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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
21 July 2016 (21.07.2016)

(10) International Publication Number
WO 2016/113779 A1

(51) International Patent Classification:
H01Q 1/48 (2006.01) *H01Q 1/24* (2006.01)
H01Q 9/42 (2006.01) *H01Q 5/371* (2015.01)

(21) International Application Number:
PCT/JP2015/003538

(22) International Filing Date:
13 July 2015 (13.07.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
14/595,267 13 January 2015 (13.01.2015) US

(71) Applicant: **SONY CORPORATION** [JP/JP]; 1-7-1 Konan, Minato-ku, Tokyo, 1080075 (JP).

(72) Inventors: **YING, Zhinong**; Fanans Grand 10, Lund, S-22648 (SE). **ZHAO, Kun**; Forskarbacken 21, LGH 1210, Stockholm, S-11415 (SE).

(74) Agent: **KAMEYA, Yoshiaki**; HAZUKI INTERNATIONAL YOTSUYA, Daiichi Tomizawa Building, 3-1-3, Yotsuya, Shinjuku-ku, Tokyo, 1600004 (JP).

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

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

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

(54) Title: DUAL-BAND INVERTED-F ANTENNA WITH MULTIPLE WAVE TRAPS FOR WIRELESS ELECTRONIC DEVICES

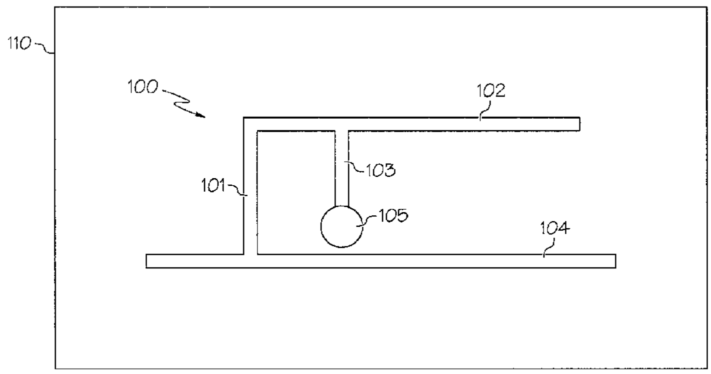

FIG. 1

(57) Abstract: A wireless electronic device includes an inverted-F antenna (IFA) having an IFA exciting element, an IFA feed, and a grounding pin. The IFA exciting element is configured to resonate at two different resonant frequencies, when excited by a signal received through the IFA feed. The wireless electronic device includes a highband wave trap having a length defined based on a first resonant frequency of the IFA exciting element. The highband wave trap is electrically coupled to the IFA exciting element through the grounding pin. A ground patch is electrically coupled between the highband wave trap and the ground plane. The wireless electronic device includes a lowband wave trap having a length defined based on a second resonant frequency of the IFA exciting element. The lowband wave trap is electrically coupled to the ground plane through the ground patch.

WO 2016/113779 A1

Description

Title of Invention: DUAL-BAND INVERTED-F ANTENNA WITH MULTIPLE WAVE TRAPS FOR WIRELESS ELECTRONIC DEVICES

Technical Field

[0001] The present inventive concepts generally relate to the field of wireless communications and, more specifically, to antennas for wireless communication devices.

[0002] CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority from US patent application No. 14/595,267, filed January 13, 2015, the entire disclosure of which hereby is incorporated by reference.

Background Art

[0003] Wireless communication devices such as cell phones and other user equipment may include antennas that may be used to communicate with external devices. These antennas may produce different types of radiation patterns in the proximity of the communication device. Some antenna designs, however, may facilitate undesirable amounts of ground currents and irregular radiation patterns.

Summary

[0004] Various embodiments of the present inventive concepts include a wireless electronic device including an inverted-F antenna (IFA). The IFA may include an IFA exciting element, an IFA feed, and a grounding pin. The IFA exciting element may be configured to resonate at both a first resonant frequency and a second resonant frequency, different from the first resonant frequency, when excited by a signal received through the IFA feed. The wireless electronic device may include a highband wave trap having a length defined based on the first resonant frequency of the IFA exciting element. The highband wave trap may be electrically coupled to the IFA exciting element through the grounding pin. A ground patch may be electrically coupled between the highband wave trap and a ground plane. The wireless electronic device may include a lowband wave trap having a length defined based on the second resonant frequency of the IFA exciting element, wherein the lowband wave trap is electrically coupled to the ground plane through the ground patch.

[0005] According to various embodiments, the length of the highband wave trap may correspond to approximately 0.5 wavelengths of the first resonant frequency of the IFA exciting element. The length of the lowband wave trap may correspond to approximately 0.5 wavelengths of the second resonant frequency of the IFA exciting element. The IFA feed may be located near the center of the highband wave trap, at approximately 0.25 wavelengths of the first resonant frequency of the IFA. The ground patch may be electrically connected to the highband wave trap near the center of the highband wave trap. In various embodiments, the width of the IFA feed on a printed circuit board (PCB) layer may be selected based on the thickness of the PCB layer such that the IFA is impedance matched to the IFA exciting element.

[0006] In some embodiments, the IFA may be configured to induce current on the highband wave trap and/or current on the lowband wave trap such that a radiation pattern of the wireless electronic device forms a dipole antenna pattern. The length of the ground patch may be between 0.1 and 0.2 wavelengths. The length of the ground patch may be between 0.1 and 0.2 wavelengths of the first resonant frequency or between 0.1 and 0.2 wavelengths of the second resonant frequency. The length of the ground patch may determine a bandwidth of the highband wave trap. The grounding pin may be electrically conductive and may be impedance matched to the IFA exciting element.

[0007] In some embodiments, the IFA feed may include a coplanar waveguide that is electrically connected to the ground plane. The coplanar waveguide may include a conductor track, a first return track on a first side of the conductor track, and a second return track on a second side of the conductor track, opposite the first return track. The first and second return tracks may be electrically isolated from the conductor track.

[0008] In some embodiments, the IFA may include a first IFA. One or more additional IFAs, each including an additional IFA feed and an additional IFA exciting element that is configured to resonate at both the first resonant frequency and the second resonant frequency when excited by the signal received through the additional IFA feed. The additional IFAs may each include an additional grounding pin, an additional highband wave trap that is electrically coupled to the additional IFA through the additional grounding pin may. An additional lowband wave trap that is electrically coupled to the ground plane through the additional ground patch be included in each additional IFA of the wireless electronic device. The first IFA and the one or more additional IFAs may extend along an edge of the wireless electronic device.

[0009] According to various embodiments, spacing between adjacent ones of the highband wave traps may be between 0.25 wavelengths and 0.5 wavelengths of the first resonant frequency. The spacing between adjacent ones of the lowband wave traps may be between 0.25 wavelengths and 0.5 wavelengths of the second resonant frequency.

[0010] In various embodiments, the one or more additional IFAs may include three additional IFAs. The first IFA and the three additional IFA may be configured to receive and/or transmit multiple-input and multiple-output (MIMO) communication.

[0011] In various embodiments, the wireless electronic device may include one or more highband IFAs. Each of the highband IFA may include a highband IFA feed, a highband IFA exciting element that is configured to resonate at either the first resonant frequency or the second resonant frequency when excited by the signal received through the highband IFA feed, a highband grounding pin, a highband ground patch, and a dedicated highband wave trap that is electrically coupled to the highband IFA exciting element through the highband grounding pin and that is electrically coupled to the ground plane through the highband ground patch. The one or more highband IFAs may extend along an edge of the wireless electronic device. The first IFA and one of the additional IFAs may be positioned in an alternating pattern with at least one of the highband IFAs along the edge of the wireless electronic device.

[0012] Various embodiments of the present inventive concepts include a wireless electronic device including a plurality of dual-band inverted-F antennas (IFAs), each including an IFA feed, an IFA exciting element, a grounding pin, and a ground patch. The IFA exciting element may be configured to resonate at both a first resonant frequency and a second resonant frequency when excited by a signal received through the IFA feed. The wireless electronic device may include a plurality of highband wave traps that are each electrically coupled to a respective one of the plurality of dual-band IFAs through a respective grounding patch. The wireless electronic device may include a plurality of lowband wave traps that are each electrically coupled to a respective one of the plurality of dual-band IFAs through the respective ground patch. The length of one of the plurality of highband wave traps may be based on the first resonant frequency of the respective IFA exciting element. The length of one of the plurality of lowband wave traps may be based on the second resonant frequency of the respective IFA exciting element. The plurality of dual-band IFAs may extend along an edge of the wireless electronic device.

[0013] The wireless electronic device including a plurality of dual-band IFA may further include a plurality of highband IFAs, each having a highband IFA feed, a highband IFA exciting element that is configured to resonate at either the first resonant frequency or the second resonant frequency when excited by the signal received through the highband IFA feed, a highband grounding pin, a highband ground patch, and a dedicated highband wave trap. The dedicated highband wave trap may be electrically coupled to the highband IFA exciting element through the highband grounding pin. The dedicated highband wave trap may be electrically coupled to the ground plane through the highband ground patch. The one or more highband IFAs may extend along an edge of the wireless electronic device. Ones of the plurality of dual-band IFAs may be positioned in an alternating pattern with ones of the plurality of the highband IFAs along the edge of the wireless electronic device such that a given highband IFA may be between adjacent ones of the plurality of dual-band IFAs.

[0014] Various embodiments of the present inventive concepts include a wireless electronic device including a ground plane, a ground patch that protrudes from an end of the ground plane, a highband wave trap that extends from an end of the ground patch that is remote from the ground plane and extends approximately parallel to the end of the ground plane. A lowband wave trap may extend across and beyond the ground patch and extend approximately parallel to the end of the ground plane and extend approximately parallel to the highband wave trap. A grounding pin may extend from the highband wave trap. The wireless electronic device may include an IFA exciting element that extends from an end of the grounding pin remote from the highband wave trap and extends approximately parallel to the highband wave trap. The wireless electronic device may include an IFA feed extending from the IFA exciting element to the highband wave trap.

[0015] Other devices and/or operations according to embodiments of the inventive concept will be or become apparent to one with skill in the art upon review of the following drawings and detailed description. It is intended that all such additional devices and/or operations be included within this description, be within the scope of the present inventive concept, and be protected by the accompanying claims. Moreover, it is intended that all embodiments disclosed herein can be implemented separately or combined in any way and/or combination.

Brief Description of Drawings

[0016] [fig.1]Figure 1 illustrates an inverted-F antenna (IFA) of a wireless electronic device, according to various embodiments of the present inventive concepts.

[fig.2]Figure 2 illustrates a wireless electronic device including the IFA of Figure 1, according to various embodiments of the present inventive concepts.

[fig.3]Figure 3 graphically illustrates the frequency response of the antenna of Figures 1 and 2, according to various embodiments of the present inventive concepts.

[fig.4]Figure 4 illustrates surface waves at 15 GHz excitation along the wireless electronic device of Figure 2, according to various embodiments of the present inventive concepts.

[fig.5]Figure 5 illustrates the radiation pattern around a wireless electronic device such as a smartphone, including the inverted-F antenna of Figure 1, according to various embodiments of the present inventive concepts.

[fig.6]Figure 6 illustrates an antenna including a highband wave trap and a lowband wave trap, according to various embodiments of the present inventive concepts.

[fig.7]Figure 7 graphically illustrates the frequency response of the antenna of Figure 6, according to various embodiments of the present inventive concepts.

[fig.8]Figure 8 illustrates surface waves, at 15 GHz excitation, along a wireless electronic device including the antenna of Figure 6, according to various embodiments of the present inventive concepts.

[fig.9]Figure 9 illustrates the radiation pattern, at 15 GHz excitation, around a wireless

electronic device such as a smartphone, including the antenna of Figure 6, according to various embodiments of the present inventive concepts.
[fig.10]Figure 10 illustrates surface waves, at 30 GHz excitation, along the wireless electronic device of Figure 6, according to various embodiments of the present inventive concepts.
[fig.11]Figure 11 illustrates the radiation pattern, at 30 GHz excitation, around a wireless electronic device such as a smartphone, including the antenna of Figure 6, according to various embodiments of the present inventive concepts.
[fig.12]Figure 12 illustrates a wireless electronic device including an array of antennas of Figure 6, according to various embodiments of the present inventive concepts.
[fig.13]Figure 13 graphically illustrates the frequency response of the antennas of Figure 12, according to various embodiments of the present inventive concepts.
[fig.14A]Figures 14A illustrates the radiation pattern, at 15 GHz excitation at various phase shifts, around a wireless electronic device such as a smartphone, including the antenna array of Figure 12, according to various embodiments of the present inventive concepts.
[fig.14B]Figures 14B illustrates the radiation pattern, at 15 GHz excitation at various phase shifts, around a wireless electronic device such as a smartphone, including the antenna array of Figure 12, according to various embodiments of the present inventive concepts.
[fig.14C]Figures 14C illustrates the radiation pattern, at 15 GHz excitation at various phase shifts, around a wireless electronic device such as a smartphone, including the antenna array of Figure 12, according to various embodiments of the present inventive concepts.
[fig.15A]Figures 15A illustrates the radiation pattern, at 30 GHz excitation at various phase shifts, around a wireless electronic device such as a smartphone, including the antenna array of Figure 12, according to various embodiments of the present inventive concepts.
[fig.15B]Figures 15B illustrates the radiation pattern, at 30 GHz excitation at various phase shifts, around a wireless electronic device such as a smartphone, including the antenna array of Figure 12, according to various embodiments of the present inventive concepts.
[fig.15C]Figures 15C illustrates the radiation pattern, at 30 GHz excitation at various phase shifts, around a wireless electronic device such as a smartphone, including the antenna array of Figure 12, according to various embodiments of the present inventive concepts.
[fig.16]Figure 16 illustrates an antenna including a highband wave trap for 30 GHz, according to various embodiments of the present inventive concepts.

[fig.17]Figure 17 graphically illustrates the frequency response of the antenna of Figure 16, according to various embodiments of the present inventive concepts.
[fig.18]Figure 18 illustrates surface waves, at 30 GHz excitation, along a wireless electronic device including the antenna of Figure 16, according to various embodiments of the present inventive concepts.
[fig.19A]Figures 19A illustrates a mixed dual band antenna array with additional high band wave trap antennas, according to various embodiments of the present inventive concepts.
[fig.19B]Figures 19B illustrates a mixed dual band antenna array with additional high band wave trap antennas, according to various embodiments of the present inventive concepts.
[fig.20]Figure 20 graphically illustrates the frequency response of the antennas of Figure 19A, according to various embodiments of the present inventive concepts.
[fig.21A]Figures 21A illustrates the radiation pattern, at 15 GHz excitation at various phase shifts, around a wireless electronic device such as a smartphone, including the antenna array of Figure 19A, according to various embodiments of the present inventive concepts.
[fig.21B]Figures 21B illustrates the radiation pattern, at 15 GHz excitation at various phase shifts, around a wireless electronic device such as a smartphone, including the antenna array of Figure 19A, according to various embodiments of the present inventive concepts.
[fig.21C]Figures 21C illustrates the radiation pattern, at 15 GHz excitation at various phase shifts, around a wireless electronic device such as a smartphone, including the antenna array of Figure 19A, according to various embodiments of the present inventive concepts.
[fig.22A]Figures 22A illustrates the radiation pattern, at 30 GHz excitation at various phase shifts, around a wireless electronic device such as a smartphone, including the antenna array of Figure 19A, according to various embodiments of the present inventive concepts.
[fig.22B]Figures 22B illustrates the radiation pattern, at 30 GHz excitation at various phase shifts, around a wireless electronic device such as a smartphone, including the antenna array of Figure 19A, according to various embodiments of the present inventive concepts.
[fig.22C]Figures 22C illustrates the radiation pattern, at 30 GHz excitation at various phase shifts, around a wireless electronic device such as a smartphone, including the antenna array of Figure 19A, according to various embodiments of the present inventive concepts.
[fig.23]Figure 23 illustrates an antenna including a highband wave trap and a lowband

wave trap and a coplanar waveguide, according to various embodiments of the present inventive concepts.

[fig.24]Figure 24 illustrates an antenna including a highband wave trap and a lowband wave trap, according to various embodiments of the present inventive concepts.

Description of Embodiments

[0017] The present inventive concepts now will be described more fully with reference to the accompanying drawings, in which embodiments of the inventive concepts are shown. However, the present application should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and to fully convey the scope of the embodiments to those skilled in the art. Like reference numbers refer to like elements throughout.

[0018] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the embodiments. As used herein, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises," "comprising," "includes," and/or "including," when used herein, specify the presence of stated features, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, steps, operations, elements, components, and/or groups thereof.

[0019] It will be understood that when an element is referred to as being "coupled," "connected," or "responsive" to another element, it can be directly coupled, connected, or responsive to the other element, or intervening elements may also be present. In contrast, when an element is referred to as being "directly coupled," "directly connected," or "directly responsive" to another element, there are no intervening elements present. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0020] Spatially relative terms, such as "above," "below," "upper," "lower," "top," "bottom," 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. It will be understood that the spatially relative terms are 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" other elements or features would then be oriented "above" the other elements or features. Thus, the 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.

Well-known functions or constructions may not be described in detail for brevity and/or clarity.

[0021] It will be understood that, although the terms "first," "second," etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. Thus, a first element could be termed a second element without departing from the teachings of the present embodiments.

[0022] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which these embodiments belong. It will be further understood that terms, such as those defined in commonly-used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly-formal sense unless expressly so defined herein.

[0023] An inverted-F antenna (IFA) is commonly used in microwave antenna designs for wireless electronic devices such as mobile terminals. IFA designs may be compact in size and easy to manufacture since they may be implemented as edge printed features on printed circuit boards (PCBs). Various wireless communication applications may use an array of IFAs. A disadvantage of IFA designs may be the that there may be a single resonant frequency with poor frequency response around the single resonant frequency. This may cause higher radiation coupling between antenna array elements and may induce irregular radiation patterns. Higher coupling between antenna array elements and irregular radiation patterns may not be suitable for extremely high frequency (EHF) radio antenna applications such as millimeter wave antenna arrays for use in the 10 to 300 GHz frequency range. These millimeter wave frequencies may be used for various types of communication in smart phones such as broadband internet access, Wi-Fi, etc. Moreover, array antennas may narrow the radiation pattern into a beam that is directional and may require the device to be directed towards the base station.

[0024] The inverted-F antenna design may be improved by adding a highband wave trap and/or a lowband wave trap that are impedance matched to the IFA exciting element of the IFA. The highband and/or lowband wave traps may improve the frequency response around selected highband and/or lowband frequencies. Additionally, the highband and/or lowband wave traps may prevent, stop, and/or reduce ground currents in the ground plane. The radiation patterns may thus be improved by adding highband and/or lowband wave traps to the IFA by reducing lobes and distortion. The IFA with a highband and/or lowband wave trap may exhibit good polarization characteristics with a broad radiation beam that is substantially symmetric with wide scanning angles.

[0025] Referring now to Figure 1, the diagram illustrates an inverted-F antenna (IFA) 100 of a wireless electronic device 110. The IFA 100 includes an IFA exciting element 102, an IFA feed 103, a ground plane 104, and a grounding pin 101. The end of the IFA feed 103 may include a test point 105. The IFA feed 103 may be a stripline. The stripline may include an electrically conductive material. In some embodiments, the stripline may include a matching network including one or more inductors, capacitors, and/or resistors. A signal received at the IFA feed 103 and/or a signal injected at the test point 105 may excite the IFA exciting element 102.

[0026] Referring now to Figure 2, a wireless electronic device 110 is illustrated that includes an antenna 100. The inverted-F antenna 100 is positioned along an edge of the wireless electronic device. Referring now to Figure 3, the frequency response of the antenna 100 of Figures 1 and 2 is graphically illustrated. In this non-limiting example, the frequency response illustrates a single lowband resonant frequency of approximately 15 GHz. The bandwidth around this lowband resonant frequency appears to be narrow. In other words, the frequency response around the lowband resonant frequency may produce a small bandwidth response around the lowband resonant frequency.

[0027] Referring now to Figure 4, surface waves at 15 GHz excitation along the wireless electronic device 110 are illustrated. Irregular surface waves that expand across much of the wireless electronic device 110 are shown. These irregular surface waves may produce poor frequency response at the lowband resonant frequency.

[0028] Referring now to Figure 5, the radiation pattern around a wireless electronic device 110 including the inverted-F antenna of Figure 1 is illustrated. When the antenna 100 is excited at 15 GHz, an irregular radiation pattern is formed around the wireless electronic device 110. The radiation pattern around the wireless electronic device 110 includes irregular lobes and distortion that may not be suitable for communication at this frequency.

[0029] The radiation pattern formed by an array of inverted-F antennas of Figure 1 may be acceptable at lower frequencies such as, for example, in the cellular band of 850 to 1900 MHz. However, distortion with many irregular lobes may occur at millimeter band radio frequencies in the electromagnetic spectrum from 10 to 300 GHz, as illustrated in Figure 5.

[0030] Referring now to Figure 6, an inverted-F antenna (IFA) 600 including a highband wave trap 605 and/or a lowband wave trap 608, according to various embodiments of the inventive concepts is illustrated. This antenna 600 may be a dual-band antenna with at least two different resonant frequencies. An IFA exciting element 602 may be excited by a signal received through an IFA feed 603. The IFA 600 may have a highband resonant frequency and/or a lowband resonant frequency. The IFA feed 603 may be connected at one end to a test point 607. According to some embodiments, the test point 607 and/or the IFA feed 603 may be electrically connected to highband wave trap 605. Signals may be introduced at the test point 607 to excite the IFA exciting element 602. The IFA feed 603 may be coupled to a transceiver for sending and receiving communication signals. The IFA exciting element 602 may be electrically connected by a grounding pin 604 to the highband wave trap 605. The grounding pin 604 may be electrically conductive and may be sized to impedance match the IFA exciting element. Impedance matching may be desirable for reducing mismatch losses to minimize reflections of signals, thereby reducing distortion in the radiation pattern of antenna 600. The grounding pin 604 may be embodied by a path coupling element, stub, or via between different layers of a printed circuit board.

[0031] Still referring to Figure 6, in some embodiments, the highband wave trap 605 may be approximately parallel to the IFA exciting element 602. The lowband wave trap 608 may be approximately parallel to the IFA exciting element 602. The highband wave trap 605 may be electrically connected to the ground plane 601 by a ground patch 606. The terms "ground pin" and "ground patch" are used to distinguish these elements from one another. However, in some embodiments, they may be embodied by a similar structure. The lowband wave trap 608 may be electrically connected to the ground plane 601 by ground patch 606. The ground patch 606 may be embodied by a path coupling element, stub, via between different layers of a printed circuit board, or as an isolated portion of the ground plane 601. The length of the highband wave trap 605 may correspond to approximately 0.5 wavelengths of the highband resonant frequency of the IFA exciting element 602. The length of the lowband wave trap 608 may correspond to approximately 0.5 wavelengths of the lowband resonant frequency of the IFA exciting element 602. The IFA feed 603 may be located near the center of the highband wave trap 605 and/or near the center of the lowband wave trap 608, at approximately 0.25 wavelengths of the highband resonant frequency and/or lowband resonant frequency of the IFA exciting element 602. In other words, an edge mounted IFA may be built on a balanced 0.25 wavelength highband wave trap and/or on a balanced 0.25 wavelength lowband wave trap. The length of the ground patch 606 may be 0.1 to 0.2 wavelengths of a lowband and/or highband resonant frequency of the IFA exciting element 602. The length of the ground patch 606 may determine the signal bandwidth supported by the highband wave trap 605 and/or the lowband wave trap 608. Reducing the length of the ground patch 606 may reduce the signal bandwidth supported by the highband wave trap 605 and/or the lowband wave trap 608. In some embodiments, the width of the ground patch 606 may be greater than the width of the IFA feed 603.

[0032] The highband wave trap 605 and/or the lowband wave trap 608 may prevent, stop, and/or reduce current and/or current loops on the ground plane 601. When excited by a signal at the IFA feed 603, a current may be induced on the highband wave trap 605 and/or on the lowband wave trap 608, forming a dipole mode on the highband wave trap 605 and/or on the lowband wave trap 608. A dipole mode may be a magnetic dipole based on a closed circulation of current. The collective structure including the highband wave trap 605 and/or the lowband wave trap 608 may thus behave as a dipole antenna. More specifically, the antenna 600 may be configured to induce current on the highband wave trap 605 and/or on the lowband wave trap 608 such that a radiation pattern of the wireless electronic device forms a dipole antenna pattern. The highband wave trap 605 may be configured to resonate at a first resonant frequency, whereas the IFA exciting element 602 may be configured to resonate at a second resonant frequency that is different from the first resonant frequency. In some embodiments, the lowband wave trap 608 may be configured to resonate at a third resonant frequency that is different from the first and second resonant frequencies. Coupling of radiation patterns related to the first, second, and/or third resonant frequencies may result in the dipole antenna pattern.

[0033] Figure 6 may also be regarded as illustrating a inverted-F antenna 600 including a ground plane 601, a ground patch 606 that protrudes from an end of the ground plane 601, a highband wave trap 605 that extends from an end of the ground patch 606 that is remote from the ground plane 601 and extends approximately parallel to the end of the ground plane 601. A lowband wave trap 608 may extend across and beyond the ground patch 606 and extend approximately parallel to the end of the ground plane 601 and extend approximately parallel to the highband wave trap 605. A grounding pin 604 may extend from the highband wave trap 605. The antenna 600 may include an IFA exciting element 602 that extends from an end of the grounding pin 604 remote from the highband wave trap 605 and extends approximately parallel to the highband wave trap 605. The antenna 600 may include an IFA feed 603 extending from the IFA exciting element 602 to the highband wave trap 605.

[0034] Referring now to Figure 7, the frequency response of the antenna of Figure 6 is graphically illustrated. In this non-limiting example, the frequency response illustrates a lowband resonant frequency of approximately 15 GHz and a highband resonant frequency of approximately 30 GHz. The -10 dB bandwidth around the lowband resonant frequency may be around 3 GHz, which may be approximately 20% of the lowband resonant frequency. The -10 dB bandwidth around the highband resonant frequency may be around 3 GHz. The very wide bandwidths provided by this antenna around the lowband and/or highband resonant frequencies offer excellent signal integrity with potential for use at several different frequencies in this bandwidth range.

[0035] Referring now to Figures 8 and 10, surface waves at 15 GHz and 30 GHz, respectively, are illustrated along the wireless electronic device 110 including the antenna of Figure 6 with a highband wave trap and/or a lowband wave trap. When compared to the surface waves for the antenna of Figure 1 illustrated in Figure 4, the irregular surface waves that expand across much of the wireless electronic device 110 appear to be reduced in Figures 8 and 10. The reduced surface waves may produce improved frequency response at the respective resonant frequencies.

[0036] Referring now to Figures 9 and 11, radiation patterns at approximately 15 GHz and 30 GHz, respectively, are illustrated for the antenna of Figure 6. The radiation patterns at approximately 15 GHz and 30 GHz each span more broadly and uniformly around the wireless electronic device 110 with fewer prominent side lobes and less distortion than the radiation pattern of Figure 5. Accordingly, the antenna design of Figure 6 described herein may provide better performance at a variety of extremely high frequencies when compared to the antenna of Figure 1.

[0037] Referring now to Figure 12, a wireless electronic device 110 including an array of antennas 600a-600h of Figure 6 along the edge of the wireless electronic device 110 is illustrated. Each of the antennas 600a-600h may include an IFA exciting element 602, a grounding pin 604, a ground patch 606, and a IFA feed 603, a highband wave trap 605 and/or a lowband wave trap 608, as illustrated in Figure 6. Each of the antennas 600a-600h may be electrically coupled to the ground plane 601, as illustrated in Figure 6. In some embodiments, a common ground may be shared between two or more antennas 600a-600h. Spacing between adjacent highband wave traps and/or lowband wave traps may be between 0.25 and 0.5 wavelengths of the highband and/or lowband resonant frequencies, measured from tip-to-tip of the highband wave traps and/or lowband wave traps. In some embodiments, spacing between adjacent highband wave traps and/or lowband wave traps may be between 0.25 and 0.5 wavelengths center-to-center of the highband wave traps and/or lowband wave traps. In some embodiments, the spacing between adjacent highband wave traps and/or lowband wave traps may be slightly less than 0.5 wavelengths, at for example, 0.45 wavelengths. In some embodiments, the spacing between adjacent highband wave traps and/or lowband wave traps may be based on the demand bandwidth of the wireless electronic device.

[0038] Still referring to Figure 12, in some embodiments, the antennas 600a-600h may include two arrays of four antennas each. For example, antennas 600a-600d may be one array while antennas 600e-600h may be a second array. The first and second arrays may each function independently as a receive antenna and/or a transmit antenna. In some embodiments, the array of antennas 600 may include four antennas 600 and may be configured to receive and/or transmit multiple-input and multiple output (MIMO) communication.

[0039] Referring now to Figure 13, the frequency response of the antennas 600a-600h of Figure 12 is illustrated. Curve 1301 illustrates the overall frequency response of the wireless electronic device 110 including antennas 600a-600h of Figure 12. Each of curves 1302 illustrates the frequency response for an individual antenna of antennas 600a-600h of Figure 12, with each curve including the mutual coupling between different antennas 600a-600h. The antenna structures 600a-600h of Figure 12 each include a highband wave trap 605 and/or a lowband wave trap 608, as illustrated in Figure 6. The antenna structure including the highband wave trap 605 and/or the lowband wave trap 608 provide low mutual coupling between various antenna elements, as illustrated by curves 1302 of Figure 13.

[0040] Referring now to Figures 14A-14C, radiation patterns at approximately 15 GHz for phase shifts of 0 degree, 60 degrees, and 120 degrees, respectively, are illustrated for the antenna array of Figure 12. The different phase shifts may be obtained based on processor post-processing of signals received at one or more of the antennas 600a-600h in order to control scanning angles to provide an equiphase wave front. The radiation patterns at approximately 15 GHz at phase shifts of 0 degree, 60 degrees, and 120 degrees each span more broadly and uniformly around the wireless electronic device 110 with fewer prominent side lobes and less distortion at 15 GHz than the radiation pattern of Figures 5 and/or 11. In some cases, phase shifts may reduce performance of the antenna. However, as illustrated by Figures 14B and 14C, application of a phase shift at 15 GHz to antenna array 600 still appears to produce excellent radiation patterns. Accordingly, the antenna array design of Figure 12 described herein may provide better performance at 15 GHz for a variety of extremely high frequencies when compared to the antennas of Figures 1 and/or 6.

[0041] Referring now to Figures 15A-15C, radiation patterns at approximately 30 GHz for phase shifts of 0 degree, 60 degrees, and 120 degrees, respectively, are illustrated for the antenna array of Figure 12. The different phase shifts may be obtained based on processor post-processing of signals received at one or more of the antennas 600a-600h in order to control scanning angles to provide an equiphase wave front. The radiation patterns at approximately 30 GHz at phase shifts of 0 degree, 60 degrees, and 120 degrees each span more broadly and uniformly around the wireless electronic device 110 with fewer prominent side lobes and less distortion than the radiation pattern of Figure 11. In some cases, phase shifts may reduce performance of the antenna. However, as illustrated by Figures 15B and 15C, application of a phase shift at 30 GHz to antenna array 600 still appears to produce excellent radiation patterns. Accordingly, the antenna array design of Figure 12 described herein may provide better performance at 30 GHz for a variety of extremely high frequencies when compared to the antenna of Figure 6.

[0042] The antenna array 600 of Figure 12 may be used for dual-band applications. A non-limiting example of a dual-band antenna array 600 with resonant frequencies at 15

GHz and 30 GHz has been discussed. The antenna elements 600a-600h include two wave traps, including a lowband wave trap for 15 GHz and a highband wave trap for 30 GHz, that suppress and/or reduce surface waves at these frequencies. As illustrated in Figures 13-15C, this dual-band antenna array 600 performed well with an array gain > 8dB with 120 degrees phase shifts at both 15 GHz and 30 GHz. However, the spacing between the antenna elements may based on the lowband resonant frequency (for example, 15 GHz), which may induce undesirable side lobes at 30 GHz.

[0043] Referring now to Figure 16, a wireless electronic device 110 with a highband antenna 1600 including a single highband wave trap 1604 is illustrated. In this non-limiting example, the highband antenna 1600 may resonate at a single highband resonant frequency of approximately 30 GHz. The highband antenna 1600 may include an IFA exciting element 1601 that may be excited by a signal received through the IFA feed 1602. A test point 1606 may be connected to one end of the IFA feed 1602. The IFA exciting element 1601 may be electrically connected by a grounding pin 1603 to a highband wave trap 1604, that is substantially parallel to the IFA exciting element 1601. The highband wave trap 1604 may be electrically connected to a ground plane 1607 through a ground patch 1605.

[0044] Referring now to Figure 17, the frequency response of the antenna of Figure 16 is graphically illustrated. In this non-limiting example, the frequency response illustrates a single highband resonant frequency of approximately 30 GHz.

[0045] Referring now to Figure 18, the radiation pattern around a wireless electronic device 110 including a highband antenna 1600 of Figure 16 is illustrated. When the highband antenna 1600 is excited at 30 GHz, a radiation pattern is formed around the wireless electronic device 110. The radiation pattern spans broadly and uniformly around the wireless electronic device 110.

[0046] Referring now to Figure 19A, a wireless electronic device 110 including an array of dual-band antennas 600 of Figure 6 and an array highband antennas 1600 of Figure 16 along the edge of the wireless electronic device 110 is illustrated. The dual-band antennas 600 may be positioned in an alternating pattern with the highband antennas 1600. For example, as illustrated in Figure 19B, highband antenna 1600b may be between dual-band antennas 600a and 600b. This antenna configuration mixing dual-band antennas with highband antennas may increase the antenna gain at the highband frequency (for example, 30 GHz). Spacing between dual-band antennas 600 and highband antennas 1600 may be at 0.5 wavelengths of the highband frequency.

[0047] Referring now to Figure 20, the frequency response of the array of dual-band antennas 600a-600h and highband antennas 1600a-1600h of Figure 19A is illustrated. Curve 2002 illustrates the overall frequency response of the wireless electronic device 110 including dual-band antennas 600a-600h and highband antennas 1600a-1600h of

Figure 19A. Curve 2002 illustrates resonant frequencies around 15 GHz and 30 GHz. Each of curves 2001 illustrates the frequency response for an individual antenna of dual-band antennas 600a-600h and highband antennas 1600a-1600h of Figure 19A, with each curve including the mutual coupling between different antennas 600a-600h and 1600a-1600h. The dual-band antennas 600a-600h of Figure 19A each include a highband wave trap 605 and/or a lowband wave trap 608, as illustrated in Figure 6. The highband antennas 1600a-1600h of Figure 16 each include a highband wave trap 1604, as illustrated in Figure 16. The array of dual-band antennas 600a-600h and highband antennas 1600a-1600h provide low mutual coupling between various antenna elements, as illustrated by curves 2001 of Figure 20.

[0048] Referring now to Figures 21A-21C, radiation patterns at approximately 15 GHz for phase shifts of 0 degree, 60 degrees, and 120 degrees, respectively, are illustrated for the antenna array of Figure 19A. The different phase shifts may be obtained based on processor post-processing of signals received at one or more of the antennas 600a-600h and 1600a-1600h in order to control scanning angles to provide an equiphase wave front. The radiation patterns at approximately 15 GHz at phase shifts of 0 degree, 60 degrees, and 120 degrees each span more broadly and uniformly around the wireless electronic device 110 with fewer prominent side lobes and less distortion at 15 GHz. In some cases, phase shifts may reduce performance of the antenna. However, as illustrated by Figures 21B and 21C, application of a phase shift at 15 GHz to antenna array 600a-600h and 1600a-1600h appears to produce excellent radiation patterns. Accordingly, the antenna array design of Figure 19A described herein may provide suitable performance at 15 GHz for a variety of extremely high frequencies.

[0049] Referring now to Figures 22A-22C, radiation patterns at approximately 30 GHz for phase shifts of 0 degree, 60 degrees, and 120 degrees, respectively, are illustrated for the antenna array of Figure 19A. The different phase shifts may be obtained based on processor post-processing of signals received at one or more of the antenna array 600a-600h and 1600a-1600h in order to control scanning angles to provide an equiphase wave front. The radiation patterns at approximately 30 GHz at phase shifts of 0 degree, 60 degrees, and 120 degrees each span more broadly and uniformly around the wireless electronic device 110 with fewer prominent side lobes and less distortion than the radiation pattern of Figures 15A-15C. Accordingly, the antenna array design of Figure 19 described herein may provide better performance at 30 GHz for a variety of extremely high frequencies when compared to the antenna array of Figure 12.

[0050] Referring now to Figure 23, an antenna 2300 is illustrated that includes an IFA exciting element 2301, a highband wave trap 2302 and a lowband wave trap 2303. The highband wave trap 2302 may include separate highband wave trap portions 2302A and 2302B. The lowband wave trap 2303 may include separate lowband wave trap portions 2303A and 2303B. Highband wave trap portions 2302A and 2302B and lowband wave trap portions 2303A and 2303B may be electrically connect to ground plane 2310.

[0051] Still referring to Figure 23, an IFA feed 2309 may electrically connect the IFA exciting element 2301 to a coplanar waveguide 2308. The coplanar waveguide 2308 may include a conducting track 2306 and a pair of return conductors 2305A and 2305B that are separated from the conducting track 2306 by an air gap and/or a dielectric substrate. A test point 2307 may be connected to the coplanar waveguide 2308. In some embodiments, the return conductors 2305A and 2305B may be a portion of the ground plane 2310.

[0052] According to some embodiments, the highband wave trap 605 and lowband wave trap 608 of Figure 6 may be interchanged in location. Referring now to Figure 24, for example, an antenna 2400 may include a highband wave trap 2405 and/or a lowband wave trap 2408. An IFA exciting element 2402 may be excited by a signal received through an IFA feed 2403. The antenna 2400 may have a highband resonant frequency and/or a lowband resonant frequency. The IFA feed 2403 may be connected at one end to a test point 2407. According to some embodiments, the test point 2407 and/or the IFA feed 2403 may be electrically connected to lowband wave trap 2408. Signals may be introduced at the test point 2407 to excite the IFA exciting element 2402. The IFA feed 2403 may be coupled to a transceiver for sending and receiving communication signals. The IFA exciting element 2402 may be electrically connected by a grounding pin 2404 to the lowband wave trap 2408. The grounding pin 2404 may be electrically conductive and may be sized to impedance match the IFA exciting element 2402. Impedance matching may be desirable for reducing mismatch losses to minimize reflections of signals, thereby reducing distortion in the radiation pattern of the antenna 2400.

[0053] The above discussed array antenna structures with highband and/or lowband wave traps may produce a dual-band antenna with uniform radiation patterns with few prominent side lobes. The highband and/or lowband wave traps may reduce surface waves, thus controlling the radiation pattern of the antenna. The antenna including the highband and/or lowband wave traps may be along an edge of the device and serve to control electromagnetic patterns along the edge. A collection of these structures with highband and/or lowband wave traps may provide beam forming functionality in addition to reduced side lobes. In some embodiments, these antenna structures may be implemented two-dimensionally on a printed circuit board and/or on a multi-dimensional printed circuit board. In some embodiments, phase shifters and/or time delay devices may be used in conjunction with array antenna elements to control scanning angles to provide an equiphase wave front. The described inventive concepts create periodic antenna dielectric structures with high quality, low loss, and wide scanning angles.

[0054] Many different embodiments have been disclosed herein, in connection with the above description and the drawings. It will be understood that it would be unduly repetitious and obfuscating to literally describe and illustrate every combination and subcombination of these embodiments. Accordingly, the present specification, including the drawings, shall be construed to constitute a complete written description of all combinations and subcombinations of the embodiments described herein, and of the manner and process of making and using them, and shall support claims to any such combination or subcombination.

[0055] In the drawings and specification, there have been disclosed various embodiments and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation.

Claims

[Claim 1] A wireless electronic device (110) comprising:
an inverted-F antenna (IFA) (600) comprising an IFA exciting element (602), an IFA feed (603), and a grounding pin (604), wherein the IFA exciting element (602)is configured to resonate at both a first resonant frequency and a second resonant frequency, different from the first resonant frequency, when excited by a signal received through the IFA feed (603);
a highband wave trap (605) having a length defined based on the first resonant frequency of the IFA exciting element (602), wherein the highband wave trap (605) is electrically coupled to the IFA exciting element (602) through the grounding pin (604);
a ground patch (606) that is electrically coupled between the highband wave trap (605) and a ground plane (601); and
a lowband wave trap (608) having a length defined based on the second resonant frequency of the IFA exciting element (602), wherein the lowband wave trap (608) is electrically coupled to the ground plane (601) through the ground patch (606).

[Claim 2] The wireless electronic device (110) of Claim 1,
wherein the length of the highband wave trap (605) corresponds to approximately 0.5 wavelengths of the first resonant frequency of the IFA exciting element (602), and
wherein the length of the lowband wave trap (608) corresponds to approximately 0.5 wavelengths of the second resonant frequency of the IFA exciting element (602).

[Claim 3] The wireless electronic device (110) of Claim 2, wherein the IFA feed is located near a center of the highband wave trap (605), at approximately 0.25 wavelengths of the first resonant frequency of the IFA (600).

[Claim 4] The wireless electronic device (110) of Claim 3, wherein the grounding pin (604) is electrically connected to the highband wave trap (605) near a center of the highband wave trap (605).

[Claim 5] The wireless electronic device (110) of Claim 1, wherein the ground patch (606) is electrically connected to the highband wave trap (605) near a center of the highband wave trap (605).

[Claim 6] The wireless electronic device (110) of Claim 1, wherein the width of the IFA feed (603) on a printed circuit board (PCB) layer is selected based on a thickness of the PCB layer such that the IFA is impedance matched to the IFA exciting element (602).

[Claim 7] The wireless electronic device (110) of Claim 1, wherein the IFA (600) is configured to induce current on the highband wave trap (605) and/or current on the lowband wave trap (608) such that a radiation pattern of the wireless electronic device (110) forms a dipole antenna pattern.

[Claim 8] The wireless electronic device (110) of Claim 1,
wherein the length of the ground patch (606) determines a bandwidth of the highband wave trap (605) and/or the lowband wave trap (608).

[Claim 9] The wireless electronic device (110) of Claim 1, wherein the grounding pin (604) is electrically conductive and is impedance matched to the IFA exciting element (602).

[Claim 10] The wireless electronic device (110) of Claim 1,
wherein the IFA feed (2309) comprises a coplanar waveguide (2308) that is electrically connected to the ground plane (2310),
wherein the coplanar waveguide (2308) comprises a conductor track (2306), a first return track (2305A) on a first side of the conductor track, and a second return track (2305B) on a second side of the conductor track (2306), opposite the first return track (2305A), and wherein the first and second return tracks (2305A, 2305B) are electrically isolated from the conductor track (2306).

[Claim 11] The wireless electronic device (110) of Claim 1, wherein the IFA (600) comprises a first IFA (600), the wireless electronic device (110) further comprising:
one or more additional IFAs (600) each comprising:
- an additional IFA feed (603);
- an additional IFA exciting element (602) that is configured to resonate at both the first resonant frequency and the second resonant frequency when excited by the signal received through the additional IFA feed (603);
- an additional grounding pin (604);
- an additional ground patch (606);
- an additional highband wave trap (605) that is electrically coupled to the additional IFA exciting element (602) through the additional grounding pin (604); and
- an additional lowband wave trap (608) that is electrically coupled to the ground plane (601) through the additional ground patch (606),
wherein the first IFA (600) and the one or more additional IFAs (600)

extend along an edge of the wireless electronic device (110).

[Claim 12] The wireless electronic device (110) of Claim 11, wherein a spacing between adjacent ones of the highband wave traps (605) is between 0.25 wavelengths and 0.5 wavelengths of the first resonant frequency.

[Claim 13] The wireless electronic device (110) of Claim 11, wherein a spacing between adjacent ones of the lowband wave traps (608) is between 0.25 wavelengths and 0.5 wavelengths of the second resonant frequency.

[Claim 14] The wireless electronic device (110) of Claim 11,
wherein the one or more additional IFAs (600) comprise three additional IFAs (600), and
wherein the first IFA (600) and the three additional IFA (600) are configured to receive and/or transmit multiple-input and multiple-output (MIMO) communication.

[Claim 15] The wireless electronic device (110) of Claim 1, further comprising:
one or more highband IFAs (1600), each comprising:
- a highband IFA feed (1602);
- a highband IFA exciting element (1601) that is configured to resonate at either the first resonant frequency or the second resonant frequency when excited by the signal received through the highband IFA feed (1602);
- a highband grounding pin (1603);
- a highband ground patch (1605); and
- a dedicated highband wave trap (1604) that is electrically coupled to the highband IFA exciting element (1601) through the highband grounding pin (1603) and that is electrically coupled to the ground plane (1607) through the highband ground patch (1605);
wherein the one or more highband IFAs (1600) extend along an edge of the wireless electronic device (110).

[Claim 16] The wireless electronic device (110) of Claim 15,
wherein the first IFA (1600) and one of the additional IFAs (1600) are positioned in an alternating pattern with at least one of the highband IFAs along the edge of the wireless electronic device (110).

[Claim 17] A wireless electronic device (110) comprising:
a plurality of dual-band inverted-F antennas (IFAs) (600), each comprising an IFA feed (603), an IFA exciting element (602) that is configured to resonate at both a first resonant frequency and a second resonant frequency when excited by a signal received through the IFA feed (603), a grounding pin (604), and a ground patch (606);

a plurality of highband wave traps (605) that are each electrically coupled to a respective one of the plurality of dual-band IFAs (600) through a respective grounding pin (604) and that are each electrically coupled to a ground plane (601) through a respective ground patch (606);
a plurality of lowband wave traps (608)that are each electrically coupled to a respective one of the plurality of dual-band IFAs (600) through the respective ground patch (606),
wherein a length of one of the plurality of highband wave traps (605) is based on the first resonant frequency of the respective IFA exciting element (602),
wherein a length of one of the plurality of lowband wave traps (608) is based on the second resonant frequency of the respective IFA exciting element (602), and
wherein the plurality of dual-band IFAs (600) extend along an edge of the wireless electronic device (110).

[Claim 18] The wireless electronic device (110) of Claim 17, the wireless electronic device (110) further comprising:
a plurality of highband IFAs (1600), each comprising:
- a highband IFA feed (1602);
- a highband IFA exciting element (1601) that is configured to resonate at either the first resonant frequency or the second resonant frequency when excited by the signal received through the highband IFA feed (1602);
- a highband grounding pin (1603);
- a highband ground patch (1605); and
- a dedicated highband wave trap (1604) that is electrically coupled to the highband IFA exciting element (1601) through the highband grounding pin (1603) and that is electrically coupled to the ground plane (601) through the highband ground patch (1605),
wherein the one or more highband IFAs (1600) extend along an edge of the wireless electronic device (110).

[Claim 19] The wireless electronic device (110) of Claim 18,
wherein ones of the plurality of dual-band IFAs (600) are positioned in an alternating pattern with ones of the plurality of the highband IFAs (1600) along the edge of the wireless electronic device (110) such that a given highband IFA (1600) is between adjacent ones of the plurality of dual-band IFAs (600).

[Claim 20] A wireless electronic device (110) comprising:
a ground plane (601);
a ground patch (606) that protrudes from an end of the ground plane (601);
a highband wave trap (605) that extends from an end of the ground patch (606) that is remote from the ground plane (601) and extends approximately parallel to the end of the ground plane (601);
a lowband wave trap (608) that extends across and beyond the ground patch (606) and extends approximately parallel to the end of the ground plane (601) and extends approximately parallel to the highband wave trap (605);
a grounding pin (604) that extends from the highband wave trap (605);
an IFA exciting element (602) that extends from an end of the grounding pin (604) remote from the highband wave trap (605) and extends approximately parallel to the highband wave trap (605); and
an IFA feed (603) extending from the IFA exciting element (602) to the highband wave trap (605).

[Fig. 1]

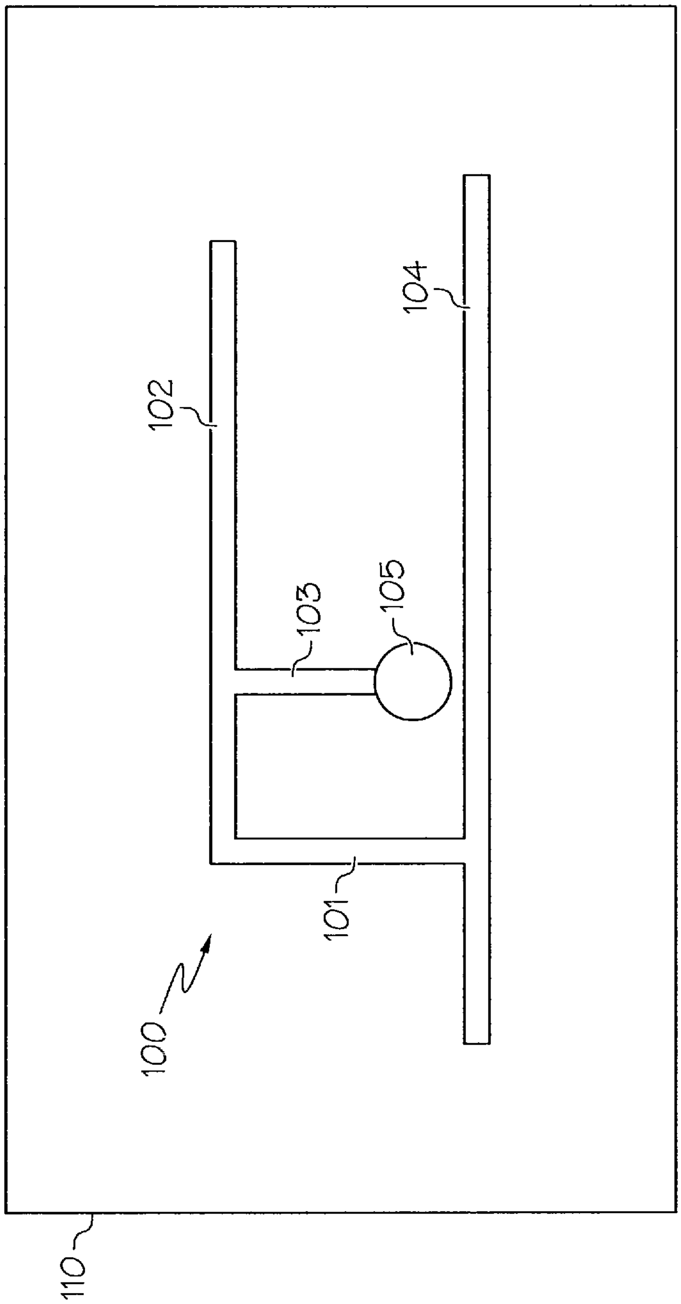

FIG. 1

[Fig. 2]

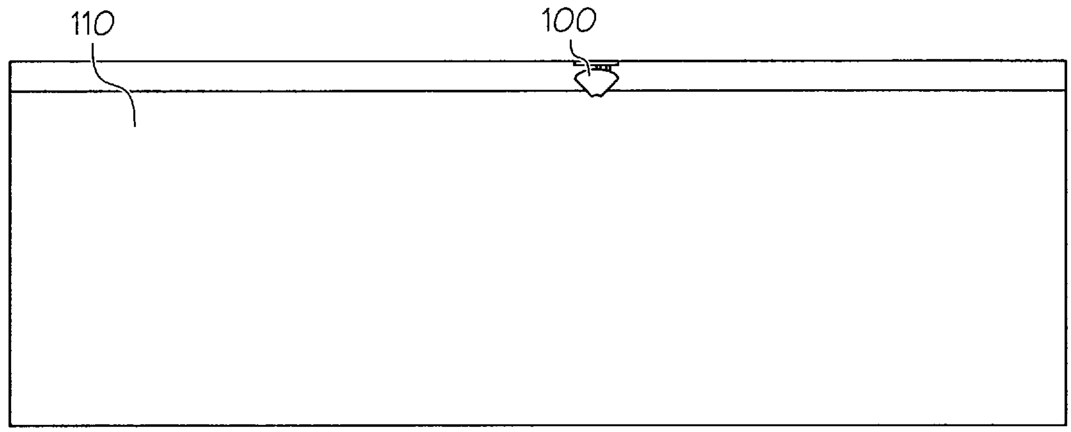

FIG. 2

[Fig. 3]

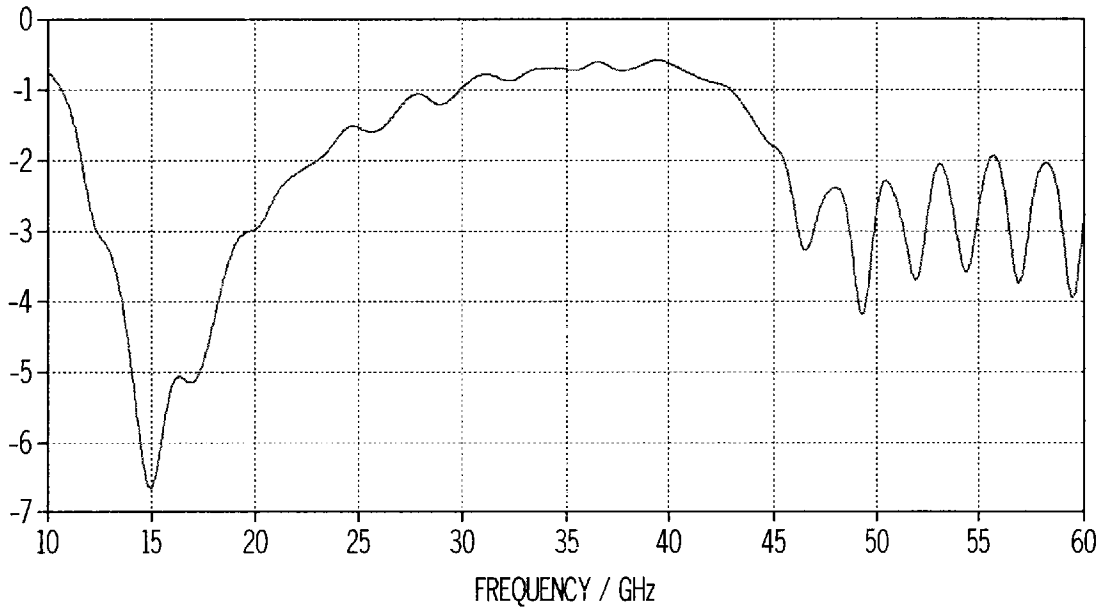

FIG. 3

[Fig. 4]

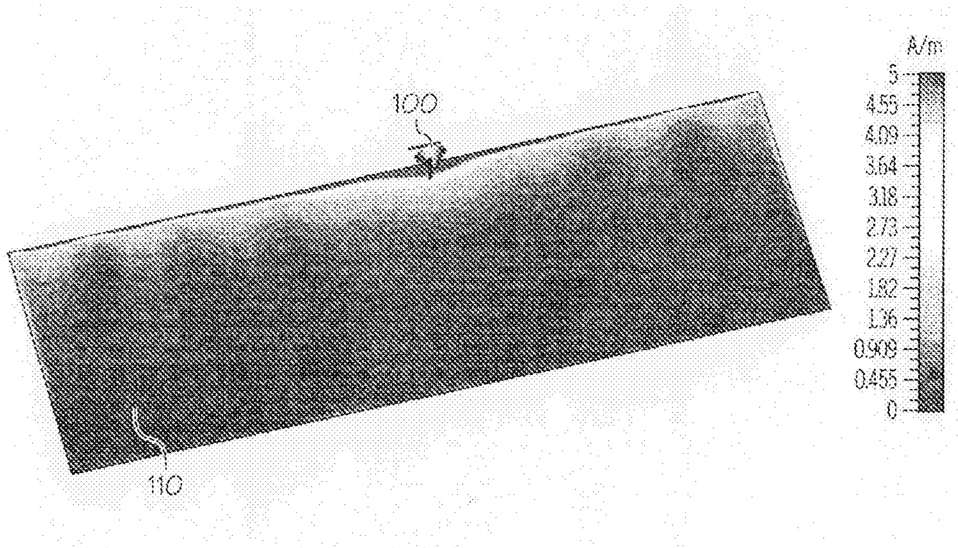

FIG. 4

[Fig. 5]

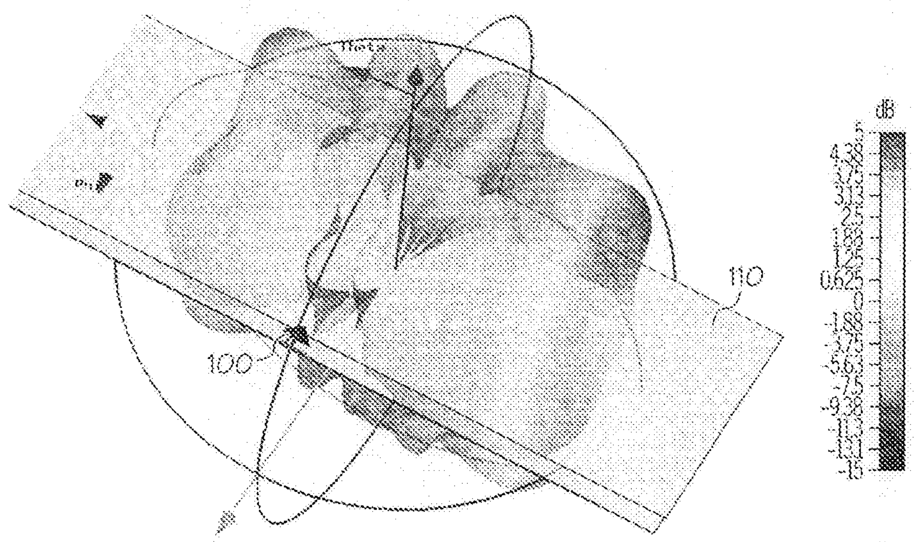

FIG. 5

[Fig. 6]

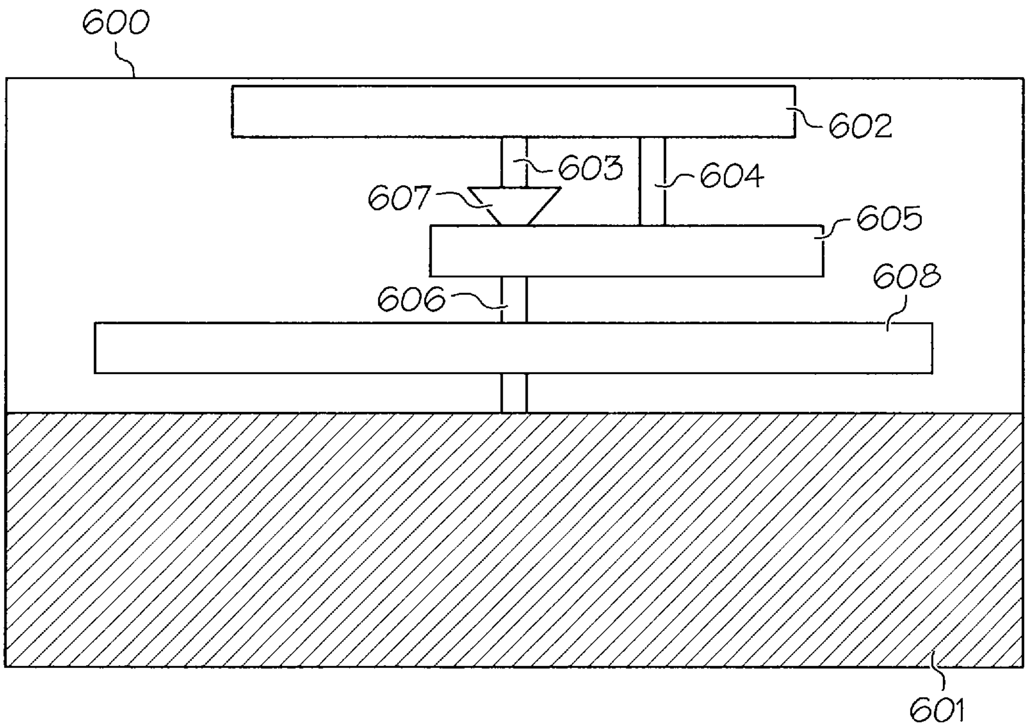

FIG. 6

[Fig. 7]

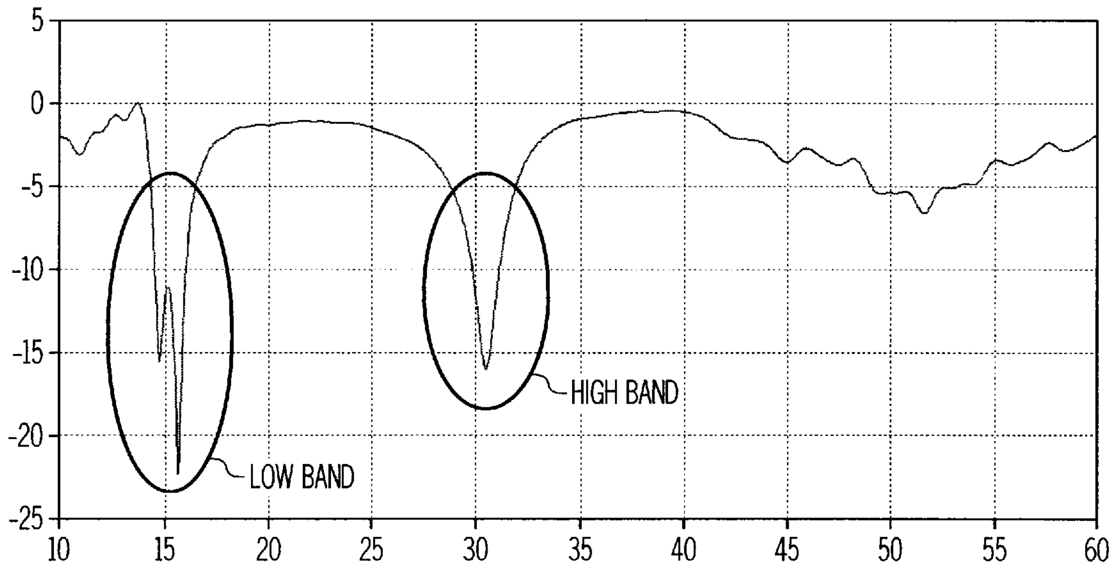

FIG. 7

[Fig. 8]

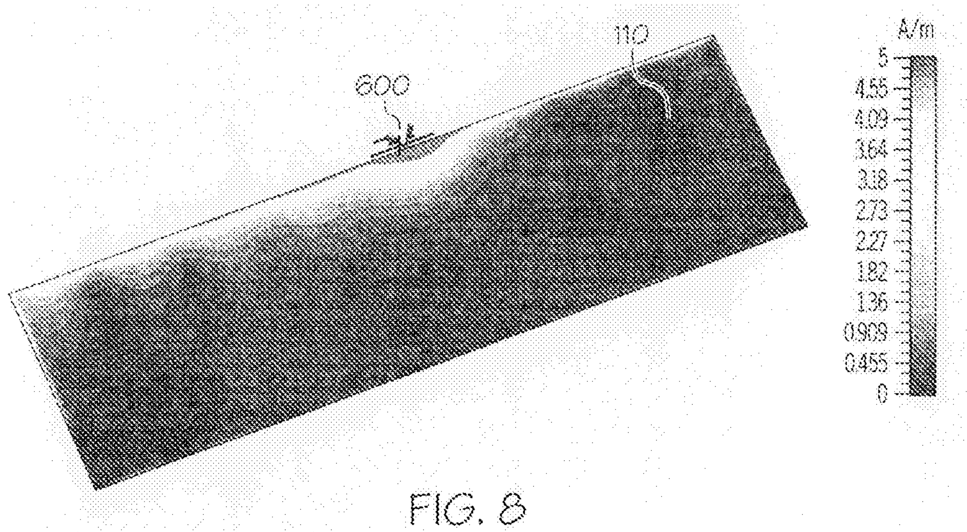

FIG. 8

[Fig. 9]

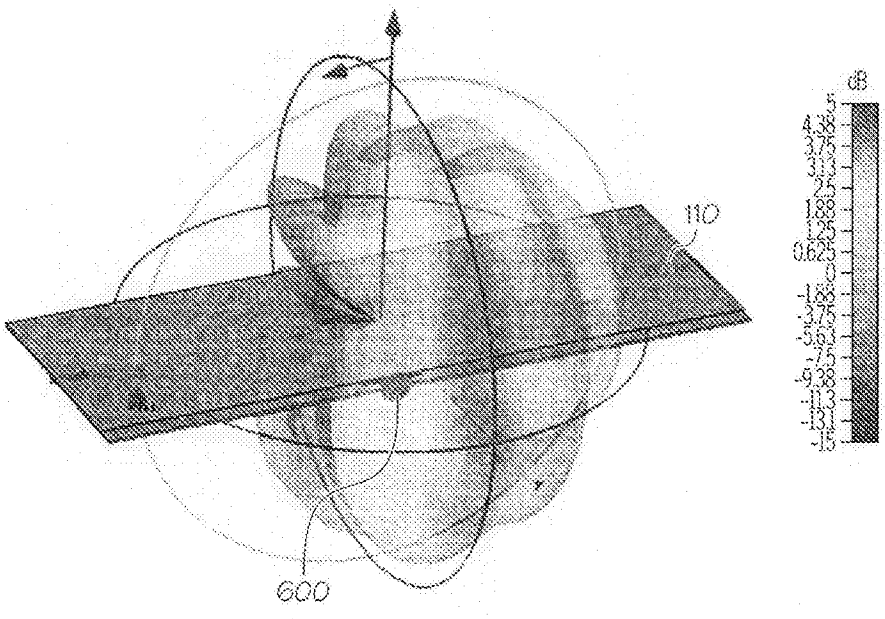

FIG. 9

[Fig. 10]

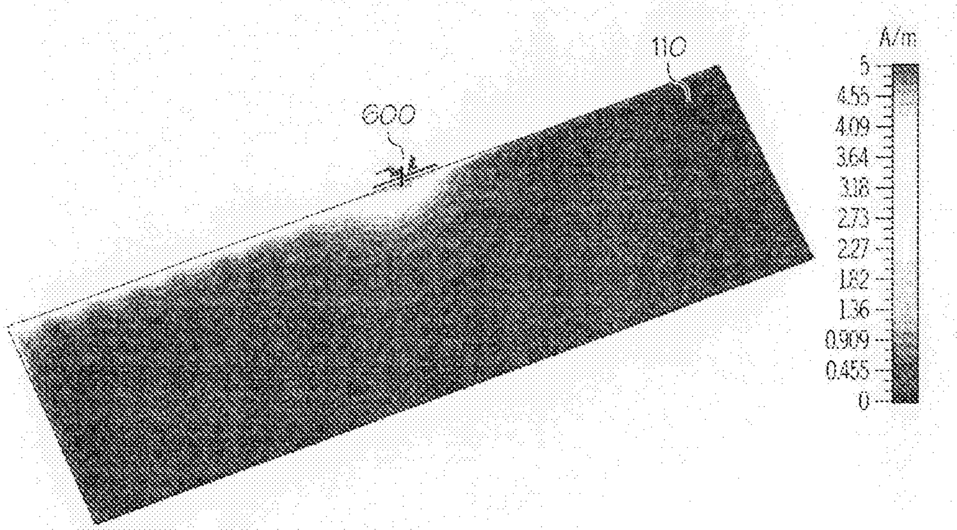

FIG. 10

[Fig. 11]

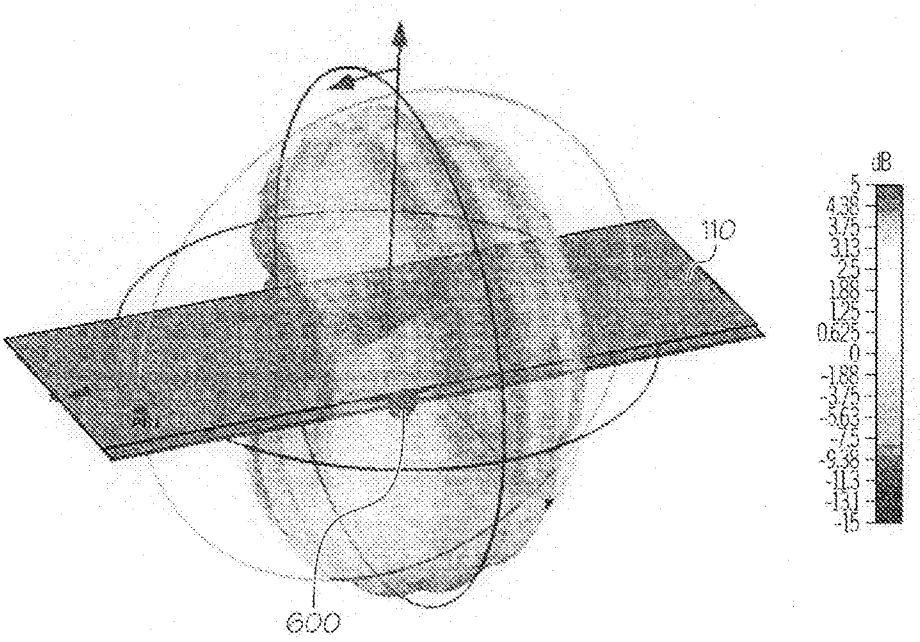
110
600
dB
5
4.38
3.75
3.13
2.5
1.88
1.25
0.625
0
-1.88
-3.75
-5.63
-7.5
-9.38
-11.3
-13.1
-15

FIG. 11

[Fig. 12]

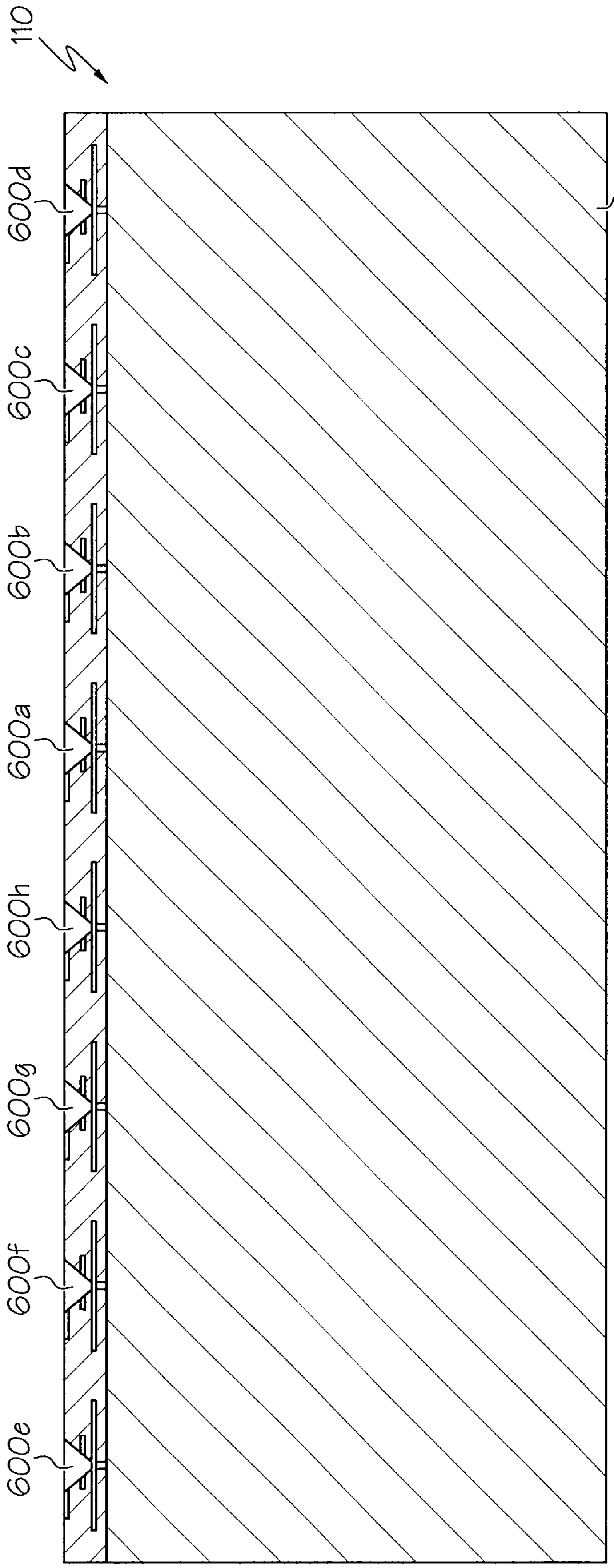

FIG. 12

[Fig. 13]

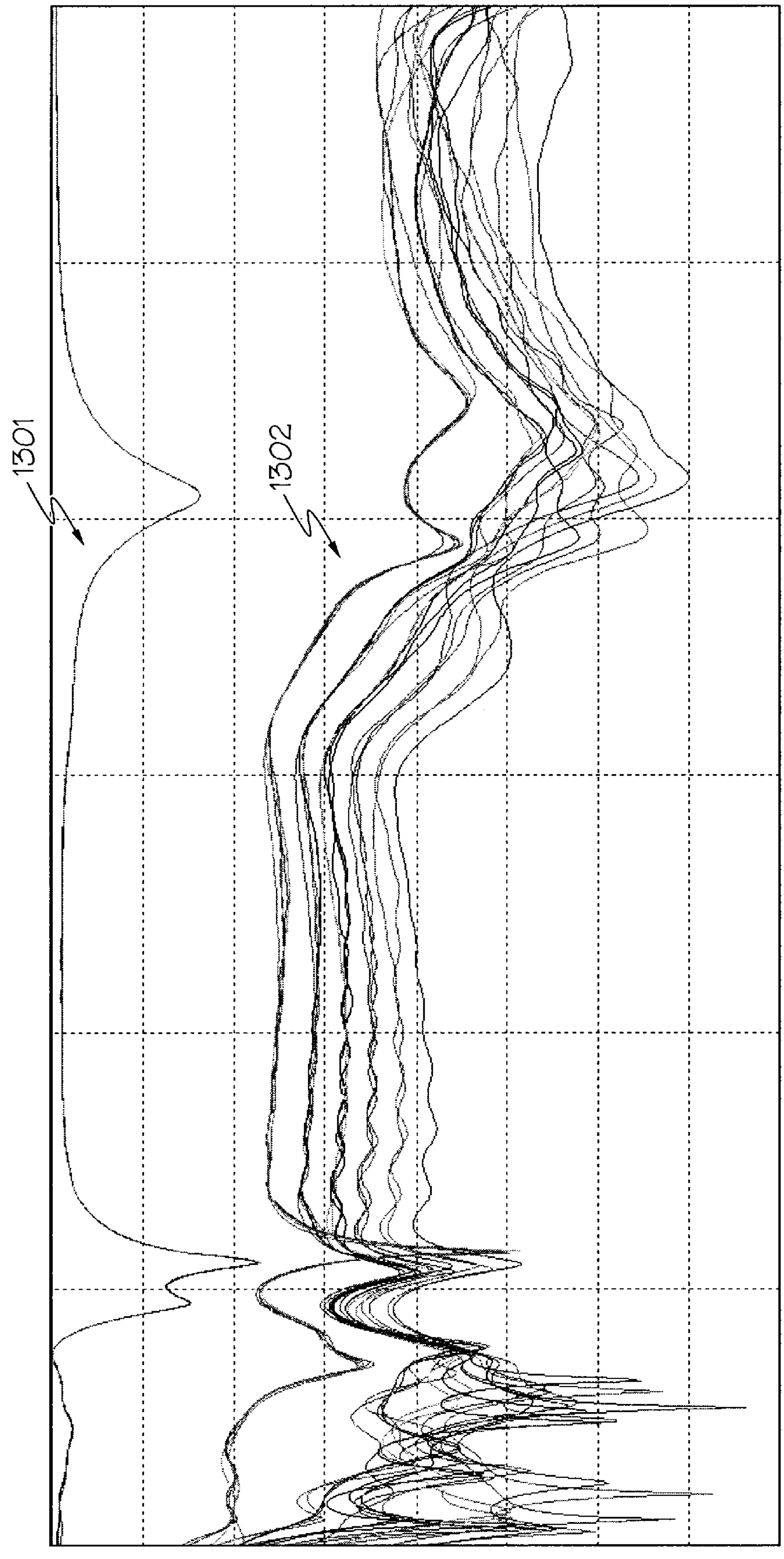

FIG. 13

[Fig. 14A]

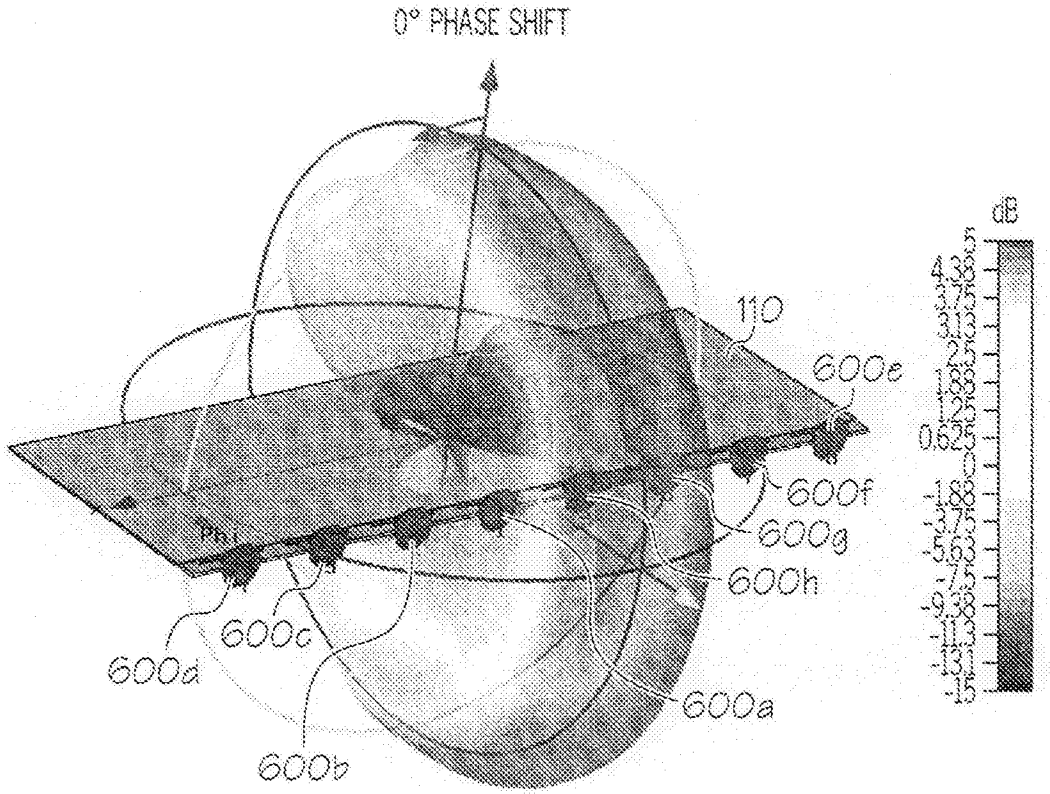

FIG. 14A

[Fig. 14B]

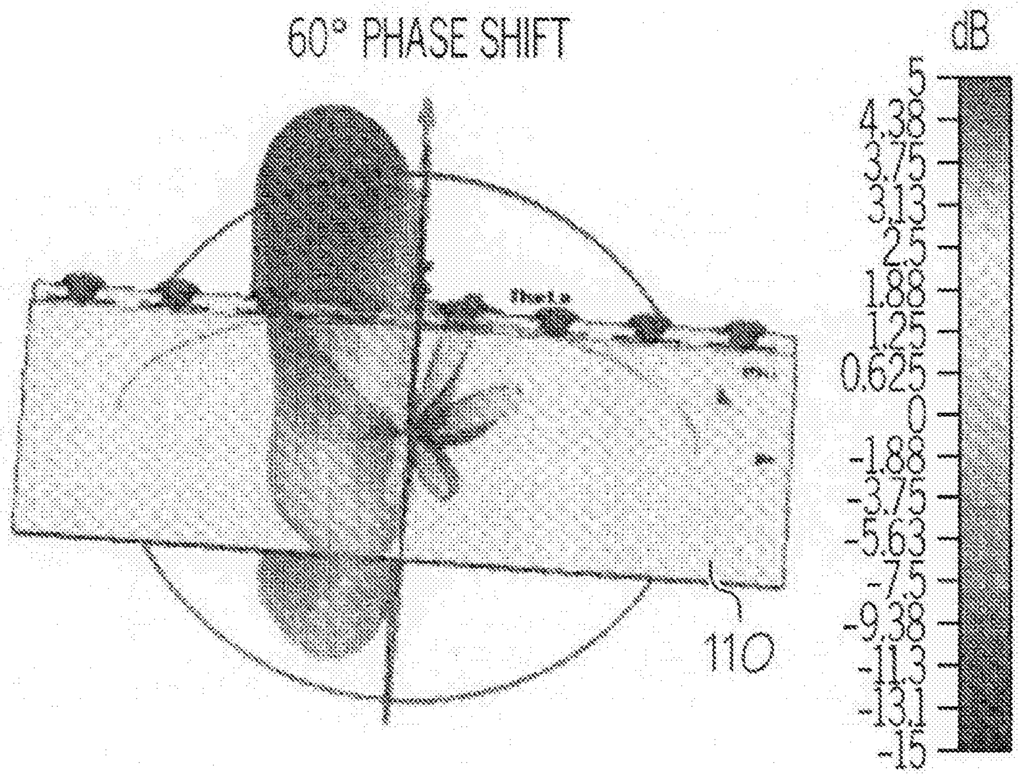

FIG. 14B

[Fig. 14C]

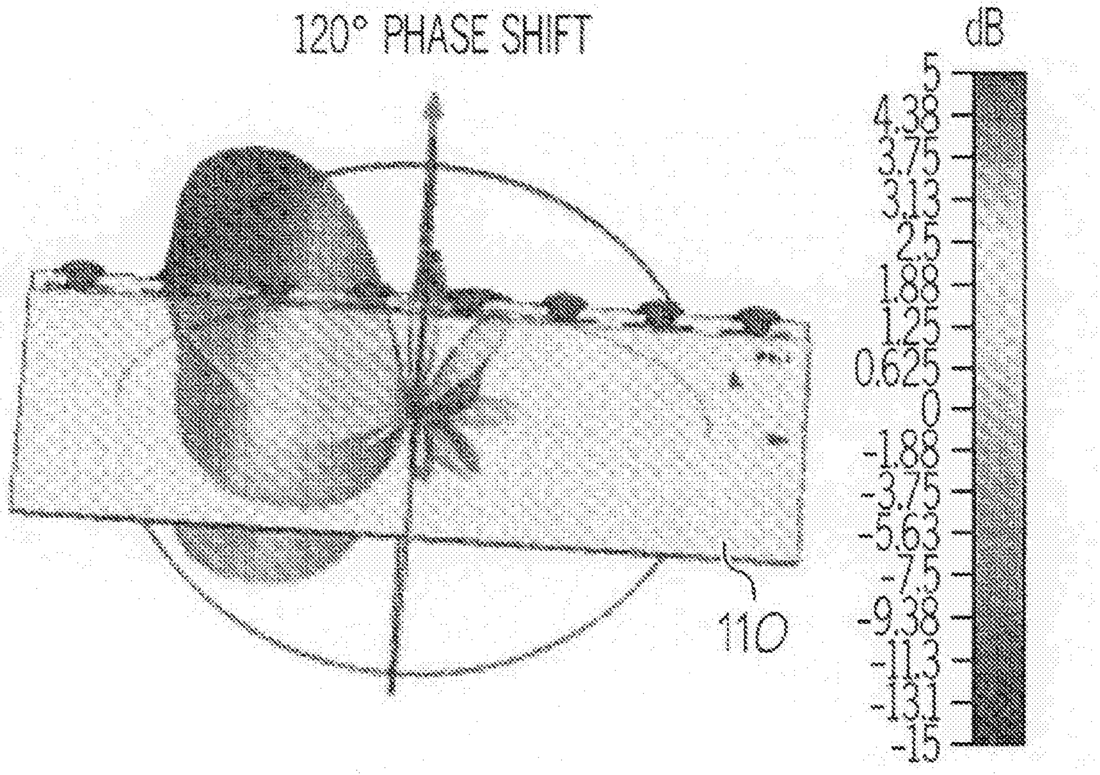

FIG. 14C

[Fig. 15A]

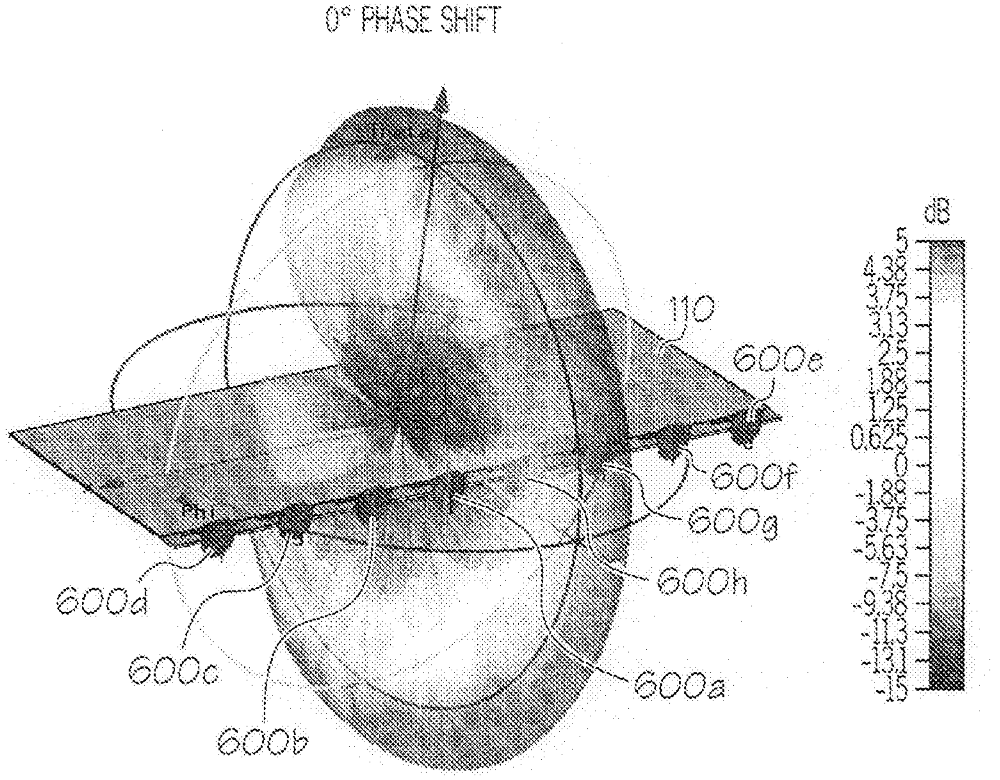

FIG. 15A

[Fig. 15B]

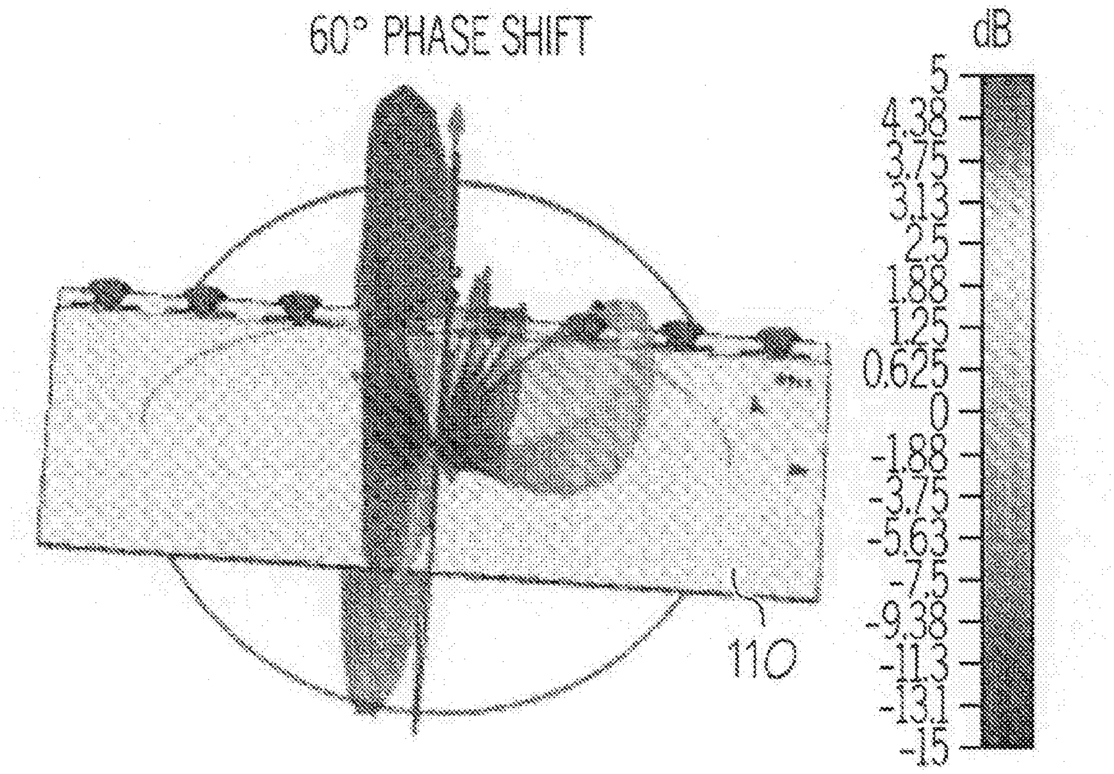

FIG. 15B

[Fig. 15C]

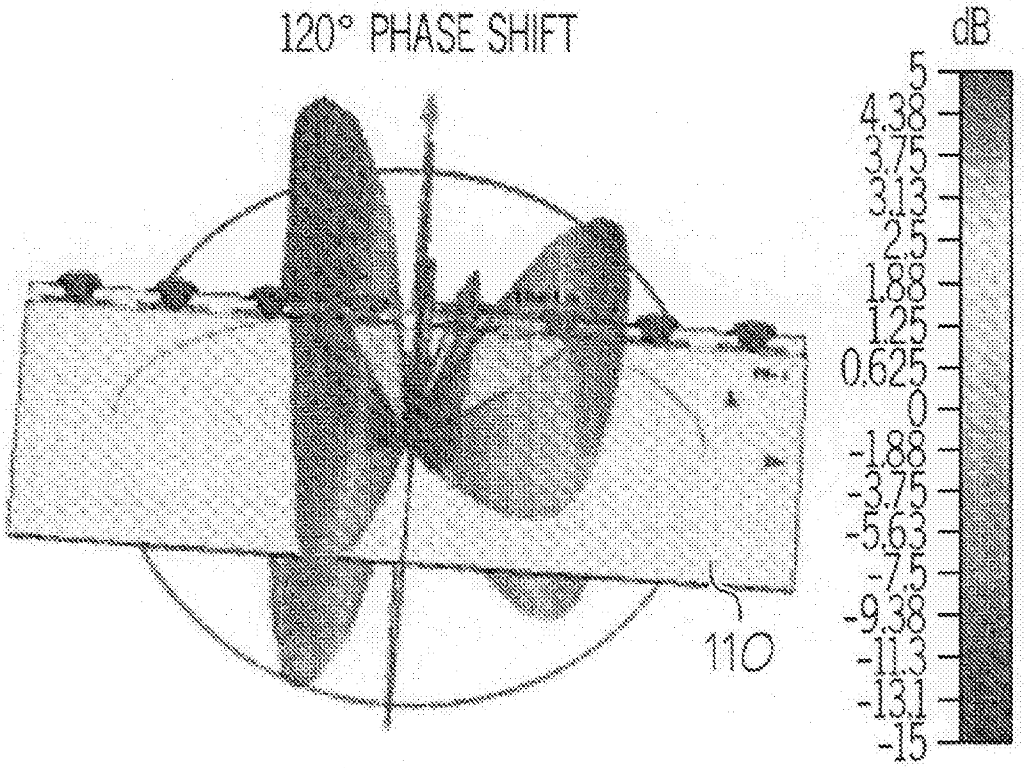

FIG. 15C

[Fig. 16]

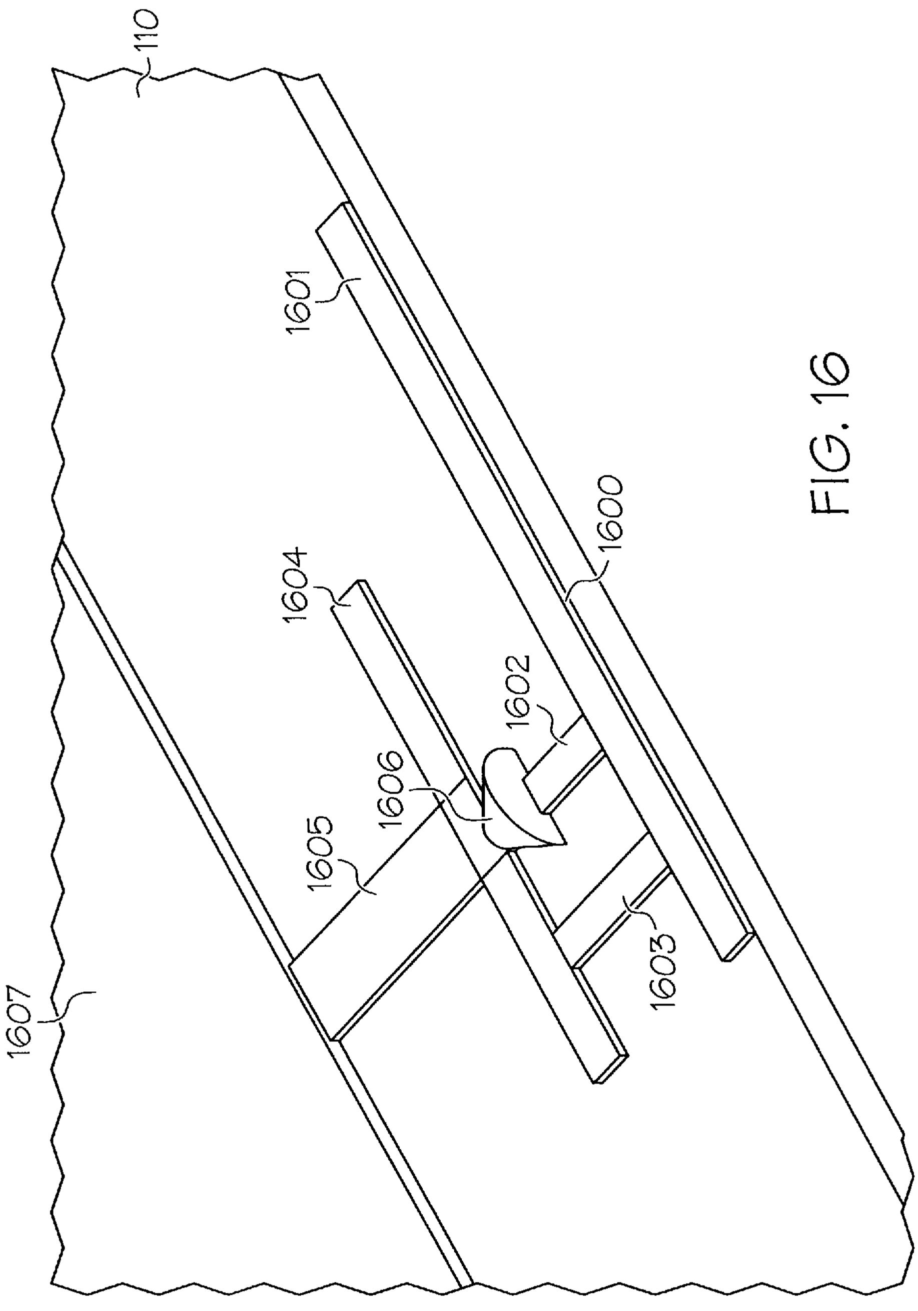

FIG. 16

[Fig. 17]

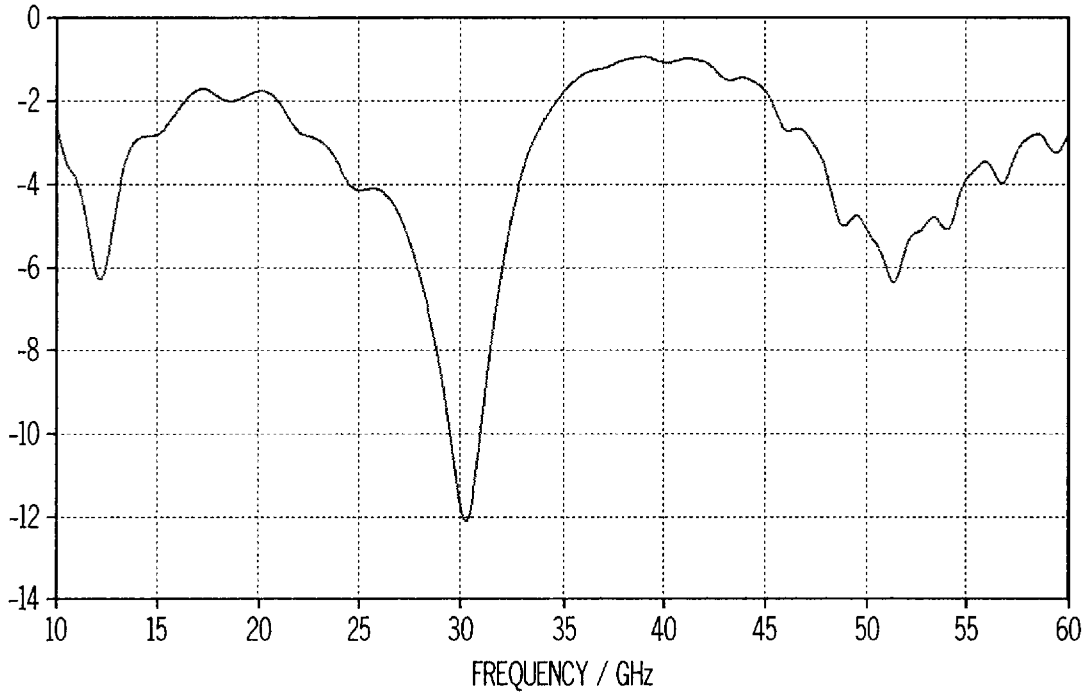

FIG. 17

[Fig. 18]

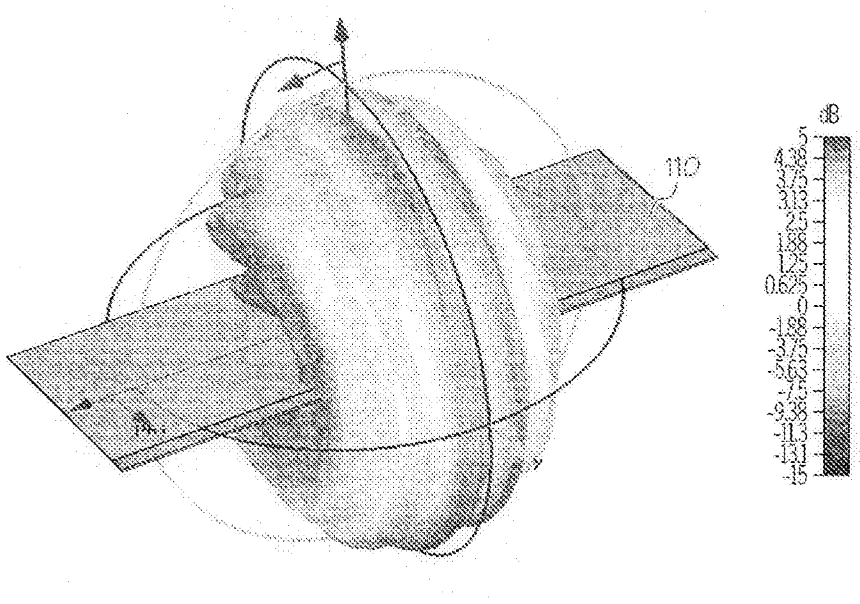

FIG. 18

[Fig. 19A]

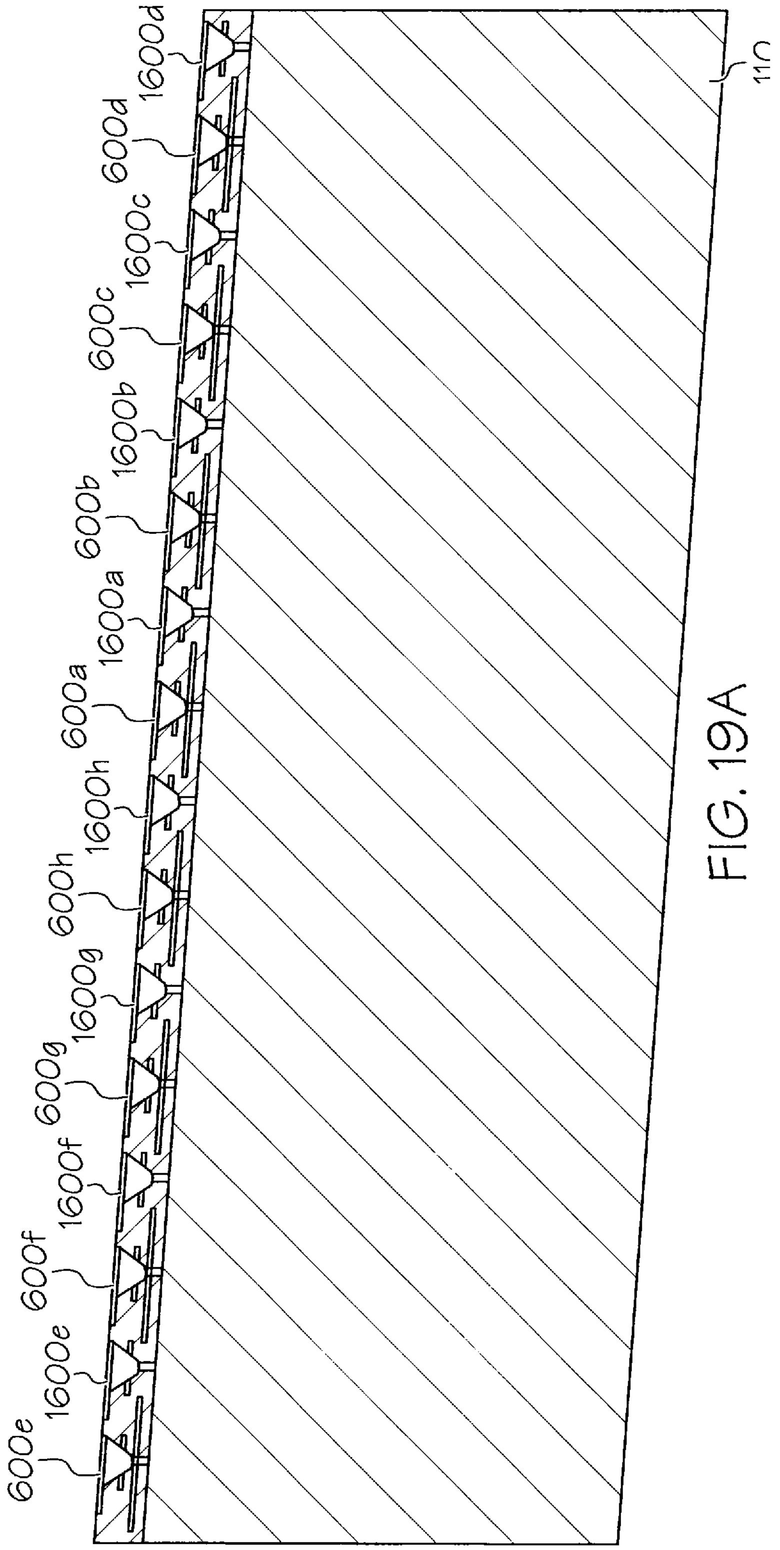

FIG. 19A

[Fig. 19B]

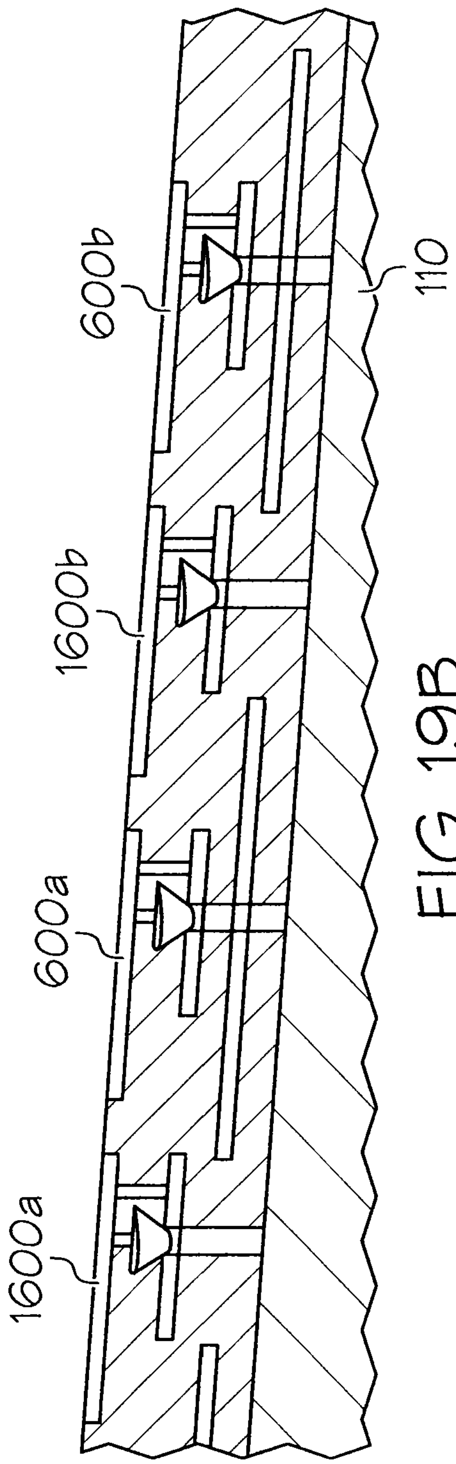

FIG. 19B

[Fig. 20]

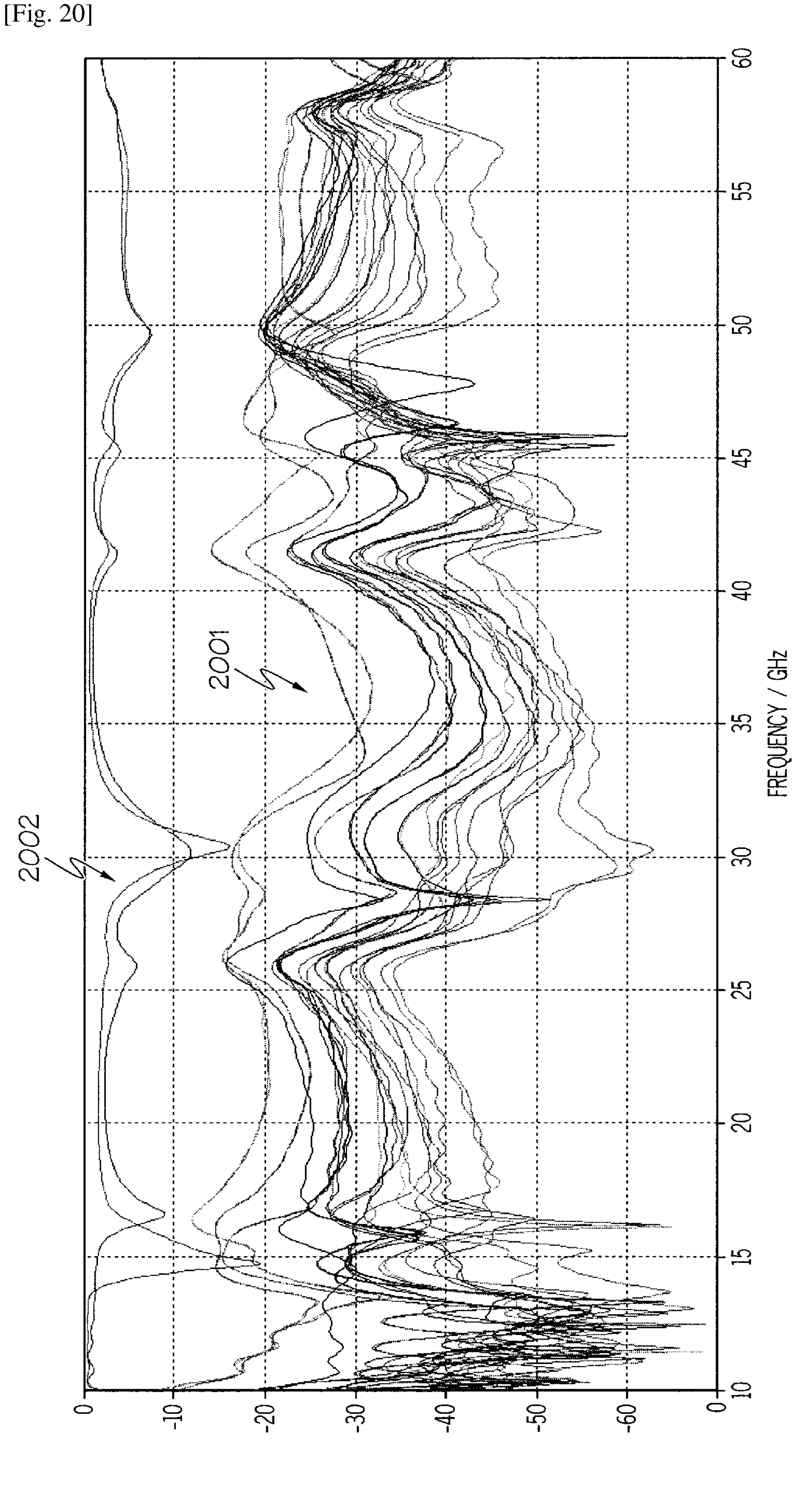
2002
2001
FREQUENCY / GHz
10
15
20
25
30
35
40
45
50
55
60
0
-10
-20
-30
-40
-50
-60

FIG. 20

[Fig. 21A]

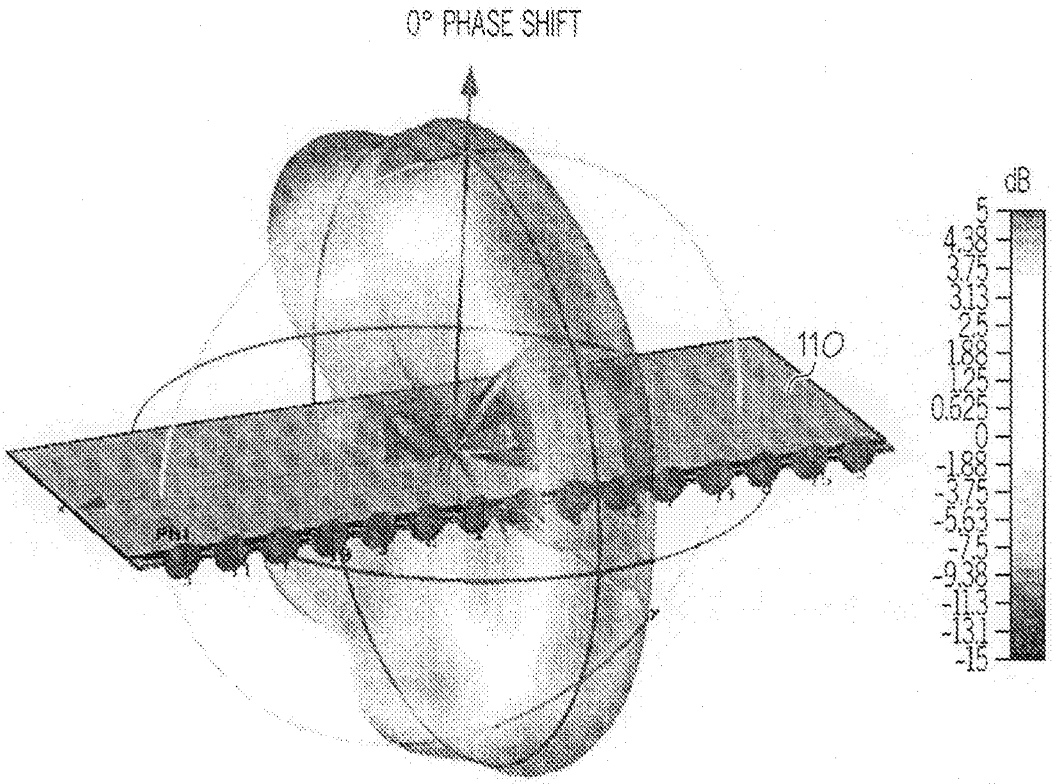

FIG. 21A

[Fig. 21B]

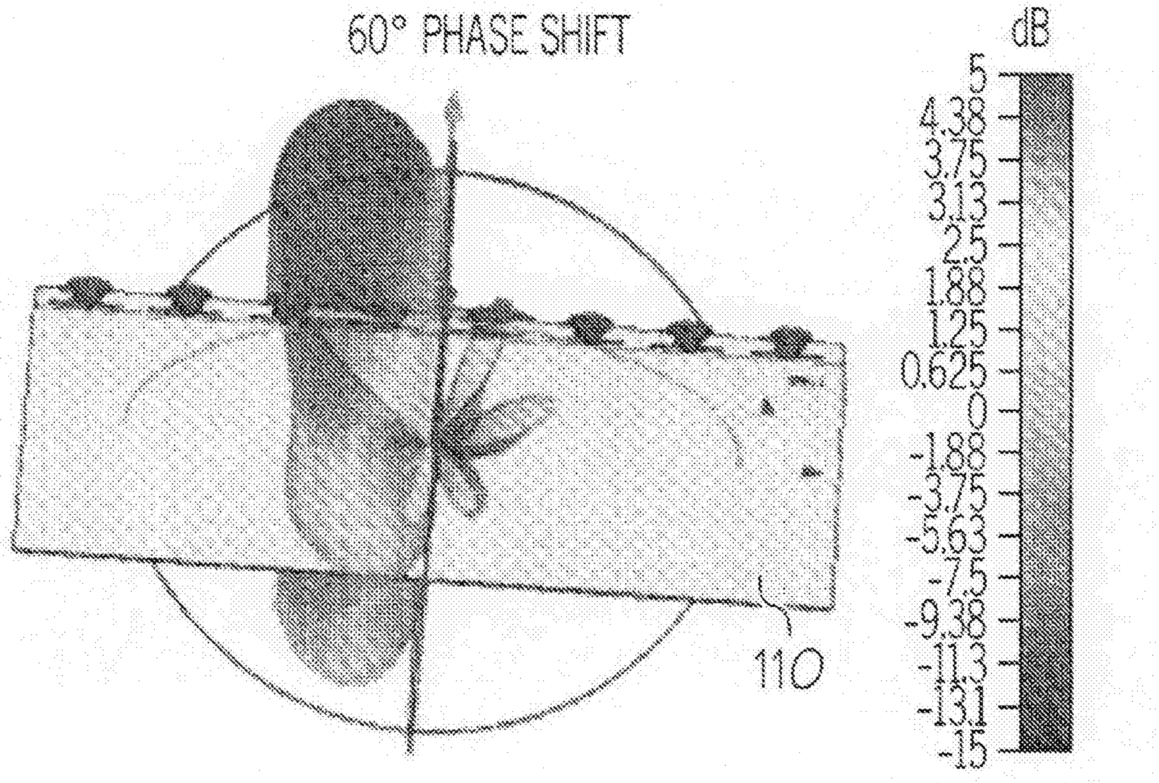

FIG. 21B

[Fig. 21C]

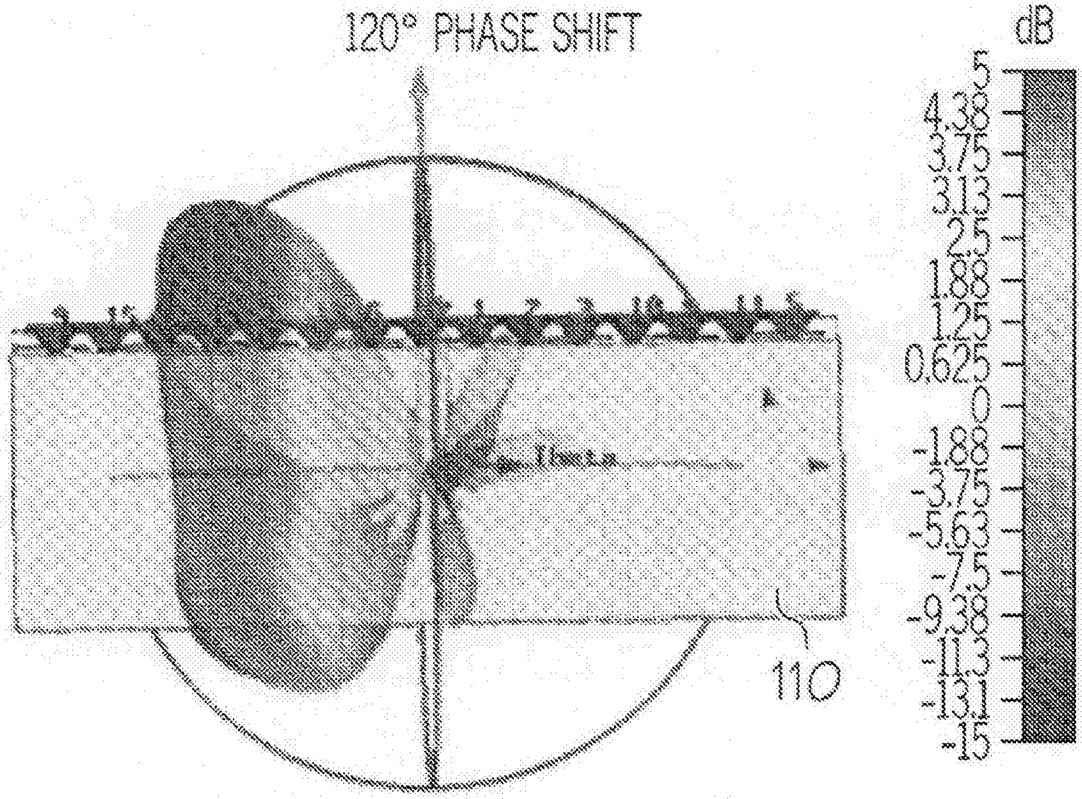

FIG. 21C

[Fig. 22A]

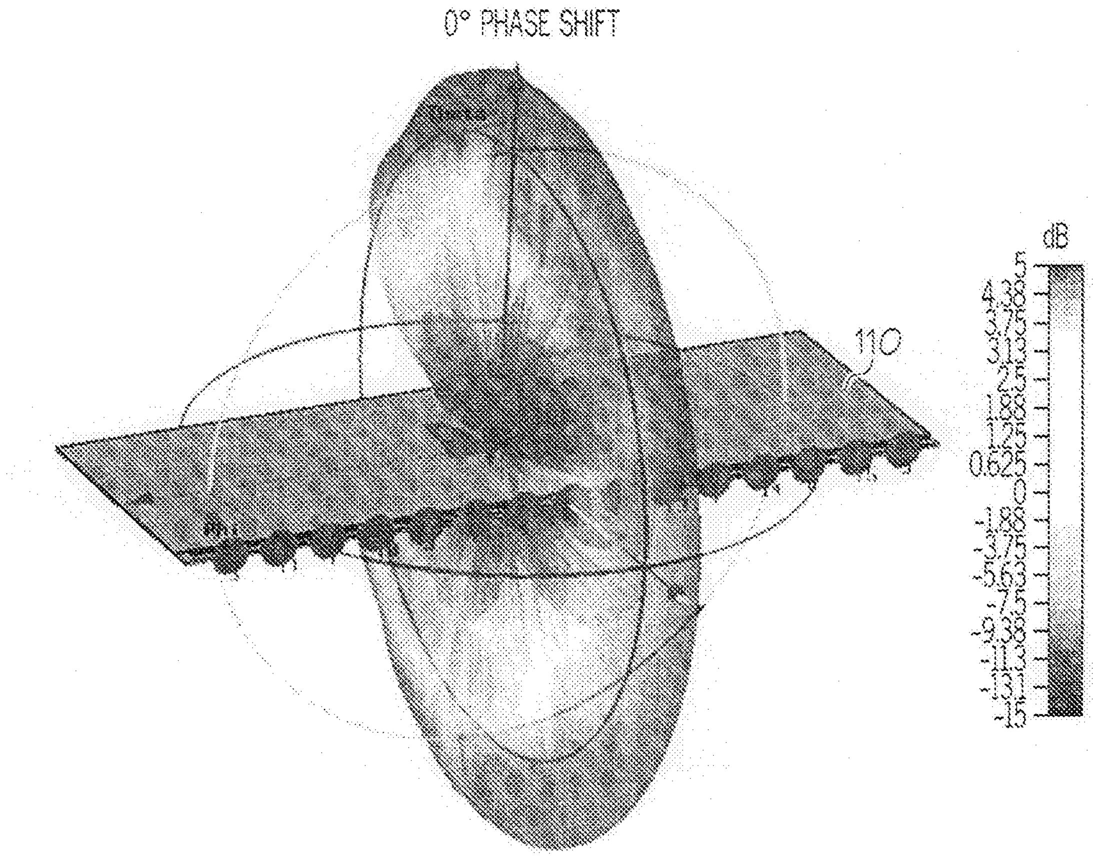

FIG. 22A

[Fig. 22B]

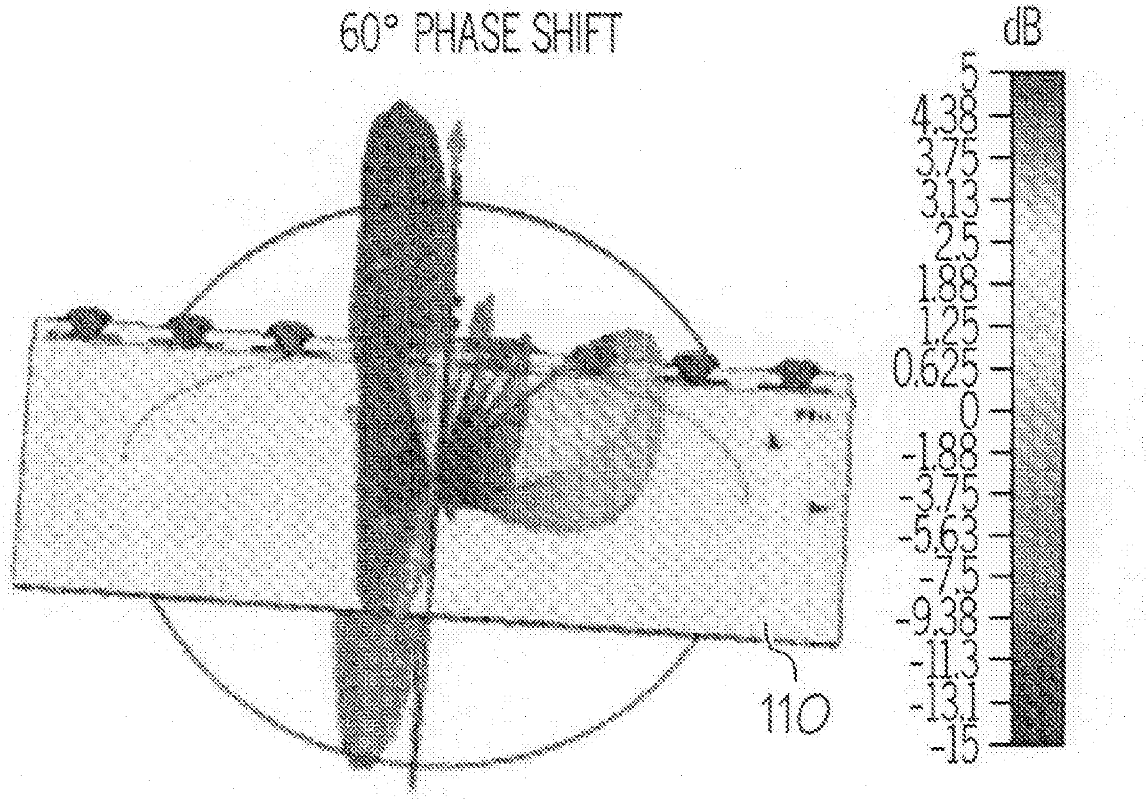

FIG. 22B

[Fig. 22C]

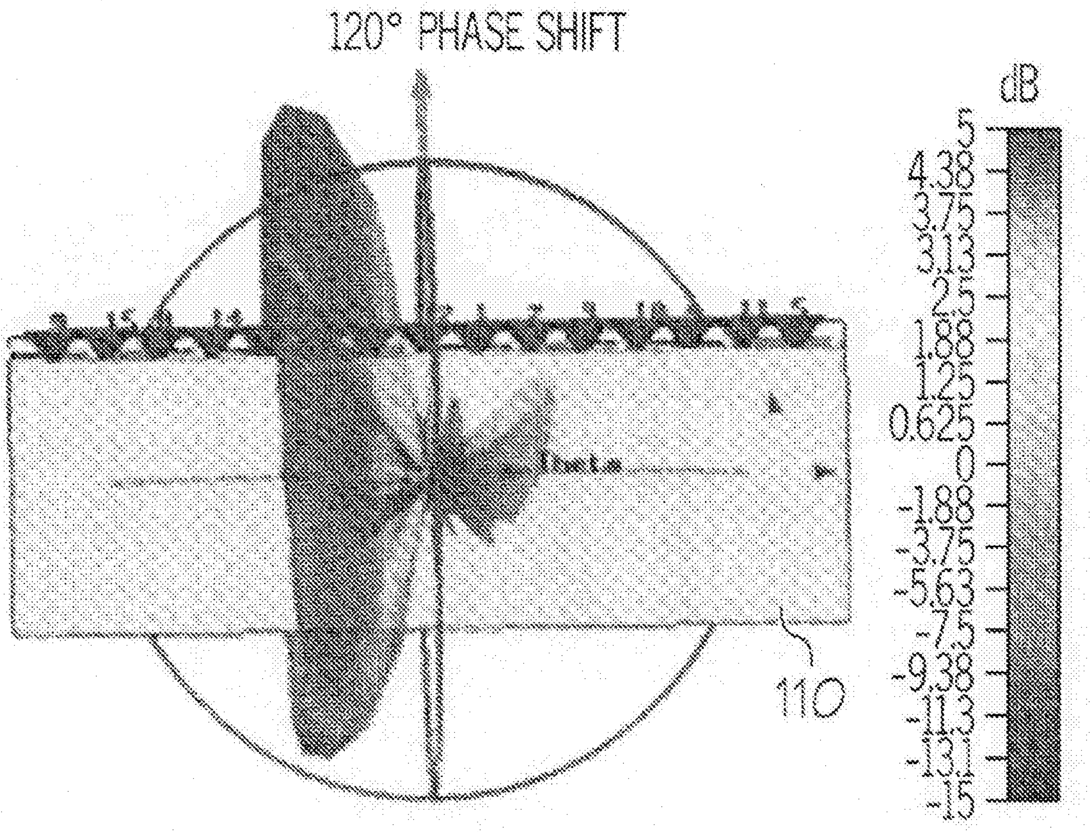

FIG. 22C

[Fig. 23]

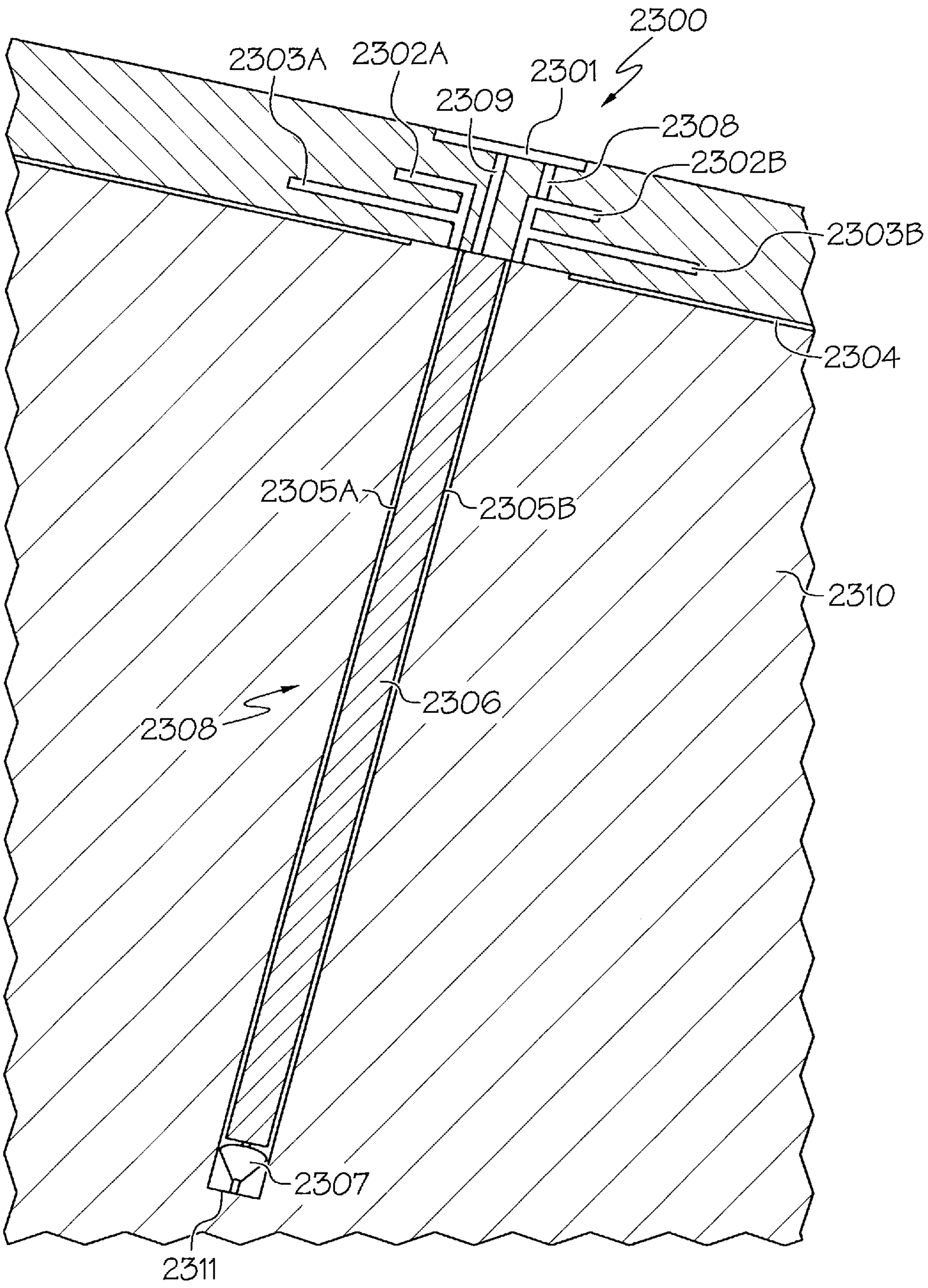
2300
2303A
2302A
2301
2309
2308
2302B
2303B
2304
2305A
2305B
2310
2308
2306
2307
2311

FIG. 23

[Fig. 24]

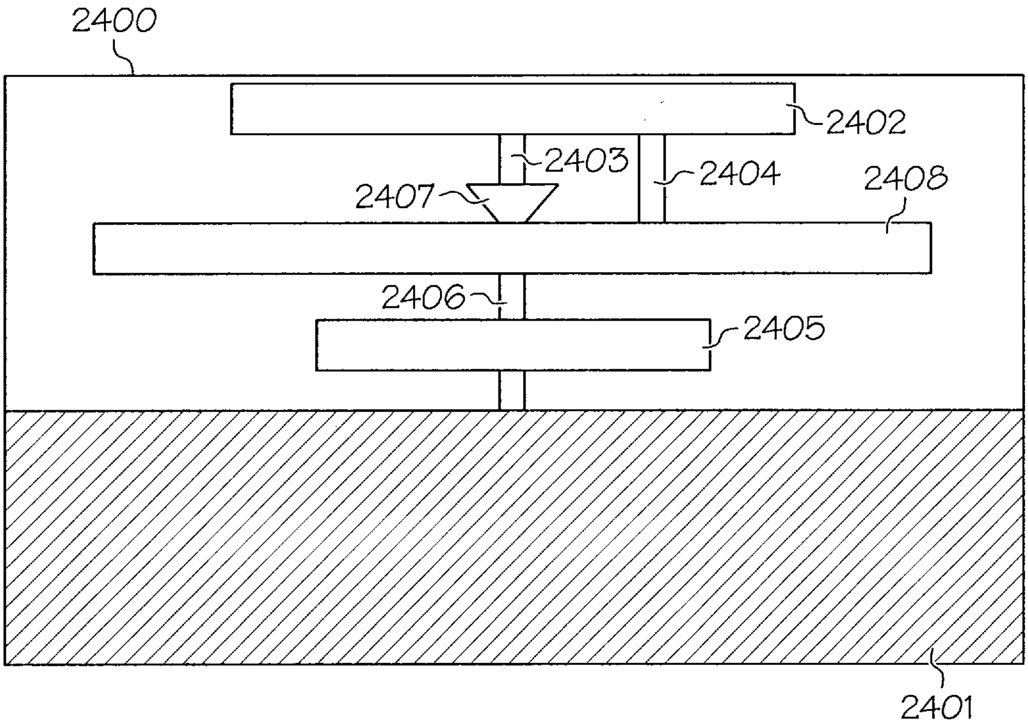

FIG. 24

INTERNATIONAL SEARCH REPORT

International application No
PCT/JP2015/003538

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01Q1/48 H01Q9/42 H01Q1/24 H01Q5/371
ADD.

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

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)

EPO-Internal, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2011/205138 A1 (YANAGI MASAHIRO [JP] ET AL) 25 August 2011 (2011-08-25) figures 1,12 paragraphs [0031] - [0037] paragraphs [0160] - [0177] -----	1-20
A	US 2010/123631 A1 (CHANG CHENG-WEI [TW] ET AL) 20 May 2010 (2010-05-20) figures 1A,7A paragraph [0029] -----	1-20
A	US 2012/013510 A1 (YAGI SHIGERU [JP] ET AL) 19 January 2012 (2012-01-19) figure 5 paragraphs [0077] - [0088] -----	1-20
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 September 2015	06/10/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Niemeijer, Reint

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2007/030198 A1 (WEI SHEN-PIN [TW]) 8 February 2007 (2007-02-08) figure 3 paragraphs [0017] - [0018] -----	1-20
A	MD RASHIDUL ISLAM ET AL: "Ground Current Modification of Mobile Terminal Antennas and Its Effects", IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, IEEE, PISCATAWAY, NJ, US, vol. 10, 2 May 2011 (2011-05-02), pages 438-441, XP011402927, ISSN: 1536-1225, DOI: 10.1109/LAWP.2011.2149490 abstract; figure 1 -----	1-20

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/JP2015/003538

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011205138 A1	25-08-2011	JP 2011176653 A	08-09-2011
		US 2011205138 A1	25-08-2011
US 2010123631 A1	20-05-2010	TW 201021295 A	01-06-2010
		US 2010123631 A1	20-05-2010
US 2012013510 A1	19-01-2012	CN 102362391 A	22-02-2012
		EP 2413426 A1	01-02-2012
		JP 5458981 B2	02-04-2014
		JP 2011135549 A	07-07-2011
		KR 20110117259 A	26-10-2011
		US 2012013510 A1	19-01-2012
		WO 2010110162 A1	30-09-2010
US 2007030198 A1	08-02-2007	TW M288014 U	21-02-2006
		US 2007030198 A1	08-02-2007