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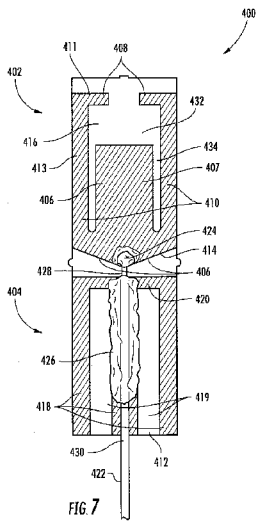


FIG.7

(57) Abstract: Disclosed herein are various exemplary embodiments of omnidirectional multi-band antennas. In an exemplary embodiment, an antenna includes upper and lower portions. The upper portion includes one or more radiating elements, one or more tapering features for impedance matching, and one or more slots configured to enable multi-band operation of the antenna. A lower portion including one or more radiating elements and one or more slots.

OMNIDIRECTIONAL MULTI-BAND ANTENNAS

FIELD

[0001] The present disclosure relates to omnidirectional multi-band antennas.

BACKGROUND

[0002] This section provides background information related to the present disclosure which is not necessarily prior art.

[0003] Wireless application devices, such as laptop computers, cellular phones, etc. are commonly used in wireless operations. Consequently, additional frequency bands are required to accommodate the increased use, and antennas capable of handling the additional different frequency bands are desired.

[0004] FIG. 1 illustrates a conventional half-wave dipole antenna 100. The antenna 100 includes a radiator element 102 and a ground element 104. The radiator element 102 and the ground element 104 are connected to, and fed by, a signal feed 106. Each of the radiator element 102 and the ground element 104 has an electrical length of about one quarter of the wavelength ($\lambda/4$) of a signal at a desired resonant frequency of the antenna. Together, the radiator element 102 and the ground element 104 have a combined electrical length of about one half of the wavelength ($\lambda/2$) 108 of signals at one desired resonant frequency of the antenna 100.

[0005] In addition, omnidirectional antennas are useful for a variety of wireless communication devices because the radiation pattern allows for good transmission and reception from a mobile unit. Generally, an omnidirectional antenna is an antenna that radiates power generally uniformly in one plane with a directive pattern shape in a perpendicular plane, where the pattern is often described as "donut shaped."

[0006] One type of omnidirectional antenna is a collinear antenna. Collinear antennas are relatively high gain antennas that are used as external antennas for wireless local area network (WLAN) applications, such as wireless modems, etc. This is because collinear antennas have relative high gain and omnidirectional gain patterns.

[0007] Collinear antennas consist of in-phase arrays of radiating elements to enhance the gain performance. But collinear antennas are limited in that they are only operable as single band high gain antennas. By way of example, FIG. 2 illustrates a conventional collinear antenna 200 including upper and lower radiator elements 202, 204 each having an electrical length of about one half of the wavelength (λ/2) of a signal at a desired resonant frequency of the antenna.

[0008] In order to achieve high gain for more than a single band, however, back-to-back dipoles may be placed on opposite sides of a printed circuit board. For example, FIGS. 3 through 5 illustrate a conventional antenna 300 having back-to-back dipoles such that the antenna 300 is operable over two bands, specifically the 2.45 gigahertz band (from 2.4 gigahertz to 2.5 gigahertz) and the 5 gigahertz band (from 4.9 gigahertz to 5.875 gigahertz). For this conventional antenna 300, there are an upper pair of dipoles 302, 304 operating on the 2.45 gigahertz band and two lower pairs (1 X 2 array) of dipoles 306, 308, 310, 312 operating on the 5 gigahertz band. FIG. 3 illustrates the dipoles 302, 306, 308 on the front of the printed circuit board (PCB) 314, while FIG. 5 illustrates the dipoles 304, 310, 312 on the back of the PCB 314. The antenna 300 also includes microstrip line or feeding network 316 with a power divider to feed and divide the power to each of the various antenna elements.

SUMMARY

[0009] This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

[0010] Disclosed herein are various exemplary embodiments of omnidirectional multi-band antennas. In an exemplary embodiment, an antenna includes upper and lower portions. The upper portion includes one or more upper radiating elements, one or more tapering features, and one or more slots configured to enable multi-band operation of the antenna. The lower portion includes one or more lower radiating elements and one or more slots.

[0011] 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

[0012] 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.

[0013] FIG. 1 is a conventional dipole antenna;

[0014] FIG. 2 is a conventional collinear antenna;

[0015] FIG. 3 is a front view of a conventional back-to-back dipole antenna;

[0016] FIG. 4 is a side view of the conventional back-to-back dipole antenna shown in FIG. 3;

[0017] FIG. 5 is a back view of the conventional back-to-back dipole antenna shown in FIG. 3;

[0018] FIG. 6 is a line graph illustrating return loss in decibels for the conventional back-to-back dipole antenna shown in FIGS. 3 through 5 over a frequency range of 2000 megahertz to 6000 megahertz;

[0019] FIG. 7 illustrates an example embodiment of an omnidirectional multi-band antenna including one or more aspects of the present disclosure, in which a coaxial cable is coupled to the antenna;

[0020] FIG. 8 illustrates the omnidirectional multi-band antenna shown in FIG. 7, and also illustrating the electrical lengths of the upper and lower portions of the antenna at the 2.45 gigahertz band and at the 5 gigahertz band where these electrical lengths are provided for purposes of illustration only according to exemplary embodiments;

[0021] FIG. 9 is a line graph illustrating measured return loss in decibels for the example omnidirectional multi-band antenna shown in FIG. 7 over a frequency range of 1 gigahertz to 6 gigahertz;

[0022] FIG. 10 illustrates measured azimuth radiation patterns (azimuth plane, theta 90 degree) for the example omnidirectional multi-band antenna shown in FIG. 7 for a frequency of 2450 megahertz;

[0023] FIG. 11 illustrates measured azimuth radiation patterns (azimuth plane, theta 90 degree) for the example omnidirectional multi-band

antenna shown in FIG. 7 for frequencies of 4900 megahertz, 5470 megahertz, and 5780 megahertz;

[0024] FIG. 12 illustrates measured zero degree elevation radiation patterns (phi zero degree plane) for the example omnidirectional multi-band antenna shown in FIG. 7 for a frequency of 2450 megahertz;

[0025] FIG. 13 illustrates measured zero degree elevation radiation patterns (phi zero degree plane) for the example omnidirectional multi-band antenna shown in FIG. 7 for frequencies of 4900 megahertz, 5470 megahertz, and 5780 megahertz;

[0026] FIG. 14 is a plan view of another example embodiment of a omnidirectional multi-band antenna including one or more aspects of the present disclosure;

[0027] FIG. 15 is a plan view of another example embodiment of a omnidirectional multi-band antenna including one or more aspects of the present disclosure;

[0028] FIG. 16 illustrates another example embodiment of an omnidirectional multi-band antenna including one or more aspects of the present disclosure, in which a coaxial cable is coupled to the antenna;

[0029] FIG. 17 illustrates the omnidirectional multi-band antenna shown in FIG. 16, and also illustrating the electrical lengths of the upper and lower portions of the antenna at the 2.45 gigahertz band and at the 5 gigahertz band where these electrical lengths are provided for purposes of illustration only according to exemplary embodiments;

[0030] FIG. 18 illustrates measured azimuth radiation patterns (azimuth plane, theta 90 degree) for the example omnidirectional multi-band antenna shown in FIG. 16 for frequencies of 2400 megahertz, 2450 megahertz, and 2500 megahertz;

[0031] FIG. 19 illustrates measured azimuth radiation patterns (azimuth plane, theta 90 degree) for the example omnidirectional multi-band antenna shown in FIG. 16 for frequencies of 4900 megahertz, 5150 megahertz, 5350 megahertz, and 5850 megahertz;

[0032] FIG. 20 illustrates measured zero degree elevation radiation patterns (phi zero degree plane) for the example omnidirectional multi-band

antenna shown in FIG. 16 for frequencies of 2400 megahertz, 2450 megahertz, and 2500 megahertz;

[0033] FIG. 21 illustrates measured zero degree elevation radiation patterns (phi zero degree plane) for the example omnidirectional multi-band antenna shown in FIG. 16 for frequencies of 4900 megahertz, 5150 megahertz, 5350 megahertz, and 5850 megahertz;

[0034] FIG. 22 illustrates another example embodiment of an omnidirectional multi-band antenna including one or more aspects of the present disclosure, in which a coaxial cable is coupled to the antenna;

[0035] FIG. 23 is a side view of the example omnidirectional multi-band antenna shown in FIG. 19;

[0036] FIG. 24 is another plan view of the example omnidirectional multi-band antenna shown in FIG. 22 with exemplary dimensions provided for purposes of illustration only according to exemplary embodiments;

[0037] FIG. 25 is a line graph illustrating computer-simulated S1,1 parameter/return loss in decibels for the example omnidirectional multi-band antenna shown in FIG. 22 over a frequency range of 2 gigahertz to 6 gigahertz;

[0038] FIG. 26 illustrates computer-simulated far field realized gain in decibels for the example omnidirectional multi-band antenna shown in FIG. 22 at a frequency of 2.45 gigahertz, where the total efficiency was -0.2961 decibels and realized gain was 2.258 decibels, thereby indicating that the omnidirectional multi-band antenna shown in FIG. 22 is essentially operable as or similar to a standard half wavelength dipole antenna at the frequency of 2.45 gigahertz;

[0039] FIG. 27 illustrates computer-simulated azimuth radiation patterns (azimuth plane, theta 90 degree) for the example omnidirectional multi-band antenna shown in FIG. 22 for a frequency of 2.45 gigahertz;

[0040] FIG. 28 illustrates computer-simulated zero degree elevation radiation patterns (phi zero degree plane) for the example omnidirectional multi-band antenna shown in FIG. 22 for a frequency of 2.45 gigahertz;

[0041] FIG. 29 illustrates computer-simulated far field realized gain in decibels for the example omnidirectional multi-band antenna shown in FIG. 22 at a frequency of 5.5 gigahertz, where the total efficiency was -0.1980

decibels and realized gain was 5.441 decibels, thereby indicating that the omnidirectional multi-band antenna shown in FIG. 22 is essentially operable as or similar to a collinear dipole antenna array antenna having high gain properties at the frequency of 5.5 gigahertz;

[0042] FIG. 30 illustrates computer-simulated azimuth radiation patterns (azimuth plane, theta 90 degree) for the example omnidirectional multi-band antenna shown in FIG. 22 for a frequency of 5.5 gigahertz;

[0043] FIG. 31 illustrates computer-simulated zero degree elevation radiation patterns (phi zero degree plane) for the example omnidirectional multi-band antenna shown in FIG. 22 for a frequency of 5.5 gigahertz;

[0044] FIG. 32 is another example embodiment of an omnidirectional multi-band antenna including one or more aspects of the present disclosure;

[0045] FIG. 33 is another example embodiment of an omnidirectional multi-band antenna including one or more aspects of the present disclosure;

[0046] FIG. 34 is another example embodiment of an omnidirectional multi-band antenna including one or more aspects of the present disclosure;

[0047] FIG. 35 illustrates an exemplary prototype of an omnidirectional multi-band antenna according to another exemplary embodiment including one or more aspects of the present disclosure;

[0048] FIG. 36 is a line graph illustrating return loss in decibels measured for the prototype antenna shown in FIG. 35 operating in free space over a frequency range of 1 gigahertz to 6 gigahertz;

[0049] FIG. 37 is a line graph illustrating return loss in decibels measured for the prototype antenna shown in FIG. 35 operating at load with plastic cover over a frequency range of 1 gigahertz to 6 gigahertz;

[0050] FIG. 38 illustrates azimuth radiation patterns (azimuth plane, theta 90 degree) measured for the prototype antenna shown in FIG. 35 for frequencies of 2400 megahertz, 2450 megahertz, and 2500 megahertz;

[0051] FIG. 39 illustrates azimuth radiation patterns (azimuth plane, theta 90 degree) measured for the prototype antenna shown in FIG. 35 for

frequencies of 4900 megahertz, 5150 megahertz, 5350 megahertz, 5470 megahertz, 5710 megahertz, 5780 megahertz, and 5850 megahertz;

[0052] FIG. 40 illustrates zero degree elevation radiation patterns (phi zero degree plane) measured for the prototype antenna shown in FIG. 35 for frequencies of 2400 megahertz, 2450 megahertz, and 2500 megahertz;

[0053] FIG. 41 illustrates zero degree elevation radiation patterns (phi zero degree plane) measured for the prototype antenna shown in FIG. 35 for frequencies of 4900 megahertz, 5150 megahertz, 5350 megahertz, 5470 megahertz, 5710 megahertz, 5780 megahertz, and 5850 megahertz;

[0054] FIG. 42 illustrates elevation radiation patterns (phi 90 degree) measured for the prototype antenna shown in FIG. 35 for frequencies of 2400 megahertz, 2450 megahertz, and 2500 megahertz; and

[0055] FIG. 43 illustrates elevation radiation patterns (phi 90 degree) measured for the prototype antenna shown in FIG. 35 for frequencies of 4900 megahertz, 5150 megahertz, 5350 megahertz, 5470 megahertz, 5710 megahertz, 5780 megahertz, and 5850 megahertz.

DETAILED DESCRIPTION

[0056] Example embodiments will now be described more fully with reference to the accompanying drawings.

[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.

[0058] 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.

[0059] 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.

[0060] 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.

[0061] 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.

[0062] Disclosure of values and ranges of values for specific parameters (such as frequency ranges, etc.) are not exclusive of other values and ranges of values useful herein. It is envisioned that two or more specific exemplified values for a given parameter may define endpoints for a range of values that may be claimed for the 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.

[0063] With reference now to FIG. 6, there is shown the measured and computer-simulated return loss in decibels for the conventional back-to-back dipole antenna 300 (discussed above and shown in FIGS. 3 through 5) over a frequency range of 2000 megahertz to 6000 megahertz. In FIG. 6, the dashed horizontal line represents a Voltage Standing Wave Ratio of 1.5:1. In addition, the antenna 200 also had a gain level of about 2.5 in decibels referenced to isotropic gain (dBi) for the 2.45 gigahertz band (2.4 gigahertz to 2.5 gigahertz), a gain level of about 4.0 dBi for a frequency range of 4.84 gigahertz to 5.450 gigahertz, and an omnidirectional ripple of less than 2 dBi.

[0064] As recognized by the inventors hereof, the 4 dBi gain of the conventional antenna 300 for the 5 gigahertz band, however, may not be high

enough for some applications. The inventors hereof have also recognized that the back-to-back dipole arrangement also necessitates a double-sided printed circuit board 314 and a relatively long antenna due to having separate, spaced- 2.45 gigahertz and 5 gigahertz band elements. For example, the conventional antenna 300 shown in FIGS. 3 through 5 included printed circuit board 314 having a length of about 160 millimeters and a width of about 12 millimeters. Accordingly, the inventors hereof have disclosed various exemplary embodiments of multi-band omnidirectional antennas (*e.g.*, antenna 400 (FIG. 7), antenna 500 (FIG. 14), antenna 600 (FIG. 15), antenna 700 (FIG. 16), antenna 800 (FIG. 22), antenna 900 (FIG. 32), antenna 1000 (FIG. 33), antenna 1100 (FIG. 34), antenna 1200 (FIG. 35)) in which the radiating elements may be disposed on one side of a printed circuit board. Having the radiating elements on the same side of the printed circuit board may improve manufacturability as compared to the more difficult to manufacture back-to-back dipole antennas that utilize a double-sided printed circuit board having dipole elements on the front and back sides of the printed circuit board. Some embodiments may achieve high gain and/or have comparable or better performance than the conventional dipole antenna 300 shown in FIGS. 3 through 5.

[0065] The inventors have recognized that the antenna radiation pattern may squint downward without properly tuned slots. Accordingly, the inventions hereof disclose various embodiments of antennas having slots that are carefully tuned so as to help inhibit the antenna radiation pattern from squinting downward and/or also to help make the radiation patterns tilt at horizontal. In addition, disclosed herein are exemplary antennas (*e.g.*, antenna 400 (FIG. 7), antenna 500 (FIG. 14), antenna 600 (FIG. 15), antenna 900 (FIG. 32), antenna 1000 (FIG. 33), antenna 1100 (FIG. 34), antenna 1200 (FIG. 35), etc.) that may be configured such that the antennas are operable at the 2.45 gigahertz band essentially as or similar to a standard half wavelength dipole antenna and operable at the 5 gigahertz band essentially as or similar to a wavelength dipole antenna. Also disclosed herein are exemplary antennas (*e.g.*, antenna 700 (FIG. 16), antenna 800 (FIG. 22)) that may be configured such that the antennas are operable at the 2.45 gigahertz band

essentially as or similar to a wavelength dipole antenna and operable at the 5 gigahertz band essentially as or similar to collinear array antenna.

[0066] Referring now to FIG. 7, there is shown an example embodiment of an omnidirectional multi-band antenna 400 including one or more aspects of the present disclosure. The antenna 400 includes upper and lower portions 402, 404 configured such that the antenna 400 is operable essentially as or similar to a standard half wavelength dipole antenna at a first frequency range (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.) with the upper and lower portions 402, 404 each having an electrical length of about λ/4. But at a second frequency range or high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.), the antenna 400 is operable essentially as or similar to a wavelength dipole antenna with the upper and lower portions 1202, 1204 each having an electrical length of about λ/2.

[0067] At the first frequency range, the antenna 400 may be operable such that the radiating element 408 has an electrical length of about λ/4. But the electrical length of the radiating element 406 at the first frequency range may be relatively small such that the radiating element 406 should not really be considered an effective radiating element at the first frequency range. Accordingly, only radiating element 408 is essentially radiating at the first frequency range. At the second frequency range or high band, both radiating elements 406, 408 are effective radiators with the radiating element 408 having an electrical wavelength of about λ/2 and the radiating element 406 having an electrical wavelength of about λ/4.

[0068] At the first and second frequency ranges, the lower portion 404 may be operable as ground, which permits the antenna 400 to be ground independent. Thus, that antenna 400 does not depend on a separate ground element or ground plane. At low band or the first frequency range (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.), the lower portion or planar skirt element 404 has an electrical length of about one quarter wavelength (λ/4). With the outer conductor 430 of coaxial cable 422 connected (*e.g.*, soldered, etc.) to the planar skirt element 404, the planar skirt element 404 may behave as a quarter wavelength (λ/4) choke at low band or the first frequency range. In which case, the antenna current (or at

least a portion thereof) does not leak into the outer surface of the coaxial cable 422. This allows the antenna 400 to operate essentially like a half wavelength dipole antenna (λ/2) at low band. At the second frequency range or high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.), the lower portion 404 has an electrical length of about λ/2, such that the lower portion 4044 may be considered more like a radiating element than a sleeve choke. This allows the antenna 400 to operate essentially like a wavelength dipole antenna (λ) at high band.

[0069] The antenna's upper portion 402 includes a tapering feature 414 for impedance matching. The illustrated tapering feature 414 is generally V-shaped (*e.g.*, having a shape similar to the English alphabetic letter "v"). As shown in FIG. 7, the tapering feature 414 comprises the lower edge of the radiating elements of the antenna's upper portion 402 that is spaced apart from the lower portion 404 and oriented such that it is pointing generally at the middle of the connecting element 420 of the antenna's lower portion 404.

[0070] Slots 416 are introduced to configure upper radiating elements 406, 408, which help enable multi-band operation of the antenna 400. By way of example, the upper radiating elements 406, 408 and slots 416 may be configured such that the upper radiating elements 406, 408 are operable as low and high band elements (*e.g.*, 2.45 gigahertz band and 5 gigahertz band, etc.), respectively. In the illustrated example, the slots 416 include a generally rectangular top portion 432 and two downwardly extending straight portions 434.

[0071] The slots disclosed herein (*e.g.*, slots 416, 419, etc.) are generally an absence of electrically-conductive material between radiating elements. By way of example, an upper or lower antenna portion may be initially formed with the slots, or the slot may be formed by removing electrically-conductive material, such as by etching, cutting, stamping, etc. In still yet other embodiments, slots may be formed by an electrically nonconductive or dielectric material, which is added to the planar radiator such as by printing, etc.

[0072] As shown in FIG. 7, the "high band" radiating element 406 includes a generally rectangular shaped portion 407 connected to the tapering feature 414 such that the rectangular portion 407 and tapering feature 414

cooperatively define an arrow shape. The "low" band radiating element 408 includes two L-shaped portions 410 (*e.g.*, portions shaped like the English alphabetic capital letter "L") separated and spaced apart from the rectangular portion 407 of the "high band" radiating element 406 by the slot portions 432, 434. Each L-shaped portion 410 includes a straight portion 413 and an end portion 411 perpendicular to and extending inwardly from the straight portion 413. The straight portion 413 is connected to the tapering feature 414 and extends away from the tapering feature 414 in a direction opposite the lower portion 404 (upwardly in FIG. 7). Each straight portion 413 of the L-shaped portion 410 extends alongside and past the general rectangular portion 407 of the "high band" radiating element 406. The end portion 411 of each L-shaped portion 410 extends inwardly from the corresponding straight portion 413 toward the end portion 411 of the other L-shaped portion 410. The end portions 411 are aligned with each other but are spaced-apart from each other and the generally rectangular portion 407 of the "high band" radiating element 406 by slots 416. In addition, each end portion 411 extends inwardly from the corresponding straight portion 413 a sufficient distance such that each end portion 411 partially overlaps the width of the rectangular portion 407 of the "high band" radiating element 406.

[0073] In the particular embodiment shown in FIG. 8, the slots 416 may be carefully tuned so that the antenna 400 operates at high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.) with the upper and lower arms or portions 402, 404 each having an electrical length of about $\lambda/2$. But at low band (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.), the upper and lower arms or portions 402, 404 each have an electrical length of about $\lambda/4$. Alternative embodiments may include radiating elements, tapering features, and/or slots configured differently than that shown in FIGS. 7 and 8, such as for producing different radiation patterns at different frequencies and/or for tuning to different operating bands.

[0074] The inventors have recognized that the antenna radiation pattern may squint downward without properly tuned slots. Accordingly, the inventions hereof disclose various embodiments of antennas having slots that are carefully tuned so as to help inhibit the antenna radiation pattern from

squinting downward and/or also to help make the radiation patterns tilt at horizontal.

[0075] As shown in FIG. 7, the lower portion 404 (which may also be referred to as a planar skirt element) includes three elements 418. For this particular example, the three elements 418 comprise two outer radiating elements with ground element disposed between the two radiating elements. The two radiating elements are spaced apart from the ground element (*e.g.*, by 3 millimeters, etc.) by slots 419. The two radiating elements and ground element are connected to a connecting element 420. The elements 418 are generally parallel with each other and extend generally perpendicular in a same direction (downward in FIG. 7) from the connecting element 420. The elements 418, 420 are generally rectangular in the illustrated embodiment. The elements 418, 420 may have identical lengths and/or widths, or they may have varied lengths and/or widths. For example, FIG. 7 illustrates the elements 418 having the same length (*e.g.*, 20 millimeters, etc.) but the middle element 418 is wider than the two outer elements 418 (*e.g.*, 3 millimeters wide, etc.). The dimensions in this paragraph are provided for purposes of illustration only and not for purposes of limitation, as alternative embodiments may include elements configured differently.

[0076] The upper and lower elements (*e.g.*, 406, 408, 418, 420, etc.) disclosed herein may be made of electrically-conductive material, such as, for example, copper, silver, gold, alloys, combinations thereof, other electrically-conductive materials, etc. Further, the upper and lower elements may all be made out of the same material, or one or more may be made of a different material than the others. Still further, the "high band" radiating element (*e.g.*, 406, etc.) may be made of a different material than the material from which the "low band" radiating element (*e.g.*, 408, etc.) is formed. Similarly, the lower elements (*e.g.*, 418, 420, etc.) may each be made out of the same material, different material, or some combination thereof. The materials provided herein are for purposes of illustration only as an antenna may be configured from different materials and/or with different shapes, dimensions, etc. depending, for example, on the particular frequency ranges desired, presence or absence of a substrate, the dielectric constant of any substrate, space considerations, etc.

[0077] The antenna 400 may include feed locations or points (*e.g.*, solder pads, etc.) for connection to a feed. In the illustrated example shown in FIG. 7, the feed is a coaxial cable 422 (*e.g.*, IPEX coaxial connector, etc.) soldered 424, 426 to the feed points of the antenna 400. More specifically, an inner conductor 428 of the coaxial cable 422 is soldered 424 to the feed location adjacent and/or on a portion of the tapering feature 414 of the upper radiating portion 402. The outer conductor 430 of the coaxial cable 422 is soldered 426 to the connecting element 420 and/or middle element 418 of the skirt or lower portion 404. The outer conductor 430 may be soldered along a length of the middle element 418 (see, *e.g.*, soldering pad 840 in FIG. 22, etc.) and/or directly to the substrate 412, for example, to provide additional strength and/or reinforcement to the connection of the coaxial cable 422. Alternative embodiments may include other feeding arrangements, such as other types of feeds besides coaxial cables and/or other types of connections besides soldering, such as snap connectors, press fit connections, etc.

[0078] As shown in FIG. 7, the upper and lower elements are all supported on the same side of a substrate 412. Accordingly, this illustrated embodiment of the antenna 400 allows the radiating elements to be on the same side, thus eliminating the need for a double-sided printed circuit board. The elements may be fabricated or provided in various ways and supported by different types of substrates and materials, such as a circuit board, a flexible circuit board, a plastic carrier, Flame Retardant 4 or FR4, flex-film, etc. In various exemplary embodiments, the substrate 412 comprises a flex material or dielectric or electrically non-conductive printed circuit board material. In embodiments in which the substrate 412 is formed from a relatively flexible material, the antenna 400 may be flexed or configured so as to follow the contour or shape of the antenna housing profile. The substrate 412 may be formed from a material having low loss and dielectric properties. According to some embodiments the antenna 400 may be, or may be part of a, printed circuit board (whether rigid or flexible) where the radiating elements are all conductive traces (*e.g.*, copper traces, etc.) on the circuit board substrate. The antenna 400 thus may be a single sided PCB antenna. Alternatively, the antenna 400 (whether mounted on a substrate or not) may be constructed from sheet metal by cutting, stamping, etching, etc. The

substrate 412 may be sized differently depending, for example, on the particular application as varying the thickness and dielectric constant of the substrate may be used to tune the frequencies. By way of example, the substrate 412 may have a length of about 45 millimeters, a width of about 16.6 millimeters, and a thickness of about .80 millimeters. Alternative embodiments may include a substrate with a different configuration (*e.g.*, different shape, size, material, etc.). The materials and dimensions provided herein are for purposes of illustration only as an antenna may be configured from different materials and/or with different shapes, dimensions, etc. depending, for example, on the particular frequency ranges desired, presence or absence of a substrate, the dielectric constant of any substrate, space considerations, etc.

[0079] FIGS. 9 through 13 illustrate measured analysis results for the omnidirectional multi-band antenna 400 shown in FIG. 7. These measured analysis results shown in FIGS. 9 through 13 are provided only for purposes of illustration and not for purposes of limitation. Generally, these results show that the omnidirectional multi-band antenna 400 is operable essentially as a dual band dipole in at least two frequency bands – a low band (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.) and a high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.).

[0080] More specifically, FIG. 9 is a line graph illustrating measured return loss in decibels for the antenna 400 over a frequency range of 1 gigahertz to 6 gigahertz. FIG. 10 illustrates measured azimuth radiation patterns (azimuth plane, theta 90 degree) for the antenna 400 for a frequency of 2450 megahertz. FIG. 11 illustrates measured azimuth radiation patterns (azimuth plane, theta 90 degree) for the antenna 400 for frequencies of 4900 megahertz, 5470 megahertz, and 5780 megahertz. FIG. 12 illustrates measured zero degree elevation radiation patterns (phi zero degree plane) for the antenna 400 for a frequency of 2450 megahertz. FIG. 13 illustrates measured zero degree elevation radiation patterns (phi zero degree plane) for the antenna 400 for frequencies of 4900 megahertz, 5470 megahertz, and 5780 megahertz.

[0081] The table 1 below provides measured performance data relating to gain and efficiency for the omnidirectional multi-band antenna 400

shown in FIG. 7. As shown, the antenna 400 may be configured to achieve about 2 dBi gain for the 2.45 gigahertz band and about 3 dBi to 6 dBi for the 5 gigahertz band. This exemplary embodiment of the antenna 400 may achieve such results with a relatively small size and be manufacturable relatively easily as compared to the manufacture of back-to-back dipole antennas that utilize a double-sided printed circuit board.

Table 1: Summary of Results for Antenna 400

Performance Summary Data

Frequency (MHz)	3D		Azimuth		Elevation 0		Elevation 90	
	Efficiency	Max Gain	Max Gain	Average Gain	Max Gain	Average Gain	Max Gain	Average Gain
2400	84%	1.91	1.36	0.71	1.31	-4.60	1.31	-4.60
2450	84%	2.28	1.73	0.47	1.66	-4.09	1.66	-4.09
2500	78%	1.94	1.42	-0.21	1.75	-3.94	1.75	-3.94
4900	79%	3.26	3.11	1.48	1.17	-4.17	1.17	-4.17
5150	74%	3.29	3.12	1.38	1.20	-4.67	1.20	-4.67
5350	87%	4.13	3.74	2.31	1.31	-4.23	1.85	-4.23
5470	96%	5.11	4.42	2.79	2.65	-3.81	2.65	-3.81
5710	96%	5.00	4.10	1.20	3.77	-1.57	3.77	-1.57
5780	99%	5.00	4.17	2.03	2.50	-2.25	2.50	-2.25
5875	94%	6.25	2.71	0.48	5.16	-1.38	2.50	-1.38

[0082] FIG. 14 and 15 illustrate two other exemplary embodiments of omnidirectional multi-band antennas 500 and 600, respectively, according to one or more aspects of the present disclosure. The lower portions or planar skirt elements 504, 604 and substrates 512, 612 may be generally similar to the lower portion 404 and substrate 412 of antenna 400 discussed above. Accordingly, the radiating and ground elements 518, 618, slots 519, 619, and connecting elements 520, 620 of the respective antennas 500, 600 may be similarly sized and shaped to the corresponding elements 418, slots 419, and connecting element 420 of antenna 400. In addition, a feed (*e.g.*, a coaxial cable, etc.) may be connected (*e.g.*, soldered, etc.) to the antennas 500, 600 in a similar manner as discussed above for the antenna 400. Alternative embodiments may include other feeding arrangements and/or differently configured lower portions and elements thereof.

[0083] As shown by a comparison of FIGS. 7, 14, and 15, there are differences in the shapes of the upper portions 502, 602 of the respective antennas 500, 600 as compared to each other and to the upper portion 402 of the antenna 400. For example, the antenna 500 includes a generally n-shaped slot feature 516 (*e.g.*, one or more slots that cooperative define a

shape similar to the English alphabetic lower case letter "n"). The antenna 600 includes a generally v-shaped slot feature 616 (*e.g.*, one or more slots that cooperative define a shape similar to the English alphabetic letter "v").

[0084] With continued reference to FIG. 14, the antenna 500 may be configured such that the antenna 500 is operable essentially as or similar to a standard half wavelength dipole antenna at a first frequency range (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.) and operable essentially as or similar to a wavelength dipole antenna at a second frequency band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.). At the first frequency range, the antenna 500 may be operable such that the radiating element 508 has an electrical length of about λ/4. In this example, the electrical length of the radiating element 506 at the first frequency range or low band is relatively small such that the radiating element 506 should not really be considered an effective radiating element at this first frequency range or low band. Accordingly, only radiating element 508 is essentially radiating at the low band. But at the second frequency range or high band, both radiating elements 506, 508 are effective radiation with the radiating element 508 having an electrical wavelength of about λ/2 and the radiating element 506 having an electrical wavelength of about λ/4.

[0085] The antenna's upper portion 502 includes a tapering feature 514 for impedance matching. The illustrated tapering feature 514 is generally V-shaped (*e.g.*, having a shape similar to the English alphabetic letter "v"). As shown in FIG. 15, the tapering feature 514 comprises the lower edge of the radiating elements of the antenna's upper portion 502 that is spaced apart from the lower portion 504 and oriented such that it is pointing generally at the middle of the connecting element 520 of the antenna's lower portion 504.

[0086] Slots 516 are introduced to the upper radiating elements 506, 508, which help enable multi-band operation of the antenna 500. The slots 516 cooperative define a shape similar to the English alphabetic lower case letter "n", such that the slots 516 include a generally rectangular top portion 532, two downwardly extending straight portions 534, and inwardly angled end portions 536.

[0087] By way of example, the upper radiating elements 506, 508 and slots 516 may be configured such that the upper radiating elements 506,

508 are operable as low and high band elements, respectively. As shown in FIG. 15, the "high band" radiating element 506 includes a generally rectangular shaped portion 507 connected to the tapering feature 514. The "low" band radiating element 508 includes two straight portions 509 separated and spaced apart from the rectangular portion 507 of the "high band" radiating element 506 by the slot portions 534. The straight portions 509 are connected to the tapering feature 514 and extend away from the tapering feature 514 in a direction opposite the lower portion 504 (upwardly in FIG. 14). Each straight portion 509 extends alongside and past the general rectangular portion 507 of the "high band" radiating element 506. The "low" band radiating element 508 also includes a connecting portion 511 perpendicular to and connecting the straight portions 509. The connecting portion 511 is separated and spaced apart from the rectangular portion 507 of the "high band" radiating element 506 by the slot portion 532.

[0088] In the particular embodiment shown in FIG. 14, the slots 516 may be carefully tuned so that the antenna 500 operates at high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.) with the upper and lower arms or portions 502, 504 each having an electrical length of about $\lambda/2$. But at low band (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.), the upper and lower arms or portions 502, 504 each have an electrical length of about $\lambda/4$. Alternative embodiments may include radiating elements, tapering features, and/or slots configured differently than that shown in FIG. 14, such as for producing different radiation patterns at different frequencies and/or for tuning to different operating bands.

[0089] With reference now to FIG. 15, the antenna 600 may be configured such that the antenna 600 is operable essentially as or similar to a standard half wavelength dipole antenna at a first frequency range (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.) and operable essentially as or similar to a wavelength dipole antenna at a second frequency band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.). At the first frequency range, the antenna 600 may be operable such that the radiating element 608 has an electrical length of about $\lambda/4$. In this example, the electrical length of the radiating element 606 at the first frequency range or low band is relatively small such that the radiating element 606 should not

really be considered an effective radiating element at this first frequency range or low band. Accordingly, only radiating element 608 is essentially radiating at the low band. But at the second frequency range or high band, both radiating elements 606, 608 are effective radiation with the radiating element 608 having an electrical wavelength of about λ/2 and the radiating element 606 having an electrical wavelength of about λ/4.

[0090] The antenna's upper portion 602 includes a tapering feature 614 for impedance matching. The illustrated tapering feature 614 is generally v-shaped (*e.g.*, having a shape similar to the English alphabetic letter "v"). As shown in FIG. 16, the tapering feature 614 comprises the lower edge of the radiating elements of the antenna's upper portion 602 that is spaced apart from the lower portion 604 and oriented such that it is pointing generally at the middle of the connecting element 620 of the antenna's lower portion 604.

[0091] Slots 616 are introduced to the upper radiating elements 606, 608, which help enable multi-band operation of the antenna 600. The slots 616 cooperative define a shape similar to the English alphabetic letter "v", such that the slots 616 include a lower generally triangular portion 632 and two upwardly extending straight portions 634.

[0092] By way of example, the upper radiating elements 606, 608 and slots 616 may be configured such that the upper radiating elements 606, 608 are operable as low and high band elements (*e.g.*, 2.45 gigahertz band and 5 gigahertz band, etc.), respectively. As shown in FIG. 15, the "high band" radiating element 606 includes a generally rectangular shaped portion 607 connected to the tapering feature 614. The "low" band radiating element 608 includes two straight portions 609 separated and spaced apart from the rectangular portion 607 of the "high band" radiating element 606 by the slots 616. The straight portions 609 are connected to the tapering feature 614 and extend away from the tapering feature 614 in a direction opposite the lower portion 604 (upwardly in FIG. 15). Each straight portion 609 extends alongside and past the general rectangular portion 607 of the "high band" radiating element 606. The "low" band radiating element 608 also includes a connecting portion 611 perpendicular to and connecting the straight portions 609.

[0093] In the particular embodiment shown in FIG. 15, the slots 616 may be carefully tuned so that the antenna 600 operates at high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.) with the upper and lower arms or portions 602, 604 each having an electrical length of about $\lambda/2$. But at low band (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.), the upper and lower arms or portions 602, 604 each have an electrical length of about $\lambda/4$. Alternative embodiments may include radiating elements, tapering features, and/or slots configured differently than that shown in FIG. 15, such as for producing different radiation patterns at different frequencies and/or for tuning to different operating bands.

[0094] FIG. 16 illustrates another example embodiment of an omnidirectional multi-band antenna 700 including one or more aspects of the present disclosure. The antenna 700 includes upper and lower portions 702, 704 configured such that the antenna 700 may be operable as or similar to a wavelength dipole antenna at a first frequency range or low band (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.) and an array antenna at a second frequency range or high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.).

[0095] In this particular embodiment, the upper portion 702 includes three segments or parts 703, 705, 709. The antenna's lower portion or planar skirt element 704 and substrate 712 may be generally similar to the lower portion 404 and substrate 412 of antenna 400 discussed above. For example, the radiating and ground elements 718, slots 719, and connecting element 720 of the antenna 700 may be similarly sized and shaped to the corresponding elements 418, slots 419, and connecting element 420 of antenna 400. In addition, a feed may be connected to the antenna 700 in a similar manner as discussed above for the antenna 400. For example, inner and outer conductors 726, 728 of a coaxial cable 722 (*e.g.*, IPEX coaxial connector, etc.) may be soldered 724, 726 to feed points of the antenna 700. Alternative embodiments may include other feeding arrangements and/or differently configured lower portions and elements thereof.

[0096] As shown in FIG. 17, the antenna 700 may be configured to be operable at low band (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.) with the upper portion 702 having an electrical length of

about three quarter wavelength (3λ/4) and the lower portion 704 having an electrical length of about one quarter wavelength (λ/4). At high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.), the antenna 70 may be operable with the lower portion 704 and each of three segments 703, 705, 709 of the upper portion 702 all having an electrical length of about one half wavelength (λ/2). Alternative embodiments may include radiating elements, tapering features, and/or slots configured differently than that shown in FIGS. 16 and 17, such as for producing different radiation patterns at different frequencies and/or for tuning to different operating bands.

[0097] With further reference to FIG. 16, each segment 703, 709 of the upper portion 702 includes a tapering feature 714 for impedance matching. The illustrated tapering feature 714 is generally V-shaped (*e.g.*, having a shape similar to the English alphabetic letter "v").

[0098] Slots 716 are introduced to the radiating elements of the segments 703, 709 of the upper portion 702, which help enable multi-band operation of the antenna 700. The slots 716 include a top portion 732, two downwardly extending straight portions 734, and inwardly angled end portions 736. When the antenna 700 is operating, the slots 716 may help inhibit the antenna radiation pattern from squinting downward and/or also help make the radiation patterns tilt at horizontal.

[0099] Also shown in FIG. 16, each segment 703, 709 includes a generally rectangular shaped portion 707 connected to the corresponding tapering feature 714. Each segment 703, 709 also includes two L-shaped portions 710 (*e.g.*, portions shaped like the English alphabetic capital letter "L") separated and spaced apart from the corresponding rectangular portion 707 by the slot portions 732, 734. Each L-shaped portion 710 includes a straight portion 713 and end portion 711 perpendicular to and extending inwardly from the straight portion 713. The straight portion 713 is connected to the tapering feature 714 and extends away from the tapering feature 714 in a direction opposite the lower portion 704 (upwardly in FIG. 16). Each straight portion 713 of the L-shaped portion 710 extends alongside and past the general rectangular portion 707. The end portion 711 of each L-shaped portion 710 extends inwardly from the corresponding straight portion 713 toward the end portion 711 of the other L-shaped portion 710. The end

portions 711 are aligned with each other but are spaced-apart from each other and the generally rectangular portion 707 by slots 716. In addition, each end portion 711 extends inwardly from the corresponding straight portion 713 a sufficient distance such that each end portion 711 partially overlaps the width of the rectangular portion 707.

[00100] The middle segment 705 includes a generally straight portion 715 connected to the tapering feature 714 of the upper segment 709 and the generally rectangular portion 707 of the lower segment 703. This connection allows the antenna 700 to be operable as or similar to an array antenna at the 5 gigahertz band.

[0100] The antenna 700 may be configured such that the lower portion or planar skirt element 704 has an electrical length of about one quarter wavelength (λ/4) at low band (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.). When the outer conductor 730 of coaxial cable 722 is connected (*e.g.*, soldered, etc.) to the planar skirt element 704, the planar skirt element 704 may behave as a quarter wavelength (λ/4) choke at low band. In which case, the antenna current (or at least a portion thereof) does not leak into the outer surface of the coaxial cable 722.

[0101] FIGS. 18 through 21 illustrate measured analysis results for the omnidirectional multi-band antenna 700 shown in FIG. 16. These measured analysis results shown in FIGS. 18 through 21 are provided only for purposes of illustration and not for purposes of limitation. Generally, these results show that the omnidirectional multi-band antenna 700 is operable essentially as or similar to a wavelength dipole at low band (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.) and a high gain array a high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.).

[0102] More specifically, FIG. 18 illustrates measured azimuth radiation patterns (azimuth plane, theta 90 degree) for the antenna 700 for frequencies of 2400 megahertz, 2450 megahertz, and 2500 megahertz. FIG. 19 illustrates measured azimuth radiation patterns (azimuth plane, theta 90 degree) for the antenna 700 for frequencies of 4900 megahertz, 5150 megahertz, 5350 megahertz, and 5850 megahertz. FIG. 20 illustrates measured zero degree elevation radiation patterns (phi zero degree plane) for

the antenna 700 for frequencies of 2400 megahertz, 2450 megahertz, and 2500 megahertz. FIG. 21 illustrates measured zero degree elevation radiation patterns (phi zero degree plane) for the antenna 700 for frequencies of 4900 megahertz, 5150 megahertz, 5350 megahertz, and 5850 megahertz.

[0103] The table 2 below provides measured performance data relating to gain and efficiency for the omnidirectional multi-band antenna 700 shown in FIG. 16. As shown, the antenna 700 may be configured to achieve 3 dBi gain for the 2.45 gigahertz band and 4.5 dBi to 6 dBi for the 5 gigahertz band. This exemplary embodiment of the antenna 700 may achieve such results with a relatively small size and be manufacturable relatively easily as compared to the manufacture of back-to-back dipole antennas that utilize a double-sided printed circuit board.

Table 2: Summary of Results for Antenna 700

Frequency (MHz)	3D		Azimuth		Elevation 0		Elevation 90	
	Efficiency	Max Gain	Max Gain	Average Gain	Max Gain	Average Gain	Max Gain	Average Gain
2400	75%	2.64	1.55	0.10	1.81	-4.60	1.81	-4.60
2450	76%	3.09	2.26	0.20	2.20	-4.23	2.20	-4.23
2500	72%	3.10	2.23	-0.29	2.13	-3.81	2.13	-3.81

Frequency (MHz)	3D		Azimuth		Elevation 0		Elevation 90	
	Efficiency	Max Gain	Max Gain	Average Gain	Max Gain	Average Gain	Max Gain	Average Gain
4900	76%	4.58	4.17	2.70	3.16	-4.12	3.16	-4.12
5150	77%	5.44	4.41	3.24	2.91	-4.92	2.91	-4.92
5350	83%	5.63	5.36	3.89	2.66	-5.27	2.66	-5.27
5450	82%	5.43	5.25	3.85	2.61	-5.52	2.61	-5.52
5550	84%	5.62	5.41	3.85	3.01	-5.60	3.01	-5.60
5850	84%	6.01	5.81	3.34	3.92	-5.04	3.92	-5.04

[0104] FIG. 22 illustrates another exemplary embodiment of an omnidirectional multi-band antenna 800 according to one or more aspects of the present disclosure. The antenna 800 includes upper and lower portions 802, 804 configured such that the antenna 800 may be operable as or similar to a wavelength dipole antenna at a first frequency range or low band (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.) and an array antenna at a second frequency range or high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.).

[0105] In this particular embodiment of antenna 800, the upper portion 802 includes three segments or parts 803, 805, 809. The lower portion

or planar skirt element 804 and substrate 812 may be generally similar to the lower portion 404, 704 and substrate 404, 712 of antennas 400 (FIG. 7), 700 (FIG. 16) discussed above. Accordingly, the radiating and ground elements 818, slots 819 and connecting elements 820 of the antenna 800 may be similarly sized and shaped to the corresponding elements 418, 718, slots 419, 719, and connecting element 420, 720 of respective antennas 400, 700.

[0106] In FIG. 22, the antenna 800 is shown without any feed connected thereto. Instead, FIG. 22 illustrates the antenna 800 with soldering pads 840 and 842. Accordingly, a feed (*e.g.*, a coaxial cable, etc.) may be soldered to the antenna 800 in a similar manner as discussed above for the antennas 400 and 700. Alternative embodiments may include other feeding arrangements and/or differently configured lower portions and elements thereof.

[0107] The antenna 800 may be configured such that the lower portion or planar skirt element 804 has an electrical length of about one quarter wavelength ($\lambda/4$) at low band (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.). When the outer conductor of a coaxial cable is connected (*e.g.*, soldered, etc.) to the planar skirt element 804, the planar skirt element 804 may behave as a quarter wavelength ($\lambda/4$) choke at low band. In which case, the antenna current (or at least a portion thereof) does not leak into the outer surface of the coaxial cable. This allows the antenna 800 to operate essentially like a wavelength (λ) dipole antenna for the 2.45 gigahertz band.

[0108] As shown in FIG. 24, the antenna 800 may be configured to be operable as or similar to a wavelength dipole antenna at the 2.45 gigahertz band with the upper portion 802 having an electrical length of about three quarter wavelength ($3\lambda/4$) and the lower portion 804 having an electrical length of about one quarter wavelength ($\lambda/4$). At the 5 gigahertz band, the lower portion 804 and each of three segments 803, 805, 809 of the upper portion 802 have an electrical length of about one half wavelength ($\lambda/2$). Alternative embodiments may include radiating elements, tapering features, and/or slots configured differently than that shown in FIGS. 22 and 24, such as for producing different radiation patterns at different frequencies and/or for tuning to different operating bands.

[0109] With further reference to FIG. 22, each segment 803, 809 of the upper portion 802 includes a tapering feature 814 for impedance matching. The illustrated tapering feature 814 is generally V-shaped (*e.g.*, having a shape similar to the English alphabetic letter "v"). The tapering feature 814 comprises the lower edge of the radiating elements of the corresponding segment 803, 809 that is oriented such that it is pointing generally downwardly.

[0110] Slots 816 are introduced to the radiating elements of the segments 803, 809 of the upper portion 802, which help enable multi-band operation of the antenna 800. The segment 803 includes a generally n-shaped slot feature (*e.g.*, one or more slots that cooperative define a shape similar to the English alphabetic lower case letter "n"). The slots 816 associated with each segment 803, 809 include top portions 832, two downwardly extending straight portions 834, and inwardly angled end portions 836. When the antenna 800 is operating, the slots 816 may help inhibit the antenna radiation pattern from squinting downward and/or may help make the radiation patterns tilt at horizontal.

[0111] Also shown in FIG. 22, the segment 803 includes a generally rectangular shaped portion 807 connected to the tapering feature 814 of the segment 803. The segment 803 also includes two L-shaped portions 810 (*e.g.*, portions shaped like the English alphabetic capital letter "L") separated and spaced apart from the corresponding rectangular portion 807 by the slots. Each L-shaped portion 810 includes a straight portion 813 and end portion 811 perpendicular to and extending inwardly from the straight portion 813. The straight portion 813 is connected to the tapering feature 814 and extends away from the tapering feature 814 in a direction opposite the lower portion 804 (upwardly in FIG. 22). Each straight portion 813 of the L-shaped portion 810 extends alongside and past the general rectangular portion 807. The end portion 811 of each L-shaped portion 810 extends inwardly from the corresponding straight portion 813 toward the end portion 811 of the other L-shaped portion 810. The end portions 811 are aligned with each other but are spaced-apart from each other and the generally rectangular portion 807 by slots 816. In addition, each end portion 811 extends inwardly from the

corresponding straight portion 813 a sufficient distance such that each end portion 811 partially overlaps the width of the rectangular portion 807.

[0112] The segment 809 includes a generally rectangular shaped portion 807 connected to the tapering feature 814 of the segment 809. The segment 809 further includes two straight portions 809 separated and spaced apart from the rectangular portion 807 by slots. The straight portions 809 are connected to and extend away from the tapering feature 814 in a direction opposite the lower portion 804 (upwardly in FIG. 22). Each straight portion 809 extends alongside and past the general rectangular portion 807. The segment 809 also includes a connecting portion 811 perpendicular to and connecting the straight portions 809. The connecting portion 811 is separated and spaced apart from the rectangular portion 807 by the slot portion 532.

[0113] The middle segment 805 includes a generally straight portion 815 connected to the tapering feature 814 of the upper segment 809 and the generally rectangular portion 807 of the lower segment 803. This connection allows the antenna 800 to be operable as or similar to an array antenna at high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.).

[0114] By way of example, FIG. 24 illustrates exemplary dimensions in millimeters for the antenna 800 according to an exemplary embodiment, where these dimensions are provided for purposes of illustration only and not for purposes of limitation. Alternative embodiments may include an antenna sized differently than what is shown in FIG. 24.

[0115] FIGS. 25 through 31 illustrate computer-simulated analysis results for the omnidirectional multi-band antenna 800 shown in FIG. 22. These computer-simulated analysis results shown in FIGS. 25 through 31 are provided only for purposes of illustration and not for purposes of limitation. Generally, these analysis results show that the omnidirectional multi-band antenna 800 is operable essentially as or similar to a wavelength dipole at low band (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.) and an array antenna at high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.).

[0116] More specifically, FIG. 25 is a line graph illustrating computer-simulated S1,1 parameter/return loss in decibels for the antenna

800 over a frequency range of 2 gigahertz to 6 gigahertz. FIG. 26 illustrates computer-simulated far field realized gain in decibels for the antenna 800 at a frequency of 2.45 gigahertz, where the total efficiency was -0.2961 decibels and realized gain was 2.258 decibels, thereby indicating that the omnidirectional multi-band antenna shown in FIG. 22 is essentially operable as or similar to a wavelength dipole antenna at the frequency of 2.45 gigahertz but with a half wavelength radiation pattern. FIG. 27 illustrates computer-simulated azimuth radiation patterns (azimuth plane, theta 90 degree) for the antenna 800 for a frequency of 2.45 gigahertz. FIG. 28 illustrates computer-simulated zero degree elevation radiation patterns (phi zero degree plane) for the antenna 800 for a frequency of 2.45 gigahertz. FIG. 29 illustrates computer-simulated far field realized gain in decibels for the antenna 800 at a frequency of 5.5 gigahertz, where the total efficiency was -0.1980 decibels and realized gain was 5.441 decibels, thereby indicating that the omnidirectional multi-band antenna shown in FIG. 22 is essentially operable as or similar to a collinear dipole antenna array having high gain properties at the frequency of 5.5 gigahertz, FIG. 30 illustrates computer-simulated azimuth radiation patterns (azimuth plane, theta 90 degree) for the antenna 800 for a frequency of 5.5 gigahertz. FIG. 31 illustrates computer-simulated zero degree elevation radiation patterns (phi zero degree plane) for the antenna 800 for a frequency of 5.5 gigahertz.

[0117] FIGS. 32 through 34 illustrate several other exemplary embodiments of omnidirectional multi-band antennas 900, 1000, 1100 according to one or more aspects of the present disclosure. Each antenna 900, 1000, 1100 is configured for operation similar to the antennas 400 (FIG. 6), 500 (FIG. 14), 600 (FIG. 15), but each antenna 900, 1000, 1100 has some differences in the shapes of their radiating elements and/or the slots. For example, each antenna 1000 (FIG. 33) and 1100 (FIG. 34) includes a lower portion or planar skirt element 1004, 1104 generally similar to the lower portion 404 of antenna 400 (FIG. 7). Each antenna 900, 1000, and 1100 includes tapering features 914, 1014, 1114. But the antennas 900, 1000, 1100 have upper portions 902, 1002, 1102 with radiating elements 906, 908, 1006, 1008, 1106, 1108 and slots 916, 1016, 1116 configured differently (e.g., sized, shaped, located, etc.) than each other and configured differently from the

radiating elements 406, 408, 416 of the antenna 400. In addition, the antenna 900 (FIG. 32) also includes a lower portion 904 configured differently than lower portion 404 of antenna 400 (FIG. 7).

[0118] For each of the antennas 900, 1000, 1100, the slots 916, 1016, 1116 may be carefully tuned so that the antennas 900, 1000, 1100 each operates at high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.) with the upper and lower arms or portions each having an electrical length of about $\lambda/2$. But at low band (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.), the upper and lower arms or portions each have an electrical length of about $\lambda/4$. Alternative embodiments may include radiating elements, tapering features, and/or slots configured differently than that shown in FIGS. 32, 33, and 34, such as for producing different radiation patterns at different frequencies and/or for tuning to different operating bands.

[0119] FIG. 35 illustrates another example embodiment of an omnidirectional multi-band antenna assembly 1200 including one or more aspects of the present disclosure. In this illustrated embodiment, the antenna 1200 may be configured as a dual band antenna for operation in similar high and low frequency bands as the antennas disclosed above, but the antenna 1200 may be smaller in size with lower gain. For example, an exemplary embodiment may include the antenna 1200 being configured to be operable with 5 dBi at the 2.45 gigahertz band and 7 dBi at the 5 gigahertz band but with a non pure omnidirectional radiation pattern. By way of further example, the antenna 1200 may include a substrate 1212 with a length of 35 millimeters and a width of 11 millimeters. By way of comparison, the substrate shown in FIG. 24 has a length of about 45 millimeters and a width of about 16.6 millimeters. Accordingly, the antenna 1200 includes a tradeoff between gain and size in that the average gain is lower for the smaller antenna 1200 than the average gain for the larger antennas 400 and 700. The gain values and dimensions in this paragraph are provided for purposes of illustration only and not for purposes of limitation, as alternative embodiments of the antenna 1200 may be configured differently (*e.g.*, larger, smaller, shaped differently, configured for operation at different frequency bands and/or with higher or lower gain, etc.).

[00101] The omnidirectional multi-band antenna 1200 includes upper and lower portions 1202, 1204 configured such that the antenna 1200 may be operable as or similar to a printed dipole antenna. In the particular example shown in FIG. 35, the antenna 1200 includes upper and lower portions 1202, 1204 configured such that the antenna 1200 is operable essentially as or similar to a standard half wavelength dipole antenna at a first frequency range or low band (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.) with the upper and lower portions 1202, 1204 each having an electrical length of about λ/4. But at a second frequency range or high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.), the antenna 1200 is operable essentially as or similar to a wavelength dipole antenna with the upper and lower portions 1202, 1204 each having an electrical length of about λ/2.

[00102] At the first frequency range, the antenna 1200 may be operable such that the radiating element 1208 has an electrical length of about λ/4. But the electrical length of the radiating element 1206 at the first frequency range may be relatively small such that the radiating element 1206 should not really be considered an effective radiating element at the first frequency range. Accordingly, only radiating element 1208 is essentially radiating at the first frequency range. At the second frequency range or high band, both radiating elements 1206, 1208 are effective radiators with the radiating element 1208 having an electrical wavelength of about λ/2 and the radiating element 1206 having an electrical wavelength of about λ/4.

[00103] At the first and second frequency ranges, the lower portion 1204 may be operable as ground, which permits the antenna 1200 to be ground independent. Thus, that antenna 1200 does not depend on a separate ground element or ground plane. At the first frequency range (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.), the lower portion or planar skirt element 1204 has an electrical length of about one quarter wavelength (λ/4). With the outer conductor 1230 of coaxial cable 122 connected (*e.g.*, soldered, etc.) to the planar skirt element 1204, the planar skirt element 1204 may behave as a quarter wavelength (λ/4) choke at the first frequency range. In which case, the antenna current (or at least a portion thereof) does not leak into the outer surface of the coaxial cable 1222. This

allows the antenna 1200 to operate essentially like a half wavelength dipole antenna (λ/2) at low band. At the second frequency range or high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.), the lower portion 1204 has an electrical length of about λ/2, such that the lower portion 1204 may be considered more like a radiating element than a sleeve choke. This allows the antenna 1200 to operate essentially like a wavelength dipole antenna (λ) at high band.

[00104] The antenna's upper portion 1202 includes a tapering feature 1214 for impedance matching. The illustrated tapering feature 1214 is generally V-shaped (*e.g.*, having a shape similar to the English alphabetic letter "v"). As shown in FIG. 35, the tapering feature 1214 comprises the lower edge of the radiating elements of the antenna's upper portion 1202 that is spaced apart from the lower portion 1204 and oriented such that it is pointing generally at the middle of the connecting element 1220 of the antenna's lower portion 1204.

[0120] Slots 1216 are introduced to the upper radiating elements 1206, 1208, which help to enable multi-band operation of the antenna 1200. By way of example, the upper radiating elements 1206, 1208 and slots 1216 may be configured such that the upper radiating elements 1206, 1208 are operable as low and high band elements (*e.g.*, 2.45 gigahertz band and 5 gigahertz, etc.), respectively. In the illustrated example, the slots 1216 include a generally rectangular top portion 1232 and two downwardly extending straight portions 1234 perpendicular to the top portion 1232.

[0121] As shown in FIG. 35, the "high band" radiating element 1206 includes a generally rectangular shaped portion 1207 connected to the tapering feature 1214 such that the rectangular portion 1207 and tapering feature 1214 cooperatively define an arrow shape. The "low" band radiating element 1208 includes two L-shaped portions 1210 (*e.g.*, portions shaped like the English alphabetic capital letter "L") separated and spaced apart from the rectangular portion 1207 of the "high band" radiating element 1206 by the slot portions 1232, 1234. Each L-shaped portion 1210 includes a straight portion 1213 and an end portion 1211 perpendicular to and extending inwardly from the straight portion 1213. The straight portion 1213 is connected to the tapering feature 1214 and extends away from the tapering feature 1214 in a

direction opposite the lower portion 1204 (upwardly in FIG. 35). Each straight portion 1213 of the L-shaped portion 1210 extends alongside and past the general rectangular portion 1207 of the "high band" radiating element 1206. The end portion 1211 of each L-shaped portion 1210 extends inwardly from the corresponding straight portion 1213 toward the end portion 1211 of the other L-shaped portion 1210. The end portions 1211 are aligned with each other but are spaced-apart from each other and the generally rectangular portion 1207 of the "high band" radiating element 1206 by slots 1216. In addition, each end portion 1211 extends inwardly from the corresponding straight portion 1213 a sufficient distance such that each end portion 1211 partially overlaps the width of the rectangular portion 1207 of the "high band" radiating element 1206.

[0122] In the particular embodiment shown in FIG. 35, the slots 1216 may be carefully tuned so that the antenna 1200 operates at high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.) with the upper and lower arms or portions 1202, 1204 each having an electrical length of about $\lambda/2$. But at low band (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.), the upper and lower arms or portions 1202, 1204 each have an electrical length of about $\lambda/4$. Alternative embodiments may include radiating elements, tapering features, and/or slots configured differently than that shown in FIG. 35, such as for producing different radiation patterns at different frequencies and/or for tuning to different operating bands.

[0123] The antenna 1200 may include feed locations or points (*e.g.*, solder pads, etc.) for connection to a feed. In the illustrated example shown in FIG. 127, the feed is a coaxial cable 1222 (*e.g.*, IPEX coaxial connector, etc.) soldered 1224, 1226 to the feed points of the antenna 1200. More specifically, an inner conductor 1228 of the coaxial cable 1222 is soldered 1224 to the feed location adjacent and/or on a portion of the tapering feature 1214 of the upper radiating portion 1202. The outer conductor 1230 of the coaxial cable 1222 is soldered 1226 to the connecting element 1220 and/or middle element 1218 of the skirt or lower portion 1204. The outer conductor 1230 may be soldered along a length of the middle element 1218 and/or directly to the substrate 1212, for example, to provide additional strength and/or reinforcement to the connection of the coaxial cable 1222. Alternative

embodiments may include other feeding arrangements, such as other types of feeds besides coaxial cables and/or other types of connections besides soldering, such as snap connectors, press fit connections, etc.

[0124] FIGS. 36 through 43 illustrate analysis results measured for a prototype of the omnidirectional multi-band antenna 1200 shown in FIG. 35. These analysis results shown in FIGS. 36 through 43 are provided only for purposes of illustration and not for purposes of limitation. Generally, these analysis results show that the omnidirectional multi-band antenna 1200 is operable essentially as a dual band dipole in at least two frequency bands – a **low band** (*e.g.*, the 2.45 gigahertz band from 2.4 gigahertz to 2.5 gigahertz, etc.) and a high band (*e.g.*, the 5 gigahertz band from 4.9 gigahertz to 5.875 gigahertz, etc.). The analysis results also show that the antenna 1200 is capable of operating at both free space and load with plastic cover unlike some existing multi-band printed dipoles that may incur significant frequency changes when loaded with dielectric.

[0125] More specifically, FIG. 36 is a line graph illustrating return loss in decibels measured for a prototype of the antenna 1200 operating in free space over a frequency range of 1 gigahertz to 6 gigahertz. FIG. 37 is a line graph illustrating return loss in decibels measured for the prototype of the antenna 1200 operating at load with plastic cover over a frequency range of 1 gigahertz to 6 gigahertz. FIG. 38 illustrates azimuth radiation patterns (azimuth plane, theta 90 degree) measured for the prototype of the antenna 1200 for frequencies of 2400 megahertz, 2450 megahertz, and 2500 megahertz. FIG. 39 illustrates azimuth radiation patterns (azimuth plane, theta 90 degree) measured for the prototype of the antenna 1200 for frequencies of 4900 megahertz, 5150 megahertz, 5350 megahertz, 5470 megahertz, 5710 megahertz, 5780 megahertz, and 5850 megahertz. FIG. 40 illustrates zero degree elevation radiation patterns (phi zero degree plane) measured for the prototype of the antenna 1200 for frequencies of 2400 megahertz, 2450 megahertz, and 2500 megahertz. FIG. 41 illustrates zero degree elevation radiation patterns (phi zero degree plane) measured for the prototype of the antenna 1200 for frequencies of 4900 megahertz, 5150 megahertz, 5350 megahertz, 5470 megahertz, 5710 megahertz, 5780 megahertz, and 5850 megahertz. FIG. 42 illustrates elevation radiation patterns (phi 90 degree)

measured for the prototype of the antenna 1200 for frequencies of 2400 megahertz, 2450 megahertz, and 2500 megahertz. FIG. 43 illustrates elevation radiation patterns (phi 90 degree) measured for the prototype of the antenna 1200 for frequencies of 4900 megahertz, 5150 megahertz, 5350 megahertz, 5470 megahertz, 5710 megahertz, 5780 megahertz, and 5850 megahertz.

[0126] The table 3 below provides performance data relating to gain and efficiency that was measured during testing of the prototype of the antenna 1200 shown in FIG. 35.

Table 3. Summary of Results for Antenna 1200

Frequency (MHz)	3D		Azimuth		Elevation 0		Elevation 90	
	Efficiency	Max Gain	Max Gain	Average Gain	Max Gain	Average Gain	Max Gain	Average Gain
2400	74%	4.69	0.78	-3.88	4.05	-2.94	4.05	-2.94
2450	75%	5.12	0.26	-4.01	4.57	-3.10	4.57	-3.10
2500	75%	4.83	-0.35	-4.24	4.56	-3.49	4.56	-3.49
4900	67%	3.55	3.53	-2.15	-2.37	-7.86	-2.37	-7.86
5150	70%	4.58	4.57	-1.73	-1.55	-7.15	-1.55	-7.15
5350	72%	5.17	4.846	-1.85	4.05	-6.49	-1.40	-6.49
5470	73%	5.68	5.47	-2.41	0.50	-5.94	0.50	-5.94
5710	92%	6.09	5.53	-1.04	3.62	-2.89	3.62	-2.89
5780	97%	7.02	6.47	-0.96	4.83	-2.65	4.83	-2.65
5850	94%	7.02	6.55	-1.14	4.846	-2.91	4.83	-2.91

[0127] The various radiating elements disclosed herein may be made of electrically-conductive material, such as, for example, copper, silver, gold, alloys, combinations thereof, other electrically-conductive materials, etc. Further, the upper and lower elements may all be made out of the same material, or one or more may be made of a different material than the others. Still further, a "high band" radiating element may be made of a different material than the material from which a "low band" radiating element is formed. Similarly, the lower elements may each be made out of the same material, different material, or some combination thereof. The materials

provided herein are for purposes of illustration only as an antenna may be configured from different materials and/or with different shapes, dimensions, etc. depending, for example, on the particular frequency ranges desired, presence or absence of a substrate, the dielectric constant of any substrate, space considerations, etc.

[0128] In the various exemplary embodiments of the antennas disclosed herein (*e.g.*, antenna 400 (FIG. 7), antenna 500 (FIG. 14), antenna 600 (FIG. 15), antenna 700 (FIG. 16), antenna 800 (FIG. 22), antenna 900 (FIG. 32), antenna 1000 (FIG. 33), antenna 1100 (FIG. 34), antenna 1200 (FIG. 35)), radiating elements may all be supported on the same side of a substrate. Allowing all the radiating elements to be on the same side of the substrate eliminates the need for a double-sided printed circuit board. The radiating elements disclosed herein may be fabricated or provided in various ways and supported by different types of substrates and materials, such as a circuit board, a flexible circuit board, sheet metal, a plastic carrier, Flame Retardant 4 or FR4, flex-film, etc. Various exemplary embodiments include a substrate comprising a flex material or dielectric or electrically non-conductive printed circuit board material. In exemplary embodiments that include substrate formed from a relatively flexible material, the antenna may be flexed or configured so as to follow the contour or shape of the antenna housing profile. The substrate may be formed from a material having low loss and dielectric properties. According to some embodiments, an antenna disclosed herein may be, or may be part of a, printed circuit board (whether rigid or flexible) where the radiating elements are all conductive traces (*e.g.*, copper traces, etc.) on the circuit board substrate. In which case, the antenna thus may be a single sided PCB antenna. Alternatively, the antenna (whether mounted on a substrate or not) may be constructed from sheet metal by cutting, stamping, etching, etc. In various exemplary embodiments, the substrate may be sized differently depending, for example, on the particular application as varying the thickness and dielectric constant of the substrate may be used to tune the frequencies. By way of example, a substrate may have a length of about 86.6 millimeters, a width of about 16.6 millimeters, and a thickness of about .80 millimeters. Alternative embodiments may include a substrate with a different configuration (*e.g.*, different shape, size, material,

etc.). The materials and dimensions provided herein are for purposes of illustration only as an antenna may be configured from different materials and/or with different shapes, dimensions, etc. depending, for example, on the particular frequency ranges desired, presence or absence of a substrate, the dielectric constant of any substrate, space considerations, etc.

[0129] As is evident by the various configurations of the illustrated embodiments of antenna 400 (FIG. 7), antenna 500 (FIG. 14), antenna 600 (FIG. 15), antenna 700 (FIG. 16), antenna 800 (FIG. 22), antenna 900 (FIG. 32), antenna 1000 (FIG. 33), antenna 1100 (FIG. 34), antenna 1200 (FIG. 35)), antennas according to the present disclosure may be varied without departing from the scope of this disclosure and the specific configurations disclosed herein are exemplary embodiments only and are not intended to limit this disclosure. For example, as shown by a comparison of FIGS. 7, 14, 15, 16, 22, 32, 33, 34, and 35, the size, shape, length, width, inclusion, etc. of the radiating elements, elements of lower portion or planar skirt element, and/or slots may be varied. One or more of such changes may be made to adapt an antenna to different frequency ranges, the different dielectric constants of any substrate (or the lack of any substrate), to increase the bandwidth of one or more resonant radiating elements, enhance one or more other features, etc.

[0130] The various antennas (*e.g.*, 400, 500, 600, 700, 800, 900, etc.) disclosed herein may be integrated in, embedded in, installed to, mounted on, etc. a wireless application device (not shown), including, for example, a personal computer, a cellular phone, personal digital assistant (PDA), etc. within the scope of the present disclosure. By way of example, an antenna disclosed herein may be mounted to a wireless application device (whether inside or outside the device housing) by means of double sided foam tape or screws. If mounted with screws, holes (not shown) may be drilled through the antenna (preferably through the substrate). The antenna may also be used as an external antenna. The antenna may be mounted in its own housing, and a coaxial cable may be terminated with a connector for connecting to an external antenna connector of a wireless application device. Such embodiments permit the antenna to be used with any suitable wireless

application device without needing to be designed to fit inside the wireless application device housing.

[0131] 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 invention. Individual elements 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 invention, and all such modifications are intended to be included within the scope of the invention.

CLAIMS

What is claimed is:

1. An omnidirectional multi-band antenna comprising:

an upper portion including at least one segment having one or more upper radiating elements, one or more tapering features, and one or more slots;

a lower portion including one or more lower radiating elements and one or more slots;

whereby the one or more slots of the upper and lower portions enable multi-band operation of the antenna and the one or more tapering features are operable for impedance matching;

whereby the antenna is operable within a first frequency range, with the lower portion and the at least one segment of the upper portion each having a electrical length of about λ/4; and

whereby the antenna is operable within a second frequency range, with the lower portion and the at least one segment of the upper portion each having a electrical length of about λ/2.

2. The antenna of claim 1, wherein:

the first frequency range is from about 2.4 gigahertz to about 2.5 gigahertz; and

the second frequency range is from 4.9 gigahertz to 5.875 gigahertz.

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

the first frequency range is the 2.45 gigahertz band; and

the second frequency range is the 5 gigahertz band.

4. The antenna of claim 1, 2, or 3, wherein the upper portion includes three segments each including one or more upper radiating elements.

5. The antenna of claim 4, wherein:

the antenna is configured to be operable within the first frequency range, such that each of the three segments of the upper portion have a electrical length of about λ/4, thereby providing the upper portion with a combined electrical length of about 3λ/4; and

the antenna is configured to be operable within the second frequency range, such that each of the three segments of the upper portion have a electrical length of about λ/2, thereby providing the upper portion with a combined electrical length of about 3λ/2.

6. The antenna of any of the preceding claims, wherein the upper portion comprises:

upper and lower segments each having one or more upper radiating elements, one or more tapering features, and one or more slots; and

a middle generally straight segment between and connected to the upper and lower segments.

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

the upper portion includes only one segment;

the antenna is configured to be operable within the first frequency range, such that the upper portion has a electrical length of about λ/4; and

the antenna is configured to be operable within the second frequency, such that the upper portion has a electrical length of about λ/2.

8. The antenna of any one of the preceding claims, wherein the one or more tapering features comprise at least one generally V-shaped edge of at least one radiating element of the at least one segment of the antenna's upper portion, and wherein the at least one generally v-shaped edge is spaced apart from the antenna's lower portion and oriented so as to point generally toward the antenna's lower portion.

9. The antenna of any one of the preceding claims, wherein the lower portion comprises a planar skirt element.

10. The antenna of any one of the preceding claims, wherein the lower portion is configured to be operable as a quarter wavelength (λ/4) choke at the first frequency range, such that at least a portion of the antenna current does not leak into an outer surface of a coaxial cable when the antenna is being fed by the coaxial cable.

11. The antenna of any one of the preceding claims, wherein the lower portion is configured to be operable as ground

12. The antenna of any one of the preceding claims, wherein the lower portion is operable as a sleeve choke at the first frequency range.

13. The antenna of any one of the preceding claims, wherein the one or more slots of the lower portion generally define a shape substantially resembling an American football field goal post (μ).

14. The antenna of any one of claims 1 through 12, wherein the lower portion comprises two generally rectangular radiating elements and a generally rectangular ground element disposed between the two radiating elements, the two radiating elements spaced apart from the ground element by the one or more slots of the lower portion of the antenna, the two radiating elements and ground element generally perpendicular to and connected to a generally rectangular connecting radiating element.

15. The antenna of any one of the preceding claims, further comprising a coaxial cable having inner and outer conductors electrically coupled to the respective upper and lower portions of the antenna.

16. The antenna of any one of the preceding claims, wherein the one or more slots of the at least one segment of the antenna's upper portion include a generally rectangular or triangular portion and two generally straight portions connected to and extending from the generally rectangular portion.

17. The antenna of claim 16, wherein the one or more slots of the at least one segment of the antenna's upper portion further comprise inwardly angled end portions connected to the straight portions.

18. The antenna of claim 16 or 17, wherein the one or more slots of the at least one segment of the antenna's upper portion includes the generally rectangular portion adjacent an upper end of the at least one segment.

19. The antenna of claim 16 or 17, wherein the one or more slots of the at least one segment of the antenna's upper portion includes the generally triangular portion adjacent the one or more tapering features of the at least one segment.

20. The antenna of any one of the preceding claims, wherein the upper radiating elements comprise high and low band radiating elements with one or more slots therebetween.

21. The antenna of claim 20, wherein the antenna is configured such that:

at the first frequency range, the low band radiating element has an electrical length of about λ/4; and

at the second frequency range, the high and low band radiating elements respectively have electrical lengths of about λ/4 and λ/2.

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

the high band radiating element includes a generally rectangular shaped portion connected to the one or more tapering features; and

the low band radiating element includes two generally straight portions connected to the one or more tapering features and extending alongside the generally rectangular portion of the high band radiating element.

23. The antenna of claim 22, wherein the generally rectangular shaped portion and the one or more tapering features cooperatively define an arrow shape.

24. The antenna of claim 22 or 23, wherein the low band radiating element further comprises a connecting element connecting the end portions of the generally straight portions.

25. The antenna of claim 22 or 23, wherein the low band radiating element further comprises two end portions generally perpendicular to and extending inwardly from a corresponding one of the generally straight portions.

26. The antenna of claim 22, 23, or 25, wherein the low band radiating element includes two generally L-shaped portions.

27. The antenna of any one of the preceding claims, wherein the one or more slots of the at least one segment of the antenna's upper portion generally define a shape substantially resembling the English alphabetic letter "v" or "n".

28. The antenna of any one of the preceding claims, wherein the antenna is operable with at least about 2 decibels referenced to isotropic gain (dBi) for the 2.45 gigahertz band and with more than 4 dBi for the 5 gigahertz band.

29. The antenna of any one of the preceding claims, wherein the antenna is configured such that:

the antenna operates essentially as a standard half wavelength dipole antenna at the 2.45 gigahertz band and a wavelength dipole antenna at the 5 gigahertz band; or

the antenna operates essentially as a wavelength dipole antenna at the 2.45 gigahertz band and a collinear array antenna at the 5 gigahertz band.

30. The antenna of any one of the preceding claims, wherein the radiating elements, the one or more tapering features, and the one or more slots are on the same side of a printed circuit board.

31. The antenna of any one of the preceding claims, further comprising a substrate supporting the upper and lower portions of the antenna on the same side of the substrate.

32. The antenna of claim 31, wherein:

the substrate comprises a circuit board; and

the upper and lower radiating elements comprise conductive traces on the circuit board.

33. A portable terminal including the antenna of any one of the preceding claims.

34. An omnidirectional multi-band antenna comprising:

an upper portion including:

an upper segment having one or more upper radiating elements, one or more tapering features, and one or more slots;

a lower segment having one or more upper radiating elements, one or more tapering features, and one or more slots;

a middle generally straight radiating segment connected to the upper and lower segments;

a lower portion including one or more lower radiating elements and one or more slots.

35. The antenna of claim 34, wherein:

the antenna is configured to be operable within a first frequency range, such that the lower portion has a electrical length of about $\lambda/4$ and such that each of the three segments of the upper portion have a electrical length of about $\lambda/4$, thereby providing the upper portion with a combined electrical length of about $3\lambda/4$; and

the antenna is configured to be operable within a second frequency range, such that the lower portion has a electrical length of about $\lambda/2$ and such that each of the three segments of the upper portion have a electrical

length of about λ/2, thereby providing the upper portion with a combined electrical length of about 3λ/2.

36. The antenna of claim 35, wherein:

the first frequency range is from about 2.4 gigahertz to about 2.5 gigahertz; and

the second frequency range is from 4.9 gigahertz to 5.875 gigahertz.

37. The antenna of claim 35 or 36, wherein:

the first frequency range is the 2.45 gigahertz band; and

the second frequency range is the 5 gigahertz band.

38. The antenna of any one of claims 34-37, wherein the one or more tapering features comprises at least one generally V-shaped edge of at least one radiating element of the corresponding upper and lower segments that is spaced apart from the antenna's lower portion and oriented so as to point generally toward the antenna's lower portion.

39. The antenna of any one of claims 35-38, wherein the lower portion is configured to be operable as a quarter wavelength (λ/4) choke at the first frequency range, such that at least a portion of the antenna current does not leak into an outer surface of a coaxial cable when the antenna is being fed by the coaxial cable.

40. The antenna of any one of the claims 35-38, wherein the lower portion is operable as a sleeve choke at the first frequency range.

41. The antenna of any one of claims 34-40, wherein the lower portion is configured to be operable as ground.

42. The antenna of any one of claims 34-41, wherein the lower portion comprises two generally rectangular radiating elements and a generally rectangular ground element disposed between the two radiating elements, the two radiating elements spaced apart from the ground element by the one or more slots of the lower portion of the antenna, the two radiating elements and ground element generally perpendicular to and connected to a generally rectangular connecting radiating element.

43. The antenna of any one of claims 34-42, further comprising a coaxial cable having inner and outer conductors electrically coupled to the respective upper and lower portions of the antenna.

44. The antenna of any one claims 34-43, wherein the one or more slots of each of the upper and lower segments includes a generally rectangular portion, two generally straight portions connected to and extending from the generally rectangular portion generally towards the antenna's lower portion, and inwardly angled end portions connected to the straight portions.

45. The antenna of any one of claims 34-44, wherein:

the upper segment includes a generally rectangular shaped portion connected to the one or more tapering features of the upper segment, two generally straight portions connected to the one or more tapering features, and a connecting element connecting the end portions of the generally straight portions; and

the lower segment includes a generally rectangular shaped portion connected to the one or more tapering features of the lower segment, and two generally L-shaped straight portions connected to the one or more tapering features and extending alongside the generally rectangular portion.

46. The antenna of any one of claims 34-45, wherein the radiating elements, the one or more tapering features, and the one or more slots are on the same side of a printed circuit board.

47. The antenna of any one of claims 34-46, further comprising a substrate supporting the upper and lower portions of the antenna on the same side of the substrate.

48. The antenna of claim 47, wherein:

the substrate comprises a circuit board; and

the radiating elements comprise conductive traces on the circuit board.

49. A portable terminal including the antenna of any one of claims 34-48.

50. An omnidirectional multi-band antenna comprising:

an upper portion including one or more upper radiating elements and one or more slots, the one or more slots including a generally rectangular portion and two generally straight portions connected to and extending from the generally rectangular portion; the one or more upper radiating elements comprise high and low band radiating elements with one or more slots

therebetween, the high band radiating element includes a generally rectangular shaped portion, the low band radiating element includes two generally straight portions extending alongside the generally rectangular portion of the high band radiating element and two end portions generally perpendicular to and extending inwardly from a corresponding one of the generally straight portions; and

a lower portion including one or more lower radiating elements;

wherein at least one of the one or more upper radiating elements defining a generally V-shaped edge oriented so as to point generally toward the antenna's lower portion.

51. The antenna of claim 50, wherein:

the antenna is operable within a first frequency range, with the upper and lower portions each having a electrical length of about λ/4; and

the antenna is operable within a second frequency range, with the upper and lower portions each having a electrical length of about λ/2.

52. The antenna of claim 51, wherein:

the first frequency range is from about 2.4 gigahertz to about 2.5 gigahertz; and

the second frequency range is from 4.9 gigahertz to 5.875 gigahertz.

53. The antenna of claim 51 or 52, wherein:

the first frequency range is the 2.45 gigahertz band; and

the second frequency range is the 5 gigahertz band.

54. The antenna of any one of claims 51-53, wherein the antenna is configured such that:

at the first frequency range, the low band radiating element has an electrical length of about λ/4; and

at the second frequency range, the high and low band radiating elements respectively have electrical lengths of about λ/4 and λ/2.

55. The antenna of any one of claims 51-54, wherein the lower portion is configured to be operable as a quarter wavelength (λ/4) choke at the first frequency range, such that at least a portion of the antenna current

does not leak into an outer surface of a coaxial cable when the antenna is being fed by the coaxial cable.

56. The antenna of any one of the claims 51-55, wherein the lower portion is operable as a sleeve choke at the first frequency range.

57. The antenna of any one of claims 50-56, wherein the lower portion is configured to be operable as ground.

58. The antenna of any one of claims 50-57, wherein the one or more slots of the lower portion generally define a shape substantially resembling an American football field goal post (μ).

59. The antenna of any one of claims 50-58, further comprising a coaxial cable having inner and outer conductors electrically coupled to the respective upper and lower portions of the antenna.

60. The antenna of any one of claims 50-59, wherein the radiating elements, the one or more tapering features, and the one or more slots are on the same side of a printed circuit board.

61. The antenna of any one of claims 50-60, further comprising a substrate supporting the upper and lower portions of the antenna on the same side of the substrate.

62. The antenna of claim 61, wherein:

the substrate comprises a circuit board; and

the radiating elements comprise conductive traces on the circuit board.

63. A portable terminal including the antenna of any one of claims 50-62.

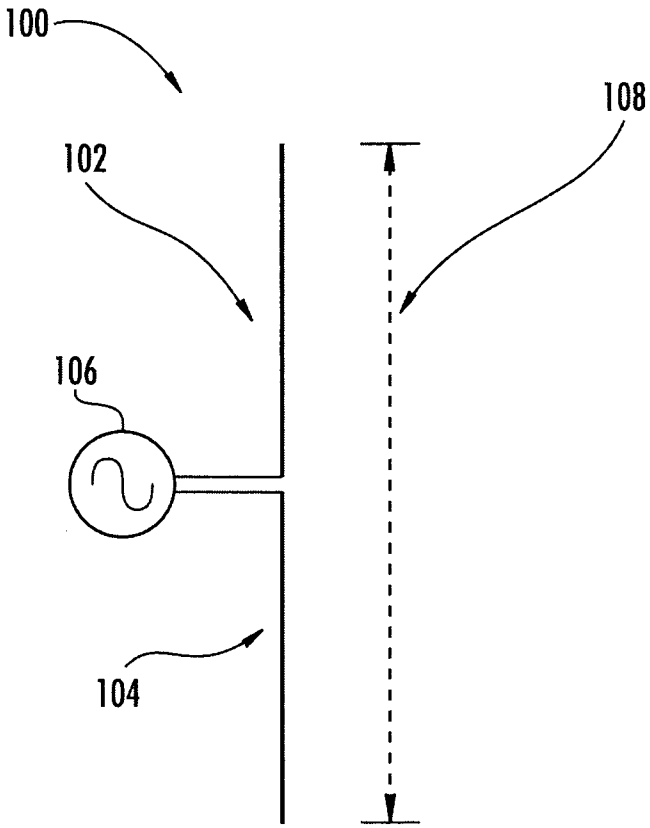


FIG. 1

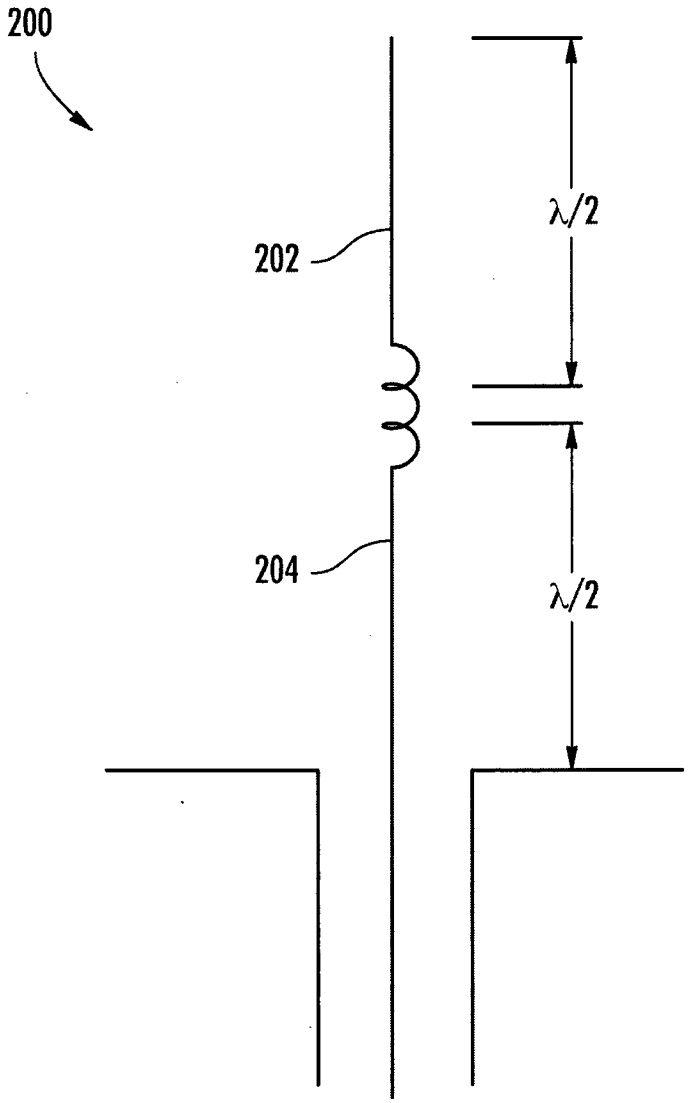


FIG. 2

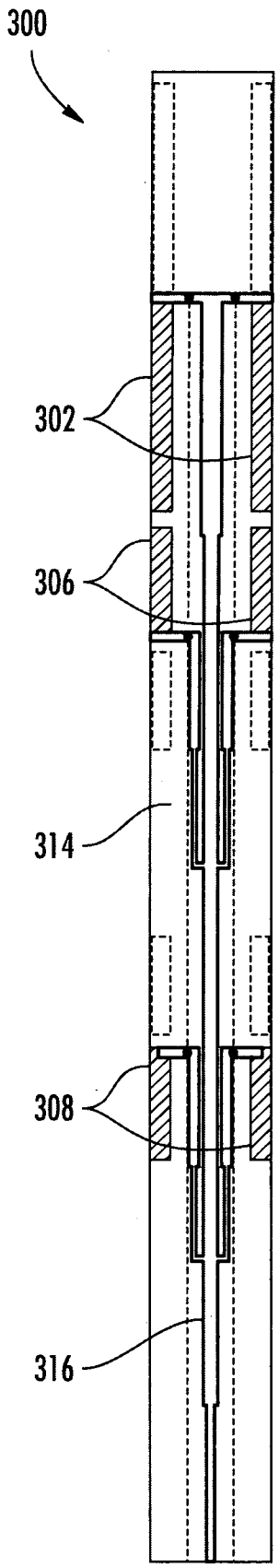


FIG. 3

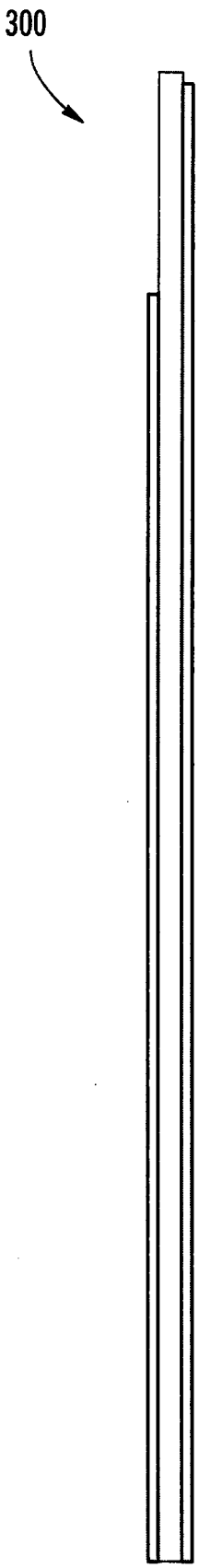


FIG. 4

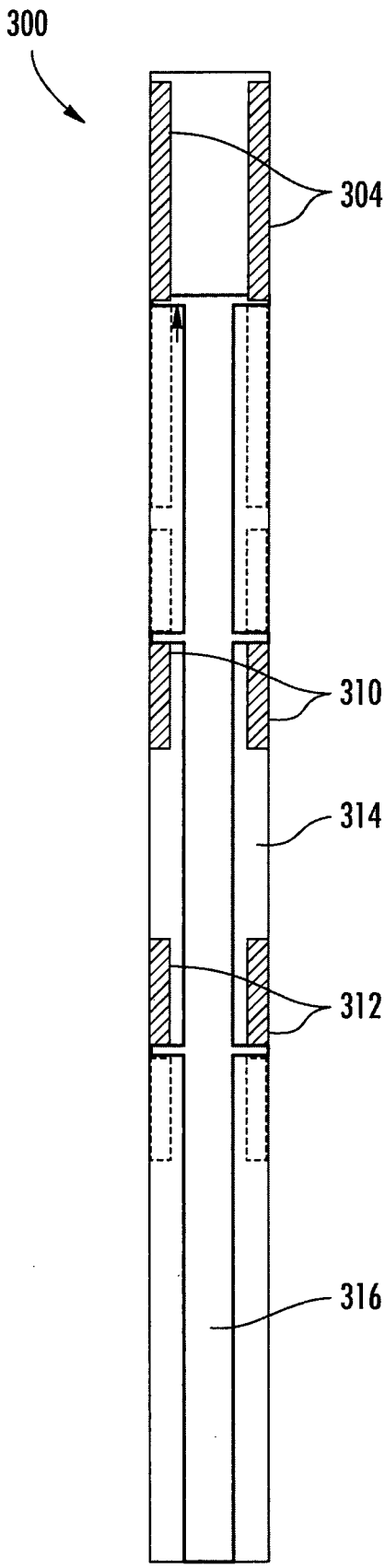


FIG. 5

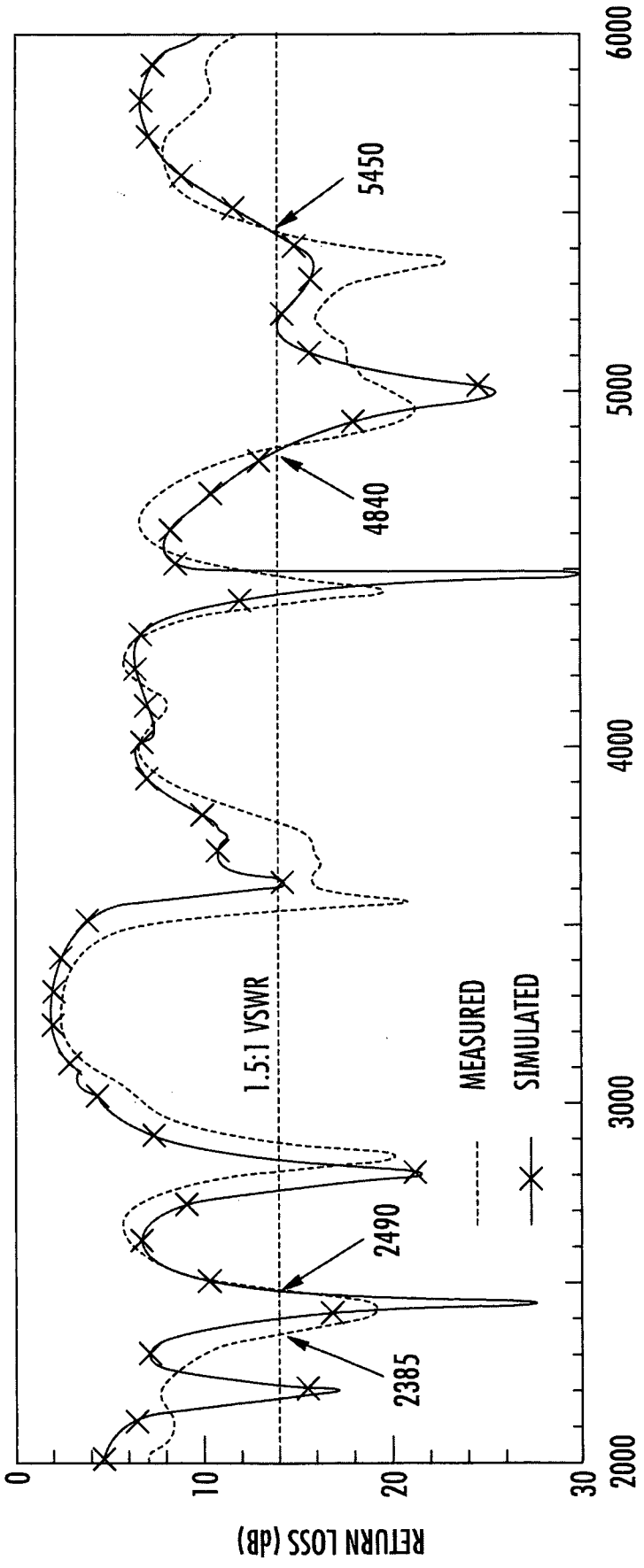

RETURN LOSS (dB)
0
10
20
30
2000
3000
4000
5000
6000
FREQUENCY (MHz)
1.5:1 VSWR
MEASURED
SIMULATED
2385
2490
4840
5450

FIG. 6

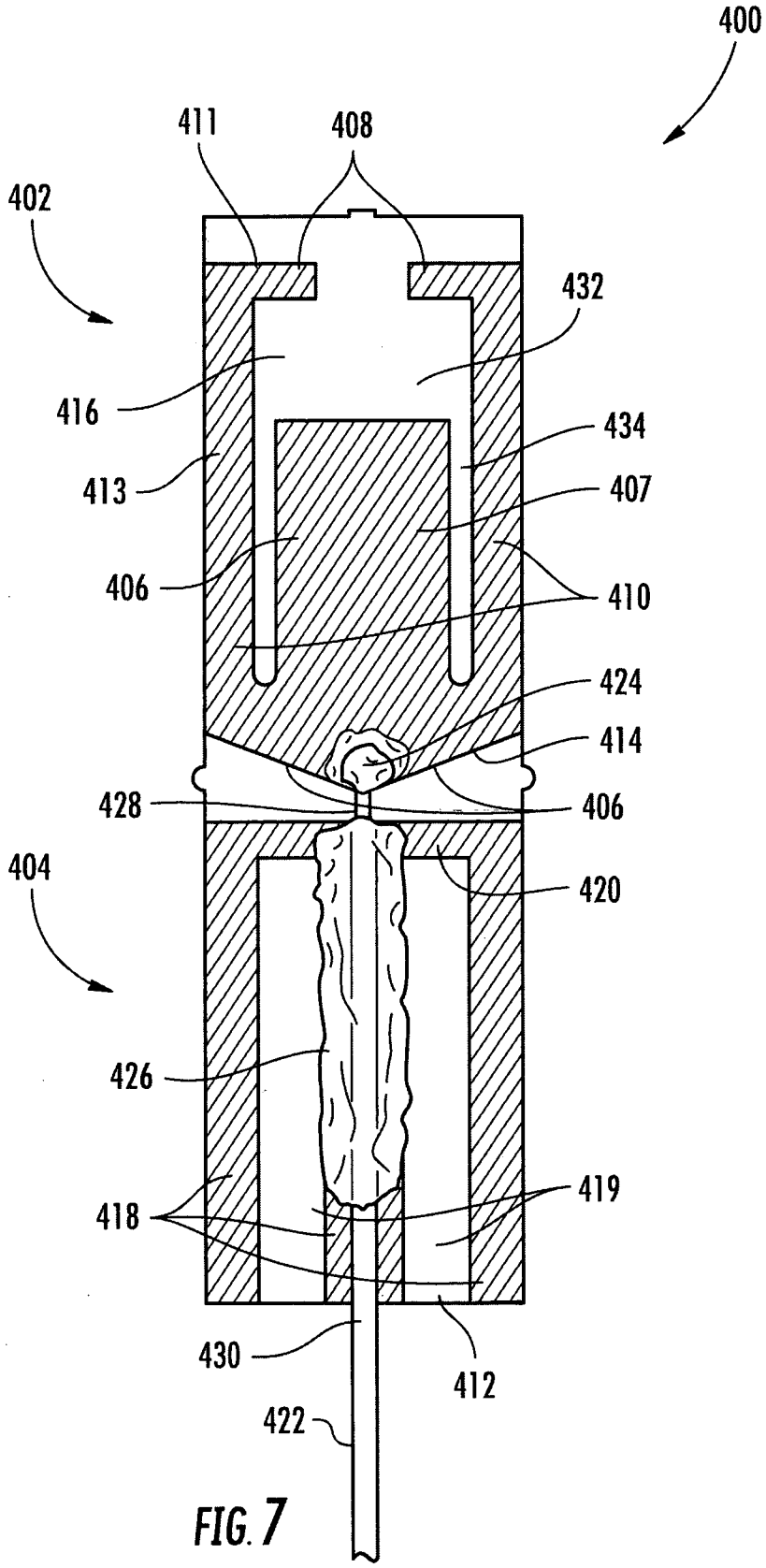

400
411
408
402
432
416
434
413
407
406
410
424
414
428
406
404
420
426
419
418
430
412
422

FIG. 7

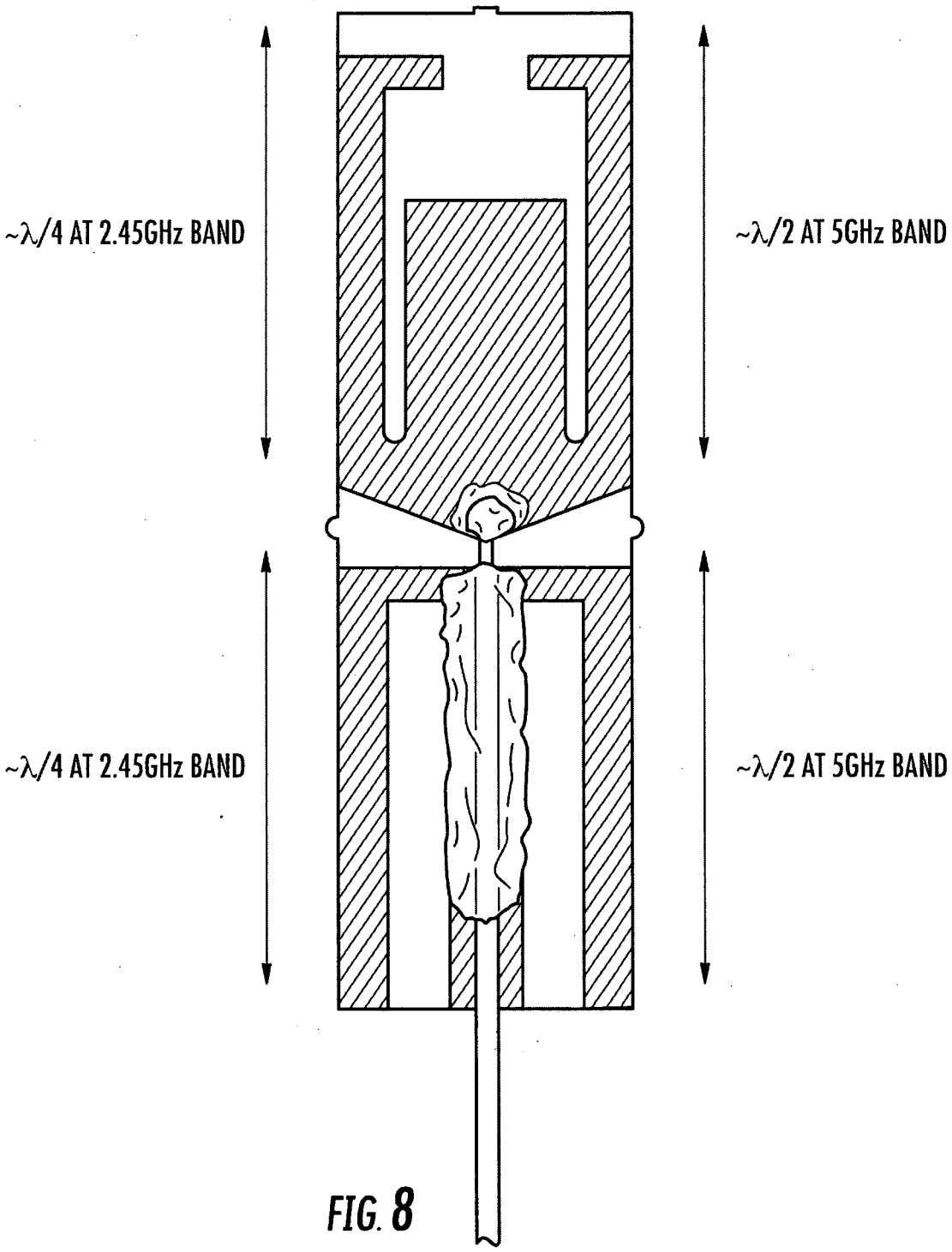

~λ/4 AT 2.45GHz BAND
~λ/2 AT 5GHz BAND
~λ/4 AT 2.45GHz BAND
~λ/2 AT 5GHz BAND

FIG. 8

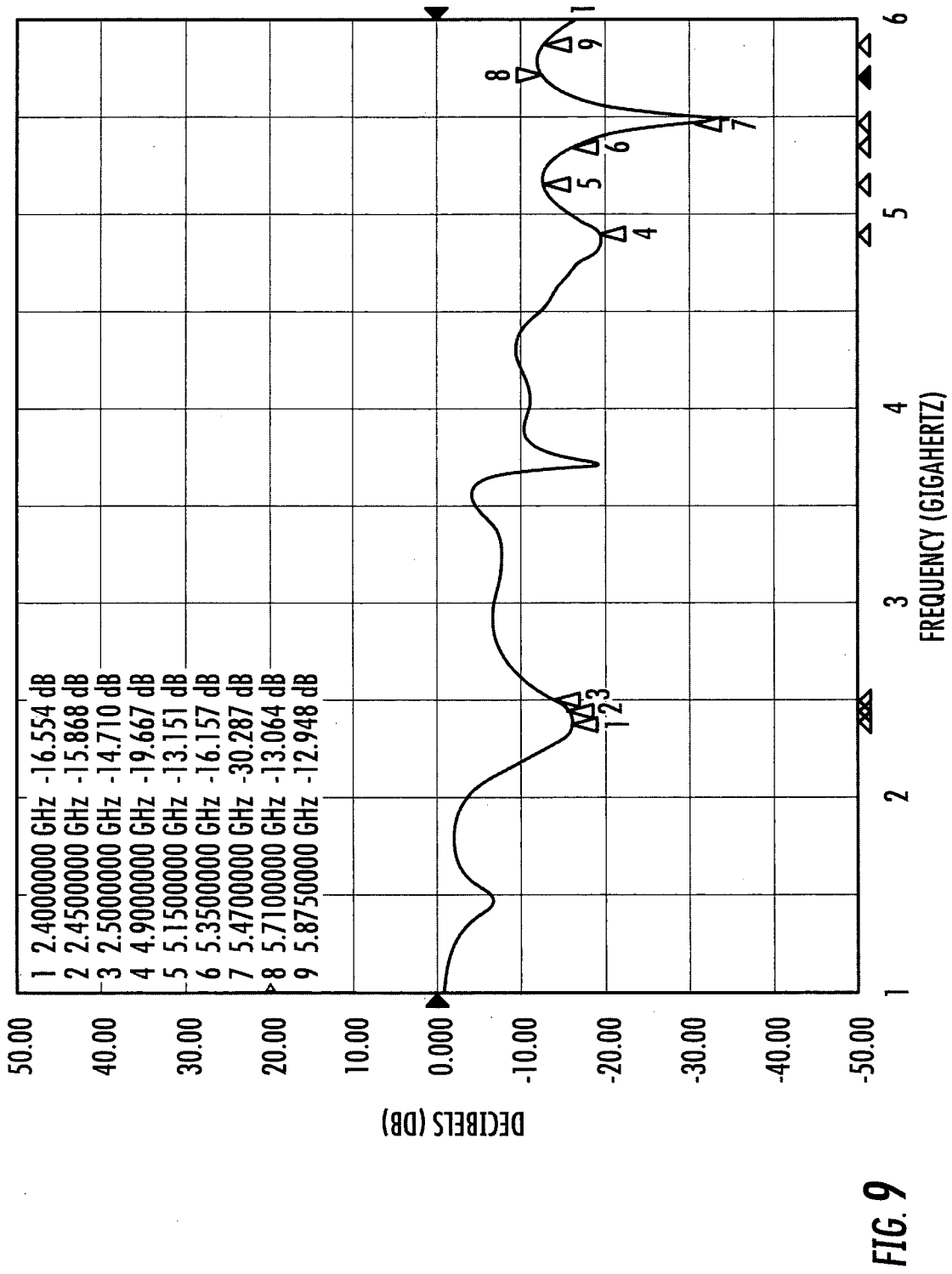

1 2.4000000 GHz -16.554 dB
2 2.4500000 GHz -15.868 dB
3 2.5000000 GHz -14.710 dB
4 4.9000000 GHz -19.667 dB
5 5.1500000 GHz -13.151 dB
6 5.3500000 GHz -16.157 dB
7 5.4700000 GHz -30.287 dB
8 5.7100000 GHz -13.064 dB
9 5.8750000 GHz -12.948 dB
50.00
40.00
30.00
20.00
10.00
0.000
-10.00
-20.00
-30.00
-40.00
-50.00
DECIBELS (DB)
1
2
3
4
5
6
FREQUENCY (GIGAHERTZ)

FIG. 9

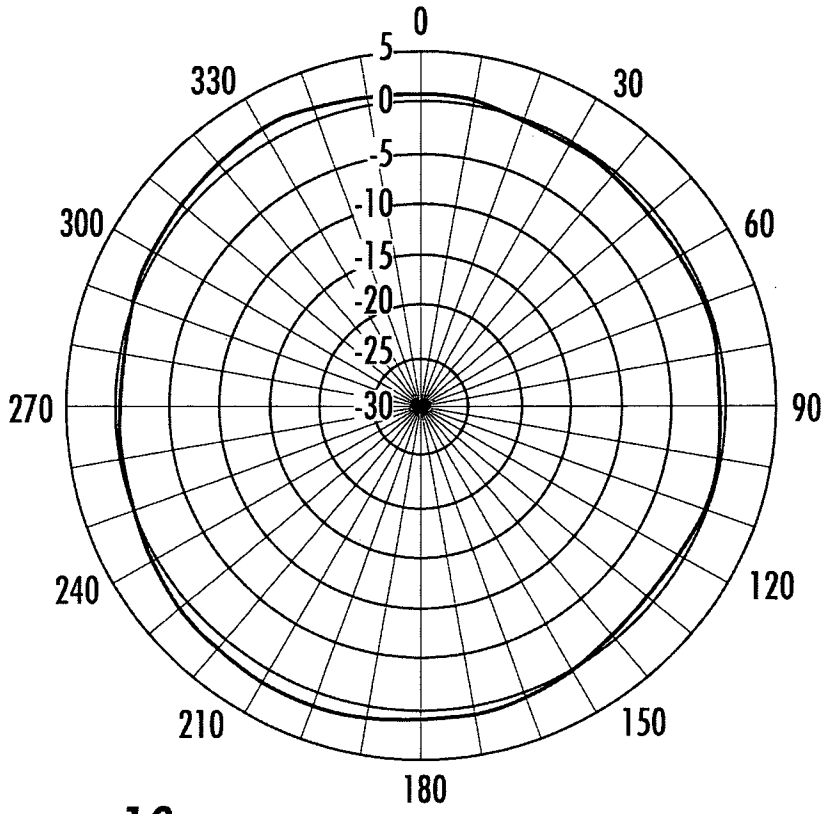

0
30
60
90
120
150
180
210
240
270
300
330
5
0
-5
-10
-15
-20
-25
-30
2450.00(MHz)

FIG. 10

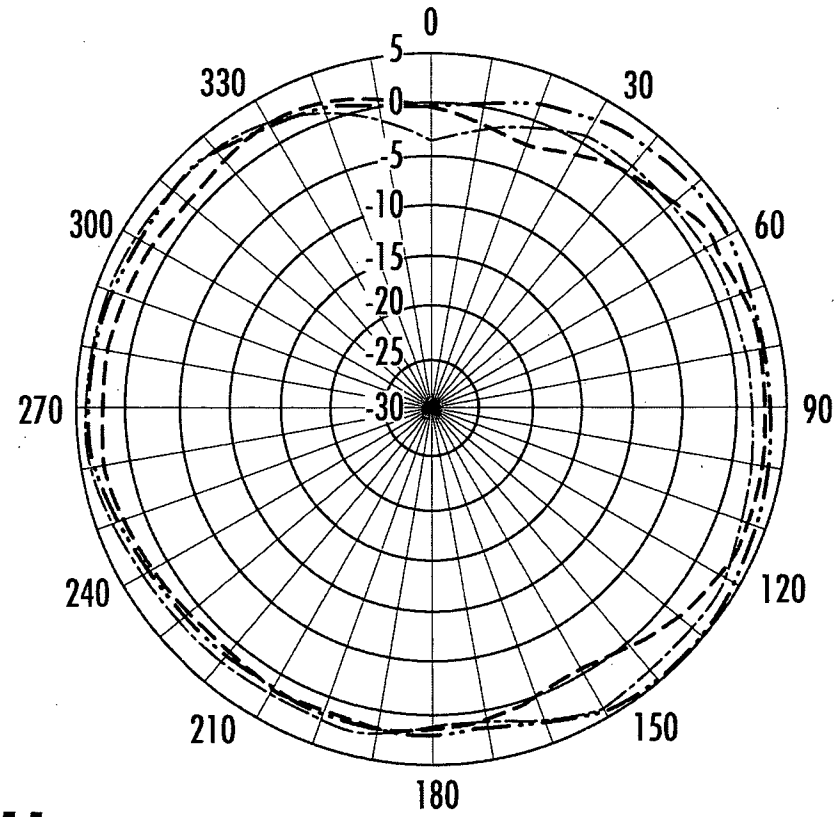

0
30
60
90
120
150
180
210
240
270
300
330
5
0
-5
-10
-15
-20
-25
-30
4900.00(MHz)
5470.00(MHz)
5780.00(MHz)

FIG. 11

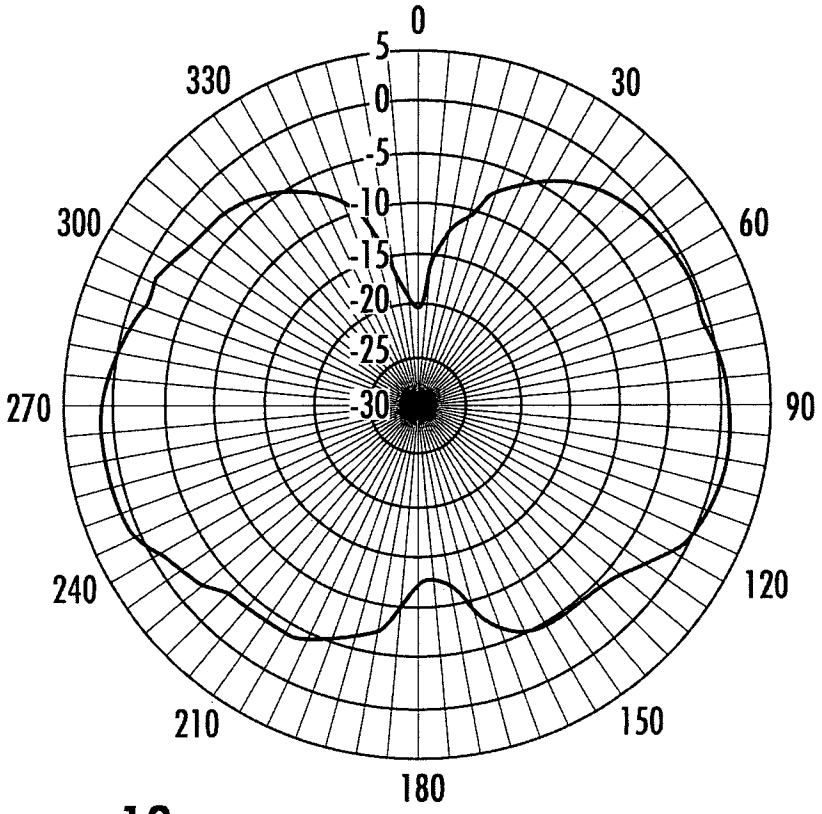

0
30
60
90
120
150
180
210
240
270
300
330
5
0
-5
-10
-15
-20
-25
-30
2450.00(MHz)

FIG. 12

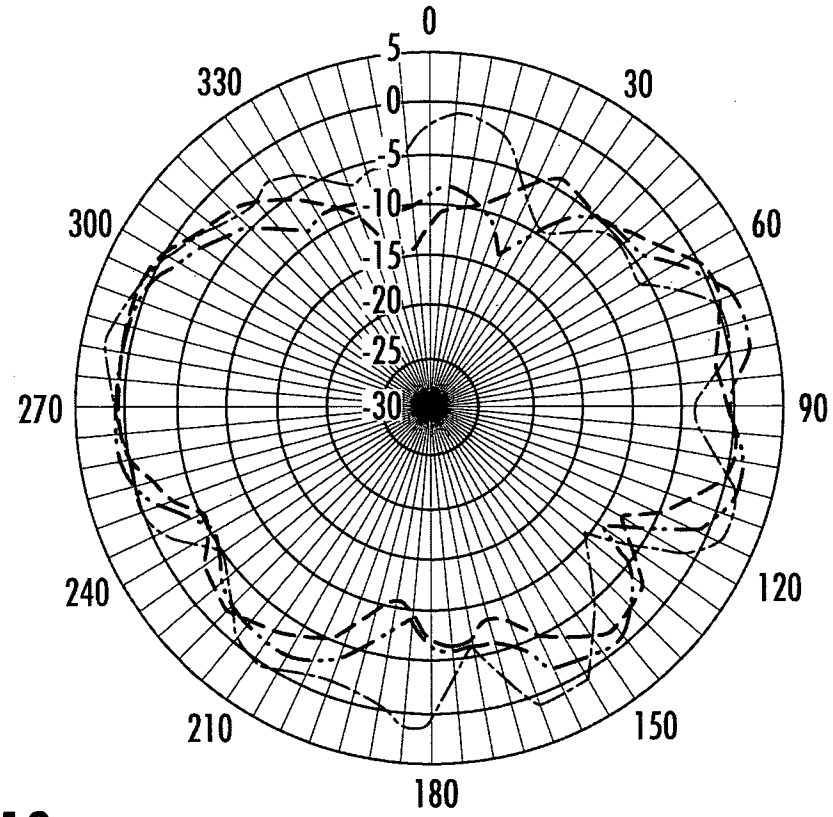

0
30
60
90
120
150
180
210
240
270
300
330
5
0
-5
-10
-15
-20
-25
-30
4900.00(MHz)
5470.00(MHz)
5780.00(MHz)

FIG. 13

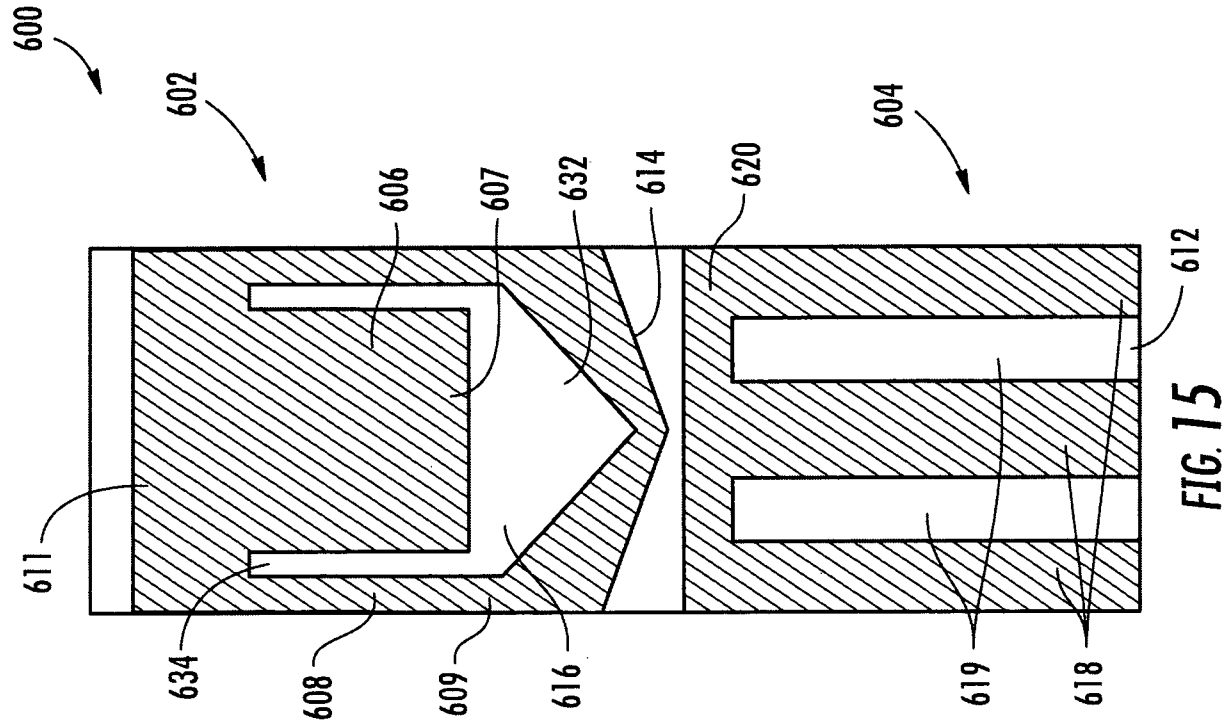

600
602
604
606
607
632
614
620
612
611
634
608
609
616
619
618

FIG. 15

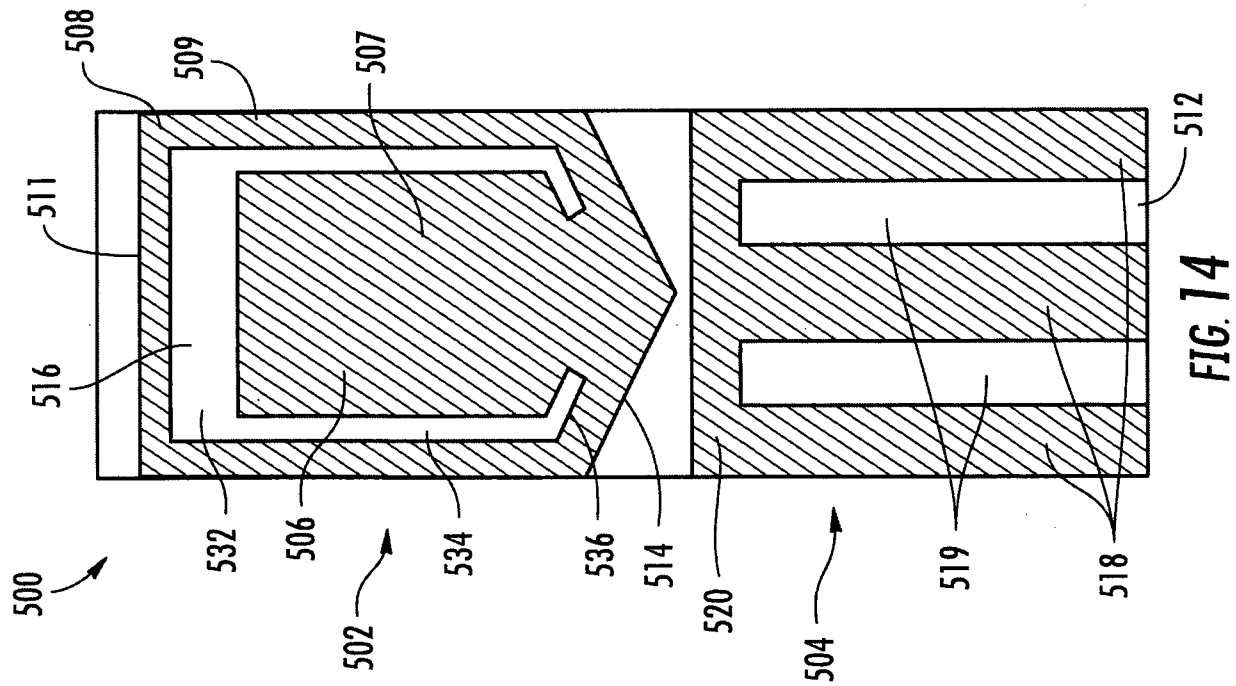

508
509
507
511
516
512
532
506
534
536
514
520
519
518
500
502
504

FIG. 14

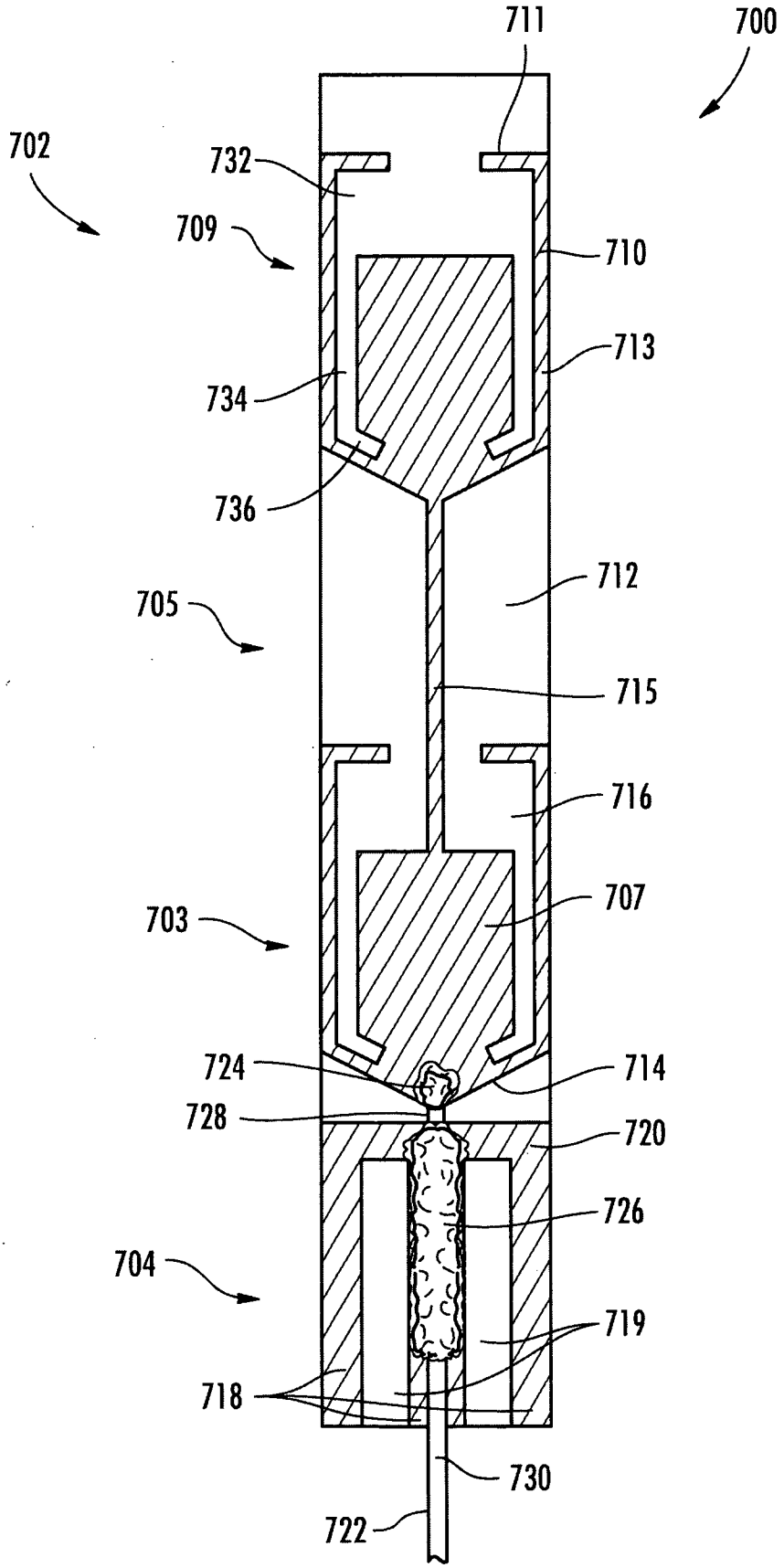

711
700
702
732
709
710
713
734
736
712
705
715
716
707
703
724
714
728
720
726
704
719
718
730
722

FIG. 16

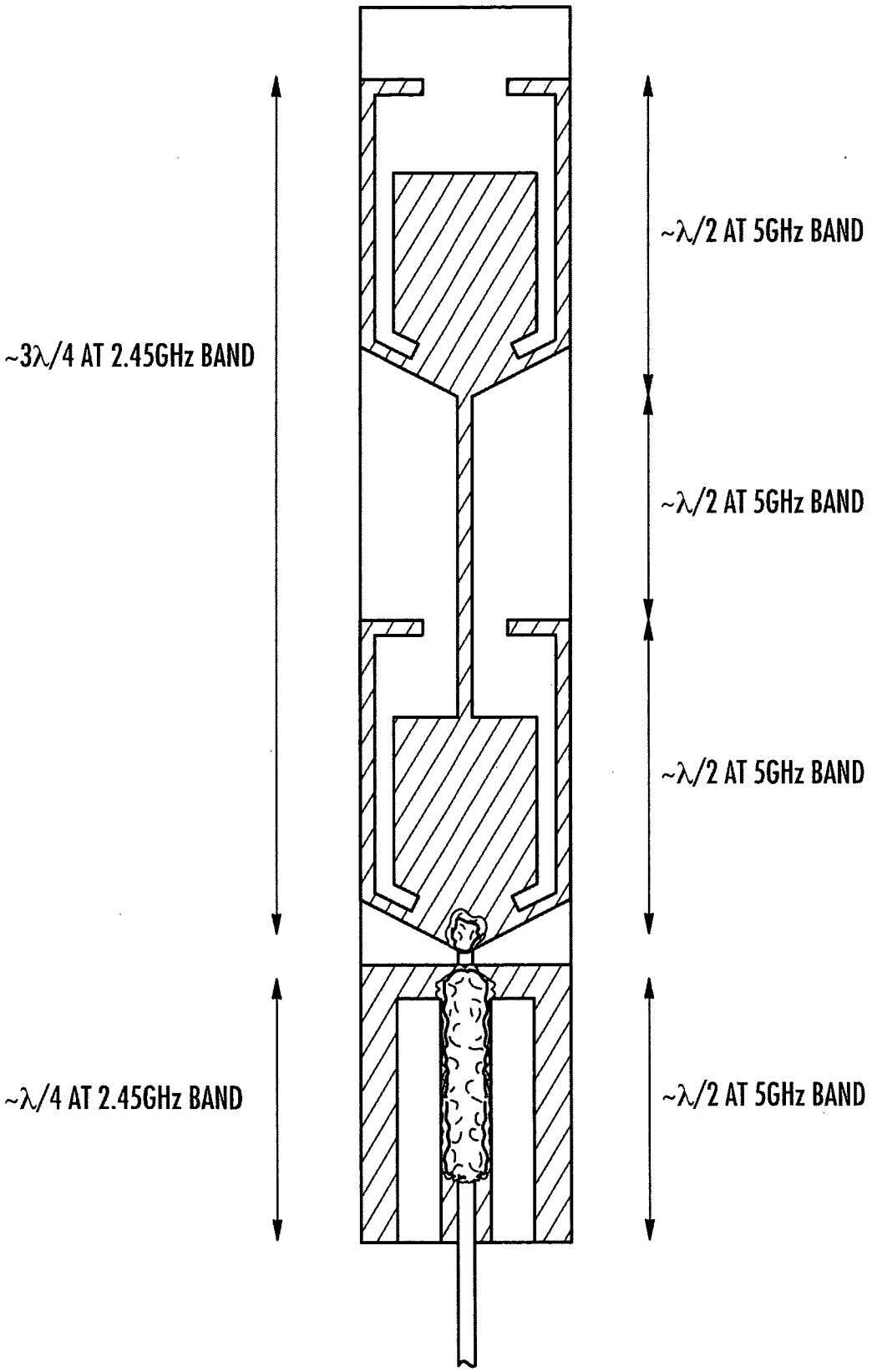

~3λ/4 AT 2.45GHz BAND
~λ/4 AT 2.45GHz BAND
~λ/2 AT 5GHz BAND
~λ/2 AT 5GHz BAND
~λ/2 AT 5GHz BAND
~λ/2 AT 5GHz BAND

FIG. 17

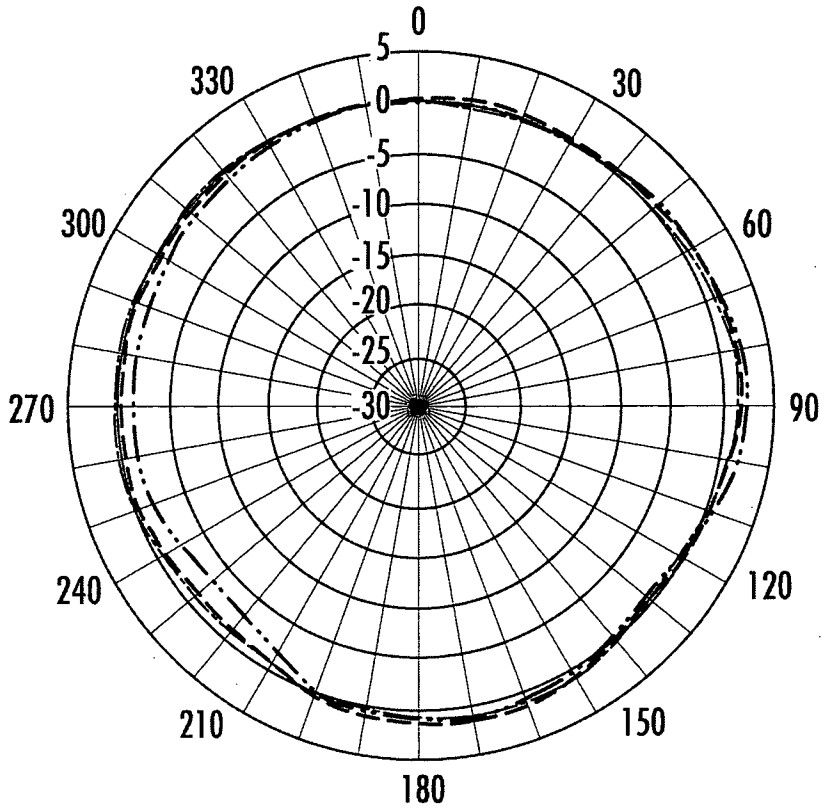


FIG. 18

2400.00(MHz) 2450.00(MHz) 2500.00(MHz)

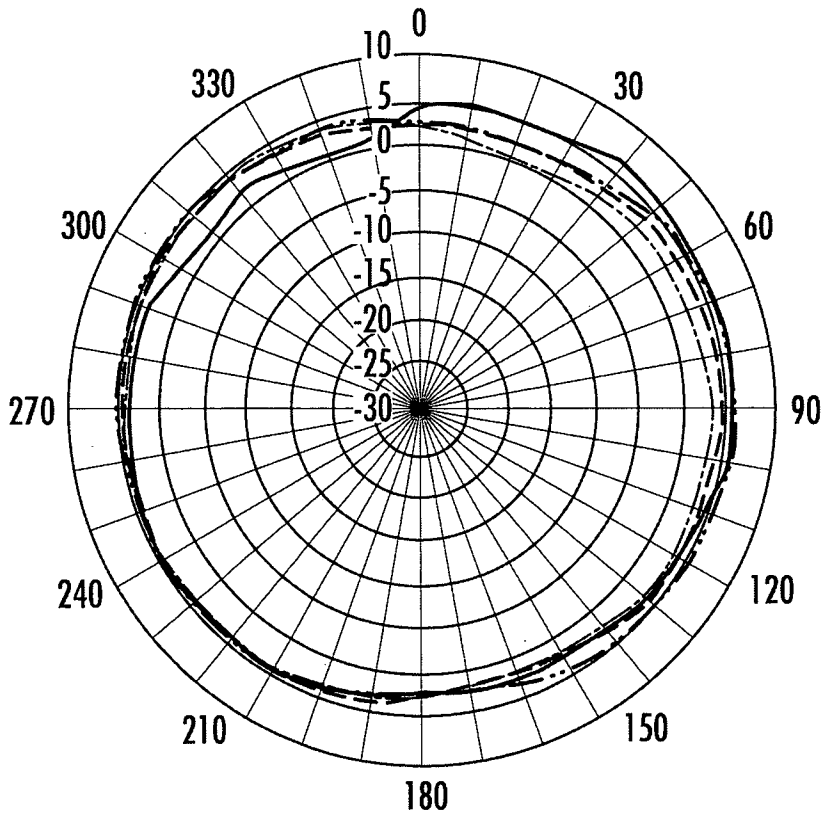


FIG. 19

4900.00(MHz) 5150.00(MHz) 5350.00(MHz) 5850.00(MHz)

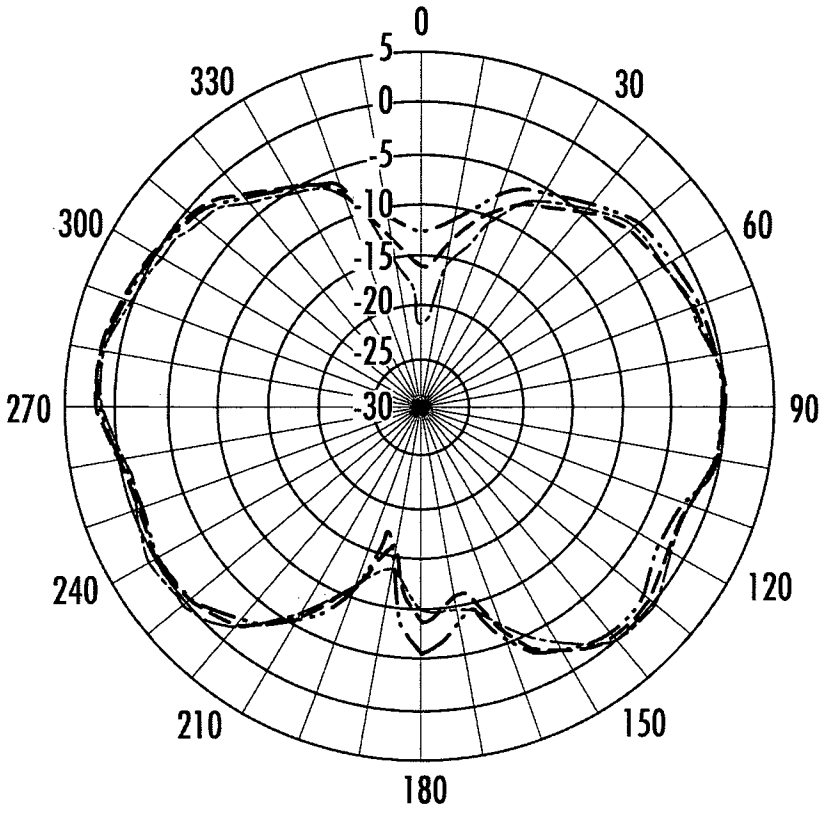

0
30
60
90
120
150
180
210
240
270
300
330
5
0
-5
-10
-15
-20
-25
-30
2400.00(MHz)
2450.00(MHz)
2500.00(MHz)

FIG. 20

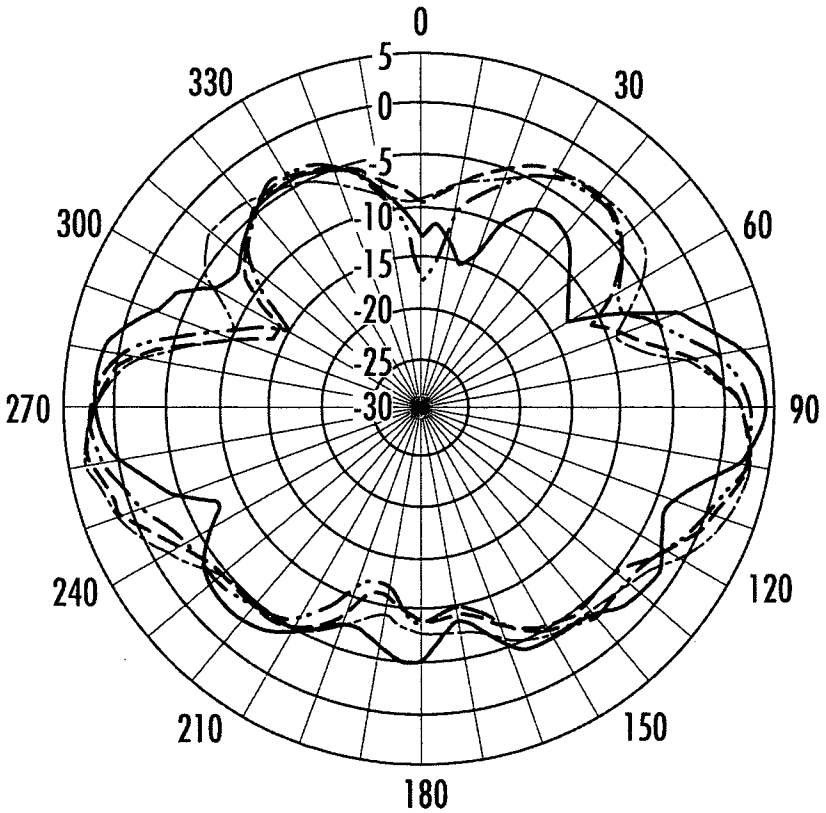

0
30
60
90
120
150
180
210
240
270
300
330
5
0
-5
-10
-15
-20
-25
-30
4900.00(MHz)
5150.00(MHz)
5350.00(MHz)
5850.00(MHz)

FIG. 21

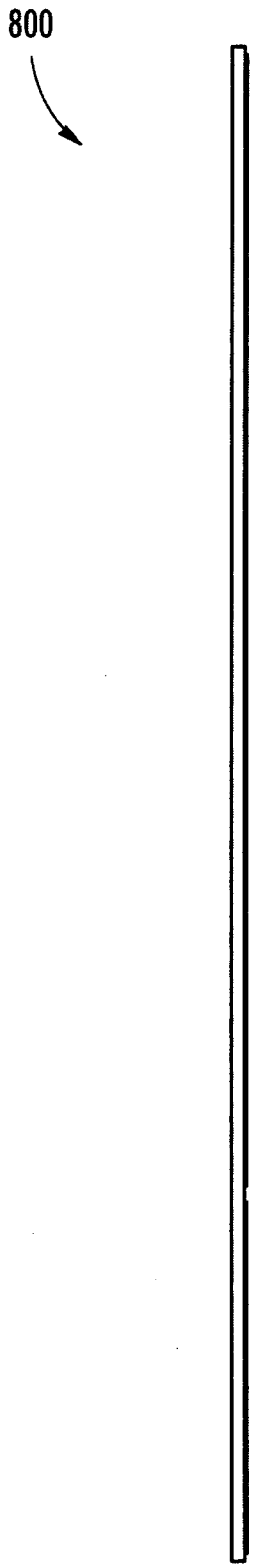

800

FIG. 23

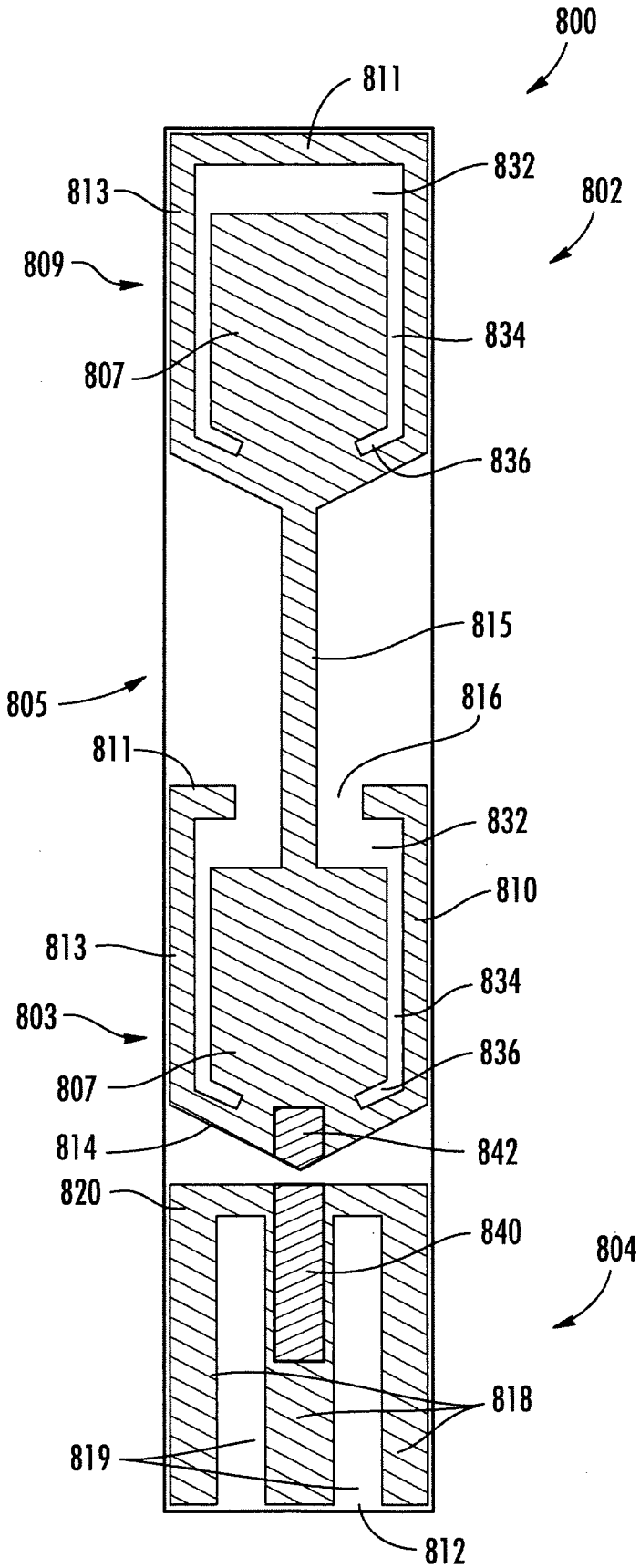

800
811
832
813
802
809
834
807
836
815
805
816
811
832
810
813
834
803
836
807
814
842
820
840
804
818
819
812

FIG. 22

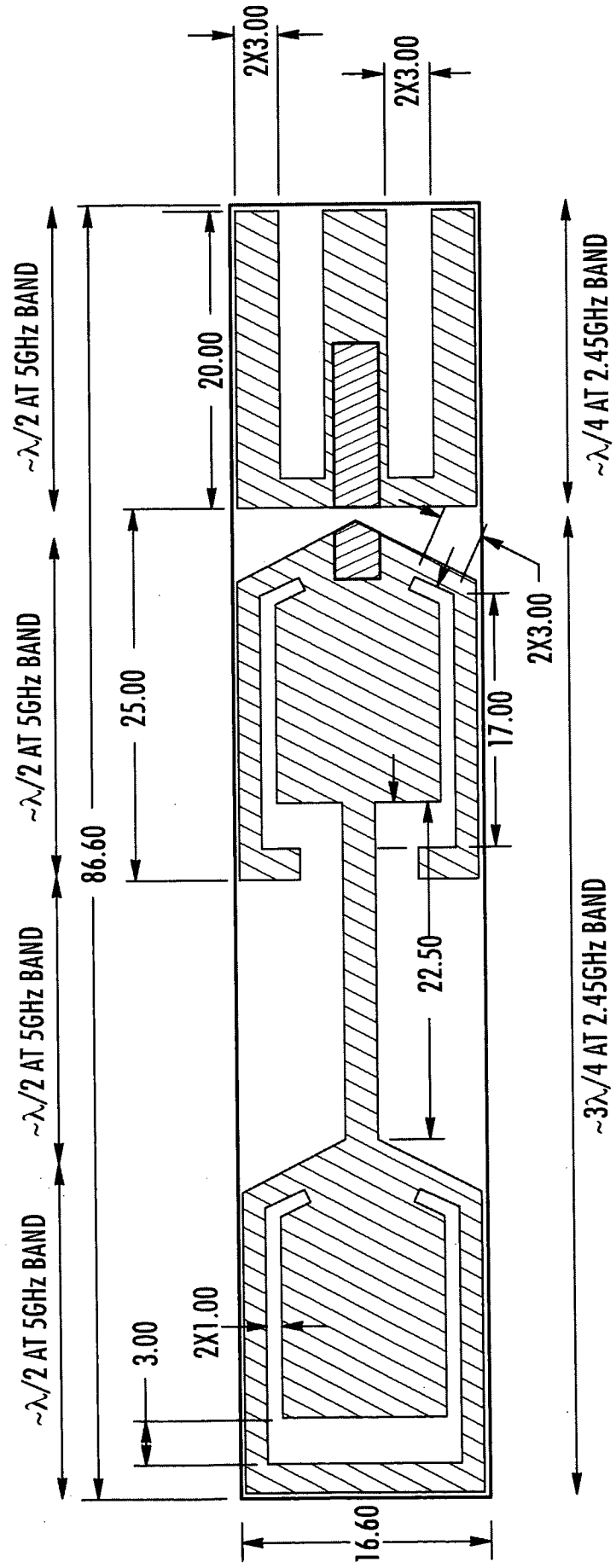

2X3.00
2X3.00
~λ/2 AT 5GHz BAND
~λ/2 AT 5GHz BAND
~λ/2 AT 5GHz BAND
~λ/2 AT 5GHz BAND
~λ/4 AT 2.45GHz BAND
~3λ/4 AT 2.45GHz BAND
20.00
25.00
86.60
2X3.00
17.00
22.50
3.00
2X1.00
16.60

FIG. 24

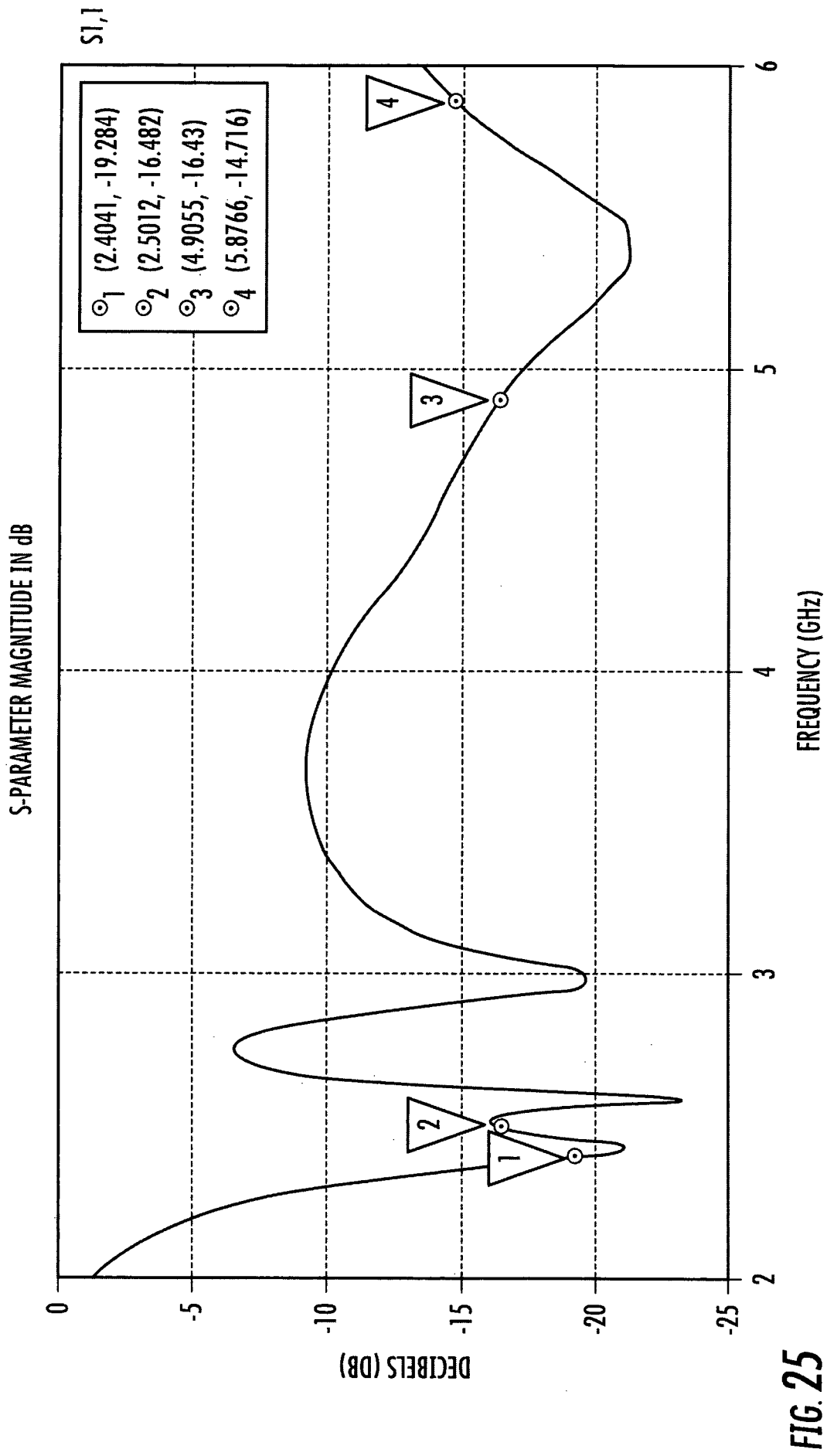

S1,1
S-PARAMETER MAGNITUDE IN dB
DECIBELS (DB)
FREQUENCY (GHz)
0
-5
-10
-15
-20
-25
2
3
4
5
6
1
2
3
4
(2.4041, -19.284)
(2.5012, -16.482)
(4.9055, -16.43)
(5.8766, -14.716)

FIG. 25

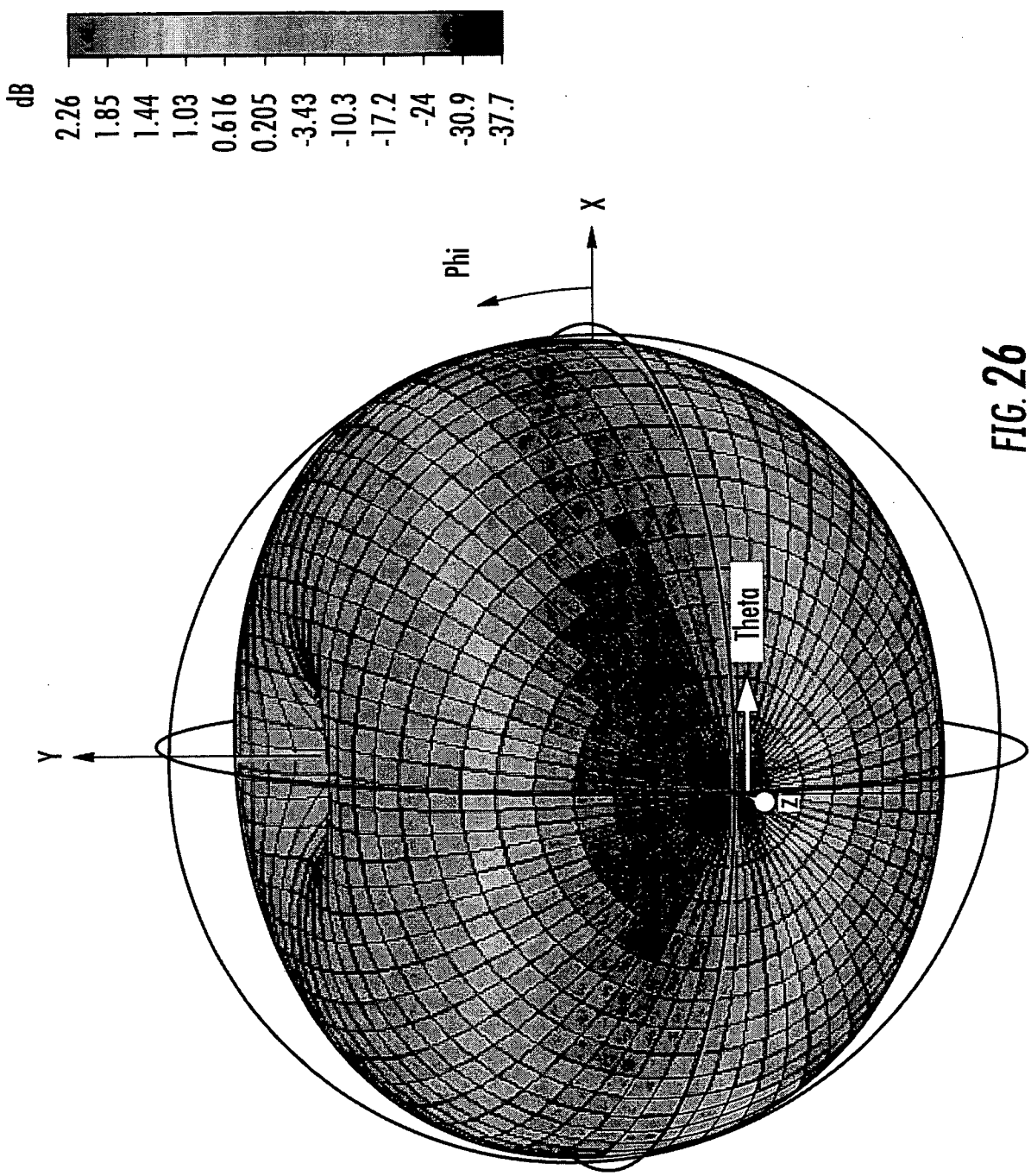

dB
2.26
1.85
1.44
1.03
0.616
0.205
-3.43
-10.3
-17.2
-24
-30.9
-37.7
X
Phi
Theta
Y
Z

FIG. 26

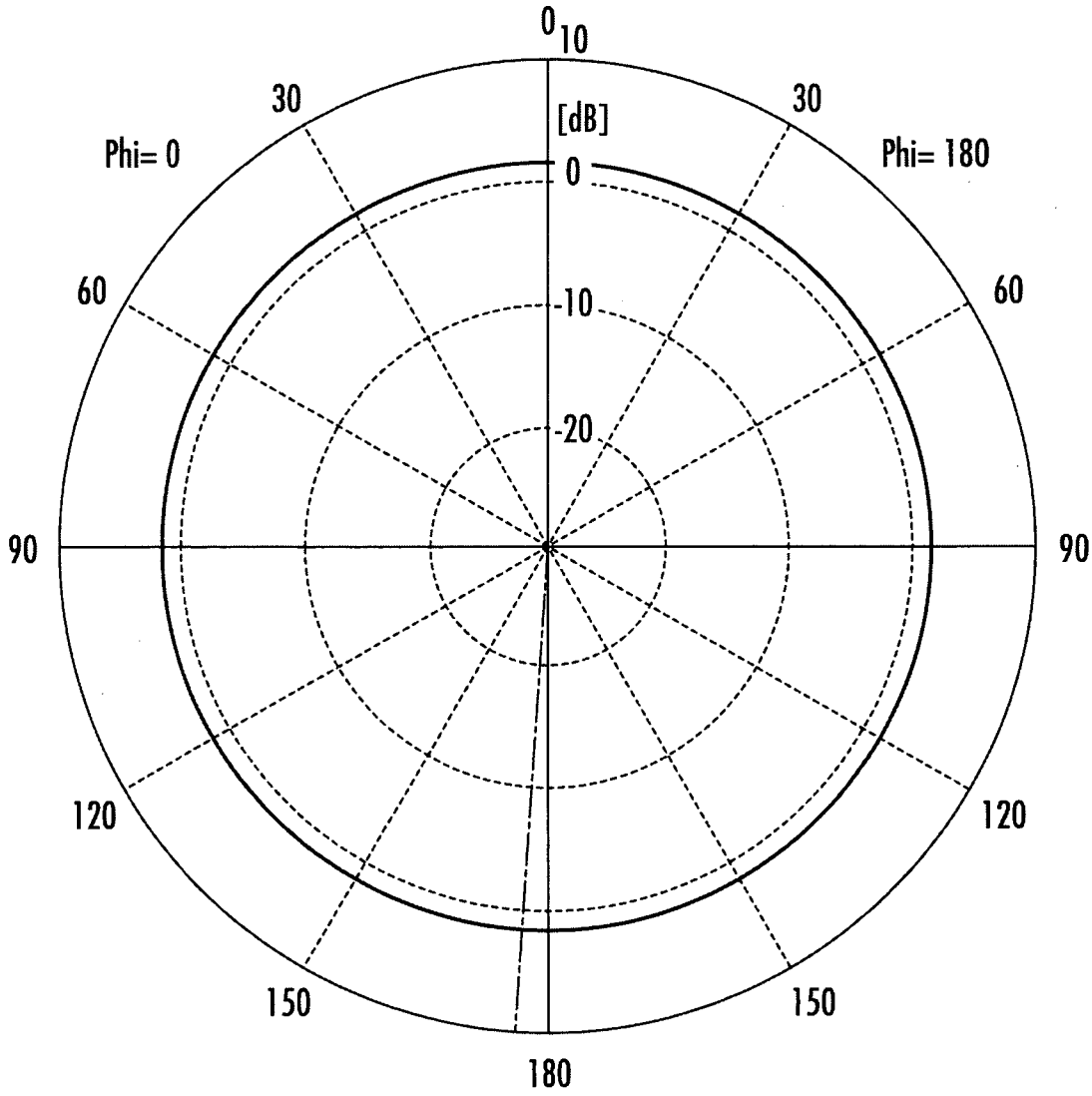


FIG. 27

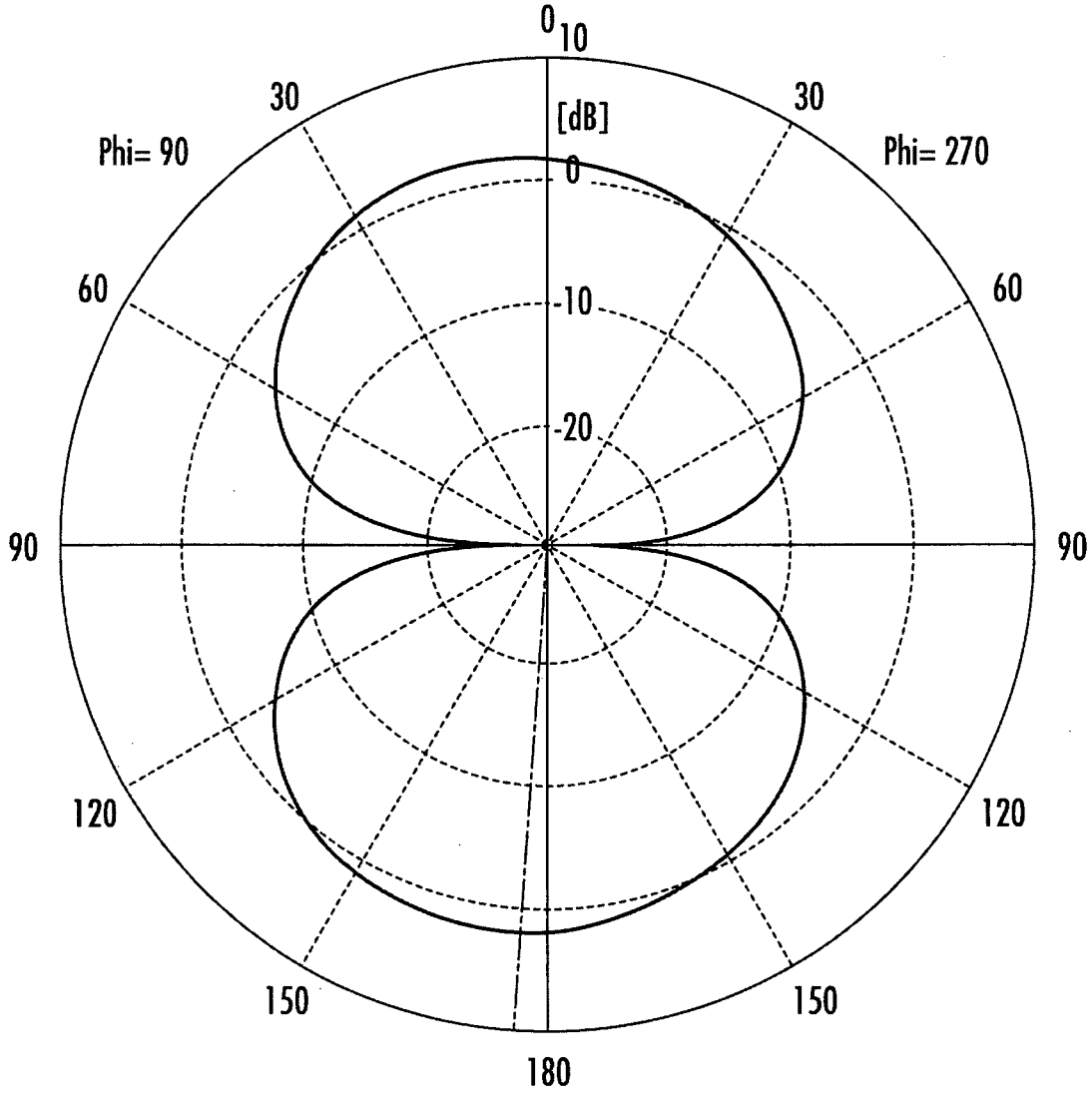


FIG. 28

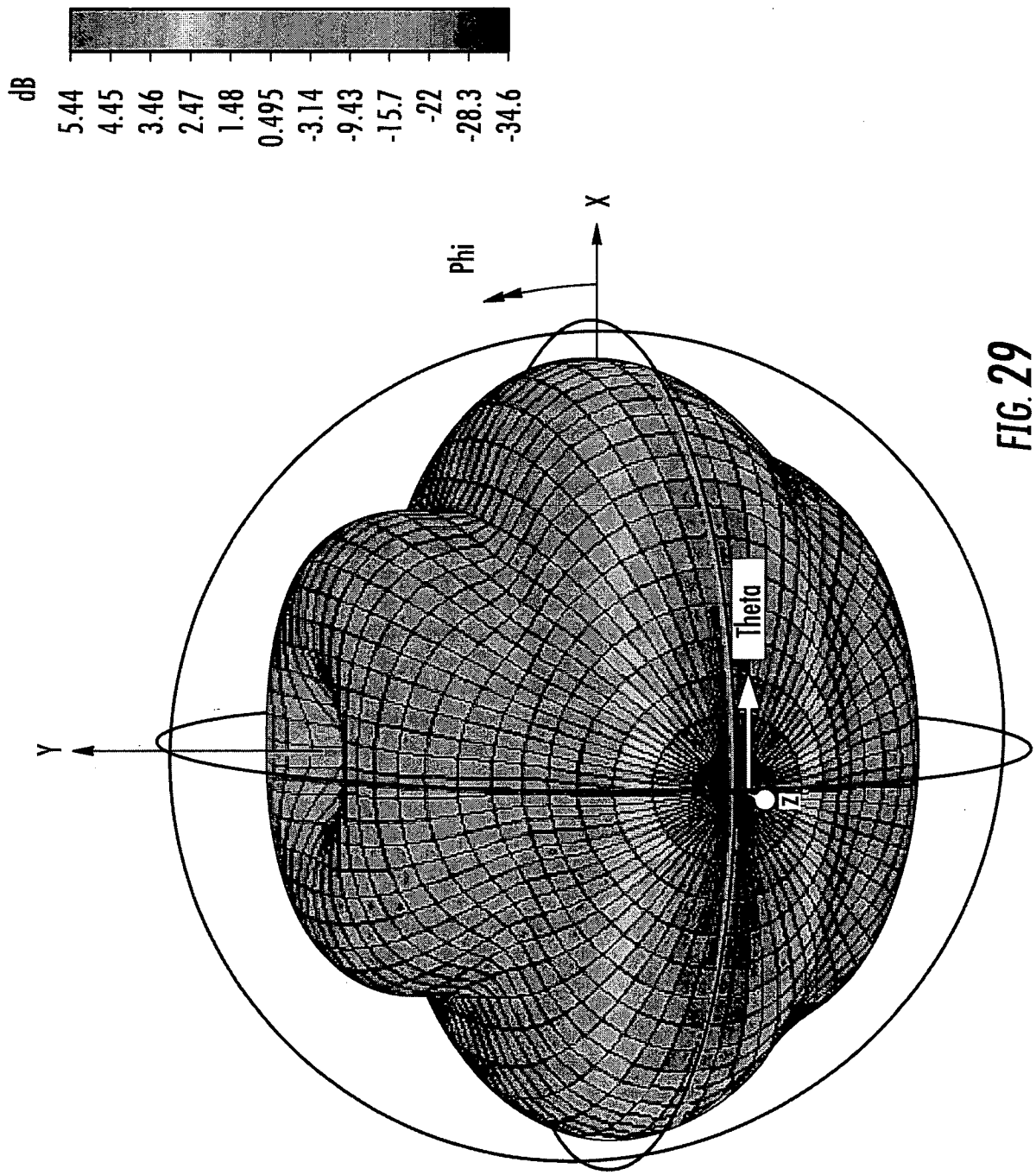


FIG. 29

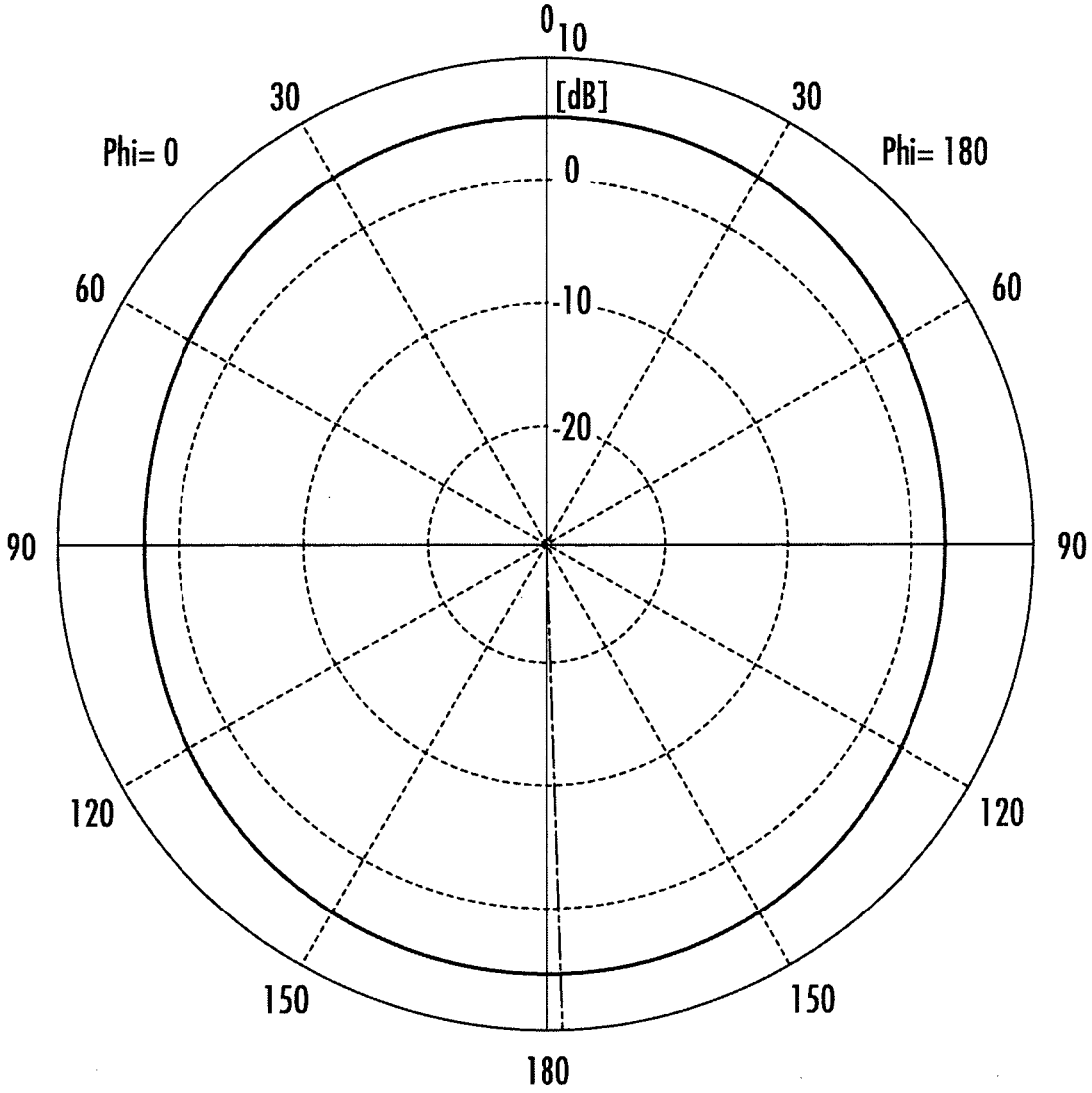


FIG. 30

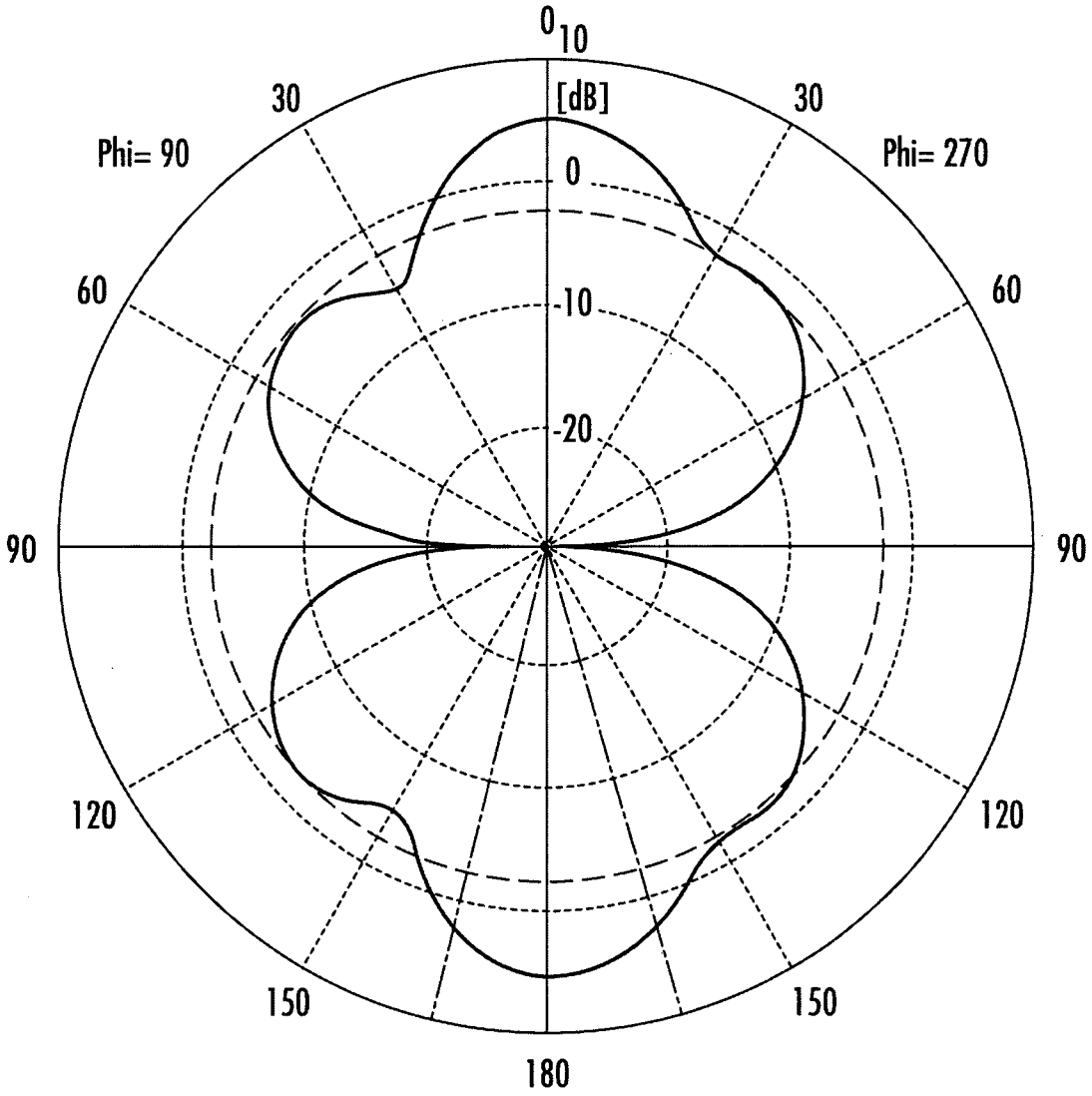


FIG. 31

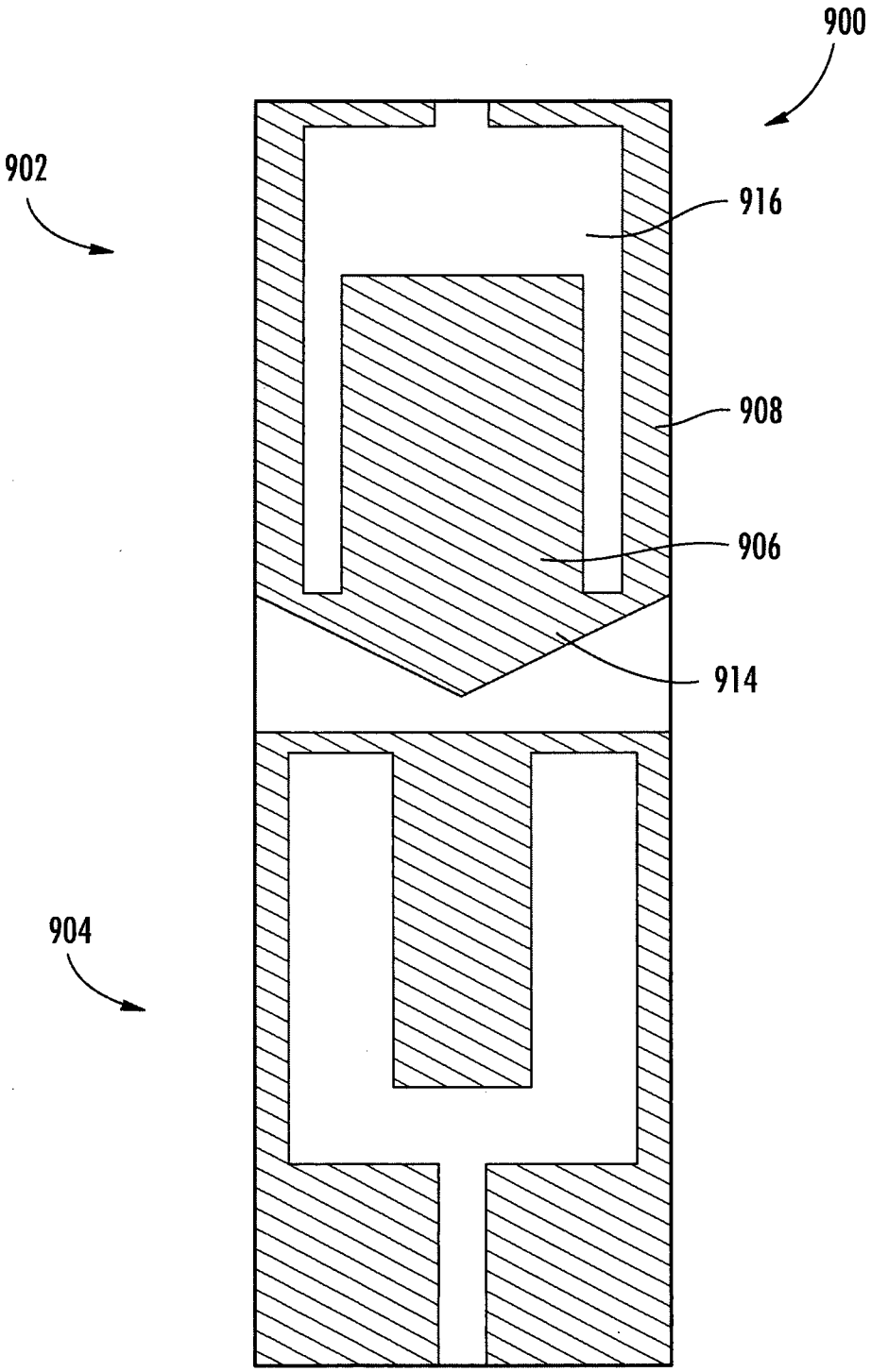


FIG. 32

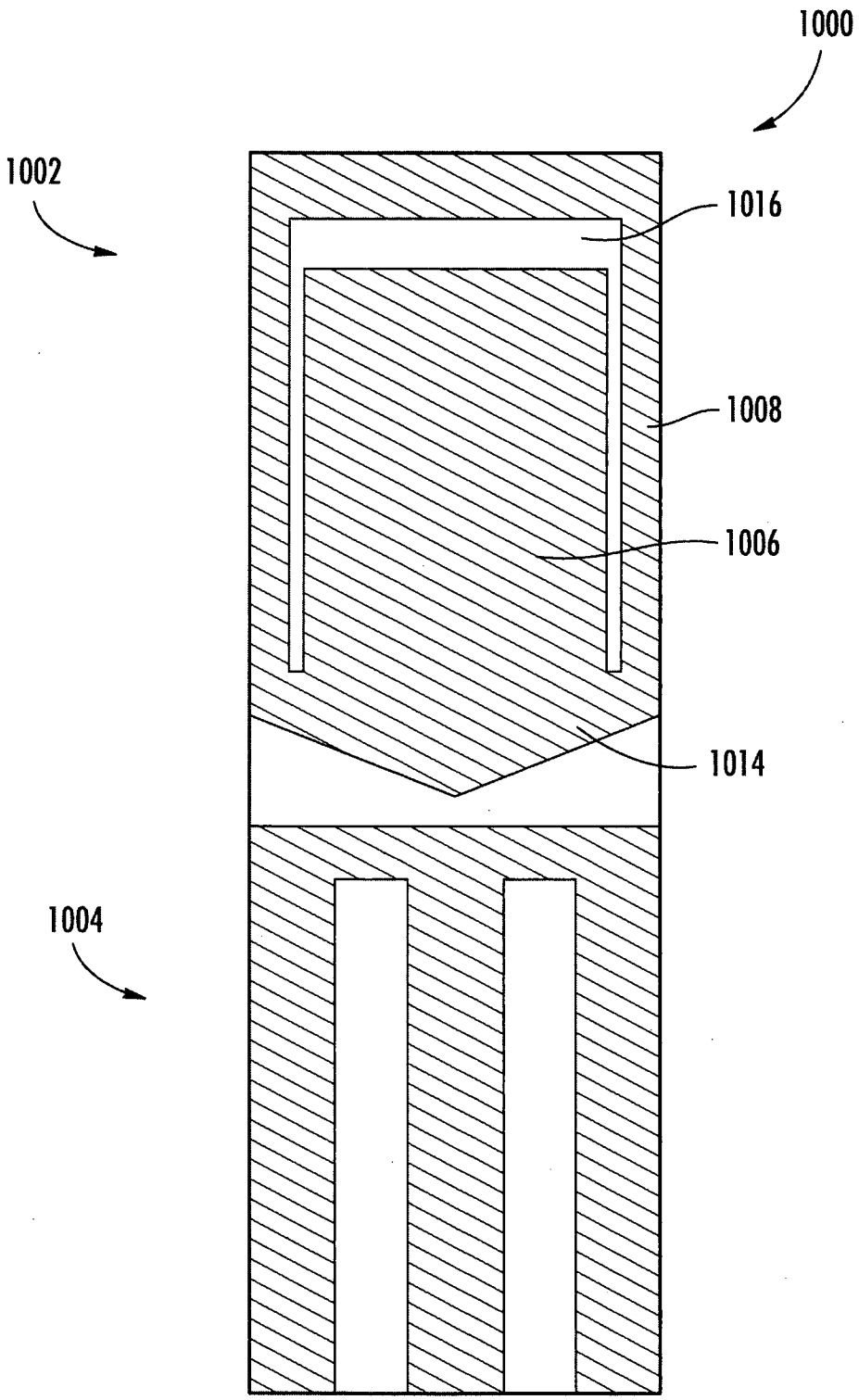


FIG. 33

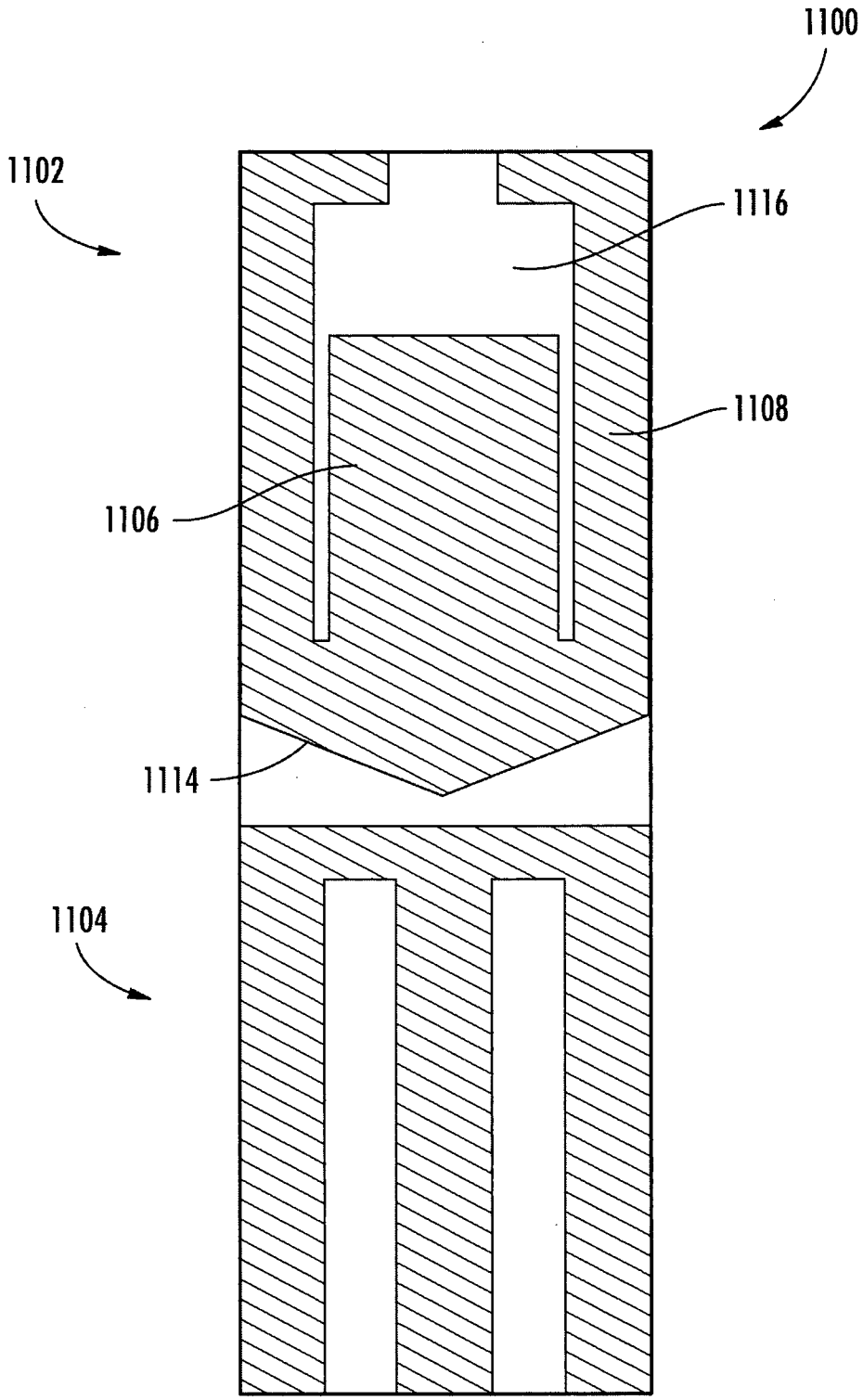


FIG. 34

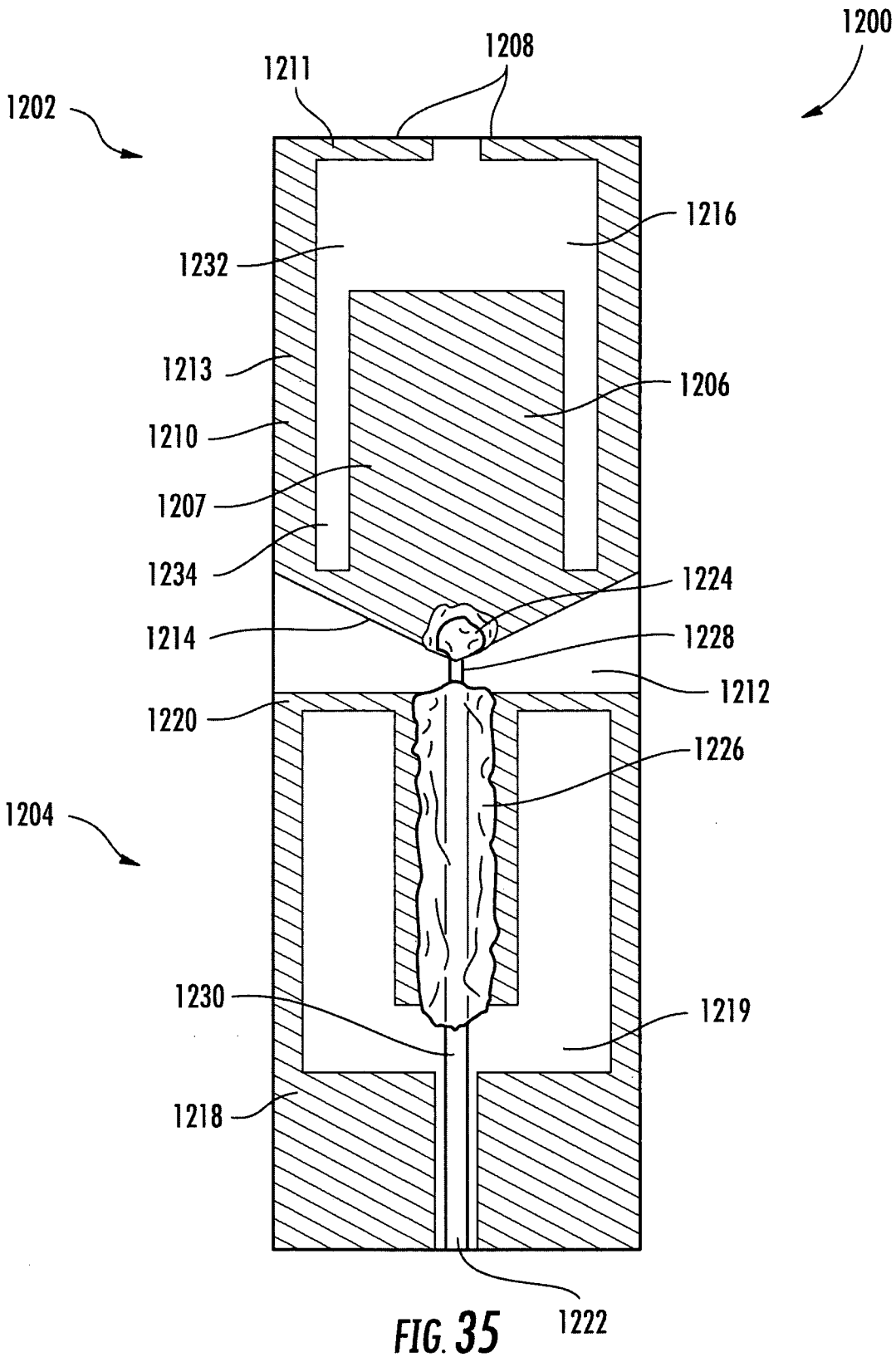

1200
1208
1211
1202
1216
1232
1213
1206
1210
1207
1234
1224
1214
1228
1212
1220
1226
1204
1230
1219
1218
1222

FIG. 35

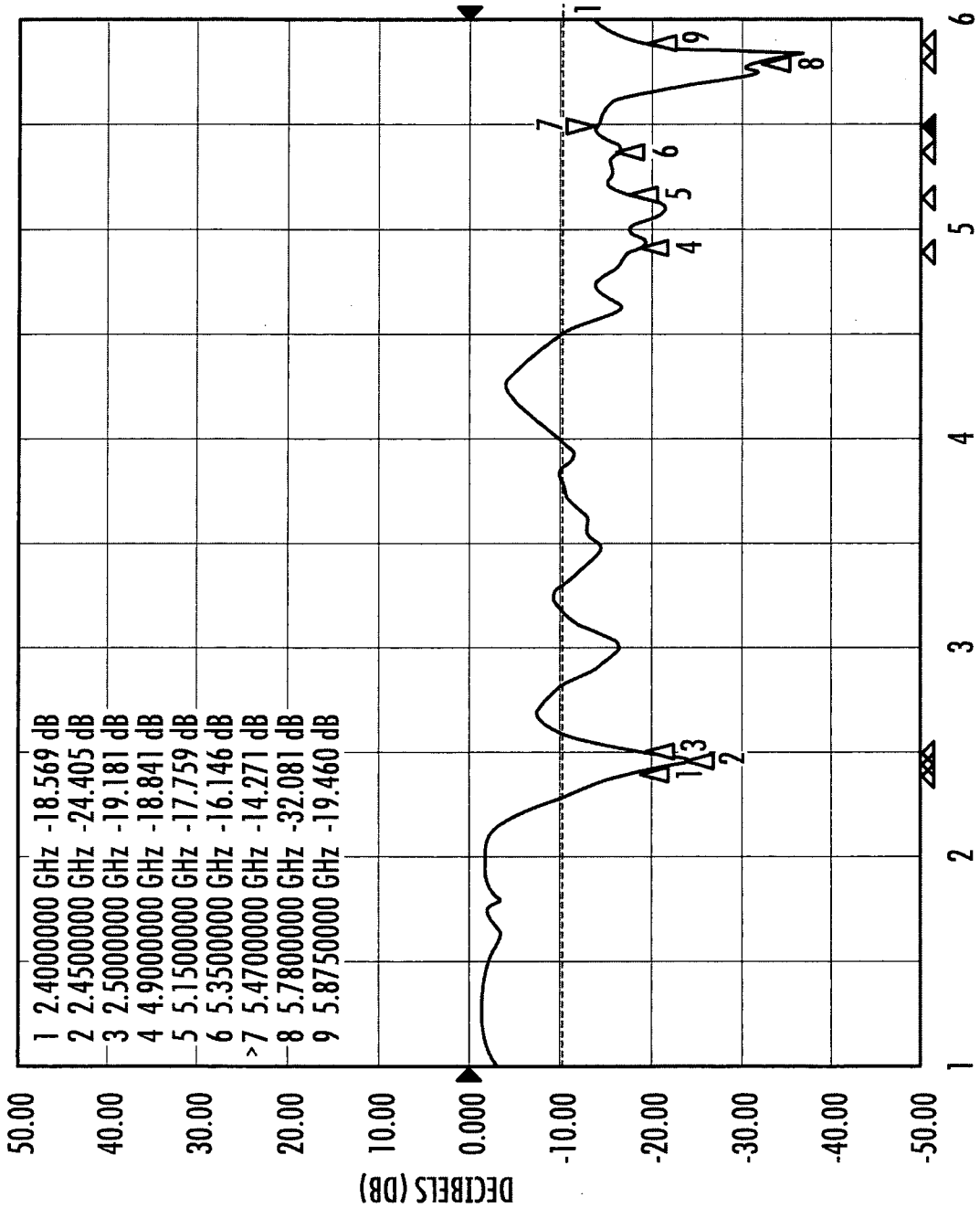

1 2.4000000 GHz -18.569 dB
2 2.4500000 GHz -24.405 dB
3 2.5000000 GHz -19.181 dB
4 4.9000000 GHz -18.841 dB
5 5.1500000 GHz -17.759 dB
6 5.3500000 GHz -16.146 dB
>7 5.4700000 GHz -14.271 dB
8 5.7800000 GHz -32.081 dB
9 5.8750000 GHz -19.460 dB
50.00
40.00
30.00
20.00
10.00
0.000
-10.00
-20.00
-30.00
-40.00
-50.00
DECIBELS (DB)
1
2
3
4
5
6
FREQUENCY (GIGAHERTZ)

FIG. 36

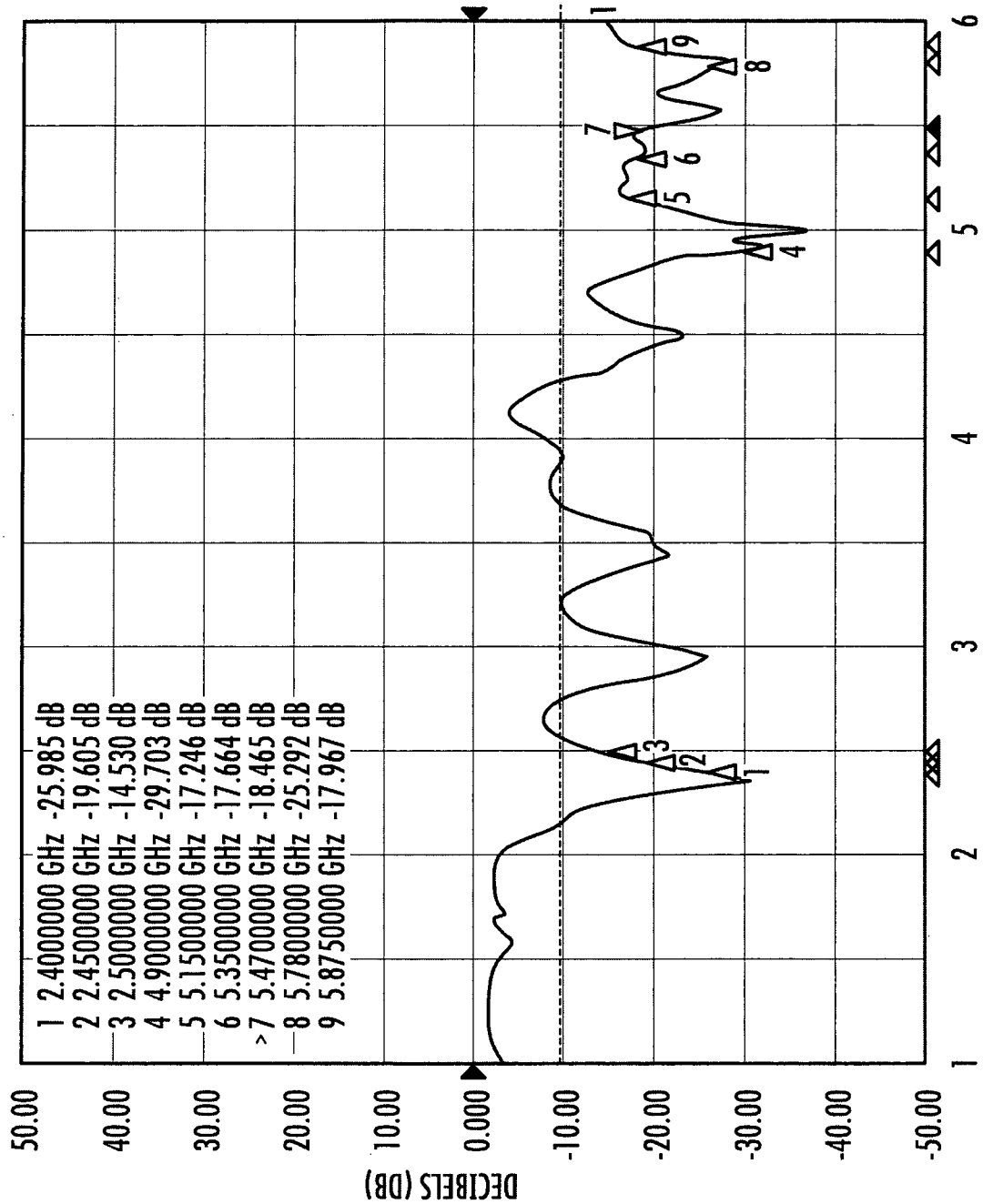

1 2.400000 GHz -25.985 dB
2 2.450000 GHz -19.605 dB
3 2.500000 GHz -14.530 dB
4 4.900000 GHz -29.703 dB
5 5.150000 GHz -17.246 dB
6 5.350000 GHz -17.664 dB
>7 5.470000 GHz -18.465 dB
8 5.780000 GHz -25.292 dB
9 5.875000 GHz -17.967 dB
50.00
40.00
30.00
20.00
10.00
0.000
-10.00
-20.00
-30.00
-40.00
-50.00
DECIBELS (DB)
1
2
3
4
5
6
FREQUENCY (GIGAHERTZ)

FIG. 37

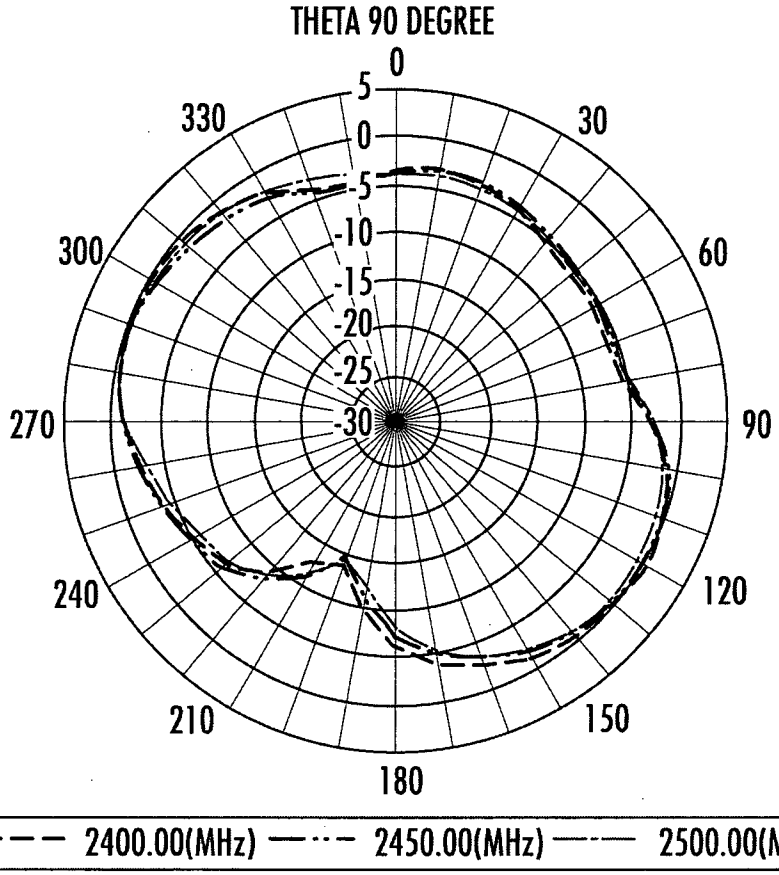

THETA 90 DEGREE
0
30
60
90
120
150
180
210
240
270
300
330
5
0
-5
-10
-15
-20
-25
-30
2400.00(MHz)
2450.00(MHz)
2500.00(MHz)

FIG. 38

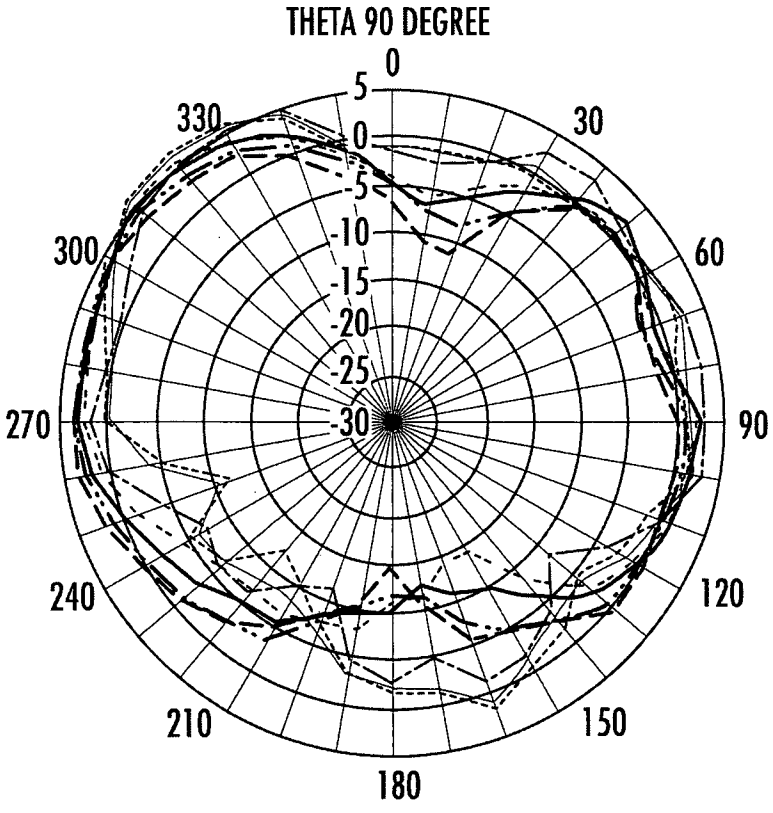

THETA 90 DEGREE
0
30
60
90
120
150
180
210
240
270
300
330
5
0
-5
-10
-15
-20
-25
-30
4900.00(MHz)
5150.00(MHz)
5350.00(MHz)
5470.00(MHz)
5710.00(MHz)
5780.00(MHz)
5850.00(MHz)

FIG. 39

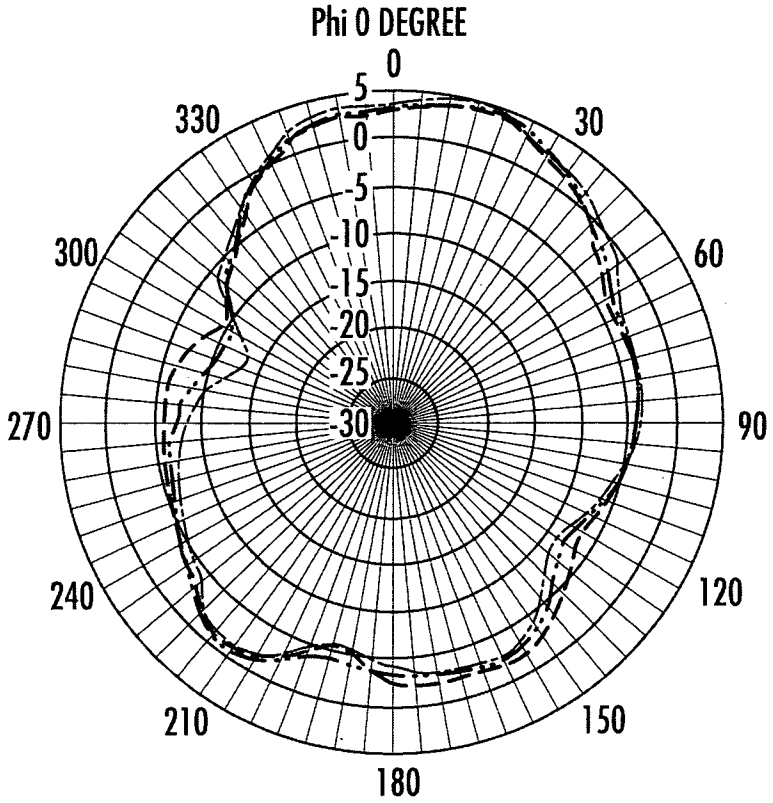

Phi 0 DEGREE
0
30
60
90
120
150
180
210
240
270
300
330
5
0
-5
-10
-15
-20
-25
-30
2400.00(MHz)
2450.00(MHz)
2500.00(MHz)

FIG. 40

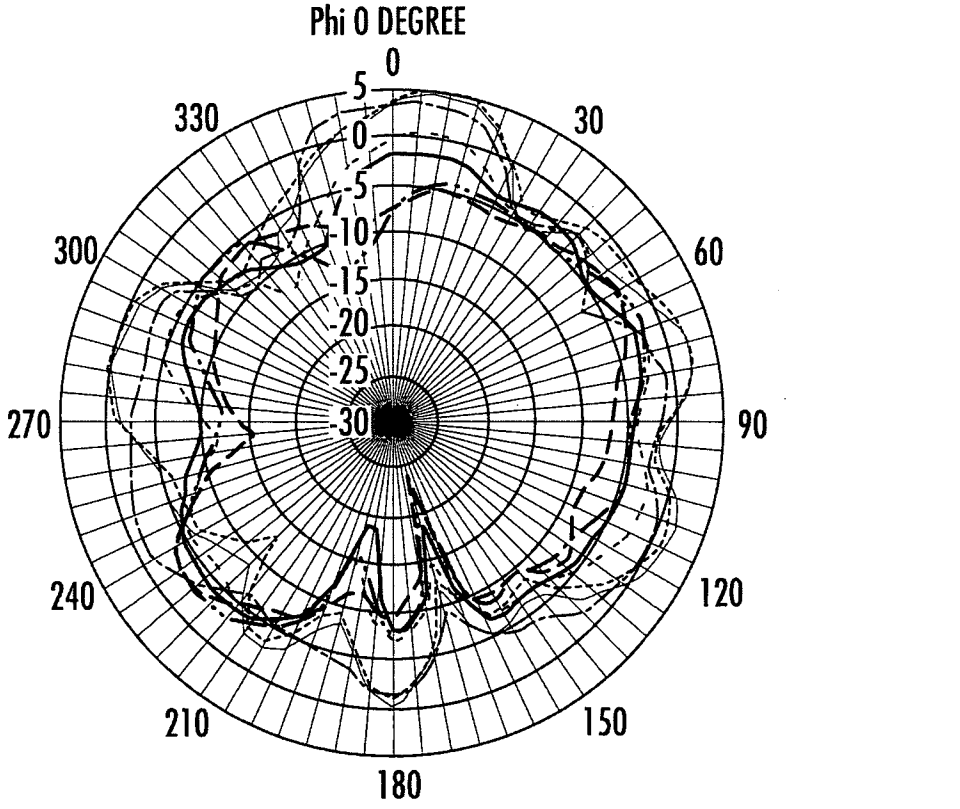

Phi 0 DEGREE
0
30
60
90
120
150
180
210
240
270
300
330
5
0
-5
-10
-15
-20
-25
-30
4900.00(MHz)
5150.00(MHz)
5350.00(MHz)
5470.00(MHz)
5710.00(MHz)
5780.00(MHz)
5850.00(MHz)

FIG. 41

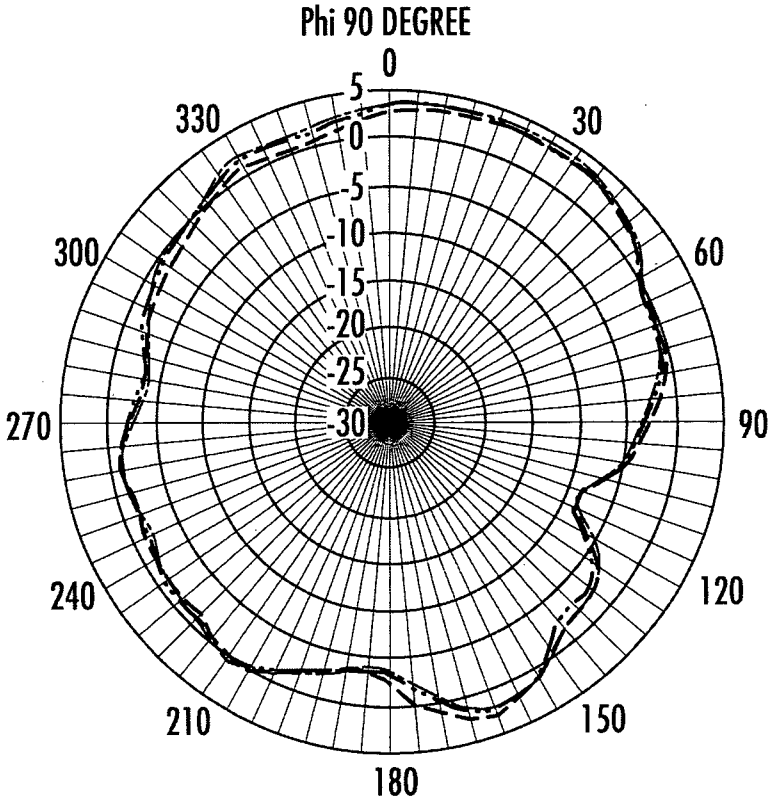

Phi 90 DEGREE
0
30
60
90
120
150
180
210
240
270
300
330
5
0
-5
-10
-15
-20
-25
-30
2400.00(MHz)
2450.00(MHz)
2500.00(MHz)

FIG. 42

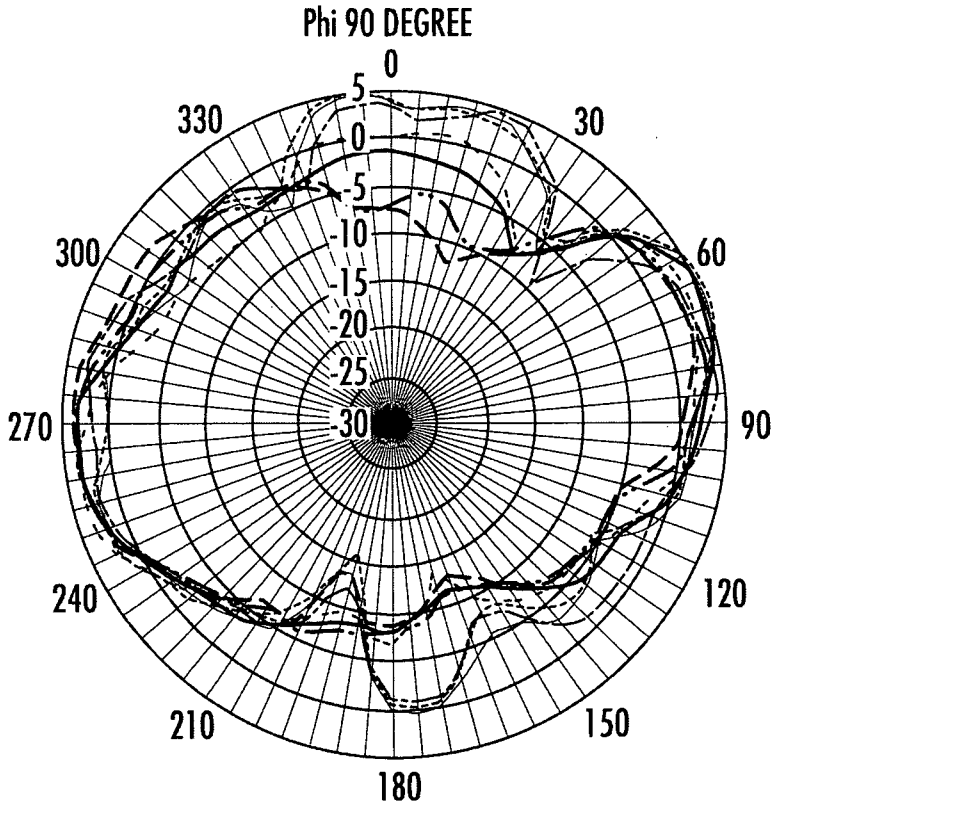

Phi 90 DEGREE
0
30
60
90
120
150
180
210
240
270
300
330
5
0
-5
-10
-15
-20
-25
-30
4900.00(MHz)
5150.00(MHz)
5350.00(MHz)
5470.00(MHz)
5710.00(MHz)
5780.00(MHz)
5850.00(MHz)

FIG. 43

INTERNATIONAL SEARCH REPORT

International application No.
PCT/MY2009/000181

A. CLASSIFICATION OF SUBJECT MATTER

H01Q 5/01(2006.01)i, H01Q 9/30(2006.01)i, H01Q 13/08(2006.01)i, H01Q 13/10(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 5/01; H01Q 9/28; H01Q 9/40

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: antenna, dual, double, triple, multi*, band, dipole, monopole, substrate, planar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2006-0158383 A1 (KWON, DO-HOON et al.) 20 July 2006 See the abstract; figures 4-6; paragraphs 36-49; and claims 1-12	1-3,50-53 34-37
Y A	JP 2008-306436 A (NTT DOCOMO INC) 18 December 2008 See the abstract; figures 1, 2; paragraphs 6-30; and claims 1-5	1-3,50-53 34-37
X A	US 2006-0170604 A1 (ALMOG, BENYAMIN et al.) 03 August 2006 See the abstract; figures 2, 3; paragraphs 53-67; and claims 1-14	1-3 34-37,50-53
A	US 2005-0073465 A1 (OLSON, STEVEN C.) 07 April 2005 See the abstract; figures 4A-5B; paragraphs 16-20; and claims 1-14	1-3,34-37,50-53
A	US 2004-0222936 A1 (HUNG, ZHEN-DA et al.) 11 November 2004 See the abstract; figures 1, 2; paragraphs 21-26; and claims 1-6	1-3,34-37,50-53

☐ 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 citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 JUNE 2010 (24.06.2010)	**01 JULY 2010 (01.07.2010)**

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
Government Complex-Daejeon, 139 Seonsa-ro, Seo-gu, Daejeon 302-701, Republic of Korea

Facsimile No. 82-42-472-7140

Authorized officer

NAM, Yun Kwon

Telephone No. 82-42-481-8357

INTERNATIONAL SEARCH REPORT

International application No.
PCT/MY2009/000181

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.: 5, 17, 21, 23, 32, 48, 62
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:

The claims 5, 17, 21, 23, 32, 48, and 62 are too unclear to make meaningful search possible because the claims 5, 17, 21, 23, 32, 48, and 62 refer to claim 4, 16, 20, 22, 31, 47, and 61 respectively, violating PCT Rule 6.4(a).

3. ☒ Claims Nos.: See Separate Sheet
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

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

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

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

International application No.
PCT/MY2009/000181

Continuation of:

(BOX No. II)

The claims 4, 6-16, 18-20, 22, 24-31, 33, 38-47, 49, 54-61, and 63 are too unclear to make meaningful search possible because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/MY2009/000181

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2006-0158383 A1	20.07.2006	KR 10-0683177 B1	15.02.2007
		KR 10-2006-0083833	21.07.2006
		US 7471256 B2	30.12.2008
JP 2008-306436 A	18.12.2008	None	
US 2006-0170604 A1	03.08.2006	AT 405003 T	15.08.2008
		AU 2006-211097 A1	10.08.2006
		AU 2006-211097 B2	01.10.2009
		CA 2596545 A1	10.08.2006
		DE 602006002252 D1	25.09.2008
		EP 1849210 A1	31.10.2007
		EP 1849210 B1	13.08.2008
		ES 2313606 T3	01.03.2009
		KR 10-2007-0107740 A	07.11.2007
		US 7113141 B2	26.09.2006
		WO 2006-082577 A1	10.08.2006
US 2005-0073465 A1	07.04.2005	US 7064729 B2	20.06.2006
US 2004-0222936 A1	11.11.2004	TW 264149 B	11.10.2006