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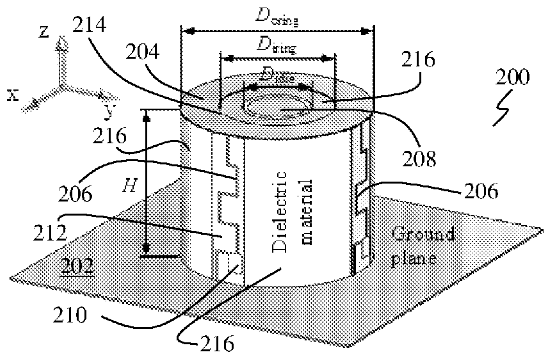

FIG. 2A

(57) **Abstract:** According to embodiments of the present invention, an antenna is provided. The antenna includes a conductive structure, a conductive ring arranged over and spaced apart from the conductive structure, at least one meandering conductor electrically coupling the conductive structure and the conductive ring to each other, and a signal feed structure configured to receive an electrical signal, the signal feed structure arranged electrically isolated from the conductive structure, and spaced apart from the conductive ring. According to further embodiments of the present invention, a method for forming an antenna and a method for controlling an antenna are also provided.

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ANTENNA, METHOD FOR FORMING THE SAME, AND METHOD FOR CONTROLLING THE SAME

Cross-Reference To Related Application

[0001] This application claims the benefit of priority of Singapore patent application No. 10201707781R, filed 21 September 2017, the content of it being hereby incorporated by reference in its entirety for all purposes.

Technical Field

[0002] Various embodiments relate to an antenna, a method for forming an antenna, and a method for controlling an antenna.

Background

[0003] Wide-band technology and wireless systems have found a large range of applications. Antenna represents an essential part of any wireless communication systems. The size of the antenna is very important especially in military/civil communication systems, in which an antenna with a low visual signature is required. In such applications, antennas are required to have wide-band characteristics with consistent polarization and radiation properties over the frequency band of operation.

[0004] Several techniques have been employed to design antennas with a low-profile and wide-band performance. Three basic strategies have been utilized: 1) multi-resonant structure, 2) monopolar-patch antenna with wide-band feed, and 3) two coupled loops. In the first strategy, the antennas occupy a cylindrical volume with a diameter of 0.19 λ_{max} and a height of 0.067 λ_{max}, where λ_{max} is the free-space wavelength at the lowest frequency of operation. Although they have a low-profile structure, the bandwidth is only one octave (2:1). The second strategy is based on the monopolar-patch antenna, which, although this design has a low-profile, it has a narrow bandwidth of 3%. By employing a slot square ring in the top patch, the bandwidth is increased, for example, to 50% and even to 70%. By utilizing wide-band feed structures instead of pin feeds, the bandwidth has been increased dramatically. The third strategy utilizes two coupled loops to achieve wide-band characteristics. By top loading this antenna, low-profile versions were designed. By integrating two different antennas of the low-profile version each of which operates at a different frequency band, a very wideband design was presented. The main and common drawback of these designs is the large lateral dimension of the antenna in the azimuth plane, so that, these designs are considered as low-profile but not compact designs.

[0005] Recently, one design has been presented to have more reduction in the lateral dimension utilizing the third technique to achieve wide-band characteristics and top loading with capacitive feed to achieve a compact design.

Summary

[0006] The invention is defined in the independent claims. Further embodiments of the invention are defined in the dependent claims.

[0007] According to an embodiment, an antenna is provided. The antenna may include a conductive structure, a conductive ring arranged over and spaced apart from the conductive structure, at least one meandering conductor electrically coupling the conductive structure and the conductive ring to each other, and a signal feed structure configured to receive an electrical signal, the signal feed structure arranged electrically isolated from the conductive structure, and spaced apart from the conductive ring.

[0008] According to an embodiment, a method for forming an antenna is provided. The method may include electrically coupling a conductive structure of the antenna and a conductive ring of the antenna to each other via at least one meandering conductor, the conductive ring being arranged over and spaced apart from the conductive structure, and arranging a signal feed structure of the antenna electrically isolated from the conductive structure, and spaced apart from the conductive ring, the signal feed structure being configured to receive an electrical signal.

[0009] According to an embodiment, a method for controlling an antenna is provided. The method may include supplying an electrical signal to a signal feed structure of the antenna as described herein.

Brief Description of the Drawings

[0010] In the drawings, like reference characters generally refer to like parts throughout the different views. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, various embodiments of the invention are described with reference to the following drawings, in which:

[0011] FIG. 1A shows a schematic side view of an antenna according to various embodiments.

[0012] FIG. 1B shows a flow chart illustrating a method for forming an antenna, according to various embodiments.

[0013] FIG. 1C shows a method for controlling an antenna, according to various embodiments.

[0014] FIGS. 2A to 2D show schematic views of an antenna, according to various embodiments.

[0015] FIG. 3A and 3B show, for the antenna of various embodiments, respective plots of simulated voltage standing wave ratio (VSWR) and simulated maximum realized gain and total efficiency.

[0016] FIGS. 4A to 4C show respectively the vector surface current distributions for the antenna of various embodiments without bottom patches at different frequencies of 0.7 GHz, 0.9 GHz, and 2.3 GHz.

[0017] FIG. 5 shows a plot of simulated voltage standing wave ratio (VSWR) as a function of meander line length.

[0018] FIG. 6 shows the simulated results of the effect of parasitic posts on the performance of the antenna.

[0019] FIG. 7 shows the simulated results of the effect of adding bottom patches on the performance of the antenna.

[0020] FIG. 8A shows the vector surface current distribution for an antenna without bottom patches at a frequency of about 2.34 GHz, while FIG. 8B shows the vector surface current distribution for an antenna with bottom patches at a frequency of about 2.18 GHz.

[0021] FIG. 9 shows a plot of simulated results of the effect of parasitic posts and bottom patches on the performance of the antenna.

[0022] FIG. 10 shows the simulated results of the effect of dielectric material on the performance of the antenna.

[0023] FIG. 11 shows a plot of simulated results of the effect of the ground size on the performance of the antenna.

[0024] FIG. 12A shows photographs of the fabricated parts for an antenna, while FIG. 12B shows a photograph of an assembled antenna on a circular ground.

[0025] FIG. 13A shows a plot of results for comparison between simulated and measured voltage standing wave ratio (VSWR), while FIG. 13B shows a plot of results for comparison between simulated and measured maximum realized gain.

[0026] FIGS. 14A to 14C show simulated and measured far field co- and cross-polarized radiation patterns for the antenna of various embodiments, at five different frequencies for different cut planes.

Detailed Description

[0027] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. Other embodiments may be utilized and structural, logical, and electrical changes may be made without departing from the scope of the invention. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[0028] Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0029] In the context of various embodiments, the articles “a”, “an” and “the” as used with regard to a feature or element include a reference to one or more of the features or elements.

[0030] In the context of various embodiments, the term “about” as applied to a numeric value encompasses the exact value and a reasonable variance.

[0031] As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0032] As used herein, the phrase of the form of "at least one of A or B" may include A or B or both A and B. Correspondingly, the phrase of the form of "at least one of A or B or C", or including further listed items, may include any and all combinations of one or more of the associated listed items.

[0033] Various embodiments may provide a compact and wide-band vertically polarized monopole antenna.

[0034] Various embodiments may provide a vertically polarized antenna with monopole-like radiation pattern.

[0035] Various embodiments may provide a compact antenna based on a monopolar-patch antenna with wide-band feed, for example, by utilizing dielectric loading and meander line(s) to reduce the lateral dimension.

[0036] The design of a compact, wide-band antenna with omnidirectional radiation pattern is described herein. The antenna may occupy a cylindrical volume and may be composed of a conducting body of revolution, a parasitic top ring shorted to a ground plane via a meander line, a dielectric material and two parasitic metallic posts. The conducting body of revolution is employed to act as a wide-band feeding structure. The parasitic top ring with the meander line and the dielectric material are utilized to reduce the lowest frequency of operation, and, hence, size reduction is achieved. Detailed analysis of the antenna performance, to be described further below, is provided with the help of vector surface current distribution. The design disclosed herein provides a voltage standing wave ratio (VSWR) lower than 2.5:1 from about 0.69 to 3.35 GHz with a bandwidth of about 4.86:1. The antenna may have a diameter of about 0.115 λ_{max} and a height of about 0.092 λ_{max}, where λ_{max} is the free-space wavelength at the lowest frequency of operation. An antenna has been designed, fabricated and measured. The measured VSWR is consistent with the simulated one. The measured maximum realized gain varies from about 2 to 6 dBi. The total efficiency of the antenna is above 80% within the operating band. By excluding the impedance mismatching, the simulated radiation efficiency is found to be above 93%. A good agreement is achieved between simulated and measured far-field radiation patterns.

[0037] Various embodiments may relate to a compact and wide-band antenna design. The antenna may include a ground plane, a cone, a plurality of parasitic posts, a circular ring electrically coupled to the ground plane via a plurality of meander lines, and a dielectric material filling up the space among the ground plane, the cone, the circular ring and the meander lines. The antenna may further include a metallic patch electrically coupled to the meander line, such that the magnitude of the reflected signal and the frequency of the first harmonic may be decreased. The antenna of various embodiments may have the smallest dimensions compared to known designs with wide-band characteristics. As the design of the antenna of various embodiments is 90° rotationally symmetric around the z-axis (e.g., defined as a vertical axis, e.g., perpendicular to the ground plane), a very good omnidirectional radiation pattern may be achieved.

[0038] FIG. 1A shows a schematic side view of an antenna 100 according to various embodiments. The antenna 100 includes a conductive structure 102, a conductive ring 104 arranged over and spaced apart from the conductive structure 102, at least one meandering conductor 106 electrically coupling the conductive structure 102 and the conductive ring 104 to each other, and a signal feed structure 108 configured to receive an electrical signal, the signal feed structure 108 arranged electrically isolated from the conductive structure 102, and spaced apart from the conductive ring 104.

[0039] In other words, an antenna 100 may be provided. The antenna 100 may include a conductive structure 102 and a conductive ring 104 arranged above the conductive structure 102. The conductive structure 102 and the conductive ring 104 may be spaced apart from each other. The conductive structure 102 and the conductive ring 104 may be arranged at least substantially parallel to each other. Each of the conductive structure 102 and the conductive ring 104 may be electrically conductive. The conductive structure 102 may be a base structure for supporting the antenna 100, and the conductive ring 104, being provided on top of the conductive structure 102, may define an upper or top ring. The conductive structure 102 may define an electrical ground, meaning that the conductive structure 102 may be a ground (GND) structure.

[0040] The antenna 100 may further include at least one meandering conductor (or conductive line) 106. The at least one meandering conductor 106 may have a longitudinal axis aligned at least substantially perpendicular to the conductive structure 102. The at least one meandering conductor 106 may be formed or provided on a dielectric substrate. The conductive structure 102 and the conductive ring 104 may be shorted to one another by means of the at least one meandering conductor 106. The shorting connection may reduce the lowest frequency of operation of the antenna 100. In other words, the at least one meandering conductor 106 may be provided to help define the lowest frequency of operation of the antenna. The length of the at least one meandering conductor 106 may help to control the lowest frequency of operation, and, as the meander line length increases, the lowest frequency decreases. Further, using a conductor that has a meandering pattern may help to realise a compact-size antenna.

[0041] The antenna 100 may further include a signal feed structure 108 which may be excited by an electrical signal that is provided to it. The signal feed structure 108 may receive an electrical signal suitable for wide-band operation. The signal feed structure 108 may also be termed as a body of revolution. The signal feed structure 108 may be (electrically) conductive.

[0042] The signal feed structure 108 may be electrically isolated from the conductive structure 102. The signal feed structure 108 may be spaced apart from the conductive ring 104. The signal feed structure 108 may be spaced apart from the conductive ring 104 by a slot or a gap. The signal feed structure 108 may be electrically isolated from the conductive ring 104 by being separated from the conductive ring 104 by the slot. The conductive ring 104 and the signal feed structure 108 may define a capacitance or provide capacitive coupling.

[0043] The signal feed structure 108 may be arranged inside or within the conductive ring 104. For example, the signal feed structure 108 may be arranged within a perimeter of the conductive ring 104, e.g., within an inner circumference of the conductive ring 104. The conductive ring 104 may be arranged surrounding the signal feed structure 108, e.g., around an entire perimeter of the signal feed structure 108. The conductive ring 104 may include an aperture or opening to receive the signal feed structure 108, with a slot being defined between the conductive ring 104 and the signal feed structure 108. The signal feed structure 108 and the conductive ring 104 may be arranged co-planar to each other.

[0044] In the context of various embodiments, the conductive structure 102 may include or may be a planar structure. The conductive structure 102 may be circular. However, it should be appreciated that the conductive structure 102 may be of any other suitable shapes, including a square, a rectangle, etc.

[0045] In the context of various embodiments, the conductive ring 104 may be a parasitic ring. The term “parasitic” as used throughout herein with reference to an element or feature may mean that the element is not connected to (or not electrically coupled to) the signal feed structure 108 and/or a signal feed port, and, further, may act as a loading to the signal feed structure 108.

[0046] In the context of various embodiments, the conductive ring 104 may include or may be a planar structure. The conductive ring 104 may be a patch structure. The conductive ring 104 may be circular. However, it should be appreciated that the conductive ring 104 may be of any other suitable shapes, including a square, a rectangle, etc. Optimization may be carried out using a full-wave simulator.

[0047] In various embodiments, the antenna 100 may include a plurality of meandering conductors (or conductive lines), each of the plurality of meandering conductors (one of which includes the meandering conductor 106) electrically coupling the conductive structure 102 and the conductive ring 104 to each other. The plurality of meandering conductors may be provided to provide a rotationally symmetric antenna, which may then produce a symmetric radiation pattern. There may be an optimal number of four meandering conductors. However, it should be appreciated that any number of meandering conductors may be provided, including two, three or any higher number.

[0048] The plurality of meandering conductors may be arranged equally spaced around the conductive ring 104. In embodiments where there may be four meandering conductors and the conductive ring 104 may be circular, a meandering conductor (e.g., 106) may be spaced from another meandering conductor around the circular conductive ring 104 by 90°.

[0049] In various embodiments, for each of the at least one meandering conductor 106, the meandering conductor may be shaped in the form of a square wave. This may mean that each meandering conductor may be defined by a series of alternating vertical and horizontal line segments. However, it should be appreciated that each of the at least one meandering conductor 106 may be of any other suitable shapes, for example, in the form of a sinusoidal wave, a triangular wave, etc.

[0050] In various embodiments, the antenna 100 may further include, for each of the at least one meandering conductor 106, a conductive patch electrically coupled to the meandering conductor along a (length) portion of the meandering conductor. Each conductive patch may be a metallic patch. Each conductive patch may be arranged along a bottom portion of the corresponding meandering conductor, proximal to the conductive structure 102. As such, each conductive patch may be a bottom patch. Each conductive patch may have a size (e.g., length and/or width) that is larger than a width of the corresponding meandering conductor. Each conductive patch may be a quadrilateral, e.g., a square or a rectangle. However, it should be appreciated that each conductive patch may be of any other suitable shapes. Optimization may be carried out using a full-wave simulator.

[0051] The antenna 100 may further include a dielectric material arranged surrounding the signal feed structure 108. The dielectric material may further be arranged between the conductive structure 102 and the conductive ring 104, e.g., covering the entire distance between the conductive structure 102 and the conductive ring 104. The dielectric material may further be arranged between the conductive ring 104 and the signal feed structure 108, for example, within a slot defined between the conductive ring 104 and the signal feed structure 108. The dielectric material may also be arranged between the signal feed structure 108 and the at least one meandering conductor 106. In embodiments where there may be a plurality of meandering conductors, the dielectric material may also be arranged between adjacent meandering conductors. In embodiments without the dielectric material, the antenna 100 may be narrow-banded.

[0052] Dielectric materials may be characterized by dielectric constant (ε_r) and dielectric losses (tanδ). A suitable dielectric material that may be employed for the antenna 100 should have dielectric losses as low as possible to achieve high radiation efficiency.

[0053] In various embodiments, the dielectric material may be employed as a loading. Any suitable material may be used as the dielectric material. As non-limiting examples, the dielectric material may have a dielectric constant (ε_r) of between about 2.9 and about 3.3, for example, about 3.15.

[0054] In various embodiments, the dielectric material may include or may be a polymer. Nevertheless, it should be appreciated that any other suitable material may be used as the dielectric material.

[0055] The antenna 100 may further include a pair of conductive posts arranged on opposite sides of the signal feed structure 108. The pair of conductive posts may be parasitic posts that act as inductive loading to the antenna 100. The pair of conductive posts may be arranged spaced apart from the signal feed structure 108. The pair of conductive posts may be electrically isolated from the signal feed structure 108. The pair of conductive posts may be electrically coupled to the conductive structure 102. At least one of the height, diameter or separation of the conductive posts from the signal feed structure 108 may be controlled or designed according to the requirements of the antenna 100.

[0056] In various embodiments, a plurality of conductive posts may be provided surrounding the signal feed structure 108, separated from the signal feed structure 108. The plurality of conductive posts may be provided to provide a rotationally symmetric antenna, which may then produce a symmetric radiation pattern. Further, the conductive posts may be provided to reduce the spark frequency and achieve wideband impedance matching. A pair of conductive posts may be optimum. However, the number of conductive posts may be increased to 4, but preferably not more than 4, which otherwise may affect the wideband matching.

[0057] In various embodiments, the signal feed structure 108 may include an inverted cone structure, the inverted cone structure having a tip (or apex, or vertex) proximal to the conductive structure 102. The inverted cone structure may include or may be a curved cone. This may mean that the inverted cone structure may have a surface connecting the tip to a base of the inverted cone structure, the surface having a curvature along a line, traced on the surface, defined from (the perimeter of) the base to the tip. The curved cone may enable wideband impedance matching to be achieved.

[0058] The antenna 100 may further include an N-type connector coupled (or connected) to the signal feed structure 108. The N-type connector may allow feeding or supply of an electrical signal to the signal feed structure 108. Any other connector type may also be employed.

[0059] In the context of various embodiments, different conductive parts or elements of the antenna 100 may be made of different materials. Any one of the conductive parts of the antenna 100 may be metallic.

[0060] FIG. 1B shows a flow chart 120 illustrating a method for forming an antenna, according to various embodiments.

[0061] At 122, a conductive structure of the antenna and a conductive ring of the antenna are electrically coupled to each other via at least one meandering conductor, the conductive ring being arranged over and spaced apart from the conductive structure.

[0062] At 124, a signal feed structure of the antenna is arranged electrically isolated from the conductive structure, and spaced apart from the conductive ring, the signal feed structure being configured to receive an electrical signal.

[0063] In various embodiments, there may be a plurality of meandering conductors, and, at 122, the conductive structure and the conductive ring may be electrically coupled to each other via each of the plurality of meandering conductors. The plurality of meandering conductors may be equally spaced around the conductive ring.

[0064] In various embodiments, for each of the at least one meandering conductor, a conductive patch may be electrically coupled to the meandering conductor along a portion of the meandering conductor.

[0065] In various embodiments, a dielectric material may be arranged surrounding the signal feed structure. The dielectric material may further be arranged between the conductive structure and the conductive ring. The dielectric material may further be arranged between the conductive ring and the signal feed structure.

[0066] In various embodiments, a pair of conductive posts may be arranged on opposite sides of the signal feed structure.

[0067] In various embodiments, the signal feed structure may include an inverted cone structure, and, at 124, the inverted cone structure may be arranged with a tip of the inverted cone structure proximal to the conductive structure.

[0068] FIG. 1C shows a method 130 for controlling an antenna, according to various embodiments. An electrical signal may be supplied to a signal feed structure of the antenna as described herein. The electrical signal may be a signal suitable for wide-band operation.

[0069] It should be appreciated that descriptions in the context of the antenna 100 may correspondingly be applicable in relation to the method for forming an antenna described in the context of the flow chart 120 and the method 130 for controlling an antenna.

[0070] The antenna structure and design of various embodiments will now be described.

[0071] FIGS. 2A to 2D show schematic views of an antenna 200, according to various embodiments. FIG. 2A shows a three-dimensional (3D) view of the assembled antenna 200, including a ground plane 202, a top circular ring 204, four meander lines 206, each of which is formed with a corresponding conductive or metallic patch 210 and on a dielectric substrate 212, a signal feed structure in the form of a curved cone 208 that is arranged separated from the circular ring 204 by a slot 214, and a dielectric material 216. The top circular ring 204 is shorted to the ground plane 202 by the meander lines 206. The dielectric material 216 may surround the curved cone 208, fill the space of the slot 214, and fill the space between the curved cone 208 and the four meander lines 206, and the space between adjacent meander lines 206. The dielectric material 216 may have a dielectric constant, ε_r, of about 3.15. FIG. 2B shows a 3D view of the antenna 200, with the dielectric material 216 removed, to show the interior of the antenna 200. Two parasitic posts 218a, 218b may be arranged on either side of the curved cone 208, spaced apart from the curved cone 208. The antenna 200 may be a wide-band antenna.

[0072] FIGS. 2C and 2D respectively show parameters defining the dimensions of the meander lines 206 and the curved cone 208. Each meander line 206 may have a shape or pattern in the form of a square wave defined by a series of alternating vertical line segments (e.g., having length l_m) and horizontal line segments (e.g., having length l_{mh}). As shown in FIG. 2C, an (one-port) N-type connector 219 may be connected to the curved cone 208 to feed the antenna 200.

[0073] The curved cone 208 may act as a wide-band feed for the antenna 200 and its curvature may be defined or generated using the following equations:

$$x = -e^{-t(z-H)} + (D_{cone}/2) + 1 \quad \text{Equation (1),}$$

where,

$$t = [ln(1 + (D_{cone}/2))]/[H - z_2] \quad \text{Equation (2).}$$

[0074] The capacitive coupling due to the slot 214 between the curved cone 208 and the top ring 204 with the meander lines 206 may be utilized to match and reduce the lowest frequency of operation. The two parasitic posts 218a, 218b may act as an inductive loading for the antenna 200 to match the high frequency band. These two posts 218a, 218b along with the four bottom patches 210 may be employed to match the spark, which may be due to high-order harmonics of the meander line 206. The cylindrical dielectric 216 may be utilized to reduce the lowest frequency and match the high frequency band as will be described further below. The antenna 200 may be mounted on a circular ground plane with a diameter of about 800 mm.

[0075] The voltage standing wave ratio (VSWR), the maximum realized gain and total efficiency for the antenna of various embodiments are simulated using the following dimensions: $H = 40$, $D_{\text{idie}} = 9$, $D_{\text{iring}} = 30$, $D_{\text{oring}} = 50$, $D_{\text{cone}} = 15$, $Z_2 = 0.2$, $h_{\text{post}} = 18$, $d_{\text{post}} = 7$, $w_m = 0.5$, $l_m = 8$, $l_{\text{mh}} = 5.2$, $w_1 = 5.25$, $w_2 = 4$, and $d_i = 3.85$, with all dimensions in mm. The dielectric material 216 may have a dielectric constant (ε_r) in the range of 2.9 to 3.3.

[0076] FIG. 3A shows a plot 350a of the simulated voltage standing wave ratio (VSWR). The antenna has a VSWR of about 2.5:1 from about 0.69 GHz to about 3.35 GHz with a bandwidth of about 4.86:1. It is obtained using the time-domain solver of CST Microwave Studio. Most of the simulations are conducted with an infinite ground plane to reduce the simulation time, unless stated otherwise. The antenna has a cylindrical volume with a diameter of about 0.115 λ_{max} and a height of about 0.092 λ_{max}, where λ_{max} is the free-space wavelength at the lowest frequency of operation.

[0077] FIG. 3B shows a plot 350b of the simulated maximum realized gain and total efficiency. Plot 350b shows result 352 for the maximum realized gain (dBi) and result 354 for the total efficiency. The maximum realized gain varies from about 3.5 dBi to about 6.2 dBi in the operating frequency band (0.69 GHz - 3.35 GHz) of the antenna and the total efficiency is above 80%.

[0078] The operation and analysis of the antenna of various embodiments will now be described.

[0079] <u>The Vector Surface Current Distribution</u>

[0080] FIGS. 4A to 4C show respectively the vector surface current distributions for the antenna of various embodiments without bottom patches (metallic patches) at different frequencies of 0.7 GHz, 0.9 GHz, and 2.3 GHz. As non-limiting examples, the antenna of FIGS. 4A to 4C is based on the antenna 200 of FIGS. 2A to 2D. The dielectric material is not shown for ease of understanding to illustrate the interior of the antenna.

[0081] At the operating frequency of about 0.7 GHz, FIG. 4A shows that the meander lines 206 have most of the current. The vertical components of the current are in the same direction (as traced by the vertical white arrows illustrated for one of the meander lines 206), which leads to enhancing the co-polarized radiation pattern. The horizontal components of the current are in the opposite directions to each other (as traced by the horizontal white arrows illustrated for one of the meander lines 206), leading to a small cross-polarized radiation pattern of the antenna 200. The current on the curved cone 208 is weak and is opposite in direction to the one on the meander line 206 so that the cone 208 with meander line 206 construct a half-loop situation. The first anti-/parallel-resonance occurs when the loop circumference equals about 0.5 λ_0, where λ_0 is the free-space operating wavelength. FIG. 5 shows a plot 550 illustrating the effect of the meander line length on the lowest frequency of operation and the middle spark (at around 2.1 - 2.5 GHz), which will be discussed further below. Plot 550 shows the simulated results of voltage standing wave ratio (VSWR) as a function of meander line length, $l_{meander}$, illustrating result 552 for $l_{meander}$ = 49.85 mm, result 554 for $l_{meander}$ = 52.85 mm, and result 556 for $l_{meander}$ = 55.85 mm. As may be observed, as the length of the meander line 206 increases, the lowest frequency decreases because the length of the half-loop increases. One of the factors affecting the lowest frequency of operation and matching at low-frequency band is the loop length, which may include the height of the curved cone 208 and the length of the meander line 206.

[0082] At the operating frequency of about 0.9 GHz, as shown in FIG. 4B, the meander line 206 has a smaller current density than the one at the frequency of about 0.7 GHz. The directions of the vertical and horizontal components (as traced by the horizontal white arrows illustrated for one of the meander lines 206) of the current on the meander line 206 are opposite to those at the frequency of 0.7 GHz shown in FIG. 4A. The current on the curved cone 208 becomes stronger and has the same direction as the one on the meander line 206, which is similar to the folded dipole situation.

[0083] At the operating frequency of about 2.3 GHz, as shown in FIG. 4C, the meander line 206 has most of the current. The meander line length affects the spark frequency, as shown in FIG. 5, where as $l_{meander}$ increases from 49.85 mm to 55.85 mm, the spark frequency decreases from about 2.5 GHz to about 2.1 GHz. However, the vertical components (as traced by the vertical white arrows illustrated for one of the meander lines 206) of the current on the meander line 206 are in opposite directions to each other because of the first high-order mode of the meander line 206. By examining the animated electric field on the antenna 200, it is found that at about 0.7 GHz and about 2.3 GHz, the antenna 200 resonates, and standing waves contribute to the radiation. For other frequencies, the antenna 200 may not or does not resonate, and traveling waves contribute to the radiation, leading to a wide-band characteristic of the antenna 200.

[0084] <u>Effect of Parasitic Posts</u>

[0085] FIG. 6 shows the simulated results of the effect of parasitic posts on the performance of the antenna, with and without parasitic posts (e.g., 218a, 218b, FIG. 2B). The reference antenna for all the comparisons is similar to the antenna 200 shown in FIGS. 2A to 2D. Plot 650a illustrates the result for VSWR as a function of frequency, plot 650b illustrates the result for input resistance as a function of frequency, and plot 650c illustrates the result for input reactance as a function of frequency. Results 652a, 652b, 652c are for an antenna without parasitic posts, while results 654a, 654b, 654c are for an antenna with parasitic posts.

[0086] It may be seen from FIG. 6 that the parasitic posts help in matching at the spark frequency at about 2.2 GHz (where a spark may be observed) and at high frequencies (e.g., from about 2.8 GHz to about 3.4 GHz). The posts act as an inductive loading before their resonant frequency to match the capacitance of the antenna at the spark frequency as shown in FIG. 6. The posts may also accommodate the real part at the spark frequency as well as high frequencies. The resonant frequency of the spark may not be affected by adding the parasitic metallic posts. By controlling at least one dimension relating to the parasitic posts, for example, at least one of their height, diameter or separation from the curved cone (e.g., 208, FIG. 2B), good matching may be achieved.

[0087] Effect of Bottom Patches

[0088] A strong reflection appears at a frequency of about 2.3 GHz due to the first harmonic of the meander line, as discussed above in relation to the vector surface current distribution in the context of FIGS. 4A to 4C. By perturbing the current distribution on the meander line, this resonance may be minimised or cured. This may be accomplished by loading the meander line with metallic patches (e.g., 210, FIG. 2B) at the location of maximum current distribution. As a non-limiting example, the metallic patches may be positioned at or towards the bottom part of the meander line.

[0089] FIG. 7 shows the simulated results of the effect of adding bottom (metallic) patches (e.g., 210, FIG. 2B) on the performance of the antenna. Plot 750a illustrates the result for VSWR as a function of frequency, plot 750b illustrates the result for input resistance as a function of frequency, and plot 750c illustrates the result for input reactance as a function of frequency. Results 752a, 752b, 752c are for an antenna without bottom patches, while results 754a, 754b, 754c are for an antenna with bottom patches. By adding the metallic patches, the magnitude of the reflected signal may be reduced and/or the frequency of the first harmonic may be decreased. Further, the frequency of the first harmonic may be decreased because of a longer current path. The vector surface current distribution on the antenna at the spark frequency with and without the bottom patches are shown respectively in FIGS. 8A and 8B. FIG. 8A shows the vector surface current distribution for an antenna with a top ring 804a and four meander lines 806a without bottom patches at a frequency of about 2.34 GHz, while FIG. 8B shows the vector surface current distribution for an antenna with a top ring 804b and four meander lines 806b with bottom patches 810 at a frequency of about 2.18 GHz. As shown in FIG. 8B, current flowing through the meander line 806b may be re-directed to flow through the patch 810, resulting in a longer flow path. The dielectric material is not shown for clarity and ease of understanding.

[0090] FIG. 9 shows a plot 950 of simulated results of the effect of parasitic posts and bottom (metallic) patches on the performance of the antenna, illustrating the effect of adding the bottom patches and the parasitic posts on the spark frequency matching. Plot 950 shows result 952 for an antenna with parasitic posts and patches, result 954 for an antenna with parasitic posts and without patches, result 956 for an antenna without parasitic posts and with patches, and result 958 for an antenna without parasitic posts and patches. As may be observed, the addition of both the patches and the parasitic posts help to match the spark frequency.

[0091] Effect of Dielectric Material

[0092] FIG. 10 shows the simulated results of the effect of dielectric material (e.g., 216, FIG. 2A) on the performance of the antenna. Plot 1050a illustrates the result for VSWR as a function of frequency, plot 1050b illustrates the result for input resistance as a function of frequency, and plot 1050c illustrates the result for input reactance as a function of frequency. Results 1052a, 1052b, 1052c are for an antenna without dielectric material, while results 1054a, 1054b, 1054c are for an antenna with dielectric material. As may be observed, the dielectric material helps with reducing the lowest frequency of operation as well as matching the high frequency band, which helps to broaden the bandwidth.

[0093] Ground Plane Size Effect

[0094] As mentioned above, an infinite ground plane is used for most of the simulations to reduce the simulation time. The effect of the ground plane size is shown in FIG. 11 illustrating a plot 1150 of simulated results of the effect of the ground size on the performance of the antenna. Plot 1150 shows result 1152 for an infinite ground, and result 1154 for a circular ground of a diameter of about 800 mm. As may be observed, the ground plane size has a minimal or small influence on the matching performance of the antenna.

[0095] Fabrication and Measurement Results

[0096] To build the antenna, six parts may be fabricated and assembled. FIG. 12A shows photographs of the fabricated parts, which include a curved cone 1208, two parasitic posts 1218, a top circular ring 1204, one of the meander line portions, having a meander line 1206 and a conductive patch 1210 on a substrate 1212, a dielectric material 1216 with a cavity 1240 (boundary traced by white dashed ellipse) for receiving the curved cone 1208, and a circular ground structure 1202 (shown in top and bottom views). FIG. 12B shows a photograph of an antenna 1200 on a circular ground 1202, assembled from the parts shown in FIG. 12A. The circular ground 1202 may define a central part of a larger ground structure 1203.

[0097] As non-limiting examples, the circular ground 1202 (therefore, also the upper ground structure 1202a and the bottom ground structure 1202b), the parasitic posts (not shown) and the curved cone 1208 are made of aluminum, and the top ring 1204 is made of copper to be soldered with the meander lines 1206. The meander lines 1206 and the conductive patches 1210 are also made of copper. ULTEM™ 1000 (Unfilled) PEI (polyetherimide) material is used as the dielectric material with a dielectric constant, $\varepsilon_r = 3.15$ and dielectric losses, $\tan\delta = 0.0013$ (e.g., from Professional Plastics, Inc.). The four meander lines 1206 are fabricated using printed circuit board technology on Rogers RT5870 substrate ($\varepsilon_r = 2.33$ and thickness = 0.38 mm).

[0098] The input VSWR of the fabricated antenna 1200 is measured using an Agilent vector network analyzer N5230. A comparison between the simulated and measured VSWR and for the maximum realized gain are shown in FIGS. 13A and 13B. FIG. 13A shows a plot 1350a for comparison between simulated (result 1352a) and measured (result 1354a) voltage standing wave ratio (VSWR), while FIG. 13B shows a plot 1350b for comparison between simulated (result 1352b) and measured (result 1354b) maximum realized gain. As shown in FIG. 13A, the antenna provides a measured VSWR better than 2.5:1 over a frequency band from about 0.69 GHz to about 3.2 GHz, which corresponds to 4.64:1 bandwidth. The measured maximum realized gain varies from about 2 dBi to about 6 dBi. As may be observed in FIGS. 13A and 13B, a good agreement between the simulated results and measured data is achieved. The total simulated efficiency of the antenna is above 80% within the operating band. By excluding the impedance mismatching, the radiation efficiency is found to be above 93%. The radiation patterns and gain are measured in an anechoic chamber. The simulated and measured far field co- and cross-polarized radiation patterns at five different frequencies are shown in FIGS. 14A to 14C. The results are shown in three different cut planes, two of them are two different elevation cuts (the *x-z* and *y-z* planes), and the other one is the azimuth plane (the *x-y* plane).

[0099] FIG. 14A shows the simulated and measured far field co- and cross-polarized radiation patterns for the antenna of various embodiments, at five different frequencies of 0.7 GHz, 1 GHz, 1.8 GHz, 2.5 GHz and 3.2 GHz in the *x-z* cut plane, while FIGS. 14B and 14C show the corresponding results for the same frequencies in the *y-z* cut plane, and the *x-y* cut plane, respectively. In FIGS. 14A to 14C, the solid line is the measured co-polarization, the dashed line (with shorter line segments) is the simulated co-polarization, the dotted line is the measured cross-polarization, and the dashed line (with longer line segments) is the simulated cross-polarization (for example, see results shown in FIG. 14A for the frequency of 3.2 GHz). The results show that the antenna exhibits monopole-like radiation pattern over the entire frequency band of operation.

[0100] A comparison between the design of various embodiments and known antenna designs is shown in Table I. This comparison focuses on known antennas occupying cubical and cylindrical volumes. It may be seen that the antenna of various embodiments has the smallest dimensions with wide-band characteristics. The design may be considered as the second compact antenna design with wide bandwidth after the one presented in reference "M. Li, et. al., *IEEE Trans. Antennas Propag.*, vol. 65, no. 3, pp. 1026–1037, Mar. 2017". However, the design of various embodiments is based on a different operating principle with a smaller lateral dimension and exhibits a wider bandwidth. The design presented in the above-mentioned reference is not rotationally symmetric around z-axis, which leads to non-ideal omnidirectional radiation pattern in *x-y* plane. In contrast, the design of various embodiments is 90° rotationally symmetric around the *z*-axis. Moreover, the design of various embodiments may also be preferable from the mechanical stability viewpoint.

TABLE I

COMPARISON BETWEEN THE DESIGN OF VARIOUS EMBODIMENTS AND KNOWN DESIGNS.

Reference	Feeding Network	Volume Type	Dimensions (λ_{max})	Frequency Band of Operation (GHz)	Bandwidth	VSWR
[1]	One-port	Cylindrical	$H = 0.067$, $D = 0.19$	0.467-0.9	1.93:1	2:1
[2] (Set 2)	One-port SMA	Cylindrical	$H = 0.084$, $D = 0.237$	0.74-2.94	3.97:1	1.92:1
[3]	One-port SMA	Cylindrical	$H = 0.087$, $D = 0.246$	0.77- more than 20	>26:1	2:1
[4]	One-port SMA	Cylindrical	$H = 0.071$, $D = 0.28$	2.15-14	6.5:1	1.93:1
[5]	One-port SMA	Cubical	$H = 0.087$, $W = 0.2$	3.06-12	4:1	1.93:1
[6]	One-port SMA	Cubical	$H = 0.061$, $W = 0.201$	0.8-2.3	2.875:1	1.93:1
[7]	One-port SMA with capacitor	Cubical	$H = 0.033$, $W = 0.22$	1-4	4:1	3:1
[8]	One-port SMA with diplexer and capacitor	Cubical	$H = 0.046$, $W = 0.26$	0.66-5.4	8.2:1	2.7:1
[9]	One-port SMA with power divider to combine two ports	Cylindrical	$H = 0.09$, $D = 0.144$	0.693-2.84	4.1:1	2:1
[10]	One-port SMA with 4-elements matching network	Cubical	$H = 0.085$, $W = 0.19$	0.6-3.2	5.5:1	2.1:1
Various embodiments	One-port N-type	Cylindrical	$H = 0.09$, $D = 0.11$	0.69-3.35	4.86:1	2.5:1

[1] G. Goubau, et. al., *IEEE Trans. Antennas Propag.*, vol. 30, no. 1, pp. 15–26, Jan. 1982.
[2] K.-L. Lau, et. al., *IEEE Trans. Antennas Propag.*, vol. 53, no. 2, pp. 655–661, Feb. 2005.
[3] K.-L. Lau, et. al., *Electron. Lett.*, vol. 44, no. 12, pp. 716–717, Jun. 2008.
[4] H. Nakano, et. al., *IEEE Trans. Antennas Propag.*, vol. 56, no. 4, pp. 1187–1192, Apr. 2008.
[5] M. Koohestani, et. al., *IEEE Trans. Antennas Propag.*, vol. 62, no. 4, pp. 1888–1894, Apr. 2014.
[6] N. N.-Trong, et. al., *IEEE Trans. Antennas Propag.*, vol. 64, no. 6, pp. 2562–2568, Jun. 2016.
[7] N. Behdad, et. al., *IEEE Antennas Wireless Propag. Lett.*, vol. 12, pp. 280–283, 2013.
[8] K. Ghaemi, et. al., *IEEE Trans. Antennas Propag.*, vol. 63, no. 8, pp. 3699–3705, Aug. 2015.
[9] M. Li, et. al., *IEEE Trans. Antennas Propag.*, vol. 65, no. 3, pp. 1026–1037, Mar. 2017.
[10] S. M. A. M. H. Abadi, et. al., *IEEE Antennas Wireless Propag. Lett.*, vol. 13, pp. 742–745, 2014.

[0101] As described above, various embodiments may provide a compact and wide-band monopole antenna design, for example, a design for a compact and wide-band vertically polarized monopole antenna. The wide-band characteristics may be achieved by employing a body of revolution as the feeding structure. The compact size may be accomplished by utilizing the dielectric loading and parasitic top ring with meander line shorted to the ground. An antenna has been fabricated and measured. The measured VSWR is better than 2.5:1 from about 0.69 to 3.2 GHz with a bandwidth of about 4.64:1. The antenna has a cylindrical volume with a diameter of about 0.11 λ_{max} and a height of about 0.09 λ_{max}. The measured maximum realized gain varies from about 2 to 6 dBi. The measured radiation pattern shows a small cross-polarization level with consistent monopole-like radiation pattern in the entire operating frequency band. A comparison with known designs shows that the design of various embodiments has the compactness volume with a wide-band characteristic. Because the design is 90° rotationally symmetric around the *z*-axis, a very good omnidirectional radiation pattern may be achieved.

[0102] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

CLAIMS

1. An antenna comprising:

a conductive structure;

a conductive ring arranged over and spaced apart from the conductive structure;

at least one meandering conductor electrically coupling the conductive structure and the conductive ring to each other; and

a signal feed structure configured to receive an electrical signal, the signal feed structure arranged electrically isolated from the conductive structure, and spaced apart from the conductive ring.

2. The antenna as claimed in claim 1, wherein the at least one meandering conductor comprises a plurality of meandering conductors, each of the plurality of meandering conductors electrically coupling the conductive structure and the conductive ring to each other.

3. The antenna as claimed in claim 2, wherein the plurality of meandering conductors are arranged equally spaced around the conductive ring.

4. The antenna as claimed in any one of claims 1 to 3, wherein, for each of the at least one meandering conductor, the meandering conductor is shaped in the form of a square wave.

5. The antenna as claimed in any one of claims 1 to 4, further comprising, for each of the at least one meandering conductor, a conductive patch electrically coupled to the meandering conductor along a portion of the meandering conductor.

6. The antenna as claimed in any one of claims 1 to 5, further comprising a dielectric material arranged surrounding the signal feed structure.

7. The antenna as claimed in claim 6, wherein the dielectric material is further arranged between the conductive structure and the conductive ring.

8. The antenna as claimed in claim 6 or 7, wherein the dielectric material is further arranged between the conductive ring and the signal feed structure.

9. The antenna as claimed in any one of claims 6 to 8, wherein the dielectric material has a dielectric constant of between about 2.9 and about 3.3.

10. The antenna as claimed in any one of claims 6 to 9, wherein the dielectric material comprises a polymer.

11. The antenna as claimed in any one of claims 1 to 10, further comprising a pair of conductive posts arranged on opposite sides of the signal feed structure.

12. The antenna as claimed in any one of claims 1 to 11, wherein the signal feed structure comprises an inverted cone structure, the inverted cone structure having a tip proximal to the conductive structure.

13. The antenna as claimed in claim 12, wherein the inverted cone structure comprises a curved cone.

14. The antenna as claimed in any one of claims 1 to 13, further comprising an N-type connector coupled to the signal feed structure.

15. A method for forming an antenna comprising:

electrically coupling a conductive structure of the antenna and a conductive ring of the antenna to each other via at least one meandering conductor, the conductive ring being arranged over and spaced apart from the conductive structure; and

arranging a signal feed structure of the antenna electrically isolated from the conductive structure, and spaced apart from the conductive ring, the signal feed structure being configured to receive an electrical signal.

16. The method as claimed in claim 15, wherein the at least one meandering conductor comprises a plurality of meandering conductors, the method further comprising electrically coupling the conductive structure and the conductive ring of the antenna to each other via each of the plurality of meandering conductors.

17. The method as claimed in claim 16, further comprising arranging the plurality of meandering conductors equally spaced around the conductive ring.

18. The method as claimed in any one of claims 15 to 17, further comprising, for each of the at least one meandering conductor, electrically coupling a conductive patch to the meandering conductor along a portion of the meandering conductor.

19. The method as claimed in any one of claims 15 to 18, further comprising arranging a dielectric material surrounding the signal feed structure.

20. The method as claimed in claim 19, wherein the dielectric material is further arranged between the conductive structure and the conductive ring.

21. The method as claimed in claim 19 or 20, wherein the dielectric material is further arranged between the conductive ring and the signal feed structure.

22. The method as claimed in any one of claims 15 to 21, further comprising arranging a pair of conductive posts on opposite sides of the signal feed structure.

23. The method as claimed in any one of claims 15 to 22, wherein the signal feed structure comprises an inverted cone structure, and wherein arranging a signal feed structure comprises arranging the inverted cone structure with a tip of the inverted cone structure proximal to the conductive structure.

24. A method for controlling an antenna as claimed in any one of claims 1 to 14, the method comprising supplying an electrical signal to a signal feed structure of the antenna.

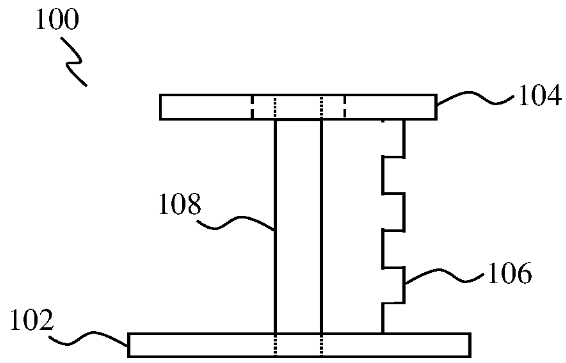


FIG. 1A

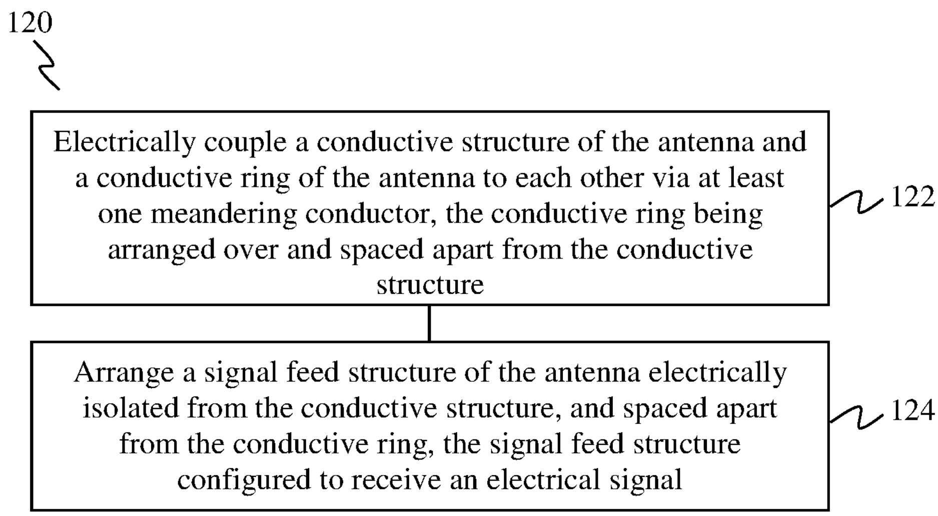


FIG. 1B

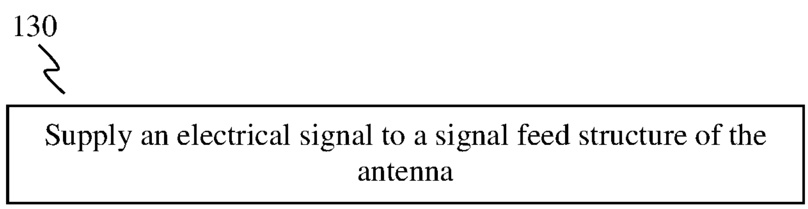


FIG. 1C

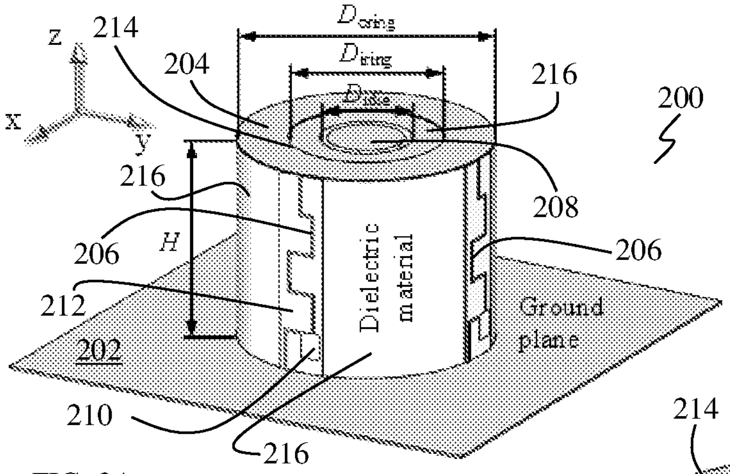


FIG. 2A

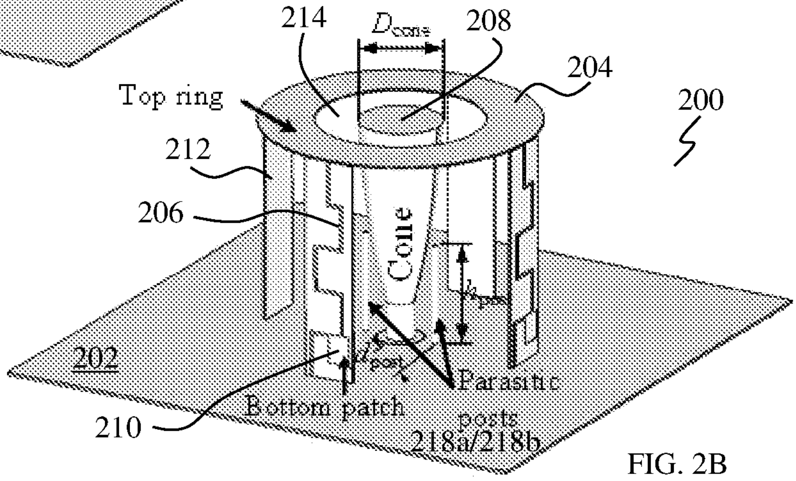


FIG. 2B

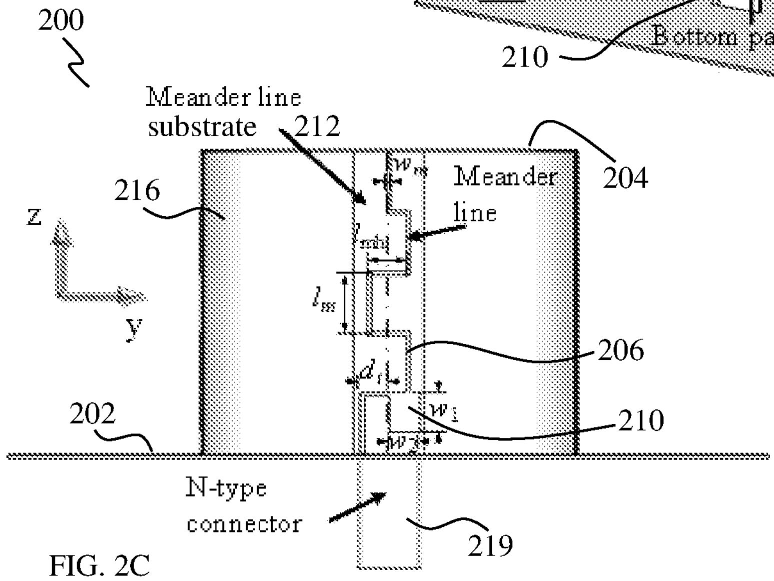


FIG. 2C

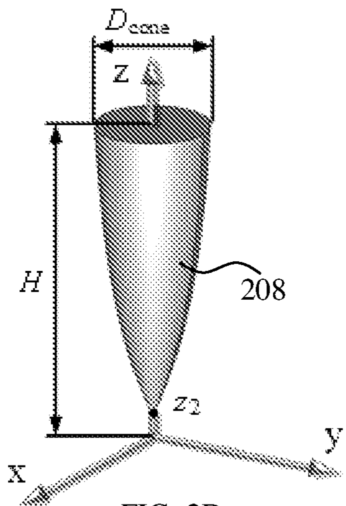


FIG. 2D

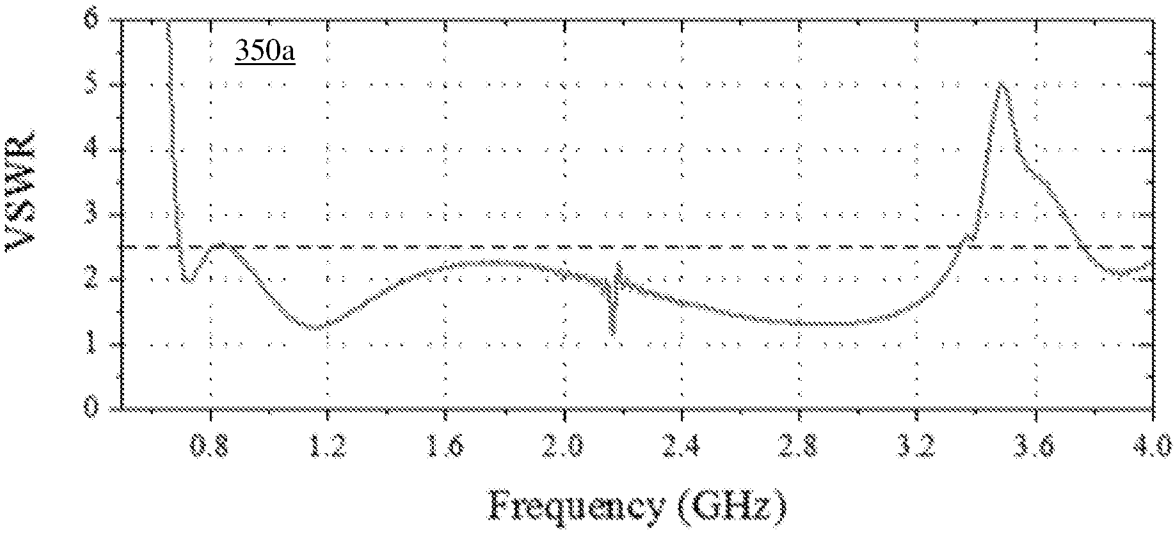

350a
VSWR
6
5
4
3
2
1
0
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
Frequency (GHz)

FIG. 3A

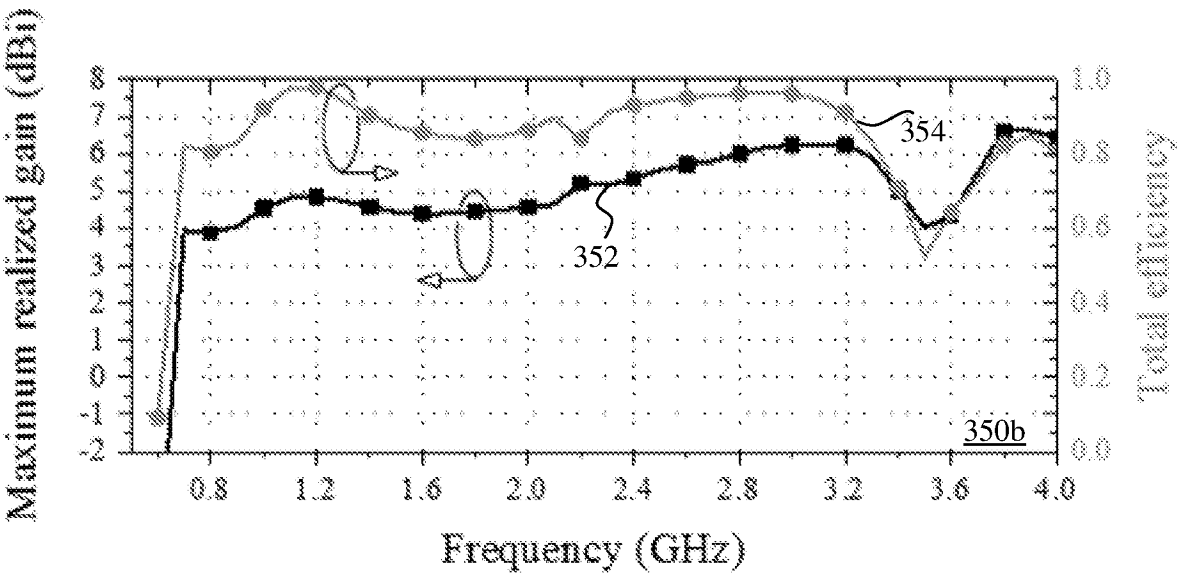

Maximum realized gain (dBi)
Total efficiency
354
352
350b
8
7
6
5
4
3
2
1
0
-1
-2
1.0
0.8
0.6
0.4
0.2
0.0
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
Frequency (GHz)

FIG. 3B

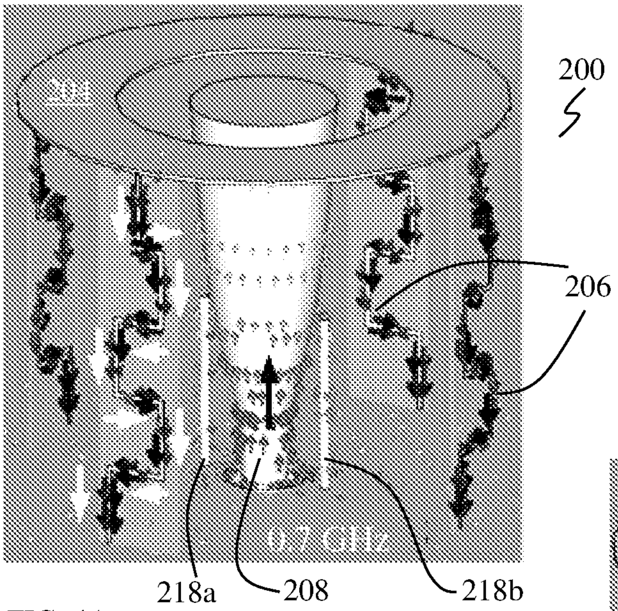


FIG. 4A

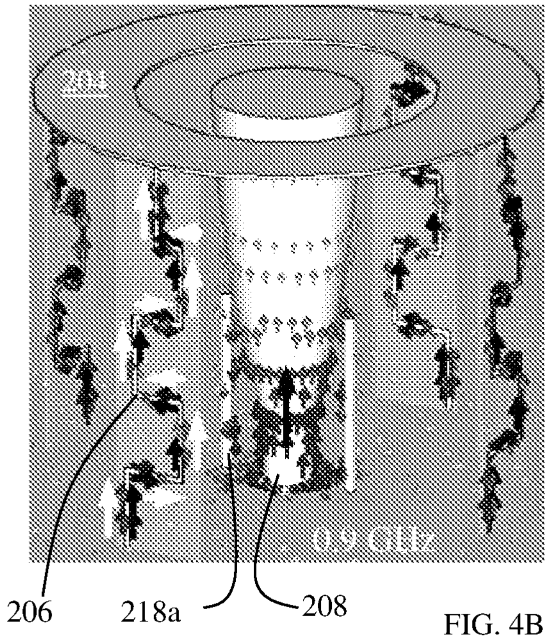


FIG. 4B

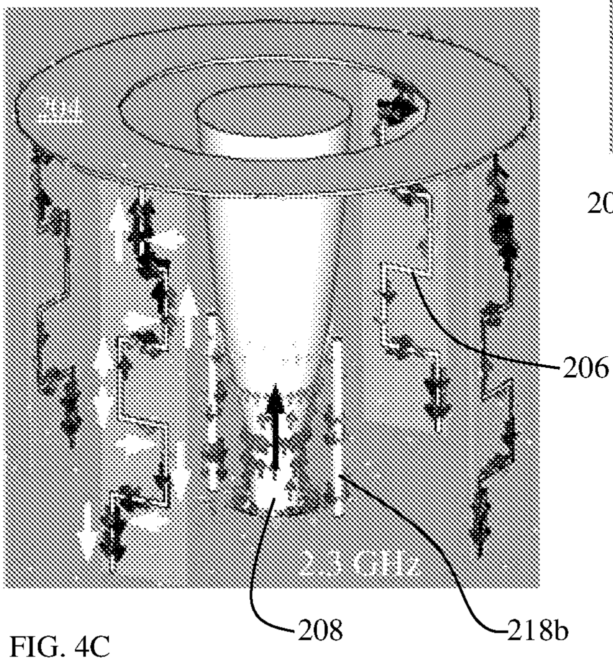


FIG. 4C

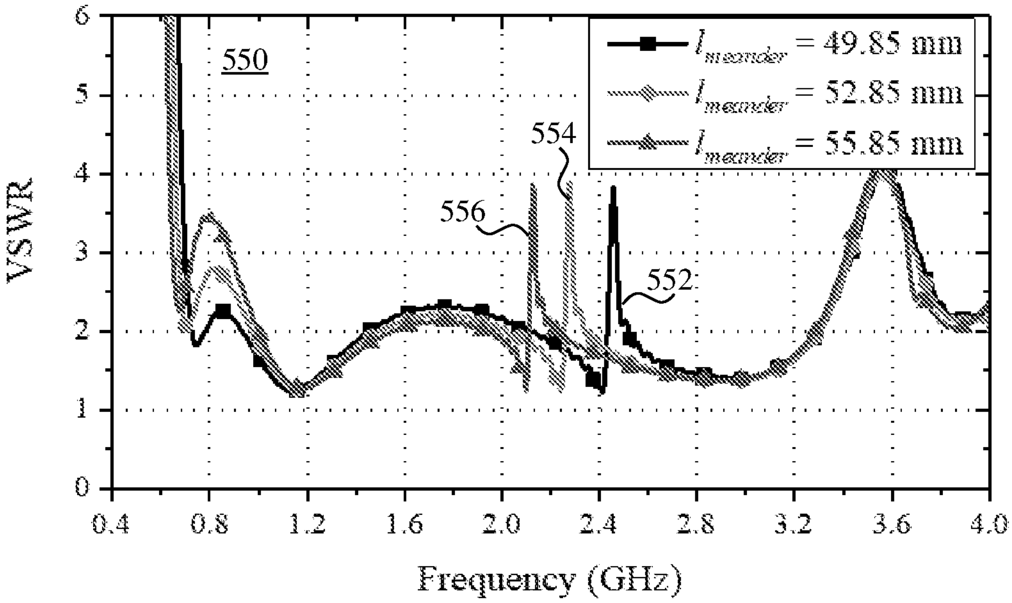


FIG. 5

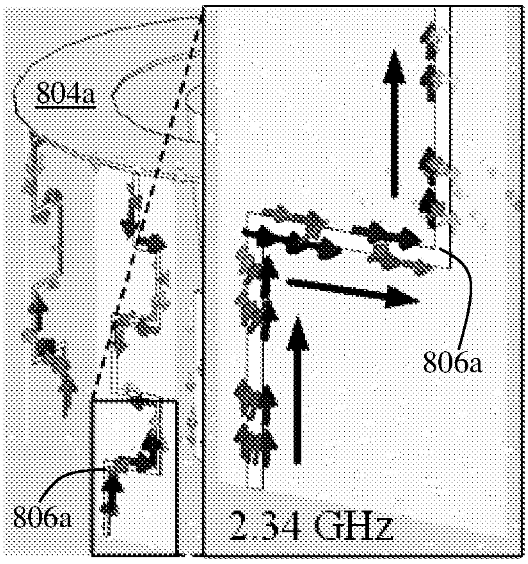


FIG. 8A

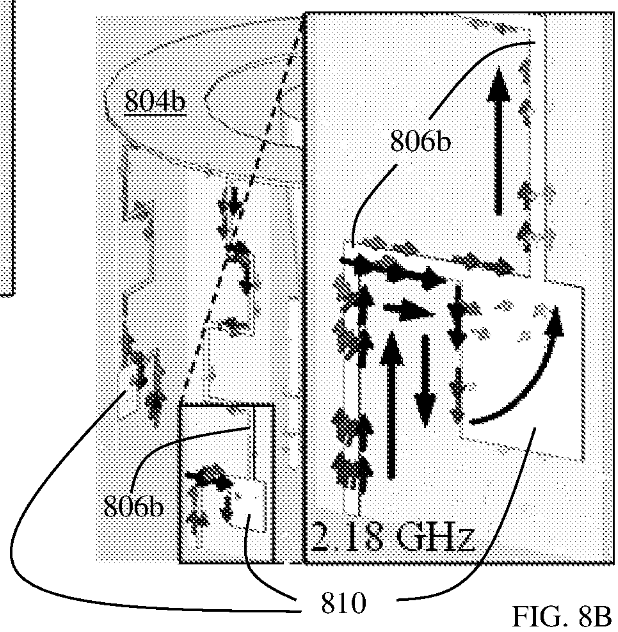
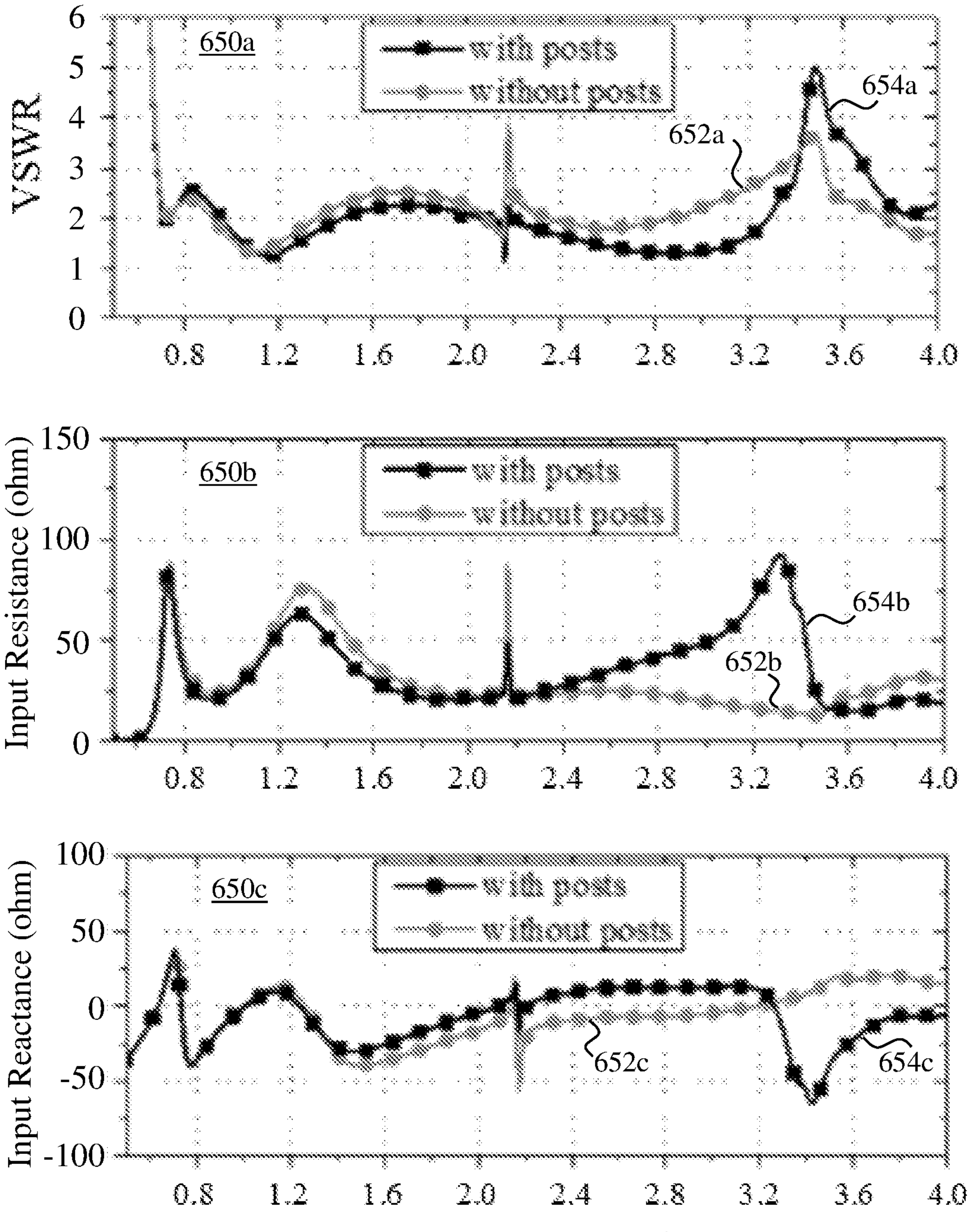


FIG. 8B



650a
with posts
without posts
654a
652a
VSWR
0
1
2
3
4
5
6
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
650b
with posts
without posts
654b
652b
Input Resistance (ohm)
0
50
100
150
650c
with posts
without posts
652c
654c
Input Reactance (ohm)
-100
-50
0
50
100
Frequency (GHz)

FIG. 6

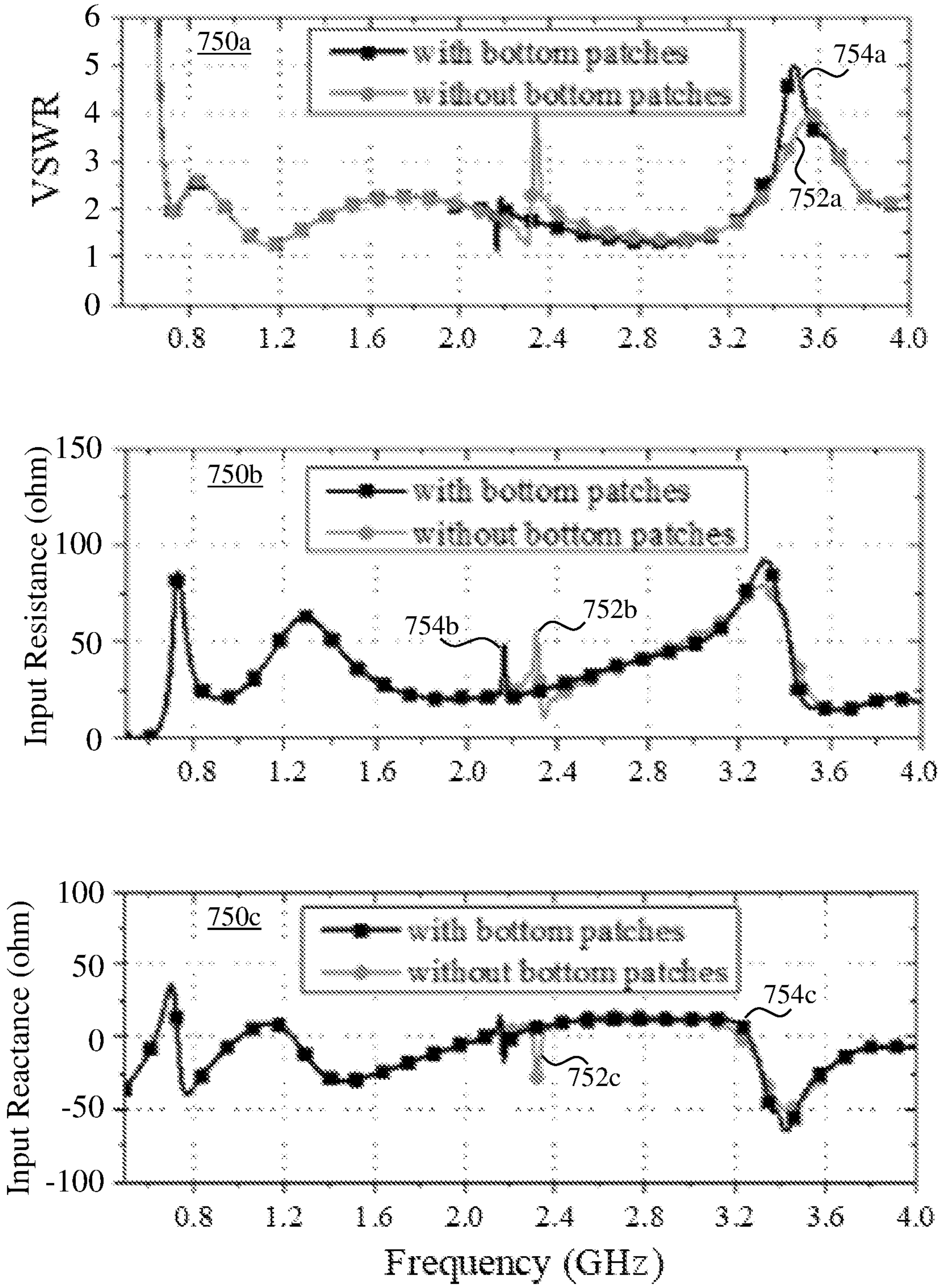

750a
with bottom patches
without bottom patches
754a
752a
VSWR
750b
Input Resistance (ohm)
754b
752b
750c
Input Reactance (ohm)
754c
752c
Frequency (GHz)

FIG. 7

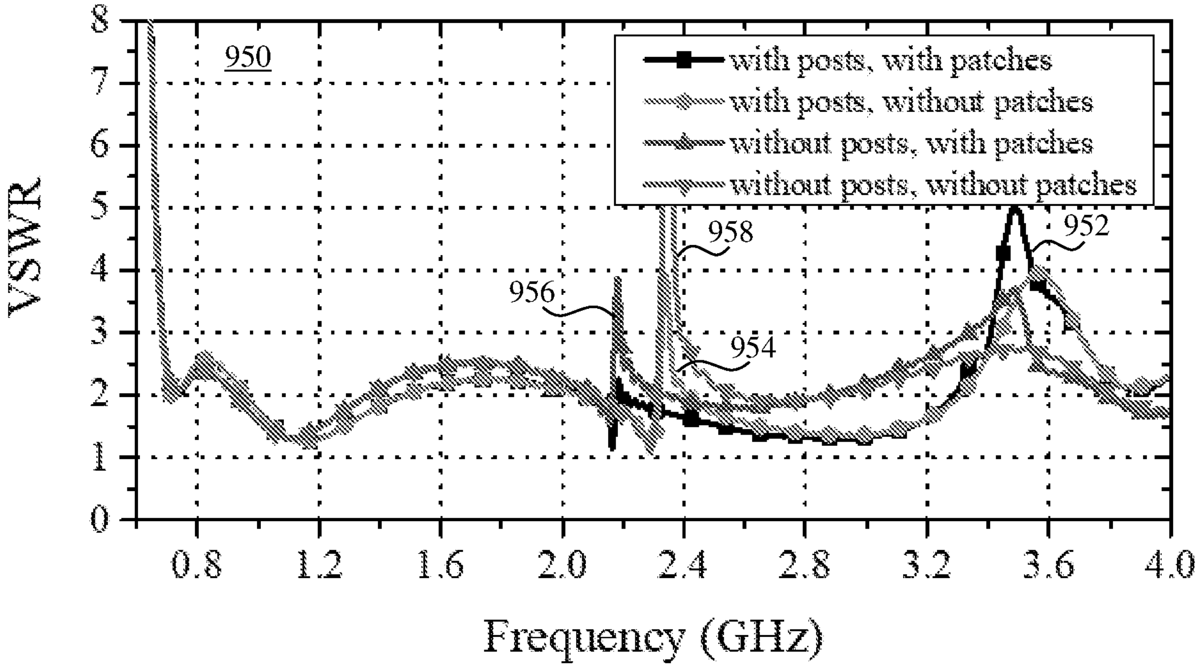

950
with posts, with patches
with posts, without patches
without posts, with patches
without posts, without patches
958
952
956
954
VSWR
Frequency (GHz)
0
1
2
3
4
5
6
7
8
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0

FIG. 9

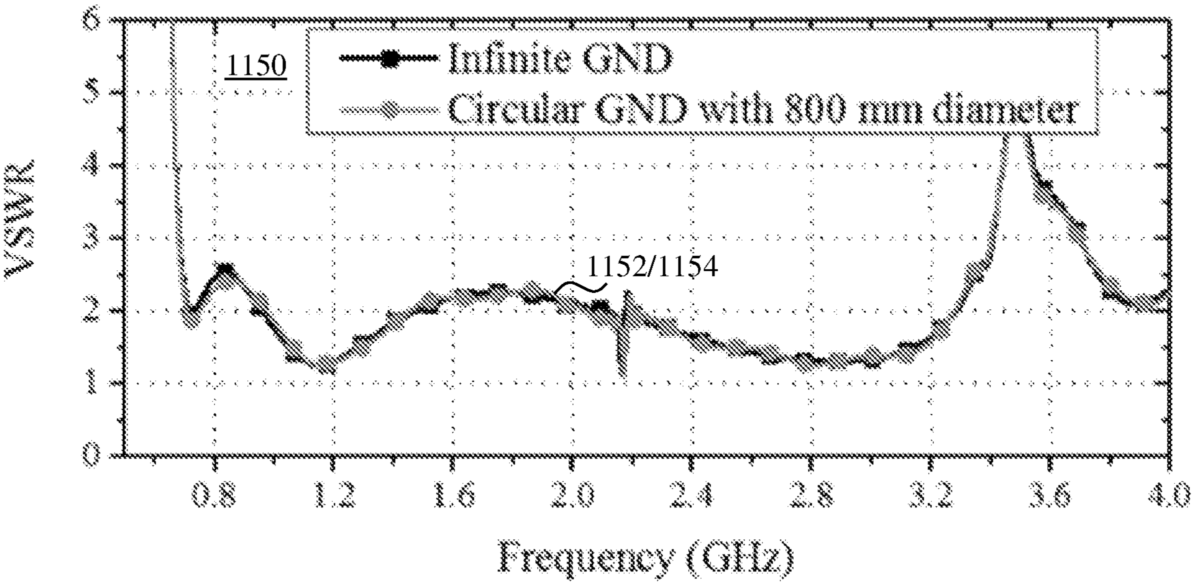

1150
Infinite GND
Circular GND with 800 mm diameter
1152/1154
VSWR
Frequency (GHz)
0
1
2
3
4
5
6
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0

FIG. 11

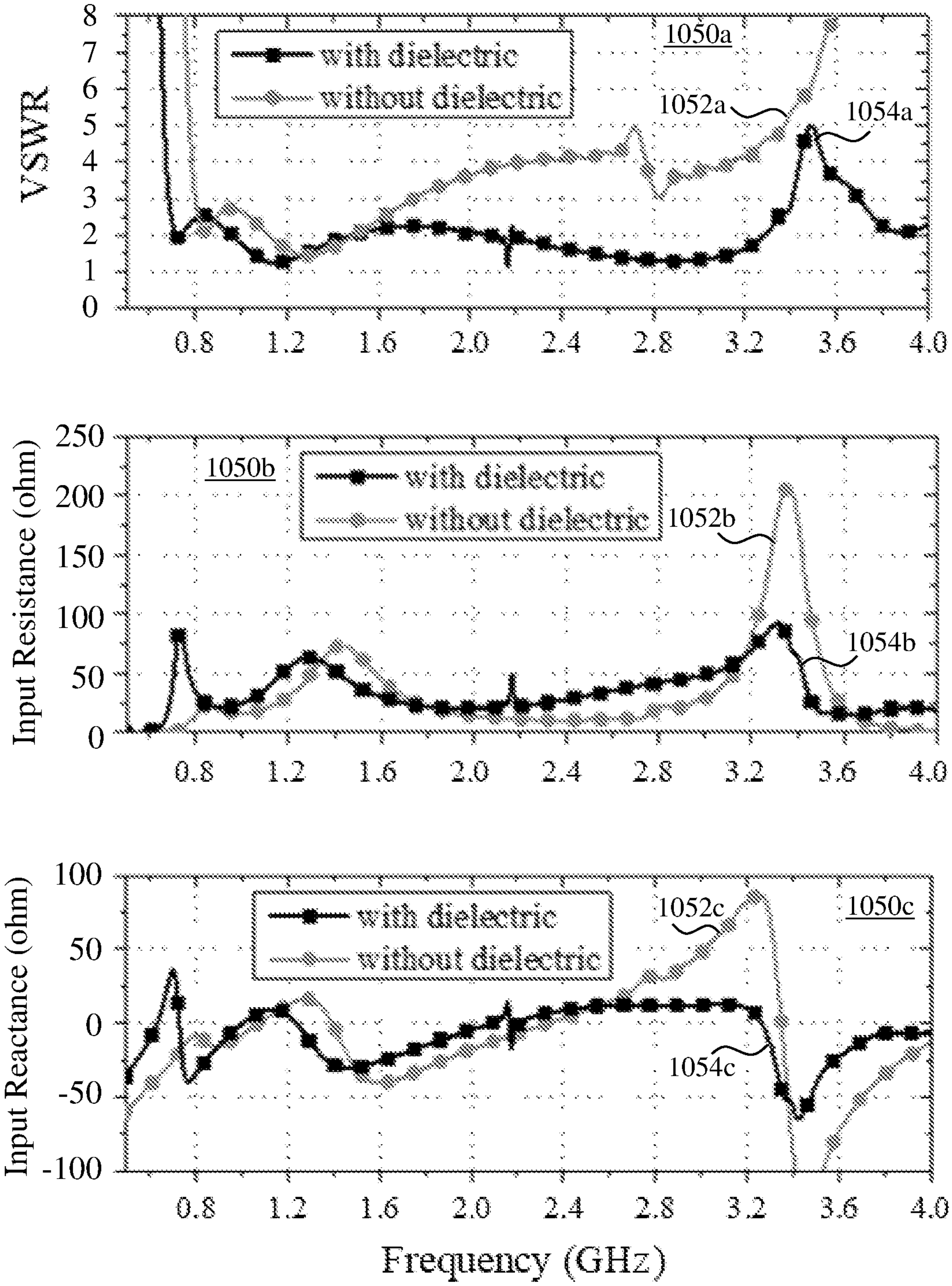

VSWR
with dielectric
without dielectric
1050a
1052a
1054a
0 1 2 3 4 5 6 7 8
0.8 1.2 1.6 2.0 2.4 2.8 3.2 3.6 4.0
Input Resistance (ohm)
1050b
1052b
1054b
0 50 100 150 200 250
Input Reactance (ohm)
1050c
1052c
1054c
-100 -50 0 50 100
Frequency (GHz)

FIG. 10

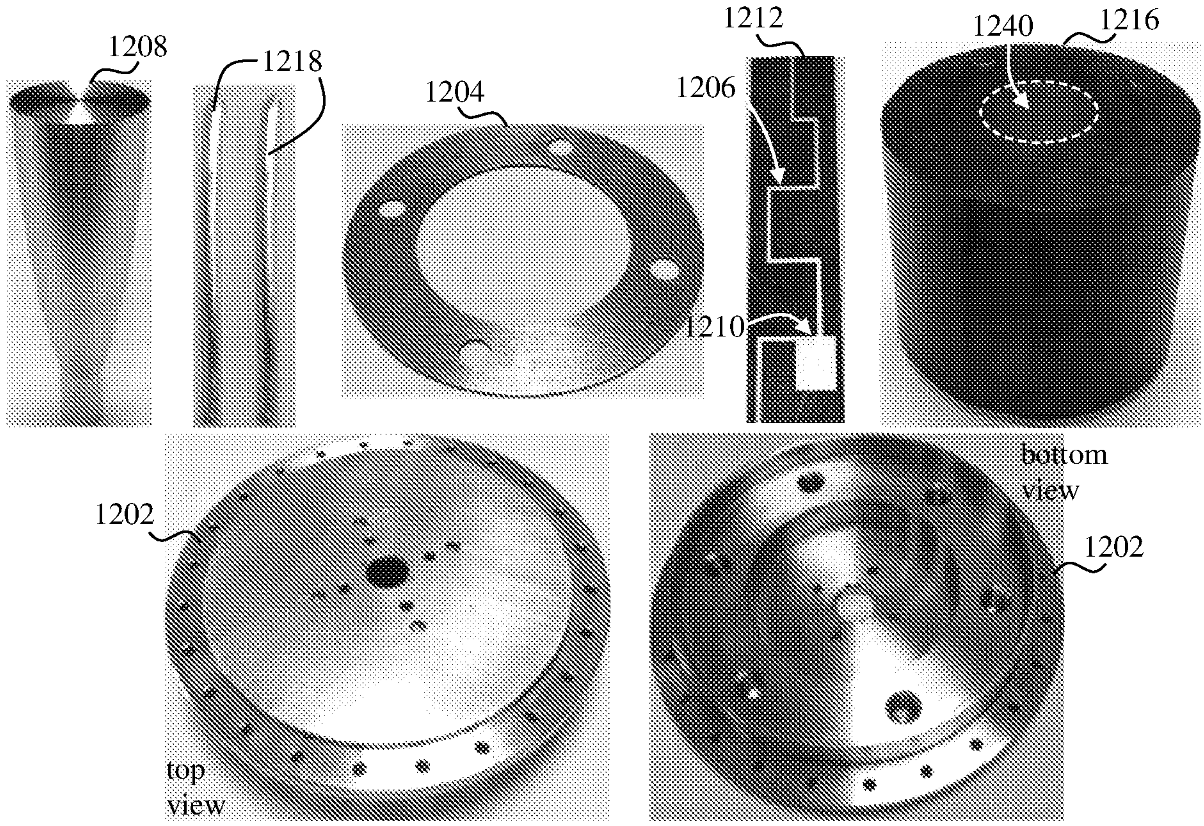


FIG. 12A

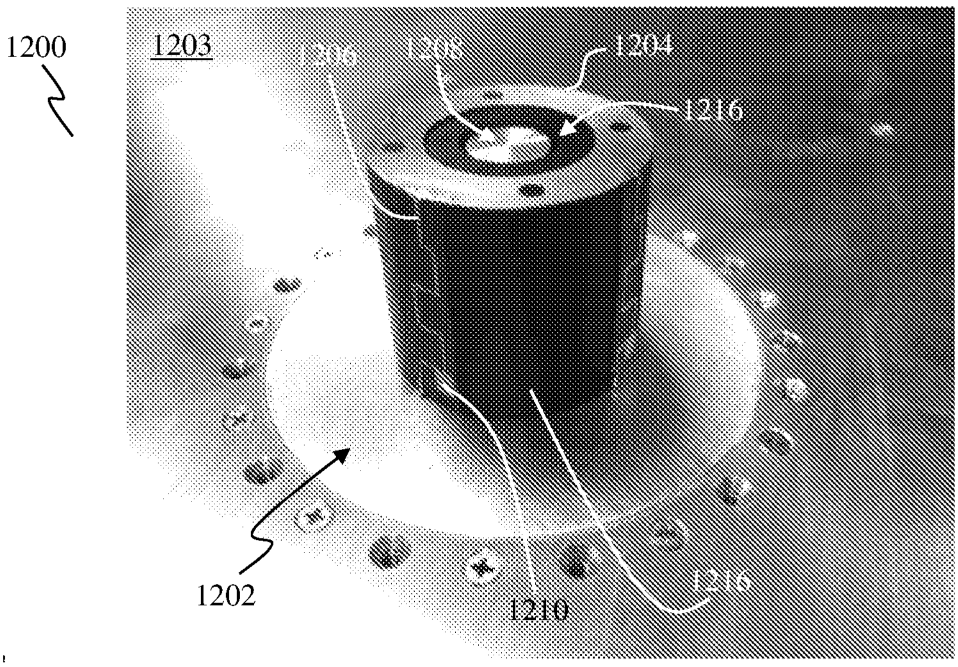


FIG. 12B

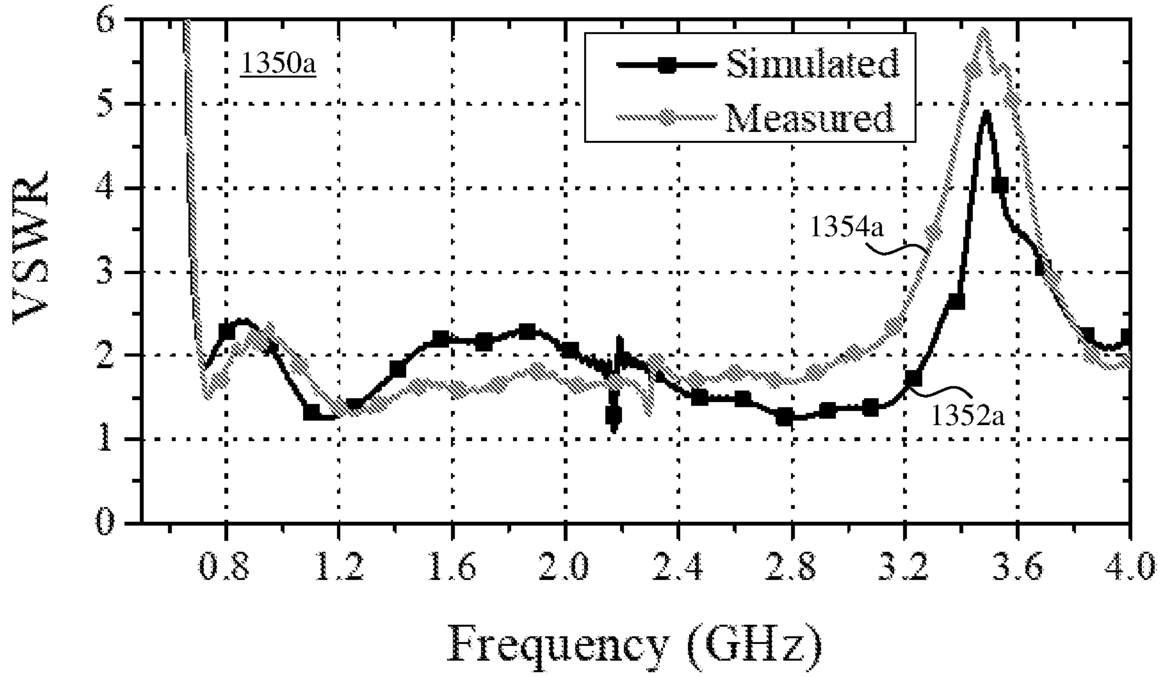


FIG. 13A

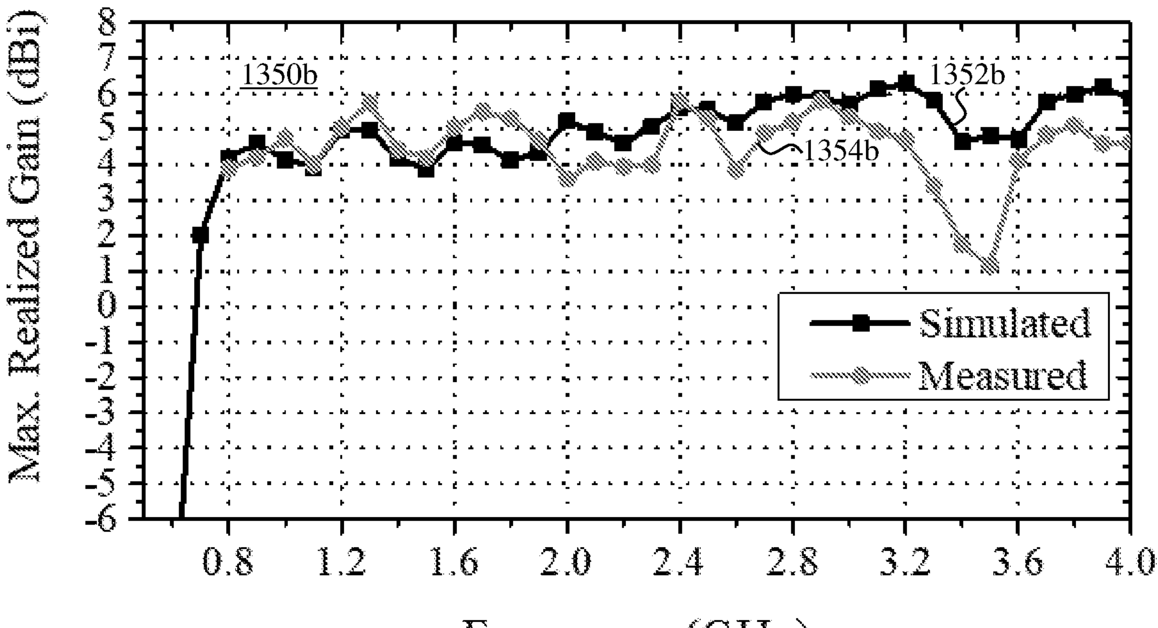


FIG. 13B

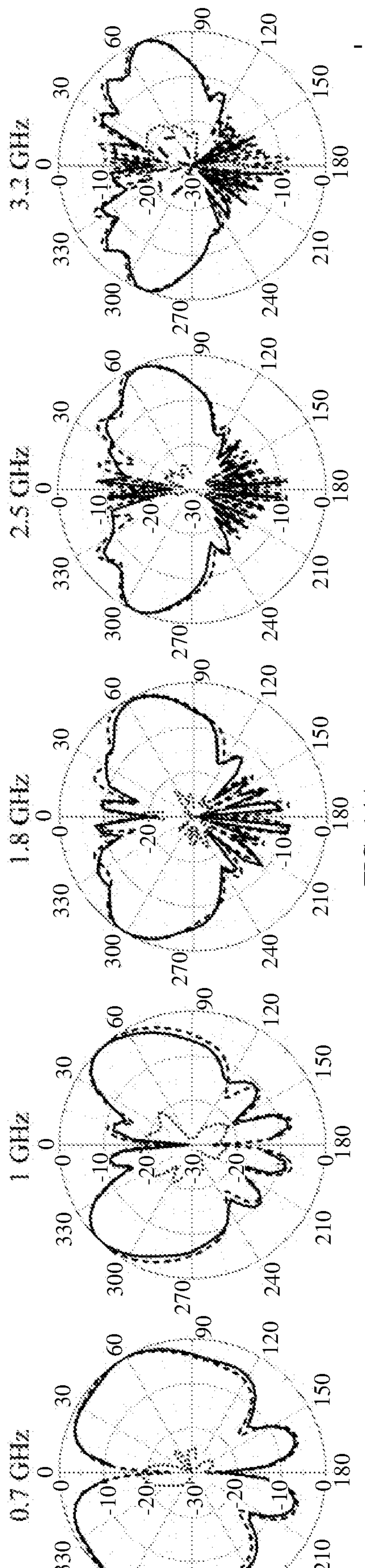


FIG. 14A

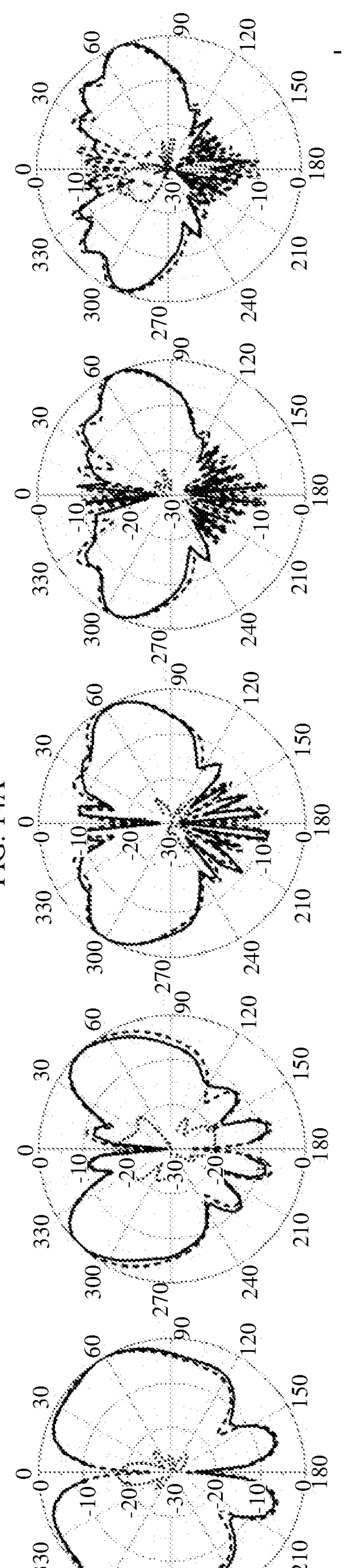


FIG. 14B

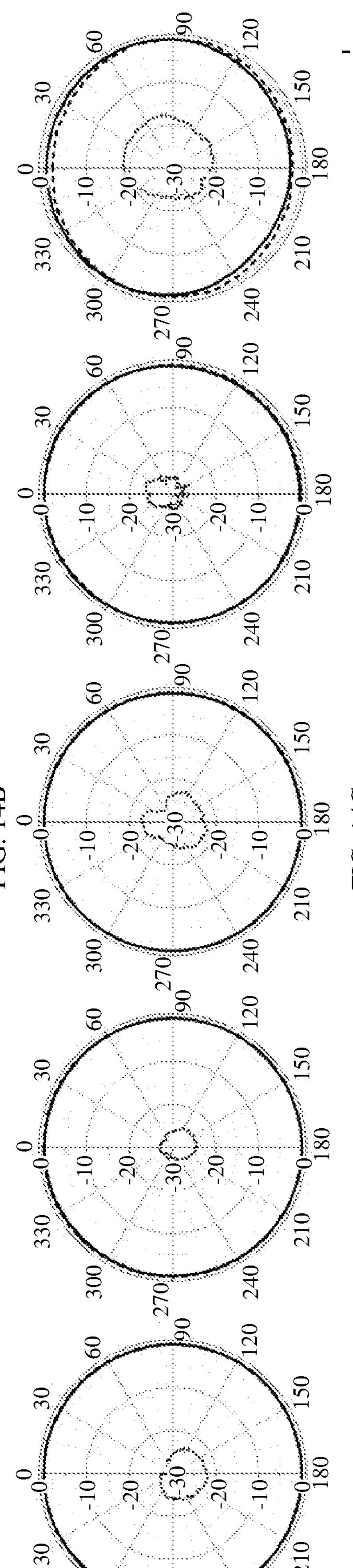


FIG. 14C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2018/050425

A. CLASSIFICATION OF SUBJECT MATTER

See Supplemental Box

According to International Patent Classification (IPC)

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

FAMPAT, IEEE, CNKI: meander, helical, shorted, grounded, capacitive, electromagnetic, parasitic, feed, patch, 蜿, 螺旋形的, 短路, 接地, 电容, 电磁, 寄生, 馈送, 补丁 and other related terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2012/144247 A1 (HARADA INDUSTRY CO. LTD.) 26 October 2012 pages 5, 6, figures 2, 4, 5, 8 of the machine translation	1-24
X	US 4313121 A (CAMPBELL D.V. ET AL.) 26 January 1982 column 3 lines 4-5, 9, 24-25, 41-43, 49, figure 1	1, 5, 6, 11, 14, 15, 18, 19, 22, 24
X	RU 2251178 C2 (KHORAJZON IMEDZHING TEKNOLODZHIZ) 27 April 2005 page 7, figures 9e, 10 of the machine translation	1, 6, 8, 9, 11, 14, 15, 19, 21, 22, 24

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

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"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

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03/12/2018 *(day/month/year)*	*05/12/2018* *(day/month/year)*

Name and mailing address of the ISA/SG	Authorized officer
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 102004024800 A1 (DAIMLERCHRYSLER AG) 3 February 2005 the whole document especially figure 1 of the machine translation	
A	JP 2008-503941 A (INTERDIGITAL TECHNOLOGY) 7 February 2008 the whole document especially figure 1 of the machine translation	
A	CN 1439182 A (MOTOROLA) 27 August 2003 the whole document of the machine translation	

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/SG2018/050425

Note: This Annex lists known patent family members relating to the patent documents cited in this International Search Report. This Authority is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2012/144247 A1	26/10/2012	JP 2012227689 A	15/11/2012
US 4313121 A	26/01/1982	CA 1149507 A	05/07/1983
RU 2251178 C2	27/04/2005	WO 2004/091047 A1	21/10/2004
DE 102004024800 A1	03/02/2005	WO 2004/102742 A1	25/11/2004
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		TW 200642162 A	01/12/2006
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		WO 02/03496 A1	10/01/2002
		AU 6980001 A	14/01/2002

Supplemental Box
(Classification of Subject Matter)

Int. Cl.

H01Q 9/36 (2006.01)

H01Q 5/321 (2015.01)

H01Q 5/371 (2015.01)

H01Q 5/385 (2015.01)

H01Q 5/50 (2015.01)

H01Q 9/04 (2006.01)

H01Q 19/09 (2006.01)