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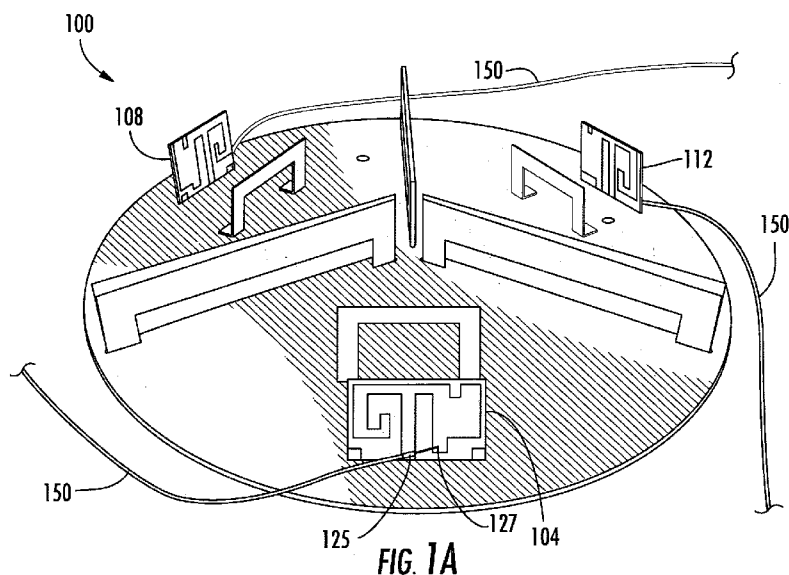
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(57) Abstract: Exemplary embodiments are provided of multiple-antenna systems with enhanced and/or good isolation and directivity. In one exemplary embodiment, a system generally includes a ground plane and two or more antenna elements coupled to the ground plane. The system also includes two or more low frequency isolators/reflectors and two or more high frequency isolators/reflectors coupled to the ground plane.

MULTIPLE-ANTENNA SYSTEMS WITH ENHANCED ISOLATION AND DIRECTIVITY

FIELD

5 **[0001]** The present disclosure generally relates to multiple-antenna systems with enhanced and/or good isolation and directivity.

BACKGROUND

10 **[0002]** This section provides background information related to the present disclosure which is not necessarily prior art.

[0003] Multiple-antenna radio systems generally use multiple antennas at the transmitter and/or receiver to improve communication performance. Such multiple-antenna systems are commonly referred to or known as Multiple Input Multiple Output (MIMO) antenna systems. Multiple-antenna radio systems are
15 commonly used in wireless communications, because these systems may offer significant increases in data throughput and link range without additional bandwidth or transmit power.

SUMMARY

20 **[0004]** This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

[0005] According to various aspects, exemplary embodiments are disclosed of multiple-antenna systems having enhanced and/or good isolation and directivity. In an exemplary embodiment, an antenna system generally
25 includes a ground plane and two or more antenna elements coupled to the ground plane. The system also includes two or more low frequency isolators/reflectors and two or more high frequency isolators/reflectors coupled to the ground plane.

[0006] Further areas of applicability will become apparent from the
30 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

5 **[0007]** 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.

10 **[0008]** FIG. 1 is a perspective view of a multiple-antenna system having three antenna elements, three high frequency isolators/reflectors, and three low frequency isolators/reflectors according to an exemplary embodiment of the present disclosure, where the internal antenna components (typically covered and hidden from view by a radome) are shown for clarity;

15 **[0009]** FIG. 1A is a perspective view of the multiple-antenna system shown in FIG. 1 and exemplary coaxial cables feeding the antenna elements according to an exemplary embodiment;

[0010] FIGS. 2A and 2B are exemplary line graphs illustrating isolation in decibels versus frequency (in gigahertz) measured for a prototype of the multiple-antenna system shown in FIG. 1 with isolators/reflectors (FIG. 2A) and without isolators/reflectors (FIG. 2B), respectively;

20 **[0011]** FIGS. 3A and 3B illustrate exemplary azimuth plane radiation patterns measured for the three antenna elements of a prototype of the multiple-antenna system shown in FIG. 1 at a frequency of 2.45 gigahertz (FIG. 3A) and 5.47 gigahertz (FIG. 3B);

25 **[0012]** FIG. 4 is a perspective view of another exemplary embodiment of a multiple-antenna system having six antenna elements, six high frequency isolators/reflectors, and six low frequency isolators/reflectors, where the internal antenna components (typically covered and hidden from view by a radome) are shown for clarity; and

30 **[0013]** FIG. 5 illustrates exemplary azimuth plane radiation patterns measured for the six antenna elements of a prototype of the multiple-antenna system shown in FIG. 4 at a frequency of 5.35 gigahertz.

DETAILED DESCRIPTION

[0014] Example embodiments will now be described more fully with reference to the accompanying drawings.

5 [0015] In multiple-antenna systems, multiple antennas are used to improve transmission robustness and/or increase transmission rate. Generally, multiple antennas for multiple input multiple output (MIMO) systems perform well under the condition that the antennas have low cross correlation in different schemes namely spatial scheme, pattern scheme, and polarization scheme. For
10 economical reasons during design and manufacturing, the multiple antennas are usually of identical design. With the market trend towards smaller and more compact devices, the decreasing overall size of the device means that the antennas are being increasingly put closer and closer together. But having multiple antennas in close proximity results in poor isolation between the
15 antennas, which, in turn, decreases the performance of the radio system. For example, the inventors have recognized that because the antennas are usually of identical design for a multiple-antenna system, the radiation patterns might overlap with equal antenna gain. In which case, stability might become an issue when the radio system constantly switches back and forth between the antennas.

20 [0016] Accordingly, the inventors have disclosed herein multiple-antenna systems including multiple antennas and multiple isolators/reflectors to enhance the isolation between antennas and at the same time increase the directivity of the individual antenna elements. In various exemplary embodiments, each antenna element has a sector-shaped radiation pattern with an equally-
25 divided coverage sector angle such that the sum of all sector angles for the antenna elements equals the total coverage angle required. This is considered to be utilizing the pattern scheme that offers higher capacity and longer range for the systems.

30 [0017] In various exemplary embodiments, a system includes a one-to-one ratio of antenna elements to the high frequency isolators/reflectors and to the low frequency isolators/reflectors. That is, these exemplary embodiments include

the same number of antenna elements, high frequency isolators/reflectors, and low frequency isolators/reflectors. For example, the inventors have disclosed exemplary embodiments (e.g., system 100 (FIG. 3), etc.) that includes three antenna elements, three high frequency isolators/reflectors, and three low frequency isolators/reflectors. The inventors have also disclosed exemplary embodiments (e.g., system 200 (FIG. 4), etc.) that includes six antenna elements, six high frequency isolators/reflectors, and six low frequency isolators/reflectors. Other exemplary embodiments may include more or less antenna elements, high frequency isolators/reflectors, and/or low frequency isolators/reflectors, as a system may be scaled (e.g., two antennas, four antennas, five antennas, seven antennas, etc.) accordingly depending on the particular requirements of the intended application or end-use. In addition, other exemplary embodiments need not include a one-to-one ratio or equal/same number of antenna elements, high frequency isolators/reflectors, and/or low frequency isolators/reflectors. For example, other exemplary embodiments may include a number of high frequency isolators/reflectors and/or low frequency isolators/reflectors equal to, greater than, or less than the number of antenna elements.

[0018] In various exemplary embodiments, a system includes multiple antenna elements and multiple isolators/reflectors. The isolators/reflectors may be positioned relative to the antenna elements to increase isolation between the antenna elements and/or increase directivity of each antenna element in the direction of the sector that the particular antenna element serves. The multiple isolators/reflectors may include one or more combined high frequency and low frequency isolators/reflectors. Additionally, or alternatively, the multiple isolators/reflectors may include one or more high frequency isolators/reflectors that are separate and/or spaced apart from one or more low frequency isolators/reflectors. By way of example only, a low frequency isolators/reflector may be configured to be operable with frequencies falling within the 2.45 gigahertz band (from 2.4 gigahertz to 2.5 gigahertz), and a high frequency isolators/reflector may be configured to be operable with frequencies falling

within the 5 gigahertz band (from 4.9 gigahertz to 5.875 gigahertz). These frequencies are only examples, however, as aspects of the present disclosure are not limited solely to these two frequency bands.

[0019] In one particular exemplary embodiment, an antenna system includes three antenna elements configured for operation in a high frequency band and low frequency band. Isolators/reflectors are mounted vertically over a ground plane. The antenna elements are placed equidistant from the center of a circular portion of the ground plane, which circular portion may simply be an imaginary or reference circle that is imagined or defined on the top surface of the ground plane for reference purposes. The mounting point of the antenna elements are on the circumference of the circular portion or imaginary circle on the ground plane. The antenna elements are spaced equally apart, so that a one hundred twenty degree (120°) arc is formed or defined between the mounting point of two adjacent antenna elements and the center of the imaginary circle or circular portion on the ground plane. Three inverted U shaped low frequency isolators/reflectors are placed in a star-shaped configuration centered at the center of the imaginary circle or circular portion on the ground plane. Another three inverted U shaped high frequency isolators/reflectors are each placed adjacent a corresponding one of the antenna element between that antenna element and the center of the imaginary circle or circular portion on the ground plane. The antenna elements may be of any type suitable, such as a monopole antenna, an inverted F antenna (IFA), planar inverted F antenna (PIFA), etc. The inverted U shaped elements are operable as both isolators and reflectors. The frequency at which each upside down or inverted U shaped element is effective is determined primarily by the length of the horizontal section of the upside down or inverted U shaped element. With this exemplary disclosed embodiment, the isolation between the antenna elements was increased (e.g., by about seven percent to about ten percent, etc.). This increased isolation allows for more antenna elements to be put in the same volume of space and/or allows the same number of antennas to be put in a smaller volume of space. This example embodiment also allows for increased directivity of each antenna element in the

direction of the sector that the particular antenna element serves. In turn, this will help improve radio stability and increase receive-sensitivity extending the range of the radio transmission.

[0020] With reference now to the figures, FIG. 1 illustrates an exemplary embodiment of a multiple-antenna system 100 embodying one or more aspects of the present disclosure. As shown, the antenna system 100 includes three antenna elements 104, 108, 112, three low frequency isolators/reflectors 116, 120, 124, and three high frequency isolators/reflectors 128, 132, 136. The antenna elements and isolators/reflectors are mounted on or to the ground plane 140 in a generally vertical orientation and perpendicularly relative to the ground plane 140.

[0021] This particular system 100 is configured for use as tri-sectorial multiple-antenna system (e.g., MIMO antenna system), although aspects of the present disclosure are not limited solely to tri-sectorial and/or MIMO antenna systems. And, each antenna element 104, 108, 112 may be identical to the other antenna elements, or one or more of the antenna elements may be differently configured (e.g., shaped, sized, different materials, etc.) than the other antenna elements depending on the particular end use or application. In addition, each of the low frequency isolators/reflectors 116, 120, 124 may be identical, or they may be different from each other. Likewise, each of the high frequency isolators/reflectors 128, 132, 136 may be identical, or they may be different from each other.

[0022] With continued reference to FIG. 1, each antenna element 104, 108, 112 includes, and/or is supported by, a substrate, such as substrate 105, 109, 113. The substrates 105, 109, and/or 113 may be a rigid insulator, such as a circuit board substrate (e.g., Flame Retardant 4 or FR4, etc.), plastic carrier, etc. Alternatively, the substrates 105, 109, and/or 113 may be a flexible insulator, such as a flexible circuit board, flex-film, etc. The antenna elements 104, 108, 112 may include electrically-conductive material (e.g., copper, gold, silver, alloys, combinations thereof, other electrically-conductive materials, etc.) in the form of traces 106, 110, 114 on the substrates 105, 109, 113, respectively. The antenna

elements 104, 108, 112 may be single or multiple layered PCB antennas. Alternatively, the antenna elements 104, 108, 112 (whether mounted on a substrate or not) may be constructed from sheet metal by cutting, stamping, etching, etc.

5 **[0023]** Each antenna element 104, 108, 112 includes a first radiating or resonant element for a low frequency band (e.g., from 2.4 gigahertz to 2.5 gigahertz, etc.) and a second radiating or resonant element for a high frequency band (e.g., from 4.9 gigahertz to 5.875 gigahertz, etc.). The first and second radiating elements of each antenna element 104, 108, 112 may be quarter
10 wavelength ($1/4 \lambda$) radiating elements, such that each of the first and second radiating elements is sized to be approximately one quarter of the wavelength of a desired resonant frequency. In this particular example, the antenna element 104 includes a first low frequency arm 107 and a second high frequency arm 110. In this exemplary embodiment, the high frequency arms are shorter than the
15 low frequency arms. The arms or elements are folded (e.g., spiral shaped, etc.), bent, and/or turned to help reduce the overall size. Antennas according to the present disclosure are not limited, however, to the particular shape, size, configuration, etc. of the antenna elements shown in FIG. 1. In addition, the frequencies set forth in this paragraph are only examples, as aspects of the
20 present disclosure are not limited solely to these two frequency bands.

[0024] The antenna elements 104, 108, and 112 also include feeding elements and ground points. As shown in FIG. 1, the antenna element 104 includes a feeding element 123 and grounding point 111. In this example, the bottom of the feeding element 123 may provide a feeding point, for example, for
25 connection to (e.g., soldering, etc.) a coaxial cable, other feed, or transmission line. For example, FIG. 1A illustrates an exemplary embodiment in which coaxial cables 150 are shown feeding the antenna elements 104, 108, 112 of the antenna 100. In this example illustrated in FIG. 1A, the coaxial cable 150 includes a braid 125 that is soldered to the grounding point 111 of the antenna
30 element 104. The coaxial cable 150 also includes a signal center conductor 127

that is soldered to the feeding point 123 of the antenna element 104. Alternative embodiments may include other feeding arrangements besides coaxial cable.

[0025] Soldering pads 115 allow the antenna element 104 to be soldered to the ground plane 140 (e.g., ground plane of PCB, metal sheet, etc.).

5 In some embodiments, the bottom of the antenna elements 104, 108, 112 may include downwardly extending tabs that are insertable or positionable within slots or holes in the ground plane 140 for aligning and mechanically mounting the antenna elements 104, 108, 112 to the ground plane 140. Alternative embodiments may include other means for aligning and/or mechanically
10 mounting an antenna element to a ground plane.

[0026] In this example, the antenna elements 104, 108, 112 are mounted to the ground plane 140 equidistant from the center of a circular portion on the ground plane 140, which circular portion may simply be an imaginary or reference circle that is on top of the ground plane 140 for reference purposes
15 when mounting the antenna components. In this illustrated example, the center of the circular portion or imaginary circle coincides with or is the same as the center of the ground plane 140 in FIG. 1, etc. The mounting points or location of the antenna elements 104, 108, 112 are placed along the perimeter or circumference of the imaginary circle or circular portion on the ground plane 140.
20 The antenna elements 104, 108, 112 are spaced equally apart, so that a one hundred twenty degree (120°) arc is formed or defined between the mounting point of two adjacent antenna elements and the center of the imaginary circle or circular portion on the ground plane 140. Alternative embodiments may include other mounting arrangements for the antenna elements on the ground plane.

25 **[0027]** The dimensions, shapes, and mounting location (e.g., location of grounding points, etc.) of the low frequency isolators/reflectors 116, 120, 124 relative to the antenna elements 104, 108, 112 may be determined (e.g., optimized, etc.) to improve the isolation between the antenna elements 104, 108, 112. In this particular example shown in FIG. 1, the low frequency
30 isolators/reflectors 116, 120, 124 are mounted generally vertically or perpendicularly relative to the ground plane 140. And, the low frequency

isolators/reflectors 116, 120, 124 comprise inverted U-shaped metallic strips 117 on a substrate 118, which are arranged or placed in a star-shaped or spoked configuration centered at the center of the imaginary circle or circular portion on the ground plane 140. In this example, the substrates 118 are positioned about
5 the center of the ground plane 140 so as to extend outwardly in a direction away from the center of the ground plane 140.

[0028] A wide range of materials may be used for any of the substrates disclosed herein. By way of example, the low frequency isolators/reflectors 116, 120, 124 may include, and/or be supported by, substrates 118 comprising a rigid
10 insulator, such as a circuit board substrate (e.g., Flame Retardant 4 or FR4, etc.), plastic carrier, etc. Alternatively, the substrates 118 may be a flexible insulator, such as a flexible circuit board, flex-film, etc. The inverted U shaped strips 117 on the substrates 118 may include electrically-conductive material (e.g., copper, etc.) in the form of traces on the substrates 118. The low frequency
15 isolators/reflectors 116, 120, 124 (whether mounted on a substrate or not) may be constructed from sheet metal by cutting, stamping, etching, etc.

[0029] In this particular example, the low frequency isolators/reflectors 116, 120, 124 include the inverted U shaped strips 117 that are operable as both
20 isolators and reflectors. The frequency at which each upside down or inverted U shaped strip 117 is effective is determined primarily by the length of the horizontal section 119 of the upside down or inverted U shaped element 117. The horizontal section 119 is generally parallel to the top surface of the ground plane 140 in this illustrated embodiment. The inverted U shaped element 117 also includes two vertical legs or grounding stubs 121 for electrically connecting
25 to the ground plane 140. Alternative embodiments may include one or more isolators/reflectors with a different configuration (e.g., different shape, size, mounting location, etc.), such as L-shaped isolator/reflector.

[0030] In addition, the low frequency isolators/reflectors 116, 120, 124 may also include tabs along the bottom thereof. The tabs may be configured to
30 be inserted or positioned within slots or holes 122 in the ground plane 140 for aligning and mechanically mounting the low frequency isolators/reflectors 116,

120, 124. Alternative embodiments may include other means for aligning and/or mechanically mounting an isolator/reflector to a ground plane.

[0031] The dimensions, shapes, and mounting location (e.g., location of grounding points, etc.) of the high frequency isolators/reflectors 128, 132, 136 relative to the antenna elements 104, 108, 112 may be determined (e.g., optimized, etc.) to improve the isolation between the antenna elements 104, 108, 112. In this particular example, the high frequency isolators/reflectors 128, 132, 136 are mounted generally vertically or perpendicularly relative to the ground plane 140. Each high frequency isolators/reflectors 128, 132, 136 is between the center of the ground plane 140 and a corresponding one of the antenna elements 104, 108 112. And, the high frequency isolators/reflectors 128, 132, 136 comprise inverted U-shaped metallic strips having end portions 130 electrically connected and mounted (e.g., soldered, etc.) to the ground plane 140. The illustrated high frequency isolators/reflectors 128, 132, 136 do not include any substrates supporting the inverted U-shaped metallic strips. Instead, the inverted U-shaped metallic strips have end portions 130 that are mounted to the ground plane 140 such that the horizontal and vertical portions 131, 133 are free-standing. Alternative embodiments may include a different configuration (e.g., different shape, size, mounting location, etc.) for one or more of the high frequency isolators/reflectors. For example, another exemplary embodiment may include one or more high frequency isolators/reflectors that include a substrate, such as a rigid insulator (e.g., plastic carrier, a circuit board substrate like Flame Retardant 4 or FR4, etc.) or a flexible circuit board, flex-film, etc.

[0032] In this particular example, the high frequency isolators/reflectors 128, 132, 136 include the inverted U shaped strips that are operable as both isolators and reflectors. The frequency at which each upside down or inverted U shaped strip is effective is determined primarily by the length of the horizontal section 131 of the upside down or inverted U shaped element. The horizontal section 131 is generally parallel to the top surface of the ground plane 140 in this illustrated embodiment.

[0033] In addition, the low frequency isolators/reflectors 116, 120, 124 may also include tabs along the bottom thereof. The tabs may be configured to be inserted or positioned within slots or holes 122 in the ground plane 140 for aligning and mechanically mounting the low frequency isolators/reflectors 116, 120, 124.

[0034] The ground plane 140 is shown as a circular metal plate. Alternative embodiment may include a ground plane having a different configuration, such as a ground plane with a different shape (e.g., non-circular etc.), different size (e.g., larger or smaller relative to the other components of the antenna 100), different materials, etc.

[0035] FIGS. 2A, 2B, 3A, and 3B illustrate analysis results measured for a prototype of the multiple-antenna system 100 shown in FIG. 1. These analysis results shown in FIGS. 2A, 2B, 3A, and 3B are provided only for purposes of illustration and not for purposes of limitation. More specifically, FIGS. 2A and 2B are exemplary line graphs illustrating isolation in decibels versus frequency (in gigahertz) measured for a prototype of the multiple-antenna system shown in FIG. 1 with isolators/reflectors (FIG. 2A) and without isolators/reflectors (FIG. 2B), respectively. FIGS. 3A and 3B illustrate exemplary azimuth plane radiation patterns measured for the three antenna elements of a prototype of the multiple-antenna system shown in FIG. 1 at a frequency of 2.45 gigahertz (FIG. 3A) and 5.47 gigahertz (FIG. 3B). Generally, these analysis results show that the isolation between the antenna elements 104, 108, 112 was increased by about seven percent to about ten percent, and show the increased directivity of each antenna element in the direction of the sector that the particular antenna element serves.

[0036] FIG. 4 illustrate another exemplary embodiment of a multiple-antenna system 200 embodying one or more aspects of the present disclosure. In this particular example, the antenna 200 includes six antenna elements 204, six low frequency isolators/reflectors 216, six high frequency isolators/reflectors 228, and a ground plane 240. The components of the antenna 200 may be similar to the antenna 100 described above.

[0037] FIG. 5 illustrates analysis results measured for a prototype of the multiple-antenna system 200 shown in FIG. 4. These analysis results shown in FIG. 5 are provided only for purposes of illustration and not for purposes of limitation. More specifically, FIG. 5 illustrates exemplary azimuth plane radiation patterns measured for the six antenna elements 204 of a prototype of the multiple-antenna system 200 shown in FIG. 4 at a frequency of 5.35 gigahertz.

[0038] Numerical dimensions and values are provided herein for illustrative purposes only. The particular dimensions and values provided are not intended to limit the scope of the present disclosure.

[0039] 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.

[0040] 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.

[0041] 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.

[0042] 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.

[0043] 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.

[0044] The disclosure herein of particular values and particular ranges of values for given parameters are not exclusive of other values and ranges of values that may be useful in one or more of the examples disclosed herein. Moreover, it is envisioned that any two particular values for a specific parameter stated herein may define the endpoints of a range of values that may be suitable for the given parameter. The disclosure of a first value and a second value for a given parameter can be interpreted as disclosing that any value between the first and second values could also be employed for the given parameter. 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.

[0045] 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:

- 5
1. A system comprising:
a ground plane
two or more antenna elements coupled to the ground plane;
two or more low frequency isolators/reflectors coupled to the ground
10 plane; and
two or more high frequency isolators/reflectors coupled to the ground
plane.
2. The system of claim 1, wherein each antenna element is configured
15 for multi-band operation such that each antenna element is operable within a first
frequency range and a second frequency range.
3. The system of claim 2, wherein:
the first frequency range is from about 2.4 gigahertz to about 2.5
20 gigahertz; and
the second frequency range is from 4.9 gigahertz to 5.875 gigahertz.
4. The system of claim 2, wherein:
the first frequency range is the 2.45 gigahertz band; and
25 the second frequency range is the 5 gigahertz band.
5. The system of any one of the preceding claims, wherein:
the low frequency isolators/reflectors have inverted U-shaped
configurations; and/or
30 the high frequency isolators/reflectors have inverted U-shaped
configurations.

6. The system of any one of the preceding claims, wherein:
each of the low frequency isolators/reflectors includes two vertical sections
and a horizontal section that is generally parallel with the ground plane;

5 each of the high frequency isolators/reflectors includes two vertical
sections and a horizontal section that is generally parallel with the ground plane.

7. The system of any one of the preceding claims, wherein the low
frequency isolators/reflectors and high frequency isolators/reflectors are
positioned relative to the antenna elements for increasing isolation between the
10 antenna elements and/or for increasing directivity of each said antenna element
in the direction of the sector that said antenna element serves.

8. The system of any one of the preceding claims, wherein the
antenna includes:

15 three antenna elements, three low frequency isolators/reflectors, and three
high frequency isolators/reflectors; or

six antenna elements, six low frequency isolators/reflectors, and six high
frequency isolators/reflectors.

20 9. The system of any one of the preceding claims, further comprising
two or more coaxial cables coupled to the two or more antenna elements,
respectively, for feeding the antenna elements.

10. The system of any one of the preceding claims, wherein each
25 antenna element comprises first and second radiating arms and a feeding
element, the first and second radiating arms and feeding element comprising
electrically-conductive traces on the same side of a circuit board.

11. The system of any one of the preceding claims, wherein the
30 antenna elements comprise one or more of a monopole antenna, an inverted F
antenna (IFA), and/or a planar inverted F antenna (PIFA).

12. The system of any one of the preceding claims, wherein the high and low frequency isolators/reflectors are configured to be operable as both isolators and reflectors.

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13. The system of any one of the preceding claims, wherein the antenna includes the same number of antenna elements, low frequency isolators/reflectors, and high frequency isolators/reflectors.

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14. The system of any one of the preceding claims, wherein:
the ratio of antenna elements to low frequency isolators/reflectors is one-to-one; and/or

the ratio of antenna elements to high frequency isolators/reflectors is one-to-one; and/or

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the ratio of low frequency isolators/reflectors to high frequency isolators/reflectors is one-to-one.

15. The system of any one of the preceding claims, wherein the system is a multiple input multiple output (MIMO) antenna system.

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16. The system of any one of the preceding claims, wherein:
the antenna elements are mounted to the ground plane along a circumference of a circular portion of the ground plane such that the antenna elements are equidistant from a center of the circular portion of the ground plane
and such that the antenna elements are spaced equally apart from each other
and such that a one hundred twenty degree (120°) arc is defined between the mounting points of two adjacent antenna elements and the center of the circular portion of the ground plane; and/or

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the low frequency isolators/reflectors are in a spoked configuration
centered at the center of the circular portion of the ground plane, such that the
low frequency isolators/reflectors are positioned about the center of the circular

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portion of the ground plane and extend outwardly in a direction away from the center of the circular portion of the ground plane; and/or

each of the high frequency isolators/reflectors is between a corresponding one of the antenna elements and the center of the circular portion of the ground plane.

17. The system of claim 16, wherein the circular portion of the ground plane is an imaginary or reference circle on a surface of the ground plane.

10 18. A system comprising:

a ground plane including a circular portion having a circumference and a center;

a plurality of antenna elements mounted to the ground plane along the circumference of the circular portion of the ground plane, the antenna elements equidistant from the center of the circular portion of the ground plane, the antenna elements spaced equally apart from each other such that a one hundred twenty degree (120°) arc is defined between mounting points of two adjacent antenna elements and the center of the circular portion of the ground plane;

a plurality of low frequency isolators/reflectors in a spoked configuration centered at the center of the circular portion of the ground plane, such that the low frequency isolators/reflectors are positioned about the center of the circular portion of the ground plane and extend outwardly in a direction away from the center of the circular portion of the ground plane; and/or

a plurality of high frequency isolators/reflectors, each placed between a corresponding one of the antenna elements and the center of the circular portion of the ground plane.

19. The system of claim 18, wherein:

each of the low frequency isolators/reflectors include two vertical sections and a horizontal section that is generally parallel with the ground plane, and

defining an inverted U-shaped configuration for each of the low frequency isolators/reflectors; and

each of the high frequency isolators/reflectors include two vertical sections and a horizontal section that is generally parallel with the ground plane, and
5 defining an inverted U-shaped configuration for each of the high frequency isolators/reflectors.

20. The system of claim 18 or 19, wherein the circular portion of the ground plane is an imaginary or reference circle on a surface of the ground
10 plane.

21. The system of claim 18, 19, or 20, wherein the antenna includes the same number of antenna elements, low frequency isolators/reflectors, and high frequency isolators/reflectors, such that the ratio of antenna elements to low
15 frequency isolators/reflectors is one-to-one and such that the ratio of antenna elements to high frequency isolators/reflectors is one-to-one.

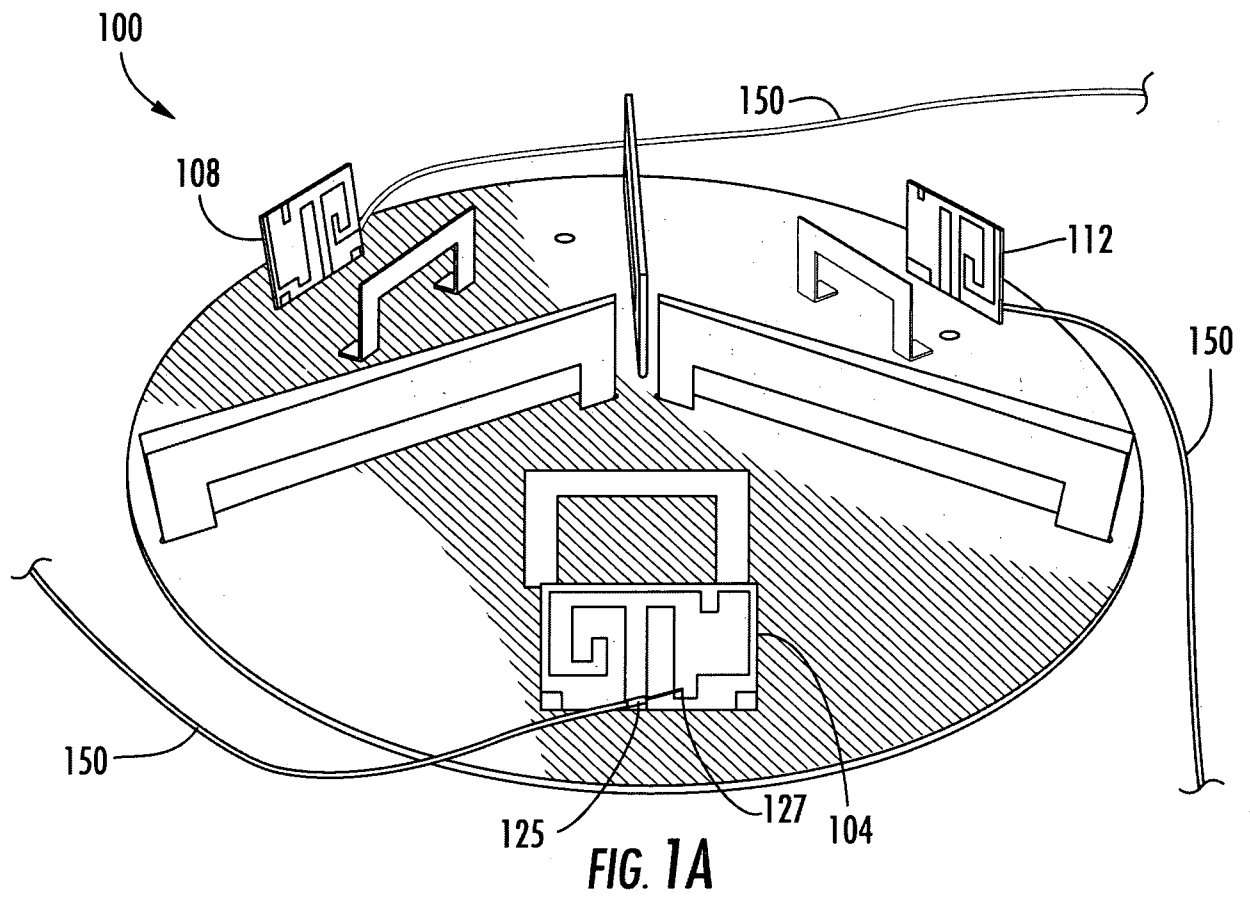
22. A multiple input multiple output (MIMO) antenna system, the antenna system comprising:

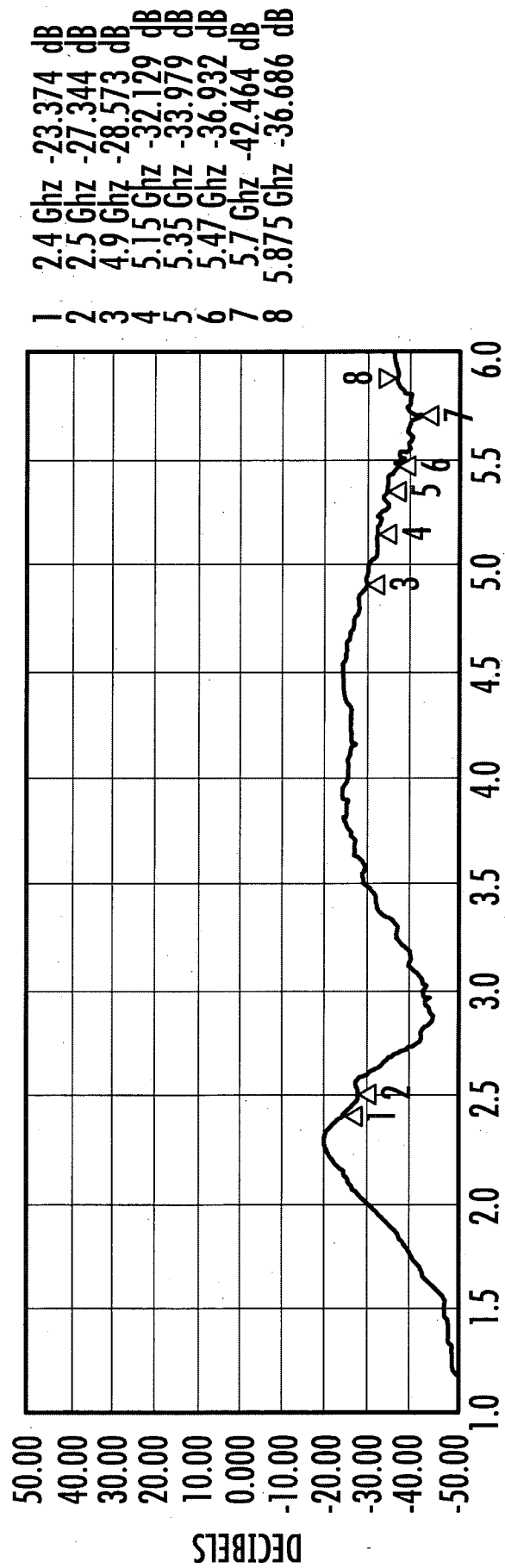
20 two or more antenna elements; and

two or more isolators/reflectors positioned relative to the antenna elements for increasing isolation between the antenna elements and for increasing directivity of each said antenna element in the direction of the sector that said antenna element serves.

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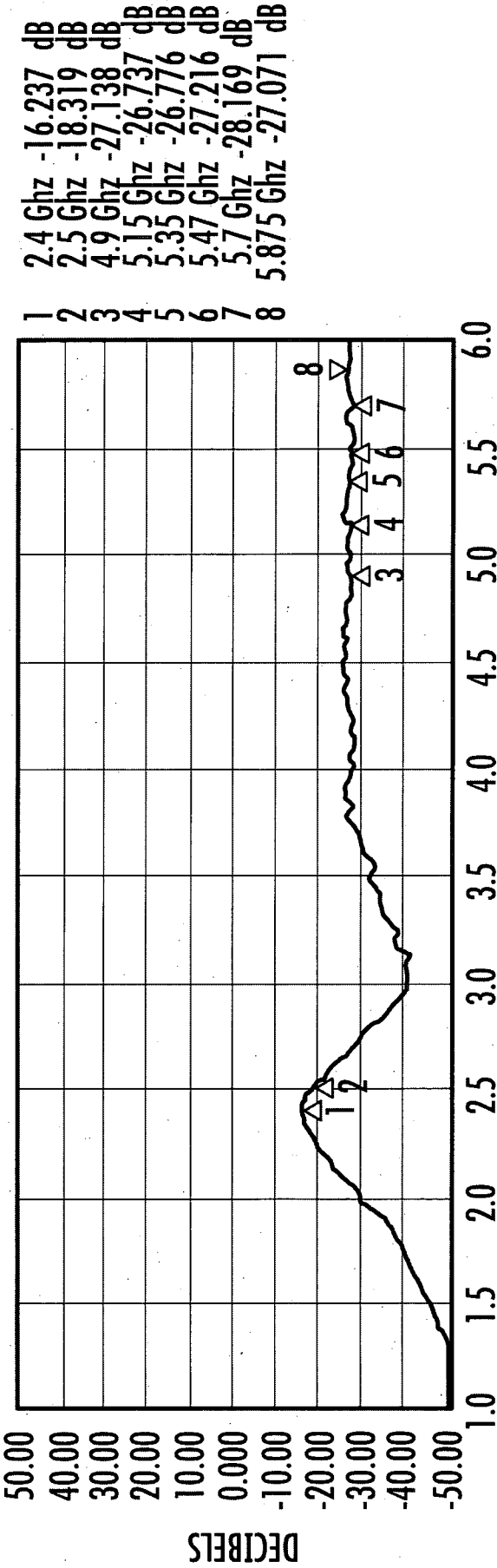
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FREQUENCY (GIGAHERTZ)

FIG. 2A



FREQUENCY (GIGAHERTZ)

FIG. 2B

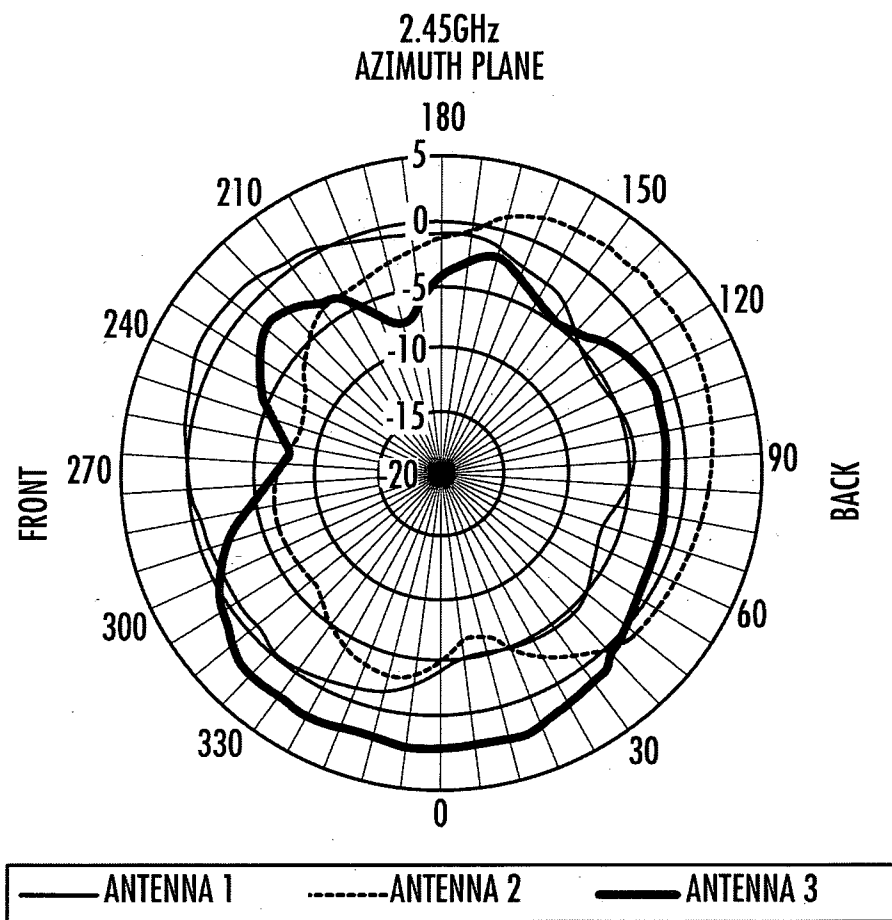
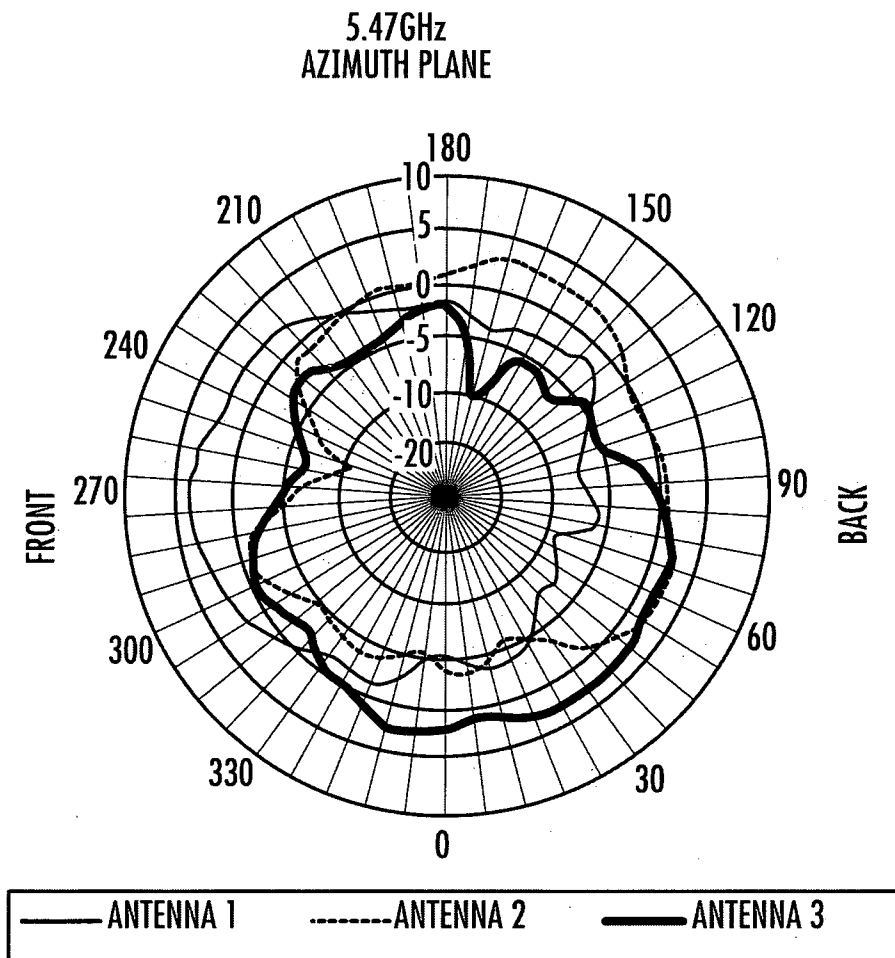
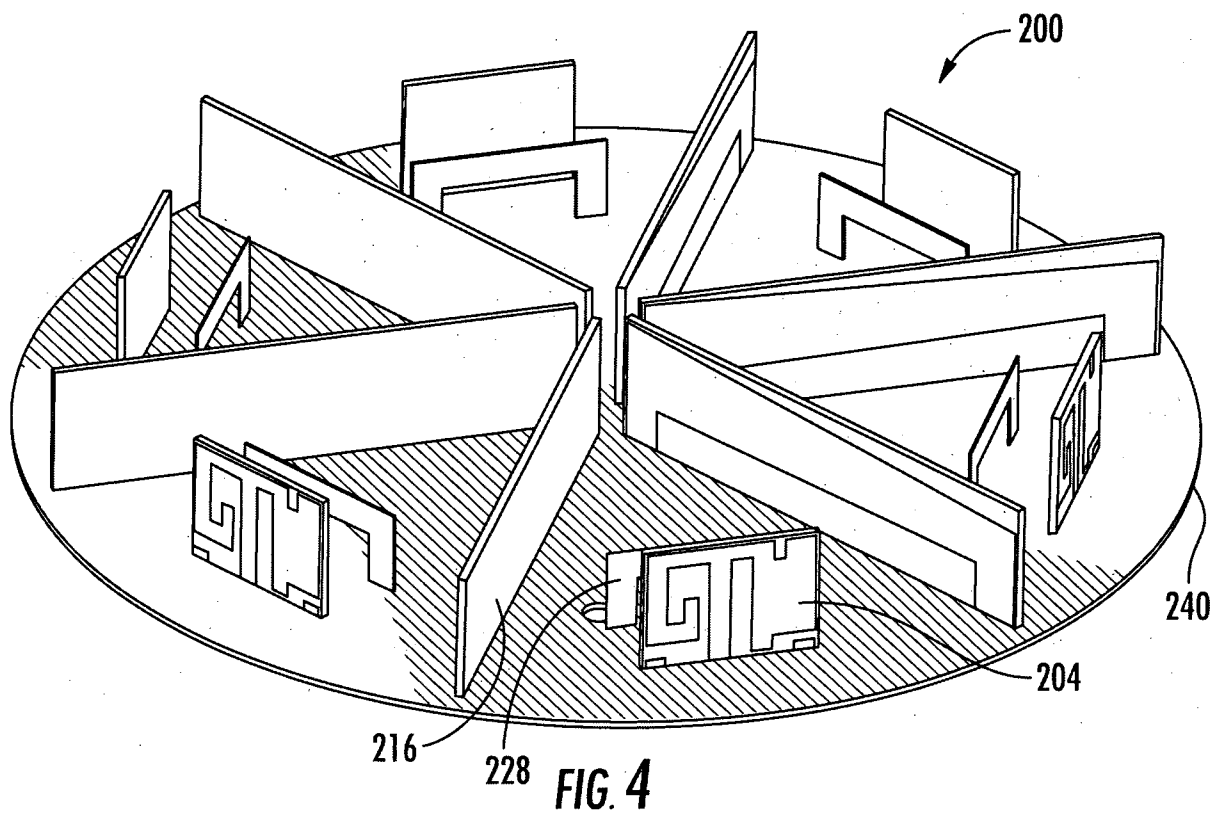
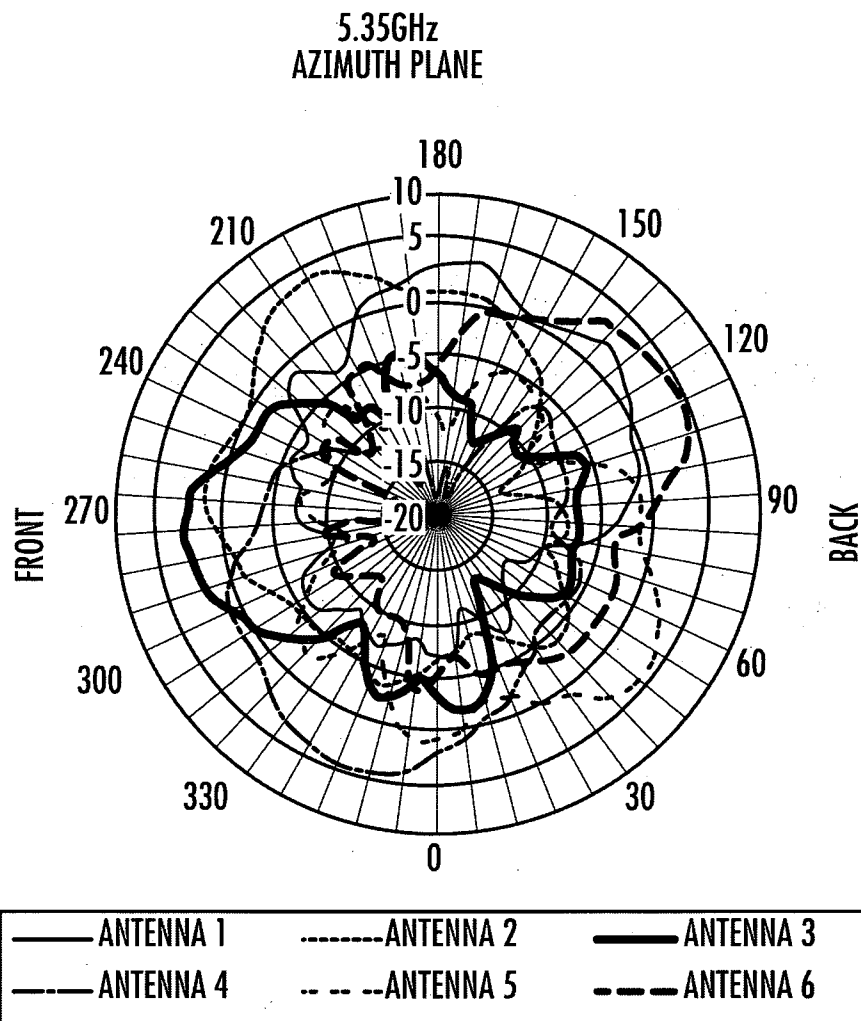


FIG. 3A

**FIG. 3B**



**FIG. 5**

INTERNATIONAL SEARCH REPORT

International application No.
PCT/MY2010/000125**A. CLASSIFICATION OF SUBJECT MATTER*****H01Q 1/52(2006.01)i, H01Q 5/00(2006.01)i, H01Q 21/20(2006.01)i***

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01Q 1/52; H01Q 9/18; H01Q 1/28; H01Q 19/17; H01Q 19/10; H01Q 21/24; H01Q 1/24

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: antenna, isolator, reflector, ground, directivity

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	WO 2010-068537 A2 (SENSIS CORPORATION et al.) 17 June 2010 See the abstract; figures 1-4; paragraphs 49-68; and claims 1-33	1-4,22 5,18-20
X A	JP 2006-148917 A (ALCATEL) 08 June 2006 See the abstract; figures 1, 2; paragraphs 11-15; and claims 1-5	22 1-5,18-20
X A	KR 10-2007-0016537 A (ELECTRONICS AND TELECOMMUNICATIONS RESEARCH INSTITUTE) 08 February 2007 See the abstract; figures 3-9; paragraphs 34-56; and claims 1-7	22 1-5,18-20
A	WO 2005-114789 A2 (AIRGAIN, INC. et al.) 01 December 2005 See the abstract; figures 1, 6, 7; paragraphs 21-26, 39; and claims 1-10	1-5,18-20,22

☐ 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

28 APRIL 2011 (28.04.2011)

Date of mailing of the international search report

02 MAY 2011 (02.05.2011)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/MY2010/000125**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.: 17
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:
claim 17 is too unclear to make meaningful search possible because the claim 17 refers to claims 6-16, violating PCT Rule 6.4(a)
3. ☒ Claims Nos.: 6-16, 21
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional 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

Information on patent family members

International application No.

PCT/MY2010/000125

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2010-068537 A2	17.06.2010	US 2010-0141530 A1 WO 2010-068537 A3	10.06.2010 17.06.2010
JP 2006-148917 A	08.06.2006	CN 1780054 A EP 1667278 A1 KR 10-2007-0084463 A MX PA05012472A RU 2005136308 A US 2006-0109193 A1 WO 2006-056536 A1	31.05.2006 07.06.2006 24.08.2007 25.05.2006 27.05.2007 25.05.2006 01.06.2006
KR 10-2007-0016537 A	08.02.2007	None	
WO 2005-114789 A2	01.12.2005	AU 2005-246674 A1 CA 2562479 A1 CN 1957506 A CN 1957506 C0 EP 1756914 A2 EP 1756914 A4 WO 2005-114789 A3 WO 2005-114789 A3	01.12.2005 01.12.2005 02.05.2007 02.05.2007 28.02.2007 02.04.2008 01.12.2005 02.11.2006