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(54) **APPARATUS AND METHODS FOR SENSING RAINFALL**

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(57) **ABSTRACT**

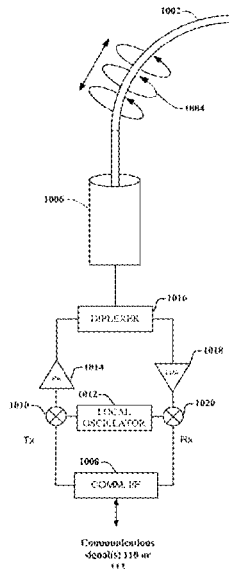
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Aspects of the subject disclosure may include, for example, a rainfall sensor having a rainfall analyzer configured to induce transmitted electromagnetic waves that are guided by a transmission medium to propagate along the transmission medium, wherein the transmitted electromagnetic waves propagate without requiring an electrical return path, wherein the rainfall analyzer receives reflected electromagnetic waves from the transmission medium in response to the transmitted electromagnetic waves and wherein the rainfall analyzer analyzes the reflected electromagnetic waves and generates rainfall data in response thereto. Other embodiments are disclosed.

(58) **Field of Classification Search**
None
See application file for complete search history.

20 Claims, 60 Drawing Sheets

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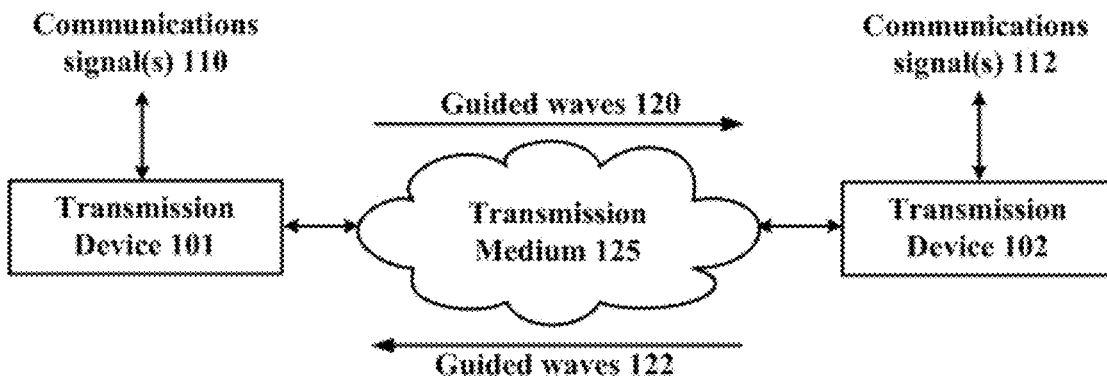
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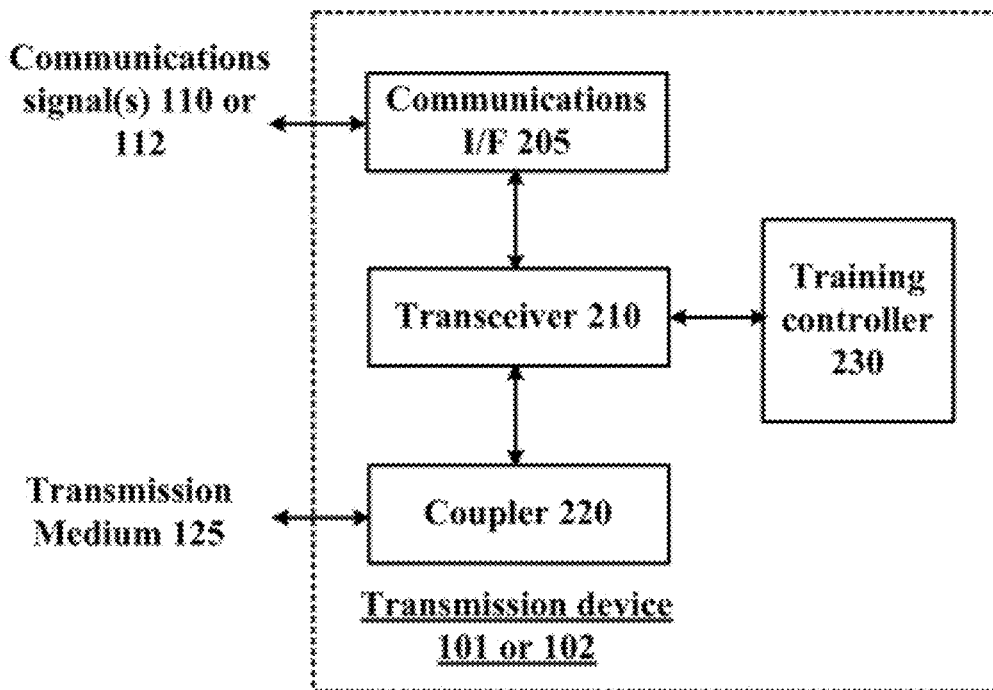
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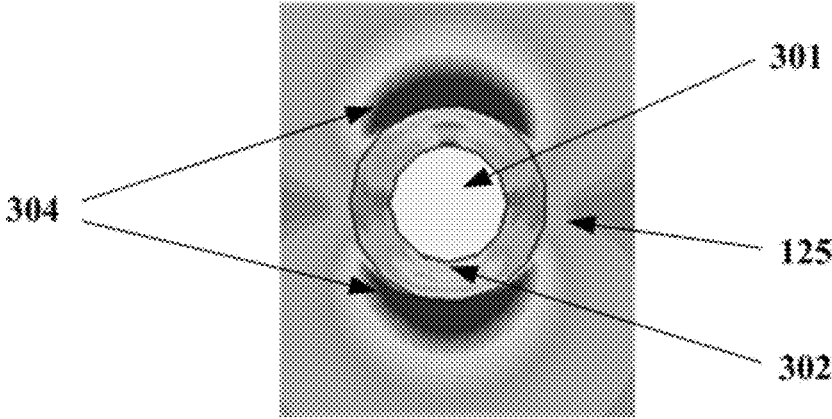
100

FIG. 1

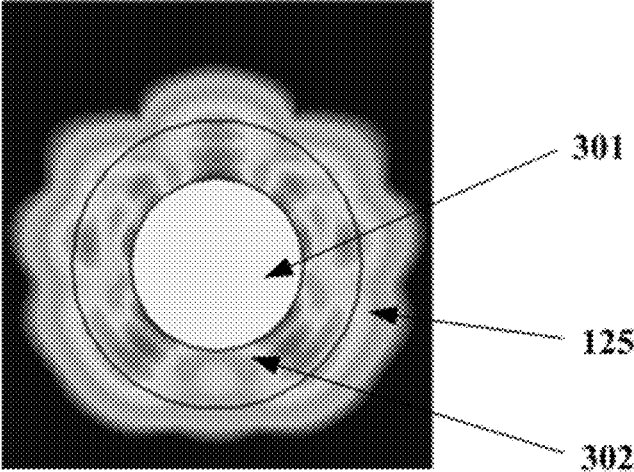


200

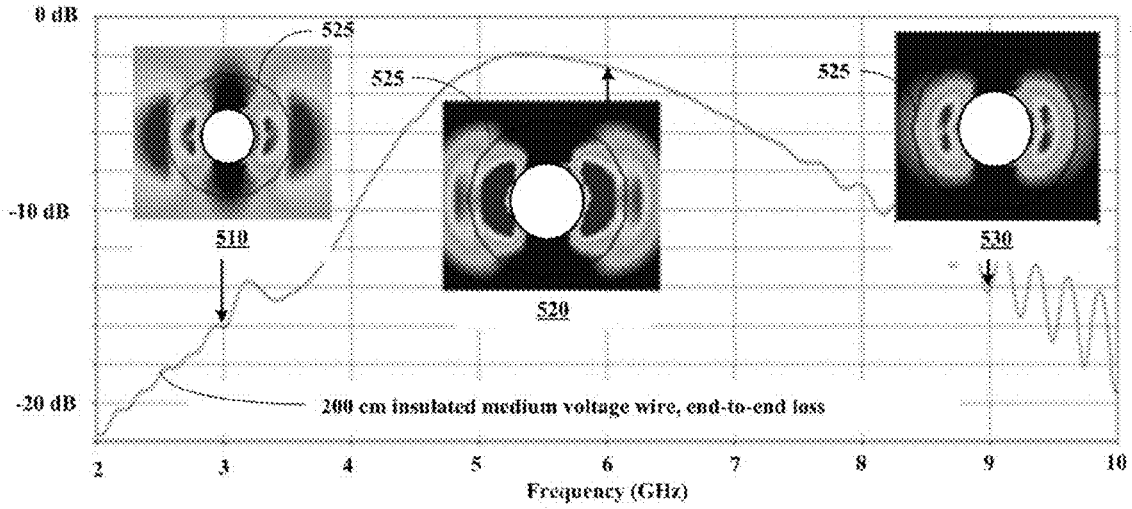
FIG. 2



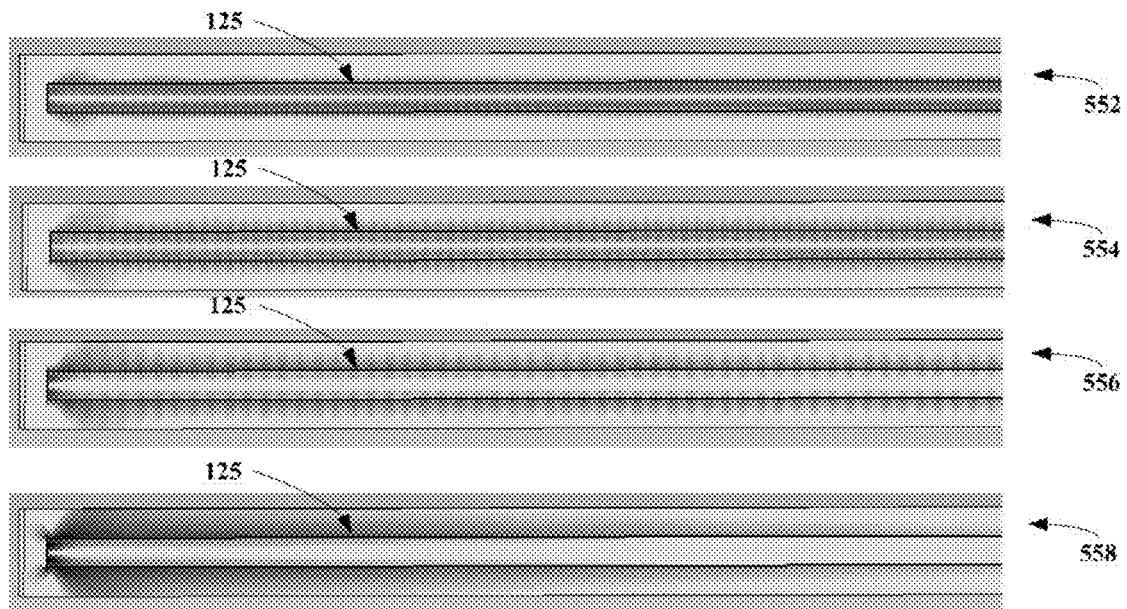
300
FIG. 3



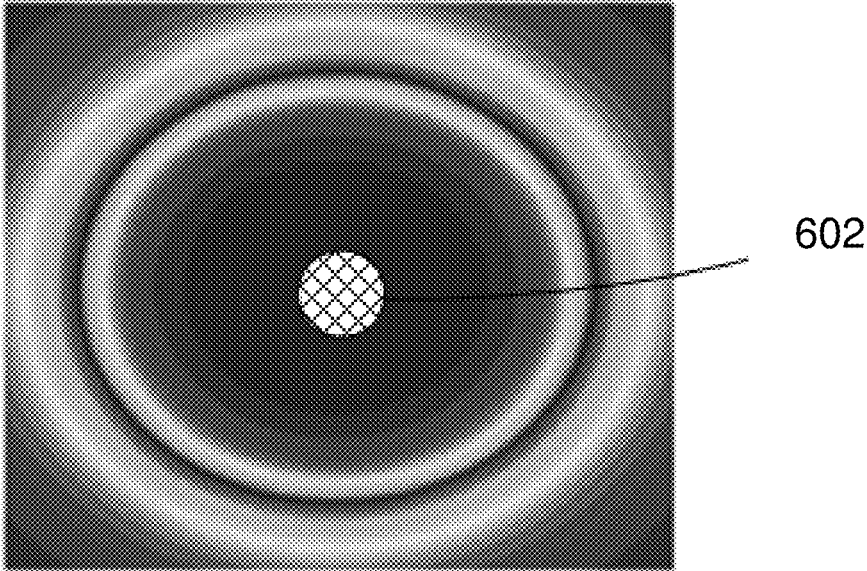
400
FIG. 4



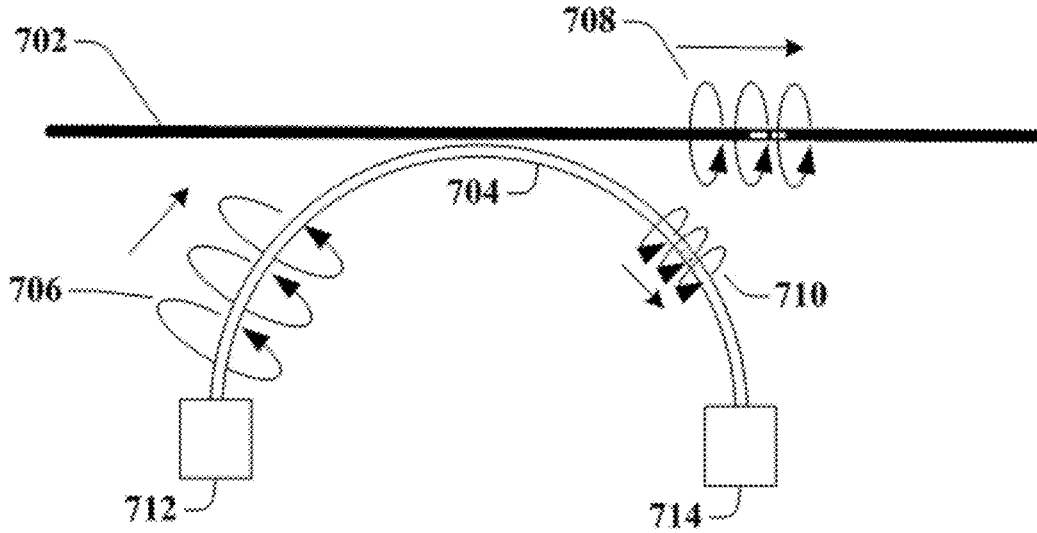
500
FIG. 5A



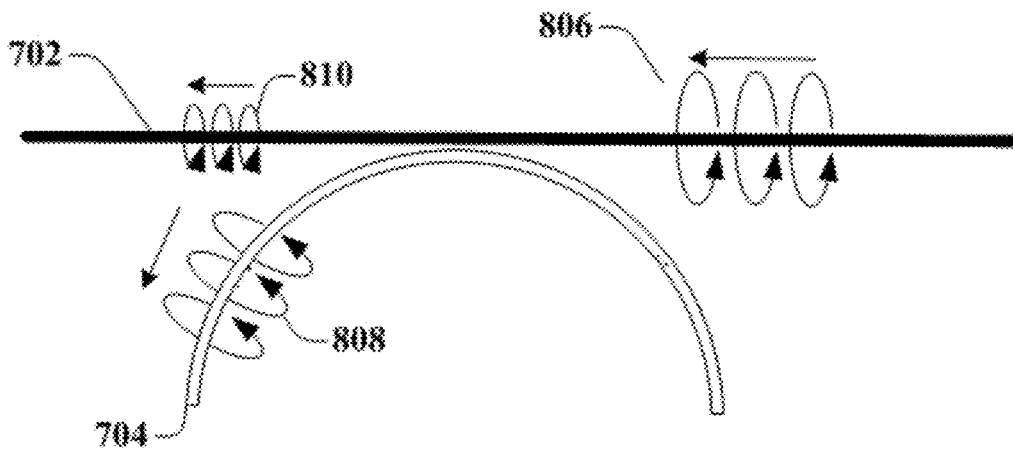
550
FIG. 5B



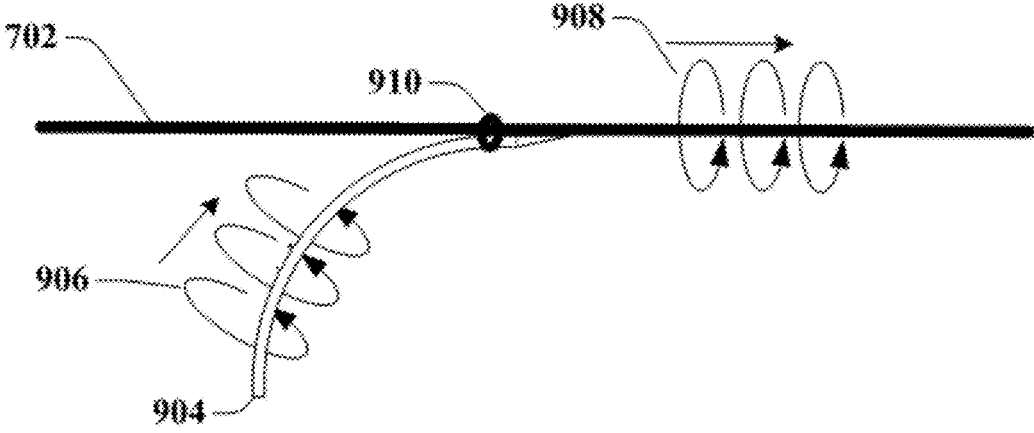
600
FIG. 6



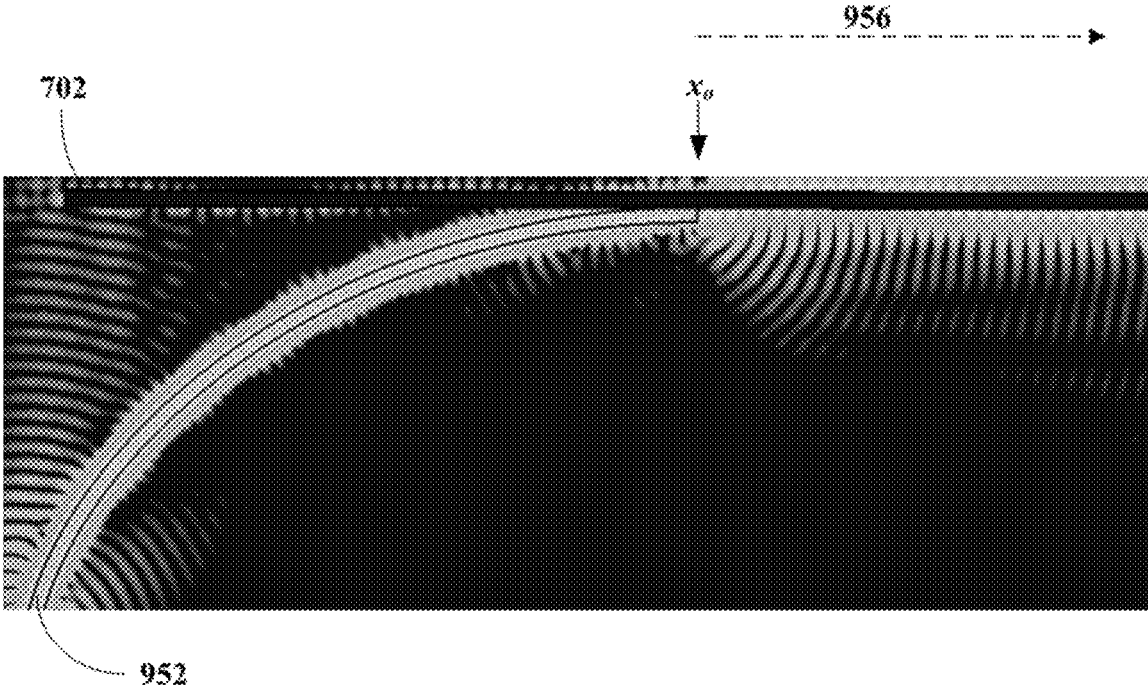
700
FIG. 7



800
FIG. 8

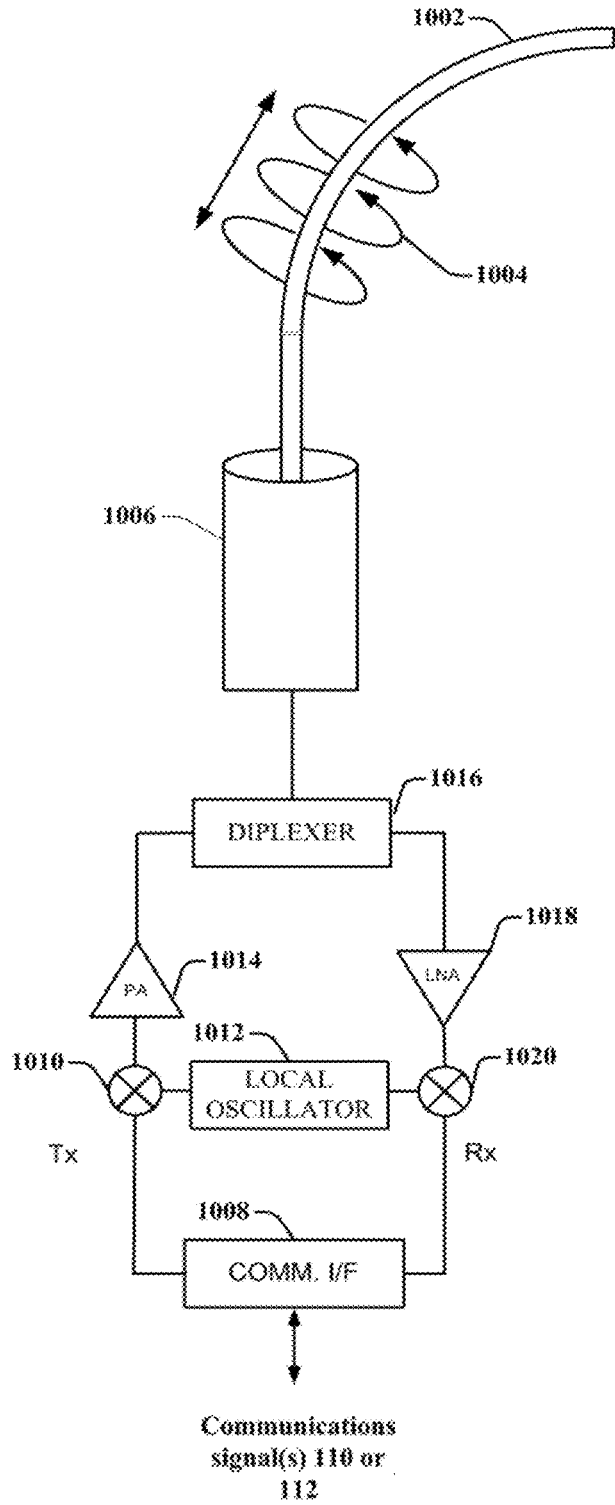


900
FIG. 9A



950
FIG. 9B

1000
FIG. 10A



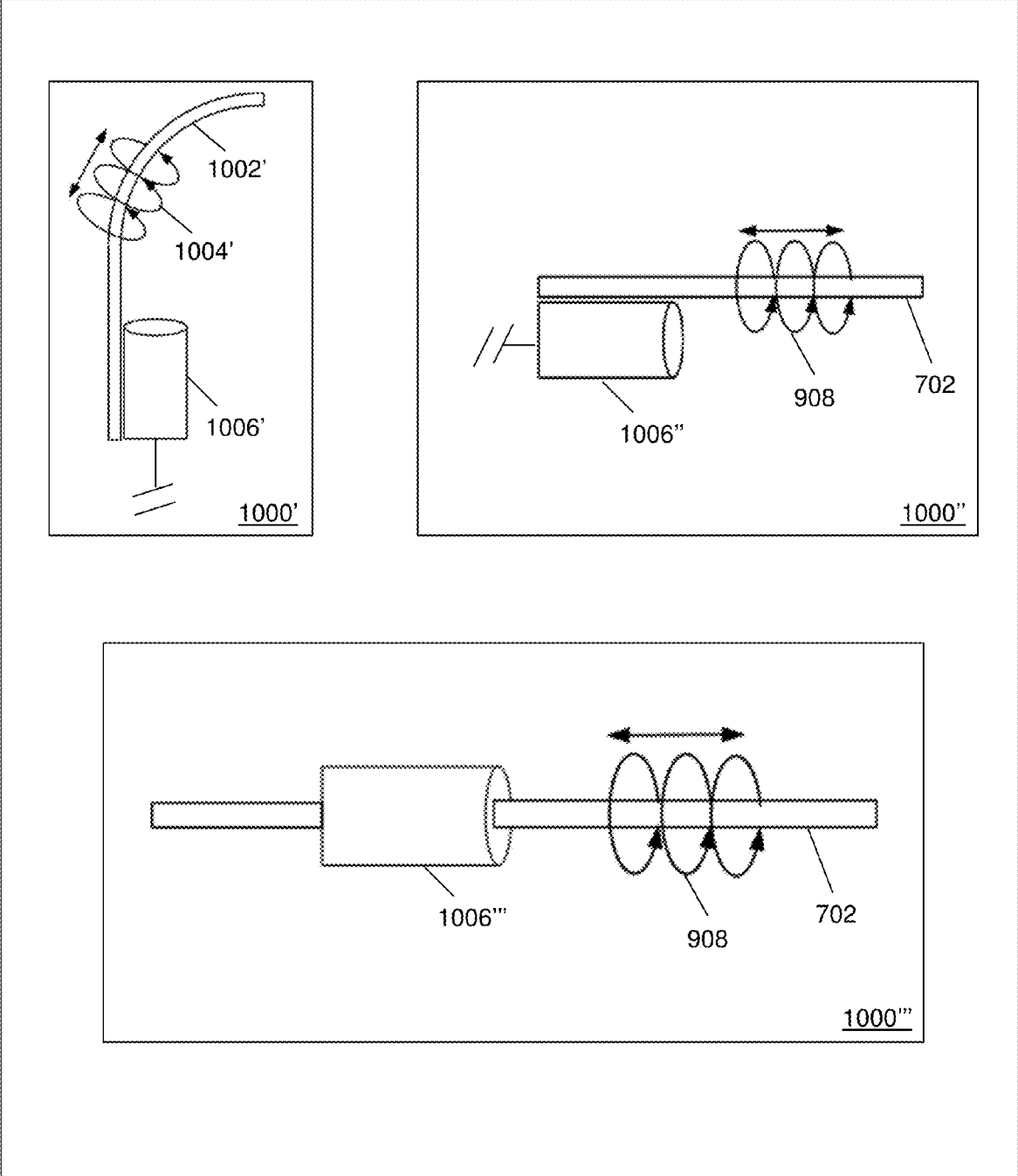
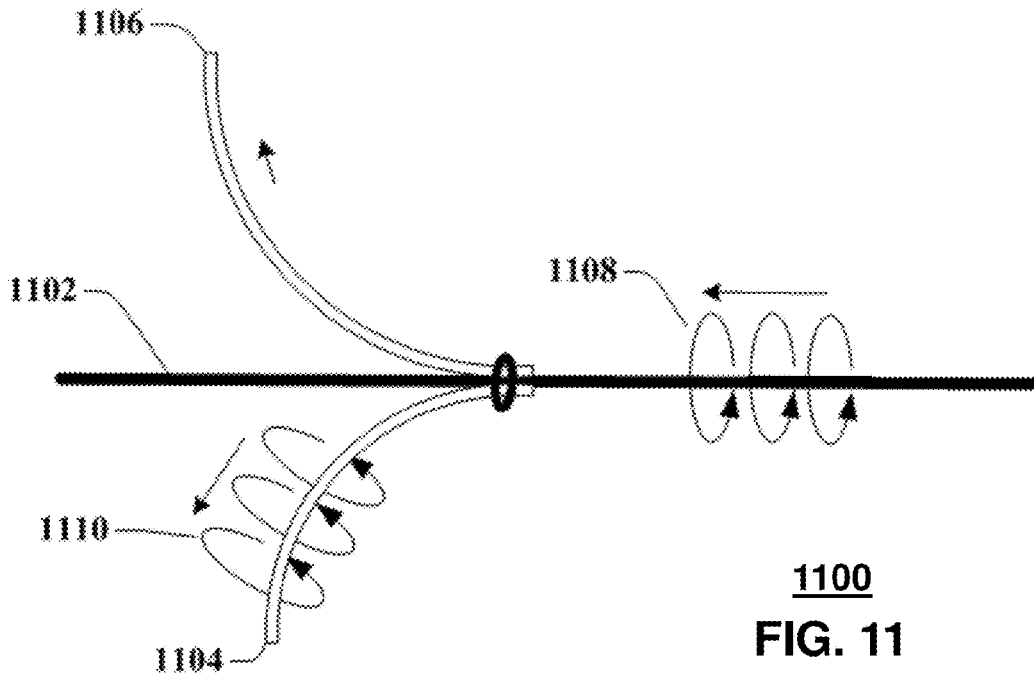
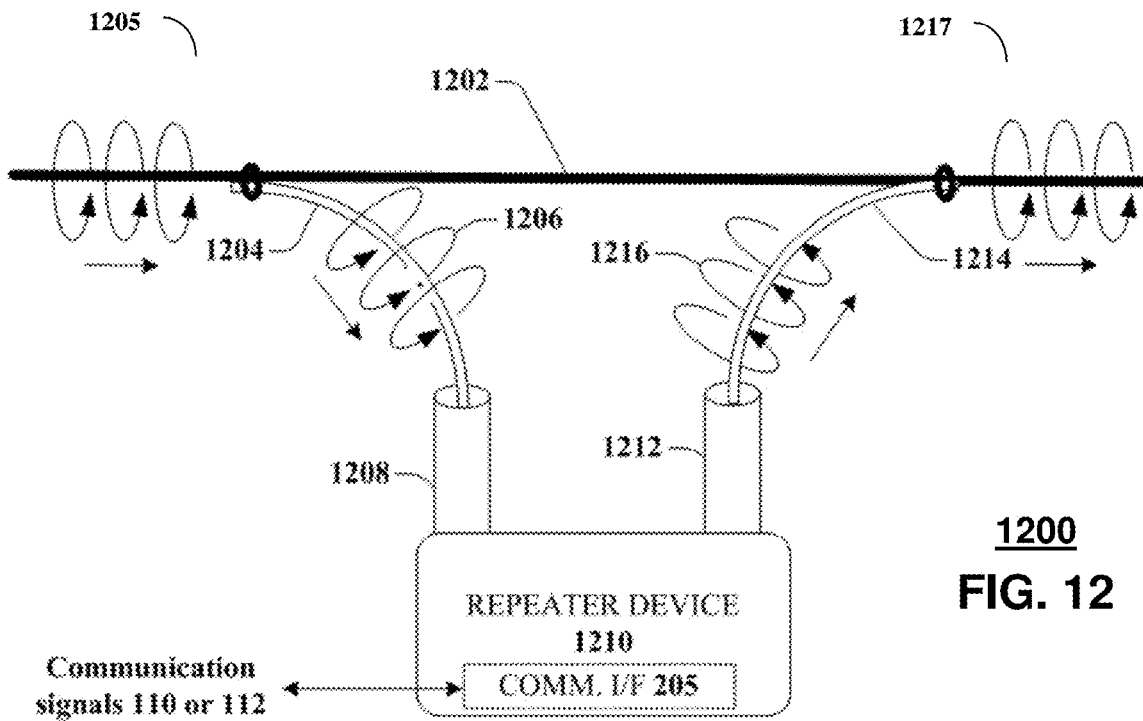


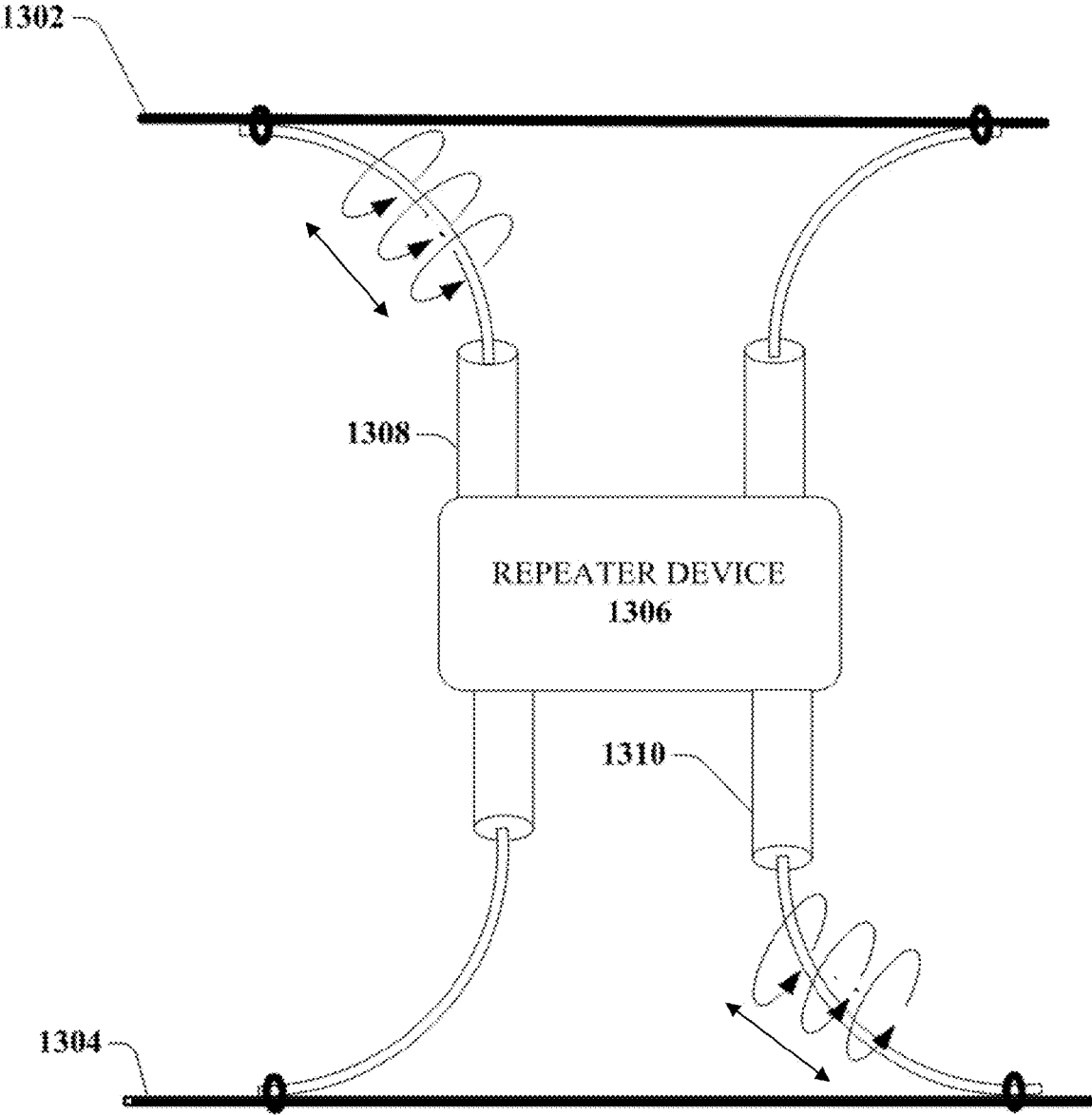
FIG. 10B



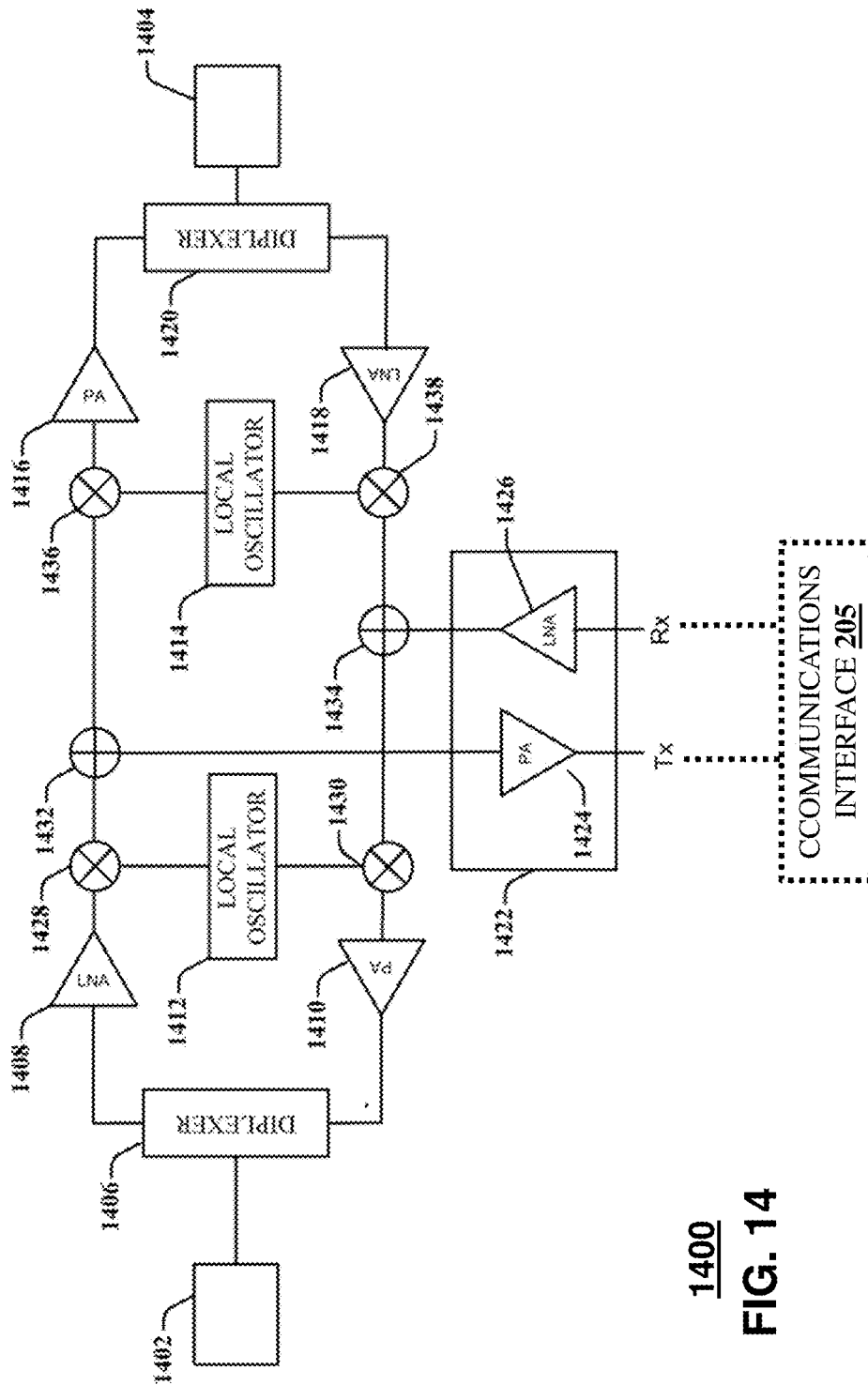
1100
FIG. 11



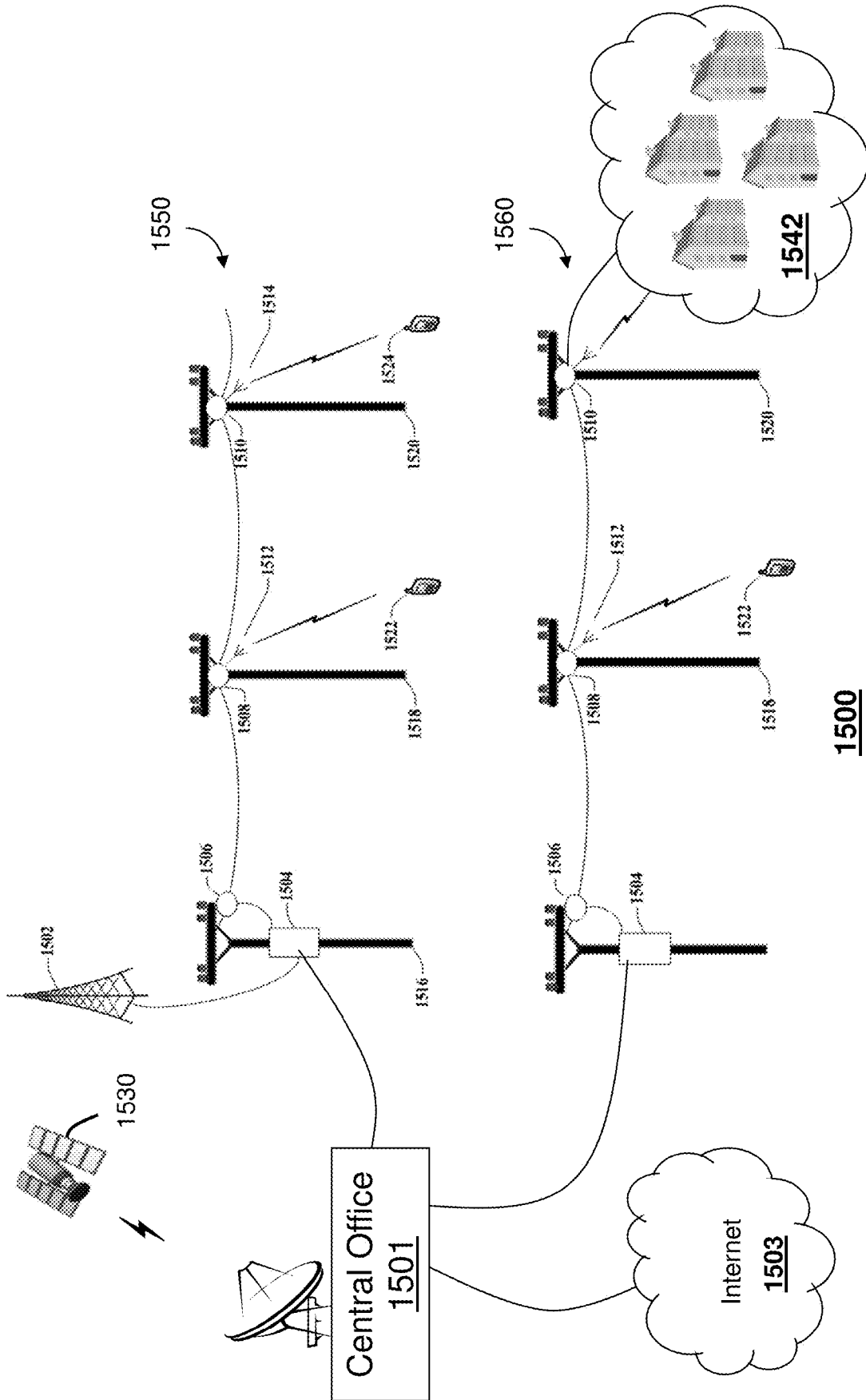
1200
FIG. 12



1300
FIG. 13



1400
FIG. 14



1500
FIG. 15

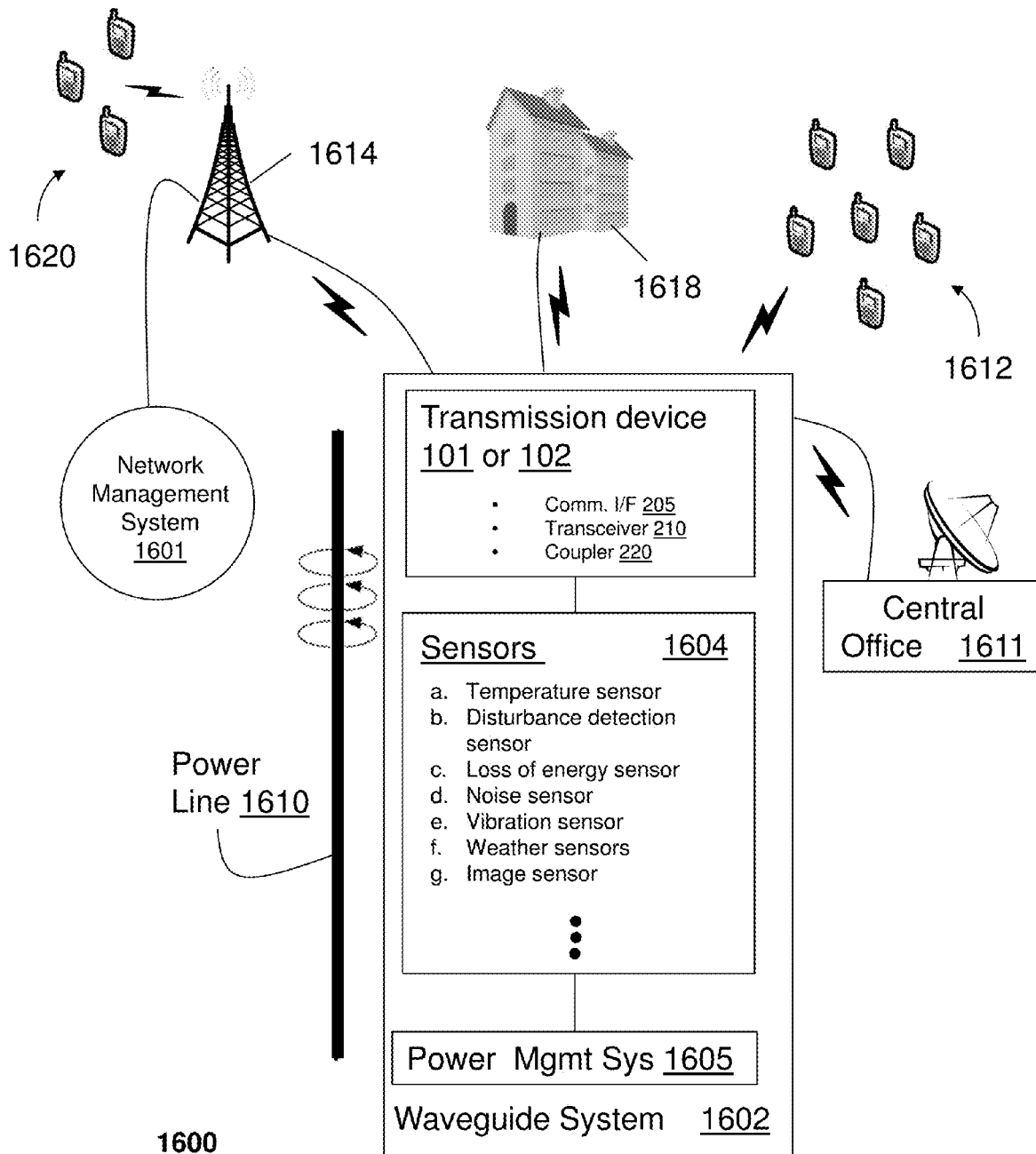
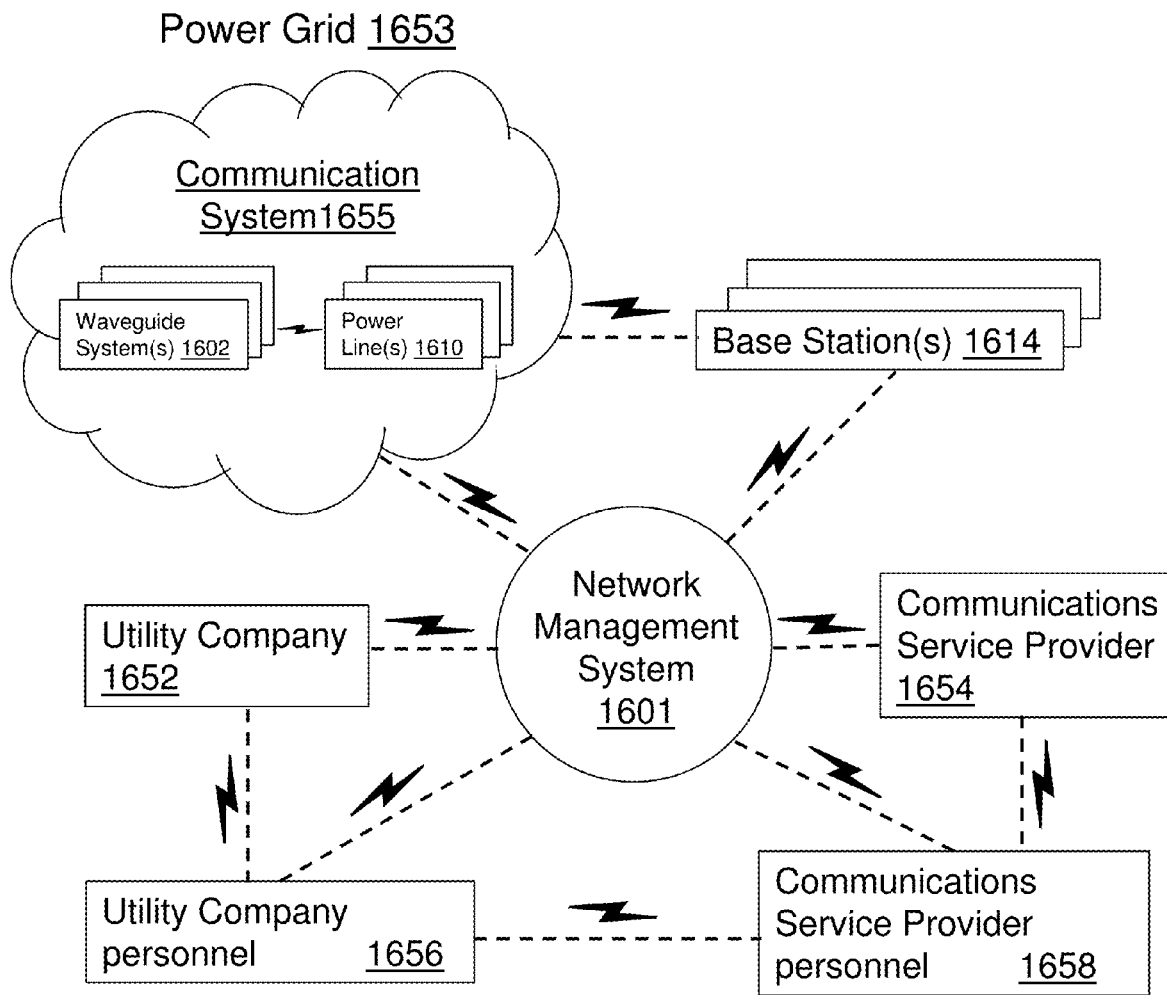
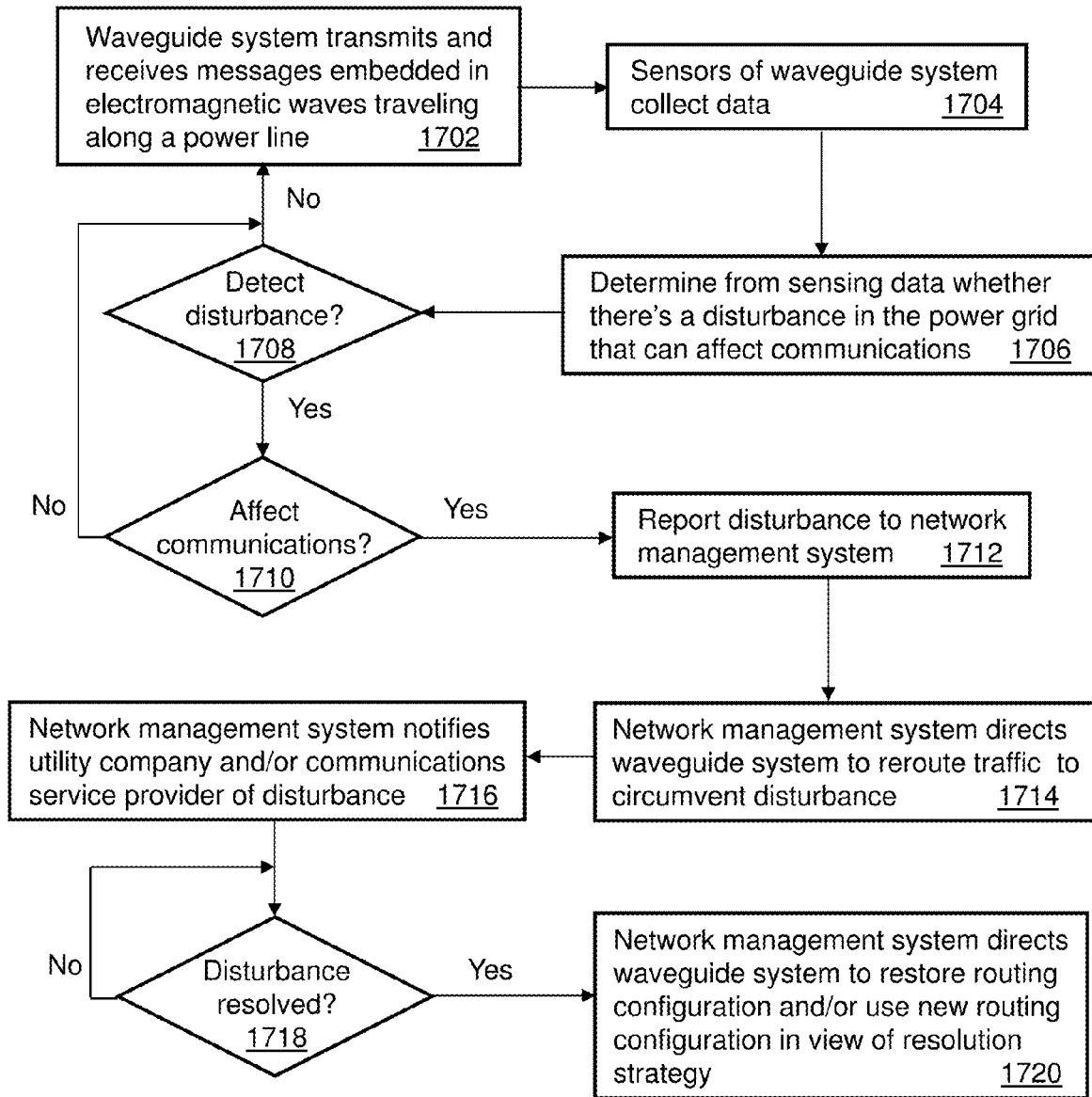


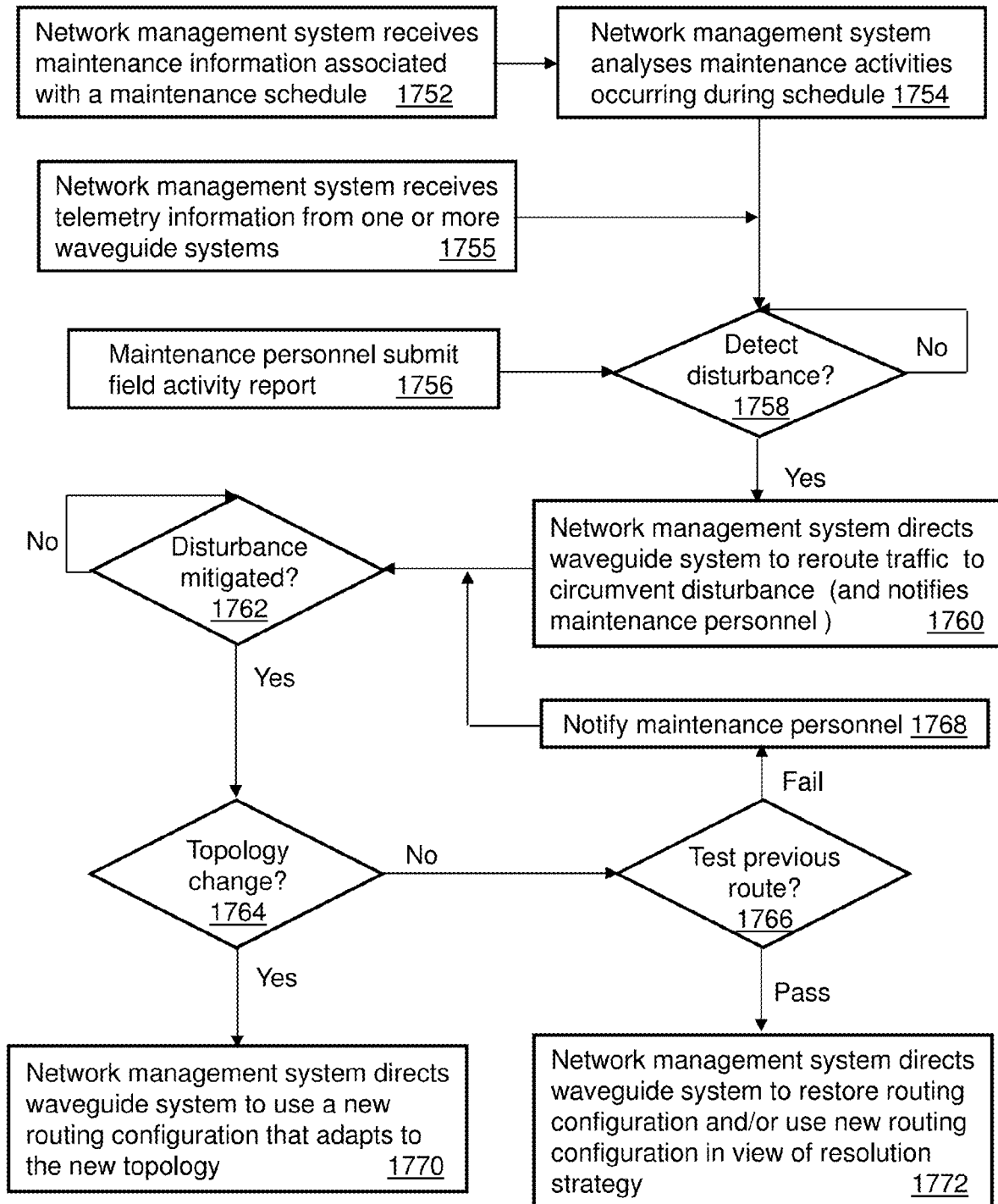
FIG. 16A



1650
FIG. 16B



1700
FIG. 17A



1750
FIG. 17B

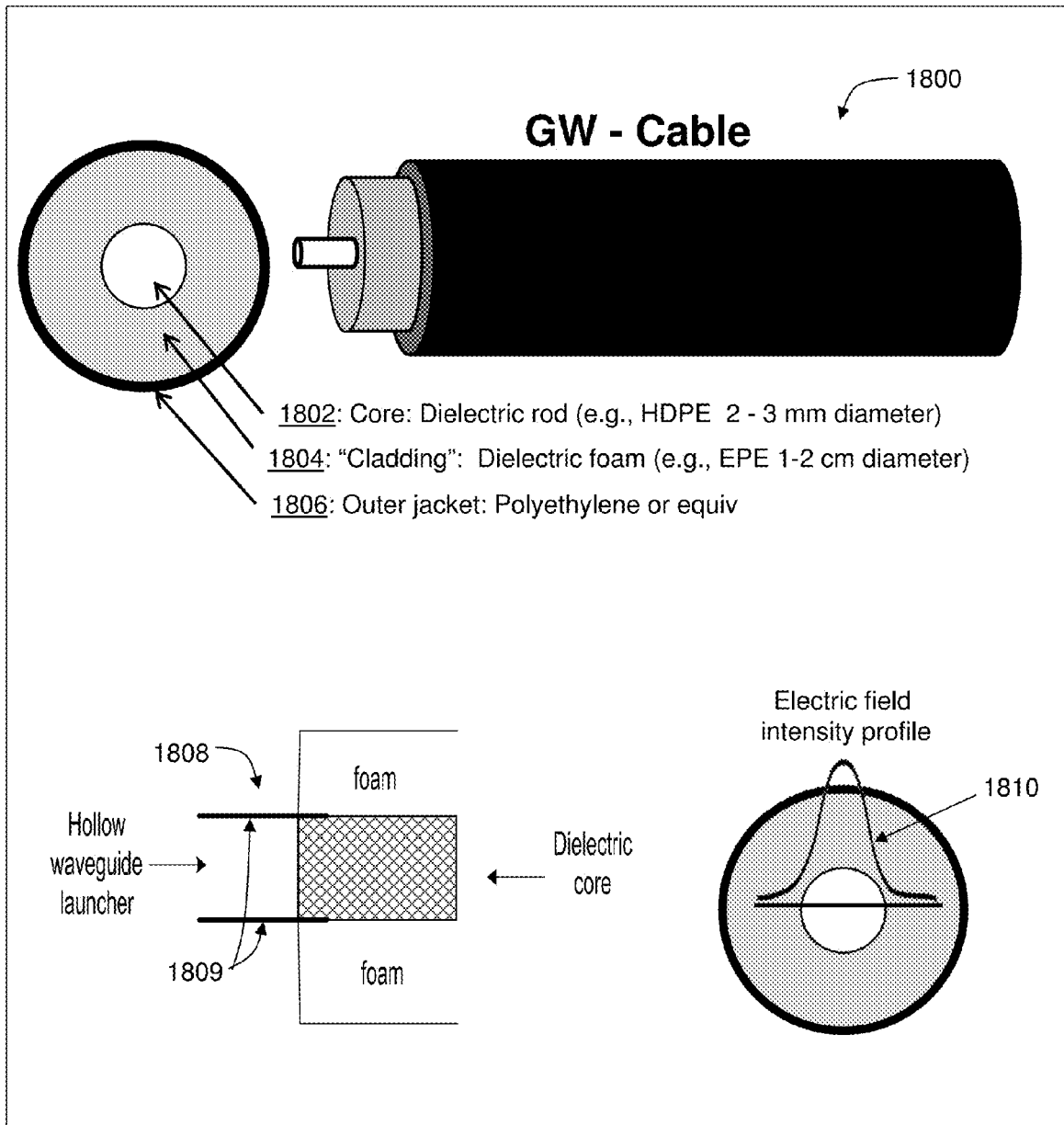


FIG. 18A

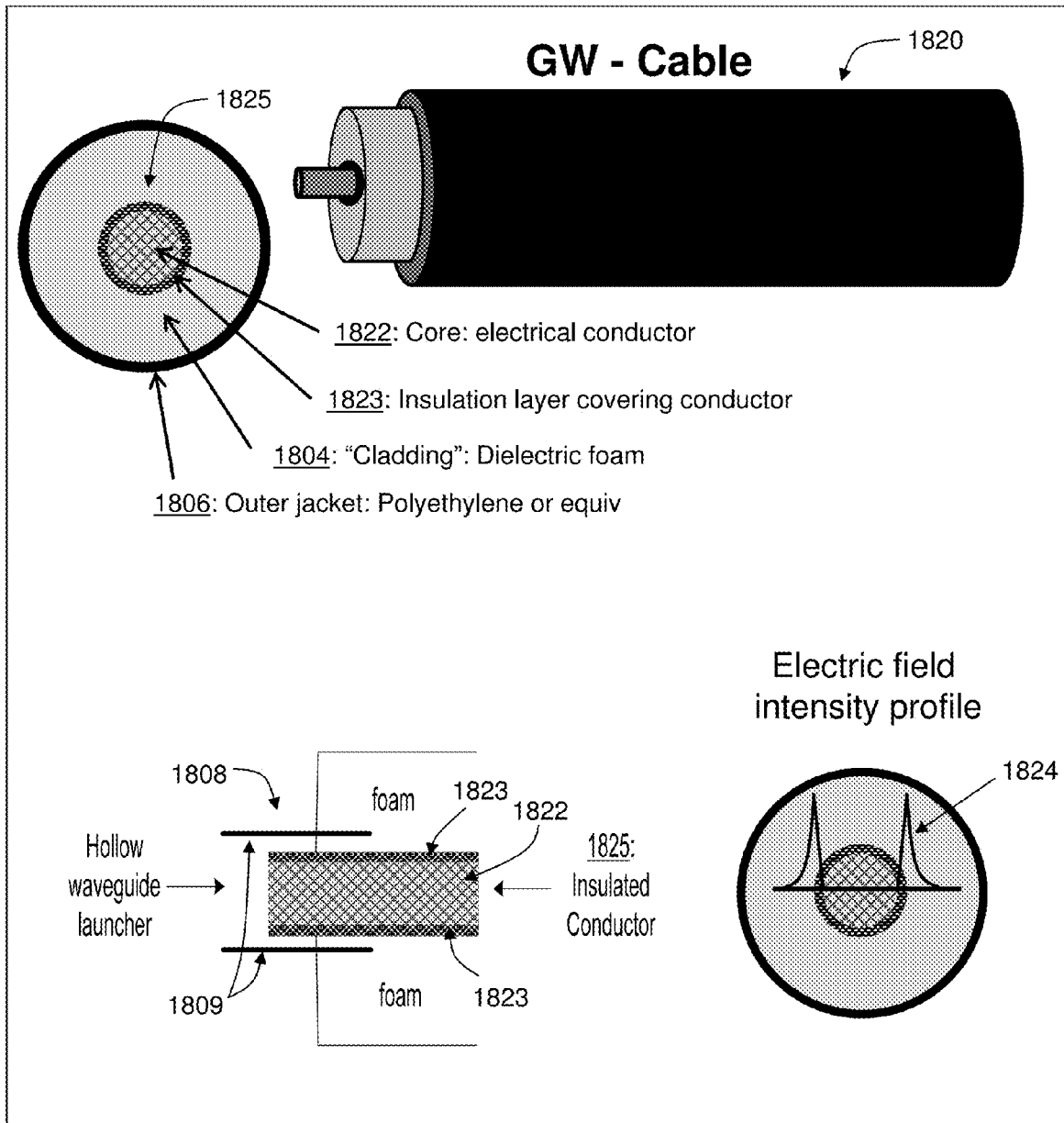


FIG. 18B

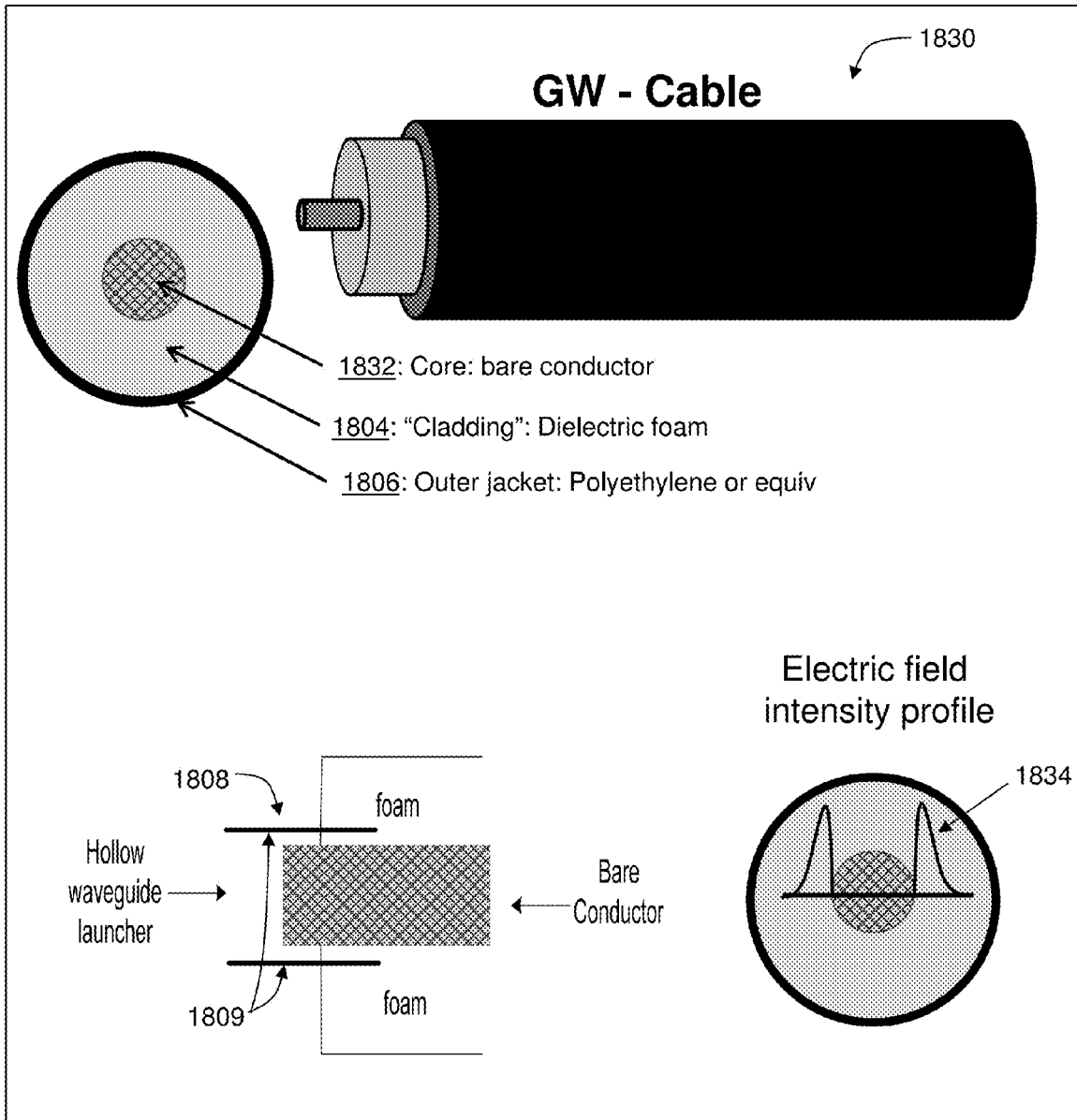


FIG. 18C

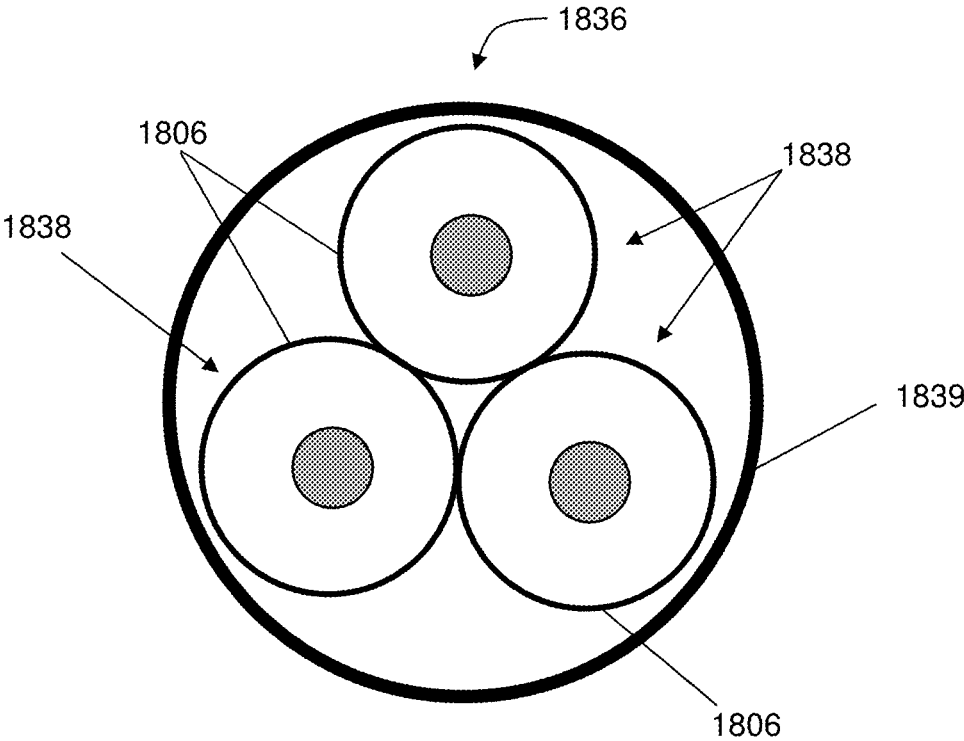


FIG. 18D

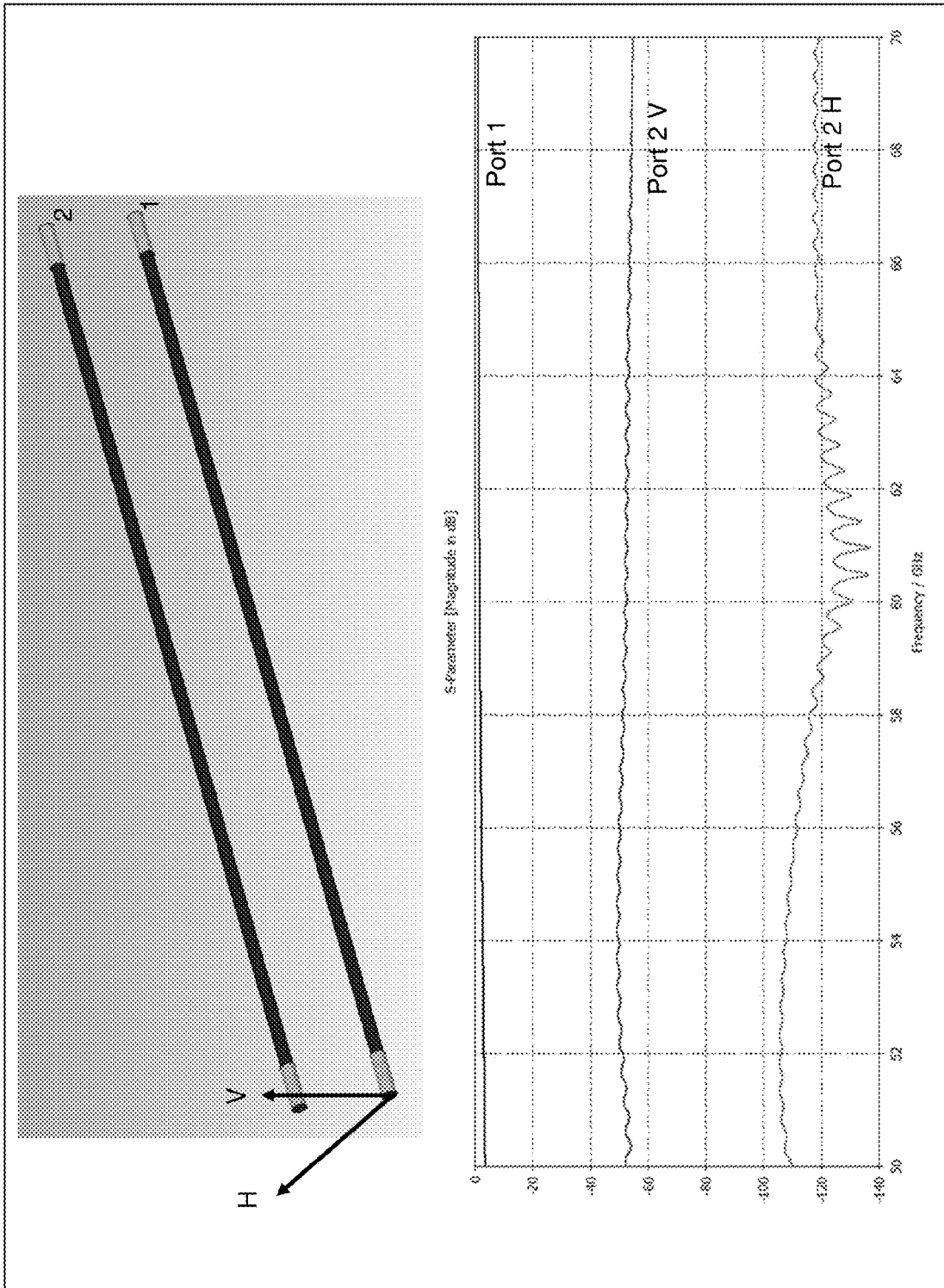


FIG. 18E

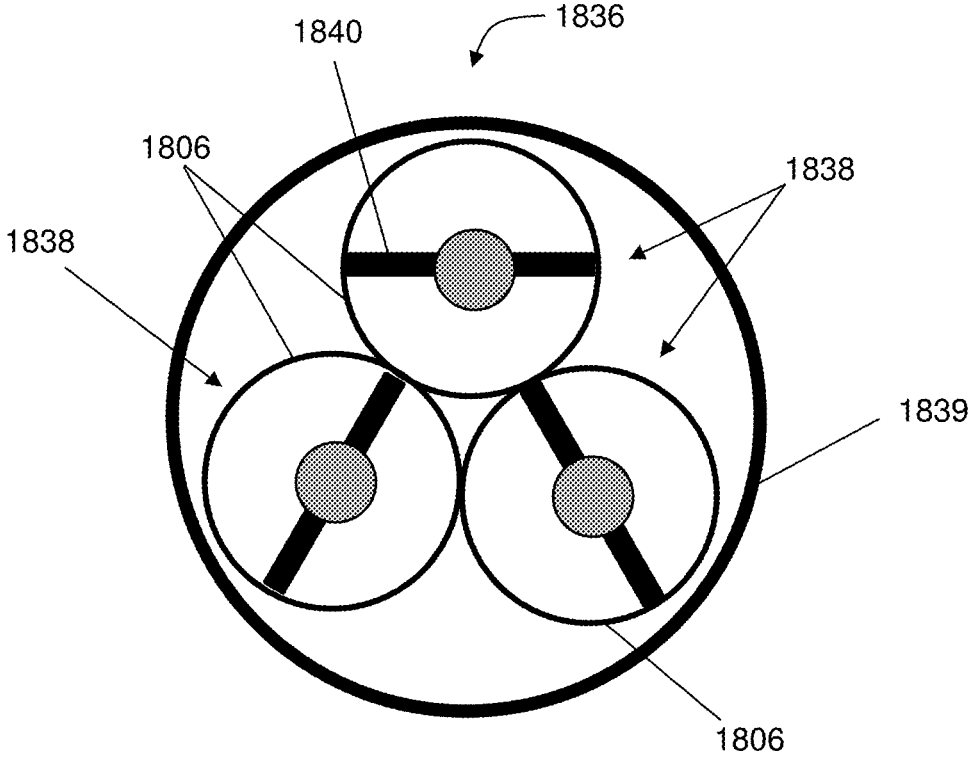
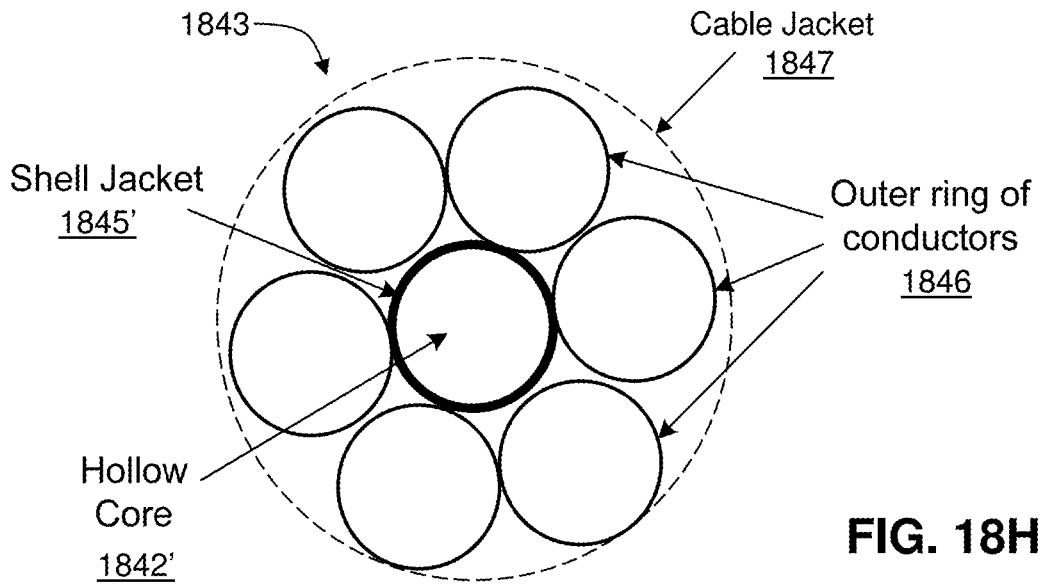
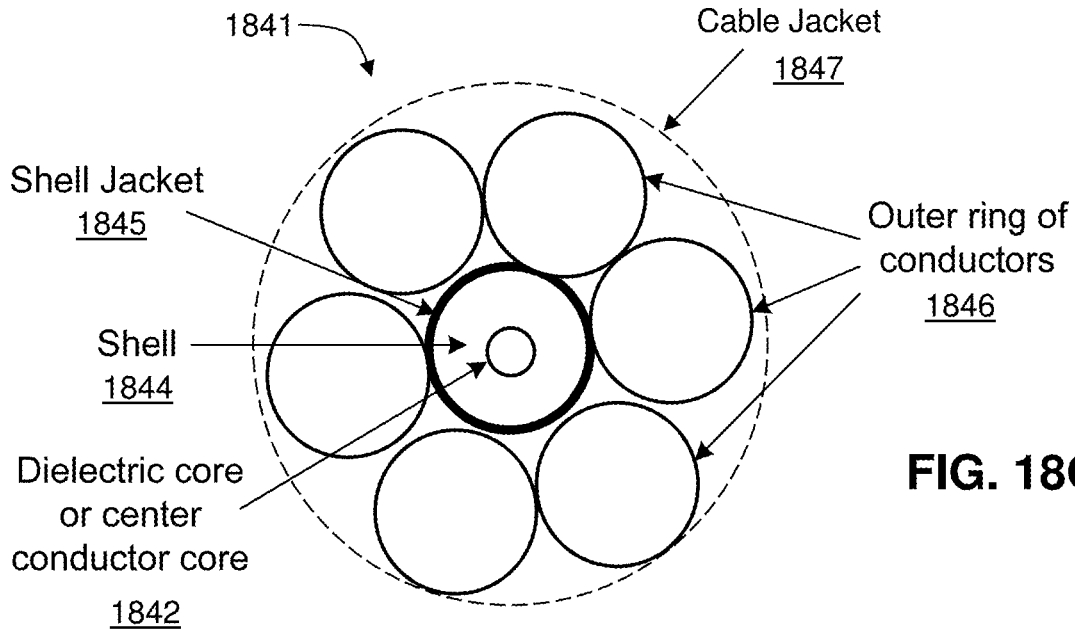


FIG. 18F



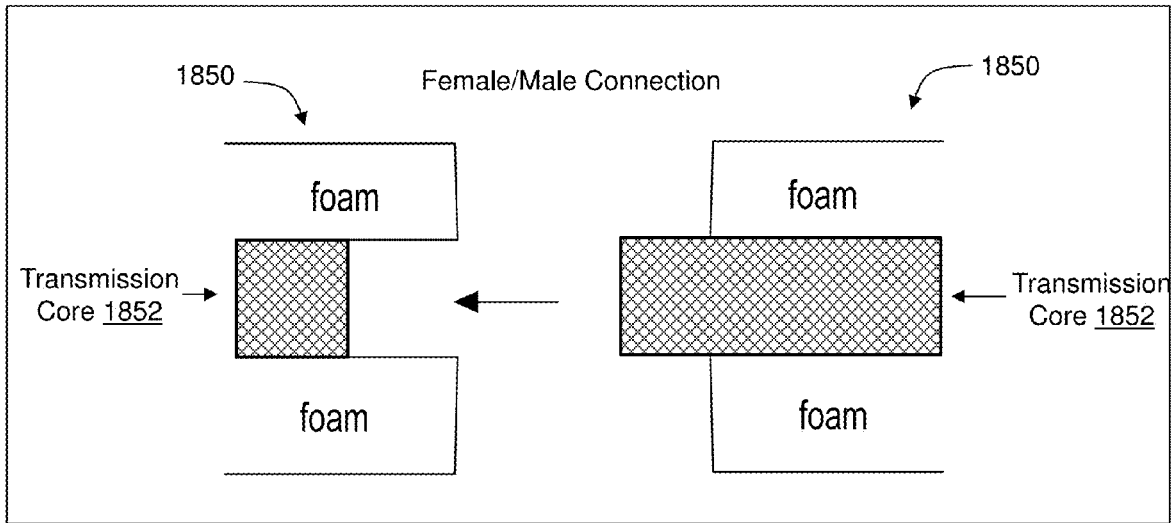


FIG. 18I

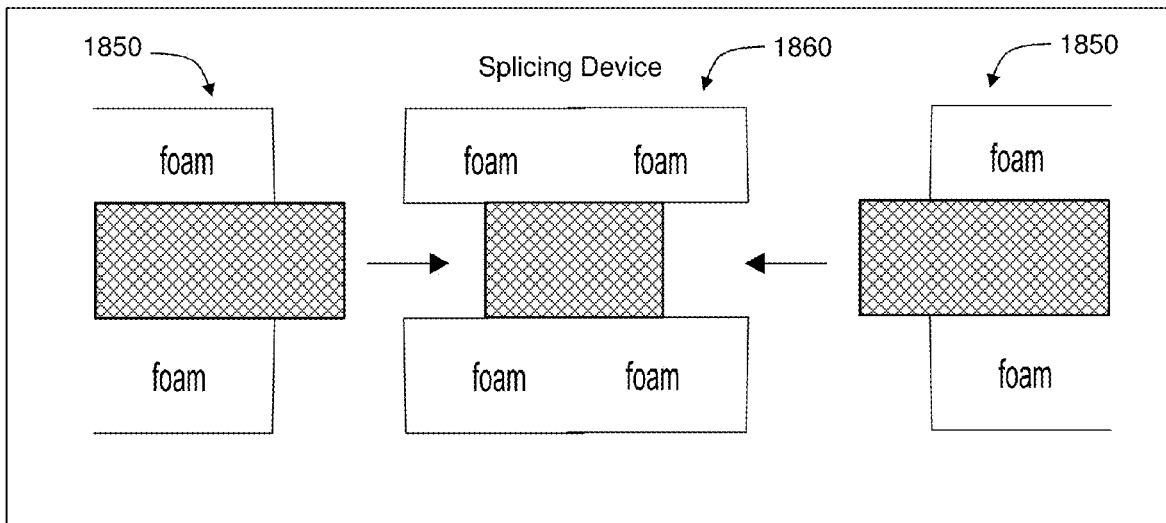


FIG. 18J

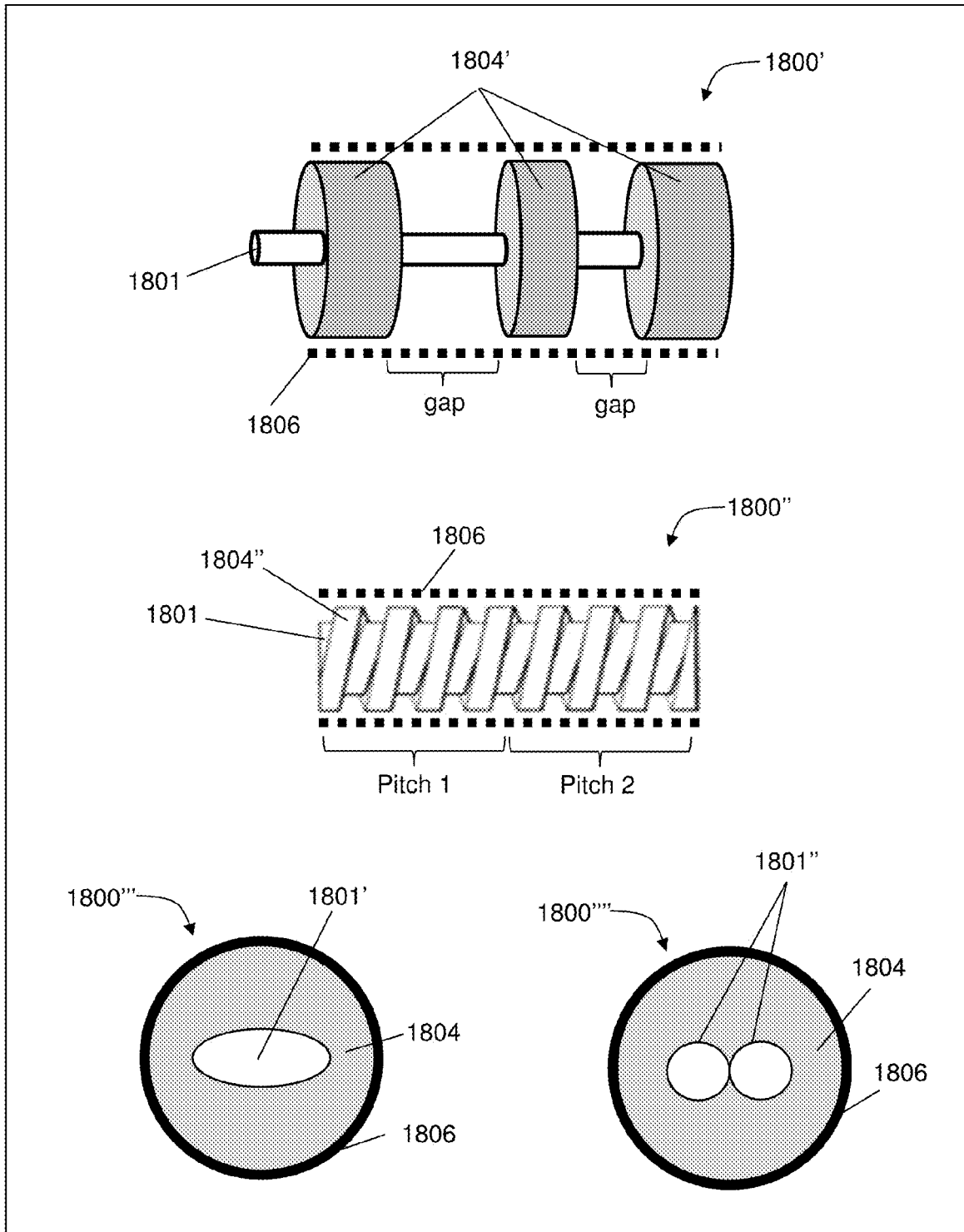


FIG. 18K

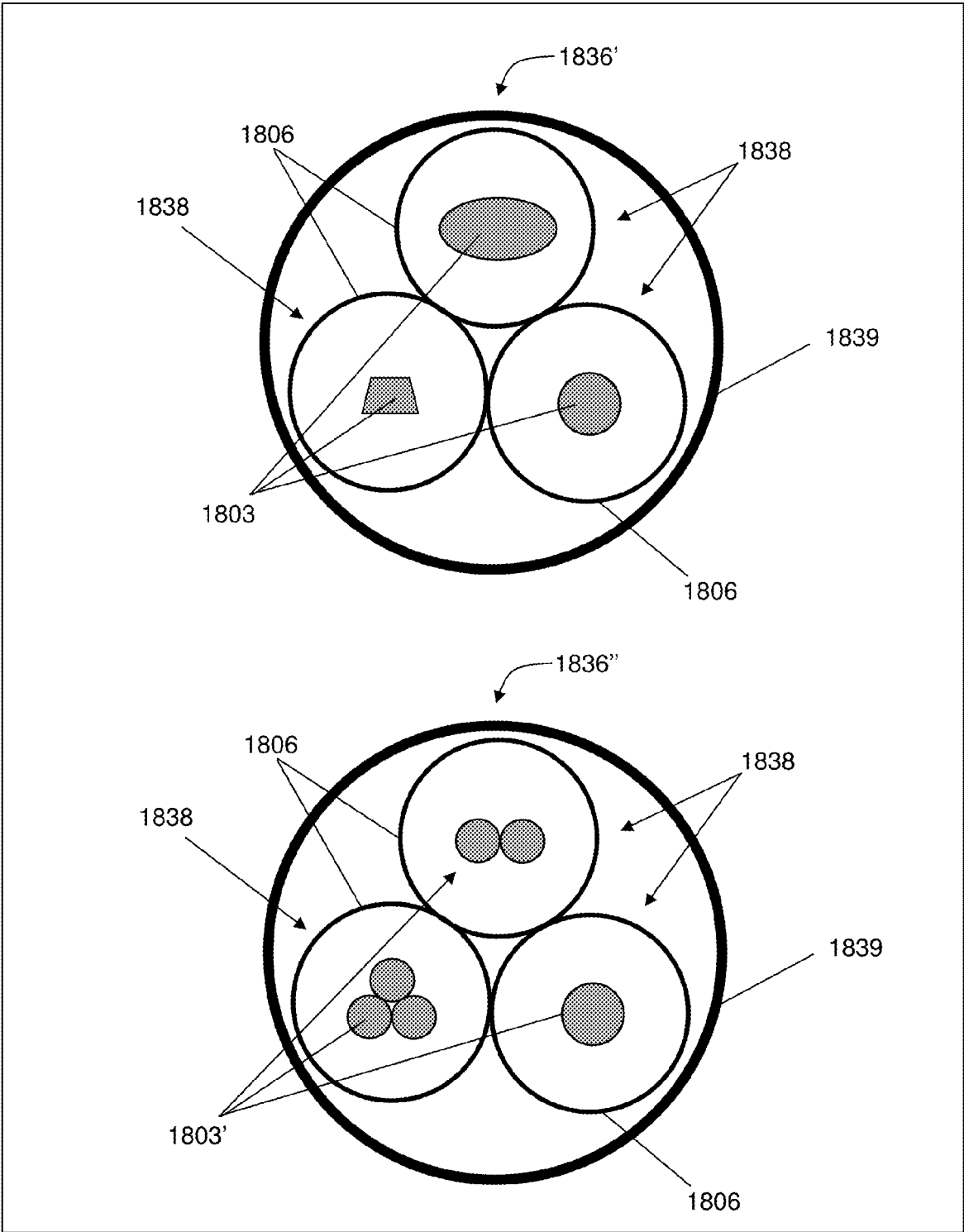


FIG. 18L

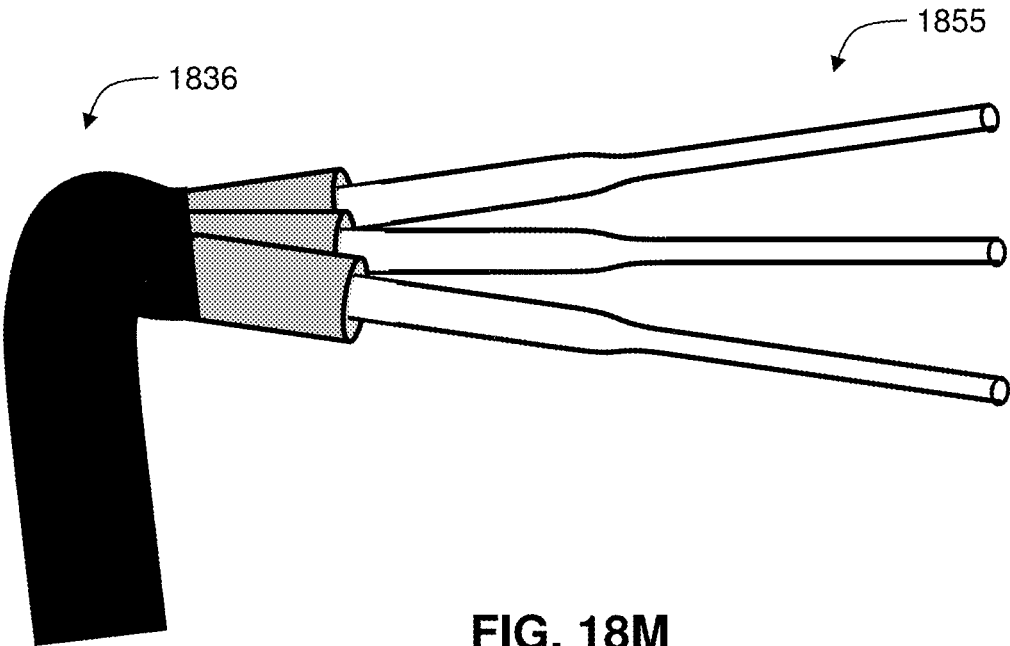


FIG. 18M

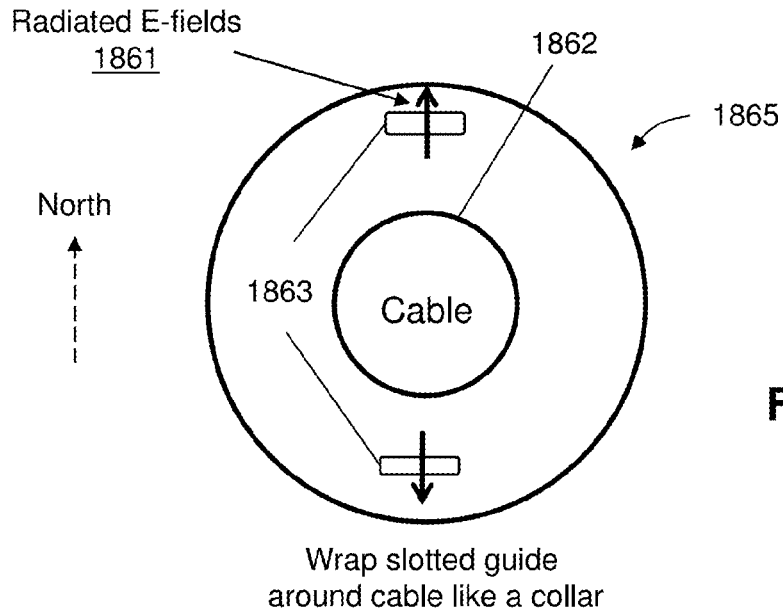


FIG. 18N

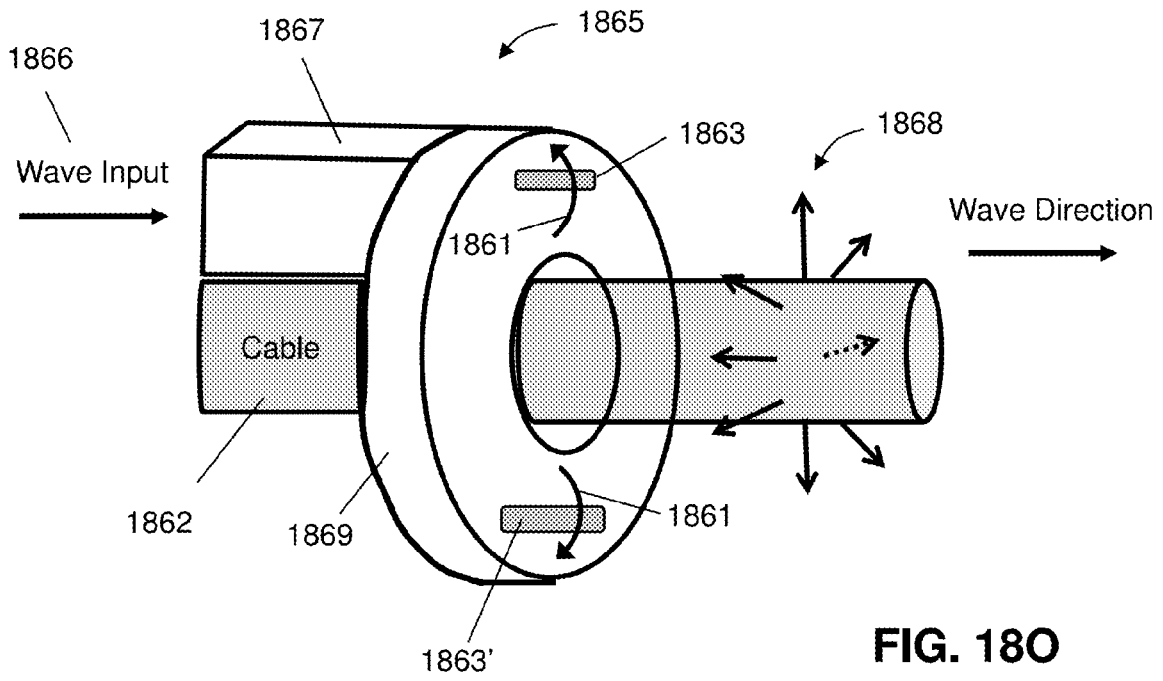


FIG. 18O

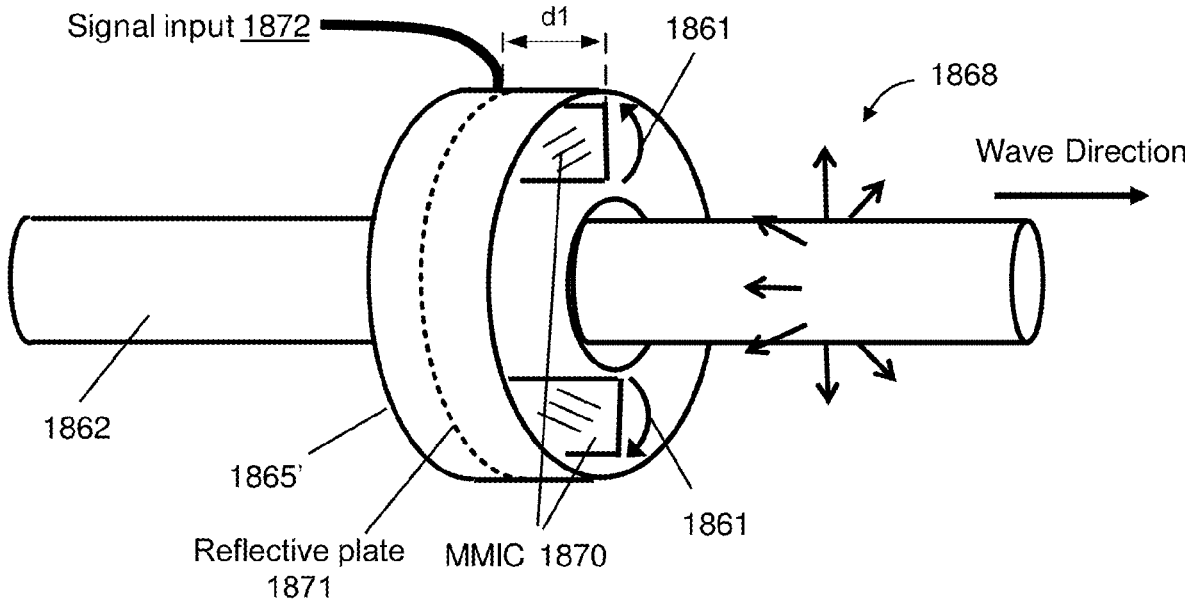


FIG. 18P

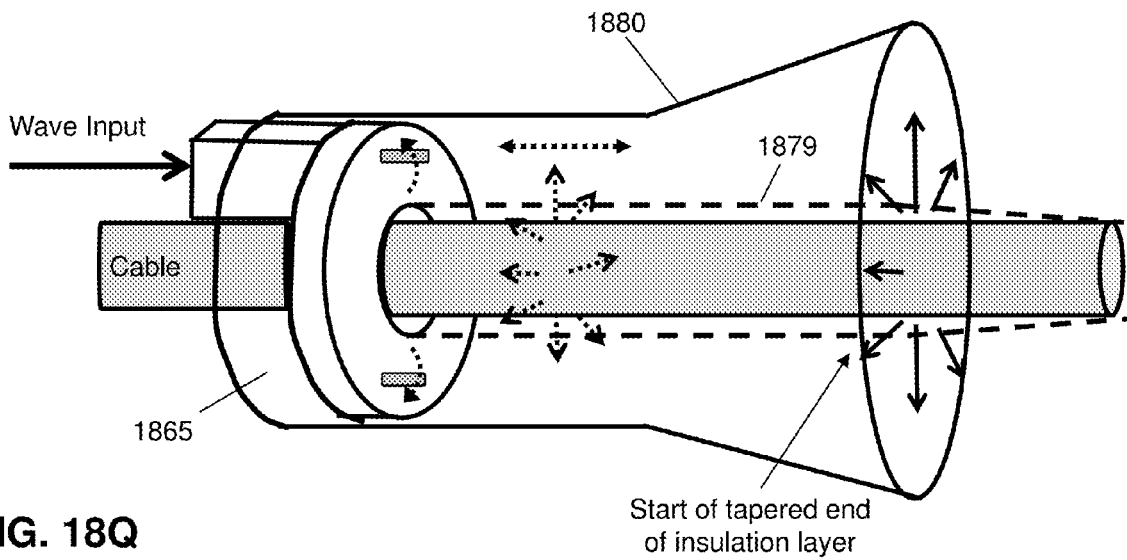


FIG. 18Q

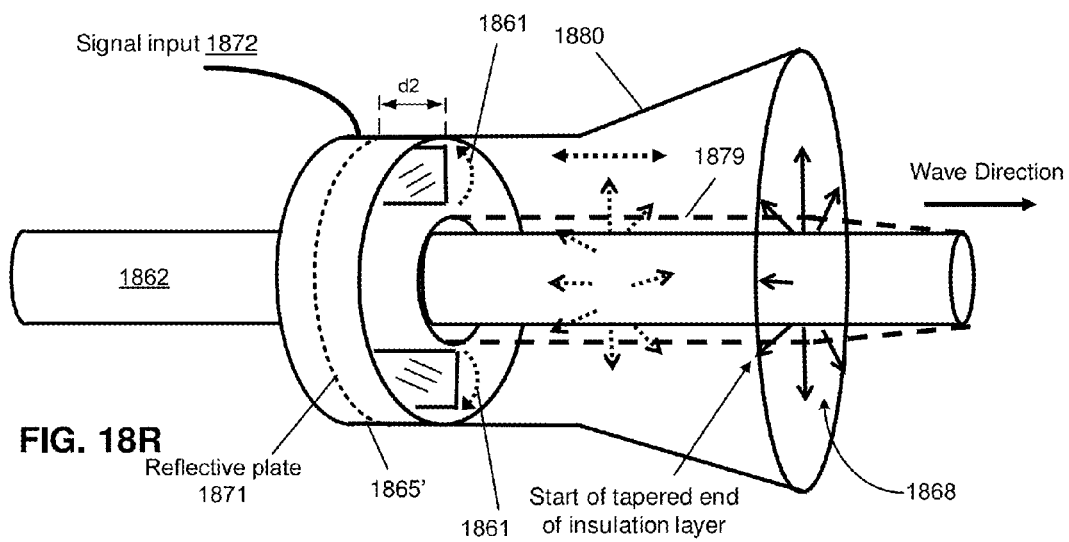
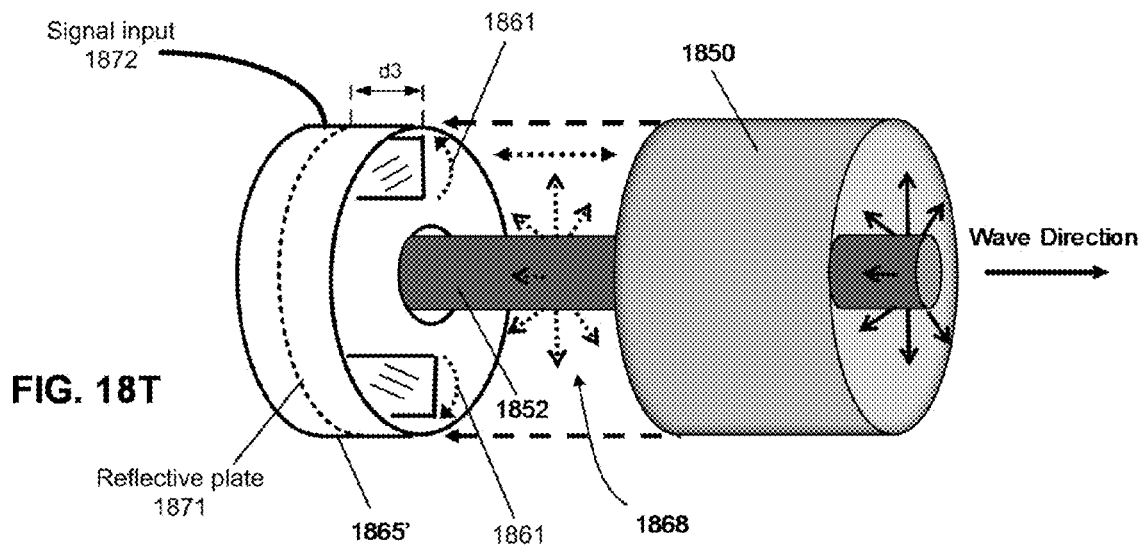
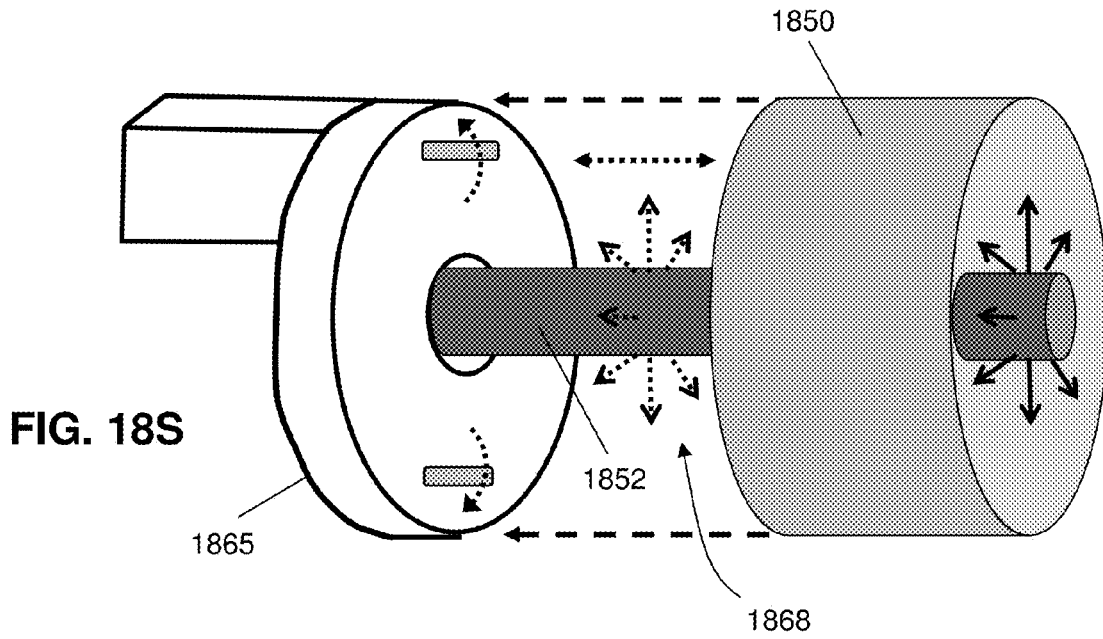
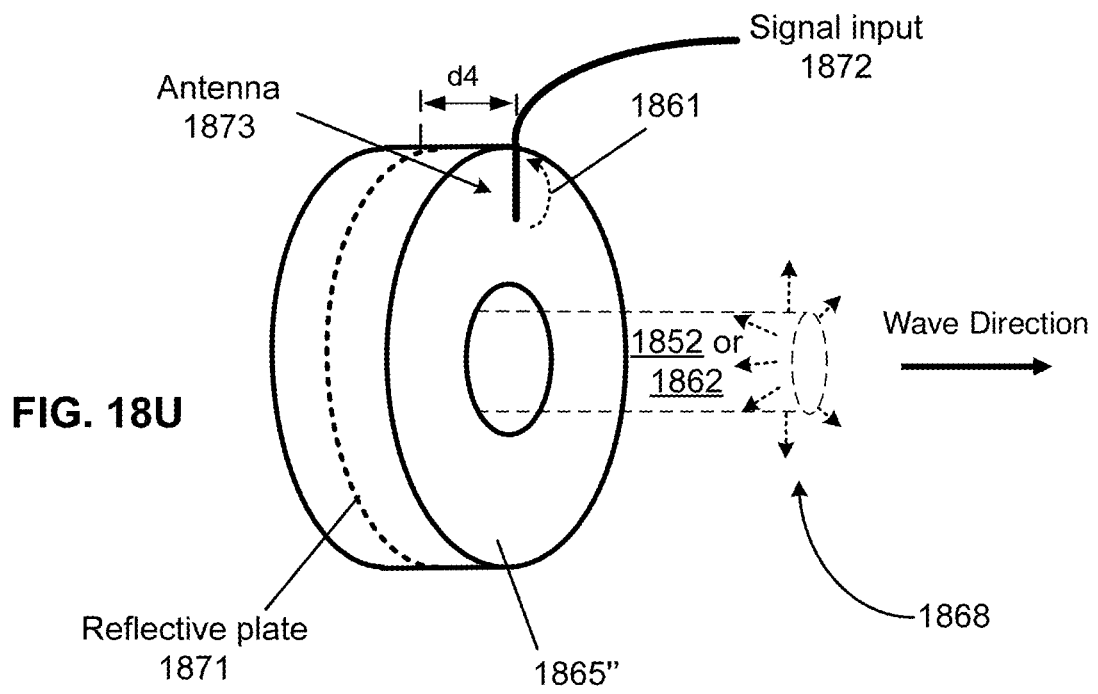


FIG. 18R





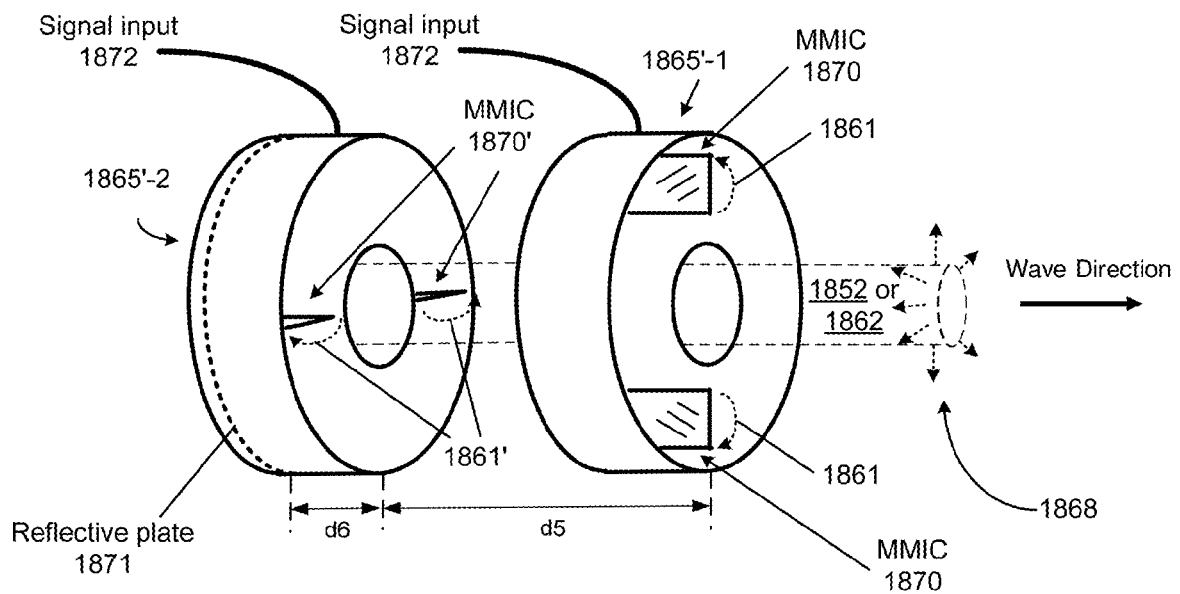


FIG. 18V

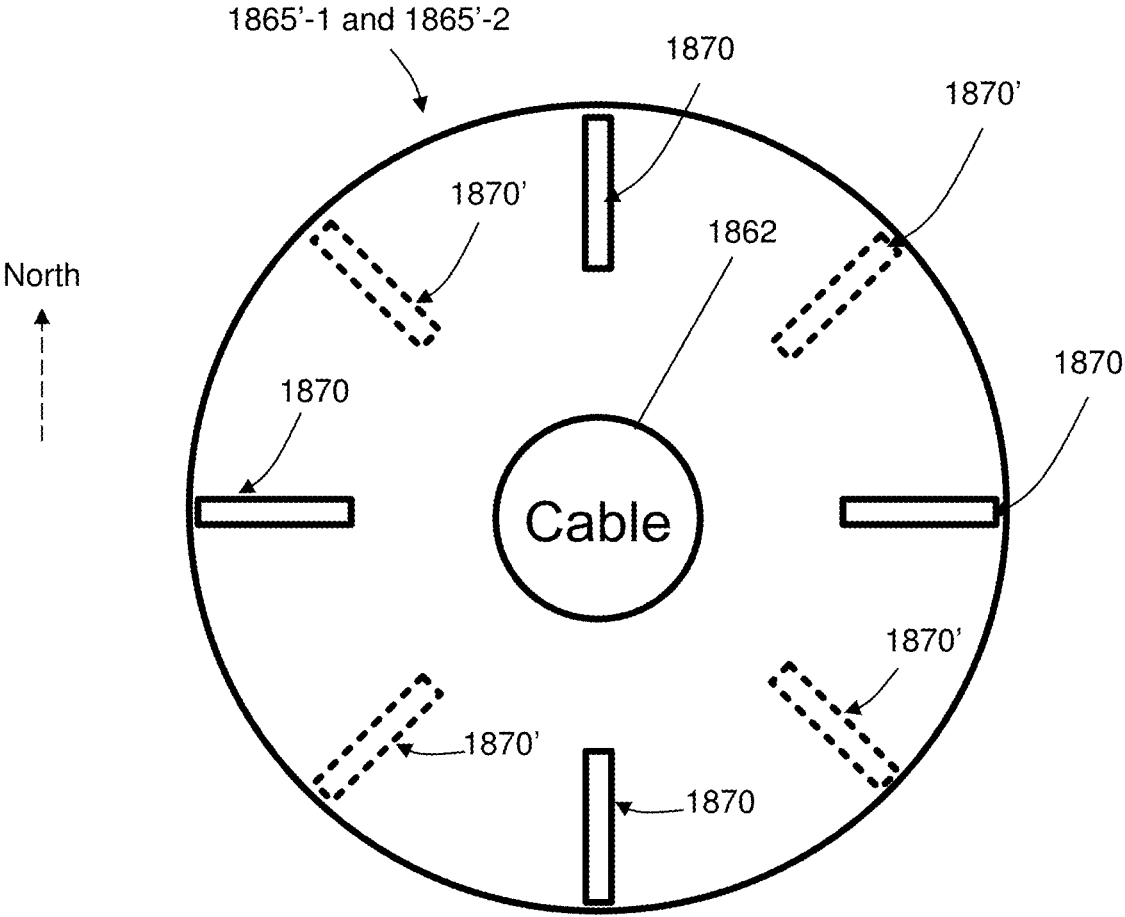


FIG. 18W

Dielectric Horn Antenna

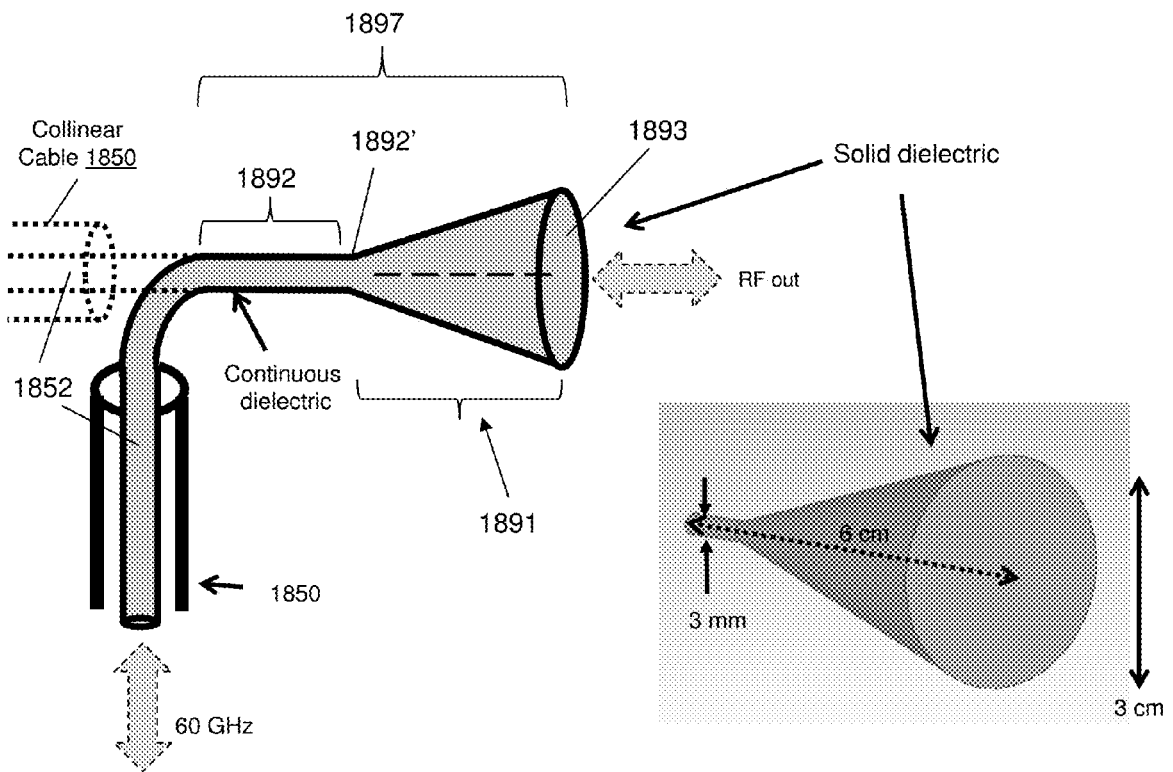
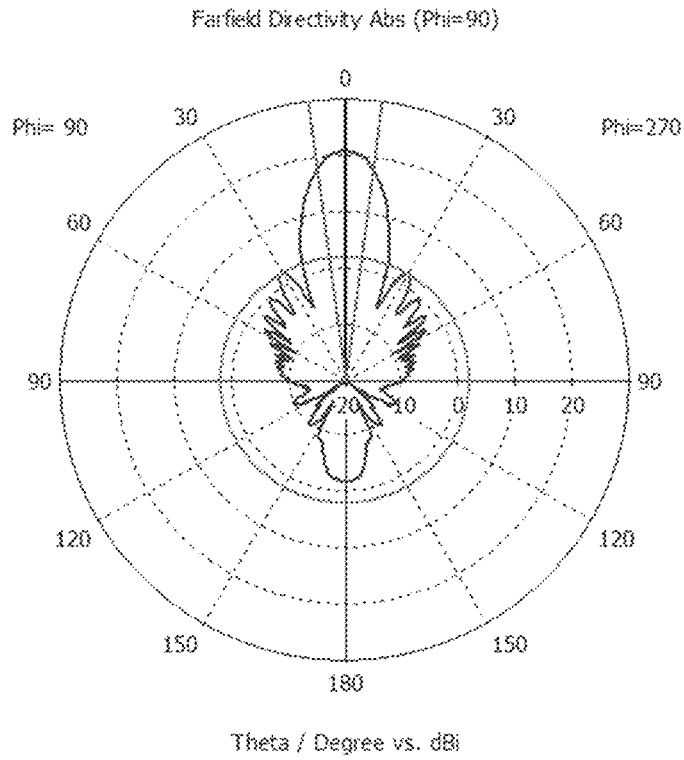
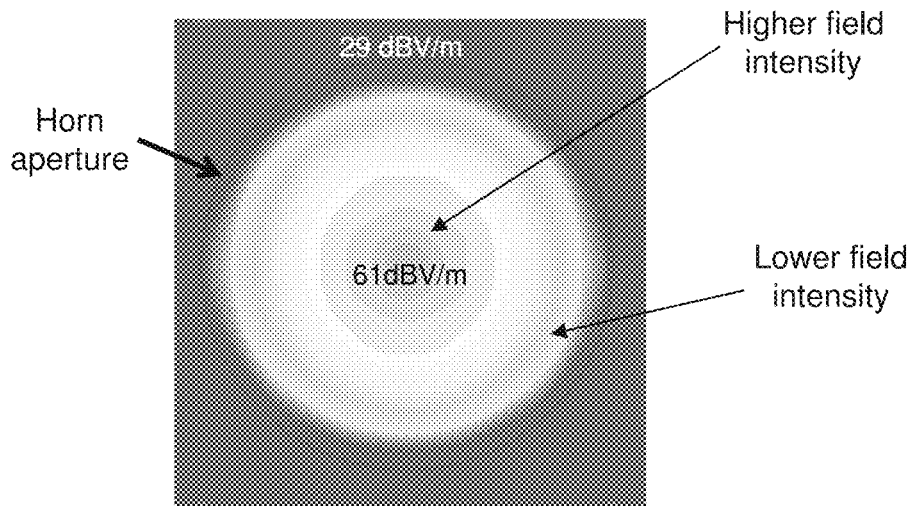


FIG. 18X



Antenna Gain Pattern



E-field Intensity Pattern

FIG. 18Y

Antenna Array Using Pyramidal Horns

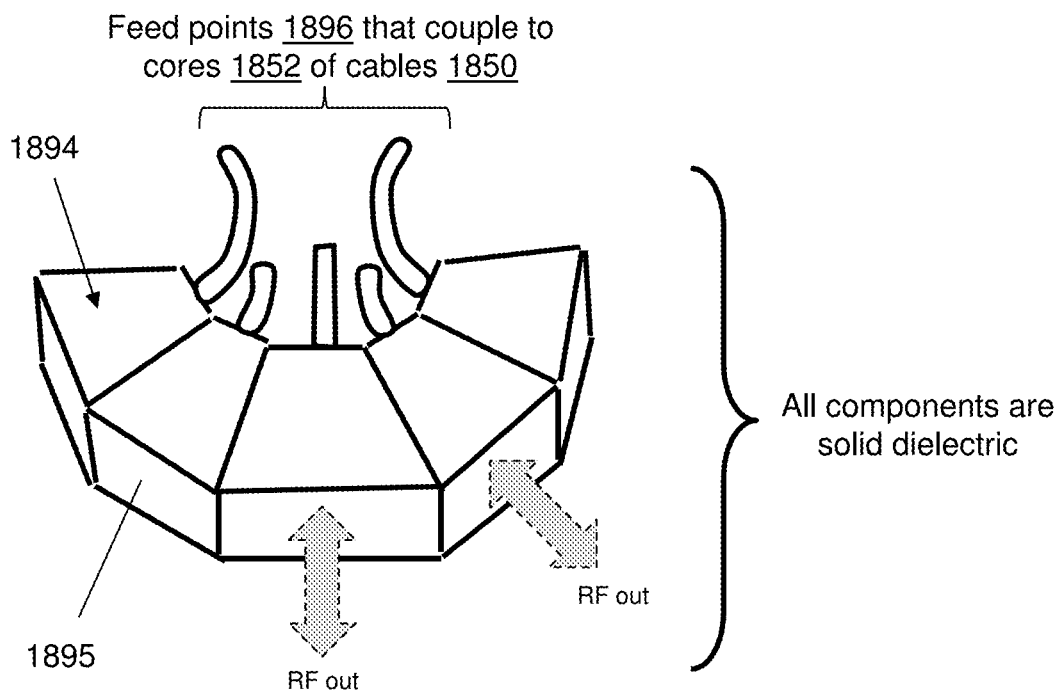


FIG. 18Z

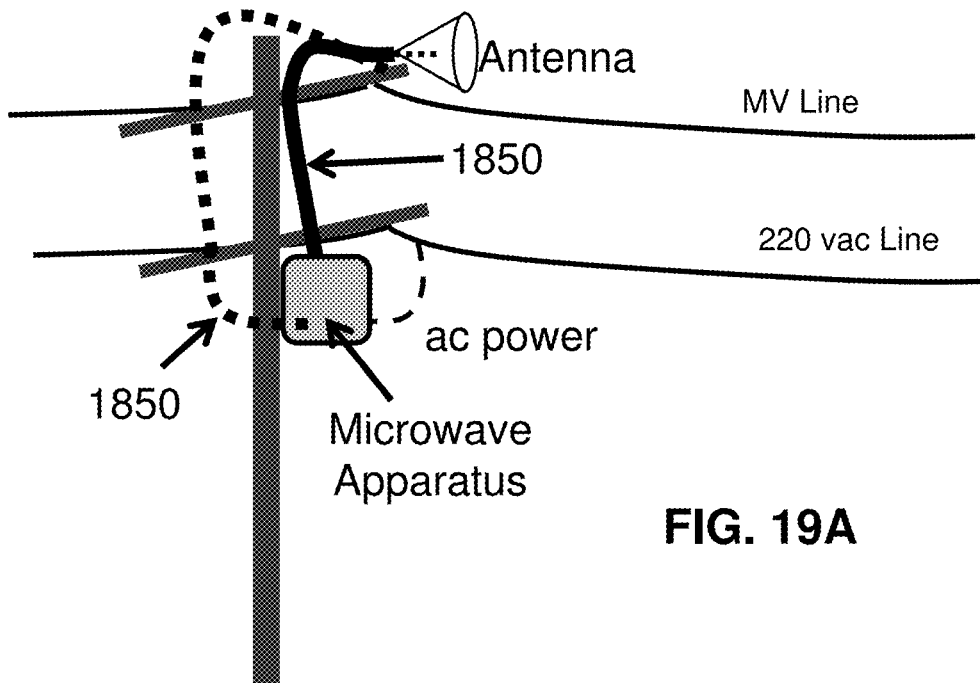


FIG. 19A

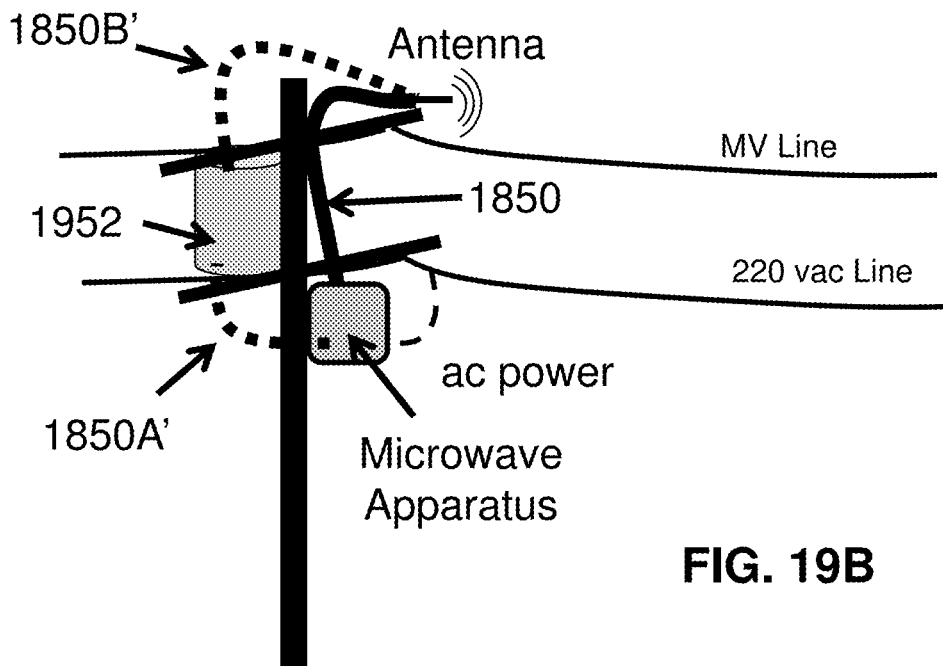
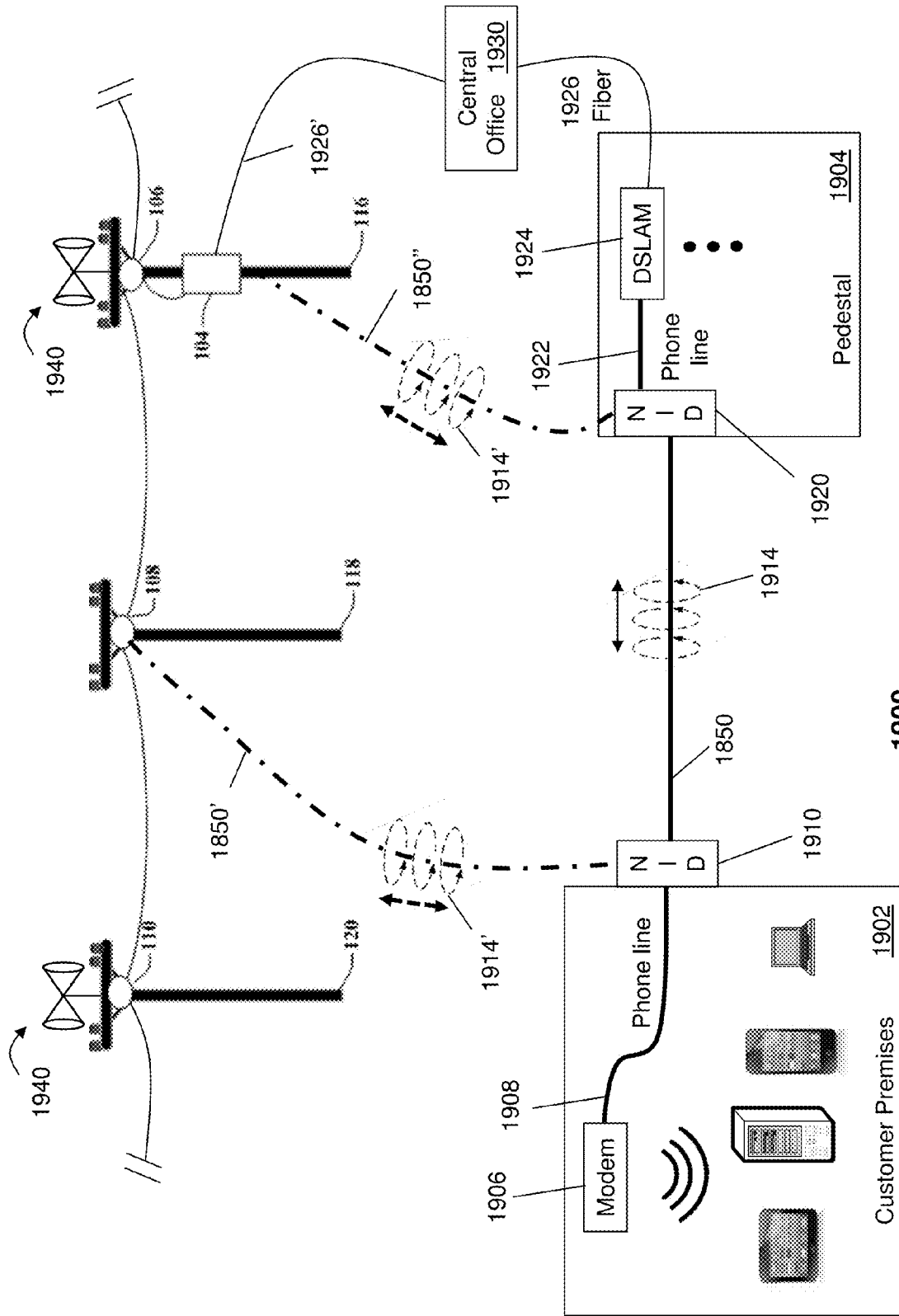
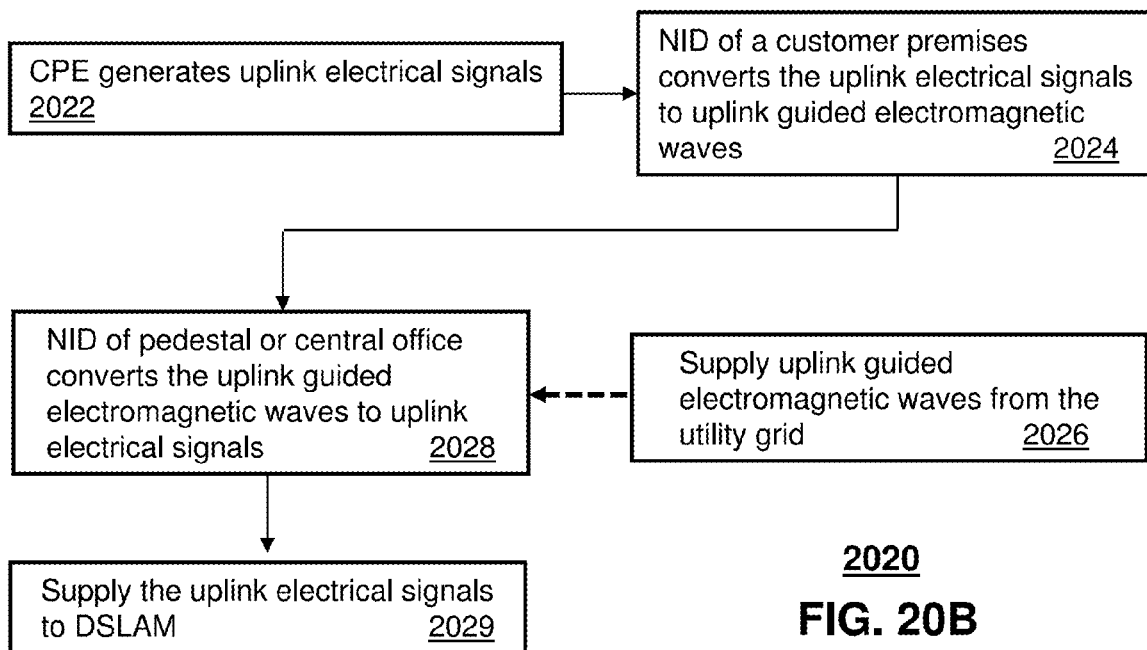
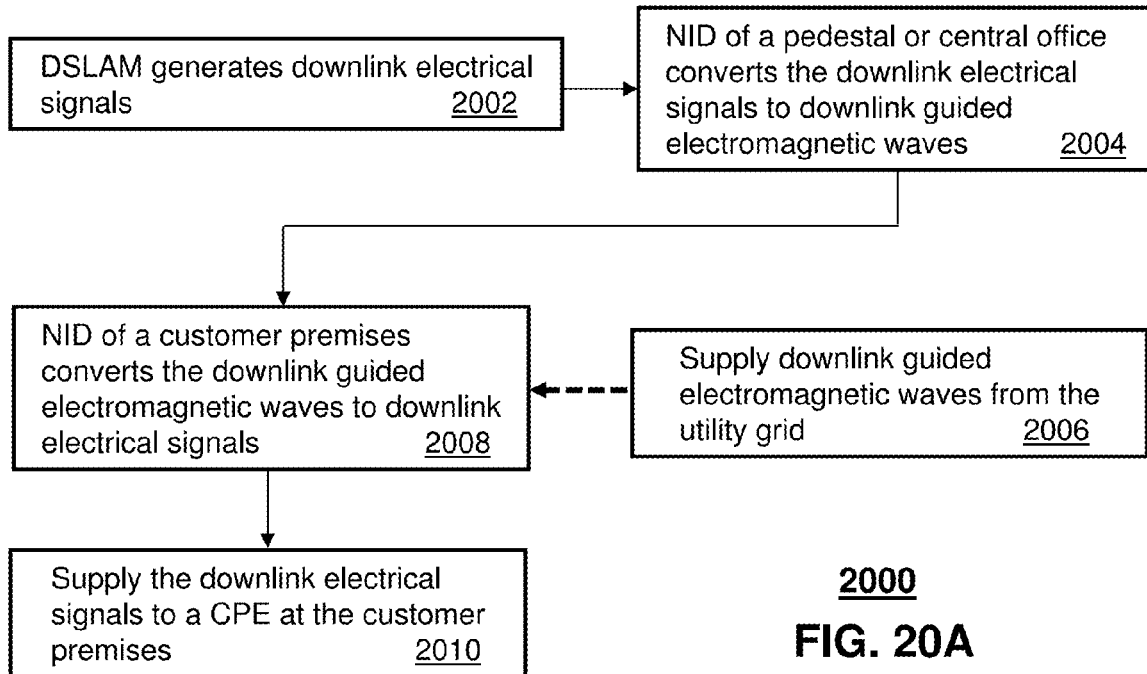


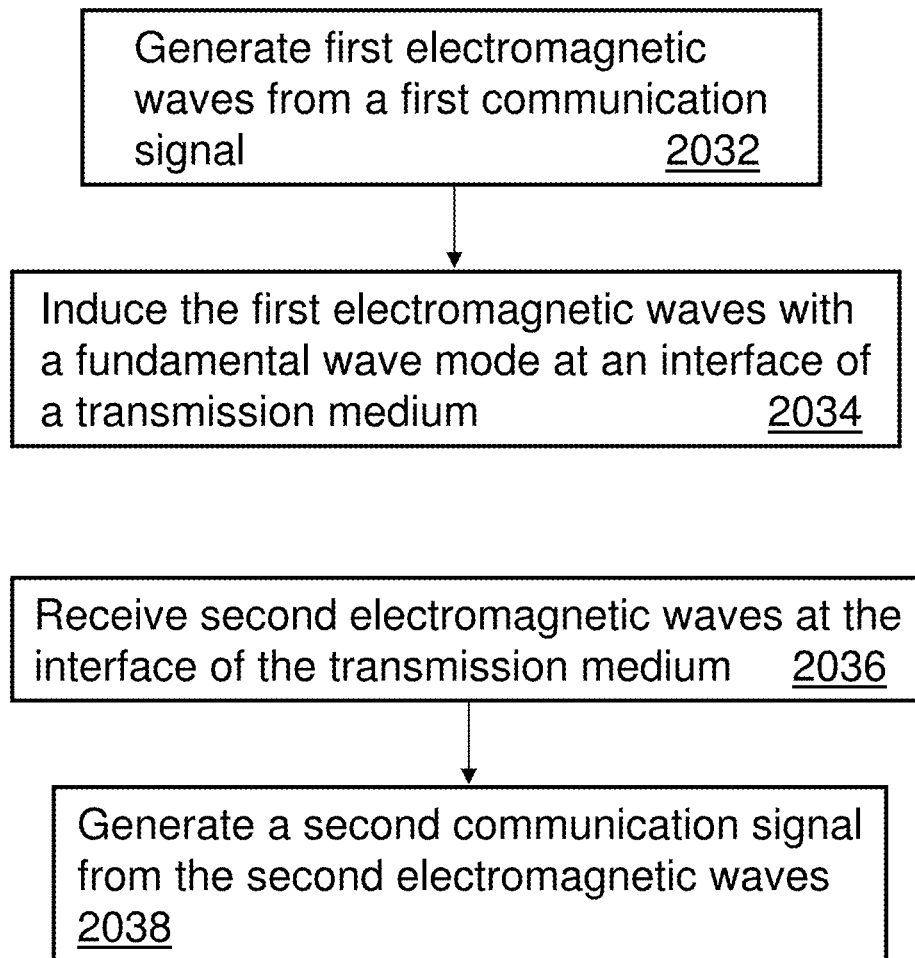
FIG. 19B



1900

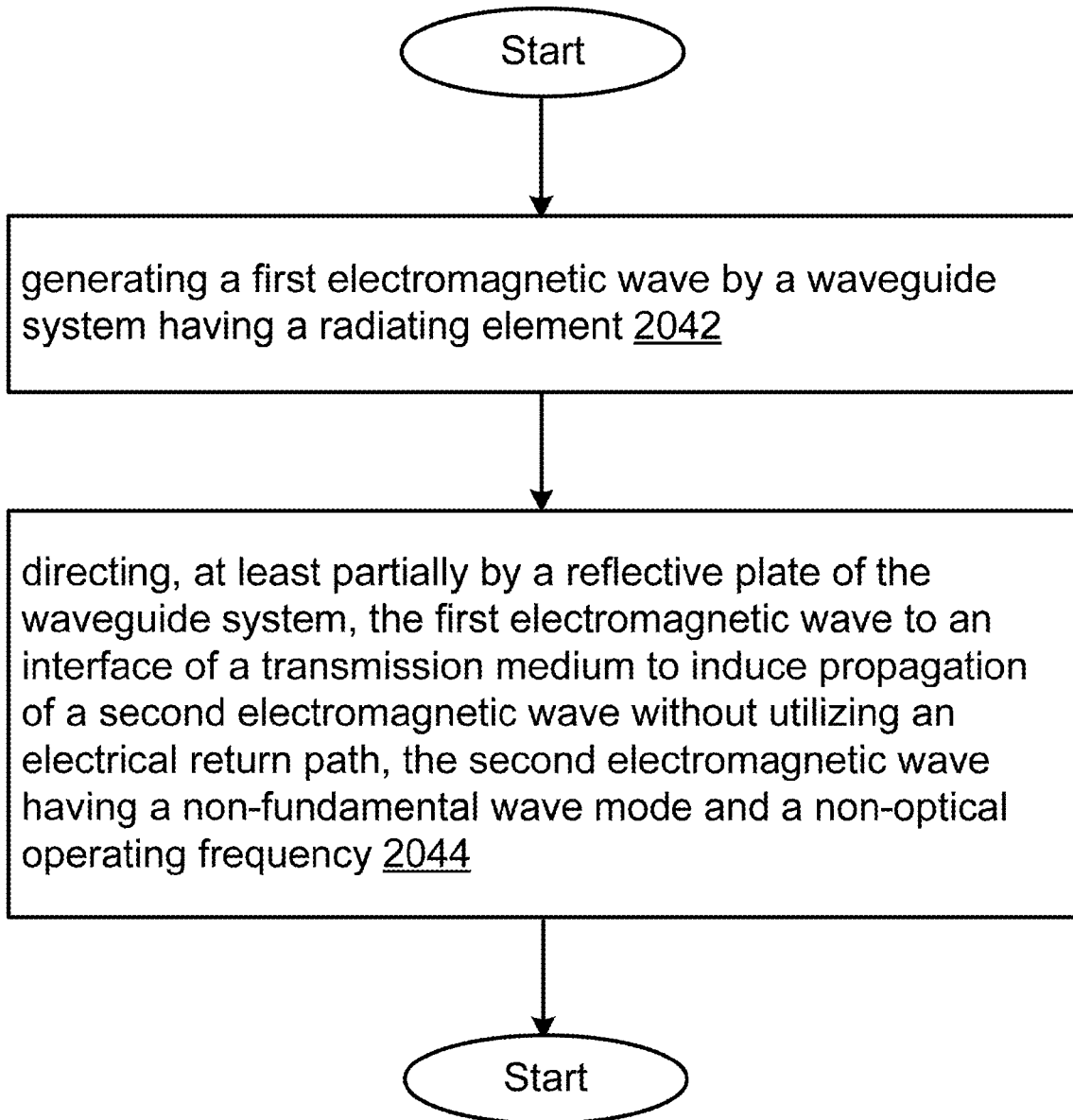
FIG. 19C





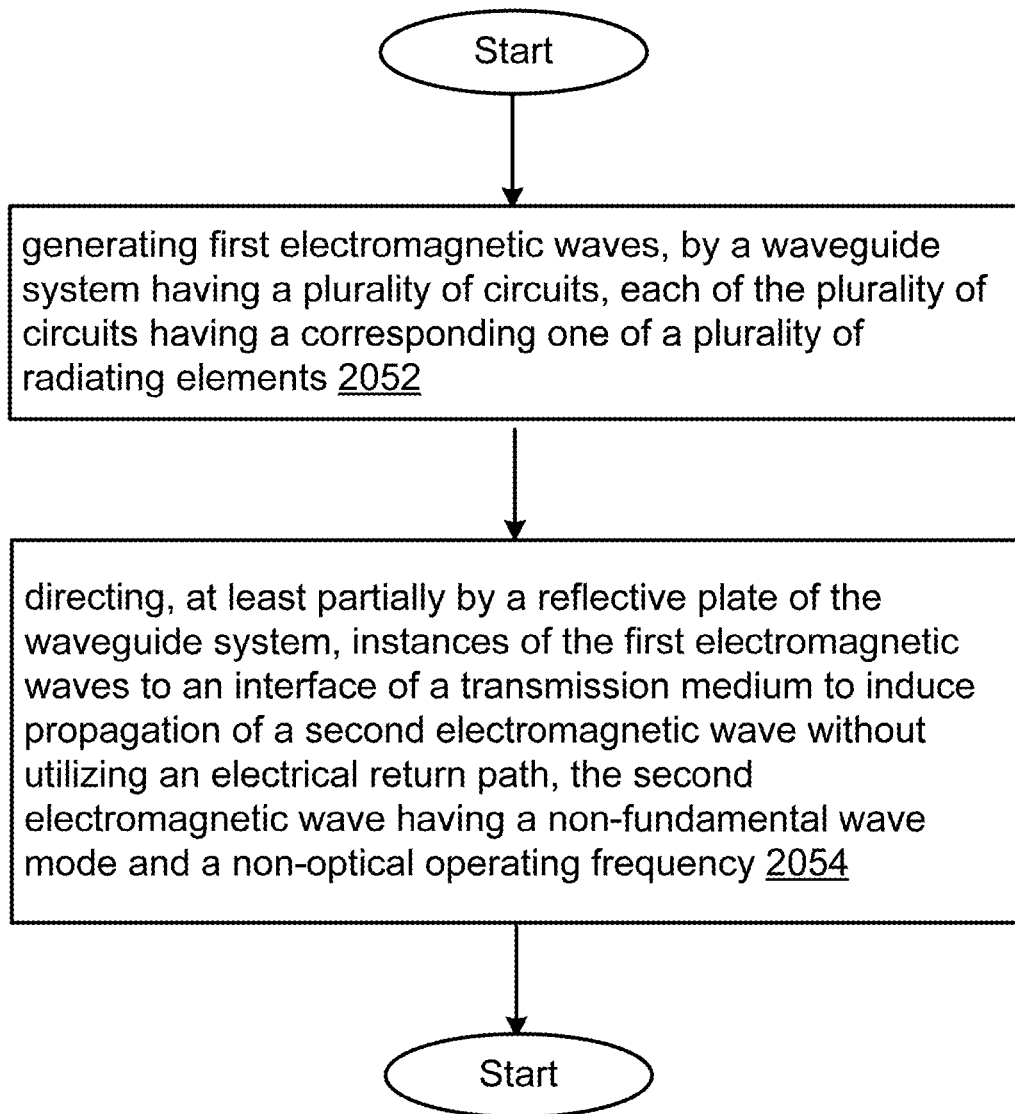
2030

FIG. 20C



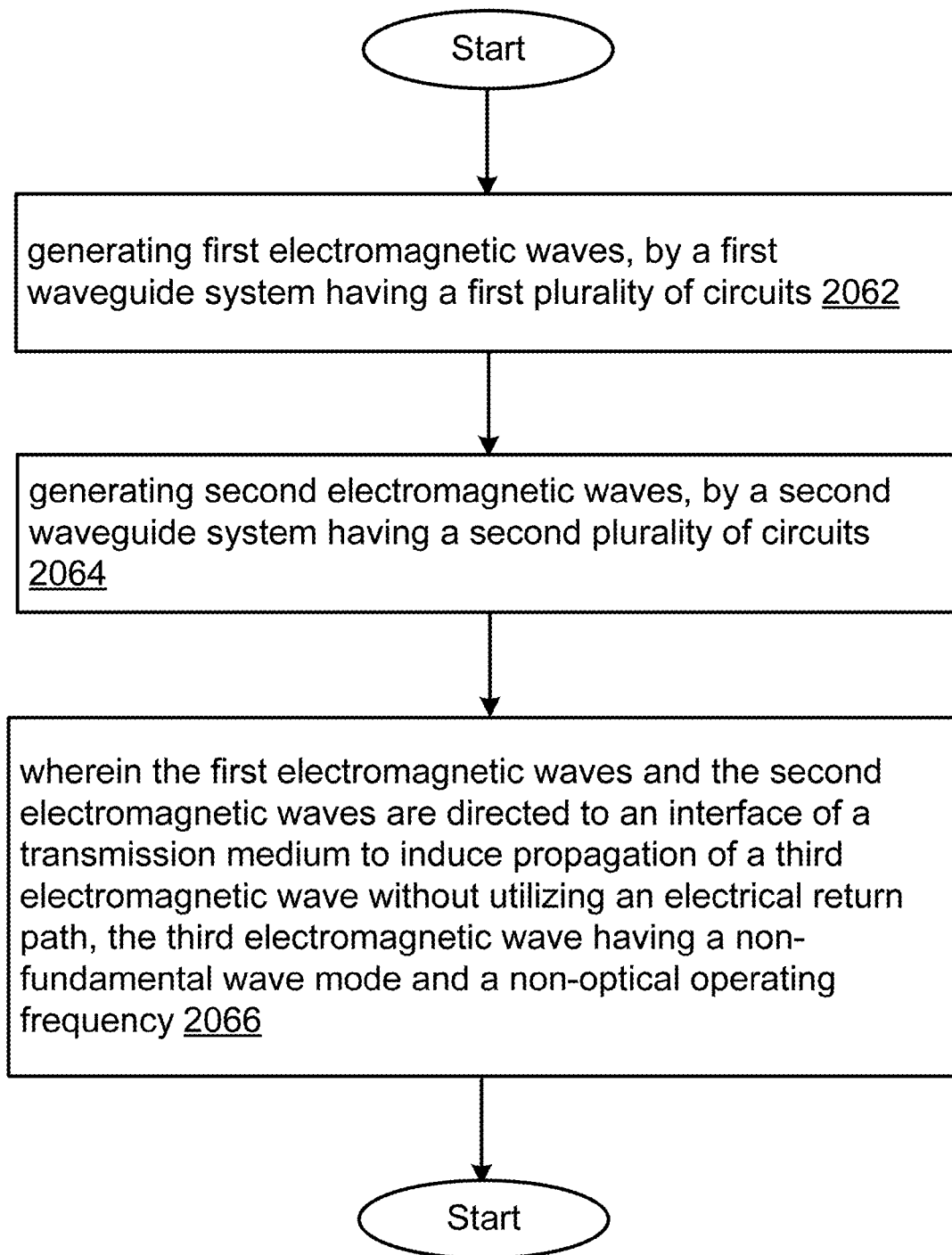
2040

FIG. 20D



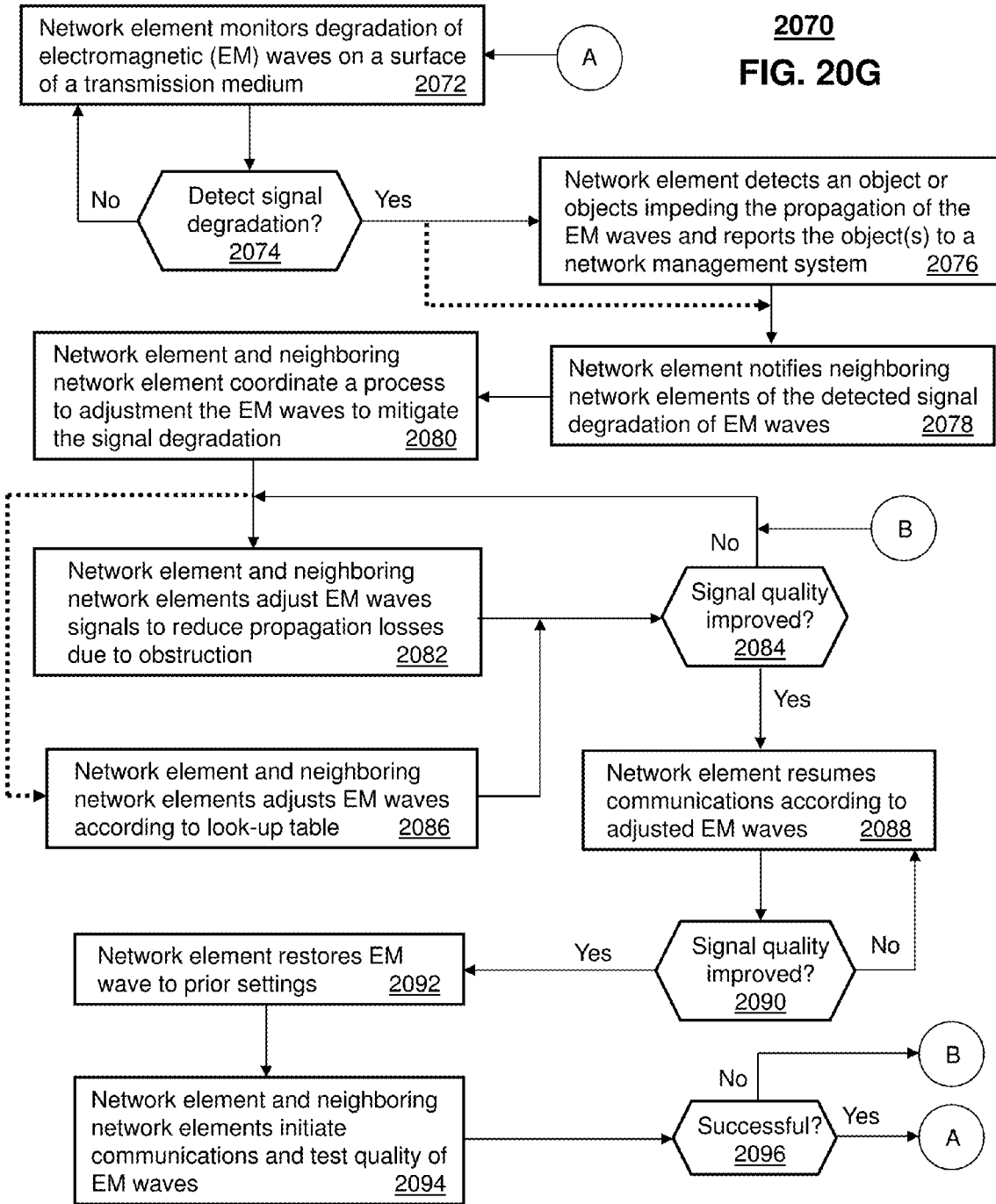
2050

FIG. 20E



2060

FIG. 20F



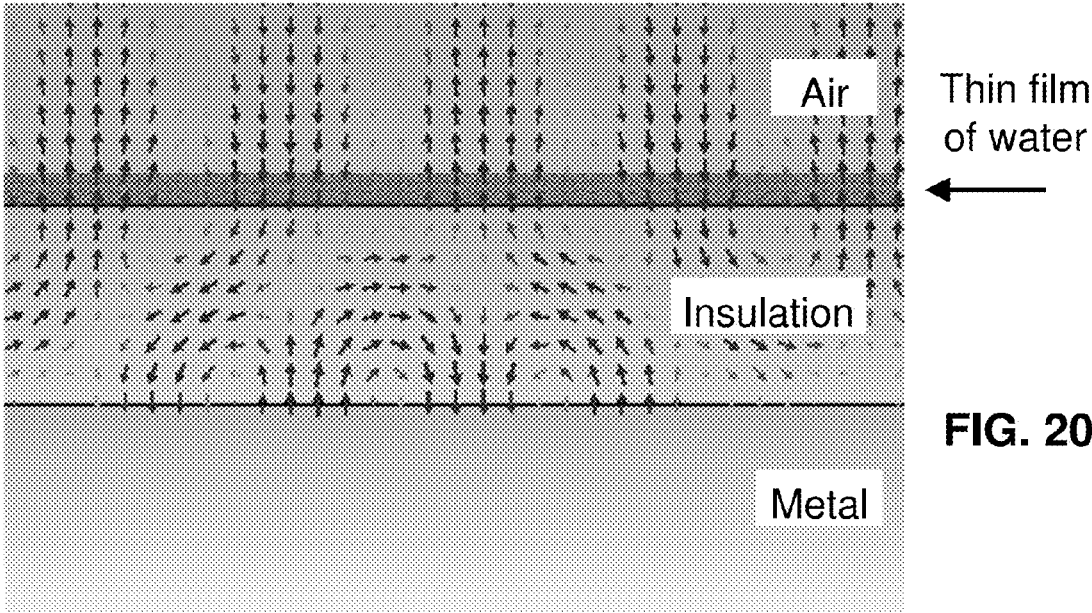


FIG. 20H

Longitudinal Section of Cable showing e-fields of waves that include a component of TM01 waves at 40 GHz

FIG. 20I

Plot shows strong e-fields in direction of propagation for TM₀₁ mode @ 45 GHz

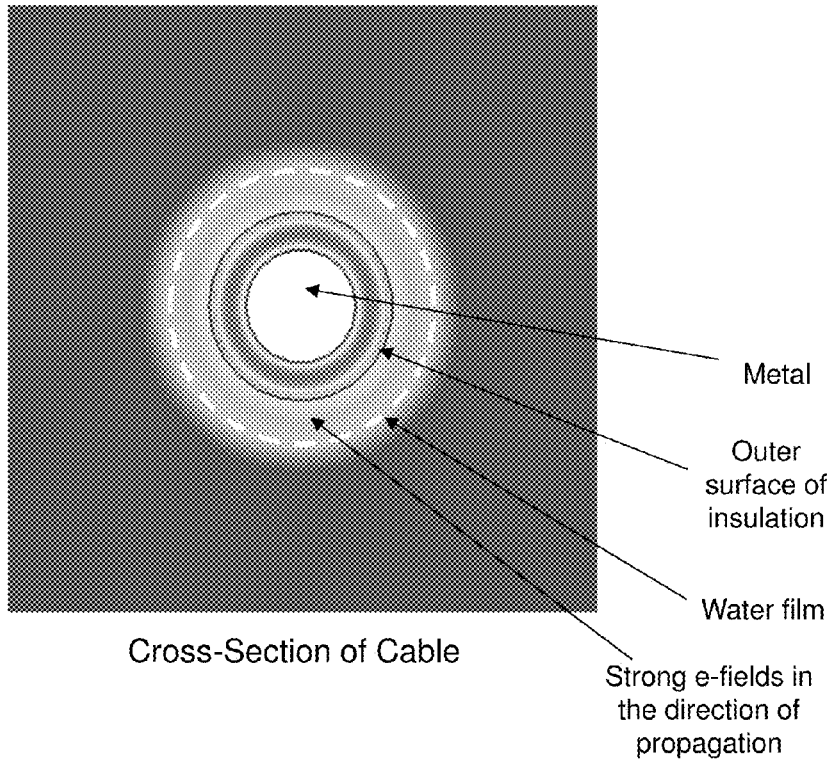


FIG. 20J

Plot shows weak e-fields in direction of propagation for TM₀₁ mode @ 40 GHz

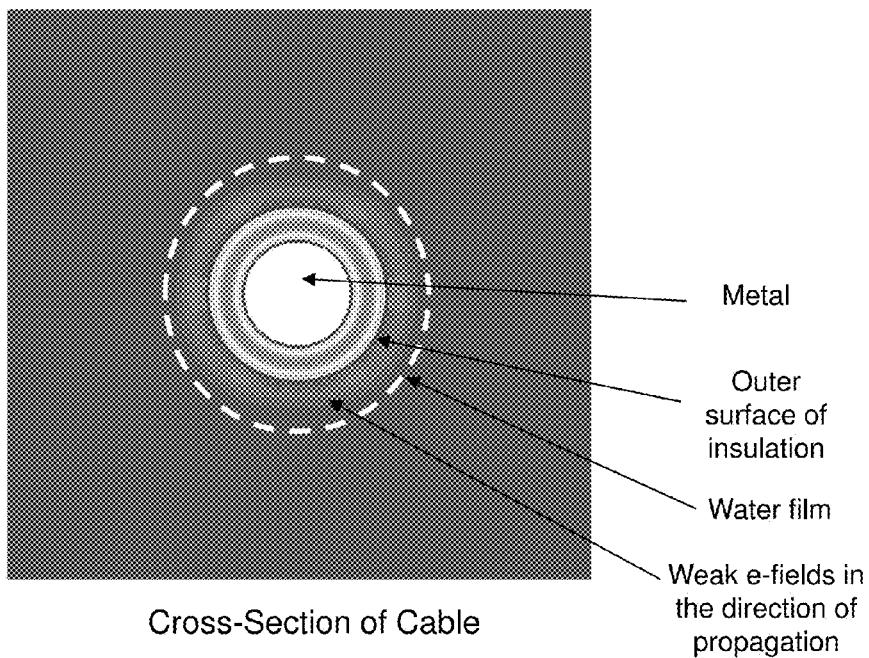
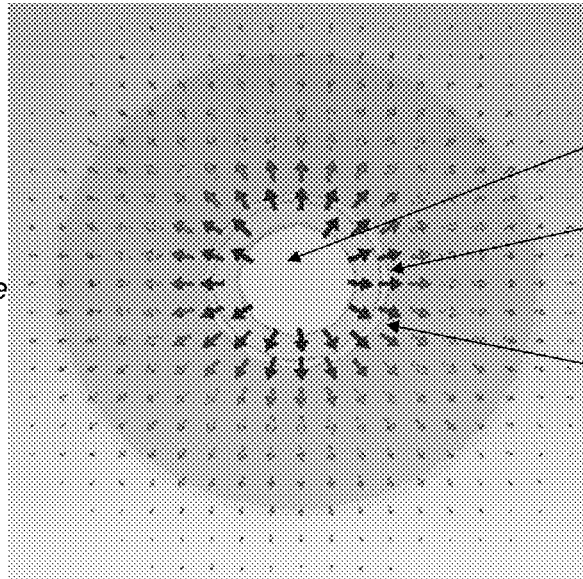
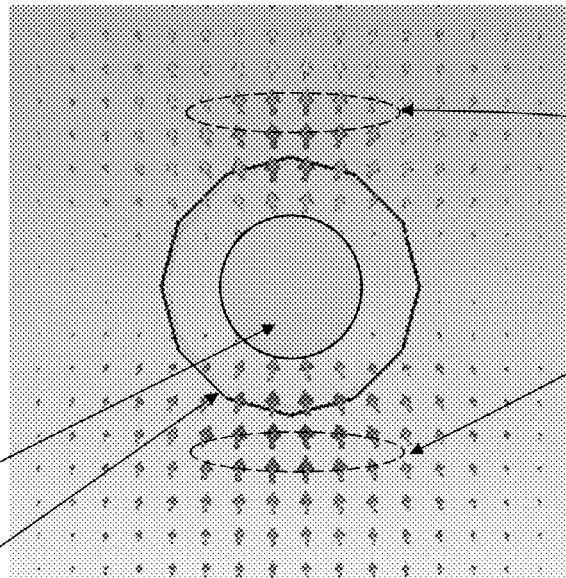


FIG. 20K
Goubau Wave Mode
(Small Mode Size)

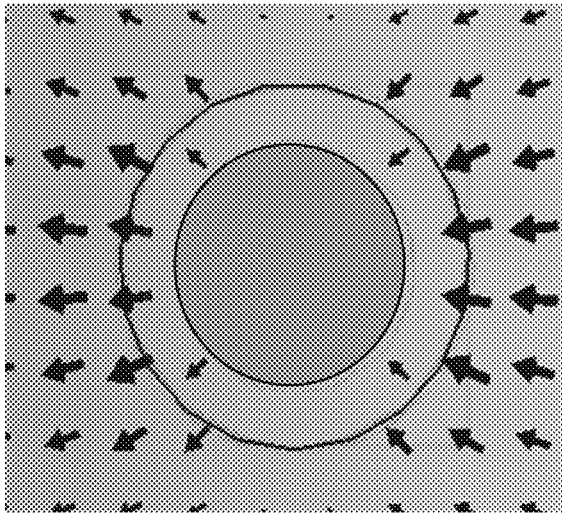


Metal
Outer surface of cable
Strong e-fields in tightly coupled to outer surface of cable

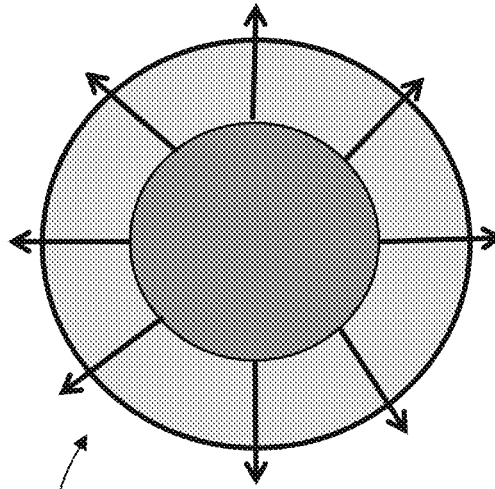
FIG. 20L
HE Wave Mode
(Large Mode Size)



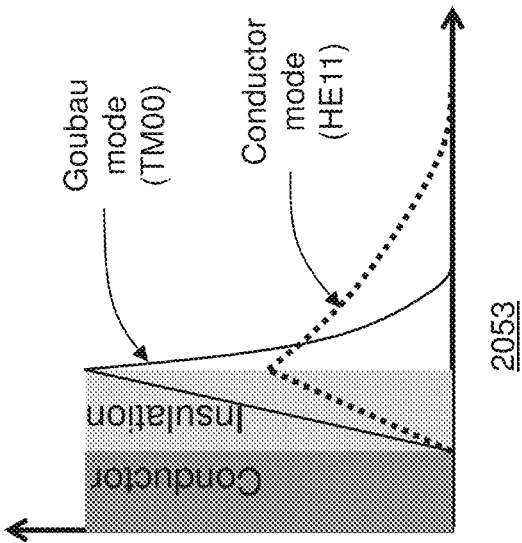
Metal
Outer surface of cable
Strong e-fields in tightly coupled to outer surface of cable



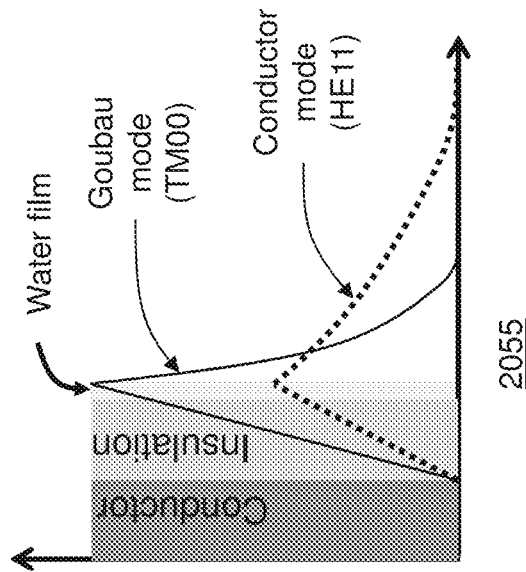
Hybrid mode (HE11)
2057



Goubau mode (TM00)
2059



2053



2055

2051

FIG. 20M

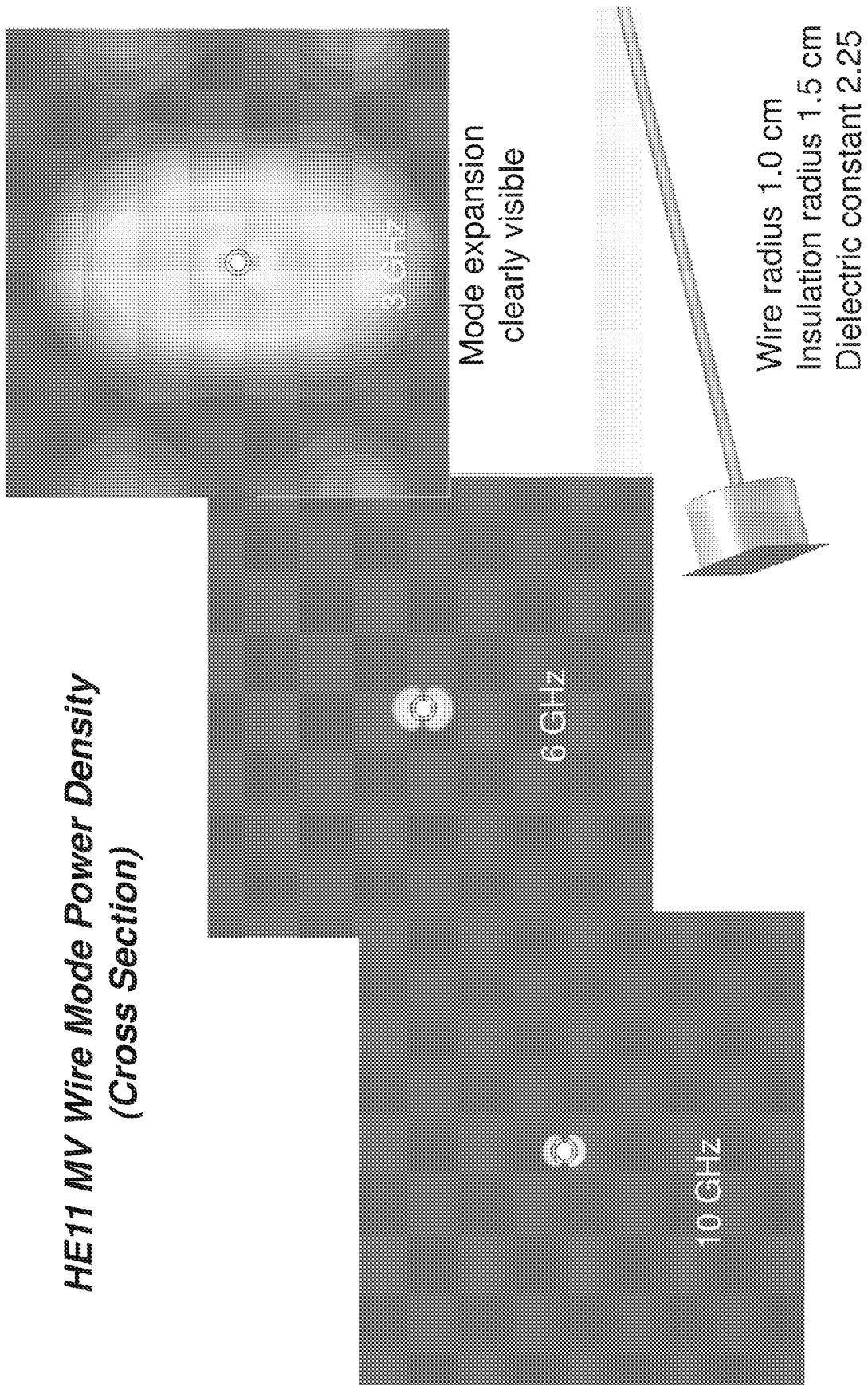


FIG. 20N

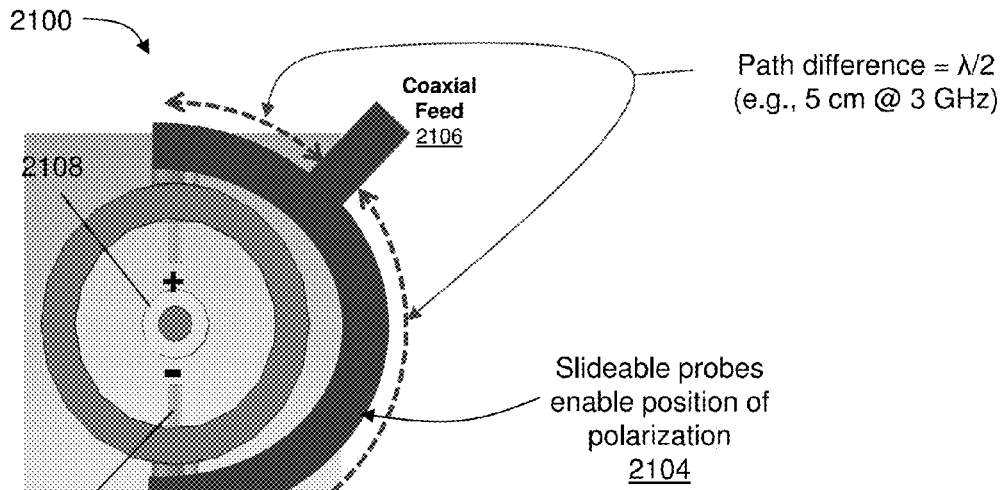


FIG. 21A

HE11 Mode Launcher

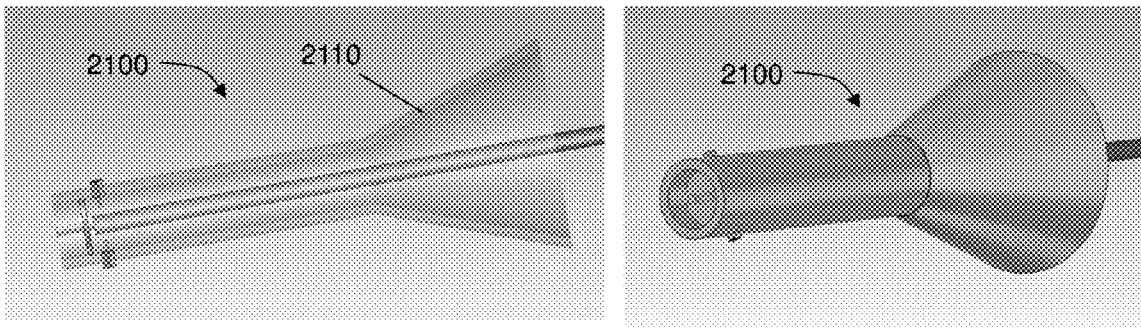
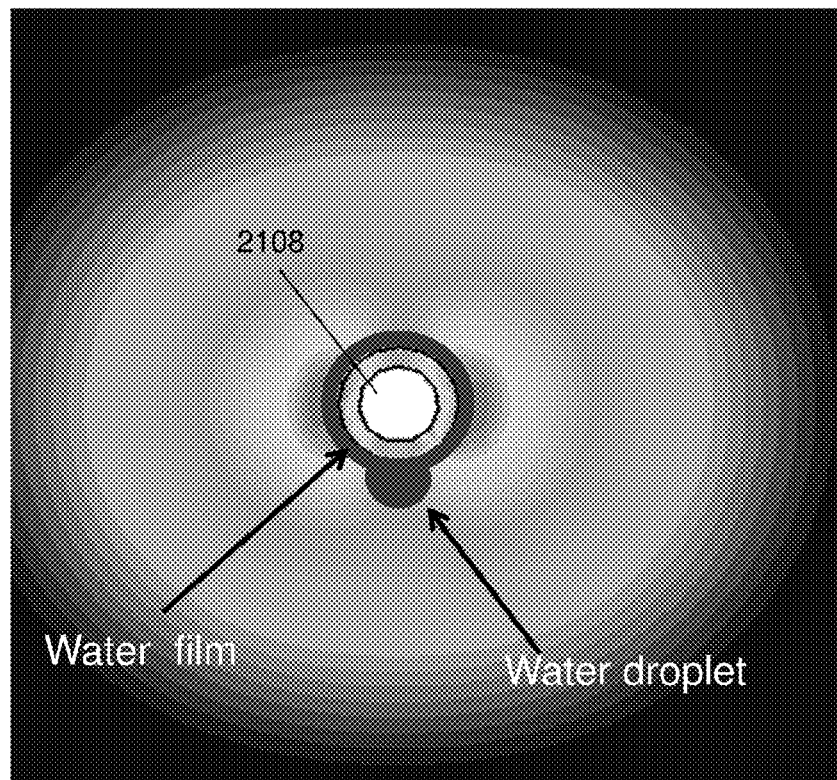


FIG. 21B

HE11 Mode Launcher

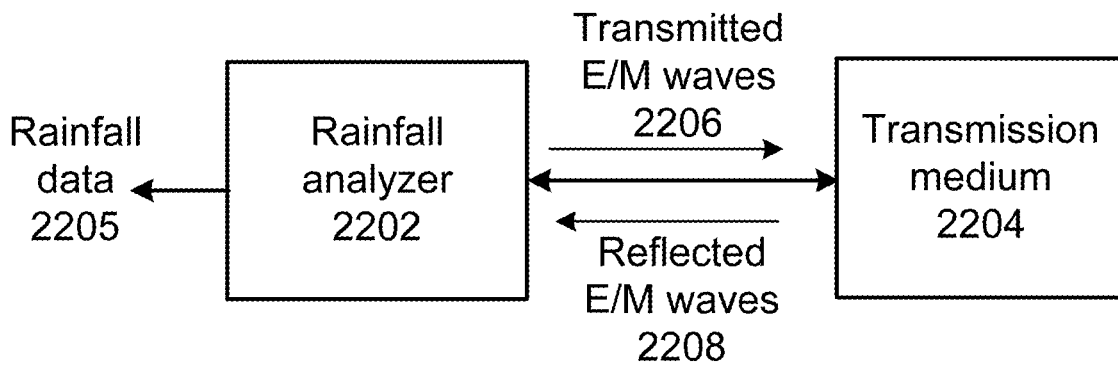
Obstruction Mitigation via HE11 Mode



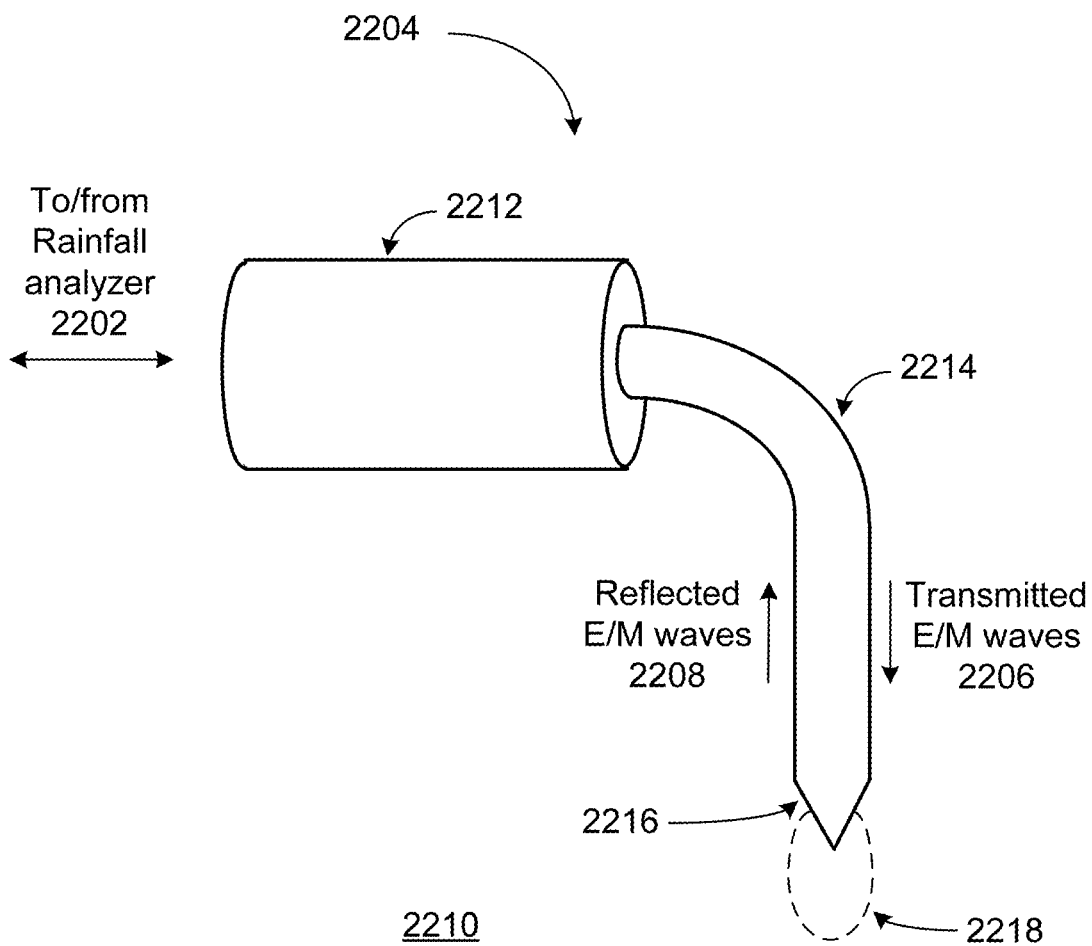
Horizontally polarized HE11 Mode

- Water film occupies small fraction of mode
- Water droplet is in least-intense area of mode
- Much lower propagation loss than Goubau mode

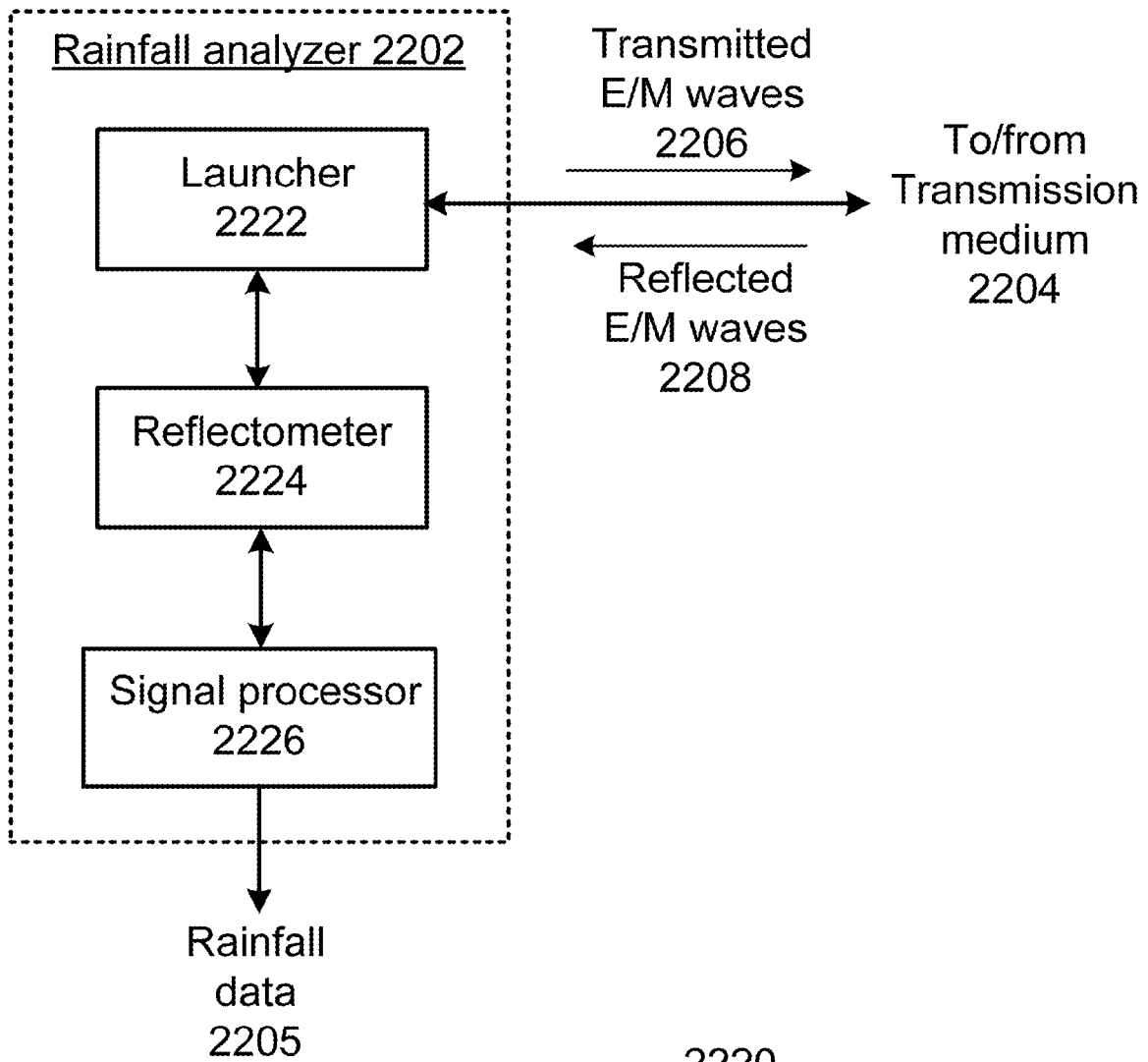
FIG. 22A



2200
FIG. 22B

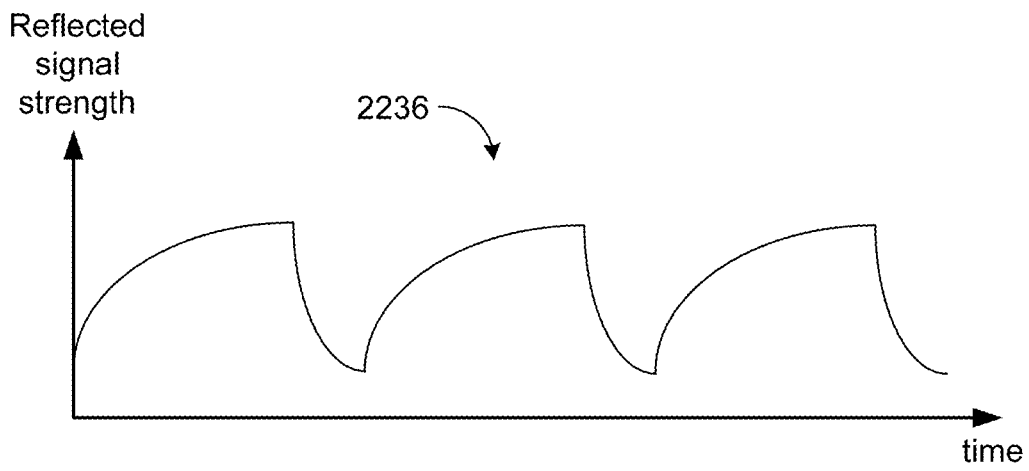
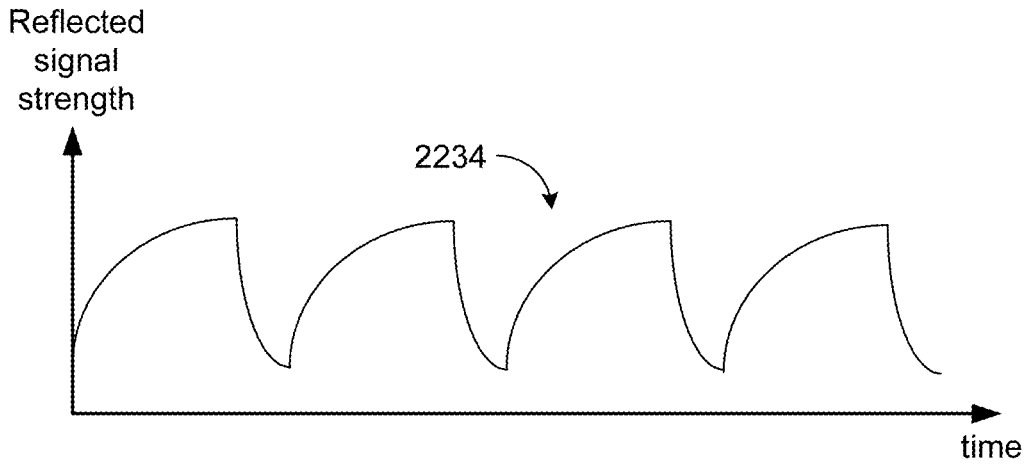
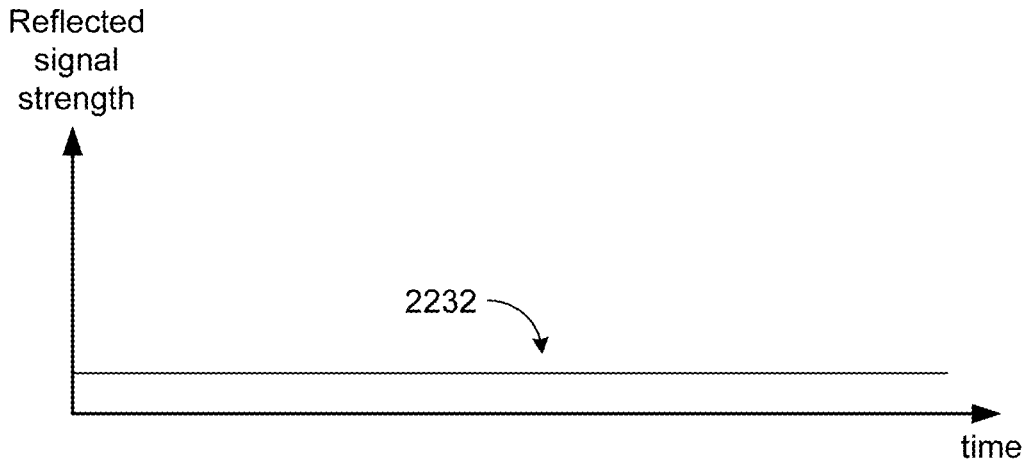


2210
FIG. 22C



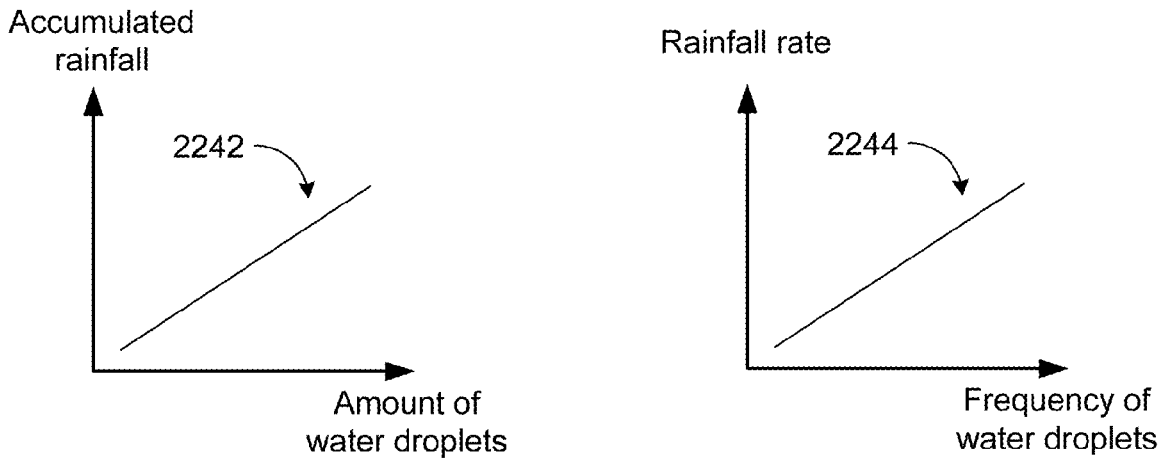
2220

FIG. 22D



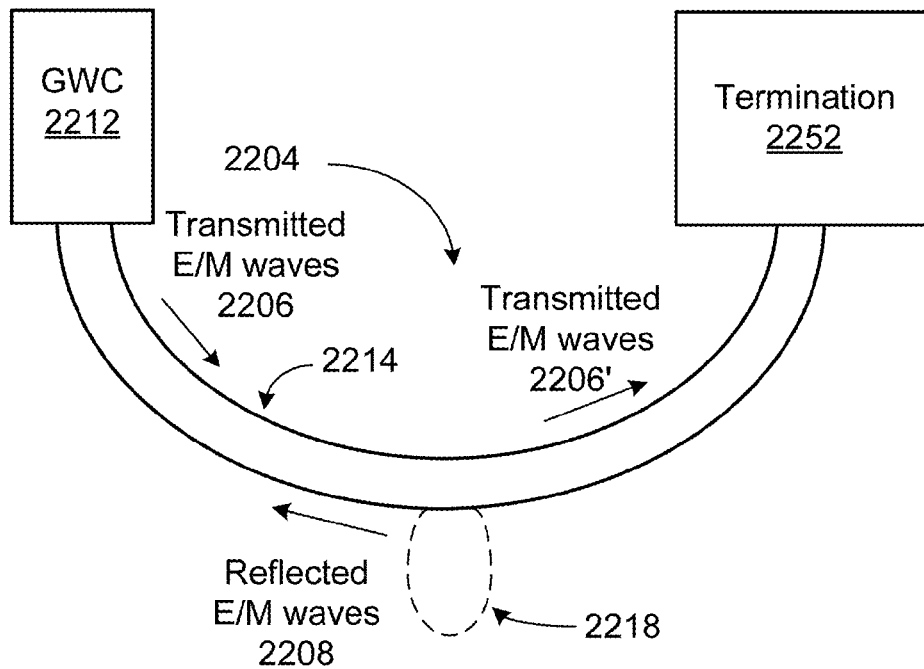
2230

FIG. 22E



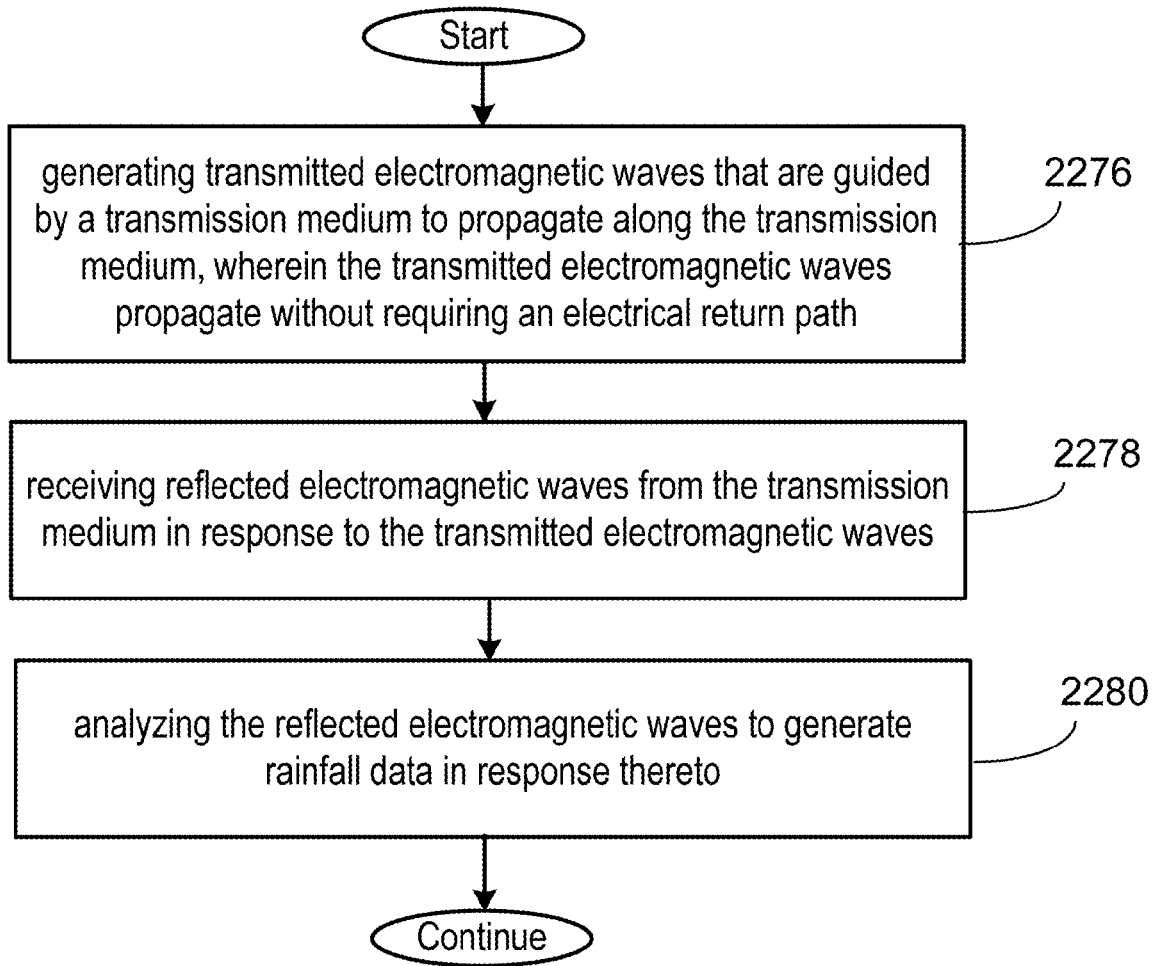
2240

FIG. 22F



2250

FIG. 22G



2275

FIG. 22H

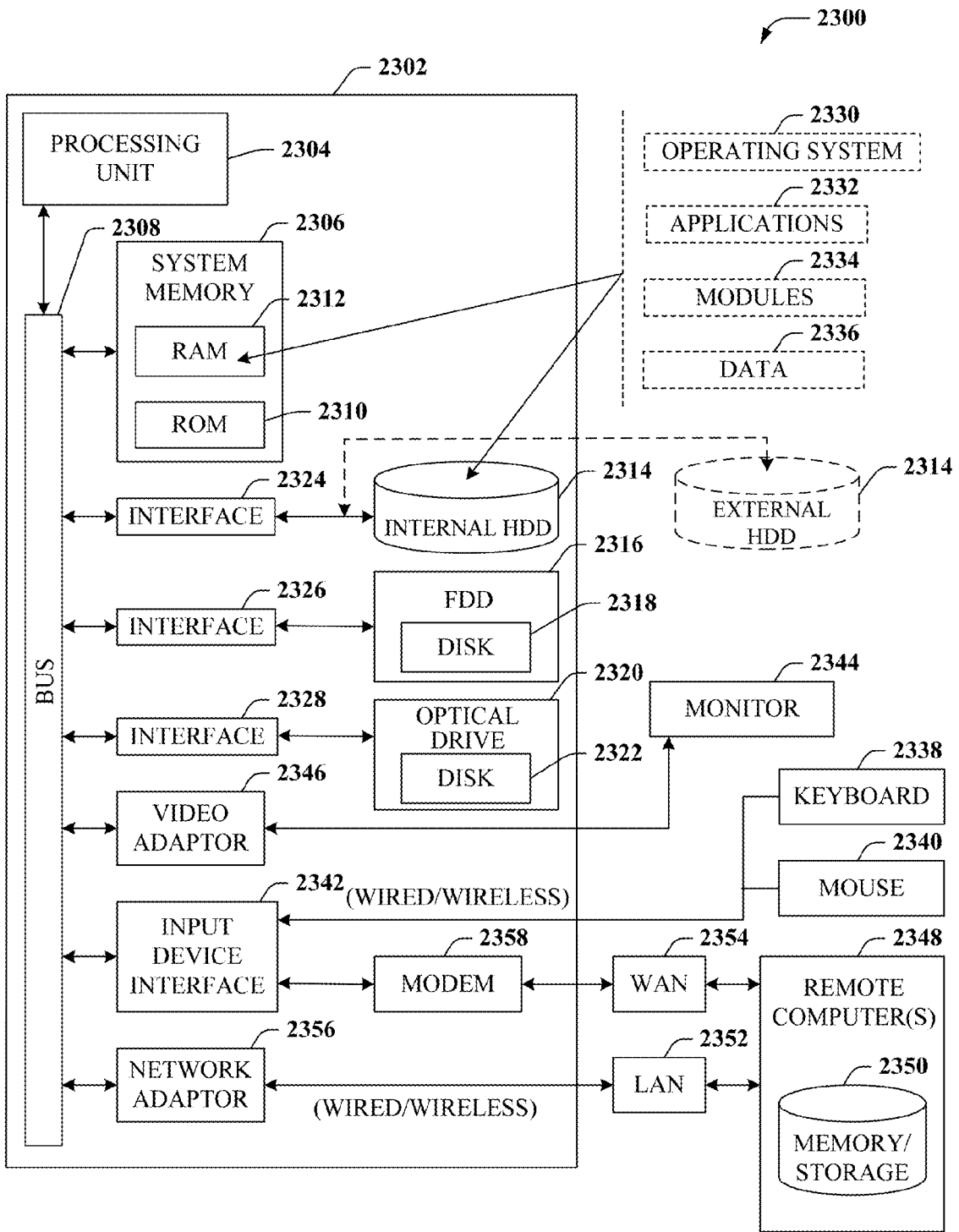


FIG. 23

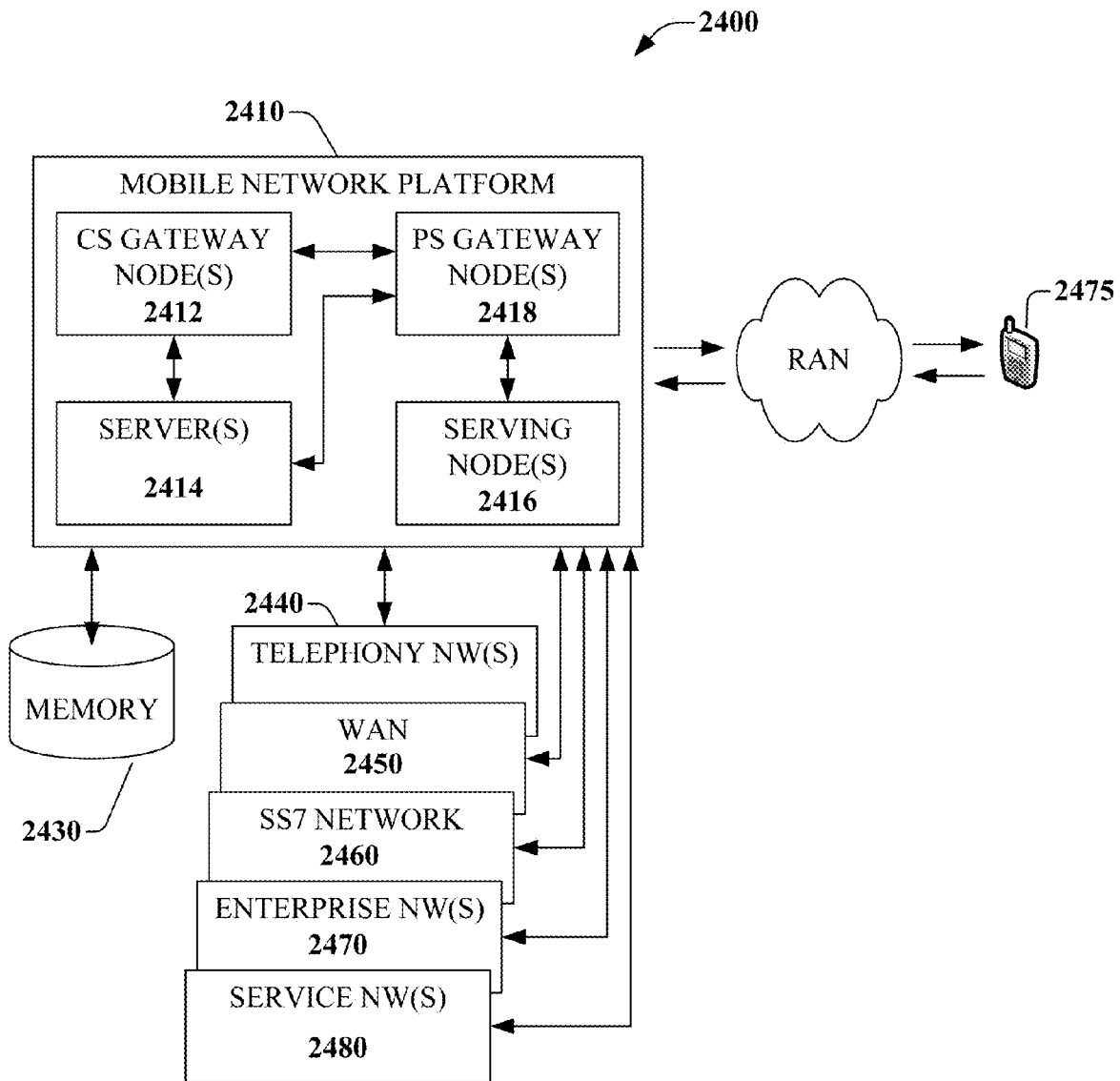
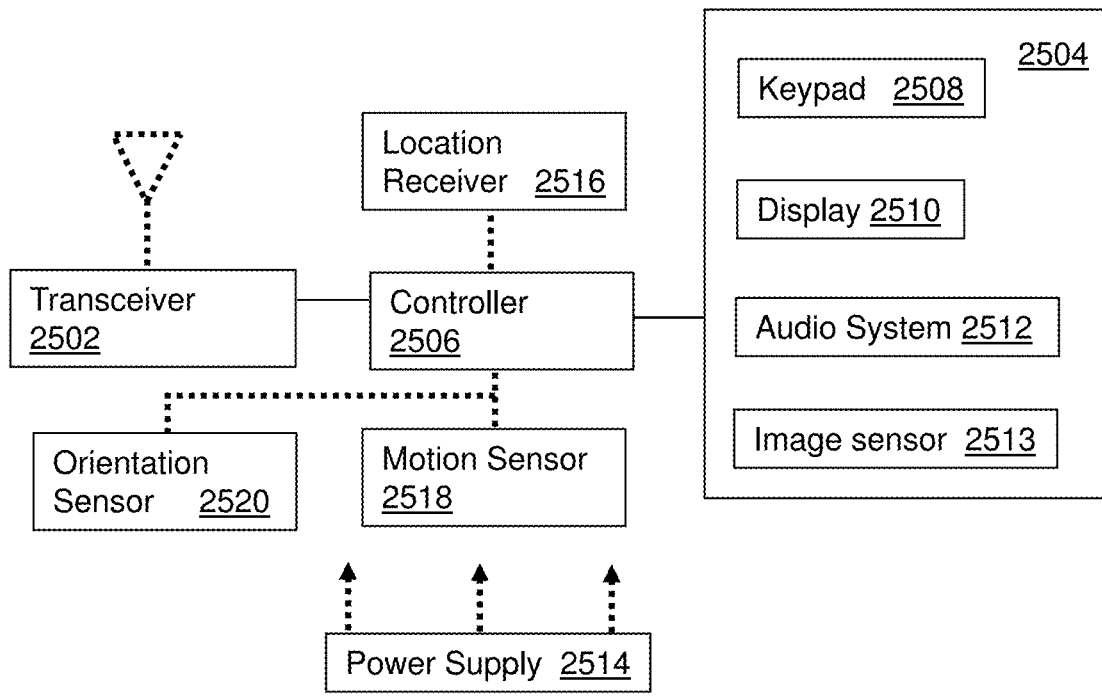


FIG. 24



2500

FIG. 25

APPARATUS AND METHODS FOR SENSING RAINFALL

FIELD OF THE DISCLOSURE

The subject disclosure relates to communications via microwave transmission in a communication network.

BACKGROUND

As smart phones and other portable devices increasingly become ubiquitous, and data usage increases, macrocell base station devices and existing wireless infrastructure in turn require higher bandwidth capability in order to address the increased demand. To provide additional mobile bandwidth, small cell deployment is being pursued, with microcells and picocells providing coverage for much smaller areas than traditional macrocells.

In addition, most homes and businesses have grown to rely on broadband data access for services such as voice, video and Internet browsing, etc. Broadband access networks include satellite, 4G or 5G wireless, power line communication, fiber, cable, and telephone networks.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. 1 is a block diagram illustrating an example, non-limiting embodiment of a guided-wave communications system in accordance with various aspects described herein.

FIG. 2 is a block diagram illustrating an example, non-limiting embodiment of a transmission device in accordance with various aspects described herein.

FIG. 3 is a graphical diagram illustrating an example, non-limiting embodiment of an electromagnetic field distribution in accordance with various aspects described herein.

FIG. 4 is a graphical diagram illustrating an example, non-limiting embodiment of an electromagnetic field distribution in accordance with various aspects described herein.

FIG. 5A is a graphical diagram illustrating an example, non-limiting embodiment of a frequency response in accordance with various aspects described herein.

FIG. 5B is a graphical diagram illustrating example, non-limiting embodiments of a longitudinal cross-section of an insulated wire depicting fields of guided electromagnetic waves at various operating frequencies in accordance with various aspects described herein.

FIG. 6 is a graphical diagram illustrating an example, non-limiting embodiment of an electromagnetic field distribution in accordance with various aspects described herein.

FIG. 7 is a block diagram illustrating an example, non-limiting embodiment of an arc coupler in accordance with various aspects described herein.

FIG. 8 is a block diagram illustrating an example, non-limiting embodiment of an arc coupler in accordance with various aspects described herein.

FIG. 9A is a block diagram illustrating an example, non-limiting embodiment of a stub coupler in accordance with various aspects described herein.

FIG. 9B is a diagram illustrating an example, non-limiting embodiment of an electromagnetic distribution in accordance with various aspects described herein.

FIGS. 10A and 10B are block diagrams illustrating example, non-limiting embodiments of couplers and transceivers in accordance with various aspects described herein.

FIG. 11 is a block diagram illustrating an example, non-limiting embodiment of a dual stub coupler in accordance with various aspects described herein.

FIG. 12 is a block diagram illustrating an example, non-limiting embodiment of a repeater system in accordance with various aspects described herein.

FIG. 13 illustrates a block diagram illustrating an example, non-limiting embodiment of a bidirectional repeater in accordance with various aspects described herein.

FIG. 14 is a block diagram illustrating an example, non-limiting embodiment of a waveguide system in accordance with various aspects described herein.

FIG. 15 is a block diagram illustrating an example, non-limiting embodiment of a guided-wave communications system in accordance with various aspects described herein.

FIGS. 16A & 16B are block diagrams illustrating an example, non-limiting embodiment of a system for managing a power grid communication system in accordance with various aspects described herein.

FIG. 17A illustrates a flow diagram of an example, non-limiting embodiment of a method for detecting and mitigating disturbances occurring in a communication network of the system of FIGS. 16A and 16B.

FIG. 17B illustrates a flow diagram of an example, non-limiting embodiment of a method for detecting and mitigating disturbances occurring in a communication network of the system of FIGS. 16A and 16B.

FIGS. 18A, 18B, and 18C are block diagrams illustrating example, non-limiting embodiment of a transmission medium for propagating guided electromagnetic waves.

FIG. 18D is a block diagram illustrating an example, non-limiting embodiment of bundled transmission media in accordance with various aspects described herein.

FIG. 18E is a block diagram illustrating an example, non-limiting embodiment of a plot depicting cross-talk between first and second transmission mediums of the bundled transmission media of FIG. 18D in accordance with various aspects described herein.

FIG. 18F is a block diagram illustrating an example, non-limiting embodiment of bundled transmission media to mitigate cross-talk in accordance with various aspects described herein.

FIGS. 18G and 18H are block diagrams illustrating example, non-limiting embodiments of a transmission medium with an inner waveguide in accordance with various aspects described herein.

FIGS. 18I and 18J are block diagrams illustrating example, non-limiting embodiments of connector configurations that can be used with the transmission medium of FIG. 18A, 18B, or 18C.

FIG. 18K is a block diagram illustrating example, non-limiting embodiments of transmission mediums for propagating guided electromagnetic waves.

FIG. 18L is a block diagram illustrating example, non-limiting embodiments of bundled transmission media to mitigate cross-talk in accordance with various aspects described herein.

FIG. 18M is a block diagram illustrating an example, non-limiting embodiment of exposed stubs from the bundled transmission media for use as antennas in accordance with various aspects described herein.

FIGS. 18N, 18O, 18P, 18Q, 18R, 18S, 18T, 18U, 18V and 18W are block diagrams illustrating example, non-limiting

embodiments of waveguide devices for transmitting or receiving electromagnetic waves in accordance with various aspects described herein.

FIGS. 18X and 18Y are block diagrams illustrating example, non-limiting embodiments of a dielectric antenna and corresponding gain and field intensity plots in accordance with various aspects described herein.

FIG. 18Z is a block diagram of an example, non-limiting embodiment of another dielectric antenna structure in accordance with various aspects described herein.

FIGS. 19A and 19B are block diagrams illustrating example, non-limiting embodiments of the transmission medium of FIG. 18A used for inducing guided electromagnetic waves on power lines supported by utility poles.

FIG. 19C is a block diagram of an example, non-limiting embodiment of a communication network in accordance with various aspects described herein.

FIG. 20A illustrates a flow diagram of an example, non-limiting embodiment of a method for transmitting downlink signals.

FIG. 20B illustrates a flow diagram of an example, non-limiting embodiment of a method for transmitting uplink signals.

FIG. 20C illustrates a flow diagram of an example, non-limiting embodiment of a method for inducing and receiving electromagnetic waves on a transmission medium in accordance with various aspects described herein.

FIG. 20D illustrates a flow diagram of an example, non-limiting embodiment of a method for inducing electromagnetic waves on a transmission medium in accordance with various aspects described herein.

FIG. 20E illustrates a flow diagram of an example, non-limiting embodiment of a method for inducing electromagnetic waves on a transmission medium in accordance with various aspects described herein.

FIG. 20F illustrates a flow diagram of an example, non-limiting embodiment of a method for inducing electromagnetic waves on a transmission medium in accordance with various aspects described herein.

FIG. 20G illustrates a flow diagram of an example, non-limiting embodiment of a method for detecting and mitigating disturbances occurring in a communication network.

FIG. 20H is a block diagram illustrating an example, non-limiting embodiment of an alignment of fields of an electromagnetic wave to mitigate propagation losses due to water accumulation on a transmission medium in accordance with various aspects described herein.

FIGS. 20I and 20J are block diagrams illustrating example, non-limiting embodiments of electric field intensities of different electromagnetic waves propagating in the cable illustrated in FIG. 20H in accordance with various aspects described herein.

FIG. 20K is a block diagram illustrating an example, non-limiting embodiment of electric fields of a Goubau wave in accordance with various aspects described herein.

FIG. 20L is a block diagram illustrating an example, non-limiting embodiment of electric fields of a hybrid wave in accordance with various aspects described herein.

FIG. 20M is a block diagram illustrating an example, non-limiting embodiment of electric field characteristics of a hybrid wave versus a Goubau wave in accordance with various aspects described herein.

FIG. 20N is a block diagram illustrating an example, non-limiting embodiment of mode sizes of hybrid waves at various operating frequencies in accordance with various aspects described herein.

FIGS. 21A and 21B are block diagrams illustrating example, non-limiting embodiments of a waveguide device for launching hybrid waves in accordance with various aspects described herein.

FIG. 22A is a block diagram illustrating an example, non-limiting embodiment of a hybrid wave launched by the waveguide device of FIGS. 21A and 21B in accordance with various aspects described herein.

FIG. 22B is a block diagram illustrating an example, non-limiting embodiment of a rainfall sensor in accordance with various aspects described herein.

FIG. 22C is a pictorial diagram illustrating an example, non-limiting embodiment of a transmission medium in accordance with various aspects described herein.

FIG. 22D is a block diagram illustrating an example, non-limiting embodiment of a rainfall analyzer in accordance with various aspects described herein.

FIG. 22E is a graphical diagram illustrating example, non-limiting embodiments of a reflected signal strength over time in accordance with various aspects described herein.

FIG. 22F is a graphical diagram illustrating example, non-limiting embodiments of accumulated rainfall as a function of the amount of water droplets and rainfall rate as a function of the frequency of water droplets in accordance with various aspects described herein.

FIG. 22G is a pictorial diagram illustrating an example, non-limiting embodiment of a transmission medium in accordance with various aspects described herein.

FIG. 22H is a flow diagram of an example, non-limiting embodiment of a method in accordance with various aspects described herein.

FIG. 23 is a block diagram of an example, non-limiting embodiment of a computing environment in accordance with various aspects described herein.

FIG. 24 is a block diagram of an example, non-limiting embodiment of a mobile network platform in accordance with various aspects described herein.

FIG. 25 is a block diagram of an example, non-limiting embodiment of a communication device in accordance with various aspects described herein.

DETAILED DESCRIPTION

One or more embodiments are now described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. In the following description, for purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the various embodiments. It is evident, however, that the various embodiments can be practiced without these details (and without applying to any particular networked environment or standard).

In an embodiment, a guided wave communication system is presented for sending and receiving communication signals such as data or other signaling via guided electromagnetic waves. The guided electromagnetic waves include, for example, surface waves or other electromagnetic waves that are bound to or guided by a transmission medium. It will be appreciated that a variety of transmission media can be utilized with guided wave communications without departing from example embodiments. Examples of such transmission media can include one or more of the following, either alone or in one or more combinations: wires, whether insulated or not, and whether single-stranded or multi-stranded; conductors of other shapes or configurations including wire bundles, cables, rods, rails, pipes; non-conductors such as dielectric pipes, rods, rails, or other

dielectric members; combinations of conductors and dielectric materials; or other guided wave transmission media.

The inducement of guided electromagnetic waves on a transmission medium can be independent of any electrical potential, charge or current that is injected or otherwise transmitted through the transmission medium as part of an electrical circuit. For example, in the case where the transmission medium is a wire, it is to be appreciated that while a small current in the wire may be formed in response to the propagation of the guided waves along the wire, this can be due to the propagation of the electromagnetic wave along the wire surface, and is not formed in response to electrical potential, charge or current that is injected into the wire as part of an electrical circuit. The electromagnetic waves traveling on the wire therefore do not require a circuit to propagate along the wire surface. The wire therefore is a single wire transmission line that is not part of a circuit. Also, in some embodiments, a wire is not necessary, and the electromagnetic waves can propagate along a single line transmission medium that is not a wire.

More generally, "guided electromagnetic waves" or "guided waves" as described by the subject disclosure are affected by the presence of a physical object that is at least a part of the transmission medium (e.g., a bare wire or other conductor, a dielectric, an insulated wire, a conduit or other hollow element, a bundle of insulated wires that is coated, covered or surrounded by a dielectric or insulator or other wire bundle, or another form of solid, liquid or otherwise non-gaseous transmission medium) so as to be at least partially bound to or guided by the physical object and so as to propagate along a transmission path of the physical object. Such a physical object can operate as at least a part of a transmission medium that guides, by way of an interface of the transmission medium (e.g., an outer surface, inner surface, an interior portion between the outer and the inner surfaces or other boundary between elements of the transmission medium), the propagation of guided electromagnetic waves, which in turn can carry energy, data and/or other signals along the transmission path from a sending device to a receiving device.

Unlike free space propagation of wireless signals such as unguided (or unbounded) electromagnetic waves that decrease in intensity inversely by the square of the distance traveled by the unguided electromagnetic waves, guided electromagnetic waves can propagate along a transmission medium with less loss in magnitude per unit distance than experienced by unguided electromagnetic waves.

Unlike electrical signals, guided electromagnetic waves can propagate from a sending device to a receiving device without requiring a separate electrical return path between the sending device and the receiving device. As a consequence, guided electromagnetic waves can propagate from a sending device to a receiving device along a transmission medium having no conductive components (e.g., a dielectric strip), or via a transmission medium having no more than a single conductor (e.g., a single bare wire or insulated wire). Even if a transmission medium includes one or more conductive components and the guided electromagnetic waves propagating along the transmission medium generate currents that flow in the one or more conductive components in a direction of the guided electromagnetic waves, such guided electromagnetic waves can propagate along the transmission medium from a sending device to a receiving device without requiring a flow of opposing currents on an electrical return path between the sending device and the receiving device.

In a non-limiting illustration, consider electrical systems that transmit and receive electrical signals between sending and receiving devices by way of conductive media. Such systems generally rely on electrically separate forward and return paths. For instance, consider a coaxial cable having a center conductor and a ground shield that are separated by an insulator. Typically, in an electrical system a first terminal of a sending (or receiving) device can be connected to the center conductor, and a second terminal of the sending (or receiving) device can be connected to the ground shield. If the sending device injects an electrical signal in the center conductor via the first terminal, the electrical signal will propagate along the center conductor causing forward currents in the center conductor, and return currents in the ground shield. The same conditions apply for a two terminal receiving device.

In contrast, consider a guided wave communication system such as described in the subject disclosure, which can utilize different embodiments of a transmission medium (including among others a coaxial cable) for transmitting and receiving guided electromagnetic waves without an electrical return path. In one embodiment, for example, the guided wave communication system of the subject disclosure can be configured to induce guided electromagnetic waves that propagate along an outer surface of a coaxial cable. Although the guided electromagnetic waves will cause forward currents on the ground shield, the guided electromagnetic waves do not require return currents to enable the guided electromagnetic waves to propagate along the outer surface of the coaxial cable. The same can be said of other transmission media used by a guided wave communication system for the transmission and reception of guided electromagnetic waves. For example, guided electromagnetic waves induced by the guided wave communication system on an outer surface of a bare wire, or an insulated wire can propagate along the bare wire or the insulated bare wire without an electrical return path.

Consequently, electrical systems that require two or more conductors for carrying forward and reverse currents on separate conductors to enable the propagation of electrical signals injected by a sending device are distinct from guided wave systems that induce guided electromagnetic waves on an interface of a transmission medium without the need of an electrical return path to enable the propagation of the guided electromagnetic waves along the interface of the transmission medium.

It is further noted that guided electromagnetic waves as described in the subject disclosure can have an electromagnetic field structure that lies primarily or substantially outside of a transmission medium so as to be bound to or guided by the transmission medium and so as to propagate non-trivial distances on or along an outer surface of the transmission medium. In other embodiments, guided electromagnetic waves can have an electromagnetic field structure that lies primarily or substantially inside a transmission medium so as to be bound to or guided by the transmission medium and so as to propagate non-trivial distances within the transmission medium. In other embodiments, guided electromagnetic waves can have an electromagnetic field structure that lies partially inside and partially outside a transmission medium so as to be bound to or guided by the transmission medium and so as to propagate non-trivial distances along the transmission medium. The desired electronic field structure in an embodiment may vary based upon a variety of factors, including the desired transmission distance, the characteristics of the transmission medium

itself, and environmental conditions/characteristics outside of the transmission medium (e.g., presence of rain, fog, atmospheric conditions, etc.).

Various embodiments described herein relate to coupling devices, that can be referred to as “waveguide coupling devices”, “waveguide couplers” or more simply as “couplers”, “coupling devices” or “launchers” for launching and/or extracting guided electromagnetic waves to and from a transmission medium at millimeter-wave frequencies (e.g., 30 to 300 GHz), wherein the wavelength can be small compared to one or more dimensions of the coupling device and/or the transmission medium such as the circumference of a wire or other cross sectional dimension, or lower microwave frequencies such as 300 MHz to 30 GHz. Transmissions can be generated to propagate as waves guided by a coupling device, such as: a strip, arc or other length of dielectric material; a horn, monopole, rod, slot or other antenna; an array of antennas; a magnetic resonant cavity, or other resonant coupler; a coil, a strip line, a waveguide or other coupling device. In operation, the coupling device receives an electromagnetic wave from a transmitter or transmission medium. The electromagnetic field structure of the electromagnetic wave can be carried inside the coupling device, outside the coupling device or some combination thereof. When the coupling device is in close proximity to a transmission medium, at least a portion of an electromagnetic wave couples to or is bound to the transmission medium, and continues to propagate as guided electromagnetic waves. In a reciprocal fashion, a coupling device can extract guided waves from a transmission medium and transfer these electromagnetic waves to a receiver.

According to an example embodiment, a surface wave is a type of guided wave that is guided by a surface of a transmission medium, such as an exterior or outer surface of the wire, or another surface of the wire that is adjacent to or exposed to another type of medium having different properties (e.g., dielectric properties). Indeed, in an example embodiment, a surface of the wire that guides a surface wave can represent a transitional surface between two different types of media. For example, in the case of a bare or uninsulated wire, the surface of the wire can be the outer or exterior conductive surface of the bare or uninsulated wire that is exposed to air or free space. As another example, in the case of insulated wire, the surface of the wire can be the conductive portion of the wire that meets the insulator portion of the wire, or can otherwise be the insulator surface of the wire that is exposed to air or free space, or can otherwise be any material region between the insulator surface of the wire and the conductive portion of the wire that meets the insulator portion of the wire, depending upon the relative differences in the properties (e.g., dielectric properties) of the insulator, air, and/or the conductor and further dependent on the frequency and propagation mode or modes of the guided wave.

According to an example embodiment, the term “about” a wire or other transmission medium used in conjunction with a guided wave can include fundamental guided wave propagation modes such as a guided waves having a circular or substantially circular field distribution, a symmetrical electromagnetic field distribution (e.g., electric field, magnetic field, electromagnetic field, etc.) or other fundamental mode pattern at least partially around a wire or other transmission medium. In addition, when a guided wave propagates “about” a wire or other transmission medium, it can do so according to a guided wave propagation mode that includes not only the fundamental wave propagation modes (e.g., zero order modes), but additionally or alternatively

non-fundamental wave propagation modes such as higher-order guided wave modes (e.g., 1st order modes, 2nd order modes, etc.), asymmetrical modes and/or other guided (e.g., surface) waves that have non-circular field distributions around a wire or other transmission medium. As used herein, the term “guided wave mode” refers to a guided wave propagation mode of a transmission medium, coupling device or other system component of a guided wave communication system.

For example, such non-circular field distributions can be unilateral or multi-lateral with one or more axial lobes characterized by relatively higher field strength and/or one or more nulls or null regions characterized by relatively low-field strength, zero-field strength or substantially zero-field strength. Further, the field distribution can otherwise vary as a function of azimuthal orientation around the wire such that one or more angular regions around the wire have an electric or magnetic field strength (or combination thereof) that is higher than one or more other angular regions of azimuthal orientation, according to an example embodiment. It will be appreciated that the relative orientations or positions of the guided wave higher order modes or asymmetrical modes can vary as the guided wave travels along the wire.

As used herein, the term “millimeter-wave” can refer to electromagnetic waves/signals that fall within the “millimeter-wave frequency band” of 30 GHz to 300 GHz. The term “microwave” can refer to electromagnetic waves/signals that fall within a “microwave frequency band” of 300 MHz to 300 GHz. The term “radio frequency” or “RF” can refer to electromagnetic waves/signals that fall within the “radio frequency band” of 10 kHz to 1 THz. It is appreciated that wireless signals, electrical signals, and guided electromagnetic waves as described in the subject disclosure can be configured to operate at any desirable frequency range, such as, for example, at frequencies within, above or below millimeter-wave and/or microwave frequency bands. In particular, when a coupling device or transmission medium includes a conductive element, the frequency of the guided electromagnetic waves that are carried by the coupling device and/or propagate along the transmission medium can be below the mean collision frequency of the electrons in the conductive element. Further, the frequency of the guided electromagnetic waves that are carried by the coupling device and/or propagate along the transmission medium can be a non-optical frequency, e.g., a radio frequency below the range of optical frequencies that begins at 1 THz.

As used herein, the term “antenna” can refer to a device that is part of a transmitting or receiving system to transmit/radiate or receive wireless signals.

In accordance with one or more embodiments, a rainfall sensor includes a rainfall analyzer configured to induce a transmitted electromagnetic waves that are guided by a transmission medium to propagate along the transmission medium, wherein the transmitted electromagnetic waves propagate without requiring an electrical return path, wherein the rainfall analyzer receives reflected electromagnetic waves from the transmission medium in response to the transmitted electromagnetic waves and wherein the rainfall analyzer analyzes the reflected electromagnetic waves and generates rainfall data in response thereto.

In accordance with one or more embodiments, a method includes: generating transmitted electromagnetic waves that are guided by a transmission medium to propagate along the transmission medium, wherein the transmitted electromagnetic waves propagate without requiring an electrical return path; receiving reflected electromagnetic waves from the

transmission medium in response to the transmitted electromagnetic waves; and analyzing the reflected electromagnetic waves to generate rainfall data in response thereto.

In accordance with one or more embodiments, a rainfall sensor includes: means for inducing transmitted electromagnetic waves that are guided by a transmission medium to propagate along the transmission medium, wherein the transmitted electromagnetic waves propagate without requiring an electrical return path; means for receiving reflected electromagnetic waves from the transmission medium in response to the transmitted electromagnetic waves; and means for analyzing the reflected electromagnetic waves and generates rainfall data in response thereto.

Referring now to FIG. 1, a block diagram 100 illustrating an example, non-limiting embodiment of a guided wave communications system is shown. In operation, a transmission device 101 receives one or more communication signals 110 from a communication network or other communications device that includes data and generates guided waves 120 to convey the data via the transmission medium 125 to the transmission device 102. The transmission device 102 receives the guided waves 120 and converts them to communication signals 112 that include the data for transmission to a communications network or other communications device. The guided waves 120 can be modulated to convey data via a modulation technique such as phase shift keying, frequency shift keying, quadrature amplitude modulation, amplitude modulation, multi-carrier modulation such as orthogonal frequency division multiplexing and via multiple access techniques such as frequency division multiplexing, time division multiplexing, code division multiplexing, multiplexing via differing wave propagation modes and via other modulation and access strategies.

The communication network or networks can include a wireless communication network such as a mobile data network, a cellular voice and data network, a wireless local area network (e.g., WiFi or an 802.xx network), a satellite communications network, a personal area network or other wireless network. The communication network or networks can also include a wired communication network such as a telephone network, an Ethernet network, a local area network, a wide area network such as the Internet, a broadband access network, a cable network, a fiber optic network, or other wired network. The communication devices can include a network edge device, bridge device or home gateway, a set-top box, broadband modem, telephone adapter, access point, base station, or other fixed communication device, a mobile communication device such as an automotive gateway or automobile, laptop computer, tablet, smartphone, cellular telephone, or other communication device.

In an example embodiment, the guided wave communication system 100 can operate in a bi-directional fashion where transmission device 102 receives one or more communication signals 112 from a communication network or device that includes other data and generates guided waves 122 to convey the other data via the transmission medium 125 to the transmission device 101. In this mode of operation, the transmission device 101 receives the guided waves 122 and converts them to communication signals 110 that include the other data for transmission to a communications network or device. The guided waves 122 can be modulated to convey data via a modulation technique such as phase shift keying, frequency shift keying, quadrature amplitude modulation, amplitude modulation, multi-carrier modulation such as orthogonal frequency division multiplexing and via multiple access techniques such as frequency division

multiplexing, time division multiplexing, code division multiplexing, multiplexing via differing wave propagation modes and via other modulation and access strategies.

The transmission medium 125 can include a cable having at least one inner portion surrounded by a dielectric material such as an insulator or other dielectric cover, coating or other dielectric material, the dielectric material having an outer surface and a corresponding circumference. In an example embodiment, the transmission medium 125 operates as a single-wire transmission line to guide the transmission of an electromagnetic wave. When the transmission medium 125 is implemented as a single wire transmission system, it can include a wire. The wire can be insulated or uninsulated, and single-stranded or multi-stranded (e.g., braided). In other embodiments, the transmission medium 125 can contain conductors of other shapes or configurations including wire bundles, cables, rods, rails, pipes. In addition, the transmission medium 125 can include non-conductors such as dielectric pipes, rods, rails, or other dielectric members; combinations of conductors and dielectric materials, conductors without dielectric materials or other guided wave transmission media. It should be noted that the transmission medium 125 can otherwise include any of the transmission media previously discussed.

Further, as previously discussed, the guided waves 120 and 122 can be contrasted with radio transmissions over free space/air or conventional propagation of electrical power or signals through the conductor of a wire via an electrical circuit. In addition to the propagation of guided waves 120 and 122, the transmission medium 125 may optionally contain one or more wires that propagate electrical power or other communication signals in a conventional manner as a part of one or more electrical circuits.

Referring now to FIG. 2, a block diagram 200 illustrating an example, non-limiting embodiment of a transmission device is shown. The transmission device 101 or 102 includes a communications interface (I/F) 205, a transceiver 210 and a coupler 220.

In an example of operation, the communications interface 205 receives a communication signal 110 or 112 that includes data. In various embodiments, the communications interface 205 can include a wireless interface for receiving a wireless communication signal in accordance with a wireless standard protocol such as LTE or other cellular voice and data protocol, WiFi or an 802.11 protocol, WIMAX protocol, Ultra Wideband protocol, Bluetooth protocol, Zigbee protocol, a direct broadcast satellite (DBS) or other satellite communication protocol or other wireless protocol. In addition or in the alternative, the communications interface 205 includes a wired interface that operates in accordance with an Ethernet protocol, universal serial bus (USB) protocol, a data over cable service interface specification (DOCSIS) protocol, a digital subscriber line (DSL) protocol, a Firewire (IEEE 1394) protocol, or other wired protocol. In addition to standards-based protocols, the communications interface 205 can operate in conjunction with other wired or wireless protocol. In addition, the communications interface 205 can optionally operate in conjunction with a protocol stack that includes multiple protocol layers including a MAC protocol, transport protocol, application protocol, etc.

In an example of operation, the transceiver 210 generates an electromagnetic wave based on the communication signal 110 or 112 to convey the data. The electromagnetic wave has at least one carrier frequency and at least one corresponding wavelength. The carrier frequency can be within a millimeter-wave frequency band of 30 GHz-300 GHz, such as 60

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GHz or a carrier frequency in the range of 30-40 GHz or a lower frequency band of 300 MHz-30 GHz in the microwave frequency range such as 26-30 GHz, 11 GHz, 6 GHz or 3 GHz, but it will be appreciated that other carrier frequencies are possible in other embodiments. In one mode of operation, the transceiver 210 merely upconverts the communications signal or signals 110 or 112 for transmission of the electromagnetic signal in the microwave or millimeter-wave band as a guided electromagnetic wave that is guided by or bound to the transmission medium 125. In another mode of operation, the communications interface 205 either converts the communication signal 110 or 112 to a baseband or near baseband signal or extracts the data from the communication signal 110 or 112 and the transceiver 210 modulates a high-frequency carrier with the data, the baseband or near baseband signal for transmission. It should be appreciated that the transceiver 210 can modulate the data received via the communication signal 110 or 112 to preserve one or more data communication protocols of the communication signal 110 or 112 either by encapsulation in the payload of a different protocol or by simple frequency shifting. In the alternative, the transceiver 210 can otherwise translate the data received via the communication signal 110 or 112 to a protocol that is different from the data communication protocol or protocols of the communication signal 110 or 112.

In an example of operation, the coupler 220 couples the electromagnetic wave to the transmission medium 125 as a guided electromagnetic wave to convey the communications signal or signals 110 or 112. While the prior description has focused on the operation of the transceiver 210 as a transmitter, the transceiver 210 can also operate to receive electromagnetic waves that convey other data from the single wire transmission medium via the coupler 220 and to generate communications signals 110 or 112, via communications interface 205 that includes the other data. Consider embodiments where an additional guided electromagnetic wave conveys other data that also propagates along the transmission medium 125. The coupler 220 can also couple this additional electromagnetic wave from the transmission medium 125 to the transceiver 210 for reception.

The transmission device 101 or 102 includes an optional training controller 230. In an example embodiment, the training controller 230 is implemented by a standalone processor or a processor that is shared with one or more other components of the transmission device 101 or 102. The training controller 230 selects the carrier frequencies, modulation schemes and/or guided wave modes for the guided electromagnetic waves based on feedback data received by the transceiver 210 from at least one remote transmission device coupled to receive the guided electromagnetic wave.

In an example embodiment, a guided electromagnetic wave transmitted by a remote transmission device 101 or 102 conveys data that also propagates along the transmission medium 125. The data from the remote transmission device 101 or 102 can be generated to include the feedback data. In operation, the coupler 220 also couples the guided electromagnetic wave from the transmission medium 125 and the transceiver receives the electromagnetic wave and processes the electromagnetic wave to extract the feedback data.

In an example embodiment, the training controller 230 operates based on the feedback data to evaluate a plurality of candidate frequencies, modulation schemes and/or transmission modes to select a carrier frequency, modulation

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scheme and/or transmission mode to enhance performance, such as throughput, signal strength, reduce propagation loss, etc.

Consider the following example: a transmission device 101 begins operation under control of the training controller 230 by sending a plurality of guided waves as test signals such as pilot waves or other test signals at a corresponding plurality of candidate frequencies and/or candidate modes directed to a remote transmission device 102 coupled to the transmission medium 125. The guided waves can include, in addition or in the alternative, test data. The test data can indicate the particular candidate frequency and/or guided-wave mode of the signal. In an embodiment, the training controller 230 at the remote transmission device 102 receives the test signals and/or test data from any of the guided waves that were properly received and determines the best candidate frequency and/or guided wave mode, a set of acceptable candidate frequencies and/or guided wave modes, or a rank ordering of candidate frequencies and/or guided wave modes. This selection of candidate frequenc(ies) or/and guided-mode(s) are generated by the training controller 230 based on one or more optimizing criteria such as received signal strength, bit error rate, packet error rate, signal to noise ratio, propagation loss, etc. The training controller 230 generates feedback data that indicates the selection of candidate frequenc(ies) or/and guided wave mode(s) and sends the feedback data to the transceiver 210 for transmission to the transmission device 101. The transmission device 101 and 102 can then communicate data with one another based on the selection of candidate frequenc(ies) or/and guided wave mode(s).

In other embodiments, the guided electromagnetic waves that contain the test signals and/or test data are reflected back, repeated back or otherwise looped back by the remote transmission device 102 to the transmission device 101 for reception and analysis by the training controller 230 of the transmission device 101 that initiated these waves. For example, the transmission device 101 can send a signal to the remote transmission device 102 to initiate a test mode where a physical reflector is switched on the line, a termination impedance is changed to cause reflections, a loop back mode is switched on to couple electromagnetic waves back to the source transmission device 102, and/or a repeater mode is enabled to amplify and retransmit the electromagnetic waves back to the source transmission device 102. The training controller 230 at the source transmission device 102 receives the test signals and/or test data from any of the guided waves that were properly received and determines selection of candidate frequenc(ies) or/and guided wave mode(s).

While the procedure above has been described in a start-up or initialization mode of operation, each transmission device 101 or 102 can send test signals, evaluate candidate frequencies or guided wave modes via non-test such as normal transmissions or otherwise evaluate candidate frequencies or guided wave modes at other times or continuously as well. In an example embodiment, the communication protocol between the transmission devices 101 and 102 can include an on-request or periodic test mode where either full testing or more limited testing of a subset of candidate frequencies and guided wave modes are tested and evaluated. In other modes of operation, the re-entry into such a test mode can be triggered by a degradation of performance due to a disturbance, weather conditions, etc. In an example embodiment, the receiver bandwidth of the transceiver 210 is either sufficiently wide or swept to receive all candidate frequencies or can be selectively adjusted by

the training controller **230** to a training mode where the receiver bandwidth of the transceiver **210** is sufficiently wide or swept to receive all candidate frequencies.

Referring now to FIG. 3, a graphical diagram **300** illustrating an example, non-limiting embodiment of an electromagnetic field distribution is shown. In this embodiment, a transmission medium **125** in air includes an inner conductor **301** and an insulating jacket **302** of dielectric material, as shown in cross section. The diagram **300** includes different gray-scales that represent differing electromagnetic field strengths generated by the propagation of the guided wave having an asymmetrical and non-fundamental guided wave mode.

In particular, the electromagnetic field distribution corresponds to a modal “sweet spot” that enhances guided electromagnetic wave propagation along an insulated transmission medium and reduces end-to-end transmission loss. In this particular mode, electromagnetic waves are guided by the transmission medium **125** to propagate along an outer surface of the transmission medium—in this case, the outer surface of the insulating jacket **302**. Electromagnetic waves are partially embedded in the insulator and partially radiating on the outer surface of the insulator. In this fashion, electromagnetic waves are “lightly” coupled to the insulator so as to enable electromagnetic wave propagation at long distances with low propagation loss.

As shown, the guided wave has a field structure that lies primarily or substantially outside of the transmission medium **125** that serves to guide the electromagnetic waves. The regions inside the conductor **301** have little or no field. Likewise regions inside the insulating jacket **302** have low field strength. The majority of the electromagnetic field strength is distributed in the lobes **304** at the outer surface of the insulating jacket **302** and in close proximity thereof. The presence of an asymmetric guided wave mode is shown by the high electromagnetic field strengths at the top and bottom of the outer surface of the insulating jacket **302** (in the orientation of the diagram)—as opposed to very small field strengths on the other sides of the insulating jacket **302**.

The example shown corresponds to a 38 GHz electromagnetic wave guided by a wire with a diameter of 1.1 cm and a dielectric insulation of thickness of 0.36 cm. Because the electromagnetic wave is guided by the transmission medium **125** and the majority of the field strength is concentrated in the air outside of the insulating jacket **302** within a limited distance of the outer surface, the guided wave can propagate longitudinally down the transmission medium **125** with very low loss. In the example shown, this “limited distance” corresponds to a distance from the outer surface that is less than half the largest cross sectional dimension of the transmission medium **125**. In this case, the largest cross sectional dimension of the wire corresponds to the overall diameter of 1.82 cm, however, this value can vary with the size and shape of the transmission medium **125**. For example, should the transmission medium **125** be of a rectangular shape with a height of 0.3 cm and a width of 0.4 cm, the largest cross sectional dimension would be the diagonal of 0.5 cm and the corresponding limited distance would be 0.25 cm. The dimensions of the area containing the majority of the field strength also vary with the frequency, and in general, increase as carrier frequencies decrease.

It should also be noted that the components of a guided wave communication system, such as couplers and transmission media can have their own cut-off frequencies for each guided wave mode. The cut-off frequency generally sets forth the lowest frequency that a particular guided wave mode is designed to be supported by that particular com-

ponent. In an example embodiment, the particular asymmetric mode of propagation shown is induced on the transmission medium **125** by an electromagnetic wave having a frequency that falls within a limited range (such as F_c to $2F_c$) of the lower cut-off frequency F_c for this particular asymmetric mode. The lower cut-off frequency F_c is particular to the characteristics of transmission medium **125**. For embodiments as shown that include an inner conductor **301** surrounded by an insulating jacket **302**, this cutoff frequency can vary based on the dimensions and properties of the insulating jacket **302** and potentially the dimensions and properties of the inner conductor **301** and can be determined experimentally to have a desired mode pattern. It should be noted however, that similar effects can be found for a hollow dielectric or insulator without an inner conductor. In this case, the cutoff frequency can vary based on the dimensions and properties of the hollow dielectric or insulator.

At frequencies lower than the lower cut-off frequency, the asymmetric mode is difficult to induce in the transmission medium **125** and fails to propagate for all but trivial distances. As the frequency increases above the limited range of frequencies about the cut-off frequency, the asymmetric mode shifts more and more inward of the insulating jacket **302**. At frequencies much larger than the cut-off frequency, the field strength is no longer concentrated outside of the insulating jacket, but primarily inside of the insulating jacket **302**. While the transmission medium **125** provides strong guidance to the electromagnetic wave and propagation is still possible, ranges are more limited by increased losses due to propagation within the insulating jacket **302**—as opposed to the surrounding air.

Referring now to FIG. 4, a graphical diagram **400** illustrating an example, non-limiting embodiment of an electromagnetic field distribution is shown. In particular, a cross section diagram **400**, similar to FIG. 3 is shown with common reference numerals used to refer to similar elements. The example shown corresponds to a 60 GHz wave guided by a wire with a diameter of 1.1 cm and a dielectric insulation of thickness of 0.36 cm. Because the frequency of the guided wave is above the limited range of the cut-off frequency of this particular asymmetric mode, much of the field strength has shifted inward of the insulating jacket **302**. In particular, the field strength is concentrated primarily inside of the insulating jacket **302**. While the transmission medium **125** provides strong guidance to the electromagnetic wave and propagation is still possible, ranges are more limited when compared with the embodiment of FIG. 3, by increased losses due to propagation within the insulating jacket **302**.

Referring now to FIG. 5A, a graphical diagram illustrating an example, non-limiting embodiment of a frequency response is shown. In particular, diagram **500** presents a graph of end-to-end loss (in dB) as a function of frequency, overlaid with electromagnetic field distributions **510**, **520** and **530** at three points for a 200 cm insulated medium voltage wire. The boundary between the insulator and the surrounding air is represented by reference numeral **525** in each electromagnetic field distribution.

As discussed in conjunction with FIG. 3, an example of a desired asymmetric mode of propagation shown is induced on the transmission medium **125** by an electromagnetic wave having a frequency that falls within a limited range (such as F_c to $2F_c$) of the lower cut-off frequency F_c of the transmission medium for this particular asymmetric mode. In particular, the electromagnetic field distribution **520** at 6 GHz falls within this modal “sweet spot” that enhances

electromagnetic wave propagation along an insulated transmission medium and reduces end-to-end transmission loss. In this particular mode, guided waves are partially embedded in the insulator and partially radiating on the outer surface of the insulator. In this fashion, the electromagnetic waves are “lightly” coupled to the insulator so as to enable guided electromagnetic wave propagation at long distances with low propagation loss.

At lower frequencies represented by the electromagnetic field distribution **510** at 3 GHz, the asymmetric mode radiates more heavily generating higher propagation losses. At higher frequencies represented by the electromagnetic field distribution **530** at 9 GHz, the asymmetric mode shifts more and more inward of the insulating jacket providing too much absorption, again generating higher propagation losses.

Referring now to FIG. **5B**, a graphical diagram **550** illustrating example, non-limiting embodiments of a longitudinal cross-section of a transmission medium **125**, such as an insulated wire, depicting fields of guided electromagnetic waves at various operating frequencies is shown. As shown in diagram **556**, when the guided electromagnetic waves are at approximately the cutoff frequency (f_c) corresponding to the modal “sweet spot”, the guided electromagnetic waves are loosely coupled to the insulated wire so that absorption is reduced, and the fields of the guided electromagnetic waves are bound sufficiently to reduce the amount radiated into the environment (e.g., air). Because absorption and radiation of the fields of the guided electromagnetic waves is low, propagation losses are consequently low, enabling the guided electromagnetic waves to propagate for longer distances.

As shown in diagram **554**, propagation losses increase when an operating frequency of the guide electromagnetic waves increases above about two-times the cutoff frequency (f_c)—or as referred to, above the range of the “sweet spot”. More of the field strength of the electromagnetic wave is driven inside the insulating layer, increasing propagation losses. At frequencies much higher than the cutoff frequency (f_c) the guided electromagnetic waves are strongly bound to the insulated wire as a result of the fields emitted by the guided electromagnetic waves being concentrated in the insulation layer of the wire, as shown in diagram **552**. This in turn raises propagation losses further due to absorption of the guided electromagnetic waves by the insulation layer. Similarly, propagation losses increase when the operating frequency of the guided electromagnetic waves is substantially below the cutoff frequency (f_c), as shown in diagram **558**. At frequencies much lower than the cutoff frequency (f_c) the guided electromagnetic waves are weakly (or nominally) bound to the insulated wire and thereby tend to radiate into the environment (e.g., air), which in turn, raises propagation losses due to radiation of the guided electromagnetic waves.

Referring now to FIG. **6**, a graphical diagram **600** illustrating an example, non-limiting embodiment of an electromagnetic field distribution is shown. In this embodiment, a transmission medium **602** is a bare wire, as shown in cross section. The diagram **300** includes different gray-scales that represent differing electromagnetic field strengths generated by the propagation of a guided wave having a symmetrical and fundamental guided wave mode at a single carrier frequency.

In this particular mode, electromagnetic waves are guided by the transmission medium **602** to propagate along an outer surface of the transmission medium—in this case, the outer surface of the bare wire. Electromagnetic waves are

“lightly” coupled to the wire so as to enable electromagnetic wave propagation at long distances with low propagation loss. As shown, the guided wave has a field structure that lies substantially outside of the transmission medium **602** that serves to guide the electromagnetic waves. The regions inside the conductor **602** have little or no field.

Referring now to FIG. **7**, a block diagram **700** illustrating an example, non-limiting embodiment of an arc coupler is shown. In particular a coupling device is presented for use in a transmission device, such as transmission device **101** or **102** presented in conjunction with FIG. **1**. The coupling device includes an arc coupler **704** coupled to a transmitter circuit **712** and termination or damper **714**. The arc coupler **704** can be made of a dielectric material, or other low-loss insulator (e.g., Teflon, polyethylene, etc.), or made of a conducting (e.g., metallic, non-metallic, etc.) material, or any combination of the foregoing materials. As shown, the arc coupler **704** operates as a waveguide and has a wave **706** propagating as a guided wave about a waveguide surface of the arc coupler **704**. In the embodiment shown, at least a portion of the arc coupler **704** can be placed near a wire **702** or other transmission medium, (such as transmission medium **125**), in order to facilitate coupling between the arc coupler **704** and the wire **702** or other transmission medium, as described herein to launch the guided wave **708** on the wire. The arc coupler **704** can be placed such that a portion of the curved arc coupler **704** is tangential to, and parallel or substantially parallel to the wire **702**. The portion of the arc coupler **704** that is parallel to the wire can be an apex of the curve, or any point where a tangent of the curve is parallel to the wire **702**. When the arc coupler **704** is positioned or placed thusly, the wave **706** travelling along the arc coupler **704** couples, at least in part, to the wire **702**, and propagates as guided wave **708** around or about the wire surface of the wire **702** and longitudinally along the wire **702**. The guided wave **708** can be characterized as a surface wave or other electromagnetic wave that is guided by or bound to the wire **702** or other transmission medium.

A portion of the wave **706** that does not couple to the wire **702** propagates as a wave **710** along the arc coupler **704**. It will be appreciated that the arc coupler **704** can be configured and arranged in a variety of positions in relation to the wire **702** to achieve a desired level of coupling or non-coupling of the wave **706** to the wire **702**. For example, the curvature and/or length of the arc coupler **704** that is parallel or substantially parallel, as well as its separation distance (which can include zero separation distance in an embodiment), to the wire **702** can be varied without departing from example embodiments. Likewise, the arrangement of arc coupler **704** in relation to the wire **702** may be varied based upon considerations of the respective intrinsic characteristics (e.g., thickness, composition, electromagnetic properties, etc.) of the wire **702** and the arc coupler **704**, as well as the characteristics (e.g., frequency, energy level, etc.) of the waves **706** and **708**.

The guided wave **708** stays parallel or substantially parallel to the wire **702**, even as the wire **702** bends and flexes. Bends in the wire **702** can increase transmission losses, which are also dependent on wire diameters, frequency, and materials. If the dimensions of the arc coupler **704** are chosen for efficient power transfer, most of the power in the wave **706** is transferred to the wire **702**, with little power remaining in wave **710**. It will be appreciated that the guided wave **708** can still be multi-modal in nature (discussed herein), including having modes that are non-fundamental or asymmetric, while traveling along a path that is parallel or substantially parallel to the wire **702**, with or without a

fundamental transmission mode. In an embodiment, non-fundamental or asymmetric modes can be utilized to minimize transmission losses and/or obtain increased propagation distances.

It is noted that the term parallel is generally a geometric construct which often is not exactly achievable in real systems. Accordingly, the term parallel as utilized in the subject disclosure represents an approximation rather than an exact configuration when used to describe embodiments disclosed in the subject disclosure. In an embodiment, substantially parallel can include approximations that are within 30 degrees of true parallel in all dimensions.

In an embodiment, the wave 706 can exhibit one or more wave propagation modes. The arc coupler modes can be dependent on the shape and/or design of the coupler 704. The one or more arc coupler modes of wave 706 can generate, influence, or impact one or more wave propagation modes of the guided wave 708 propagating along wire 702. It should be particularly noted however that the guided wave modes present in the guided wave 706 may be the same or different from the guided wave modes of the guided wave 708. In this fashion, one or more guided wave modes of the guided wave 706 may not be transferred to the guided wave 708, and further one or more guided wave modes of guided wave 708 may not have been present in guided wave 706. It should also be noted that the cut-off frequency of the arc coupler 704 for a particular guided wave mode may be different than the cutoff frequency of the wire 702 or other transmission medium for that same mode. For example, while the wire 702 or other transmission medium may be operated slightly above its cutoff frequency for a particular guided wave mode, the arc coupler 704 may be operated well above its cut-off frequency for that same mode for low loss, slightly below its cut-off frequency for that same mode to, for example, induce greater coupling and power transfer, or some other point in relation to the arc coupler's cutoff frequency for that mode.

In an embodiment, the wave propagation modes on the wire 702 can be similar to the arc coupler modes since both waves 706 and 708 propagate about the outside of the arc coupler 704 and wire 702 respectively. In some embodiments, as the wave 706 couples to the wire 702, the modes can change form, or new modes can be created or generated, due to the coupling between the arc coupler 704 and the wire 702. For example, differences in size, material, and/or impedances of the arc coupler 704 and wire 702 may create additional modes not present in the arc coupler modes and/or suppress some of the arc coupler modes. The wave propagation modes can comprise the fundamental transverse electromagnetic mode (Quasi-TEM₀₀), where only small electric and/or magnetic fields extend in the direction of propagation, and the electric and magnetic fields extend radially outwards while the guided wave propagates along the wire. This guided wave mode can be donut shaped, where few of the electromagnetic fields exist within the arc coupler 704 or wire 702.

Waves 706 and 708 can comprise a fundamental TEM mode where the fields extend radially outwards, and also comprise other, non-fundamental (e.g., asymmetric, higher-level, etc.) modes. While particular wave propagation modes are discussed above, other wave propagation modes are likewise possible such as transverse electric (TE) and transverse magnetic (TM) modes, based on the frequencies employed, the design of the arc coupler 704, the dimensions and composition of the wire 702, as well as its surface characteristics, its insulation if present, the electromagnetic properties of the surrounding environment, etc. It should be

noted that, depending on the frequency, the electrical and physical characteristics of the wire 702 and the particular wave propagation modes that are generated, guided wave 708 can travel along the conductive surface of an oxidized uninsulated wire, an unoxidized uninsulated wire, an insulated wire and/or along the insulating surface of an insulated wire.

In an embodiment, a diameter of the arc coupler 704 is smaller than the diameter of the wire 702. For the millimeter-band wavelength being used, the arc coupler 704 supports a single waveguide mode that makes up wave 706. This single waveguide mode can change as it couples to the wire 702 as guided wave 708. If the arc coupler 704 were larger, more than one waveguide mode can be supported, but these additional waveguide modes may not couple to the wire 702 as efficiently, and higher coupling losses can result. However, in some alternative embodiments, the diameter of the arc coupler 704 can be equal to or larger than the diameter of the wire 702, for example, where higher coupling losses are desirable or when used in conjunction with other techniques to otherwise reduce coupling losses (e.g., impedance matching with tapering, etc.).

In an embodiment, the wavelength of the waves 706 and 708 are comparable in size, or smaller than a circumference of the arc coupler 704 and the wire 702. In an example, if the wire 702 has a diameter of 0.5 cm, and a corresponding circumference of around 1.5 cm, the wavelength of the transmission is around 1.5 cm or less, corresponding to a frequency of 70 GHz or greater. In another embodiment, a suitable frequency of the transmission and the carrier-wave signal is in the range of 30-100 GHz, perhaps around 30-60 GHz, and around 38 GHz in one example. In an embodiment, when the circumference of the arc coupler 704 and wire 702 is comparable in size to, or greater, than a wavelength of the transmission, the waves 706 and 708 can exhibit multiple wave propagation modes including fundamental and/or non-fundamental (symmetric and/or asymmetric) modes that propagate over sufficient distances to support various communication systems described herein. The waves 706 and 708 can therefore comprise more than one type of electric and magnetic field configuration. In an embodiment, as the guided wave 708 propagates down the wire 702, the electrical and magnetic field configurations will remain the same from end to end of the wire 702. In other embodiments, as the guided wave 708 encounters interference (distortion or obstructions) or loses energy due to transmission losses or scattering, the electric and magnetic field configurations can change as the guided wave 708 propagates down wire 702.

In an embodiment, the arc coupler 704 can be composed of nylon, Teflon, polyethylene, a polyamide, or other plastics. In other embodiments, other dielectric materials are possible. The wire surface of wire 702 can be metallic with either a bare metallic surface, or can be insulated using plastic, dielectric, insulator or other coating, jacket or sheathing. In an embodiment, a dielectric or otherwise non-conducting/insulated waveguide can be paired with either a bare/metallic wire or insulated wire. In other embodiments, a metallic and/or conductive waveguide can be paired with a bare/metallic wire or insulated wire. In an embodiment, an oxidation layer on the bare metallic surface of the wire 702 (e.g., resulting from exposure of the bare metallic surface to oxygen/air) can also provide insulating or dielectric properties similar to those provided by some insulators or sheathings.

It is noted that the graphical representations of waves 706, 708 and 710 are presented merely to illustrate the principles

that wave 706 induces or otherwise launches a guided wave 708 on a wire 702 that operates, for example, as a single wire transmission line. Wave 710 represents the portion of wave 706 that remains on the arc coupler 704 after the generation of guided wave 708. The actual electric and magnetic fields generated as a result of such wave propagation may vary depending on the frequencies employed, the particular wave propagation mode or modes, the design of the arc coupler 704, the dimensions and composition of the wire 702, as well as its surface characteristics, its optional insulation, the electromagnetic properties of the surrounding environment, etc.

It is noted that arc coupler 704 can include a termination circuit or damper 714 at the end of the arc coupler 704 that can absorb leftover radiation or energy from wave 710. The termination circuit or damper 714 can prevent and/or minimize the leftover radiation or energy from wave 710 reflecting back toward transmitter circuit 712. In an embodiment, the termination circuit or damper 714 can include termination resistors, and/or other components that perform impedance matching to attenuate reflection. In some embodiments, if the coupling efficiencies are high enough, and/or wave 710 is sufficiently small, it may not be necessary to use a termination circuit or damper 714. For the sake of simplicity, these transmitter 712 and termination circuits or dampers 714 may not be depicted in the other figures, but in those embodiments, transmitter and termination circuits or dampers may possibly be used.

Further, while a single arc coupler 704 is presented that generates a single guided wave 708, multiple arc couplers 704 placed at different points along the wire 702 and/or at different azimuthal orientations about the wire can be employed to generate and receive multiple guided waves 708 at the same or different frequencies, at the same or different phases, at the same or different wave propagation modes.

FIG. 8, a block diagram 800 illustrating an example, non-limiting embodiment of an arc coupler is shown. In the embodiment shown, at least a portion of the coupler 704 can be placed near a wire 702 or other transmission medium, (such as transmission medium 125), in order to facilitate coupling between the arc coupler 704 and the wire 702 or other transmission medium, to extract a portion of the guided wave 806 as a guided wave 808 as described herein. The arc coupler 704 can be placed such that a portion of the curved arc coupler 704 is tangential to, and parallel or substantially parallel to the wire 702. The portion of the arc coupler 704 that is parallel to the wire can be an apex of the curve, or any point where a tangent of the curve is parallel to the wire 702. When the arc coupler 704 is positioned or placed thusly, the wave 806 travelling along the wire 702 couples, at least in part, to the arc coupler 704, and propagates as guided wave 808 along the arc coupler 704 to a receiving device (not expressly shown). A portion of the wave 806 that does not couple to the arc coupler propagates as wave 810 along the wire 702 or other transmission medium.

In an embodiment, the wave 806 can exhibit one or more wave propagation modes. The arc coupler modes can be dependent on the shape and/or design of the coupler 704. The one or more modes of guided wave 806 can generate, influence, or impact one or more guide-wave modes of the guided wave 808 propagating along the arc coupler 704. It should be particularly noted however that the guided wave modes present in the guided wave 806 may be the same or different from the guided wave modes of the guided wave 808. In this fashion, one or more guided wave modes of the

guided wave 806 may not be transferred to the guided wave 808, and further one or more guided wave modes of guided wave 808 may not have been present in guided wave 806.

Referring now to FIG. 9A, a block diagram 900 illustrating an example, non-limiting embodiment of a stub coupler is shown. In particular a coupling device that includes stub coupler 904 is presented for use in a transmission device, such as transmission device 101 or 102 presented in conjunction with FIG. 1. The stub coupler 904 can be made of a dielectric material, or other low-loss insulator (e.g., Teflon, polyethylene and etc.), or made of a conducting (e.g., metallic, non-metallic, etc.) material, or any combination of the foregoing materials. As shown, the stub coupler 904 operates as a waveguide and has a wave 906 propagating as a guided wave about a waveguide surface of the stub coupler 904. In the embodiment shown, at least a portion of the stub coupler 904 can be placed near a wire 702 or other transmission medium, (such as transmission medium 125), in order to facilitate coupling between the stub coupler 904 and the wire 702 or other transmission medium, as described herein to launch the guided wave 908 on the wire.

In an embodiment, the stub coupler 904 is curved, and an end of the stub coupler 904 can be tied, fastened, or otherwise mechanically coupled to a wire 702. When the end of the stub coupler 904 is fastened to the wire 702, the end of the stub coupler 904 is parallel or substantially parallel to the wire 702. Alternatively, another portion of the dielectric waveguide beyond an end can be fastened or coupled to wire 702 such that the fastened or coupled portion is parallel or substantially parallel to the wire 702. The fastener 910 can be a nylon cable tie or other type of non-conducting/dielectric material that is either separate from the stub coupler 904 or constructed as an integrated component of the stub coupler 904. The stub coupler 904 can be adjacent to the wire 702 without surrounding the wire 702.

Like the arc coupler 704 described in conjunction with FIG. 7, when the stub coupler 904 is placed with the end parallel to the wire 702, the guided wave 906 travelling along the stub coupler 904 couples to the wire 702, and propagates as guided wave 908 about the wire surface of the wire 702. In an example embodiment, the guided wave 908 can be characterized as a surface wave or other electromagnetic wave.

It is noted that the graphical representations of waves 906 and 908 are presented merely to illustrate the principles that wave 906 induces or otherwise launches a guided wave 908 on a wire 702 that operates, for example, as a single wire transmission line. The actual electric and magnetic fields generated as a result of such wave propagation may vary depending on one or more of the shape and/or design of the coupler, the relative position of the dielectric waveguide to the wire, the frequencies employed, the design of the stub coupler 904, the dimensions and composition of the wire 702, as well as its surface characteristics, its optional insulation, the electromagnetic properties of the surrounding environment, etc.

In an embodiment, an end of stub coupler 904 can taper towards the wire 702 in order to increase coupling efficiencies. Indeed, the tapering of the end of the stub coupler 904 can provide impedance matching to the wire 702 and reduce reflections, according to an example embodiment of the subject disclosure. For example, an end of the stub coupler 904 can be gradually tapered in order to obtain a desired level of coupling between waves 906 and 908 as illustrated in FIG. 9A.

In an embodiment, the fastener 910 can be placed such that there is a short length of the stub coupler 904 between

the fastener **910** and an end of the stub coupler **904**. Maximum coupling efficiencies are realized in this embodiment when the length of the end of the stub coupler **904** that is beyond the fastener **910** is at least several wavelengths long for whatever frequency is being transmitted.

Turning now to FIG. 9B, a diagram **950** illustrating an example, non-limiting embodiment of an electromagnetic distribution in accordance with various aspects described herein is shown. In particular, an electromagnetic distribution is presented in two dimensions for a transmission device that includes coupler **952**, shown in an example stub coupler constructed of a dielectric material. The coupler **952** couples an electromagnetic wave for propagation as a guided wave along an outer surface of a wire **702** or other transmission medium.

The coupler **952** guides the electromagnetic wave to a junction at x_0 via a symmetrical guided wave mode. While some of the energy of the electromagnetic wave that propagates along the coupler **952** is outside of the coupler **952**, the majority of the energy of this electromagnetic wave is contained within the coupler **952**. The junction at x_0 couples the electromagnetic wave to the wire **702** or other transmission medium at an azimuthal angle corresponding to the bottom of the transmission medium. This coupling induces an electromagnetic wave that is guided to propagate along the outer surface of the wire **702** or other transmission medium via at least one guided wave mode in direction **956**. The majority of the energy of the guided electromagnetic wave is outside or, but in close proximity to the outer surface of the wire **702** or other transmission medium. In the example shown, the junction at x_0 forms an electromagnetic wave that propagates via both a symmetrical mode and at least one asymmetrical surface mode, such as the first order mode presented in conjunction with FIG. 3, that skims the surface of the wire **702** or other transmission medium.

It is noted that the graphical representations of guided waves are presented merely to illustrate an example of guided wave coupling and propagation. The actual electric and magnetic fields generated as a result of such wave propagation may vary depending on the frequencies employed, the design and/or configuration of the coupler **952**, the dimensions and composition of the wire **702** or other transmission medium, as well as its surface characteristics, its insulation if present, the electromagnetic properties of the surrounding environment, etc.

Turning now to FIG. 10A, illustrated is a block diagram **1000** of an example, non-limiting embodiment of a coupler and transceiver system in accordance with various aspects described herein. The system is an example of transmission device **101** or **102**. In particular, the communication interface **1008** is an example of communications interface **205**, the stub coupler **1002** is an example of coupler **220**, and the transmitter/receiver device **1006**, diplexer **1016**, power amplifier **1014**, low noise amplifier **1018**, frequency mixers **1010** and **1020** and local oscillator **1012** collectively form an example of transceiver **210**.

In operation, the transmitter/receiver device **1006** launches and receives waves (e.g., guided wave **1004** onto stub coupler **1002**). The guided waves **1004** can be used to transport signals received from and sent to a host device, base station, mobile devices, a building or other device by way of a communications interface **1008**. The communications interface **1008** can be an integral part of system **1000**. Alternatively, the communications interface **1008** can be tethered to system **1000**. The communications interface **1008** can comprise a wireless interface for interfacing to the host device, base station, mobile devices, a building or other

device utilizing any of various wireless signaling protocols (e.g., LTE, WiFi, WiMAX, IEEE 802.xx, etc.) including an infrared protocol such as an infrared data association (IrDA) protocol or other line of sight optical protocol. The communications interface **1008** can also comprise a wired interface such as a fiber optic line, coaxial cable, twisted pair, category 5 (CAT-5) cable or other suitable wired or optical mediums for communicating with the host device, base station, mobile devices, a building or other device via a protocol such as an Ethernet protocol, universal serial bus (USB) protocol, a data over cable service interface specification (DOCSIS) protocol, a digital subscriber line (DSL) protocol, a Firewire (IEEE 1394) protocol, or other wired or optical protocol. For embodiments where system **1000** functions as a repeater, the communications interface **1008** may not be necessary.

The output signals (e.g., Tx) of the communications interface **1008** can be combined with a carrier wave (e.g., millimeter-wave carrier wave) generated by a local oscillator **1012** at frequency mixer **1010**. Frequency mixer **1010** can use heterodyning techniques or other frequency shifting techniques to frequency shift the output signals from communications interface **1008**. For example, signals sent to and from the communications interface **1008** can be modulated signals such as orthogonal frequency division multiplexed (OFDM) signals formatted in accordance with a Long-Term Evolution (LTE) wireless protocol or other wireless 3G, 4G, 5G or higher voice and data protocol, a Zigbee, WiMAX, UltraWideband or IEEE 802.11 wireless protocol; a wired protocol such as an Ethernet protocol, universal serial bus (USB) protocol, a data over cable service interface specification (DOCSIS) protocol, a digital subscriber line (DSL) protocol, a Firewire (IEEE 1394) protocol or other wired or wireless protocol. In an example embodiment, this frequency conversion can be done in the analog domain, and as a result, the frequency shifting can be done without regard to the type of communications protocol used by a base station, mobile devices, or in-building devices. As new communications technologies are developed, the communications interface **1008** can be upgraded (e.g., updated with software, firmware, and/or hardware) or replaced and the frequency shifting and transmission apparatus can remain, simplifying upgrades. The carrier wave can then be sent to a power amplifier ("PA") **1014** and can be transmitted via the transmitter receiver device **1006** via the diplexer **1016**.

Signals received from the transmitter/receiver device **1006** that are directed towards the communications interface **1008** can be separated from other signals via diplexer **1016**. The received signal can then be sent to low noise amplifier ("LNA") **1018** for amplification. A frequency mixer **1020**, with help from local oscillator **1012** can downshift the received signal (which is in the millimeter-wave band or around 38 GHz in some embodiments) to the native frequency. The communications interface **1008** can then receive the transmission at an input port (Rx).

In an embodiment, transmitter/receiver device **1006** can include a cylindrical or non-cylindrical metal (which, for example, can be hollow in an embodiment, but not necessarily drawn to scale) or other conducting or non-conducting waveguide and an end of the stub coupler **1002** can be placed in or in proximity to the waveguide or the transmitter/receiver device **1006** such that when the transmitter/receiver device **1006** generates a transmission, the guided wave couples to stub coupler **1002** and propagates as a guided wave **1004** about the waveguide surface of the stub coupler **1002**. In some embodiments, the guided wave **1004** can propagate in part on the outer surface of the stub coupler

1002 and in part inside the stub coupler 1002. In other embodiments, the guided wave 1004 can propagate substantially or completely on the outer surface of the stub coupler 1002. In yet other embodiments, the guided wave 1004 can propagate substantially or completely inside the stub coupler 1002. In this latter embodiment, the guided wave 1004 can radiate at an end of the stub coupler 1002 (such as the tapered end shown in FIG. 4) for coupling to a transmission medium such as a wire 702 of FIG. 7. Similarly, if guided wave 1004 is incoming (coupled to the stub coupler 1002 from a wire 702), guided wave 1004 then enters the transmitter/receiver device 1006 and couples to the cylindrical waveguide or conducting waveguide. While transmitter/receiver device 1006 is shown to include a separate waveguide—an antenna, cavity resonator, klystron, magnetron, travelling wave tube, or other radiating element can be employed to induce a guided wave on the coupler 1002, with or without the separate waveguide.

In an embodiment, stub coupler 1002 can be wholly constructed of a dielectric material (or another suitable insulating material), without any metallic or otherwise conducting materials therein. Stub coupler 1002 can be composed of nylon, Teflon, polyethylene, a polyamide, other plastics, or other materials that are non-conducting and suitable for facilitating transmission of electromagnetic waves at least in part on an outer surface of such materials. In another embodiment, stub coupler 1002 can include a core that is conducting/metallic, and have an exterior dielectric surface. Similarly, a transmission medium that couples to the stub coupler 1002 for propagating electromagnetic waves induced by the stub coupler 1002 or for supplying electromagnetic waves to the stub coupler 1002 can, in addition to being a bare or insulated wire, be wholly constructed of a dielectric material (or another suitable insulating material), without any metallic or otherwise conducting materials therein.

It is noted that although FIG. 10A shows that the opening of transmitter receiver device 1006 is much wider than the stub coupler 1002, this is not to scale, and that in other embodiments the width of the stub coupler 1002 is comparable or slightly smaller than the opening of the hollow waveguide. It is also not shown, but in an embodiment, an end of the coupler 1002 that is inserted into the transmitter/receiver device 1006 tapers down in order to reduce reflection and increase coupling efficiencies.

Before coupling to the stub coupler 1002, the one or more waveguide modes of the guided wave generated by the transmitter/receiver device 1006 can couple to the stub coupler 1002 to induce one or more wave propagation modes of the guided wave 1004. The wave propagation modes of the guided wave 1004 can be different than the hollow metal waveguide modes due to the different characteristics of the hollow metal waveguide and the dielectric waveguide. For instance, wave propagation modes of the guided wave 1004 can comprise the fundamental transverse electromagnetic mode (Quasi-TEM₀₀), where only small electrical and/or magnetic fields extend in the direction of propagation, and the electric and magnetic fields extend radially outwards from the stub coupler 1002 while the guided waves propagate along the stub coupler 1002. The fundamental transverse electromagnetic mode wave propagation mode may or may not exist inside a waveguide that is hollow. Therefore, the hollow metal waveguide modes that are used by transmitter/receiver device 1006 are waveguide modes that can couple effectively and efficiently to wave propagation modes of stub coupler 1002.

It will be appreciated that other constructs or combinations of the transmitter/receiver device 1006 and stub coupler 1002 are possible. For example, a stub coupler 1002' can be placed tangentially or in parallel (with or without a gap) with respect to an outer surface of the hollow metal waveguide of the transmitter/receiver device 1006' (corresponding circuitry not shown) as depicted by reference 1000' of FIG. 10B. In another embodiment, not shown by reference 1000', the stub coupler 1002' can be placed inside the hollow metal waveguide of the transmitter/receiver device 1006' without an axis of the stub coupler 1002' being coaxially aligned with an axis of the hollow metal waveguide of the transmitter/receiver device 1006'. In either of these embodiments, the guided wave generated by the transmitter/receiver device 1006' can couple to a surface of the stub coupler 1002' to induce one or more wave propagation modes of the guided wave 1004' on the stub coupler 1002' including a fundamental mode (e.g., a symmetric mode) and/or a non-fundamental mode (e.g., asymmetric mode).

In one embodiment, the guided wave 1004' can propagate in part on the outer surface of the stub coupler 1002' and in part inside the stub coupler 1002'. In another embodiment, the guided wave 1004' can propagate substantially or completely on the outer surface of the stub coupler 1002'. In yet other embodiments, the guided wave 1004' can propagate substantially or completely inside the stub coupler 1002'. In this latter embodiment, the guided wave 1004' can radiate at an end of the stub coupler 1002' (such as the tapered end shown in FIG. 9) for coupling to a transmission medium such as a wire 702 of FIG. 9.

It will be further appreciated that other constructs the transmitter/receiver device 1006 are possible. For example, a hollow metal waveguide of a transmitter/receiver device 1006" (corresponding circuitry not shown), depicted in FIG. 10B as reference 1000", can be placed tangentially or in parallel (with or without a gap) with respect to an outer surface of a transmission medium such as the wire 702 of FIG. 4 without the use of the stub coupler 1002. In this embodiment, the guided wave generated by the transmitter/receiver device 1006" can couple to a surface of the wire 702 to induce one or more wave propagation modes of a guided wave 908 on the wire 702 including a fundamental mode (e.g., a symmetric mode) and/or a non-fundamental mode (e.g., asymmetric mode). In another embodiment, the wire 702 can be positioned inside a hollow metal waveguide of a transmitter/receiver device 1006' (corresponding circuitry not shown) so that an axis of the wire 702 is coaxially (or not coaxially) aligned with an axis of the hollow metal waveguide without the use of the stub coupler 1002—see FIG. 10B reference 1000". In this embodiment, the guided wave generated by the transmitter/receiver device 1006" can couple to a surface of the wire 702 to induce one or more wave propagation modes of a guided wave 908 on the wire including a fundamental mode (e.g., a symmetric mode) and/or a non-fundamental mode (e.g., asymmetric mode).

In the embodiments of 1000" and 1000"', for a wire 702 having an insulated outer surface, the guided wave 908 can propagate in part on the outer surface of the insulator and in part inside the insulator. In embodiments, the guided wave 908 can propagate substantially or completely on the outer surface of the insulator, or substantially or completely inside the insulator. In the embodiments of 1000" and 1000"', for a wire 702 that is a bare conductor, the guided wave 908 can propagate in part on the outer surface of the conductor and in part inside the conductor. In another embodiment, the guided wave 908 can propagate substantially or completely on the outer surface of the conductor.

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Referring now to FIG. 11, a block diagram 1100 illustrating an example, non-limiting embodiment of a dual stub coupler is shown. In particular, a dual coupler design is presented for use in a transmission device, such as transmission device 101 or 102 presented in conjunction with FIG. 1. In an embodiment, two or more couplers (such as the stub couplers 1104 and 1106) can be positioned around a wire 1102 in order to receive guided wave 1108. In an embodiment, one coupler is enough to receive the guided wave 1108. In that case, guided wave 1108 couples to coupler 1104 and propagates as guided wave 1110. If the field structure of the guided wave 1108 oscillates or undulates around the wire 1102 due to the particular guided wave mode(s) or various outside factors, then coupler 1106 can be placed such that guided wave 1108 couples to coupler 1106. In some embodiments, four or more couplers can be placed around a portion of the wire 1102, e.g., at 90 degrees or another spacing with respect to each other, in order to receive guided waves that may oscillate or rotate around the wire 1102, that have been induced at different azimuthal orientations or that have non-fundamental or higher order modes that, for example, have lobes and/or nulls or other asymmetries that are orientation dependent. However, it will be appreciated that there may be less than or more than four couplers placed around a portion of the wire 1102 without departing from example embodiments.

It should be noted that while couplers 1106 and 1104 are illustrated as stub couplers, any other of the coupler designs described herein including arc couplers, antenna or horn couplers, magnetic couplers, etc., could likewise be used. It will also be appreciated that while some example embodiments have presented a plurality of couplers around at least a portion of a wire 1102, this plurality of couplers can also be considered as part of a single coupler system having multiple coupler subcomponents. For example, two or more couplers can be manufactured as single system that can be installed around a wire in a single installation such that the couplers are either pre-positioned or adjustable relative to each other (either manually or automatically with a controllable mechanism such as a motor or other actuator) in accordance with the single system.

Receivers coupled to couplers 1106 and 1104 can use diversity combining to combine signals received from both couplers 1106 and 1104 in order to maximize the signal quality. In other embodiments, if one or the other of the couplers 1104 and 1106 receive a transmission that is above a predetermined threshold, receivers can use selection diversity when deciding which signal to use. Further, while reception by a plurality of couplers 1106 and 1104 is illustrated, transmission by couplers 1106 and 1104 in the same configuration can likewise take place. In particular, a wide range of multi-input multi-output (MIMO) transmission and reception techniques can be employed for transmissions where a transmission device, such as transmission device 101 or 102 presented in conjunction with FIG. 1 includes multiple transceivers and multiple couplers.

It is noted that the graphical representations of waves 1108 and 1110 are presented merely to illustrate the principles that guided wave 1108 induces or otherwise launches a wave 1110 on a coupler 1104. The actual electric and magnetic fields generated as a result of such wave propagation may vary depending on the frequencies employed, the design of the coupler 1104, the dimensions and composition of the wire 1102, as well as its surface characteristics, its insulation if any, the electromagnetic properties of the surrounding environment, etc.

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Referring now to FIG. 12, a block diagram 1200 illustrating an example, non-limiting embodiment of a repeater system is shown. In particular, a repeater device 1210 is presented for use in a transmission device, such as transmission device 101 or 102 presented in conjunction with FIG. 1. In this system, two couplers 1204 and 1214 can be placed near a wire 1202 or other transmission medium such that guided waves 1205 propagating along the wire 1202 are extracted by coupler 1204 as wave 1206 (e.g. as a guided wave), and then are boosted or repeated by repeater device 1210 and launched as a wave 1216 (e.g. as a guided wave) onto coupler 1214. The wave 1216 can then be launched on the wire 1202 and continue to propagate along the wire 1202 as a guided wave 1217. In an embodiment, the repeater device 1210 can receive at least a portion of the power utilized for boosting or repeating through magnetic coupling with the wire 1202, for example, when the wire 1202 is a power line or otherwise contains a power-carrying conductor. It should be noted that while couplers 1204 and 1214 are illustrated as stub couplers, any other of the coupler designs described herein including arc couplers, antenna or horn couplers, magnetic couplers, or the like, could likewise be used.

In some embodiments, repeater device 1210 can repeat the transmission associated with wave 1206, and in other embodiments, repeater device 1210 can include a communications interface 205 that extracts data or other signals from the wave 1206 for supplying such data or signals to another network and/or one or more other devices as communication signals 110 or 112 and/or receiving communication signals 110 or 112 from another network and/or one or more other devices and launch guided wave 1216 having embedded therein the received communication signals 110 or 112. In a repeater configuration, receiver waveguide 1208 can receive the wave 1206 from the coupler 1204 and transmitter waveguide 1212 can launch guided wave 1216 onto coupler 1214 as guided wave 1217. Between receiver waveguide 1208 and transmitter waveguide 1212, the signal embedded in guided wave 1206 and/or the guided wave 1216 itself can be amplified to correct for signal loss and other inefficiencies associated with guided wave communications or the signal can be received and processed to extract the data contained therein and regenerated for transmission. In an embodiment, the receiver waveguide 1208 can be configured to extract data from the signal, process the data to correct for data errors utilizing for example error correcting codes, and regenerate an updated signal with the corrected data. The transmitter waveguide 1212 can then transmit guided wave 1216 with the updated signal embedded therein. In an embodiment, a signal embedded in guided wave 1206 can be extracted from the transmission and processed for communication with another network and/or one or more other devices via communications interface 205 as communication signals 110 or 112. Similarly, communication signals 110 or 112 received by the communications interface 205 can be inserted into a transmission of guided wave 1216 that is generated and launched onto coupler 1214 by transmitter waveguide 1212.

It is noted that although FIG. 12 shows guided wave transmissions 1206 and 1216 entering from the left and exiting to the right respectively, this is merely a simplification and is not intended to be limiting. In other embodiments, receiver waveguide 1208 and transmitter waveguide 1212 can also function as transmitters and receivers respectively, allowing the repeater device 1210 to be bi-directional.

In an embodiment, repeater device 1210 can be placed at locations where there are discontinuities or obstacles on the

wire **1202** or other transmission medium. In the case where the wire **1202** is a power line, these obstacles can include transformers, connections, utility poles, and other such power line devices. The repeater device **1210** can help the guided (e.g., surface) waves jump over these obstacles on the line and boost the transmission power at the same time. In other embodiments, a coupler can be used to jump over the obstacle without the use of a repeater device. In that embodiment, both ends of the coupler can be tied or fastened to the wire, thus providing a path for the guided wave to travel without being blocked by the obstacle.

Turning now to FIG. **13**, illustrated is a block diagram **1300** of an example, non-limiting embodiment of a bidirectional repeater in accordance with various aspects described herein. In particular, a bidirectional repeater device **1306** is presented for use in a transmission device, such as transmission device **101** or **102** presented in conjunction with FIG. **1**. It should be noted that while the couplers are illustrated as stub couplers, any other of the coupler designs described herein including arc couplers, antenna or horn couplers, magnetic couplers, or the like, could likewise be used. The bidirectional repeater **1306** can employ diversity paths in the case of when two or more wires or other transmission media are present. Since guided wave transmissions have different transmission efficiencies and coupling efficiencies for transmission medium of different types such as insulated wires, un-insulated wires or other types of transmission media and further, if exposed to the elements, can be affected by weather, and other atmospheric conditions, it can be advantageous to selectively transmit on different transmission media at certain times. In various embodiments, the various transmission media can be designated as a primary, secondary, tertiary, etc. whether or not such designation indicates a preference of one transmission medium over another.

In the embodiment shown, the transmission media include an insulated or uninsulated wire **1302** and an insulated or uninsulated wire **1304** (referred to herein as wires **1302** and **1304**, respectively). The repeater device **1306** uses a receiver coupler **1308** to receive a guided wave traveling along wire **1302** and repeats the transmission using transmitter waveguide **1310** as a guided wave along wire **1304**. In other embodiments, repeater device **1306** can switch from the wire **1304** to the wire **1302**, or can repeat the transmissions along the same paths. Repeater device **1306** can include sensors, or be in communication with sensors (or a network management system **1601** depicted in FIG. **16A**) that indicate conditions that can affect the transmission. Based on the feedback received from the sensors, the repeater device **1306** can make the determination about whether to keep the transmission along the same wire, or transfer the transmission to the other wire.

Turning now to FIG. **14**, illustrated is a block diagram **1400** illustrating an example, non-limiting embodiment of a bidirectional repeater system. In particular, a bidirectional repeater system is presented for use in a transmission device, such as transmission device **101** or **102** presented in conjunction with FIG. **1**. The bidirectional repeater system includes waveguide coupling devices **1402** and **1404** that receive and transmit transmissions from other coupling devices located in a distributed antenna system or backhaul system.

In various embodiments, waveguide coupling device **1402** can receive a transmission from another waveguide coupling device, wherein the transmission has a plurality of subcarriers. Diplexer **1406** can separate the transmission from other transmissions, and direct the transmission to

low-noise amplifier (“LNA”) **1408**. A frequency mixer **1428**, with help from a local oscillator **1412**, can downshift the transmission (which is in the millimeter-wave band or around 38 GHz in some embodiments) to a lower frequency, such as a cellular band (~1.9 GHz) for a distributed antenna system, a native frequency, or other frequency for a backhaul system. An extractor (or demultiplexer) **1432** can extract the signal on a subcarrier and direct the signal to an output component **1422** for optional amplification, buffering or isolation by power amplifier **1424** for coupling to communications interface **205**. The communications interface **205** can further process the signals received from the power amplifier **1424** or otherwise transmit such signals over a wireless or wired interface to other devices such as a base station, mobile devices, a building, etc. For the signals that are not being extracted at this location, extractor **1432** can redirect them to another frequency mixer **1436**, where the signals are used to modulate a carrier wave generated by local oscillator **1414**. The carrier wave, with its subcarriers, is directed to a power amplifier (“PA”) **1416** and is retransmitted by waveguide coupling device **1404** to another system, via diplexer **1420**.

An LNA **1426** can be used to amplify, buffer or isolate signals that are received by the communication interface **205** and then send the signal to a multiplexer **1434** which merges the signal with signals that have been received from waveguide coupling device **1404**. The signals received from coupling device **1404** have been split by diplexer **1420**, and then passed through LNA **1418**, and downshifted in frequency by frequency mixer **1438**. When the signals are combined by multiplexer **1434**, they are upshifted in frequency by frequency mixer **1430**, and then boosted by PA **1410**, and transmitted to another system by waveguide coupling device **1402**. In an embodiment bidirectional repeater system can be merely a repeater without the output device **1422**. In this embodiment, the multiplexer **1434** would not be utilized and signals from LNA **1418** would be directed to mixer **1430** as previously described. It will be appreciated that in some embodiments, the bidirectional repeater system could also be implemented using two distinct and separate unidirectional repeaters. In an alternative embodiment, a bidirectional repeater system could also be a booster or otherwise perform retransmissions without downshifting and upshifting. Indeed in example embodiment, the retransmissions can be based upon receiving a signal or guided wave and performing some signal or guided wave processing or reshaping, filtering, and/or amplification, prior to retransmission of the signal or guided wave.

Referring now to FIG. **15**, a block diagram **1500** illustrating an example, non-limiting embodiment of a guided wave communications system is shown. This diagram depicts an exemplary environment in which a guided wave communication system, such as the guided wave communication system presented in conjunction with FIG. **1**, can be used.

To provide network connectivity to additional base station devices, a backhaul network that links the communication cells (e.g., macrocells and microcells) to network devices of a core network correspondingly expands. Similarly, to provide network connectivity to a distributed antenna system, an extended communication system that links base station devices and their distributed antennas is desirable. A guided wave communication system **1500** such as shown in FIG. **15** can be provided to enable alternative, increased or additional network connectivity and a waveguide coupling system can be provided to transmit and/or receive guided wave (e.g., surface wave) communications on a transmission medium

such as a wire that operates as a single-wire transmission line (e.g., a utility line), and that can be used as a waveguide and/or that otherwise operates to guide the transmission of an electromagnetic wave.

The guided wave communication system **1500** can comprise a first instance of a distribution system **1550** that includes one or more base station devices (e.g., base station device **1504**) that are communicably coupled to a central office **1501** and/or a macrocell site **1502**. Base station device **1504** can be connected by a wired (e.g., fiber and/or cable), or by a wireless (e.g., microwave wireless) connection to the macrocell site **1502** and the central office **1501**. A second instance of the distribution system **1560** can be used to provide wireless voice and data services to mobile device **1522** and to residential and/or commercial establishments **1542** (herein referred to as establishments **1542**). System **1500** can have additional instances of the distribution systems **1550** and **1560** for providing voice and/or data services to mobile devices **1522-1524** and establishments **1542** as shown in FIG. **15**.

Macrocells such as macrocell site **1502** can have dedicated connections to a mobile network and base station device **1504** or can share and/or otherwise use another connection. Central office **1501** can be used to distribute media content and/or provide internet service provider (ISP) services to mobile devices **1522-1524** and establishments **1542**. The central office **1501** can receive media content from a constellation of satellites **1530** (one of which is shown in FIG. **15**) or other sources of content, and distribute such content to mobile devices **1522-1524** and establishments **1542** via the first and second instances of the distribution system **1550** and **1560**. The central office **1501** can also be communicatively coupled to the Internet **1503** for providing internet data services to mobile devices **1522-1524** and establishments **1542**.

Base station device **1504** can be mounted on, or attached to, utility pole **1516**. In other embodiments, base station device **1504** can be near transformers and/or other locations situated nearby a power line. Base station device **1504** can facilitate connectivity to a mobile network for mobile devices **1522** and **1524**. Antennas **1512** and **1514**, mounted on or near utility poles **1518** and **1520**, respectively, can receive signals from base station device **1504** and transmit those signals to mobile devices **1522** and **1524** over a much wider area than if the antennas **1512** and **1514** were located at or near base station device **1504**.

It is noted that FIG. **15** displays three utility poles, in each instance of the distribution systems **1550** and **1560**, with one base station device, for purposes of simplicity. In other embodiments, utility pole **1516** can have more base station devices, and more utility poles with distributed antennas and/or tethered connections to establishments **1542**.

A transmission device **1506**, such as transmission device **101** or **102** presented in conjunction with FIG. **1**, can transmit a signal from base station device **1504** to antennas **1512** and **1514** via utility or power line(s) that connect the utility poles **1516**, **1518**, and **1520**. To transmit the signal, radio source and/or transmission device **1506** upconverts the signal (e.g., via frequency mixing) from base station device **1504** or otherwise converts the signal from the base station device **1504** to a microwave band signal and the transmission device **1506** launches a microwave band wave that propagates as a guided wave traveling along the utility line or other wire as described in previous embodiments. At utility pole **1518**, another transmission device **1508** receives the guided wave (and optionally can amplify it as needed or desired or operate as a repeater to receive it and regenerate

it) and sends it forward as a guided wave on the utility line or other wire. The transmission device **1508** can also extract a signal from the microwave band guided wave and shift it down in frequency or otherwise convert it to its original cellular band frequency (e.g., 1.9 GHz or other defined cellular frequency) or another cellular (or non-cellular) band frequency. An antenna **1512** can wireless transmit the down-shifted signal to mobile device **1522**. The process can be repeated by transmission device **1510**, antenna **1514** and mobile device **1524**, as necessary or desirable.

Transmissions from mobile devices **1522** and **1524** can also be received by antennas **1512** and **1514** respectively. The transmission devices **1508** and **1510** can upshift or otherwise convert the cellular band signals to microwave band and transmit the signals as guided wave (e.g., surface wave or other electromagnetic wave) transmissions over the power line(s) to base station device **1504**.

Media content received by the central office **1501** can be supplied to the second instance of the distribution system **1560** via the base station device **1504** for distribution to mobile devices **1522** and establishments **1542**. The transmission device **1510** can be tethered to the establishments **1542** by one or more wired connections or a wireless interface. The one or more wired connections may include without limitation, a power line, a coaxial cable, a fiber cable, a twisted pair cable, a guided wave transmission medium or other suitable wired mediums for distribution of media content and/or for providing internet services. In an example embodiment, the wired connections from the transmission device **1510** can be communicatively coupled to one or more very high bit rate digital subscriber line (VDSL) modems located at one or more corresponding service area interfaces (SAIs—not shown) or pedestals, each SAI or pedestal providing services to a portion of the establishments **1542**. The VDSL modems can be used to selectively distribute media content and/or provide internet services to gateways (not shown) located in the establishments **1542**. The SAIs or pedestals can also be communicatively coupled to the establishments **1542** over a wired medium such as a power line, a coaxial cable, a fiber cable, a twisted pair cable, a guided wave transmission medium or other suitable wired mediums. In other example embodiments, the transmission device **1510** can be communicatively coupled directly to establishments **1542** without intermediate interfaces such as the SAIs or pedestals.

In another example embodiment, system **1500** can employ diversity paths, where two or more utility lines or other wires are strung between the utility poles **1516**, **1518**, and **1520** (e.g., for example, two or more wires between poles **1516** and **1520**) and redundant transmissions from base station/macrocell site **1502** are transmitted as guided waves down the surface of the utility lines or other wires. The utility lines or other wires can be either insulated or uninsulated, and depending on the environmental conditions that cause transmission losses, the coupling devices can selectively receive signals from the insulated or uninsulated utility lines or other wires. The selection can be based on measurements of the signal-to-noise ratio of the wires, or based on determined weather/environmental conditions (e.g., moisture detectors, weather forecasts, etc.). The use of diversity paths with system **1500** can enable alternate routing capabilities, load balancing, increased load handling, concurrent bi-directional or synchronous communications, spread spectrum communications, etc.

It is noted that the use of the transmission devices **1506**, **1508**, and **1510** in FIG. **15** are by way of example only, and that in other embodiments, other uses are possible. For

instance, transmission devices can be used in a backhaul communication system, providing network connectivity to base station devices. Transmission devices **1506**, **1508**, and **1510** can be used in many circumstances where it is desirable to transmit guided wave communications over a wire, whether insulated or not insulated. Transmission devices **1506**, **1508**, and **1510** are improvements over other coupling devices due to no contact or limited physical and/or electrical contact with the wires that may carry high voltages. The transmission device can be located away from the wire (e.g., spaced apart from the wire) and/or located on the wire so long as it is not electrically in contact with the wire, as the dielectric acts as an insulator, allowing for cheap, easy, and/or less complex installation. However, as previously noted conducting or non-dielectric couplers can be employed, for example in configurations where the wires correspond to a telephone network, cable television network, broadband data service, fiber optic communications system or other network employing low voltages or having insulated transmission lines.

It is further noted, that while base station device **1504** and macrocell site **1502** are illustrated in an embodiment, other network configurations are likewise possible. For example, devices such as access points or other wireless gateways can be employed in a similar fashion to extend the reach of other networks such as a wireless local area network, a wireless personal area network or other wireless network that operates in accordance with a communication protocol such as a 802.11 protocol, WIMAX protocol, UltraWideband protocol, Bluetooth protocol, Zigbee protocol or other wireless protocol.

Referring now to FIGS. **16A** & **16B**, block diagrams illustrating an example, non-limiting embodiment of a system for managing a power grid communication system are shown. Considering FIG. **16A**, a waveguide system **1602** is presented for use in a guided wave communications system, such as the system presented in conjunction with FIG. **15**. The waveguide system **1602** can comprise sensors **1604**, a power management system **1605**, a transmission device **101** or **102** that includes at least one communication interface **205**, transceiver **210** and coupler **220**.

The waveguide system **1602** can be coupled to a power line **1610** for facilitating guided wave communications in accordance with embodiments described in the subject disclosure. In an example embodiment, the transmission device **101** or **102** includes coupler **220** for inducing electromagnetic waves on a surface of the power line **1610** that longitudinally propagate along the surface of the power line **1610** as described in the subject disclosure. The transmission device **101** or **102** can also serve as a repeater for retransmitting electromagnetic waves on the same power line **1610** or for routing electromagnetic waves between power lines **1610** as shown in FIGS. **12-13**.

The transmission device **101** or **102** includes transceiver **210** configured to, for example, up-convert a signal operating at an original frequency range to electromagnetic waves operating at, exhibiting, or associated with a carrier frequency that propagate along a coupler to induce corresponding guided electromagnetic waves that propagate along a surface of the power line **1610**. A carrier frequency can be represented by a center frequency having upper and lower cutoff frequencies that define the bandwidth of the electromagnetic waves. The power line **1610** can be a wire (e.g., single stranded or multi-stranded) having a conducting surface or insulated surface. The transceiver **210** can also receive signals from the coupler **220** and down-convert the

electromagnetic waves operating at a carrier frequency to signals at their original frequency.

Signals received by the communications interface **205** of transmission device **101** or **102** for up-conversion can include without limitation signals supplied by a central office **1611** over a wired or wireless interface of the communications interface **205**, a base station **1614** over a wired or wireless interface of the communications interface **205**, wireless signals transmitted by mobile devices **1620** to the base station **1614** for delivery over the wired or wireless interface of the communications interface **205**, signals supplied by in-building communication devices **1618** over the wired or wireless interface of the communications interface **205**, and/or wireless signals supplied to the communications interface **205** by mobile devices **1612** roaming in a wireless communication range of the communications interface **205**. In embodiments where the waveguide system **1602** functions as a repeater, such as shown in FIGS. **12-13**, the communications interface **205** may or may not be included in the waveguide system **1602**.

The electromagnetic waves propagating along the surface of the power line **1610** can be modulated and formatted to include packets or frames of data that include a data payload and further include networking information (such as header information for identifying one or more destination waveguide systems **1602**). The networking information may be provided by the waveguide system **1602** or an originating device such as the central office **1611**, the base station **1614**, mobile devices **1620**, or in-building devices **1618**, or a combination thereof. Additionally, the modulated electromagnetic waves can include error correction data for mitigating signal disturbances. The networking information and error correction data can be used by a destination waveguide system **1602** for detecting transmissions directed to it, and for down-converting and processing with error correction data transmissions that include voice and/or data signals directed to recipient communication devices communicatively coupled to the destination waveguide system **1602**.

Referring now to the sensors **1604** of the waveguide system **1602**, the sensors **1604** can comprise one or more of a temperature sensor **1604a**, a disturbance detection sensor **1604b**, a loss of energy sensor **1604c**, a noise sensor **1604d**, a vibration sensor **1604e**, an environmental (e.g., weather) sensor **1604f**, and/or an image sensor **1604g**. The temperature sensor **1604a** can be used to measure ambient temperature, a temperature of the transmission device **101** or **102**, a temperature of the power line **1610**, temperature differentials (e.g., compared to a setpoint or baseline, between transmission device **101** or **102** and **1610**, etc.), or any combination thereof. In one embodiment, temperature metrics can be collected and reported periodically to a network management system **1601** by way of the base station **1614**.

The disturbance detection sensor **1604b** can perform measurements on the power line **1610** to detect disturbances such as signal reflections, which may indicate a presence of a downstream disturbance that may impede the propagation of electromagnetic waves on the power line **1610**. A signal reflection can represent a distortion resulting from, for example, an electromagnetic wave transmitted on the power line **1610** by the transmission device **101** or **102** that reflects in whole or in part back to the transmission device **101** or **102** from a disturbance in the power line **1610** located downstream from the transmission device **101** or **102**.

Signal reflections can be caused by obstructions on the power line **1610**. For example, a tree limb may cause electromagnetic wave reflections when the tree limb is lying on the power line **1610**, or is in close proximity to the power

line **1610** which may cause a corona discharge. Other obstructions that can cause electromagnetic wave reflections can include without limitation an object that has been entangled on the power line **1610** (e.g., clothing, a shoe wrapped around a power line **1610** with a shoe string, etc.), a corroded build-up on the power line **1610** or an ice build-up. Power grid components may also impede or obstruct with the propagation of electromagnetic waves on the surface of power lines **1610**. Illustrations of power grid components that may cause signal reflections include without limitation a transformer and a joint for connecting spliced power lines. A sharp angle on the power line **1610** may also cause electromagnetic wave reflections.

The disturbance detection sensor **1604b** can comprise a circuit to compare magnitudes of electromagnetic wave reflections to magnitudes of original electromagnetic waves transmitted by the transmission device **101** or **102** to determine how much a downstream disturbance in the power line **1610** attenuates transmissions. The disturbance detection sensor **1604b** can further comprise a spectral analyzer circuit for performing spectral analysis on the reflected waves. The spectral data generated by the spectral analyzer circuit can be compared with spectral profiles via pattern recognition, an expert system, curve fitting, matched filtering or other artificial intelligence, classification or comparison technique to identify a type of disturbance based on, for example, the spectral profile that most closely matches the spectral data. The spectral profiles can be stored in a memory of the disturbance detection sensor **1604b** or may be remotely accessible by the disturbance detection sensor **1604b**. The profiles can comprise spectral data that models different disturbances that may be encountered on power lines **1610** to enable the disturbance detection sensor **1604b** to identify disturbances locally. An identification of the disturbance if known can be reported to the network management system **1601** by way of the base station **1614**. The disturbance detection sensor **1604b** can also utilize the transmission device **101** or **102** to transmit electromagnetic waves as test signals to determine a roundtrip time for an electromagnetic wave reflection. The round trip time measured by the disturbance detection sensor **1604b** can be used to calculate a distance traveled by the electromagnetic wave up to a point where the reflection takes place, which enables the disturbance detection sensor **1604b** to calculate a distance from the transmission device **101** or **102** to the downstream disturbance on the power line **1610**.

The distance calculated can be reported to the network management system **1601** by way of the base station **1614**. In one embodiment, the location of the waveguide system **1602** on the power line **1610** may be known to the network management system **1601**, which the network management system **1601** can use to determine a location of the disturbance on the power line **1610** based on a known topology of the power grid. In another embodiment, the waveguide system **1602** can provide its location to the network management system **1601** to assist in the determination of the location of the disturbance on the power line **1610**. The location of the waveguide system **1602** can be obtained by the waveguide system **1602** from a pre-programmed location of the waveguide system **1602** stored in a memory of the waveguide system **1602**, or the waveguide system **1602** can determine its location using a GPS receiver (not shown) included in the waveguide system **1602**.

The power management system **1605** provides energy to the aforementioned components of the waveguide system **1602**. The power management system **1605** can receive energy from solar cells, or from a transformer (not shown)

coupled to the power line **1610**, or by inductive coupling to the power line **1610** or another nearby power line. The power management system **1605** can also include a backup battery and/or a super capacitor or other capacitor circuit for providing the waveguide system **1602** with temporary power. The loss of energy sensor **1604c** can be used to detect when the waveguide system **1602** has a loss of power condition and/or the occurrence of some other malfunction. For example, the loss of energy sensor **1604c** can detect when there is a loss of power due to defective solar cells, an obstruction on the solar cells that causes them to malfunction, loss of power on the power line **1610**, and/or when the backup power system malfunctions due to expiration of a backup battery, or a detectable defect in a super capacitor. When a malfunction and/or loss of power occurs, the loss of energy sensor **1604c** can notify the network management system **1601** by way of the base station **1614**.

The noise sensor **1604d** can be used to measure noise on the power line **1610** that may adversely affect transmission of electromagnetic waves on the power line **1610**. The noise sensor **1604d** can sense unexpected electromagnetic interference, noise bursts, or other sources of disturbances that may interrupt reception of modulated electromagnetic waves on a surface of a power line **1610**. A noise burst can be caused by, for example, a corona discharge, or other source of noise. The noise sensor **1604d** can compare the measured noise to a noise profile obtained by the waveguide system **1602** from an internal database of noise profiles or from a remotely located database that stores noise profiles via pattern recognition, an expert system, curve fitting, matched filtering or other artificial intelligence, classification or comparison technique. From the comparison, the noise sensor **1604d** may identify a noise source (e.g., corona discharge or otherwise) based on, for example, the noise profile that provides the closest match to the measured noise. The noise sensor **1604d** can also detect how noise affects transmissions by measuring transmission metrics such as bit error rate, packet loss rate, jitter, packet retransmission requests, etc. The noise sensor **1604d** can report to the network management system **1601** by way of the base station **1614** the identity of noise sources, their time of occurrence, and transmission metrics, among other things.

The vibration sensor **1604e** can include accelerometers and/or gyroscopes to detect 2D or 3D vibrations on the power line **1610**. The vibrations can be compared to vibration profiles that can be stored locally in the waveguide system **1602**, or obtained by the waveguide system **1602** from a remote database via pattern recognition, an expert system, curve fitting, matched filtering or other artificial intelligence, classification or comparison technique. Vibration profiles can be used, for example, to distinguish fallen trees from wind gusts based on, for example, the vibration profile that provides the closest match to the measured vibrations. The results of this analysis can be reported by the vibration sensor **1604e** to the network management system **1601** by way of the base station **1614**.

The environmental sensor **1604f** can include a barometer for measuring atmospheric pressure, ambient temperature (which can be provided by the temperature sensor **1604a**), wind speed, humidity, wind direction, and rainfall, among other things. The environmental sensor **1604f** can collect raw information and process this information by comparing it to environmental profiles that can be obtained from a memory of the waveguide system **1602** or a remote database to predict weather conditions before they arise via pattern recognition, an expert system, knowledge-based system or other artificial intelligence, classification or other weather

modeling and prediction technique. The environmental sensor **1604f** can report raw data as well as its analysis to the network management system **1601**.

The image sensor **1604g** can be a digital camera (e.g., a charged coupled device or CCD imager, infrared camera, etc.) for capturing images in a vicinity of the waveguide system **1602**. The image sensor **1604g** can include an electromechanical mechanism to control movement (e.g., actual position or focal points/zooms) of the camera for inspecting the power line **1610** from multiple perspectives (e.g., top surface, bottom surface, left surface, right surface and so on). Alternatively, the image sensor **1604g** can be designed such that no electromechanical mechanism is needed in order to obtain the multiple perspectives. The collection and retrieval of imaging data generated by the image sensor **1604g** can be controlled by the network management system **1601**, or can be autonomously collected and reported by the image sensor **1604g** to the network management system **1601**.

Other sensors that may be suitable for collecting telemetry information associated with the waveguide system **1602** and/or the power lines **1610** for purposes of detecting, predicting and/or mitigating disturbances that can impede the propagation of electromagnetic wave transmissions on power lines **1610** (or any other form of a transmission medium of electromagnetic waves) may be utilized by the waveguide system **1602**.

Referring now to FIG. **16B**, block diagram **1650** illustrates an example, non-limiting embodiment of a system for managing a power grid **1653** and a communication system **1655** embedded therein or associated therewith in accordance with various aspects described herein. The communication system **1655** comprises a plurality of waveguide systems **1602** coupled to power lines **1610** of the power grid **1653**. At least a portion of the waveguide systems **1602** used in the communication system **1655** can be in direct communication with a base station **1614** and/or the network management system **1601**. Waveguide systems **1602** not directly connected to a base station **1614** or the network management system **1601** can engage in communication sessions with either a base station **1614** or the network management system **1601** by way of other downstream waveguide systems **1602** connected to a base station **1614** or the network management system **1601**.

The network management system **1601** can be communicatively coupled to equipment of a utility company **1652** and equipment of a communications service provider **1654** for providing each entity, status information associated with the power grid **1653** and the communication system **1655**, respectively. The network management system **1601**, the equipment of the utility company **1652**, and the communications service provider **1654** can access communication devices utilized by utility company personnel **1656** and/or communication devices utilized by communications service provider personnel **1658** for purposes of providing status information and/or for directing such personnel in the management of the power grid **1653** and/or communication system **1655**.

FIG. **17A** illustrates a flow diagram of an example, non-limiting embodiment of a method **1700** for detecting and mitigating disturbances occurring in a communication network of the systems of FIGS. **16A** & **16B**. Method **1700** can begin with step **1702** where a waveguide system **1602** transmits and receives messages embedded in, or forming part of, modulated electromagnetic waves or another type of electromagnetic waves traveling along a surface of a power line **1610**. The messages can be voice messages, streaming

video, and/or other data/information exchanged between communication devices communicatively coupled to the communication system **1655**. At step **1704** the sensors **1604** of the waveguide system **1602** can collect sensing data. In an embodiment, the sensing data can be collected in step **1704** prior to, during, or after the transmission and/or receipt of messages in step **1702**. At step **1706** the waveguide system **1602** (or the sensors **1604** themselves) can determine from the sensing data an actual or predicted occurrence of a disturbance in the communication system **1655** that can affect communications originating from (e.g., transmitted by) or received by the waveguide system **1602**. The waveguide system **1602** (or the sensors **1604**) can process temperature data, signal reflection data, loss of energy data, noise data, vibration data, environmental data, or any combination thereof to make this determination. The waveguide system **1602** (or the sensors **1604**) may also detect, identify, estimate, or predict the source of the disturbance and/or its location in the communication system **1655**. If a disturbance is neither detected/identified nor predicted/estimated at step **1708**, the waveguide system **1602** can proceed to step **1702** where it continues to transmit and receive messages embedded in, or forming part of, modulated electromagnetic waves traveling along a surface of the power line **1610**.

If at step **1708** a disturbance is detected/identified or predicted/estimated to occur, the waveguide system **1602** proceeds to step **1710** to determine if the disturbance adversely affects (or alternatively, is likely to adversely affect or the extent to which it may adversely affect) transmission or reception of messages in the communication system **1655**. In one embodiment, a duration threshold and a frequency of occurrence threshold can be used at step **1710** to determine when a disturbance adversely affects communications in the communication system **1655**. For illustration purposes only, assume a duration threshold is set to 500 ms, while a frequency of occurrence threshold is set to 5 disturbances occurring in an observation period of 10 sec. Thus, a disturbance having a duration greater than 500 ms will trigger the duration threshold. Additionally, any disturbance occurring more than 5 times in a 10 sec time interval will trigger the frequency of occurrence threshold.

In one embodiment, a disturbance may be considered to adversely affect signal integrity in the communication systems **1655** when the duration threshold alone is exceeded. In another embodiment, a disturbance may be considered as adversely affecting signal integrity in the communication systems **1655** when both the duration threshold and the frequency of occurrence threshold are exceeded. The latter embodiment is thus more conservative than the former embodiment for classifying disturbances that adversely affect signal integrity in the communication system **1655**. It will be appreciated that many other algorithms and associated parameters and thresholds can be utilized for step **1710** in accordance with example embodiments.

Referring back to method **1700**, if at step **1710** the disturbance detected at step **1708** does not meet the condition for adversely affected communications (e.g., neither exceeds the duration threshold nor the frequency of occurrence threshold), the waveguide system **1602** may proceed to step **1702** and continue processing messages. For instance, if the disturbance detected in step **1708** has a duration of 1 msec with a single occurrence in a 10 sec time period, then neither threshold will be exceeded. Consequently, such a disturbance may be considered as having a nominal effect on signal integrity in the communication system **1655** and thus would not be flagged as a disturbance requiring mitigation. Although not flagged, the occurrence

of the disturbance, its time of occurrence, its frequency of occurrence, spectral data, and/or other useful information, may be reported to the network management system 1601 as telemetry data for monitoring purposes.

Referring back to step 1710, if on the other hand the disturbance satisfies the condition for adversely affected communications (e.g., exceeds either or both thresholds), the waveguide system 1602 can proceed to step 1712 and report the incident to the network management system 1601. The report can include raw sensing data collected by the sensors 1604, a description of the disturbance if known by the waveguide system 1602, a time of occurrence of the disturbance, a frequency of occurrence of the disturbance, a location associated with the disturbance, parameters readings such as bit error rate, packet loss rate, retransmission requests, jitter, latency and so on. If the disturbance is based on a prediction by one or more sensors of the waveguide system 1602, the report can include a type of disturbance expected, and if predictable, an expected time occurrence of the disturbance, and an expected frequency of occurrence of the predicted disturbance when the prediction is based on historical sensing data collected by the sensors 1604 of the waveguide system 1602.

At step 1714, the network management system 1601 can determine a mitigation, circumvention, or correction technique, which may include directing the waveguide system 1602 to reroute traffic to circumvent the disturbance if the location of the disturbance can be determined. In one embodiment, the waveguide coupling device 1402 detecting the disturbance may direct a repeater such as the one shown in FIGS. 13-14 to connect the waveguide system 1602 from a primary power line affected by the disturbance to a secondary power line to enable the waveguide system 1602 to reroute traffic to a different transmission medium and avoid the disturbance. In an embodiment where the waveguide system 1602 is configured as a repeater the waveguide system 1602 can itself perform the rerouting of traffic from the primary power line to the secondary power line. It is further noted that for bidirectional communications (e.g., full or half-duplex communications), the repeater can be configured to reroute traffic from the secondary power line back to the primary power line for processing by the waveguide system 1602.

In another embodiment, the waveguide system 1602 can redirect traffic by instructing a first repeater situated upstream of the disturbance and a second repeater situated downstream of the disturbance to redirect traffic from a primary power line temporarily to a secondary power line and back to the primary power line in a manner that avoids the disturbance. It is further noted that for bidirectional communications (e.g., full or half-duplex communications), repeaters can be configured to reroute traffic from the secondary power line back to the primary power line.

To avoid interrupting existing communication sessions occurring on a secondary power line, the network management system 1601 may direct the waveguide system 1602 to instruct repeater(s) to utilize unused time slot(s) and/or frequency band(s) of the secondary power line for redirecting data and/or voice traffic away from the primary power line to circumvent the disturbance.

At step 1716, while traffic is being rerouted to avoid the disturbance, the network management system 1601 can notify equipment of the utility company 1652 and/or equipment of the communications service provider 1654, which in turn may notify personnel of the utility company 1656 and/or personnel of the communications service provider 1658 of the detected disturbance and its location if known.

Field personnel from either party can attend to resolving the disturbance at a determined location of the disturbance. Once the disturbance is removed or otherwise mitigated by personnel of the utility company and/or personnel of the communications service provider, such personnel can notify their respective companies and/or the network management system 1601 utilizing field equipment (e.g., a laptop computer, smartphone, etc.) communicatively coupled to network management system 1601, and/or equipment of the utility company and/or the communications service provider. The notification can include a description of how the disturbance was mitigated and any changes to the power lines 1610 that may change a topology of the communication system 1655.

Once the disturbance has been resolved (as determined in decision 1718), the network management system 1601 can direct the waveguide system 1602 at step 1720 to restore the previous routing configuration used by the waveguide system 1602 or route traffic according to a new routing configuration if the restoration strategy used to mitigate the disturbance resulted in a new network topology of the communication system 1655. In another embodiment, the waveguide system 1602 can be configured to monitor mitigation of the disturbance by transmitting test signals on the power line 1610 to determine when the disturbance has been removed. Once the waveguide system 1602 detects an absence of the disturbance it can autonomously restore its routing configuration without assistance by the network management system 1601 if it determines the network topology of the communication system 1655 has not changed, or it can utilize a new routing configuration that adapts to a detected new network topology.

FIG. 17B illustrates a flow diagram of an example, non-limiting embodiment of a method 1750 for detecting and mitigating disturbances occurring in a communication network of the system of FIGS. 16A and 16B. In one embodiment, method 1750 can begin with step 1752 where a network management system 1601 receives from equipment of the utility company 1652 or equipment of the communications service provider 1654 maintenance information associated with a maintenance schedule. The network management system 1601 can at step 1754 identify from the maintenance information, maintenance activities to be performed during the maintenance schedule. From these activities, the network management system 1601 can detect a disturbance resulting from the maintenance (e.g., scheduled replacement of a power line 1610, scheduled replacement of a waveguide system 1602 on the power line 1610, scheduled reconfiguration of power lines 1610 in the power grid 1653, etc.).

In another embodiment, the network management system 1601 can receive at step 1755 telemetry information from one or more waveguide systems 1602. The telemetry information can include among other things an identity of each waveguide system 1602 submitting the telemetry information, measurements taken by sensors 1604 of each waveguide system 1602, information relating to predicted, estimated, or actual disturbances detected by the sensors 1604 of each waveguide system 1602, location information associated with each waveguide system 1602, an estimated location of a detected disturbance, an identification of the disturbance, and so on. The network management system 1601 can determine from the telemetry information a type of disturbance that may be adverse to operations of the waveguide, transmission of the electromagnetic waves along the wire surface, or both. The network management system 1601 can also use telemetry information from multiple

waveguide systems **1602** to isolate and identify the disturbance. Additionally, the network management system **1601** can request telemetry information from waveguide systems **1602** in a vicinity of an affected waveguide system **1602** to triangulate a location of the disturbance and/or validate an identification of the disturbance by receiving similar telemetry information from other waveguide systems **1602**.

In yet another embodiment, the network management system **1601** can receive at step **1756** an unscheduled activity report from maintenance field personnel. Unscheduled maintenance may occur as result of field calls that are unplanned or as a result of unexpected field issues discovered during field calls or scheduled maintenance activities. The activity report can identify changes to a topology configuration of the power grid **1653** resulting from field personnel addressing discovered issues in the communication system **1655** and/or power grid **1653**, changes to one or more waveguide systems **1602** (such as replacement or repair thereof), mitigation of disturbances performed if any, and so on.

At step **1758**, the network management system **1601** can determine from reports received according to steps **1752** through **1756** if a disturbance will occur based on a maintenance schedule, or if a disturbance has occurred or is predicted to occur based on telemetry data, or if a disturbance has occurred due to an unplanned maintenance identified in a field activity report. From any of these reports, the network management system **1601** can determine whether a detected or predicted disturbance requires rerouting of traffic by the affected waveguide systems **1602** or other waveguide systems **1602** of the communication system **1655**.

When a disturbance is detected or predicted at step **1758**, the network management system **1601** can proceed to step **1760** where it can direct one or more waveguide systems **1602** to reroute traffic to circumvent the disturbance. When the disturbance is permanent due to a permanent topology change of the power grid **1653**, the network management system **1601** can proceed to step **1770** and skip steps **1762**, **1764**, **1766**, and **1772**. At step **1770**, the network management system **1601** can direct one or more waveguide systems **1602** to use a new routing configuration that adapts to the new topology. However, when the disturbance has been detected from telemetry information supplied by one or more waveguide systems **1602**, the network management system **1601** can notify maintenance personnel of the utility company **1656** or the communications service provider **1658** of a location of the disturbance, a type of disturbance if known, and related information that may be helpful to such personnel to mitigate the disturbance. When a disturbance is expected due to maintenance activities, the network management system **1601** can direct one or more waveguide systems **1602** to reconfigure traffic routes at a given schedule (consistent with the maintenance schedule) to avoid disturbances caused by the maintenance activities during the maintenance schedule.

Returning back to step **1760** and upon its completion, the process can continue with step **1762**. At step **1762**, the network management system **1601** can monitor when the disturbance(s) have been mitigated by field personnel. Mitigation of a disturbance can be detected at step **1762** by analyzing field reports submitted to the network management system **1601** by field personnel over a communications network (e.g., cellular communication system) utilizing field equipment (e.g., a laptop computer or handheld computer/device). If field personnel have reported that a disturbance has been mitigated, the network management system **1601** can proceed to step **1764** to determine from the field report

whether a topology change was required to mitigate the disturbance. A topology change can include rerouting a power line **1610**, reconfiguring a waveguide system **1602** to utilize a different power line **1610**, otherwise utilizing an alternative link to bypass the disturbance and so on. If a topology change has taken place, the network management system **1601** can direct at step **1770** one or more waveguide systems **1602** to use a new routing configuration that adapts to the new topology.

If, however, a topology change has not been reported by field personnel, the network management system **1601** can proceed to step **1766** where it can direct one or more waveguide systems **1602** to send test signals to test a routing configuration that had been used prior to the detected disturbance(s). Test signals can be sent to affected waveguide systems **1602** in a vicinity of the disturbance. The test signals can be used to determine if signal disturbances (e.g., electromagnetic wave reflections) are detected by any of the waveguide systems **1602**. If the test signals confirm that a prior routing configuration is no longer subject to previously detected disturbance(s), then the network management system **1601** can at step **1772** direct the affected waveguide systems **1602** to restore a previous routing configuration. If, however, test signals analyzed by one or more waveguide coupling device **1402** and reported to the network management system **1601** indicate that the disturbance(s) or new disturbance(s) are present, then the network management system **1601** will proceed to step **1768** and report this information to field personnel to further address field issues. The network management system **1601** can in this situation continue to monitor mitigation of the disturbance(s) at step **1762**.

In the aforementioned embodiments, the waveguide systems **1602** can be configured to be self-adapting to changes in the power grid **1653** and/or to mitigation of disturbances. That is, one or more affected waveguide systems **1602** can be configured to self-monitor mitigation of disturbances and reconfigure traffic routes without requiring instructions to be sent to them by the network management system **1601**. In this embodiment, the one or more waveguide systems **1602** that are self-configurable can inform the network management system **1601** of its routing choices so that the network management system **1601** can maintain a macro-level view of the communication topology of the communication system **1655**.

While for purposes of simplicity of explanation, the respective processes are shown and described as a series of blocks in FIGS. **17A** and **17B**, respectively, it is to be understood and appreciated that the claimed subject matter is not limited by the order of the blocks, as some blocks may occur in different orders and/or concurrently with other blocks from what is depicted and described herein. Moreover, not all illustrated blocks may be required to implement the methods described herein.

Turning now to FIG. **18A**, a block diagram illustrating an example, non-limiting embodiment of a transmission medium **1800** for propagating guided electromagnetic waves is shown. In particular, a further example of transmission medium **125** presented in conjunction with FIG. **1** is presented. In an embodiment, the transmission medium **1800** can comprise a first dielectric material **1802** and a second dielectric material **1804** disposed thereon. In an embodiment, the first dielectric material **1802** can comprise a dielectric core (referred to herein as dielectric core **1802**) and the second dielectric material **1804** can comprise a cladding or shell such as a dielectric foam that surrounds in whole or in part the dielectric core (referred to herein as

dielectric foam **1804**). In an embodiment, the dielectric core **1802** and dielectric foam **1804** can be coaxially aligned to each other (although not necessary). In an embodiment, the combination of the dielectric core **1802** and the dielectric foam **1804** can be flexed or bent at least by 45 degrees without damaging the materials of the dielectric core **1802** and the dielectric foam **1804**. In an embodiment, an outer surface of the dielectric foam **1804** can be further surrounded in whole or in part by a third dielectric material **1806**, which can serve as an outer jacket (referred to herein as jacket **1806**). The jacket **1806** can prevent exposure of the dielectric core **1802** and the dielectric foam **1804** to an environment that can adversely affect the propagation of electromagnetic waves (e.g., water, soil, etc.).

The dielectric core **1802** can comprise, for example, a high density polyethylene material, a high density polyurethane material, or other suitable dielectric material(s). The dielectric foam **1804** can comprise, for example, a cellular plastic material such as an expanded polyethylene material, or other suitable dielectric material(s). The jacket **1806** can comprise, for example, a polyethylene material or equivalent. In an embodiment, the dielectric constant of the dielectric foam **1804** can be (or substantially) lower than the dielectric constant of the dielectric core **1802**. For example, the dielectric constant of the dielectric core **1802** can be approximately 2.3 while the dielectric constant of the dielectric foam **1804** can be approximately 1.15 (slightly higher than the dielectric constant of air).

The dielectric core **1802** can be used for receiving signals in the form of electromagnetic waves from a launcher or other coupling device described herein which can be configured to launch guided electromagnetic waves on the transmission medium **1800**. In one embodiment, the transmission **1800** can be coupled to a hollow waveguide **1808** structured as, for example, a circular waveguide **1809**, which can receive electromagnetic waves from a radiating device such as a stub antenna (not shown). The hollow waveguide **1808** can in turn induce guided electromagnetic waves in the dielectric core **1802**. In this configuration, the guided electromagnetic waves are guided by or bound to the dielectric core **1802** and propagate longitudinally along the dielectric core **1802**. By adjusting electronics of the launcher, an operating frequency of the electromagnetic waves can be chosen such that a field intensity profile **1810** of the guided electromagnetic waves extends nominally (or not at all) outside of the jacket **1806**.

By maintaining most (if not all) of the field strength of the guided electromagnetic waves within portions of the dielectric core **1802**, the dielectric foam **1804** and/or the jacket **1806**, the transmission medium **1800** can be used in hostile environments without adversely affecting the propagation of the electromagnetic waves propagating therein. For example, the transmission medium **1800** can be buried in soil with no (or nearly no) adverse effect to the guided electromagnetic waves propagating in the transmission medium **1800**. Similarly, the transmission medium **1800** can be exposed to water (e.g., rain or placed underwater) with no (or nearly no) adverse effect to the guided electromagnetic waves propagating in the transmission medium **1800**. In an embodiment, the propagation loss of guided electromagnetic waves in the foregoing embodiments can be 1 to 2 dB per meter or better at an operating frequency of 60 GHz. Depending on the operating frequency of the guided electromagnetic waves and/or the materials used for the transmission medium **1800** other propagation losses may be possible. Additionally, depending on the materials used to construct the transmission medium **1800**, the transmission

medium **1800** can in some embodiments be flexed laterally with no (or nearly no) adverse effect to the guided electromagnetic waves propagating through the dielectric core **1802** and the dielectric foam **1804**.

FIG. **18B** depicts a transmission medium **1820** that differs from the transmission medium **1800** of FIG. **18A**, yet provides a further example of the transmission medium **125** presented in conjunction with FIG. **1**. The transmission medium **1820** shows similar reference numerals for similar elements of the transmission medium **1800** of FIG. **18A**. In contrast to the transmission medium **1800**, the transmission medium **1820** comprises a conductive core **1822** having an insulation layer **1823** surrounding the conductive core **1822** in whole or in part. The combination of the insulation layer **1823** and the conductive core **1822** will be referred to herein as an insulated conductor **1825**. In the illustration of FIG. **18B**, the insulation layer **1823** is covered in whole or in part by a dielectric foam **1804** and jacket **1806**, which can be constructed from the materials previously described. In an embodiment, the insulation layer **1823** can comprise a dielectric material, such as polyethylene, having a higher dielectric constant than the dielectric foam **1804** (e.g., 2.3 and 1.15, respectively). In an embodiment, the components of the transmission medium **1820** can be coaxially aligned (although not necessary). In an embodiment, a hollow waveguide **1808** having metal plates **1809**, which can be separated from the insulation layer **1823** (although not necessary) can be used to launch guided electromagnetic waves that substantially propagate on an outer surface of the insulation layer **1823**, however other coupling devices as described herein can likewise be employed. In an embodiment, the guided electromagnetic waves can be sufficiently guided by or bound by the insulation layer **1823** to guide the electromagnetic waves longitudinally along the insulation layer **1823**. By adjusting operational parameters of the launcher, an operating frequency of the guided electromagnetic waves launched by the hollow waveguide **1808** can generate an electric field intensity profile **1824** that results in the guided electromagnetic waves being substantially confined within the dielectric foam **1804** thereby preventing the guided electromagnetic waves from being exposed to an environment (e.g., water, soil, etc.) that adversely affects propagation of the guided electromagnetic waves via the transmission medium **1820**.

FIG. **18C** depicts a transmission medium **1830** that differs from the transmission mediums **1800** and **1820** of FIGS. **18A** and **18B**, yet provides a further example of the transmission medium **125** presented in conjunction with FIG. **1**. The transmission medium **1830** shows similar reference numerals for similar elements of the transmission mediums **1800** and **1820** of FIGS. **18A** and **18B**, respectively. In contrast to the transmission mediums **1800** and **1820**, the transmission medium **1830** comprises a bare (or uninsulated) conductor **1832** surrounded in whole or in part by the dielectric foam **1804** and the jacket **1806**, which can be constructed from the materials previously described. In an embodiment, the components of the transmission medium **1830** can be coaxially aligned (although not necessary). In an embodiment, a hollow waveguide **1808** having metal plates **1809** coupled to the bare conductor **1832** can be used to launch guided electromagnetic waves that substantially propagate on an outer surface of the bare conductor **1832**, however other coupling devices described herein can likewise be employed. In an embodiment, the guided electromagnetic waves can be sufficiently guided by or bound by the bare conductor **1832** to guide the guided electromagnetic waves longitudinally along the bare conductor **1832**. By

adjusting operational parameters of the launcher, an operating frequency of the guided electromagnetic waves launched by the hollow waveguide **1808** can generate an electric field intensity profile **1834** that results in the guided electromagnetic waves being substantially confined within the dielectric foam **1804** thereby preventing the guided electromagnetic waves from being exposed to an environment (e.g., water, soil, etc.) that adversely affects propagation of the electromagnetic waves via the transmission medium **1830**.

It should be noted that the hollow launcher **1808** used with the transmission mediums **1800**, **1820** and **1830** of FIGS. **18A**, **18B** and **18C**, respectively, can be replaced with other launchers or coupling devices. Additionally, the propagation mode(s) of the electromagnetic waves for any of the foregoing embodiments can be fundamental mode(s), a non-fundamental (or asymmetric) mode(s), or combinations thereof.

FIG. **18D** is a block diagram illustrating an example, non-limiting embodiment of bundled transmission media **1836** in accordance with various aspects described herein. The bundled transmission media **1836** can comprise a plurality of cables **1838** held in place by a flexible sleeve **1839**. The plurality of cables **1838** can comprise multiple instances of cable **1800** of FIG. **18A**, multiple instances of cable **1820** of FIG. **18B**, multiple instances of cable **1830** of FIG. **18C**, or any combinations thereof. The sleeve **1839** can comprise a dielectric material that prevents soil, water or other external materials from making contact with the plurality of cables **1838**. In an embodiment, a plurality of launchers, each utilizing a transceiver similar to the one depicted in FIG. **10A** or other coupling devices described herein, can be adapted to selectively induce a guided electromagnetic wave in each cable, each guided electromagnetic wave conveys different data (e.g., voice, video, messaging, content, etc.). In an embodiment, by adjusting operational parameters of each launcher or other coupling device, the electric field intensity profile of each guided electromagnetic wave can be fully or substantially confined within layers of a corresponding cable **1838** to reduce cross-talk between cables **1838**.

In situations where the electric field intensity profile of each guided electromagnetic wave is not fully or substantially confined within a corresponding cable **1838**, cross-talk of electromagnetic signals can occur between cables **1838** as illustrated by signal plots associated with two cables depicted in FIG. **18E**. The plots in FIG. **18E** show that when a guided electromagnetic wave is induced on a first cable, the emitted electric and magnetic fields of the first cable can induce signals on the second cable, which results in cross-talk. Several mitigation options can be used to reduce cross-talk between the cables **1838** of FIG. **18D**. In an embodiment, an absorption material **1840** that can absorb electromagnetic fields, such as carbon, can be applied to the cables **1838** as shown in FIG. **18F** to polarize each guided electromagnetic wave at various polarization states to reduce cross-talk between cables **1838**. In another embodiment (not shown), carbon beads can be added to gaps between the cables **1838** to reduce cross-talk.

In yet another embodiment (not shown), a diameter of cable **1838** can be configured differently to vary a speed of propagation of guided electromagnetic waves between the cables **1838** in order to reduce cross-talk between cables **1838**. In an embodiment (not shown), a shape of each cable **1838** can be made asymmetric (e.g., elliptical) to direct the guided electromagnetic fields of each cable **1838** away from each other to reduce cross-talk. In an embodiment (not shown), a filler material such as dielectric foam can be added between cables **1838** to sufficiently separate the cables **1838**

to reduce cross-talk therebetween. In an embodiment (not shown), longitudinal carbon strips or swirls can be applied to on an outer surface of the jacket **1806** of each cable **1838** to reduce radiation of guided electromagnetic waves outside of the jacket **1806** and thereby reduce cross-talk between cables **1838**. In yet another embodiment, each launcher can be configured to launch a guided electromagnetic wave having a different frequency, modulation, wave propagation mode, such as an orthogonal frequency, modulation or mode, to reduce cross-talk between the cables **1838**.

In yet another embodiment (not shown), pairs of cables **1838** can be twisted in a helix to reduce cross-talk between the pairs and other cables **1838** in a vicinity of the pairs. In some embodiments, certain cables **1838** can be twisted while other cables **1838** are not twisted to reduce cross-talk between the cables **1838**. Additionally, each twisted pair cable **1838** can have different pitches (i.e., different twist rates, such as twists per meter) to further reduce cross-talk between the pairs and other cables **1838** in a vicinity of the pairs. In another embodiment (not shown), launchers or other coupling devices can be configured to induce guided electromagnetic waves in the cables **1838** having electromagnetic fields that extend beyond the jacket **1806** into gaps between the cables to reduce cross-talk between the cables **1838**. It is submitted that any one of the foregoing embodiments for mitigating cross-talk between cables **1838** can be combined to further reduce cross-talk therebetween.

FIGS. **18G** and **18H** are block diagrams illustrating example, non-limiting embodiments of a transmission medium with an inner waveguide in accordance with various aspects described herein. In an embodiment, a transmission medium **1841** can comprise a core **1842**. In one embodiment, the core **1842** can be a dielectric core **1842** (e.g., polyethylene). In another embodiment, the core **1842** can be an insulated or uninsulated conductor. The core **1842** can be surrounded by a shell **1844** comprising a dielectric foam (e.g., expanded polyethylene material) having a lower dielectric constant than the dielectric constant of a dielectric core, or insulation layer of a conductive core. The difference in dielectric constants enables electromagnetic waves to be bound and guided by the core **1842**. The shell **1844** can be covered by a shell jacket **1845**. The shell jacket **1845** can be made of rigid material (e.g., high density plastic) or a high tensile strength material (e.g., synthetic fiber). In an embodiment, the shell jacket **1845** can be used to prevent exposure of the shell **1844** and core **1842** from an adverse environment (e.g., water, moisture, soil, etc.). In an embodiment, the shell jacket **1845** can be sufficiently rigid to separate an outer surface of the core **1842** from an inner surface of the shell jacket **1845** thereby resulting in a longitudinal gap between the shell jacket **1845** and the core **1842**. The longitudinal gap can be filled with the dielectric foam of the shell **1844**.

The transmission medium **1841** can further include a plurality of outer ring conductors **1846**. The outer ring conductors **1846** can be strands of conductive material that are woven around the shell jacket **1845**, thereby covering the shell jacket **1845** in whole or in part. The outer ring conductors **1846** can serve the function of a power line having a return electrical path similar to the embodiments described in the subject disclosure for receiving power signals from a source (e.g., a transformer, a power generator, etc.). In one embodiment, the outer ring conductors **1846** can be covered by a cable jacket **1847** to prevent exposure of the outer ring conductors **1846** to water, soil, or other environmental factors. The cable jacket **1847** can be made of an insulating material such as polyethylene. The core **1842** can be used as a center waveguide for the propagation of

electromagnetic waves. A hollow waveguide launcher **1808**, such as the circular waveguide previously described, can be used to launch signals that induce electromagnetic waves guided by the core **1842** in ways similar to those described for the embodiments of FIGS. **18A**, **18B**, and **18C**. The electromagnetic waves can be guided by the core **1842** without utilizing the electrical return path of the outer ring conductors **1846** or any other electrical return path. By adjusting electronics of the launcher **1808**, an operating frequency of the electromagnetic waves can be chosen such that a field intensity profile of the guided electromagnetic waves extends nominally (or not at all) outside of the shell jacket **1845**.

In another embodiment, a transmission medium **1843** can comprise a hollow core **1842'** surrounded by a shell jacket **1845'**. The shell jacket **1845'** can have an inner conductive surface or other surface materials that enable the hollow core **1842'** to be used as a conduit for electromagnetic waves. The shell jacket **1845'** can be covered at least in part with the outer ring conductors **1846** described earlier for conducting a power signal. In an embodiment, a cable jacket **1847** can be disposed on an outer surface of the outer ring conductors **1846** to prevent exposure of the outer ring conductors **1846** to water, soil or other environmental factors. A waveguide launcher **1808** can be used to launch electromagnetic waves guided by the hollow core **1842'** and the conductive inner surface of the shell jacket **1845'**. In an embodiment (not shown) the hollow core **1842'** can further include a dielectric foam such as described earlier.

Transmission medium **1841** can represent a multi-purpose cable that conducts power on the outer ring conductors **1846** utilizing an electrical return path and that provides communication services by way of an inner waveguide comprising a combination of the core **1842**, the shell **1844** and the shell jacket **1845**. The inner waveguide can be used for transmitting or receiving electromagnetic waves (without utilizing an electrical return path) guided by the core **1842**. Similarly, transmission medium **1843** can represent a multi-purpose cable that conducts power on the outer ring conductors **1846** utilizing an electrical return path and that provides communication services by way of an inner waveguide comprising a combination of the hollow core **1842'** and the shell jacket **1845'**. The inner waveguide can be used for transmitting or receiving electromagnetic waves (without utilizing an electrical return path) guided the hollow core **1842'** and the shell jacket **1845'**.

It is submitted that embodiments of FIGS. **18G-18H** can be adapted to use multiple inner waveguides surrounded by outer ring conductors **1846**. The inner waveguides can be adapted to use to cross-talk mitigation techniques described above (e.g., twisted pairs of waveguides, waveguides of different structural dimensions, use of polarizers within the shell, use of different wave modes, etc.).

For illustration purposes only, the transmission mediums **1800**, **1820**, **1830** **1836**, **1841** and **1843** will be referred to herein as a cable **1850** with an understanding that cable **1850** can represent any one of the transmission mediums described in the subject disclosure, or a bundling of multiple instances thereof. For illustration purposes only, the dielectric core **1802**, insulated conductor **1825**, bare conductor **1832**, core **1842**, or hollow core **1842'** of the transmission mediums **1800**, **1820**, **1830**, **1836**, **1841** and **1843**, respectively, will be referred to herein as transmission core **1852** with an understanding that cable **1850** can utilize the dielectric core **1802**, insulated conductor **1825**, bare conductor

1832, core **1842**, or hollow core **1842'** of transmission mediums **1800**, **1820**, **1830**, **1836**, **1841** and/or **1843**, respectively.

Turning now to FIGS. **18I** and **18J**, block diagrams illustrating example, non-limiting embodiments of connector configurations that can be used by cable **1850** are shown. In one embodiment, cable **1850** can be configured with a female connection arrangement or a male connection arrangement as depicted in FIG. **18I**. The male configuration on the right of FIG. **18I** can be accomplished by stripping the dielectric foam **1804** (and jacket **1806** if there is one) to expose a portion of the transmission core **1852**. The female configuration on the left of FIG. **18I** can be accomplished by removing a portion of the transmission core **1852**, while maintaining the dielectric foam **1804** (and jacket **1806** if there is one). In an embodiment in which the transmission core **1852** is hollow as described in relation to FIG. **18H**, the male portion of the transmission core **1852** can represent a hollow core with a rigid outer surface that can slide into the female arrangement on the left side of FIG. **18I** to align the hollow cores together. It is further noted that in the embodiments of FIGS. **18G-18H**, the outer ring of conductors **1846** can be modified to connect male and female portions of cable **1850**.

Based on the aforementioned embodiments, the two cables **1850** having male and female connector arrangements can be mated together. A sleeve with an adhesive inner lining or a shrink wrap material (not shown) can be applied to an area of a joint between cables **1850** to maintain the joint in a fixed position and prevent exposure (e.g., to water, soil, etc.). When the cables **1850** are mated, the transmission core **1852** of one cable will be in close proximity to the transmission core **1852** of the other cable. Guided electromagnetic waves propagating by way of either the transmission core **1852** of cables **1850** traveling from either direction can cross over between the disjoint the transmission cores **1852** whether or not the transmission cores **1852** touch, whether or not the transmission cores **1852** are coaxially aligned, and/or whether or not there is a gap between the transmission cores **1852**.

In another embodiment, a splicing device **1860** having female connector arrangements at both ends can be used to mate cables **1850** having male connector arrangements as shown in FIG. **18J**. In an alternative embodiment not shown in FIG. **18J**, the splicing device **1860** can be adapted to have male connector arrangements at both ends which can be mated to cables **1850** having female connector arrangements. In another embodiment not shown in FIG. **18J**, the splicing device **1860** can be adapted to have a male connector arrangement and a female connector arrangement at opposite ends which can be mated to cables **1850** having female and male connector arrangements, respectively. It is further noted that for a transmission core **1852** having a hollow core, the male and female arrangements described in FIG. **18I** can be applied to the splicing device **1860** whether the ends of the splicing device **1860** are both male, both female, or a combination thereof.

The foregoing embodiments for connecting cables illustrated in FIGS. **18I-18J** can be applied to each single instance of cable **1838** of bundled transmission media **1836**. Similarly, the foregoing embodiments illustrated in FIGS. **18I-18J** can be applied to each single instance of an inner waveguide for a cable **1841** or **1843** having multiple inner waveguides.

Turning now to FIG. **18K**, a block diagram illustrating example, non-limiting embodiments of transmission mediums **1800'**, **1800''**, **1800'''** and **1800''''** for propagating guided

electromagnetic waves is shown. In an embodiment, a transmission medium **1800'** can include a core **1801**, and a dielectric foam **1804'** divided into sections and covered by a jacket **1806** as shown in FIG. **18K**. The core **1801** can be represented by the dielectric core **1802** of FIG. **18A**, the insulated conductor **1825** of FIG. **18B**, or the bare conductor **1832** of FIG. **18C**. Each section of dielectric foam **1804'** can be separated by a gap (e.g., air, gas, vacuum, or a substance with a low dielectric constant). In an embodiment, the gap separations between the sections of dielectric foam **1804'** can be quasi-random as shown in FIG. **18K**, which can be helpful in reducing reflections of electromagnetic waves occurring at each section of dielectric foam **1804'** as they propagate longitudinally along the core **1801**. The sections of the dielectric foam **1804'** can be constructed, for example, as washers made of a dielectric foam having an inner opening for supporting the core **1801** in a fixed position. For illustration purposes only, the washers will be referred to herein as washers **1804'**. In an embodiment, the inner opening of each washer **1804'** can be coaxially aligned with an axis of the core **1801**. In another embodiment, the inner opening of each washer **1804'** can be offset from the axis of the core **1801**. In another embodiment (not shown), each washer **1804'** can have a variable longitudinal thickness as shown by differences in thickness of the washers **1804'**.

In an alternative embodiment, a transmission medium **1800''** can include a core **1801**, and a strip of dielectric foam **1804''** wrapped around the core in a helix covered by a jacket **1806** as shown in FIG. **18K**. Although it may not be apparent from the drawing shown in FIG. **18K**, in an embodiment the strip of dielectric foam **1804''** can be twisted around the core **1801** with variable pitches (i.e., different twist rates) for different sections of the strip of dielectric foam **1804''**. Utilizing variable pitches can help reduce reflections or other disturbances of the electromagnetic waves occurring between areas of the core **1801** not covered by the strip of dielectric foam **1804''**. It is further noted that the thickness (diameter) of the strip of dielectric foam **1804''** can be substantially larger (e.g., 2 or more times larger) than diameter of the core **1801** shown in FIG. **18K**.

In an alternative embodiment, a transmission medium **1800'''** (shown in a cross-sectional view) can include a non-circular core **1801'** covered by a dielectric foam **1804** and jacket **1806**. In an embodiment, the non-circular core **1801'** can have an elliptical structure as shown in FIG. **18K**, or other suitable non-circular structure. In another embodiment, the non-circular core **1801'** can have an asymmetric structure. A non-circular core **1801'** can be used to polarize the fields of electromagnetic waves induced on the non-circular core **1801'**. The structure of the non-circular core **1801'** can help preserve the polarization of the electromagnetic waves as they propagate along the non-circular core **1801'**.

In an alternative embodiment, a transmission medium **1800''''** (shown in a cross-sectional view) can include multiple cores **1801''** (only two cores are shown but more are possible). The multiple cores **1801''** can be covered by a dielectric foam **1804** and jacket **1806**. The multiple cores **1801''** can be used to polarize the fields of electromagnetic waves induced on the multiple cores **1801''**. The structure of the multiple cores **1801''** can preserve the polarization of the guided electromagnetic waves as they propagate along the multiple cores **1801''**.

It will be appreciated that the embodiments of FIG. **18K** can be used to modify the embodiments of FIGS. **18G-18H**. For example, core **1842** or core **1842'** can be adapted to utilized sectionalized shells **1804'** with gaps therebetween,

or one or more strips of dielectric foam **1804''**. Similarly, core **1842** or core **1842'** can be adapted to have a non-circular core **1801'** that may have symmetric or asymmetric cross-sectional structure. Additionally, core **1842** or core **1842'** can be adapted to use multiple cores **1801''** in a single inner waveguide, or different numbers of cores when multiple inner waveguides are used. Accordingly, any of the embodiments shown in FIG. **18K** can be applied singly or in combination to the embodiments of **18G-18H**.

Turning now to FIG. **18L** is a block diagram illustrating example, non-limiting embodiments of bundled transmission media to mitigate cross-talk in accordance with various aspects described herein. In an embodiment, a bundled transmission medium **1836'** can include variable core structures **1803**. By varying the structures of cores **1803**, fields of guided electromagnetic waves induced in each of the cores of transmission medium **1836'** may differ sufficiently to reduce cross-talk between cables **1838**. In another embodiment, a bundled transmission media **1836''** can include a variable number of cores **1803'** per cable **1838**. By varying the number of cores **1803'** per cable **1838**, fields of guided electromagnetic waves induced in the one or more cores of transmission medium **1836''** may differ sufficiently to reduce cross-talk between cables **1838**. In another embodiment, the cores **1803** or **1803'** can be of different materials. For example, the cores **1803** or **1803'** can be a dielectric core **1802**, an insulated conductor core **1825**, a bare conductor core **1832**, or any combinations thereof.

It is noted that the embodiments illustrated in FIGS. **18A-18D** and **18F-18H** can be modified by and/or combined with some of the embodiments of FIGS. **18K-18L**. It is further noted that one or more of the embodiments illustrated in FIGS. **18K-18L** can be combined (e.g., using sectionalized dielectric foam **1804'** or a helix strip of dielectric foam **1804''** with cores **1801'**, **1801''**, **1803** or **1803'**). In some embodiments guided electromagnetic waves propagating in the transmission mediums **1800'**, **1800''**, **1800'''**, and/or **1800''''** of FIG. **18K** may experience less propagation losses than guided electromagnetic waves propagating in the transmission mediums **1800**, **1820** and **1830** of FIGS. **18A-18C**. Additionally, the embodiments illustrated in FIGS. **18K-18L** can be adapted to use the connectivity embodiments illustrated in FIGS. **18I-18J**.

Turning now to FIG. **18M**, a block diagram illustrating an example, non-limiting embodiment of exposed tapered stubs from the bundled transmission media **1836** for use as antennas **1855** is shown. Each antenna **1855** can serve as a directional antenna for radiating wireless signals directed to wireless communication devices or for inducing electromagnetic wave propagation on a surface of a transmission medium (e.g., a power line). In an embodiment, the wireless signals radiated by the antennas **1855** can be beam steered by adapting the phase and/or other characteristics of the wireless signals generated by each antenna **1855**. In an embodiment, the antennas **1855** can individually be placed in a pie-pan antenna assembly for directing wireless signals in various directions.

It is further noted that the terms "core", "cladding", "shell", and "foam" as utilized in the subject disclosure can comprise any types of materials (or combinations of materials) that enable electromagnetic waves to remain bound to the core while propagating longitudinally along the core. For example, a strip of dielectric foam **1804'** described earlier can be replaced with a strip of an ordinary dielectric material (e.g., polyethylene) for wrapping around the dielectric core **1802** (referred to herein for illustration purposes only as a "wrap"). In this configuration an average density of the wrap

can be small as a result of air space between sections of the wrap. Consequently, an effective dielectric constant of the wrap can be less than the dielectric constant of the dielectric core **1802**, thereby enabling guided electromagnetic waves to remain bound to the core. Accordingly, any of the embodiments of the subject disclosure relating to materials used for core(s) and wrappings about the core(s) can be structurally adapted and/or modified with other dielectric materials that achieve the result of maintaining electromagnetic waves bound to the core(s) while they propagate along the core(s). Additionally, a core in whole or in part as described in any of the embodiments of the subject disclosure can comprise an opaque material (e.g., polyethylene). Accordingly, electromagnetic waves guided and bound to the core will have a non-optical frequency range (e.g., less than the lowest frequency of visible light).

FIGS. **18N**, **18O**, **18P**, **18Q**, **18R**, **18S** and **18T** are block diagrams illustrating example, non-limiting embodiments of waveguide devices for transmitting or receiving electromagnetic waves in accordance with various aspects described herein. In an embodiment, FIG. **18N** illustrates a front view of a waveguide system **1865** having a plurality of slots **1863** (e.g., openings or apertures) for emitting electromagnetic waves having radiated electric fields (e-fields) **1861**. In an embodiment, the radiated e-fields **1861** of pairs of symmetrically positioned slots **1863** (e.g., north and south slots of the waveguide system **1865**) can be directed away from each other (i.e., polar opposite radial orientations about the cable **1862**). While the slots **1863** are shown as having a rectangular shape, other shapes such as other polygons, sector and arc shapes, ellipsoid shapes and other shapes are likewise possible. For illustration purposes only, the term north will refer to a relative direction as shown in the figures. All references in the subject disclosure to other directions (e.g., south, east, west, northwest, and so forth) will be relative to northern illustration. In an embodiment, to achieve e-fields with opposing orientations at the north and south slots **1863**, for example, the north and south slots **1863** can be arranged to have a circumferential distance between each other that is approximately one wavelength of electromagnetic waves signals supplied to these slots. The waveguide system **1865** can have a cylindrical cavity in a center of the waveguide system **1865** to enable placement of a cable **1862**. In one embodiment, the cable **1862** can comprise an insulated conductor. In another embodiment, the cable **1862** can comprise an uninsulated conductor. In yet other embodiments, the cable **1862** can comprise any of the embodiments of a transmission core **1852** of cable **1850** previously described.

In one embodiment, the cable **1862** can slide into the cylindrical cavity of the waveguide system **1865**. In another embodiment, the waveguide system **1865** can utilize an assembly mechanism (not shown). The assembly mechanism (e.g., a hinge or other suitable mechanism that provides a way to open the waveguide system **1865** at one or more locations) can be used to enable placement of the waveguide system **1865** on an outer surface of the cable **1862** or otherwise to assemble separate pieces together to form the waveguide system **1865** as shown. According to these and other suitable embodiments, the waveguide system **1865** can be configured to wrap around the cable **1862** like a collar.

FIG. **18O** illustrates a side view of an embodiment of the waveguide system **1865**. The waveguide system **1865** can be adapted to have a hollow rectangular waveguide portion **1867** that receives electromagnetic waves **1866** generated by a transmitter circuit as previously described in the subject disclosure (e.g., see reference **101**, **1000** of FIGS. **1** and

10A). The electromagnetic waves **1866** can be distributed by the hollow rectangular waveguide portion **1867** into in a hollow collar **1869** of the waveguide system **1865**. The rectangular waveguide portion **1867** and the hollow collar **1869** can be constructed of materials suitable for maintaining the electromagnetic waves within the hollow chambers of these assemblies (e.g., carbon fiber materials). It should be noted that while the waveguide portion **1867** is shown and described in a hollow rectangular configuration, other shapes and/or other non-hollow configurations can be employed. In particular, the waveguide portion **1867** can have a square or other polygonal cross section, an arc or sector cross section that is truncated to conform to the outer surface of the cable **1862**, a circular or ellipsoid cross section or cross sectional shape. In addition, the waveguide portion **1867** can be configured as, or otherwise include, a solid dielectric material.

As previously described, the hollow collar **1869** can be configured to emit electromagnetic waves from each slot **1863** with opposite e-fields **1861** at pairs of symmetrically positioned slots **1863** and **1863'**. In an embodiment, the electromagnetic waves emitted by the combination of slots **1863** and **1863'** can in turn induce electromagnetic waves **1868** on that are bound to the cable **1862** for propagation according to a fundamental wave mode without other wave modes present—such as non-fundamental wave modes. In this configuration, the electromagnetic waves **1868** can propagate longitudinally along the cable **1862** to other downstream waveguide systems coupled to the cable **1862**.

It should be noted that since the hollow rectangular waveguide portion **1867** of FIG. **18O** is closer to slot **1863** (at the northern position of the waveguide system **1865**), slot **1863** can emit electromagnetic waves having a stronger magnitude than electromagnetic waves emitted by slot **1863'** (at the southern position). To reduce magnitude differences between these slots, slot **1863'** can be made larger than slot **1863**. The technique of utilizing different slot sizes to balance signal magnitudes between slots can be applied to any of the embodiments of the subject disclosure relating to FIGS. **18N**, **18O**, **18Q**, **18S**, **18U** and **18V**—some of which are described below.

In another embodiment, FIG. **18P** depicts a waveguide system **1865'** that can be configured to utilize circuitry such as monolithic microwave integrated circuits (MMICs) **1870** each coupled to a signal input **1872** (e.g., coaxial cable or other signal input that provides a communication signal). The signal input **1872** can be generated by a transmitter circuit as previously described in the subject disclosure (e.g., see reference **101**, **1000** of FIGS. **1** and **10A**) adapted to provide electrical signals to the MMICs **1870**. Each MMIC **1870** can be configured to receive signal **1872** which the MMIC **1870** can modulate and transmit with a radiating element (e.g., an antenna or other device) to emit electromagnetic waves having radiated e-fields **1861**. In one embodiment, the MMICs **1870** can be configured to receive the same signal **1872**, but transmit electromagnetic waves having e-fields **1861** of different orientations. This can be accomplished by configuring one of the MMICs **1870** to transmit electromagnetic waves that are at a controllable phase from the electromagnetic waves transmitted by the other MMIC **1870**. In the example shown, the e-fields **1861** are generated with opposing phases (180 degrees out of phase), however other configurations, including transmission of signals in phase with one another are likewise possible, depending on the selected guided wave mode to be generated. In an embodiment, the combination of the electromagnetic waves emitted by the MMICs **1870** can together

induce electromagnetic waves **1868** that are bound to the cable **1862** for propagation according to a particular wave mode without other wave modes present. In this configuration, the electromagnetic waves **1868** can propagate longitudinally along the cable **1862** to other downstream waveguide systems coupled to the cable **1862**.

In various embodiments a reflective plate **1871** is also included in a region behind the radiating elements of the MMICs **1870** relative to the direction of propagation of the electromagnetic wave **1868** that is guided by the cable **1862**, indicated by the wave direction arrow that is shown. The reflective plate can be constructed of a metallic plate, a metallic coated surface, a wire mesh having a density sufficient to reflect electromagnetic waves travelling toward the reflective plate **1871** from the MMICs **1870**, or other reflective plate.

In operation, the reflective plate **1871** aids in directing the instances of the electromagnetic waves **1861** to an interface of a transmission medium, such as the surface of the cable **1862**, to induce propagation of the electromagnetic wave **1868** along the cable **1862**. For example, the reflective plate **1871** can be shorted to ground and/or the outer housing of the waveguide system **1865** to as to interact with the e-fields **1861** generated by the MMICs.

In the embodiment shown, the reflective plate **1871** is positioned inside the outer housing of the waveguide system **1865'** in a configuration that is perpendicular to the longitudinal axis of the cable **1862** and the wave direction, and optionally is parallel to a plane containing the radiating elements of the MMICs **1870**, however other configurations are likewise possible. In various embodiments, the distance **d1** between the reflective plate and the radiating elements of the MMICs **1870** can be adjusted or otherwise set to support inducing the propagation of the electromagnetic wave **1868** via a selected fundamental or non-fundamental wave mode such as such as TM_{00} , HE_{11} , EH_{1m} , TM_{0m} , (where $m=1, 2, \dots$) or other non-fundamental and/or asymmetrical mode at a chosen frequency of operation. For example, the distance **d1** can be adjusted incrementally to determine the particular value of **d1** that yields the greatest signal strength of one or more selected modes of the electromagnetic wave **1868**.

A tapered horn **1880**, such as a conductive horn, or other coaxial reflector can be added to the embodiments of FIGS. **18O** and **18P** to assist in directing the e-fields **1861** for the induction of the electromagnetic waves **1868** on cable **1862** as depicted in FIGS. **18Q** and **18R**. While a particular configuration of a tapered horn **1880** is shown, other configurations of cones including a flared cone, a pyramidal horn or other horn designs could likewise be employed.

In an embodiment where the cable **1862** is an uninsulated conductor, the electromagnetic waves induced on the cable **1862** can have a large radial dimension (e.g., 1 meter). To enable use of a smaller tapered horn **1880**, an insulation layer **1879** can be applied on a portion of the cable **1862** at or near the cavity as depicted with hash lines in FIGS. **18Q** and **18R**. The insulation layer **1879** can have a tapered end facing away from the waveguide system **1865**. The added insulation enables the electromagnetic waves **1868** initially launched by the waveguide system **1865** (or **1865'**) to be tightly bound to the insulation, which in turn reduces the radial dimension of the electromagnetic fields **1868** (e.g., centimeters). As the electromagnetic waves **1868** propagate away from the waveguide system **1865** (**1865'**) and reach the tapered end of the insulation layer **1879**, the radial dimension of the electromagnetic waves **1868** begin to increase eventually achieving the radial dimension they would have had had the electromagnetic waves **1868** been induced on

the uninsulated conductor without an insulation layer. In the illustration of FIGS. **18Q** and **18R** the tapered end begins at an end of the tapered horn **1880**. In other embodiments, the tapered end of the insulation layer **1879** can begin before or after the end of the tapered horn **1880**. The tapered horn can be metallic or constructed of other conductive material or constructed of a plastic or other non-conductive material that is coated or clad with a dielectric layer or doped with a conductive material to provide reflective properties similar to a metallic horn.

In various embodiments, the distance **d2** between the reflective plate and the radiating elements of the MMICs **1870** can be adjusted or otherwise set to support inducing the propagation of the electromagnetic wave **1868** via a selected fundamental or non-fundamental wave mode such as such as TM_{00} , HE_{11} , EH_{1m} , TM_{0m} , (where $m=1, 2, \dots$) or other non-fundamental and/or asymmetrical mode at a chosen frequency of operation. For example, the distance **d2** can be adjusted incrementally to determine the particular value of **d2** that yields the greatest signal strength of one or more selected modes of the electromagnetic wave **1868**.

As previously noted, the cable **1862** can comprise any of the embodiments of cable **1850** described earlier. In this embodiment, waveguides **1865** and **1865'** can be coupled to a transmission core **1852** of cable **1850** as depicted in FIGS. **18S** and **18T**. The waveguides **1865** and **1865'** can induce, as previously described, electromagnetic waves **1868** on the transmission core **1852** for propagation entirely or partially within inner layers of cable **1850**.

It is noted that for the foregoing embodiments of FIGS. **18Q**, **18R**, **18S** and **18T**, electromagnetic waves **1868** can be bidirectional. For example, electromagnetic waves **1868** of a different operating frequency can be received by slots **1863** or MMICs **1870** of the waveguides **1865** and **1865'**, respectively. Once received, the electromagnetic waves can be converted by a receiver circuit (e.g., see reference **101**, **1000** of FIGS. **1** and **10A**) for generating a communication signal for processing.

In various embodiments, the distance **d3** between the reflective plate and the radiating elements of the MMICs **1870** can be adjusted or otherwise set to support inducing the propagation of the electromagnetic wave **1868** via a selected fundamental or non-fundamental wave mode such as such as TM_{00} , HE_{11} , EH_{1m} , TM_{0m} , (where $m=1, 2, \dots$) or other non-fundamental and/or asymmetrical mode at a chosen frequency of operation. For example, the distance **d3** can be adjusted incrementally to determine the particular value of **d3** that yields the greatest signal strength of one or more selected modes of the electromagnetic wave **1868**.

Although not shown, it is further noted that the waveguides **1865** and **1865'** can be adapted so that the waveguides **1865** and **1865'** can direct electromagnetic waves **1868** upstream or downstream longitudinally. For example, a first tapered horn **1880** coupled to a first instance of a waveguide system **1865** or **1865'** can be directed westerly on cable **1862**, while a second tapered horn **1880** coupled to a second instance of a waveguide system **1865** or **1865'** can be directed easterly on cable **1862**. The first and second instances of the waveguides **1865** or **1865'** can be coupled so that in a repeater configuration, signals received by the first waveguide system **1865** or **1865'** can be provided to the second waveguide system **1865** or **1865'** for retransmission in an easterly direction on cable **1862**. The repeater configuration just described can also be applied from an easterly to westerly direction on cable **1862**.

The waveguide system **1865'** of FIGS. **18P**, **18R** and **18T** can also be constructed in other ways to generate electro-

magnetic fields having non-fundamental or asymmetric wave modes. FIG. 18U depicts an embodiment of a waveguide system 1865" that is adapted to generate electromagnetic fields having one or more selected non-fundamental wave modes. The waveguide system 1865" includes similar functions and features to waveguide system 1865' that are referred to by common reference numerals. In place of MMICs 1870, an antenna 1861 operates to radiate the electromagnetic wave that is directed to an interface of the transmission medium 1862 or 1852 to propagate in the wave direction via one or more selected non-fundamental wave modes. In the example shown, the antenna 1873 is a monopole antenna, however other antenna configurations and radiating elements can likewise be employed.

The reflective plate 1871 is also included in a region behind the antenna 1873 relative to the direction of propagation of the electromagnetic wave 1868 that is guided by the cable 1862, indicated by the wave direction arrow that is shown. The reflective plate 1871 can be constructed of metallic plate, a metallic coated surface, a wire mesh having a density sufficient to reflect electromagnetic waves traveling toward the reflective plate 1871 from the antenna 1873, or other reflective plate.

In operation, the reflective plate 1871 aids in directing the electromagnetic wave 1861 to an interface of a transmission medium, such as the surface of the cable 1862, to induce propagation of the electromagnetic wave 1868 along the cable 1862—the propagation not requiring an electrical return path. For example, the reflective plate 1871 can be shorted to ground and/or the outer housing of the waveguide system 1865 to as to interact with the e-fields 1861 generated by the antenna 1873.

In the embodiment shown, the reflective plate 1871 is positioned inside the outer housing of the waveguide system 1865' in a configuration that is perpendicular to the longitudinal axis of the cable 1862 and the wave direction, and optionally is parallel to a plane containing the antenna 1873, however other configurations are likewise possible. In various embodiments, the distance d4 between the reflective plate and the antenna 1873 can be adjusted or otherwise set to support inducing the propagation of the electromagnetic wave 1868 via a selected fundamental or non-fundamental wave mode such as such as TM_{00} , HE_{11} , EH_{1m} , TM_{0m} , (where $m=1, 2, \dots$) or other non-fundamental and/or asymmetrical mode at a chosen frequency of operation. For example, the distance d4 can be adjusted incrementally to determine the particular value of d4 that yields the greatest signal strength of one or more selected modes of the electromagnetic wave 1868.

While not expressly shown, a conductive horn, or other coaxial reflector can be added to the embodiments of FIG. 18U to assist in directing the e-fields 1861 for the induction of the electromagnetic wave 1868 on cable 1862.

The waveguide system 1865' of FIGS. 18P, 18R and 18T can also be used on concert to generate electromagnetic fields having non-fundamental or asymmetric wave modes. FIG. 18V depicts an embodiment of a waveguide system including two waveguide systems 1865'-1 and 1865'-2 that are adapted to generate electromagnetic fields having one or more selected non-fundamental wave modes. The waveguide systems 1865'-1 and 1865'-2 include similar functions and features to waveguide system 1865' that are referred to by common reference numerals.

The signal input 1872 can be generated by a transmitter circuit as previously described in the subject disclosure (e.g., see reference 101, 1000 of FIGS. 1 and 10A) adapted to provide electrical signals to the MMICs 1870 and 1870'.

Each MMIC 1870 and 1870' can be configured to receive signal 1872 which the MMIC 1870 or 1870' can modulate and transmit with a radiating element (e.g., an antenna or other device) to emit electromagnetic waves having radiated e-fields 1861 and 1861'. In the configuration shown, MMICs 1870 each include a radiating element that is arranged concentrically about the cable 1852 or 1862. The MMICs 1870' also each include a radiating element that is arranged concentrically about the cable 1852 or 1862, but at an angular offset from the radiating elements of MMICs 1870. In the orientation shown, the radiating elements of MMICs 1870 are arranged at angles 90 and 270 degrees, while the radiating elements of MMICs 1870' are arranged at angles 0 and 180 degrees. It should be noted that, the selection of angular displacements of the MMICs 1870 from one another and from the angular displacements of MMICs 1870 along with the phases offsets of signal input 1872 generated by each circuit can be used to support a fundamental mode of the electromagnetic wave 1868 or a non-fundamental wave mode of the electromagnetic wave 1868 with a desired spatial orientation.

In the embodiment shown, the MMICs 1870 can be configured to receive the same signal 1872, but transmit electromagnetic waves having e-fields 1861 of opposing orientation. Similarly, the MMICs 1870' can be configured to receive the same signal 1872, but transmit electromagnetic waves having e-fields 1861' of opposing orientation, but with a particular phase offset from the e-fields 1861. This can be accomplished by configuring the MMICs 1870 and MMICs 1870' to transmit electromagnetic waves with controllable phases. In an embodiment, the combination of the electromagnetic waves emitted by the MMICs 1870 can together induce electromagnetic waves 1868 that are bound to the cable 1862 for propagation according to a fundamental wave mode without other wave modes present—such as non-fundamental wave modes, however, depending on the phases chosen for the MMICs and the distance d5, other modes such as non-fundamental modes can be selected as well. In this configuration, the electromagnetic waves 1868 can propagate longitudinally along the cable 1862 to other downstream waveguide systems coupled to the cable 1862.

In the embodiment shown, the waveguide systems 1865'-1 and 1865'-2 are each in a configuration that is perpendicular to the longitudinal axis of the cable 1862 and the wave direction, and so that a plane containing the radiating elements of the MMICs 1870 is parallel to a plane containing the radiating elements of the MMICs 1870', however other configurations are likewise possible. In various embodiments, the distance d5 between the waveguides 1865'-1 and 1865'-2 corresponds to the distance between the planes of the radiating elements of the MMICs 1870 and 1870'. The distance d5 can be adjusted or otherwise set to support inducing the propagation of the electromagnetic wave 1868 via a selected fundamental or non-fundamental wave mode such as such as TM_{00} , HE_{11} , EH_{1m} , TM_{0m} , (where $m=1, 2, \dots$) or other non-fundamental and/or asymmetrical mode at a chosen frequency of operation. For example, the distance d5 can be adjusted incrementally to determine the particular value of d5 that yields the greatest signal strength of one or more selected modes of the electromagnetic wave 1868.

In various embodiments, the waveguide system 1865'-2 has a reflective plate 1871 in a region behind the radiating elements of the MMICs 1870' relative to the direction of propagation of the electromagnetic wave 1868. The reflective plate can be constructed of metallic plate, a metallic coated surface, a wire mesh having a density sufficient to

reflect electromagnetic waves travelling toward the reflective plate **1871** from the MMICs **1870'**, or other reflective plate.

In operation, the reflective plate **1871** aids in directing the instances of the electromagnetic waves **1861'** to an interface of a transmission medium, such as the surface of the cable **1862**, to induce propagation of the electromagnetic wave **1868** along the cable **1862**—the propagation not requiring an electrical return path. For example, the reflective plate **1871** can be shorted to ground and/or the outer housing of the waveguide system **1865** to as to interact with the e-fields **1861** generated by the MMICs.

In the embodiment shown, the reflective plate **1871** is positioned inside the outer housing of the waveguide system **1865'-2** in a configuration that is perpendicular to the longitudinal axis of the cable **1862** and the wave direction, and optionally is parallel to a plane containing the radiating elements of the MMICs **1870'**, however other configurations are likewise possible. In various embodiments, the distance **d6** between the reflective plate and the radiating elements of the MMICs **1870** can be adjusted or otherwise set to support inducing the propagation of the electromagnetic wave **1868** via a selected fundamental or non-fundamental wave mode such as such as TM_{00} , HE_{11} , EH_{1m} , TM_{0m} , (where $m=1, 2, \dots$) or other non-fundamental and/or asymmetrical mode at a chosen frequency of operation. For example, the distance **d6** can be adjusted incrementally to determine the particular value of **d6** that yields the greatest signal strength of one or more selected modes of the electromagnetic wave **1868**. Furthermore, the selection of angular displacements of the MMICs **1870** from one another and from the angular displacements of MMICs **1870** along with the phases offsets of signal input **1872** generated by each circuit can be used in addition to the distances **d6** and the distance **d5** to support a non-fundamental wave mode of the electromagnetic wave **1868** with a desired spatial orientation.

While not expressly shown, a conductive horn, or other coaxial reflector can be added to the waveguide system **1865'-1** to assist in directing the e-fields **1861** for the induction of the electromagnetic wave **1868** on cable **1862**. Furthermore, while not expressly shown, a housing, or radome can be provided between the waveguide systems **1865'-1** and **1865'-2** to protect the launcher from the environment, and/or to reduce emissions and further direct the electromagnetic waves **1861'** to the cable **1862** or **1852**.

In another embodiment, the waveguide systems **1865'-1** and **1865'-2** of FIG. **18V** can also be configured to generate electromagnetic waves having only non-fundamental wave modes. This can be accomplished by adding more MMICs **1870** and **1870'** as depicted in FIG. **18W**. In particular, a concentric alignment of MMICs **1870** of waveguide system **1865'-1** is presented along with the concentric alignment of MMICs **1870'** of waveguide system **1865'-2** that is behind.

Each MMIC **1870** and **1870'** can be configured to receive the same signal input **1872**. However, MMICs **1870** can selectively be configured to emit electromagnetic waves having differing phases using controllable phase-shifting circuitry in each MMIC **1870** and **1870'**. For example, the distance **d5** can be set at an integer number of wavelengths and the northerly and southerly MMICs **1870** can be configured to emit electromagnetic waves having a 180 degree phase difference, thereby aligning the e-fields either in a northerly or southerly direction. Any combination of pairs of MMICs **1870** and **1870'** (e.g., westerly and easterly MMICs **1870**, northwesterly and southeasterly MMICs **1870'**, northeasterly and southwestly MMICs **1870'**) can be configured with opposing or aligned e-fields. Consequently, waveguide

system **1865'** can be configured to generate electromagnetic waves with one or more non-fundamental wave modes, electromagnetic waves with one or more fundamental wave modes, or any combinations thereof.

Not all MMICs need be transmitting at any given time. A single MMIC **1870** or **1870'** of the MMICs **1870** and **1870'** shown in FIG. **18W** can be configured to generate electromagnetic waves having a non-fundamental wave mode while all other MMICs **1870** and **1870'** are not in use or disabled. Likewise, other wave modes and wave mode combinations can be induced by enabling other non-null proper subsets of the MMICs **1870** and **1870'** with controllable phases.

It is further noted that in some embodiments, the waveguide systems **1865**, **1865'** and **1865''** of FIGS. **18N-18W** may generate combinations of fundamental and non-fundamental wave modes where one wave mode is dominant over the other. For example, in one embodiment electromagnetic waves generated by the waveguide systems **1865**, **1865'** and **1865''** of FIGS. **18N-18W** may have a weak signal component that has a non-fundamental wave mode, and a substantially strong signal component that has a fundamental wave mode. Accordingly, in this embodiment, the electromagnetic waves have a substantially fundamental wave mode. In another embodiment electromagnetic waves generated by the waveguide systems **1865**, **1865'** and **1865''** of FIGS. **18N-18W** may have a weak signal component that has a fundamental wave mode, and a substantially strong signal component that has a non-fundamental wave mode. Accordingly, in this embodiment, the electromagnetic waves have a substantially non-fundamental wave mode. Further, a non-dominant wave mode may be generated that propagates only trivial distances along the length of the transmission medium.

It is also noted that the waveguide systems **1865**, **1865'** and **1865''** of FIGS. **18N-18W** can be configured to generate instances of electromagnetic waves that have wave modes that can differ from a resulting wave mode or modes of the combined electromagnetic wave. It is further noted that each MMIC **1870** or **1870'** of the waveguide system **1865'** of FIG. **18W** can be configured to generate an instance of electromagnetic waves having wave characteristics that differ from the wave characteristics of another instance of electromagnetic waves generated by another MMIC **1870** or **1870'**. One MMIC **1870** or **1870'**, for example, can generate an instance of an electromagnetic wave having a spatial orientation and a phase, frequency, magnitude, electric field orientation, and/or magnetic field orientation that differs from the spatial orientation and phase, frequency, magnitude, electric field orientation, and/or magnetic field orientation of a different instance of another electromagnetic wave generated by another MMIC **1870** or **1870'**. The waveguide system **1865'** can thus be configured to generate instances of electromagnetic waves having different wave and spatial characteristics, which when combined achieve resulting electromagnetic waves having one or more desirable wave modes.

From these illustrations, it is submitted that the waveguide systems **1865** and **1865'** of FIGS. **18N-18W** can be adapted to generate electromagnetic waves with one or more selectable wave modes. In one embodiment, for example, the waveguide systems **1865** and **1865'** can be adapted to select one or more wave modes and generate electromagnetic waves having a single wave mode or multiple wave modes selected and produced from a process of combining instances of electromagnetic waves having one or more configurable wave and spatial characteristics. In an embodiment, for example, parametric information can be stored in

a look-up table. Each entry in the look-up table can represent a selectable wave mode. A selectable wave mode can represent a single wave mode, or a combination of wave modes. The combination of wave modes can have one or dominant wave modes. The parametric information can provide configuration information for generating instances of electromagnetic waves for producing resultant electromagnetic waves that have the desired wave mode.

For example, once a wave mode or modes is selected, the parametric information obtained from the look-up table from the entry associated with the selected wave mode(s) can be used to identify which of one or more MMICs **1870** and **1870'** to utilize, and/or their corresponding configurations to achieve electromagnetic waves having the desired wave mode(s). The parametric information may identify the selection of the one or more MMICs **1870** and **1870'** based on the spatial orientations of the MMICs **1870** and **1870'**, which may be required for producing electromagnetic waves with the desired wave mode. The parametric information can also provide information to configure each of the one or more MMICs **1870** and **1870'** with a particular phase, frequency, magnitude, electric field orientation, and/or magnetic field orientation which may or may not be the same for each of the selected MMICs **1870** or **1870'**. A look-up table with selectable wave modes and corresponding parametric information can be adapted for configuring the slotted waveguide system **1865**, **1865'** and **1865''**.

In some embodiments, a guided electromagnetic wave can be considered to have a desired wave mode if the corresponding wave mode propagates non-trivial distances on a transmission medium and has a field strength that is substantially greater in magnitude (e.g., 20 dB higher in magnitude) than other wave modes that may or may not be desirable. Such a desired wave mode or modes can be referred to as dominant wave mode(s) with the other wave modes being referred to as non-dominant wave modes. In a similar fashion, a guided electromagnetic wave that is said to be substantially without the fundamental wave mode has either no fundamental wave mode or a non-dominant fundamental wave mode. A guided electromagnetic wave that is said to be substantially without a non-fundamental wave mode has either no non-fundamental wave mode(s) or only non-dominant non-fundamental wave mode(s). In some embodiments, a guided electromagnetic wave that is said to have only a single wave mode or a selected wave mode may have only one corresponding dominant wave mode.

It is further noted that the embodiments of FIGS. **18U-18W** can be applied to other embodiments of the subject disclosure. For example, the embodiments of FIGS. **18U-18W** can be used as alternate embodiments to the embodiments depicted in FIGS. **18N-18T** or can be combined with the embodiments depicted in FIGS. **18N-18T**.

Turning now to FIGS. **18X** and **18Z**, block diagrams illustrating example, non-limiting embodiments of a dielectric antenna and corresponding gain and field intensity plots in accordance with various aspects described herein are shown. FIG. **18X** depicts a dielectric horn antenna **1891** having a conical structure. The dielectric horn antenna **1891** is coupled to a feed point **1892**, which can also be comprised of a dielectric material. In one embodiment, for example, the dielectric horn antenna **1891** and the feed point **1892** can be constructed of dielectric materials such as a polyethylene material, a polyurethane material or other suitable dielectric material (e.g., a synthetic resin). In an embodiment, the dielectric horn antenna **1891** and the feed point **1892** can be adapted to be void of any conductive materials. For example, the external surfaces **1897** of the dielectric horn

antenna **1891** and the feed point **1892** can be non-conductive and the dielectric materials used to construct the dielectric horn antenna **1891** and the feed point **1892** can be such that they substantially do not contain impurities that may be conductive.

The feed point **1892** can be adapted to couple to a core **1852** such as previously described by way of illustration in FIGS. **18I** and **18J**. In one embodiment, the feed point **1892** can be coupled to the core **1852** utilizing a joint (not shown in FIG. **18X**) such as the splicing device **1860** of FIG. **18J**. Other embodiments for coupling the feed point **1892** to the core **1852** can be used. In an embodiment, the joint can be configured to cause the feed point **1892** to touch an endpoint of the core **1852**. In another embodiment, the joint can create a gap between the feed point **1892** and the endpoint of the core **1852**. In yet another embodiment, the joint can cause the feed point **1892** and the core **1852** to be coaxially aligned or partially misaligned. Notwithstanding any combination of the foregoing embodiments, electromagnetic waves can in whole or at least in part propagate between the junction of the feed point **1892** and the core **1852**.

The cable **1850** can be coupled to the waveguide system **1865** depicted in FIG. **18S** or the waveguide system **1865'** depicted in FIG. **18T**. For illustration purposes only, reference will be made to the waveguide system **1865'** of FIG. **18T**. It is understood, however, that the waveguide system **1865** of FIG. **18S** can also be utilized in accordance with the discussions that follow. The waveguide system **1865'** can be configured to select a wave mode (e.g., non-fundamental wave mode, fundamental wave mode, a hybrid wave mode, or combinations thereof as described earlier) and transmit instances of electromagnetic waves having a non-optical operating frequency (e.g., 60 GHz). The electromagnetic waves can be directed to an interface of the cable **1850** as shown in FIG. **18T**.

The instances of electromagnetic waves generated by the waveguide system **1865'** can induce a combined electromagnetic wave having the selected wave mode that propagates from the core **1852** to the feed point **1892**. The combined electromagnetic wave can propagate partly inside the core **1852** and partly on an outer surface of the core **1852**. Once the combined electromagnetic wave has propagated through the junction between the core **1852** and the feed point **1892**, the combined electromagnetic wave can continue to propagate partly inside the feed point **1892** and partly on an outer surface of the feed point **1892**. In some embodiments, the portion of the combined electromagnetic wave that propagates on the outer surface of the core **1852** and the feed point **1892** is small. In these embodiments, the combined electromagnetic wave can be said to tightly coupled to the core **1852** and the feed point **1892** while propagating longitudinally towards the dielectric antenna **1891**.

When the combined electromagnetic wave reaches a proximal portion of the dielectric antenna **1891** (at a junction **1892'** between the feed point **1892** and the dielectric antenna **1891**), the combined electromagnetic wave enters the proximal portion of the dielectric antenna **1891** and propagates longitudinally along an axis of the dielectric antenna **1891** (shown as a hashed line). By the time the combined electromagnetic wave reaches the aperture **1893**, the combined electromagnetic wave has an intensity pattern similar to the one shown in FIG. **18Y**. The electric field intensity pattern of FIG. **18Y** shows that the electric fields of the combined electromagnetic waves are strongest in a center region of the aperture **1893** and weaker in the outer regions. In an embodiment, where the wave mode of the electromagnetic waves propagating in the dielectric antenna **1891** is a hybrid

wave mode (e.g., HE₁₁), the leakage of the electromagnetic waves at the external surfaces **1897** is reduced or in some instances eliminated. Methods for launching a hybrid wave mode on cable **1850** is discussed below.

In an embodiment, the far field antenna gain pattern depicted in FIG. **18Y** can be widened by decreasing the operating frequency of the combined electromagnetic wave. Similarly, the gain pattern can be narrowed by increasing the operating frequency of the combined electromagnetic wave. Accordingly, a width of a beam of wireless signals emitted by the aperture **1893** can be controlled by configuring the waveguide system **1865'** to increase or decrease the operating frequency of the combined electromagnetic wave.

The dielectric antenna **1891** of FIG. **18X** can also be used for receiving wireless signals. Wireless signals received by the dielectric antenna **1891** at the aperture **1893** induce electromagnetic waves in the dielectric antenna **1891** that propagate towards the feed point **1892**. The electromagnetic waves continue to propagate from the feed point **1892** to the core **1852**, and are thereby delivered to the waveguide system **1865'** coupled to the cable **1850** as shown in FIG. **18T**. In this configuration, the waveguide system **1865'** can perform bidirectional communications utilizing the dielectric antenna **1891**. It is further noted that in some embodiments the core **1852** of the cable **1850** (shown with dashed lines) can be configured to be collinear with the feed point **1892** to avoid a bend shown in FIG. **18X**. In some embodiments, a collinear configuration can reduce an alteration of the electromagnetic due to the bend in cable **1850**.

Turning now to FIG. **18Z**, a block diagram of an example, non-limiting embodiment of another dielectric antenna structure in accordance with various aspects described herein is shown. FIG. **18Z** depicts an array of pyramidal-shaped dielectric horn antennas **1894**. Each antenna of the array of pyramidal-shaped dielectric horn antennas **1894** can have a feed point **1896** that couples to a core **1852** of a plurality of cables **1850**. Each cable **1850** can be coupled to a different waveguide system **1865'** such as shown in FIG. **18T**. The array of pyramidal-shaped dielectric horn antennas **1894** can be used to transmit wireless signals having a plurality of spatial orientations. An array of pyramidal-shaped dielectric horn antennas **1894** covering 360 degrees can enable a plurality of waveguide systems **1865'** coupled to the antennas to perform omnidirectional communications with other communication devices or antennas of similar type.

The bidirectional propagation properties of electromagnetic waves previously described for the dielectric antenna **1891** of FIG. **18X** are also applicable for electromagnetic waves propagating from the core **1852** to the feed point **1896** to the aperture **1895** of the pyramidal-shaped dielectric horn antennas **1894**, and in the reverse direction. Similarly, the array of pyramidal-shaped dielectric horn antennas **1894** can be void of conductive surfaces and internal conductive materials. For example, in some embodiments, the array of pyramidal-shaped dielectric horn antennas **1894** and their corresponding feed points **1896** can be constructed of dielectric-only materials such as polyethylene or polyurethane materials.

It is further noted that each antenna of the array of pyramidal-shaped dielectric horn antennas **1894** can have similar gain and electric field intensity maps as shown for the dielectric antenna **1891** in FIG. **18Y**. Each antenna of the array of pyramidal-shaped dielectric horn antennas **1894** can also be used for receiving wireless signals as previously described for the dielectric antenna **1891** of FIG. **18X**. In some embodiments, a single instance of a pyramidal-shaped

dielectric horn antenna can be used. Similarly, multiple instances of the dielectric antenna **1891** of FIG. **18X** can be used in an array configuration similar to the one shown in FIG. **18Z**.

Turning now to FIGS. **19A** and **19B**, block diagrams illustrating example, non-limiting embodiments of the cable **1850** of FIG. **18A** used for inducing guided electromagnetic waves on power lines supported by utility poles. In one embodiment, as depicted in FIG. **19A**, a cable **1850** can be coupled at one end to a microwave apparatus that launches guided electromagnetic waves within one or more inner layers of cable **1850** utilizing, for example, the hollow waveguide **1808** shown in FIGS. **18A-18C**. The microwave apparatus can utilize a microwave transceiver such as shown in FIG. **10A** for transmitting or receiving signals from cable **1850**. The guided electromagnetic waves induced in the one or more inner layers of cable **1850** can propagate to an exposed stub of the cable **1850** located inside a horn antenna (shown as a dotted line in FIG. **19A**) for radiating the electromagnetic waves via the horn antenna. The radiated signals from the horn antenna in turn can induce guided electromagnetic waves that propagate longitudinally on a medium voltage (MV) power line. In one embodiment, the microwave apparatus can receive AC power from a low voltage (e.g., 220V) power line. Alternatively, the horn antenna can be replaced with a stub antenna as shown in FIG. **19B** to induce guided electromagnetic waves that propagate longitudinally on the MV power line or to transmit wireless signals to other antenna system(s).

In an alternative embodiment, the hollow horn antenna shown in FIG. **19A** can be replaced with a solid dielectric antenna such as the dielectric antenna **1891** of FIG. **18X**, or the pyramidal-shaped horn antenna **1894** of FIG. **18Z**. In this embodiment the horn antenna can radiate wireless signals directed to another horn antenna such as the bidirectional horn antennas **1940** shown in FIG. **19C**. In this embodiment, each horn antenna **1940** can transmit wireless signals to another horn antenna **1940** or receive wireless signals from the other horn antenna **1940** as shown in FIG. **19C**. Such an arrangement can be used for performing bidirectional wireless communications between antennas. Although not shown, the horn antennas **1940** can be configured with an electromechanical device to steer a direction of the horn antennas **1940**.

In alternate embodiments, first and second cables **1850A'** and **1850B'** can be coupled to the microwave apparatus and to a transformer **1952**, respectively, as shown in FIGS. **19A** and **19B**. The first and second cables **1850A'** and **1850B'** can be represented by, for example, cable **1820** or cable **1830** of FIGS. **18B** and **18C**, respectively, each having a conductive core. A first end of the conductive core of the first cable **1850A'** can be coupled to the microwave apparatus for propagating guided electromagnetic waves launched therein. A second end of the conductive core of the first cable **1850A'** can be coupled to a first end of a conductive coil of the transformer **1952** for receiving the guided electromagnetic waves propagating in the first cable **1850A'** and for supplying signals associated therewith to a first end of a second cable **1850B'** by way of a second end of the conductive coil of the transformer **1952**. A second end of the second cable **1850B'** can be coupled to the horn antenna of FIG. **19A** or can be exposed as a stub antenna of FIG. **19B** for inducing guided electromagnetic waves that propagate longitudinally on the MV power line.

In an embodiment where cable **1850**, **1850A'** and **1850B'** each comprise multiple instances of transmission mediums **1800**, **1820**, and/or **1830**, a poly-rod structure of antennas

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1855 can be formed such as shown in FIG. **18K**. Each antenna **1855** can be coupled, for example, to a horn antenna assembly as shown in FIG. **19A** or a pie-pan antenna assembly (not shown) for radiating multiple wireless signals. Alternatively, the antennas **1855** can be used as stub antennas in FIG. **19B**. The microwave apparatus of FIGS. **19A-19B** can be configured to adjust the guided electromagnetic waves to beam steer the wireless signals emitted by the antennas **1855**. One or more of the antennas **1855** can also be used for inducing guided electromagnetic waves on a power line.

Turning now to FIG. **19C**, a block diagram of an example, non-limiting embodiment of a communication network **1900** in accordance with various aspects described herein is shown. In one embodiment, for example, the waveguide system **1602** of FIG. **16A** can be incorporated into network interface devices (NIDs) such as NIDs **1910** and **1920** of FIG. **19C**. A NID having the functionality of waveguide system **1602** can be used to enhance transmission capabilities between customer premises **1902** (enterprise or residential) and a pedestal **1904** (sometimes referred to as a service area interface or SAJ).

In one embodiment, a central office **1930** can supply one or more fiber cables **1926** to the pedestal **1904**. The fiber cables **1926** can provide high-speed full-duplex data services (e.g., 1-100 Gbps or higher) to mini-DSLAMs **1924** located in the pedestal **1904**. The data services can be used for transport of voice, internet traffic, media content services (e.g., streaming video services, broadcast TV), and so on. In prior art systems, mini-DSLAMs **1924** typically connect to twisted pair phone lines (e.g., twisted pairs included in category 5e or Cat. 5e unshielded twisted-pair (UTP) cables that include an unshielded bundle of twisted pair cables, such as 24 gauge insulated solid wires, surrounded by an outer insulating sheath), which in turn connect to the customer premises **1902** directly. In such systems, DSL data rates taper off at 100 Mbps or less due in part to the length of legacy twisted pair cables to the customer premises **1902** among other factors.

The embodiments of FIG. **19C**, however, are distinct from prior art DSL systems. In the illustration of FIG. **19C**, a mini-DSLAM **1924**, for example, can be configured to connect to NID **1920** via cable **1850** (which can represent in whole or in part any of the cable embodiments described in relation to FIGS. **18A-18D** and **18F-18L** singly or in combination). Utilizing cable **1850** between customer premises **1902** and a pedestal **1904**, enables NIDs **1910** and **1920** to transmit and receive guided electromagnetic waves for uplink and downlink communications. Based on embodiments previously described, cable **1850** can be exposed to rain, or can be buried without adversely affecting electromagnetic wave propagation either in a downlink path or an uplink path so long as the electric field profile of such waves in either direction is confined at least in part or entirely within inner layers of cable **1850**. In the present illustration, downlink communications represent a communication path from the pedestal **1904** to customer premises **1902**, while uplink communications represents a communication path from customer premises **1902** to the pedestal **1904**. In an embodiment where cable **1850** comprises one of the embodiments of FIGS. **18G-18H**, cable **1850** can also serve the purpose of supplying power to the NID **1910** and **1920** and other equipment of the customer premises **1902** and the pedestal **1904**.

In customer premises **1902**, DSL signals can originate from a DSL modem **1906** (which may have a built-in router and which may provide wireless services such as WiFi to

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user equipment shown in the customer premises **1902**). The DSL signals can be supplied to NID **1910** by a twisted pair phone **1908**. The NID **1910** can utilize the integrated waveguide **1602** to launch within cable **1850** guided electromagnetic waves **1914** directed to the pedestal **1904** on an uplink path. In the downlink path, DSL signals generated by the mini-DSLAM **1924** can flow through a twisted pair phone line **1922** to NID **1920**. The waveguide system **1602** integrated in the NID **1920** can convert the DSL signals, or a portion thereof, from electrical signals to guided electromagnetic waves **1914** that propagate within cable **1850** on the downlink path. To provide full duplex communications, the guided electromagnetic waves **1914** on the uplink can be configured to operate at a different carrier frequency and/or a different modulation approach than the guided electromagnetic waves **1914** on the downlink to reduce or avoid interference. Additionally, on the uplink and downlink paths, the guided electromagnetic waves **1914** are guided by a core section of cable **1850**, as previously described, and such waves can be configured to have a field intensity profile that confines the guided electromagnetic waves in whole or in part in the inner layers of cable **1850**. Although the guided electromagnetic waves **1914** are shown outside of cable **1850**, the depiction of these waves is for illustration purposes only. For this reason, the guided electromagnetic waves **1914** are drawn with "hash marks" to indicate that they are guided by the inner layers of cable **1850**.

On the downlink path, the integrated waveguide system **1602** of NID **1910** receives the guided electromagnetic waves **1914** generated by NID **1920** and converts them back to DSL signals conforming to the requirements of the DSL modem **1906**. The DSL signals are then supplied to the DSL modem **1906** via a set of twisted pair wires of phone line **1908** for processing. Similarly, on the uplink path, the integrated waveguide system **1602** of NID **1920** receives the guided electromagnetic waves **1914** generated by NID **1910** and converts them back to DSL signals conforming to the requirements of the mini-DSLAM **1924**. The DSL signals are then supplied to the mini-DSLAM **1924** via a set of twisted pair wires of phone line **1922** for processing. Because of the short length of phone lines **1908** and **1922**, the DSL modem **1908** and the mini-DSLAM **1924** can send and receive DSL signals between themselves on the uplink and downlink at very high speeds (e.g., 1 Gbps to 60 Gbps or more). Consequently, the uplink and downlink paths can in most circumstances exceed the data rate limits of traditional DSL communications over twisted pair phone lines.

Typically, DSL devices are configured for asymmetric data rates because the downlink path usually supports a higher data rate than the uplink path. However, cable **1850** can provide much higher speeds both on the downlink and uplink paths. With a firmware update, a legacy DSL modem **1906** such as shown in FIG. **19C** can be configured with higher speeds on both the uplink and downlink paths. Similar firmware updates can be made to the mini-DSLAM **1924** to take advantage of the higher speeds on the uplink and downlink paths. Since the interfaces to the DSL modem **1906** and mini-DSLAM **1924** remain as traditional twisted pair phone lines, no hardware change is necessary for a legacy DSL modem or legacy mini-DSLAM other than firmware changes and the addition of the NIDs **1910** and **1920** to perform the conversion from DSL signals to guided electromagnetic waves **1914** and vice-versa. The use of NIDs enables a reuse of legacy modems **1906** and mini-DSLAMs **1924**, which in turn can substantially reduce installation costs and system upgrades. For new construction, updated versions of mini-DSLAMs and DSL modems

can be configured with integrated waveguide systems to perform the functions described above, thereby eliminating the need for NIDs 1910 and 1920 with integrated waveguide systems. In this embodiment, an updated version of modem 1906 and updated version of mini-DSLAM 1924 would connect directly to cable 1850 and communicate via bidirectional guided electromagnetic wave transmissions, thereby averting a need for transmission or reception of DSL signals using twisted pair phone lines 1908 and 1922.

In an embodiment where use of cable 1850 between the pedestal 1904 and customer premises 1902 is logistically impractical or costly, NID 1910 can be configured instead to couple to a cable 1850' (similar to cable 1850 of the subject disclosure) that originates from a waveguide 108 on a utility pole 118, and which may be buried in soil before it reaches NID 1910 of the customer premises 1902. Cable 1850' can be used to receive and transmit guided electromagnetic waves 1914' between the NID 1910 and the waveguide 108. Waveguide 108 can connect via waveguide 106, which can be coupled to base station 104. Base station 104 can provide data communication services to customer premises 1902 by way of its connection to central office 1930 over fiber 1926'. Similarly, in situations where access from the central office 1926 to pedestal 1904 is not practical over a fiber link, but connectivity to base station 104 is possible via fiber link 1926', an alternate path can be used to connect to NID 1920 of the pedestal 1904 via cable 1850" (similar to cable 1850 of the subject disclosure) originating from pole 116. Cable 1850" can also be buried before it reaches NID 1920.

FIGS. 20A and 20B describe embodiments for downlink and uplink communications. Method 2000 of FIG. 20A can begin with step 2002 where electrical signals (e.g., DSL signals) are generated by a DSLAM (e.g., mini-DSLAM 1924 of pedestal 1904 or from central office 1930), which are converted to guided electromagnetic waves 1914 at step 2004 by NID 1920 and which propagate on a transmission medium such as cable 1850 for providing downlink services to the customer premises 1902. At step 2008, the NID 1910 of the customer premises 1902 converts the guided electromagnetic waves 1914 back to electrical signals (e.g., DSL signals) which are supplied at step 2010 to customer premises equipment (CPE) such as DSL modem 1906 over phone line 1908. Alternatively, or in combination, power and/or guided electromagnetic waves 1914' can be supplied from a power line 1850' of a utility grid (having an inner waveguide as illustrated in FIG. 18G or 18H) to NID 1910 as an alternate or additional downlink (and/or uplink) path.

At 2022 of method 2020 of FIG. 20B, the DSL modem 1906 can supply electrical signals (e.g., DSL signals) via phone line 1908 to NID 1910, which in turn at step 2024, converts the DSL signals to guided electromagnetic waves directed to NID 1920 by way of cable 1850. At step 2028, the NID 1920 of the pedestal 1904 (or central office 1930) converts the guided electromagnetic waves 1914 back to electrical signals (e.g., DSL signals) which are supplied at step 2029 to a DSLAM (e.g., mini-DSLAM 1924). Alternatively, or in combination, power and guided electromagnetic waves 1914' can be supplied from a power line 1850' of a utility grid (having an inner waveguide as illustrated in FIG. 18G or 18H) to NID 1920 as an alternate or additional uplink (and/or downlink) path.

Turning now to FIG. 20C, a flow diagram of an example, non-limiting embodiment of a method 2030 for inducing and receiving electromagnetic waves on a transmission medium is shown. At step 2032, the waveguides 1865 and 1865' of FIGS. 18N-18T can be configured to generate first electromagnetic waves from a first communication signal (sup-

plied, for example, by a communication device), and induce at step 2034 the first electromagnetic waves with "only" a fundamental wave mode at an interface of the transmission medium. In an embodiment, the interface can be an outer surface of the transmission medium as depicted in FIGS. 18Q and 18R. In another embodiment, the interface can be an inner layer of the transmission medium as depicted in FIGS. 18S and 18T. At step 2036, the waveguides 1865 and 1865' of FIGS. 18N-18T can be configured to receive second electromagnetic waves at an interface of a same or different transmission medium described in FIG. 20C. In an embodiment, the second electromagnetic waves can have "only" a fundamental wave mode. In other embodiments, the second electromagnetic waves may have a combination of wave modes such as a fundamental and non-fundamental wave modes. At step 2038, a second communication signal can be generated from the second electromagnetic waves for processing by, for example, a same or different communication device. The embodiments of FIGS. 20C and 20D can be applied to any embodiments described in the subject disclosure.

Turning now to FIG. 20D, a flow diagram of an example, non-limiting embodiment of a method 2040 for inducing electromagnetic waves on a transmission medium is shown. In particular, the method can be used with one more functions and features described above. Step 2042 includes generating a first electromagnetic wave by a waveguide system having a radiating element. Step 2044 includes directing, at least partially by a reflective plate of the waveguide system, the first electromagnetic wave to an interface of a transmission medium to induce propagation of a second electromagnetic wave without utilizing an electrical return path, the second electromagnetic wave having a non-fundamental wave mode and a non-optical operating frequency.

In various embodiments, the method further includes setting a distance between the reflective plate and the radiating element to support inducing the propagation of second electromagnetic waves having the non-fundamental wave mode. The radiating element can be configured to generate an electric signal from a third electromagnetic wave propagating along the transmission medium. The radiating element can comprise an antenna, such as a monopole antenna that is aligned substantially parallel to the reflective plate. The non-fundamental wave mode of the second electromagnetic wave can have a spatial orientation based on a position of the radiating element.

In various embodiments, directing the first electromagnetic wave can further include providing a conductive horn that surrounds the transmission medium and that further directs the first electromagnetic wave to facilitate inducing the propagation of the second electromagnetic wave at the interface of the transmission medium. The waveguide system can include a waveguide structure for further directing the first electromagnetic wave to the interface of the transmission medium. The waveguide structure can have a tapered cross-section and/or a cylindrical cross-section.

In various embodiments, the interface of the transmission medium can include a core, and the second electromagnetic wave can be guided and bound to the core. The interface of the transmission medium can comprise an outer surface of an insulated conductor or uninsulated conductor for guiding the second electromagnetic wave.

FIG. 20E illustrates a flow diagram of an example, non-limiting embodiment of a method 2050 for inducing electromagnetic waves on a transmission medium. In particular, the method can be used with one more functions and

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features described above. Step **2052** includes generating first electromagnetic waves, by a waveguide system having a plurality of circuits, each of the plurality of circuits having a corresponding one of a plurality of radiating elements. Step **2054** includes directing, at least partially by a reflective plate of the waveguide system, instances of the first electromagnetic waves to an interface of a transmission medium to induce propagation of a second electromagnetic wave without utilizing an electrical return path, the second electromagnetic wave having a non-fundamental wave mode and a non-optical operating frequency.

In various embodiments, a distance between the reflective plate and at least one of the plurality of radiating elements is set to support inducing the propagation of the second electromagnetic wave via the non-fundamental wave mode. The first and second circuits of the plurality of circuits can be configured to generate the first electromagnetic waves with electric field orientations that are substantially aligned. The radiating elements can each comprise an antenna. The plurality of circuits can comprise a plurality of microwave circuits. Each of the plurality of circuits can comprise a transmitter portion for transmitting the instances of the first electromagnetic waves. Each of the plurality of circuits can further comprise a receiver portion for receiving third electromagnetic waves.

In various embodiments, the method can further include receiving, by the plurality of circuits, a third electromagnetic wave guided by the transmission medium. The non-fundamental wave mode of the second electromagnetic wave can have a spatial orientation based on a position of each of one or more of the plurality of circuits surrounding the transmission medium. Directing the first electromagnetic waves can further include configuring a first circuit of the plurality of circuits to supply an electromagnetic wave having a first phase, and configuring a second circuit of the plurality of circuits to supply the electromagnetic wave having a second phase.

In various embodiments, the waveguide system can comprise a waveguide structure for directing the first electromagnetic waves to the interface of the transmission medium. The waveguide structure can have a tapered cross-section and/or a cylindrical cross-section. The interface of the transmission medium can comprise a core, and the second electromagnetic wave can be guided and bound to the core. The interface of the transmission medium can comprise an outer surface of an insulated conductor or uninsulated conductor for guiding the second electromagnetic wave.

FIG. **20F** illustrates a flow diagram of an example, non-limiting embodiment of a method **2060** for inducing electromagnetic waves on a transmission medium. In particular, the method can be used with one more functions and features described above. Step **2062** includes generating first electromagnetic waves, by a first waveguide system having a first plurality of circuits. Step **2064** includes generating second electromagnetic waves, by a second waveguide system having a second plurality of circuits. As indicated in **2066**, the first electromagnetic waves and the second electromagnetic waves are directed to an interface of a transmission medium to induce propagation of a third electromagnetic wave without utilizing an electrical return path, the third electromagnetic wave having a non-fundamental wave mode and a non-optical operating frequency.

In various embodiments, the method further includes setting a distance between the first waveguide system and the second waveguide system to support inducing the propagation of the third electromagnetic wave via the non-fundamental wave mode. The first and second circuits of the

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first plurality of circuits can be configured to generate the first electromagnetic waves with electric field orientations that are substantially aligned. The first and second circuits of the second plurality of circuits can be configured to generate the second electromagnetic waves with electric field orientations that are substantially aligned. The first plurality of circuits and the second plurality of circuits can each comprise a plurality of microwave circuits. The first plurality of circuits and the second plurality of circuits can each comprise a transmitter portion for transmitting the first electromagnetic waves and the second electromagnetic waves. The first plurality of circuits and the second plurality of circuits can each further comprise a receiver portion for receiving third electromagnetic waves. The first plurality of circuits can include a first plurality of radiating elements that are arranged concentrically about the transmission medium, and the second plurality of circuits can include a second plurality of radiating elements that are arranged concentrically about the transmission medium at an angular offset from the first plurality of radiating elements.

In various embodiments, the non-fundamental wave mode of the third electromagnetic wave has a spatial orientation based on positions of the first plurality of circuits and the second plurality of circuits. The first electromagnetic waves and the second electromagnetic waves can be at least partially directed by configuring transmission phases of the first plurality of circuits and the second plurality of circuits. The first waveguide system can comprise a waveguide structure for directing the first electromagnetic waves to the interface of the transmission medium. The waveguide structure can have a tapered cross-section and/or have a cylindrical cross-section.

In various embodiments, the interface of the transmission medium can include a core, and the third electromagnetic wave can be guided and bound to the core. The interface of the transmission medium can comprise an outer surface of an insulated conductor or uninsulated conductor for guiding the third electromagnetic wave.

While for purposes of simplicity of explanation, the respective processes are shown and described as a series of blocks in FIGS. **20A-20F**, it is to be understood and appreciated that the claimed subject matter is not limited by the order of the blocks, as some blocks may occur in different orders and/or concurrently with other blocks from what is depicted and described herein. Moreover, not all illustrated blocks may be required to implement the methods described herein.

FIG. **20G** illustrates a flow diagram of an example, non-limiting embodiment of a method **2070** for detecting and mitigating disturbances occurring in a communication network, such as, for example, the system of FIGS. **16A** and **16B**. Method **2070** can begin with step **2072** where a network element, such as the waveguide system **1602** of FIGS. **16A-16B**, can be configured to monitor degradation of guided electromagnetic waves on an outer surface of a transmission medium, such as power line **1610**. A signal degradation can be detected according to any number of factors including without limitation, a signal magnitude of the guided electromagnetic waves dropping below a certain magnitude threshold, a signal to noise ratio (SNR) dropping below a certain SNR threshold, a Quality of Service (QoS) dropping below one or more thresholds, a bit error rate (BER) exceeding a certain BER threshold, a packet loss rate (PLR) exceeding a certain PLR threshold, a ratio of reflected electromagnetic waves to forward electromagnetic waves exceeding a certain threshold, an unexpected change or alteration to a wave mode, a spectral change in the guided

electromagnetic waves indicating an object or objects are causing a propagation loss or scattering of the guided electromagnetic waves (e.g., water accumulation on an outer surface of the transmission medium, a splice in the transmission medium, a broken tree limb, etc.), or any combinations thereof.

If signal degradation is detected at step **2074**, the network element can proceed to step **2076** where it can determine which object or objects may be causing the degradation, and once detected, report the detected object(s) to the network management system **1601** of FIGS. **16A-16B**. Object detection can be accomplished by spectral analysis or other forms of signal analysis, environmental analysis (e.g., barometric readings, rain detection, etc.), or other suitable techniques for detecting foreign objects that may adversely affect propagation of electromagnetic waves guided by the transmission medium. For example, the network element can be configured to generate spectral data derived from an electromagnetic wave received by the network element. The network element can then compare the spectral data to a plurality of spectral profiles stored in its memory. The plurality of spectral profiles can be pre-stored in a memory of the network element, and can be used to characterize or identify obstructions that may cause a propagation loss or signal degradation when such obstructions are present on an outer surface of the transmission medium.

For example, an accumulation of water on an outer surface of a transmission medium, such as a thin layer of water and/or water droplets, may cause a signal degradation in electromagnetic waves guided by the transmission medium that may be identifiable by a spectral profile comprising spectral data that models such an obstruction. The spectral profile can be generated in a controlled environment (such as a laboratory or other suitable testing environment) by collecting and analyzing spectral data generated by test equipment (e.g., a waveguide system with spectrum analysis capabilities) when receiving electromagnetic waves over an outer surface of a transmission medium that has been subjected to water (e.g., simulated rain water). An obstruction such as water can generate a different spectral signature than other obstructions (e.g., a splice between transmission mediums). A unique spectral signature can be used to identify certain obstructions over others. With this technique, spectral profiles can be generated for characterizing other obstructions such as a fallen tree limb on the transmission medium, a splice, and so on. In addition to spectral profiles, thresholds can be generated for different metrics such as SNR, BER, PLR, and so on. These thresholds can be chosen by a service provider according to desired performance measures for a communication network that utilizing guided electromagnetic waves for transport of data. Some obstructions may also be detected by other methods. For example, rain water may be detected by a rain detector coupled to a network element, fallen tree limbs may be detected by a vibration detector coupled to the network element, and so on.

If a network element does not have access to equipment to detect objects that may be causing a degradation of electromagnetic waves, then the network element can skip step **2076** and proceed to step **2078** where it notifies one or more neighboring network elements (e.g., other waveguide system(s) **1602** in a vicinity of the network element) of the detected signal degradation. If signal degradation is significant, the network element can resort to a different medium for communicating with neighboring network element(s), such as, for example, wireless communications. Alternatively, the network element can substantially reduce the

operating frequency of the guided electromagnetic waves (e.g., from 40 GHz to 1 GHz), or communicate with neighboring network elements utilizing other guided electromagnetic waves operating at a low frequency, such as a control channel (e.g., 1 MHz). A low frequency control channel may be much less susceptible to interference by the object(s) causing the signal degradation at much higher operating frequencies.

Once an alternate means of communication is established between network elements, at step **2080** the network element and neighboring network elements can coordinate a process to adjust the guided electromagnetic waves to mitigate the detected signal degradation. The process can include, for example, a protocol for choosing which of the network elements will perform the adjustments to the electromagnetic waves, the frequency and magnitude of adjustments, and goals to achieve a desired signal quality (e.g., QoS, BER, PLR, SNR, etc.). If, for example, the object causing the signal degradation is water accumulation on the outer surface of the transmission medium, the network elements can be configured to adjust a polarization of the electrical fields (e-fields) and/or magnetic fields (h-fields) of the electromagnetic waves to attain a radial alignment of the e-fields as shown in FIG. **20H**. In particular, FIG. **20H** presents a block diagram **2001** illustrating an example, non-limiting embodiment of an alignment of e-fields of an electromagnetic wave to mitigate propagation losses due to water accumulation on a transmission medium in accordance with various aspects described herein. In this example, the longitudinal section of a cable, such as an insulated metal cable implementation of transmission medium **125**, is presented along with field vectors that illustrate the e-fields associated with guided electromagnetic waves that propagate at 40 GHz. Stronger e-fields are presented by darker field vectors relative to weaker e-fields.

In one embodiment, an adjustment in polarization can be accomplished by generating a specific wave mode of the electromagnetic waves (e.g., transverse magnetic (TM) mode, transverse electric (TE) mode, transverse electromagnetic (TEM) mode, or a hybrid of a TM mode and TE mode also known as an HE mode). Assuming, for example, that the network element comprises the waveguide system **1865'** of FIG. **18W**, an adjustment in a polarization of e-fields can be accomplished by configuring two or more MMIC's **1870** to alter a phase, frequency, amplitude or combinations thereof of the electromagnetic waves generated by each MMIC **1870**. Certain adjustments may cause, for example, the e-fields in the region of the water film shown in FIG. **20H** to align perpendicularly to the surface of the water. Electric fields that are perpendicular (or approximately perpendicular) to the surface of water will induce weaker currents in the water film than e-fields parallel to the water film. By inducing weaker currents, the electromagnetic waves propagating longitudinally will experience less propagation loss. Additionally, it is also desirable for the concentration of the e-fields to extend above the water film into the air. If the concentration of e-fields in the air remains high and the majority of the total field strength is in the air instead of being concentrated in the region of the water and the insulator, then propagation losses will also be reduced. For example, e-fields of electromagnetic waves that are tightly bound to an insulation layer such as, Goubau waves (or TM_{00} waves—see block diagram **2031** of FIG. **20K**), will experience higher propagation losses even though the e-fields may be perpendicular (or radially aligned) to the water film because more of the field strength is concentrated in the region of the water.

Accordingly, electromagnetic waves with e-fields perpendicular (or approximately perpendicular) to a water film having a higher proportion of the field strength in a region of air (i.e., above the water film) will experience less propagation loss than tightly bound electromagnetic waves having more field strength in the insulating or water layers or electromagnetic waves having e-fields in the direction of propagation within the region of the water film that generate greater losses.

FIG. 20H depicts, in a longitudinal view of an insulated conductor, e-field for TM_{01} electromagnetic waves operating at 40 GHz. FIGS. 20I and 20J, in contrast, depict cross-sectional views 2011 and 2021, respectively, of the insulated conductor of FIG. 20H illustrating the field strength of e-fields in the direction of propagation of the electromagnetic waves (i.e., e-fields directed out of the page of FIGS. 20I and 20J). The electromagnetic waves shown in FIGS. 20I and 20J have a TM_{01} wave mode at 45 GHz and 40 GHz, respectively. FIG. 20I shows that the intensity of the e-fields in the direction of propagation of the electromagnetic waves is high in a region between the outer surface of the insulation and the outer surface of the water film (i.e., the region of the water film). The high intensity is depicted by a light color (the lighter the color the higher the intensity of the e-fields directed out of the page). FIG. 20I illustrates that there is a high concentration of e-fields polarized longitudinally in the region of the water film, which causes high currents in the water film and consequently high propagation losses. Thus, under certain circumstances, electromagnetic waves at 45 GHz (having a TM_{01} wave mode) are less suitable to mitigate rain water or other obstructions located on the outer surface of the insulated conductor.

In contrast, FIG. 20J shows that the intensity of the e-fields in the direction of propagation of the electromagnetic waves is weaker in the region of the water film. The lower intensity is depicted by the darker color in the region of the water film. The lower intensity is a result of the e-fields being polarized mostly perpendicular or radial to the water film. The radially aligned e-fields also are highly concentrated in the region of air as shown in FIG. 20H. Thus, electromagnetic waves at 40 GHz (having a TM_{01} wave mode) produce e-fields that induce less current in the water film than 45 GHz waves with the same wave mode. Accordingly, the electromagnetic waves of FIG. 20J exhibit properties more suitable for reducing propagation losses due to a water film or droplets accumulating on an outer surface of an insulated conductor.

Since the physical characteristics of a transmission medium can vary, and the effects of water or other obstructions on the outer surface of the transmission medium may cause non-linear effects, it may not always be possible to precisely model all circumstances so as to achieve the e-field polarization and e-field concentration in air depicted in FIG. 20H on a first iteration of step 2082. To increase a speed of the mitigation process, a network element can be configured to choose from a look-up table at step 2086 a starting point for adjusting electromagnetic waves. In one embodiment, entries of the look-up table can be searched for matches to a type of object detected at step 2076 (e.g., rain water). In another embodiment, the look-up table can be searched for matches to spectral data derived from the affected electromagnetic wave received by the network elements. Table entries can provide specific parameters for adjusting electromagnetic waves (e.g., frequency, phase, amplitude, wave mode, etc.) to achieve at least a coarse adjustment that achieves similar e-field properties as shown in FIG. 20H. A coarse adjustment can serve to improve the likelihood of

converging on a solution that achieves the desirable propagation properties previously discussed in relation to FIGS. 20H and 20J.

Once a coarse adjustment is made at step 2086, the network element can determine at step 2084 whether the adjustment has improved signal quality to a desirable target. Step 2084 can be implemented by a cooperative exchange between network elements. For example, suppose the network element at step 2086 generates an adjusted electromagnetic wave according to parameters obtained from the look-up table and transmits the adjusted electromagnetic wave to a neighboring network element. At step 2084 the network element can determine whether the adjustment has improved signal quality by receiving feedback from a neighboring network element receiving the adjusted electromagnetic waves, analyzing the quality of the received waves according to agreed target goals, and providing the results to the network element. Similarly, the network element can test adjusted electromagnetic waves received from neighboring network elements and can provide feedback to the neighboring network elements including the results of the analysis. While a particular search algorithm is discussed above, other search algorithms such as a gradient search, genetic algorithm, global search or other optimization techniques can likewise be employed. Accordingly, steps 2082, 2086 and 2084 represent an adjustment and testing process performed by the network element and its neighbor(s).

With this in mind, if at step 2084 a network element (or its neighbors) determine that signal quality has not achieved one or more desired parametric targets (e.g., SNR, BER, PLR, etc.), then incremental adjustments can begin at step 2082 for each of the network element and its neighbors. At step 2082, the network element (and/or its neighbors) can be configured to adjust a magnitude, phase, frequency, wave mode and/or other tunable features of the electromagnetic waves incrementally until a target goal is achieved. To perform these adjustments, a network element (and its neighbors) can be configured with the waveguide system 1865' of FIG. 18W. The network element (and its neighbors) can utilize two or more MMIC's 1870 to incrementally adjust one or more operational parameters of the electromagnetic waves to achieve e-fields polarized in a particular direction (e.g., away from the direction of propagation in the region of the water film). The two or more MMIC's 1870 can also be configured to incrementally adjust one or more operational parameters of the electromagnetic waves that achieve e-fields having a high concentration in a region of air (outside the obstruction).

The iteration process can be a trial-and-error process coordinated between network elements to reduce a time for converging on a solution that improves upstream and downstream communications. As part of the coordination process, for example, one network element can be configured to adjust a magnitude but not a wave mode of the electromagnetic waves, while another network element can be configured to adjust the wave mode and not the magnitude. The number of iterations and combination of adjustments to achieve desirable properties in the electromagnetic waves to mitigate obstructions on an outer surface of a transmission medium can be established by a service provider according to experimentation and/or simulations and programmed into the network elements.

Once the network element(s) detect at step 2084 that signal quality of upstream and downstream electromagnetic waves has improved to a desirable level that achieves one or more parametric targets (e.g. SNR, BER, PLR, etc.), the network elements can proceed to step 2088 and resume

communications according to the adjusted upstream and downstream electromagnetic waves. While communications take place at step 2088, the network elements can be configured to transmit upstream and downstream test signals based on the original electromagnetic waves to determine if the signal quality of such waves has improved. These test signals can be transmitted at periodic intervals (e.g., once every 30 seconds or other suitable periods). Each network element can, for example, analyze spectral data of the received test signals to determine if they achieve a desirable spectral profile and/or other parametric target (e.g. SNR, BER, PLR, etc.). If the signal quality has not improved or has improved nominally, the network elements can be configured to continue communications at step 2088 utilizing the adjusted upstream and downstream electromagnetic waves.

If, however, signal quality has improved enough to revert back to utilizing the original electromagnetic waves, then the network element(s) can proceed to step 2092 to restore settings (e.g., original wave mode, original magnitude, original frequency, original phase, original spatial orientation, etc.) that produce the original electromagnetic waves. Signal quality may improve as a result of a removal of the obstruction (e.g., rain water evaporates, field personnel remove a fallen tree limb, etc.). At step 2094, the network elements can initiate communications utilizing the original electromagnetic waves and perform upstream and downstream tests. If the network elements determine at step 2096 from tests performed at step 2094 that signal quality of the original electromagnetic waves is satisfactory, then the network elements can resume communications with the original electromagnetic waves and proceed to step 2072 and subsequent steps as previously described.

A successful test can be determined at step 2096 by analyzing test signals according to parametric targets associated with the original electromagnetic waves (e.g., BER, SNR, PLR, etc.). If the tests performed at step 2094 are determined to be unsuccessful at step 2096, the network element(s) can proceed to steps 2082, 2086 and 2084 as previously described. Since a prior adjustment to the upstream and downstream electromagnetic waves may have already been determined successfully, the network element(s) can restore the settings used for the previously adjusted electromagnetic waves. Accordingly, a single iteration of any one of steps 2082, 2086 and 2084 may be sufficient to return to step 2088.

It should be noted that in some embodiments restoring the original electromagnetic waves may be desirable if, for example, data throughput when using the original electromagnetic waves is better than data throughput when using the adjusted electromagnetic waves. However, when data throughput of the adjusted electromagnetic waves is better or substantially close to the data throughput of the original electromagnetic waves, the network element(s) may instead be configured to continue from step 2088.

It is also noted that although FIGS. 20H and 20K describe a TM₀₁ wave mode, other wave modes (e.g., HE waves, TE waves, TEM waves, etc.) or combination of wave modes may achieve the desired effects shown in FIG. 20H. Accordingly, a wave mode singly or in combination with one or more other wave modes may generate electromagnetic waves with e-field properties that reduce propagation losses as described in relation to FIGS. 20H and 20J. Such wave modes are therefore contemplated as possible wave modes the network elements can be configured to produce.

It is further noted that method 2070 can be adapted to generate at steps 2082 or 2086 other wave modes that may

not be subject to a cutoff frequency. For example, FIG. 20L depicts a block diagram 2041 of an example, non-limiting embodiment of electric fields of a hybrid wave in accordance with various aspects described herein. Waves having an HE mode have linearly polarized e-fields which point away from a direction of propagation of electromagnetic waves and can be perpendicular (or approximately perpendicular) to a region of obstruction (e.g., water film shown in FIGS. 20H-20J). Waves with an HE mode can be configured to generate e-fields that extend substantially outside of an outer surface of an insulated conductor so that more of the total accumulated field strength is in air. Accordingly, some electromagnetic waves having an HE mode can exhibit properties of a large wave mode with e-fields orthogonal or approximately orthogonal to a region of obstruction. As described earlier, such properties can reduce propagation losses. Electromagnetic waves having an HE mode also have the unique property that they do not have a cutoff frequency (i.e., they can operate near DC) unlike other wave modes which have non-zero cutoff frequencies.

Turning now to FIG. 20M, a block diagram 2051 illustrating an example, non-limiting embodiment of electric field characteristics of a hybrid wave versus a Goubau wave in accordance with various aspects described herein is shown. Diagram 2053 shows a distribution of energy between HE₁₁ mode waves and Goubau waves for an insulated conductor. The energy plots of diagram 2053 assume that the amount of power used to generate the Goubau waves is the same as the HE₁₁ waves (i.e., the area under the energy curves is the same). In the illustration of diagram 2053, Goubau waves have a steep drop in power when Goubau waves extend beyond the outer surface of an insulated conductor, while HE₁₁ waves have a substantially lower drop in power beyond the insulation layer. Consequently, Goubau waves have a higher concentration of energy near the insulation layer than HE₁₁ waves. Diagram 2055 depicts similar Goubau and HE₁₁ energy curves when a water film is present on the outer surface of the insulator. The difference between the energy curves of diagrams 2053 and 2055 is that the drop in power for the Goubau and the HE₁₁ energy curves begins on an outer edge of the insulator for diagram 2053 and on an outer edge of the water film for diagram 2055. The energy curves diagrams 2053 and 2055, however, depict the same behavior. That is, the electric fields of Goubau waves are tightly bound to the insulation layer, which when exposed to water results in greater propagation losses than electric fields of HE₁₁ waves having a higher concentration outside the insulation layer and the water film. These properties are depicted in the HE₁₁ and Goubau diagrams 2057 and 2059, respectively.

By adjusting an operating frequency of HE₁₁ waves, e-fields of HE₁₁ waves can be configured to extend substantially above a thin water film as shown in block diagram 2061 of FIG. 20N having a greater accumulated field strength in areas in the air when compared to fields in the insulator and a water layer surrounding the outside of the insulator. FIG. 20N depicts a wire having a radius of 1 cm and an insulation radius of 1.5 cm with a dielectric constant of 2.25. As the operating frequency of HE₁₁ waves is reduced, the e-fields extend outwardly expanding the size of the wave mode. At certain operating frequencies (e.g., 3 GHz) the wave mode expansion can be substantially greater than the diameter of the insulated wire and any obstructions that may be present on the insulated wire.

By having e-fields that are perpendicular to a water film and by placing most of its energy outside the water film, HE₁₁ waves have less propagation loss than Goubau waves

when a transmission medium is subjected to water or other obstructions. Although Goubau waves have radial e-fields which are desirable, the waves are tightly coupled to the insulation layer, which results in the e-fields being highly concentrated in the region of an obstruction. Consequently, Goubau waves are still subject to high propagation losses when an obstruction such as a water film is present on the outer surface of an insulated conductor.

Turning now to FIGS. 21A and 21B, block diagrams illustrating example, non-limiting embodiments of a waveguide system 2100 for launching hybrid waves in accordance with various aspects described herein is shown. The waveguide system 2100 can comprise probes 2102 coupled to a slideable or rotatable mechanism 2104 that enables the probes 2102 to be placed at different positions or orientations relative to an outer surface of an insulated conductor 2108. The mechanism 2104 can comprise a coaxial feed 2106 or other coupling that enables transmission of electromagnetic waves by the probes 2102. The coaxial feed 2106 can be placed at a position on the mechanism 2104 so that the path difference between the probes 2102 is one-half a wavelength or some odd integer multiple thereof. When the probes 2102 generate electromagnetic signals of opposite phase, electromagnetic waves can be induced on the outer surface of the insulated conductor 2108 having a hybrid mode (such as an HE_{11} mode).

The mechanism 2104 can also be coupled to a motor or other actuator (not shown) for moving the probes 2102 to a desirable position. In one embodiment, for example, the waveguide system 2100 can comprise a controller that directs the motor to rotate the probes 2102 (assuming they are rotatable) to a different position (e.g., east and west) to generate electromagnetic waves that have a horizontally polarized HE_{11} mode as shown in a block diagram of FIG. 22A. To guide the electromagnetic waves onto the outer surface of the insulated conductor 2108, the waveguide system 2100 can further comprise a tapered horn 2110 shown in FIG. 21B. The tapered horn 2110 can be coaxially aligned with the insulated conductor 2108. To reduce the cross-sectional dimension of the tapered horn 2110, an additional insulation layer (not shown) can be placed on the insulated conductor 2108. The additional insulation layer can be similar to the tapered insulation layer 1879 shown in FIGS. 18Q and 18R. The additional insulation layer can have a tapered end that points away from the tapered horn 2110. The tapered insulation layer 1879 can reduce a size of an initial electromagnetic wave launched according to an HE_{11} mode. As the electromagnetic waves propagate towards the tapered end of the insulation layer, the HE_{11} mode expands until it reaches its full size as shown in FIG. 22. In other embodiments, the waveguide system 2100 may not need to use the tapered insulation layer 1879.

FIG. 22 illustrates that HE_{11} mode waves can be used to mitigate obstructions such as rain water. For example, suppose that rain water has caused a water film to surround an outer surface of the insulated conductor 2108 as shown in FIG. 22. Further assume that water droplets have collected at the bottom of the insulated conductor 2108. As illustrated in FIG. 22, the water film occupies a small fraction of the total HE_{11} wave. Also, by having horizontally polarized HE_{11} waves, the water droplets are in a least-intense area of the HE_{11} waves reducing losses caused by the droplets. Consequently, the HE_{11} waves experience much lower propagation losses than Goubau waves or waves having a mode that is tightly coupled to the insulated conductor 2108 and thus greater energy in the areas occupied by the water.

It is submitted that the waveguide system 2100 of FIGS. 21A-21B can be replaced with other waveguide systems of the subject disclosure capable of generating electromagnetic waves having an HE mode. For example, the waveguide system 1865' of FIG. 18W can be configured to generate electromagnetic waves having an HE mode. In an embodiment, two or more MMIC's 1870 of the waveguide system 1865' can be configured to generate electromagnetic waves of opposite phase to generate polarized e-fields such as those present in an HE mode. In another embodiment, different pairs of MMIC's 1870 can be selected to generate HE waves that are polarized at different spatial positions (e.g., north and south, west and east, northwest and southeast, northeast and southeast, or other sub-fractional coordinates). Additionally, the waveguide systems of FIGS. 18N-18W can be configured to launch electromagnetic waves having an HE mode onto the core 1852 of one or more embodiments of cable 1850 suitable for propagating HE mode waves.

Although HE waves can have desirable characteristics for mitigating obstructions on a transmission medium, it is submitted that certain wave modes having a cutoff frequency (e.g., TE modes, TM modes, TEM modes or combinations thereof) may also exhibit waves that are sufficiently large and have polarized e-fields that are orthogonal (or approximately orthogonal) to a region of an obstruction enabling their use for mitigating propagation losses caused by the obstruction. Method 2070 can be adapted, for example, to generate such wave modes from a look-up table at step 2086. Wave modes having a cutoff frequency that exhibit, for example, a wave mode larger than the obstruction and polarized e-fields perpendicular (or approximately perpendicular) to the obstruction can be determined by experimentation and/or simulation. Once a combination of parameters (e.g., magnitude, phase, frequency, wave mode(s), spatial positioning, etc.) for generating one or more waves with cutoff frequencies having low propagation loss properties is determined, the parametric results for each wave can be stored in a look-up table in a memory of a waveguide system. Similarly, wave modes with cutoff frequencies exhibiting properties that reduce propagation losses can also be generated iteratively by any of the search algorithms previously described in the process of steps 2082-2084.

FIG. 22B is a block diagram 2200 illustrating an example, non-limiting embodiment of a rainfall sensor in accordance with various aspects described herein. In particular, a rainfall sensor is presented that includes a transmission medium 2204, such as a transmission medium 125, and a rainfall analyzer 2202.

The rainfall analyzer is configured to induce transmitted electromagnetic waves 2206 that are guided by the transmission medium 2204 to propagate along the transmission medium without requiring an electrical return path. The rainfall analyzer 2202 receives reflected electromagnetic waves 2208 from the transmission medium 2204 in response to the transmitted electromagnetic waves 2206. The rainfall analyzer analyzes the reflected electromagnetic waves 2208 and generates rainfall data 2205 in response thereto.

FIG. 22C is a pictorial diagram 2210 illustrating an example, non-limiting embodiment of a transmission medium in accordance with various aspects described herein. For example, the transmission medium 2204 comprises a guided wave cable 2212, such as any of the cables 1850 for example, having an exposed core portion 2214 that forms water droplets 2218 in response to rainfall. In the example shown the exposed core portion 2214 includes a tapered end 2216 that facilitates formation of the water droplets 2218.

The exposed core portion **2214** and tapered end **2216** can be composed of a dielectric material that operates as an antenna, such as the tapered dielectric antenna **1855**, to radiate a wireless signal from the tapered end **2216**. In particular, the tapered end **2216** operates as an aperture of the antenna. In the absence of a water droplet **2218**, the transmitted electromagnetic waves **2206** are guided by the exposed core portion **2214** and radiate from the aperture as a corresponding wireless signal. In this case, the reflected electromagnetic waves **2208** are either not present, or exhibit a nominally small signal strength. When a water droplet **2218** is present however, more of the transmitted electromagnetic waves **2206** are reflected by the water droplet **2218** as reflected electromagnetic waves **2208**, and the reflected electromagnetic waves **2208** have a larger signal strength, compared to the case where water droplet **2018** is absent.

While a particular configuration of the tapered end **2216** is shown, other taper configurations can likewise be employed to facilitate formation of the water droplets **2218**. Furthermore, while the guided wave cable **2212** and exposed core **2214** are shown in a particular right-angle configuration with a bend in the exposed core **2214**, other configurations are likewise possible.

FIG. **22D** is a block diagram **2220** illustrating an example, non-limiting embodiment of a rainfall analyzer in accordance with various aspects described herein. In particular, a rainfall analyzer **2202** is shown that includes a reflectometer **2224** configured to generate transmitted RF signals. The launcher **2222** induces the transmitted electromagnetic waves **2206** in response to the transmitted RF signals and receives the reflected electromagnetic waves **2208** and generates reflected RF signals in response thereto. The reflectometer **2224** generates a reflected signal strength in response to the reflected RF signals and the signal processor **2226** generates the rainfall data **2205** based on the reflected signal strength.

In various embodiments, the launcher **2222** can be implemented by any of the guided wave launchers previously described or other launching devices for sending and receiving guided electromagnetic waves that are bound to a transmission medium **2204**. The reflectometer **2224** can be implemented via a time domain reflectometer, a frequency domain reflectometer or other device or devices that generate transmitted RF signals and measure signal strength of the reflected RF signals received in response thereto. The signal processor **2226** can be implemented via a digital signal processor or another processing device, either analog or digital.

In various embodiments, the rainfall data **2205** can merely indicate whether a rain droplet is present on the rain sensor. In this case, the signal processor **2226** operates to compare the reflected signal strength to a threshold that is set to distinguish a reflected signal strength indicative of water droplet presence from nominal reflected signal strengths indicative of water droplet absence. In addition or in the alternative, the signal processor **2226** operates to further process the reflected signal strengths over time to track the formation and drop-off of individual water droplets and identify an amount of the water droplets and/or a frequency of water droplets. This information can be accumulated by the signal processor **2226** and can be used to generate rainfall data **2205** in the form of an amount of accumulated rainfall over a time period and/or a current rainfall rate.

FIG. **22E** is a graphical diagram **2230** illustrating example, non-limiting embodiments of a reflected signal strength over time in accordance with various aspects

described herein. In particular, plot **2232** represents a case in the absence of a water droplet. The reflected signal strength has a nominal value.

In plot **2234** however, the reflected signal strength varies with time. As individual water droplets form on the rain sensor, they grow and are characterized by increasing reflected signal strength. When the water droplets drop from the rain sensor, the reflected signal strength rapidly decreases and then increases again as a new water droplet forms. As previously discussed, the signal processor **2226** can operate to process the reflected signal strength over time to track the formation and drop-off of individual water droplets and identify an amount of the water droplets and/or a frequency of water droplets. In the time period covered by the plot **2234**, four water droplets are formed. In plot **2236**, a different rainfall rate is shown where only three water droplets are formed during the same time period. This information can be accumulated by the signal processor **2226** and can be used to generate rainfall data **2205** in the form of an amount of accumulated rainfall over a time period such as an amount of daily rainfall, and/or a current rainfall rate such as an hourly rate of rainfall.

FIG. **22F** is a graphical diagram **2240** illustrating example, non-limiting embodiments of accumulated rainfall as a function of the amount of water droplets and rainfall rate as a function of the frequency of water droplets in accordance with various aspects described herein. As previously discussed, the signal processor **2226** can operate to process the reflected signal strengths over time to track the formation and drop-off of individual water droplets and identify an amount of the water droplets (such as the number of raindrops occurring over a time interval) and/or a frequency of water droplets.

The amount of water droplets formed in a time period, (e.g., a minute or other predetermined periods), can be correlated, based on experimental data for the rain sensor, to a corresponding value of the accumulated rainfall. Plot **2242** presents such a relationship that can be stored in a look-up table or as a linear function in the programmed in the signal processor **2226**. In this fashion, the signal processor **2226** can generate rainfall data indicating **2205** an amount of accumulated rainfall from the amount of water droplets formed in a particular time period.

Similarly, the frequency of water droplets formed can be correlated, based on experimental data for the rain sensor, to a corresponding value of the rainfall rate. Plot **2244** presents such a relationship that can be stored in a look-up table or as a linear function in the programmed in the signal processor **2226**. In this fashion, the signal processor **2226** can generate rainfall data indicating **2205** a rainfall rate from the frequency of water droplets formed.

FIG. **22G** is a pictorial diagram **2250** illustrating an example, non-limiting embodiment of a transmission medium in accordance with various aspects described herein. In the embodiment shown, the guided wave cable **2212** has an exposed core portion **2214** that includes a bend that facilitates formation of the water droplets **2218**. In this configuration, some residual portions of the transmitted electromagnetic waves **2206** are not reflected by the water droplet **2218** and continue on the exposed core **2214** beyond the water droplet **2218** as transmitted electromagnetic waves **2206'**. The termination **2252** operates to absorb the transmitted electromagnetic waves **2206'** to reduce or mitigate unwanted reflection from the termination **2252** that might otherwise interfere with the reflected electromagnetic waves **2208**. It should also be noted that while the foregoing has focused rainfall measurements based on an analysis of the

reflected electromagnetic waves **2208**, measurement at the termination **2252** of the transmitted electromagnetic waves **2206'** could also be used, in addition or in the alternative, due to the relationship between the reflected electromagnetic waves **2208** and the transmitted electromagnetic waves **2206'**—i.e., the smaller the reflected electromagnetic waves **2208**, the larger the transmitted electromagnetic waves **2206'** and vice versa.

FIG. **22H** is a flow diagram of an example, non-limiting embodiment of a method in accordance with various aspects described herein. In particular, a method **2275** is presented for use with one or more functions and features described in conjunction with FIGS. **22B-22G**. Step **2276** includes generating transmitted electromagnetic waves that are guided by a transmission medium to propagate along the transmission medium, wherein the transmitted electromagnetic waves propagate without requiring an electrical return path. Step **2278** includes receiving reflected electromagnetic waves from the transmission medium in response to the transmitted electromagnetic waves. Step **2280** includes analyzing the reflected electromagnetic waves to generate rainfall data in response thereto.

In various embodiments, the transmission medium comprises a guided wave cable having an exposed core portion that forms water droplets in response to rainfall, and wherein the reflected electromagnetic waves are reflected by the water droplets. The exposed core portion can include a tapered end that facilitates formation of the water droplets and/or a bend that facilitates formation of the water droplets.

In various embodiments, analyzing the reflected electromagnetic waves comprises: generating a reflected signal strength in response to the reflected electromagnetic waves; and generating the rainfall data based on the reflected signal strength. Generating the rainfall data based on the reflected signal strength can include identifying an amount of the water droplets and/or identifying a frequency of the water droplets. The transmission medium can comprise a guided wave cable coupled to a dielectric antenna that forms water droplets in response to rainfall at an aperture of the dielectric antenna, wherein the reflected electromagnetic waves are reflected by the water droplets.

While for purposes of simplicity of explanation, the respective processes are shown and described as a series of blocks in FIG. **22H**, it is to be understood and appreciated that the claimed subject matter is not limited by the order of the blocks, as some blocks may occur in different orders and/or concurrently with other blocks from what is depicted and described herein. Moreover, not all illustrated blocks may be required to implement the methods described herein.

Referring now to FIG. **23**, there is illustrated a block diagram of a computing environment in accordance with various aspects described herein. In order to provide additional context for various embodiments of the embodiments described herein, FIG. **23** and the following discussion are intended to provide a brief, general description of a suitable computing environment **2300** in which the various embodiments of the subject disclosure can be implemented. While the embodiments have been described above in the general context of computer-executable instructions that can run on one or more computers, those skilled in the art will recognize that the embodiments can be also implemented in combination with other program modules and/or as a combination of hardware and software.

Generally, program modules comprise routines, programs, components, data structures, etc., that perform particular tasks or implement particular abstract data types. Moreover, those skilled in the art will appreciate that the

inventive methods can be practiced with other computer system configurations, comprising single-processor or multiprocessor computer systems, minicomputers, mainframe computers, as well as personal computers, hand-held computing devices, microprocessor-based or programmable consumer electronics, and the like, each of which can be operatively coupled to one or more associated devices.

As used herein, a processing circuit includes processor as well as other application specific circuits such as an application specific integrated circuit, digital logic circuit, state machine, programmable gate array or other circuit that processes input signals or data and that produces output signals or data in response thereto. It should be noted that while any functions and features described herein in association with the operation of a processor could likewise be performed by a processing circuit.

The terms “first,” “second,” “third,” and so forth, as used in the claims, unless otherwise clear by context, is for clarity only and doesn't otherwise indicate or imply any order in time. For instance, “a first determination,” “a second determination,” and “a third determination,” does not indicate or imply that the first determination is to be made before the second determination, or vice versa, etc.

The illustrated embodiments of the embodiments herein can be also practiced in distributed computing environments where certain tasks are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, program modules can be located in both local and remote memory storage devices.

Computing devices typically comprise a variety of media, which can comprise computer-readable storage media and/or communications media, which two terms are used herein differently from one another as follows. Computer-readable storage media can be any available storage media that can be accessed by the computer and comprises both volatile and nonvolatile media, removable and non-removable media. By way of example, and not limitation, computer-readable storage media can be implemented in connection with any method or technology for storage of information such as computer-readable instructions, program modules, structured data or unstructured data.

Computer-readable storage media can comprise, but are not limited to, random access memory (RAM), read only memory (ROM), electrically erasable programmable read only memory (EEPROM), flash memory or other memory technology, compact disk read only memory (CD-ROM), digital versatile disk (DVD) or other optical disk storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices or other tangible and/or non-transitory media which can be used to store desired information. In this regard, the terms “tangible” or “non-transitory” herein as applied to storage, memory or computer-readable media, are to be understood to exclude only propagating transitory signals per se as modifiers and do not relinquish rights to all standard storage, memory or computer-readable media that are not only propagating transitory signals per se.

Computer-readable storage media can be accessed by one or more local or remote computing devices, e.g., via access requests, queries or other data retrieval protocols, for a variety of operations with respect to the information stored by the medium.

Communications media typically embody computer-readable instructions, data structures, program modules or other structured or unstructured data in a data signal such as a modulated data signal, e.g., a carrier wave or other transport

mechanism, and comprises any information delivery or transport media. The term “modulated data signal” or signals refers to a signal that has one or more of its characteristics set or changed in such a manner as to encode information in one or more signals. By way of example, and not limitation, communication media comprise wired media, such as a wired network or direct-wired connection, and wireless media such as acoustic, RF, infrared and other wireless media.

With reference again to FIG. 23, the example environment 2300 for transmitting and receiving signals via or forming at least part of a base station (e.g., base station devices 1504, macrocell site 1502, or base stations 1614) or central office (e.g., central office 1501 or 1611). At least a portion of the example environment 2300 can also be used for transmission devices 101 or 102. The example environment can comprise a computer 2302, the computer 2302 comprising a processing unit 2304, a system memory 2306 and a system bus 2308. The system bus 2308 couple’s system components including, but not limited to, the system memory 2306 to the processing unit 2304. The processing unit 2304 can be any of various commercially available processors. Dual microprocessors and other multiprocessor architectures can also be employed as the processing unit 2304.

The system bus 2308 can be any of several types of bus structure that can further interconnect to a memory bus (with or without a memory controller), a peripheral bus, and a local bus using any of a variety of commercially available bus architectures. The system memory 2306 comprises ROM 2310 and RAM 2312. A basic input/output system (BIOS) can be stored in a non-volatile memory such as ROM, erasable programmable read only memory (EPROM), EEPROM, which BIOS contains the basic routines that help to transfer information between elements within the computer 2302, such as during startup. The RAM 2312 can also comprise a high-speed RAM such as static RAM for caching data.

The computer 2302 further comprises an internal hard disk drive (HDD) 2314 (e.g., EIDE, SATA), which internal hard disk drive 2314 can also be configured for external use in a suitable chassis (not shown), a magnetic floppy disk drive (FDD) 2316, (e.g., to read from or write to a removable diskette 2318) and an optical disk drive 2320, (e.g., reading a CD-ROM disk 2322 or, to read from or write to other high capacity optical media such as the DVD). The hard disk drive 2314, magnetic disk drive 2316 and optical disk drive 2320 can be connected to the system bus 2308 by a hard disk drive interface 2324, a magnetic disk drive interface 2326 and an optical drive interface 2328, respectively. The interface 2324 for external drive implementations comprises at least one or both of Universal Serial Bus (USB) and Institute of Electrical and Electronics Engineers (IEEE) 1394 interface technologies. Other external drive connection technologies are within contemplation of the embodiments described herein.

The drives and their associated computer-readable storage media provide nonvolatile storage of data, data structures, computer-executable instructions, and so forth. For the computer 2302, the drives and storage media accommodate the storage of any data in a suitable digital format. Although the description of computer-readable storage media above refers to a hard disk drive (HDD), a removable magnetic diskette, and a removable optical media such as a CD or DVD, it should be appreciated by those skilled in the art that other types of storage media which are readable by a computer, such as zip drives, magnetic cassettes, flash memory cards, cartridges, and the like, can also be used in

the example operating environment, and further, that any such storage media can contain computer-executable instructions for performing the methods described herein.

A number of program modules can be stored in the drives and RAM 2312, comprising an operating system 2330, one or more application programs 2332, other program modules 2334 and program data 2336. All or portions of the operating system, applications, modules, and/or data can also be cached in the RAM 2312. The systems and methods described herein can be implemented utilizing various commercially available operating systems or combinations of operating systems. Examples of application programs 2332 that can be implemented and otherwise executed by processing unit 2304 include the diversity selection determining performed by transmission device 101 or 102.

A user can enter commands and information into the computer 2302 through one or more wired/wireless input devices, e.g., a keyboard 2338 and a pointing device, such as a mouse 2340. Other input devices (not shown) can comprise a microphone, an infrared (IR) remote control, a joystick, a game pad, a stylus pen, touch screen or the like. These and other input devices are often connected to the processing unit 2304 through an input device interface 2342 that can be coupled to the system bus 2308, but can be connected by other interfaces, such as a parallel port, an IEEE 1394 serial port, a game port, a universal serial bus (USB) port, an IR interface, etc.

A monitor 2344 or other type of display device can be also connected to the system bus 2308 via an interface, such as a video adapter 2346. It will also be appreciated that in alternative embodiments, a monitor 2344 can also be any display device (e.g., another computer having a display, a smart phone, a tablet computer, etc.) for receiving display information associated with computer 2302 via any communication means, including via the Internet and cloud-based networks. In addition to the monitor 2344, a computer typically comprises other peripheral output devices (not shown), such as speakers, printers, etc.

The computer 2302 can operate in a networked environment using logical connections via wired and/or wireless communications to one or more remote computers, such as a remote computer(s) 2348. The remote computer(s) 2348 can be a workstation, a server computer, a router, a personal computer, portable computer, microprocessor-based entertainment appliance, a peer device or other common network node, and typically comprises many or all of the elements described relative to the computer 2302, although, for purposes of brevity, only a memory/storage device 2350 is illustrated. The logical connections depicted comprise wired/wireless connectivity to a local area network (LAN) 2352 and/or larger networks, e.g., a wide area network (WAN) 2354. Such LAN and WAN networking environments are commonplace in offices and companies, and facilitate enterprise-wide computer networks, such as intranets, all of which can connect to a global communications network, e.g., the Internet.

When used in a LAN networking environment, the computer 2302 can be connected to the local network 2352 through a wired and/or wireless communication network interface or adapter 2356. The adapter 2356 can facilitate wired or wireless communication to the LAN 2352, which can also comprise a wireless AP disposed thereon for communicating with the wireless adapter 2356.

When used in a WAN networking environment, the computer 2302 can comprise a modem 2358 or can be connected to a communications server on the WAN 2354 or has other means for establishing communications over the WAN

2354, such as by way of the Internet. The modem 2358, which can be internal or external and a wired or wireless device, can be connected to the system bus 2308 via the input device interface 2342. In a networked environment, program modules depicted relative to the computer 2302 or portions thereof, can be stored in the remote memory/storage device 2350. It will be appreciated that the network connections shown are example and other means of establishing a communications link between the computers can be used.

The computer 2302 can be operable to communicate with any wireless devices or entities operatively disposed in wireless communication, e.g., a printer, scanner, desktop and/or portable computer, portable data assistant, communications satellite, any piece of equipment or location associated with a wirelessly detectable tag (e.g., a kiosk, news stand, restroom), and telephone. This can comprise Wireless Fidelity (Wi-Fi) and BLUETOOTH® wireless technologies. Thus, the communication can be a predefined structure as with a conventional network or simply an ad hoc communication between at least two devices.

Wi-Fi can allow connection to the Internet from a couch at home, a bed in a hotel room or a conference room at work, without wires. Wi-Fi is a wireless technology similar to that used in a cell phone that enables such devices, e.g., computers, to send and receive data indoors and out; anywhere within the range of a base station. Wi-Fi networks use radio technologies called IEEE 802.11 (a, b, g, n, ac, ag etc.) to provide secure, reliable, fast wireless connectivity. A Wi-Fi network can be used to connect computers to each other, to the Internet, and to wired networks (which can use IEEE 802.3 or Ethernet). Wi-Fi networks operate in the unlicensed 2.4 and 5 GHz radio bands for example or with products that contain both bands (dual band), so the networks can provide real-world performance similar to the basic 10BaseT wired Ethernet networks used in many offices.

FIG. 24 presents an example embodiment 2400 of a mobile network platform 2410 that can implement and exploit one or more aspects of the disclosed subject matter described herein. In one or more embodiments, the mobile network platform 2410 can generate and receive signals transmitted and received by base stations (e.g., base station devices 1504, macrocell site 1502, or base stations 1614), central office (e.g., central office 1501 or 1611), or transmission device 101 or 102 associated with the disclosed subject matter. Generally, wireless network platform 2410 can comprise components, e.g., nodes, gateways, interfaces, servers, or disparate platforms, that facilitate both packet-switched (PS) (e.g., internet protocol (IP), frame relay, asynchronous transfer mode (ATM)) and circuit-switched (CS) traffic (e.g., voice and data), as well as control generation for networked wireless telecommunication. As a non-limiting example, wireless network platform 2410 can be included in telecommunications carrier networks, and can be considered carrier-side components as discussed elsewhere herein. Mobile network platform 2410 comprises CS gateway node(s) 2422 which can interface CS traffic received from legacy networks like telephony network(s) 2440 (e.g., public switched telephone network (PSTN), or public land mobile network (PLMN)) or a signaling system #7 (SS7) network 2470. Circuit switched gateway node(s) 2422 can authorize and authenticate traffic (e.g., voice) arising from such networks. Additionally, CS gateway node(s) 2422 can access mobility, or roaming, data generated through SS7 network 2470; for instance, mobility data stored in a visited location register (VLR), which can reside in memory 2430. Moreover, CS gateway node(s) 2422 interfaces CS-based traffic and sig-

naling and PS gateway node(s) 2418. As an example, in a 3GPP UMTS network, CS gateway node(s) 2422 can be realized at least in part in gateway GPRS support node(s) (GGSN). It should be appreciated that functionality and specific operation of CS gateway node(s) 2422, PS gateway node(s) 2418, and serving node(s) 2416, is provided and dictated by radio technology(ies) utilized by mobile network platform 2410 for telecommunication.

In addition to receiving and processing CS-switched traffic and signaling, PS gateway node(s) 2418 can authorize and authenticate PS-based data sessions with served mobile devices. Data sessions can comprise traffic, or content(s), exchanged with networks external to the wireless network platform 2410, like wide area network(s) (WANs) 2450, enterprise network(s) 2470, and service network(s) 2480, which can be embodied in local area network(s) (LANs), can also be interfaced with mobile network platform 2410 through PS gateway node(s) 2418. It is to be noted that WANs 2450 and enterprise network(s) 2460 can embody, at least in part, a service network(s) like IP multimedia subsystem (IMS). Based on radio technology layer(s) available in technology resource(s) 2417, packet-switched gateway node(s) 2418 can generate packet data protocol contexts when a data session is established; other data structures that facilitate routing of packetized data also can be generated. To that end, in an aspect, PS gateway node(s) 2418 can comprise a tunnel interface (e.g., tunnel termination gateway (TTG) in 3GPP UMTS network(s) (not shown)) which can facilitate packetized communication with disparate wireless network(s), such as Wi-Fi networks.

In embodiment 2400, wireless network platform 2410 also comprises serving node(s) 2416 that, based upon available radio technology layer(s) within technology resource(s) 2417, convey the various packetized flows of data streams received through PS gateway node(s) 2418. It is to be noted that for technology resource(s) 2417 that rely primarily on CS communication, server node(s) can deliver traffic without reliance on PS gateway node(s) 2418; for example, server node(s) can embody at least in part a mobile switching center. As an example, in a 3GPP UMTS network, serving node(s) 2416 can be embodied in serving GPRS support node(s) (SGSN).

For radio technologies that exploit packetized communication, server(s) 2414 in wireless network platform 2410 can execute numerous applications that can generate multiple disparate packetized data streams or flows, and manage (e.g., schedule, queue, format . . .) such flows. Such application(s) can comprise add-on features to standard services (for example, provisioning, billing, customer support . . .) provided by wireless network platform 2410. Data streams (e.g., content(s) that are part of a voice call or data session) can be conveyed to PS gateway node(s) 2418 for authorization/authentication and initiation of a data session, and to serving node(s) 2416 for communication thereafter. In addition to application server, server(s) 2414 can comprise utility server(s), a utility server can comprise a provisioning server, an operations and maintenance server, a security server that can implement at least in part a certificate authority and firewalls as well as other security mechanisms, and the like. In an aspect, security server(s) secure communication served through wireless network platform 2410 to ensure network's operation and data integrity in addition to authorization and authentication procedures that CS gateway node(s) 2422 and PS gateway node(s) 2418 can enact. Moreover, provisioning server(s) can provision services from external network(s) like networks operated by a disparate service provider; for instance, WAN 2450 or

Global Positioning System (GPS) network(s) (not shown). Provisioning server(s) can also provision coverage through networks associated to wireless network platform **2410** (e.g., deployed and operated by the same service provider), such as the distributed antennas networks shown in FIG. **1** that enhance wireless service coverage by providing more network coverage. Repeater devices such as those shown in FIGS. **7**, **8**, and **9** also improve network coverage in order to enhance subscriber service experience by way of UE **2475**.

It is to be noted that server(s) **2414** can comprise one or more processors configured to confer at least in part the functionality of macro network platform **2410**. To that end, the one or more processor can execute code instructions stored in memory **2430**, for example. It should be appreciated that server(s) **2414** can comprise a content manager **2415**, which operates in substantially the same manner as described hereinbefore.

In example embodiment **2400**, memory **2430** can store information related to operation of wireless network platform **2410**. Other operational information can comprise provisioning information of mobile devices served through wireless platform network **2410**, subscriber databases; application intelligence, pricing schemes, e.g., promotional rates, flat-rate programs, couponing campaigns; technical specification(s) consistent with telecommunication protocols for operation of disparate radio, or wireless, technology layers; and so forth. Memory **2430** can also store information from at least one of telephony network(s) **2440**, WAN **2450**, enterprise network(s) **2470**, or SS7 network **2460**. In an aspect, memory **2430** can be, for example, accessed as part of a data store component or as a remotely connected memory store.

In order to provide a context for the various aspects of the disclosed subject matter, FIG. **24**, and the following discussion, are intended to provide a brief, general description of a suitable environment in which the various aspects of the disclosed subject matter can be implemented. While the subject matter has been described above in the general context of computer-executable instructions of a computer program that runs on a computer and/or computers, those skilled in the art will recognize that the disclosed subject matter also can be implemented in combination with other program modules. Generally, program modules comprise routines, programs, components, data structures, etc. that perform particular tasks and/or implement particular abstract data types.

FIG. **25** depicts an illustrative embodiment of a communication device **2500**. The communication device **2500** can serve as an illustrative embodiment of devices such as mobile devices and in-building devices referred to by the subject disclosure (e.g., in FIGS. **15**, **16A** and **16B**).

The communication device **2500** can comprise a wireline and/or wireless transceiver **2502** (herein transceiver **2502**), a user interface (UI) **2504**, a power supply **2514**, a location receiver **2516**, a motion sensor **2518**, an orientation sensor **2520**, and a controller **2506** for managing operations thereof. The transceiver **2502** can support short-range or long-range wireless access technologies such as Bluetooth®, ZigBee®, WiFi, DECT, or cellular communication technologies, just to mention a few (Bluetooth® and ZigBee® are trademarks registered by the Bluetooth® Special Interest Group and the ZigBee® Alliance, respectively). Cellular technologies can include, for example, CDMA-1X, UMTS/HSDPA, GSM/GPRS, TDMA/EDGE, EV/DO, WiMAX, SDR, LTE, as well as other next generation wireless communication technologies as they arise. The transceiver **2502** can also be adapted to support circuit-switched wireline access tech-

nologies (such as PSTN), packet-switched wireline access technologies (such as TCP/IP, VoIP, etc.), and combinations thereof.

The UI **2504** can include a depressible or touch-sensitive keypad **2508** with a navigation mechanism such as a roller ball, a joystick, a mouse, or a navigation disk for manipulating operations of the communication device **2500**. The keypad **2508** can be an integral part of a housing assembly of the communication device **2500** or an independent device operably coupled thereto by a tethered wireline interface (such as a USB cable) or a wireless interface supporting for example Bluetooth®. The keypad **2508** can represent a numeric keypad commonly used by phones, and/or a QWERTY keypad with alphanumeric keys. The UI **2504** can further include a display **2510** such as monochrome or color LCD (Liquid Crystal Display), OLED (Organic Light Emitting Diode) or other suitable display technology for conveying images to an end user of the communication device **2500**. In an embodiment where the display **2510** is touch-sensitive, a portion or all of the keypad **2508** can be presented by way of the display **2510** with navigation features.

The display **2510** can use touch screen technology to also serve as a user interface for detecting user input. As a touch screen display, the communication device **2500** can be adapted to present a user interface having graphical user interface (GUI) elements that can be selected by a user with a touch of a finger. The touch screen display **2510** can be equipped with capacitive, resistive or other forms of sensing technology to detect how much surface area of a user's finger has been placed on a portion of the touch screen display. This sensing information can be used to control the manipulation of the GUI elements or other functions of the user interface. The display **2510** can be an integral part of the housing assembly of the communication device **2500** or an independent device communicatively coupled thereto by a tethered wireline interface (such as a cable) or a wireless interface.

The UI **2504** can also include an audio system **2512** that utilizes audio technology for conveying low volume audio (such as audio heard in proximity of a human ear) and high volume audio (such as speakerphone for hands free operation). The audio system **2512** can further include a microphone for receiving audible signals of an end user. The audio system **2512** can also be used for voice recognition applications. The UI **2504** can further include an image sensor **2513** such as a charged coupled device (CCD) camera for capturing still or moving images.

The power supply **2514** can utilize common power management technologies such as replaceable and rechargeable batteries, supply regulation technologies, and/or charging system technologies for supplying energy to the components of the communication device **2500** to facilitate long-range or short-range portable communications. Alternatively, or in combination, the charging system can utilize external power sources such as DC power supplied over a physical interface such as a USB port or other suitable tethering technologies.

The location receiver **2516** can utilize location technology such as a global positioning system (GPS) receiver capable of assisted GPS for identifying a location of the communication device **2500** based on signals generated by a constellation of GPS satellites, which can be used for facilitating location services such as navigation. The motion sensor **2518** can utilize motion sensing technology such as an accelerometer, a gyroscope, or other suitable motion sensing technology to detect motion of the communication device **2500** in three-dimensional space. The orientation sensor

2520 can utilize orientation sensing technology such as a magnetometer to detect the orientation of the communication device 2500 (north, south, west, and east, as well as combined orientations in degrees, minutes, or other suitable orientation metrics).

The communication device 2500 can use the transceiver 2502 to also determine a proximity to a cellular, WiFi, Bluetooth®, or other wireless access points by sensing techniques such as utilizing a received signal strength indicator (RSSI) and/or signal time of arrival (TOA) or time of flight (TOF) measurements. The controller 2506 can utilize computing technologies such as a microprocessor, a digital signal processor (DSP), programmable gate arrays, application specific integrated circuits, and/or a video processor with associated storage memory such as Flash, ROM, RAM, SRAM, DRAM or other storage technologies for executing computer instructions, controlling, and processing data supplied by the aforementioned components of the communication device 2500.

Other components not shown in FIG. 25 can be used in one or more embodiments of the subject disclosure. For instance, the communication device 2500 can include a slot for adding or removing an identity module such as a Subscriber Identity Module (SIM) card or Universal Integrated Circuit Card (UICC). SIM or UICC cards can be used for identifying subscriber services, executing programs, storing subscriber data, and so on.

In the subject specification, terms such as “store,” “storage,” “data store,” data storage,” “database,” and substantially any other information storage component relevant to operation and functionality of a component, refer to “memory components,” or entities embodied in a “memory” or components comprising the memory. It will be appreciated that the memory components described herein can be either volatile memory or nonvolatile memory, or can comprise both volatile and nonvolatile memory, by way of illustration, and not limitation, volatile memory, non-volatile memory, disk storage, and memory storage. Further, non-volatile memory can be included in read only memory (ROM), programmable ROM (PROM), electrically programmable ROM (EPROM), electrically erasable ROM (EEPROM), or flash memory. Volatile memory can comprise random access memory (RAM), which acts as external cache memory. By way of illustration and not limitation, RAM is available in many forms such as synchronous RAM (SRAM), dynamic RAM (DRAM), synchronous DRAM (SDRAM), double data rate SDRAM (DDR SDRAM), enhanced SDRAM (ESDRAM), Synchlink DRAM (SLDRAM), and direct Rambus RAM (DRRAM). Additionally, the disclosed memory components of systems or methods herein are intended to comprise, without being limited to comprising, these and any other suitable types of memory.

Moreover, it will be noted that the disclosed subject matter can be practiced with other computer system configurations, comprising single-processor or multiprocessor computer systems, mini-computing devices, mainframe computers, as well as personal computers, hand-held computing devices (e.g., PDA, phone, smartphone, watch, tablet computers, netbook computers, etc.), microprocessor-based or programmable consumer or industrial electronics, and the like. The illustrated aspects can also be practiced in distributed computing environments where tasks are performed by remote processing devices that are linked through a communications network; however, some if not all aspects of the subject disclosure can be practiced on stand-alone comput-

ers. In a distributed computing environment, program modules can be located in both local and remote memory storage devices.

Some of the embodiments described herein can also employ artificial intelligence (AI) to facilitate automating one or more features described herein. For example, artificial intelligence can be used in optional training controller 230 evaluate and select candidate frequencies, modulation schemes, MIMO modes, and/or guided wave modes in order to maximize transfer efficiency. The embodiments (e.g., in connection with automatically identifying acquired cell sites that provide a maximum value/benefit after addition to an existing communication network) can employ various AI-based schemes for carrying out various embodiments thereof. Moreover, the classifier can be employed to determine a ranking or priority of the each cell site of the acquired network. A classifier is a function that maps an input attribute vector, $x=(x_1, x_2, x_3, x_4, \dots, x_n)$, to a confidence that the input belongs to a class, that is, $f(x)=\text{confidence}$ (class). Such classification can employ a probabilistic and/or statistical-based analysis (e.g., factoring into the analysis utilities and costs) to prognose or infer an action that a user desires to be automatically performed. A support vector machine (SVM) is an example of a classifier that can be employed. The SVM operates by finding a hypersurface in the space of possible inputs, which the hypersurface attempts to split the triggering criteria from the non-triggering events. Intuitively, this makes the classification correct for testing data that is near, but not identical to training data. Other directed and undirected model classification approaches comprise, e.g., naïve Bayes, Bayesian networks, decision trees, neural networks, fuzzy logic models, and probabilistic classification models providing different patterns of independence can be employed. Classification as used herein also is inclusive of statistical regression that is utilized to develop models of priority.

As will be readily appreciated, one or more of the embodiments can employ classifiers that are explicitly trained (e.g., via a generic training data) as well as implicitly trained (e.g., via observing UE behavior, operator preferences, historical information, receiving extrinsic information). For example, SVMs can be configured via a learning or training phase within a classifier constructor and feature selection module. Thus, the classifier(s) can be used to automatically learn and perform a number of functions, including but not limited to determining according to a predetermined criteria which of the acquired cell sites will benefit a maximum number of subscribers and/or which of the acquired cell sites will add minimum value to the existing communication network coverage, etc.

As used in some contexts in this application, in some embodiments, the terms “component,” “system” and the like are intended to refer to, or comprise, a computer-related entity or an entity related to an operational apparatus with one or more specific functionalities, wherein the entity can be either hardware, a combination of hardware and software, software, or software in execution. As an example, a component may be, but is not limited to being, a process running on a processor, a processor, an object, an executable, a thread of execution, computer-executable instructions, a program, and/or a computer. By way of illustration and not limitation, both an application running on a server and the server can be a component. One or more components may reside within a process and/or thread of execution and a component may be localized on one computer and/or distributed between two or more computers. In addition, these components can execute from various computer readable

media having various data structures stored thereon. The components may communicate via local and/or remote processes such as in accordance with a signal having one or more data packets (e.g., data from one component interacting with another component in a local system, distributed system, and/or across a network such as the Internet with other systems via the signal). As another example, a component can be an apparatus with specific functionality provided by mechanical parts operated by electric or electronic circuitry, which is operated by a software or firmware application executed by a processor, wherein the processor can be internal or external to the apparatus and executes at least a part of the software or firmware application. As yet another example, a component can be an apparatus that provides specific functionality through electronic components without mechanical parts, the electronic components can comprise a processor therein to execute software or firmware that confers at least in part the functionality of the electronic components. While various components have been illustrated as separate components, it will be appreciated that multiple components can be implemented as a single component, or a single component can be implemented as multiple components, without departing from example embodiments.

Further, the various embodiments can be implemented as a method, apparatus or article of manufacture using standard programming and/or engineering techniques to produce software, firmware, hardware or any combination thereof to control a computer to implement the disclosed subject matter. The term "article of manufacture" as used herein is intended to encompass a computer program accessible from any computer-readable device or computer-readable storage/communications media. For example, computer readable storage media can include, but are not limited to, magnetic storage devices (e.g., hard disk, floppy disk, magnetic strips), optical disks (e.g., compact disk (CD), digital versatile disk (DVD)), smart cards, and flash memory devices (e.g., card, stick, key drive). Of course, those skilled in the art will recognize many modifications can be made to this configuration without departing from the scope or spirit of the various embodiments.

In addition, the words "example" and "exemplary" are used herein to mean serving as an instance or illustration. Any embodiment or design described herein as "example" or "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments or designs. Rather, use of the word example or exemplary is intended to present concepts in a concrete fashion. As used in this application, the term "or" is intended to mean an inclusive "or" rather than an exclusive "or". That is, unless specified otherwise or clear from context, "X employs A or B" is intended to mean any of the natural inclusive permutations. That is, if X employs A; X employs B; or X employs both A and B, then "X employs A or B" is satisfied under any of the foregoing instances. In addition, the articles "a" and "an" as used in this application and the appended claims should generally be construed to mean "one or more" unless specified otherwise or clear from context to be directed to a singular form.

Moreover, terms such as "user equipment," "mobile station," "mobile," "subscriber station," "access terminal," "terminal," "handset," "mobile device" (and/or terms representing similar terminology) can refer to a wireless device utilized by a subscriber or user of a wireless communication service to receive or convey data, control, voice, video, sound, gaming or substantially any data-stream or signaling-

stream. The foregoing terms are utilized interchangeably herein and with reference to the related drawings.

Furthermore, the terms "user," "subscriber," "customer," "consumer" and the like are employed interchangeably throughout, unless context warrants particular distinctions among the terms. It should be appreciated that such terms can refer to human entities or automated components supported through artificial intelligence (e.g., a capacity to make inference based, at least, on complex mathematical formalisms), which can provide simulated vision, sound recognition and so forth.

As employed herein, the term "processor" can refer to substantially any computing processing unit or device comprising, but not limited to comprising, single-core processors; single-processors with software multithread execution capability; multi-core processors; multi-core processors with software multithread execution capability; multi-core processors with hardware multithread technology; parallel platforms; and parallel platforms with distributed shared memory. Additionally, a processor can refer to an integrated circuit, an application specific integrated circuit (ASIC), a digital signal processor (DSP), a field programmable gate array (FPGA), a programmable logic controller (PLC), a complex programmable logic device (CPLD), a discrete gate or transistor logic, discrete hardware components or any combination thereof designed to perform the functions described herein. Processors can exploit nano-scale architectures such as, but not limited to, molecular and quantum-dot based transistors, switches and gates, in order to optimize space usage or enhance performance of user equipment. A processor can also be implemented as a combination of computing processing units.

As used herein, terms such as "data storage," "data storage," "database," and substantially any other information storage component relevant to operation and functionality of a component, refer to "memory components," or entities embodied in a "memory" or components comprising the memory. It will be appreciated that the memory components or computer-readable storage media, described herein can be either volatile memory or nonvolatile memory or can include both volatile and nonvolatile memory.

What has been described above includes mere examples of various embodiments. It is, of course, not possible to describe every conceivable combination of components or methodologies for purposes of describing these examples, but one of ordinary skill in the art can recognize that many further combinations and permutations of the present embodiments are possible. Accordingly, the embodiments disclosed and/or claimed herein are intended to embrace all such alterations, modifications and variations that fall within the spirit and scope of the appended claims. Furthermore, to the extent that the term "includes" is used in either the detailed description or the claims, such term is intended to be inclusive in a manner similar to the term "comprising" as "comprising" is interpreted when employed as a transitional word in a claim.

In addition, a flow diagram may include a "start" and/or "continue" indication. The "start" and "continue" indications reflect that the steps presented can optionally be incorporated in or otherwise used in conjunction with other routines. In this context, "start" indicates the beginning of the first step presented and may be preceded by other activities not specifically shown. Further, the "continue" indication reflects that the steps presented may be performed multiple times and/or may be succeeded by other activities not specifically shown. Further, while a flow diagram indi-

cates a particular ordering of steps, other orderings are likewise possible provided that the principles of causality are maintained.

As may also be used herein, the term(s) “operably coupled to”, “coupled to”, and/or “coupling” includes direct coupling between items and/or indirect coupling between items via one or more intervening items. Such items and intervening items include, but are not limited to, junctions, communication paths, components, circuit elements, circuits, functional blocks, and/or devices. As an example of indirect coupling, a signal conveyed from a first item to a second item may be modified by one or more intervening items by modifying the form, nature or format of information in a signal, while one or more elements of the information in the signal are nevertheless conveyed in a manner than can be recognized by the second item. In a further example of indirect coupling, an action in a first item can cause a reaction on the second item, as a result of actions and/or reactions in one or more intervening items.

Although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement which achieves the same or similar purpose may be substituted for the embodiments described or shown by the subject disclosure. The subject disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, can be used in the subject disclosure. For instance, one or more features from one or more embodiments can be combined with one or more features of one or more other embodiments. In one or more embodiments, features that are positively recited can also be negatively recited and excluded from the embodiment with or without replacement by another structural and/or functional feature. The steps or functions described with respect to the embodiments of the subject disclosure can be performed in any order. The steps or functions described with respect to the embodiments of the subject disclosure can be performed alone or in combination with other steps or functions of the subject disclosure, as well as from other embodiments or from other steps that have not been described in the subject disclosure. Further, more than or less than all of the features described with respect to an embodiment can also be utilized.

What is claimed is:

1. A rainfall sensor comprising:
 - a transmission medium; and
 - a rainfall analyzer configured to induce transmitted electromagnetic waves that are guided by the transmission medium to propagate along the transmission medium, wherein the transmitted electromagnetic waves propagate without requiring an electrical return path, wherein the rainfall analyzer receives reflected electromagnetic waves from the transmission medium in response to the transmitted electromagnetic waves and wherein the rainfall analyzer analyzes the reflected electromagnetic waves and generates rainfall data in response thereto; wherein the transmission medium comprises a guided wave cable having an exposed core portion that facilitates formation of water droplets in response to rainfall, and wherein the reflected electromagnetic waves are reflected by the water droplets.
2. The rainfall sensor of claim 1, wherein the exposed core portion includes a tapered end that facilitates formation of the water droplets.
3. The rainfall sensor of claim 1, wherein the exposed core portion includes a bend that facilitates formation of the water droplets.

4. The rainfall sensor of claim 1, wherein the rainfall analyzer comprises:

- a reflectometer configured to generate transmitted RF signals;
- a launcher that induces the transmitted electromagnetic waves in response to the transmitted RF signals and that receives the reflected electromagnetic waves and generates reflected RF signals in response thereto; wherein the reflectometer generates a reflected signal strength in response to the reflected RF signals; and
- a signal processor that generates the rainfall data based on the reflected signal strength.

5. The rainfall sensor of claim 4, wherein the signal processor generates the rainfall data based on the reflected signal strength by identifying an amount of the water droplets.

6. The rainfall sensor of claim 4, wherein the signal processor generates the rainfall data based on the reflected signal strength by identifying a frequency of the water droplets.

7. A method comprising:
generating transmitted electromagnetic waves that are guided by a transmission medium to propagate along the transmission medium, wherein the transmitted electromagnetic waves propagate without requiring an electrical return path;
receiving reflected electromagnetic waves from the transmission medium in response to the transmitted electromagnetic waves, wherein the transmission medium comprises a guided wave cable coupled to a dielectric antenna that forms water droplets in response to rainfall at an aperture of the dielectric antenna, and wherein the reflected electromagnetic waves are reflected by the water droplets; and
analyzing the reflected electromagnetic waves to generate rainfall data.

8. The method of claim 7, wherein the analyzing the reflected electromagnetic waves comprises:
generating a reflected signal strength in response to the reflected electromagnetic waves; and
generating the rainfall data based on the reflected signal strength.

9. The method of claim 8, wherein the generating the rainfall data based on the reflected signal strength includes identifying an amount of the water droplets.

10. The method of claim 8, wherein the generating the rainfall data based on the reflected signal strength includes identifying a frequency of the water droplets.

11. A rainfall sensor comprising:
means for inducing transmitted electromagnetic waves that are guided by a transmission medium to propagate along the transmission medium, wherein the transmitted electromagnetic waves propagate without requiring an electrical return path;
means for receiving reflected electromagnetic waves from the transmission medium in response to the transmitted electromagnetic waves; and
means for analyzing the reflected electromagnetic waves and for generating rainfall data in response thereto.

12. The rainfall sensor of claim 11, wherein the transmission medium comprises a guided wave cable having an exposed core portion that forms water droplets in response to rainfall, and wherein the reflected electromagnetic waves are reflected by the water droplets.

13. The rainfall sensor of claim 11, wherein the transmission medium comprises a guided wave cable having an exposed core portion that forms water droplets in response

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to rainfall, and wherein the reflected electromagnetic waves reflect from the water droplets, and wherein the means for analyzing generates the rainfall data by identifying an amount of the water droplets or a frequency of the water droplets.

14. The rainfall sensor of claim 11, wherein the transmission medium comprises a guided wave cable coupled to a dielectric antenna that forms water droplets in response to rainfall at an aperture of the dielectric antenna, and wherein the reflected electromagnetic waves are reflected by the water droplets.

15. The rainfall sensor of claim 12, wherein the exposed core portion includes a tapered end that facilitates formation of the water droplets.

16. The rainfall sensor of claim 12, wherein the exposed core portion includes a bend that facilitates formation of the water droplets.

17. The rainfall sensor of claim 12, wherein the means for inducing comprises:

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a reflectometer configured to generate transmitted RF signals; and

a launcher that induces the transmitted electromagnetic waves in response to the transmitted RF signals and that receives the reflected electromagnetic waves and generates reflected RF signals in response thereto.

18. The rainfall sensor of claim 17, wherein the means for analyzing comprises:

a signal processor that generates the rainfall data based on a reflected signal strength.

19. The rainfall sensor of claim 18, wherein the signal processor generates the rainfall data based on the reflected signal strength by identifying an amount of the water droplets.

20. The rainfall sensor of claim 18, wherein the signal processor generates the rainfall data based on the reflected signal strength by identifying a frequency of the water droplets.

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