



(51) International Patent Classification:  
*H01Q 1/42* (2006.01)

(21) International Application Number:  
PCT/US2014/012429

(22) International Filing Date:  
22 January 2014 (22.01.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
61/898,986 1 November 2013 (01.11.2013) US

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

(72) Inventors: RUSSELL, Erick, Joseph; 3481 Rider Trail  
South, Earth City, MO 63045 (US). RAMBERG, Henrik,  
Karl; 3481 Rider Trail South, Earth City, MO 63045 (US).

(74) Agent: FUSSNER, Anthony, G.; 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, 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, KN, KP, KR,  
KZ, LA, LC, LK, LR, LS, LT, 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.

(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, 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).

[Continued on next page]

(54) Title: DUAL POLARIZED LOW PROFILE HIGH GAIN PANEL ANTENNAS

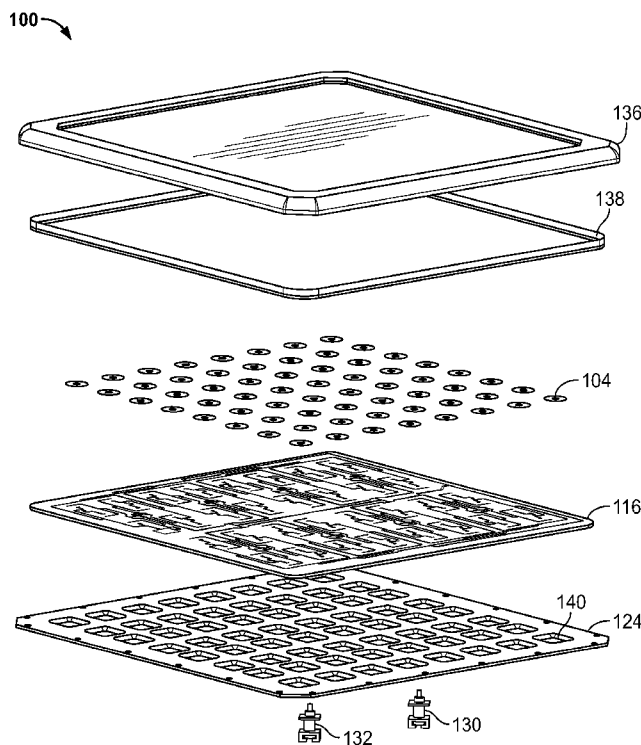


FIG. 1

(57) Abstract: According to various aspects, exemplary em-  
bodiments are disclosed of panel antennas and methods of  
manufacturing the same. A panel antenna may generally in-  
clude a ground plane, a radome, a printed circuit board, and  
one or more antenna elements or radiators. In exemplary em-  
bodiments, the antenna elements or radiators may comprise  
one or more dual slot coupled patches.



---

**Published:**

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

## DUAL POLARIZED LOW PROFILE HIGH GAIN PANEL ANTENNAS

### CROSS-REFERENCE TO RELATED APPLICATION

**[0001]** This application is a PCT International Application of U.S. Provisional Application No. 61/898,986 filed November 1, 2013. The entire disclosure of the above application is incorporated herein by reference.

### FIELD

**[0002]** The present disclosure generally relates to panel antennas assemblies and methods of manufacturing or assembling the same.

### BACKGROUND

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

**[0004]** Stacked patch antennas are commonly used for panel antennas that are high gain (*e.g.*, gain > 14 decibels isotropic (dBi), *etc.*). For the stacked patch antenna concept, the high gain panel antenna includes a radome, a ground plane, and two printed circuit boards (PCBs).

**[0005]** One of the two PCBs includes the top patches. The other PCB includes a microstrip feed network and the bottom patches. The horizontal and vertical polarization feeding for the stacked patches is on the same bottom PCB board. The bottom board with the feed network and bottom patches may be made of Neltec Polytetrafluoroethylene (PTFE) PCB material. The top board with the top patches may be made of flame retardant 4 (FR4) fiberglass reinforced epoxy laminates.

### SUMMARY

**[0006]** This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

**[0007]** According to various aspects, exemplary embodiments are disclosed of panel antennas and methods of manufacturing the same. A panel antenna may generally include a ground plane, a radome, a printed circuit board, and one or more antenna elements or radiators. In exemplary embodiments, the

antenna elements or radiators may comprise one or more dual slot coupled patches.

**[0008]** Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

## **DRAWINGS**

**[0009]** 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.

**[0010]** FIG. 1 is an exploded perspective view of a panel antenna having an 8x8 array of antenna elements or radiators that comprise dual slot coupled patches according to an exemplary embodiment;

**[0011]** FIG. 2 is a front view of the panel antenna shown in FIG. 1 after being assembled, where the radome is shown transparent to illustrate components under the radome;

**[0012]** FIG. 3 is a bottom view of the panel antenna shown in FIG. 2 without the ground plane in order to illustrate slots of a slot element along a bottom of the PCB;

**[0013]** FIG. 4 illustrates an example feedline network for exciting the slots shown in FIG. 3, and also illustrating a patch for grounding the feedline network according to an exemplary embodiment;

**[0014]** FIG. 5 is a front view of the ground plane and PCB of the panel antenna shown in FIG. 1, and also illustrating the feedline network and grounding patch shown in FIG. 4;

**[0015]** FIG. 6 is a bottom view of the ground plane shown in FIG. 5, and also illustrating two ports or connectors along a bottom of the ground plane;

**[0016]** FIG. 7 is an exploded perspective view of two dual slot coupled patches of the panel antenna shown in FIG. 1, and illustrating the components thereof including the ground plane with the cavities, the slots, the feed network, and the patches above;

**[0017]** FIG. 8 is a front view of the dual slot coupled patches shown in FIG. 7;

**[0018]** FIG. 9 is a side view of the dual slot coupled patches shown in FIG. 7;

**[0019]** FIG. 10 is a front view of four dual slot coupled patches of the panel antenna shown in FIG. 1, and illustrating an unequal spacing of the cavities of the ground plane and equal spacing of the patches over the slot element according to an exemplary embodiment;

**[0020]** FIG. 11 includes front views of the panel antenna portion shown in FIG. 10 with and without the patches, where the arrows represent the horizontal and vertical polarization directions for the slots;

**[0021]** FIG. 12 is a perspective view of another exemplary embodiment of a panel antenna having an 8x8 array of antenna elements or radiators that comprise dual slot coupled patches, where patches are mechanically coupled to or supported by (*e.g.*, attached, mounted, or snap fitted onto integrated snap in features or fasteners, *etc.*) to an inner surface of a radome;

**[0022]** FIG. 13 is a perspective view of a panel antenna having a 4x4 array of antenna elements or radiators that comprise dual slot coupled patches, where patches are mechanically coupled to or supported by (*e.g.*, attached, mounted to, *etc.*) to an inner surface of a radome according to another exemplary embodiment;

**[0023]** FIG. 14 is a front view of the panel antenna shown in FIG. 13;

**[0024]** FIGS. 15 and 16 includes exemplary line graphs of Voltage Standing Wave Ratio (VSWR) (S22) versus frequency for horizontal and vertical polarizations, respectively, measured for a prototype of the example 8x8 panel antenna shown in FIG. 1;

**[0025]** FIG. 17 includes an exemplary line graph of isolation (S21 in decibels) versus frequency measured for the 8x8 panel antenna prototype;

**[0026]** FIGS. 18 through 22 are exemplary line graphs of azimuth and elevation radiation patterns for horizontal polarization measured for the 8x8 panel antenna prototype; and

**[0027]** FIGS. 23 through 27 are exemplary line graphs of azimuth and elevation radiation patterns for vertical polarization measured for the 8x8 panel antenna prototype.

**[0028]** Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

### **DETAILED DESCRIPTION**

**[0029]** Example embodiments will now be described more fully with reference to the accompanying drawings.

**[0030]** As noted above in the background, conventional high gain panel antennas may include stacked patches, a radome, a ground plane, a first PCB with the top patches, and a second PCB with the feed network and bottom patches. Although such conventional panel antennas are relatively low cost with relatively few components and provide good performance for a bandwidth of less than about 16%, the inventors hereof recognized that it would be preferable and desirable to develop and provide panel antennas that have lower costs, less components, better performance, and/or wider bandwidth.

**[0031]** Accordingly, the inventors hereof disclose exemplary embodiments of panel antennas and methods of manufacturing or assembling the same. In exemplary embodiments disclosed herein, the panel antenna is based on a dual slot coupled patch design. The panel antenna may be configured to be operable within one or more frequency ranges or bandwidths, such as from about 4.9 GHz to about 6 GHz, *etc.* In this example, the panel antenna generally includes a radome, a ground plane, a single PCB, and a plurality of antenna elements or radiators. The antenna elements may be arranged in an array or other grouping, such as an 8 x 8 array, 4 x 4 array, *etc.*

**[0032]** In some exemplary embodiments, there are one or more antenna elements that comprise one or more slot coupled patches, such as one or more single slot coupled patches, one or more dual coupled patches, one or more multi-slot coupled patches (*e.g.*, patches coupled to two, three, or more slots, *etc.*). As disclosed herein, a panel antenna may comprise dual slot coupled patches in illustrated embodiments, wherein patches (*e.g.*, adhesive aluminum

patches, stamped patches, *etc.*) are mechanically supported by or mechanically coupled to (*e.g.*, attached, mounted, connected directly to, *etc.*) an inner surface of a radome. In addition to the patches, the dual slot coupled patches or antenna elements also comprise a ground plane with cavities, two slots above each cavity, and a feed network in illustrated embodiments disclosed herein.

**[0033]** The radome may be a spring loaded radome in which the radome material (*e.g.*, polycarbonate, other resilient material, *etc.*) is configured to have a built-in warp. The built-in warp allows the radome to be positioned precisely above the PCB. The radome may be held in place over the PCB with mechanical fasteners in and around the perimeter of the radome. With the built-in warp or spring loaded feature, the radome compresses downwardly toward the PCB (*e.g.*, pushes against edge portions of the PCB, *etc.*), such that standoffs (*e.g.*, molded into the radome, *etc.*) will maintain a constant distance between the PCB and the radome's inner surface to which the patches are attached or mounted. This means that the distance between the PCB and the patches will also remain constant, with the radome acting as the mechanical support for the patches.

**[0034]** In exemplary embodiments, adhesive aluminum patches are adhesively mounted to the inner surface of the radome's flat or planar top portion. Alternatively, the radome may include integrated fasteners (*e.g.*, integrated snap in features for mounting patches, *etc.*). For example, the radome may include downwardly extending posts or stakes configured to be engagingly received (*e.g.*, snapped into, press fit, interference fit, *etc.*) within openings of the patches to thereby mount the patches (*e.g.*, stamped patches having holes therethrough, *etc.*) to the radome. Accordingly, the panel antenna does not include top and bottom layers of stacked patches. Instead, the panel antenna includes a single layer of patches (*e.g.*, array, *etc.*) integrated or attached directly to the radome. Thus, the panel antenna will have less patches than a conventional panel antenna having stacked patch antennas in the same array size, *e.g.*, 4x4, 8x8, *etc.*

**[0035]** In exemplary embodiments, the ground plane includes recessed portions (e.g., pockets, cavities, enclosures, wall portions, *etc.*). An electrically-conductive member, layer, or portion (e.g., copper foil, *etc.*) is on or along the bottom of the PCB. Slots are defined by or included in the electrically-conductive member, which may also be referred to herein as a slot element. The slot element is positioned between the PCB and the ground plane (e.g., abutting, physically contacting, or directly against portions of the PCB and ground plane, *etc.*) such that the slots are positioned over or above the recessed portions or cavities of the ground plane. For dual polarization, two slots are above each cavity of the ground plane where the fields from the dual slots are orthogonally polarized. A patch is above each pair of slots for widening the bandwidth of the antenna element, which in this example may also be referred to as a dual slot coupled patch.

**[0036]** By way of example, the ground plane may comprise a stamped ground plane comprising metal that is stamped to form the recessed portions or cavities. The cavities in the ground plane are configured (e.g., sized, shaped, spaced apart, *etc.*) to align with (e.g., cover, *etc.*) the slots. Without a ground plane below the slots, the radiation field would be equal up and down. The cavities in the ground plane provide clearance for the slots towards ground. With the clearance provided by the cavities, the PCB does not have to be suspended or spaced apart above the ground plane to provide that clearance. This is advantageous as suspending the PCB above the ground plane would cause high fields to travel between the ground plane and the PCB and create poor isolation and poor pattern because of the high coupling between the slots. By using the cavities, the field between the PCB ground and the ground plane may be eliminated.

**[0037]** In exemplary embodiments, the panel antenna includes a single PCB that includes a feed network (e.g., a microstrip feedline network, traces, *etc.*). The feed network is on the side of the PCB opposite the slot element. The feedline network is operable for exciting the slots to thereby feed horizontal and vertical polarizations for the dual slot coupled patches of the panel antenna. The

single PCB may also include a patch for grounding the feed network feedline. As noted above, conventional panel antennas having stacked patches include two PCBs, where one PCB includes the top patches and the other PCB includes the feed network and bottom patches. Accordingly, this exemplary embodiment of the panel antenna has one less PCB and lower losses (higher gain) with only one layer of low loss PCB material as compared to those conventional panel antennas having two PCBs and thus two layers of PCB materials.

**[0038]** Exemplary embodiment of the panel antenna may also include only two ports or connectors and relatively few screws, standoffs, *etc.* For example, the panel antenna may be operable for producing vertically polarized coverage for a first port and horizontally polarized coverage for a second port. The reduced number of mechanical fasteners to assemble the panel antenna also reduces the time needed to assemble the panel antenna. Exemplary embodiment of the panel antenna may also be efficient, low profile (*e.g.*, height of 11 millimeters, *etc.*), relatively easy to manufacture and relatively low cost (*e.g.*, less PCB material, *etc.*). The panel antenna may have a wider bandwidth and lower part count (*e.g.*, single layer of radiators, single PCB, *etc.*) than some conventional panel antennas. The panel antenna may have low loss and low sidelobes.

**[0039]** With reference now to the drawings, FIGS. 1 and 2 illustrate an example embodiment of a panel antenna 100 (or array antenna module or antenna assembly, *etc.*) including one or more aspects of the present disclosure. As shown in FIG. 1, the panel antenna 100 generally includes antenna elements or radiators, a single PCB 116, a ground plane 124, and a radome 136. In this illustrated embodiment, the complete antenna elements or radiators comprise dual slot coupled patches. The dual slot coupled patches comprise the following components including the ground plane 124 with cavities 140, the slots 128, the feed network 108, and the patches 104.

**[0040]** As shown in FIG. 2, the dual slot coupled patches are generally oriented or arranged in an eight-by-eight array as shown in FIG. 2. Alternative embodiments may include other antenna array sizes, groupings, or orientations,

such as four-by-four arrays (e.g., FIGS. 13 and 14, *etc.*), two-by-two arrays, three-by-three arrays, two-by-eight arrays, four-by-three arrays, rectangular arrays, non-rectangular arrays, triangular arrays, linear arrays, circular arrays, other groupings or arrangements of antenna elements or radiators that are not in an array, *etc.* Alternative embodiments may include other antenna element or radiator configurations and types besides the illustrated dual slot coupled patches, such as non-circular patches and/or non-patch antenna elements.

**[0041]** FIG. 3 is a bottom view of the panel antenna 100 shown without the ground plane 124 in order to illustrate slots 128 of a slot element 126. The slot element 126 may comprise a wide range of materials, such as a copper foil, *etc.* The slots 128 may be defined by an absence of electrically-conductive material in the slot element 126. For example, the slot element 126 may be initially formed with the slots 128. Or, for example, the slots 128 may be formed by removing electrically-conductive material from the slot element 126, such as etching, cutting, stamping, *etc.* In other embodiments, the slots 128 may be formed by an electrically nonconductive or dielectric material added to the slot element 126 such as by printing, *etc.*

**[0042]** The slot element 126 is on or along the bottom of the PCB 116. The slot element 126 is positioned between the PCB 116 and the ground plane 124 (e.g., directly against the PCB 116 and ground plane 124, *etc.*) such that the slots 128 are aligned with (e.g., positioned over or above, *etc.*) recessed portions or cavities 140 of the ground plane 124 as shown in FIGS. 7 through 11. For dual polarization, two slots 128 are above each cavity 140 of the ground plane 124 where the fields from the dual slots 128 are orthogonally polarized. A patch 104 is above each pair of slots 128 for widening the bandwidth of the antenna element or dual slot coupled patch.

**[0043]** By way of example, the ground plane 124 may comprise a stamped ground plane. For example, the ground 124 may comprise an electrically-conductive material (e.g., aluminum-plated steel, tin-plated steel, brass, metal, metal alloy, *etc.*) that is stamped or otherwise formed to include recessed portions, cavities, or pockets 140. The cavities 140 in the ground plane

124 are configured (e.g., sized, shaped, spaced apart, *etc.*) to align with (e.g., cover, *etc.*) the slots 128. As shown in FIG. 10, the cavities 140 are not equally spaced apart as represented by distance X being greater than distance Y in this illustrated embodiment. But the parasitic patches are preferably equally spaced by a distance D over the slot element 126 that defines the slots 128.

**[0044]** Without the ground plane 124 below the slots 128, the radiation field would be equal up and down. The cavities 140 in the ground plane 124 provide clearance for the slots 128 towards ground. With the clearance provided by the cavities 140, the PCB 116 does not have to be suspended or spaced apart above the ground plane 124 to provide that clearance. This is advantageous as suspending a PCB above a ground plane would cause high fields to travel between the ground plane and the PCB and create poor isolation and poor pattern because of the high coupling between the slots. By using the cavities 140, the field between the PCB ground and the ground plane 124 may be eliminated in this illustrated embodiment.

**[0045]** As shown in FIG. 2, the PCB 116 includes the feed network 108 (e.g., a microstrip feedline network, transmission line network, electrically-conductive traces, *etc.*) on a side of the PCB 116 opposite the slot element 126. The feed network 108 is operable for exciting the slots 128 to thereby feed horizontal and vertical polarizations for the dual slot coupled patches of the panel antenna 100. The arrows in FIG. 11 represent the horizontal and vertical polarization directions for the slots 128, and also show how the left slot is fed with a 180 degree phase delay for the horizontal polarization. The feedline network 108 may be capacitively coupled to the slots 128 and patches 104.

**[0046]** A patch 112 is used for electrically grounding the feed network 108. The patch 112 and a pin 120 therethrough may be used for electrically grounding the feedline 108 to the ground plane or reflector 124. Alternative embodiments may include other feed networks having different network patterns and/or different angular orientations and/or connecting lines with different orientations than disclosed herein within the scope of the present disclosure.

**[0047]** The PCB 116 is mounted to and/or supported by the ground plane 124. In this illustrated embodiment, the panel antenna 100 includes only the single PCB 116. The PCB 116 may be made of a low loss PCB material, such as a Teflon<sup>®</sup> based material or other polytetrafluoroethylene (PTFE) materials, *etc.* As noted above, conventional panel antennas having stacked patches include two PCBs, where one PCB includes the top patches and the other PCB includes the feed network and bottom patches. Accordingly, the panel antenna 100 has one less PCB and lower losses (higher gain) with only one layer of low loss PCB material as compared to those conventional panel antennas having two PCBs and thus two layers of PCB materials.

**[0048]** As shown in FIG. 6, the panel antenna 100 includes first and second ports or connectors 130, 132. The ports 130, 132 may be coupled to or comprise part of the feed network 108. The panel antenna 100 is operable for producing vertically polarized coverage for the first port 130 and horizontally polarized coverage for the second port 132.

**[0049]** With reference to FIG. 1, the radome 136 may be a spring loaded radome in which the radome material (*e.g.*, polycarbonate, other resilient material, *etc.*) is configured to have a built-in warp. The built-in warp allows the radome 136 to be positioned precisely above the PCB. The radome 136 may be held in place over the PCB 116 with mechanical fasteners in and around the perimeter of the radome 136. With the built-in warp or spring loaded feature, the radome 136 compresses downwardly toward the PCB 116 (*e.g.*, pushes against edge portions of the PCB, *etc.*), such that standoffs (*e.g.*, molded into the radome 136, *etc.*) will maintain a constant distance between the PCB 116 and the radome's inner surface to which the patches 104 are attached or mounted. This means that the distance between the PCB 116 and the patches 104 will also remain constant, with the radome acting as the mechanical support for the patches 104. In alternative embodiments, the radome 136 may be coupled to the ground plane 124 by various other suitable means.

**[0050]** FIG. 1 also illustrates an exemplary a sealing member 138 (*e.g.*, a weather proof gasket, *etc.*). The sealing member 138 is positionable generally

between the radome 136 and the ground plane 124 to help prevent or inhibit the ingress or migration of water, moisture, dust, *etc.* into the inside or interior enclosure under the radome 136. Other embodiments may include one or more sealing members, (*e.g.*, an O-ring, a resiliently compressible elastomeric or foam gasket, caulk, adhesives, other suitable packing or sealing members, integral sealing features, *etc.*) for substantially sealing the interface between the radome 136 and ground plane 124, in addition to or as an alternative to the sealing member 138.

**[0051]** The illustrated panel antenna 100 included an 8x8 array of patches 104 and the additional patch 112 for grounding the feedline network 108. Accordingly, this example panel antenna 100 includes a total of sixty-five patches, *i.e.*, the sixty-four patches 104 and the patch 112. Also in this example, the panel antenna included a length dimension of about 370 millimeters (mm), a width dimension of about 370 mm, and a very low profile or slim design with a thickness dimension of only about 11 mm or less.

**[0052]** The illustrated panel antenna 100 does not include stacked patches. By way of example, the panel antenna 100 may comprise adhesive aluminum patches that are adhesively attached to an interior surface of the radome 136. Alternatively, the radome may include integrated fasteners (*e.g.*, integrated snap in features for mounting the patches, *etc.*). For example, FIG. 12 illustrates an exemplary embodiment of a panel antenna 200 that includes a radome 236. The radome 236 includes downwardly extending posts or stakes 250 configured to be engagingly received (*e.g.*, snapped into, press fit, interference fit, *etc.*) within openings of patches 204 to thereby mount the patches 204 (*e.g.*, stamped patches having holes therethrough, *etc.*) to the radome 236. The panel antenna 200 also includes a feed network 208, which may be operable similarly to feed network 108. The panel antenna 200 may further include slots defined by a slot element similar to panel antenna 100. The antenna elements or radiators of the panel antenna 200 may also be referred to a dual slot coupled patches.

**[0053]** FIGS. 13 and 14 illustrate another exemplary embodiment of a panel antenna 300 embodying one or more aspects of the present disclosure. As shown, the panel antenna 300 includes a 4x4 array of antenna elements or radiators that comprise dual slot coupled patches. The dual slot coupled patches comprise a ground plane with cavities 340, the slots, the feed network 308, and the patches 304 above. The patches 304 are attached or mounted to an inner surface of the radome 336. The panel antenna 300 also include the feed network 308, which may be operable similarly to feed network 108. The panel antenna 300 further include slots defined by a slot element and a ground plane that includes cavities 340. The slots are aligned with (e.g., positioned over or above, etc.) the cavities 340 of the ground plane. For dual polarization, two slots are above each cavity 340 of the ground plane where the fields from the dual slots are orthogonally polarized. A patch 304 is above each pair of slots for widening the bandwidth of the antenna element or dual slot coupled patch.

**[0054]** FIGS. 15 through 27 provide analysis results measured for a prototype of the panel antenna 100, where the prototype had a 370 mm x 370 mm footprint. These analysis results are provided only for purposes of illustration and not for purposes of limitation.

**[0055]** More specifically, FIGS. 15 and 16 include exemplary line graphs of Voltage Standing Wave Ratio (VSWR) (S22) versus frequency for horizontal and vertical polarizations, respectively, measured for the prototype 8x8 panel antenna. FIG. 17 includes an exemplary line graph of isolation (S21 in decibels) versus frequency measured for the 8x8 panel antenna prototype. FIGS. 18 through 22 are exemplary line graphs of azimuth and elevation radiation patterns for horizontal polarization measured for the 8x8 panel antenna prototype. FIGS. 23 through 27 are exemplary line graphs of azimuth and elevation radiation patterns for vertical polarization measured for the 8x8 panel antenna prototype.

**[0056]** Immediately below is table 1 with radio frequency (RF) measurements for the prototype 8x8 panel antenna, such as half-power beam width (HPBW), etc. As shown by FIGS. 15 through 27 and the table below, the

prototype 8x8 panel antenna had good performance in terms of sidelobes, gain, beamwidth spread, and size while also covering a large frequency range from 4.9 GHz to 6 GHz.

**Table 1: RF Measurements**

| <b>Parameter Measured</b>               | <b>8x8 Panel Antenna</b>                         |
|-----------------------------------------|--------------------------------------------------|
| Dual slant element, Port 1 and Port 2   |                                                  |
| Frequency                               | 4.9 GHz to 6 GHz                                 |
| VSWR Vertical Polarization              | 2:1                                              |
| VSWR Horizontal Polarization            | 1.8:1                                            |
| Isolation                               | > 33 dB                                          |
| Directivity Horizontal Polarization     | 24.5 dB to 26 dB                                 |
| Directivity Vertical Polarization       | 25 dB to 26.5 dB                                 |
| Loss Horizontal Polarization            | 2 dB to 2.5 dB                                   |
| Loss Vertical Polarization              | 1.5 dB                                           |
| Gain Horizontal Polarization            | 22.5 dB to 24 dB                                 |
| Gain Vertical Polarization              | 24 dB to 25 dB                                   |
| HPBW Azimuth, Horizontal Polarization   | 8° - 9°                                          |
| HPBW Azimuth, Vertical Polarization     | 8° - 9.5°                                        |
| HPBW Elevation, Horizontal Polarization | 8° - 9.5°                                        |
| HPBW Elevation, Vertical Polarization   | 8° - 9.5°                                        |
| Sidelobes Horizontal Polarization       | 1 <sup>st</sup> > 10 dB, 3 <sup>rd</sup> > 14 dB |
| Sidelobes Vertical Polarization         | > 12 dB                                          |
| Beam Squinting Horizontal Polarization  | 1.5°                                             |
| Beam Squinting Vertical Polarization    | 1°                                               |
| Front to Back Ratio                     | > 36 dB                                          |
| Cross Polarization $\pm 30$             | > 24 dB                                          |

**[0057]** 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 the 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.

**[0058]** 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.

**[0059]** 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.

**[0060]** 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.

**[0061]** 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.

**[0062]** 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 discussed below could be termed a

second element, component, region, layer or section without departing from the teachings of the example embodiments.

**[0063]** 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.

**[0064]** 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. A panel antenna comprising:  
a ground plane including one or more cavities;  
a radome;  
a slot element having slots positioned over the cavities of the ground plane; and  
one or more patches mechanically coupled to an inner surface of the radome and positioned above the slots.
2. The panel antenna of claim 1, wherein:  
the panel antenna includes a printed circuit board having a feed network;  
the panel antenna includes one or more antenna elements comprising one or more dual slot coupled patches; and  
the one or more dual slot coupled patches include the ground plane having the cavities, the slots, the feed network, and the patches.
3. The panel antenna of claim 2, wherein:  
the feed network is along on a first side of the printed circuit board;  
the feed network is operable for exciting the slots of the slot element and feeding horizontal and vertical polarizations for dual slot coupled patches; and  
the slot element is on a second side of the printed circuit board opposite the first side such that the slot element is between the printed circuit board and the ground plane.
4. The panel antenna of claim 2 or 3, wherein the cavities are configured to cover the slots and provide clearance for the slots towards ground such that the printed circuit board does not have to be suspended above the ground plane.
5. The panel antenna of any one of claims 2 to 4, wherein the radome comprises a spring loaded radome having a built-in warp that allows the radome to be positioned precisely above the printed circuit board, whereby the built-in warp causes the radome to compress downwardly toward the printed circuit board such that standoffs maintain a constant distance between the printed circuit board and the inner surface of the radome having the patches mechanically coupled thereto.

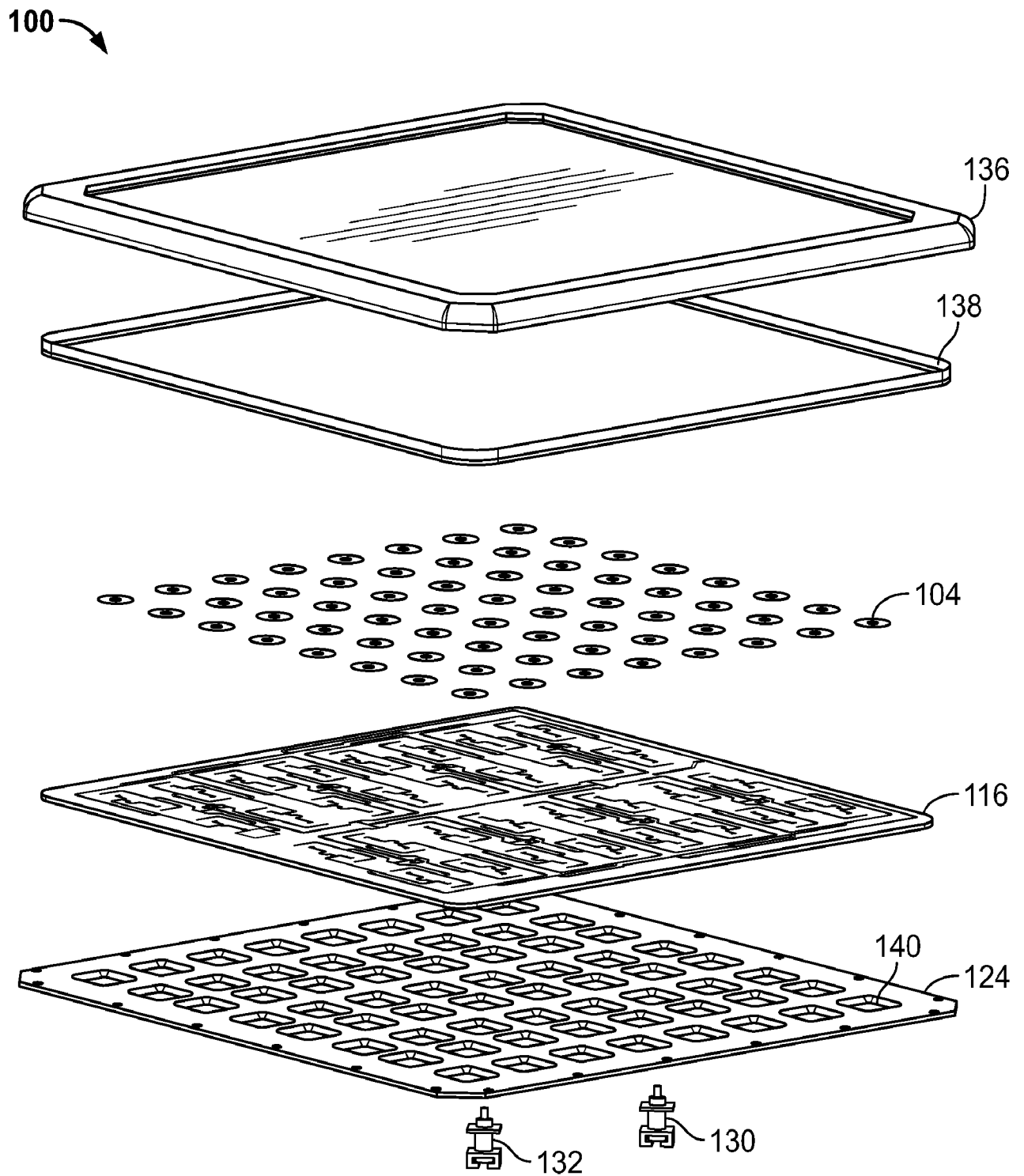
6. The panel antenna of any one of claims 2 to 5, wherein the panel antenna includes only the single printed circuit board.

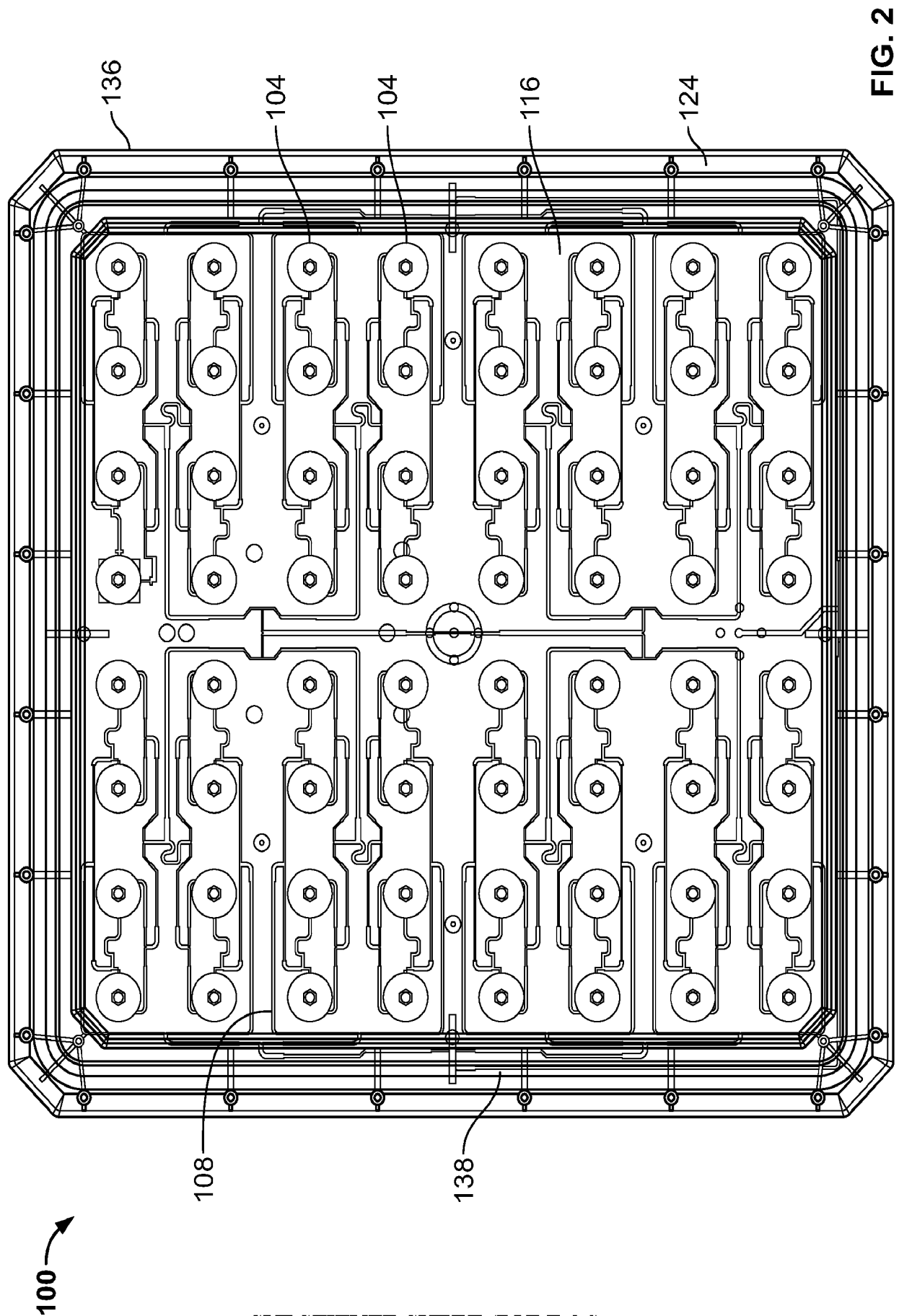
7. The panel antenna of any one of the preceding claims, wherein the panel antenna is configured such that two slots are above each cavity of the ground plane for dual polarization with the fields from the two slots being orthogonally polarized.

8. The panel antenna of any one of the preceding claims, wherein:  
the patches are adhesively attached to the inner surface of the radome; or  
the radome include one or more integrated fasteners, and the patches are mechanically coupled to the inner surface of the radome via the integrated fasteners; or  
the radome includes one or more posts or stakes downwardly depending from the inner surface of the radome and configured to be engagingly received within openings of the patches to thereby mount the patches to the radome.

9. The panel antenna of any one of the preceding claims, wherein:  
the slot element comprises a copper foil having the slots;  
the ground plane comprises metal that is stamped to form the cavities; and/or  
the radome mechanical supports the patches.

10. The panel antenna of any one of the preceding claims, wherein:  
the panel antenna comprises an array of dual slot coupled patches; and/or  
the panel antenna is configured to be operable within a frequency range or bandwidth from about 4.9 GHz to about 6 GHz.

**FIG. 1**



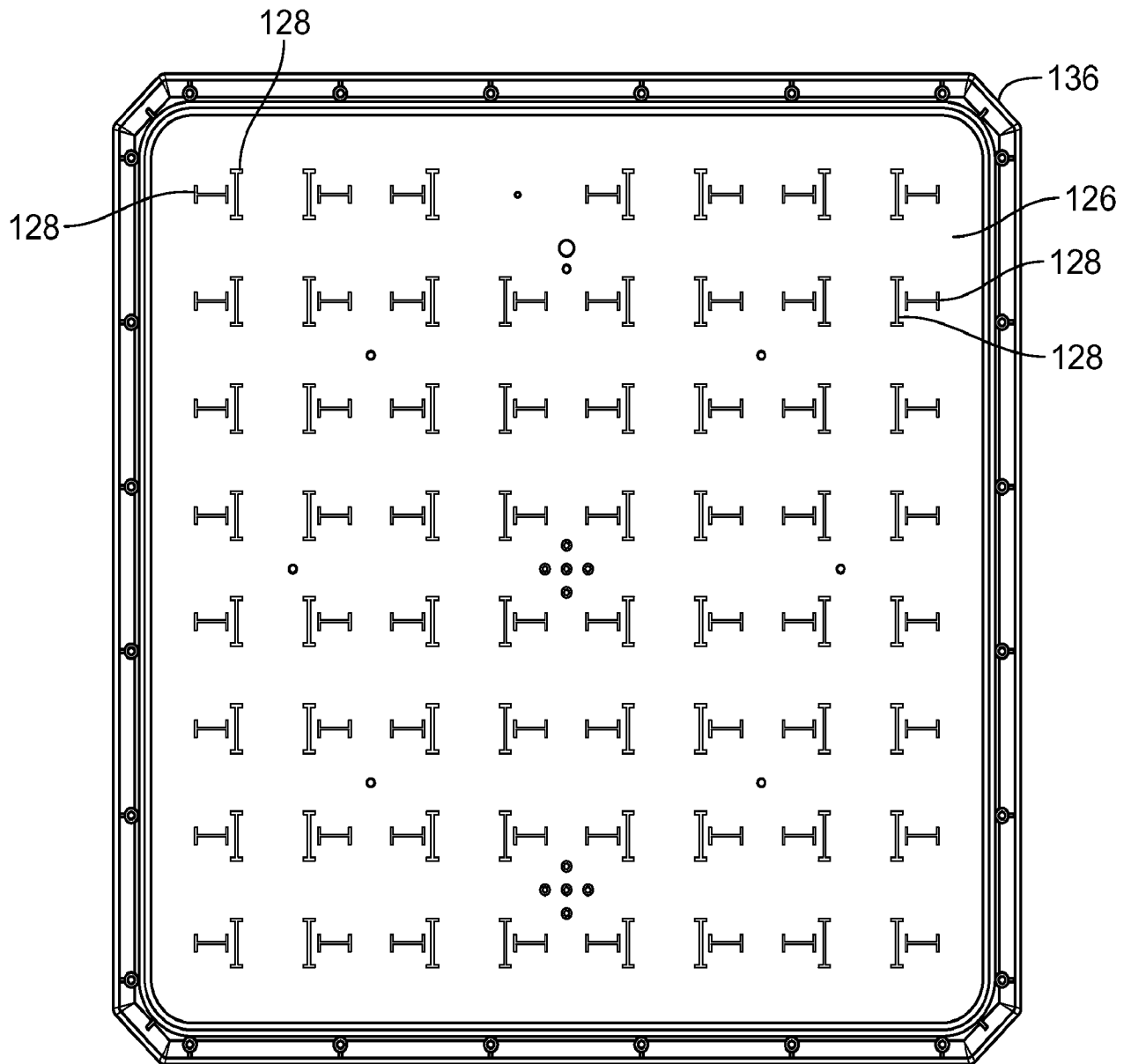


**FIG. 3**

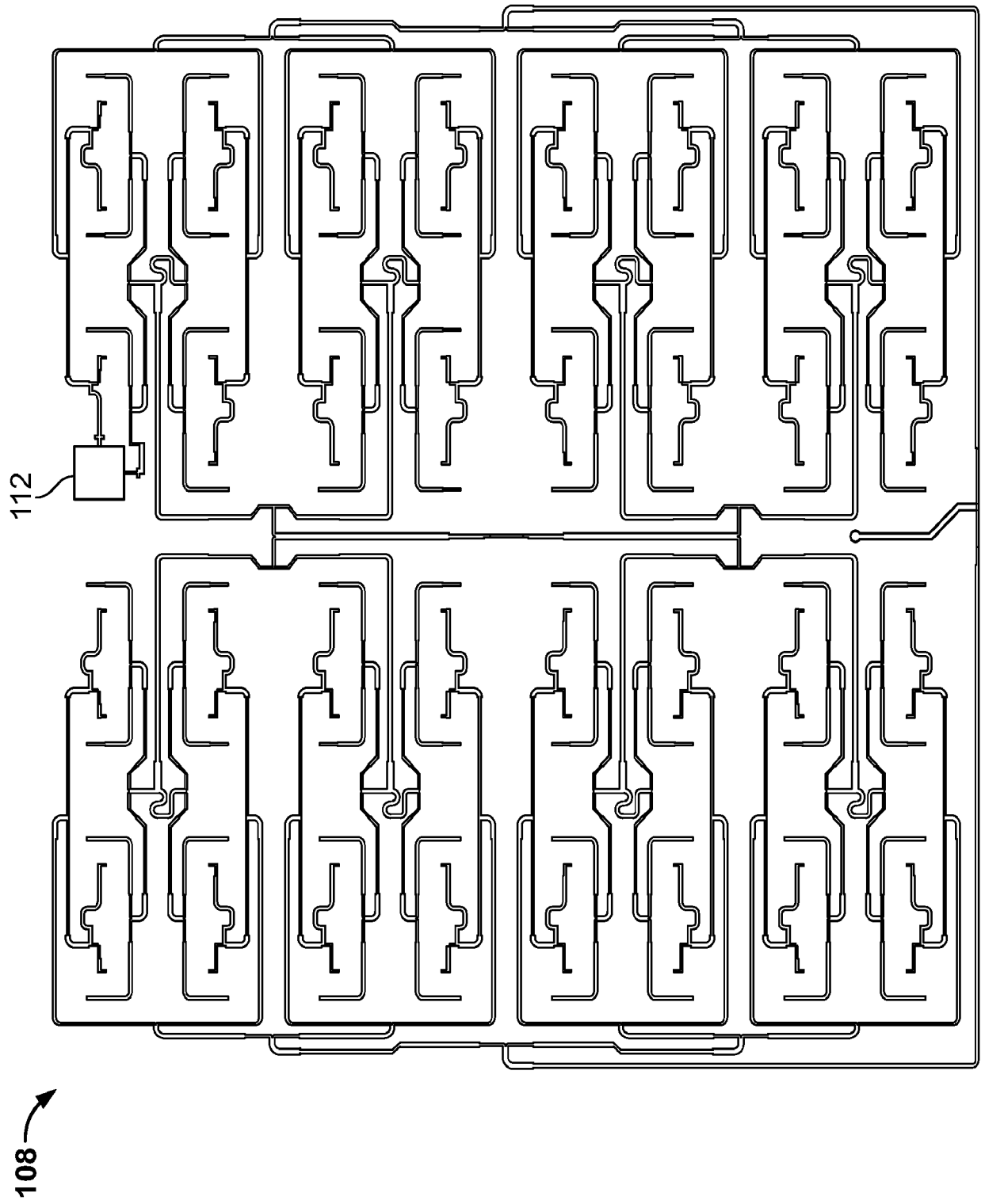


FIG. 4

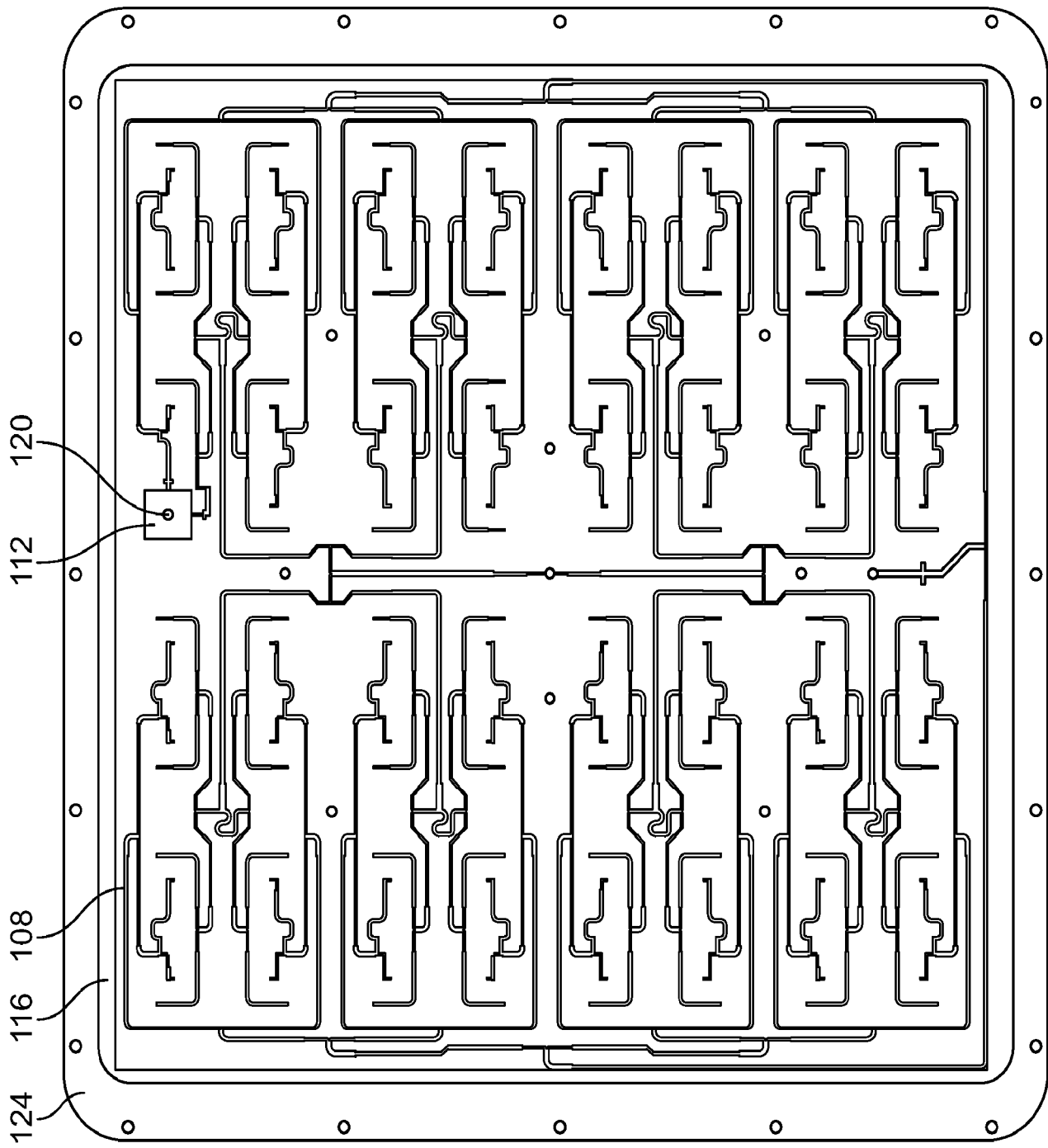


FIG. 5

6/25

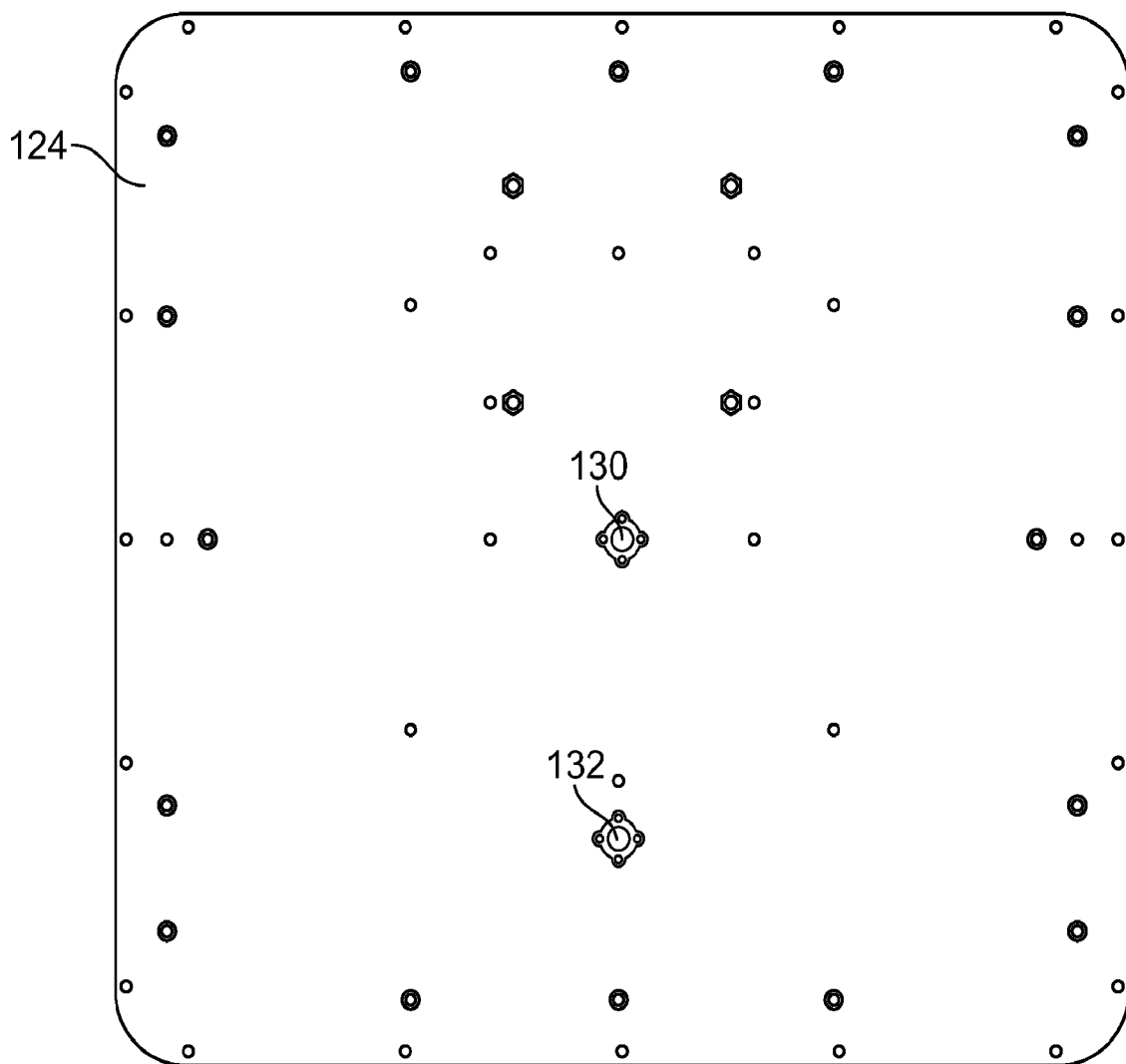


FIG. 6

7/25

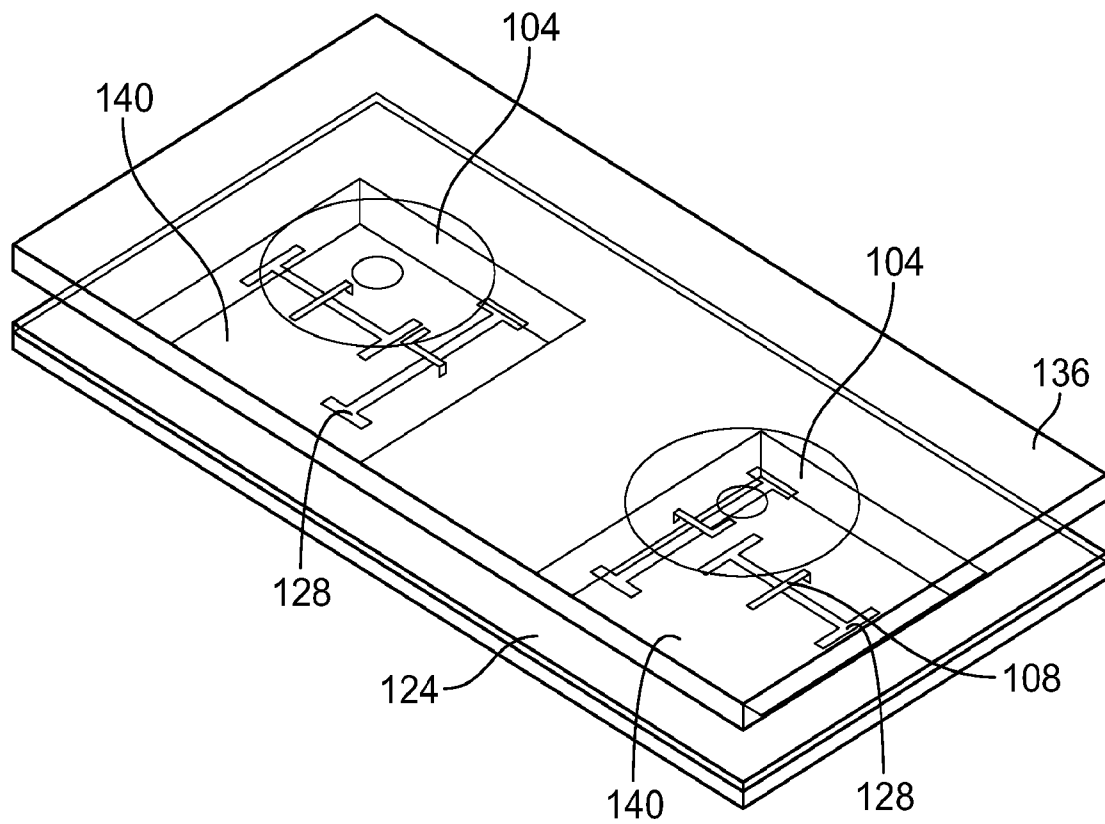
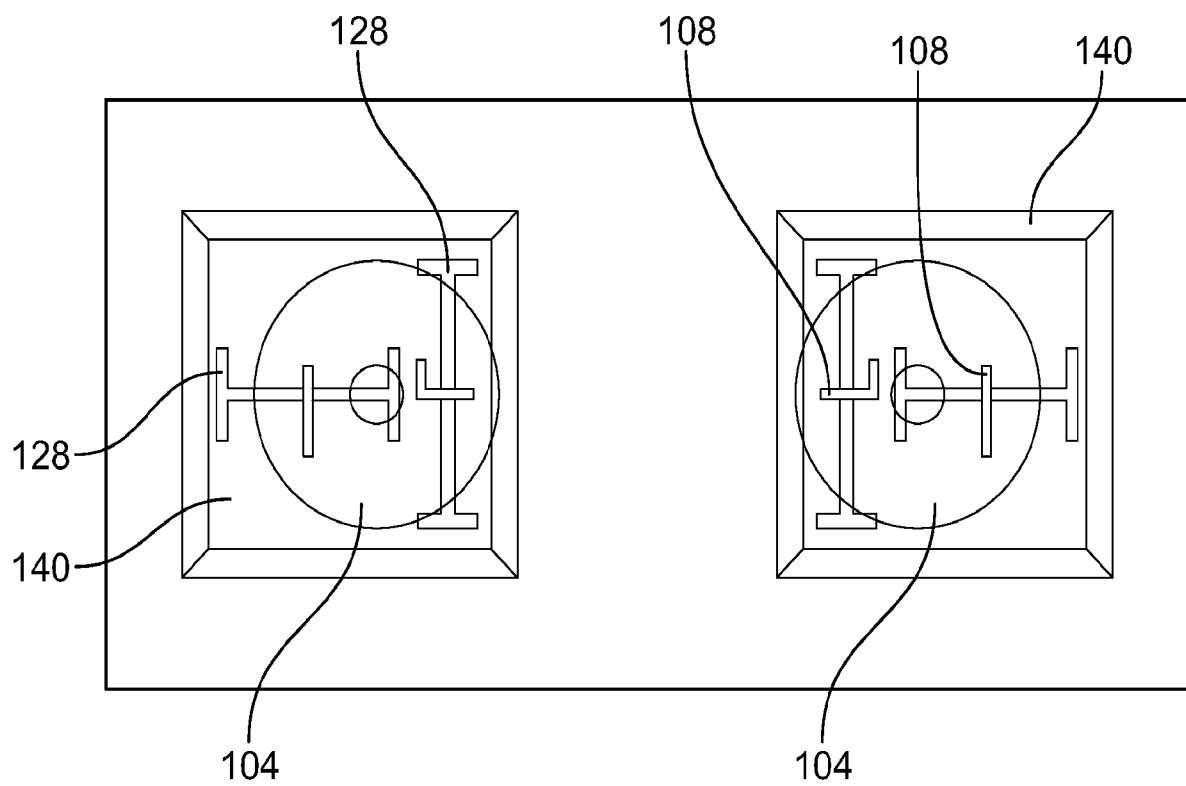


FIG. 7



SUBSTITUTE SHEET (RULE 26)

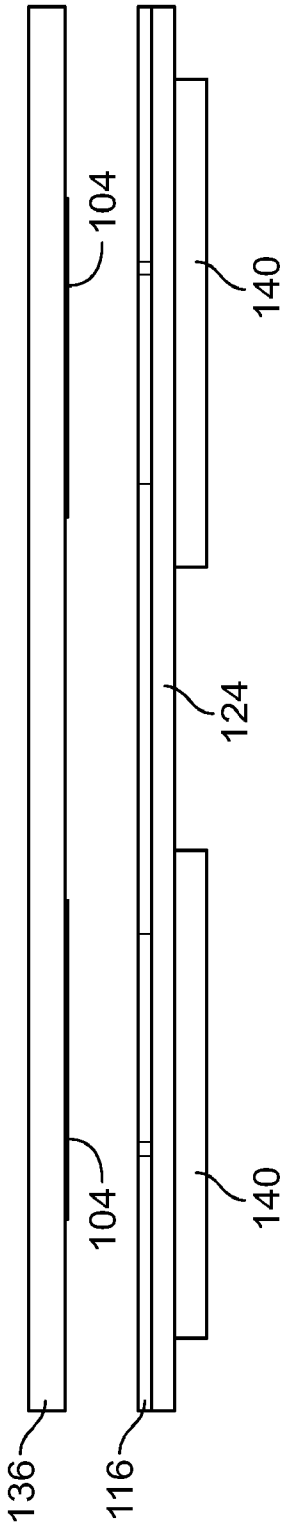


FIG. 9

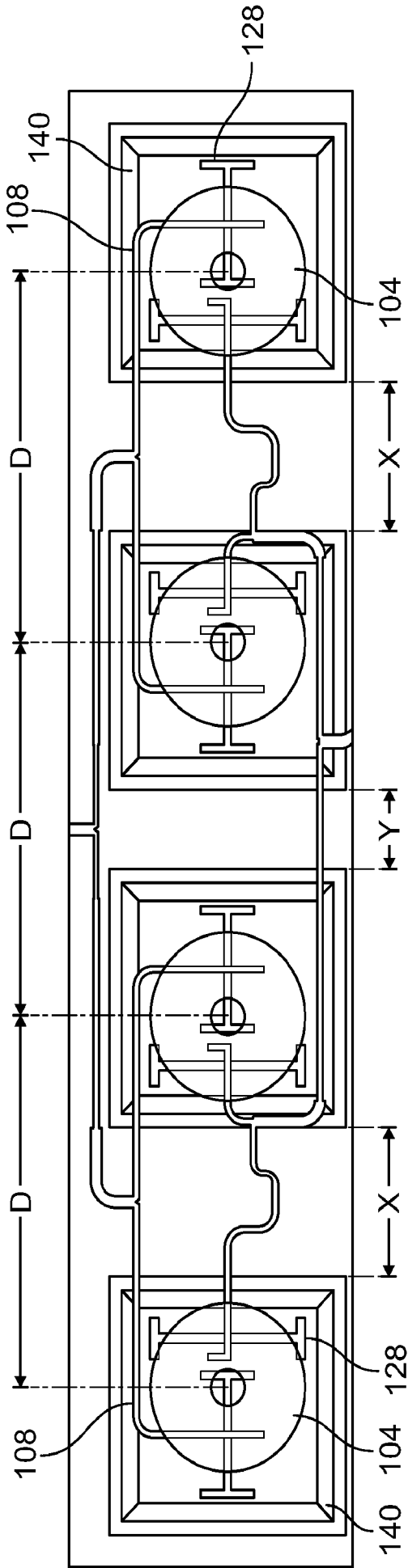


FIG. 10

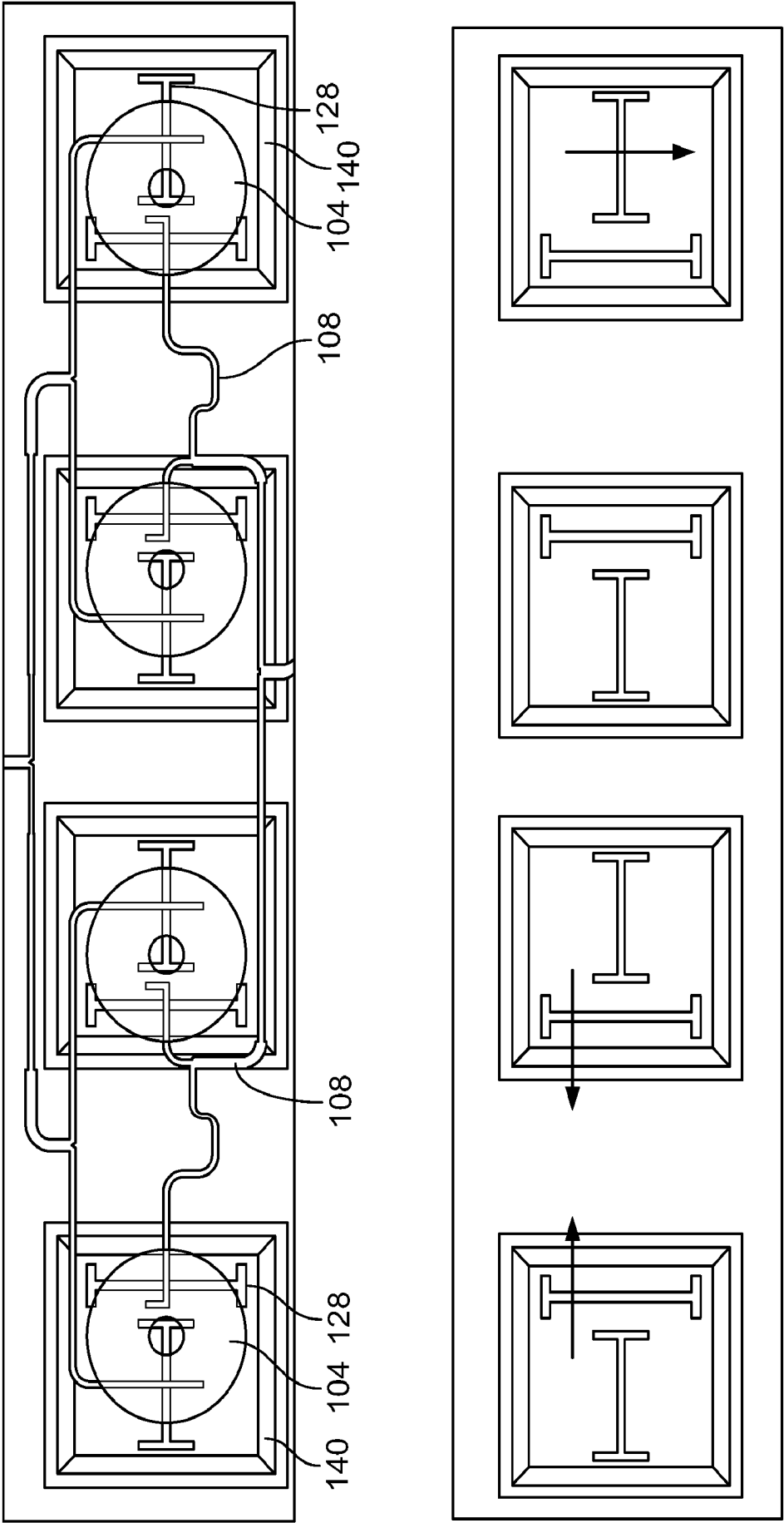


FIG. 11

10/25

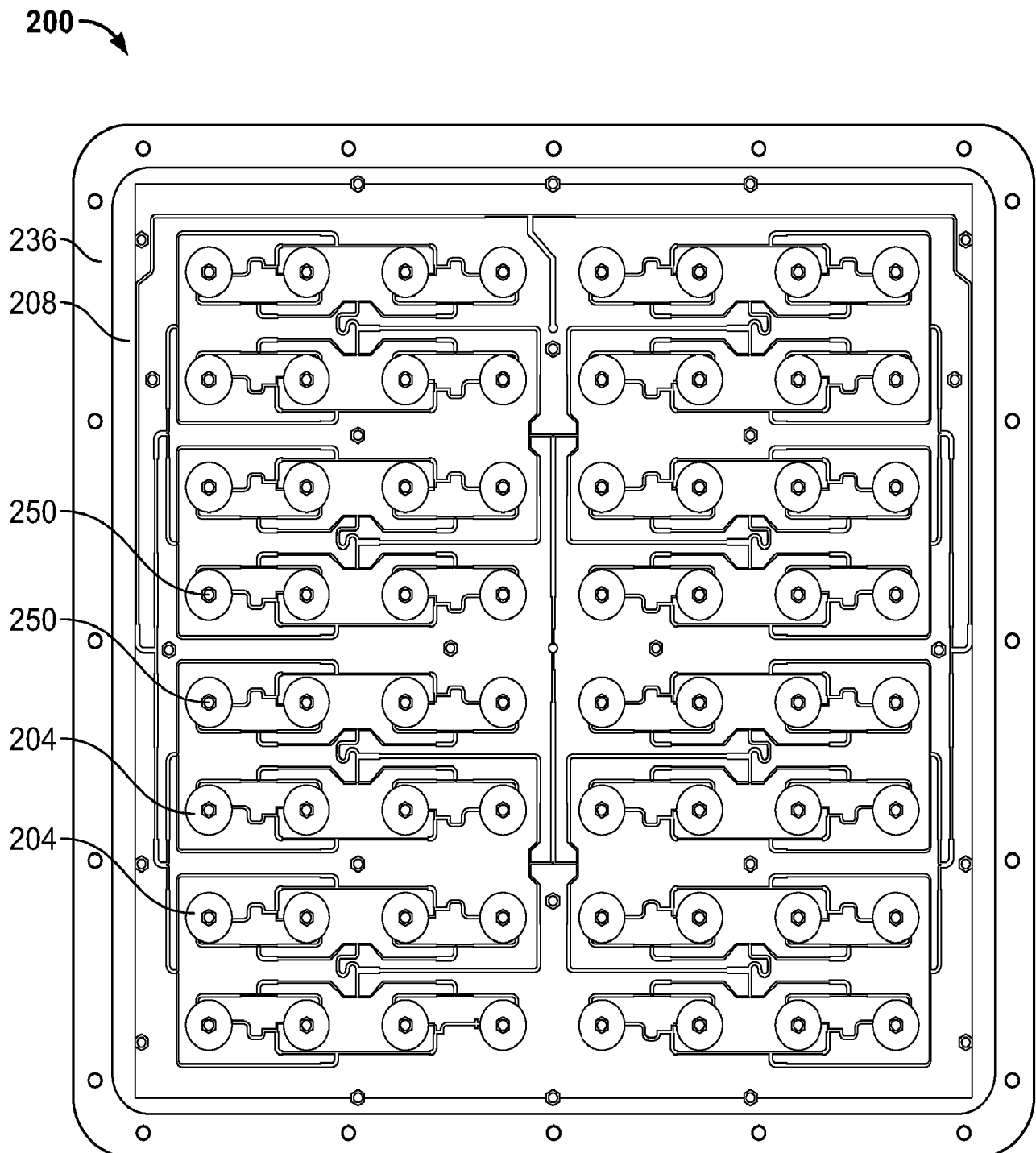


FIG. 12

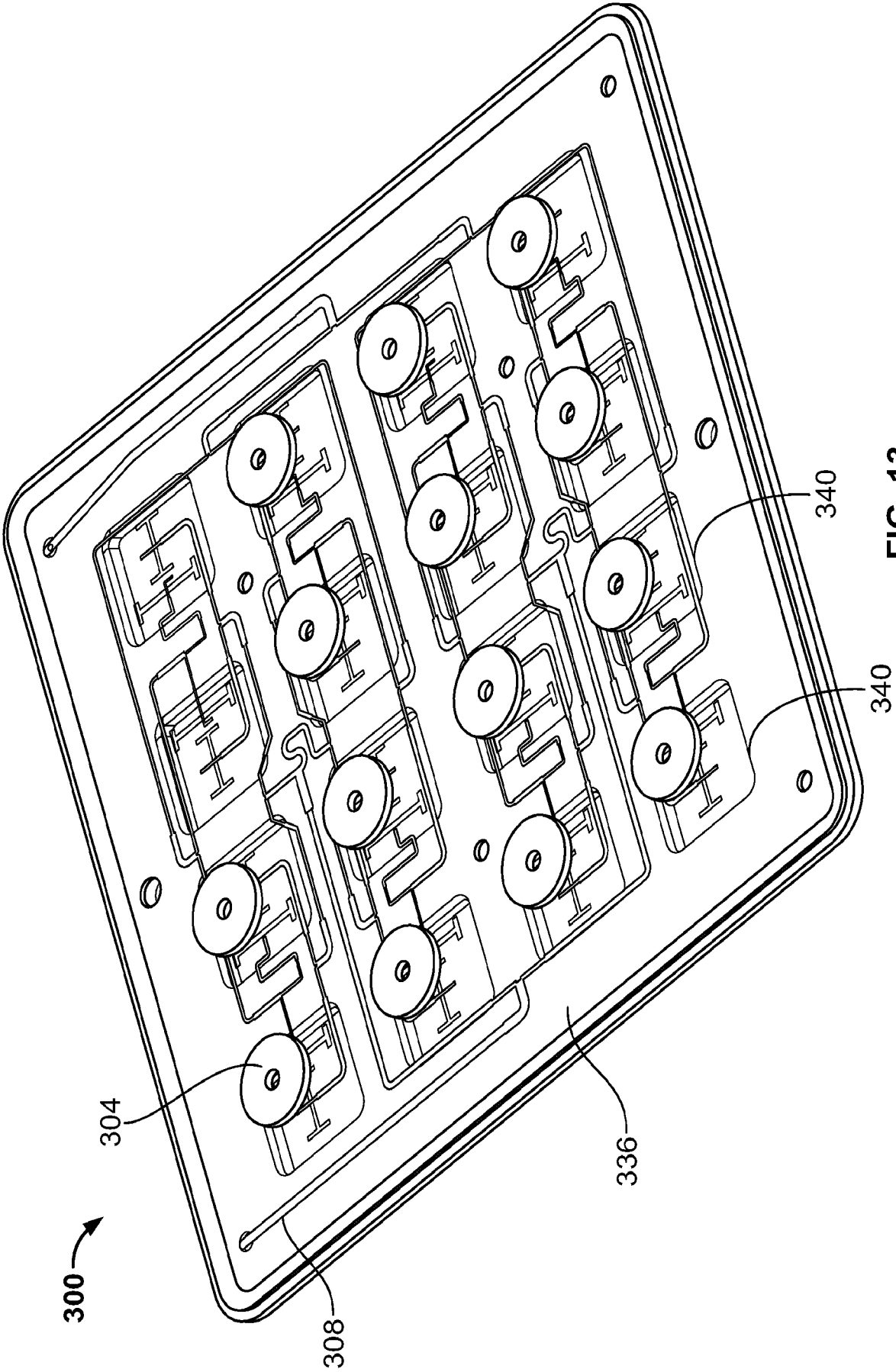
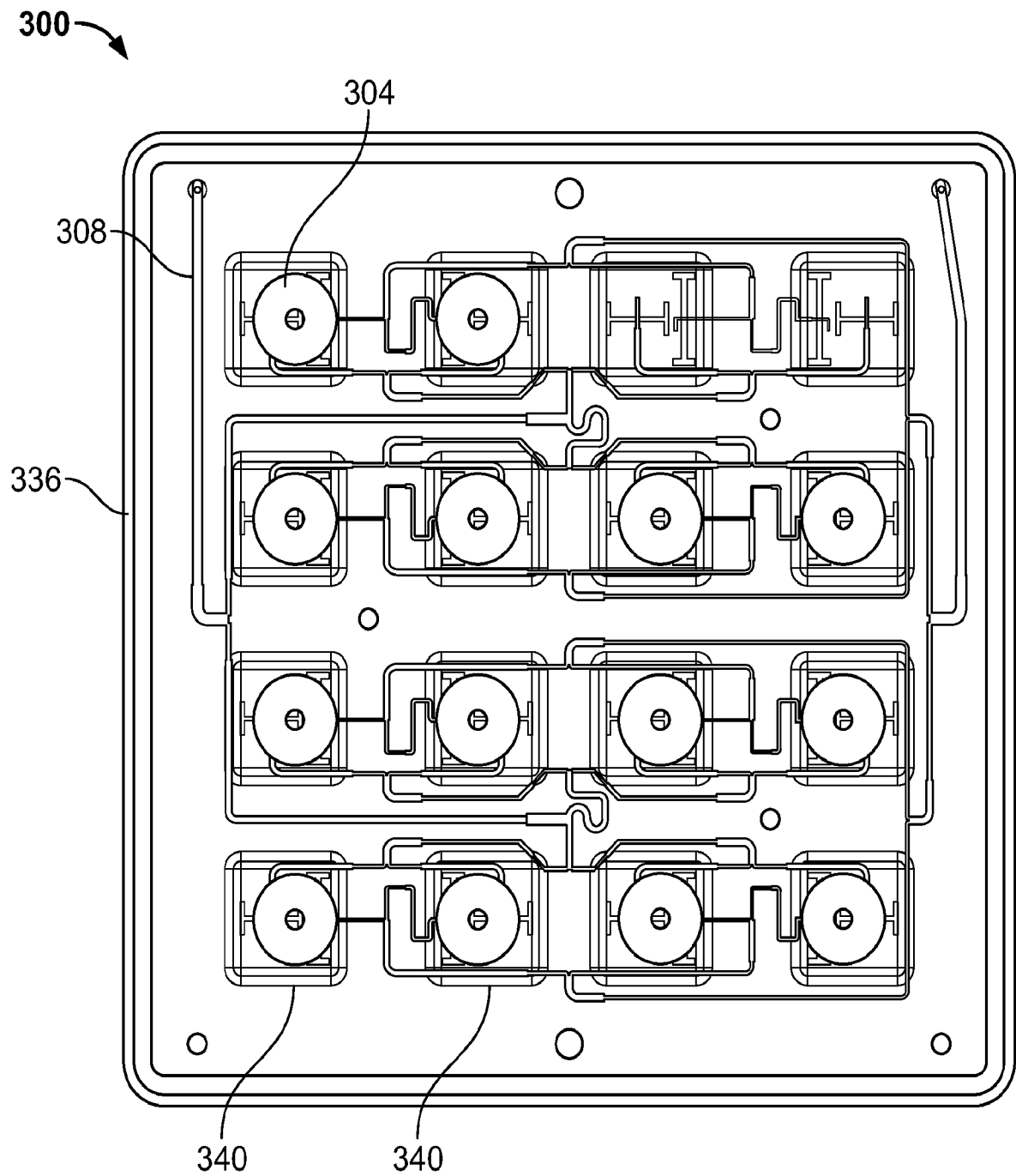


FIG. 13

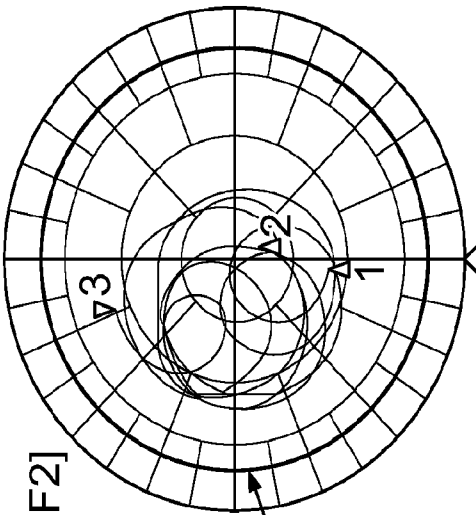
12/25

**FIG. 14**

**S11- Parameters Horizontal Polarization**

Tr1 S22 Polar (Log/Phase) Scale 400.0mU [F2]

- 1 4.9000000 GHz -15.851 dB -95.961 °
- 2 5.4500000 GHz -27.379 dB -64.006 °
- >3 6.0000000 GHz -13.130 dB 111.99 °



VSWR 2.0

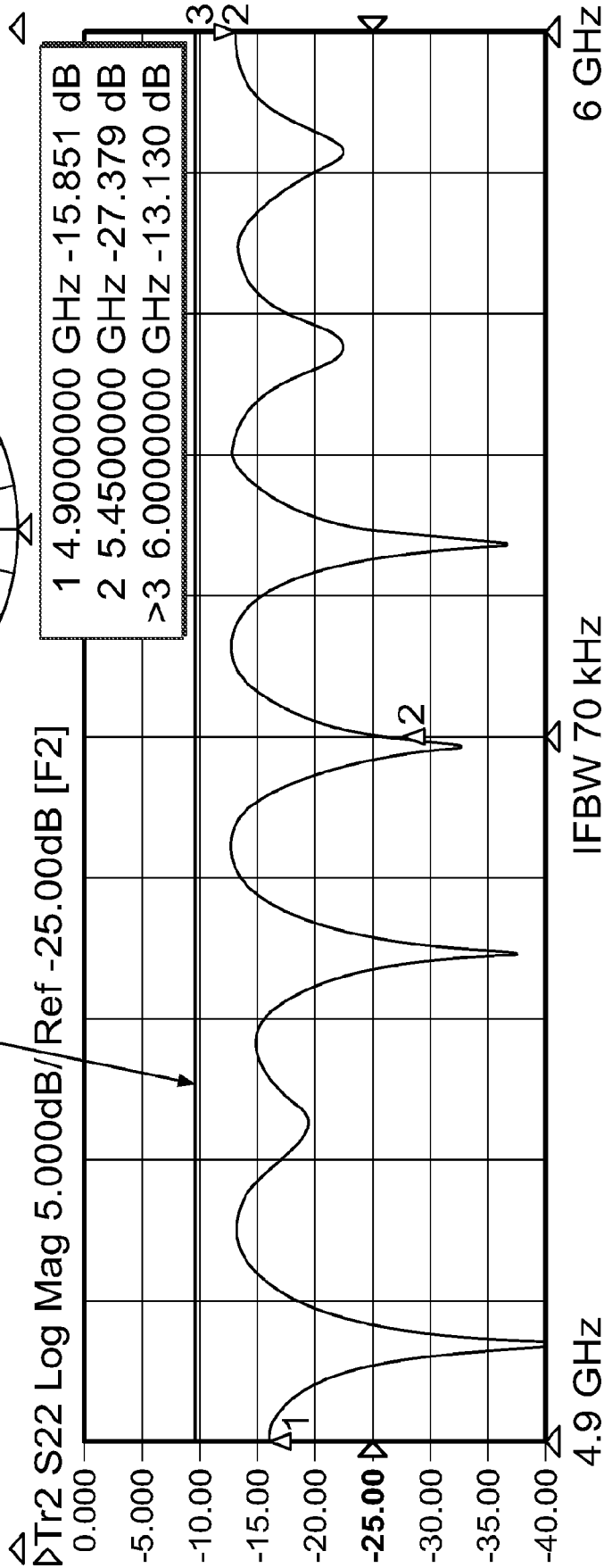
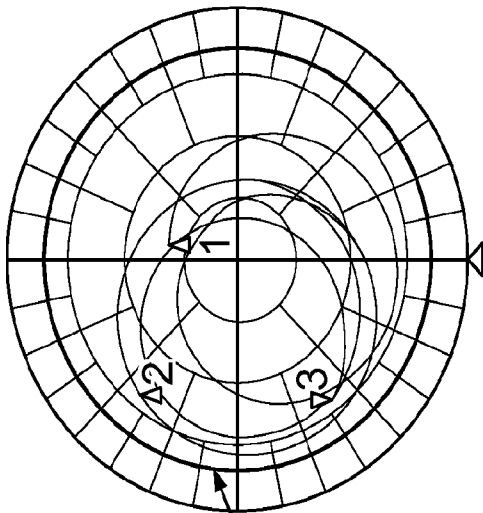


FIG. 15

S22- Parameters Vertical Polarization

- 1 4.9000000 GHz -17.853 dB 78.837 °
- 2 5.4500000 GHz -11.209 dB 142.40 °
- 3 6.0000000 GHz -11.145 dB -144.03 °



VSWR 2.0

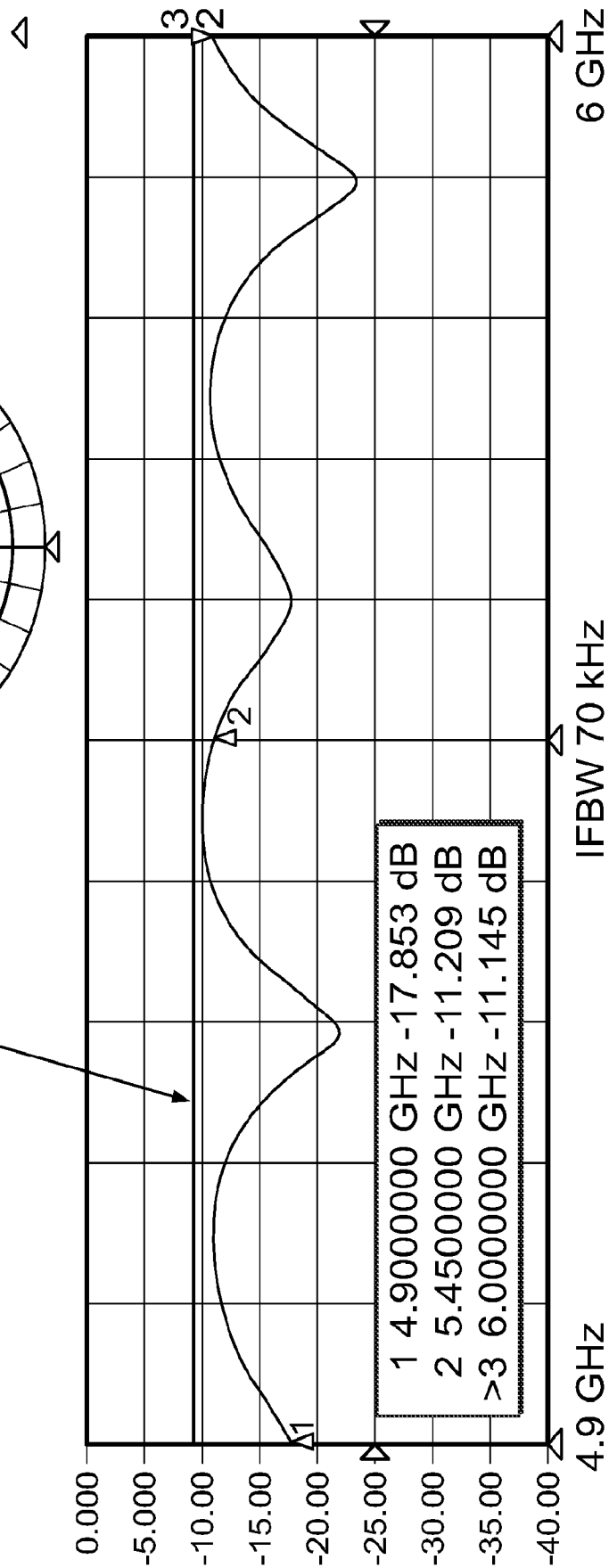


FIG. 16

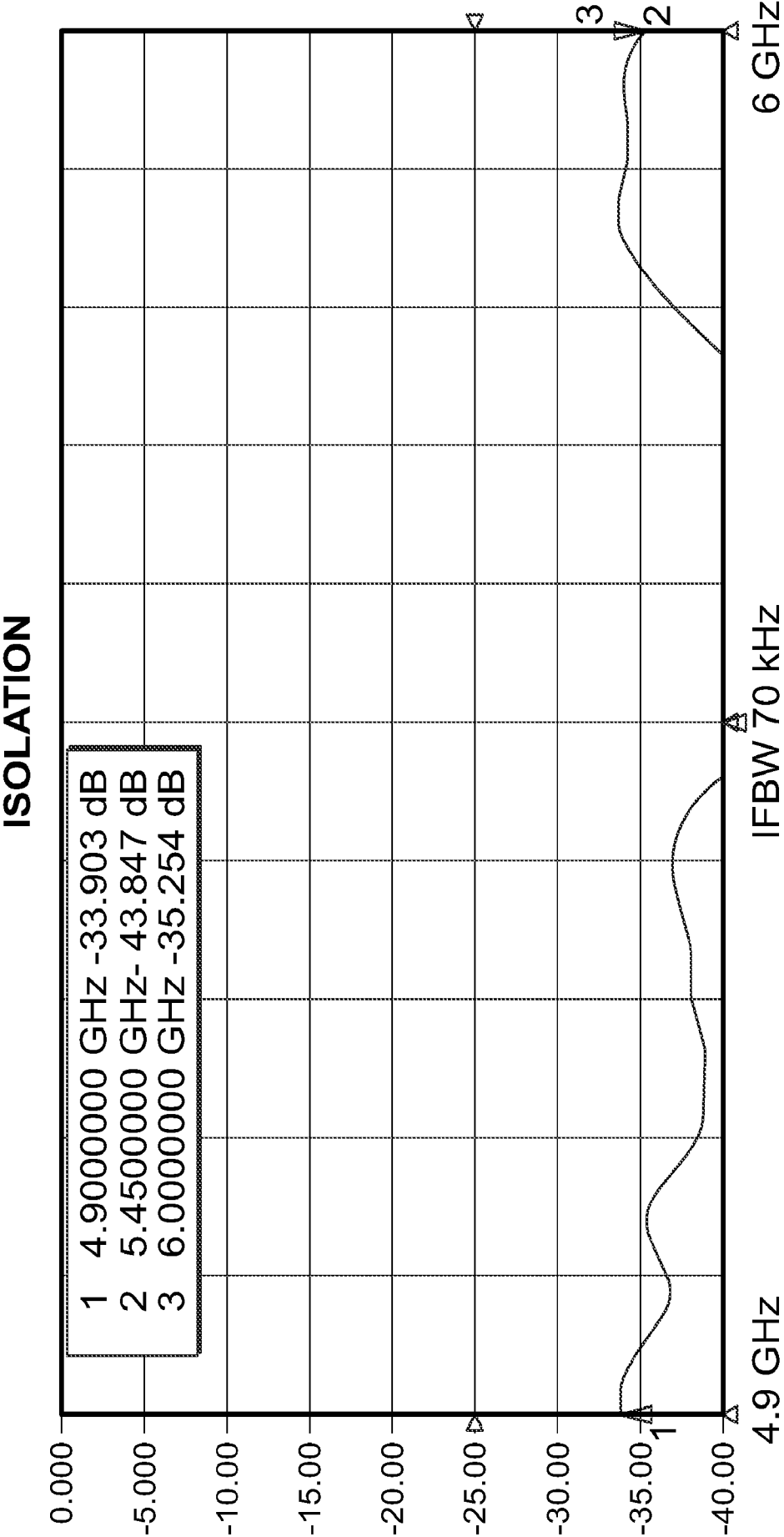


**FIG. 17**

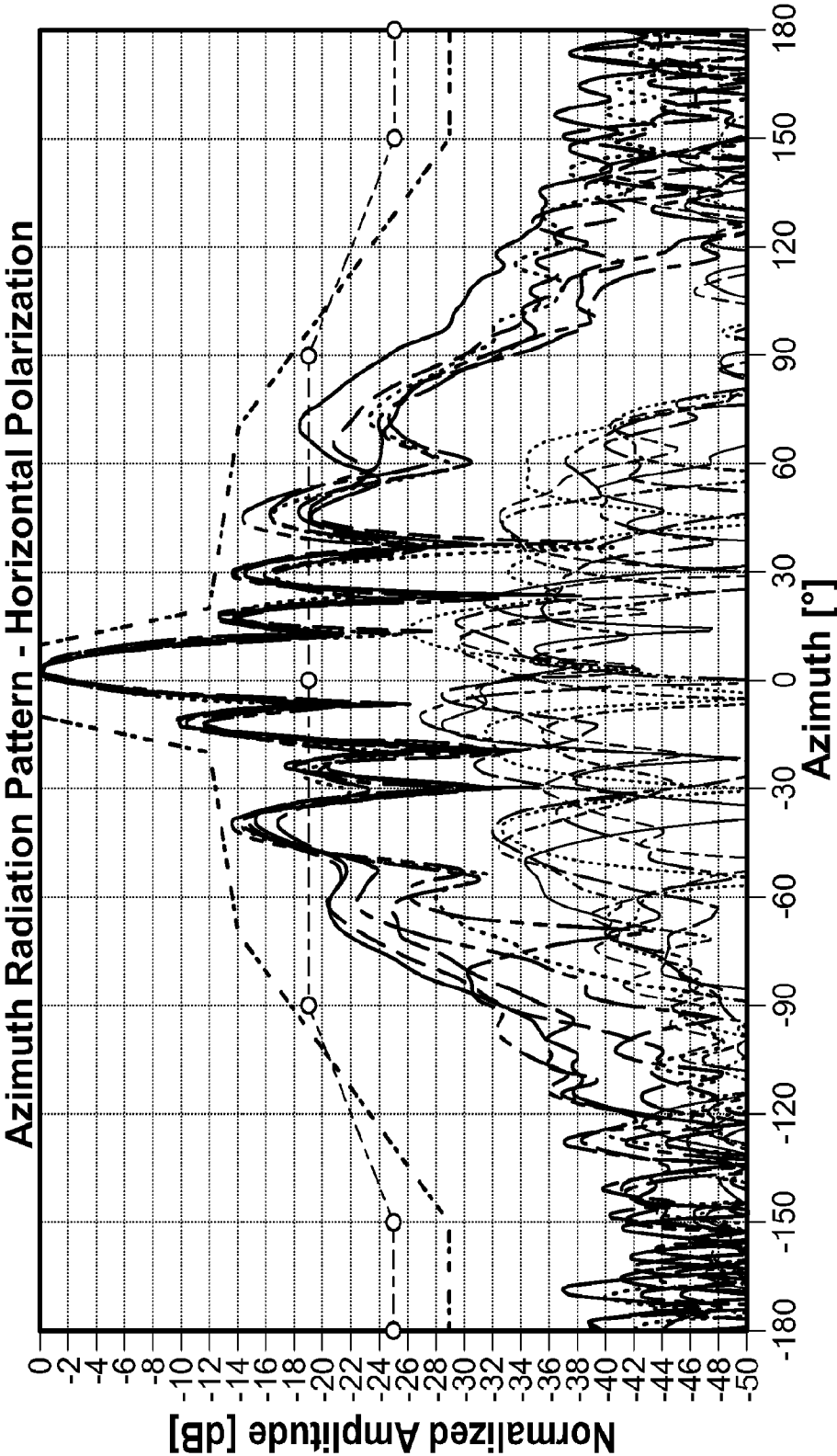
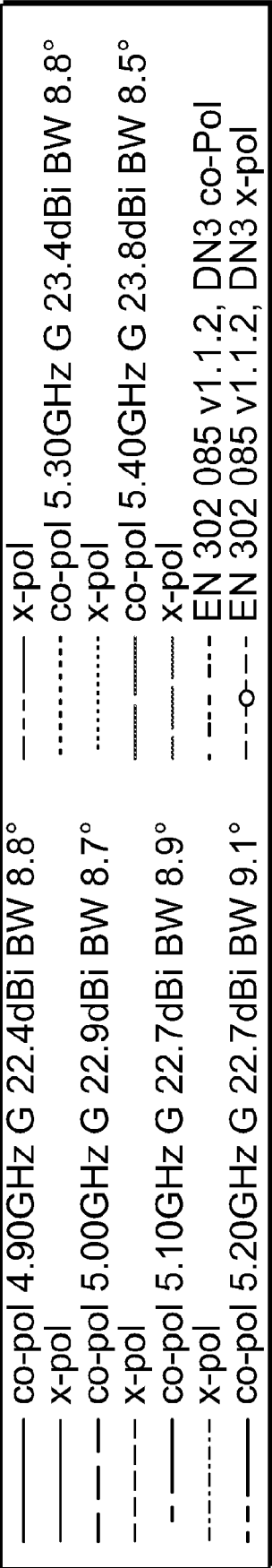


FIG. 18

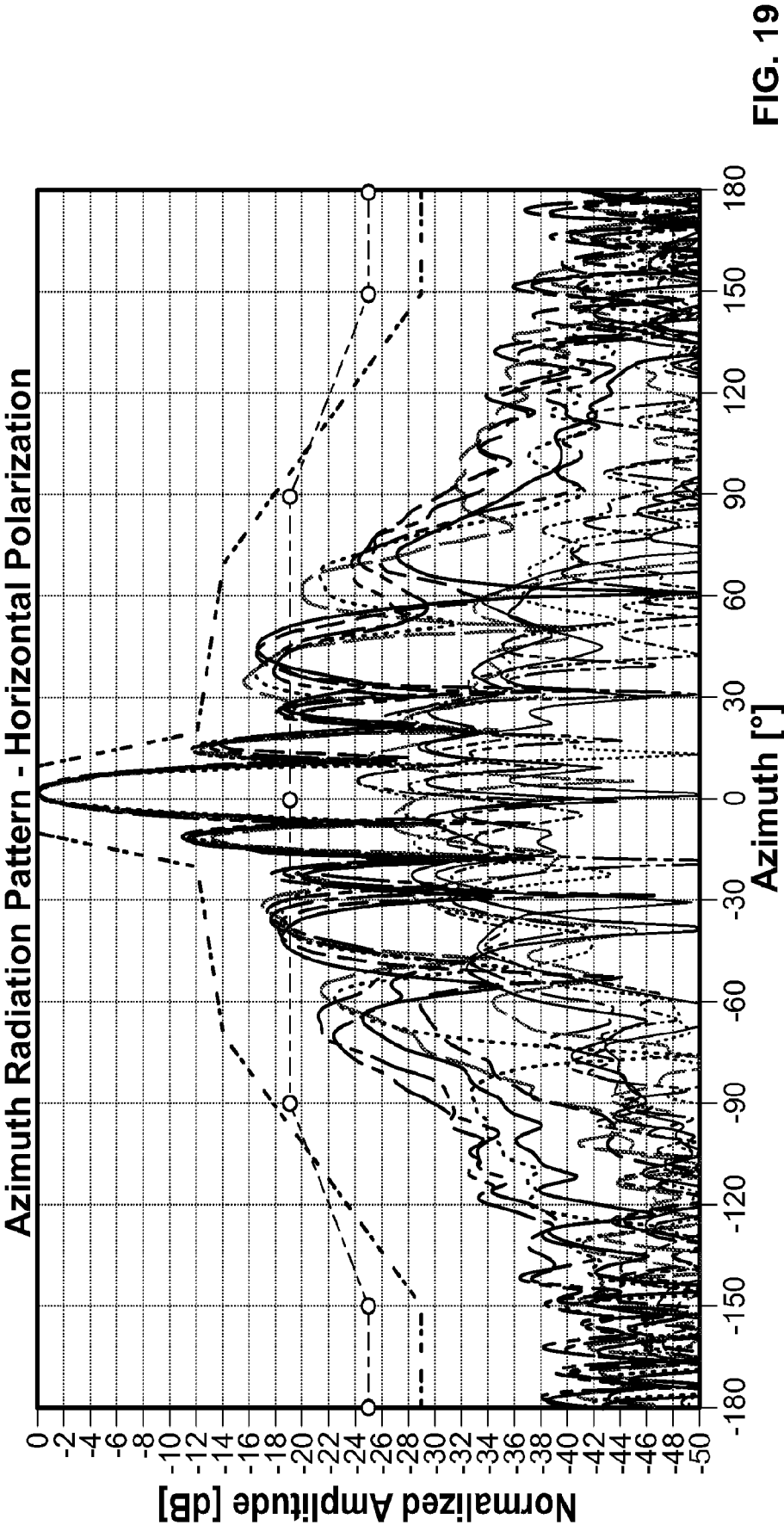
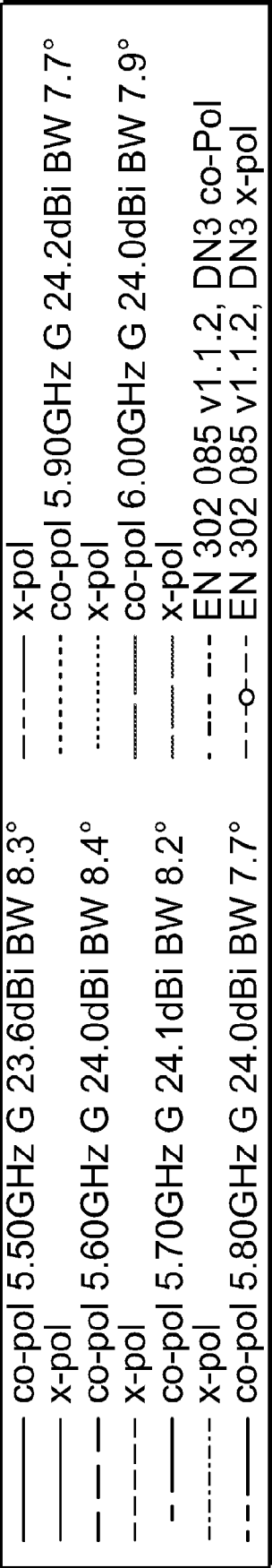
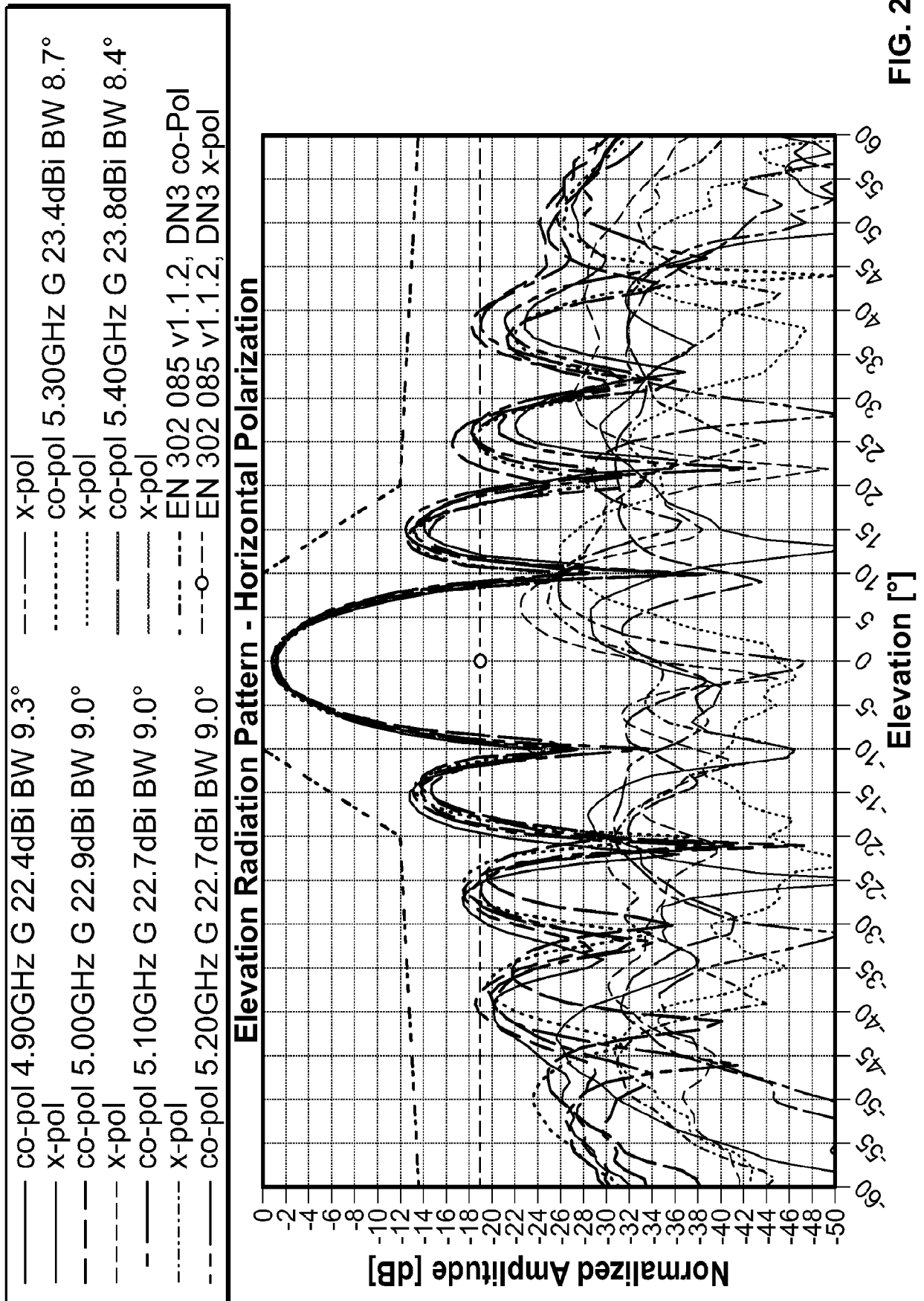


FIG. 19



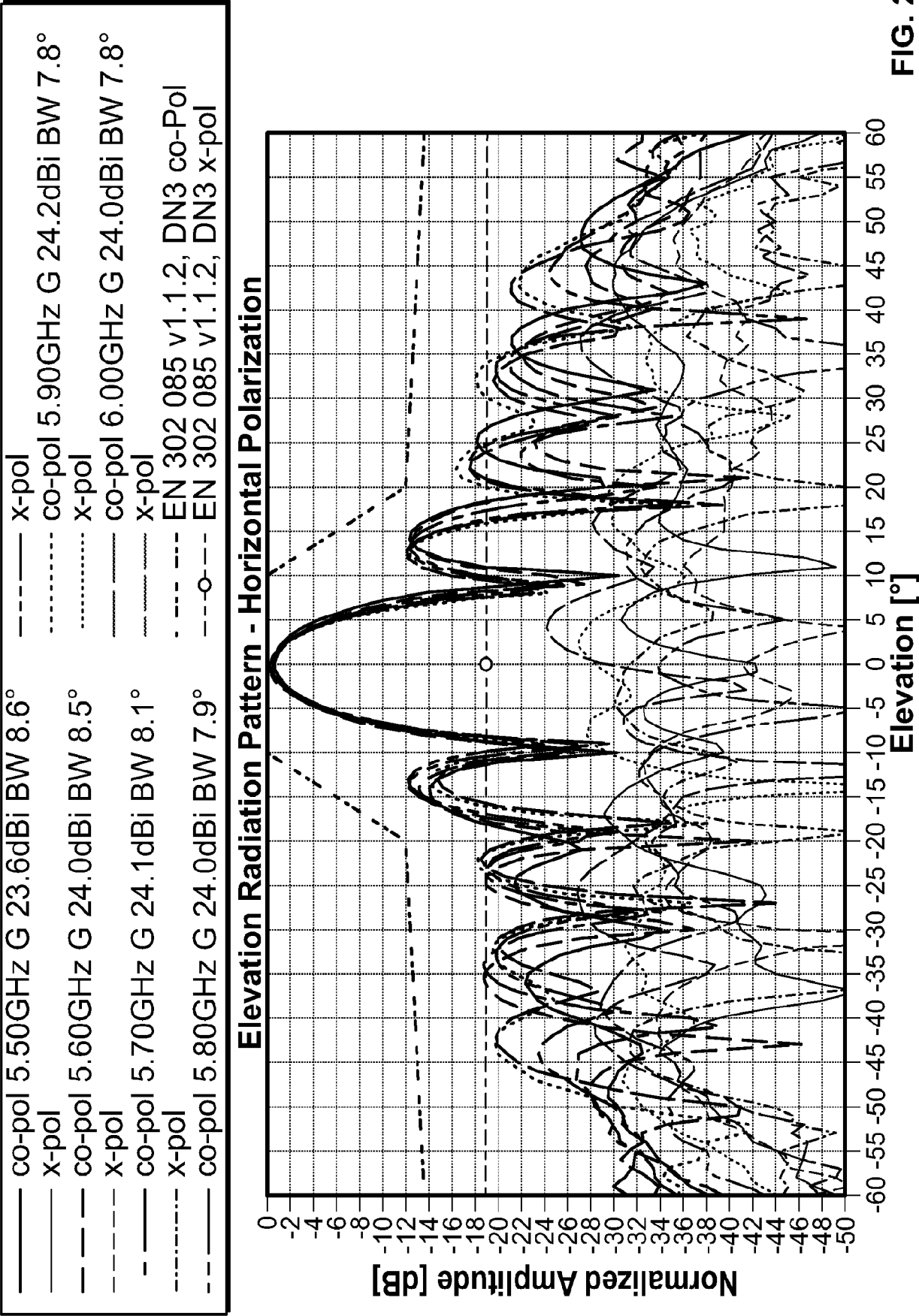


FIG. 21

Summary Radiation Pattern - Horizontal Polarization

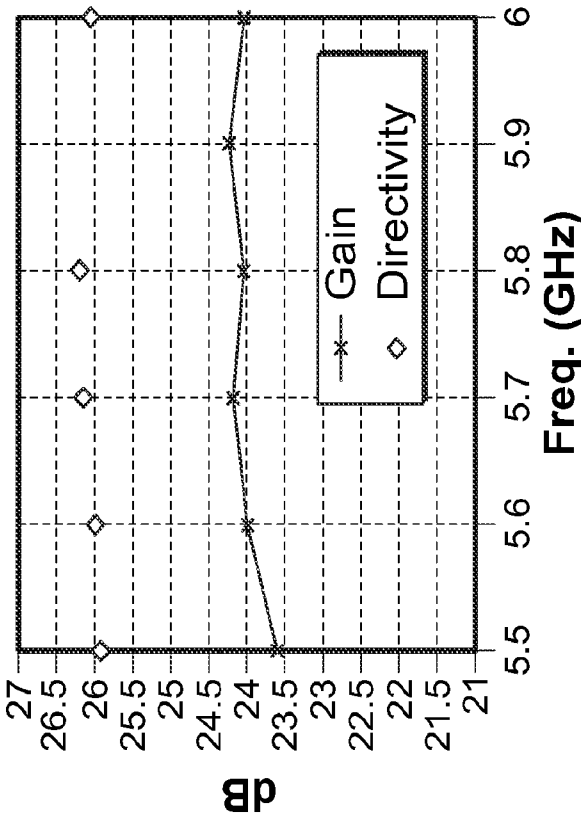
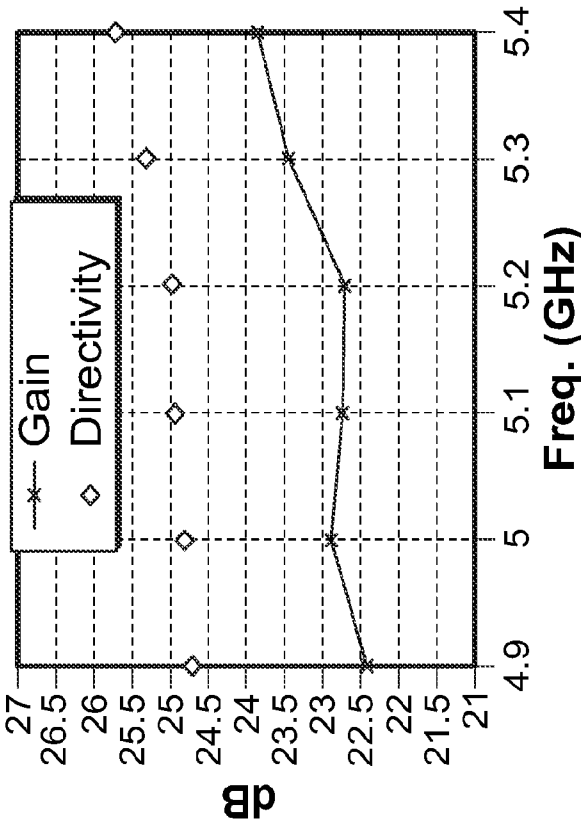
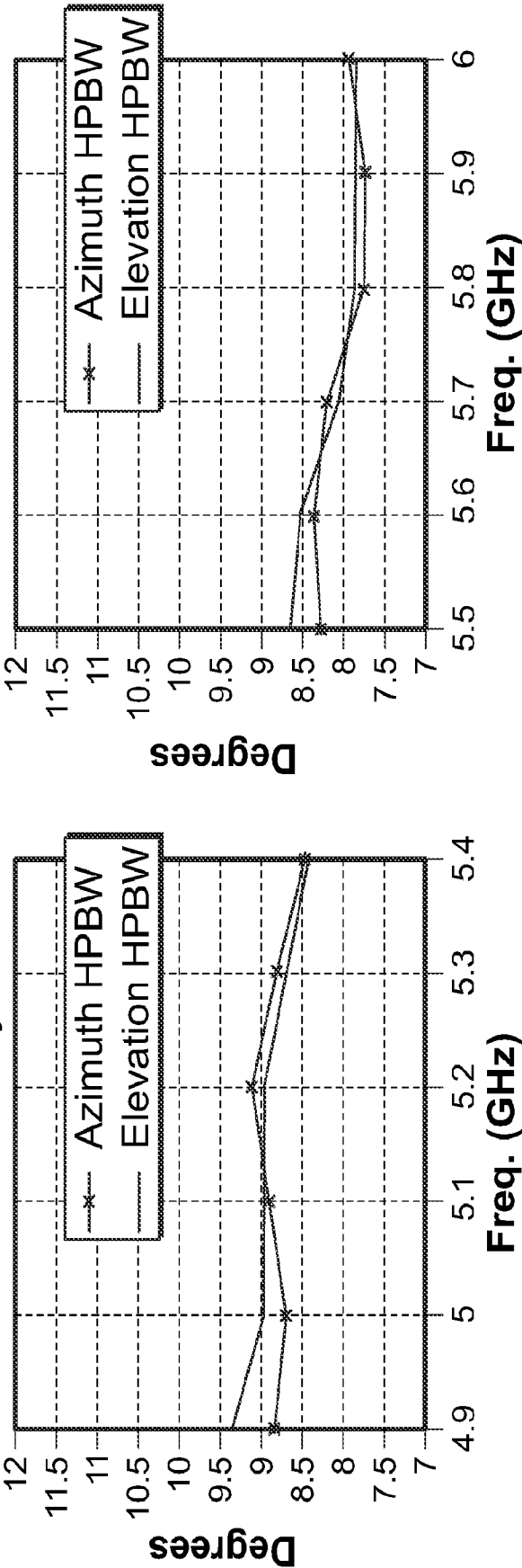
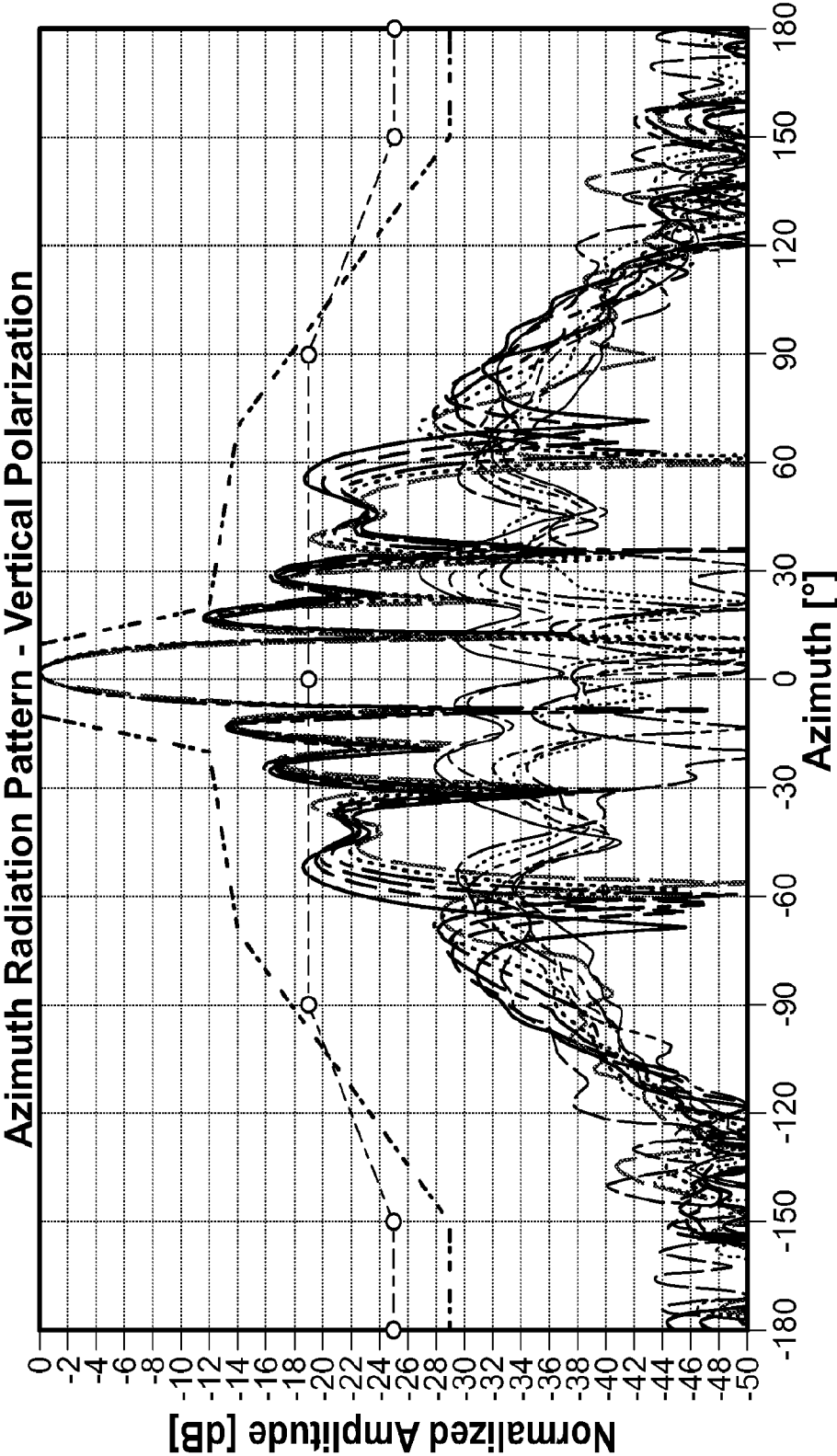
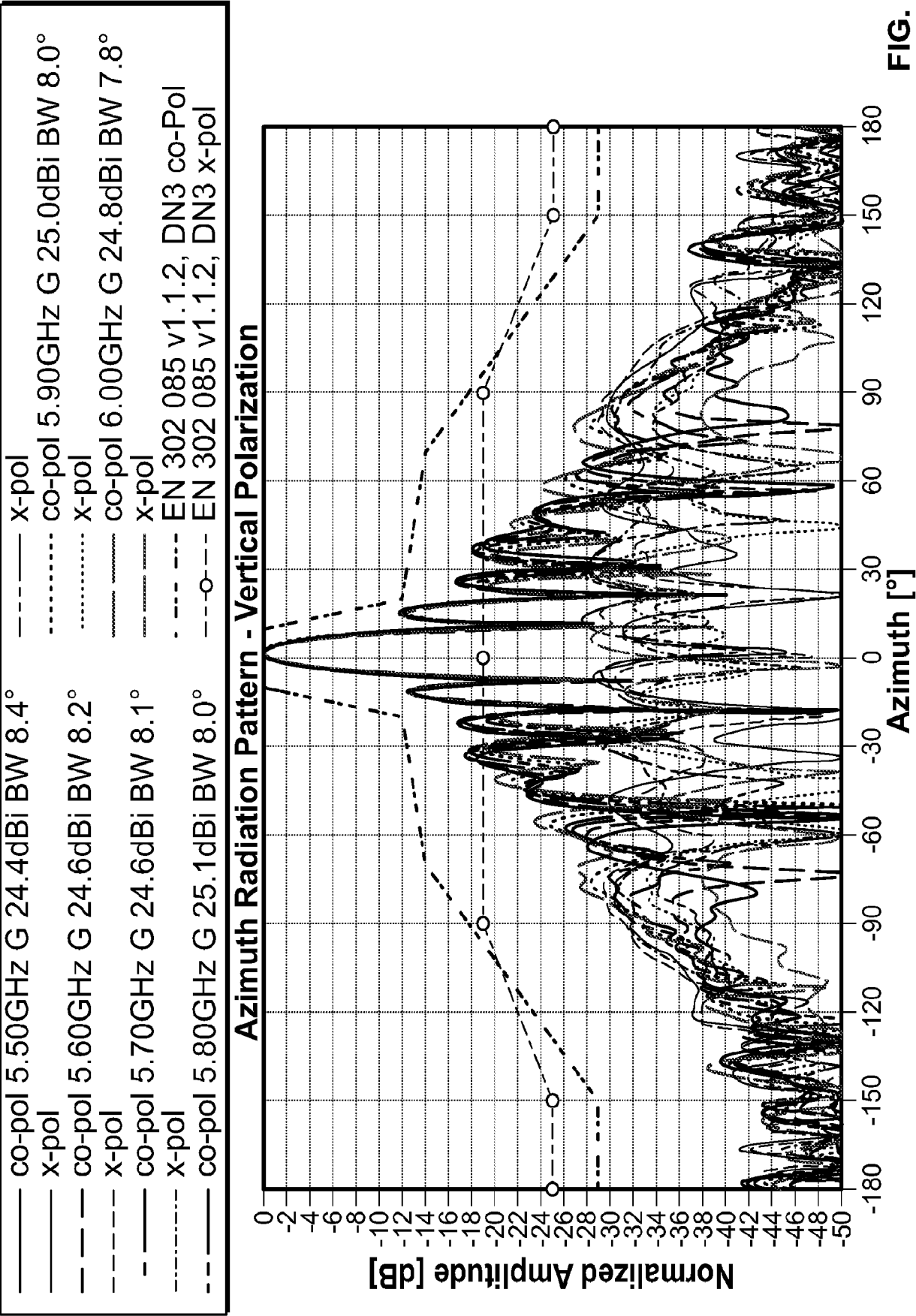
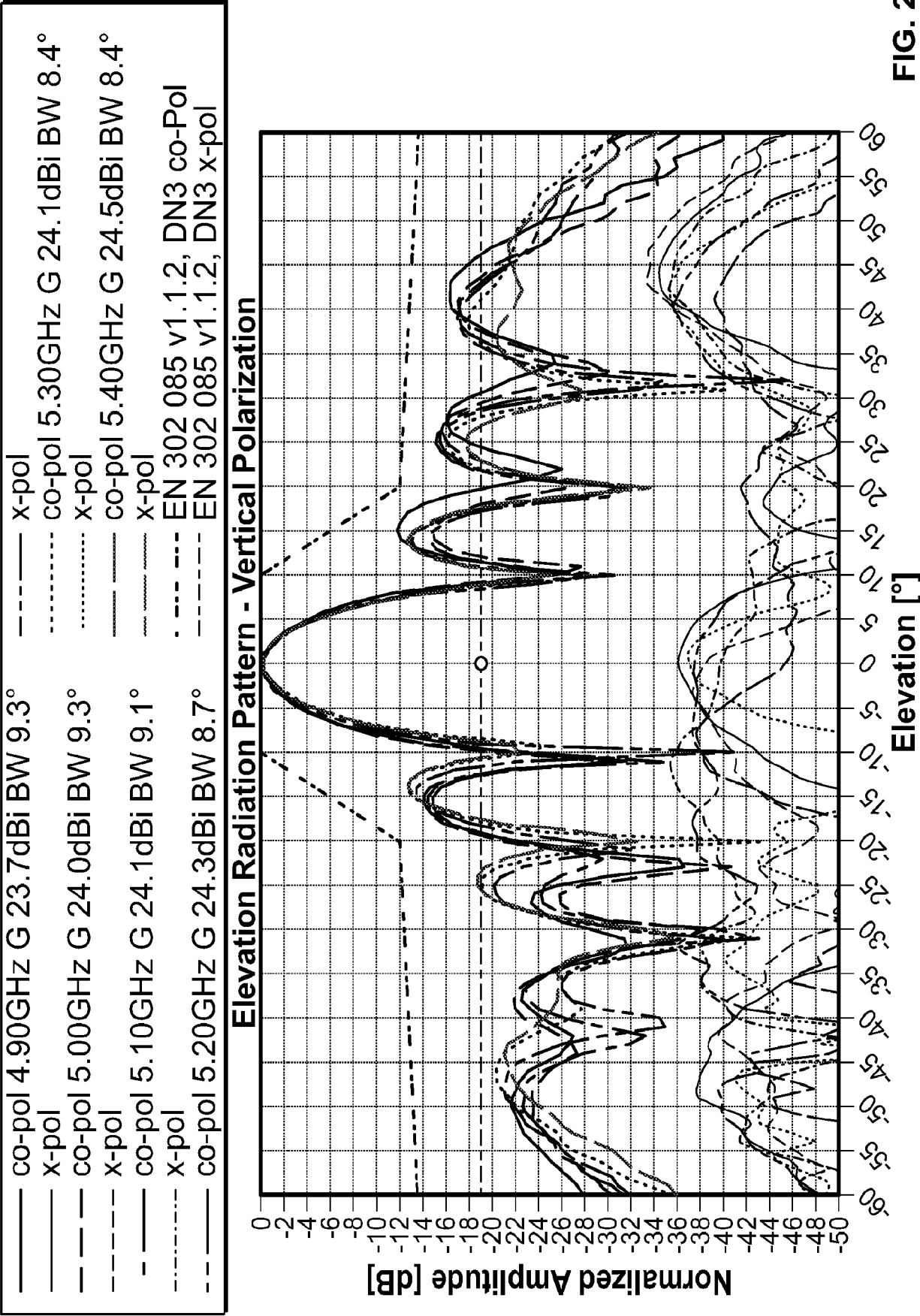


FIG. 22

|       |                                  |           |                                  |
|-------|----------------------------------|-----------|----------------------------------|
| —     | co-pol 4.90GHz G 23.7dBi BW 9.4° | —         | x-pol                            |
| —     | x-pol                            | - - -     | co-pol 5.30GHz G 24.1dBi BW 8.7° |
| - - - | co-pol 5.00GHz G 24.0dBi BW 9.2° | - - -     | x-pol                            |
| - - - | x-pol                            | —         | co-pol 5.40GHz G 24.5dBi BW 8.6° |
| -     | co-pol 5.10GHz G 24.1dBi BW 9.1° | —         | x-pol                            |
| - - - | x-pol                            | - - -     | EN 302 085 v1.1.2, DN3 co-Pol    |
| —     | co-pol 5.20GHz G 24.3dBi BW 8.9° | - - o - - | EN 302 085 v1.1.2, DN3 x-pol     |







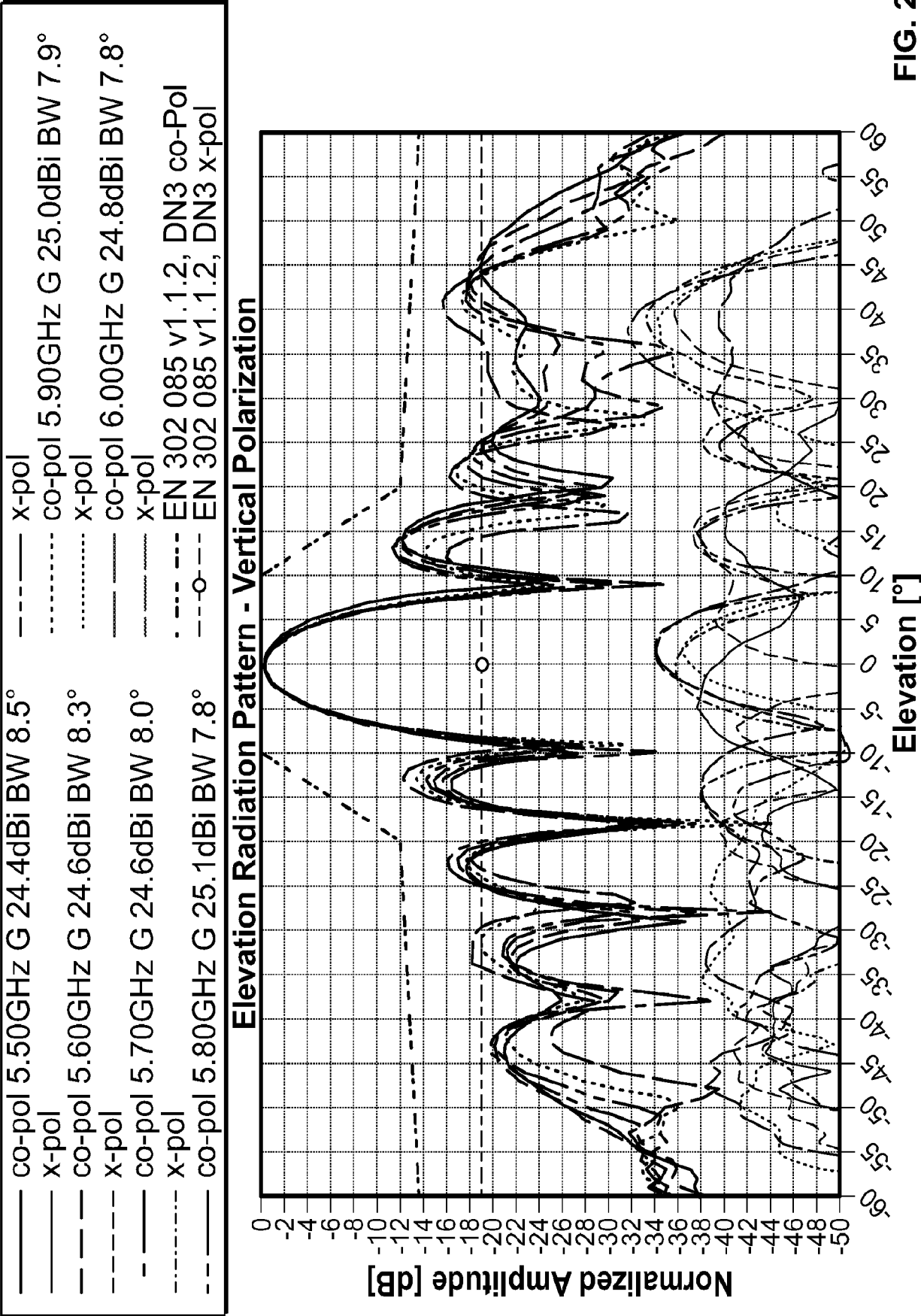
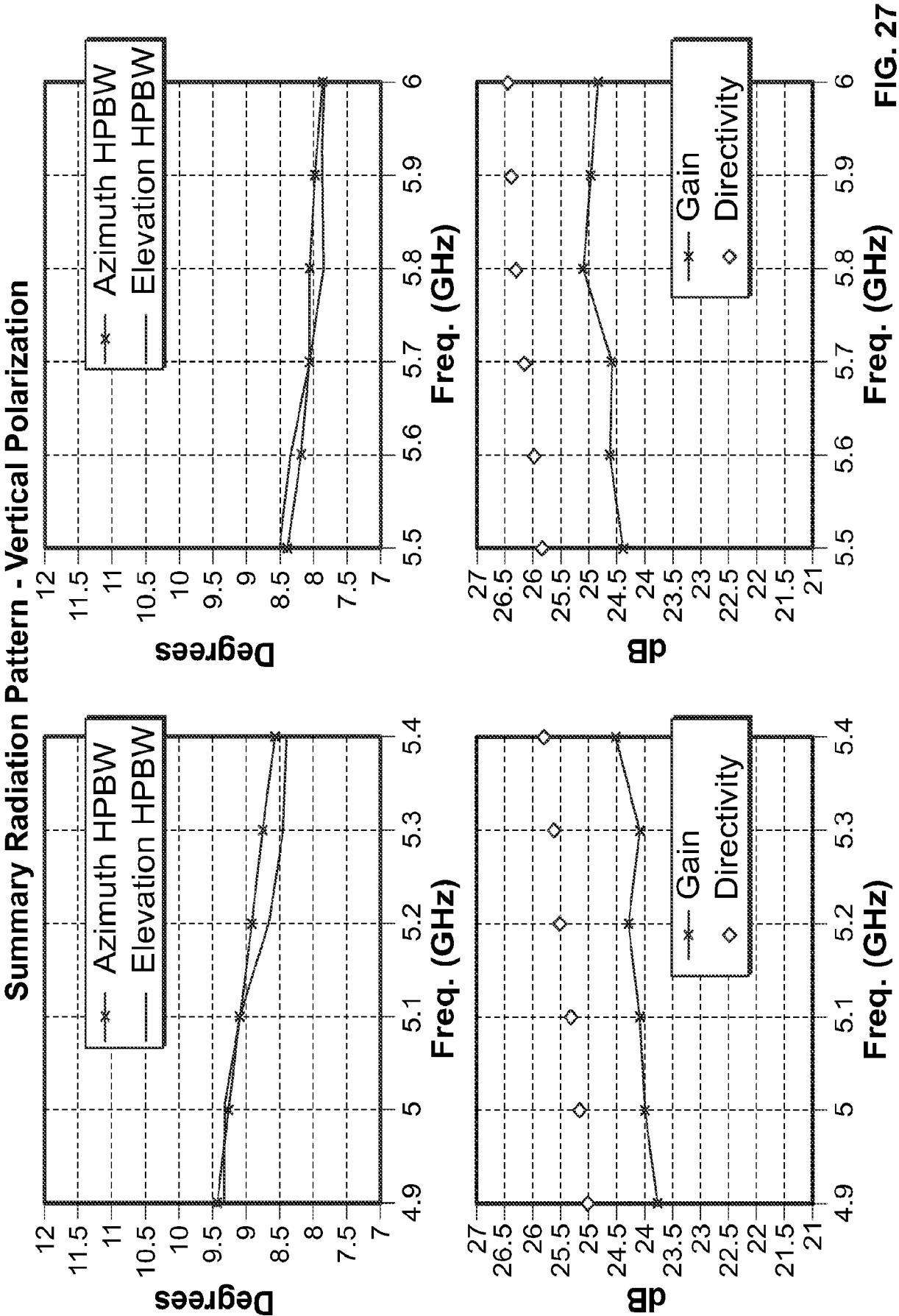


FIG. 26



## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2014/012429****A. CLASSIFICATION OF SUBJECT MATTER****H01Q 1/42(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 1/42; H01Q 1/38; H01Q 21/00; H01Q 13/10

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) &amp; keywords: antenna, patch, slot, cavity

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                              | Relevant to claim No. |
|-----------|-----------------------------------------------------------------------------------------------------------------|-----------------------|
| Y         | US 5949376 A (MCDONALD et al.) 07 September 1999<br>See abstract, columns 2-4 and figures 1-3.                  | 1-4                   |
| Y         | US 2013-0044035 A1 (ZHUANG) 21 February 2013<br>See abstract, paragraphs [0127], [0162] and figures 1-2, 11-12. | 1-4                   |
| A         | US 2009-0091499 A1 (DEAN) 09 April 2009<br>See abstract, paragraph [0044] and figure 3.                         | 1-4                   |
| A         | US 2003-0043076 A1 (CARSON et al.) 06 March 2003<br>See abstract, paragraphs [0063]-[0065] and figures 8-9.     | 1-4                   |
| A         | US 2003-0067410 A1 (PUZELLA et al.) 10 April 2003<br>See abstract, paragraphs [0021]-[0033] and figure 1.       | 1-4                   |



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

"&amp;" document member of the same patent family

Date of the actual completion of the international search

28 July 2014 (28.07.2014)

Date of mailing of the international search report

**28 July 2014 (28.07.2014)**

Name and mailing address of the ISA/KR

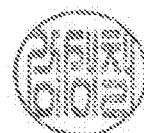
International Application Division  
Korean Intellectual Property Office  
189 Cheongsu-ro, Seo-gu, Daejeon Metropolitan City, 302-701,  
Republic of Korea

Facsimile No. +82-42-472-7140

Authorized officer

KANG, Sung Chul

Telephone No. +82-42-481-8405



**INTERNATIONAL SEARCH REPORT**International application No.  
**PCT/US2014/012429****Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

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

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☒ Claims Nos.: 5-10  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2014/012429**

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s)                                                                                                                                                                     | Publication<br>date                                                                                                                      |
|-------------------------------------------|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| US 05949376 A                             | 07/09/1999          | EP 0901185 A1<br>EP 0901185 B1                                                                                                                                                                 | 10/03/1999<br>14/11/2001                                                                                                                 |
| US 2013-0044035 A1                        | 21/02/2013          | CN 102332635 A<br>CN 102332635 B<br>CN 103222114 A<br>EP 2565985 A1<br>JP 2013-527657 A<br>KR 10-1318830 B1<br>WO 2011-124094 A1                                                               | 25/01/2012<br>25/12/2013<br>24/07/2013<br>06/03/2013<br>27/06/2013<br>17/10/2013<br>13/10/2011                                           |
| US 2009-0091499 A1                        | 09/04/2009          | CA 2540219 A1<br>CA 2645718 A1<br>CA 2645718 C<br>CN 101411027 A<br>CN 101411027 B<br>EP 2005517 A1<br>US 8077093 B2<br>WO 2007-106975 A1                                                      | 17/09/2007<br>27/09/2007<br>09/10/2012<br>15/04/2009<br>01/05/2013<br>24/12/2008<br>13/12/2011<br>27/09/2007                             |
| US 2003-0043076 A1                        | 06/03/2003          | US 6462710 B1<br>US 6911939 B2                                                                                                                                                                 | 08/10/2002<br>28/06/2005                                                                                                                 |
| US 2003-0067410 A1                        | 10/04/2003          | AU 2002-334695 B2<br>DE 60221868 D1<br>EP 1436859 A1<br>EP 1436859 B1<br>EP 1764863 A1<br>JP 2005-505963 A<br>KR 10-2004-0035802 A<br>KR 10-2009-0003369 A<br>US 6624787 B2<br>WO 03-030301 A1 | 12/07/2007<br>27/09/2007<br>14/07/2004<br>15/08/2007<br>21/03/2007<br>24/02/2005<br>29/04/2004<br>09/01/2009<br>23/09/2003<br>10/04/2003 |