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(54) Title: ELECTRONIC EQUIPMENT CABINETS HAVING RADIO FREQUENCY RELAYS

(57) Abstract: Electronic equipment cabinets include a relay that has an. internal antenna, an external antenna and a transmission path therebetween. The internal antenna is located at least partially within the cabinet and the external antenna is located at least partially exterior to a wall of the cabinet The relay is configured to receive uplink wireless transmissions from the wireless Intemet-of-Things transceivers included on electronic devices mounted within the cabinet and. to forward and rebroadcast these uplink wireless transmission to the exterior of the cabinet via the external antenna.

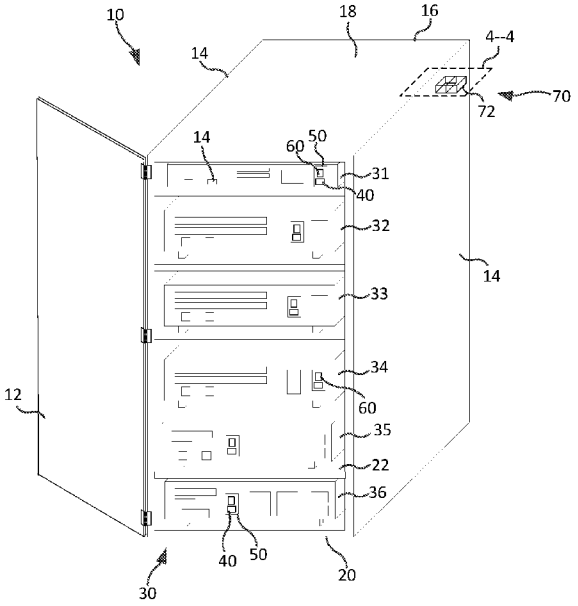


FIG. 1

ELECTRONIC EQUIPMENT CABINETS HAVING RADIO FREQUENCY RELAYS

CROSS-REFRENCE TO RELATED APPLICATION

[0001] The present application claims priority under 35 U.S.C. § 119 from U.S. Provisional Application Serial No. 62/378,783, entitled "ELECTRONIC EQUIPMENT CABINETS HAVING RADIO FREQUENCY RELAYS," filed on August 24, 2016, the entire disclosure of which is hereby incorporated by reference herein for all purposes as if set forth in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates generally to cabinets, and more specifically to cabinets for electronic equipment.

BACKGROUND

[0003] Cabinets for electronic equipment have become popular in recent years, and are now routinely used in both indoor and outdoor applications. These cabinets, which are typically made of metal, are used to protect and provide convenient access to a wide variety of electronic equipment. For example, electronic equipment cabinets are used at cellular base stations to store radios, multicarrier power amplifiers, power supplies, batteries, backhaul equipment, baseband units and other equipment. Electronic equipment cabinets are also used in various other applications such as, for example, in data centers, computer rooms and microwave radio installations. These cabinets can protect the electronic equipment from environmental conditions and/or tampering, and may also provide RF shielding to the electronic equipment.

SUMMARY

[0004] Aspects of the present disclosure provide an electronic equipment cabinet. The electronic equipment cabinet may include a cabinet having a plurality of walls including at least a rear wall, two side walls and a top wall, and a plurality of electronic devices. Each electronic device located within the cabinet and at least some of the electronic devices may include a respective wireless transceiver. The electronic equipment cabinet may include a relay comprising an internal antenna, an external antenna and a transmission path therebetween. The internal antenna may be located at least partially within the cabinet and the

external antenna may be located at least partially exterior to a wall of the cabinet. The relay may be configured to receive uplink wireless transmissions from the wireless transceivers of the electronic devices and to forward and rebroadcast these uplink wireless transmission to the exterior of the cabinet via the external antenna.

[0005] Other aspects of the present disclosure provide a method. The method may include receiving at an internal antenna of a relay a radio frequency ("RF") signal transmitted by an electronic device that is mounted within a metal cabinet. The internal antenna may be at least partially within the metal cabinet. The method may further include forwarding the received RF signal to an external antenna that transmits the received RF signal externally to the metal cabinet.

[0006] Other aspects of the present disclosure provide a relay. The relay may include an internal antenna, an external antenna, and a transmission path between the internal antenna and the external antenna. The internal antenna may be dimensioned to sit at least partially within an electronics cabinet and the external antenna is dimensioned to sit at least partially exterior to a wall of the electronics cabinet.

BRIEF DESCRIPTION OF FIGURES

[0007] **FIG. 1** is a schematic perspective view of an electronic equipment cabinet according to embodiments of the present invention.

[0008] **FIG. 2** is a schematic view of a cellular base station at which the cabinets according to embodiments of the present invention may be used.

[0009] **FIG. 3** is a schematic block diagram of a relay that may be included in the cabinets according to embodiments of the present invention.

[0010] **FIGS. 4A-4C** are schematic cross-sectional views illustrating three example ways that a relay according to embodiments of the present invention may be mounted in a wall of an electronic equipment cabinet.

[0011] **FIGS. 5-10** are schematic views of relays for electronic equipment cabinets according to certain embodiments of the present invention.

DETAILED DESCRIPTION

[0012] A current trend is for electronic devices to have increased sensing and communications connectivity, along with an increased ability to monitor their own status and

communicate that status to remote devices. For example, the nascent Internet-of-Things ("IoT") movement envisions providing a wide variety of electronic devices and other objects (e.g., clothing, accessories, etc.) with sensors, processing capabilities and low power wireless transceivers. This hardware allows these devices/objects to broadcast information such as status, location, health, environmental and/or other information to an external communications network such as, for example, a low power wide access IoT communications network such as the low power networks provided by Sigfox® or LoRa® or the recently standardized narrow-band Internet-of-Things (NB-IOT). As an example, an electronic device such as an appliance may have internal sensors that monitor the health of appliance's internal electronics and upon detecting a potential issue may transmit a few ultra-low power bytes of information to notify a user or other entity that a potential problem has been detected. The functionality of electronic devices that are installed in various electronic equipment cabinets may similarly be enhanced with access to a wireless data network, which may allow these devices to, for example, intermittently transmit status information, alarms and/or sensor data to remote locations. This may reduce maintenance requirements, outages due to equipment failure and/or equipment redundancy requirements as the electronic devices themselves may request maintenance or replacement prior to failure.

[0013] Electronic devices that are stored in cabinets at cellular base stations and other locations may similarly be configured to communicate with other devices using one or more wireless data transmission protocols, such as protocols which use radio frequencies in the industrial, scientific, and medical (ISM) radio bands. For example, amplifiers and cellular base station back-up batteries may include a Bluetooth or ZigBee transceiver, backhaul equipment may include an LTE transceiver, and power supplies may also include wired or wireless communications capabilities. Unfortunately, a metal cabinet acts like a Faraday cage that blocks the transmission of radio frequency ("RF") signals. Thus, when IoT-equipped electronic devices such as, for example, radios, amplifiers, power supplies, batteries, backhaul equipment and the like are stored in metal electronic equipment cabinets, the IoT functionality may not be operable as the wireless IoT transceivers included in these devices may not be able to communicate through the metal cabinet with the wide access IoT communication network. It will be appreciated that the metal cabinets often are not completely sealed by metal as they typically have openings for cable egress or other functions. However, the amount of metal is typically sufficient that there may be significant

impairment disrupting any RF communications link such that the IoT transceivers may not be able to reliably communicate through the metal cabinet.

[0014] Pursuant to embodiments of the present invention, electronic equipment cabinets are provided that include relays that allow IoT or other RF transceivers included on electronic equipment that is stored within the cabinet to communicate with networks that are external to the cabinet such as the above-mentioned wide access IoT communication network. These relays may extend through a wall of the cabinet and receive IoT signals transmitted therein and then pass these signals through the cabinet and re-radiate the signals to the external network. In some embodiments, the relays may operate entirely at RF. In some embodiments, the relays may be completely passive relays, while in other embodiments the relays may include active equipment such as, for example, low noise amplifiers that are used to increase the power level of the retransmitted RF signals. The relays may also be two-way devices that may be used not only to transmit signals from the devices in the cabinet to an external network, but also to transmit signals from the external network to devices within the cabinet.

[0015] The present invention will now be described in greater detail with reference to the attached figures in which example embodiments of the invention are illustrated.

[0016] An electronic equipment cabinet, designated broadly at **10**, is shown in **FIG. 1**. The cabinet **10** may be a generally box-shaped structure, with a front door **12**, opposed sidewalls **14**, a rear wall **16** (which may include removable panels that cover access windows), a top wall (ceiling) **18**, and a bottom wall (floor) **20**. The structural components of the cabinet **10** may be conventional in nature and need not be described in detail herein. In example embodiments, the front door **12** may be positioned between about 18 and 28 inches from the rear wall **16**, and the cabinet **10** may be between about **60** and **84** inches in height.

[0017] A plurality of shelves **22** may be provided and various electronic devices **30** may be mounted on these shelves **22**. While the electronic devices **30** are mounted on shelves **22** in the depicted embodiment, it will be appreciated that the electronic equipment **30** may alternatively be mounted within the cabinet **10** using vertical rack structures (not shown).

[0018] The electronic devices **30** depicted within the example cabinet **10** are a cabinet controller **31**, a power supply **32**, a multicarrier power amplifiers **33**, a battery **34**, a baseband unit **35** and backhaul equipment **36**. The depicted electronic devices **30** are

examples of representative types of electronic equipment that are often stored in metal cabinets at cellular base stations. Each of these depicted electronic devices **30** may provide conventional functionality, which is not described at length herein. The electronic devices **30** illustrated in **FIG. 1** are drawn schematically and are for illustrative purposes only. The sizes and locations of the electronic devices **30** within the cabinet **10** are not necessarily to scale.

[0019] The electronic devices **30** may be connected to each other and/or to electronic devices that are external to the cabinet **10**. For example, **FIG. 2** is a schematic diagram illustrating a cellular base station **100** that includes an equipment enclosure **110** that has the cabinet of **FIG. 1** installed therein. As shown in **FIG. 2**, the base station **100** further includes a tower **120**, a plurality of antennas **130** mounted thereon, and a remote radio head **140** mounted behind each antenna **130**. A trunk cable **150** may extend from the equipment enclosure **110** to the top of the tower **120**. Jumper cables **160** such as, for example, power jumper cables and optical jumper cables may extend from the cabinet **10** to the trunk cable **150** within the equipment enclosure **110** and from the trunk cable **150** to the remote radio heads **140** at the top of the tower **120**.

[0020] Referring again to **FIG. 1**, some or all of the electronic devices **30** may include wireless transceivers **40**, IoT processors **50** and/or sensors **60**. Each of the wireless transceivers **40**, and by extension their associated electronic devices **30**, may be individually addressable. The wireless transceivers **40** may include both transmit and receive functionality, or only have one of transmit or receive capabilities. It will be appreciated that the term "wireless transceiver" is used broadly herein to cover all three types of devices. The sensors **60** may include any of a wide variety of sensors that monitor internal conditions and operation of the electronic device **30** and/or that monitor external conditions such as, for example, environmental conditions. The processor **50** may control and/or receive information from the sensors **60**, may process the received information (e.g., to make predictions) and may control the wireless transceiver **40** to transmit messages to an external communications network. The processor **50** may also receive messages (via the wireless transceiver **40**) from the external communications network and control operation of the electronic device **30** in response thereto.

[0021] The wireless transceivers **40** may be, for example, low power wireless transceivers that are configured to communicate using Bluetooth, Wi-Fi, Zigbee, Z Wave, Sigfox®, LoRa®, RPMA, Weightless, NB-IoT, cellular Low Power Wide Access (LPWA),

or other networks or communication protocols. In other embodiments, the wireless transceivers **40** may transmit and/or receive signals using radio waves in the industrial, scientific, and medical (ISM) radio bands, e.g., radio bands reserved for purposes other than telecommunications. In some embodiments, the communications may be in licensed radio bands while in other embodiments unlicensed radio bands may be used. In some embodiments, the wireless transceivers **40** may be configured to communicate according to a standardized Internet-of-Things communications protocol such as, for example, the protocols for the Sigfox® or LoRa® IoT communications networks or the recently standardized NB-IOTcommunications protocol that may communicate via either Global System for Mobile Communications ("GSM") or Long-Term Evolution ("LTE") cellular radio systems. It will be appreciated that the wireless transceivers **40** may also be configured to communicate with other wide area networks such as WiFi networks (e.g., 802.11 networks), Worldwide Interoperability for Microwave Access (WiMAX), Universal Mobile Telecommunications System (UMTS), CDMA2000, Evolution-Data Optimized (EV-DO), Ultra Mobile Broadband (UMB), any other 2nd, 3rd, 4th and higher generation cellular communications networks and various other wide band wireless networks.

[0022] The sensors **60** may provide device and/or environmental data to the processor **50**. The device data may comprise, for example, various measured voltage, current and/or temperature levels at nodes within the electronic device and/or components thereof. The processor **50** may, for example, process the received voltage, current and/or temperature levels and identify faults or error conditions and/or make predictions regarding future failures. For example, a power amplifier, capacitor or the like within an electronic device **30** that is starting to fail may exhibit increased and/or decreased voltage, current or temperature levels that alone or in combination indicate a failure or an increased probability of a failure. The sensors **60** may detect such changes and pass this information to the processor **50** which processes the information and predicts a possible current or future fault condition based thereon. The processor **50** may generate a message and cause this message to be transmitted by the wireless transceiver **40** over an external communications network to notify an external entity of the possible current or future fault condition.

[0023] While fault prediction and detection is one type of functionality that may be provided in electronic devices **30** that include IoT transceivers **40**, it will be appreciated that the electronic devices **30** may collect and transmit a wide variety of other information. For

example, IoT enabled devices may include external environmental sensors such as thermometers, barometers, moisture detectors and the like that collect environmental data and/or sense motion. Numerous other environmental sensors are possible. As another example, the electronic devices **30** may include motion detectors and/or accelerometers that may be used to detect movement of the electronic devices **30** or motion in the vicinity thereof.

[0024] The processor **50** and/or the sensors **60** associated with a given electronic device **30** may be used to monitor various aspects of the electronic device **30** and may generate status information such as location information, health information, environmental information and the like. For example, the processor **50** and sensors **60** associated with a particular electronic device **30** may detect failure of components of the electronic device **30**, may predict when future failure of components is likely, may detect when the electronic device **30** is not operating within specifications and the like. When component failures or out-of-specification operation is detected or predicted, the processor **50** may forward messages to the wireless transceiver **40** associated with the electronic device **30** for communication to an external communications network. The processor **50** may likewise intermittently transmit status information or environmental information collected by the sensors **60** to the external communications network.

[0025] As noted above, the construction of the cabinet **10** may prevent wireless signals emanating from sources outside the cabinet **10** from entering the cabinet **10**, and/or may prevent wireless signals emitted from electronic devices **30** inside the cabinet **10** from exiting the cabinet **10**. For example, the wireless transceivers **40** on the electronic devices **30** may intermittently transmit status and/or alarm signals that are to be transmitted to an intended recipient over a wireless communications network such as, for example, a NB-IoT network operating over an LTE cellular network. Because the metal walls of the cabinet **10** provide RF shielding, the NB-IoT signals transmitted by the wireless transceivers **40** may not exit the cabinet **10** with sufficient power to be received by the NB-IoT network.

[0026] To address this problem, the electronics cabinet **10** according to embodiments of the present invention also includes a relay **70**. The relay **70** may be manufactured integral with the cabinet **10** or may be a separate unit that is mounted on or in the cabinet **10**. The relay **70** may be located at any suitable location within the cabinet **10**. Typically, a first part of the relay **70** will be within the cabinet **10** and a second portion of the

relay may be located outside the cabinet **10**. The relay **70** may be used to relay signals transmitted by the wireless transceivers **40** outside the cabinet **10** and may be used to relay signals transmitted by an external communications network into the interior of the cabinet **10** where such signals may be received by the wireless transceivers **40**.

[0027] As will be discussed in greater detail below, the relay **70** may comprise a passive or active device that is configured to forward transmissions from within the cabinet **10** to the exterior of the cabinet **10** and to forward signals incident on the exterior of the cabinet **10** into the interior of the cabinet **10**. When implemented as a passive device, the relay **70** may be as simple as a first antenna that is on the exterior of the cabinet **10**, a second antenna that is on the interior of the cabinet **10** and a transmission line connecting these two antennas. When implemented as an active device, the relay **70** may include, for example, one or more amplifiers such as a low-noise amplifier that amplify signals received at the first antenna before they are passed to the second antenna (and vice versa). The relay **70** may also, in some embodiments, convert between communications protocols and/or have other functionality. The relay **70** may forward messages, instructions, commands, requests, status updates, status predictions, data, or other information both to and from the electronic devices **30** to remote locations.

[0028] **FIG. 3** is a schematic block diagram that illustrates the basic components of an example relay according to some embodiments of the present invention. As shown in **FIG. 3**, the relay includes an internal antenna **72**, an external antenna **74** and a transmission path **76**. The antennas **72** and **74** may be omnidirectional or quasi omnidirectional antennas in some embodiments. The use of such omnidirectional antennas may allow the wireless transceivers **40** on the electronic devices **30** to be located at any orientation within the cabinet **10** with respect to the antenna **72**, which may provide maximum flexibility regarding the locations for the electronic devices **30**, the wireless transceivers **40** mounted thereon and the relay **70**. In some embodiments, either or both the antennas **72**, **74** may comprise monopole antennas. If the communications with the wireless transceivers **40** are two-way communications and the communications occur in separate transmit and receive frequency bands, then, in some embodiments, the antennas **72**, **74** may comprise "wideband" antennas that may be used to transmit and receive signals in both the transmit and receive frequency bands. As will be discussed herein, in other embodiments, the relay **70** may include two internal antennas **72** that are used to transmit and receive signals in the separate transmit and

receive frequency bands and two external antennas **74** that are likewise used to transmit and receive signals in the separate transmit and receive frequency bands. In such embodiments, a transmission line **76** may be provided between each pair of internal and external antennas **72**, **74**. The relay **70** may also include various processing and transmission functionality **80** which may be located along the transmission path **76** between the internal antenna **72** and the external antenna **74**.

[0029] In some embodiments, the relay may be an RF relay that receives RF signals at a first antenna **72**, **74** thereof and relays these received RF signals to the other of the antennas **72**, **74** for retransmission at RF. In such embodiments, the signals are always maintained at RF without conversion to an intermediate frequency or baseband. The use of such RF relays may greatly simplify the design of the relay **70**. When such RF relays are used, the transmission path **76** may be any appropriate RF transmission path such as, for example, a coaxial cable, an RF stripline, a microstrip transmission line or the like. In other embodiments, the relay **70** may include additional functionality such as, for example, the ability to convert between different communications protocols, separate intelligence such as, for example, its own sensors and processing capabilities and/or the ability to read and process communications from the wireless transceivers **40** which may allow the relay **70** to make predictions based on the information from a plurality of electronic devices to more quickly and accurately identify when problems are occurring within the cabinet **10**.

[0030] **FIGS. 4A-4C** are schematic horizontal cross-sectional views of the portion of **FIG. 1** within the dashed box labelled 4—4. **FIGS. 4A-4C** schematically illustrate several exemplary ways that relays according to embodiments of the present invention may be mounted within an electronic equipment cabinet such as the cabinet **10** of **FIG. 1**.

[0031] Referring first to **FIG. 4A**, a relay **200-1** is illustrated that is primarily mounted external to the cabinet **10**. As shown in **FIG. 4A**, the relay **200-1** includes a housing **210** that extends outwardly from the sidewall **14** of cabinet **10**. The housing **210** may comprise, for example, a rigid material that readily passes RF signals such as various plastics (e.g., plastic materials that are used to form radomes). The housing **210** may be affixed to the sidewall **14** of the cabinet **10** via screws, tape, glue, epoxy and the like. An external antenna **230** is mounted within the housing **210** such that the external antenna **230** at least extends partly beyond the sidewall **14** to the exterior of the cabinet **10**. The external antenna **230** may comprise for example, a monopole antenna **230** that includes a monopole radiating element

232 that is mounted above a ground plane 234. The external antenna 230 may receive signals from an external communications network and may also be used to transmit signals that are received from within the cabinet 10 to the external network.

[0032] The relay 200-1 further includes an internal antenna 220 that is mounted at least partly within the interior of the cabinet 10. The internal antenna 220 may also comprise, for example, a monopole antenna 220 that includes a monopole radiating element 222 that is mounted above a ground plane 224. The relay 200-1 further includes a transmission path 240 that connects the external antenna 230 to the internal antenna 220. The transmission path 240 may comprise any suitable transmission path for RF signals. The sidewall 14 includes an opening 250. The transmission path 240 may extend though the opening 250 in some embodiments, while the internal antenna 220 may extend through the opening 250 in other embodiments.

[0033] Referring next to FIG. 4B, a relay 200-2 is illustrated that is primarily mounted internal to the cabinet 10. As shown in FIG. 4B, the relay 200-2 may be identical to relay 200-1 except that the housing 210 and other components of relay 200-2 are primarily located within the interior of the cabinet 10, except that at least a portion of the external antenna 230 protrudes through an opening 250 in sidewall 14 external to the cabinet 10. In light of the similarities to relay 200-1, further description of relay 200-2 will be omitted.

[0034] FIG. 4C illustrates another relay 200-3 according to embodiments of the present invention that is mounted through an opening 250 in a sidewall 14 of the cabinet 10. As shown in FIG. 4C, the relay 200-3 includes a housing 210' that extends through the opening 250. For example, the opening 250 may comprise a rectangular slot in the sidewall 14 and the relay housing 210 may be a rectangular box that fits through this slot 250. As shown in FIG. 4C, the internal antenna 220 may be mounted within the housing 210 to extend into the interior of the cabinet 10 and the external antenna 230 may be mounted within the housing 210 to be external to the cabinet. A transmission path 240 may connect the antennas 220, 230.

[0035] While FIGS. 4A-4C illustrate the relay mounted on or through a sidewall 14 of the cabinet, it will be appreciated that relays disclosed therein could be mounted on or through the ceiling 18, floor 20, rear wall 16 or front door/wall 12 in other embodiments.

[0036] FIG. 5 is a schematic perspective view of a relay for an electronic equipment cabinet according to embodiments of the present invention. As shown in FIG. 5, the relay

300 includes a housing 310 that has a board 320 mounted therein. The housing 310 may include slots or tabs or other mounting structures (not shown) on internal walls thereof that are used to mount the board 320. The board 320 may comprise, for example, a microstrip or stripline structure that includes an RF transmission line 322 formed therein or thereon. In the depicted embodiment, a portion of the RF transmission line 322 is formed on the lower side of the board 320 and hence is depicted using a dashed line. The board 320 may further include a pair of metallic pads 324 near either end thereof. An opening 326 may be provided through each pad 324 and may extend through the board. An internal monopole antenna 330 is mounted in a first of the openings 326 and an external monopole antenna 340 is mounted in the second of the openings 326. Each monopole antenna 330, 340 may be connected to the microstrip or stripline transmission line 322. The pads 324 may serve as reflective ground planes for the monopole antennas 330, 340, and may be electrically connected to a ground conductor of the transmission line 322. The relay 300 may have a very small footprint, with the board having a length of a few inches or less in some embodiments. A slot may be cut through a wall of the cabinet 10, and the relay 300 may be mounted in this slot.

[0037] FIG. 6 is a schematic perspective view of a relay 400 for an electronic equipment cabinet according to further embodiments of the present invention. As shown in FIG. 6, the relay 400 includes a housing 410, a coaxial cable 420, an internal antenna 430 that is connected to one end of the coaxial cable 420 and an external antenna 440 that is connected to the other end of the coaxial cable 420. The antennas 430, 440 may comprise, for example, monopole antennas. The relay 400 may be mounted to extend through an opening in a wall of an electronic equipment cabinet.

[0038] FIG. 7 is a schematic side view of a portion of a relay 500 according to still further embodiments of the present invention. In FIG. 7, only the internal antenna 560 and a portion of the transmission line 510 are illustrated to simplify the drawing. It will be appreciated that an external antenna may be formed on the opposite end of the transmission line 510 and may be identical to the internal antenna 560.

[0039] As shown in FIG. 7, the relay 500 includes a transmission line 510 in the form of a coaxial cable. The coaxial cable 510 includes a center conductor 520, a dielectric spacer 530 that circumferentially surrounds the center conductor 520, an outer conductor 540 that circumferentially surrounds the dielectric spacer 530, and a tubular cable jacket 550 that covers the outer surface of the outer conductor 540. The dielectric spacer 530 and the outer

conductor **540** may each have an annular cross-section. The internal antenna **560** is formed using a first end portion of the center conductor **520** and a conductive ground plane **562**. The portion **522** of the center conductor **520** that extends beyond the conductive ground plane **562** may be, for example, about one-quarter a wavelength in length, where the wavelength is the center frequency of the frequency band at which the antenna **560** transmits and receives signals. The conductive ground plane **562** may comprise a thin sheet of metal that is electrically connected to the outer conductor **540**. As shown, the coaxial cable **510** may be cut so that the outer conductor **540** has an extension **542** that extends beyond the dielectric spacer **530**. This extension **542** may be bent toward the center of the coaxial cable **510**. This may help provide a better electrical contact between the outer conductor **540** and the ground plane **562**. An insulating spacer **564** may surround the center conductor **520** to isolate the outer conductor **540** and the ground plane **562** from the center conductor **520**. The internal antenna **560** may comprise an omnidirectional monopole antenna that may be very simply formed. While not shown in **FIG. 7**, the relay **500** may have a housing in which the coaxial cable **510**, the internal antenna **560** and the external antenna are mounted in some embodiments.

[0040] The relays **300, 400, 500** of **FIGS. 5-7** are passive relays. As noted above, in other embodiments the relay may comprise an active device that includes, for example, an amplifier. **FIG. 8** is a schematic circuit diagram of one such active relay **600**. The active relay **600** may be implemented, for example, on a board in the same manner as the relay **300** of **FIG. 5** described above, except that the relay may include additional components on the board such as, for example, a pair of diplexers, a pair of amplifiers and a DC voltage regulator to provide DC power to the amplifiers. Thus, the description of the relay **600** will focus on the differences between the relay **600** and the relay **300**.

[0041] As shown in **FIG. 8**, the relay **600** includes a board such as a circuit board **620** that may be mounted in a housing (not shown). The circuit board **620** may comprise, for example, a microstrip or stripline structure that includes RF transmission line segments **622** formed therein or thereon. An internal monopole antenna **630** is mounted proximate a first end of the circuit board **620** and an external monopole antenna **640** is mounted proximate a second end of the circuit board **620**. Each monopole antenna **630, 640** may be connected to one of the microstrip or stripline transmission line segments **622**. The circuit board **620** may further include surface mount components in the form of a pair of diplexers **650, 652** and a

pair of amplifiers **660**, **662**. The diplexers **650**, **652** may filter signals received at the respective antennas 630, **640** into respective uplink and downlink portions, where the uplink signals refer to the signals transmitted from the electronic devices 30 within the cabinet 10 to an external communications network, and the downlink signals refer to the signals transmitted from the external communications network to the electronic devices 30 within the cabinet 10. Uplink signals received by the internal antenna **630** may be routed by the diplexer **650** to the uplink amplifier **660** and these signals are then passed by the diplexer **652** to the external antenna **640** for retransmission external to the cabinet 10. Downlink signals received by the external antenna **640** may be routed by the diplexer **652** to the downlink amplifier **662** and these signals are then passed by the diplexer **650** to the internal antenna **630** for retransmission within the cabinet 10. A DC linear regulator **670** may receive power from an external source **680** and provide an operating voltage VCC to the amplifiers **660**, **662**.

[0042] While in the above-describe d embodiments the external antenna is located in the immediate vicinity of the cabinet, it will be appreciated that this need not be the case. Cabinets are now routinely being located underground as Metrocell and other cellular base stations are deployed where the base stations antennas are mounted on streetlights, utility poles and other locations in urban areas to serve small, densely populated areas. When cabinets are located underground in the above-described or other applications, communications from the IoT transceivers 40 to the external communications network may be blocked by both the metal cabinet and the underground cabinet placement.

[0043] **FIG. 9** is a schematic diagram illustrating an installation **700** in which an electronic equipment cabinet **10** according to embodiments of the present invention is installed in an underground location. As shown in **FIG. 9**, a metal cabinet **10** is located below the surface **710** of the earth. Electronic equipment **30** is mounted in the cabinet **10** and connected to a remote radio head **720** and an antenna **730** that are mounted on a streetlight **740** via a trunk cable **750**. The cabinet **10** includes a relay **70** which may be, for example, any of the relays disclosed herein. As described above with respect to **FIG. 3**, the relay **70** may have an internal antenna **72** (not shown in **FIG. 9**) and an external antenna **74** that are connected by a transmission path **76**. The transmission path **76** may be extended so that the external antenna **74** may be located above ground in, for example, an enclosure **760** (which may be located at any convenient location). The transmission path **76** may comprise a single

transmission line such as a coaxial cable or may comprise a plurality of transmission lines (e.g., a printed circuit board transmission line and a coaxial cable that is attached thereto). By locating the external antenna **74** above ground, reliable communications between the IoT transceivers **40** on the electronic devices **30** and the external communications network may be maintained.

[0044] The relays described above with reference to **FIGS. 5-8** are relatively simple, low cost implementations that maintain the signals at RF. As noted above in the discussion of **FIG. 3**, in other embodiments more sophisticated relays may be provided that, for example, down-convert signals received from the electronic devices **30** and/or from the external communications network to an intermediate frequency or baseband and then up-convert the signals to RF where they are retransmitted. In such embodiments, the relay may, for example, convert from one communication protocol to another (e.g., from Zigbee to NB-IoT). It will also be appreciated that the relays according to embodiments of the present invention may include their own sensors and/or processing capabilities. In such embodiments, the relays may monitor communications from the electronic devices **30** and may transmit messages based on conclusions drawn from the aggregated communications.

[0045] Most of the relays described above include a single internal antenna and a single external antenna. It will be appreciated that in other embodiments more than one internal and/or external antenna may be provided. For example, in some embodiments two internal antennas and two external antennas may be provided for purposes of diversity. In such embodiments, a second transmission line may be provided to connect the second internal antenna to the second external antenna. In still further embodiments, the internal antenna may be replaced with a distributed antenna system that has a plurality of radiating elements distributed throughout the interior of the cabinet **10**. In still other embodiments, a distributed external antenna may be provided (e.g., with external radiating elements located on multiple walls of the cabinet **10**). It will be appreciated that any of the above embodiments may be combined and that numerous other embodiments are possible.

[0046] The relays according to embodiments of the present disclosure may operate as follows. Referring to **FIG. 1**, an electronic device **30** within a cabinet **10** may, for example, collect information from an internal or external sensor **60**. The processor **50** on the electronic device **30** may form a message in response thereto and pass the message to the

wireless transceiver **40** for transmission. A signal containing the message is transmitted by the transceiver **40**, but will typically not escape the cabinet **10** due to the metal walls.

[0047] Referring to **FIG. 3**, the internal antenna **72** on the relay **70** is disposed within the interior of the cabinet **10** and hence may receive the signal transmitted by the wireless transceiver **40**. The received signal is carried over the transmission line **76** to the external antenna **74** which reradiates the signal external to the cabinet **10**. This reradiated signal may then be received by an external communications network. As noted above, the signal received by the internal antenna **72** may be amplified and/or further processed in some embodiments. Signals from the external communications network may be forwarded by the relay **70** in the same manner (but in the reverse direction) to the wireless transceiver **40** on the electronic device **30**.

[0048] Pursuant to further embodiments of the present invention, electronic equipment cabinets are provided that include internal radio frequency identification ("RFID") antennas mounted within the interior of the cabinet and relays that transmit signals received by the RFID antennas to an external communications network. RFID is now used in a number of applications to track electronic equipment. However, RFID signals may be blocked by metal cabinets in the same manner that IoT wireless transmissions may be blocked as described above. FIG. **10** is a schematic block diagram of an RFID relay **800** according to embodiments of the present invention that may be mounted in or on a metal electronic equipment cabinet (not shown). As shown in FIG. **10**, the relay includes an internal antenna **810**, an external antenna **820** and a transmission path **830**. The antennas **810**, **820** may be conventional RFID antennas in some embodiments. The transmission line **830** connects the internal and external antennas **810**, **820**. The relay **800** may also include various processing and transmission functionality **840** which may be located along the transmission path **830** between the internal antenna **810** and the external antenna **820**.

[0049] In some embodiments, the relay **800** may be an RF relay that receives RFID excitation signals at the external antenna **820** and relays these excitation signals to the internal antenna **810** via the transmission line **830**. The internal antenna **810** broadcasts the RFID excitation signal within the metal cabinet that the relay **800** is installed in or on. Electronic devices within the cabinet may have RFID tags mounted thereon. As known in the art, RFID tags include an RFID antenna and an integrated circuit that includes a memory. The RFID excitation signal is used to power the RFID tags and in response to the RFID

excitation signal each RFID tag may transmit a responsive signal that includes data stored in the memory thereof. RFID tags may be designed to follow arbitration procedures that ensure that when multiple RFID tags are excited by an RFID excitation signal the RFID tags respond serially to avoid interfering with each other. The internal antenna **810** receives the responsive RFID signals from the RFID tags and this signal is carried over the transmission line **830** to the external antenna **820** that rebroadcasts these signals so that they may be received by an RFID reader that transmitted the RFID excitation signal.

[0050] While in the above description the relay **800** maintains the RFID signals at their original RF frequencies, it will be appreciated that in other embodiments the RFID signals may be converted to an intermediate frequency ("IF") or baseband in the same manner, discussed above, that IoT transmissions can be converted to IF or baseband. It will likewise be appreciated that the relay **800** may include one or more amplifiers that may amplify either or both the RFID excitation signal and/or the responsive RFID signals. Finally, it will also be appreciated that the RFID relay **800** may be added to any of the IoT relays according to embodiments of the present invention.

[0051] Embodiments of the present invention have been described above with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

[0052] It will be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first element could be termed a second element, and, similarly, a second element could be termed a first element, without departing from the scope of the present invention. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0053] It will be understood that when an element is referred to as being "on" another element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being "directly on" another element,

there are no intervening elements present. It will also be understood that when an element is referred to as being "connected" or "coupled" to another element, it can be directly connected or coupled to the other element or intervening elements may be present. In contrast, when an element is referred to as being "directly connected" or "directly coupled" to another element, there are no intervening elements present. Other words used to describe the relationship between elements should be interpreted in a like fashion (i.e., "between" versus "directly between", "adjacent" versus "directly adjacent", etc.).

[0054] Relative terms such as "below" or "above" or "upper" or "lower" or "horizontal" or "vertical" may be used herein to describe a relationship of one element, layer or region to another element, layer or region as illustrated in the figures. It will be understood that these terms are intended to encompass different orientations of the device in addition to the orientation depicted in the figures.

[0055] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" "comprising," "includes" and/or "including" when used herein, specify the presence of stated features, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, operations, elements, components, and/or groups thereof.

[0056] Aspects and elements of all of the embodiments disclosed above can be combined in any way and/or combination with aspects or elements of other embodiments to provide a plurality of additional embodiments.

That Which is Claimed is:

1. An electronic equipment cabinet, comprising:

a cabinet having a plurality of walls including at least a rear wall, two side walls and a top wall;

a plurality of electronic devices, each electronic device located within the cabinet and at least some of the electronic devices including a respective wireless transceiver; and

a relay comprising an internal antenna, an external antenna and a transmission path therebetween, wherein the internal antenna is located at least partially within the cabinet and the external antenna is located at least partially exterior to a wall of the cabinet, and wherein the relay is configured to receive uplink wireless transmissions from the wireless transceivers of the electronic devices and to forward and rebroadcast these uplink wireless transmission to the exterior of the cabinet via the external antenna.

2. The electronic equipment cabinet of Claim 1, wherein the relay is further configured to receive, via the external antenna, a downlink wireless transmission destined for a first of the electronic devices and to forward and rebroadcast the downlink wireless transmission to the first electronic device via the internal antenna.

3. The electronic equipment cabinet of Claims 1 or 2, wherein the relay comprises a board with an RF transmission line thereon.

4. The electronic equipment cabinet of Claim 3, wherein at least one of the internal antenna and the external antenna is mounted on the board.

5. The electronic equipment cabinet of any of the preceding claims, wherein the internal antenna comprises a monopole antenna and the external antenna comprises a monopole antenna.

6. The electronic equipment cabinet of any of the preceding claims, wherein the relay further comprises an amplifier that amplifies signals received by the internal antenna.

7. The electronic equipment cabinet of any of the preceding claims, wherein the transmission path comprises a coaxial cable.

8. The electronic equipment cabinet of Claim 7, wherein a first end of the center conductor of the coaxial cable comprises part of the internal antenna, and a second end of the center conductor of the coaxial cable comprises part of the external antenna.

9. The electronic equipment cabinet of any of the preceding claims, wherein the transmission path comprises an RF transmission line that directly connects the internal and external antennas.

10. The electronic equipment cabinet of any of the preceding claims, wherein the relay includes at least one sensor.

11. The electronic equipment cabinet of any of the preceding claims, wherein the external antenna is located remotely from the cabinet.

12. The electronic equipment cabinet of Claim 11, wherein the cabinet is located underground and the external antenna is above ground.

13. The electronic equipment cabinet of any of the preceding claims, further comprising an internal RFID antenna, an external RFID antenna, and an RFID transmission line connecting the internal RFID antenna to the external RFID antenna.

14. A method comprising:

receiving at an internal antenna of a relay a radio frequency ("RF") signal transmitted by an electronic device that is mounted within a metal cabinet, wherein the internal antenna is at least partially within the metal cabinet; and

forwarding the received RF signal to an external antenna that transmits the received RF signal externally to the metal cabinet.

15. The method of Claim 14, wherein the RF signal is within a first frequency band, and wherein the forwarding comprises transmitting the RF signal without converting the RF signal to a different frequency band.

16. The method of Claims 14 or 15, further comprising amplifying the received RF signal prior to transmitting the received RF signal externally to the metal cabinet.

17. A relay comprising:

an internal antenna,

an external antenna,

a transmission path between the internal antenna and the external antenna, wherein the internal antenna is dimensioned to sit at least partially within an electronics cabinet and the external antenna is dimensioned to sit at least partially exterior to a wall of the electronics cabinet.

18. The relay of Claim 17, wherein the transmission path comprises a coaxial cable.

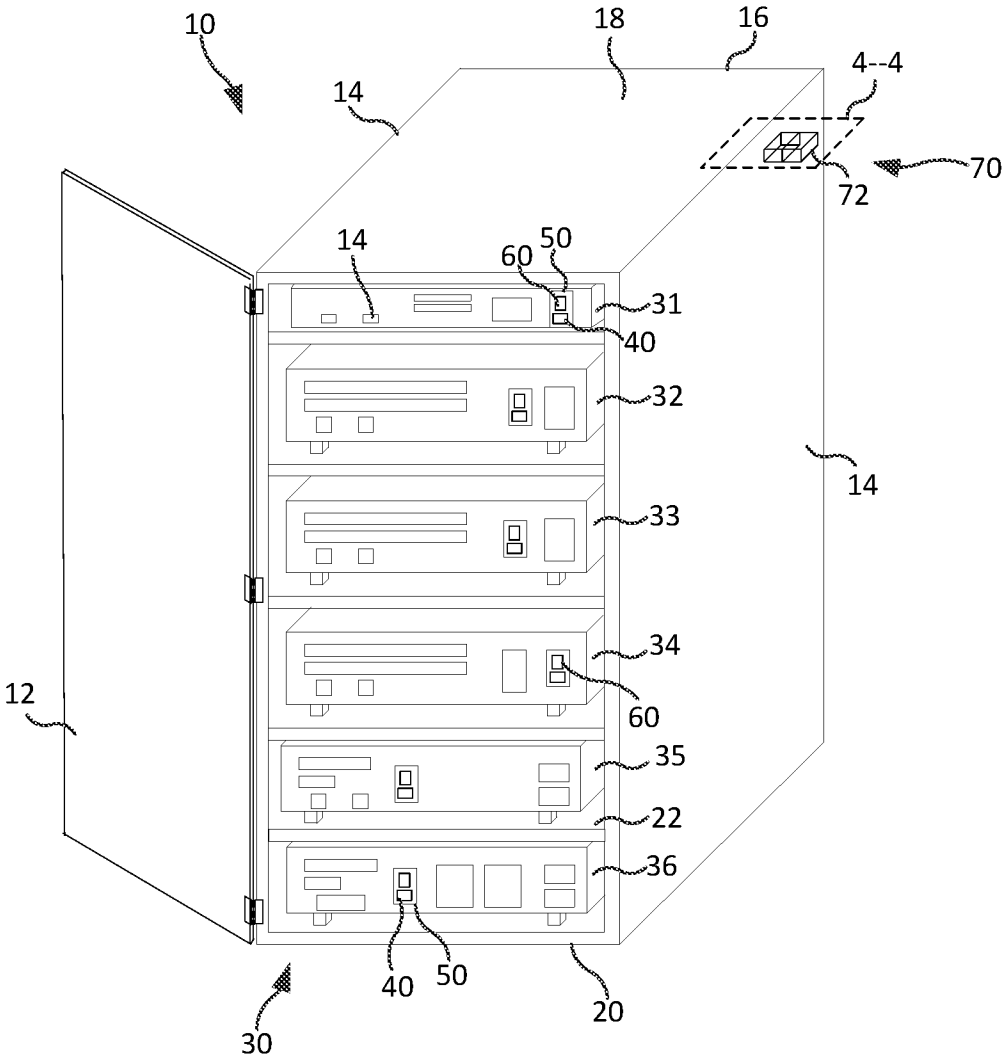
19. The relay of Claims 17 or 18, further comprising:

a pair of diplexers,

a pair of amplifiers; and

a voltage regulator.

20. The relay of any of Claims 17-19, wherein at least one of the internal antenna and the external antenna comprises an RFID antenna.


10
18
16
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14
70
72
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31
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60
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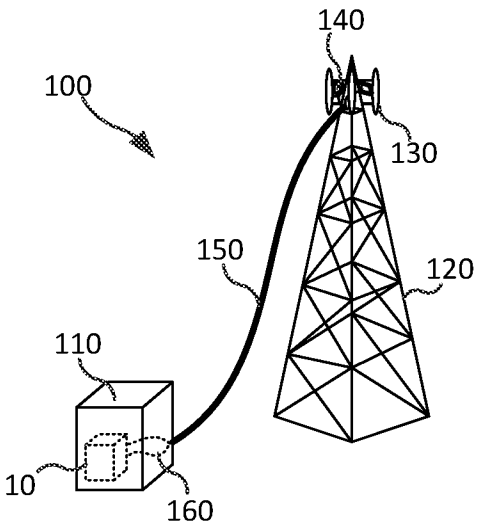
40
50
20
30

FIG. 1


140
100
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150
120
110
10
160

FIG. 2

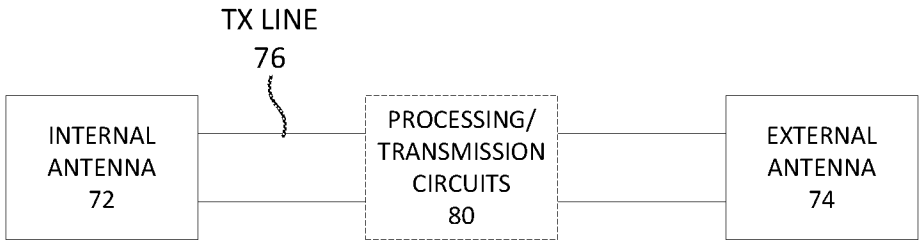
TX LINE
76
INTERNAL ANTENNA 72
PROCESSING/ TRANSMISSION CIRCUITS 80
EXTERNAL ANTENNA 74

FIG. 3

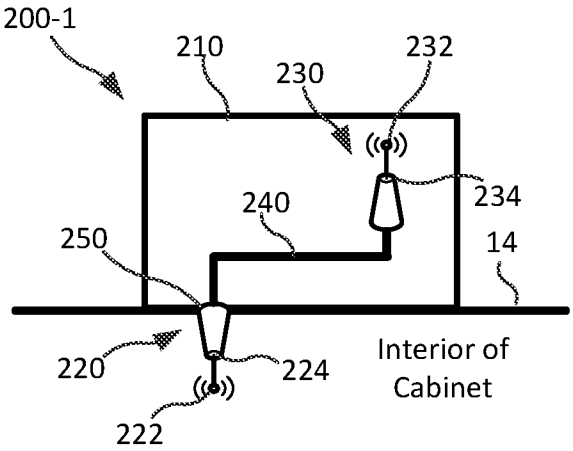

FIG. 4A

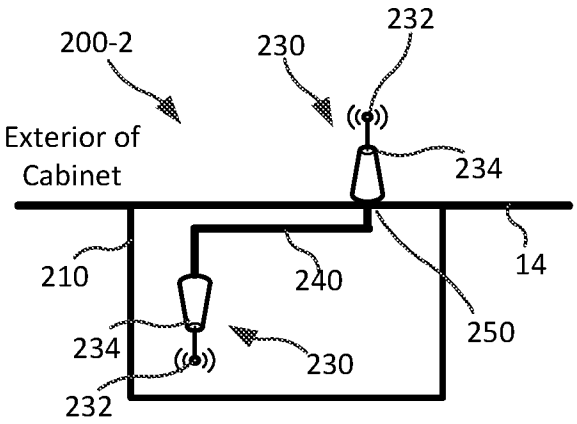

FIG. 4B

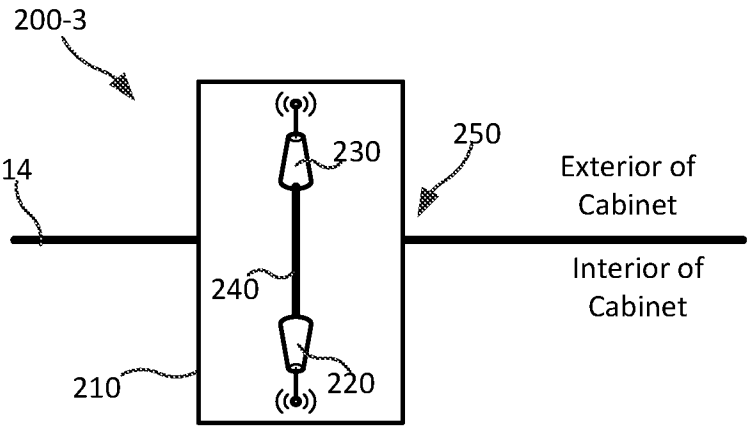

FIG. 4C

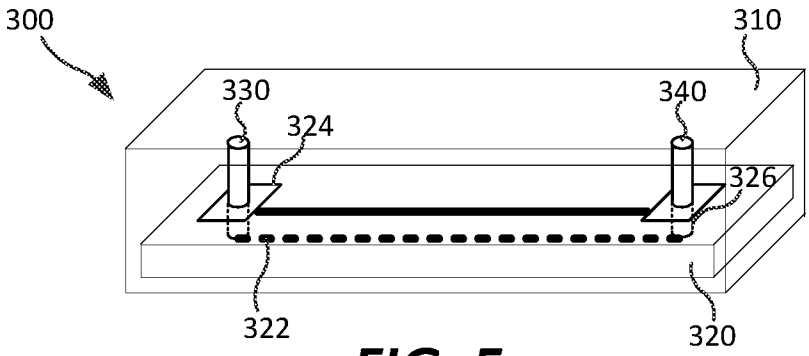

FIG. 5

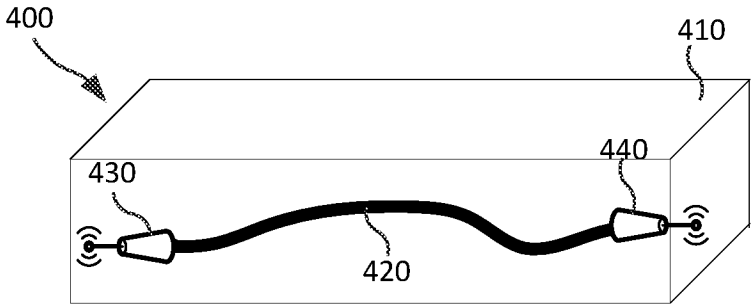

FIG. 6

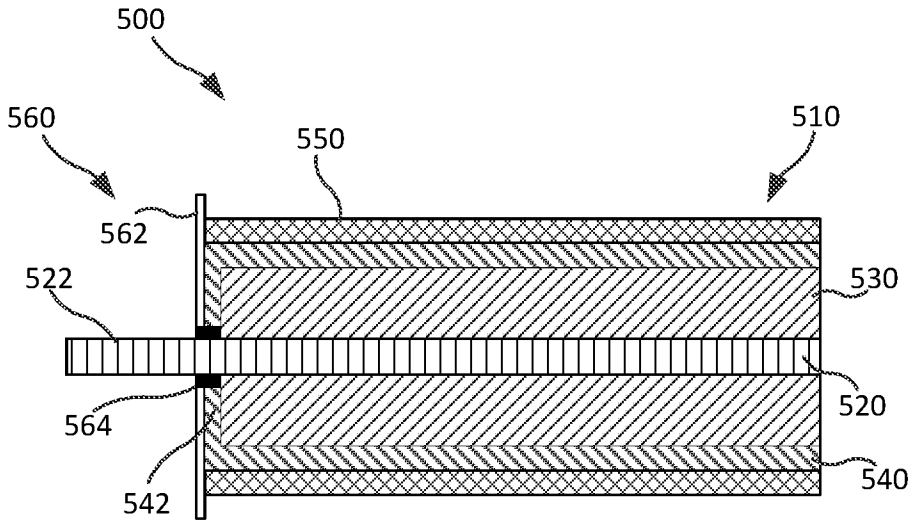

FIG. 7

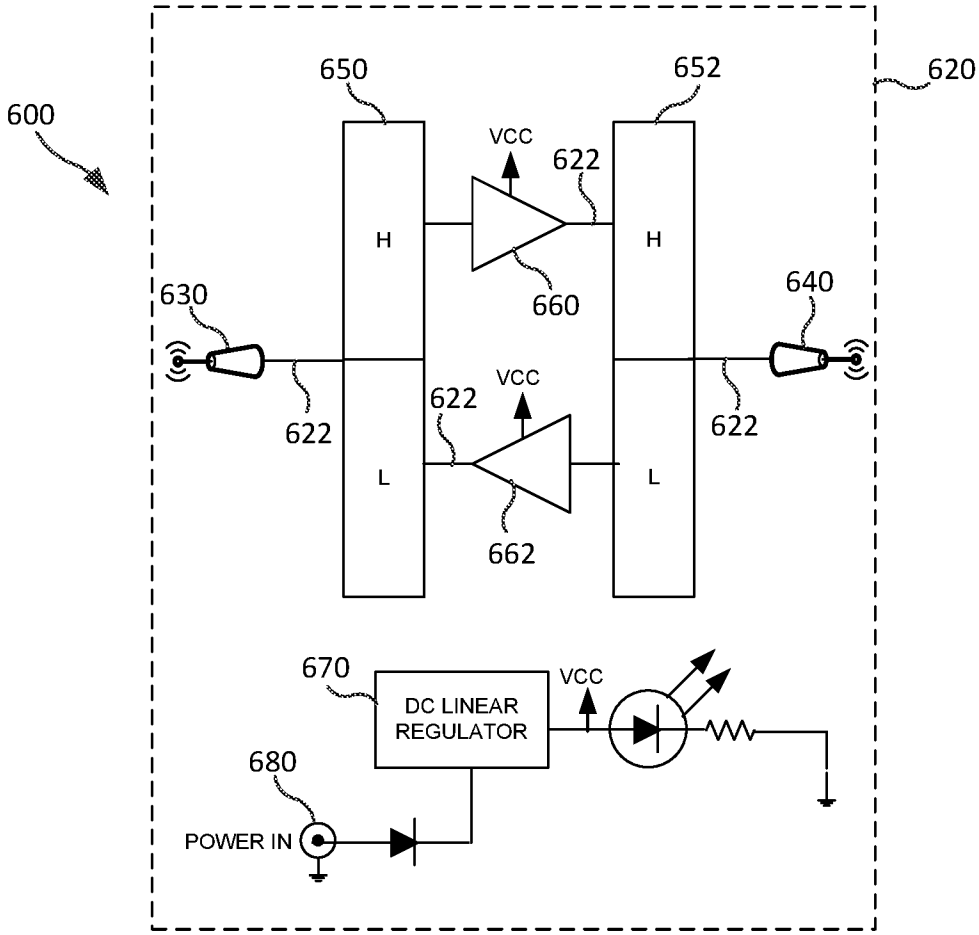
600
620
650
652
VCC
622
H
H
660
630
640
622
622
VCC
622
L
L
662
670
DC LINEAR REGULATOR
VCC
680
POWER IN

FIG. 8

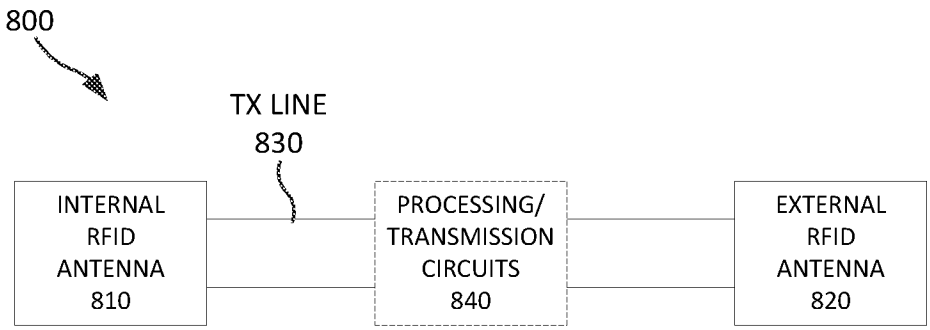
800
TX LINE
830
INTERNAL RFID ANTENNA 810
PROCESSING/ TRANSMISSION CIRCUITS 840
EXTERNAL RFID ANTENNA 820

FIG. 10

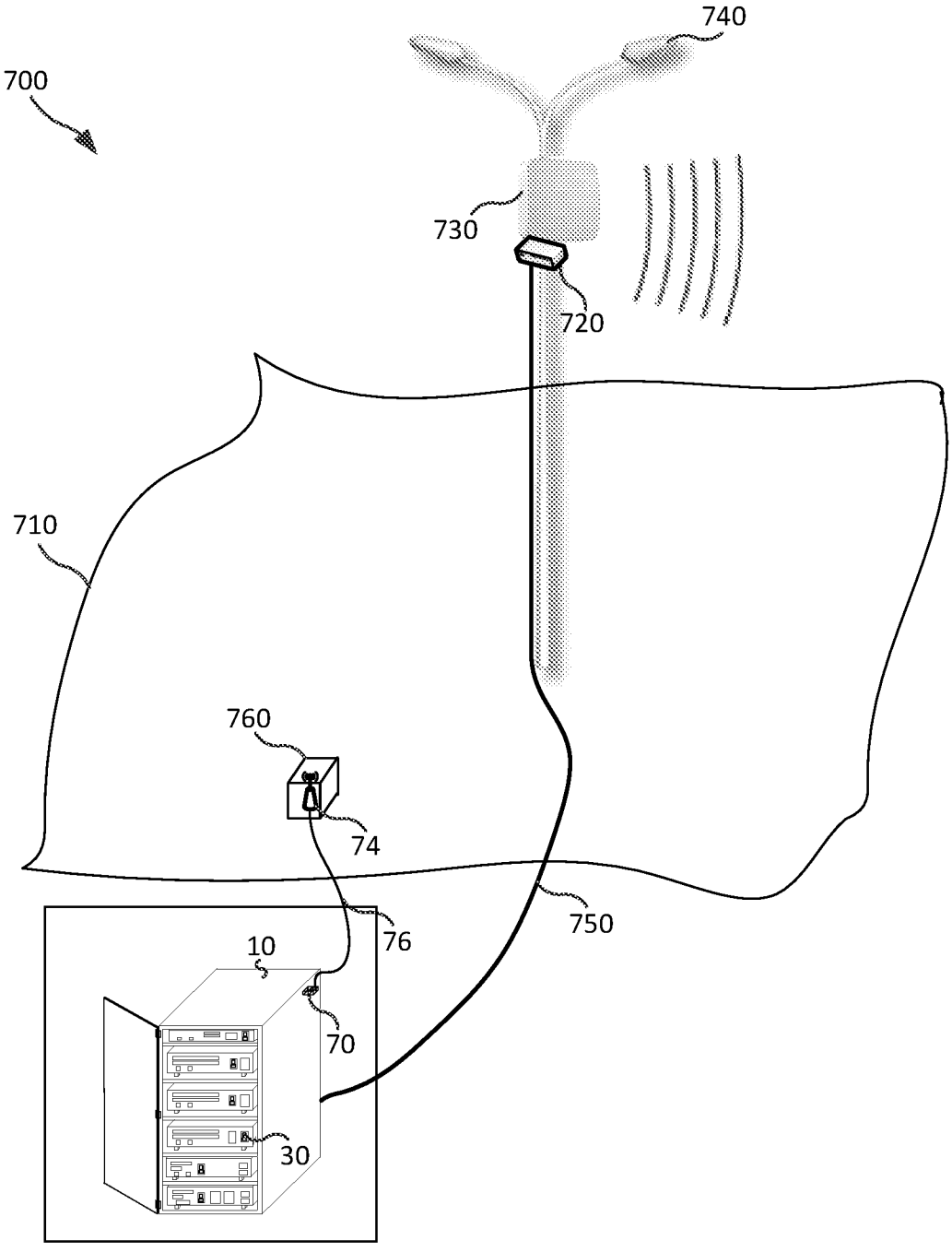

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/047483

A. CLASSIFICATION OF SUBJECT MATTER

H04Q 1/02(2006.01)i, H04Q 1/08(2006.01)i, H04Q 1/18(2006.01)i

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)
H04Q 1/02; G06K 7/10; H04B 7/00; H04L 5/00; H04L 12/931; H04Q 5/22; H04W 24/08; H04Q 1/08; H04Q 1/18

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: cabinet, internal antenna, external antenna, transmission path, relay, transceiver

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013-0161386 A1 (ROUND ROCK RESEARCH, LLC.) 27 June 2013 See paragraphs [0012]-[0015], [0023]-[0026]; claim 1; and figures 1-3.	14-15,17-18
Y		1-4,16,19
Y	US 2012-0214415 A1 (PAUL J. HARVEY) 23 August 2012 See paragraphs [0014]-[0015]; and figure 4.	1-4
Y	US 2007-0001809 A1 (VENKATA KODUKULA et al.) 04 January 2007 See paragraphs [0034], [0059]; and figure 1.	16,19
A	US 2016-0036574 A1 (TUNNEL RADIO OF AMERICA, INC.) 04 February 2016 See paragraphs [0025]-[0051]; and figures 1-2D.	1-4,14-19
A	US 2014-0233460 A1 (MICHAEL GREGORY PETTUS et al.) 21 August 2014 See paragraphs [0038]-[0086]; and figures 2-6B.	1-4,14-19

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

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 November 2017 (10.11.2017)	**10 November 2017 (10.11.2017)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea
Facsimile No. +82-42-481-8578

Authorized officer
YANG, Jeong Rok
Telephone No. +82-42-481-5709

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/047483

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

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

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

2. ☒ Claims Nos.: 8,12
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
Claims 8 and 12 are regarded to be unclear because they refer to multiple dependent claims which do not comply with PCT Rule 6.4(a).

3. ☒ Claims Nos.: 5-7,9-11,13,20
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

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

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

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

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

Remark on Protest

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

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

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2017/047483

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		US 2009-0207090 A1	20/08/2009
		US 2011-0181484 A1	28/07/2011
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		US 9537794 B2	03/01/2017
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		WO 2009-002464 A3	19/03/2009
		WO 2009-002478 A2	31/12/2008
		WO 2009-002478 A3	02/04/2009
		WO 2013-019736 A1	07/02/2013