(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
09 November 2017 (09.11.2017)

(10) International Publication Number
WO 2017/192954 A1

(51) International Patent Classification:
H01Q 5/25 (2015.01) ***H01Q 1/38*** (2006.01)
H01Q 9/04 (2006.01)

(21) International Application Number: PCT/US2017/031229

(22) International Filing Date: 05 May 2017 (05.05.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

PI2016701614	05 May 2016 (05.05.2016)	MY
15/241,890	19 August 2016 (19.08.2016)	US

(71) Applicant: LAIRD TECHNOLOGIES, INC. [US/US]; 3481 Rider Trail South, Earth City, Missouri 63045 (US).

(72) Inventors: NG, Kok Jiunn; 3481 Rider Trail South, Earth City, Missouri 63045 (US). **SU, Choon Chung**; 3481 Rider Trail South, Earth City, Missouri 63045 (US). **HANG, Chit Yong**; 3481 Rider Trail South, Earth City, Missouri 63045 (US).

(74) Agent: FUSSNER, Anthony G.; Harness, Dickey & Pierce, P.L.C., 7700 Bonhomme, Suite 400, St. Louis, MO 63105 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(54) Title: LOW PROFILE OMNIDIRECTIONAL ANTENNAS

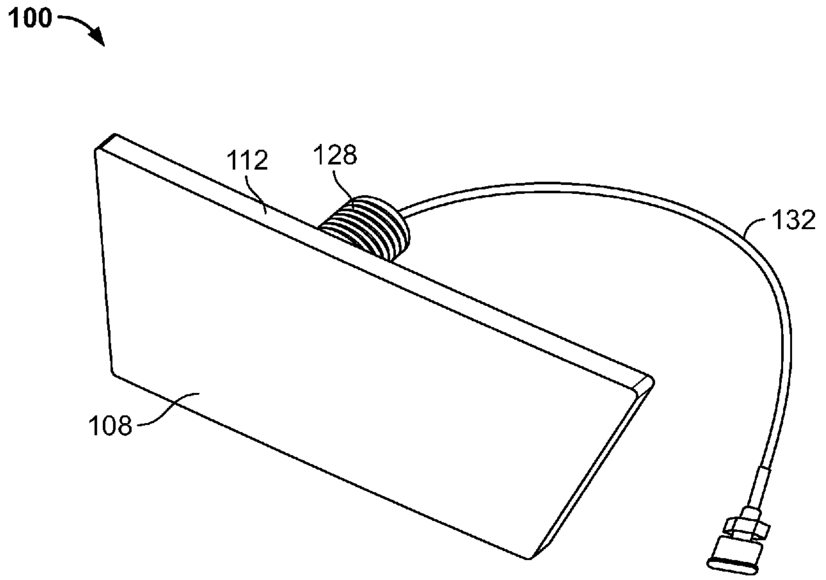


FIG. 1

(57) Abstract: Disclosed are exemplary embodiments of a low profile wideband and/or multiband omnidirectional antennas. In an exemplary embodiment, an antenna generally includes a radiator and a ground plane. The ground plane may include a slanted surface along or defining an edge portion of the ground plane. The slanted surface may be configured to be operable for reducing null at azimuth plane to thereby allow the antenna to have more omnidirectional radiation patterns for the azimuth plane. In another exemplary embodiment, an antenna generally includes a substrate, a radiator along the substrate, and electrically-conductive tape or foil defining at least part of a ground plane. The electrically-conductive tape or foil is coupled to a ground of the radiator via proximity coupling and electrically insulated by masking of the substrate.

WO 2017/192954 A1

[Continued on next page]

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

LOW PROFILE OMNIDIRECTIONAL ANTENNAS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a PCT International Application that claims benefit of and priority to:

(1) Malaysian Patent Application No. PI2016701614 filed May 5, 2016; and

(2) U.S. Patent Application No. 15/241,890 filed August 19, 2016, which, in turn, claims the benefit of and priority to Malaysian Patent Application No. PI2016701614 filed May 5, 2016.

The entire disclosures of the above applications are incorporated herein by reference.

FIELD

[0002] The present disclosure relates to low profile omnidirectional antennas.

BACKGROUND

[0003] This section provides background information related to the present disclosure which is not necessarily prior art.

[0004] For in-building cellular network applications, certain applications require a single-input single-output (SISO) antenna that is ultra-low profile and that is aesthetic looking for the building ceiling. Conventionally, this antenna type has been designed with a dipole parallel to the ceiling, which has a large null and has poor omnidirectionality in azimuth plane.

DRAWINGS

[0005] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

[0006] FIG. 1 is a perspective view of a low profile wideband/multiband omnidirectional SISO antenna according to an exemplary embodiment;

[0007] FIGS. 2A and 2B are respective back and front views of a prototype of the antenna shown in FIG. 1, where the antenna includes a transparent radome (FIG. 2B) and a transparent baseplate or support member (FIG. 2A);

[0008] FIG. 3 is an exploded perspective view of the antenna shown in FIGS. 2A and 2B, and illustrating the printed circuit board positioned between the radome and the baseplate;

[0009] FIG. 4 is a back view of the antenna shown in FIG. 2A without the baseplate and illustrating the ground plane and the patch along the back side of the printed circuit board (PCB) and a feed cable coupled (*e.g.*, soldered, *etc.*) to the ground plane;

[0010] FIG. 5 is a front view of the PCB shown in FIG. 4 and illustrating a radiator along the front side of the PCB;

[0011] FIG. 6 is a perspective view of the baseplate and radome shown in FIG. 3 after the baseplate is coupled to the radome;

[0012] FIG. 7 is a lower perspective view of the radome and baseplate shown in FIG. 6;

[0013] FIG. 8 is a perspective view of the PCB shown in FIG. 4, and illustrating the ground plane and the patch along the back side of the PCB;

[0014] FIG. 9 is another front view of the PCB shown in FIG. 5, and illustrating the radiator along the front side of the PCB;

[0015] FIGS. 10, 11, and 12 are respective back, side, and front views of the PCB shown in FIGS. 8 and 9 where exemplary dimensions (in millimeters) are provided for purposes of illustration only according to an exemplary embodiment;

[0016] FIG. 13 is a perspective view of a PCB that may be used with the antenna shown in FIGS. 1 through 3 according to another exemplary embodiment in which the PCB includes a radiator and a ground plane along opposite front and back sides of the PCB but does not include a patch along the back side of the PCB;

[0017] FIGS. 14A and 14B are respective back and side views of the PCB shown in FIG. 13 where exemplary dimensions (in millimeters) are provided for purposes of illustration only according to an exemplary embodiment;

[0018] FIG. 15A is an exemplary line graph of voltage standing wave ratio (VSWR) versus frequency in megahertz (MHz) measured for a prototype antenna as shown in FIGS. 1 through 3 with the PCB as shown in FIGS. 14A and 14B that did not include a patch along the back side of the PCB;

[0019] FIG. 15B is an exemplary line graph of voltage standing wave ratio (VSWR) versus frequency in megahertz (MHz) measured for a prototype antenna as shown in FIGS. 1

through 3 with the PCB as shown in FIGS. 10 through 12 including the patch along the back side of the PCB;

[0020] FIGS. 16 through 81 illustrate radiation patterns (azimuth plane, Phi 0° plane, and Phi 90° plane) at various frequencies measured for a prototype antenna as shown in FIGS. 1 through 3 with the PCB as shown in FIGS. 14A and 14B that did not include a patch along the back side of the PCB;

[0021] FIGS. 82 and 83 are exemplary line graphs of passive intermodulation level (PIM) in decibels relative to carrier (dBc) versus frequency in megahertz (MHz) measured for a prototype antenna as shown in FIGS. 1 through 3 with the PCB as shown in FIGS. 14A and 14B that did not include a patch along the back side of the PCB, and showing PIM (IM3) performance for two transmitted carriers (20W each) at respective transmission (Tx) frequencies of 728 MHz to 757 MHz and 1930 MHz to 1990 MHz;

[0022] FIGS. 84 through 137 illustrate radiation patterns (azimuth plane, Phi 0° plane, and Phi 90° plane) at various frequencies measured for a prototype antenna as shown in FIGS. 1 through 3 with the PCB as shown in FIGS. 10 through 12 including the patch along the back side of the PCB;

[0023] FIGS. 138 and 139 are exemplary line graphs of passive intermodulation level (PIM) in decibels relative to carrier (dBc) versus frequency in megahertz (MHz) measured for a prototype antenna as shown in FIGS. 1 through 3 with the PCB as shown in FIGS. 10 through 12 including the patch along the back side of the PCB, and showing PIM (IM3) performance for two transmitted carriers (20W each) at respective transmission (Tx) frequencies of 728 MHz to 757 MHz and 1930 MHz to 1990 MHz;

[0024] FIG. 140 illustrates a low profile wideband/multiband omnidirectional SISO antenna according to another exemplary embodiment that includes a radiator along a PCB and an electrically-conductive tape or foil, wherein the electrically-conductive tape or foil is coupled to a ground of the radiator via proximity coupling and electrically insulated by the masking of the PCB itself;

[0025] FIG. 141 provides exemplary dimensions in millimeters and angles in degrees for the electrically-conductive tape or foil shown in FIG. 140, which are provided for purposes of illustration only according to an exemplary embodiment;

[0026] FIG. 142 is an exemplary line graph of voltage standing wave ratio (VSWR) versus frequency in megahertz (MHz) measured for a prototype of the antenna shown in FIG. 140;

[0027] FIG. 143 is an exploded perspective view of a low profile wideband/multiband omnidirectional SISO antenna according to another exemplary embodiment in which a dielectric spacer is positioned between the baseplate or support member and a PCB generally around an opening of the threaded stud of the baseplate;

[0028] FIG. 144 is a partial cross-sectional side view of the antenna shown in FIG. 143 after the PCB and dielectric spacer have been positioned within an interior enclosure cooperatively defined between the baseplate and a radome;

[0029] FIG. 145 is a perspective view of a low profile wideband/multiband omnidirectional SISO antenna according to an exemplary embodiment;

[0030] FIG. 146 is a side view of the of the antenna shown in FIG. 1;

[0031] FIG. 147 is a side view of the of the antenna shown in FIG. 1, and also illustrating a gasket and mounting nut;

[0032] FIG. 148 is a bottom perspective view of the antenna shown in FIGS. 145 and 147, and illustrating exemplary locations for placement of QR code and unit labels;

[0033] FIG. 149 is a an exploded perspective view showing a printed circuit board (PCB) and electrically-conductive tape or foil (*e.g.*, aluminum foil, *etc.*) that may be used with the antenna shown in FIGS. 145 through 148;

[0034] FIGS. 150 and 151 are exploded perspective views of the antenna shown in FIGS. 145 through 148, and illustrating the PCB and electrically-conductive tape or foil (*e.g.*, aluminum foil, *etc.*) shown in FIG. 149 and a cable assembly fed through an opening in the base plate, where the cable center conductor (FIG. 150) and cable braid (FIG. 151) are soldered to the PCB;

[0035] FIG. 152 is a an exploded perspective view of the antenna shown in FIGS. 145 through 148, and illustrating exemplary guide pins for guiding and aligning the radome and the base plate and snap fit connections for coupling the radome and base plate to each other with the PCB sandwiched therebetween;

[0036] FIGS. 153 and 154 are bottom views of the antenna shown in FIG. 152, and illustrating exemplary heat stakes or posts and label locations;

[0037] FIG. 155 is a perspective view of the electrically-conductive tape or foil (*e.g.*, aluminum foil, *etc.*) shown in FIG. 149, and also illustrating a release liner along the surface that includes the adhesive and a release or peel-off line for the release liner;

[0038] FIGS. 156 and 157 are front and back views of the PCB shown in FIG. 149, and illustrating the radiator (FIG. 156) and the ground plane (FIG. 157) along the opposite front and back sides of the PCB.

[0039] Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION

[0040] Example embodiments will now be described more fully with reference to the accompanying drawings.

[0041] Disclosed herein are exemplary embodiments of low profile wideband and/or multiband omnidirectional SISO antennas. In some exemplary embodiments, the antenna is configured for wideband operation such that the antenna is operable within a wide frequency range (*e.g.*, from about 600 MHz to about 3800 MHz, across most of the Long Term Evolution (LTE) band, *etc.*). In other exemplary embodiments, the antenna is configured for multiband operation such that the antenna is operable within at least a first frequency range (*e.g.*, from about 698 MHz to about 960 MHz, *etc.*) and a second frequency range (*e.g.*, from about 1350 MHz to about 1525 MHz, from about 1690 MHz to about 3800 MHz, from about 1350 MHz to 3800 MHz, *etc.*) different than the first frequency range. For example, the antenna may be operable within a first frequency range from about 698 MHz to about 960 MHz, a second frequency range from about 1350 MHz to about 1525 MHz, and a third frequency range from about 1690 MHz to about 3800 MHz. In other possible exemplary embodiments, the antenna may cover more than the frequency ranges mentioned above (*e.g.*, 600 to 6000 MHz, *etc.*) with some tradeoff of the radiation pattern null.

[0042] In exemplary embodiments, the antenna includes a radiator within an interior cooperatively defined between a radome and a baseplate or support member. The baseplate may include a threaded stud feature (broadly, a mounting feature or fixture) for installing the antenna to a ceiling (broadly, a mounting surface). The radiator may comprise a PCB radiator, stamped radiator, flexible PCB radiator, combination thereof, *etc.* For example, the antenna may include a radiator and a ground plane (broadly, a ground element) along opposite first and second (or front and back) sides of a PCB (broadly, a substrate).

[0043] In exemplary embodiments, the antenna may include asymmetrical arms (*e.g.*, arms 120 and 124 along opposite sides of a PCB as shown in FIGS. 8 and 9, *etc.*) and thus is not a typical dipole antenna having symmetrical arms. The longer/larger asymmetrical arm may be referred to as a ground plane while the other asymmetrical arm may be referred to as the radiator.

[0044] The inventors hereof have recognized that there are several factors that play important roles to have reduced null and more omnidirectional radiation patterns at azimuth plane for a horizontal planar asymmetrical dipole antenna as disclosed herein:

- ratio of the length between the radiator and the ground plane;
- the edge angle of the ground plane against the radiator;
- the location of the feeding point; and
- the length of one of the radiator arms.

[0045] The inventors hereof have also recognized that there are also several factors to maintain the reduced null and more omnidirectional radiation patterns at azimuth plane for a horizontal planar asymmetrical dipole antenna while broadbanding the antenna bandwidth:

- wide arm or ground plane of the antenna;
- coupling between the arm and the ground plane;
- impedance matching via a slot introduced to an edge of the ground plane that overlaps the radiator;
- a slot introduced adjacent the solder location of the feeding cable; and
- width and length of the transmission line.

[0046] The inventors hereof have further recognized that there are several factors to lengthen the antenna electrically without significantly increasing antenna size when having a lower frequency option to cover frequencies from 600 MHz:

- slight lengthening of the trace defining the ground plane;
- extension of the radiator via suspended loading or proximity trace (broadly, a patch) to increase the electrical length; and
- having additional dielectric loading provided by at least one rib within or under the radome at predetermined or certain locations.

[0047] The inventors hereof have additionally recognized that there are several factors that lower the risk of PIM level:

- using pigtail coaxial cable option instead of a fixed connector that has less freedom for matching the antenna; and
- slot(s) at the feeding ground point to reduce soldering surface.

[0048] Accordingly, disclosed herein are exemplary embodiments of antennas that may have or provide one or more of the following features or advantages over conventional dipole antennas. For example, a low profile wideband and/or multiband omnidirectional SISO antenna disclosed herein may have less null at azimuth plane as compared to a conventional dipole. A low profile wideband and/or multiband omnidirectional SISO antenna disclosed herein may also have a wide bandwidth, may enable a stable low PIM product, and/or may have a low profile as compared to other conventional antennas. Additionally, exemplary embodiments may include one or more features to realize or achieve low PIM level. For example, some exemplary embodiments may have an improved or low PIM level due to slots (broadly, openings) adjacent to the feeding ground point for the feeding cable that reduces the soldering surface.

[0049] With reference now to the figures, FIGS. 1, 2A, and 2B illustrate an exemplary embodiment of an omnidirectional SISO antenna 100 embodying one or more aspects of the present disclosure. As disclosed herein, the antenna 100 may be configured for wideband operation or multiband operation depending on whether or not the antenna 100 includes the patch 104 shown in FIGS. 4 and 8. When the antenna 100 includes the patch 104, the antenna 100 may be configured to be operable within a wideband frequency range (*e.g.*, from about 600 MHz to about 3800 MHz, *etc.*). When the antenna 100 does not include the patch 104, the antenna 100 may be configured to be operable within multiple frequency ranges (*e.g.*, a first frequency range from about 698 MHz to about 960 MHz, a second frequency range from about 1350 MHz to about 1525 MHz, and a third frequency range from about 1690 MHz to about 3800 MHz, *etc.*).

[0050] As shown in FIGS. 1 through 3, the antenna 100 includes a radome or cover 108 (*e.g.*, a plastic flat rectangular radome, *etc.*) and a baseplate or support member 112 (*e.g.*, plastic baseplate, *etc.*). The radome 108 and baseplate 112 cooperatively defining an interior in which the printed circuit board (PCB) 116 is positioned as shown in FIG. 3.

[0051] The radome 108 and baseplate 112 are configured to protect the PCB 116 and electrically-conductive elements (*e.g.*, patch 104, ground plane 120, radiator 124, copper traces, *etc.*) on the PCB 116 from damage due to environmental conditions such as vibration or shock during use. The radome 108 and baseplate 112 may be formed from a wide range of materials, such as, for example, polymers, urethanes, plastic materials (*e.g.*, polycarbonate blends, Polycarbonate-Acrylnitril-Butadien-Styrol-Copolymer (PC/ABS) blend, *etc.*), glass-reinforced plastic materials, synthetic resin materials, thermoplastic materials (*e.g.*, GE Plastics Geloy® XP4034 Resin, *etc.*), other dielectric materials, *etc.* within the scope of the present disclosure.

[0052] The baseplate 112 includes a threaded stud feature 128 (broadly, a mounting feature or fixture) for installing the antenna 100 to a ceiling (broadly, a mounting surface). In this example, the baseplate 112 integrally includes the threaded stud feature 128 such that the baseplate 112 and threaded stud feature have a monolithic construction. Alternatively, the threaded stud feature 128 may instead be attached (*e.g.*, adhesively attached, mechanically fastened, *etc.*) to the baseplate 112.

[0053] As shown in FIG. 3, the threaded stud feature 128 is generally hollow such that the feed cable 132 (*e.g.*, coaxial cable, other transmission line, *etc.*) may be fed through the hollow interior of the threaded stud feature 128. As shown in FIG. 6, the threaded stud feature 128 may have a relatively small hole or opening 136 for the cable 132 to inhibit cable movement (*e.g.*, via an interference or friction fit, *etc.*) and reduce the risk of damage to the cable braid. Also, the feed cable 132 may be a coaxial cable that provides better PIM performance as compared to a fixed connector having less freedom of matching the antenna 100.

[0054] The radome 108 and baseplate 112 may be initially or temporarily coupled together by engaging catches 140 of the radome 108 with openings or recesses 144 of the baseplate 112. As shown in FIG. 6, the catches 140 are along the edges of the radome 108, while the recesses 144 are along the edges of the baseplate 112 as shown in FIG. 7.

[0055] The radome 108 includes heat stakes 148 for final assembly. The heat stakes 148 may be configured (*e.g.*, sized, shaped, located, *etc.*) to be positioned within corresponding holes or openings 152 in the PCB 116 (FIG. 5). Positioning the heat stakes 148 within the PCB holes 152 (as shown in FIGS. 3 and 4) aligns the PCB 116 and helps retain the positioning of the PCB 116 relative to the baseplate 112 and radome 108. The heat stakes 148 may be configured to allow the antenna 100 to withstand drop and vibration tests without being mechanically fastened together with screws. Also, the engagement of the radome's catches 140 with the baseplate's recesses 144 enable the antenna 100 to be tested before heat staking the radome 108 and baseplate 112 together. Alternatively, the radome 108 and baseplate 112 may be coupled together using other suitable means, such as mechanical fasteners, adhesives, *etc.*

[0056] As shown in FIG. 2B, the radome 108 includes at least one rib or protruding portion 156 that extends across a portion of the radome 108 such that the at least one rib 156 and ground plane 120 overlap. In this exemplary embodiment, the radome 108 includes three ribs 156 that are parallel with each other. The ribs 156 provide additional dielectric loading to the antenna 100 to add electrical length to the ground plane 120.

[0057] As shown in FIG. 8, the back side of the PCB 116 includes a ground plane 120 and the patch 104. The patch 104 proximity couples to the radiator 124 (FIG. 9) along the opposite front side of the PCB 116. The patch 104 is operable for increasing the electrical length of the radiator 124 for broadbanding the antenna bandwidth by extending or broadening the frequency range downward. For example, the addition of the patch 104 may reduce the bottom of the frequency range from 698 MHz to 600 MHz such that the antenna 100 has a greater bandwidth with acceptable omnidirectional radiation patterns. The patch 104 may also be referred to herein as a suspended loading patch or a proximity patch.

[0058] With continued reference to FIG. 8, the ground plane 120 includes a slanted surface 162 configured to reduce null and provide better radiation pattern for azimuth plane. For example, the slanted surface 162 may comprise a linear or straight surface along an upper portion of the ground plane 120 extending between and at an angle relative to two horizontal portions 164, 166 of the ground plane 120. The inventors hereof have recognized that the slant angle and the ratio between the radiator length and the ground plane length (*e.g.*, the length from top to bottom of the ground plane along the left hand side of FIG. 10, *etc.*) are important for the radiation pattern at azimuth plane. By way of example, the slant angle of the slanted surface 162 relative to horizontal may be from about 132 degrees to about 133 degrees (*e.g.*, 132 degrees, 132.5 degrees, 132.7 degrees, 132.9 degrees, 133 degrees, *etc.*) in exemplary embodiments.

[0059] The ground plane portion 166 extends or increases the size of the ground plane 120. The ground plane 120 also includes another portion 168 that extends or increases the size of the ground plane 120. Accordingly, the ground plane portions 166 and 168 electrically lengthen the ground plane 120.

[0060] The ground plane 120 includes a slot 170 for increasing the electrical path of the surface of the ground plane 120 that overlaps the radiator 124 to thereby increase impedance.

In this exemplary embodiment, the slot 170 is generally rectangular and extends generally perpendicular to and inwardly from the slanted surface 162. Alternatively, the slot 170 may be configured differently, *e.g.*, with a different shape, at a different location, with a different orientation relative to the slanted surface 162, *etc.*

[0061] The ground plane 120 also includes slots 172 (broadly, openings) along opposite sides of the feeding ground point 174 (FIGS. 4 and 8). As shown in FIG. FIGS. 4 and 8, the braid of the cable 132 may be soldered to the ground plane exposed solder pad. The slots 172 may be configured to improve bandwidth especially for the high band. In addition, the slots 172 may also be configured to reduce the surface for soldering to reduce the risk of high PIM level. In this exemplary embodiment, the slots 172 are generally rectangular and aligned or parallel with each other. Alternatively, the slots 172 may be configured differently, *e.g.*, with a different shape, at a different location, with a different orientation relative to each other, *etc.*

[0062] Generally, the slots 170, 172 are an absence of electrically-conductive material in the ground plane 120. For example, the ground plane 120 may be initially formed with the slots 170, 172, or the slots 170, 172 may be formed by removing electrically-conductive material from the ground plane 120, such as etching, cutting, stamping, *etc.* In still yet other embodiments, the slots 170, 172 may be formed by an electrically nonconductive or dielectric material, which is added to the ground plane 120 such as by printing, *etc.*

[0063] As shown in FIG. 9, the front side of the PCB 116 includes the radiator 124. The radiator 124 includes a main or first radiating element 176 configured to be operable to excite or drive the radiator 124 to resonate at low band down to 698 MHz. The radiator 124 further includes two high band (or second and third) radiating elements or arms 178 and 180. The high band radiating element or arm 178 is configured to be operable to excite or drive the resonator 124 to resonate at high band from 1350 MHz to 1710 MHz. The other high band radiating element or arm 180 is configured to be operable to excite or drive the radiator 124 to resonate at high band from 1710 MHz to 3800 MHz and above. The high band radiating elements 178 and/or 180 may have a sufficient length to maintain or improve omnidirectionality, as a shorter length may provide a greater bandwidth at the expense of the radiation pattern. The inventors hereof have also recognized that the gap 181, 183 between the bottom radiator arms or portions of the radiator 124 to the ground plane 120 are important for high band matching.

[0064] FIG. 9 also shows a microstrip line 182 extending between the radiator 124 and a feed point 184 for center core soldering of the cable 132. The width of the microstrip line 182 may be used to match the impedance of the antenna 100. Therefore, the microstrip line 182 is not necessarily designed with characteristic impedance at 50 Ohms.

[0065] As shown in FIG. 4, the feed cable 132 is electrically coupled (*e.g.*, soldered, *etc.*) to the feeding ground point 174 along the back side of the PCB 116. The feed cable 132 is also electrically coupled to the radiator 124 on the opposite front side of the PCB 116. In this exemplary embodiment, the PCB 116 includes a hole 186 (FIG. 5) through which the center core of the feed cable 132 is electrically coupled to the feed point 184 (FIG. 8). The feed point 184 is electrically coupled to the microstrip electrical transmission line 182, which, in turn, is electrically coupled to the radiator 124.

[0066] In this exemplary embodiment, the patch 104, the ground plane 120, the radiator 124, and the microstrip line 182 comprise electrically-conductive traces (*e.g.*, copper, *etc.*) along the PCB 116. Alternatively, the patch 104, ground plane 120, radiator 124, and/or microstrip line 182 may comprise other electrically-conductive elements besides copper traces on a PCB, *e.g.*, elements fabricated via stamping parts, plastic plating methods, constructed from sheet metal by cutting, stamping, etching, *etc.*

[0067] The PCB 116 may include a circuit board substrate made of flame retardant 4 (FR4) glass-reinforced epoxy laminate, *etc.* Additionally, or alternatively, the antenna 100 may include a flexible or rigid substrate, a plastic carrier, an insulator, a flexible circuit board, a flex-film, *etc.*

[0068] FIGS. 10, 11, and 12 provide exemplary dimensions (in millimeters) for the PCB 116. As shown, the PCB 116 may have a height of about 170 mm, a width of about 100 mm, and a thickness of about 0.83 mm. The dimensions in this paragraph (and elsewhere in this application and the drawings) are provided for purposes of illustration only according to exemplary embodiments as alternative embodiments may be configured differently, *e.g.*, smaller or larger, *etc.*

[0069] FIG. 13 illustrates another PCB 216 that may be used with the antenna 100 shown in FIGS. 1 through 3 according to another exemplary embodiment. The PCB 216 may be similar or substantially identical to the PCB 116 described above and shown in FIGS. 8 and 9. For example, the PCB 216 also includes a radiator 224 and a ground plane 220 along opposite front and back sides of the PCB 216. In this exemplary embodiment, however, the PCB 216 does not include a patch 104 along the back side of the PCB 216. Also, the radiator 224 includes a main or first radiating element 276 with a different shape than the corresponding main or first radiating element 176 of the radiator 124.

[0070] As shown in FIG. 13, the ground plane 220 includes a slanted surface 262, horizontal portion 264, and slots 270, 272 similar in construction and operation as the corresponding slanted surface 162, horizontal portion 164, and slots 170, 172 of the ground plane 120.

[0071] For example, the slanted surface 262 may be configured to reduce null and provide better radiation pattern for azimuth plane. By way of example, the slant angle of the slanted surface 262 relative to horizontal may be from about 132 degrees to about 133 degrees (*e.g.*, 132 degrees, 132.5 degrees, 132.7 degrees, 132.9 degrees, 133 degrees, *etc.*) in exemplary embodiments.

[0072] The horizontal portion 264 extends or increases the size of and electrically lengthens the ground plane 220. The slot 270 may increase the electrical path of the surface of the ground plane 220 that overlaps the radiator 224 to thereby increase impedance. The slots 272 (broadly, openings) along opposite sides of the feeding ground point may improve bandwidth especially for the high band and reduce the surface for soldering to reduce the risk of high PIM level.

[0073] The radiator 224 includes a main or first radiating element 276 and two high band (or second and third) radiating elements or arms 278 and 280. The main radiating element 276 may be configured to be operable to excite or drive the radiator 224 to resonate at low band, *e.g.*, down to about 698 MHz, *etc.* The high band radiating element or arm 278 may be configured to be operable to excite or drive the radiator 224 to resonate at a first high band, *e.g.*, from about 1350 MHz to about 1525 MHz, *etc.* The other high band radiating element or arm 280 may be configured to be operable to excite or drive the radiator 224 to resonate at second high higher than the first high band, *e.g.*, from about 1690 MHz to about 3800 MHz, *etc.*

[0074] FIG. 13 also shows a microstrip electrical transmission line 282. The microstrip line 282 extends between the radiator 224 and a feed point 284. The feed point 284 may be configured for center core soldering of the cable 232.

[0075] The antenna 100 may have an ultra-low profile design (*e.g.*, a radome height or thickness of about 7.6 mm or less, *etc.*). For example, the dimensions of the radome 108 may be 180.3 mm x 117.2 mm x 7.6 mm. The antenna 100 may be used as an in-building ceiling mounted cellular network antenna. The antenna 100 may be configured to be aesthetic looking, unobtrusive, and/or have an outer appearance for blending with or matching the color of the ceiling or other mounting surface for the antenna 100. For example, the radome 108 of the antenna 100 may be white or other color to match or blend with the color of the ceiling (*e.g.*, drop ceiling tiles or panels, *etc.*) to which the antenna 100 may be mounted. Also, the radome 108 may be relatively flat so that the radome 108 will be flush against the ceiling, unobtrusive, and not protrude significantly outwardly from the ceiling after the antenna 100 is mounted to the ceiling. The dimensions in this paragraph (and elsewhere in this application and the drawings) are provided for purposes of illustration only according to exemplary embodiments as alternative embodiments may be configured differently, *e.g.*, smaller or larger, *etc.*

[0076] FIGS. 15B through 81 provide results measured for a prototype of the antenna 100 as shown in FIGS. 1 through 3 with the PCB 116 as shown in FIGS. 10 through 12 that includes the patch 104. FIG. 15A and FIGS. 84 through 137 provide results measured for a prototype of the antenna 100 as shown in FIGS. 1 through 3 with the PCB 216 as shown in FIGS. 14A and 14B that did not include the patch 104. These analysis results are provided only for purposes of illustration and not for purposes of limitation as other exemplary embodiments may be configured differently and/or have different performance.

[0077] More specifically, FIG. 15A is an exemplary line graph of voltage standing wave ratio (VSWR) versus frequency in megahertz (MHz) measured for the prototype of the antenna 100 as shown in FIGS. 1 through 3 with the PCB 216 as shown in FIGS. 14A and 14B that did not include the patch 104. Generally, FIG. 15A shows that the prototype antenna without the patch is operable with good voltage standing wave ratio (VSWR) of less than 1.8:1 for frequencies within a first frequency range from about 698 MHz to about 960 and for frequencies within a second frequency range from about 1690 MHz to about 3800 MHz.

[0078] FIG. 15B is an exemplary line graph of voltage standing wave ratio (VSWR) versus frequency in megahertz (MHz) measured for the prototype of the antenna 100 as shown in FIGS. 1 through 3 with the PCB 116 as shown in FIGS. 10 through 12 that includes the patch 104. Generally, FIG. 15B shows that the prototype antenna with the patch is operable with good voltage standing wave ratio (VSWR) of less than 1.8:1 for frequencies within a wideband frequency range from about 600 MHz to about 3800 MHz. A comparison of FIGS. 15A and 15B also shows that the addition of the patch 104 can extend the frequency down to 600 MHz.

[0079] FIGS. 16 through 81 illustrate radiation patterns (azimuth plane, Phi 0° plane, and Phi 90° plane) measured for the prototype of the antenna 100 as shown in FIGS. 1 through 3 with the PCB 216 as shown in FIGS. 14A and 14B that did not include the patch 104 at frequencies of 698 MHz, 746 MHz, 824 MHz, 894 MHz, 850 MHz, 960 MHz, 1350 MHz, 1448 MHz, 1427 MH, 1525 MHz, 1710 MHz, 1850 MHz, 1930 MHz, 2130 MHz, 2170 MHz, 2310 MHz, 2412 MHz, 2506.5 MHz, 2600 MHz, 2700 MHz, 3300 MHz, and 3800 MHz, respectively. Generally, FIGS. 16 through 81 show the reasonable omnidirectional radiation patterns and good efficiency of the prototype antenna without the patch at these various frequencies that fall within a first frequency range from about 698 MHz to about 960 MHz, a second frequency range from about 1350 MHz to about 1525 MHz, and a third frequency range from about 1710 MHz to 3800 MHz.

[0080] FIGS. 82 and 83 are exemplary line graphs of passive intermodulation level (PIM) in decibels relative to carrier (dBc) versus frequency in megahertz (MHz) measured for the prototype of the antenna 100 as shown in FIGS. 1 through 3 with the PCB 216 as shown in FIGS. 14A and 14B that did not include the patch 104. FIGS. 82 and 83 show PIM (IM3) performance for two transmitted carriers (20W each) at respective transmission (Tx) frequencies of 728 MHz to 757 MHz and at 1930 MHz to 1990 MHz. As shown, the prototype antenna without the patch has good low PIM performance (*e.g.*, better or less than -150 dBc, *etc.*) with a low band peak of -158.9 dBc at 776 MHz and with a high band peak of -153.5 at 1899 MHz.

[0081] FIGS. 84 through 137 illustrate radiation patterns (azimuth plane, Phi 0° plane, and Phi 90° plane) measured for the prototype of the antenna 100 as shown in FIGS. 1 through 3 with the PCB 116 as shown in FIGS. 10 through 12 that includes the patch 104 at frequencies of 600 MHz, 645 MHz, 698 MHz, 824 MHz, 850 MHz, 960 MHz, 1350 MHz, 1500 MHz, 1525 MHz, 1680 MHz, 1850 MHz, 1990 MHz, 2170 MHz, 2310 MHz, 2510 MHz, 2700 MHz, 3300 MHz, and 3800 MHz, respectively. Generally, FIGS. 84 through 137 show the reasonable omnidirectional radiation patterns and good efficiency of the prototype antenna with the patch at these various frequencies that fall within a wideband frequency range from about 600 MHz to about 3800 MHz.

[0082] FIGS. 138 and 139 are exemplary line graphs of passive intermodulation level (PIM) in decibels relative to carrier (dBc) versus frequency in megahertz (MHz) measured for the prototype of the antenna 100 as shown in FIGS. 1 through 3 with the PCB 116 as shown in FIGS. 10 through 12 that includes the patch 104. FIGS. 138 and 139 show PIM (IM3) performance for two transmitted carriers (20W each) at respective transmission (Tx) frequencies of 728 MHz to 757 MHz and at 1930 MHz to 1990 MHz. As shown, the prototype antenna with the patch has good low PIM performance (*e.g.*, better or less than -150 dBc, *etc.*) with a low band peak of -160.7 dBc at 776 MHz and a high band peak of -156.5 at 1901 MHz.

[0083] FIG. 140 illustrates another exemplary embodiment of an omnidirectional SISO antenna 300 embodying one or more aspects of the present disclosure. As shown, the antenna 300 includes a radiator 324 along a PCB 316 and an electrically-conductive (*e.g.*, aluminum, *etc.*) tape or foil 320 (broadly, a ground plane). The electrically-conductive tape or foil 320 (*e.g.*, aluminum foil, *etc.*) defines at least part of the ground plane of the antenna 300.

[0084] In this exemplary embodiment, the electrically-conductive tape or foil 320 is coupled to a ground of the radiator 324 via proximity coupling and electrically insulated by the masking of the PCB 316 itself. As shown in FIG. 140, a portion 388 of the electrically-conductive tape or foil 320 is disposed over and overlaps a portion 322 of the PCB 316. The portion 322 of the PCB 316 that overlaps the electrically-conductive tape or foil 320 includes at least a portion of the ground (*e.g.*, copper trace, *etc.*) for the radiator 324. The overlapping of the portion 388 of the electrically-conductive tape or foil 320 with the portion 322 of the PCB 316 provides proximity coupling between the electrically-conductive tape or foil 320 and the ground 322 of the radiator 324.

[0085] The radiator 324 may be similar or identical to the radiator 124 shown in FIGS. 5 and 9. Accordingly, the radiator 324 may also include a main or first radiating element 376 and two high band radiating elements or arms 378 and 380. Alternatively, the radiator 324 may have a different configuration, *e.g.*, similar or identical to the radiator 224 shown in FIG. 13, *etc.*

[0086] With continued reference to FIG. 140, the electrically-conductive tape or foil 320 includes a slanted surface 362 and horizontal portions or stubs 364, 368 that may be similar in construction and operation as the corresponding slanted surface 162 and horizontal portions 164, 168 of the ground plane 120. For example, the horizontal portions 364, 368 extend or increase the size of and electrically lengthen the electrically-conductive tape or foil 320. The slanted surface 362 may be configured to reduce null and provide better radiation pattern for azimuth plane.

[0087] The portion 322 of the PCB 316 that overlaps the electrically-conductive tape or foil 320 includes slots 370 and 372. The slots 370 and 372 may be similar in construction and operation as the slots 170 and 172 of the ground plane 120.

[0088] The PCB 316 does not extend entirely over the electrically-conductive tape or foil 320 such that less PCB material is needed. As shown in FIG. 140, the PCB 316 extends across or overlaps only a portion 388 of the electrically-conductive tape or foil 320. In this exemplary embodiment, the PCB 316 is about half the size of the PCB 116 shown in FIG. 5. By using less of the relatively expensive PCB material (*e.g.*, FR4 glass-reinforced epoxy laminate, *etc.*), the cost of the antenna can be reduced.

[0089] The antenna 300 includes a patch 304 similar or identical to the patch 104 shown in FIGS. 4 and 8 and described above. The patch 304 may comprise an electrically-conductive (*e.g.*, copper, *etc.*) trace along the back side of the PCB 316. The patch 304 may proximity couple to the radiator 324 along the opposite front side of the PCB 316. The patch 304 may be operable for increasing the electrical length of the radiator 324 for broadbanding the antenna bandwidth by extending or broadening the frequency range downward. In other embodiments, the antenna 300 does not include any patch on the back side of the PCB 316.

[0090] FIG. 140 also shows a microstrip electrical transmission line 382. The transmission line 382 extends between the radiator 324 and a feed point 384. The feed point 384 may allow for center core soldering of a coaxial feed cable 390. For example, inner conductor of the coaxial feed cable 390 may be electrically connected (*e.g.*, soldered, *etc.*) to the radiator 324. The outer cable braid of the coaxial feed cable 390 may be electrically connected (*e.g.*, soldered, *etc.*) to the portion 322 of the PCB 316 that overlaps the electrically-conductive tape or foil 320 and includes at least a portion of the ground.

[0091] The antenna 300 may also include a baseplate and radome similar or identical to the baseplate 112 and radome 108 shown in FIG. 1 and described above.

[0092] The antenna 300 may be configured for wideband operation or multiband operation. For example, the antenna 300 may be configured to be operable within a wideband frequency range, such as from about 600 MHz to about 3800 MHz, *etc.* Or, for example, the antenna 300 may be configured to be operable within multiple frequency ranges, such as a first frequency range from about 698 MHz to about 960 MHz, a second frequency range from about 1350 MHz to about 1525 MHz, and a third frequency range from about 1690 MHz to about 3800 MHz, *etc.*

[0093] The antenna 300 may have an ultra-low profile design (*e.g.*, a radome height or thickness of about 7.6 mm or less, *etc.*). For example, the dimensions of the radome may be 180.3 mm x 117.2 mm x 7.6 mm. The antenna 300 may be used as an in-building ceiling mounted cellular network antenna. The antenna 300 may be configured to be aesthetic looking, unobtrusive, and/or have an outer appearance for blending with or matching the color of the ceiling or other mounting surface for the antenna 300. For example, the radome of the antenna 300 may be white or other color to match or blend with the color of the ceiling (*e.g.*, drop ceiling tiles or panels, *etc.*) to which the antenna 300 may be mounted. Also, the radome may be relatively flat so that the radome will be flush against the ceiling, unobtrusive, and not protrude significantly outwardly from the ceiling after the antenna 300 is mounted to the ceiling. The dimensions in this paragraph (and elsewhere in this application and the drawings) are provided for purposes of illustration only according to exemplary embodiments as alternative embodiments may be configured differently, *e.g.*, smaller or larger, *etc.*

[0094] FIG. 141 provides exemplary dimensions in millimeters and angles in degrees for the electrically-conductive tape or foil 320 shown in FIG. 140, which are provided for purposes of illustration only according to an exemplary embodiment. In this exemplary embodiment shown in FIG. 141, the height is 100 millimeters, and the slant angle of the slanted surface relative to horizontal is 133 degrees. Alternative embodiments may be configured differently, *e.g.*, smaller, larger, differently shaped, *etc.*

[0095] FIG. 142 is an exemplary line graph of voltage standing wave ratio (VSWR) versus frequency in megahertz (MHz) measured for a prototype of the antenna 300 shown in FIG. 140 including the PCB 316, radiator 324, and aluminum tape or foil 320 with dimensions similar to the dimensions disclosed herein. Generally, FIG. 142 shows the achievable bandwidth of an antenna including PCB 316, radiator 324, and aluminum tape or foil 320. FIG. 142 also shows that an antenna with the PCB 316, radiator 324, and aluminum tape or foil 320 is operable with good voltage standing wave ratio (VSWR) of less than 1.8:1 for frequencies within a frequency range from about 608 MHz to about 960 and for frequencies from about 1520 MHz to about 2700 MHz. As shown in FIG. 142, the VSWR was 1.72 at 608 MHz, 1.21 at 698 MHz, 1.1 at 824 MHz, 1.21 at 960 MHz, 1.58 at 1520 MHz, 1.45 at 1710 MHz, 1.11 at 2170 MHz, and 1.16 at 2700 MHz. These VSWR results are provided only for purposes of illustration and not for purposes of limitation as other exemplary embodiments may be configured differently and/or have different performance.

[0096] FIGS. 143 and 144 illustrates another exemplary embodiment of an omnidirectional SISO antenna 400 embodying one or more aspects of the present disclosure. As shown in FIG. 143, the antenna 400 includes a dielectric spacer 492 (*e.g.*, plastic washer, *etc.*) positioned between the baseplate or support member 412 and a back side of the PCB 416. The dielectric spacer 492 is disposed generally around a second opening or hole 494 of the threaded stud feature 428 of the baseplate 412.

[0097] The antenna 400 also includes a feed cable 432 (*e.g.*, coaxial cable, other transmission line, *etc.*) that is fed through a first opening into and through the hollow interior of the threaded stud feature 428 and out the second opening 494 to a feeding ground point. The first opening of the threaded stud feature 428 may be relatively small to inhibit cable movement (*e.g.*, via an interference or friction fit, *etc.*) and reduce the risk of damage to the cable braid. Also, the feed cable 432 may be a coaxial cable that provides better PIM performance as compared to a fixed connector having less freedom of matching the antenna 400.

[0098] FIG. 144 shows the PCB 416 and dielectric spacer 492 positioned within an interior enclosure cooperatively defined between the baseplate 412 and a radome 408. Without the dielectric 492, the area indicated by ovals 496 adjacent the hole 494 of the threaded stud feature 428 may be subject to deformation or flexing during a pull test. The pull test is indicated by the downward arrow in FIG. 144.

[0099] The dielectric spacer 492 is configured to help reduce or eliminate deformation or flexing of the PCB 416 adjacent or around the hole 494 that might otherwise occur due to the softness or flexibility of the substrate material (*e.g.*, type and/or thickness, *etc.*) of PCB 416. Deformation or flexing of the PCB 416 might elevate the PIM level and change the VSWR of the antenna 400. The dielectric spacer 492 helps make the area 496 adjacent the relatively large stud hole 494 firmer and less susceptible to deformation or flexing without damaging the PCB and elevating the PIM level. Accordingly, the dielectric spacer 492 may thus help make the PCB firmer, reduce the deformation or flexing caused by the pull test, and help maintain an acceptable PIM level and VSWR of the antenna 400.

[00100] The PCB 416 may be similar or substantially identical to a PCB disclosed herein, such as the PCB 116 shown in FIGS. 8 and 9, PCB shown in FIGS. 10 through 12, PCB 216 shown in FIG. 13, PCB shown in FIGS. 14A and 14B, PCB 316 shown in FIG. 140, PCB shown in FIG. 140, *etc.* The baseplate 412 and radome 408 may be similar or substantially identical to a baseplate and radome disclosed herein, such as the baseplate 112 and radome 108 shown in FIGS. 1 through 4, 6, and 7, *etc.* The radome 408 may be similar or substantially identical to a radome disclosed herein, such as the radome 108 shown in FIGS. 1 through 4. Any one of more of the antennas disclosed herein (*e.g.*, antenna 100 (FIGS. 1 through 4), antenna 300 (FIG. 140), *etc.*) may also include a dielectric spacer 492 as shown in FIGS. 143 and 144.

[00101] FIGS. 145 through 157 illustrates another exemplary embodiment of an omnidirectional SISO antenna 500 embodying one or more aspects of the present disclosure. The antenna 500 includes a radiator 524 (FIGS. 156) along a PCB 516 and an electrically-conductive (*e.g.*, aluminum, *etc.*) tape or foil 520 (broadly, a ground plane) (FIGS. 149-151 and 155). The electrically-conductive tape or foil 520 (*e.g.*, aluminum foil, *etc.*) defines at least part of the ground plane of the antenna 500.

[00102] In this exemplary embodiment, the electrically-conductive tape or foil 520 may be coupled to a ground of the radiator 524 via proximity coupling and may be electrically insulated by the masking of the PCB 516 itself. As shown in FIGS. 149 through 151, a portion of the electrically-conductive tape or foil 520 is disposed over and overlaps a portion along the PCB 516. The portion of the PCB 516 that overlaps the electrically-conductive tape or foil 520 includes at least a portion of the ground 522 (*e.g.*, copper trace, *etc.*) for the radiator 524. The overlapping of the portion of the electrically-conductive tape or foil 520 with the portion of the ground 522 along the PCB 516 provides proximity coupling between the electrically-conductive tape or foil 520 and the ground 522 of the radiator 524. The electrically-conductive tape or foil 520 may also include an extended ground plane portion 521 (FIG. 155) as compared to the electrically-conductive foil or tape 320 shown in FIG. 140.

[00103] The radiator 524 may be similar or identical to the radiator 124 shown in FIGS. 5 and 9. Accordingly, the radiator 524 may also include a main or first radiating element 576 and two high band radiating elements or arms 578 and 580 as shown in FIG. 156.

Alternatively, the radiator 524 may have a different configuration, *e.g.*, similar or identical to the radiator 224 shown in FIG. 13, *etc.*

[00104] As shown in FIG. 157, the ground 522 along the PCB 516 includes a slanted surface 562 and a horizontal portion or stub 568 that may be similar in construction and operation as the corresponding slanted surface 162 and horizontal portion 168 of the ground plane 120. For example, the horizontal portion 568 may extend or increase the size of and electrically lengthen the ground 522. The slanted surface 562 may be configured to reduce null and provide better radiation pattern for azimuth plane.

[00105] The ground plane 522 of the PCB 516 that overlaps the electrically-conductive tape or foil 520 includes slots 570 and 572. The slots 570 and 572 may be similar in construction and operation as the slots 570 and 572 of the ground plane 120.

[00106] The PCB 516 does not extend entirely over the electrically-conductive tape or foil 520 such that less PCB material is needed. As shown in FIGS. 149 and 150, the PCB 516 extends across or overlaps only a portion of the electrically-conductive tape or foil 520. In this exemplary embodiment, the PCB 516 may be about half the size of the PCB 116 shown in FIG. 5. By using less of the relatively expensive PCB material (*e.g.*, FR4 glass-reinforced epoxy laminate, *etc.*), the cost of the antenna can be reduced.

[00107] The antenna 500 includes a radome or cover 508 (*e.g.*, a plastic flat round radome, *etc.*) and a baseplate or support member 512 (*e.g.*, plastic baseplate, *etc.*). The radome 508 and baseplate 512 cooperatively defining an interior in which the printed circuit board (PCB) 516 and electrically-conductive foil or tape 520 are positioned.

[00108] The radome 508 and baseplate 112 are configured to protect the electrically-conductive foil or tape 520, the PCB 516 and electrically-conductive elements (*e.g.*, ground plane 522, radiator 524, copper traces, *etc.*) on the PCB 516 from damage due to environmental conditions such as vibration or shock during use. The radome 508 and baseplate 512 may be formed from a wide range of materials, such as, for example, polymers, urethanes, plastic materials (*e.g.*, polycarbonate blends, Polycarbonate-Acrylnitril-Butadien-Styrol-Copolymer (PC/ABS) blend, *etc.*), glass-reinforced plastic materials, synthetic resin materials, thermoplastic materials (*e.g.*, GE Plastics Geloy® XP4034 Resin, *etc.*), other dielectric materials, *etc.* within the scope of the present disclosure.

[00109] The baseplate 512 includes a threaded stud feature 528 (broadly, a mounting feature or fixture) for installing the antenna 500 to a ceiling (broadly, a mounting surface). In this example, the baseplate 512 integrally includes the threaded stud feature 528 such that the baseplate 512 and threaded stud feature have a monolithic construction. Alternatively, the threaded stud feature 528 may instead be attached (*e.g.*, adhesively attached, mechanically fastened, *etc.*) to the baseplate 512.

[00110] The threaded stud feature 528 is generally hollow such that the feed cable 590 (*e.g.*, coaxial cable, other transmission line, *etc.*) may be fed through the hollow interior of the threaded stud feature 528. Also, the feed cable 590 may be a coaxial cable that provides better PIM performance as compared to a fixed connector having less freedom of matching the antenna 500.

[00111] FIG. 156 shows a microstrip electrical transmission line 582 that extends between the radiator 524 and a feed point 584. In this illustrated embodiment, the cable feed location is generally centered relative to the round radome 508 and round base plate 512, to thereby allow the cable 590 (*e.g.*, coaxial cable, other transmission line, *etc.*) to be fed through the generally hollow interior of the threaded stud feature 528. The threaded stud feature 528 (e.g., plastic stud, etc.) is also generally centered (*e.g.*, not offset from a center ,*etc.*) or located at or co-aligned with the center of the round radome 508 and base plate 512. This allows an installer to rotate or turn the antenna 500 to a certain angle to troubleshoot the external PIM level without changing an overall appearance of the antenna 500 or relative positioning of the threaded stud feature 528 of the antenna 500 to the mounting surface. By way of comparison, the threaded stud feature 128 of the antenna 100 is offset and not centered relative to the rectangular base plate 112 and rectangular radome 108 as shown in FIGS. 2A and 6. The offset stud 128 and rectangular radome 108 may be an obstacle for an installer to rotate and change an angle of the antenna 100 during installation. This is because rotating the antenna 100 to troubleshoot the external PIM level will reposition the threaded stud feature 128 relative to the mounting surface, which, in turn, may affect the design of the ceiling of the building where aesthetics may be important factor for the installation.

[00112] The feed point 584 may allow for center core soldering of a coaxial feed cable 590. For example, inner conductor of the coaxial feed cable 590 may be electrically connected (*e.g.*, soldered, *etc.*) to the radiator 524 as shown in FIG. 150. The outer cable braid of the coaxial feed cable 590 may be electrically connected (*e.g.*, soldered, *etc.*) to the portion 522 of the PCB 516 that overlaps the electrically-conductive tape or foil 520 and includes at least a portion of the ground as shown in FIG. 151.

[00113] The radome 508 and baseplate 512 may be initially or temporarily coupled together by engaging catches 540 of the radome 508 with openings or recesses 544 of the baseplate 112 as shown in FIG. 152. The radome 508 includes heat stakes 548 (FIG. 153) for final assembly. The heat stakes 548 may be configured (*e.g.*, sized, shaped, located, *etc.*) to be positioned within corresponding holes or openings in the PCB 516. Positioning the heat stakes 548 within the PCB holes aligns the PCB 516 and helps retain the positioning of the PCB 516 relative to the baseplate 512 and radome 508. The heat stakes 548 may be configured to allow the antenna 500 to withstand drop and vibration tests without being mechanically fastened together with screws. Also, the engagement of the radome's catches 540 with the baseplate's recesses 544 enable the antenna 500 to be tested before heat staking the radome 508 and baseplate 512 together. Alternatively, the radome 508 and baseplate 512 may be coupled together using other suitable means, such as mechanical fasteners, adhesives, *etc.*

[00114] As shown in FIG. 152, the radome 508 includes at least one rib or protruding portion 556 that extends across a portion of the radome 508 such that the at least one rib 556 and ground plane 520 overlap. In this exemplary embodiment, the radome 508 includes multiple ribs 556 that may be curved and/or concentric with each other. The ribs 556 may provide additional dielectric loading to the antenna 500 to add electrical length to the ground plane 520.

[00115] As shown in FIG. 150, a dielectric step or member 513 (*e.g.*, a plastic substrate or other dielectric material, *etc.*) may be provided or disposed along a portion of the base plate 512. The dielectric step 513 may be configured to overlap and provide dielectric loading to the electrically-conductive tape or foil 520 (*e.g.*, aluminum tape, *etc.*). The dielectric step or member 513 takes the place or replaces a portion of a PCB substrate that might otherwise be used to overlap and provide dielectric loading to the electrically-conductive tape or foil 520. The dielectric step or member 513 helps ensure the ground plane has sufficient electrical length for the lowest operating frequency.

[00116] The antenna 500 may be configured for wideband operation or multiband operation. For example, the antenna 500 may be configured to be operable within a wideband frequency range, such as from about 600 MHz to about 3800 MHz, *etc.* Or, for example, the antenna 500 may be configured to be operable within multiple frequency ranges, such as a first frequency range from about 698 MHz to about 960 MHz, a second frequency range from about 1350 MHz to about 1525 MHz, and a third frequency range from about 1690 MHz to about 3800 MHz, *etc.*

[00117] The antenna 500 may have an ultra-low profile design (*e.g.*, a radome height or thickness of about 7.6 mm or less, *etc.*). The antenna 500 may be used as an in-building ceiling mounted cellular network antenna. The antenna 500 may be configured to be aesthetic looking, unobtrusive, and/or have an outer appearance for blending with or matching the color of the ceiling or other mounting surface for the antenna 500. For example, the radome of the antenna 500 may be white or other color to match or blend with the color of the ceiling (*e.g.*, drop ceiling tiles or panels, *etc.*) to which the antenna 300 may be mounted. Also, the radome may be relatively flat so that the radome will be flush against the ceiling, unobtrusive, and not protrude significantly outwardly from the ceiling after the antenna 500 is mounted to the ceiling. The dimensions in this paragraph (and elsewhere in this application and the drawings) are provided for purposes of illustration only according to exemplary embodiments as alternative embodiments may be configured differently, *e.g.*, smaller or larger, *etc.*

[00118] Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail. In addition, advantages and improvements that may be achieved with one or more exemplary embodiments of the present disclosure are provided for purpose of illustration only and do not limit scope of the present disclosure, as exemplary embodiments disclosed herein may provide all or none of the above mentioned advantages and improvements and still fall within the scope of the present disclosure.

[00119] Specific dimensions, specific materials, and/or specific shapes disclosed herein are example in nature and do not limit the scope of the present disclosure. The disclosure herein of particular values and particular ranges of values for given parameters are not exclusive of other values and ranges of values that may be useful in one or more of the examples disclosed herein. Moreover, it is envisioned that any two particular values for a specific parameter stated herein may define the endpoints of a range of values that may be suitable for the given parameter (i.e., the disclosure of a first value and a second value for a given parameter can be interpreted as disclosing that any value between the first and second values could also be employed for the given parameter). For example, if Parameter X is exemplified herein to have value A and also exemplified to have value Z, it is envisioned that parameter X may have a range of values from about A to about Z. Similarly, it is envisioned that disclosure of two or more ranges of values for a parameter (whether such ranges are nested, overlapping or distinct) subsume all possible combination of ranges for the value that might be claimed using endpoints of the disclosed ranges. For example, if parameter X is exemplified herein to have values in the range of 1 – 10, or 2 – 9, or 3 – 8, it is also envisioned that Parameter X may have other ranges of values including 1 – 9, 1 – 8, 1 – 3, 1 - 2, 2 – 10, 2 – 8, 2 – 3, 3 – 10, and 3 – 9.

[00120] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms “a,” “an,” and “the” may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms “comprises,” “comprising,” “including,” and “having,” are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[00121] When an element or layer is referred to as being “on,” “engaged to,” “connected to,” or “coupled to” another element or layer, it may be directly on, engaged, connected or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being “directly on,” “directly engaged to,” “directly connected to,” or “directly coupled to” another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (*e.g.*, “between” versus “directly between,” "adjacent" versus "directly adjacent," *etc.*). As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[00122] The term "about" when applied to values indicates that the calculation or the measurement allows some slight imprecision in the value (with some approach to exactness in the value; approximately or reasonably close to the value; nearly). If, for some reason, the imprecision provided by "about" is not otherwise understood in the art with this ordinary meaning, then "about" as used herein indicates at least variations that may arise from ordinary methods of measuring or using such parameters. For example, the terms "generally," "about," and "substantially," may be used herein to mean within manufacturing tolerances.

[00123] Although the terms first, second, third, *etc.* may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as "first," "second," and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

[00124] Spatially relative terms, such as "inner," "outer," "beneath," "below," "lower," "above," "upper" and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the example term "below" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

[00125] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements, intended or stated uses, or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

CLAIMS

What is claimed is:

1. An antenna comprising:

a radiator; and

a ground plane including a slanted surface along or defining an edge portion of the ground plane, whereby the slanted surface is configured to be operable for reducing null at azimuth plane to thereby allow the antenna to have more omnidirectional radiation patterns for the azimuth plane.

2. The antenna of claim 1, further comprising a substrate having opposite front and back sides, and wherein:

the radiator is along the front side of the substrate; and

the ground plane is along the back side of the substrate.

3. The antenna of claim 2, further comprising a patch along the back side of the substrate spaced apart from the ground plane, whereby the patch proximity couples to the radiator along the front side of the substrate for increasing an electrical length of the radiator and thereby broaden antenna bandwidth by extending the frequency range downward.

4. The antenna of claim 2 or 3, wherein:

the antenna comprises a horizontal planar asymmetrical dipole antenna having first and second asymmetrical arms along the respective front and back sides of the substrate;

the first asymmetrical arm defines or includes the radiator; and

the second asymmetrical arm defines or includes the ground plane.

5. The antenna of claim 2 or 3, wherein:

a microstrip electrical transmission line along the front side of the substrate extends between the radiator and a feed point;

the substrate comprises a printed circuit board;

the radiator comprises an electrically-conductive trace along the front side of the printed circuit board; and

the ground plane comprises an electrically-conductive tape or foil and/or an electrically-conductive trace along the back side of the printed circuit board.

6. The antenna of claim 1, 2, or 3, wherein the ground plane includes:

a slot extending inwardly from the edge portion of the ground plane defined by the slanted surface, the slot configured to be operable for increasing an electrical path of a surface of the ground plane that overlaps the radiator to thereby increase impedance for impedance matching; and/or

at least one slot adjacent a feeding ground point that is configured to be operable for improving bandwidth and/or for reducing a surface for soldering to thereby reduce a risk of high passive intermodulation level.

7. The antenna of claim 1, 2, or 3, wherein the antenna includes:

a slot extending generally perpendicular to and inwardly from the edge portion of the ground plane defined by the slanted surface; and/or

a pair of slots respectively along opposite sides of a feeding ground point.

8. The antenna of claim 1, 2, or 3, wherein the ground plane includes:

a first portion adjacent an end portion of the slanted surface and extending outwardly relative to the ground plane to electrically lengthen the ground plane; and/or

a second portion spaced apart from the slanted surface and extending outwardly relative to the ground plane to electrically lengthen the ground plane.

9. The antenna of claim 1, 2, or 3, wherein:

the antenna is a single-input single-output (SISO) in-building ceiling mountable cellular network antenna; and/or

the antenna has an ultra-low profile with a radome height of about 7.6 millimeters.

10. The antenna of claim 1, 2, or 3, wherein the radiator includes:

a first radiating element configured to be operable to excite the radiator to resonate at low band;

a second radiating element configured to be operable to excite the radiator to resonate at a first high band; and

a third radiating element configured to be operable to excite the radiator to resonate at a second high band higher than the first high band.

11. The antenna of claim 1, further comprising:

a baseplate including a mounting feature for mounting the antenna to a mounting surface;

a radome coupled to the baseplate;

wherein the radiator and the ground plane are positioned within an interior cooperatively defined between the radome and the baseplate; and

wherein the mounting feature includes a hollow interior to allow a coaxial feed cable to be fed through the hollow interior to a feeding ground point; and

wherein:

the radome includes at least one rib or protruding portion at a predetermined location along the radome that provides additional dielectric loading to the antenna to thereby add electrical length to the ground plane; and/or

the mounting feature includes a first opening into the hollow interior of the mounting feature for the coaxial feed cable that is sized to inhibit cable movement thereby reducing risk of damage to a cable braid of the coaxial feed cable; and/or

the antenna further comprises a substrate having opposite front and back sides along which the radiator and the ground plane are respectively positioned, and a dielectric spacer between the baseplate and the back side of the substrate, whereby the dielectric spacer is disposed generally around a second opening of the mounting feature and configured to help reduce deformation or flexing of the substrate adjacent the second opening.

12. The antenna of claim 1, 2, or 3, wherein:

the antenna is configured for wideband operation such that the antenna is operable across a wide frequency range; or

the antenna is configured for multiband operation such that the antenna is operable within at least a first frequency range and a second frequency range different than the first frequency range.

13. The antenna of claim 1, 2, or 3, wherein:

the antenna is configured to be operable within a frequency range from about 600 MHz to about 3800 MHz, and the antenna is omnidirectional in the azimuth plane at frequencies within the frequency range from about 600 MHz to about 3800 MHz; or

the antenna is to be operable within a first frequency range from about 698 MHz to about 960 MHz, a second frequency range from about 1350 MHz to about 1525 MHz, and a third frequency range from about 1690 MHz to about 3800 MHz, and the antenna is omnidirectional in the azimuth plane at frequencies within the first, second, and third frequencies.

14. The antenna of claim 1, 2, or 3, further comprising an electrically-conductive tape or foil defining at least part of the ground plane.

15. The antenna of claim 14, wherein:

the antenna further comprises a substrate having opposite front and back sides;

the radiator is along the front side of the substrate; and

a portion of a ground of the radiator along a back side of the substrate overlaps a portion of the electrically-conductive tape or foil to thereby provide proximity coupling between the electrically-conductive tape or foil and the ground of the radiator.

16. The antenna of claim 15, wherein the electrically-conductive tape or foil is electrically insulated by masking of the substrate.

17. The antenna of claim 15, wherein:

the substrate covers only a portion of the electrically-conductive tape or foil; and/or

the electrically-conductive tape or foil includes the slanted surface defining the edge portion of the ground plane; and/or

the electrically-conductive tape or foil does not include any slots; and/or

the electrically-conductive tape or foil includes at least one portion extending outwardly relative to the ground plane defined by the electrically-conductive tape or foil to thereby electrically lengthen the ground plane.

18. The antenna of claim 1, 2, or 3, wherein the antenna is configured to be operable with a voltage standing wave ratio (VSWR) of less than 1.8:1 and/or with a passive intermodulation (IM3) less than -150 decibels relative to carrier (dBc) within a frequency range from about 600 MHz to about 3800 MHz.

19. The antenna of claim 1, 2, or 3, wherein:

the antenna is configured to be operable with a voltage standing wave ratio (VSWR) of less than 1.8:1 and/or with a passive intermodulation (IM3) less than -150 decibels relative to carrier (dBc) within a first frequency range from about 698 MHz to about 960 MHz;

the antenna is configured to be operable with a voltage standing wave ratio (VSWR) of less than 2:1 and/or with a passive intermodulation (IM3) less than -150 decibels relative to carrier (dBc) within a second frequency range from about 1350 MHz to about 1525 MHz; and the antenna is configured to be operable with a voltage standing wave ratio (VSWR) of less than 1.8:1 and/or with a passive intermodulation (IM3) less than -150 decibels relative to carrier (dBc) within a third frequency range from about 1690 MHz to about 3800 MHz.

20. An antenna comprising:

a substrate;

a radiator along the substrate; and

an electrically-conductive tape or foil defining at least part of a ground plane, the electrically-conductive tape or foil coupled to a ground of the radiator via proximity coupling and electrically insulated by masking of the substrate.

21. The antenna of claim 20, wherein the electrically-conductive tape or foil includes a slanted surface along or defining an edge portion of the ground plane, whereby the slanted surface is configured to be operable for reducing null at azimuth plane to thereby allow the antenna to have more omnidirectional radiation patterns for the azimuth plane.

22. The antenna of claim 20 or 21, wherein:

the substrate includes opposite front and back sides;

the radiator is along the front side of the substrate; and

a portion of a ground of the radiator along a back side of the substrate overlaps a portion of the electrically-conductive tape or foil to thereby provide proximity coupling between the electrically-conductive tape or foil and the ground of the radiator,

23. The antenna of claim 22, further comprising a patch along the back side of the substrate spaced apart from the ground plane, whereby the patch proximity couples to the radiator along the front side of the substrate for increasing an electrical length of the radiator and thereby broaden antenna bandwidth by extending the frequency range downward.

24. The antenna of claim 20 or 21, wherein:

the substrate covers only a portion of the electrically-conductive tape or foil; and/or

the electrically-conductive tape or foil includes at least one portion extending outwardly relative to the ground plane defined by the electrically-conductive tape or foil to thereby electrically lengthen the ground plane; and/or

wherein the radiator includes:

a first radiating element configured to be operable to excite the radiator to resonate at low band;

a second radiating element configured to be operable to excite the radiator to resonate at a first high band; and

a third radiating element configured to be operable to excite the radiator to resonate at a second high band higher than the first high band.

25. The antenna of claim 20 or 21, further comprising:

a baseplate including a mounting feature for mounting the antenna to a mounting surface;

a radome coupled to the baseplate;

wherein the substrate, the radiator, and the electrically-conductive tape or foil are positioned within an interior cooperatively defined between the radome and the baseplate; and

wherein the mounting feature includes a hollow interior to allow a coaxial feed cable to be fed through the hollow interior to a feeding ground point; and

wherein:

the radome includes at least one rib or protruding portion at a predetermined location along the radome that provides additional dielectric loading to the antenna to thereby add electrical length to the ground plane; and/or

the mounting feature includes a first opening for the coaxial feed cable that is sized to inhibit cable movement thereby reducing risk of damage to a cable braid of the coaxial feed cable; and/or

the antenna further comprises a dielectric spacer between the baseplate and the substrate, whereby the dielectric spacer is disposed generally around a second opening of the mounting feature and configured to help reduce deformation or flexing of the substrate adjacent the second opening.

26. The antenna of claim 20 or 21, wherein:

the antenna is a single-input single-output (SISO) in-building ceiling mountable cellular network antenna; and/or

the antenna has an ultra-low profile with a radome height of about 7.6 millimeters.

27. The antenna of claim 20 or 21, wherein:

the antenna is configured to operable within a frequency range from about 600 MHz to about 3800 MHz, and the antenna is omnidirectional in the azimuth plane at frequencies within the frequency range from about 600 MHz to about 3800 MHz; or the antenna is to be operable within a first frequency range from about 698 MHz to about 960 MHz, a second frequency range from about 1350 MHz to about 1525 MHz, and a third frequency range from about 1690 MHz to about 3800 MHz, and the antenna is omnidirectional in the azimuth plane at frequencies within the first, second, and third frequencies.

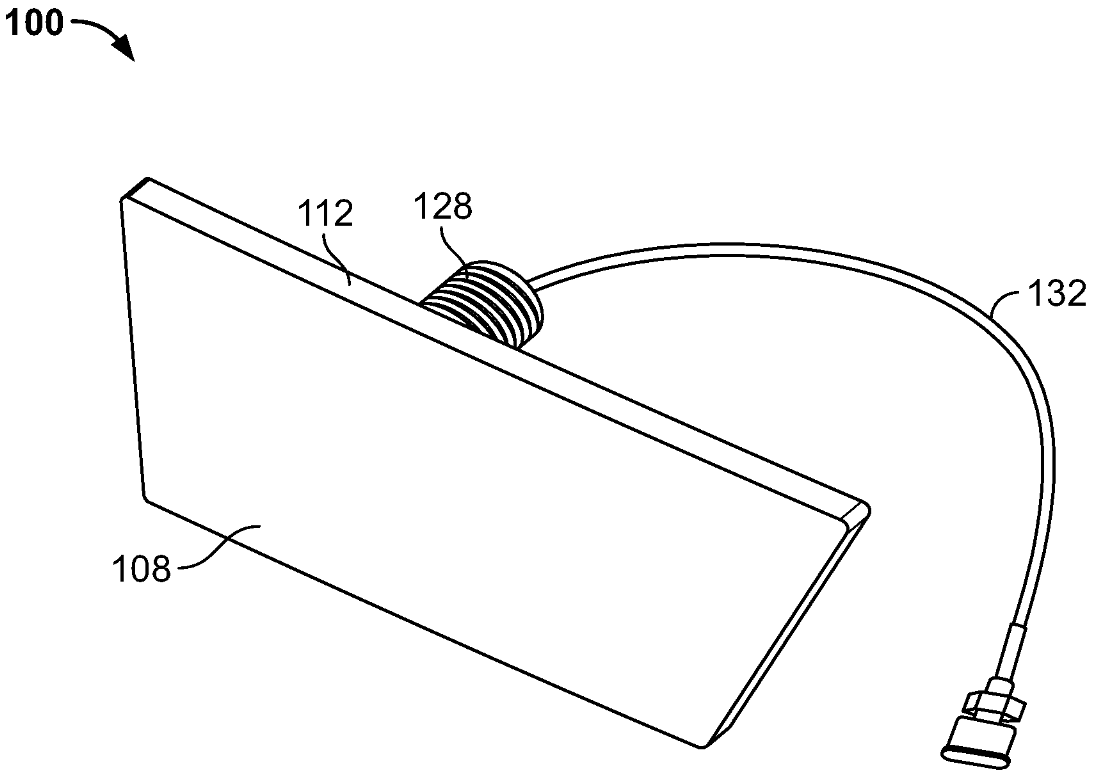


FIG. 1

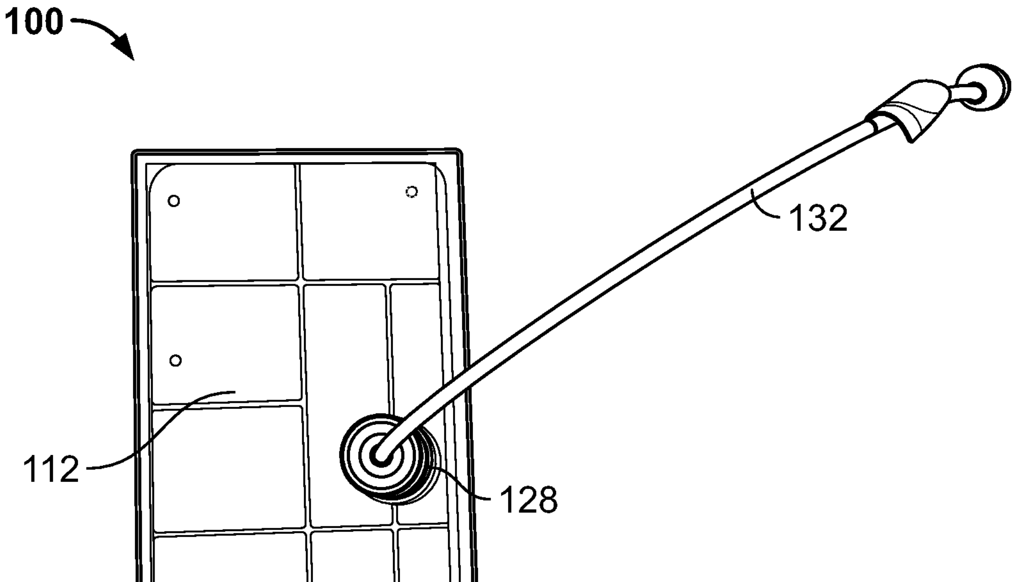


FIG. 2A

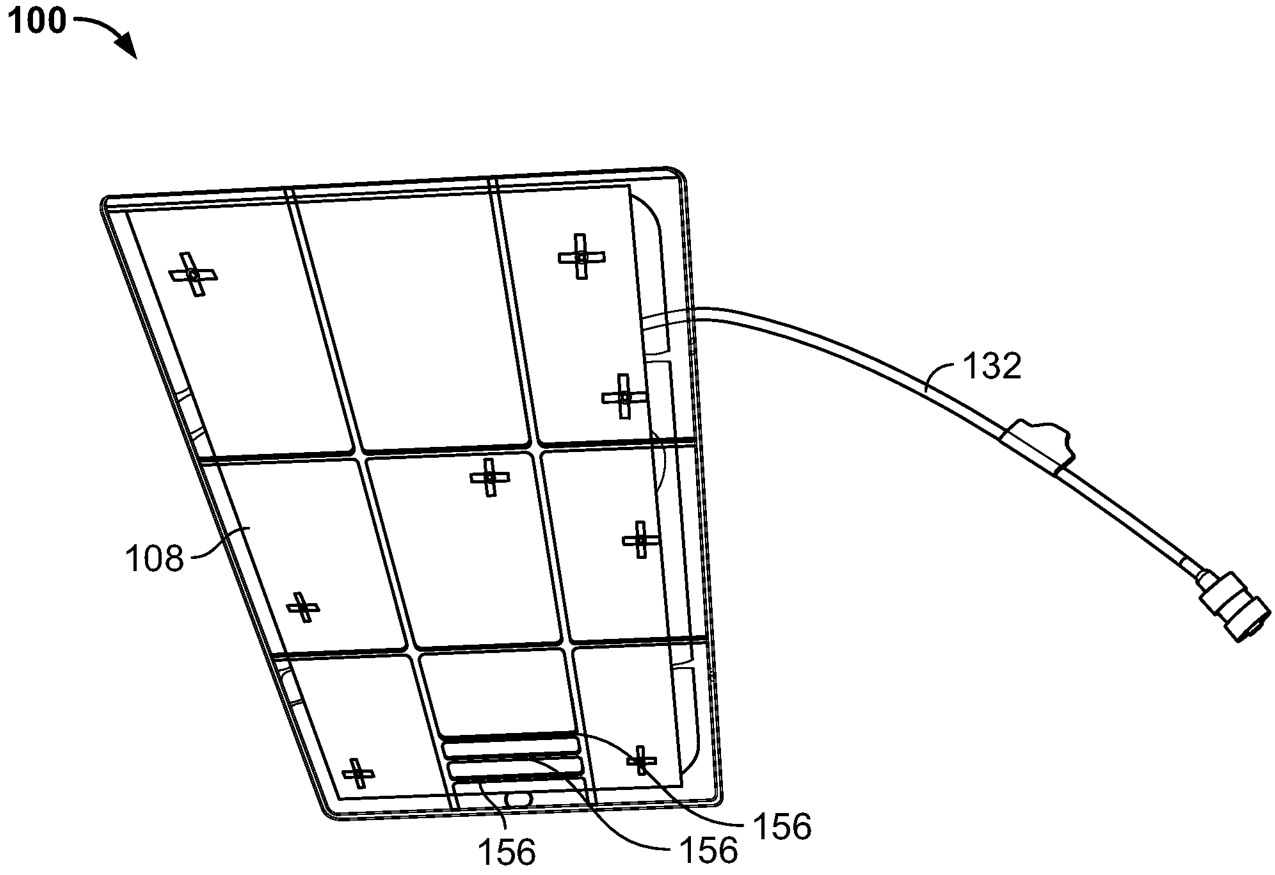


FIG. 2B

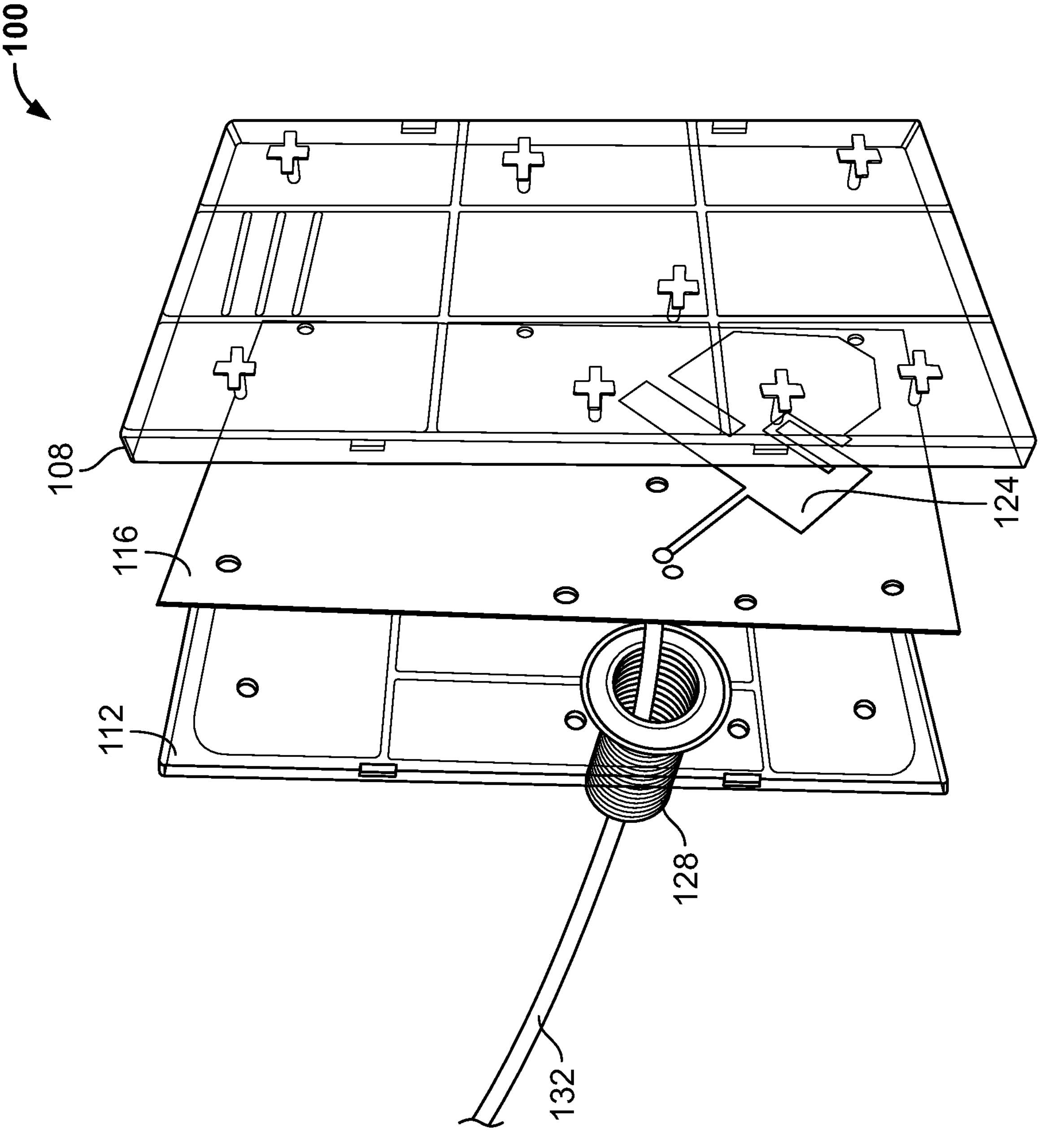


FIG. 3

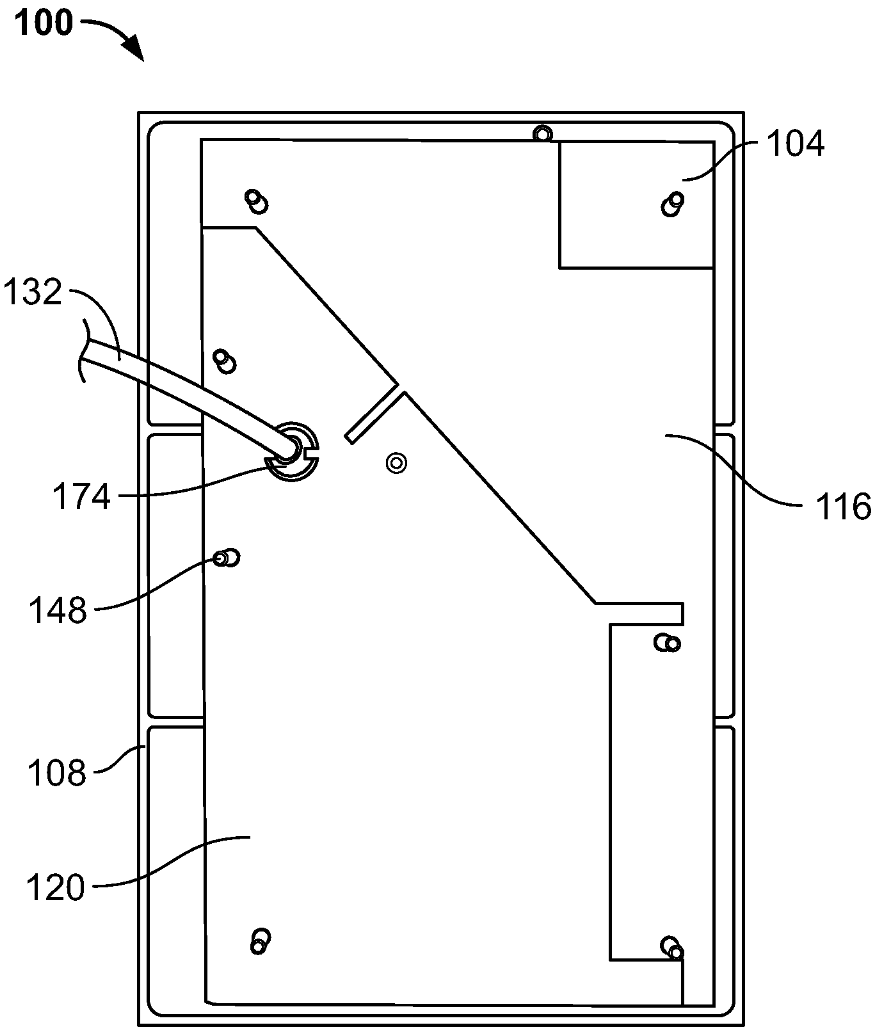


FIG. 4

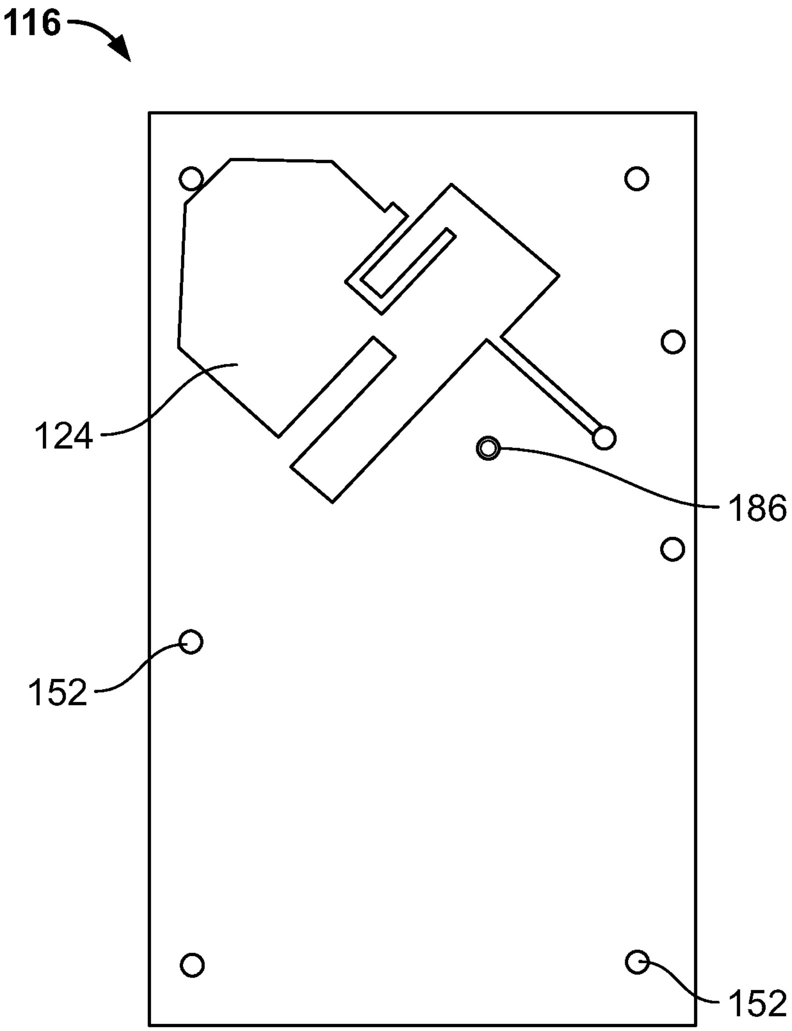


FIG. 5

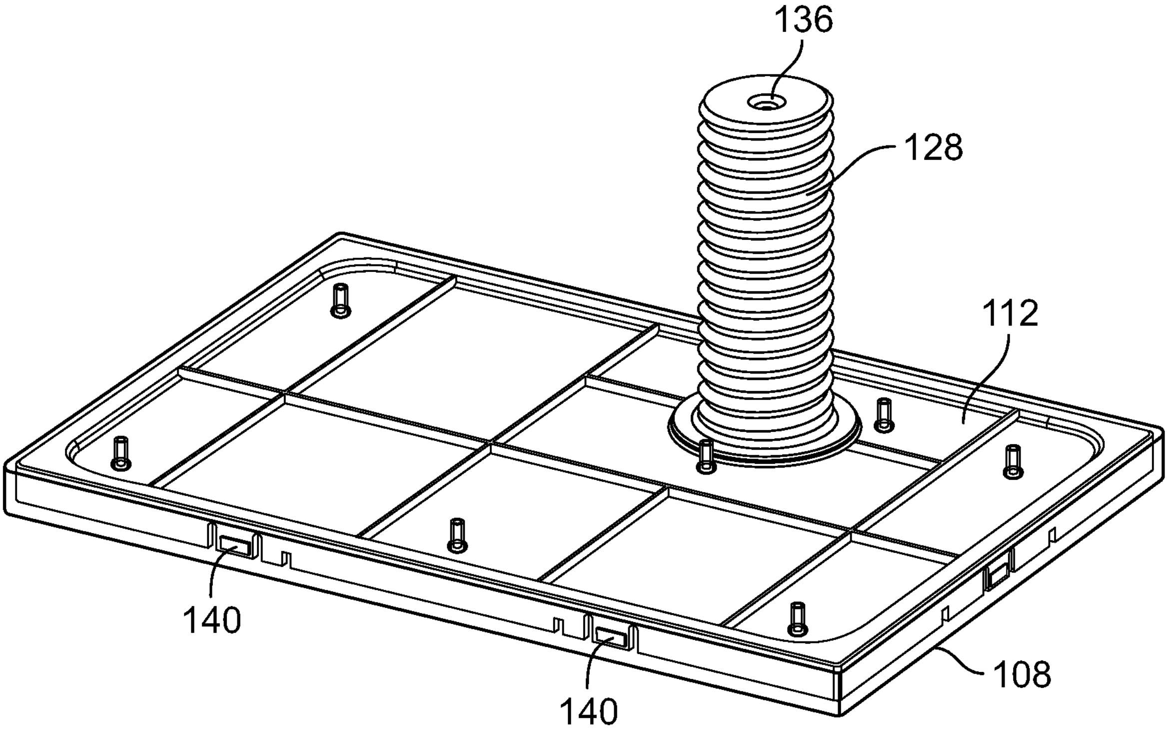


FIG. 6

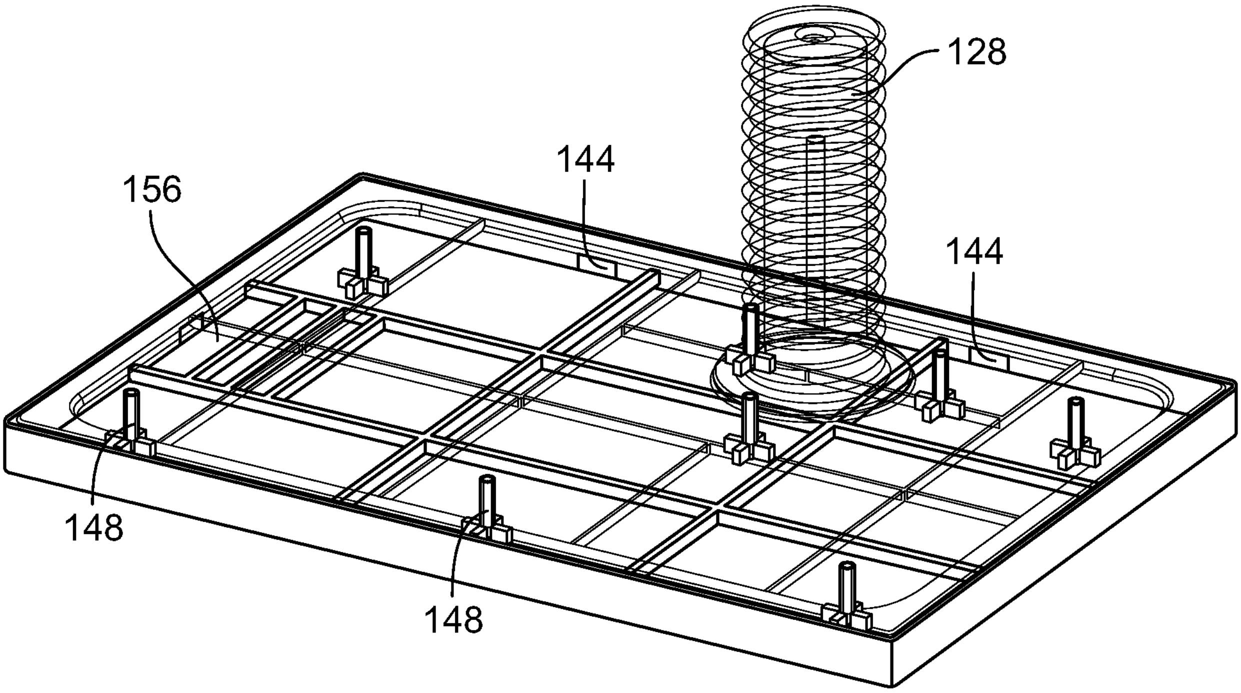


FIG. 7

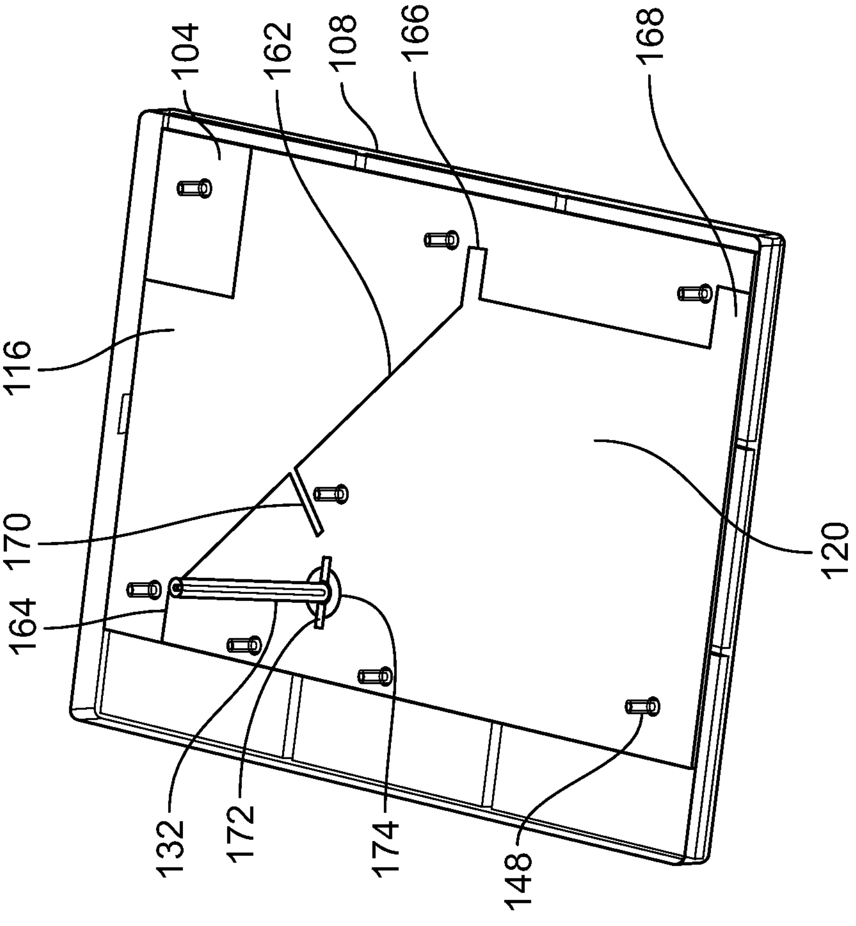

104
162
108
166
168
116
170
164
132
172
174
148
120

FIG. 8

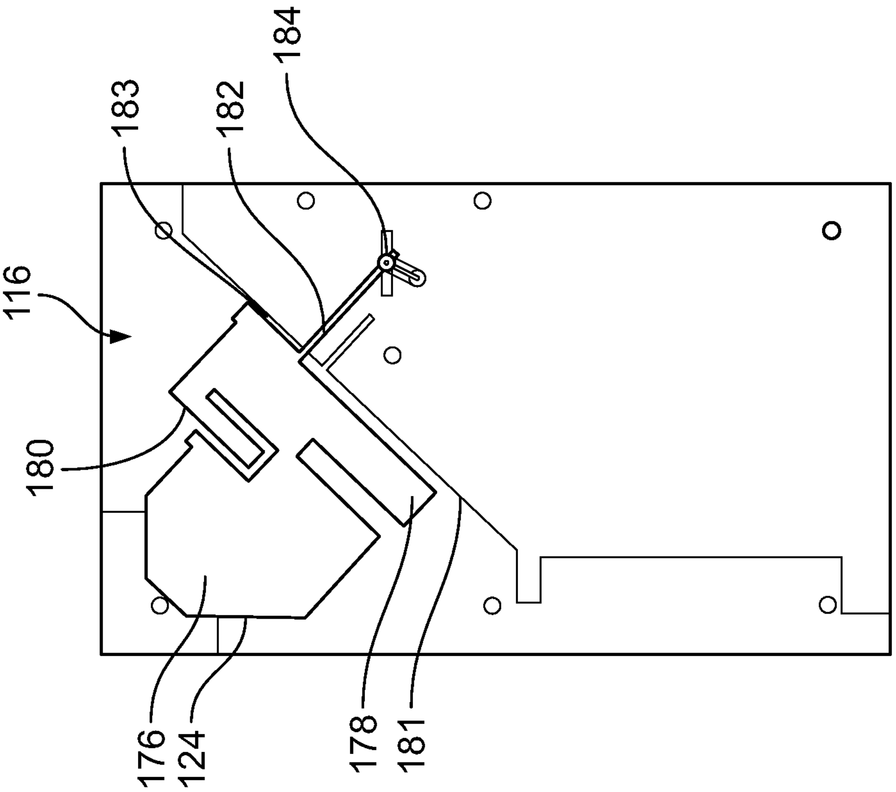

116
180
183
182
184
176
124
178
181

FIG. 9

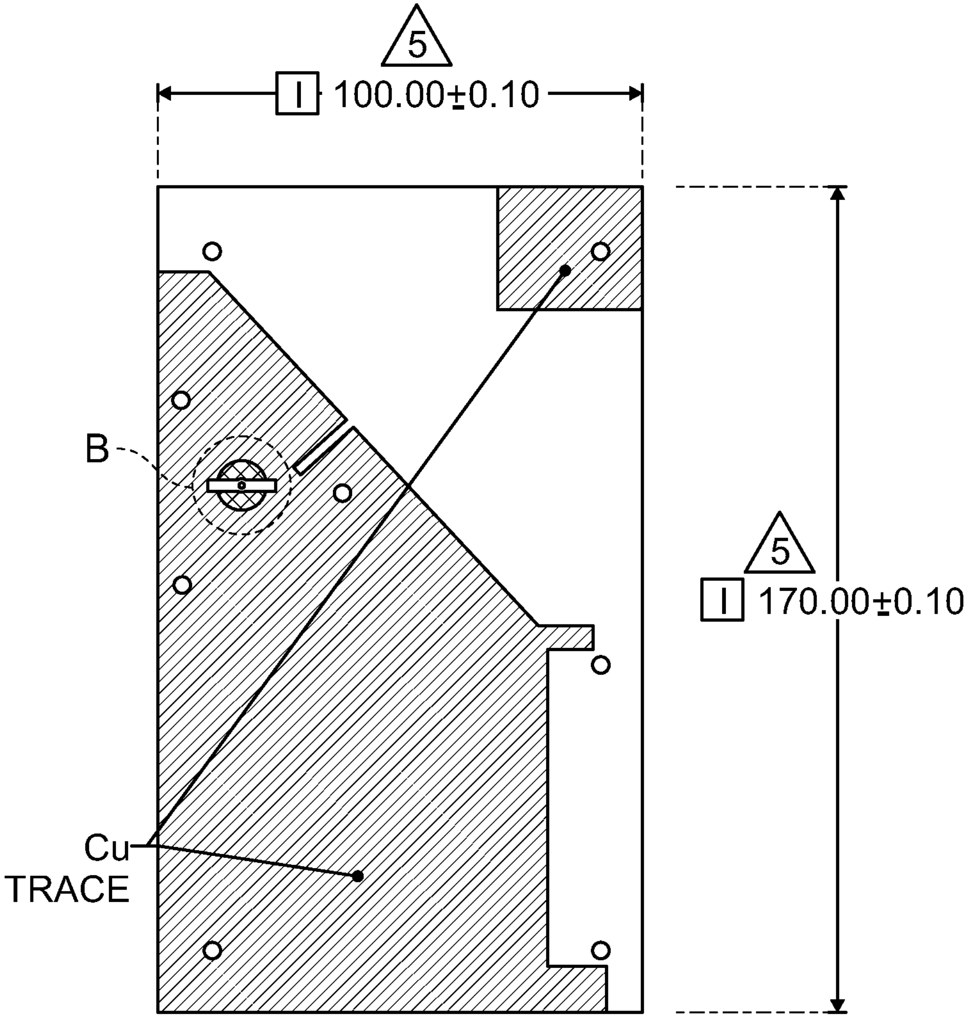


FIG. 10

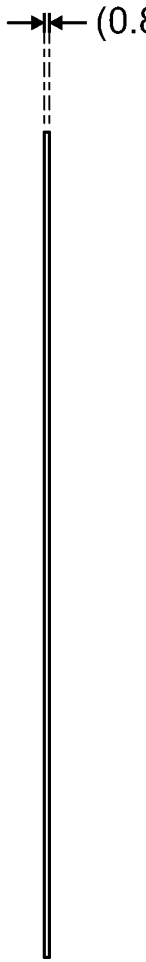


FIG. 11

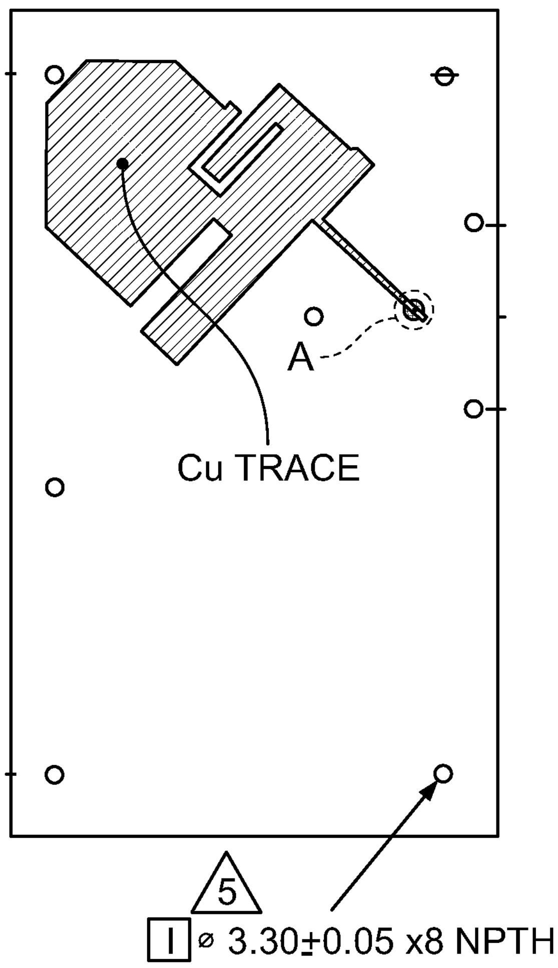


FIG. 12

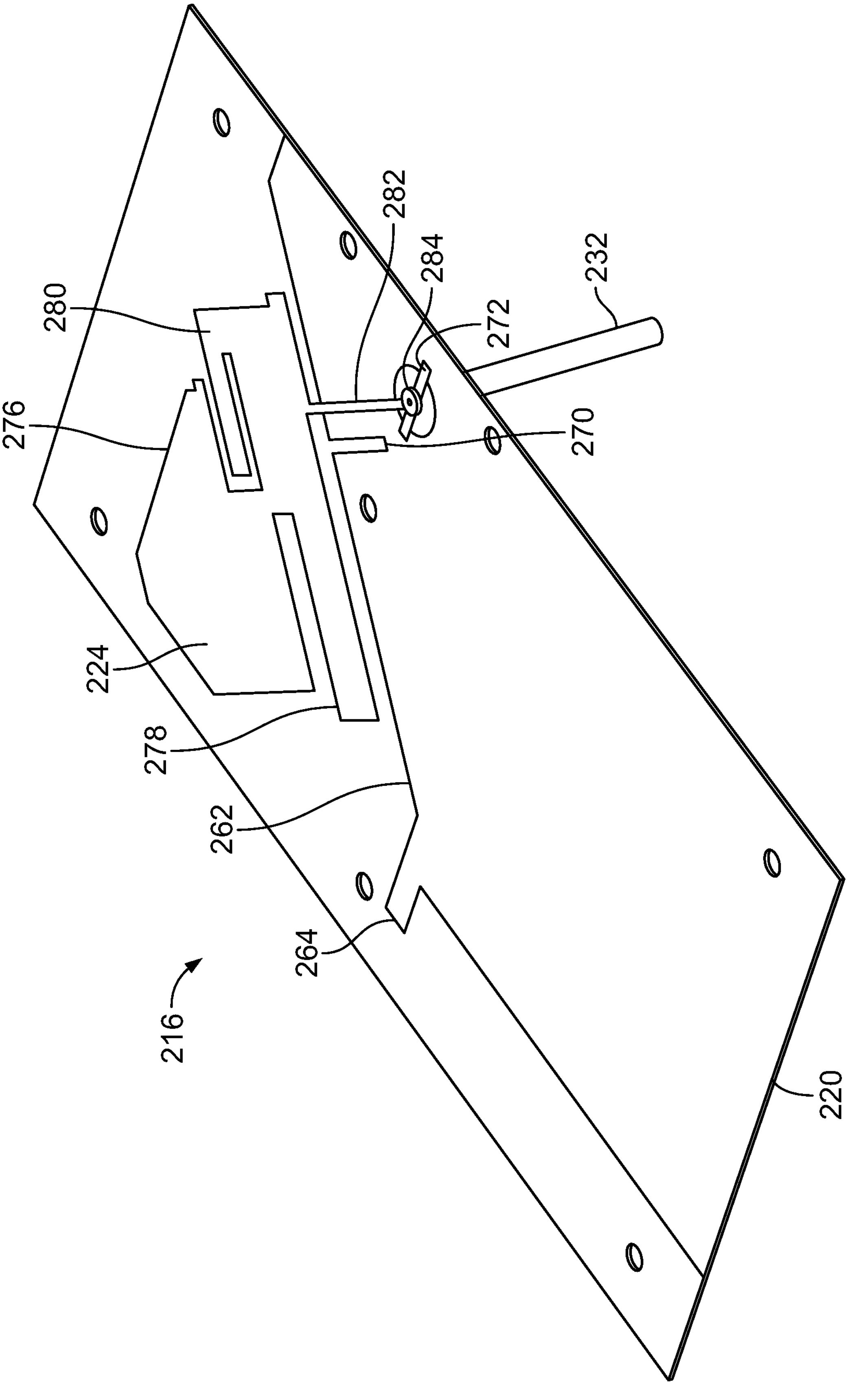


FIG. 13

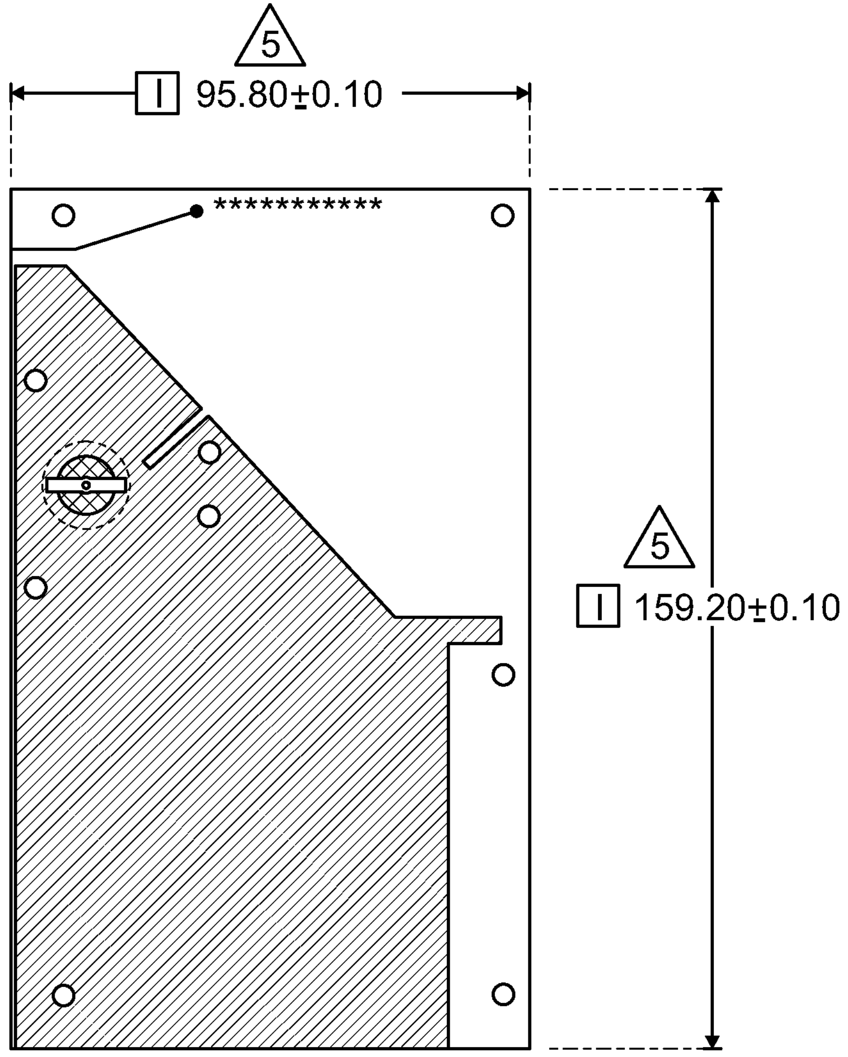


FIG. 14A

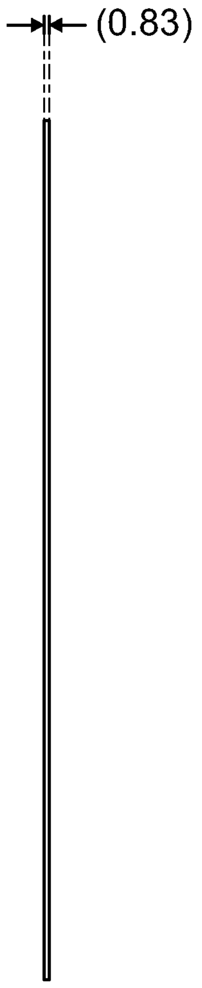


FIG. 14B

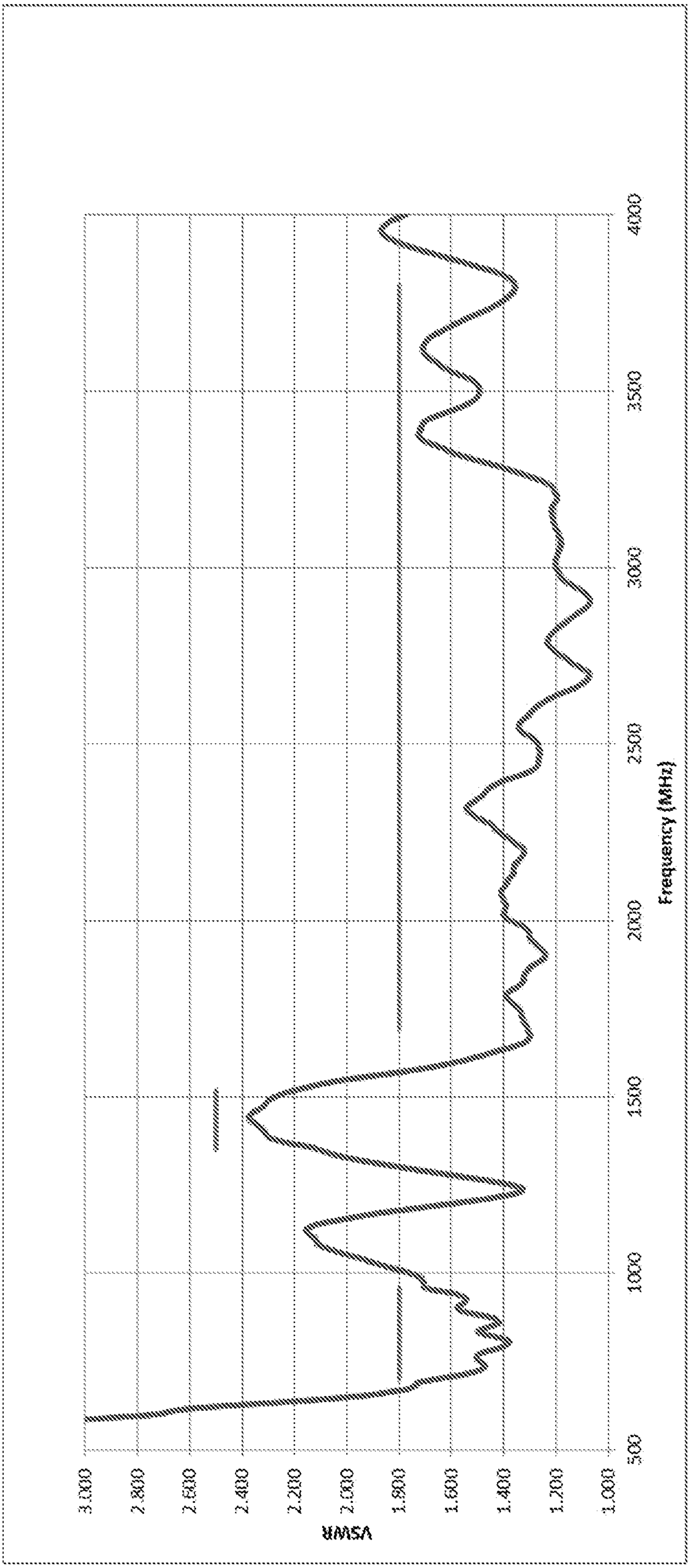

VSWR
3.000
2.800
2.600
2.400
2.200
2.000
1.800
1.600
1.400
1.200
1.000
500
1000
1500
2000
2500
3000
3500
4000
Frequency (MHz)

FIG. 15A

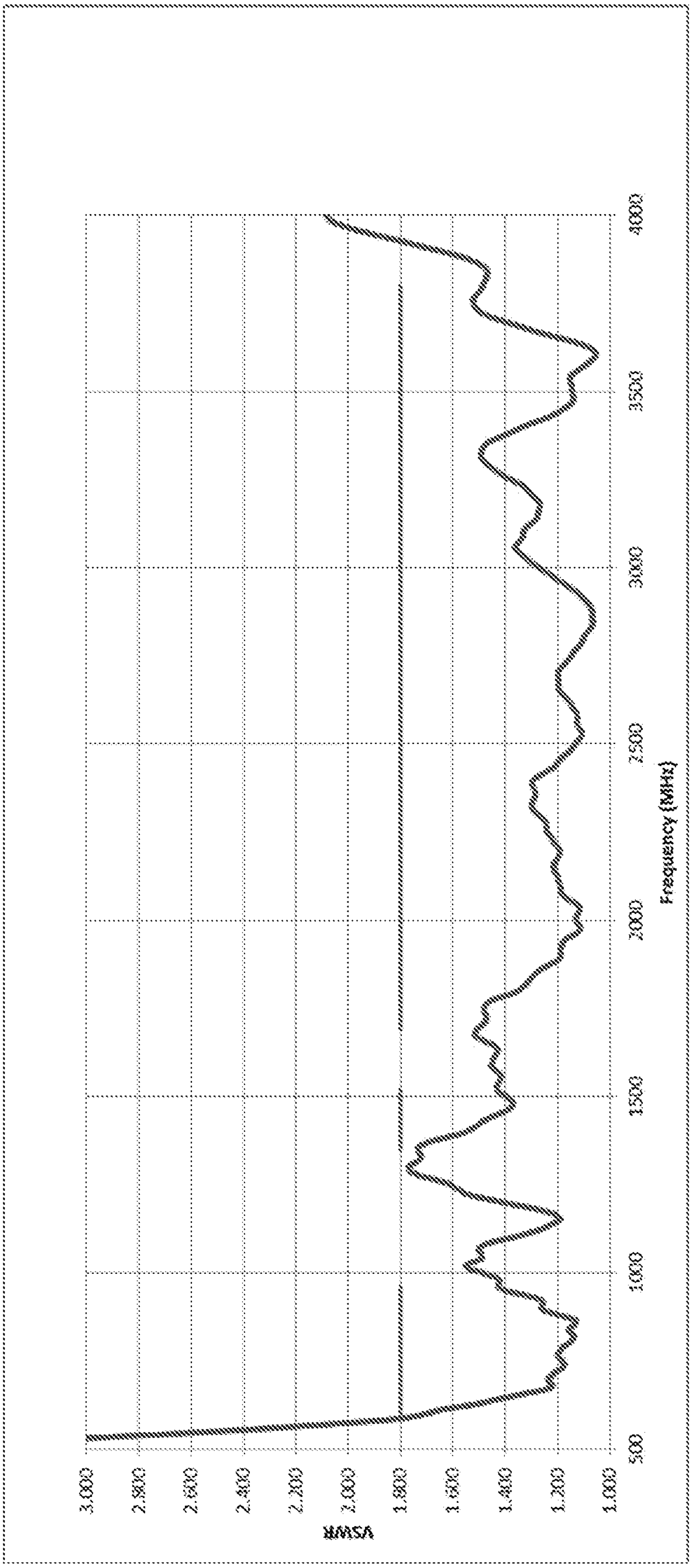

VSWR
3.000
2.800
2.600
2.400
2.200
2.000
1.800
1.600
1.400
1.200
1.000
500
1000
1500
2000
2500
3000
3500
4000
Frequency (MHz)

FIG. 15B

Radiation Pattern at 698 MHz

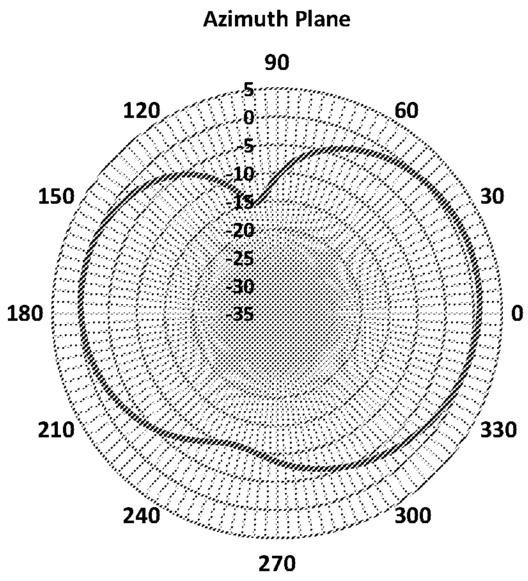


FIG. 16

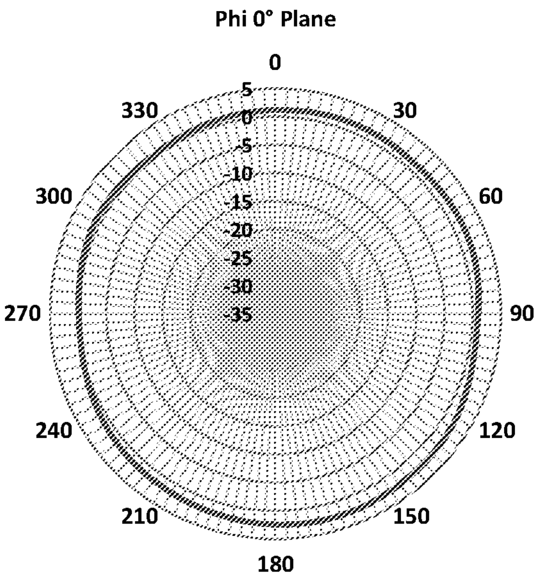


FIG. 17

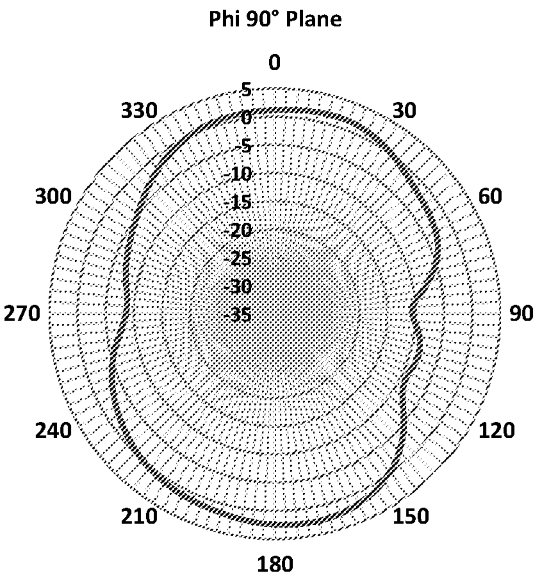


FIG. 18

Radiation Pattern at 746 MHz

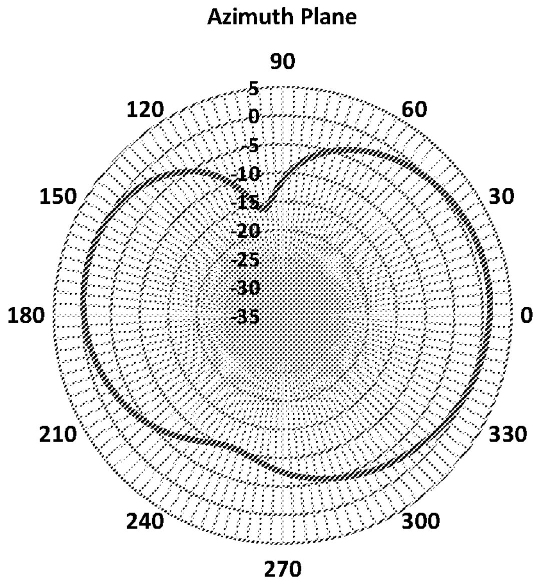


FIG. 19

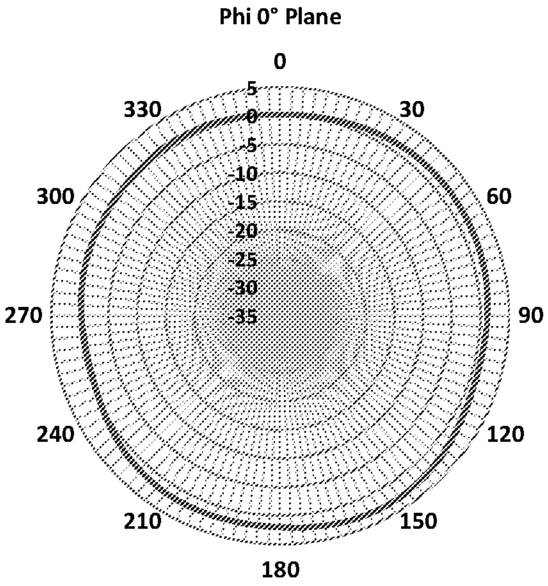


FIG. 20

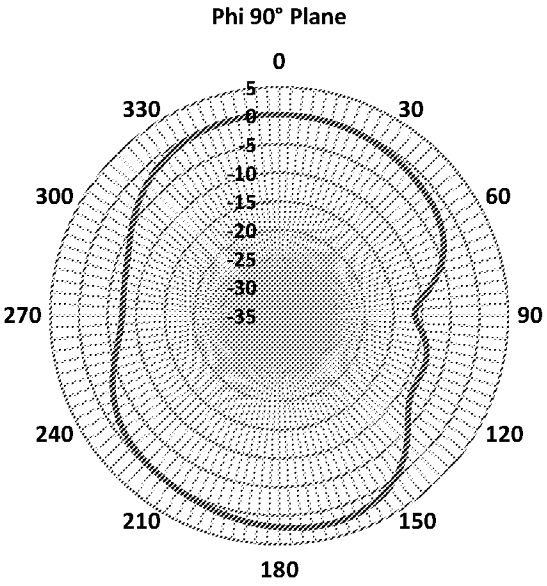


FIG. 21

Radiation Pattern at 824 MHz

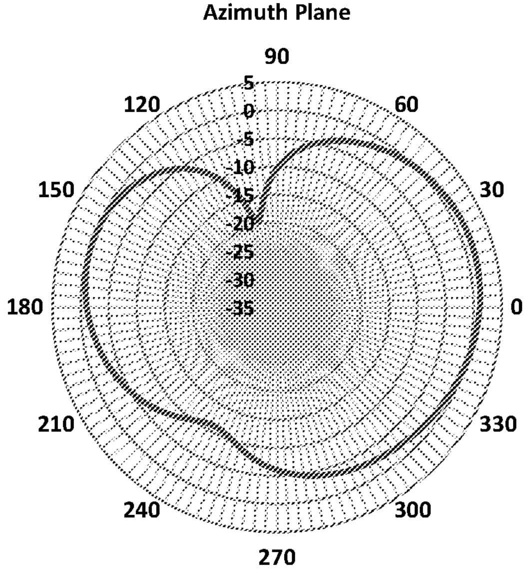

Azimuth Plane

FIG. 22

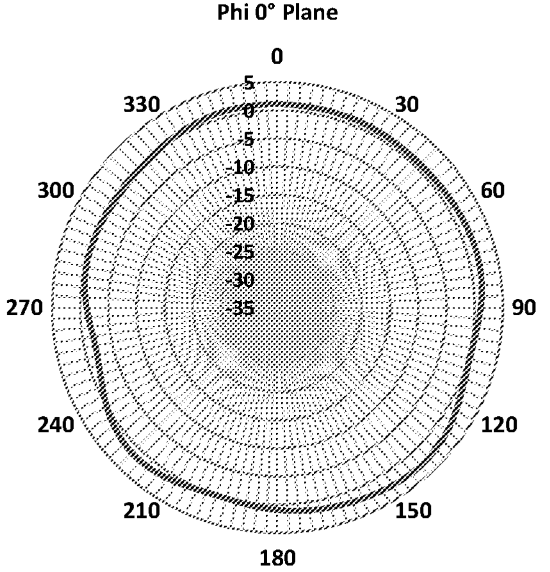

Phi 0° Plane

FIG. 23

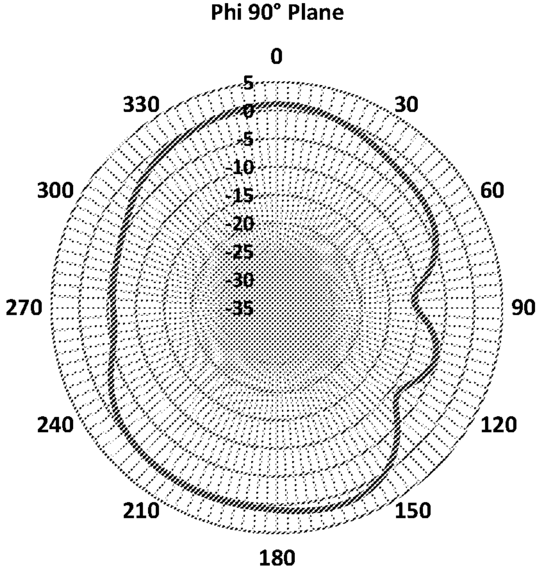

Phi 90° Plane

FIG. 24

Radiation Pattern at 894 MHz

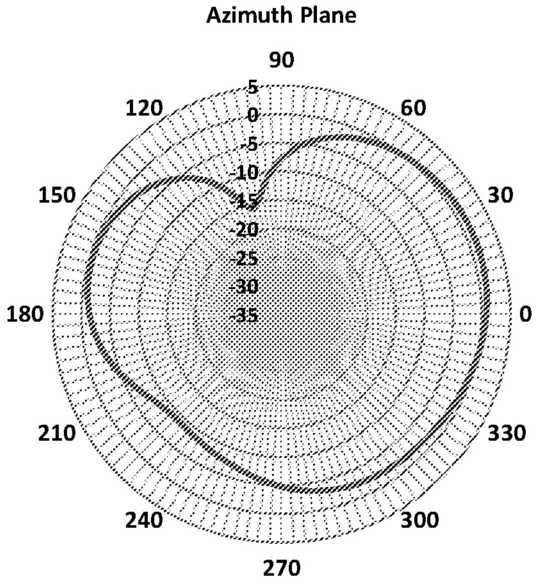

Azimuth Plane

FIG. 25

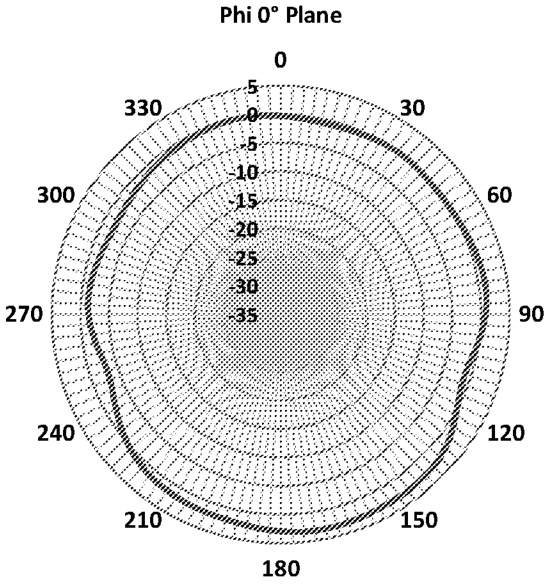

Phi 0° Plane

FIG. 26

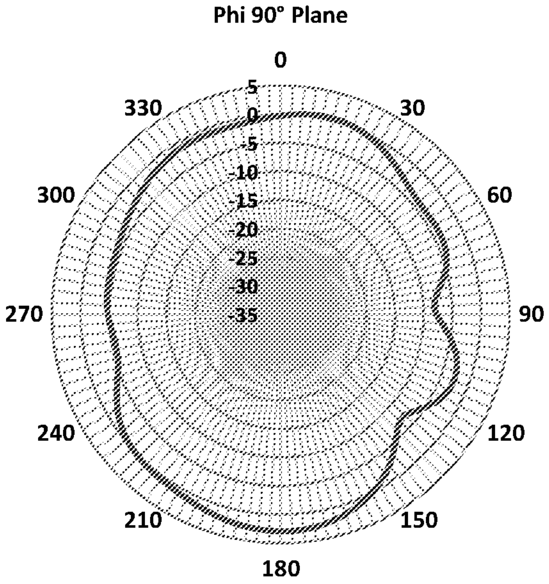
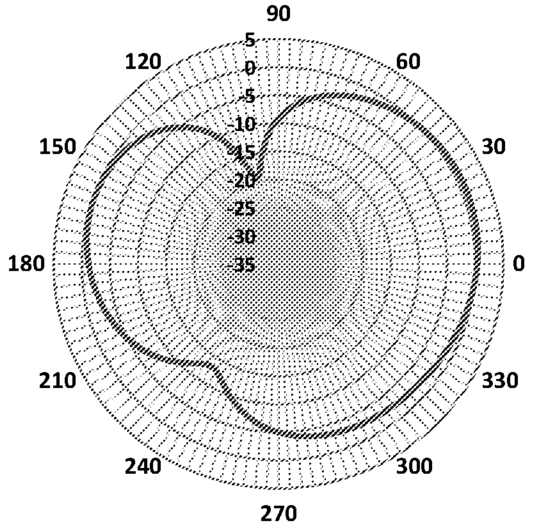

Phi 90° Plane

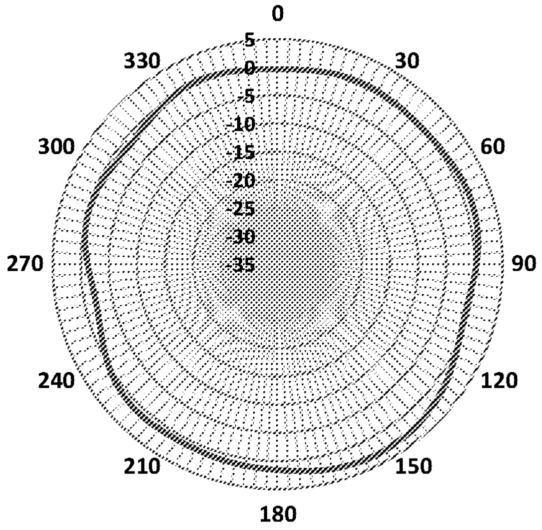
FIG. 27

Radiation Pattern at 850 MHz



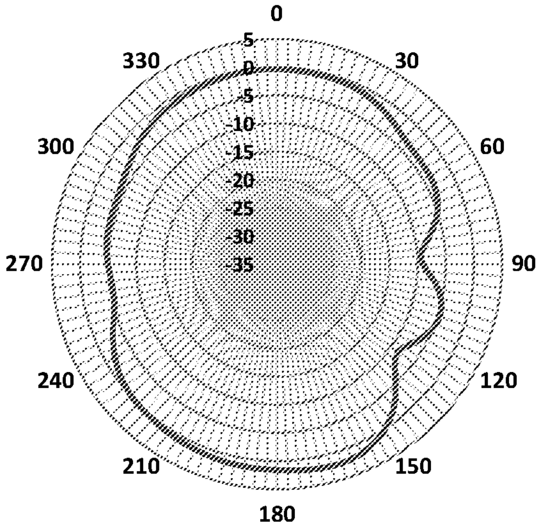
Azimuth Plane

FIG. 28



Phi 0° Plane

FIG. 29



Phi 90° Plane

FIG. 30

Radiation Pattern at 960 MHz

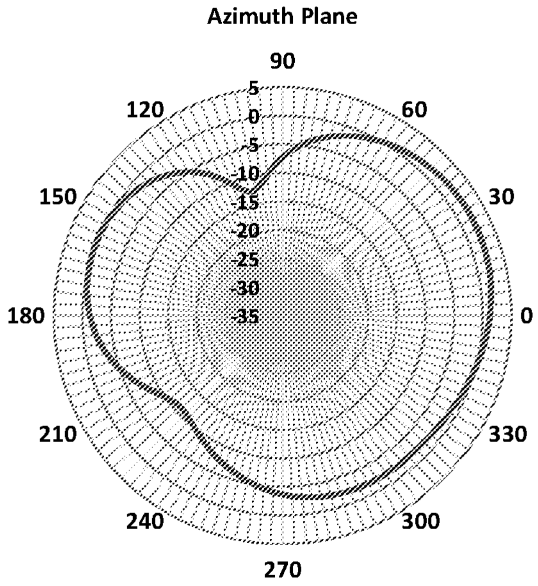


FIG. 31

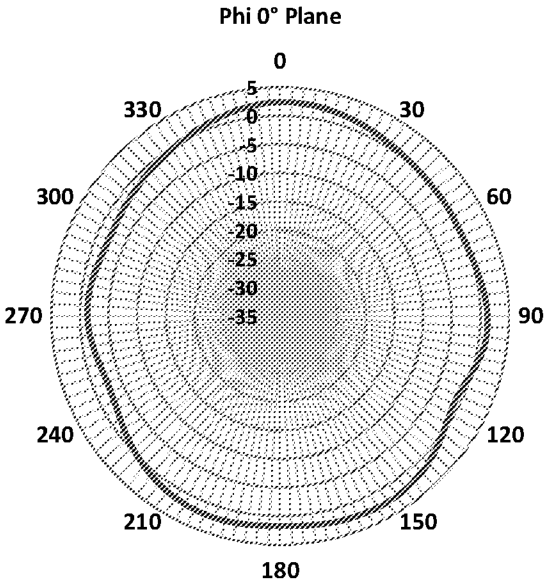


FIG. 32

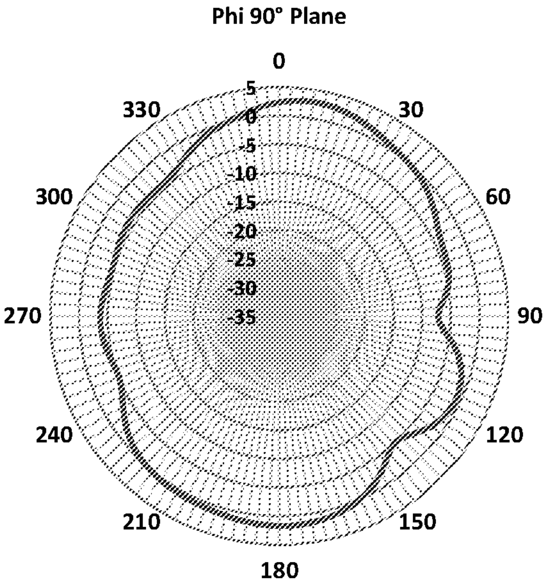


FIG. 33

Radiation Pattern at 1350 MHz

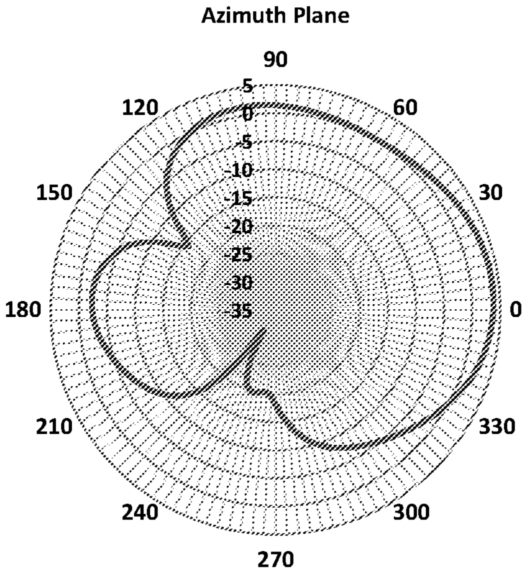


FIG. 34

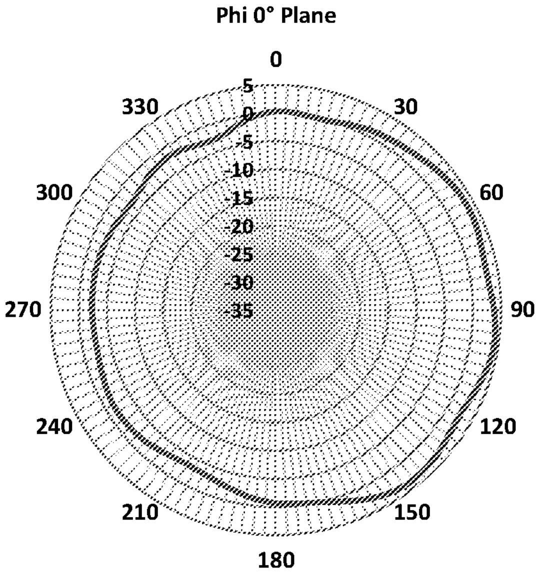


FIG. 35

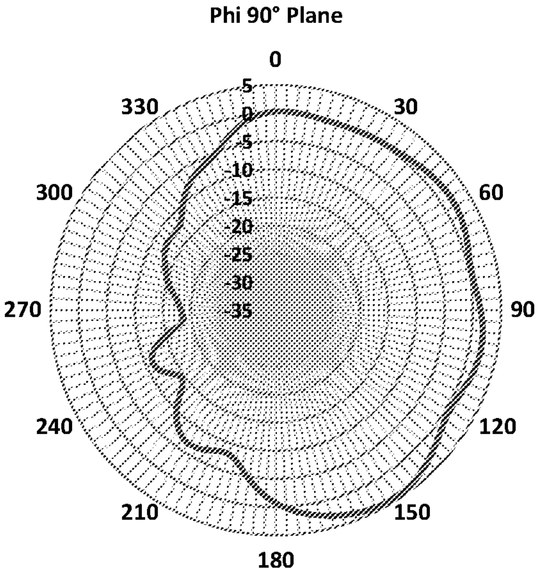


FIG. 36

Radiation Pattern at 1448 MHz

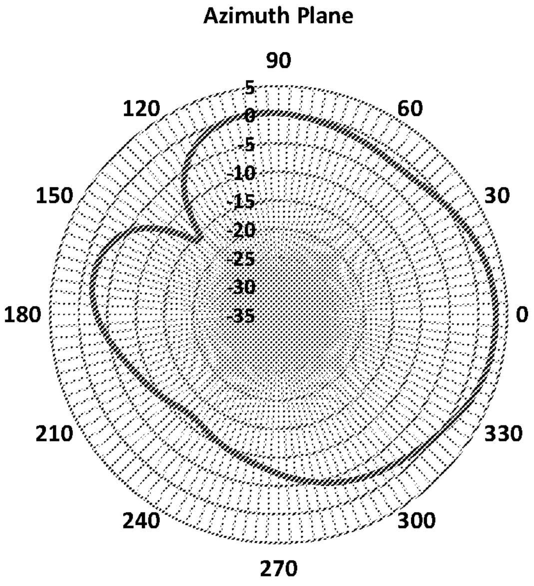


FIG. 37

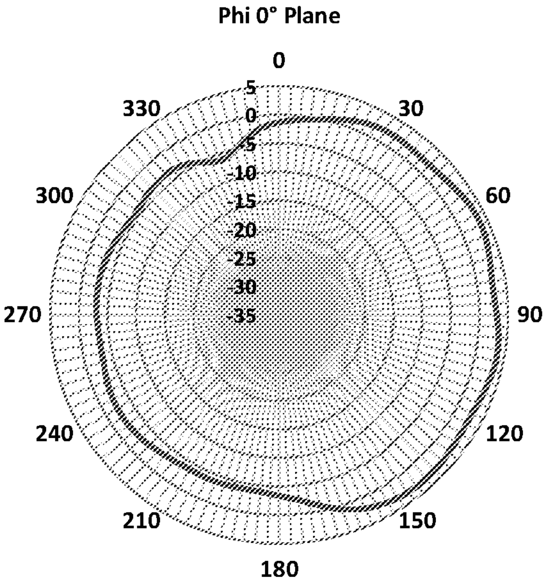


FIG. 38

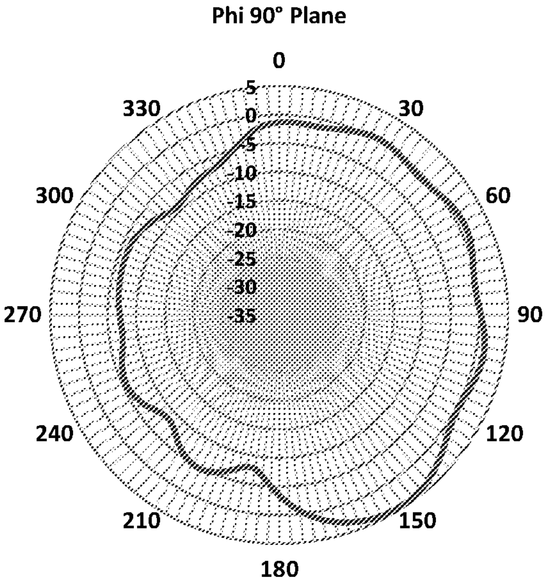


FIG. 39

Radiation Pattern at 1427 MHz

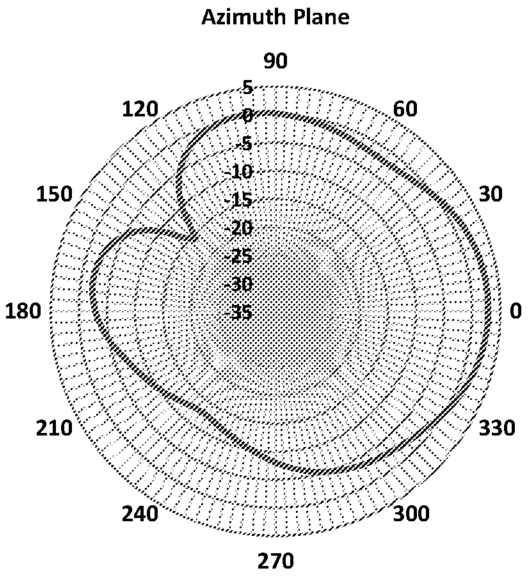


FIG. 40

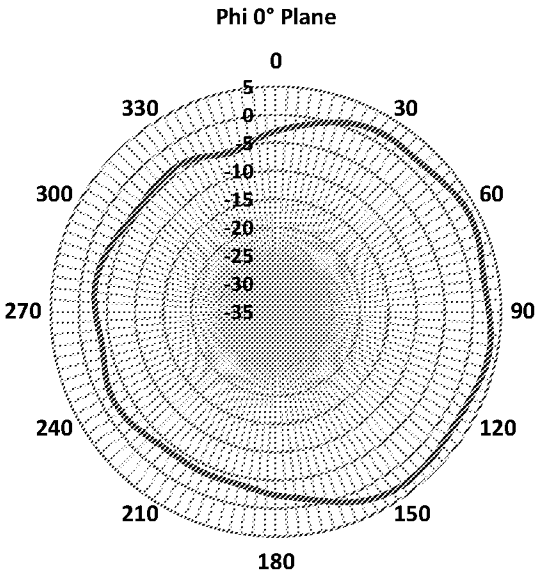


FIG. 41

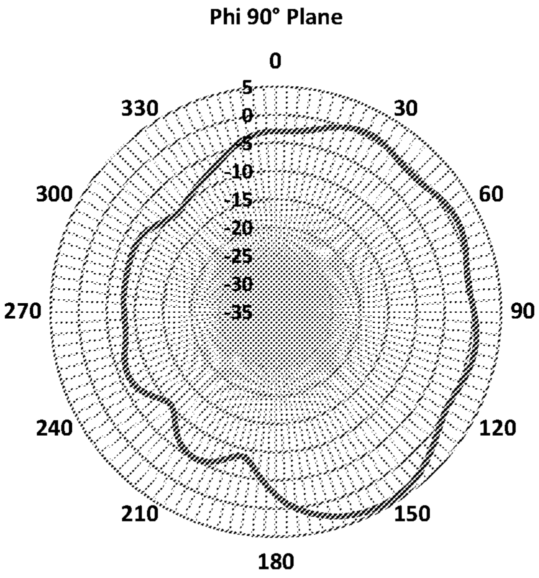


FIG. 42

Radiation Pattern at 1525 MHz

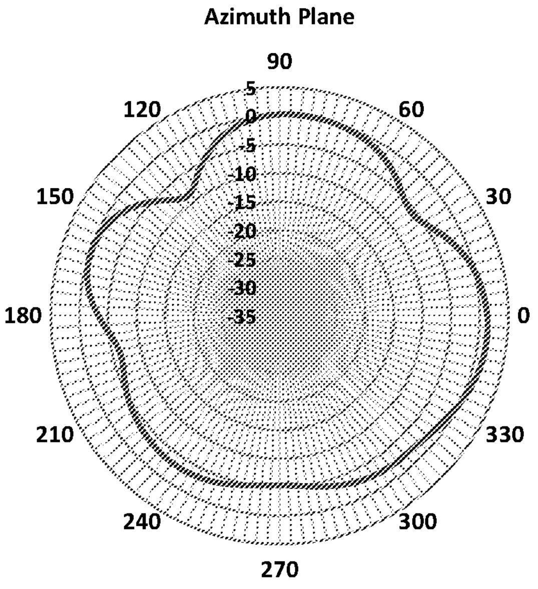


FIG. 43

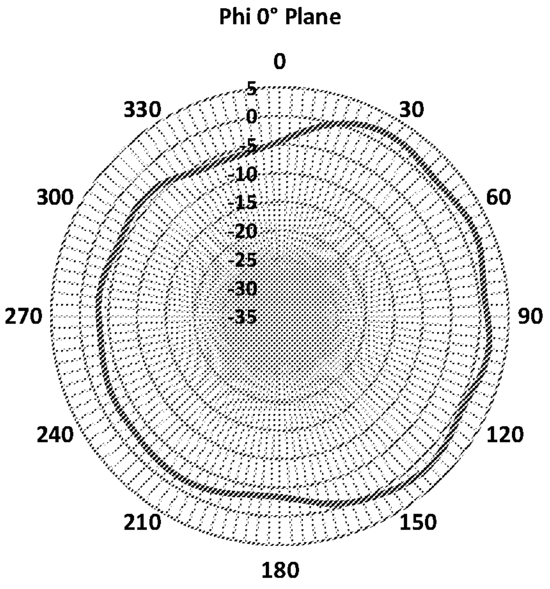


FIG. 44

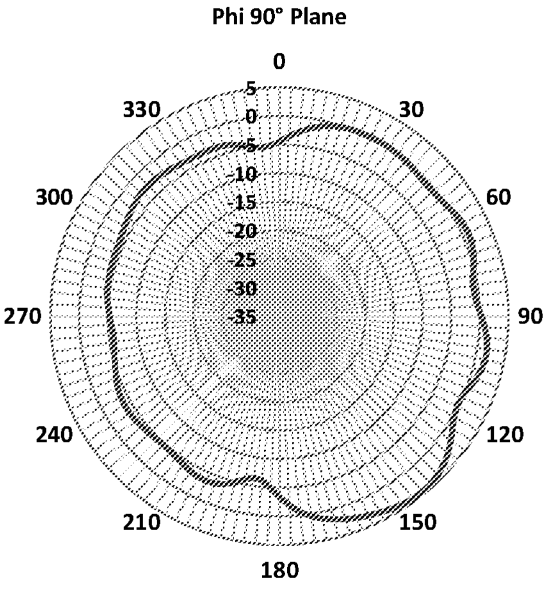


FIG. 45

Radiation Pattern at 1710 MHz

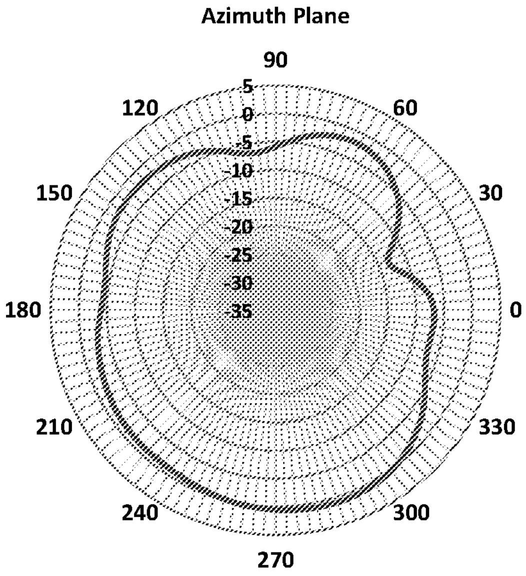


FIG. 46

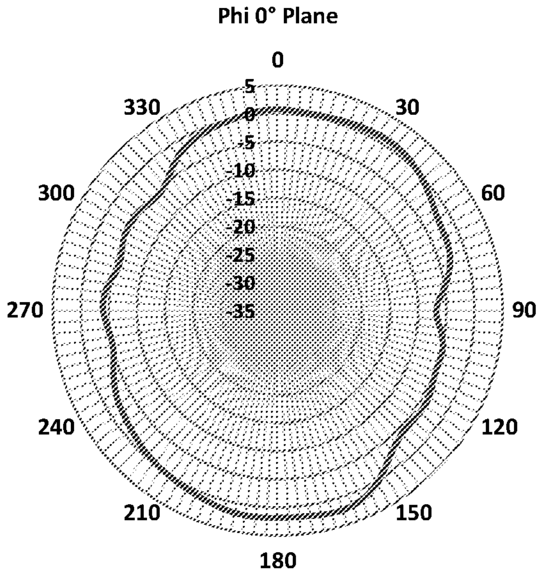


FIG. 47

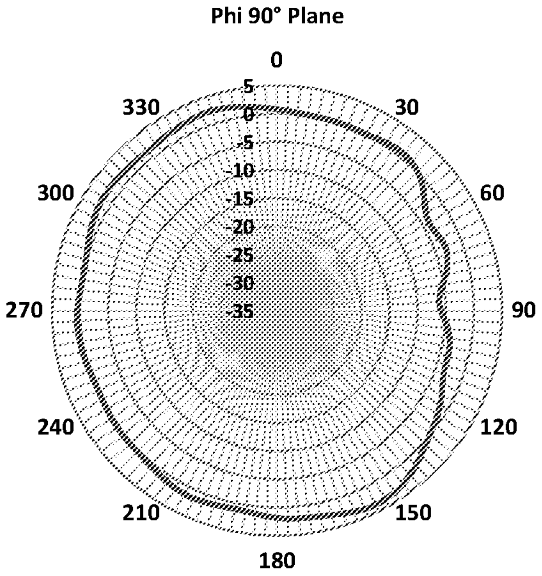


FIG. 48

Radiation Pattern at 1850 MHz

Azimuth Plane

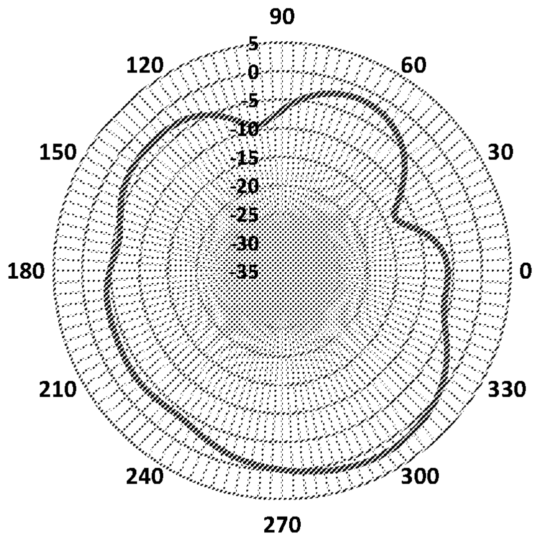


FIG. 49

Phi 0° Plane

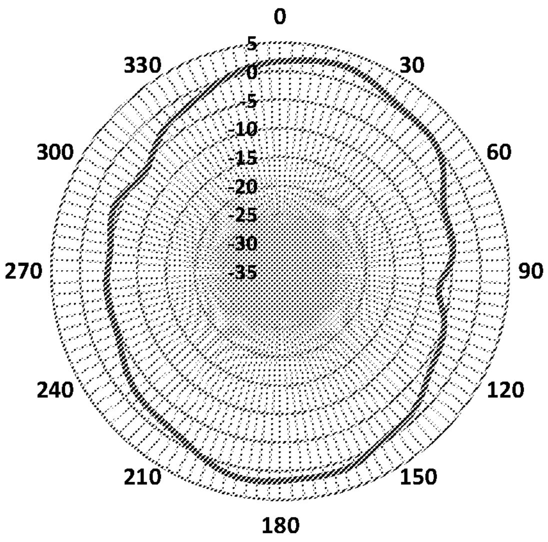


FIG. 50

Phi 90° Plane

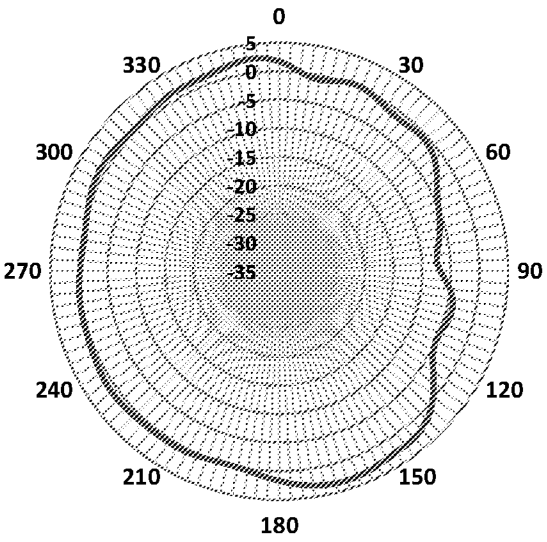


FIG. 51

Radiation Pattern at 1930 MHz

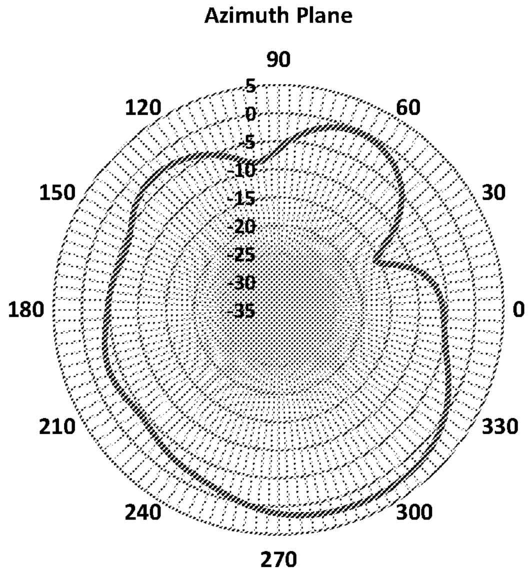


FIG. 52

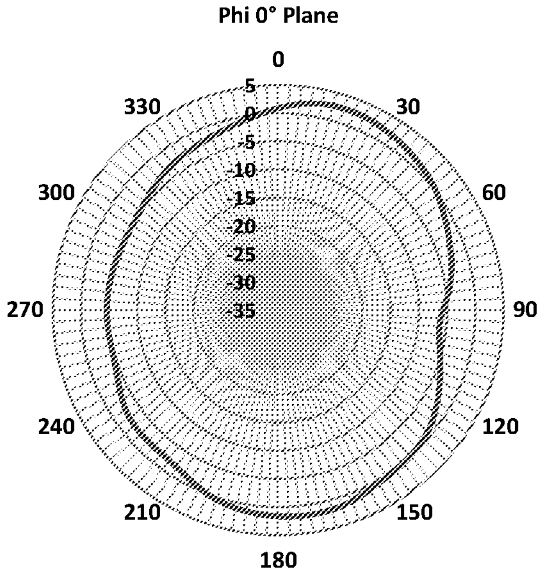


FIG. 53

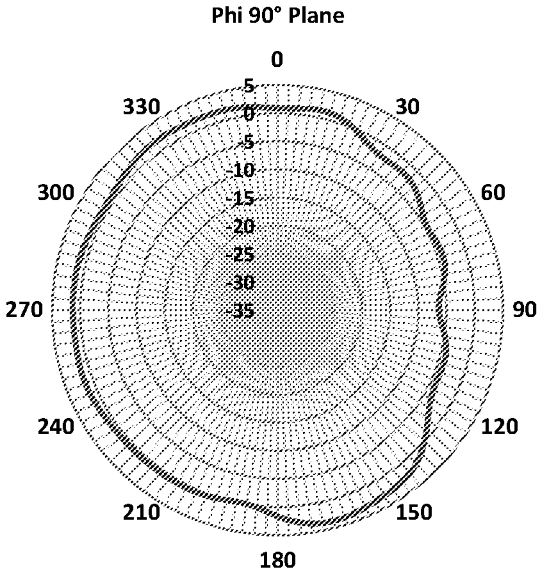


FIG. 54

Radiation Pattern at 2130 MHz

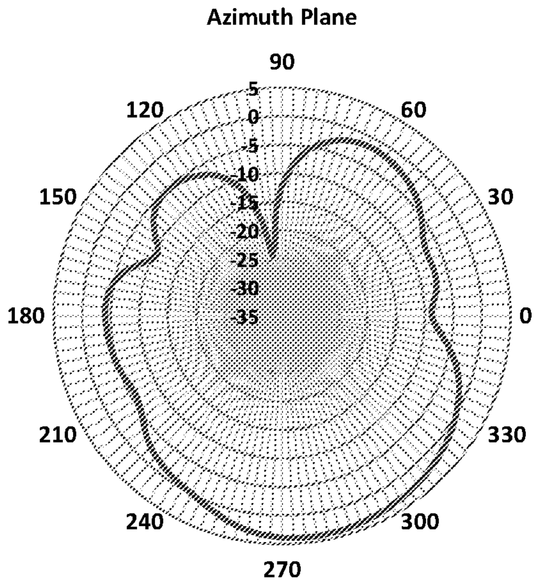


FIG. 55

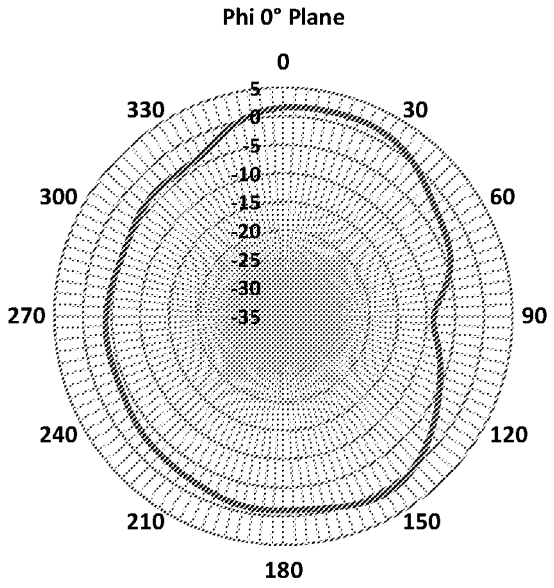


FIG. 56

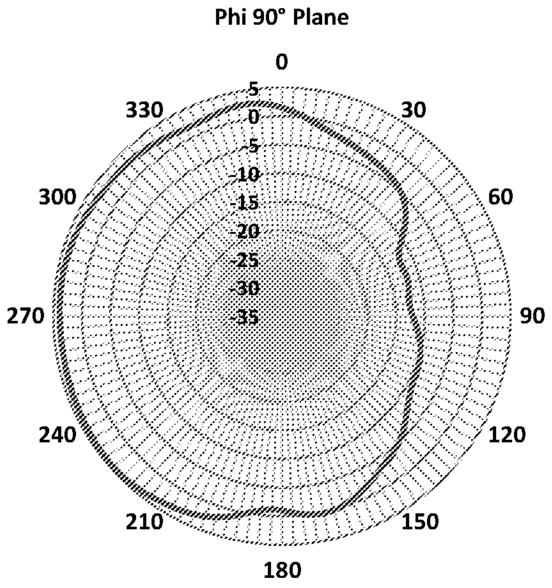


FIG. 57

Radiation Pattern at 2170 MHz

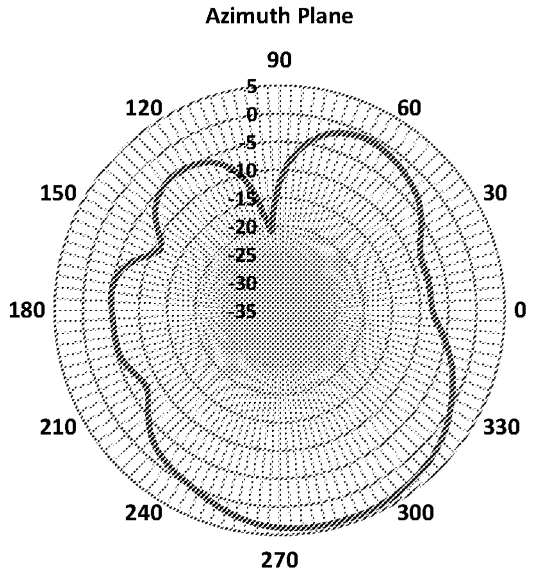


FIG. 58

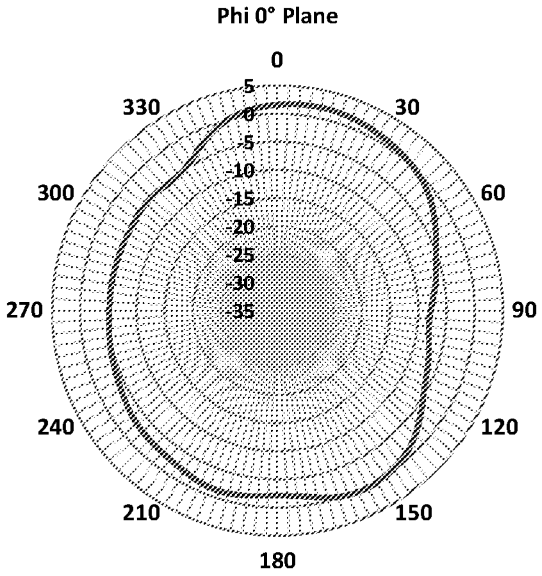


FIG. 59

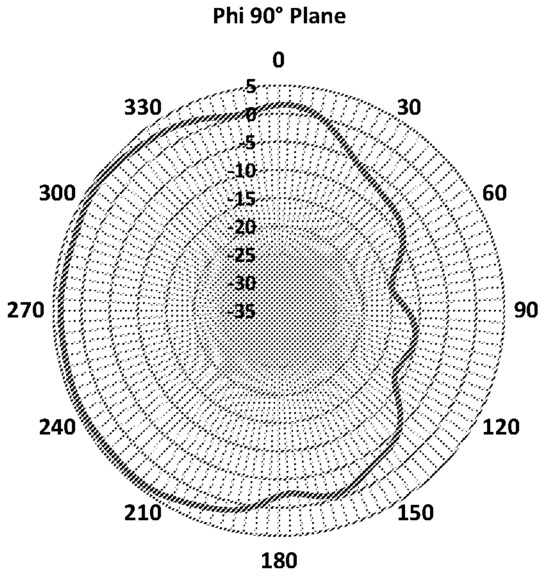


FIG. 60

Radiation Pattern at 2310 MHz

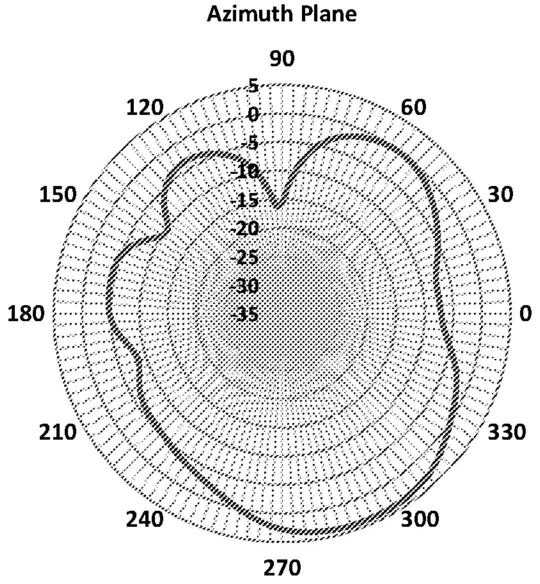


FIG. 61

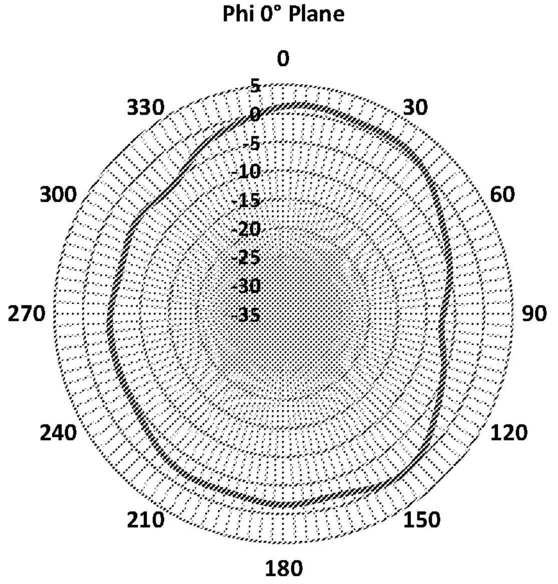


FIG. 62

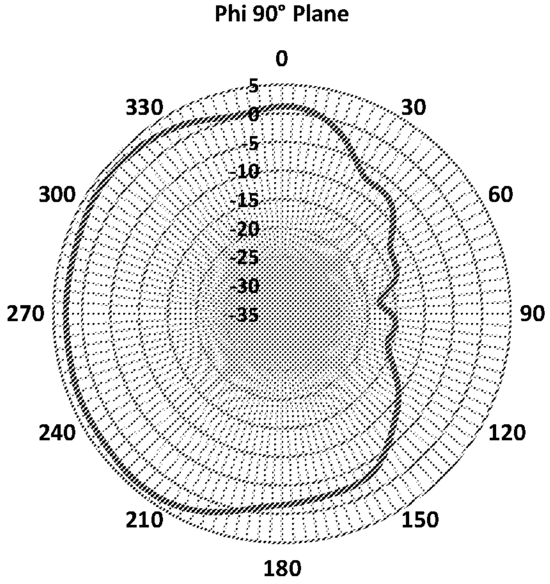


FIG. 63

Radiation Pattern at 2412 MHz

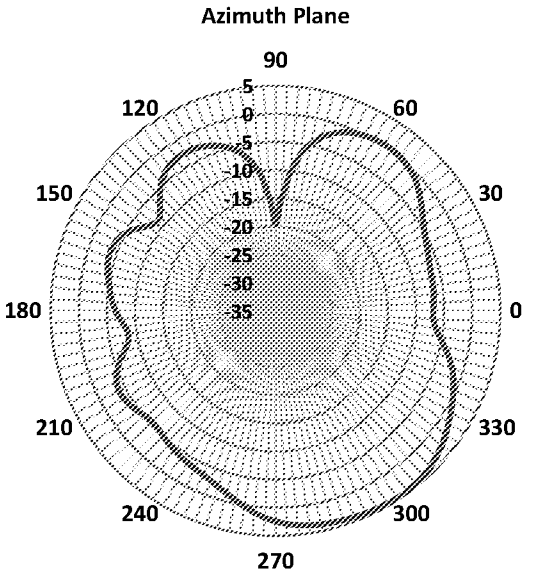

Azimuth Plane

FIG. 64

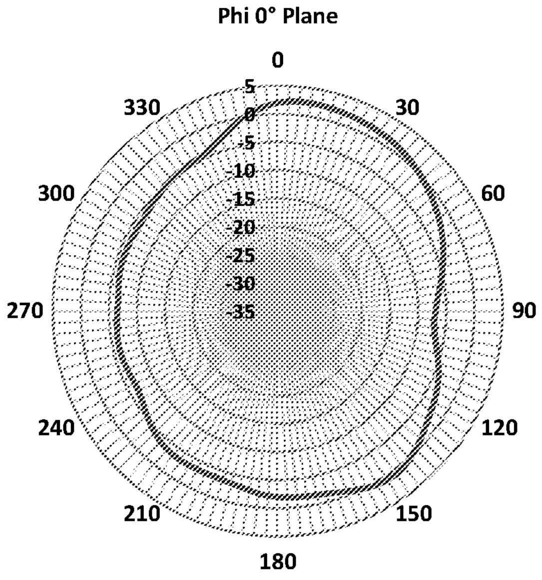

Phi 0° Plane

FIG. 65

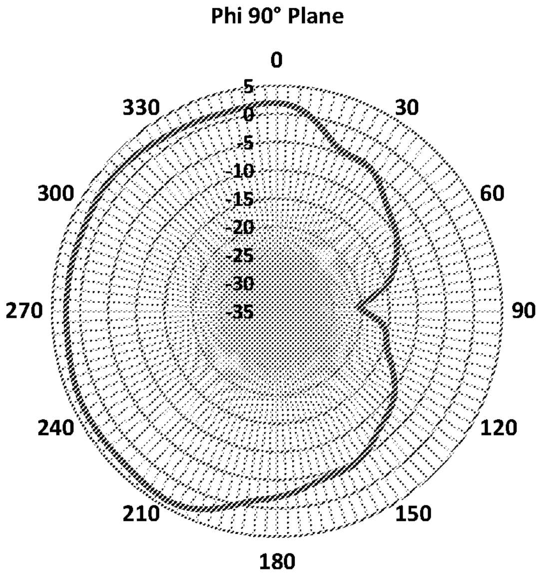

Phi 90° Plane

FIG. 66

Radiation Pattern at 2506.5 MHz

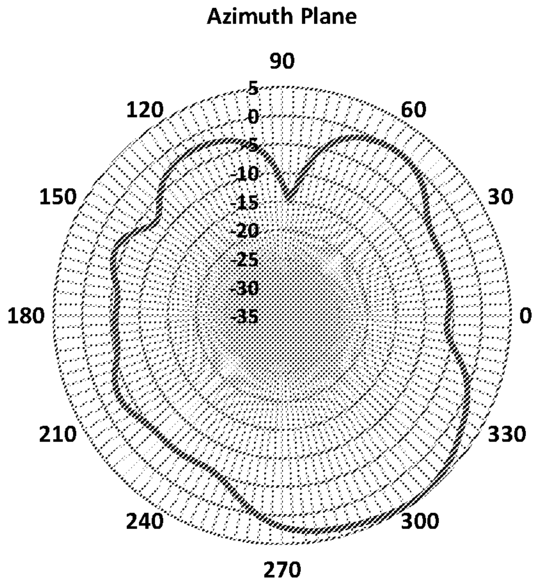


FIG. 67

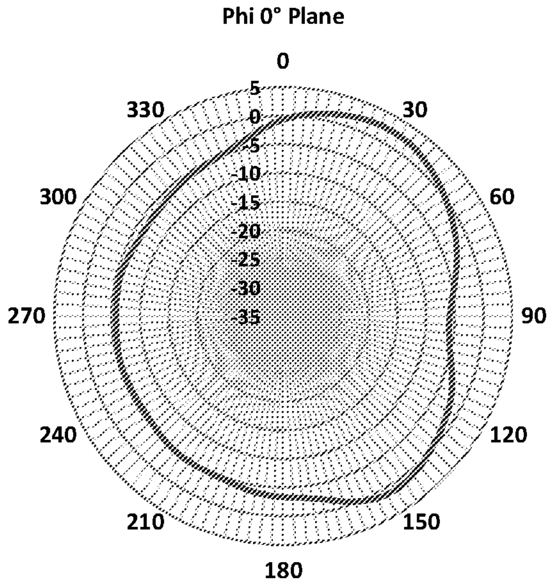


FIG. 68

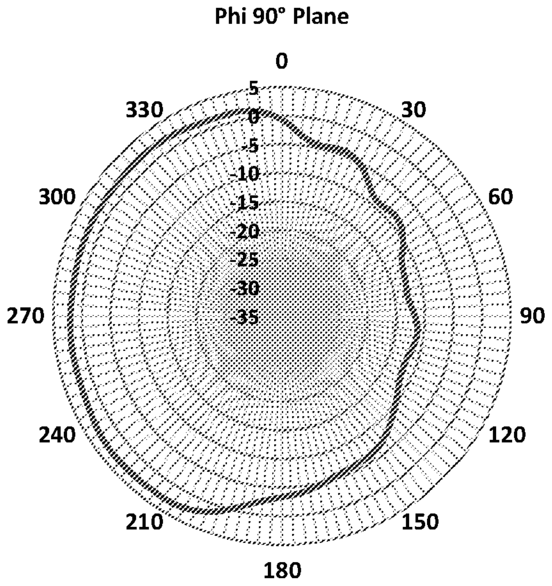


FIG. 69

Radiation Pattern at 2600 MHz

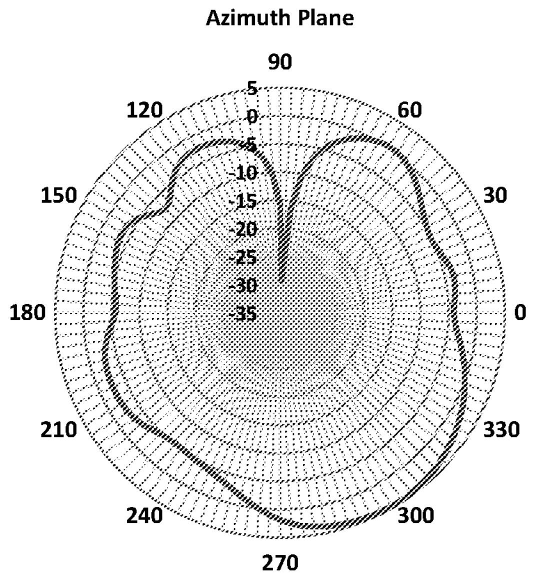


FIG. 70

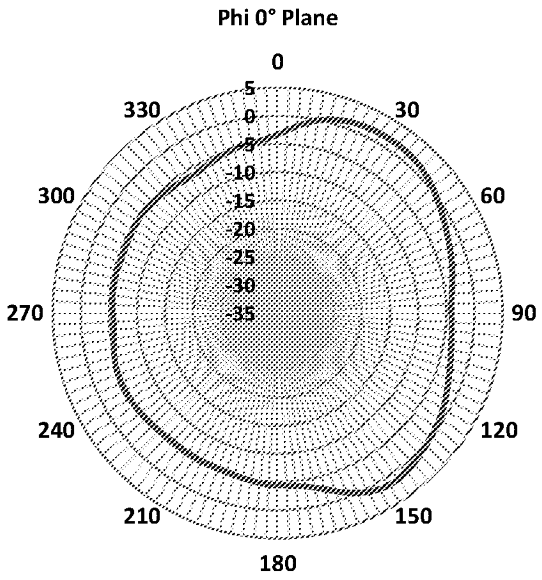


FIG. 71

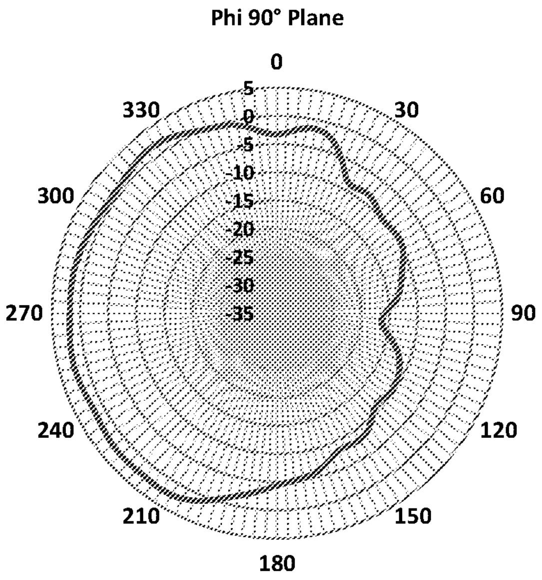


FIG. 72

Radiation Pattern at 2700 MHz

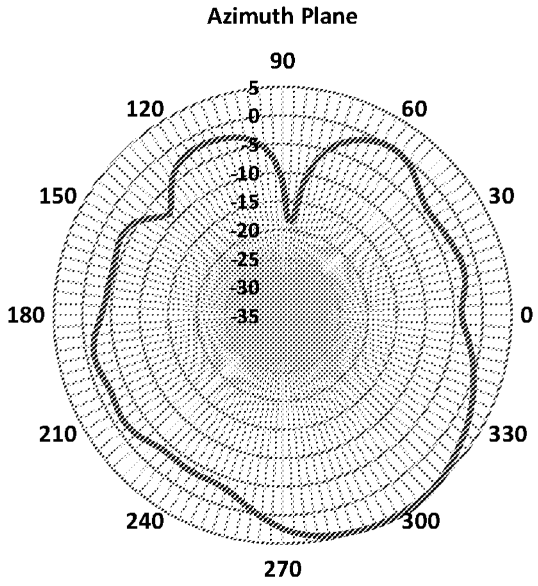

Azimuth Plane

FIG. 73

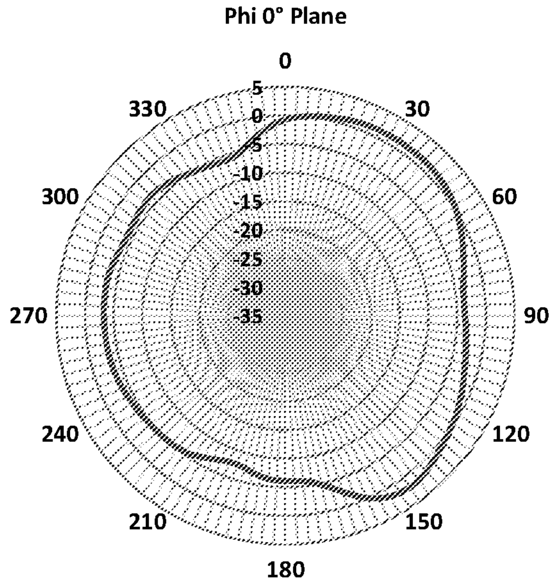

Phi 0° Plane

FIG. 74

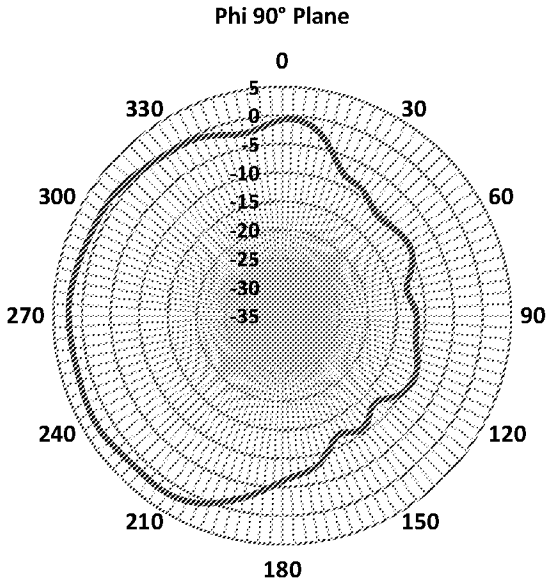

Phi 90° Plane

FIG. 75

Radiation Pattern at 3300 MHz

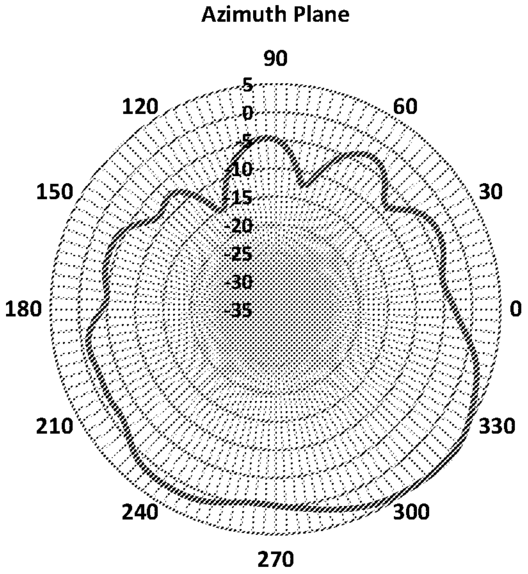


FIG. 76

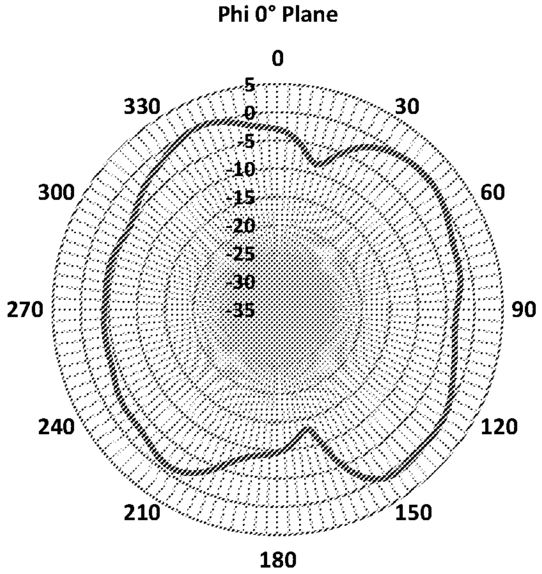


FIG. 77

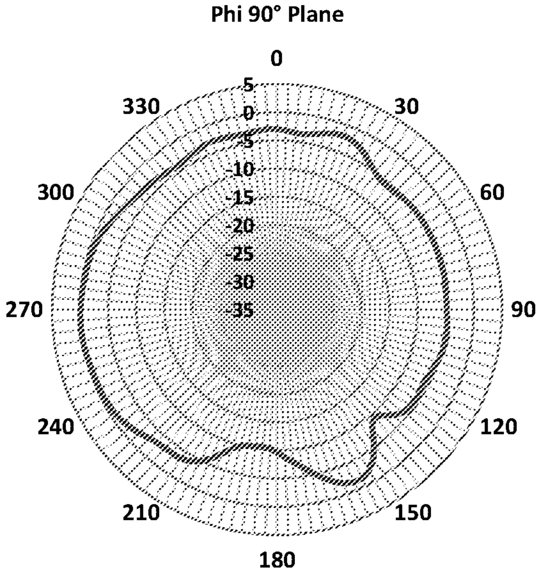


FIG. 78

Radiation Pattern at 3800 MHz

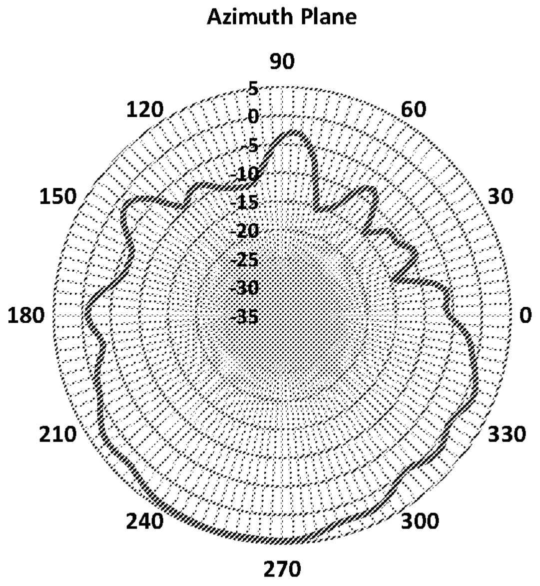


FIG. 79

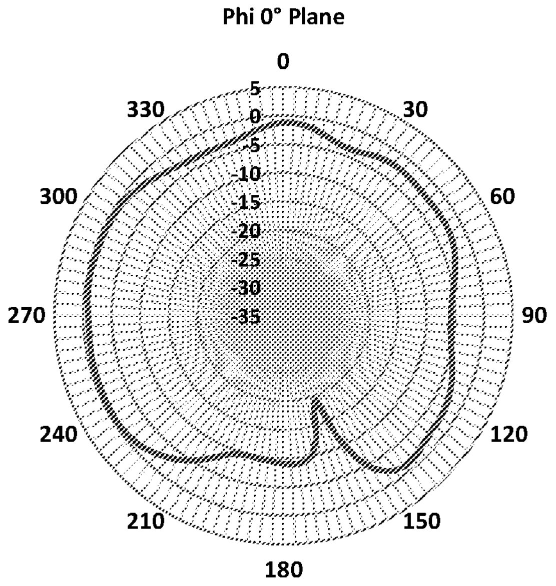


FIG. 80

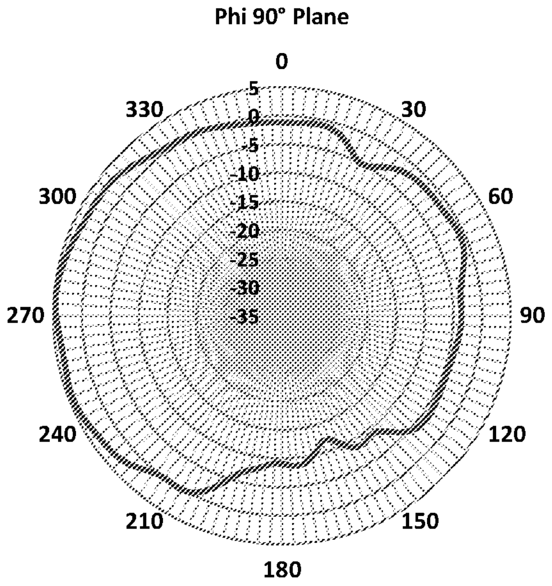
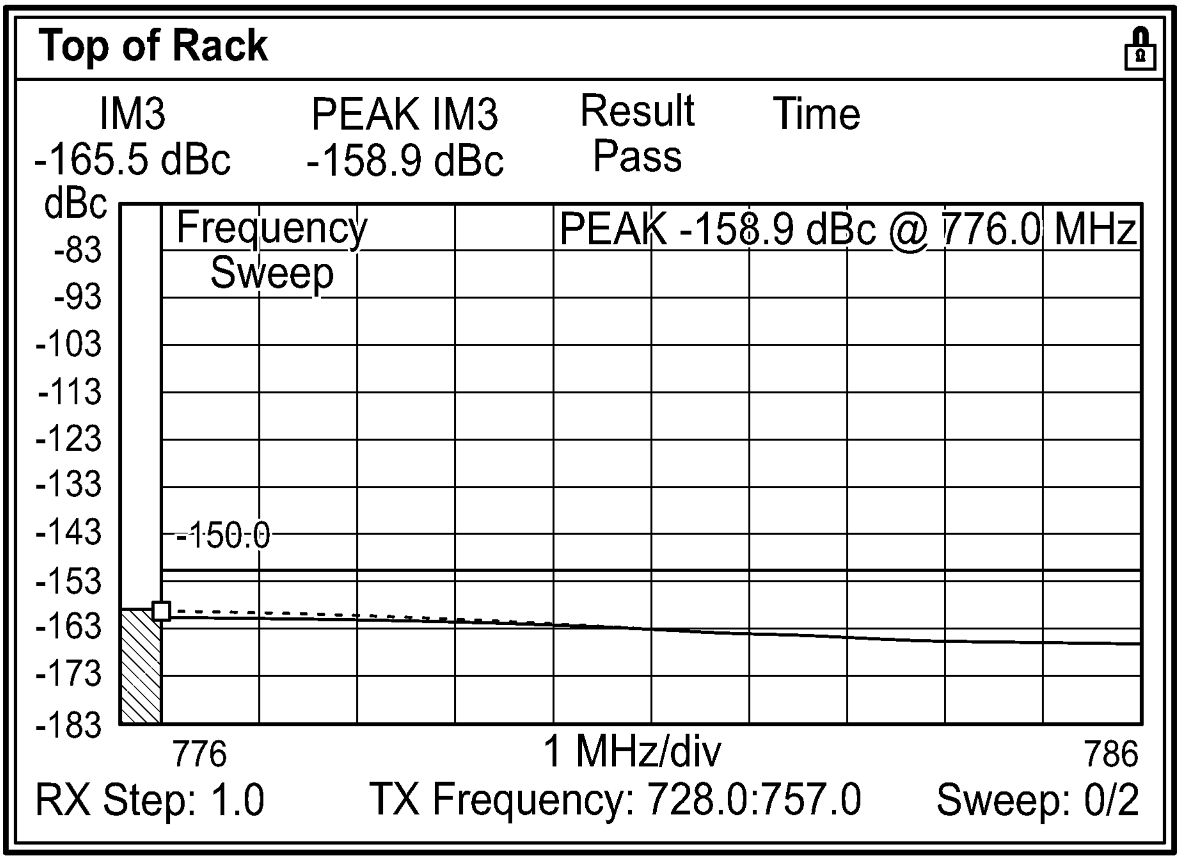


FIG. 81



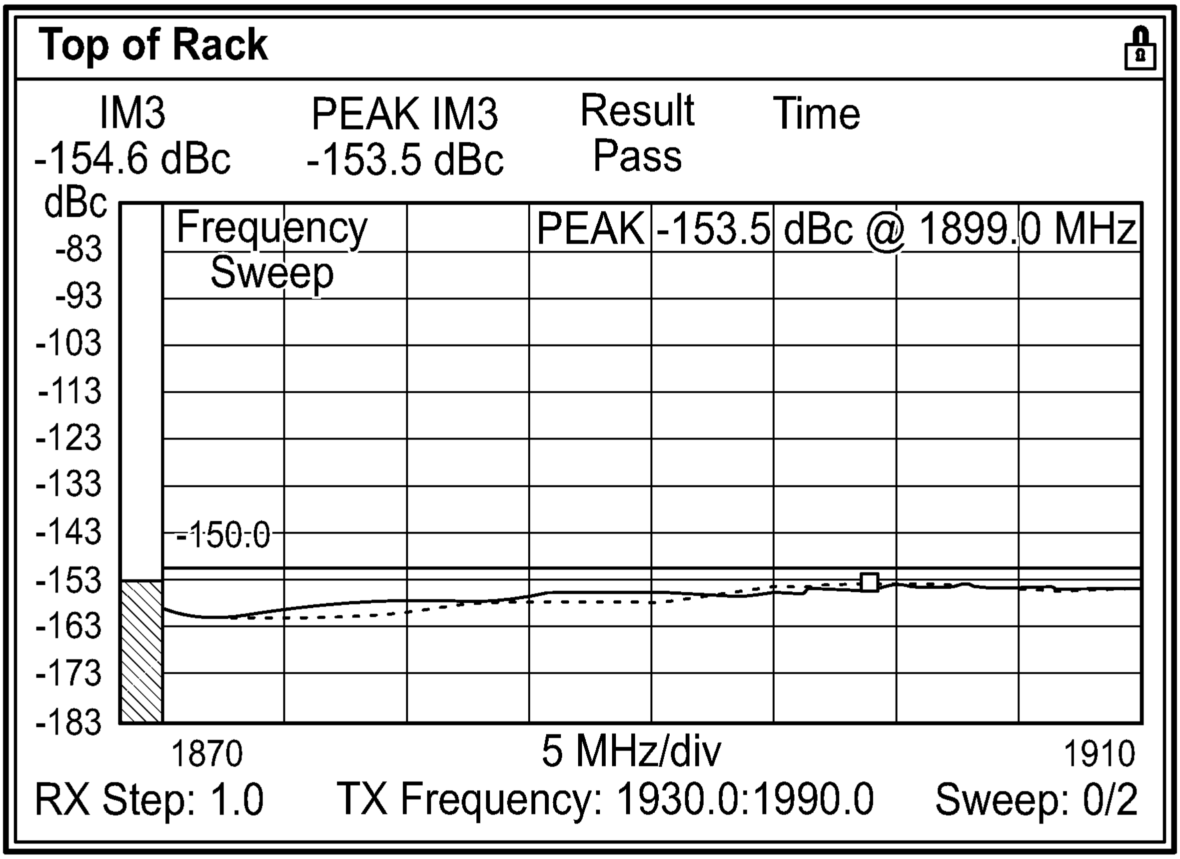
Top of Rack

IM3 -165.5 dBc
PEAK IM3 -158.9 dBc
Result Pass
Time

PEAK -158.9 dBc @ 776.0 MHz

RX Step: 1.0
TX Frequency: 728.0:757.0
Sweep: 0/2

FIG. 82



Top of Rack

IM3 -154.6 dBc
PEAK IM3 -153.5 dBc
Result Pass
Time

PEAK -153.5 dBc @ 1899.0 MHz

RX Step: 1.0
TX Frequency: 1930.0:1990.0
Sweep: 0/2

FIG. 83

Radiation Pattern at 600 MHz

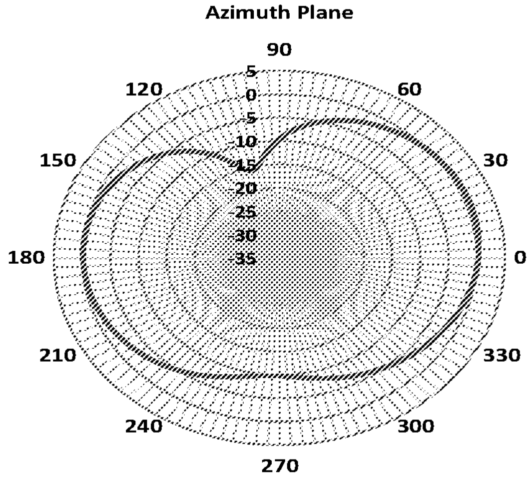


FIG. 84

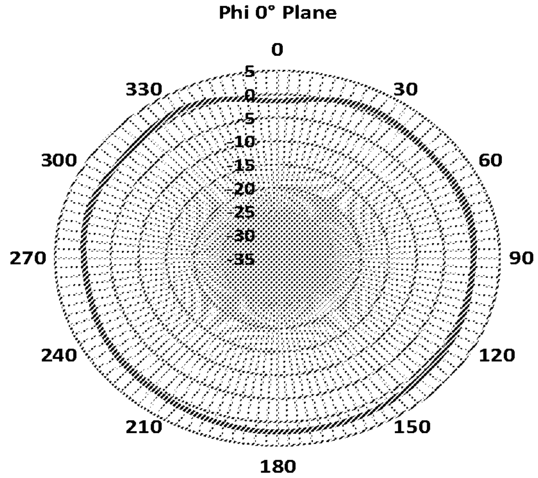


FIG. 85

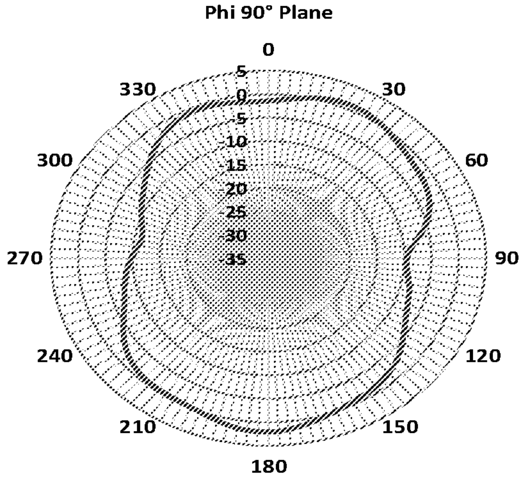


FIG. 86

Radiation Pattern at 645 MHz

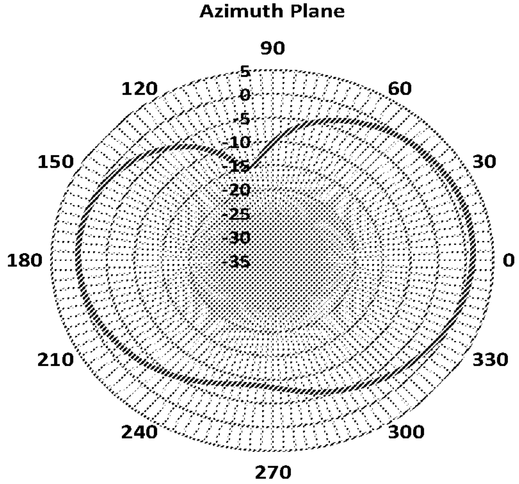


FIG. 87

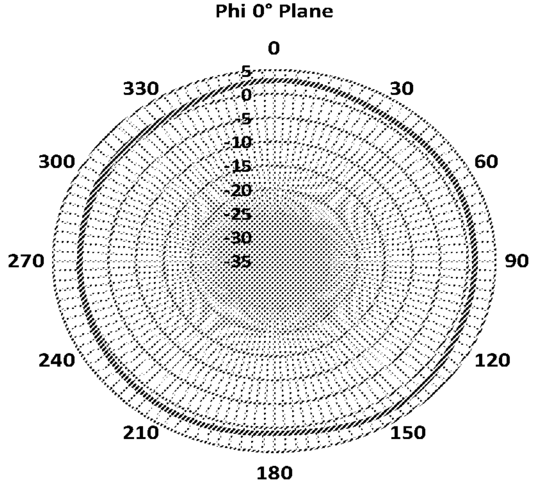


FIG. 88

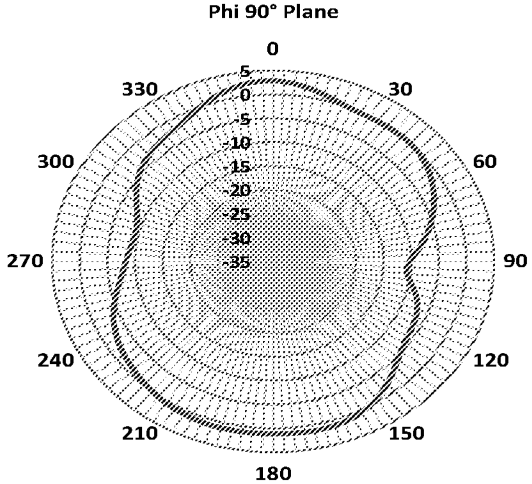


FIG. 89

Radiation Pattern at 698 MHz

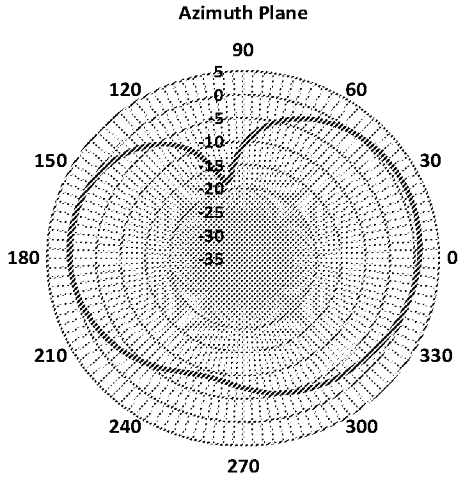


FIG. 90

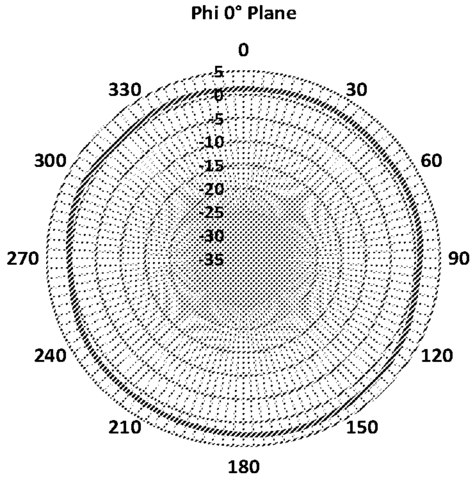


FIG. 91

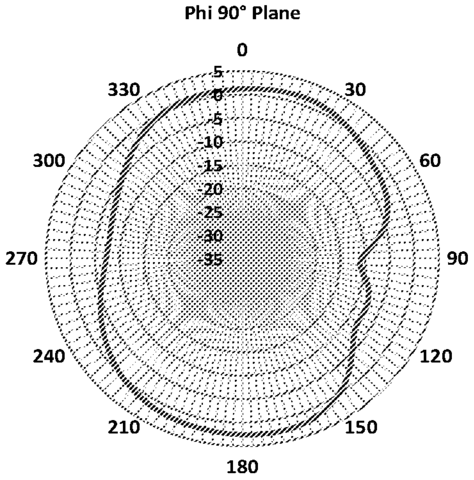


FIG. 92

Radiation Pattern at 824 MHz

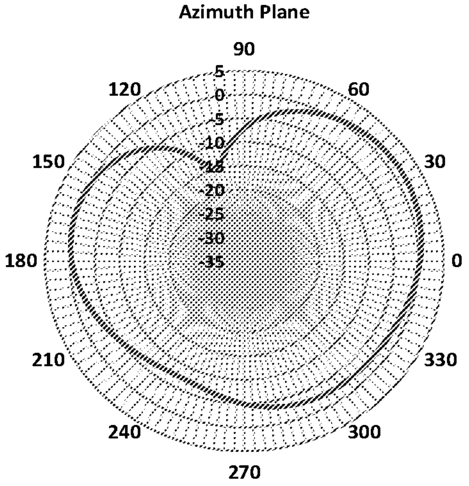


FIG. 93

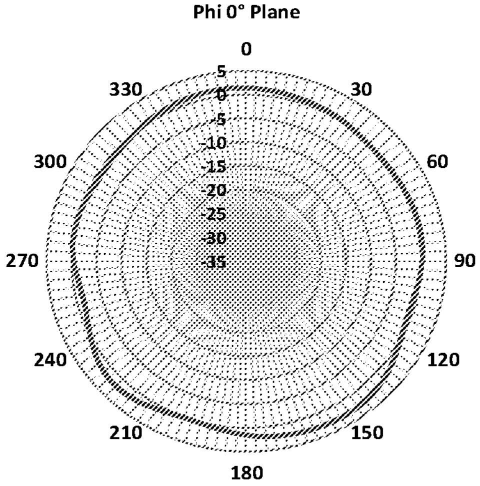


FIG. 94

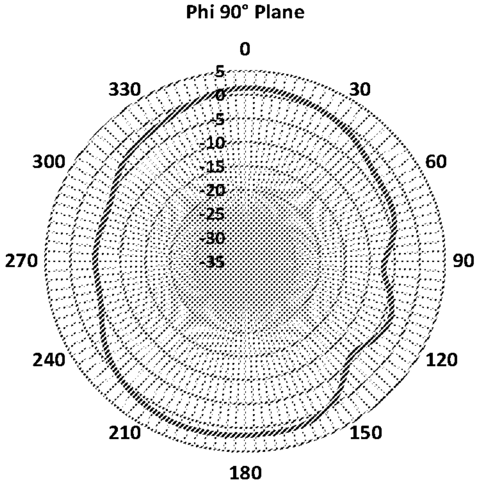


FIG. 95

Radiation Pattern at 850 MHz

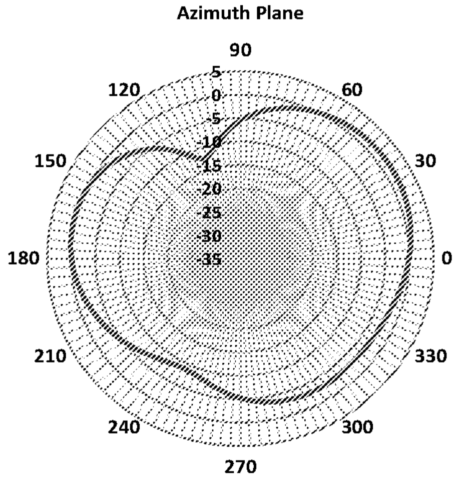


FIG. 96

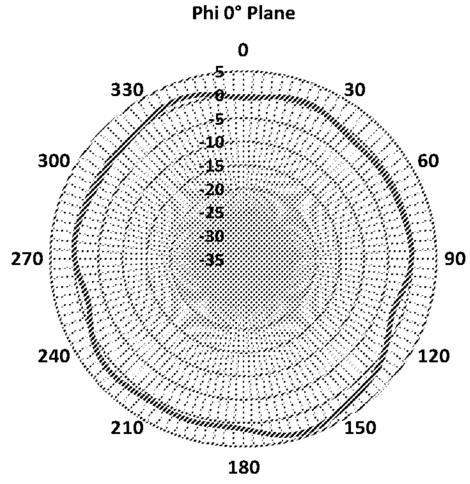


FIG. 97

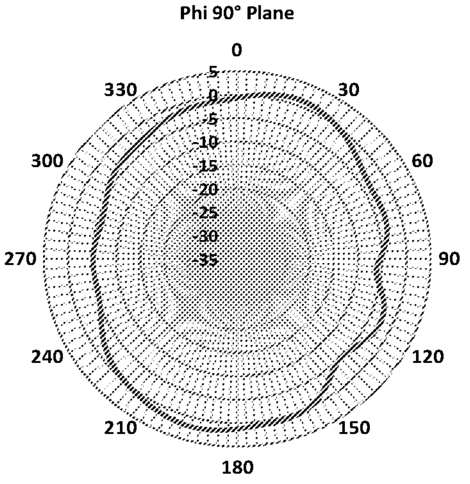


FIG. 98

Radiation Pattern at 960 MHz

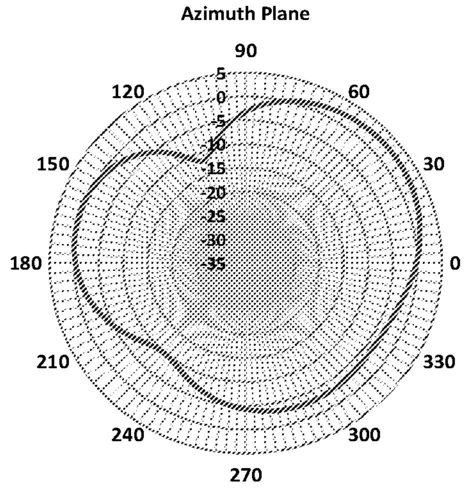


FIG. 99

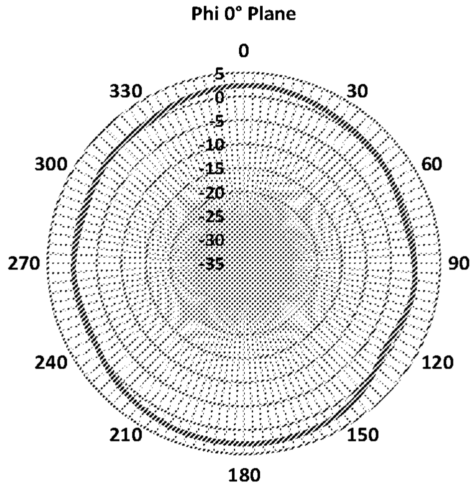


FIG. 100

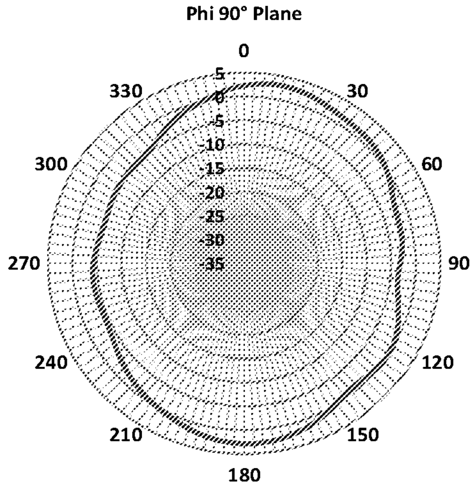


FIG. 101

Radiation Pattern at 1350 MHz

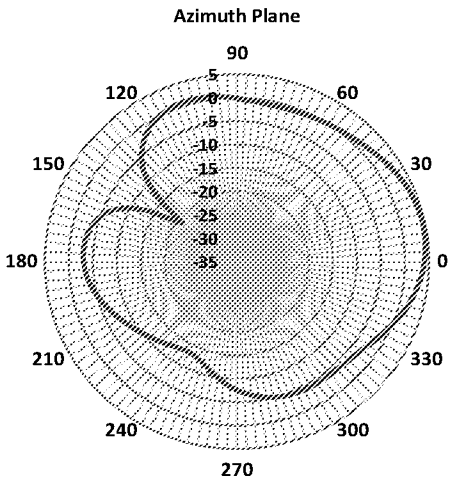


FIG. 102

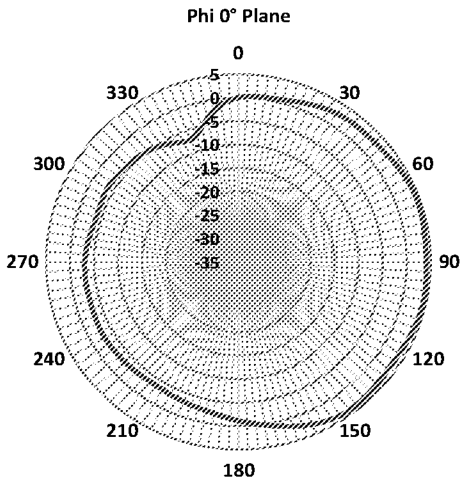


FIG. 103

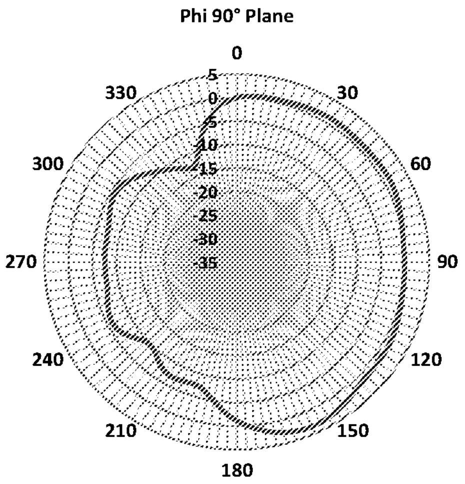


FIG. 104

Radiation Pattern at 1500 MHz

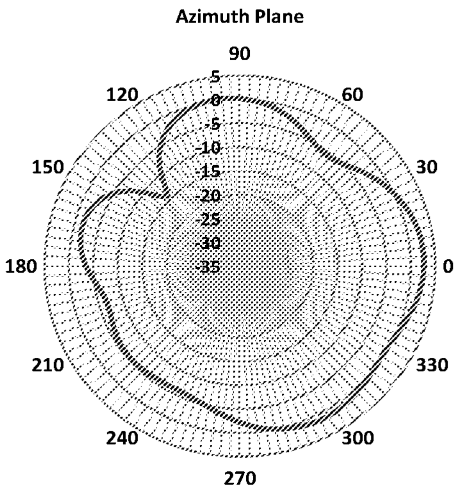


FIG. 105

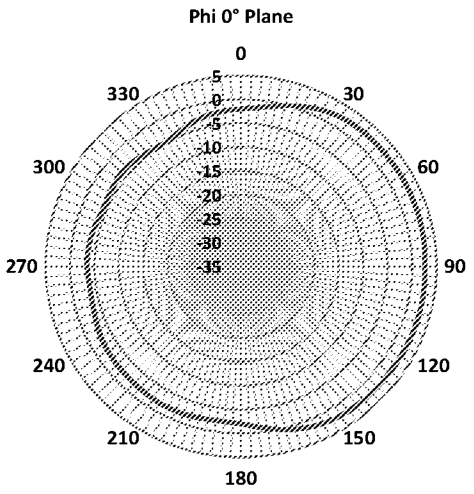


FIG. 106

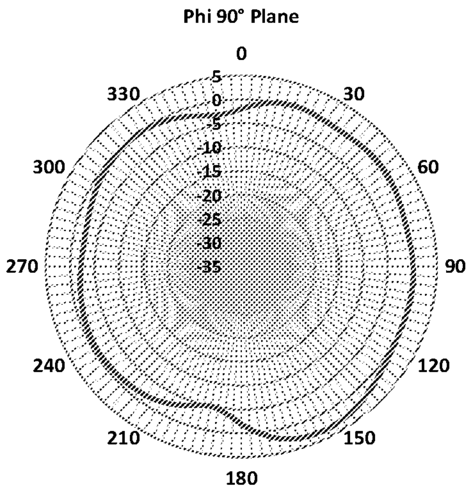


FIG. 107

Radiation Pattern at 1525 MHz

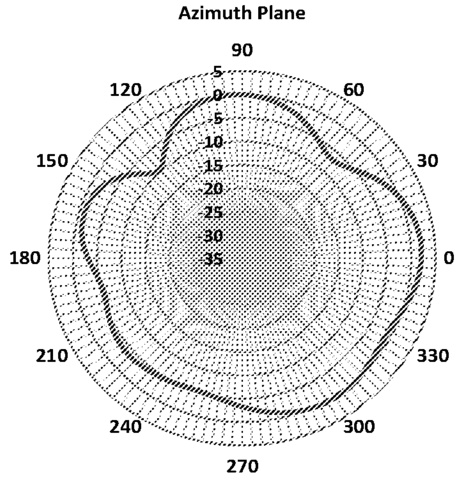


FIG. 108

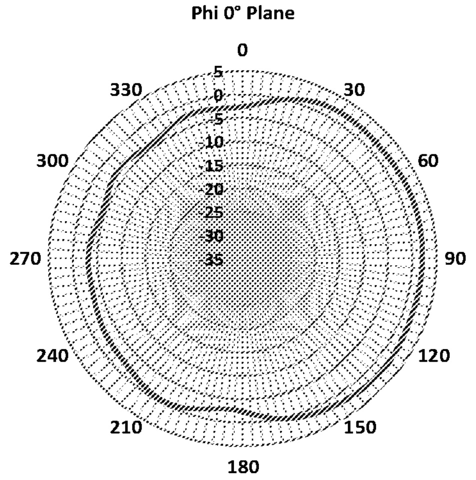


FIG. 109

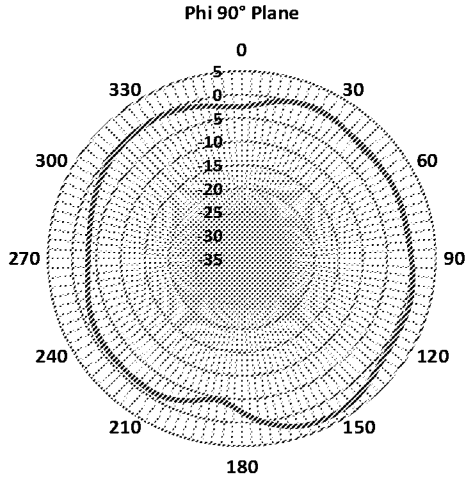


FIG. 110

Radiation Pattern at 1680 MHz

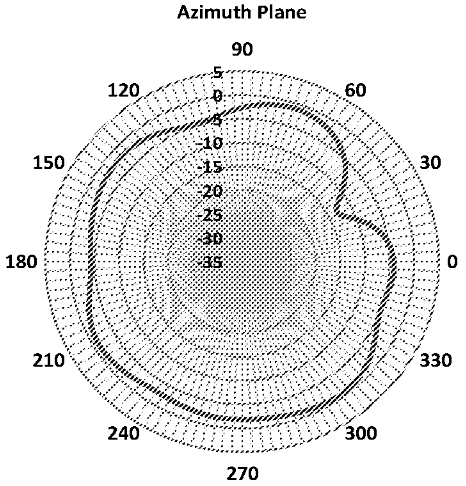


FIG. 111

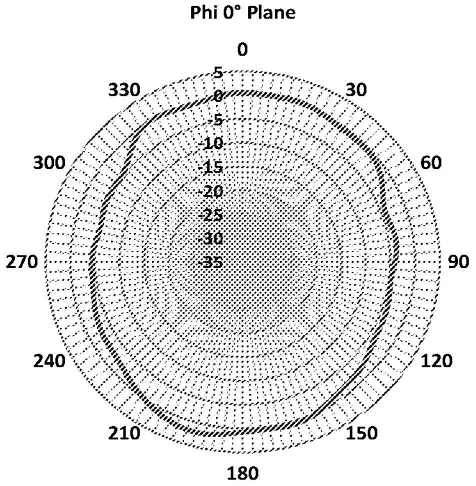


FIG. 112

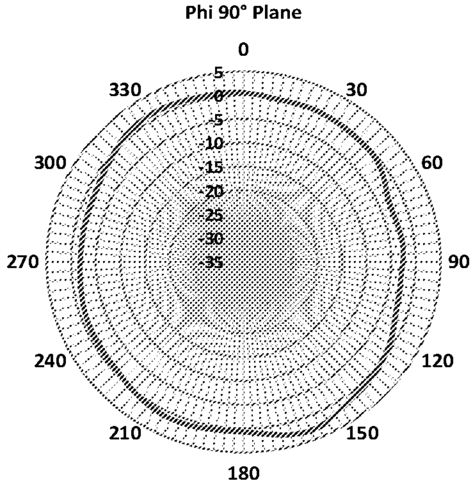


FIG. 113

Radiation Pattern at 1850 MHz

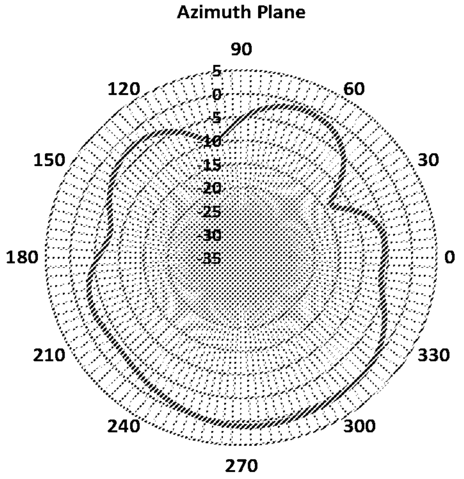


FIG. 114

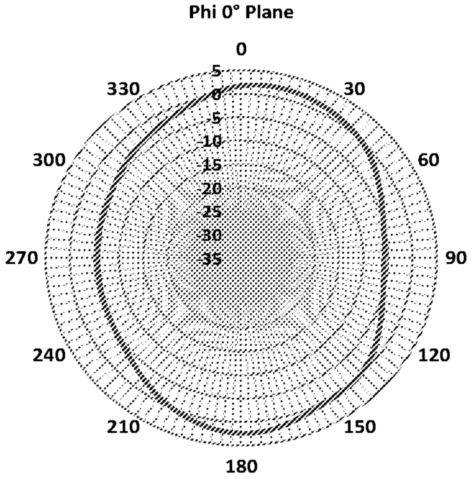


FIG. 115

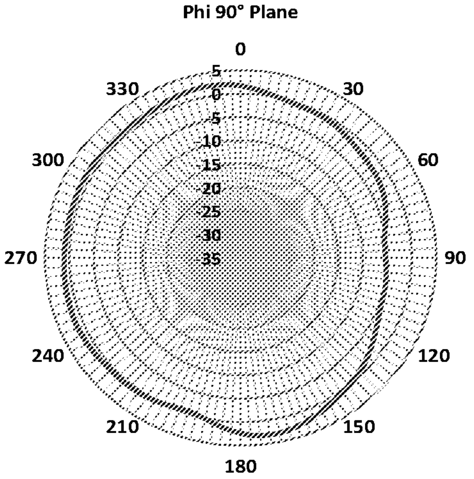


FIG. 116

Radiation Pattern at 1990 MHz

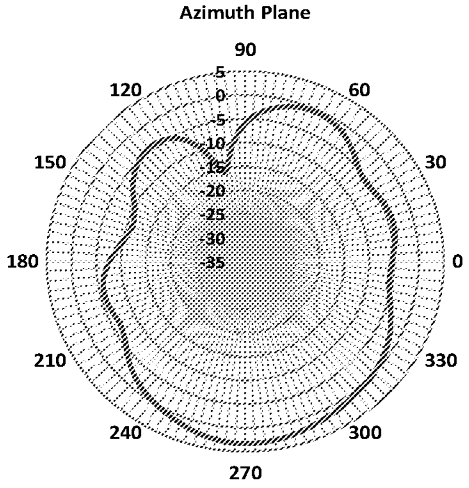


FIG. 117

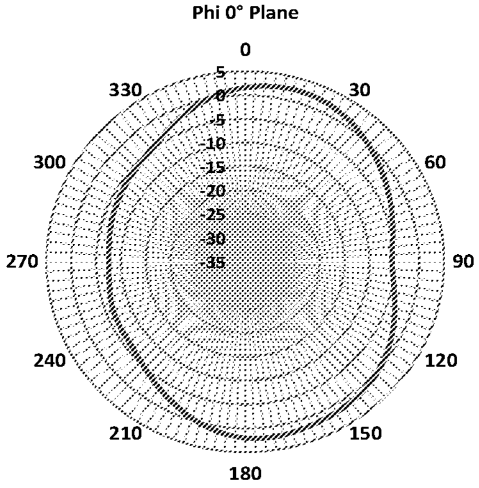


FIG. 118

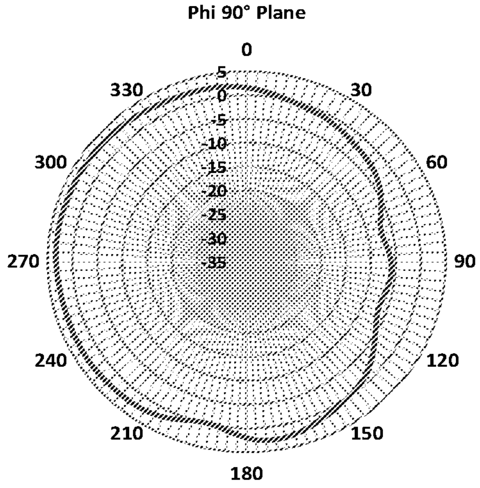


FIG. 119

Radiation Pattern at 2170 MHz

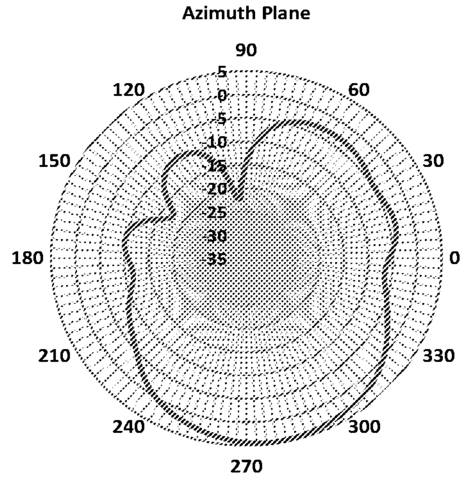


FIG. 120

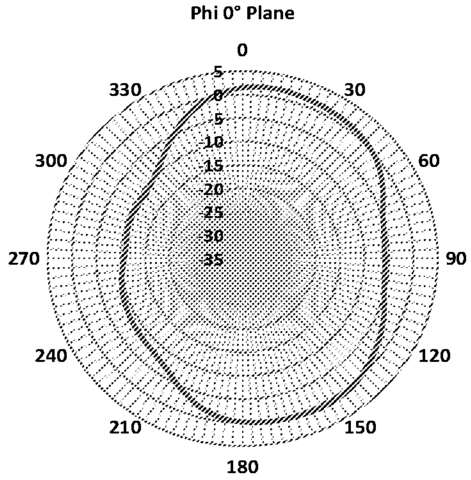


FIG. 121

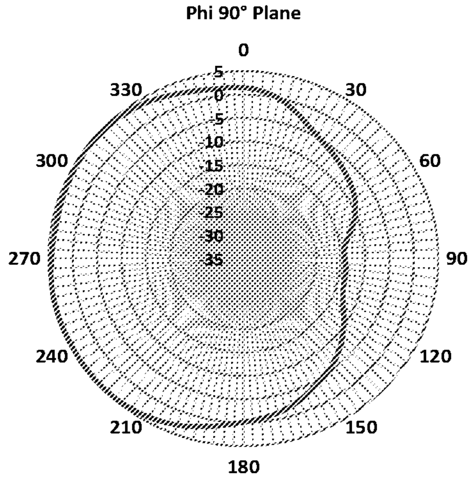


FIG. 122

Radiation Pattern at 2310 MHz

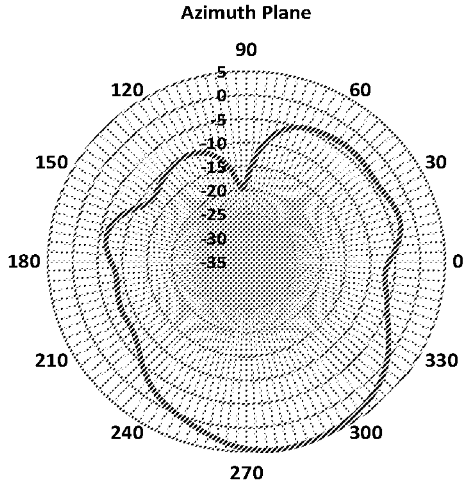


FIG. 123

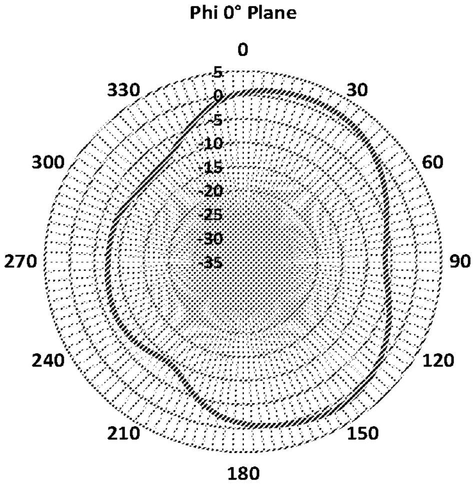


FIG. 124

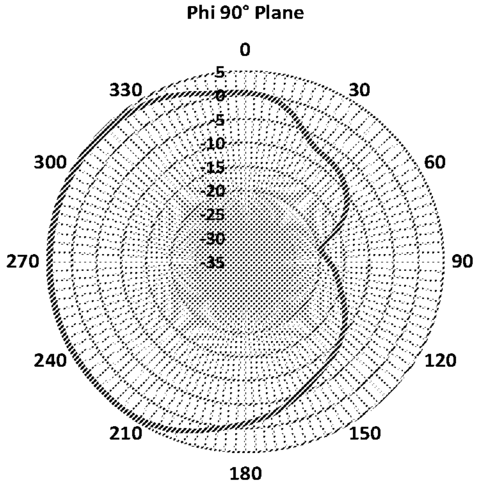


FIG. 125

Radiation Pattern at 2510 MHz

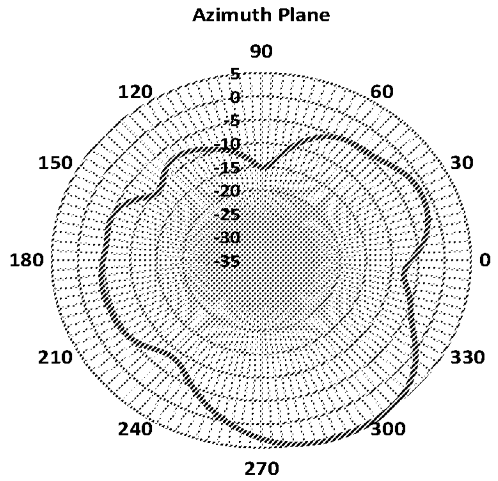


FIG. 126

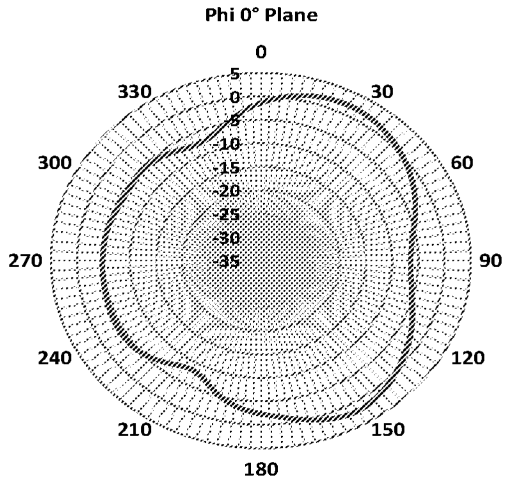


FIG. 127

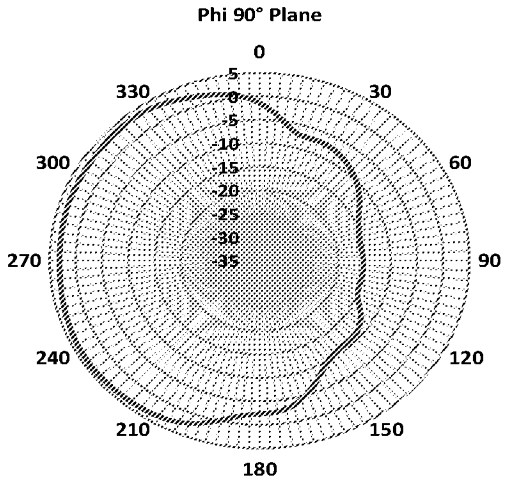


FIG. 128

Radiation Pattern at 2700 MHz

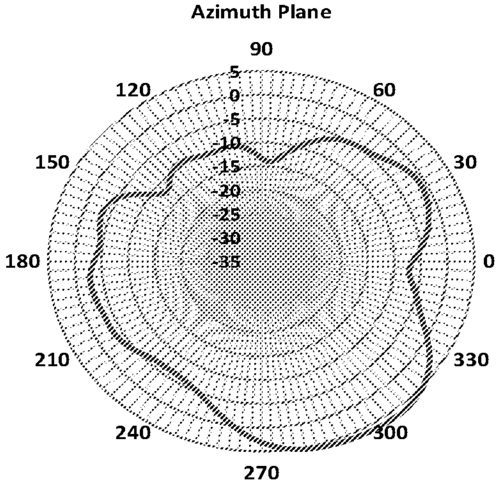


FIG. 129

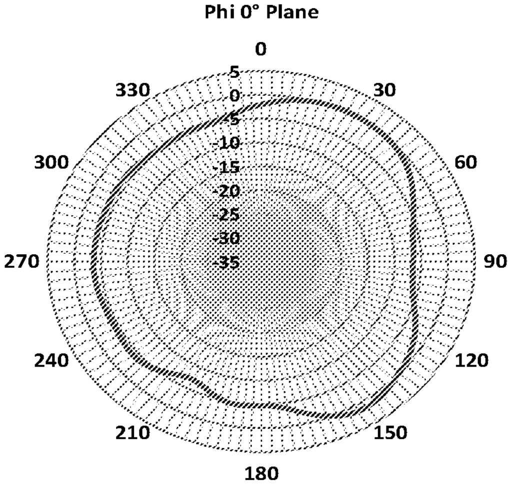


FIG. 130

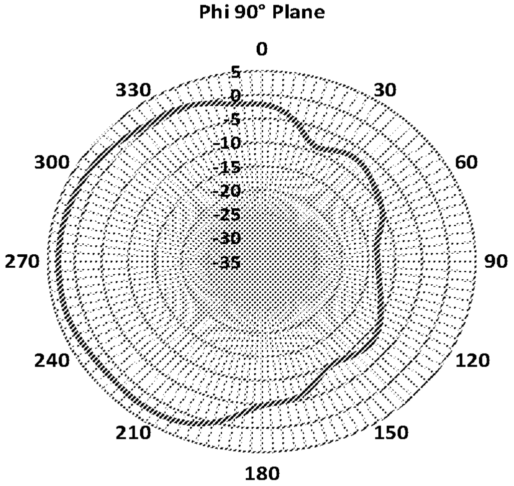


FIG. 131

Radiation Pattern at 3300 MHz

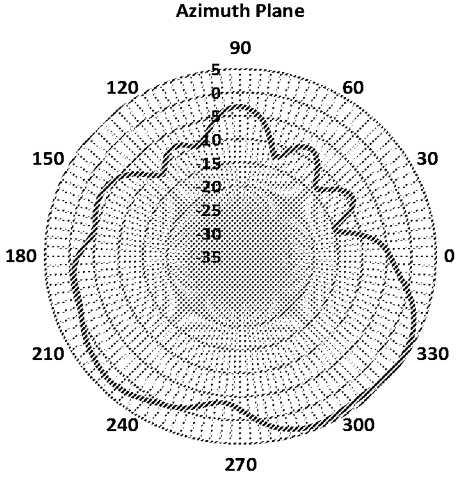


FIG. 132

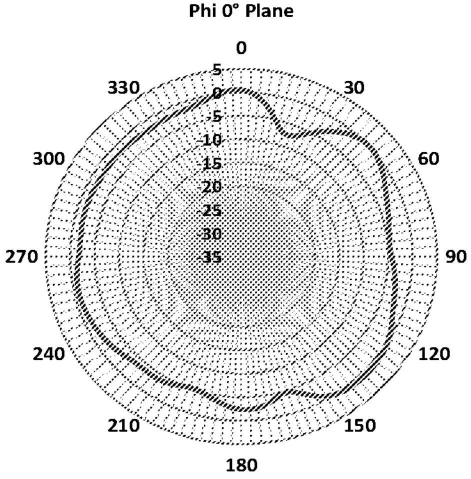


FIG. 133

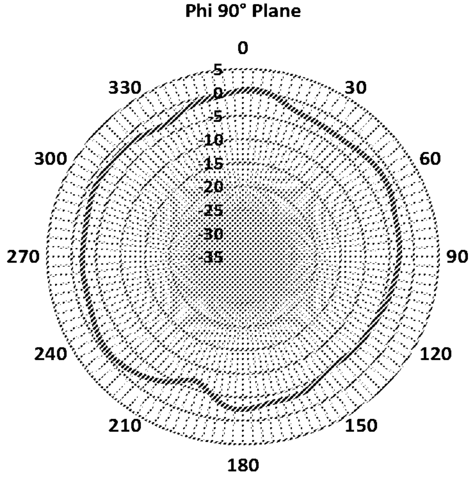


FIG. 134

Radiation Pattern at 3800 MHz

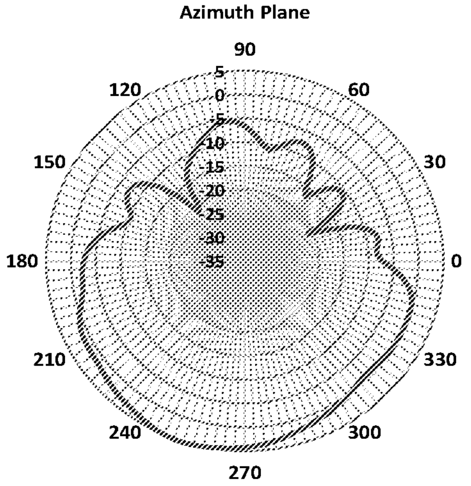


FIG. 135

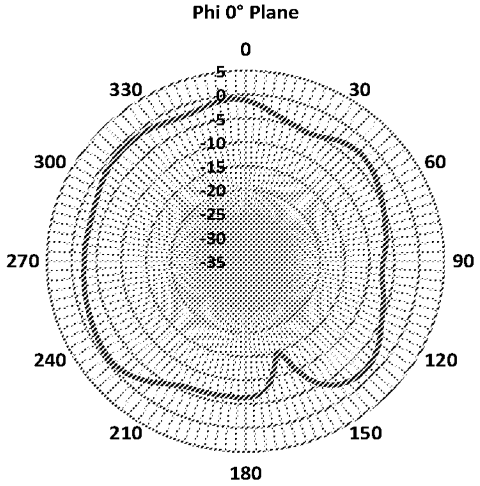


FIG. 136

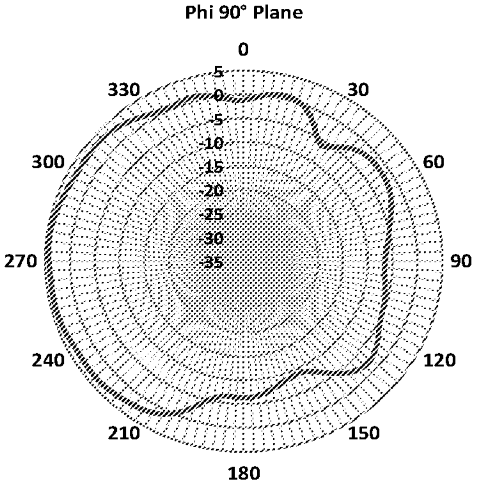
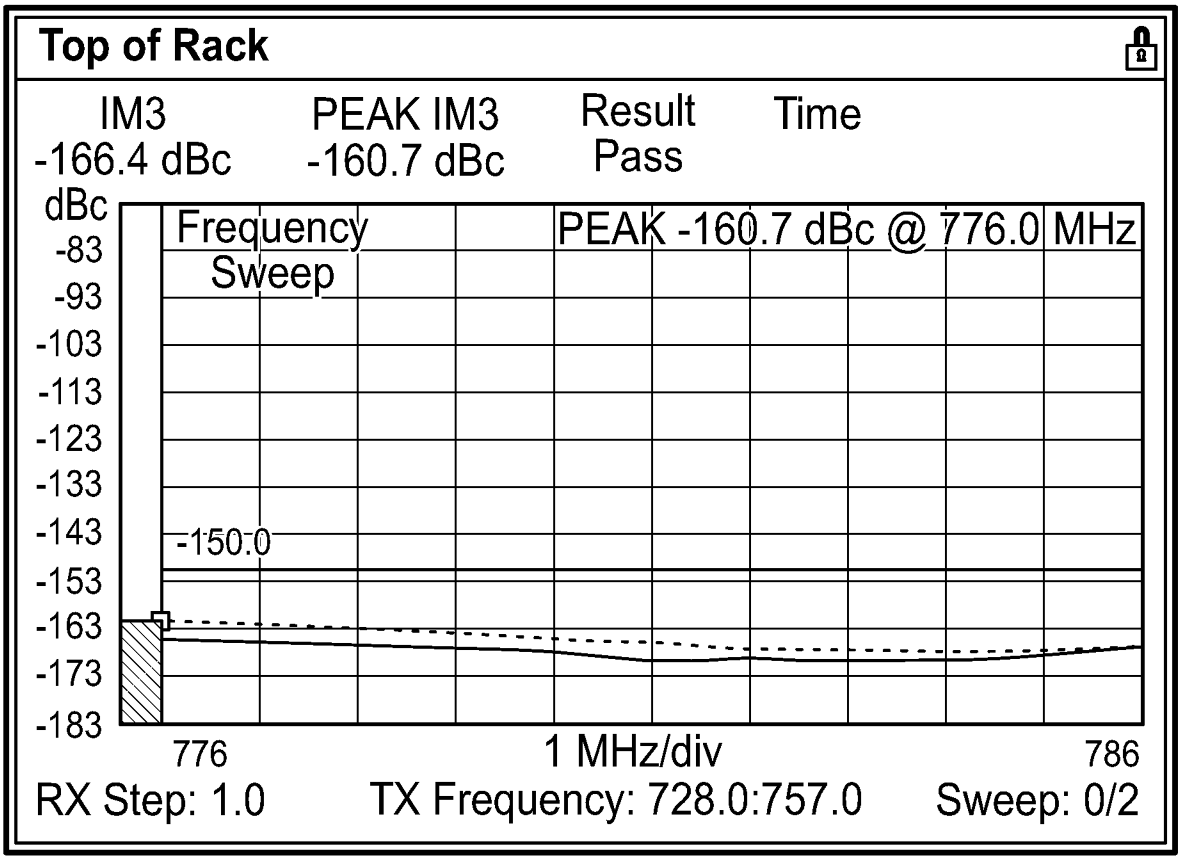


FIG. 137


Top of Rack

IM3 -166.4 dBc

PEAK IM3 -160.7 dBc

Result Pass

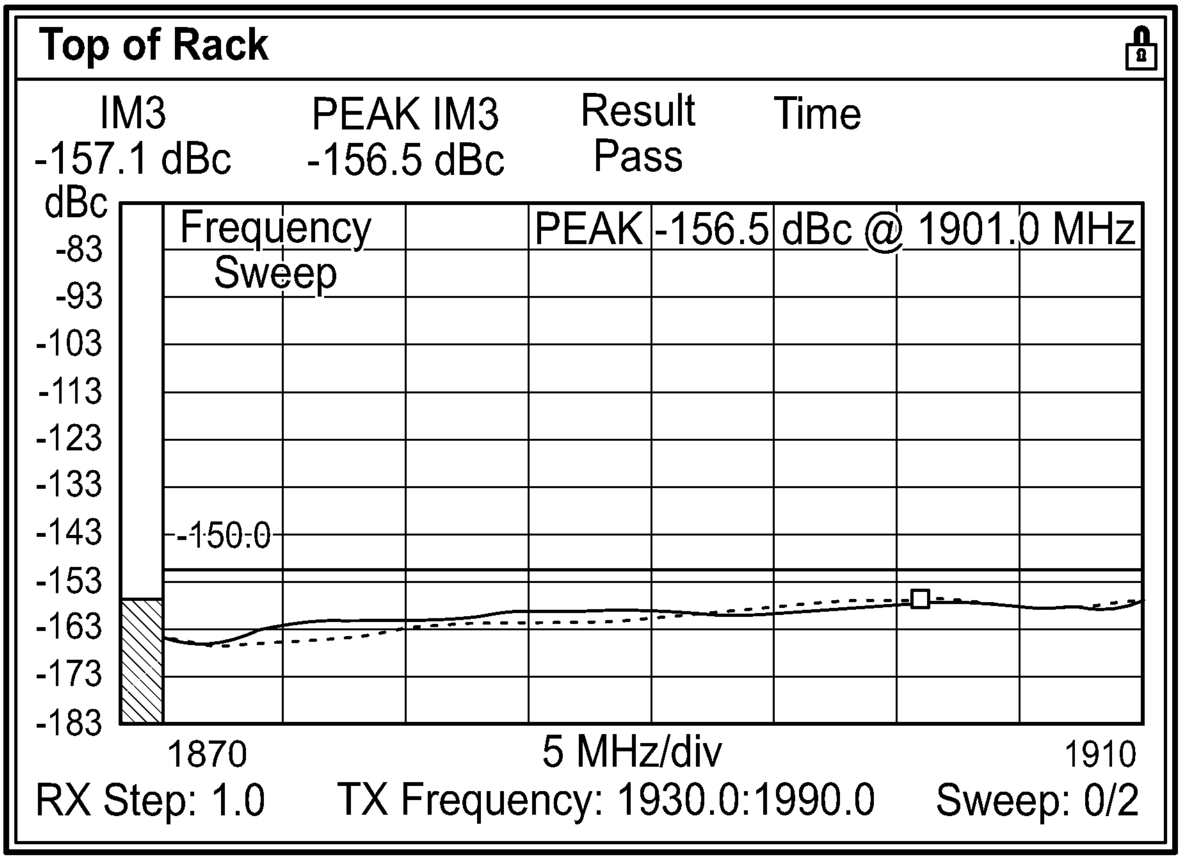
Time

RX Step: 1.0

TX Frequency: 728.0:757.0

Sweep: 0/2

FIG. 138


Top of Rack

IM3 -157.1 dBc

PEAK IM3 -156.5 dBc

Result Pass

Time

RX Step: 1.0

TX Frequency: 1930.0:1990.0

Sweep: 0/2

FIG. 139

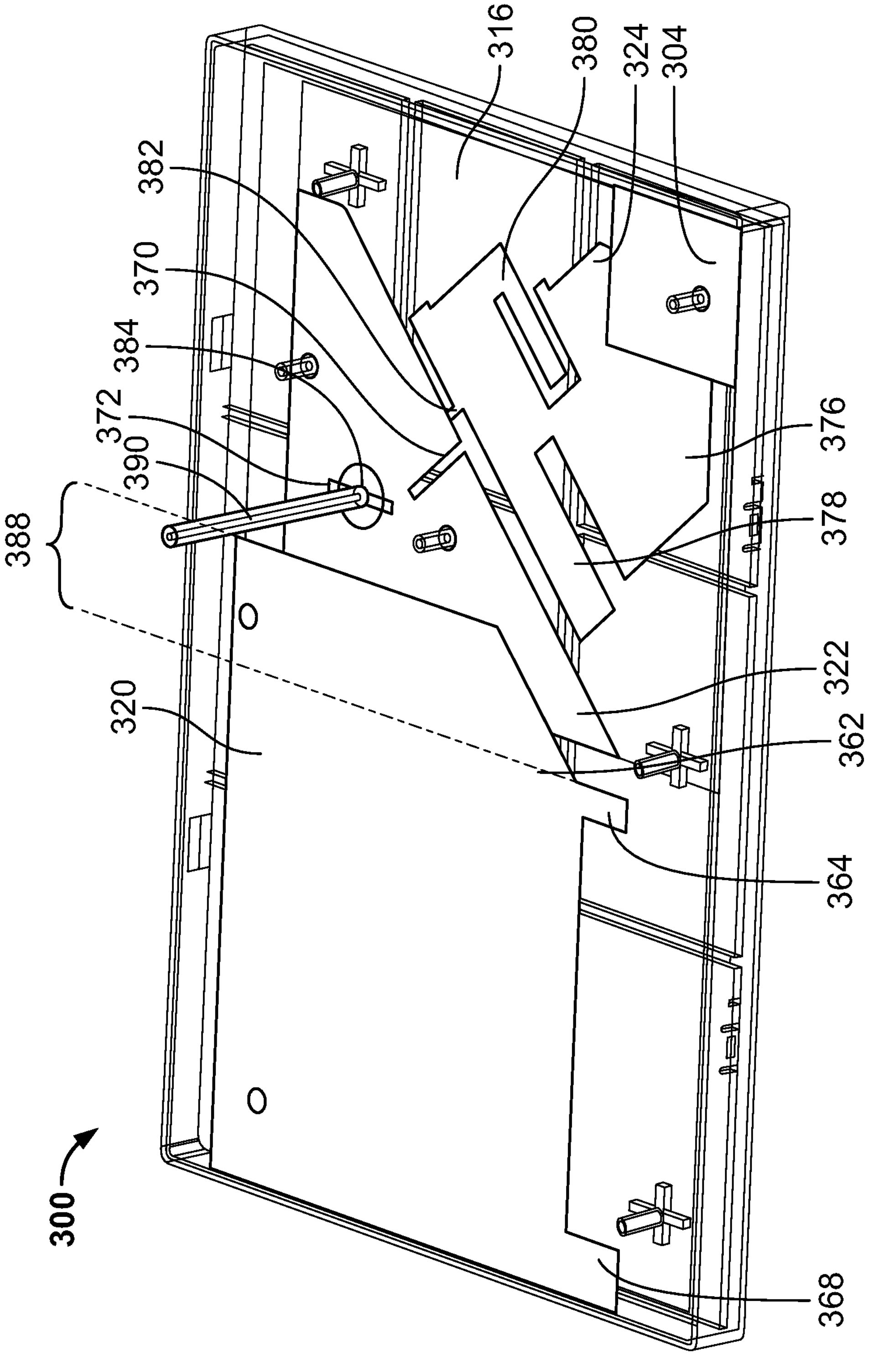

300
388
390
372
384
370
382
316
380
324
304
376
378
322
362
364
320
368

FIG. 140

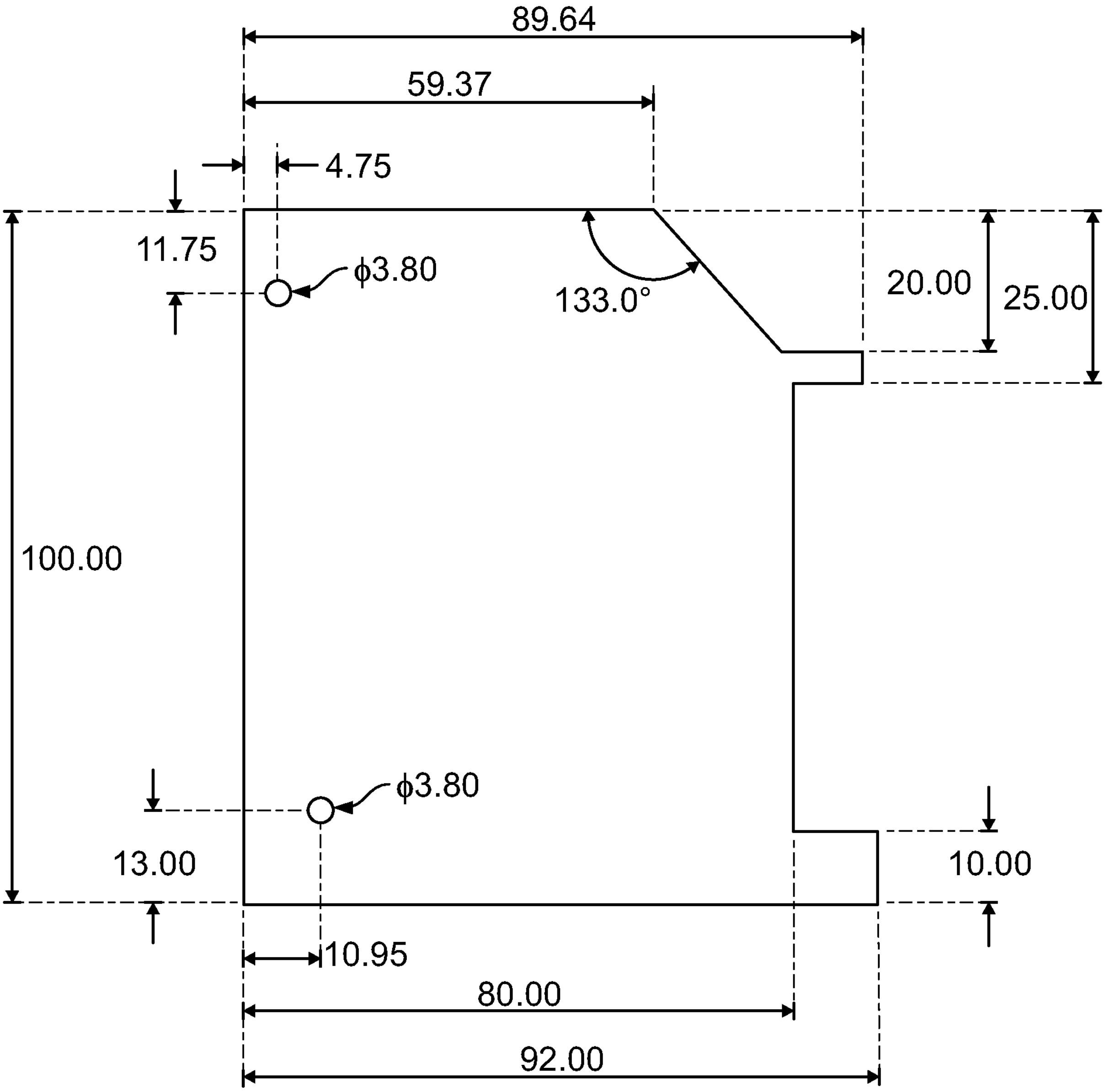

89.64
59.37
4.75
11.75
ϕ3.80
133.0°
20.00
25.00
100.00
ϕ3.80
13.00
10.00
10.95
80.00
92.00

FIG. 141

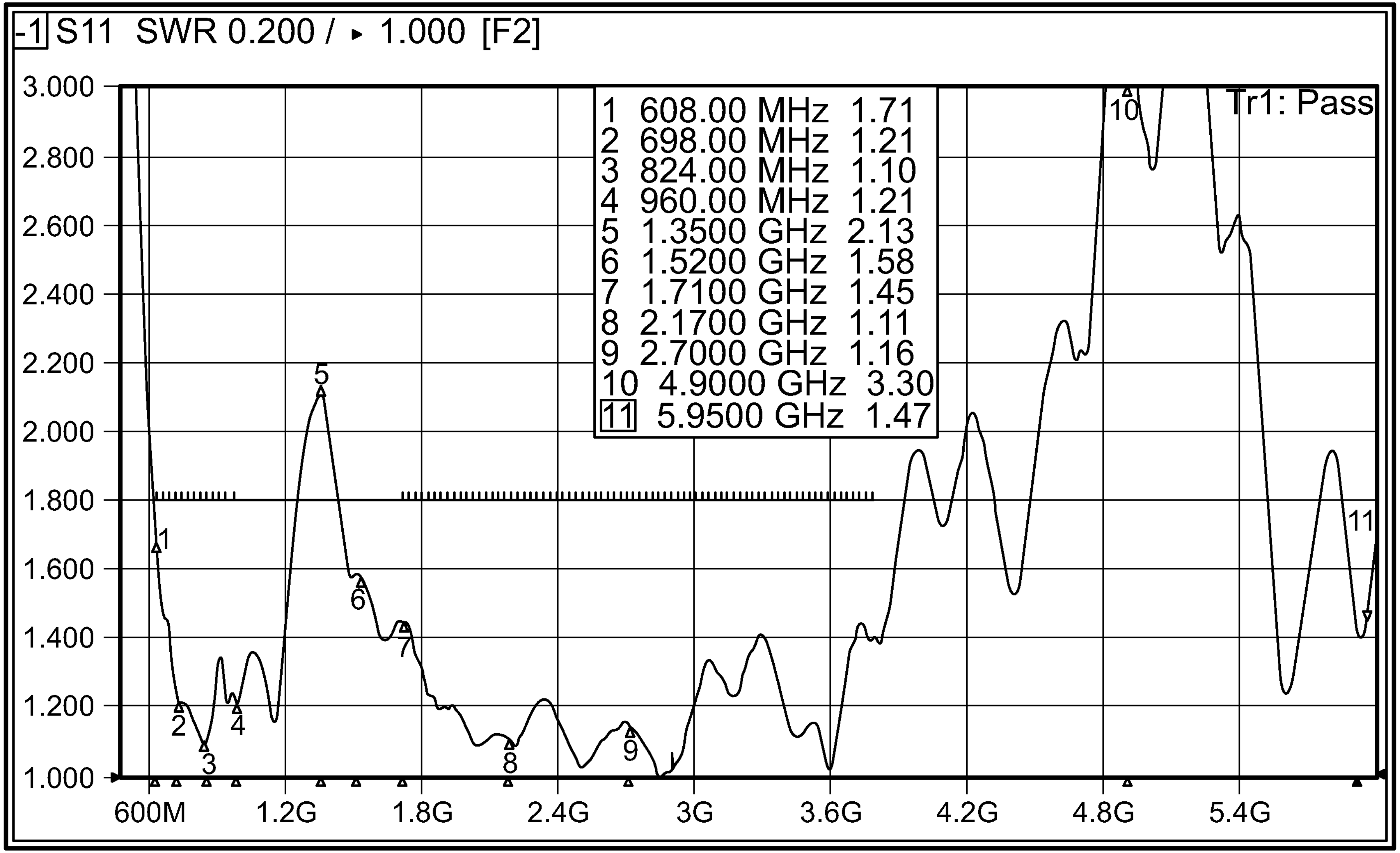

-1 S11 SWR 0.200 / ▸ 1.000 [F2]
3.000
2.800
2.600
2.400
2.200
2.000
1.800
1.600
1.400
1.200
1.000
600M
1.2G
1.8G
2.4G
3G
3.6G
4.2G
4.8G
5.4G
Tr1: Pass
1 608.00 MHz 1.71
2 698.00 MHz 1.21
3 824.00 MHz 1.10
4 960.00 MHz 1.21
5 1.3500 GHz 2.13
6 1.5200 GHz 1.58
7 1.7100 GHz 1.45
8 2.1700 GHz 1.11
9 2.7000 GHz 1.16
10 4.9000 GHz 3.30
11 5.9500 GHz 1.47
1
2
3
4
5
6
7
8
9
10
11

FIG. 142

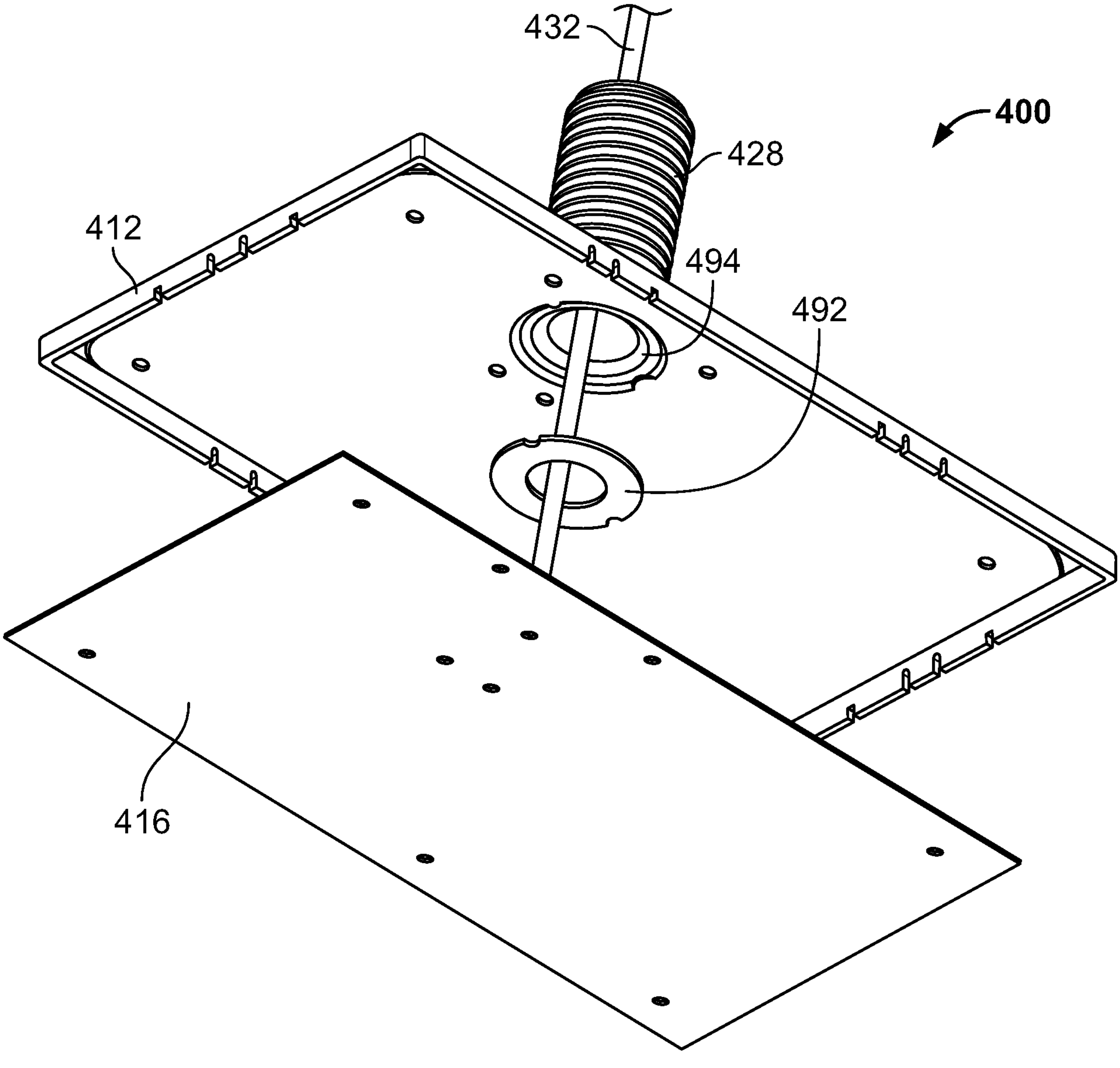


FIG. 143

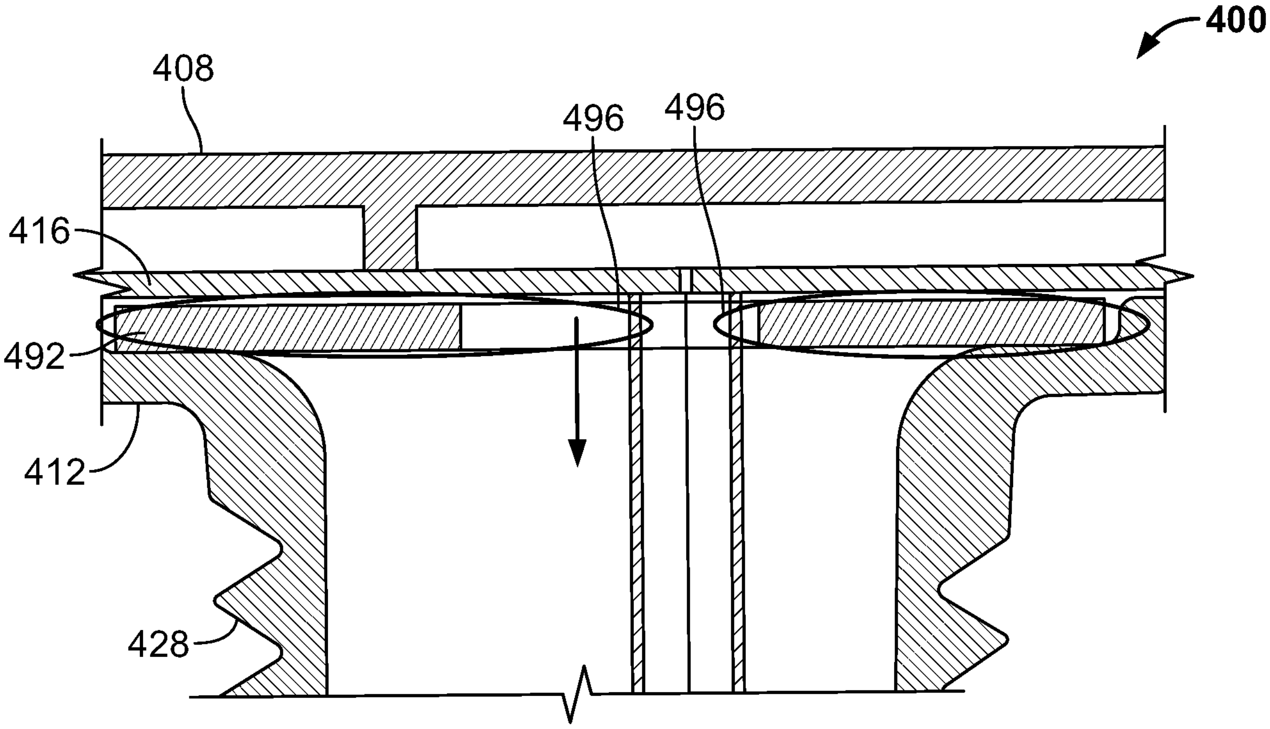


FIG. 144

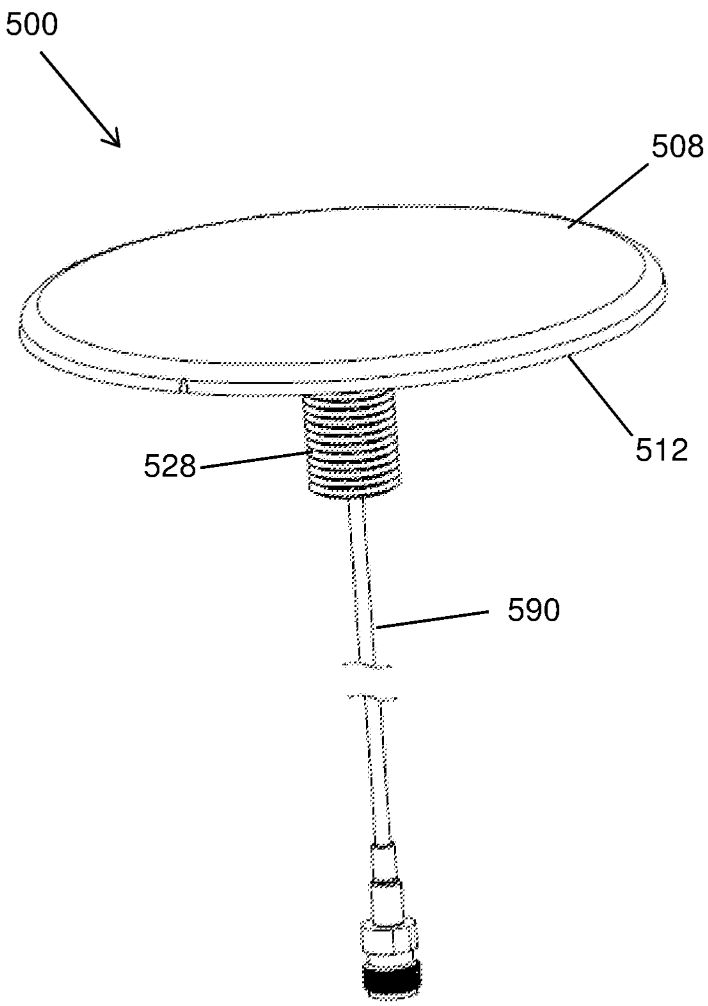


FIG. 145

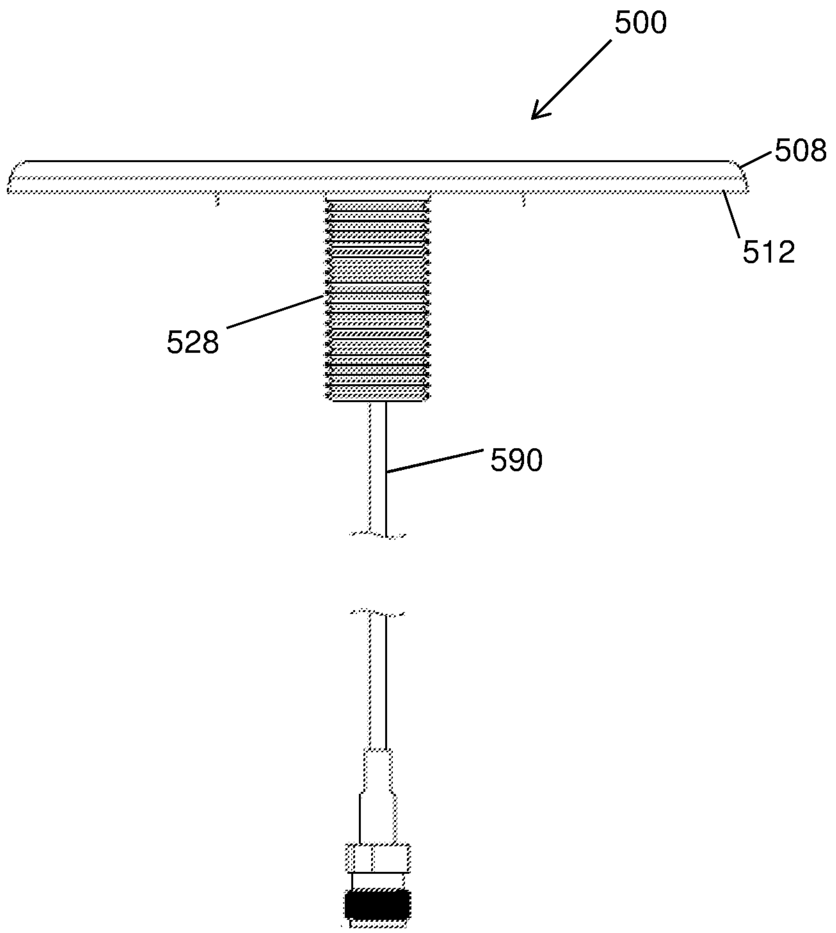


FIG. 146

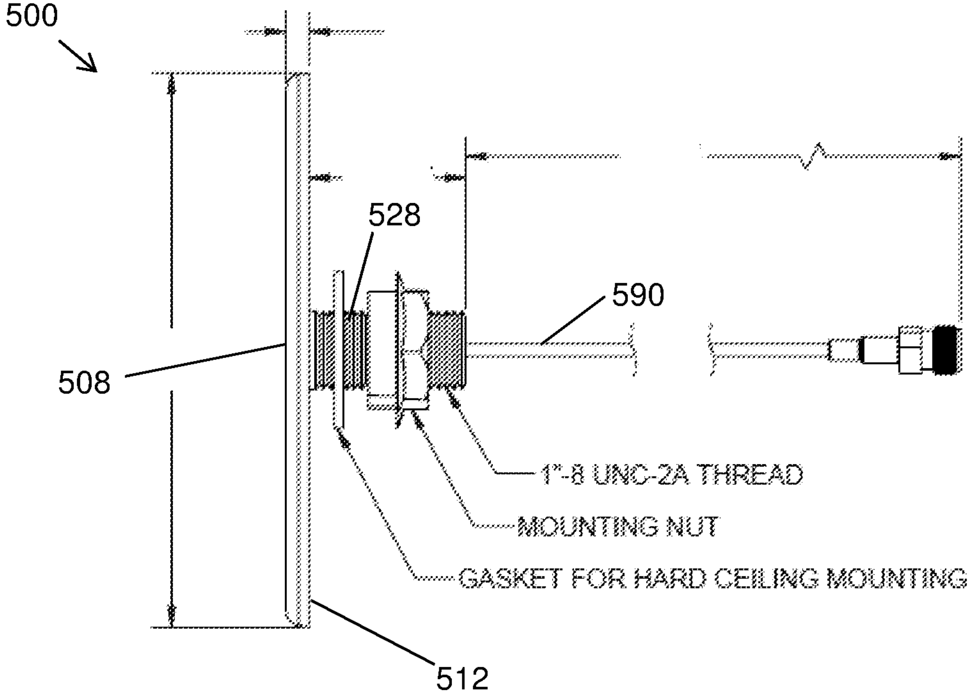


FIG. 147

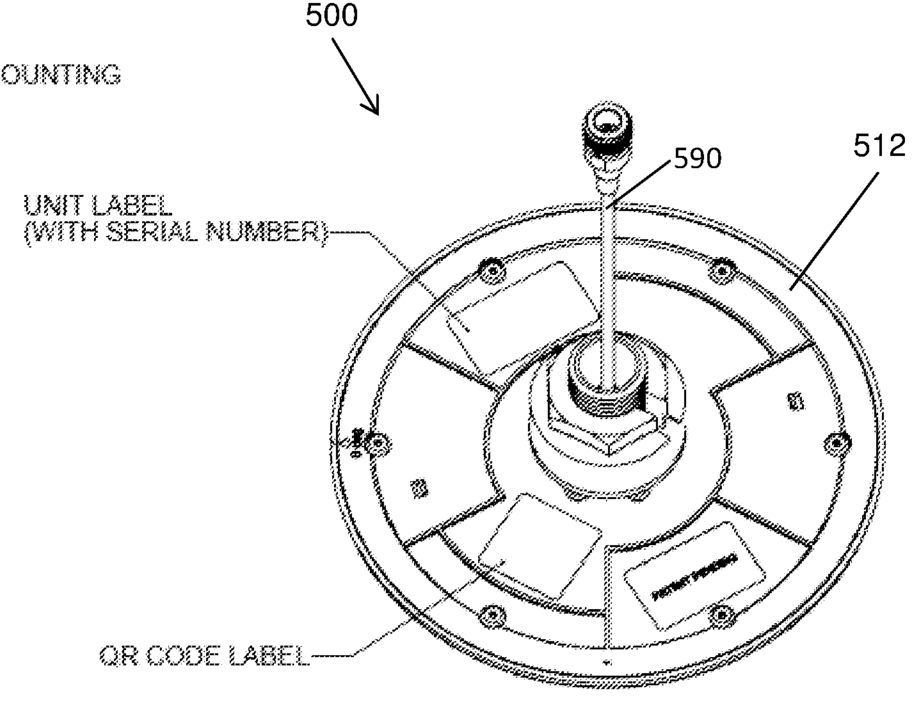
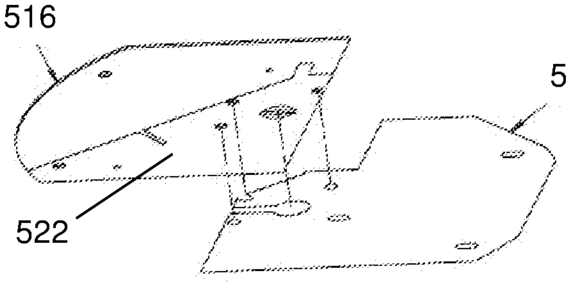


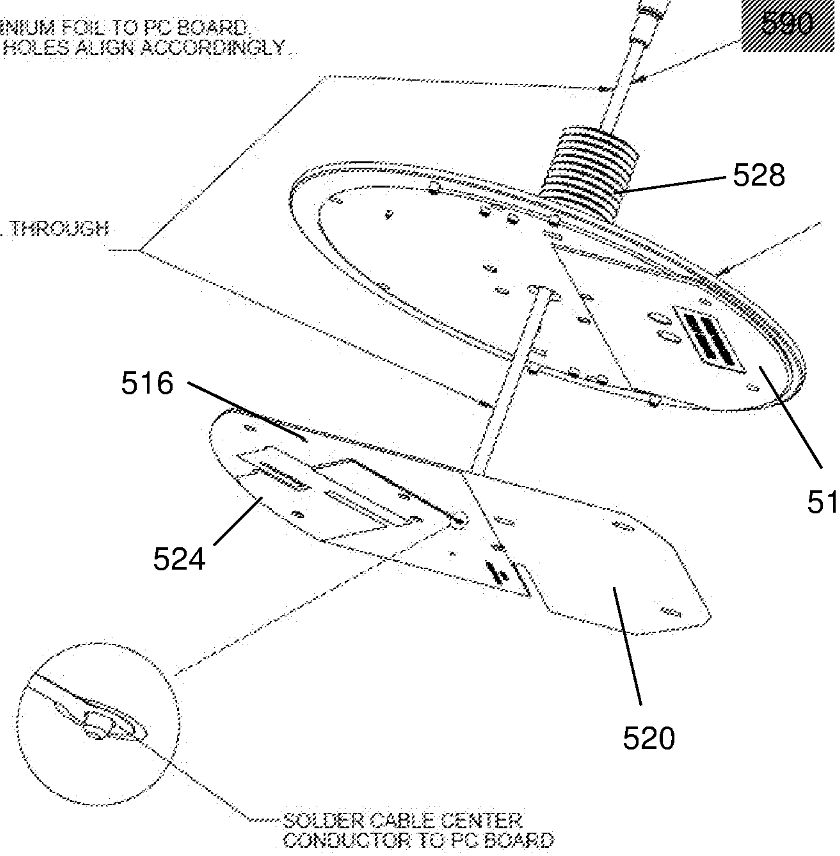
FIG. 148



ATTACH ALUMINIUM FOIL TO PC BOARD.
MAKESURE 4x HOLES ALIGN ACCORDINGLY.

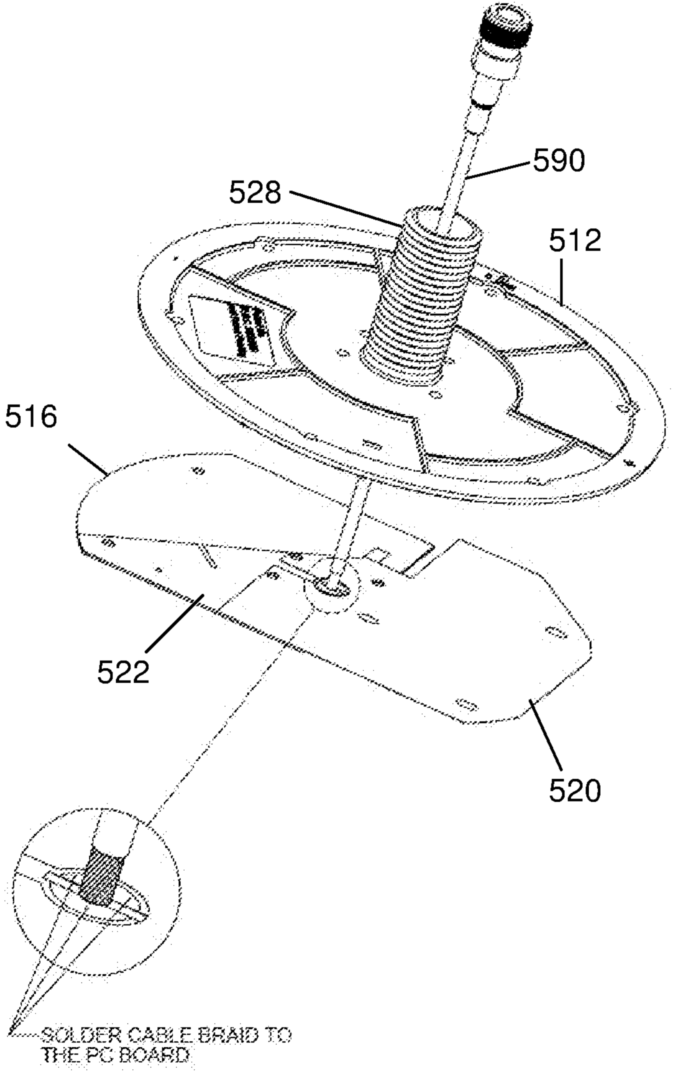
FIG. 149

INSERT CABLE ASSY. THROUGH
THE BASE PLATE



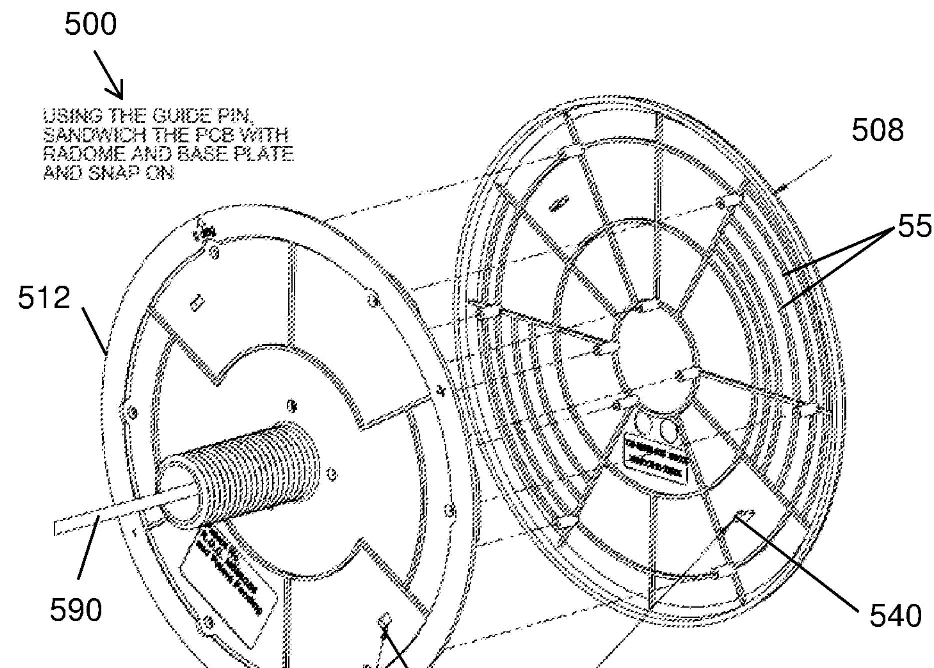
SOLDER CABLE CENTER
CONDUCTOR TO PC BOARD

FIG. 150

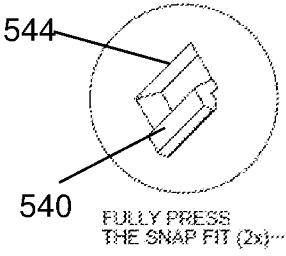


SOLDER CABLE BRAID TO
THE PC BOARD

FIG. 151

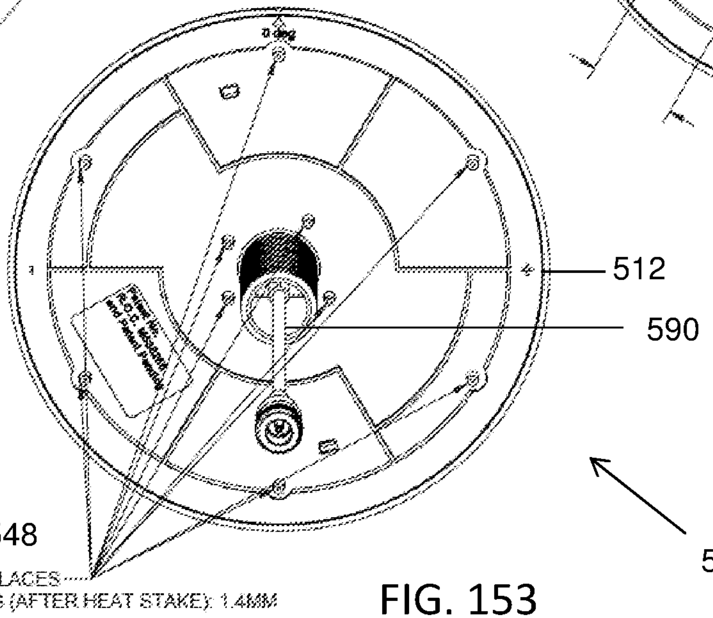


USING THE GUIDE PIN, SANDWICH THE PCB WITH RADOME AND BASE PLATE AND SNAP ON



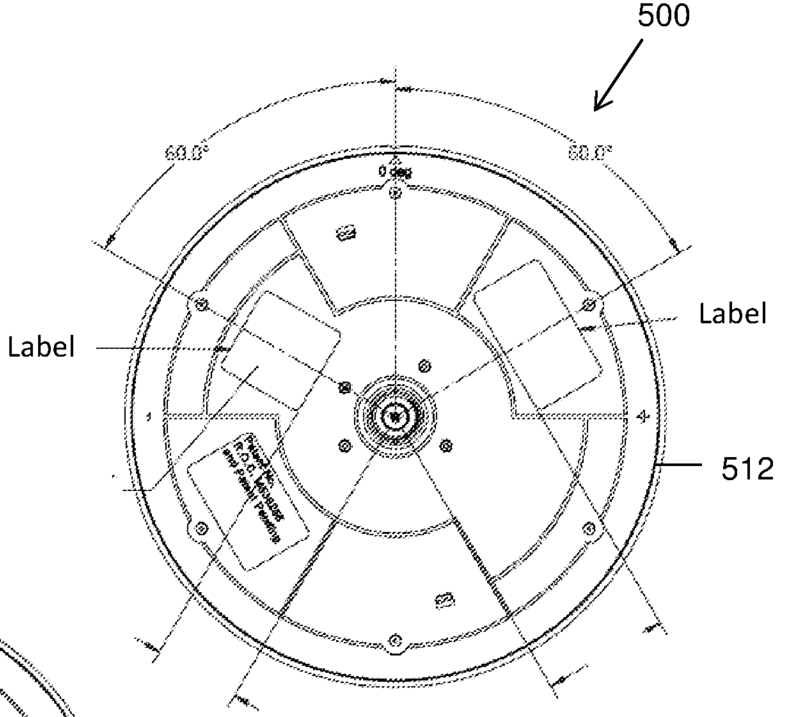
FULLY PRESS THE SNAP FIT (2x)

FIG. 152



HEATSTAKE PROCESS x10 PLACES
MAXIMUM HEIGHT OF POSTS (AFTER HEAT STAKE): 1.4MM

FIG. 153



ATTACH UNIT LABEL AND OR LABEL AS SHOWN

FIG. 154

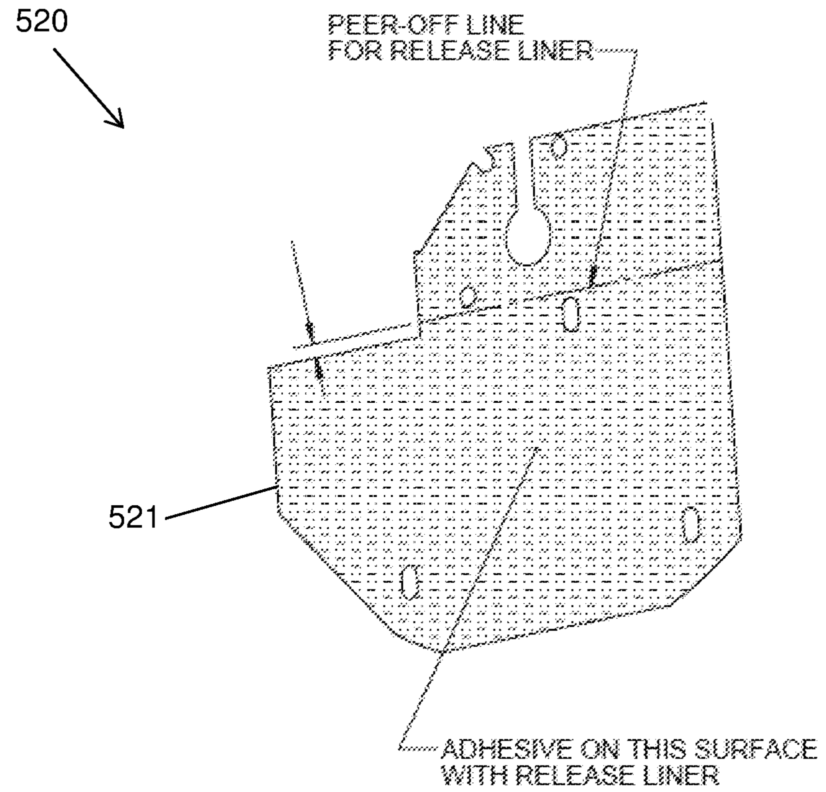

520
PEER-OFF LINE
FOR RELEASE LINER
521
ADHESIVE ON THIS SURFACE
WITH RELEASE LINER

FIG. 155

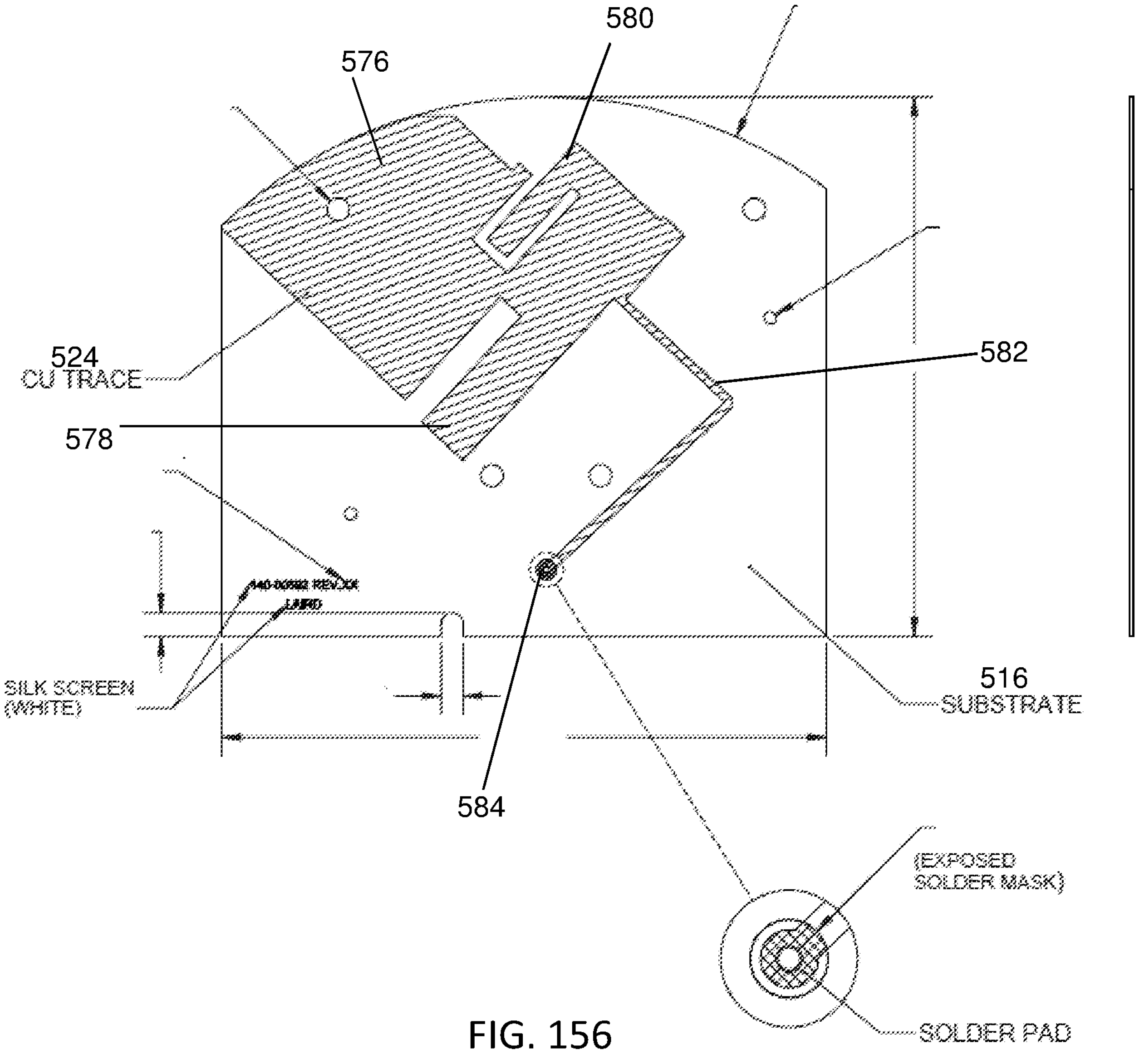

576
580
524
CU TRACE
582
578
SILK SCREEN
(WHITE)
516
SUBSTRATE
584
(EXPOSED
SOLDER MASK)
SOLDER PAD

FIG. 156

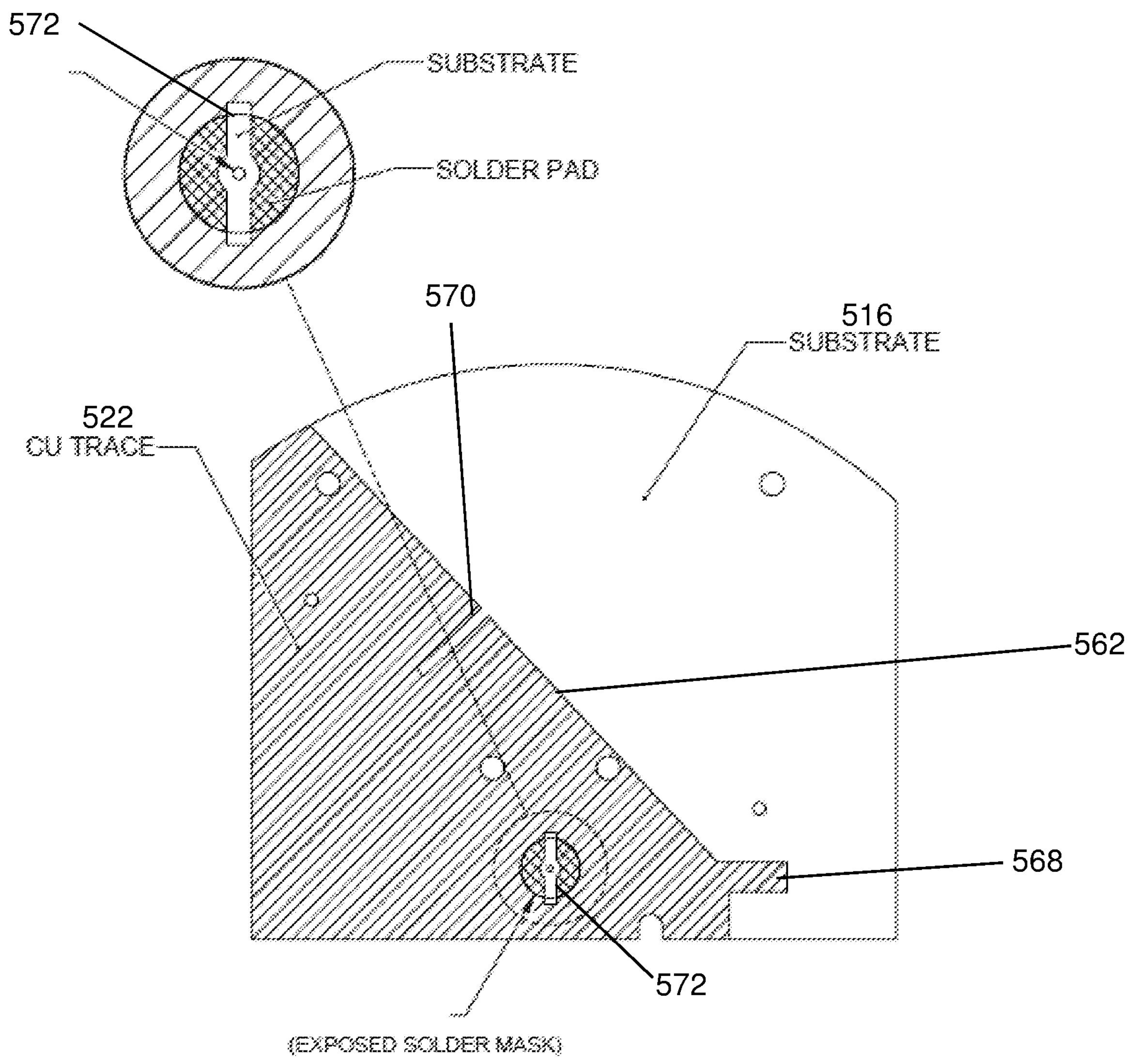

572
SUBSTRATE
SOLDER PAD
570
516
SUBSTRATE
522
CU TRACE
562
568
572
(EXPOSED SOLDER MASK)

FIG. 157

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/031229

A. CLASSIFICATION OF SUBJECT MATTER

H01Q 5/25(2014.01)i, H01Q 9/04(2006.01)i, H01Q 1/38(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01Q 5/25; H01Q 1/38; H01Q 9/04; H01Q 13/04; H01Q 1/24

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: omnidirectional, antenna, ground, slant

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007-0103369 A1 (MOHAMED RATNI et al) 10 May 2007 See paragraphs [0001], [0054]-[0086], claims 1, 4 and figures 1-8.	1-4,6-10,18-19
Y		5,11-17,20-27
Y	US 2003-0164798 A1 (PETER NEVERMANN) 04 September 2003 See claims 1, 10-13 and figure 2.	5,14-17,20-27
Y	WO 2016-018547 A1 (LAIRD TECHNOLOGIES, INC.) 04 February 2016 See paragraphs [0078]-[0083] and figures 3-10.	11-13,25,27
A	US 2003-0103008 A1 (TOM PETROPOULOS et al.) 05 June 2003 See claims 1-9 and figures 1-8, 12.	1-27
A	US 2014-0118209 A1 (GALTRONICS CORPORATION LTD.) 01 May 2014 See claims 1-5 and figures 1-4.	1-27

☐ Further documents are listed in the continuation of Box C.　　☒ See patent family annex.

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

Date of the actual completion of the international search
17 August 2017 (17.08.2017)

Date of mailing of the international search report
17 August 2017 (17.08.2017)

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

Authorized officer
JANG, Gijeong
Telephone No. +82-42-481-8364

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2007-0103369 A1	10/05/2007	EP 1786064 A1	16/05/2007
		US 7545339 B2	09/06/2009
US 2003-0164798 A1	04/09/2003	CN 100459291 C	04/02/2009
		CN 1639909 A	13/07/2005
		CN 1650473 C	03/08/2005
		EP 1481443 A2	01/12/2004
		EP 1481443 A4	17/06/2009
		EP 1481444 A2	01/12/2004
		JP 2005-519509 A	30/06/2005
		JP 2006-501699 A	12/01/2006
		KR 10-1006296 B1	06/01/2011
		KR 10-2004-0083475 A	02/10/2004
		KR 10-2004-0088577 A	16/10/2004
		TW 200304247 A	16/09/2003
		TW 200304713 A	01/10/2003
		TW I223468 B	01/11/2004
		TW I223470 B	01/11/2004
		US 2003-0184482 A1	02/10/2003
		US 6856285 B2	15/02/2005
		US 6882318 B2	19/04/2005
		WO 03-075395 A2	12/09/2003
		WO 03-077355 A2	18/09/2003
		WO 2003-075395 A3	18/03/2004
		WO 2003-077355 A3	24/06/2004
WO 2016-018547 A1	04/02/2016	TW 201608764 A	01/03/2016
		TW I563732 B	21/12/2016
		US 2017-0141480 A1	18/05/2017
US 2003-0103008 A1	05/06/2003	None	
US 2014-0118209 A1	01/05/2014	CN 104885299 A	02/09/2015
		CN 203312446 U	27/11/2013
		TW 201424117 A	16/06/2014
		US 9356354 B2	31/05/2016
		WO 2014-068564 A2	08/05/2014
		WO 2014-068564 A3	26/06/2014