicators corresponding to group or way 4 (206d) are shown to be connected in FIGS. 2A and 2B, this may indicate a problem in the connection of the faulted circuit indicators.

[0081] In FIG. 11C, the status of the faulted circuit indicators attached to the radio interface unit with address 5 are being displayed. However, during the previous scan, a number of the faulted circuit indicators attached to the radio interface unit with address 5 reported a fault condition. For instance, LEDs 1009, 1011, and 1013 all indicate that the faulted circuit indicators corresponding to those LEDs reported a fault. For illustration purposes, the faulted circuit indicator associated with phase B of group or way 2 (e.g., 206b of FIG. 2) is faulted whereas the faulted circuit indicators associated with phases A and C of group or way 2 (e.g., 206d of FIG. 2) are connected and not faulted.

[0082] According to one embodiment, the user interface 102 will display on the group (way) 1022 and phase 1008 indicators the status of the faulted circuit indicators attached to the radio interface unit that first reports a faulted circuit. If none of the radio interface units report a faulted circuit, then the user interface 102 will display on the group (way) 1022 and phase 1008 indicators the status of the faulted circuit indicators attached to the radio interface unit with the lowest numbered address. For example, FIG. 11D indicates that at least one faulted circuit indicator attached to radio interface unit at address 3 reports a fault, as well as at least one faulted circuit indicator attached to radio interface unit at address 8. As soon as the radio interface unit with address 3 reports a fault, the status of the faulted circuit indicators connected to the radio interface unit associated with address 3 will be displayed on the group (way) and phase 1022, 1008 indicators. In order to view the status of the faulted circuit indicators attached to the radio interface unit at address 8, the "next" button 1010 may be pushed enough times to scroll to that report.

[0083] During operation, a user will approach an area with one or more groups of faulted circuit indicators installed. The user will then start a scan operation using the wireless device 102 by pressing the "scan" button 1012. The radio address indicator 1006 will provide an overview of the status of the faulted circuit indicators attached to the different radio interface units. For those radio interface units with no attached faulted circuit indicators asserting a fault condition, the corresponding LEDs within the radio address indicator will display green. Conversely, for those radio interface units attached to faulted circuit indicators which have asserted a fault, the corresponding LEDs within the radio address indicator will display red. And for those radio interface units which are not installed or which have radio communication, the corresponding LEDs within the radio address indicator will not be illuminated.

[0084] The radio interface is indicated within the radio address indicator by the corresponding LED being illuminated amber within the radio address indicator 1006. The user may view the scan results for a different radio interface unit by pressing the "next" button 1010, which selects the radio interface unit with the next lowest address, until the desired radio interface unit is selected. Using this technique, the user can determine which faulted circuit indicators are asserting a fault within range of the wireless device. The user can also tell if any radio interface units are malfunctioning due to a low battery or other reason. The system health indicator 118 will show the system health of the radio interface unit currently being displayed according to the radio

address indicator 1006. And the user can determine if a faulted circuit indicator has become disconnected from the appropriate radio interface unit. All of the above can be done without accessing any of the faulted circuit indicators, which can result in enormous time savings, particularly when dealing with underground installations.

5 **[0085]** In yet another embodiment, the handheld wireless device 102 may be adapted to indicate an interference or collision of signals received from more than one radio interface device. For example, LEDs associated with the radio address indicator 1006 may flash between two colors to indicate that at least two signals have been received from radio interface devices having different unique serial numbers but using
10 the same address in the vicinity. In one embodiment, an LED associated with radio address indicator 1006 may flash between green and amber to signal that neither radio interface unit contains a fault. Alternatively, an LED associated with radio address indicator 1006 may flash between red and amber to signal that at least one of the radio interface units contains a fault. When selecting the display for the address in which a
15 collision has occurred, the way 1022 and phase 1008 indicators may alternate between indications for the data of each of the radio interface units. In yet another embodiment, a particular designation may be shown (e.g., a particular serial number associated with a particular radio interface unit) in order to differentiate between two radio interface units having the same address.

20 **[0086]** In addition to the wireless devices LED display, the user interface may further include other means for communicating information. Such information may include, but is not limited to, radio interface unit address, radio interface unit serial number, faulted circuit indicator status, faulted circuit indicator fault location, diagnostic parameters, firmware revisions, radio interface unit health, counter information, radio interface unit
25 GPS position, handheld device GPS position, navigation information or any other information. In one embodiment, the additional communication means may be a liquid crystal display (LCD) as shown in 1002 on FIGS. 11A-11D.

[0087] In another embodiment, the communication means may be a speaker 1004. This speaker 1004 can communicate the occurrence of an event 1019 to a user through
30 prerecorded or synthesized messages, chirps, dog barks, beeps, or other sounds. Further, the speaker 1004 may communicate more complicated messages through Morse code. In particular, among other messages, Morse code may be used to communicate the occurrence of a fault by a monitored faulted circuit indicator or the

occurrence of low system life in a radio interface unit or a faulted circuit indicator. As Morse code is well known in the art, its particulars are not discussed here.

[0088] The foregoing embodiments are drawn toward using faulted circuit indicators 206 as a sensing probe to indicate the presence of a predetermined condition, namely, a faulted circuit. However, because the faulted circuit indicator sends either a positive (fault) or negative (no fault) signal to the radio interface unit 400, any sensing probe that is capable of detecting a predetermined condition and sending a positive or negative signal to the radio interface unit 400 may be used. For example, it may be necessary to communicate information about the temperature inside the vault underground 200. In this embodiment, as illustrated in FIGS. 2A and 2B, instead of using a faulted circuit indicator 206, a temperature transducer 208 may be used as the sensing probe. The temperature transducer 208 may be coupled to the article from which knowledge about the temperature needs to be communicated. The temperature transducer 208 may be configured to send a positive signal in the case that the temperature sensed is either above or below a predetermined threshold. Thus, the user would be able to determine whether the temperature sensed by the transducer 208 was above or below a predetermined level, or if the temperature transducer probe had become disconnected from the radio interface unit 400 by the display of the appropriate LED 1008. For example, if the temperature transducer 208 corresponds to group (way) 4 phase C, the user will understand the state of this probe by the display of the LED in group (way) 4, phase C.

[0089] In one embodiment, the various LEDs may function so as to indicate different colors for a colorblind person. For example, if the LEDs are capable of showing red or green, the LED may be programmed to flash for red, and stay constant for green. In this way, a user who cannot otherwise distinguish between red and green would be able to determine if the LED was reporting a red or a green color.

[0090] An embodiment of the schematic of the circuitry of the wireless device 102 is shown in FIG. 11e. The reference numbers in FIG. 11e correspond to the functions as shown in FIGS. 1a-d.

[0091] The wireless device 102 of FIGS. 2a and 2b may further be adapted to communicate data to and from the radio interface units 400a-400h. Referring to the drawings, and back to FIG. 3 in particular, a wireless device communicates with a radio interface unit connected to a number of power system devices (e.g., detection devices or faulted circuit indicators). The radio frequency faulted circuit indicator monitor 400

also includes a microprocessor 310 with some amount of memory 342. The memory may be in the form of randomly accessible memory (e.g., any type of randomly accessible memory, such as SRAM, DRAM, internal registers, FLASH, etc.). Note that the memory need not be integrated within the microprocessor. The microprocessor is coupled to an RF transceiver 322, which is coupled to an antenna 202 directly or via a radio frequency cable 208. The radio frequency faulted circuit indicator monitor 400 communicates with a wireless device 102. A wide variety of wireless communications protocols could be used, such as 802.11. The particular wireless communications protocol used is not significant to this invention, and as wireless communications protocols are well known in the art, no such protocol is described.

[0092] FIG. 12 illustrates an application for the system for communicating information between a detection device and a wireless device, which is adapted to endure harsh conditions (e.g., prolonged exposure to water). More specifically, two underground vaults 200a, 200b are connected by underground power transmission lines 3302, 3304, 3306 (one for each phase, A, B, and C) for distributing electrical power therebetween. The underground vaults 200a, 200b may include additional power transmission lines entering and exiting, but for simplicity, only three are shown.

[0093] Further, within each underground vault 200a, 200b, each of the power transmission lines 3302, 3304, 3306 are spliced into electrical conductors for distribution of electricity therefrom into discrete ways (e.g., Way 1 (206a), Way 1 (206b)). Each way (e.g., Way 1 (206a), Way 1 (206b)) includes three phases (e.g., Phase A, Phase B, Phase C) as described above. A detection device (e.g., 3300a, 3300b) is adapted to monitor each phase corresponding to one of the ways. Again, for simplicity, only a single way and corresponding pair of detection device are enumerated in each vault, but all ways (and their corresponding phases) may be monitored by separate detection devices.

[0094] The detection devices (e.g., 3300a, 3300b) are each adapted to determine the phase angle of the current on each phase corresponding to each way at their respective locations. Each of the detection devices (e.g., 3300a, 3300b) includes at least one current sensor for measuring the current on each phase (Phase A, Phase B, Phase C). For example, the current sensors may be split core current transformers 3402a, 3402b, 3402c as shown in FIGs. 13. The detection devices (e.g., 3300a, 3300b) are each adapted to share the phase angle data at their respective locations with the other detection device via a communications link. For example, the detection

devices may be coupled using a fiber optics line 3404. Other means of communication may be used, including copper communications cable, radio-frequency communication, and the like. Using the remote and local phase angle data, each detection device (e.g., 3300a, 3300b) determines whether a fault exists at one of the ways.

5 **[0095]** For example, as shown in FIG. 14, the detection devices 3300a, 3300b each measure the current signal (and specifically the phase angle) for each phase A, phase B, and phase C at their respective locations. Each detection device 3300a, 3300b then determines whether the locally measured current signal is either a positive portion 3502 or negative portion 3504 of the power system waveform. The positive and negative
10 portions 3502, 3504 of the current signal are converted into one of two frequencies corresponding to the positive or negative portion of the power system waveform. The detection devices 3300a, 3300b are each adapted to share the phase angle data and, specifically, the frequency information at their respective locations with the other detection device via a fiber optics line 3402. Using the remote and local phase angle
15 data, each detection device 3300a, 3300b determines whether a fault exists by decoding the frequency information into positive and negative current phases of the power system waveform. Each detection device 3300a, 3300b then uses the local and remote phase information to determine whether the current is in-phase (e.g., no fault exists) or out-of-phase (e.g., fault exists).

20 **[0096]** Now referring back to FIG. 13, each detection device (e.g., 3300a, 3300b) is connected to a corresponding radio interface unit (e.g., 400a, 400b) such that detection device information may be transmitted to a handheld device 102. The detection device (e.g., 3300a, 3300b) may be connected to its corresponding radio interface unit (e.g., 400a, 400b) using the various embodiments shown and described herein (e.g., the
25 embodiments shown and described with respect to FIGs. 6a-6d). The radio interface unit (e.g., 400a, 400b), the handheld device 102, and the communication methods therebetween may be in the form of the various embodiments shown and described herein.

[0097] The systems of FIGs. 12-14 may be used to determine whether there is a fault
30 between underground vaults (e.g., for intervault fault determination). For example, as shown in FIG. 15, no fault exists between underground vaults 200a and 200b; however, a fault exists between underground vaults 200b and 200c. Detection devices 3600a, 3600b, 3600c, and 3600d are each adapted to determine the phase angle of the current on an electrical conductor at their respective locations in the underground vaults 200a,

200b, 200c. Using a communications link, detection device 3600a shares phase angle data with detection device 3600b. At the same time, detection device 3600c shares phase angle data with detection device 3600d. Using the local and remote phase angle data, each of the detection devices determines whether a fault exists. Specifically, detection devices 3600a and 3600b each determine that there is a in-phase condition and, therefore, no fault exists. On the other hand, detection devices 3600c and 3600d each determine that there is an out-of-phase condition and, therefore, a fault exists. Each of the detection devices 3600a, 3600b, 3600c, 3600d transmits its corresponding data (including whether there is a fault) to a respective radio interface unit 400a, 400b, 400c. In this example, detection devices 3600a and 3600b do not signal a fault condition to their respective radio interface units 400a and 400b; however, detection devices 3600c and 3600d signal a fault location to their respective radio interface units 400b and 400c. Each radio interface unit 400a, 400b, 400c transmits this data to a handheld device 102 which provides an indication that there is a fault condition at underground vaults 200b and 200c.

[0098] The systems of FIGs. 12-14 may be used to determine whether there is a fault within an underground vault 200 (e.g. for intravault fault determination). For example, as shown in FIG. 16, each phase conductor A, B, and C includes a splice 3702a, 3702b, and 3702c. On either side of the splices is a current transformer that provides current signals to a detection device on the entrance 3700a, or a detection device on the exit 3700b of the underground vault 200. The detection device 3700a, 3700b are each adapted to determine the phase angle of the current on an electrical conductor at their respective locations in the underground vault 200. Using a communications link, detection device 3700a shares phase angle data with detection device 3700b. Using the local and remote phase angle data, each of the detection devices 3700a, 3700b determines whether a fault exists. Specifically, detection devices 3700a and 3700b each determine that there is an out-of-phase condition and, therefore, a fault exists. Each of the detection devices 3700a, 3700b transmits its corresponding data (including whether there is a fault) to the radio interface unit 400. The radio interface unit 400 transmits this data to a handheld device 102 which provides an indication that there is a fault condition at underground vault.

[0099] FIG. 17A illustrates a logic diagram of circuitry contained within the detection devices of FIGs. 12-16 for rectifying, modulating and transmitting the current information measured locally by the current sensors of those figures. The current

signal locally obtained by the current sensor may be rectified at 3800. The positive portion of the current signal may then be modulated with a first signal, such as a 25kHz signal, and the negative portion of the current signal may be modulated using a second signal, such as a 12.5kHz signal at 3802. The two signals are then OR'ed together to produce a modulated signal that is sent via a communications link to the other detection device.

[00100] FIG. 17B illustrates a logic diagram of the circuitry in another detection device for processing the modulated signal transmitted by the circuitry of the first detection device of FIG. 17A. Specifically, the other detection device includes circuitry that decodes the modulated 25 kHz or 12.5 kHz signals to determine the corresponding positive and negative portions of the sine wave received from the first detection device at 3804. The local positive and negative signals are then compared with the received and decoded positive and negative signal to determine if they are in-phase or out-of-phase at 3806. If they are out of phase, the other detection device signals the radio interface unit that a fault exists at 3808. The radio interface unit then signals the handheld wireless device that a fault exists.

[00101] FIG. 18 illustrates a timing diagram of the signals shared between the detection devices of FIGs. 17A and 17B. One frame, as illustrated, is 16 clocks long. A positive or negative portion of a cycle is declared if all 16 bits of the frame match the frame pattern.

[00102] FIG. 19 illustrates a logic diagram of yet another circuit which may be used in one of the detection devices of FIGs. 12-16 for transmitting the current information measured locally by one of the current sensors of those figures; and another logic diagram of yet another circuit for receiving and processing the transmitted current information by another detection device of those figures. Specifically, one of the detection devices may include transmit logic (or module) 4002 for rectifying a current signal obtained locally via an associated current sensor and for generating pulses during a select cycle (e.g., during each half cycle of input current on each phase). Such rectifying may be performed inside or outside of a processing device (such as a complex programmable logic device (CPLD) or the like). The pulses may be sampled by a complex programmable logic device (or other comparable device) at a select rate (e.g., at about 512μs or at about 1.95 KHz) and transmitted to another detection device via a communications link 4004.

[00103] The sampled pulses may be sent in a select data packet (e.g., a serial data packet). For example, the transmit logic 4002 of FIG. 19 may be adapted to packetize the sampled pulses into a serial data packet 4102 as shown in FIG. 20. As specifically shown in the figure, the data packet 4102 includes a plurality of bits which contain sampled pulse information (e.g., bits 5, 6, 8, 9, 11, and 12) for the positive and negative portions of the three phases. The data packet 4102 may further include a plurality of bits (e.g., bits 0 to 4, 10001), which serve as a preamble having a select sequence to help the other detection device synchronize data packets during receipt. The data packet 4102 may further include a plurality of bits (e.g., bits 7, 10, and 13), which are at fixed logic high state to ensure that the preamble sequence does not repeat within the data packet 4102. A parity bit (e.g., bit 14) is further provided at the end of the data packet 4102 for error detection purposes as will be further described below.

[00104] Referring back to FIG. 19, the sampled pulses from the detection device are transmitted to another detection device (e.g., in the form of the data packet 4102 of FIG. 41). The other detection device includes receive logic (or module) 4006, which scans the data packet 4102 for the select preamble sequence (e.g., 10001 of FIG. 20). The receive logic 4006 is further adapted to record the remaining data from the data packet 4102 upon detection of the preamble sequence. The receive logic 4006 is further adapted to compare the received parity bit (e.g., bit 14 from FIG. 41) with a calculated parity bit and determine whether to discard the data packet 4102 based on this comparison. If the data packet 4102 passes the parity bit comparison (and is therefore considered valid data), the data (e.g., bits 5, 6, 8, 9, 11, and 12) contained within the data packet 4102 for the positive and negative portions of the three phases is further processed.

[00105] During processing, the data from the receive logic (or module) 4006 is processed through a combinational logic circuit 4008a, 4008b, and 4008c or comparable compare module, where the data from the data packet 4102 for each phase is logically ANDed with the inverted versions of the respective pulses measured locally from a current sensor associated with the local detection device. The results of each pair of AND gates 4008a, 4008b, 4008c are then combined through OR gates. The output 4010a, 4010b, and 4010c of the combinational logic for each phase is then fed into a Pickup-Dropout delay blocks (or modules) 4012a, 4012b, and 4012c.

[00106] When already in low state, the output of the Pickup-Dropout delay block 4012a, 4012b, and 4012c goes high if the input remains high for a select period (e.g., at least

DELAY_Z ms). Once high, the output goes low when input remains low for a select period (e.g, about DELAY_Z1 sec). The pick-up and drop-out delays also provide an angle margin such that the detection device does not pick-up a fault until the phase difference increases above a select threshold (e.g., at about 60° at about 60 Hz and 50° at about 50 Hz). The drop-out delay also prevents the output from chattering or decreases chattering as the phase difference approaches about 180°.

5 [00107] The outputs from Pickup-Dropout delay block (or module) 4012a, 4012b, and 4012c for each phase are then transmitted to Detection Device Set/Clear pulse generation logic 4014, where they are combined through an OR gate. Whenever the
10 output of this OR gate asserts high, a pulse (e.g., 30μs pulse) is generated on the “fault set” line 4016 to signal a fault. When this output changes to low, a pulse (e.g., 30μs pulse) is generated on the “fault clr” line 4018 to signal clearance of a fault. In this way, a single communications line (“fault set”, “fault clr”) may be used to indicate fault on any of the phases by transmission of these pulses to the radio interface unit. The radio
15 interface unit then signals the handheld wireless device that a fault exists.

[00108] In one embodiment, in addition to signaling fault conditions, the system may further be adapted to signal if there are parity errors in the data packet of FIG. 20. For example, the other detection device may be adapted to signal to the radio interface device and, ultimately the handheld wireless device, that valid data is being processed.
20 The system may similarly be adapted such that the handheld wireless device ends such signaling if a select number of parity errors (e.g., three parity errors in succession) are received. Moreover, the system may be adapted to signal through the handheld wireless device that no data is received through the communications link.

[00109] The system may be further adapted to indicate communication diagnostics and/or the faulted phase during a cleared-fault condition. The outputs from Receive Logic 4006 and/or Pickup-Dropout delay blocks (or modules) 4012a, 4012b, and 4012c may be directed to a diagnostic LED driver 4020. In one embodiment, the diagnostic LED driver uses the output from the Receive Logic 4006 to determine the state of communications, and direct an LED to illuminate if the state of communications meets
25 certain criteria. For example, if a fiber optic cable is broken or malfunctioning, the diagnostic LED driver may be configured to direct an LED to illuminate in a predetermined fashion (flash pattern, color, etc.). Similarly, if the communications are delayed or include a predetermined number of parity errors, the diagnostic LED driver
30 4020 may be configured to direct an LED to illuminate in a predetermined fashion.

[00110] In one embodiment, the diagnostic LED driver may be configured to use the outputs of Pickup-Dropout delay blocks (or modules) 4012a, 4012b, and 4012c to signal the faulted phase by directing an LED associated with the particular phase. The LED may be located on the underground system. For example, where the system is
5 powered using the line current, a fault may be detected and cleared by another protective device (e.g. a recloser and recloser control). In such a case, the system would remain without power until after the fault condition has been remedied and the line has been re-energized. In such an event, a user may not have an indication as to which of the phases was faulted. Accordingly, the system may include a battery that is
10 used to illuminate an LED that indicates the faulted phase even when the system is not able to obtain power from the monitored conductor. The system may be configured to illuminate the LED associated with the faulted phase for a predetermined amount of time to allow a user to properly identify the faulted phase.

[00111] The foregoing description of the invention has been presented for purposes of
15 illustration and description, and is not intended to be exhaustive or to limit the invention to the precise form disclosed. The description was selected to best explain the principles of the invention and practical application of these principles to enable others skilled in the art to best utilize the invention in various embodiments and various modifications as are suited to the particular use contemplated. It is intended that the
20 scope of the invention not be limited by the specification, but be defined by the claims set forth below.

Claims

1. A system for indicating a fault on an electric power distribution system, comprising:

a first detection device in electrical communication with a phase conductor, adapted to obtain a first current signal therefrom, and including:

a first current signal modulator for modulating the first current signal; and

a transmit module for communicating the first modulated current signal to a second monitoring device;

a second detection device in electrical communication with the phase conductor at a different location, adapted to obtain a second current signal therefrom, and including:

a second current signal modulator for modulating the second current signal;

a receive module for receiving the first modulated current signal; and

a compare module for comparing the first modulated current signal and the second current signal and determining whether the first current signal is in phase with the second current signal.

2. The system of claim 1, wherein the transmit module comprises a fiber-optic transmitter.

3. The system of claim 1, wherein the receive module comprises a fiber-optic receiver.

4. The system of claim 1, wherein the second detection device comprises a fault indication module for signaling when the compare module determines that the first current signal is not in phase with the second current signal, wherein the system further comprises:

a radio interface unit in communication with the second detection device, for receiving the signal from the fault indication module and transmitting a signal upon receipt thereof.

5. The system of claim 1, wherein the transmit module is configured to transmit a communication frame that includes a predetermined number of clock counts.

6. The system of claim 5, wherein a sign of the first current signal is communicated depending on a number of the predetermined number of clock counts corresponding with a predetermined pattern.

5

7. The system of claim 1, wherein the transmit module is further adapted to packetize the current signal into a select data packet.

8. The system of claim 7, wherein the select data packet further includes a preamble, and the receive module synchronizes the select data packet based on the preamble.

10

9. The system of claim 7, wherein the select data packet further includes a parity bit, and the receive module is adapted to detect errors in the select data packet based on the parity bit.

15

10. The system of claim 1, further comprising a pick-up delay module coupled to the compare module, wherein the pick-up delay module determines whether the first current signal is in phase with the second current signal at a select threshold.

20

11. The system of claim 1, further comprising a drop-out delay module coupled to the compare module, wherein the drop-out delay module decreases chattering as the phase difference between the first and second current signals approaches about 0°.

12. A system for communicating information between a detection device and a wireless device, comprising:

25

a detection device adapted to measure a current signal from an electrical conductor and compare the current signal with another current signal received from another detection device, said detection device further adapted to determine whether the current signal is in phase with the other current signal;

30

a communication member coupled to the detection device,
a radio interface unit in communication with said communication member, and
a wireless device in radio communication with said radio interface unit, such that said detection device communicates information between the wireless device via the radio interface unit.

13. The system of claim 12, wherein the communication member is substantially self-contained.

5 14. The system of claim 12, wherein the radio interface unit is substantially self-contained.

15. The system of claim 12, wherein the communication member communicates power system information to the radio interface unit without a mechanical connection
10 therebetween.

16. The system of claim 12, wherein the communication member communicates power system information to the radio interface unit without an electrical connection
15 therebetween.

17. The system of claim 12, wherein the detection device is located in an underground location.

18. The system of claim 12, wherein the radio interface unit is generally submergible
20 in water.

19. The system of claim 12, wherein the radio interface unit is generally constructed to endure harsh conditions.

25 20. The system of claim 12, wherein the radio interface unit is adapted to communicate information regarding the detection device between the detection device and the wireless device.

30 21. The system of claim 12, wherein the another detection device is further adapted to packetize the another current signal into a select data packet and transmit the select data packet to the detection device.

22. The system of claim 21, wherein the select data packet further includes a preamble, and the detection device synchronizes the select data packet based on the preamble.

5 23. The system of claim 21, wherein the select data packet further includes a parity bit, and the detection device is adapted to detect errors in the select data packet based on the parity bit.

10 24. The system of claim 12, wherein the detection device is further adapted to determine whether the current signal is in phase with the another current signal at a select threshold.

15 25. The system of claim 12, wherein the detection device is further adapted to decrease chattering as the phase difference between the current signal and the another current signal approaches about 0° .

26. The system of claim 12, wherein the radio interface unit is adapted to communicate information regarding the radio interface unit to the wireless device.

20 27. The system of claim 12, wherein the radio interface unit is adapted to receive information from the wireless device and transmit the information received from the wireless device to the detection device.

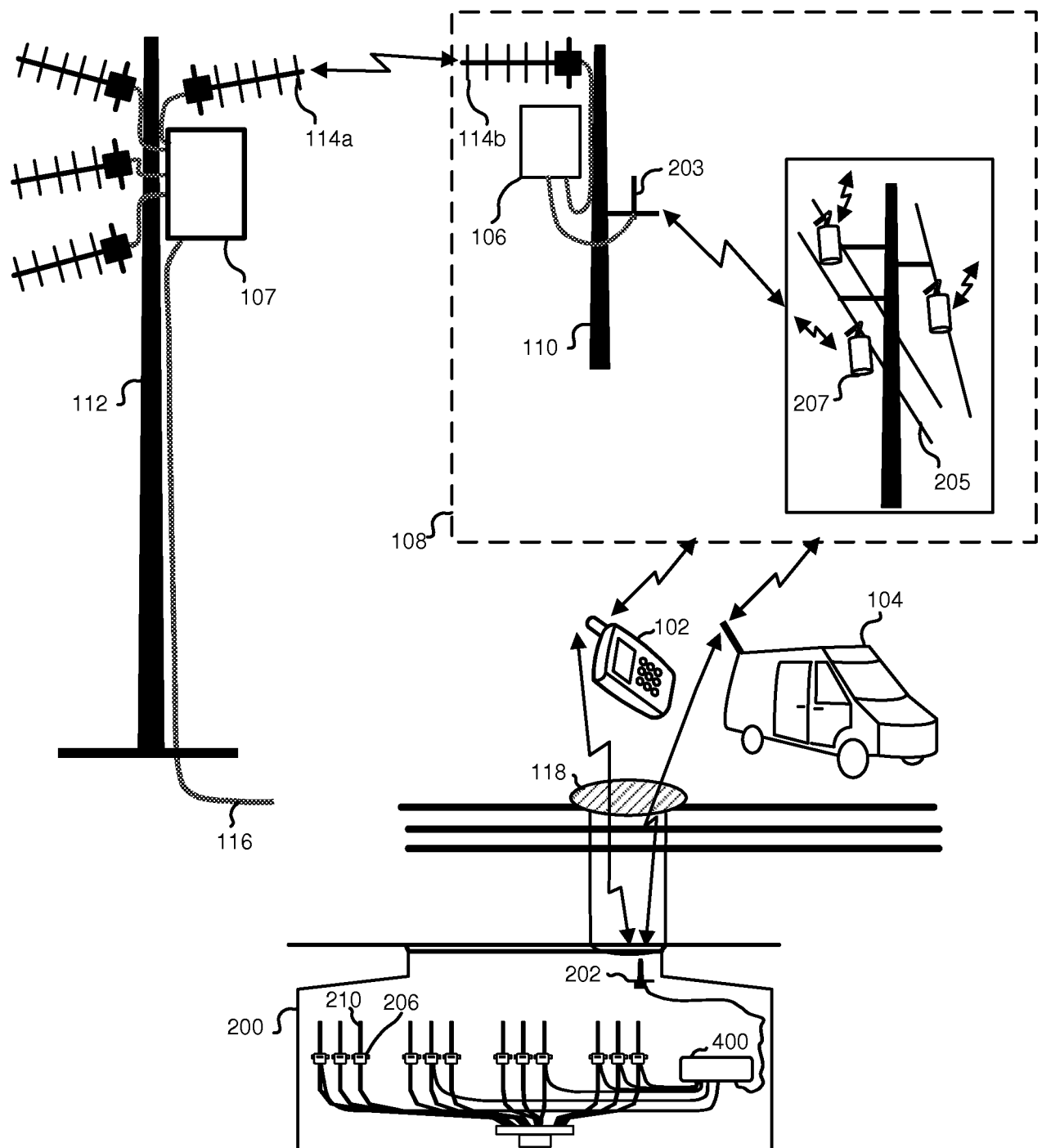


FIG. 1

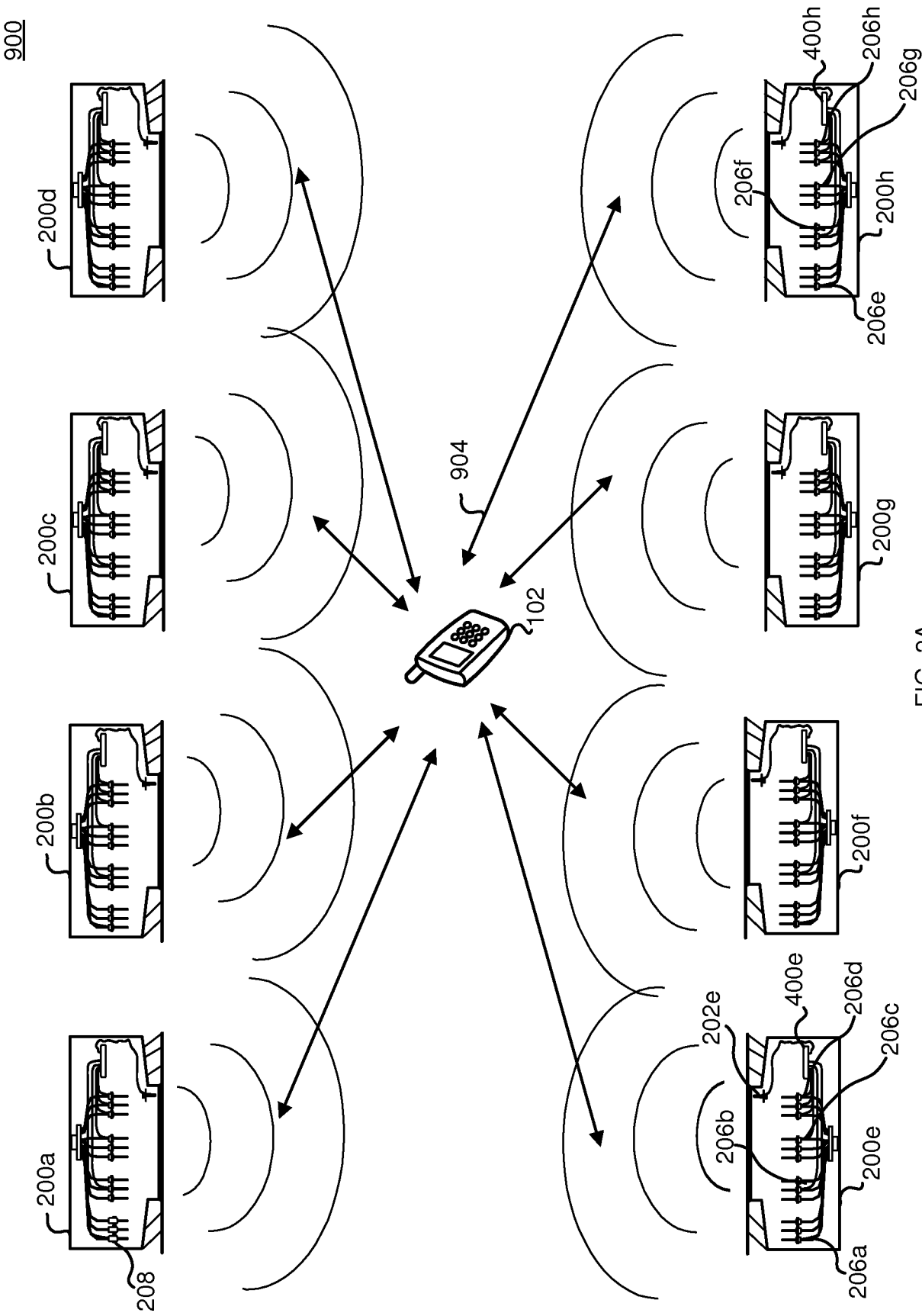


FIG. 2A

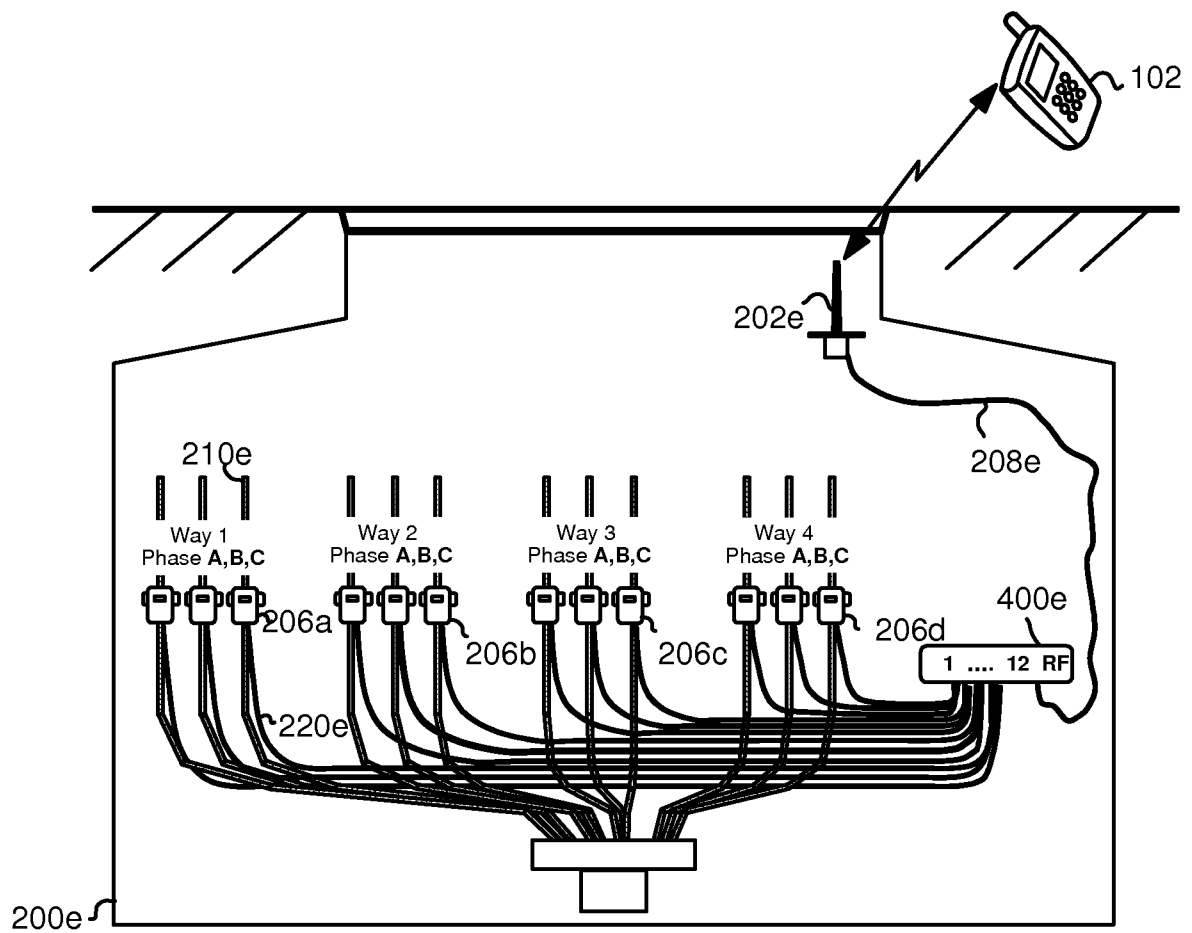


FIG. 2B

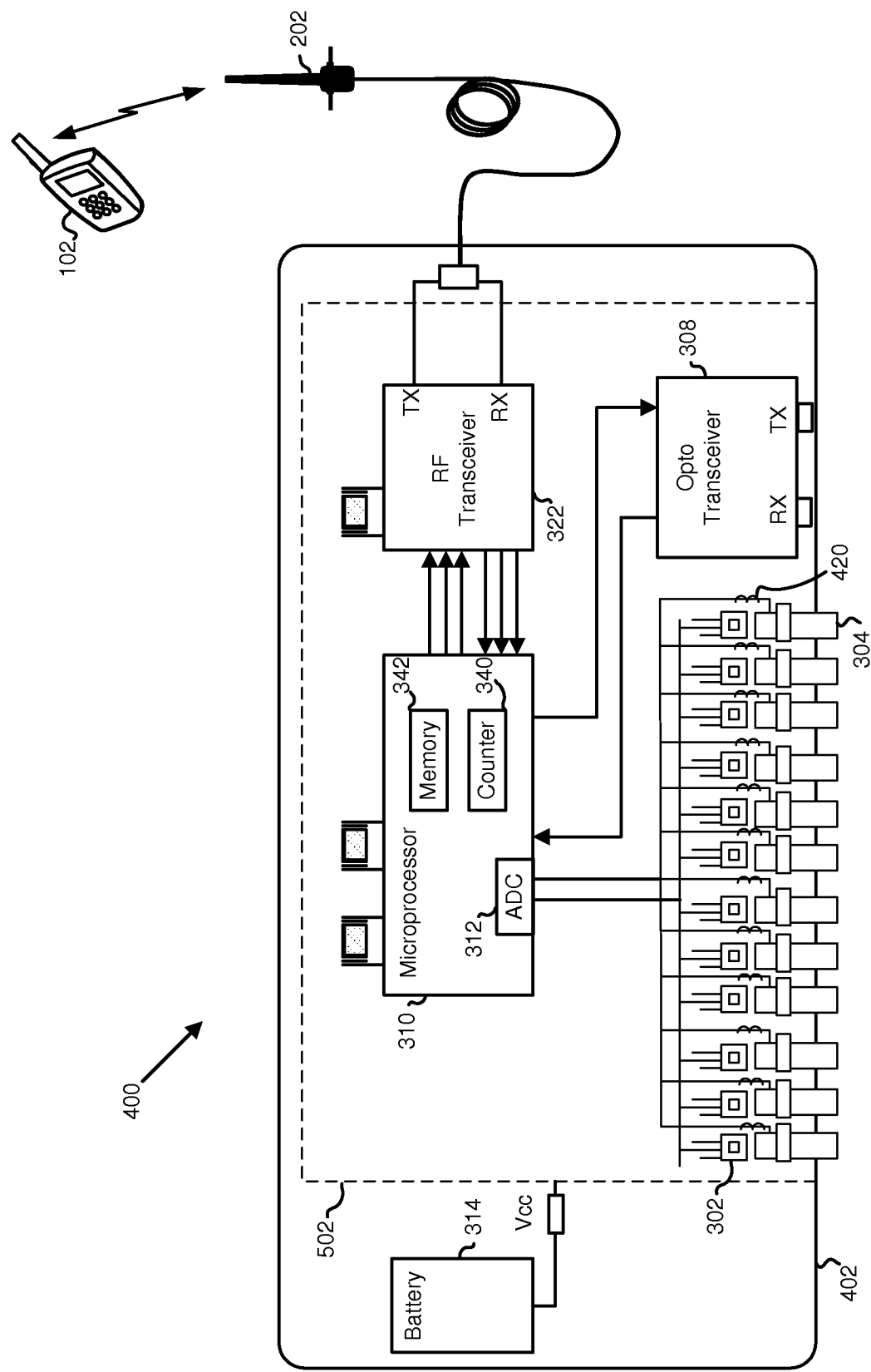


FIG. 3

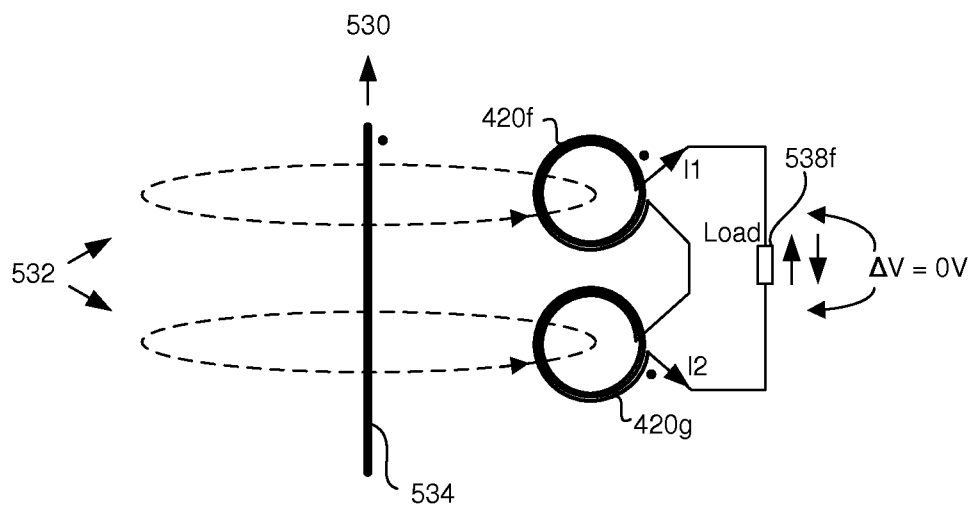


FIG. 4

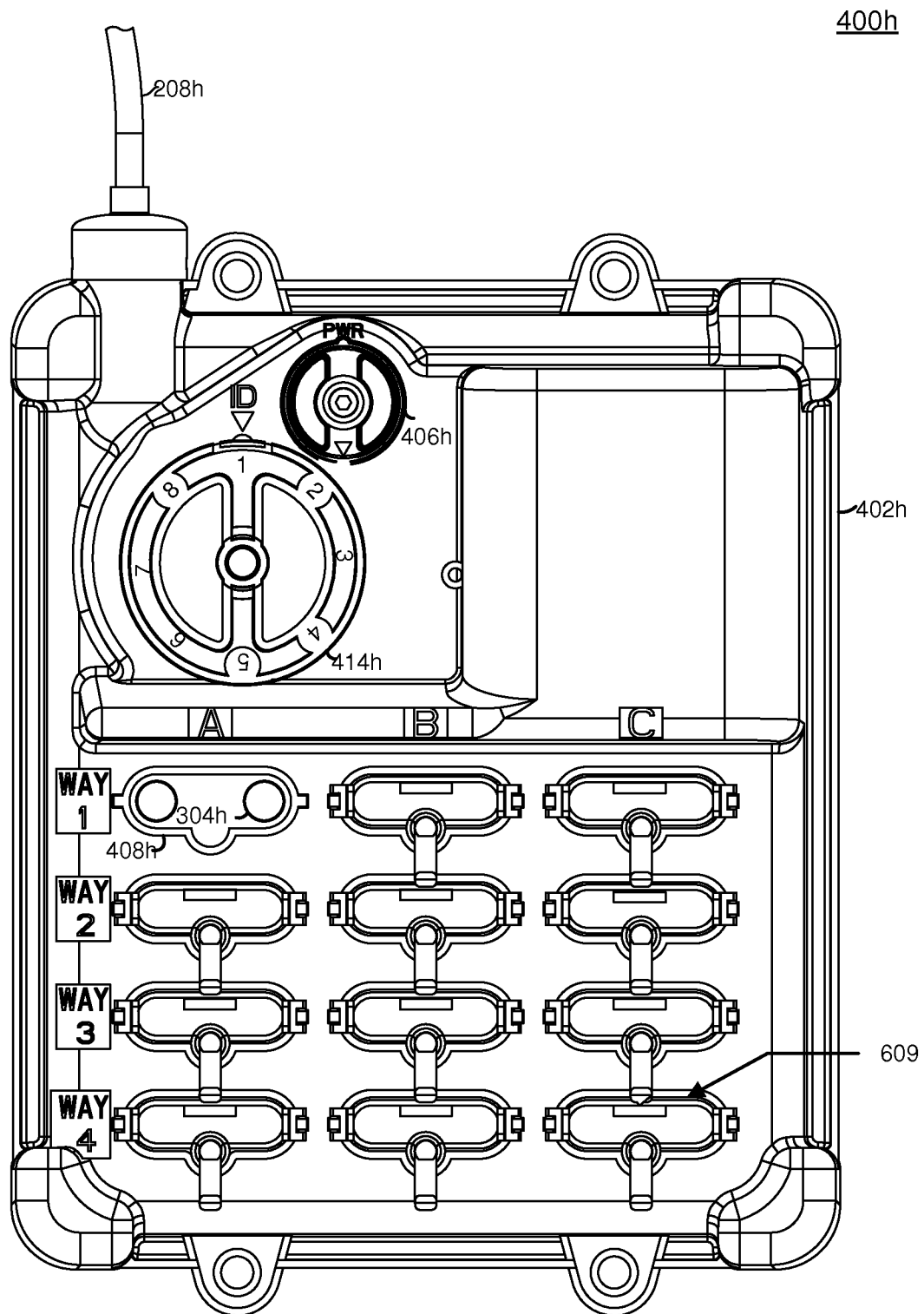


FIG. 5

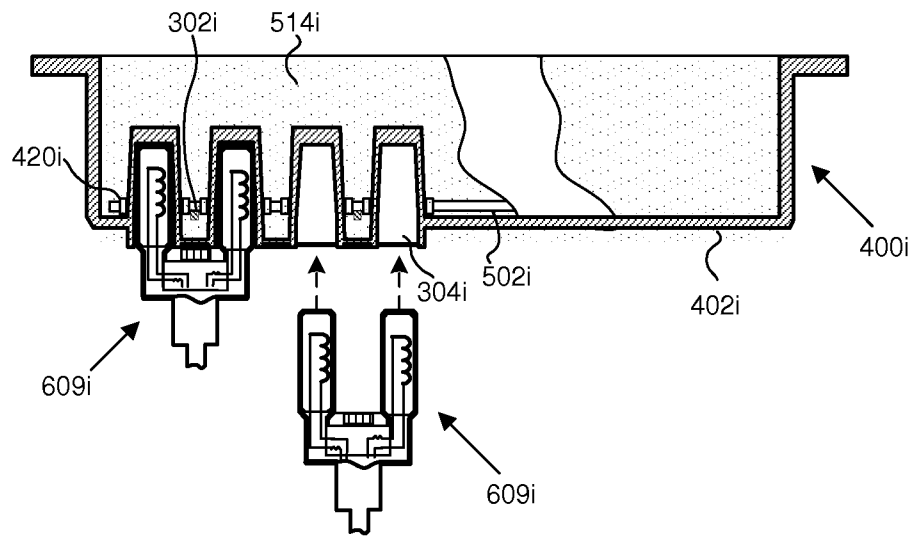


FIG. 6A

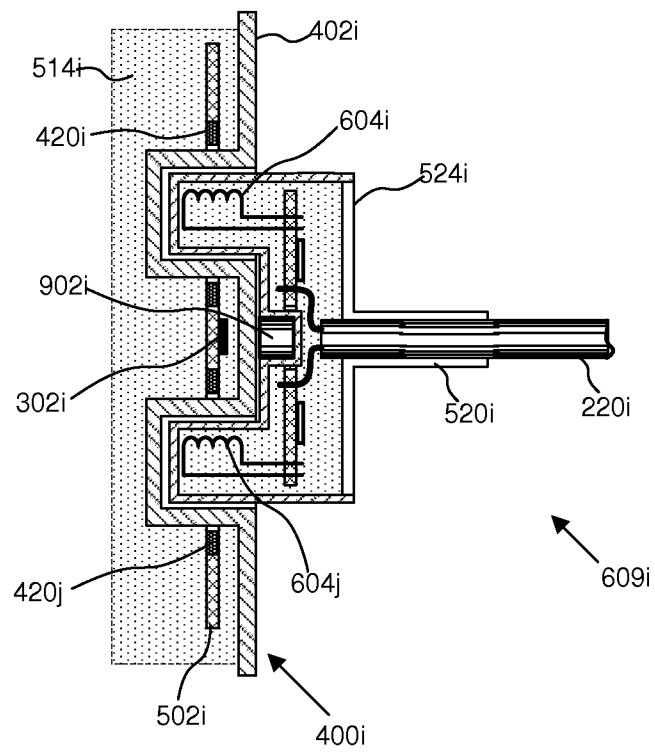


FIG. 6B

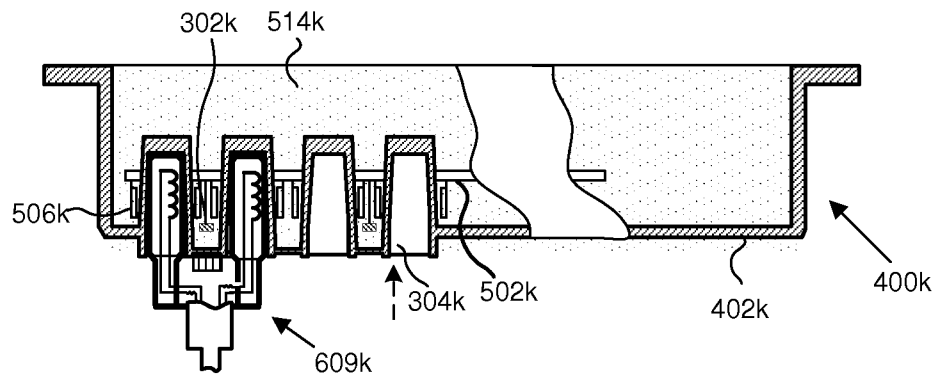


FIG. 6C

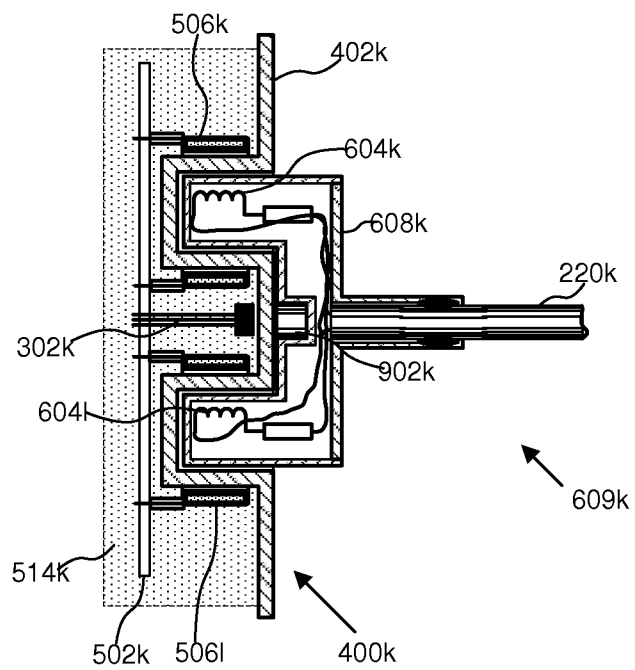


FIG. 6D

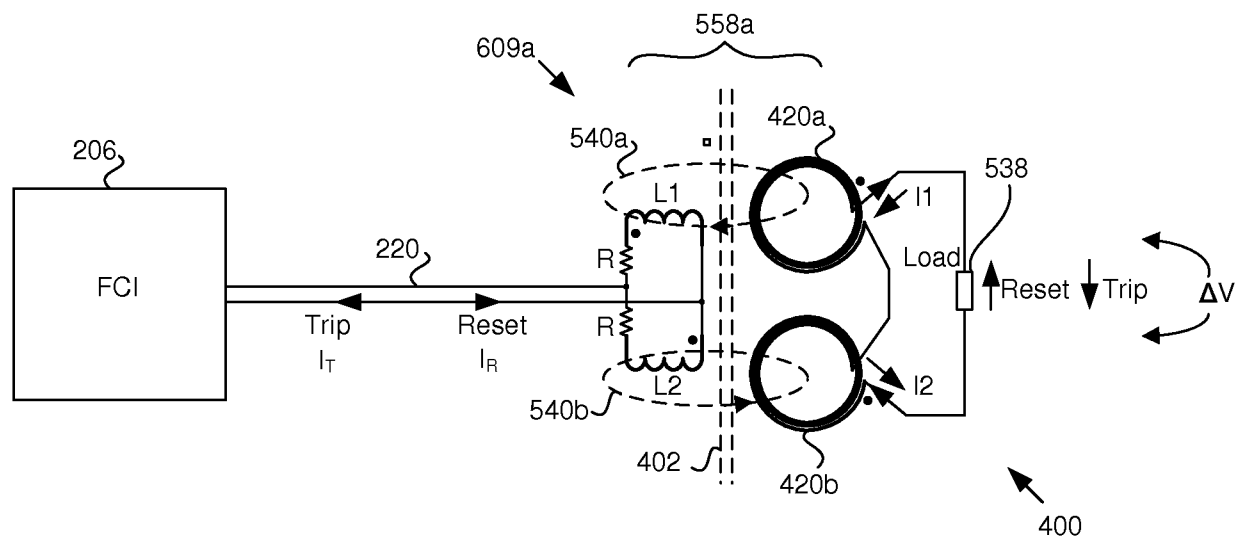


FIG. 7

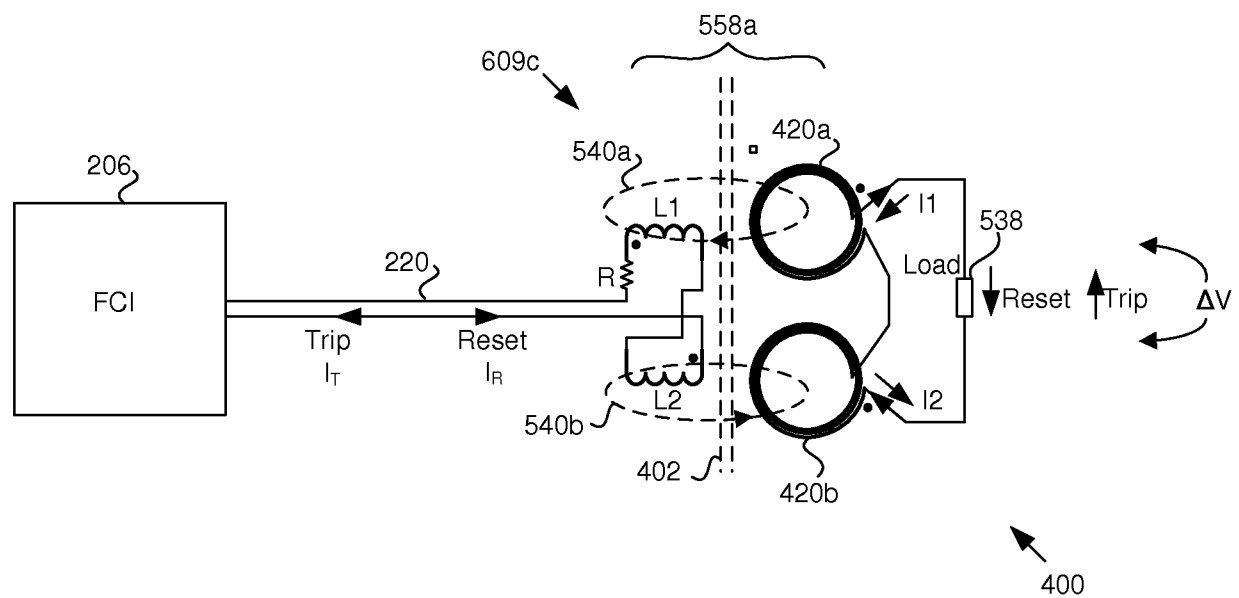


FIG. 8

400

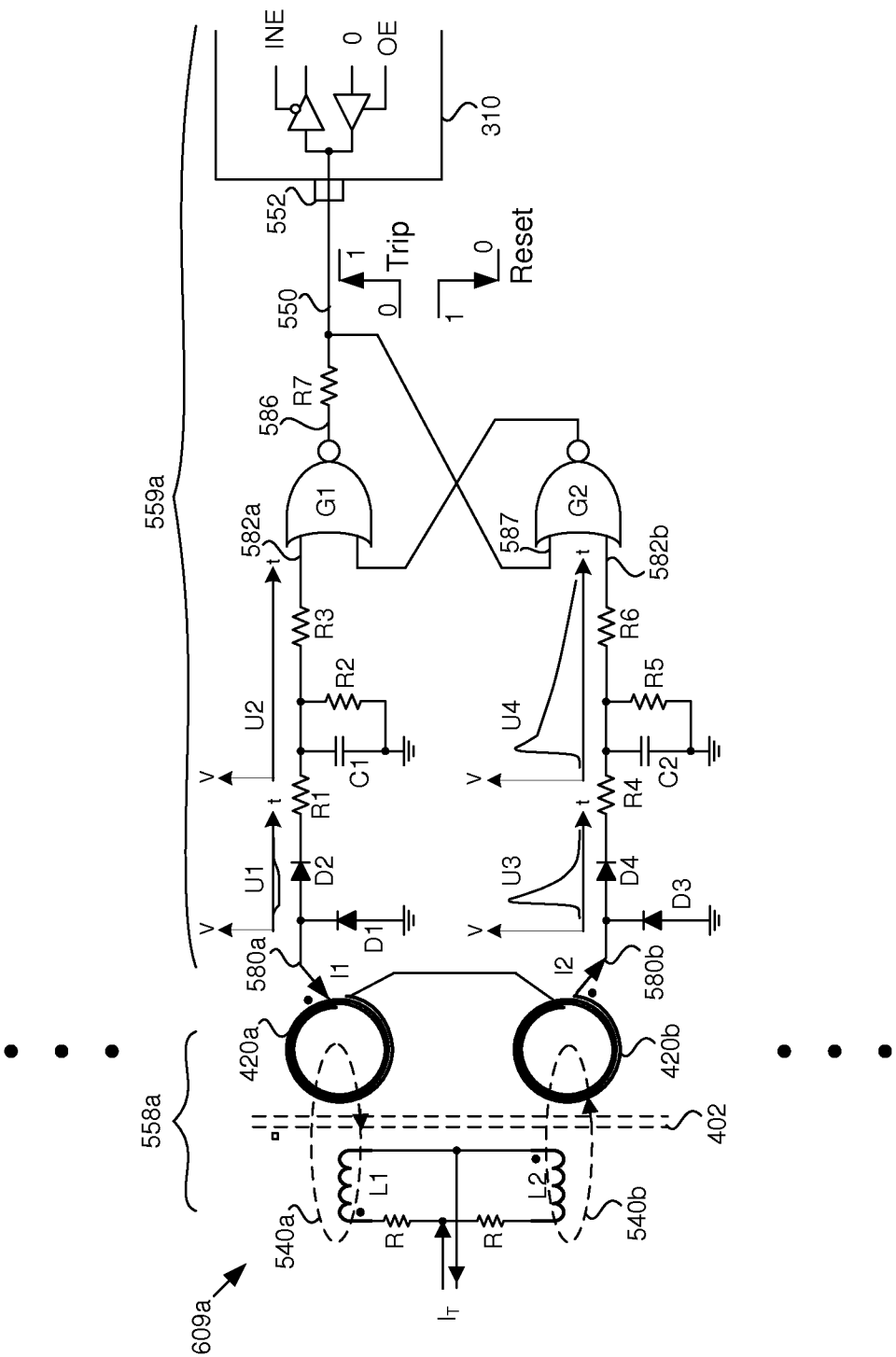


FIG. 9

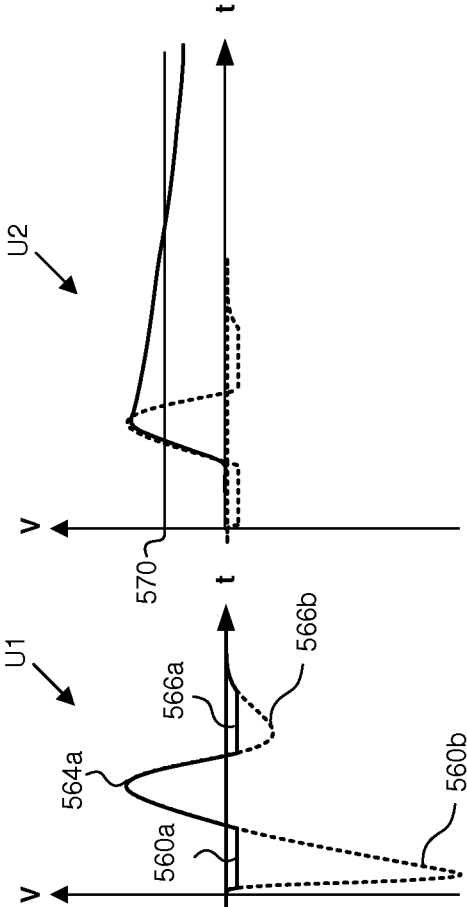


FIG. 10Bi

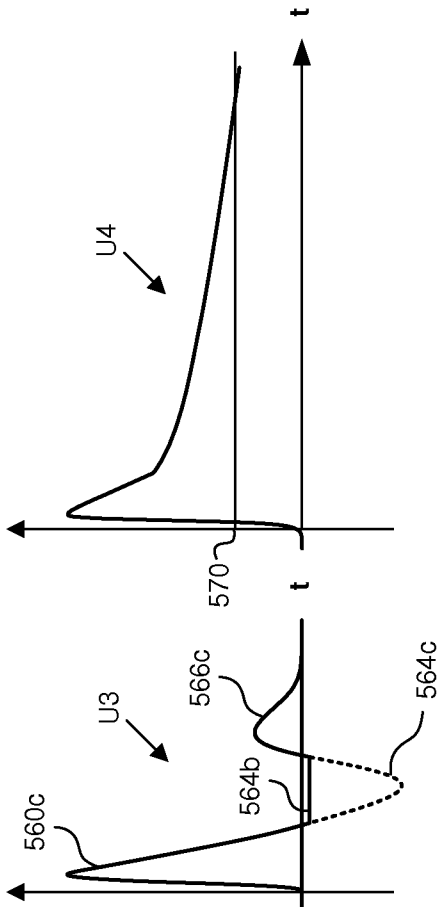
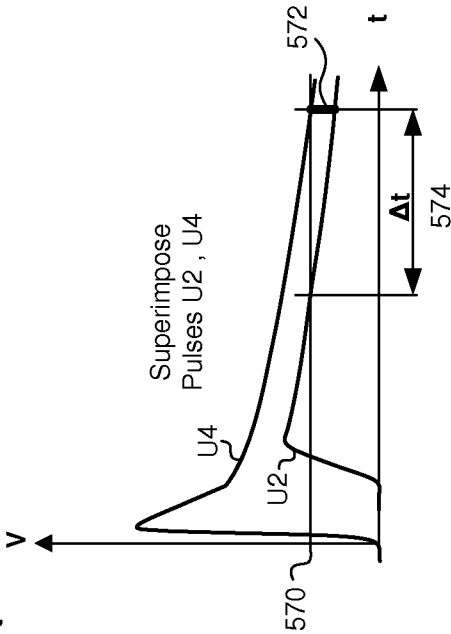


FIG. 10Bii

FIG. 10C

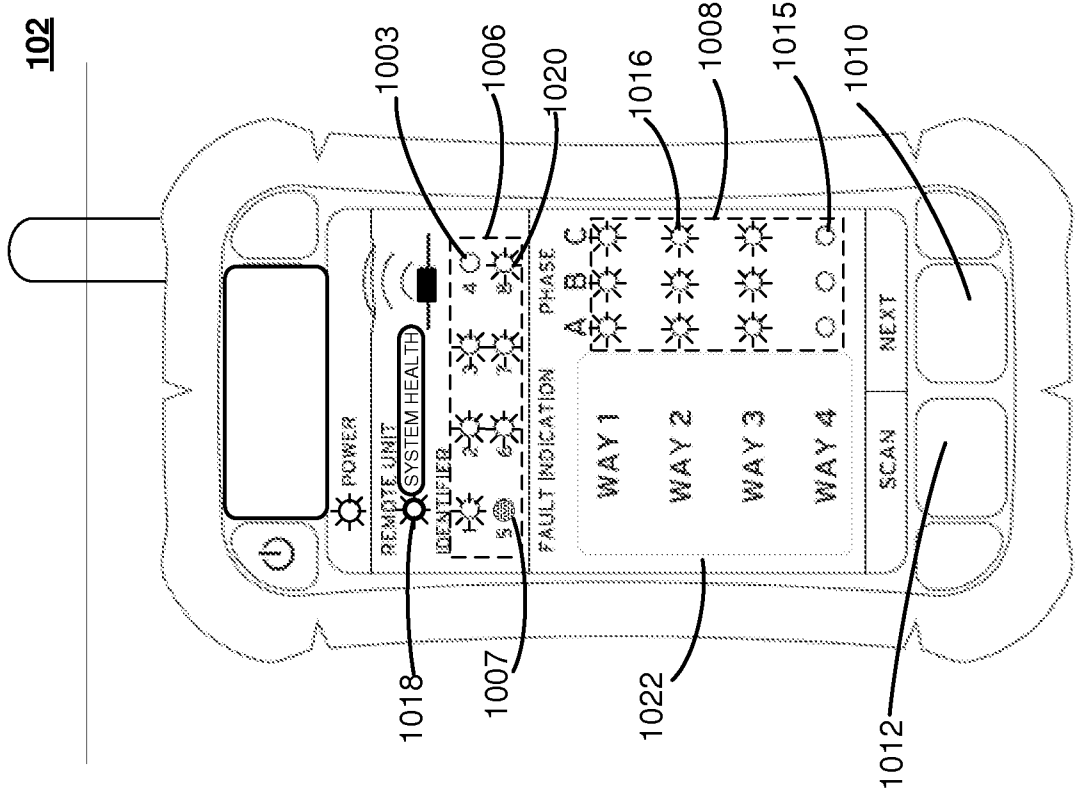


FIG. 11B

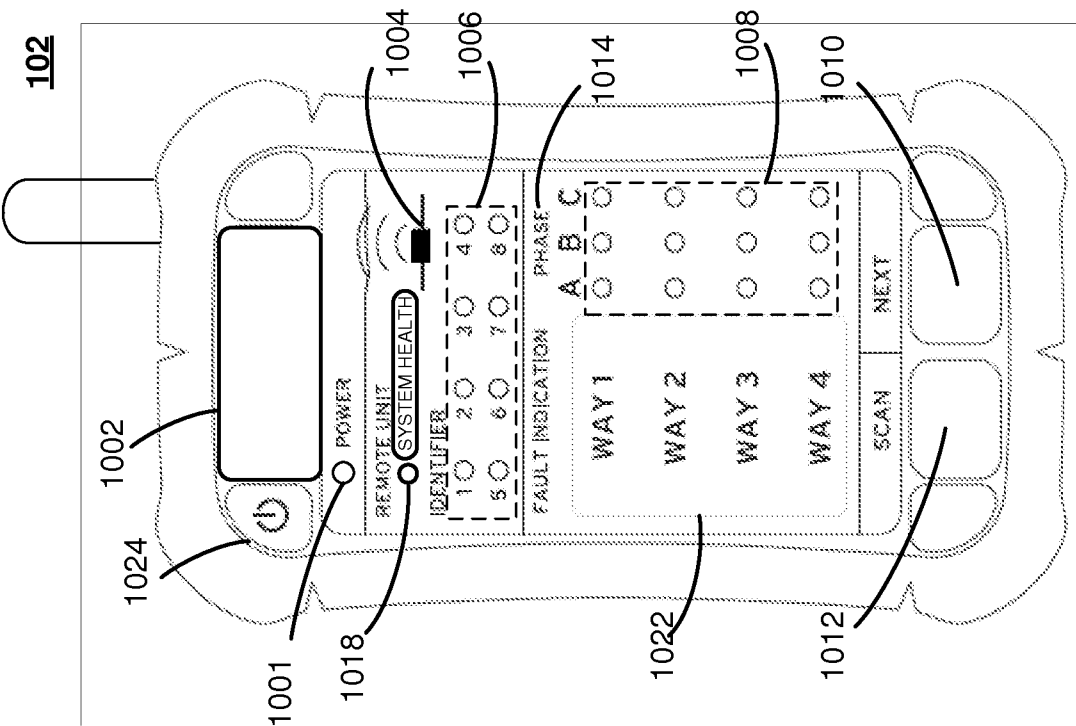


FIG. 11A

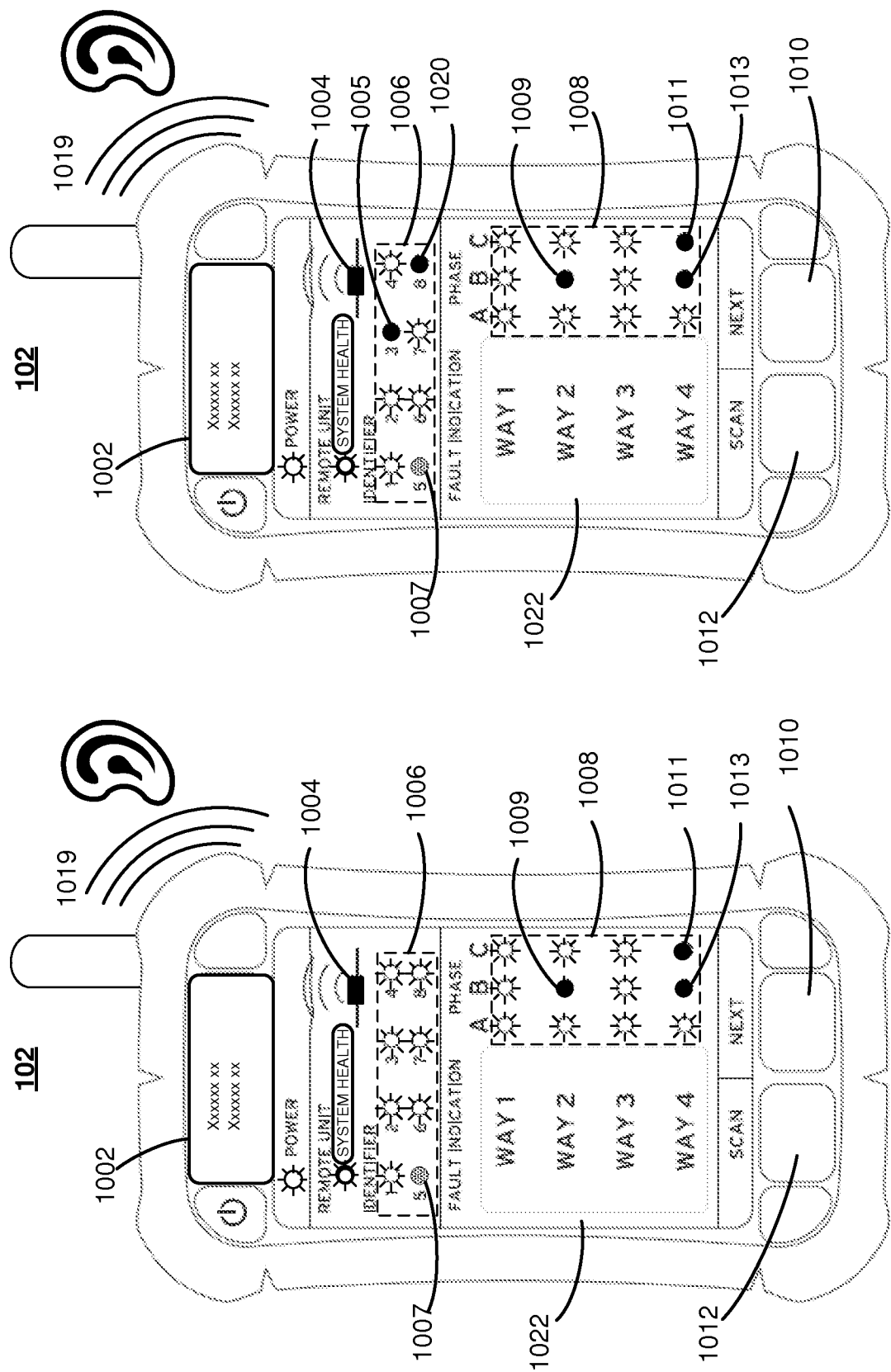
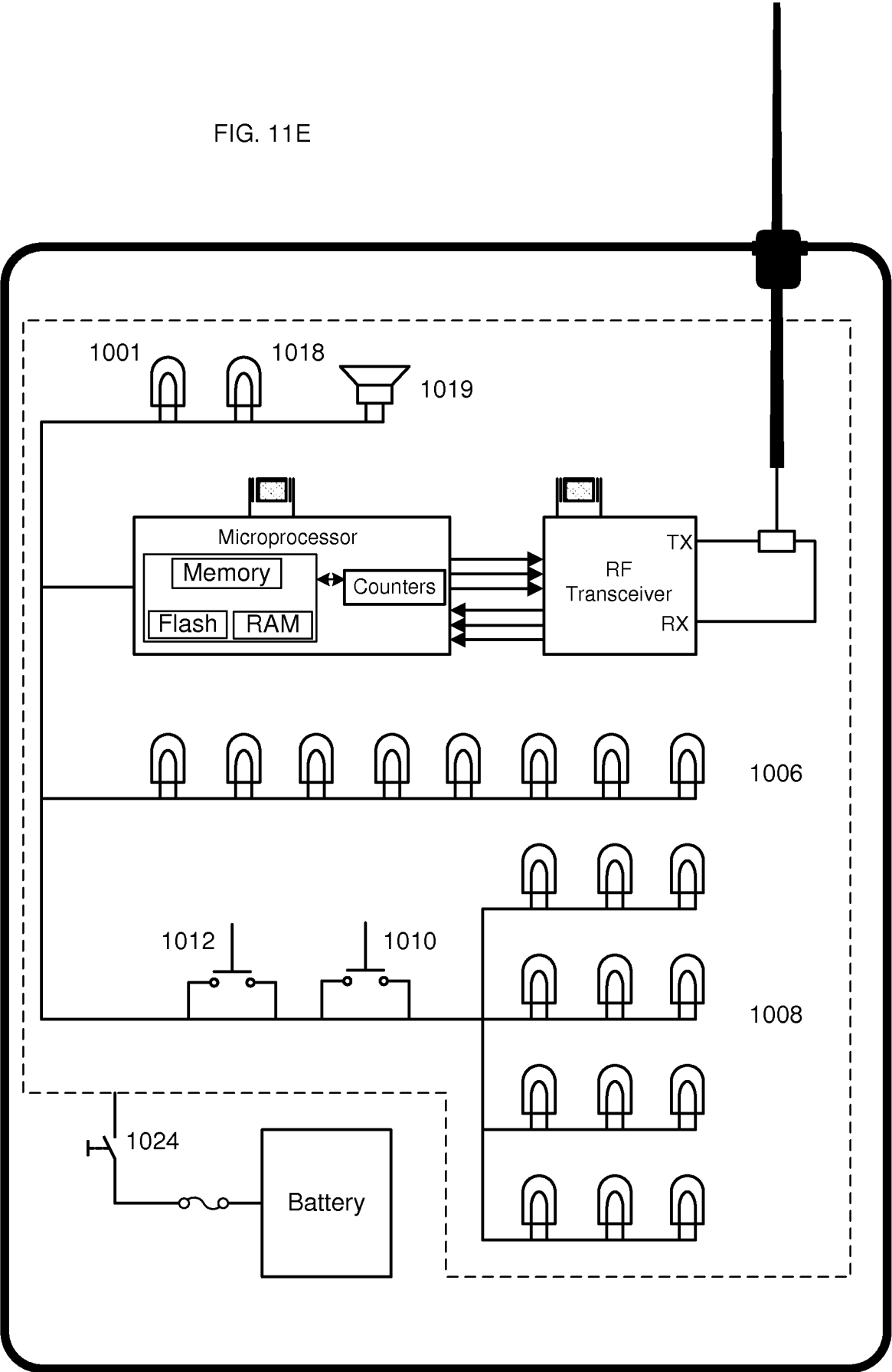
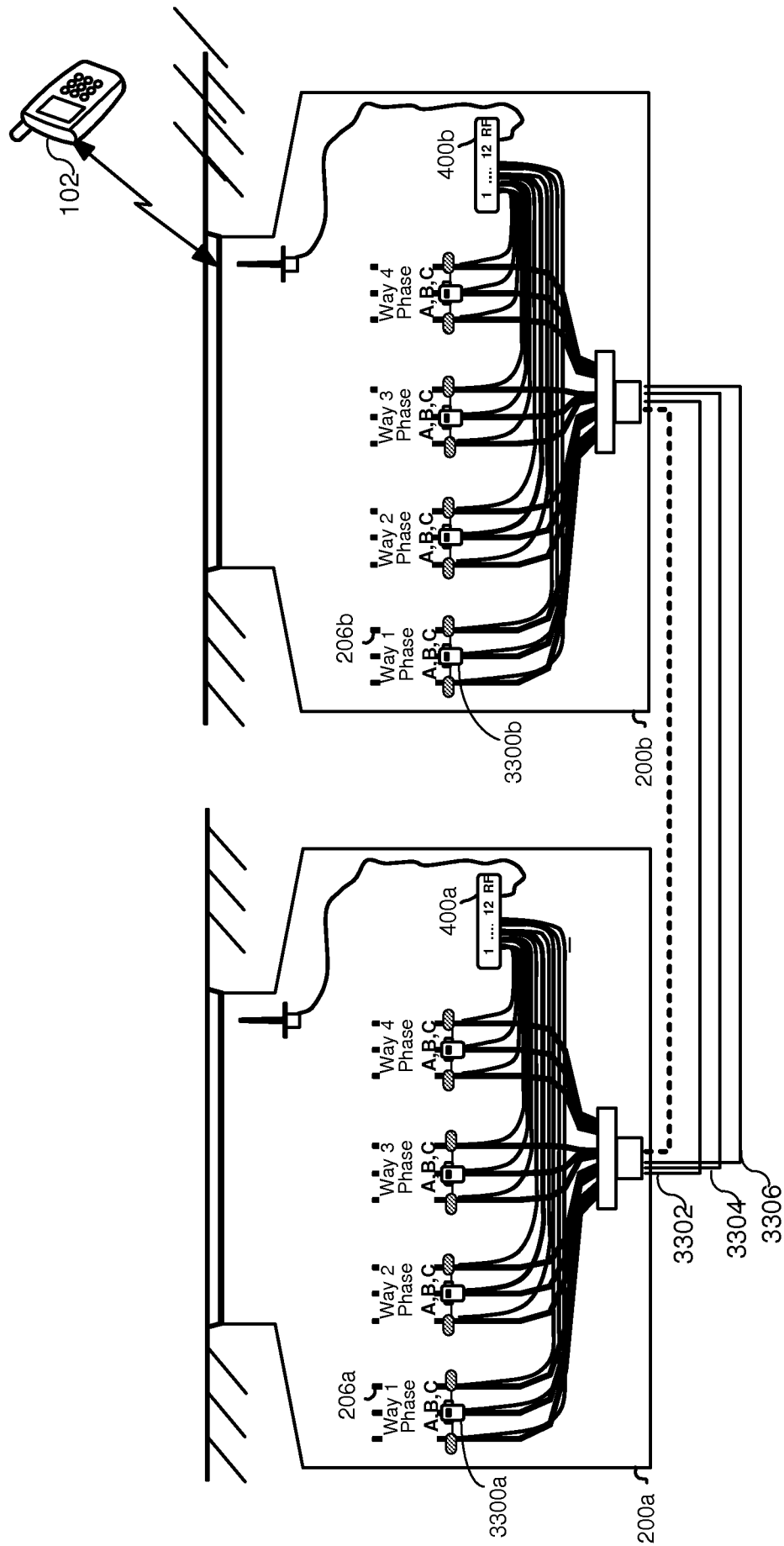


FIG. 11C

FIG. 11D

FIG. 11E





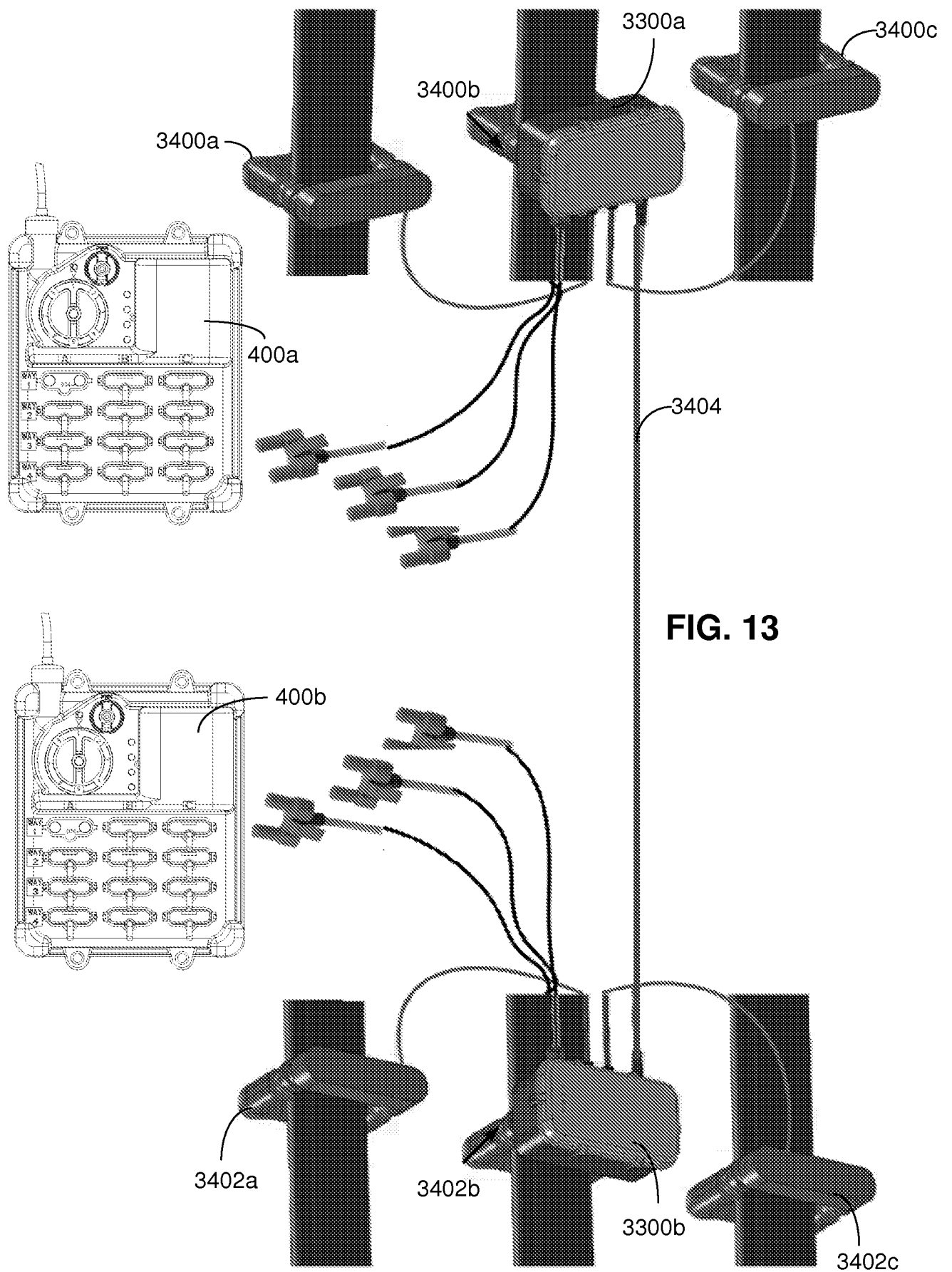
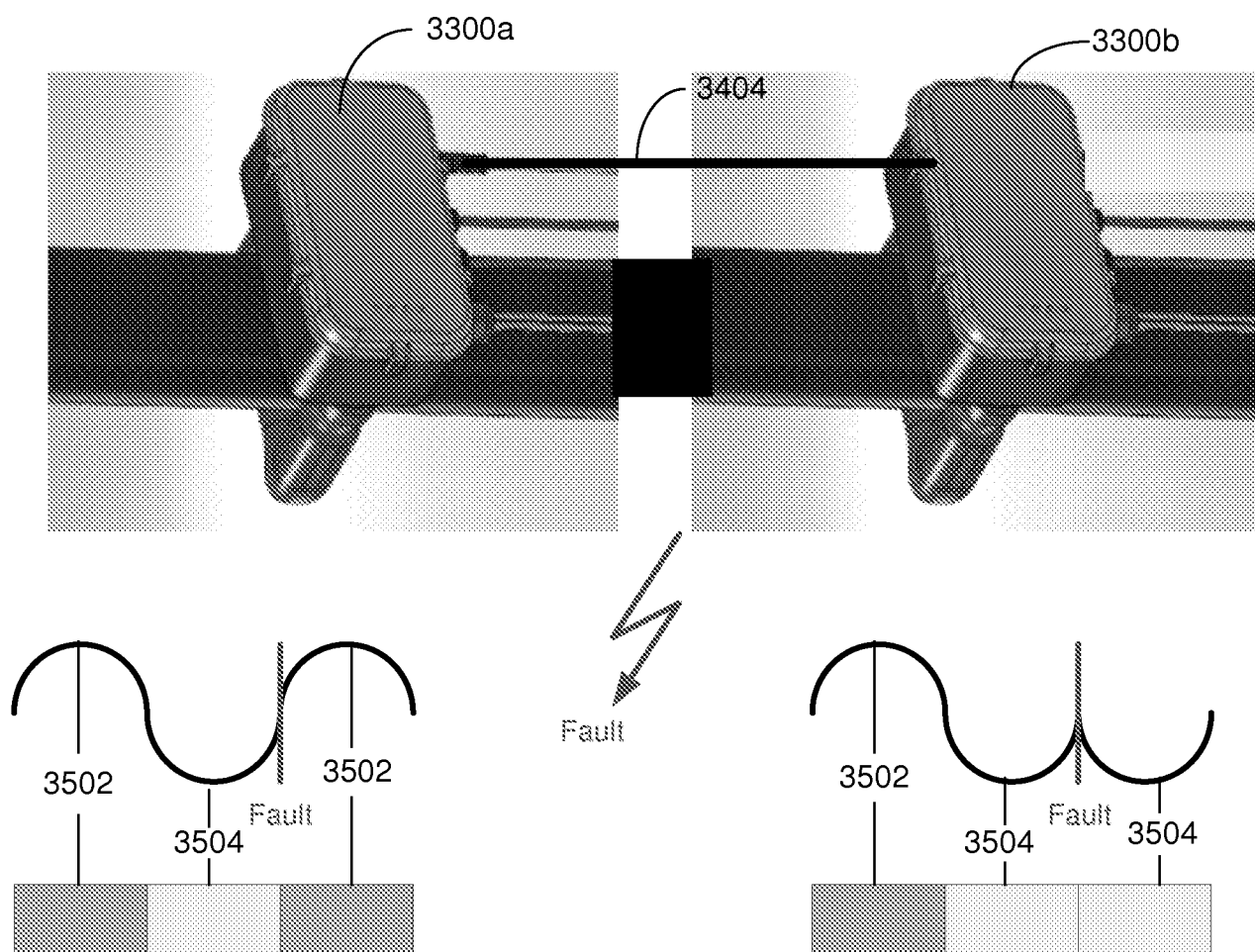
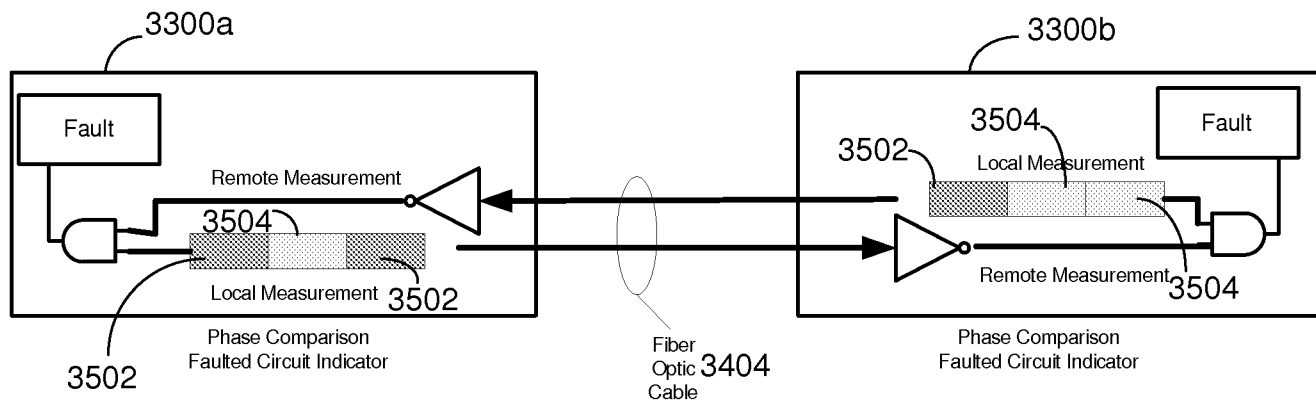
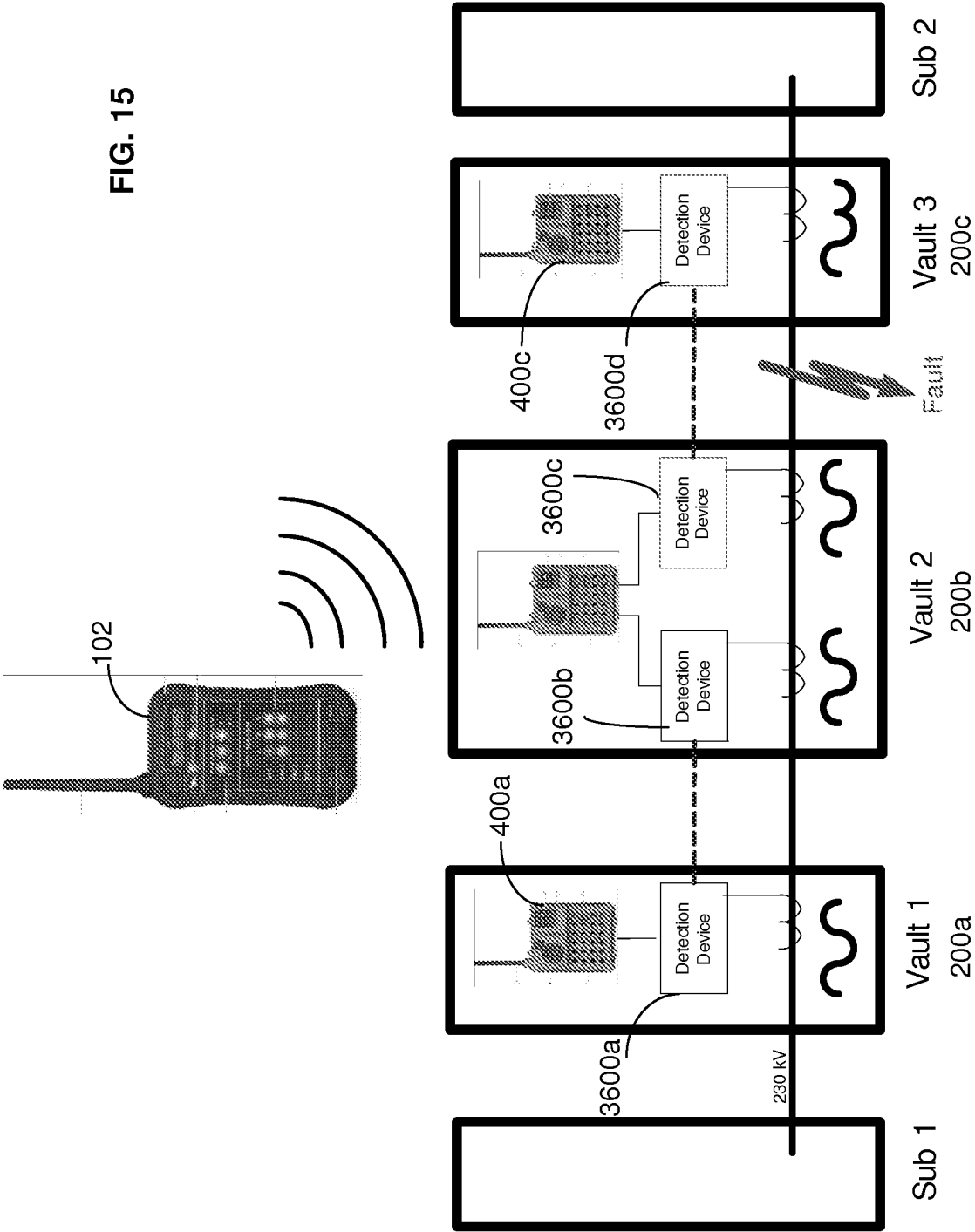


FIG. 14





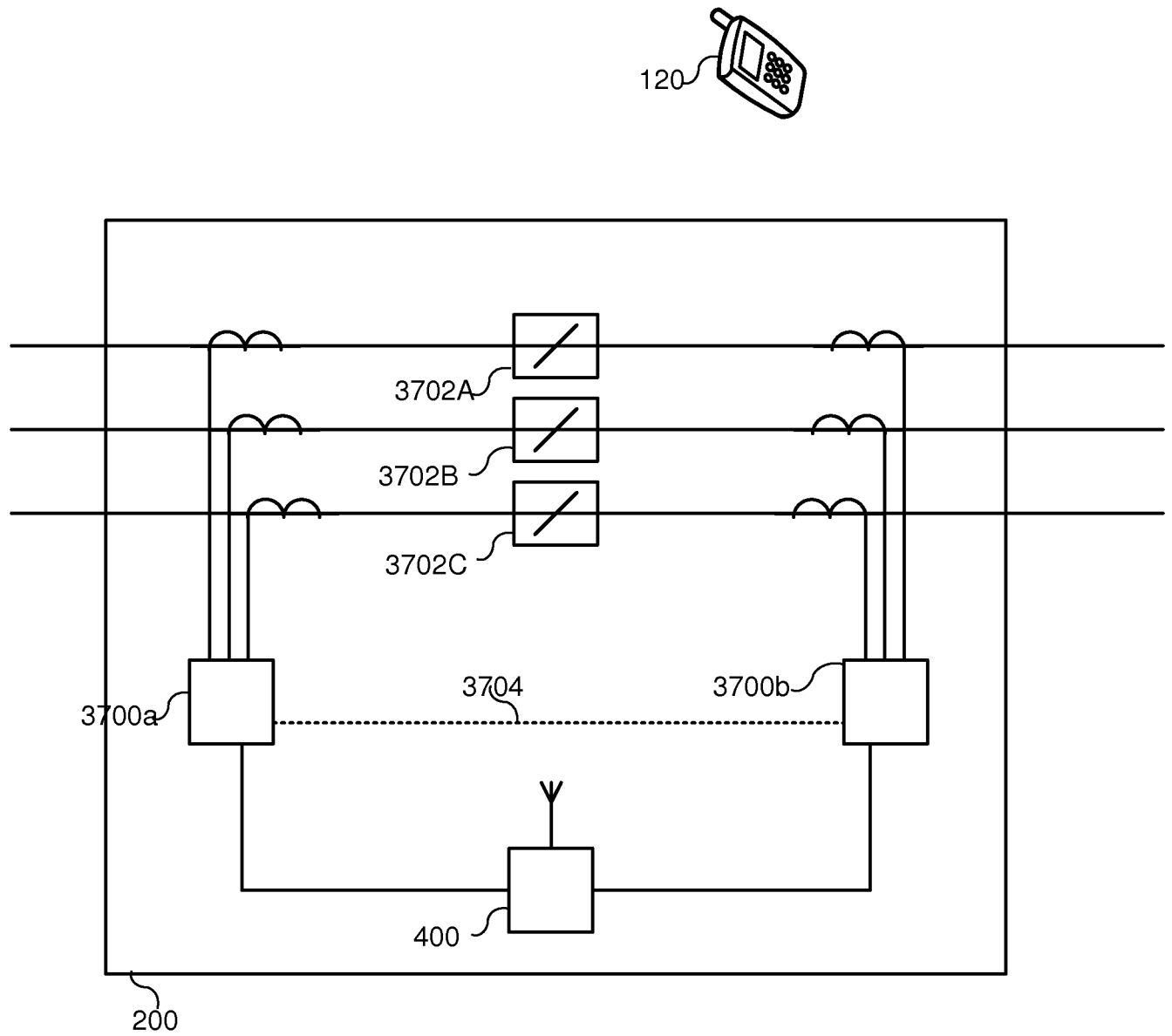
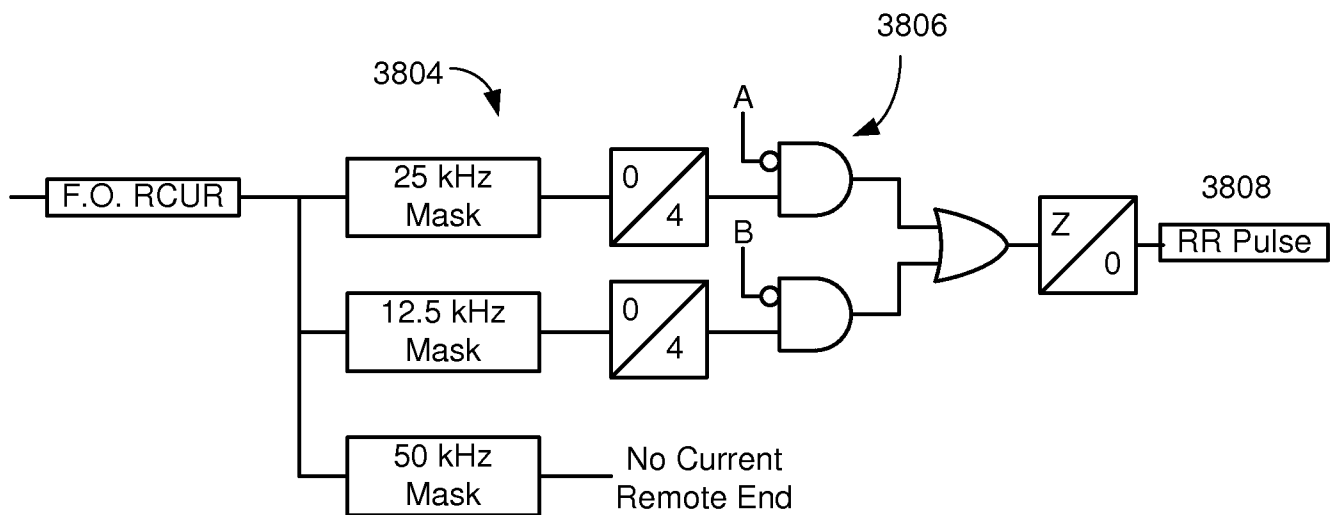
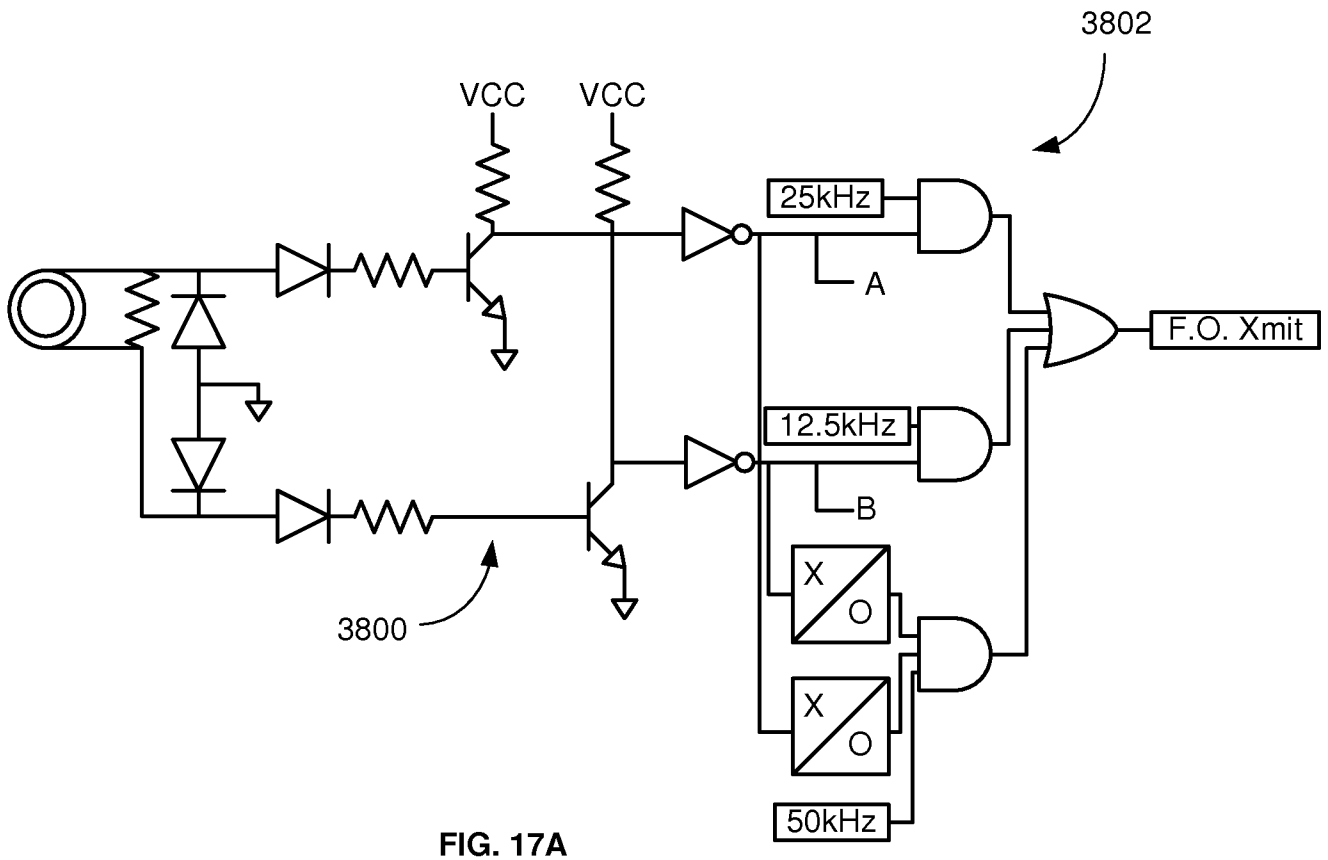


FIG. 16



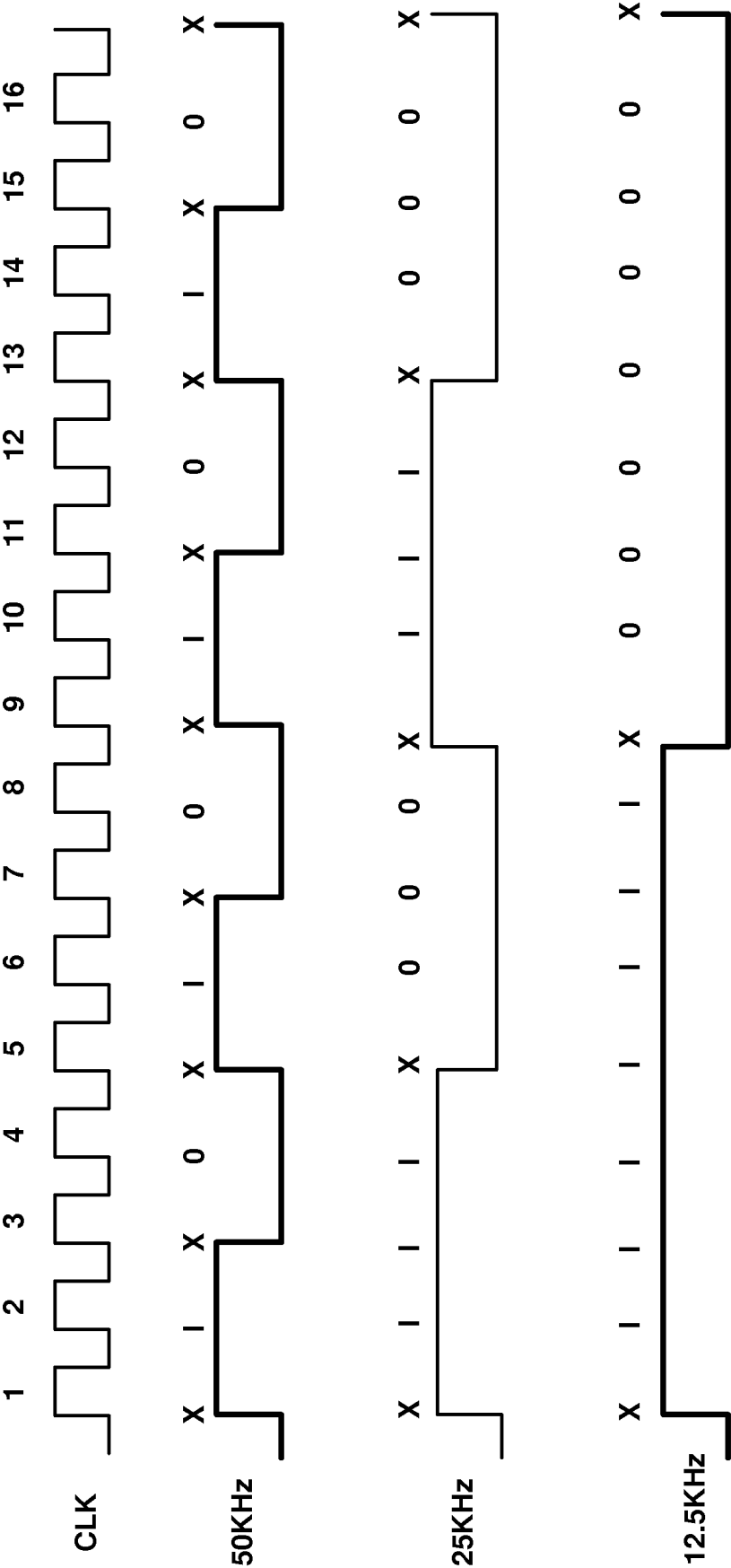
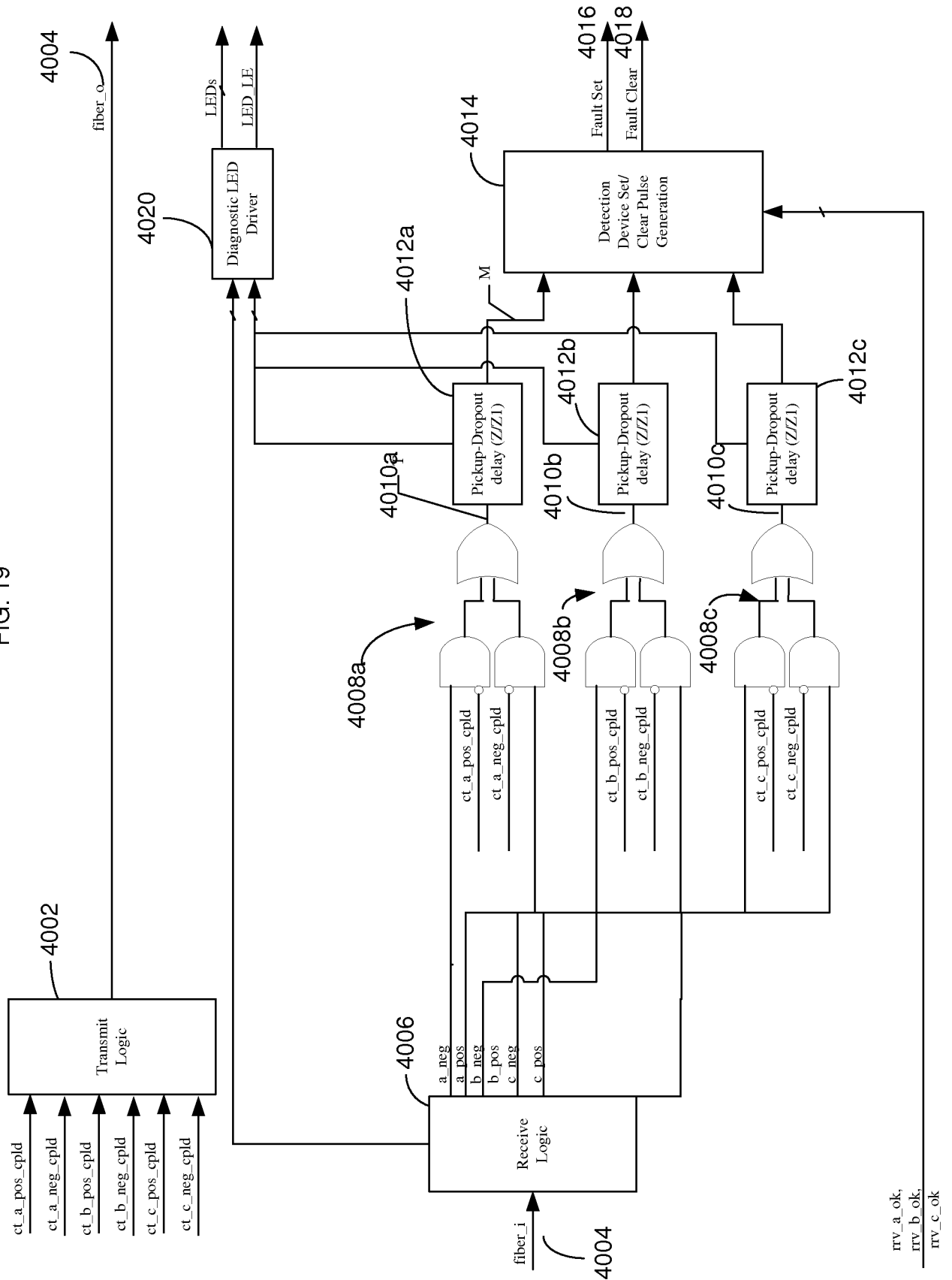


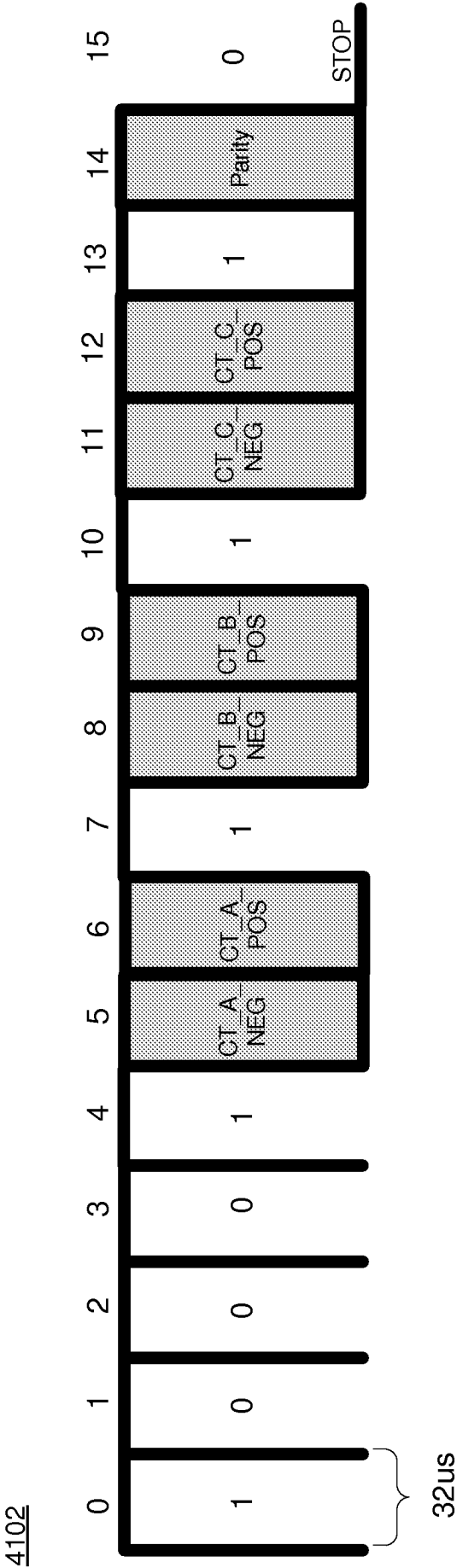
FIG. 18

FIG. 19



rvv_a_ok,
rvv_b_ok,
rvv_c_ok

FIG. 20



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 10/53116

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01R 31/00 (2010.01)

USPC - 702/58

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)

USPC: 702/58

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 702/72; 370/242 (keyword limited - see search terms below)

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

PubWEST (PGPB, USPT, USOC, EPAB, JPAB); GOOGLE; Google Scholar

Terms: power, distribution, fault, detector, circuit, phase, wireless, rf, interface, transmitter, modulator, packet, frame, difference, current, location, substation, preamble.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2008/0284585 A1 (Schweitzer et al.) 20 November 2008 (20.11.2008), entire document, especially abstract, FIG. 1, para [0003], [0004], [0053], [0054], [0056], [0059], [0063], [0068], [0071], [0101], [0136], [0143], [0164], [0174], [0175].	1-27
Y	US 2009/0240449 A1 (Gibala et al.) 24 September 2009 (24.09.2009), entire document, especially abstract, para [0006], [0007], [0008], [0044], [0068], [0093], [0096], [0119], [0133], [0134], [0164], [0170], [0175].	1-27
A	US 2009/0231150 A1 (Feight) 17 September 2009 (17.09.2009), entire document, especially abstract, para [0003], [0019], [0024], [0027], [0031], [0032], [0035].	1-27

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

* Special categories of cited documents:

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

06 December 2010 (06.12.2010)

Date of mailing of the international search report

14 DEC 2010

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