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(54) ANTENNA UNIT, ANTENNA ARRAY, AND COMMUNICATION DEVICE

(57) Embodiments of this application disclose an antenna element, an antenna array, and a communication device. A radiation patch of the antenna element includes a first additional sub-patch, a first sub-patch, a second sub-patch, and a second additional sub-patch that are sequentially arranged in a first direction. The radiation patch includes a first slit and a second slit that penetrate the radiation patch in a second direction. The first slit is formed between the first sub-patch and the second sub-patch. The second slit includes a first sub-slit and a second sub-slit. The first sub-slit is formed between the first sub-patch and the first additional sub-patch. The second sub-slit is formed between the second sub-patch and the second additional sub-patch. A ratio of a length of the radiation patch in the first direction to a width of the radiation patch in the second direction is greater than or equal to 2. The antenna element provided in this application can implement a low profile and ensure that a bandwidth, a gain, and coverage of an antenna meet design requirements.

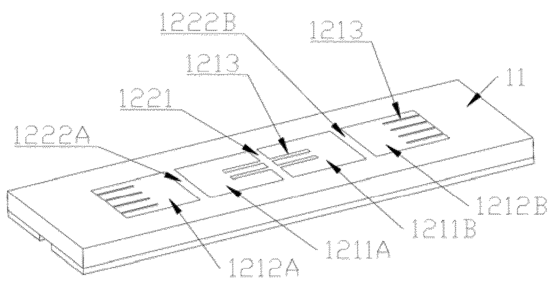

FIG. 15

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Description

[0001] This application claims priority to Chinese Patent Application No. 202211147258.5, filed with the China National Intellectual Property Administration on September 19, 2022 and entitled "ANTENNA ELEMENT, ANTENNA ARRAY, AND COMMUNICATION DEVICE", which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present invention relates to the field of radio frequency communication technologies, and in particular, to an antenna element, an antenna array, and a communication device.

BACKGROUND

[0003] As wireless communication specifications develop and application scenarios become diverse, terminal products have increasingly strong requirements for smart antenna beams in medium and high frequency bands. A router and customer premises equipment (customer premises equipment, CPE) are used as an example. A pattern-reconfigurable feature of a high Wi-Fi frequency band has become an important selling point in a next-generation smart home solution. A low-profile antenna solution is usually designed based on a patch (patch) antenna, and implements high-gain omnidirectional coverage in a horizontal plane by using a phase control method. In practice, it is difficult to make a bandwidth, a gain, and coverage of an antenna meet design requirements in limited product space. For example, an increased gain of a dual-polarized antenna element usually narrows a beam width of a scanning plane, and finally reduces a scanning coverage angle range, and a reduced array spacing increases a scanning angle and significantly reduces an array factor gain.

[0004] A continuous research and development direction in the industry is how to design a dual-polarized antenna element to ensure that a bandwidth, a gain, and coverage of an antenna meet design requirements while implementing a low profile.

SUMMARY

[0005] Specific implementations of this application provide an antenna element, an antenna array, and a communication device. The antenna element is dual-polarized, to implement a low profile and ensure that a bandwidth, a gain, and coverage of an antenna meet design requirements.

[0006] According to a first aspect, an embodiment of this application provides an antenna element, including a radiation patch and a feeding assembly, where the radiation patch includes a first additional sub-patch, a first sub-patch, a second sub-patch, and a second additional sub-patch that are sequentially arranged in a first direction, the radiation patch includes a first slit and a second slit that penetrate the radiation patch in a second direction, the first slit is formed between the first sub-patch and the second sub-patch, the second slit includes a first sub-slit and a second sub-slit, the first sub-slit is formed between the first sub-patch and the first additional sub-patch, the second sub-slit is formed between the second sub-patch and the second additional sub-patch, a maximum size of the radiation patch in the first direction is a length of the radiation patch, a maximum size of the radiation patch in the second direction is a width of the radiation patch, and a length-to-width ratio R of the radiation patch satisfies $R \geq 2$. The feeding assembly is configured to feed the radiation patch.

[0007] This application has an advantage of a low profile by using the radiation patch as a radiator of the antenna element.

[0008] In an implementation, a radiation patch whose length is greater than a width can be used, to reduce a size of the radiation patch in a width direction. In an implementation, a size of the radiation patch in the first direction may be limited to be greater than a size of the radiation patch in the second direction, so that the antenna element can generate a fan-shaped beam, to meet a coverage requirement. In an implementation, the length-to-width ratio of the radiation patch is limited, so that the antenna element can be limited within a proper bandwidth range.

[0009] In an implementation, the first slit and the second slit that penetrate the radiation patch in the second direction are provided, so that in a process in which the feeding assembly excites the radiation patch, the antenna element can be excited to generate at least two operating modes. This application helps implement the low profile of the antenna and ensure a bandwidth and a gain of the antenna.

[0010] In a possible implementation, the first slit and the second slit each include a first end and a second end, both an extension direction of the first slit and an extension direction of the second slit are a direction in which the first end points to the second end, and both the extension direction of the first slit and the extension direction of the second slit are the second direction. In this solution, specific definitions of the extension direction of the first slit and the extension direction of the second slit are limited, and a specific implementation in which the extension direction is the width direction (the second direction) of the radiation patch is specified. In view of this, specific shapes of the first slit and the second slit may not be limited to rectangles.

[0011] In a possible implementation, both a length of the first slit and a length of the second slit are a size of an extension path extending from the first end to the second end, both a width of the first slit and a width of the second slit are a size in a direction perpendicular to the extension path, and both the width of the first slit and the width of the second slit are within a range of 0.03 mm to 3 mm. In this solution, the width of the first slit and the width of the second slit are limited within the range of 0.03 mm to 3 mm, so that the antenna element can be limited within the proper bandwidth range. High coverage rate effect is implemented while a high-gain fan-shaped beam is formed. This solution helps ensure that the antenna element can generate two different operating modes in both vertical polarization and horizontal polarization.

[0012] In a possible implementation, both the width of the first slit and the width of the second slit are within a range of 0.5 mm to 1.5 mm. In this solution, both the width of the first slit and the width of the second slit are limited, so that the antenna element can be limited within the proper bandwidth range.

[0013] In a possible implementation, the width of the second slit is less than or equal to 2 mm. In this solution, the width of the second slit is limited, so that the antenna element can be limited within the proper bandwidth range.

[0014] In a specific implementation, the width of the first slit is 1.2 mm, and the width of the second slit is 0.8 mm.

[0015] In a possible implementation, the length-to-width ratio R of the radiation patch satisfies $3 \leq R \leq 5$. In this solution, the length-to-width ratio of the radiation patch is limited, so that the antenna element can be limited within a proper bandwidth range.

[0016] In a possible implementation, the radiation patch does not have a slit that penetrates the radiation patch in the first direction, or the radiation patch has only one slit that penetrates the radiation patch in the first direction.

[0017] In an implementation, the first slit and the second slit that penetrate the radiation patch in the second direction are provided, and the radiation patch does not have a slit that penetrates the radiation patch in the first direction, or has only one slit that penetrates the radiation patch in the first direction, so that in a process in which a first feed structure and a second feed structure excite the radiation patch, the antenna element can be excited to generate two different polarizations, and each polarization has two operating modes. This application helps implement the low profile of the antenna and ensure the bandwidth and the gain of the antenna.

[0018] In a possible implementation, the first slit is in a middle position of the radiation patch in the first direction. Because the second slit penetrates the radiation patch in the second direction and the second slit is symmetrically distributed on two sides of the first slit in the first direction, in this solution, the middle position is limited only to the middle position of the radiation patch in the first direction, and whether the middle position is a middle position in the second direction is not limited. In this solution, the first slit is limited to be symmetrically distributed on the two sides of the first slit, so that the radiation patch forms a symmetrical distribution architecture centered on the first slit. This helps control a beam pattern of the antenna element.

[0019] In a possible implementation, a plurality of sub-patches are symmetrically distributed on the two sides of the first slit in the first direction. In this solution, the plurality of sub-patches of the radiation patch are limited to forming the symmetrical distribution architecture centered on the first slit. This helps control the beam pattern of the antenna element.

[0020] In a possible implementation, the feeding assembly includes a ground plane and a feeding layer, the ground plane is disposed between the feeding layer and the radiation patch in a stacked manner, the feeding layer includes a first feed structure and a second feed structure, the ground plane is provided with a first coupling slit and a second coupling slit that are provided in a cross manner, the first feed structure and the first coupling slit are provided directly opposite to each other, and the second feed structure and the second coupling slit are provided directly opposite to each other.

[0021] In a possible implementation, the first coupling slit at least partially overlaps the first sub-patch, the first coupling slit at least partially overlaps the second sub-patch, and the second coupling slit is provided directly opposite to the first slit. The first feed structure is coupled to the first coupling slit to excite first polarization of the radiation patch.

[0022] In a possible implementation, the second coupling slit does not overlap the first sub-patch, and the second coupling slit does not overlap the second sub-patch. The second feed structure is coupled to the second coupling slit to excite second polarization of the radiation patch.

[0023] In an embodiment, the first feed structure is coupled to the first coupling slit to excite horizontal polarization of the radiation patch, and the second feed structure is coupled to the second coupling slit to excite vertical polarization of the radiation patch. In this solution, a specific architecture of the feeding assembly is limited. The ground plane is disposed between the feeding layer and the radiation patch in a stacked manner, so that features of a small size and a low profile of the antenna element can be easily implemented. A manner in which the first feed structure and the second feed structure separately perform coupled feeding on the two coupling slits on the ground plane implements a simple feeding solution design, and also helps improve transmission efficiency of a radio frequency signal and reduce a loss.

[0024] In a possible implementation, the first coupling slit does not overlap the first additional sub-patch and the second additional sub-patch, and the second coupling slit does not overlap the first additional sub-patch and the second additional sub-patch.

[0025] In an embodiment, the radiation patch is excited (for example, in a horizontal polarization state) through the first coupling slit to generate a main operating mode and a parasitic operating mode. In the main operating mode, the first sub-patch is excited to generate a current in the second direction. In the parasitic operating mode, the additional sub-patch is excited to generate a current in the second direction.

[0026] In an embodiment, the radiation patch generates a first operating mode and a second operating mode through excitation (for example, in a vertical polarization state) of the second coupling slit. In the first operating mode and the second operating mode, all current directions on the radiation patch are the first direction. In the first operating mode, an electric field generates weak point reverse between the first slit and the ground plane of the feeding assembly. In the second mode, the electric field generates strong point reverse between the second slit and the ground plane of the feeding assembly.

[0027] In a possible implementation, the first sub-patch and the additional sub-patch are collectively referred to as sub-patches, at least one sub-patch is provided with a slot, the slot extends from an edge of the sub-patch to inside of the sub-patch, and an extension direction of the slot includes a third direction.

[0028] The third direction is the same as the first direction, or there are an included angle between the third direction and the second direction and an included angle between the third direction and the first direction. In this solution, a slot is provided on a sub-patch, so that a frequency response in horizontal polarization can be independently adjusted and controlled.

[0029] In a possible implementation, the slot includes a first slot and a second slot, the first slot is provided at a first position of the first sub-patch, the second slot is provided at a second position of the second sub-patch, and the first position and the second position are symmetrical with respect to the first slit. In this solution, the first slot and the second slot are designed, so that a resonance frequency in the main operating mode can be designed in a first target frequency band.

[0030] In a possible implementation, the slot includes a third slot and a fourth slot, the third slot is provided at a third position of the first additional sub-patch, the fourth slot is provided at a fourth position of the second additional sub-patch, and the third position and the fourth position are symmetrical with respect to the first slit. In this solution, the third slot and the fourth slot are designed, so that a resonance frequency in the parasitic operating mode can be designed in a second target frequency band.

[0031] In a possible implementation, the additional sub-patch includes a patch body and a protruding structure connected to the patch body. In the first direction, the protruding structure is positioned on a side that is of the patch body and that is away from the first sub-patch, and an extension direction of the protruding structure includes the third direction.

[0032] The third direction is the same as the first direction, or there are an included angle between the third direction and the second direction and an included angle between the third direction and the first direction. In this solution, the protruding structure is disposed at an edge of the sub-patch, so that a path of a current in horizontal polarization can be changed, and a frequency in horizontal polarization can be changed.

[0033] In a possible implementation, the first coupling slit and the second coupling slit form a cross-shaped slit structure. In this solution, the horizontal polarization and the vertical polarization are easily implemented by limiting two coupling slits on the ground plane to the cross-shaped structure. This helps reduce design difficulty and manufacturing process difficulty, easily ensure manufacturing precision of the antenna element, and improve a yield rate.

[0034] In a possible implementation, the feeding assembly includes a first interface and a second interface that are configured to connect to a radio frequency cable, one end of the first feed structure is connected to the first interface, another end of the first feed structure is coupled to the first coupling slit, one end of the second feed structure is connected to the second interface, another end of the second feed structure is coupled to the second coupling slit, and in the first direction, the first interface and the second interface are respectively disposed on two sides of a projection of the radiation patch on the feeding layer. In this solution, the first interface and the second interface are limited to be distributed on two sides of the radiation patch in the first direction. In this way, when antenna elements are arranged in an antenna array, the first interface and the second interface do not occupy space between the antenna elements, so that the antenna elements may be arranged more compactly, and a position of the first interface and a position of the second interface are more convenient for connection, that is, the radio frequency cable is connected.

[0035] According to a second aspect, an embodiment of this application provides an antenna array, including at least two antenna elements according to any one of the possible implementations of the first aspect, where the at least two antenna elements are sequentially arranged in a second direction. In the antenna array provided in this application, antenna elements are arranged in the second direction so that a small-size design of the antenna array can be easily implemented, and a slit is provided between the antenna elements so that good isolation can be implemented.

[0036] According to a third aspect, an embodiment of this application provides a communication device, including a feeding network and the antenna array according to the second aspect, where the first feed structure and the second feed structure of the antenna element are electrically connected to the feeding network.

[0037] According to a fourth aspect, an embodiment of this application provides a communication device, including a feeding network and the antenna element according to any one of the possible implementations of the first aspect, where the first feed structure and the second feed structure are electrically connected to the feeding network.

BRIEF DESCRIPTION OF DRAWINGS

[0038] To describe the technical solutions in embodiments or the background of the present invention more clearly, the following briefly describes the accompanying drawings used in embodiments or the background of the present invention.

FIG. 1 is a basic architecture of a connection relationship between an antenna module in a communication device and a baseband according to an implementation of this application;
FIG. 2 is a diagram in which an antenna module may cover different terminal devices according to an implementation of this application;
FIG. 3A is a diagram of a solution of arranging an antenna module in a communication device according to an implementation of this application;
FIG. 3B is a diagram of a solution of arranging an antenna module in a communication device according to an implementation of this application;
FIG. 4 is a diagram of one direction of an antenna element according to an implementation of this application;
FIG. 5 is a diagram of another direction of an antenna element according to an implementation of this application;
FIG. 6 is a plane diagram of a radiation patch of the antenna element according to the implementation shown in FIG. 4;
FIG. 7 is a plane diagram of a radiation patch of an antenna element according to an implementation of this application;
FIG. 8A is a diagram of a current direction of an antenna element in a main operating mode in a horizontal polarization state according to an implementation of this application;
FIG. 8B is a diagram of a current direction of an antenna element in a parasitic operating mode in a horizontal polarization state according to an implementation of this application;
FIG. 9A is a curve graph in which a width of a first slit affects a resonance of an antenna element in a first operating mode in a vertical polarization state according to an implementation of this application;
FIG. 9B is a curve graph in which a width of a second slit affects a resonance of an antenna element in a second operating mode in a vertical polarization state according to an implementation of this application;
FIG. 10A is a diagram of a current direction of an antenna element in a first operating mode in vertical polarization according to an implementation of this application;
FIG. 10B is a distribution diagram of electric fields of an antenna element in a first operating mode in vertical polarization according to an implementation of this application;
FIG. 11A is a diagram of a current direction of an antenna element in a second operating mode in vertical polarization according to an implementation of this application;
FIG. 11B is a distribution diagram of electric fields of an antenna element in a second operating mode in vertical polarization according to an implementation of this application;
FIG. 12 is a three-dimensional exploded view of an antenna element according to an implementation of this application;
FIG. 13 is an exploded view of a layer structure of an antenna element according to an implementation of this application;
FIG. 14 is a diagram of position relationships between a first coupling transmission line and a second coupling transmission line of an antenna element, and two coupling slits on a ground plane according to an implementation of this application;
FIG. 15 is a diagram of one direction of an antenna element according to an implementation of this application;
FIG. 16 is a plane diagram of a radiation patch of the antenna element according to the implementation shown in FIG. 15;
FIG. 17 is a diagram of a current direction at a slot position of a sub-patch of a radiation patch of an antenna element according to an implementation of this application;
FIG. 18 is a diagram of a current direction at a slot position of a sub-patch of a radiation patch of an antenna element according to an implementation of this application;
FIG. 19 is a plane diagram of a radiation patch of an antenna element according to an implementation of this application;
FIG. 19A is a plane diagram of a radiation patch of an antenna element according to an implementation of this application;
FIG. 20 is a curve graph of S-parameters of an antenna element according to an implementation of this application;
FIG. 21(a) and FIG. 21(b) are radiation patterns of a vertical polarization port of an antenna element during excitation at 5 GHz and 5.6 GHz according to an implementation of this application;
FIG. 22(a) and FIG. 22(b) are radiation patterns of a horizontal polarization port of an antenna element during excitation at 5.25 GHz and 5.8 GHz according to an implementation of this application;
FIG. 23 is an efficiency curve graph of an antenna element according to an implementation of this application;
FIG. 24 is a gain curve graph of an antenna element according to an implementation of this application;

FIG. 25(a) to FIG. 25(d) are distribution diagrams of currents and electric fields of an antenna element in vertical polarization at 5 GHz and 5.6 GHz according to an implementation of this application;

FIG. 26(a) to FIG. 26(d) are distribution diagrams of currents and electric fields of an antenna element in horizontal polarization at 5.25 GHz and 5.8 GHz according to an implementation of this application;

FIG. 27, FIG. 28, FIG. 29, and FIG. 30 are respective diagrams of S-parameters of a horizontal polarization port and a vertical polarization port during excitation when slots extending in a third direction have different sizes;

FIG. 31 is a diagram of one direction of an antenna array according to an implementation of this application;

FIG. 32 is a diagram of another direction of an antenna array according to an implementation of this application;

FIG. 33 is a diagram of a situation in which an array factor in an antenna array including four antenna elements changes with a spacing d between the antenna elements;

FIG. 34 is an architecture of an antenna array of a patch 1*4 array;

FIG. 35 is a diagram of a situation in which an array gain of a patch 1*4 array changes with a spacing between elements;

FIG. 36 is a diagram of a situation in which an array gain of a low-profile high-performance dual-polarized 1*4 antenna array changes with a spacing between elements according to this application;

FIG. 37A to FIG. 37C are diagrams of beam consistency of a patch 1*4 array at different spacings;

FIG. 38A to FIG. 38C are diagrams of beam consistency of a low-profile high-performance dual-polarized 1*4 antenna array at different spacings according to this application;

FIG. 39(a) to FIG. 39(c) are diagrams of S-parameters of a low-profile high-performance dual-polarized array antenna according to a specific implementation of this application; and

FIG. 40(a) and FIG. 40(b) are diagrams of scanning capabilities of a low-profile high-performance dual-polarized array antenna in horizontal polarization and vertical polarization at 5.2 GHz, 5.5 GHz, and 5.8 GHz according to a specific implementation of this application.

DESCRIPTION OF EMBODIMENTS

Explanation of some terms

[0039] Parallelism: The parallelism defined in this application is not limited to absolute parallelism; as defined, the parallelism may be understood as basic parallelism; non-absolute parallelism caused by factors such as an assembly tolerance, a design tolerance, and a structure flatness is allowed; and an error within a small angle range is allowed, for example, a relationship within an assembly error range of 10 degrees may be understood as a parallel relationship.

[0040] Verticality: The verticality defined in this application is not limited to an absolute vertical intersection (an included angle is 90 degrees) relationship; a non-absolute vertical intersection relationship caused by factors such as an assembly tolerance, a design tolerance, and a structure flatness is allowed; and an error within a small angle range is allowed, for example, a relationship within an assembly error range of 80 degrees to 100 degrees may be understood as a vertical relationship.

[0041] Coupling: The coupling may be understood as direct coupling and/or indirect coupling, and "coupling connection" may be understood as a direct coupling connection and/or an indirect coupling connection. The direct coupling may also be referred to as "electrical connection", which may be understood as physical touch and electrical conductivity of components, or may be understood as a form in which different components in a line structure are connected through a physical line that can transmit an electrical signal, like printed circuit board (printed circuit board, PCB) copper foil or a conducting wire. "Indirect coupling" may be understood as electrical conductivity of two conductors in a spaced/non-touch manner. In an embodiment, the indirect coupling may also be referred to as capacitive coupling. For example, signal transmission is implemented by forming an equivalent capacitor through coupling of a gap between two conductive components.

[0042] Connection: That two or more components are conducted or connected in the "electrical connection" or "indirect coupling" manner to perform signal/energy transmission may be referred to as the connection. Antenna pattern: The antenna pattern is also referred to as a radiation pattern. The antenna pattern is a pattern in which a relative field strength (a normalized modulus value) of an antenna radiation field changes with a direction at a specific distance from an antenna. The antenna pattern is usually represented by two plane patterns that are perpendicular to each other in a maximum radiation direction of the antenna.

[0043] The antenna pattern usually includes a plurality of radiation beams. A radiation beam with a maximum radiation strength is referred to as a main lobe, and other radiation beams are referred to as minor lobes or side lobes. In the minor lobes, a minor lobe in an opposite direction of the main lobe is also referred to as a back lobe.

[0044] Antenna return loss: The antenna return loss may be understood as a ratio of power of a signal reflected back to an antenna port through an antenna circuit to transmit power of the antenna port. A smaller reflected signal indicates a larger signal radiated through an antenna into space and higher radiation efficiency of the antenna. A larger reflected signal indicates a smaller signal radiated through the antenna into space and lower radiation efficiency of the antenna.

[0045] The antenna return loss may be represented by an S11 parameter, and the S11 parameter is usually a negative number. A smaller S11 parameter indicates a smaller antenna return loss and higher radiation efficiency of the antenna. A larger S11 parameter indicates a larger antenna return loss and lower radiation efficiency of the antenna.

[0046] Isolation: The isolation is a ratio of power of a signal transmitted through an antenna to power of a signal received through another antenna, and may be represented by an S21 parameter and an S12 parameter.

[0047] Antenna system efficiency: The antenna system efficiency is a ratio of power radiated through an antenna into space (namely, power that is effectively converted into an electromagnetic wave) to input power of the antenna.

[0048] Radiation efficiency: The radiation efficiency is a ratio of power radiated through an antenna into space (namely, power that is effectively converted into an electromagnetic wave) to active power input to the antenna. Herein, the active power input to the antenna is a value obtained by subtracting an antenna loss from the input power of the antenna. The antenna loss mainly includes an ohmic loss and/or a dielectric loss of metal.

Ground plane (reference ground):

[0049] The ground plane may generally mean at least a part of any grounding plane, grounding plate, ground metal layer, or the like of an electronic device (for example, a mobile phone), or at least a part of any combination of the foregoing grounding plane, grounding plate, grounding component, or the like. "Ground/ground plane" may be used for grounding of a component of the electronic device. In an embodiment, "ground/ground plane" may include any one or more of the following: a grounding plane of a circuit board of the electronic device, a grounding plate formed by a middle frame of the electronic device, a ground metal layer formed by a thin metal film below a screen, a conductive grounding plane of a battery, and a conductive member or metal member electrically connected to the grounding plane/grounding plate/metal layer. In an embodiment, the circuit board may be a printed circuit board (printed circuit board, PCB), for example, an 8-layer board, a 10-layer board, a 12-layer board, a 13-layer board, or a 14-layer board respectively having 8, 10, 12, 13, or 14 layers of conductive materials, or an element that is separated and electrically insulated by a dielectric layer or an insulation layer, for example, glass fiber or polymer. In an embodiment, the circuit board includes a dielectric substrate, a grounding plane, and a cable layer, where the cable layer and the grounding plane are electrically connected through a via. In an embodiment, components such as a display 120, a touchscreen, an input button, a transmitter, a processor, a memory, a battery 140, a charging circuit, and a system on chip (system on chip, SoC) structure may be mounted on or connected to the circuit board, or electrically connected to the cable layer and/or the grounding plane in the circuit board. For example, a radio frequency source is disposed at the cable layer.

[0050] Any one of the grounding plane, the grounding plate, or the ground metal layer is made of a conductive material. In an embodiment, the conductive material may be any one of the following materials: copper, aluminum, stainless steel, brass, an alloy thereof, copper foil on an insulation substrate, aluminum foil on an insulation substrate, gold foil on an insulation substrate, silver-plated copper, silver-plated copper foil on an insulation substrate, silver foil and tin-plated copper on an insulation substrate, cloth impregnated with graphite powder, a graphite-coated substrate, a copper-plated substrate, a brass-plated substrate, and an aluminum-plated substrate. A person skilled in the art may understand that the grounding plane/grounding plate/ground metal layer may alternatively be made of another conductive material.

[0051] Scanning direction of an electromagnetic wave beam: A wave beam (wave beam) is a shape, formed on a surface of the earth, of an electromagnetic wave emitted through a satellite antenna (for example, a light beam emitted by a flashlight to a dark place). An antenna beam is usually a main lobe or a main beam in an antenna pattern, is an area in which antenna energy is most concentrated, and is also most commonly used. Generally, there is only one main beam. Beam scanning means covering a spatial area with a group of transmit and receive beams at a prespecified time interval and direction. The scanning direction of the electromagnetic wave beam is a beam scanning direction in which the antenna receives and transmits electromagnetic waves.

[0052] Horizontal polarization and vertical polarization: The horizontal polarization means that when a satellite transmits a signal to the ground, a vibration direction of radio waves is a horizontal direction; the vertical polarization means that when a satellite transmits a signal to the ground, a vibration direction of radio waves is a vertical direction; and instantaneous orientation of an electric field vector corresponding to a case in which electromagnetic waves are propagated in space is referred to as polarization.

[0053] Operating frequency band: The operating frequency band means that no matter what type of antenna is used, the antenna always operates within a specific frequency range (frequency bandwidth). For example, an operating frequency band of an antenna supporting a B40 frequency band includes a frequency ranging from 2300 MHz to 2400 MHz. In other words, the operating frequency band of the antenna includes a B40 frequency band. A frequency range that meets an indicator requirement may be considered as the operating frequency band of the antenna.

[0054] Bandwidth (bandwidth): A width of an operating frequency band is referred to as an operating bandwidth. An operating bandwidth of an omnidirectional antenna may reach 3% to 5% of a center frequency. An operating bandwidth of a directional antenna may reach 5% to 10% of the center frequency. The bandwidth may be considered as a range of frequencies on both sides of the center frequency (for example, a resonance frequency of a dipole), where an antenna characteristic is within an acceptable range of values for the center frequency. In an embodiment, an antenna frequency bandwidth is an antenna frequency range corresponding to a case in which a directional gain of the antenna decreases by 3 dB.

[0055] Resonance: The resonance is also referred to as "resonance". The resonance is a phenomenon that an amplitude of an oscillating system increases sharply when a frequency of periodic external force is the same as or close to an inherent oscillation frequency of the system under the external force. A frequency at which the resonance is generated is referred to as "resonance frequency", a range of the resonance frequency is a resonant frequency band, and a return loss characteristic of any frequency in the resonant frequency band may be less than -6 dB or -5 dB. The resonant frequency band may be the same as or different from an operating frequency band, or frequency ranges of the resonant frequency band and the operating frequency band may partially overlap. In an embodiment, a resonant frequency band of an antenna may cover a plurality of operating frequency bands of the antenna.

[0056] Operating resonance: The operating resonance is resonance generated by an antenna element in an operating frequency band.

[0057] Gain: The gain is used to represent a degree to which an antenna intensively radiates input power. Usually, a narrower main lobe of an antenna pattern indicates a smaller minor lobe, and a higher antenna gain.

[0058] Antenna array: Several radiating elements are arranged in a specific manner to form an antenna array that is also referred to as an antenna array. The radiating element is referred to as an antenna element or an array element.

[0059] Radiation field of an antenna array: The radiation field is obtained in a manner in which vector fields generated by an antenna element are superimposed, and distribution of current amplitudes and phases on the vector field meets a proper relationship.

[0060] Array factor: The array factor represents directivity of an antenna array including isotropic elements, and a value of the array factor depends on an arrangement mode of the antenna array and a relative amplitude and phase of an excitation current on an antenna element in the antenna array. The value is irrelevant to a type and size of the antenna element.

[0061] Terms "First" and "second" are merely intended for a purpose of description, and shall not be understood as an indication or implication of relative importance or implicit indication of a quantity of indicated technical features. Therefore, a feature limited by "first", "second", or the like may explicitly or implicitly include one or more features.

[0062] The following describes solutions of this application by using an example with reference to embodiments.

[0063] An antenna element and an antenna array provided in this application are used in a WLAN system, and are specifically used in a communication device or a terminal device. The communication device may be but is not limited to a router, CPE (Customer Premises Equipment, customer premises equipment), or the like.

[0064] FIG. 1 is a basic architecture of a connection relationship between an antenna module in a communication device and a baseband according to an implementation. FIG. 2 is a diagram in which the antenna module may cover different terminal devices according to an implementation. In FIG. 1 and FIG. 2, an element 1, an element 2, an element 3, and an element 4 all represent antenna elements, and Φ1, Φ2, Φ3, and Φ4 all represent phase-shift elements.

[0065] Refer to FIG. 1. In an implementation, the communication device includes the antenna module, and the antenna module is electrically connected to a baseband circuit (in FIG. 1, the baseband represents the baseband circuit or a baseband chip) through a radio frequency channel. The baseband circuit transmits a radio frequency signal to the antenna module through the radio frequency channel. In a specific implementation, there are two radio frequency channels between the baseband circuit and the antenna module, where one radio frequency channel is configured to excite horizontal polarization of the antenna module, and the other radio frequency channel is configured to excite vertical polarization of the antenna module. The antenna module includes an antenna array. The antenna array may be formed by arranging one or more antenna elements, and connection relationships between the antenna elements and the radio frequency channels are the same. One of the antenna elements is used as an example. One end of the antenna element is connected to one radio frequency channel through a phase-shift element, and the other end of the antenna element is connected to the other radio frequency channel through a phase-shift element. In another implementation, the antenna elements may not be connected to phase-shift elements, or some antenna elements are connected to phase-shift elements, and some antenna elements are not connected to phase-shift elements. The phase-shift element is configured to perform phase adjustment on a specific antenna element, to change a scanning direction of an electromagnetic wave beam of the antenna element, so that the antenna element can communicate with terminal devices at different positions.

[0066] Specifically, refer to FIG. 2. The four antenna elements each are connected to a phase-shift element, so that a direction of an electromagnetic wave beam of the antenna module may be varied. An electromagnetic wave signal of the antenna module may cover terminal devices such as a smartphone, intelligent security, a smart television, and a smart home that are distributed at different positions in a specific scenario. In FIG. 2, the element 1, the element 2, the element 3, and the element 4 represent four antenna elements, phase-shift elements Φ1 are positioned on two sides of the element 1, phase-shift elements Φ2 are positioned on two sides of the element 2, and phase-shift elements Φ3 are positioned on two sides of the element 3, and phase-shift elements Φ4 are positioned on two sides of the element 4.

[0067] For a communication device, different communication devices may have different forms, for example, a vertical column shape, a flat disk shape, or a square box shape. To ensure that an antenna module meets a radiation angle of a specific application scenario, positions of the antenna modules are different in communication products of different forms. Refer to FIG. 3A. In an implementation, the entire communication device is a three-dimensional columnar architecture. A top surface of the communication device is in a runway shape. The communication device includes a top area and a bottom area. Antenna modules are disposed in the top area. There are two antenna modules. An antenna module I is disposed closely to the front surface of the top area, and the antenna module II is disposed closely to the back surface of the top area. The front surface and the back surface may be referred to by using an appearance surface of a housing of the communication device. For example, the front surface is a side surface of the communication device with the housing facing a main signal environment when the communication device is in a use state, and the back surface is a side surface of the communication device with the housing being opposite to the main signal environment when the communication device is in the use state. In an implementation, a size of the communication device is small, and only one antenna module I may be disposed inside the communication device. Refer to FIG. 3B. In an implementation, the communication device is in a square box shape. Four surfaces of the communication device can radiate an electromagnetic wave signal. Four antenna modules may be disposed in the communication device. An antenna module I is close to a front surface, an antenna module II is close to a left side surface, an antenna module III is close to a back surface, and an antenna module IV is close to a right side surface. In the implementation, the front surface, the back surface, the left side surface, and the right side surface may also be referred to by using an appearance surface of a housing of the communication device. It should be understood that, that the antenna module is positioned on the front surface, the back surface, or the side surface is not limited to being positioned on an appearance surface or being disposed closely to the surface.

[0068] FIG. 4 is a diagram of one direction of an antenna element 10 according to an implementation of this application. FIG. 5 is a diagram of another direction of the antenna element 10 according to the implementation of this application. Refer to FIG. 4 and FIG. 5. In an implementation, the antenna element 10 provided in this application includes a radiation patch 12 and a feeding assembly 14, and the feeding assembly 14 is electrically connected to a radio frequency circuit in a communication device. The feeding assembly 14 is configured to feed the radiation patch 12. In an embodiment, the feeding assembly 14 is configured to allow the radiation patch 12 to generate dual-polarized signals, for example, a horizontally polarized signal and a vertically polarized signal (hereinafter referred to as generating horizontal polarization/vertical polarization). In an embodiment, two operating modes are generated during horizontal polarization feeding of the radiation patch 12, and the two operating modes are also generated during vertical polarization feeding of the radiation patch 12.

[0069] In an implementation, the radiation patch 12 is a microstrip patch structure disposed on a dielectric board 11, and the radiation patch 12 formed by using the microstrip patch structure gives the antenna element 10 advantages of a low profile and miniaturization. In an implementation, the feeding assembly 14 may include a microstrip structure disposed on the dielectric board 11.

[0070] Refer to FIG. 4 and FIG. 6. FIG. 6 is a plane diagram of the radiation patch 12 of the antenna element according to the implementation shown in FIG. 4. The radiation patch 12 includes a first additional sub-patch 1212A, a first sub-patch 1211A, a second sub-patch 1211B, and a second additional sub-patch 1212B that are sequentially arranged in a first direction A1. The radiation patch 12 includes a first slit 1221 and a second slit 1222 that penetrate the radiation patch 12 in a second direction A2. The first slit is formed between the first sub-patch 1211A and the second sub-patch 1211B. The second slit 1222 includes a first sub-slit 1222A and a second sub-slit 1222B. The first sub-slit 1222A is formed between the first sub-patch 1211A and the first additional sub-patch 1212A. The second sub-slit 1222B is formed between the second sub-patch 1211B and the second additional sub-patch 1212B. The radiation patch 12 does not have a slit that penetrates the radiation patch 12 in the first direction A1. An extension direction of the first slit 1221, an extension direction of the first sub-slit 1222A, and an extension direction of the second sub-slit 1222B are all the second direction A2. A size of the radiation patch 12 in the first direction A1 is greater than a size of the radiation patch 12 in the second direction A2. In an implementation, the first direction A1 is perpendicular to the second direction A2. In another implementation, an included angle may alternatively be formed between the first direction A1 and the second direction A2. In this application, the radiation patch 12 of the antenna element 10 is designed as follows: A length size in the first direction A1 is greater than a width size in the second direction A2, so that the antenna element 10 forms an elongated asymmetric structure, where the asymmetric structure means that a structure size in the first direction A1 is different from a structure size in the second direction A2, and the entire radiation patch 12 is not a square patch structure. The antenna element 10 provided in this application can generate a fan-shaped beam, implement wide coverage on a horizontal plane while maintaining a high gain, and is designed for a dual-polarized antenna.

[0071] In an implementation, the radiation patch 12 is a metal sheet-like structure formed on the dielectric board 11. In an implementation, in a manufacturing process, a rectangular metal patch may be first manufactured on the dielectric board 11, where a length direction of the metal patch is a first direction A1, and a width direction of the metal patch is a second direction A2; and a slit (namely, the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B) is then manufactured on the metal patch, where extension directions are all the second direction A2, and it may be understood that an extension direction of the first slit 1221, an extension direction of the first sub-slit 1222A, and an extension direction of the second sub-slit 1222B are all parallel to the width direction of the metal patch, so that the metal patch is divided into a plurality of sub-patches (namely, the first additional sub-patch 1212A, the first sub-patch 1211A, the second sub-patch 1211B, and the second additional sub-patch 1212B) by providing the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B.

[0072] An overall outer profile of the radiation patch 12 is a rectangle. A size of the radiation patch 12 in the first direction A1 is a length of the radiation patch 12, and a size of the radiation patch 12 in the second direction A2 is a width of the radiation patch 12. In an implementation, a length-to-width ratio R of the radiation patch 12 satisfies $R \geq 2$. For example, in a specific implementation, the length-to-width ratio R of the radiation patch 12 satisfies $3 \leq R \leq 5$. The entire radiation patch 12 is a slender rectangle. In view of this, the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B are provided, so that the radiation patch 12 has good radiation performance in a case in which dual polarization and two operating modes of each polarization are met. The first additional sub-patch 1212A, the first sub-patch 1211A, the second sub-patch 1211B, and the second additional sub-patch 1212B are collectively referred to as sub-patches. A size of each sub-patch in the second direction A2 is a width of the sub-patch, and a size of each sub-patch in the first direction A1 is a length of the sub-patch. In an implementation, widths of all sub-patches may be equal, and lengths of all sub-patches may also be equal. In another implementation, lengths of some sub-patches in a plurality of sub-patches may alternative be different, and widths of the some patches in the plurality of sub-patches may alternative be different. A single sub-patch may be a rectangle or a square, or the sub-patch may be in another shape, for example, an ellipse, a trapezoid, or a polygon. This is not specifically limited in this application. In an implementation, the radiation patch 12 of the antenna element 10 has four sub-patches. In another implementation, there may alternatively be six, eight, or more sub-patches. The following describes a specific structure of the antenna element 10 in detail by using a specific implementation in which the radiation patch 12 has four sub-patches. Various limitations in this specific implementation are also applicable to other different implementations (for example, an implementation in which there may alternatively be six sub-patches).

[0073] Refer to FIG. 6. In an implementation, the radiation patch 12 includes at least three slits (namely, the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B) that penetrate the radiation patch in the second direction A2, where a slit provided in a middle position of the radiation patch 12 in the first direction A1 is the first slit 1221, and the remaining slits are the second slit 1222. In an implementation, there are an odd quantity of slits in total. In an implementation, there is one first slit 1221, and there are an even quantity of second slits 1222. In this implementation, the radiation patch 12 is provided with three slits, including one first slit 1221 and two second slits 1222 (including the first sub-slit 1222A and the second sub-slit 1222B).

[0074] That the extension direction of the slit on the radiation patch 12 is the second direction A2 may be understood as that each slit (including the first slit 1221 and the second slit 1222) includes a first end E1 and a second end E2, the first end E1 is positioned on one long edge of the radiation patch 12, the second end E2 is positioned on the other long edge of the radiation patch 12, and both the extension direction of the first slit 1221 and an extension direction of the second slit 1222 may be a direction in which the first end E1 points to the second end E2. In an implementation, both the extension direction of the first slit 1221 and a width direction of the radiation patch 12 are the second direction A2, and the extension direction of the second slit 1222 is parallel to the extension direction of the first slit 1221. Both the first slit 1221 and the second slit 1222 may be provided as a rectangle (or referred to as a long strip).

[0075] The radiation patch does not have a slit that penetrates the radiation patch in the first direction, or the radiation patch has only one slit that penetrates the radiation patch in the first direction. In this application, the radiation patch is limited to including at least three slits that penetrate the radiation patch in the second direction, and at most one slit that penetrates the radiation patch in the first direction (which may be understood as that the radiation patch does not have a slit that penetrates the radiation patch in the first direction, or the radiation patch has only one slit that penetrates the radiation patch in the first direction), so that the antenna element 10 can be adjusted to two different operating modes (a main operating mode and a parasitic operating mode) in first polarization (for example, horizontal polarization) and two different operating modes in second polarization (for example, vertical polarization), and further the antenna element 10 can implement a dual-polarized multi-mode (at least four operating modes) state.

[0076] In the implementation shown in FIG. 6, when the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B are rectangles, the extension directions of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B are the same as extension paths, namely, the second direction A2, of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B.

[0077] Refer to FIG. 7. In an implementation, the first slit 1221 is used as an example. When the first slit 1221 is a curved shape, for example, serpentine, an extension path of the first slit 1221 is different from the extension direction of the first slit 1221, where the extension path is a curved extension track; but the extension direction is still a direction in which the first end E1 points to the second end E2, and the extension direction is still the second direction A2. In the implementation shown in FIG. 7, the first slit 1221 is a curved shape, and the first sub-slit 1222A and the second sub-slit 1222B are rectangles. In another implementation, the first slit 1221 is a rectangle, and the first sub-slit 1222A and the second sub-slit 1222B are a curved shape; or the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B may all be a curved shape.

[0078] Extension paths of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B are not limited in this application. When the extension directions of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B are limited to the second direction A2, the extension paths of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B may be a straight line shape, a curved shape (for example, a serpentine shape or an arc shape), a sawtooth shape, or the like. Lengths of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B are sizes of extension paths that of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B and that extend from the first end E1 to the second end E2. When the extension paths of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B are a straight line shape, lengths of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B are the shortest, and the lengths of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B may be the width of the radiation patch 12. When the extension paths of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B are a curved shape or a sawtooth shape, lengths of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B are long. Widths of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B are a size perpendicular to a direction of the extension paths that are of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B, and the widths of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B may be within a range of 0.03 mm to 3 mm. In a specific implementation, a width of the slit is within a range of 0.5 mm to 1.5 mm. In this application, an operating frequency band and a bandwidth of the antenna element 10 may be adjusted by adjusting specific forms and widths of the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B. For example, in an implementation, when the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B are rectangles, the operating frequency band of the antenna element 10 is 5.15 GHz to 5.85 GHz.

[0079] In an implementation, both a width of the first slit 1221 and a width of the second slit 1222 may be within a range of 0.03 mm to 3 mm. In an implementation, the width of the second slit 1222 is less than or equal to 2 mm. The width of the first slit 1221 and the width of the second slit 1222 may be the same or different. For example, the width of the first slit 1221 may be greater than the width of the second slit 1222. For example, the width of the first slit 1221 is 1.2 mm, and the width of the second slit 1222 is 0.8 mm. In an implementation, widths of all second slits 1222 are the same. In an implementation, the second slits 1222 are symmetrically distributed on two sides of the first slit 1221 in the first direction A1, and minimum spacings between the first slit 1221 and the second slits 1222 positioned on the two sides of the first slit 1221 are the same.

[0080] Refer to FIG. 6. In an implementation, the radiation patch 12 has a center line C1 extending in the second direction A2, and the radiation patch 12 is symmetrically distributed on two sides of the center line C1. In an implementation, that the first slit 1221 is in a middle position of the radiation patch 12 in a length direction may be understood as that the center line C1 is within a range covered by the first slit 1221, or the center line C1 passes through at least a part of an area of the first slit 1221. In an implementation, the center line C1 of the radiation patch 12 coincides with a center position of the first slit 1221 in a width direction.

[0081] In an implementation, the second slit 1222 (namely, the first sub-slit 1222A and the second sub-slit 1222B) is symmetrically distributed on the two sides of the center line C1 in the first direction A1. Herein, symmetry may not be understood as strict symmetry in a mathematical sense. In this solution, the symmetry means that edge openings (the first end E1 and the second end E2) of the second slit 1222 are symmetrically provided on the two sides of the center line C1, a middle part of the second slit is not limited, and forms of the second slits are not limited to be completely consistent. In an implementation, there are an even quantity of second slits 1222. When there are two second slits 1222, distances between the two second slits 1222 and the first slit 1221 are equal, and the two second slits 1222 are the same in size and form. When there are four or more second slits 1222, two second slits 1222 having equal distances from the first slit 1221 are the same in size and form, and second slits 1222 having different distances from the first slit 1221 may be different in size and form. In this application, frequency ranges of the antenna element 10 in different operating modes in the horizontal polarization and the vertical polarization are adjusted by adjusting a specific position of the second slit 1222 and adjusting a width value of the second slit 1222, so that an operating frequency band and a bandwidth of the antenna element 10 can be adjusted.

[0082] In an implementation, the first additional sub-patch 1212A, the first sub-patch 1211A, the second sub-patch 1211B, and the second additional sub-patch 1212B are symmetrically distributed on the two sides of the first slit 1221 in the first direction A1.

[0083] A main operating mode and a parasitic operating mode are generated during horizontal polarization feeding of the radiation patch 12 provided in this application. Refer to FIG. 8A. In the main operating mode, the first sub-patch 1211A and the second sub-patch 1211B are excited to generate currents in the second direction A2, and the first sub-patch 1211A and the second sub-patch 1211B are configured to radiate electromagnetic wave signals in the main operating mode. In this implementation, a limitation on directions of the currents on the first sub-patch 1211A and the second sub-patch 1211B may be understood as follows: In the main operating mode, main currents of the first sub-patch 1211A and the second sub-patch 1211B are in the second direction A2, or the currents on the first sub-patch 1211A and the second sub-patch 1211B roughly flow in the second direction A2 from one end to the other end of the first sub-patch 1211A and from one end to the other end of the second sub-patch 1211B respectively. Directions of arrow indication lines on the first sub-patch 1211A and the second sub-patch 1211B in FIG. 8A represent directions of main currents or approximate directions of currents.

[0084] Refer to FIG. 8B. In the parasitic operating mode, the first additional sub-patch 1212A and the second additional sub-patch 1212B are excited to generate currents in the second direction A2, and the first additional sub-patch 1212A and the second additional sub-patch 1212B are configured to radiate electromagnetic wave signals in the parasitic operating mode. In this implementation, a limitation on directions of the currents on the first additional sub-patch 1212A and the second additional sub-patch 1212B may be understood as follows: In the parasitic operating mode, main currents of the first additional sub-patch 1212A and the second additional sub-patch 1212B are in the second direction A2, or the currents on the first additional sub-patch 1212A and the second additional sub-patch 1212B roughly flow in the second direction A2 from one end to the other end of the first additional sub-patch 1212A and from one end to the other end of the second additional sub-patch 1212B respectively. Directions of arrow indication lines on the first additional sub-patch 1212A and the second additional sub-patch 1212B in FIG. 8B represent directions of main currents or approximate directions of currents.

[0085] During horizontal polarization feeding of the radiation patch 12 provided in this application, currents on the first sub-patch 1211A and the second sub-patch 1211B in the main operating mode and currents on the first additional sub-patch 1212A and the second additional sub-patch 1212B in the parasitic operating mode may be in a same direction (as shown in FIG. 8A and FIG. 8B, in the second direction, the currents are in a leftward direction or a rightward direction) or may be in opposite directions (for example, in the second direction, the currents on the first sub-patch 1211A and the second sub-patch 1211B in the main operating mode are in a leftward direction, and the currents on the first additional sub-patch 1212A and the second additional sub-patch 1212B in the parasitic operating mode are in a rightward direction).

[0086] In this application, an operating frequency band of the antenna element 10 in the main operating mode may be adjusted by adjusting widths of the first sub-patch 1211A and the second sub-patch 1211B (namely, sizes of the first sub-patch 1211A and the second sub-patch 1211B in the second direction A2), and an operating frequency band of the antenna element 10 in the parasitic operating mode may be adjusted by adjusting widths of the first additional sub-patch 1212A and the second additional sub-patch 1212B (namely, sizes of the first additional sub-patch 1212A and the second additional sub-patch 1212B in the second direction A2). In this application, an operating frequency band of the antenna element 10 in the main operating mode may also be adjusted by adjusting edge shapes of the first sub-patch 1211A and the second sub-patch 1211B, and an operating frequency band of the antenna element 10 in the parasitic operating mode may also be adjusted by adjusting edge shapes of the first additional sub-patch 1212A and the second additional sub-patch 1212B. This part of content is described in detail below.

[0087] A first operating mode and a second operating mode are generated during vertical polarization feeding of the radiation patch 12 provided in this application. In this application, operating frequencies of the antenna element in the first operating mode and the second operating mode may be adjusted by adjusting a width of the first slit (namely, a size of the first slit in the first direction A1) and a width of the second slit (namely, a size of the second slit in the first direction A1) respectively. Refer to FIG. 9A and FIG. 9B. It can be seen that, when a width of a slit increases, a resonance moves toward a high frequency, where the width of the first slit (marked as ws1 in FIG. 9A) mainly affects a resonance in the first operating mode, and the second slit (marked as ws2 in FIG. 9B) mainly affects a resonance in the second operating mode.

[0088] FIG. 10A shows a current direction of the radiation patch in the first operating mode, where a straight line with an arrow that continuously extends from the bottom end of the radiation patch to a position adjacent to the top end represents the current direction. Refer to FIG. 10A. In the first operating mode, a current on the radiation patch 12 flows from one end to the other end of the radiation patch 12 in the first direction A1. FIG. 10A schematically illustrates a current direction in a state, where the current flows from the bottom end to the top end of the radiation patch 12, and positions at the bottom end and the top end may be positions of current zero points. Whether specific distribution of currents on the first sub-patch 1211A and the second sub-patch 1211B is completely consistent or specific distribution of currents on the first additional sub-patch 1212A and the second additional sub-patch 1212B is completely consistent is not limited in this application, and current intensity is not limited either. FIG. 10B shows a current direction and distribution of electric fields of the radiation patch in the first operating mode. A straight line with an arrow that extends in a Y direction represents the current direction. An indication line with an arrow that extends in a Z direction represents an electric field direction and electric field strength. Dashed-line rectangular boxes represent the first sub-patch 1211A, the second sub-patch 1211B, the first additional sub-patch 1212A, and the second additional sub-patch 1212B respectively. Gaps between adjacent dashed-line boxes represent the first slit 1221 and the second slit 1222 respectively. Refer to FIG. 10B. In the first operating mode, an electric field generated by the antenna element 10 generates weak point reverse between the first slit 1221 and a ground plane of the feeding assembly 14.

[0089] FIG. 11A shows a current direction of the radiation patch in the second operating mode, where a straight line with an arrow that continuously extends from the bottom end of the radiation patch to a position adjacent to the top end represents the current direction. Refer to FIG. 11A. In the second operating mode, a current on the radiation patch 12 flows from one end to the other end of the radiation patch 12 in the first direction A1. FIG. 11A schematically illustrates a current direction in a state, where the current flows from the bottom end to the top end of the radiation patch 12, and positions at the bottom end and the top end may be positions of current zero points. Whether specific distribution of currents on the first sub-patch 1211A, the second sub-patch 1211B, the first additional sub-patch 1212A, and the second additional sub-patch 1212B is completely consistent is not limited in this application, and current intensity is not limited either. FIG. 11B shows a current direction and distribution of electric fields of the radiation patch in the second operating mode. A straight line with an arrow that extends in a Y direction represents the current direction. An indication line with an arrow that extends in a Z direction represents an electric field direction and electric field strength. Dashed-line rectangular boxes represent the first sub-patch 1211A, the second sub-patch 1211B, the first additional sub-patch 1212A, and the second additional sub-patch 1212B respectively. Gaps between adjacent dashed-line boxes represent the first slit 1221 and the second slit 1222 respectively. Refer to FIG. 11B. In the second operating mode, an electric field generated by the antenna element 10 generates strong point reverse between the second slit 1222 and a ground plane.

[0090] In an implementation of this application, the radiation patch 12 is fed by coupling a microstrip feed structure to a slit on the ground plane. FIG. 12 is a three-dimensional exploded view of the antenna element 10 according to this implementation of this application. Specifically, the feeding assembly 14 includes a ground plane 15 and a feeding layer 16, the ground plane 15 is disposed between the feeding layer 16 and the radiation patch 12 in a stacked manner, and the ground plane 15 is provided with a first coupling slit 151 and a second coupling slit 152 that are provided in a cross manner. In an implementation, the ground plane 15 forms a metal grounding plane architecture on the dielectric board 11, and the first coupling slit 151 and the second coupling slit 152 are slit structures formed by removing metal materials from the ground plane 15. The first coupling slit 151 and the second coupling slit 152 may be filled with insulation media, and the media in the first coupling slit 151 and the second coupling slit 152 may also be air. In a specific implementation, an extension direction of the first coupling slit 151 is the first direction A1, an extension direction of the second coupling slit 152 is the second direction A2, and the first coupling slit 151 and the second coupling slit 152 form a cross-shaped slit structure. In an implementation, that the first coupling slit 151 and the second coupling slit 152 are perpendicular to each other may be understood as that the first coupling slit 151 and the second coupling slit 152 are generally perpendicular to each other. The first coupling slit 151 and the second coupling slit 152 are not limited to straight-line slits in this application, provided that extension trends of the first coupling slit 151 and the second coupling slit 152 are perpendicular to each other. Specific shapes of the first coupling slit 151 and the second coupling slit 152 may be straight line shapes, wavy line shapes, sawtooth shapes, or the like. The first coupling slit 151 and the second coupling slit 152 may include slit parts in a bent form.

[0091] In an implementation, a part of the first coupling slit 151 overlaps the first sub-patch 1211A, and a part of the first coupling slit 151 overlaps the second sub-patch 1211B. In an implementation, the second coupling slit 152 does not overlap the first sub-patch 1211A, and the second coupling slit 152 does not overlap the second sub-patch 1211B either. Alternatively, the second coupling slit 152 does not overlap one of the first sub-patch 1211A and the second sub-patch 1211B, and a part of the second coupling slit 152 overlaps an edge of the other one of the first sub-patch 1211A and the second sub-patch 1211B. Alternatively, the second coupling slit 152 overlaps both an edge of the first sub-patch 1211A and an edge of the second sub-patch 1211B. In an implementation, the first coupling slit 151 does not overlap neither the first additional sub-patch 1212A nor the second additional sub-patch 1212B. Similarly, the second coupling slit 152 does not overlap neither the first additional sub-patch 1212A nor the second additional sub-patch 1212B.

[0092] The second coupling slit 152 is provided directly opposite to the first slit 1221 on the radiation patch 12. In this embodiment of this application, "directly opposite" should be understood as that a vertical projection 152A of the second coupling slit 152 on the radiation patch 12 and the first slit 1221 are at least partially overlapped. "Directly opposite" described elsewhere in this document should be understood in the same or similar way. In an implementation, a width of the second coupling slit 152 is less than or equal to that of the first slit 1221, and a length of the second coupling slit 152 is greater than that of the first slit 1221. The vertical projection 152A of the second coupling slit 152 on the radiation patch 12 exceeds two ends of the first slit 1221 in the second direction A2. In other words, the width of the radiation patch 12 is less than the length of the second coupling slit 152. In an implementation, a center position of the second coupling slit 152 in the second direction A2 coincides with a center position of the first slit 1221 of the radiation patch 12 in the second direction A2.

[0093] In another implementation, a width of the second coupling slit 152 may alternatively be greater than that of the first slit 1221, and a length of the second coupling slit 152 may alternatively be less than that of the first slit 1221.

[0094] In another implementation, the second coupling slit 152 may alternatively be provided directly opposite to a sub-patch (for example, the first sub-patch 1211A or the second sub-patch 1211B) of the radiation patch 12. The second coupling slit 152 and the first slit 1221 may be provided in a staggered manner (that is, the second coupling slit 152 and the first slit 1221 are not provided directly opposite to each other and are not partially overlapped).

[0095] In an implementation, a center position of the first coupling slit 151 in the first direction A1 is directly opposite to a center position of the first slit 1221 of the radiation patch 12 in the second direction A2. In an implementation, a vertical projection 1511A of the first coupling slit 151 on the radiation patch 12 at a center position 1511 in the first direction A1 is within a range of the first slit 1221. In another implementation, a center position 1511 of the first coupling slit 151 in the first direction may alternatively be directly opposite to a sub-patch (for example, the first sub-patch 1211A or the second sub-patch 1211B) of the radiation patch 12. To be specific, a vertical projection 1511A of the first coupling slit 151 on the radiation patch 12 at the center position 1511 in the first direction A1 is within a range of the first sub-patch 1211A or the second sub-patch 1211B.

[0096] In an implementation, a vertical projection, on the radiation patch 12, of an area in which the first coupling slit 151 intersects with the second coupling slit 152 is within a range of the first slit 1221. Alternatively, a part of a vertical projection, on the radiation patch 12, of an area in which the first coupling slit 151 intersects with the second coupling slit 152 is within a range of the first slit 1221. Alternatively, a vertical projection, on the radiation patch 12, of an area in which the first coupling slit 151 intersects with the second coupling slit 152 is positioned on a periphery of the first slit 1221. To be specific, the vertical projection, on the radiation patch 12, of an area in which the first coupling slit 151 intersects with the second coupling slit 152 is within a range of the first sub-patch 1211A or the second sub-patch 1211B.

[0097] The antenna element 10 provided in an implementation of this application includes two feed units: a first feed structure and a second feed structure. The radiation patch 12 is fed by using the two feed units, to excite two operating modes in the horizontal polarization and two operating modes in the vertical polarization. Refer to FIG. 12. A first feed structure 17 and a second feed structure 18 are disposed on the feeding layer 16. The first feed structure 17 is disposed directly opposite to the first coupling slit 151. The second feed structure 18 is disposed directly opposite to the second coupling slit 152. It should be understood that, in embodiments of this application, "directly opposite" should be understood as that a vertical projection of a coupling slit on the feeding layer and a feed structure are at least partially overlapped, or a vertical projection of a feed structure on the ground plane and a coupling slit are at least partially overlapped. "Directly opposite" described elsewhere in this document should be understood in the same or similar way. The first feed structure 17 is coupled to the first coupling slit 151 to excite the horizontal polarization of the radiation patch 12, and the second feed structure 18 is coupled to the second coupling slit 152 to excite the vertical polarization of the radiation patch 12.

[0098] In an implementation, the feeding layer 16 may be a two-layer metal cabling structure disposed on the dielectric board 11. A part of a transmission line for coupling the first feed structure 17 to the first coupling slit 151 and a part of a transmission line for coupling the second feed structure 18 to the second coupling slit 152 are distributed on different layers of the feeding layer 16; to be specific, the two parts of transmission lines are separated through some areas (which may also be a part of the dielectric board or air) of the dielectric board 11, to implement a stacking relationship in space and facilitate a small-size design of an overall feeding architecture.

[0099] FIG. 13 is an exploded view of a layer structure of the antenna element 10. The antenna element 10 is successively layered into the radiation patch 12, one layer of the dielectric board 11, the ground plane 15, another layer of the dielectric board 11, a second layer 162 of the feeding layer 16, another layer of the dielectric board 11, and a first layer 161 of the feeding layer 16 from top to bottom. In this implementation, the feeding layer 16 includes the first layer 161 and the second layer 162. The second layer 162 is disposed between the ground plane 15 and the first layer 161 in a stacked manner. The ground plane 15 and the second layer 162, and the second layer 162 and the first layer 161 are respectively separated through different layers of the dielectric board 11. The first layer 161 may be one layer of an outer surface of the antenna element 10.

[0100] In an implementation, with reference to FIG. 12 and FIG. 13, some transmission lines of the first feed structure 17 are distributed at the first layer 161, remaining transmission lines of the first feed structure 17 are distributed at the second layer 162, and all transmission lines of the second feed structure 18 are distributed at the first layer 161. The second feed structure 18 and a part of the first feed structure 17 are disposed at the first layer 161, and only a part of the first feed structure 17 is disposed at the second layer 162. Specifically, the first feed structure 17 includes a first part 171 and a second part 172, the first part 171 is positioned at the first layer 161, the second part 172 is positioned at the second layer 162, and one end of the first part 171 is positioned at an edge of the dielectric board 11 or near an edge of the dielectric board 11. The first part 171 is configured to connect to a radio frequency channel through a first interface 191. The other end of the first part 171 passes through a via of the dielectric board 11 and is electrically connected to one end of the second part 172, and the other end of the second part 172 is coupled to the first coupling slit 151. One end of the second feed structure 18 is positioned at an edge of the dielectric board 11 or near an edge of the dielectric board 11, and the one end of the second feed structure 18 is configured to connect to the radio frequency channel through a second interface 192. The other end of the second feed structure 18 is coupled to the second coupling slit 152. In this implementation, at the first coupling slit 151 and the second coupling slit 152, a part of the first feed structure 17 is disposed between a part of the second feed structure 18 and the ground plane 15 in a stacked manner in a thickness direction of the dielectric board 11.

[0101] In another implementation, alternatively, all transmission lines of the first feed structure 17 may be disposed at the first layer 161, some transmission lines of the second feed structure 18 may be disposed at the first layer 161, and remaining transmission lines of the second feed structure 18 may be disposed at the second layer 162. In this implementation, at the first coupling slit 151 and the second coupling slit 152, a part of the second feed structure 18 is disposed between a part of the first feed structure 17 and the ground plane 15 in a stacked manner in a thickness direction of the dielectric board 11.

[0102] Refer to FIG. 12. In an implementation, the first feed structure 17 includes a first coupling transmission line 175. The first coupling transmission line 175 includes a first segment 1751, a second segment 1752, and a third segment 1753 that are sequentially connected. The first segment 1751 and the third segment 1753 are spaced apart from each other. The second segment 1752 is connected between one end of the first segment 1751 and one end of the third segment 1753. Extension directions of the first segment 1751 and the third segment 1753 are the second direction A2. An extension direction of the second segment 1752 may be the first direction A1. Both the first segment 1751 and the third segment 1753 cross the first coupling slit 151. A part of the first segment 1751 is positioned on one side of the first coupling slit 151 in the second direction A2, and a part of the first segment 1751 is positioned on the other side of the first coupling slit 151 in the second direction A2. Similarly, a part of the second segment 1752 is positioned on one side of the first coupling slit 151 in the second direction A2, and a part of the second segment 1752 is positioned on the other side of the first coupling slit 151 in the second direction A2.

[0103] Refer to FIG. 12. In an implementation, the second feed structure 18 includes a second coupling transmission line 185. The second coupling transmission line 185 includes a fourth segment 1851, a fifth segment 1852, and a sixth segment 1853 that are sequentially connected. The fourth segment 1851 and the sixth segment 1853 are spaced apart from each other. The fifth segment 1852 is connected between one end of the fourth segment 1851 and one end of the sixth segment 1853. Extension directions of the fourth segment 1851 and the sixth segment 1853 are the first direction A1. An extension direction of the fifth segment 1852 may be the second direction A2. Both the fourth segment 1851 and the sixth segment 1853 cross the second coupling slit 152. Apart of the fourth segment 1851 is positioned on one side of the second coupling slit 152 in the first direction A1, and a part of the fourth segment 1851 is positioned on the other side of the second coupling slit 152 in the first direction A1. Similarly, a part of the sixth segment 1853 is positioned on one side of the second coupling slit 152 in the first direction A1, and a part of the sixth segment 1853 is positioned on the other side of the second coupling slit 152 in the first direction A1.

[0104] Both the first coupling transmission line 175 and the second coupling transmission line 185 may be in a Π shape or a U shape. Refer to FIG. 14. Relationships between a vertical projection of the first coupling transmission line 175 on the ground plane 15, and the first coupling slit 151 and the second coupling slit 152 are as follows: Vertical projections of the first segment 1751 and the third segment 1753 on the ground plane 15 intersect with the first coupling slit 151. In a specific implementation, the vertical projections of the first segment 1751 and the third segment 1753 on the ground plane are separately perpendicular to the first coupling slit 151. The vertical projections of the first segment 1751 and the third segment 1753 on the ground plane 15 are symmetrically distributed on two sides of the second coupling slit 152. In a specific implementation, the vertical projections of the first segment 1751 and the third segment 1753 on the ground plane 15 are parallel to the second coupling slit 152. A vertical projection of the second segment 1752 on the ground plane 15 is positioned at a periphery of the second coupling slit 152, and does not intersect with the second coupling slit 152. In a specific implementation, the vertical projection of the second segment 1752 on the ground plane 15 is parallel to the first coupling slit 151. Relationships between a vertical projection of the second coupling transmission line 185 on the ground plane 15, and the first coupling slit 151 and the second coupling slit 152 are as follows: Vertical projections of the fourth segment 1851 and the sixth segment 1853 on the ground plane 15 intersect with the second coupling slit 152. In a specific implementation, the vertical projections of the fourth segment 1851 and the sixth segment 1853 on the ground plane 15 are separately perpendicular to the second coupling slit 152. The vertical projections of the fourth segment 1851 and the sixth segment 1853 on the ground plane 15 are symmetrically distributed on two sides of the first coupling slit 151. In a specific implementation, the vertical projections of the fourth segment 1851 and the sixth segment 1853 on the ground plane 15 are parallel to the first coupling slit 151. A vertical projection of the fifth segment 1852 on the ground plane 15 is positioned at a periphery of the first coupling slit 151, and does not intersect with the first coupling slit 151. In a specific implementation, the vertical projection of the fifth segment 1852 on the ground plane 15 is parallel to the second coupling slit 152.

[0105] In a specific implementation, the vertical projection of the first segment 1751 on the ground plane 15 vertically intersects with the vertical projection of the fourth segment 1851 on the ground plane 15. A free end of the vertical projection of the first segment 1751 on the ground plane 15 touches the vertical projection of the sixth segment 1853 on the ground plane 15. A free end of the vertical projection of the fourth segment 1851 on the ground plane 15 touches the vertical projection of the third segment 1753 on the ground plane 15. The vertical projection of the first segment 1751 on the ground plane 15, the vertical projection of the fourth segment 1851 on the ground plane 15, the vertical projection of the third segment 1753 on the ground plane 15, and the vertical projection of the sixth segment 1853 on the ground plane 15 enclose a rectangular or square area.

[0106] Refer to FIG. 12. The feeding assembly 14 includes the first interface 191 and the second interface 192 that are configured to connect to a radio frequency cable. Both the first interface 191 and the second interface 192 are electrically connected to a feeding network in the baseband through the radio frequency cable. The first interface 191 and the second interface 192 may be disposed at the first layer, so that a connection between the first interface 191 and the radio frequency cable and a connection between the second interface 192 and the radio frequency cable are more convenient, to play an advantage of easy connection. A radio frequency channel between the first interface 191 and the feeding network is configured to transmit a horizontally polarized radio frequency signal, and the radio frequency channel between the second interface 192 and the feeding network is configured to transmit a vertically polarized radio frequency signal. In the first direction, the first interface 191 and the second interface 192 are respectively disposed on two sides of a projection of the radiation patch 12 on the feeding layer 16, that is, the first interface 191 and the second interface 192 are distributed on two sides in the length direction of the radiation patch 12.

[0107] Structures of the first interface 191 and the second interface 192 may be the same. The first interface 191 is used as an example to describe a specific structure. In an implementation, the first interface 191 is disposed at the first layer 161. The first interface 191 includes a grounding part 1911 and a conductive part 1912. The grounding part 1911 and the conductive part 1912 are insulated from each other. Specifically, the grounding part 1911 includes a pair of ground pads disposed oppositely to each other. The conductive part 1912 may be integrally interconnected to the first feed structure 17 (or the second feed structure 18). The conductive part 1912 may be one end of the first feed structure 17 (or the second feed structure 18). The grounding part 1911 and the ground plane 15 are electrically connected, and specifically, may be electrically connected through a conductive through hole. An outer conductor of the radio frequency cable is welded to the grounding part 1911, and an inner conductor of the radio frequency cable is welded to the conductive part 1912. The grounding part 1911 and the conductive part 1912 may be separated by using air as an insulation medium.

[0108] Refer to FIG. 4 and FIG. 5. In an implementation, the dielectric board 11 of the antenna element 10 includes a first surface S1 and a second surface S2 that are disposed back to each other. The radiation patch 12 is disposed on the first surface S1. The first interface 191 and the second interface 192 are positioned on the second surface S2. A part of the first feed structure 17 and a part of the second feed structure 18 are disposed on the second surface S2. As shown in FIG. 5, a part that is of the first feed structure 17 and that is connected to the first interface 191 is positioned on the second surface S2, some transmission lines that are on the first feed structure 17 and that are coupled to the first coupling slit 151 are positioned inside the dielectric board 11, and all transmission lines of the second feed structure 18 are positioned on the second surface S2. In an implementation, the dielectric board 11 is entirely in a shape of a cuboid. The second surface S2 is a rectangle. The second surface S2 of the dielectric board 11 is provided with a first groove 1101 and a second groove 1102. The first groove 1101 and the second groove 1102 are respectively positioned on two short sides of the second surface S2. The first interface 191 is disposed on a periphery of the first groove 1101. The second interface 192 is disposed on a periphery of the second groove 1102. The first groove 1101 and the second groove 1102 are used to accommodate the radio frequency cable. Connectors of the radio frequency cable are accommodated in the first groove 1101 and the second groove 1102, to ensure structural flatness of a position at which the antenna element 10 is connected to the radio frequency cable, facilitate a miniaturization design of an overall size of the antenna element 10, and avoid a case in which the overall size of the antenna element 10 increases because the connector of the radio frequency cable protrudes from an outer surface of the dielectric board 11. For example, the first groove 1101 and the second groove 1102 may be used to place an SMA connector. The radio frequency cable is electrically connected to the antenna element 10 by using the SMA connector.

[0109] The feeding assembly 14 provided in an implementation may be a microstrip architecture disposed on the dielectric board. A feeding manner of the microstrip architecture helps implement size miniaturization of the antenna element 10, and helps implement a low-profile feature of the antenna element. In another implementation, the feeding assembly 14 may alternatively be in another feeding manner, for example, probe feeding. Both a first feed unit and a second feed unit are probe structures. The first feed unit performs feeding at one end of the radiation patch 12 in the first direction to stimulate the vertical polarization of the radiation patch, and the second feed unit performs feeding at a position that is in a middle position of the radiation patch 12 and that is adjacent to one end of the first slit 1221, to excite the horizontal polarization of the radiation patch. Alternatively, the feeding assembly 14 may be another type of feeding architecture, provided that the horizontal polarization and the vertical polarization of the radiation patch can be excited.

[0110] Refer to FIG. 15 and FIG. 16. In an implementation, the first sub-patch 1211A, the second sub-patch 1211B, the first additional sub-patch 1212A, and the second additional sub-patch 1212B are collectively referred to as sub-patches. At least one of the sub-patches is provided with a slot 1213. In an embodiment, an outer profile of each sub-patch is generally a quadrilateral, for example, a square or a rectangle. A slot of the sub-patch should be understood as a slot extending from an outer contour edge of the sub-patch to inside of the sub-patch. It should be understood that the slot of the sub-patch may be in communication with the first slit or the second slit. In the implementations shown in FIG. 15 and FIG. 16, the first sub-patch 1211A, the second sub-patch 1211B, the first additional sub-patch 1212A, and the second additional sub-patch 1212B each are provided with slots 1213. In another implementation, only one sub-patch or two symmetric sub-patches in the sub-patches may be provided with slots 1213. The slot 1213 extends from an edge of the sub-patch to the inside of the sub-patch.

[0111] In an embodiment, the slot 1213 includes a first slot and a second slot. The first slot is provided at a first position of the first sub-patch, and the second slot is provided at a second position of the second sub-patch. In a specific embodiment, the first position and the second position are symmetrical with respect to the first slit 1221. It should be understood that positions of slots being "symmetrical" with respect to the first slit 1221 may not be understood as strict symmetry in a mathematical sense. In this solution, edge openings of the slots are approximately symmetrically provided on two sides of the first slit 1221, and forms of the slots are not limited to be completely consistent.

[0112] In an embodiment, the slot 1213 includes a third slot and a fourth slot. The third slot is provided at a third position of the first additional sub-patch, and the fourth slot is provided at a fourth position of the second additional sub-patch. In a specific embodiment, the third position and the fourth position are symmetrical with respect to the first slit.

[0113] For sub-patches of a same width, an extension path of a current on a sub-patch with a slot increases compared with an extension path of a current on a sub-patch without a slot. In an implementation, in this solution, a current length of the antenna element 10 in the first polarization (for example, the horizontal polarization) may be increased. The slot 1213 allows the antenna element 10 to operate at an expected frequency in the horizontal polarization in limited width space of the sub-patch. In an implementation, during horizontal polarization feeding of the antenna element 10, a current flows along an edge of the sub-patch in the second direction A2. Refer to FIG. 17. In an implementation, the slot 1213 is provided, so that the current can flow along an edge of the slot 1213.

[0114] In an implementation, an extension direction of the slot 1213 includes a third direction A3. In the implementation shown in FIG. 17, the third direction A3 is the same as the first direction A1. In an implementation shown in FIG. 18, there is an included angle between the third direction A3 and the second direction A2 and between the third direction A3 and the first direction A1. In an implementation, the extension direction of the slot 1213 may further include the first direction A1 and the second direction A2. The extension direction of the slot 1213 is not limited in this application, provided that the slot 1213 can increase a current direction of the antenna element 10 in the horizontal polarization, to allow the antenna element 10 to operate at an expected frequency.

[0115] In an implementation, one sub-patch is provided with a plurality of (for example, two or more) slots 1213, and the plurality of slots 1213 are spaced apart from each other, so that an edge of the sub-patch is in a comb-shaped structure. In an implementation shown in FIG. 16, manners (including a quantity and sizes of slots) of providing slots 1213 on the first sub-patch 1211A and the second sub-patch 1211B are the same or similar. For example, the first sub-patch 1211A and the second sub-patch 1211B each are provided with two slots 1213. The two slots 1213 extend from edges that are of the first sub-patch 1211A and the second sub-patch 1211B and that are adjacent to the first slit 1221 to inside of the first sub-patch 1211A and inside of the second sub-patch 1211B, that is, openings of the slots 1213 on the first sub-patch 1211A and the second sub-patch 1211B face the first slit 1221. In an implementation, the slots 1213 provided on the first sub-patch 1211A and the second sub-patch 1211B are symmetrical with respect to the first slit 1221. Manners (including a quantity and sizes of slots 1213) of providing slots 1213 on the first additional sub-patch 1212A and the second additional sub-patch 1212B are the same or similar. For example, the first additional sub-patch 1212A and the second additional sub-patch 1212B each are provided with four slots 1213. The four slots 1213 extend from edges that are of the first additional sub-patch 1212A and the second additional sub-patch 1212B and that are away from the first sub-patch 1211A and the second sub-patch 1211B to inside of the first additional sub-patch 1212A and inside of the second additional sub-patch 1212B, that is, openings of the slots 1213 on the first additional sub-patch 1212A and the second additional sub-patch 1212B are positioned at a top edge or a bottom edge of the radiation patch 12. In an implementation, the slots 1213 provided on the first additional sub-patch 1212A and the second additional sub-patch 1212B are symmetrical with respect to the first slit 1221. A quantity of slots 1213 on each sub-patch is not limited in this application. For example, there may be three, four, or more slots 1213 on the first sub-patch 1211A or the second sub-patch 1211B, and there may be two, three, or more than four slots 1213 on the first additional sub-patch 1212A or the second additional sub-patch 1212B. Certainly, there may be only one slot 1213 on each sub-patch.

[0116] A specific form of the slot 1213 provided on each sub-patch may be a long strip, a rectangle, or a triangle, and an edge of the slot 1213 may be a straight line or an arc.

[0117] Refer to FIG. 19. In an implementation, a sub-patch arranged at the head or tail of a row of sub-patches of the radiation patch 12 is an edge patch. In the implementation shown in FIG. 19, the first additional sub-patch 1212A and the second additional sub-patch 1212B are edge patches. The first additional sub-patch 1212A and the second additional sub-patch 1212B each include a patch body 1214 and protruding structures 1215 connected to the patch body 1214. In the first direction A1, the protruding structures 1215 are positioned on a side that is of the patch body 1214 and that is away from the first sub-patch 1211A and the second sub-patch 1211B, and an extension direction of the protruding structures 1215 includes the third direction A3. The third direction A3 is the same as the first direction A1, or there is an included angle between the third direction A3 and the first direction A1. A principle of disposing the protruding structure 1215 is the same as or similar to a design principle of the slot 1213. In this solution, the protruding structure 1215 is disposed at an edge of the edge patch, so that a path of a current flow direction of the antenna element 10 in the horizontal polarization changes, and a current path becomes longer, to adjust a frequency. A shape of the protruding structure 1215 may be a rectangle or a triangle. If another shape is used, an edge of the protruding structure 1215 may be a straight-line edge, or may include a curved edge or an arc edge.

[0118] In a specific implementation of this application, the sub-patches of the radiation patch are arranged in one row, and the radiation patch has at least three slits (the first slit 1221 and the second slit 1222) that penetrate the radiation patch in the second direction A2 and at most one slit that penetrates the radiation patch in the first direction A1, to limit the radiation patch to a long strip shape, that is, the length of the radiation patch is greater than the width of the radiation patch. The length-to-width ratio is limited, so that the first feed unit can excite the radiation patch to generate two modes in the horizontal polarization and the second feed unit can excite the radiation patch to generate two modes in the vertical polarization. In a specific implementation of this application, size limitations such as a limitation on the length-to-width ratio of the radiation patch and a limitation on a slit width size are merely states presented in a specific implementation. In another implementation, a specific size may be adjusted based on a specific design requirement, an application requirement, and the like.

[0119] Refer to FIG. 19A. In an implementation shown in FIG. 19A, the radiation patch 12 has a slit 1225 that penetrates the radiation patch in the first direction A1. In this implementation, the radiation patch 12 includes the first sub-patch 1211A, the second sub-patch 1211B, the first additional sub-patch 1212A, and the second additional sub-patch 1212B. The slit 1225 passes through, in the first direction A1, middle positions that are of the first sub-patch 1211A, the second sub-patch 1211B, the first additional sub-patch 1212A, and the second additional sub-patch 1212B and that are in the second direction. The slit 1225 intersects with the first slit 1221, the first sub-slit 1222A, and the second sub-slit 1222B.

[0120] FIG. 20 is a curve graph of S-parameters of the antenna element 10 according to the implementation of this application. As shown in FIG. 20, the antenna element 10 separately generates three operating resonances in the vertical polarization (a curve represented by S2,2-VP) and the horizontal polarization (a curve represented by S1,1-HP). Operating bandwidths cover 4.88 GHz to 6.45 GHz and 5.1 GHz to 6.07 GHz respectively. Isolation (a curve represented by S2,1) between the vertical polarization and the horizontal polarization is greater than 17 dB within an operating bandwidth (or referred to as an in-band), indicating that the antenna element 10 has good bandwidth performance. The antenna element provided in a specific implementation of this application operates in a 5G Wi-Fi frequency band, with an operating bandwidth of 5.15 GHz to 5.85 GHz.

[0121] FIG. 21(a) and FIG. 21(b) are radiation patterns of the vertical polarization port of the antenna element 10 during excitation at 5 GHz and 5.6 GHz according to the implementation of this application. FIG. 22(a) and FIG. 22(b) are radiation patterns of the horizontal polarization port of the antenna element 10 during excitation at 5.25 GHz and 5.8 GHz according to the implementation of this application. It can be learned from FIG. 21(a) to FIG. 22(b) that, in the vertical polarization and the horizontal polarization, a high-gain fan-shaped beam with a wide horizontal beam and a narrow pitch plane beam is observed at different frequencies, indicating that the antenna element 10 provided in this application has a good coverage capability.

[0122] FIG. 23 is an efficiency curve graph of the antenna element 10 according to the implementation of this application. FIG. 24 is a gain curve graph of the antenna element 10 according to the implementation of this application. As shown in FIG. 23 and FIG. 24, for the antenna element 10 provided in this application, a gain level (a curve marked as "horizontal polarization" and indicated by an elliptical dashed line) in the horizontal polarization is 6 dBi to 7 dBi at 5.15 GHz to 5.90 GHz, a gain level (marked as "vertical polarization" and indicated by an elliptical dashed line) in the vertical polarization is 6 dBi to 8 dBi at 5 GHz to 6 GHz, and in-band system efficiency is greater than -1.5 dB in the horizontal polarization and the vertical polarization, indicating that the antenna element 10 provided in this application has a good radiation capability and a good gain level.

[0123] FIG. 25(a) and FIG. 25(b) are distribution diagrams of currents of the antenna element 10 in the vertical polarization at 5 GHz and 5.6 GHz according to the implementation of this application. FIG. 25(c) and FIG. 25(d) are distribution diagrams of electric fields of the antenna element 10 in the vertical polarization at 5 GHz and 5.6 GHz according to the implementation of this application. As shown in FIG. 25(a) to FIG. 25(d), the antenna element operates in the first operating mode at 5.0 GHz, and the antenna element operates in the reverse second operating mode at 5.6 GHz.

[0124] FIG. 26(a) and FIG. 26(b) are distribution diagrams of currents of the antenna element 10 in the horizontal polarization at 5.25 GHz and 5.8 GHz according to the implementation of this application. FIG. 26(c) and FIG. 26(d) are distribution diagrams of electric fields of the antenna element 10 in the horizontal polarization at 5.25 GHz and 5.8 GHz according to the implementation of this application. As shown in FIG. 26(a) to FIG. 26(d), at an operating frequency of 5.25 GHz, two middle sub-patches (the first sub-patch) generate resonances, and at an operating frequency of 5.8 GHz, namely, in a parasitic mode, two additional sub-patches generate resonances. During the vertical polarization, three slits on the radiation patch that are parallel to a wide side are mainly used to increase a bandwidth through capacitive loading and increase a radiation aperture, so as to improve a gain level. Three slits on the radiation patch that are parallel to a broad side are mainly used in horizontal polarization to expand a bandwidth in a parasitic mode and avoid generation of a transverse mode at a radiating edge.

[0125] In order to illustrate independent regulation effect of a slot or protruding structure extending in the third direction on a frequency response in the vertical polarization and the horizontal polarization, FIG. 27, FIG. 28, FIG. 29, and FIG. 30 are respective diagrams of S-parameters of the horizontal polarization port and the vertical polarization port during excitation when slots extending in the third direction have different sizes. FIG. 27 shows impact of adjusting a size, namely, Ld1, of a slot on the first sub-patch on a main mode and a parasitic mode that are generated when the antenna element is horizontally polarized. FIG. 28 shows impact of adjusting a size, namely, Ld2, of a slot on the additional sub-patch on a main mode and a parasitic mode that are generated when the antenna element is horizontally polarized. FIG. 29 shows impact of adjusting a size, namely, Ld1, of a slot on the first sub-patch on two modes that are generated when the antenna element is vertically polarized. FIG. 30 shows impact of adjusting a size, namely, Ld2, of a slot on the additional sub-patch on two modes that are generated when the antenna element is vertically polarized. In FIG. 27, a size range of Ld1 is 4.9 mm to 5.2 mm. In FIG. 28, a size range of Ld2 is 4.8 mm to 5.2 mm. As shown in FIG. 27 and FIG. 29, when a quantity of slots remains unchanged and the length Ld1 of the slot increases, a main operating mode under horizontal polarization feeding moves toward a low frequency, a frequency in the parasitic operating mode basically remains unchanged, and a frequency in the vertical polarization also remains unchanged. As shown in FIG. 28 and FIG. 30, when the length Ld2 of the slot increases, a parasitic operating mode under horizontal polarization feeding moves toward a low frequency, a frequency in the main operating mode basically remains unchanged, and a frequency in the vertical polarization also remains unchanged. Therefore, in this application, a slot or protruding structure is provided on a sub-patch, so that a frequency response of a horizontal polarization port can be independently controlled; and a dual-polarized symmetric slot or protruding structure is designed, so that resonance frequencies in the main operating mode and the parasitic operating mode during horizontal polarization feeding can be separately adjusted. Specifically, if only the resonance frequency in the main operating mode needs to be controlled, only the first sub-patch needs to be provided with a slot, or if the resonance frequency in the parasitic mode needs to be controlled, only the additional sub-patch needs to be provided with a slot. In a specific implementation, a direction of the slot is the first direction, and the slot does not affect distribution of currents in the vertical polarization. Therefore, the slot does not affect an operating frequency in the vertical polarization.

[0126] In an implementation, the antenna array provided in this application includes at least two antenna elements, and the at least two antenna elements are sequentially arranged in the second direction. The antenna array provided in this application is a low-profile dual-polarized array. Refer to FIG. 31. In an implementation, the antenna array 100 includes four antenna elements 10 sequentially arranged in the second direction, and an electrical length of a spacing d between adjacent antenna elements 10 is within a range of 0.2 λ to 0.7 λ. In a specific implementation, d=0.31 λ. A physical length of the spacing d between the adjacent antenna elements 10 varies greatly depending on a frequency band range. In a 5G Wi-Fi frequency band, the physical length of the spacing d between the adjacent antenna elements 10 ranges from 10 mm to 42 mm. In a specific implementation, the physical length of the spacing d between the adjacent antenna elements 10 is 18.75 mm. Specifically, the spacing d between the adjacent antenna elements 10 may be a distance between the radiation patches 12 in the second direction A2. The four antenna elements 10 may have a same structure or size, or may have different structures or sizes. Different structures of the antenna elements 10 may be reflected in different quantities, forms, and positions of slits, different quantities, shapes, and sizes of sub-patches, different shapes, sizes, or distribution of slots or protruding structures extending in the third direction, or the like.

[0127] Refer to FIG. 32. First interfaces 191 of all antenna elements 10 are positioned on one edge of the antenna array 100, and second interfaces 192 of all antenna elements 10 are positioned on the other edge of the antenna array 100. Specifically, in the implementation shown in FIG. 32, the four antenna elements 10 have eight feeding ports (which are four first interfaces 191 and four second interfaces 192 respectively), the four first interfaces 191 are arranged at a first edge position (for example, a bottom edge in the figure) of the antenna array 100, and the four second interfaces 192 are arranged at a second edge position (for example, a top edge in the figure) of the antenna array 100. This design facilitates cable connection. In this application, feeding ports of adjacent antenna elements are isolated from each other, for example, horizontal polarization feeding ports or vertical polarization feeding ports are isolated from each other at an equal or similar spacing, to facilitate circuit configuration and ensure consistency of electromagnetic wave signal beams.

[0128] The antenna array 100 may be connected to the phase-shift element. For a specific connection manner, refer to FIG. 1 (described above, and details are not described again).

[0129] FIG. 33 is a diagram of a situation in which an array factor in an antenna array (which may be a one-dimensional linear array) including four antenna elements changes with a spacing d between the antenna elements. In FIG. 33, a size of the spacing d between the antenna elements is marked as a multiple relationship of an electrical length of the spacing d between the antenna elements, and changes of a parameter value of the array factor in which d=0.25 λ, 0.5 λ, and 0.75 λ are respectively marked. A specific spacing d between the antenna elements that is marked in the upper right corner of the curve graph as FIG. 33 points to a specific curve by using an indication line with an arrow. It can be seen from FIG. 33 that when the spacing d between the antenna elements increases, a value of the array factor increases, but a beam width of a main lobe greatly narrows. In FIG. 33, for three curves corresponding to areas in which horizontal coordinates are between 80 and 100, peak values are different at different widths. It is clear that the larger the spacing d between the antenna elements, the smaller the beam width. A beam width corresponding to a minimum spacing d (0.25 λ) between the antenna elements is the widest (a radius of a radian at a peak position is the largest), and a beam width corresponding to a maximum spacing d (0.75 λ) between the antenna elements is the narrowest (a radius of a radian at a peak position is the smallest). Therefore, in this application, after an array gain is improved by increasing an array spacing, an array scanning range is significantly reduced because an array factor beam becomes narrower.

[0130] FIG. 34 is an architecture of an antenna array of a patch 1*4 array. The antenna array 100A includes four antenna elements 10A. FIG. 35 shows a situation in which an array gain of a patch 1*4 array changes with a spacing between elements.

[0131] FIG. 36 shows a situation in which an array gain of a low-profile high-performance dual-polarized 1*4 antenna array changes with a spacing between elements according to this application.

[0132] It can be seen from FIG. 35 and FIG. 36 that, when the spacing decreases, gains of the two arrays decrease significantly, and beams become wider; however, the low-profile high-performance dual-polarized 1*4 antenna array shown in FIG. 36 provided in this application can maintain, at a smaller spacing λ/4, a gain level the same as that of the patch 1*4 array antenna shown in FIG. 35 at a spacing λ/2, while with a wider beam. Beam widening may be understood as a width of a horizontal coordinate in a peak area of a main lobe corresponding to a same vertical coordinate.

[0133] FIG. 37A to FIG. 37C are diagrams of beam consistency of a patch 1*4 array at different spacings (namely, spacings d between antenna elements are λ/4, λ/3, and λ/2 respectively). FIG. 38A to FIG. 38C are diagrams of beam consistency of a low-profile high-performance dual-polarized 1*4 antenna array at different spacings (namely, spacings d between antenna elements are λ/4, λ/3, and λ/2 respectively) according to this application. It can be learned by comparing FIG. 37A to FIG. 37C with FIG. 38A to FIG. 38C that, at a same spacing, beam consistency of antenna elements of the low-profile high-performance dual-polarized 1*4 antenna array provided in this application is greatly better than that of the patch 1*4 array antenna. Beam consistency may be reflected through peak value distribution. A distance between peak values of beams shown in FIG. 37A to FIG. 37C is large, and a distance between peak values of corresponding beams shown in FIG. 38A to FIG. 38C is small.

[0134] FIG. 39(a) to FIG. 39(c) are diagrams of S-parameters of an antenna array according to a specific implementation of this application. As shown in FIG. 39(a) to FIG. 39(c), an operating bandwidth of the antenna array provided in this application in the vertical polarization may cover 5.1 GHz to 5.9 GHz, and in-band isolation between each port is greater than 13.2 dB. An operating bandwidth in the horizontal polarization may cover 5.1 GHz to 5.8 GHz, and in-band isolation between each port is greater than 10.4 dB. The in-band isolation between the horizontal polarization and the vertical polarization is higher than 16.6 dB. This indicates that the antenna array provided in this application has good bandwidth and isolation performance when the antenna array is arranged at a small spacing.

[0135] FIG. 40(a) and FIG. 40(b) are diagrams of scanning capabilities of the antenna array in the horizontal polarization and the vertical polarization at 5.2 GHz, 5.5 GHz, and 5.8 GHz according to a specific implementation of this application. As shown in FIG. 40(a) and FIG. 40(b), scanning angles of 3 dB gain roll-off at 5.2 GHz, 5.5 GHz, and 5.8 GHz in the vertical polarization are 70°, 69°, and 66°, respectively, scanning angles of 5 dB gain roll-off at 5.2 GHz, 5.5 GHz, and 5.8 GHz in the vertical polarization are 85°, 81°, and 78°, respectively, scanning angles of 3 dB gain roll-off at 5.2 GHz, 5.5 GHz, and 5.8 GHz in the horizontal polarization are 71°, 67°, and 66°, respectively, and scanning angles of 5 dB gain roll-off at 5.2 GHz, 5.5 GHz, and 5.8 GHz in the horizontal polarization are 81°, 80°, and 79°, respectively.

[0136] Table 1 and Table 2 respectively show scanning performance and a phase requirement of an antenna array provided in an implementation of this application in the vertical polarization and the horizontal polarization. It can be learned from the tables that both the vertical polarization and the horizontal polarization show good gain levels and scanning/coverage performance, gain and scanning performance of the vertical polarization are slightly better than those of horizontal polarization. States in status bars in Table 1 and Table 2 is a phase difference between two adjacent feeding ports. Specifically, Table 1 reflects a phase difference between two adjacent feeding ports in a vertical polarization port group, where a state I indicates that all feeding ports have a same phase, that is, a phase difference between two adjacent feeding ports is 0°; a state II indicates that a phase difference between two adjacent feeding ports is 45°; and a state III indicates that a phase difference between two adjacent feeding ports is 120°. Similarly, FIG. 2 reflects a phase difference between two adjacent feeding ports in a horizontal polarization port group, where a state I indicates that all feeding ports have a same phase, that is, a phase difference between two adjacent feeding ports is 0°; a state II indicates that a phase difference between two adjacent feeding ports is 45°; and a state III indicates that a phase difference between two adjacent feeding ports is 120°.

Table 1 Scanning performance and phase requirements of the array in the vertical polarization

Vertical polarization	Frequency (GHz)	Isolation (dB)	Peak gain (dBi)	Scanning angle (3 dB gain drop)	Scanning angle (5 dB gain drop)	Status	Phase	Beam direction	Gain (dBi)
	5.2	13.3	10.9	70	85	State I	0°	0°	10.9
						State II	45°	27°	10.7
						State III	120°	52°	9.2
	5.5	14.4	11.5	69	81	State I	0°	0°	11.5
						State II	45°	24°	11.2
						State III	120°	53°	9.5

(continued)

Vertical polarization	Frequency (GHz)	Isolation (dB)	Peak gain (dBi)	Scanning angle (3 dB gain drop)	Scanning angle (5 dB gain drop)	Status	Phase	Beam direction	Gain (dBi)
	5.8	13.2	12.0	66	78	State I	0°	0°	12.0
						State II	45°	23°	11.7
						State III	120°	50°	10.1

Table 2 Scanning performance and phase requirements of the array in the horizontal polarization

Horizontal polarization	Frequency (GHz)	Isolation (dB)	Peak gain (dBi)	Scanning angle (3 dB gain drop)	Scanning angle (5 dB gain drop)	Status	Phase	Beam direction	Gain (dBi)
	5.2	10.4	10.1	71	81	State I	0°	0°	10.1
						State II	45°	25°	8.6
						State III	120°	50°	9.1
	5.5	14.2	11.2	67	80	State I	0°	0°	11.2
						State II	45°	20°	10.1
						State III	120°	48°	9.5
	5.8	17.6	11.5	66	79	State I	0°	0°	11.5
						State II	45°	20°	10.6
						State III	120°	47°	9.6

[0137] Embodiments of this application are described above. The foregoing descriptions are examples, are not exhaustive, and are not limited to the disclosed embodiments. Many modifications and changes are apparent to a person of ordinary skill in the art without departing from the scope and spirit of the illustrated embodiments. Selection of terms used in this specification is intended to best explain the principles of embodiments, actual application, or improvements to technologies in the market, or to enable another person of ordinary skill in the art to understand embodiments disclosed in this specification.

Claims

1. An antenna element, comprising:

a radiation patch, comprising a first additional sub-patch, a first sub-patch, a second sub-patch, and a second additional sub-patch that are sequentially arranged in a first direction, wherein the radiation patch comprises a first slit and a second slit that penetrate the radiation patch in a second direction, the first slit is formed between the first sub-patch and the second sub-patch, the second slit comprises a first sub-slit and a second sub-slit, the first sub-slit is formed between the first sub-patch and the first additional sub-patch, the second sub-slit is formed between the second sub-patch and the second additional sub-patch, a maximum size of the radiation patch in the first direction is a length of the radiation patch, a maximum size of the radiation patch in the second direction is a width of the radiation patch, and a length-to-width ratio R of the radiation patch satisfies $R \geq 2$; and
a feeding assembly, configured to excite the radiation patch.

2. The antenna element according to claim 1, wherein the first slit and the second slit each comprise a first end and a second end, both an extension direction of the first slit and an extension direction of the second slit are a direction in which the first end points to the second end, and both the extension direction of the first slit and the extension direction of the second slit are the second direction.

3. The antenna element according to claim 2, wherein both a length of the first slit and a length of the second slit are a size of an extension path extending from the first end to the second end, both a width of the first slit and a width of the second slit are a size in a direction perpendicular to the extension path, and both the width of the first slit and the width of the second slit are within a range of 0.03 mm to 3 mm.

4. The antenna element according to claim 3, wherein both the width of the first slit and the width of the second slit are within a range of 0.5 mm to 1.5 mm.

5. The antenna element according to claim 3, wherein the width of the second slit is less than or equal to 2 mm.

6. The antenna element according to any one of claims 1 to 5, wherein the length-to-width ratio R of the radiation patch satisfies $3 \leq R \leq 5$.

7. The antenna element according to any one of claims 1 to 6, wherein the radiation patch does not have a slit that penetrates the radiation patch in the first direction, or the radiation patch has only one slit that penetrates the radiation patch in the first direction.

8. The antenna element according to any one of claims 1 to 7, wherein the first slit is in a middle position of the radiation patch in the first direction, and the second slit is symmetrically distributed on two sides of the first slit in the first direction.

9. The antenna element according to any one of claims 1 to 8, wherein the feeding assembly comprises a ground plane and a feeding layer, the ground plane is disposed between the feeding layer and the radiation patch in a stacked manner, the feeding layer comprises a first feed structure and a second feed structure, the ground plane is provided with a first coupling slit and a second coupling slit that are provided in a cross manner, the first feed structure and the first coupling slit are provided directly opposite to each other, and the second feed structure and the second coupling slit are provided directly opposite to each other.

10. The antenna element according to claim 9, wherein the first coupling slit at least partially overlaps the first sub-patch, the first coupling slit at least partially overlaps the second sub-patch, and the second coupling slit is provided directly opposite to the first slit.

11. The antenna element according to claim 9 or 10, wherein the second coupling slit does not overlap the first sub-patch, and the second coupling slit does not overlap the second sub-patch.

12. The antenna element according to any one of claims 9 to 11, wherein the first coupling slit does not overlap the first additional sub-patch and the second additional sub-patch, and the second coupling slit does not overlap the first additional sub-patch and the second additional sub-patch.

13. The antenna element according to any one of claims 9 to 12, wherein the first sub-patch, the second sub-patch, the first additional sub-patch, and the second additional sub-patch are collectively referred to as sub-patches, at least one sub-patch is provided with a slot, the slot extends from an edge of the sub-patch to inside of the sub-patch, and an extension direction of the slot comprises a third direction; and
the third direction is the same as the first direction, or there are an included angle between the third direction and the second direction and an included angle between the third direction and the first direction.

14. The antenna element according to claim 13, wherein the slot comprises a first slot and a second slot, the first slot is provided at a first position of the first sub-patch, the second slot is provided at a second position of the second sub-patch, and the first position and the second position are symmetrical with respect to the first slit.

15. The antenna element according to claim 13 or 14, wherein the slot comprises a third slot and a fourth slot, the third slot is provided at a third position of the first additional sub-patch, the fourth slot is provided at a fourth position of the second additional sub-patch, and the third position and the fourth position are symmetrical with respect to the first slit.

16. The antenna element according to any one of claims 9 to 15, wherein the first coupling slit and the second coupling slit form a cross-shaped slit structure.

17. The antenna element according to claim 16, wherein the feeding assembly comprises a first interface and a second interface that are configured to connect to a radio frequency cable, one end of the first feed structure is connected to the first interface, another end of the first feed structure is disposed directly opposite to the first coupling slit, one end of the second feed structure is connected to the second interface, another end of the second feed structure is disposed directly opposite to the second coupling slit, and in the first direction, the first interface and the second interface are respectively disposed on two sides of a projection of the radiation patch on the feeding layer.

18. An antenna array, comprising at least two antenna elements according to any one of claims 1 to 17, wherein the at least two antenna elements are sequentially arranged in a second direction.

19. A communication device, comprising a feeding network and the antenna array according to claim 18, wherein the first feed structure and the second feed structure of the antenna element are electrically connected to the feeding network.

20. A communication device, comprising a feeding network and the antenna element according to any one of claims 1 to 17, wherein the first feed structure and the second feed structure are electrically connected to the feeding network.

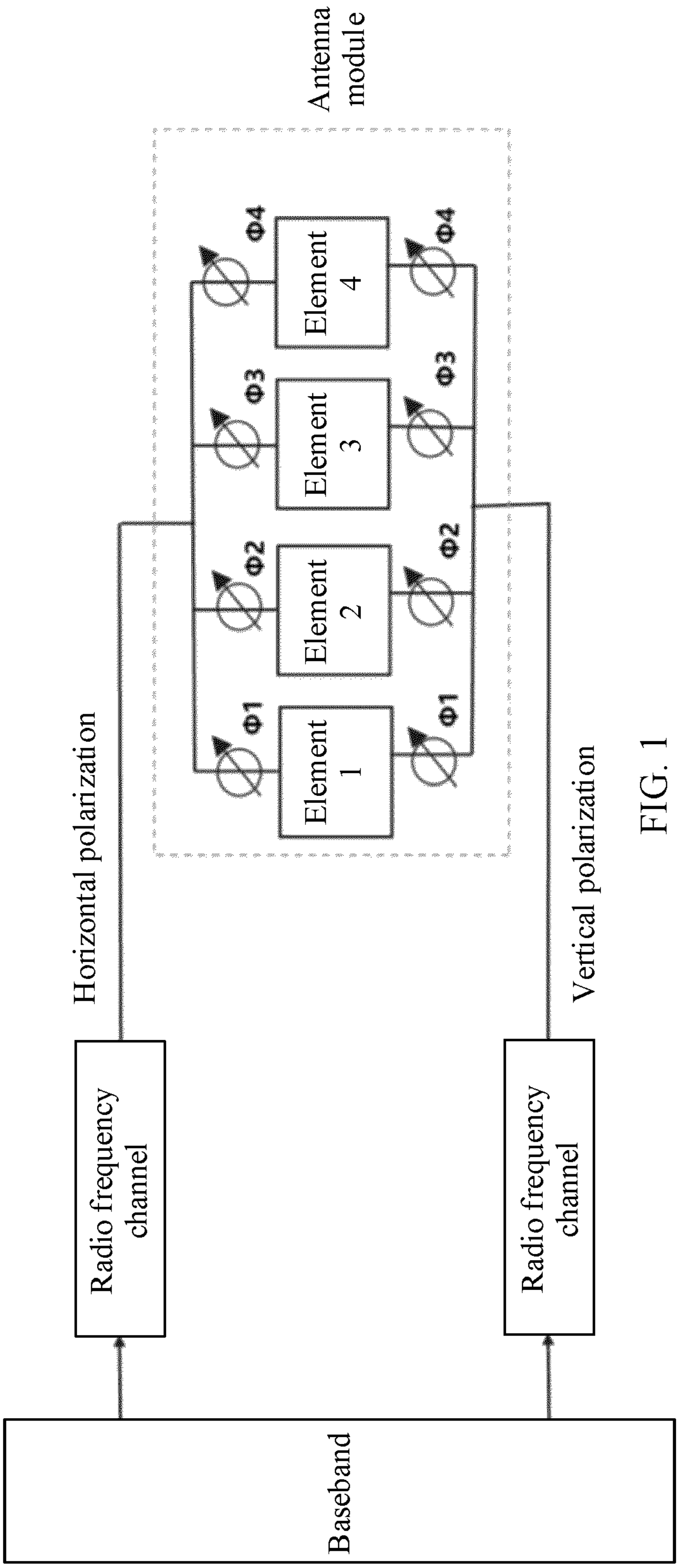

Antenna module
Element 1
Element 2
Element 3
Element 4
Φ1
Φ2
Φ3
Φ4
Horizontal polarization
Vertical polarization
Radio frequency channel
Radio frequency channel
Baseband

FIG. 1

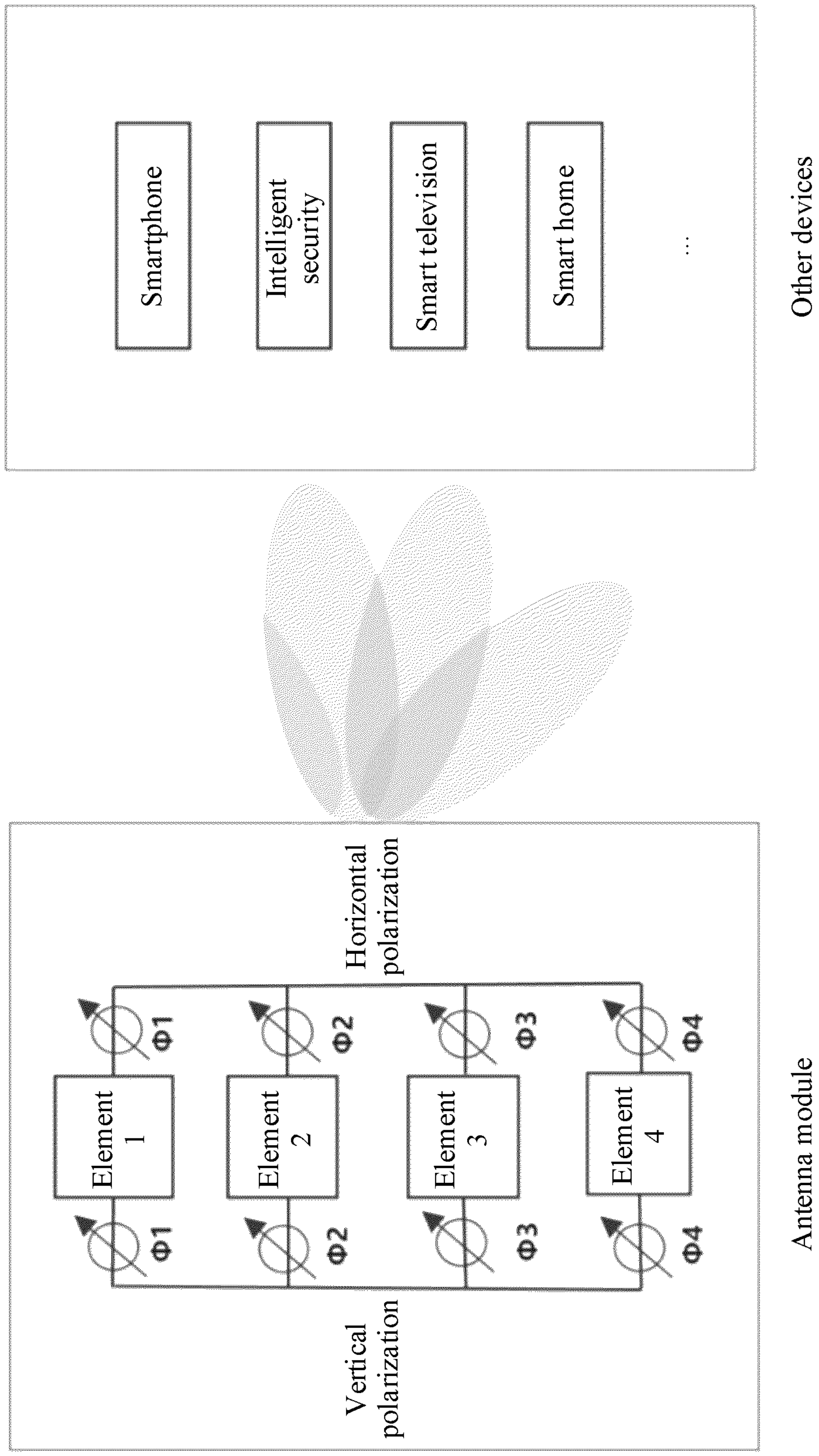

Smartphone
Intelligent security
Smart television
Smart home
...
Other devices
Element 1
Element 2
Element 3
Element 4
Φ1
Φ2
Φ3
Φ4
Φ1
Φ2
Φ3
Φ4
Horizontal polarization
Vertical polarization
Antenna module

FIG. 2

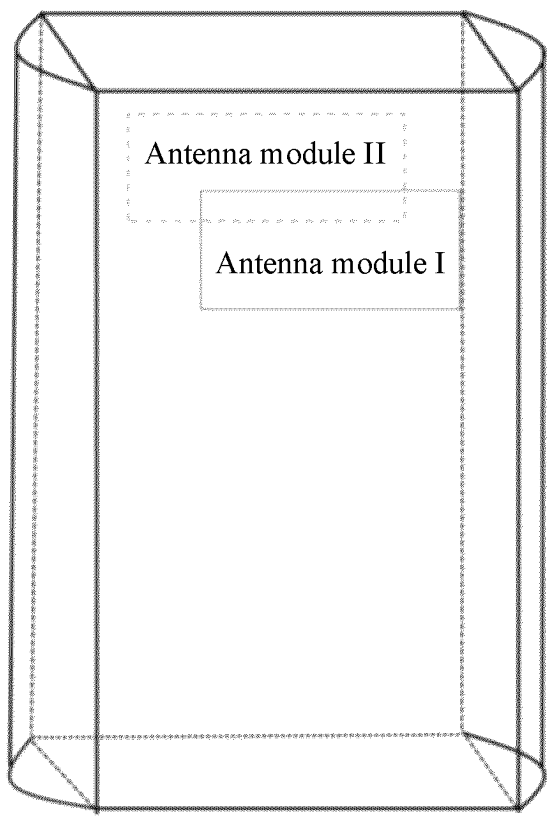


FIG. 3A

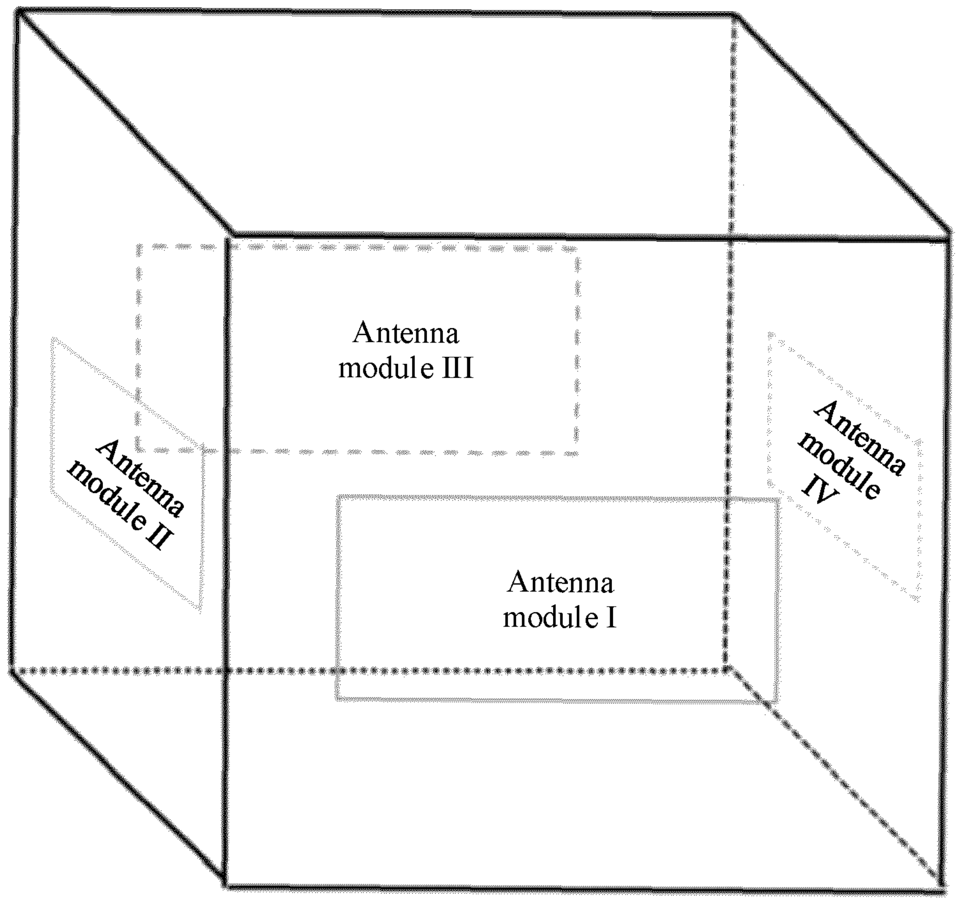

Antenna
module III
Antenna
module II
Antenna
module IV
Antenna
module I

FIG. 3B

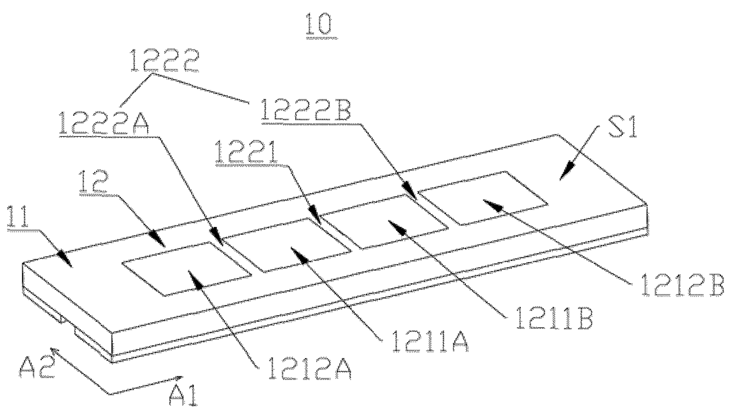

10
1222
1222A
1222B
S1
1221
12
11
1212B
1211B
1211A
A2
1212A
A1

FIG. 4

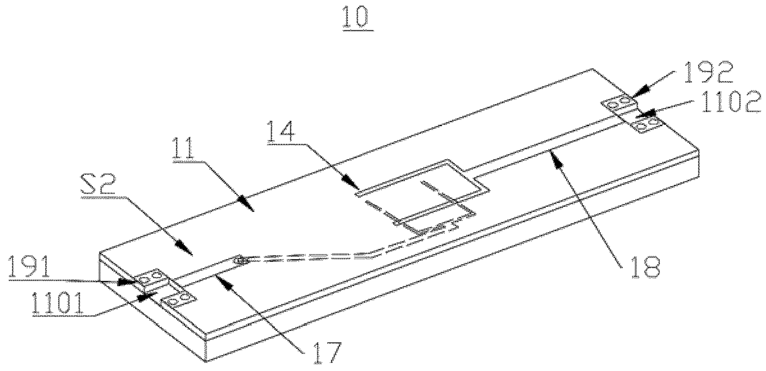

10
192
1102
14
11
S2
191
1101
18
17

FIG. 5

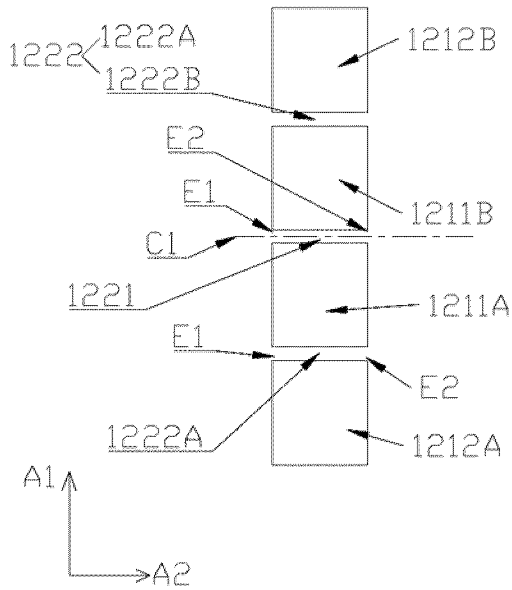

1222
1222A
1222B
1212B
E2
E1
1211B
C1
1221
1211A
E1
E2
1222A
1212A
A1
A2

FIG. 6

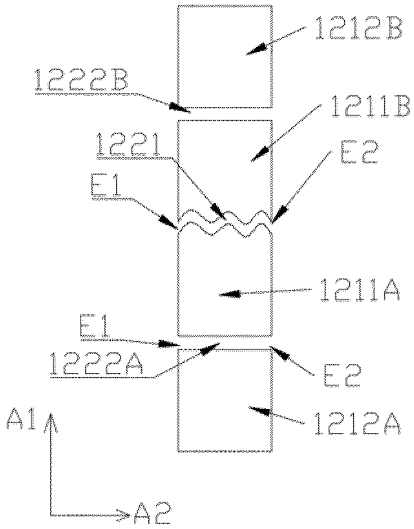


FIG. 7

Main operating mode

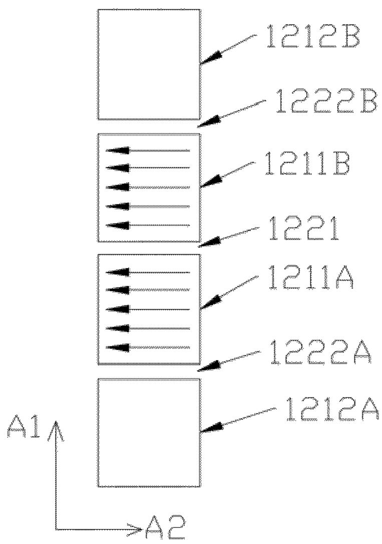


FIG. 8A

Parasitic operating mode

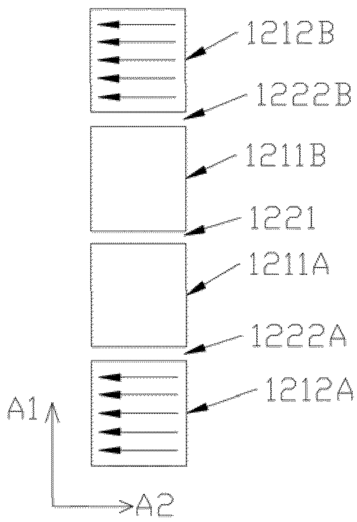


FIG. 8B

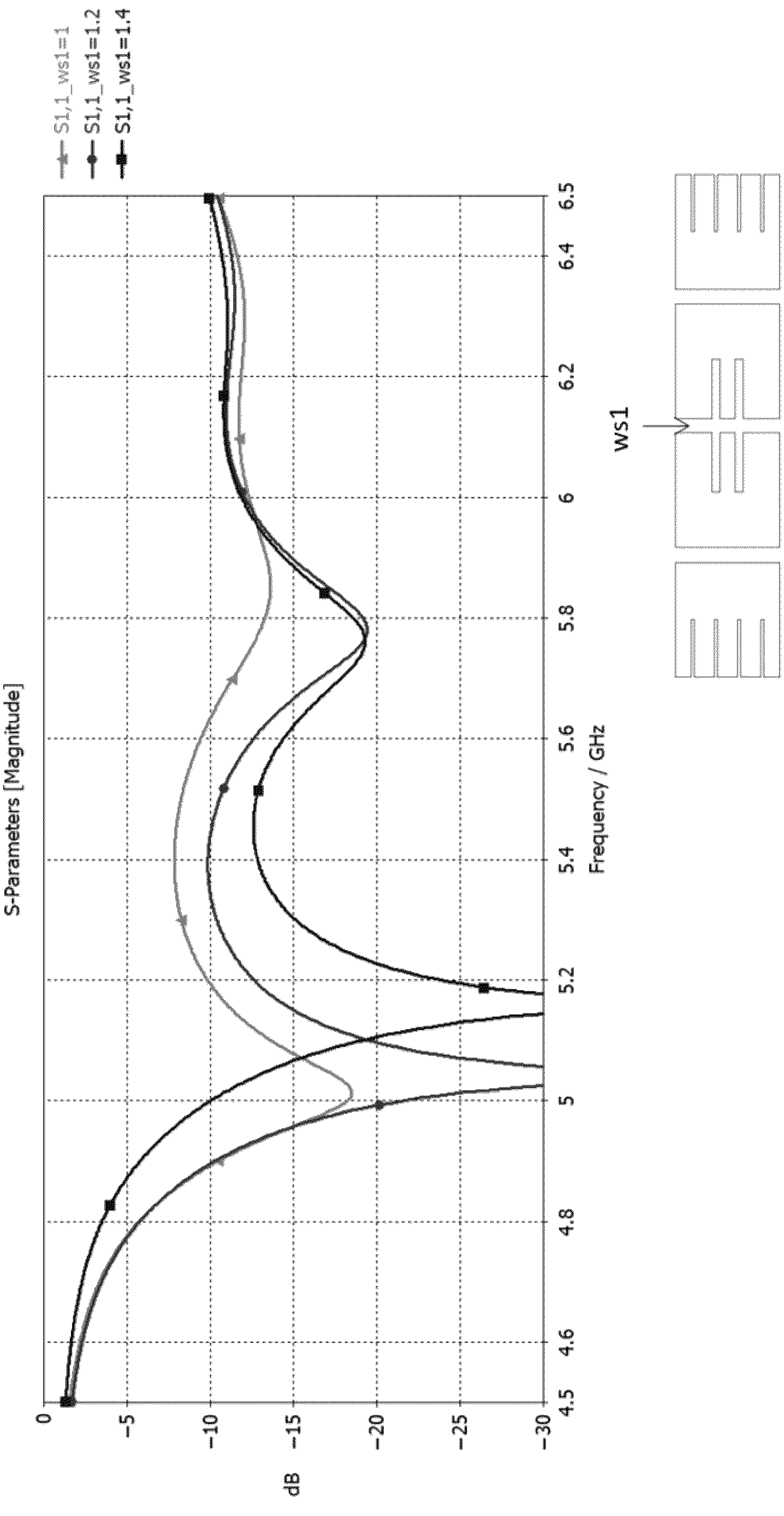

S-Parameters [Magnitude]
S1,1_ws1=1
S1,1_ws1=1.2
S1,1_ws1=1.4
dB
0
−5
−10
−15
−20
−25
−30
4.5
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4
6.5
Frequency / GHz
ws1

FIG. 9A

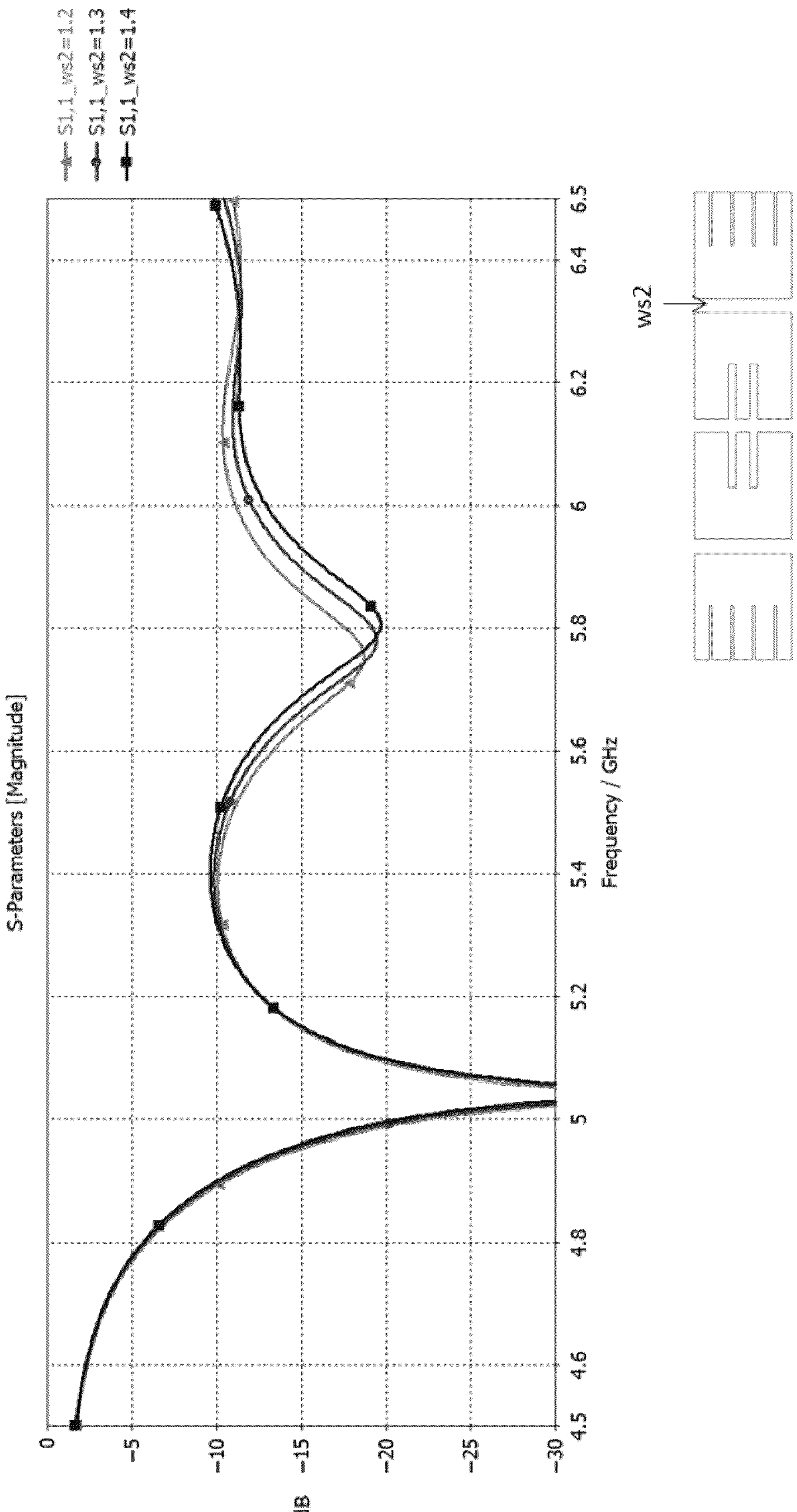

S-Parameters [Magnitude]
S1,1_ws2=1.2
S1,1_ws2=1.3
S1,1_ws2=1.4
dB
0
−5
−10
−15
−20
−25
−30
4.5
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4
6.5
Frequency / GHz
ws2

FIG. 9B

First operating mode

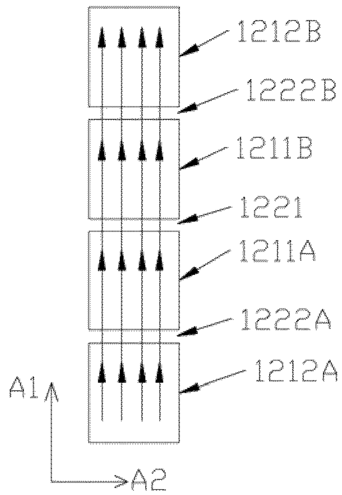


FIG. 10A

First operating mode

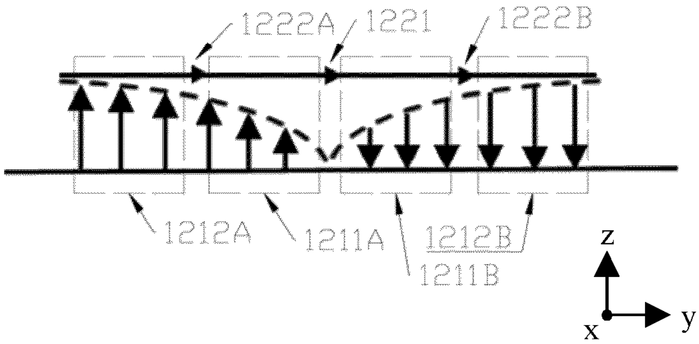


FIG. 10B

Second operating mode

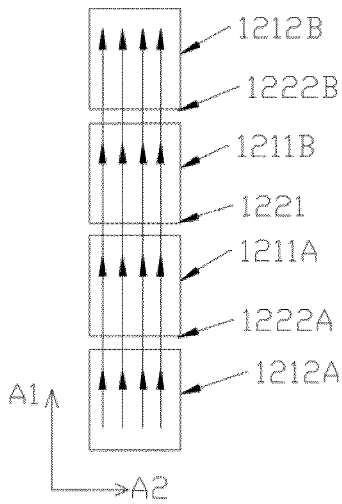


FIG. 11A

Second operating mode

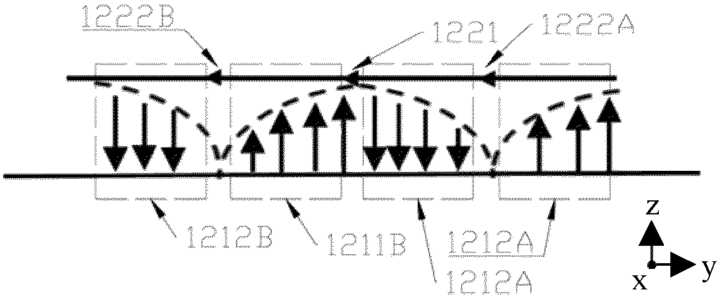


FIG. 11B

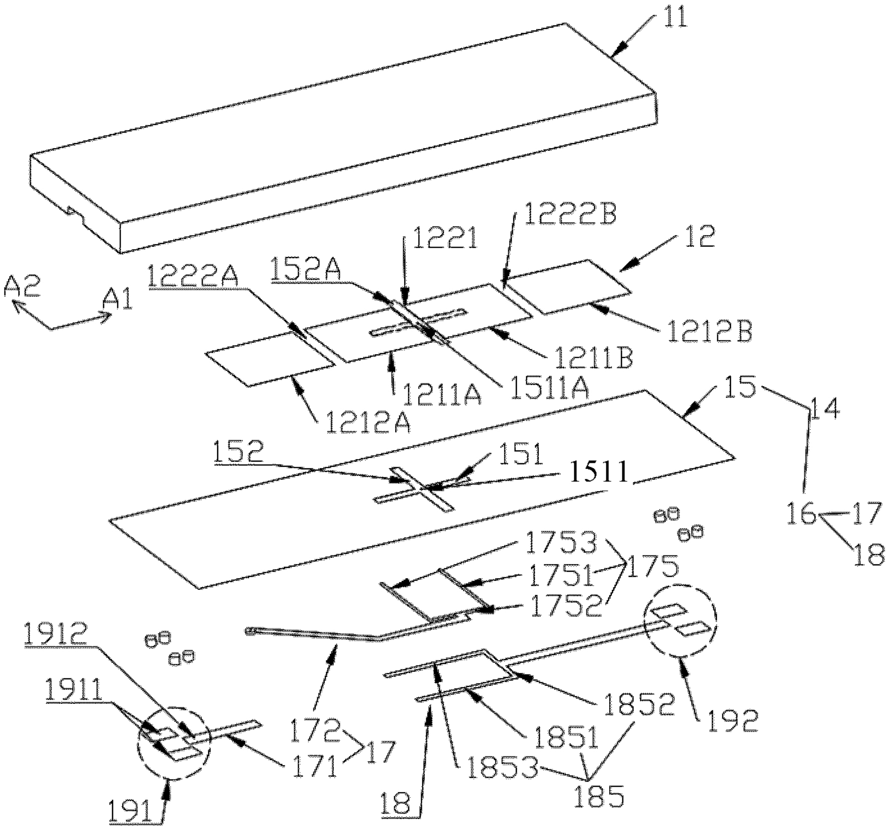

11
1222B
12
1221
152A
1222A
A2
A1
1212B
1211B
1511A
1211A
1212A
15
14
152
151
1511
16
17
18
1753
1751
175
1752
1912
1911
172
17
171
1852
192
1851
1853
185
191
18

FIG. 12

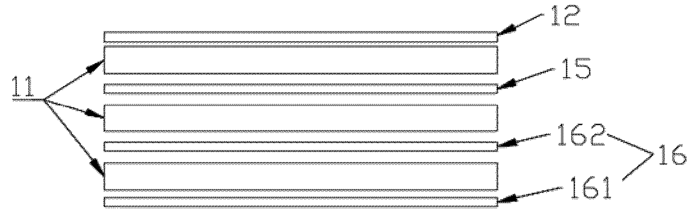

12
15
11
162
16
161

FIG. 13

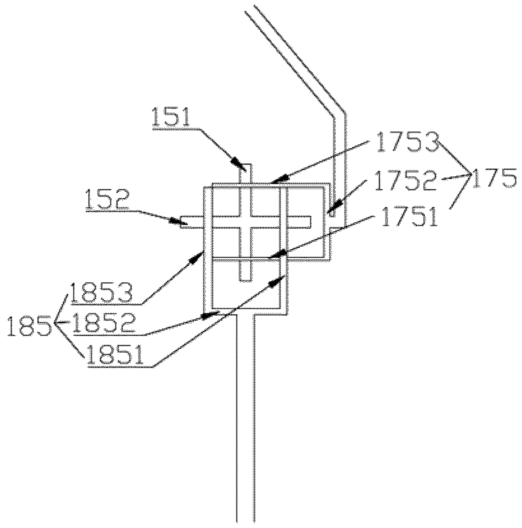

151
152
1753
1752
175
1751
1853
185
1852
1851

FIG. 14

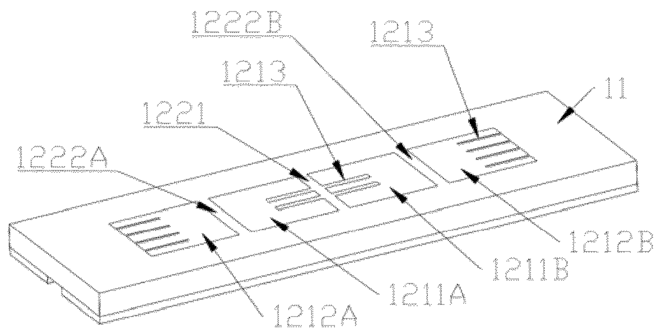

1222B
1213
1213
11
1221
1222A
1212B
1211B
1211A
1212A

FIG. 15

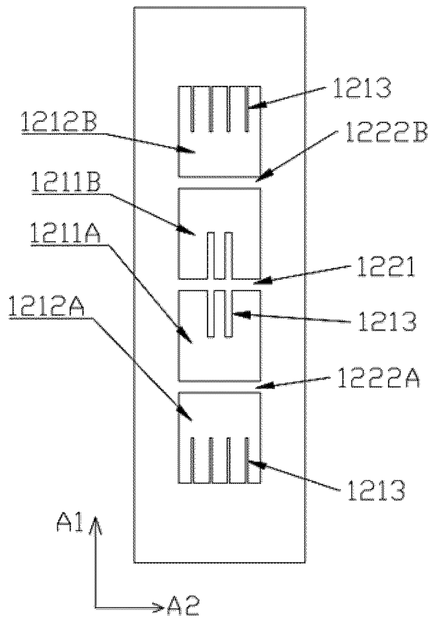

1213
1212B
1222B
1211B
1211A
1221
1213
1212A
1222A
1213
A1
A2

FIG. 16

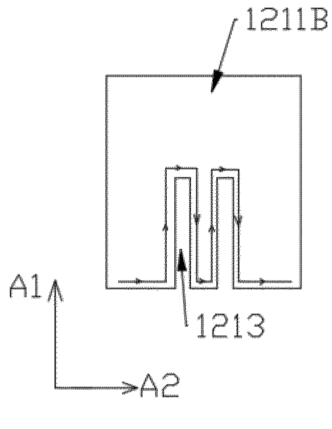

1211B
A1
1213
A2

FIG. 17

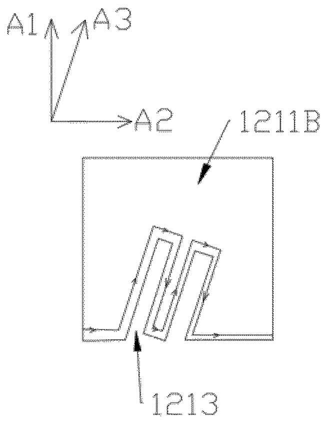

A1
A3
A2
1211B
1213

FIG. 18

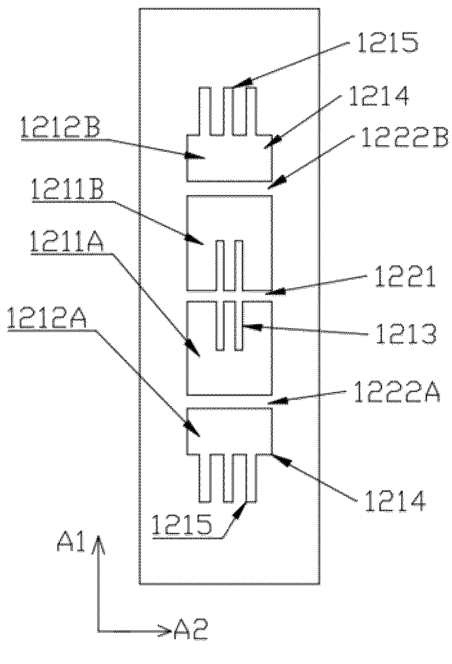

1215
1214
1212B
1222B
1211B
1211A
1221
1213
1212A
1222A
1214
1215
A1
A2

FIG. 19

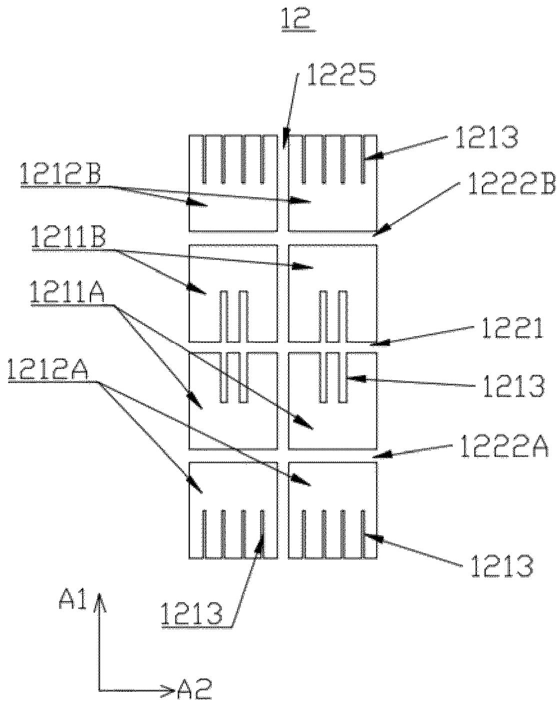

12
1225
1213
1212B
1222B
1211B
1211A
1221
1212A
1213
1222A
1213
A1
1213
A2

FIG. 19A

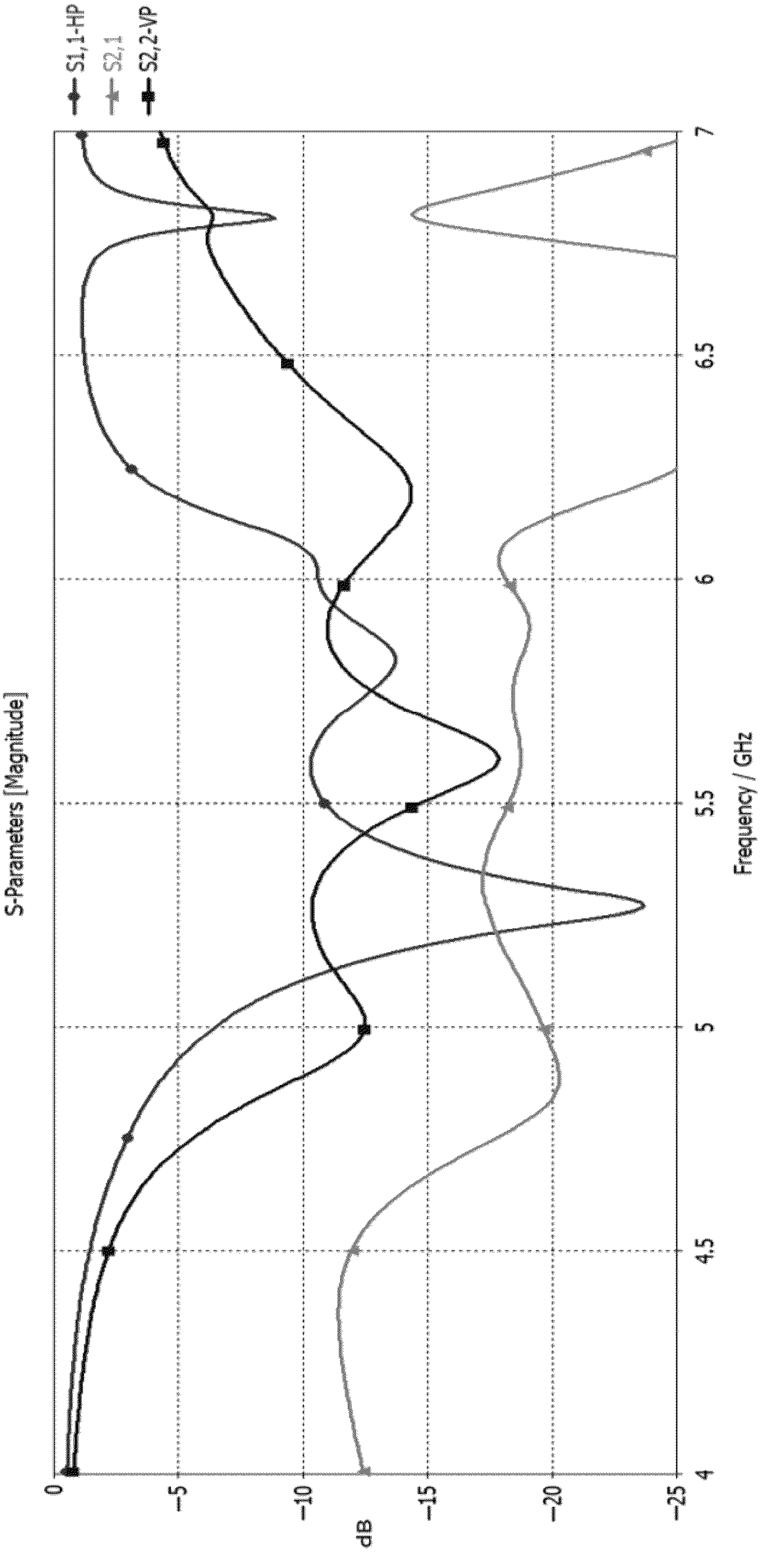

S-Parameters [Magnitude]
S1,1-HP
S2,1
S2,2-VP
dB
0
−5
−10
−15
−20
−25
4
4.5
5
5.5
6
6.5
7
Frequency / GHz

FIG. 20

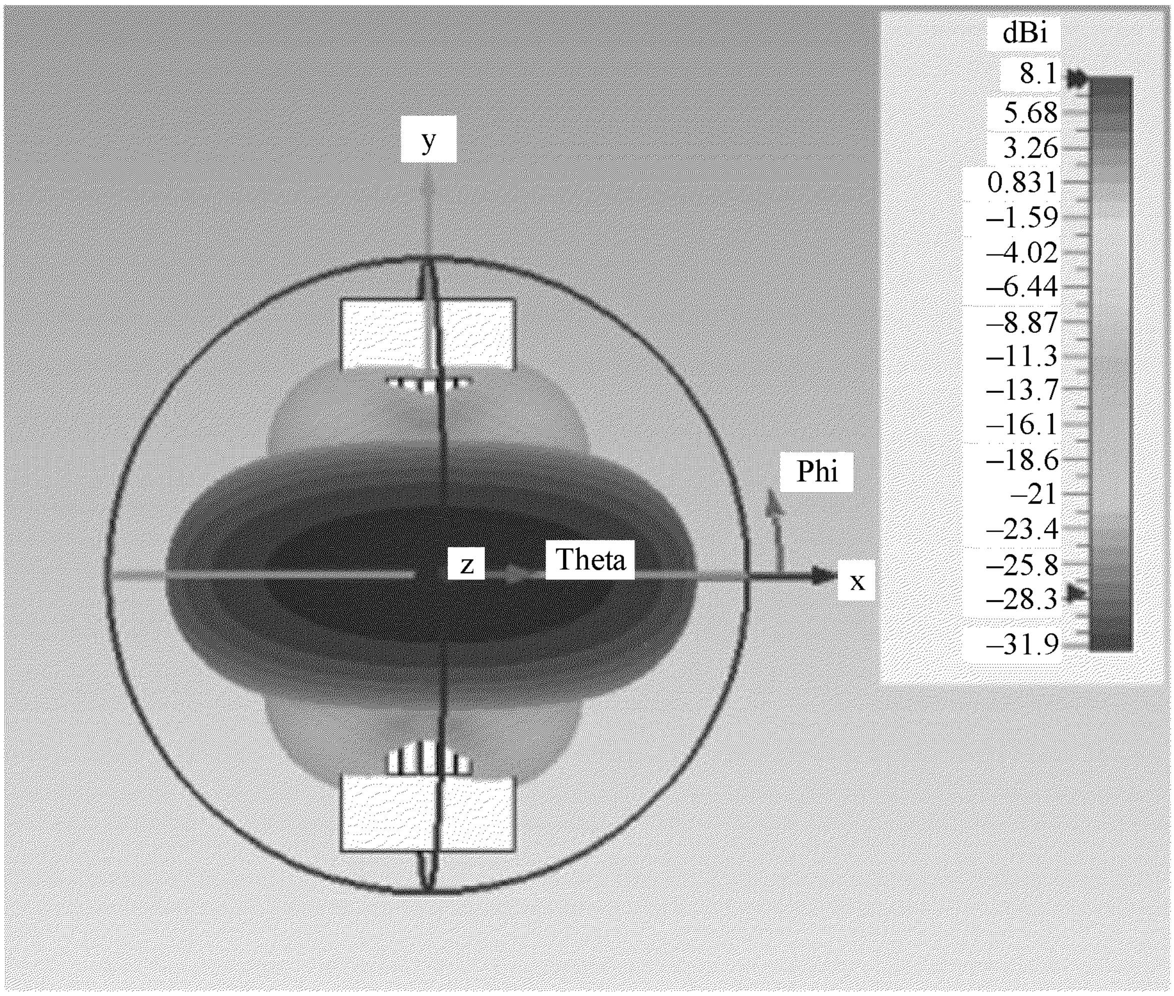

dBi
8.1
5.68
3.26
0.831
–1.59
–4.02
–6.44
–8.87
–11.3
–13.7
–16.1
–18.6
–21
–23.4
–25.8
–28.3
–31.9
y
Phi
z
Theta
x

FIG. 21(a) 5 GHz

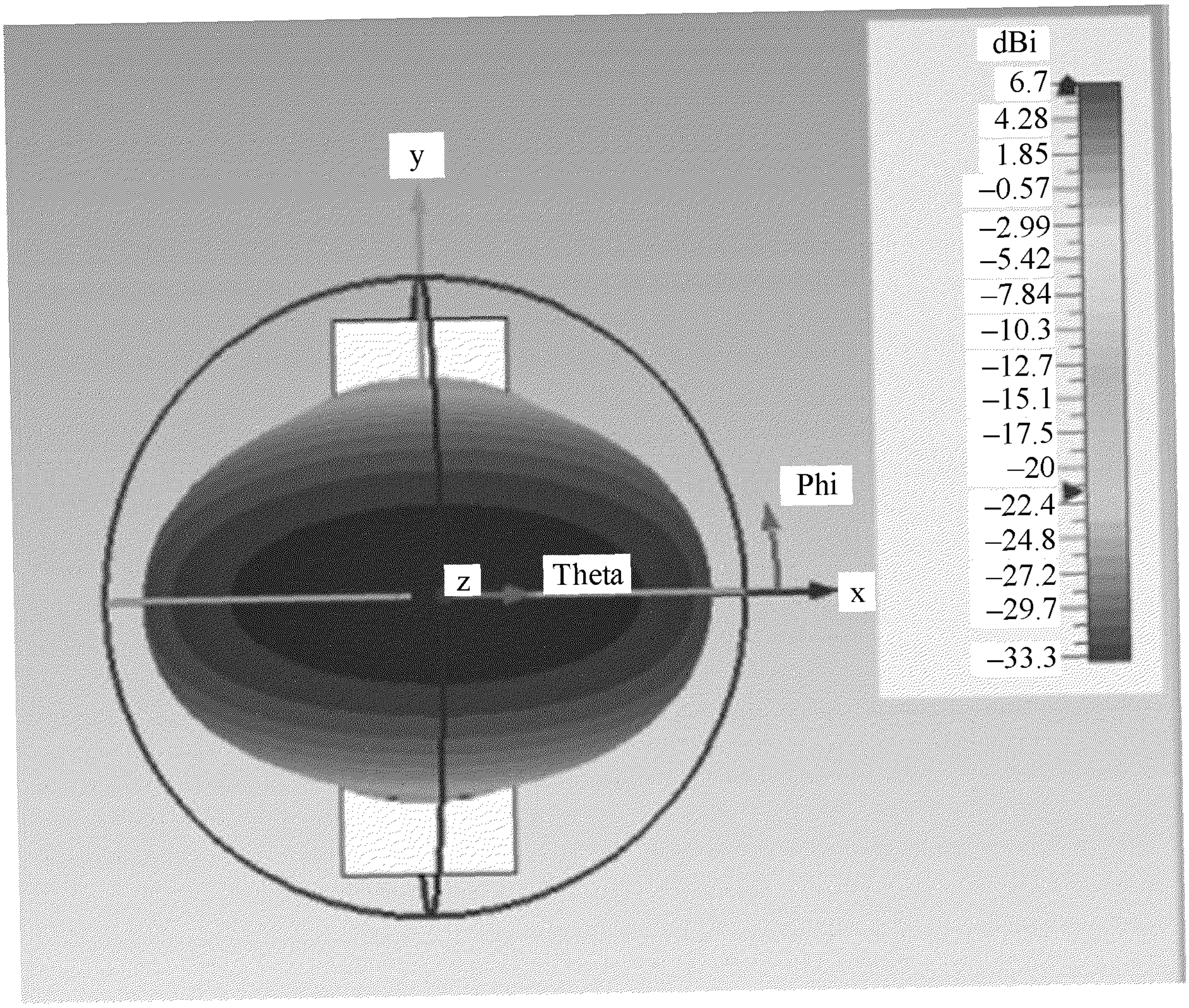


FIG. 21(b) 5.6 GHz

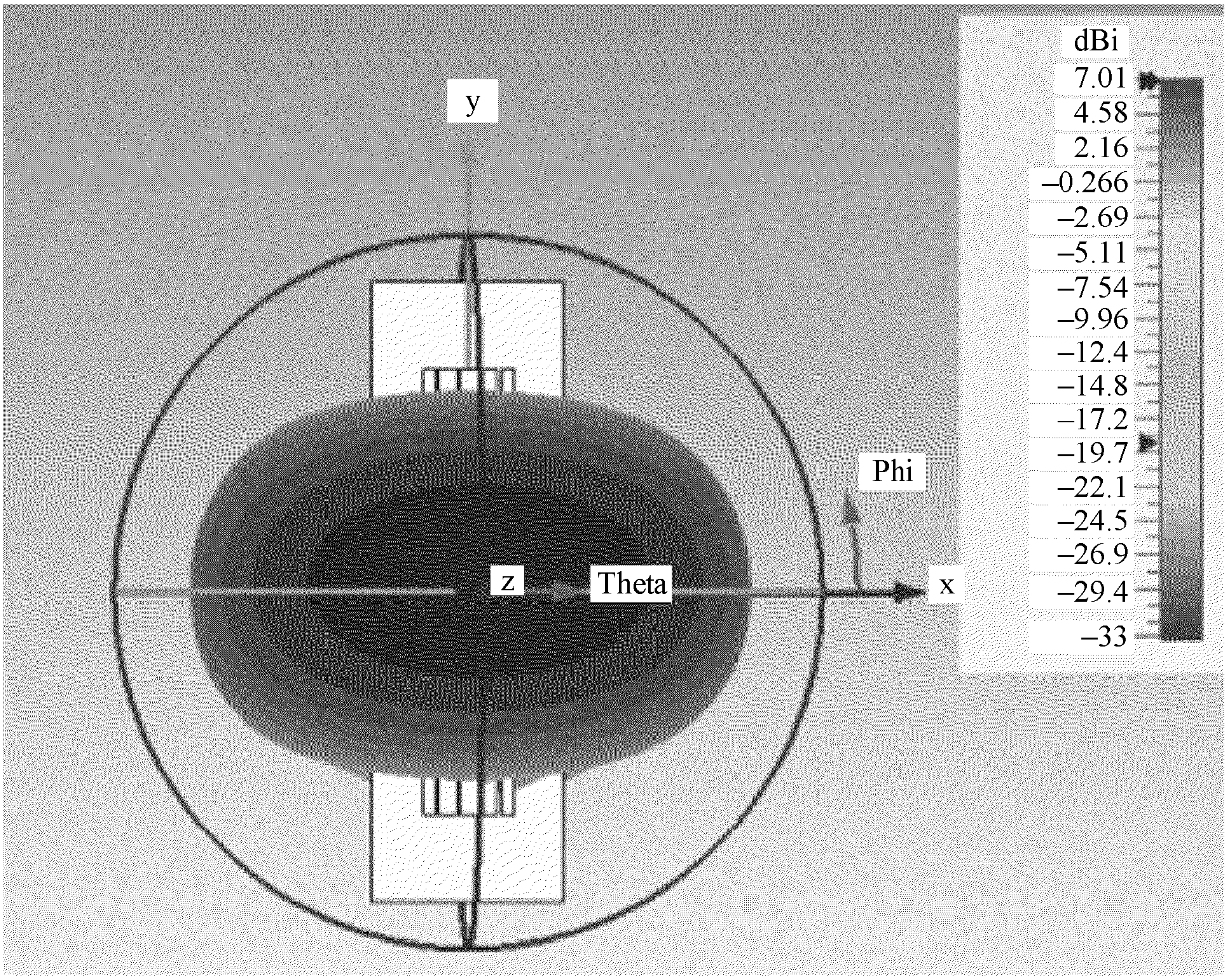


FIG. 22(a) 5.25 GHz

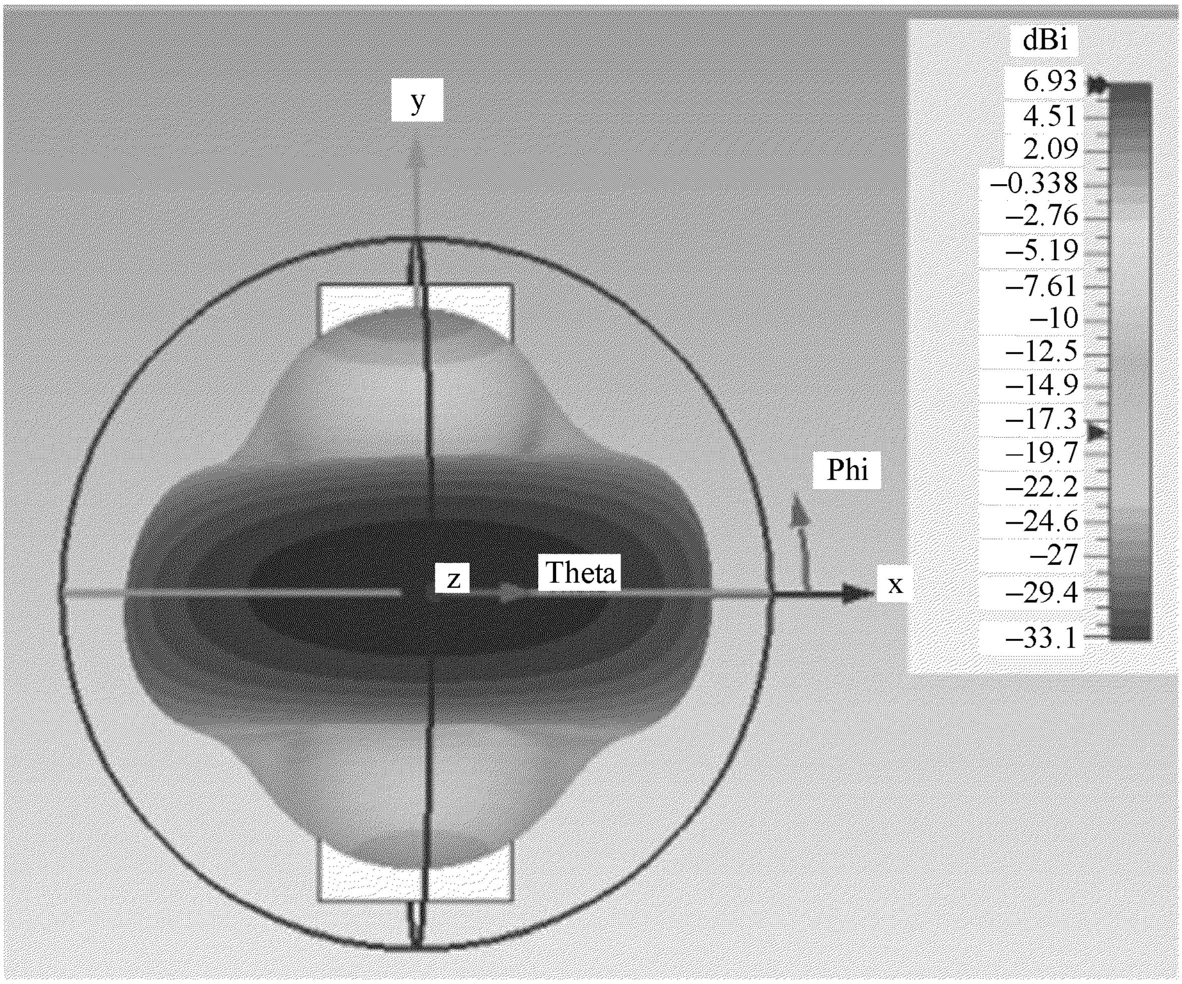


FIG. 22(b) 5.8 GHz

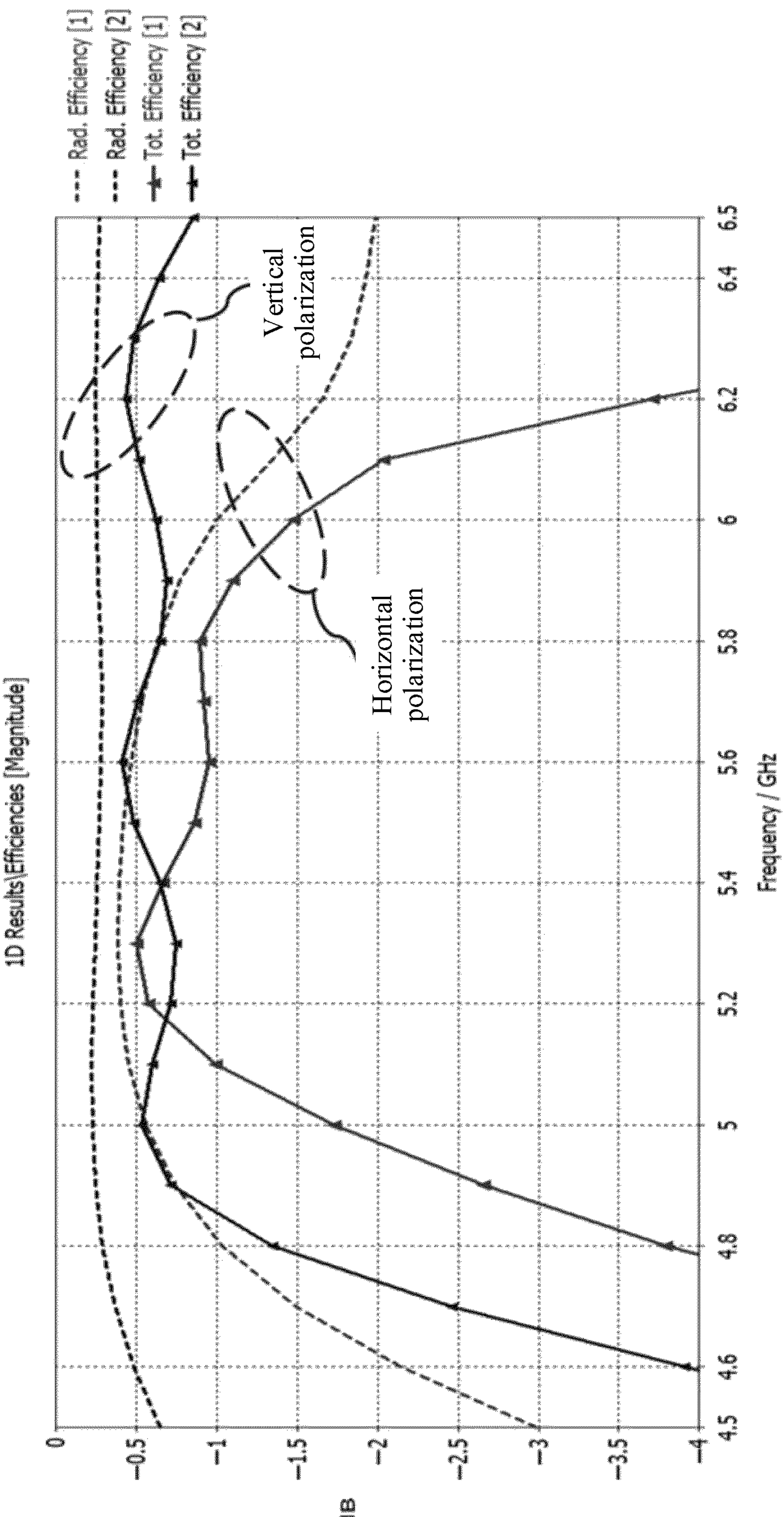

1D Results\Efficiencies [Magnitude]
Rad. Efficiency [1]
Rad. Efficiency [2]
Tot. Efficiency [1]
Tot. Efficiency [2]
dB
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
4.5
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4
6.5
Frequency / GHz
Vertical polarization
Horizontal polarization

FIG. 23

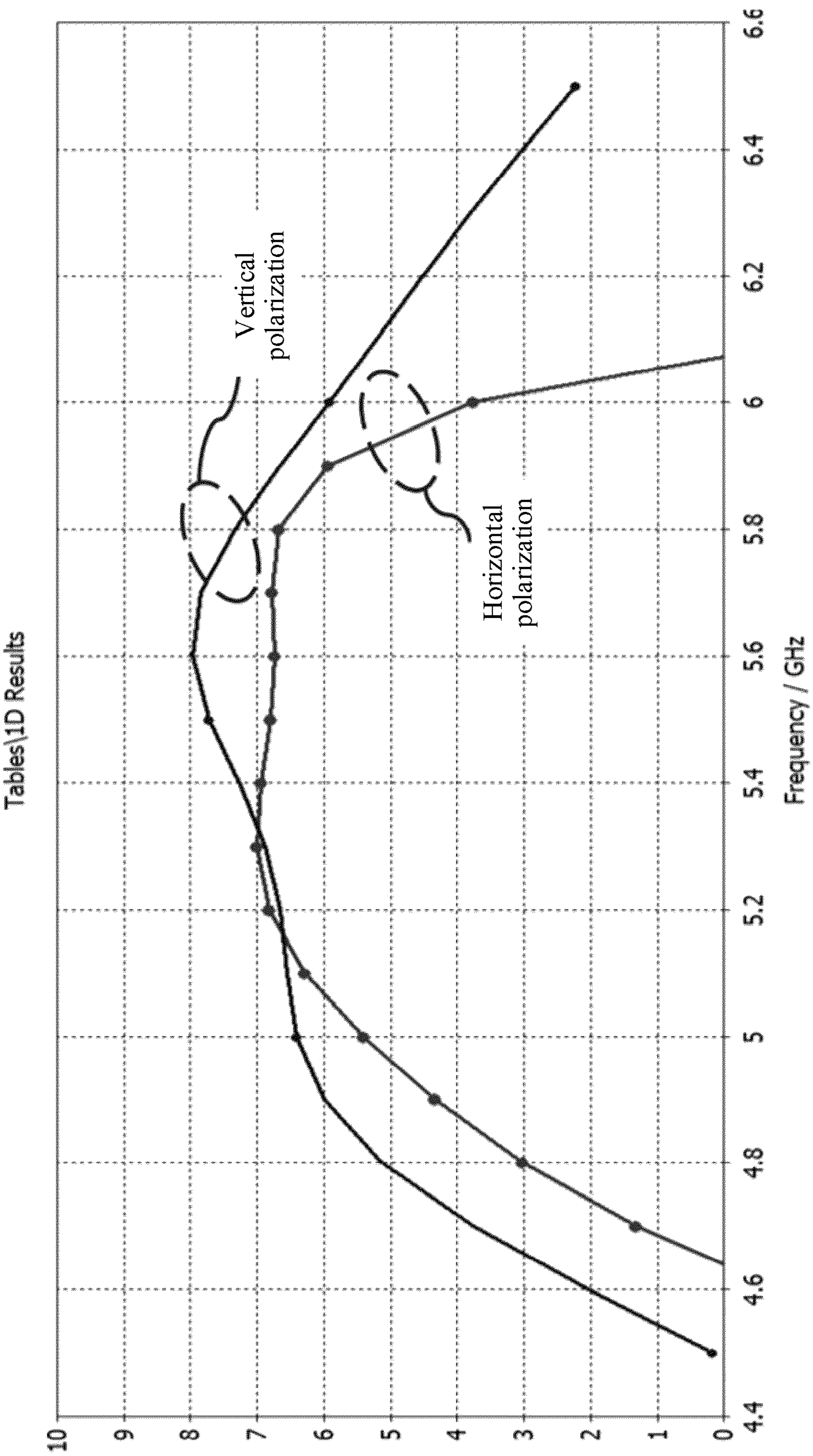

Tables\1D Results
Vertical polarization
Horizontal polarization
Frequency / GHz
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4
6.6
0
1
2
3
4
5
6
7
8
9
10

FIG. 24

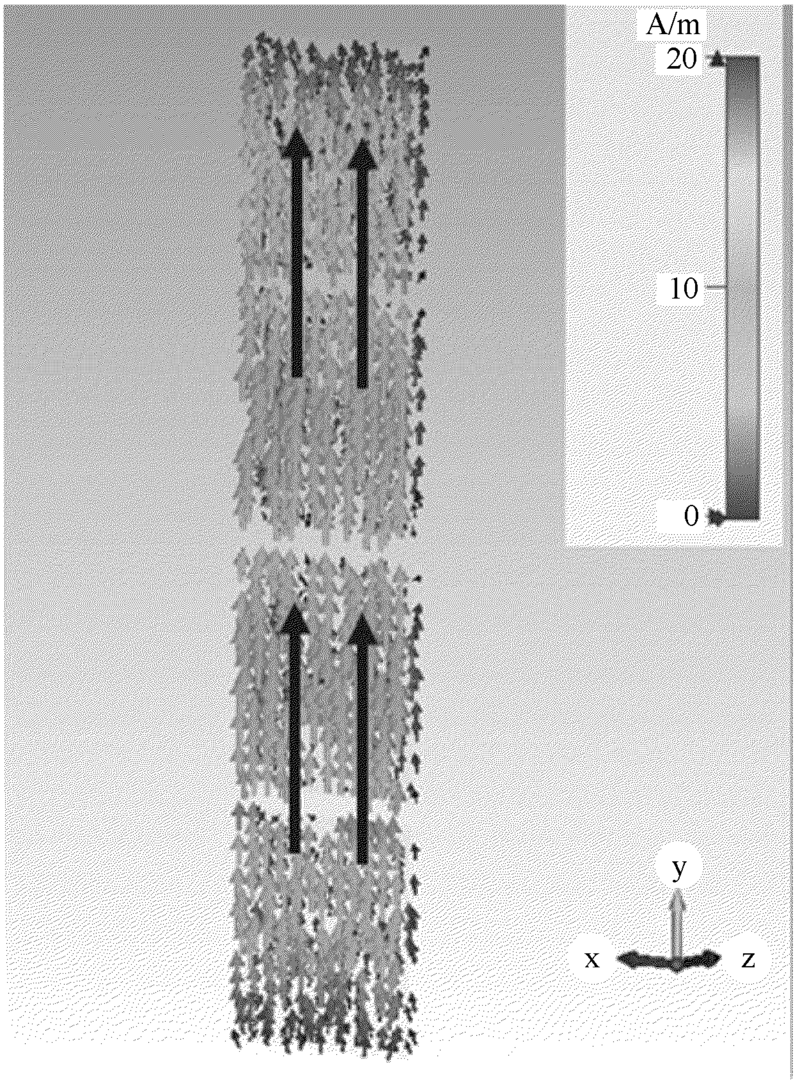


FIG. 25(a) 5 GHz

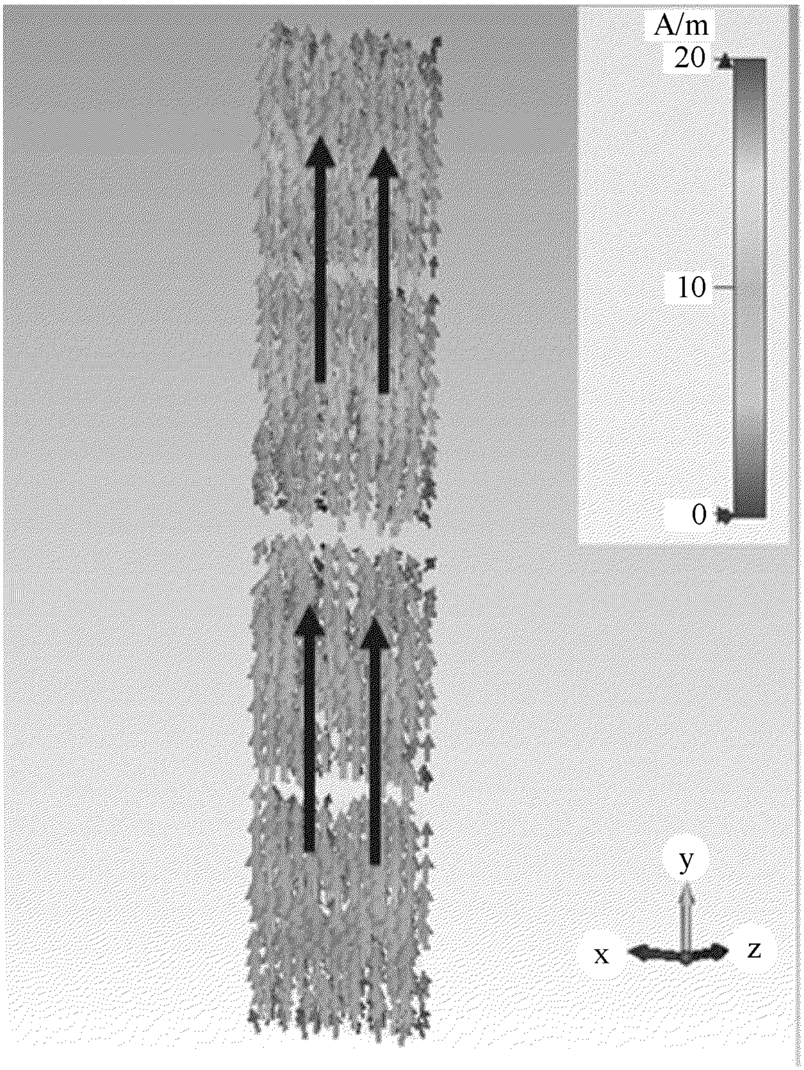


FIG. 25(b) 5.6 GHz

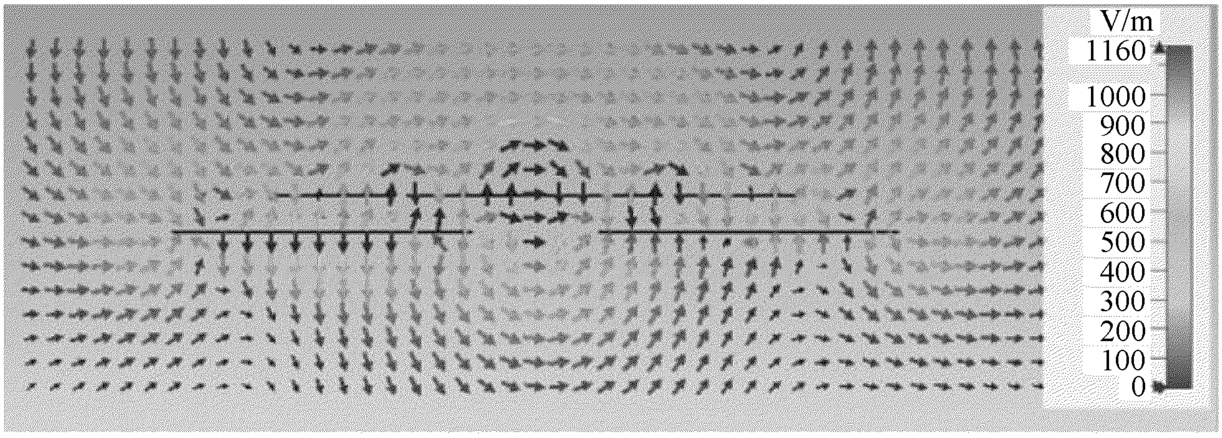


FIG. 25(c) 5 GHz

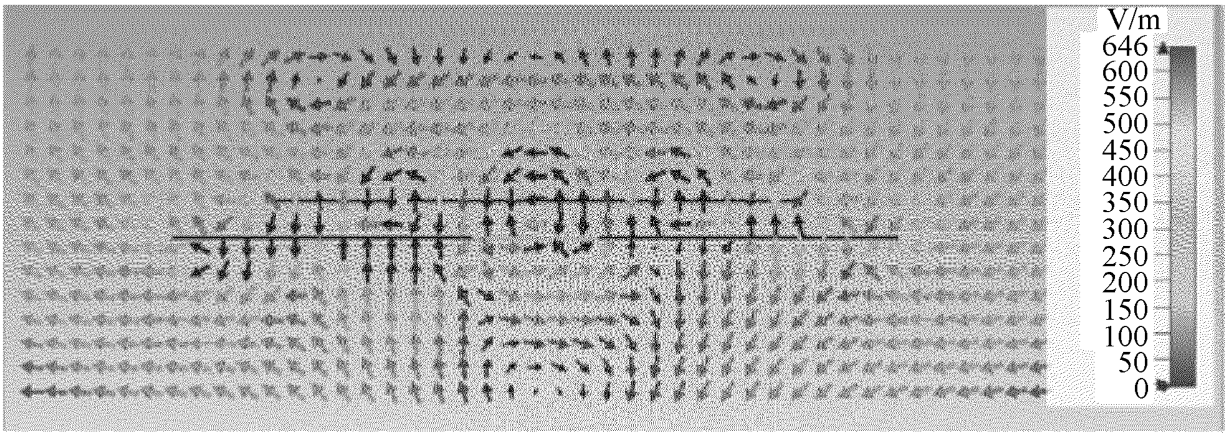


FIG. 25(d) 5.6 GHz

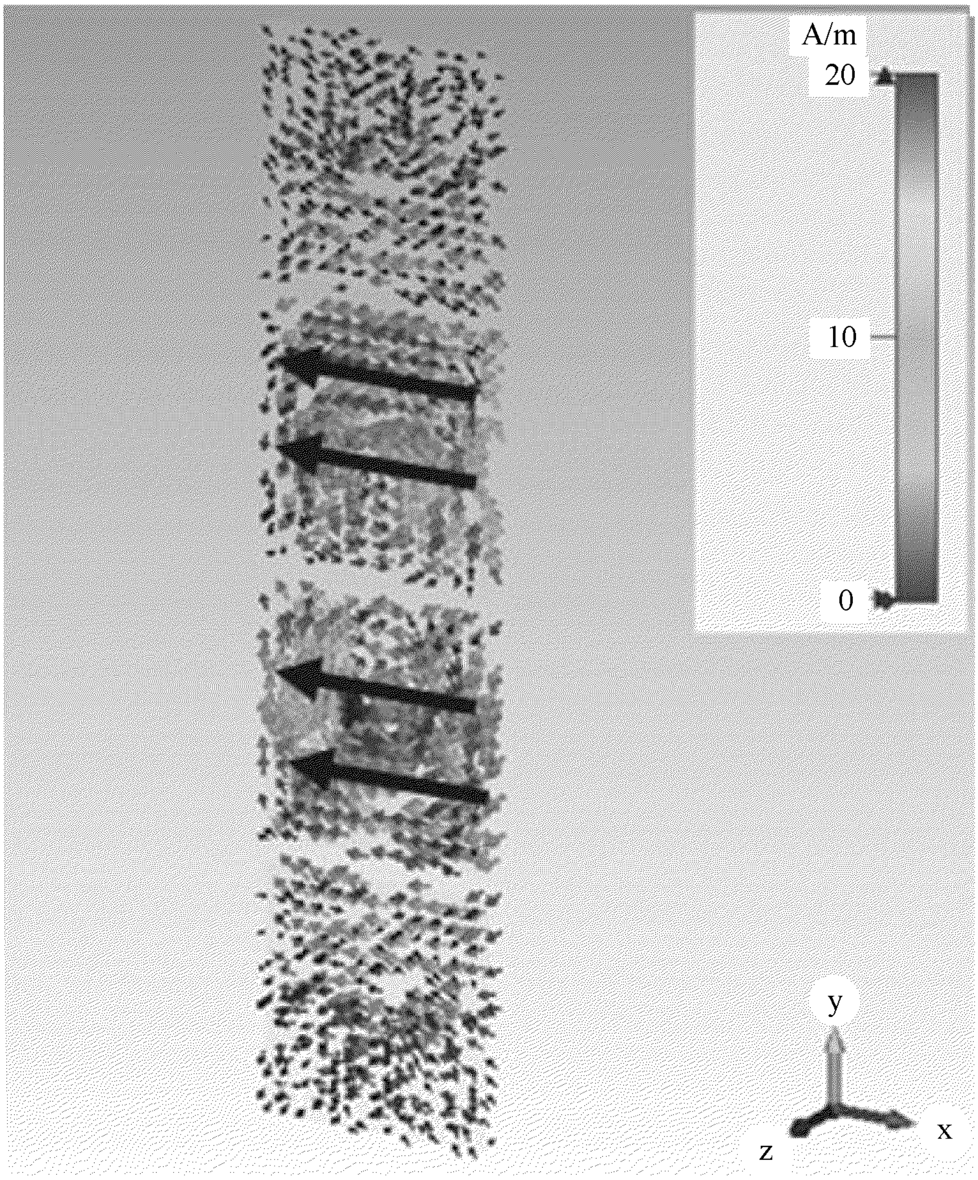


FIG. 26(a) 5.25 GHz

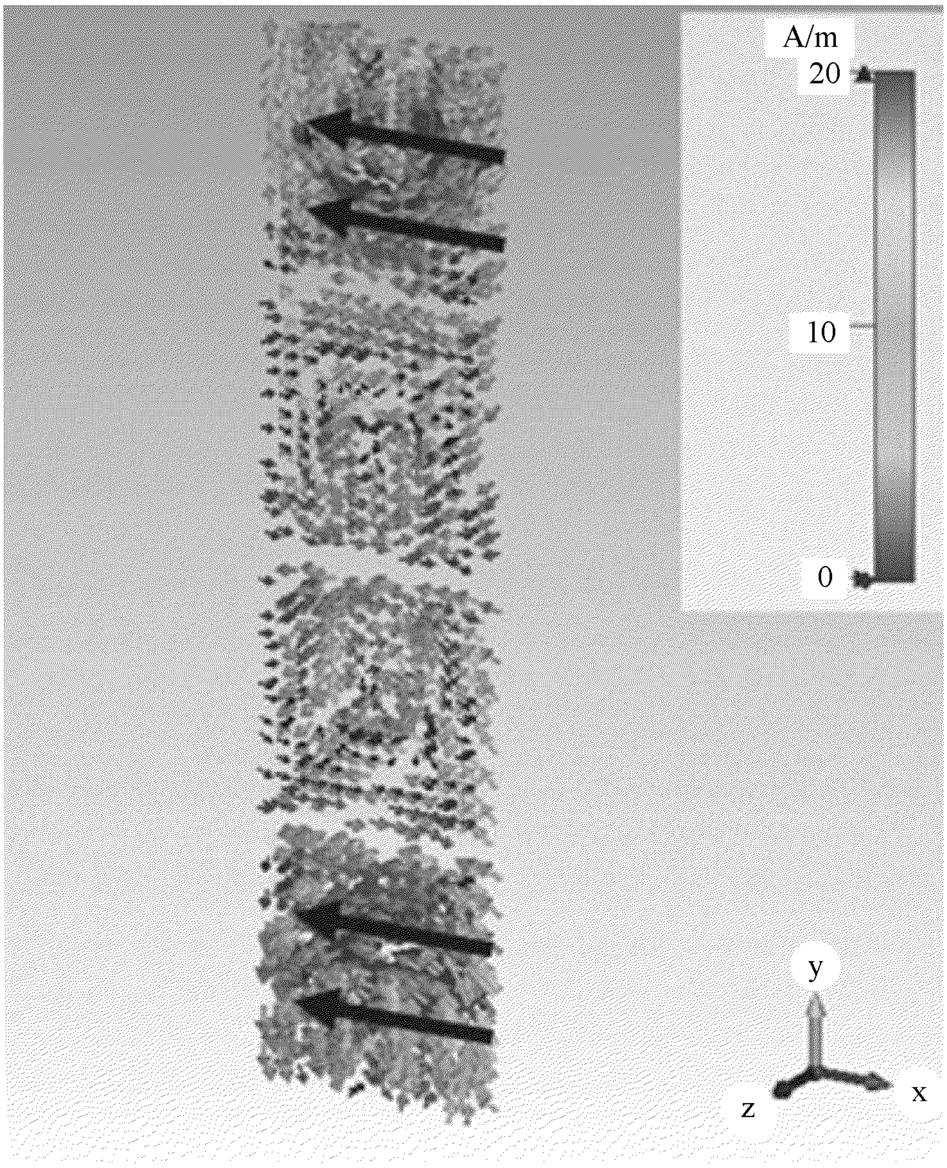


FIG. 26(b) 5.8 GHz

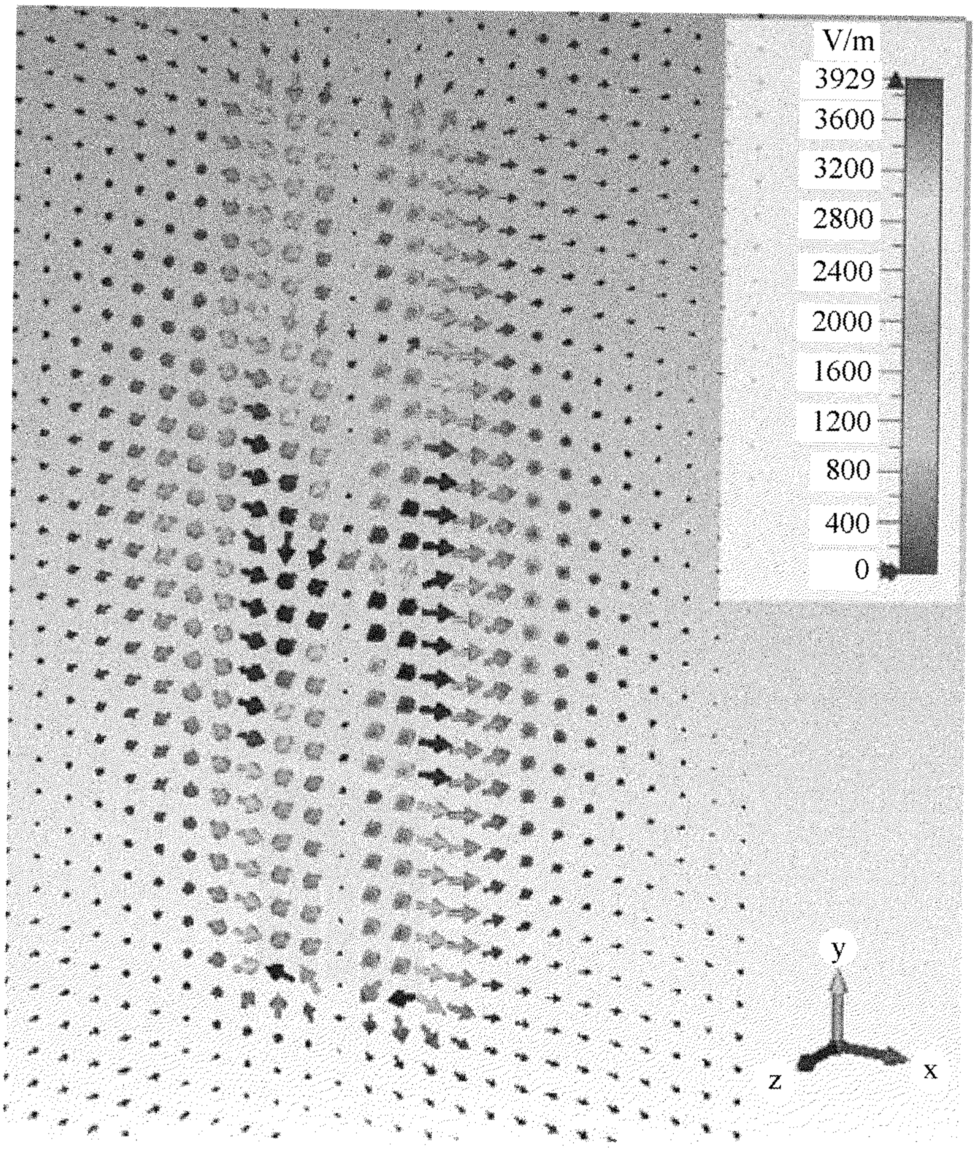


FIG. 26(c) 5.25 GHz

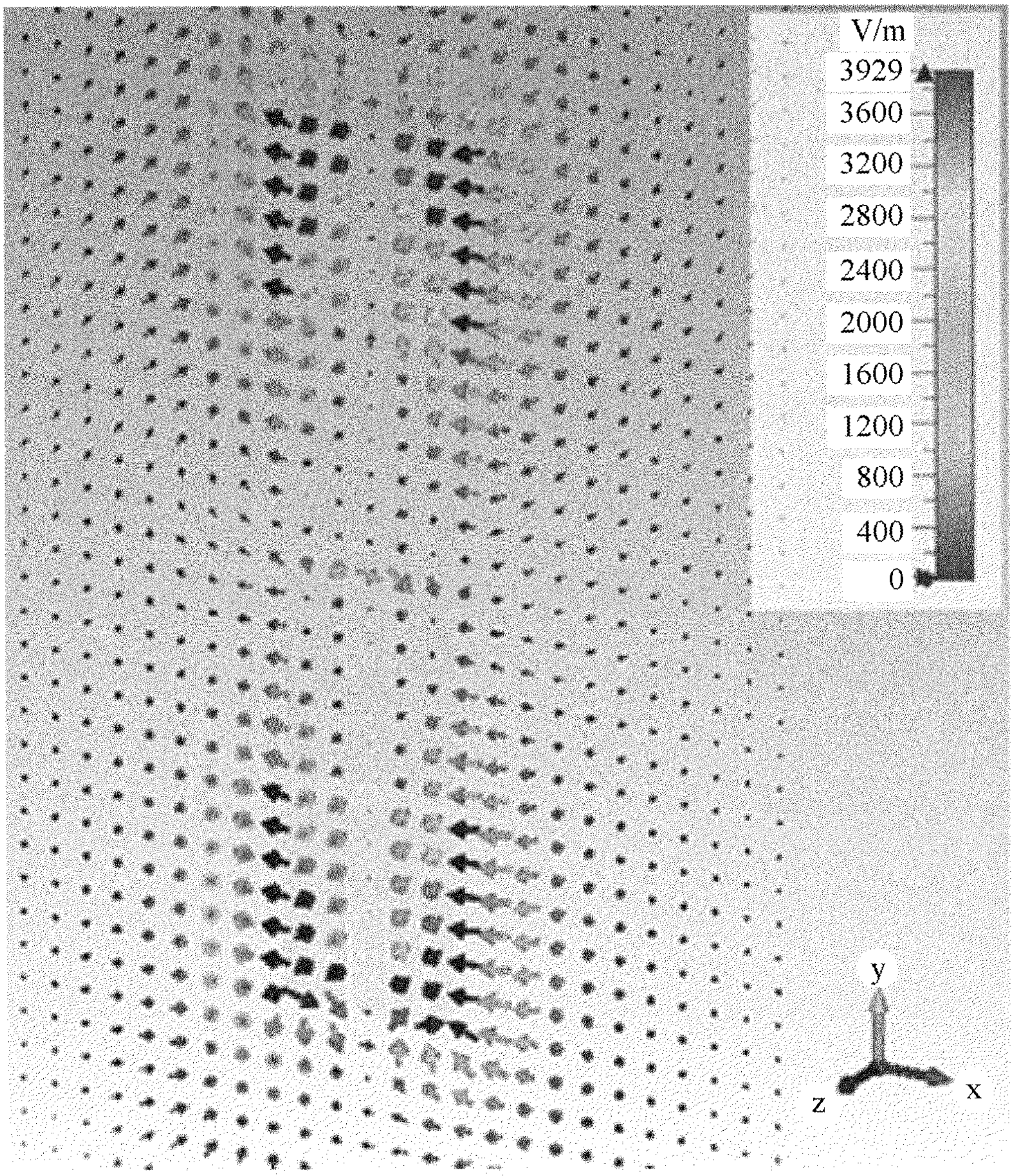


FIG. 26(d) 5.8 GHz

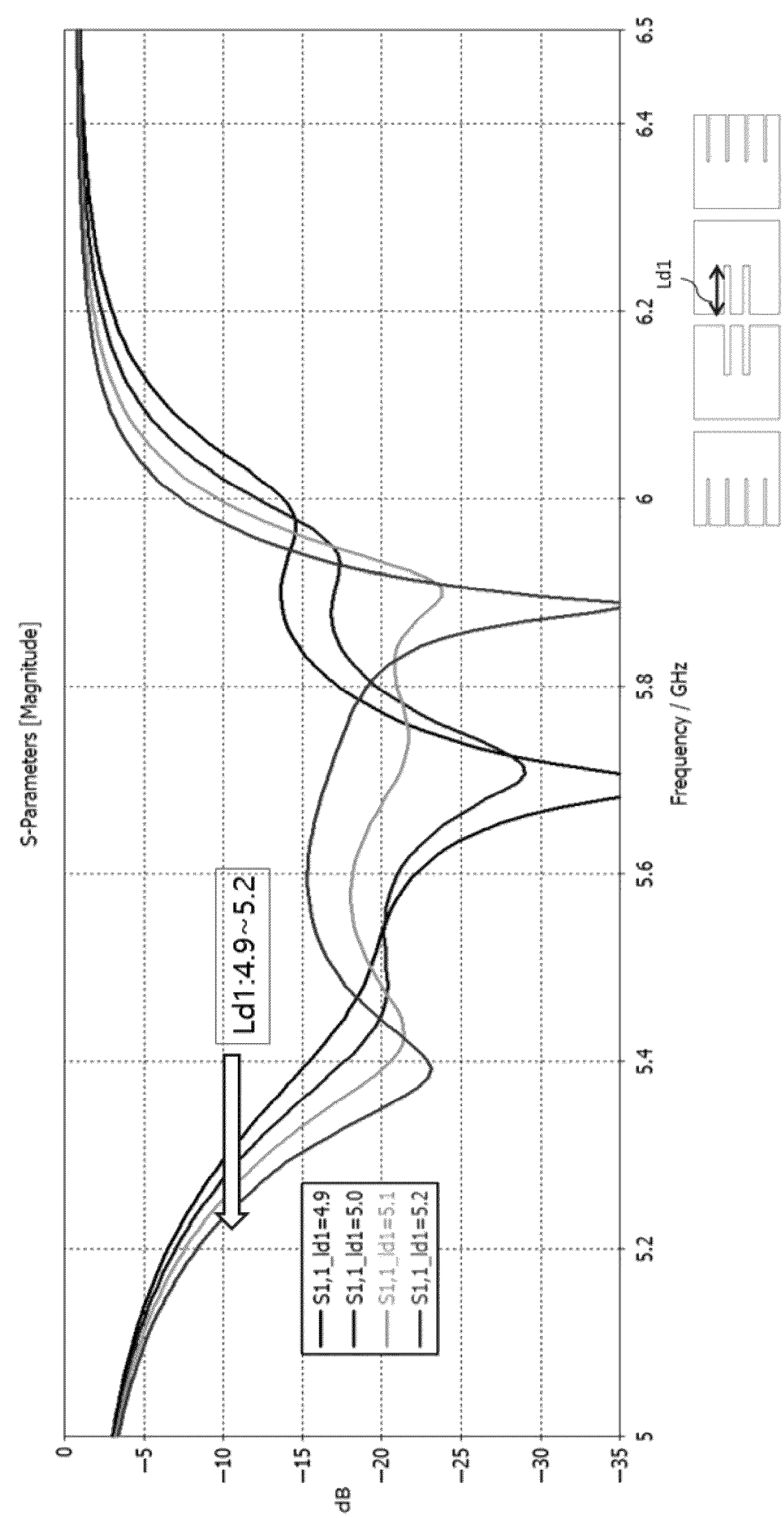

S-Parameters [Magnitude]
Ld1:4.9~5.2
S1,1_ld1=4.9
S1,1_ld1=5.0
S1,1_ld1=5.1
S1,1_ld1=5.2
dB
0
−5
−10
−15
−20
−25
−30
−35
5
5.2
5.4
5.6
5.8
6
6.2
6.4
6.5
Frequency / GHz
Ld1

FIG. 27

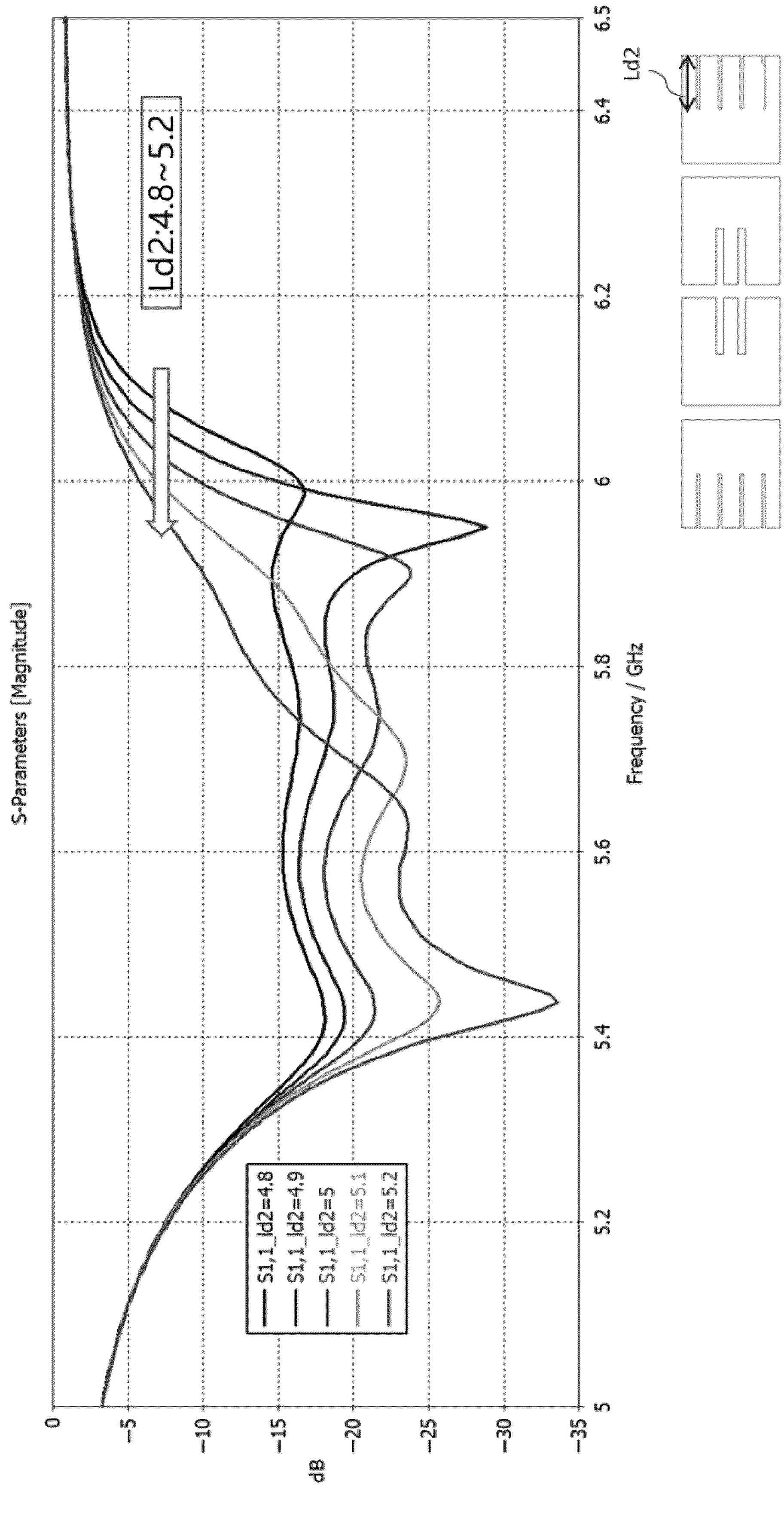

S-Parameters [Magnitude]
Ld2:4.8~5.2
S1,1_ld2=4.8
S1,1_ld2=4.9
S1,1_ld2=5
S1,1_ld2=5.1
S1,1_ld2=5.2
dB
0
−5
−10
−15
−20
−25
−30
−35
5
5.2
5.4
5.6
5.8
6
6.2
6.4
6.5
Frequency / GHz
Ld2

FIG. 28

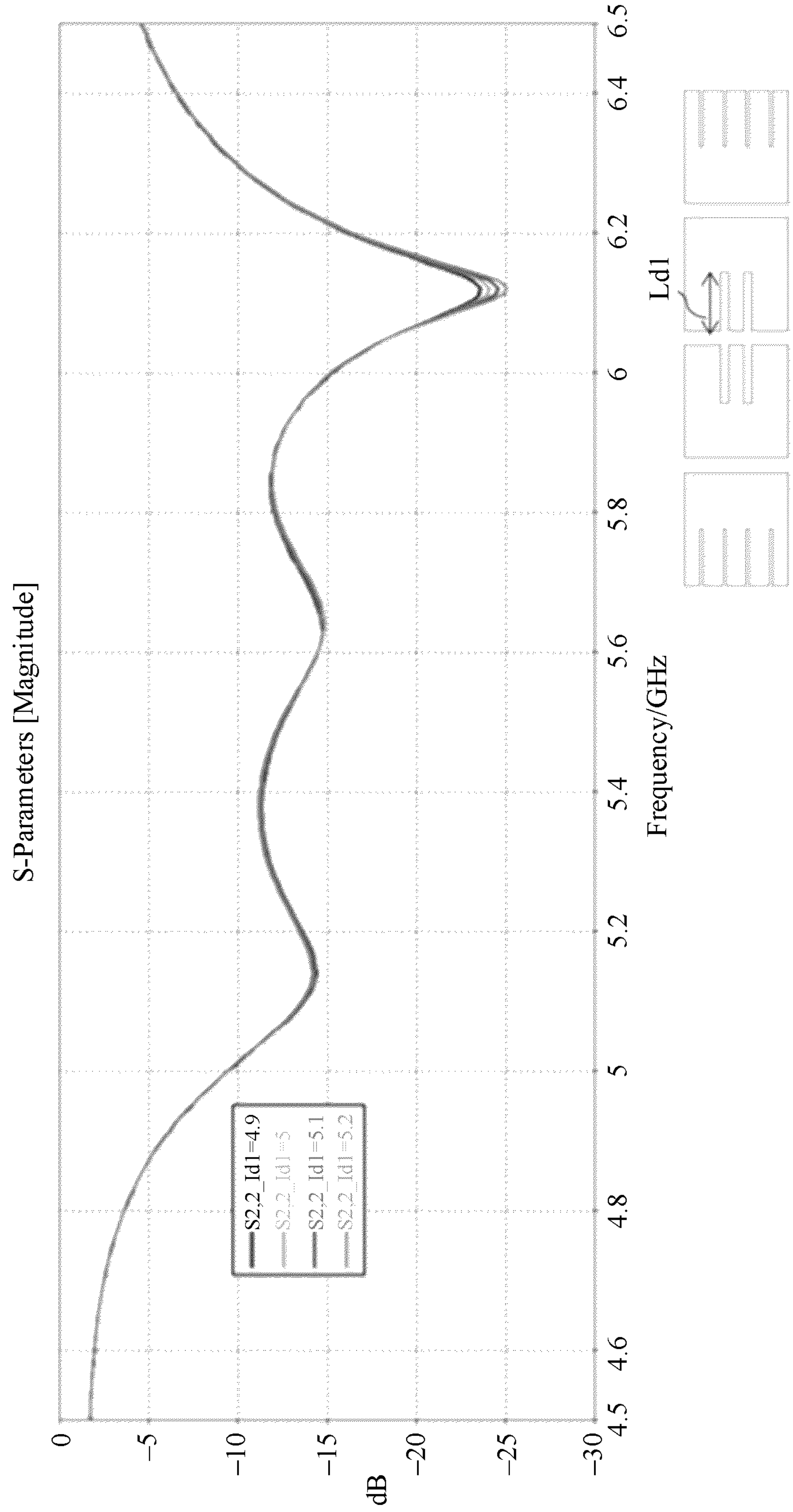

S-Parameters [Magnitude]
dB
0
−5
−10
−15
−20
−25
−30
4.5
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4
6.5
Frequency/GHz
S2,2_ld1=4.9
S2,2_ld1=5
S2,2_ld1=5.1
S2,2_ld1=5.2
Ld1

FIG. 29

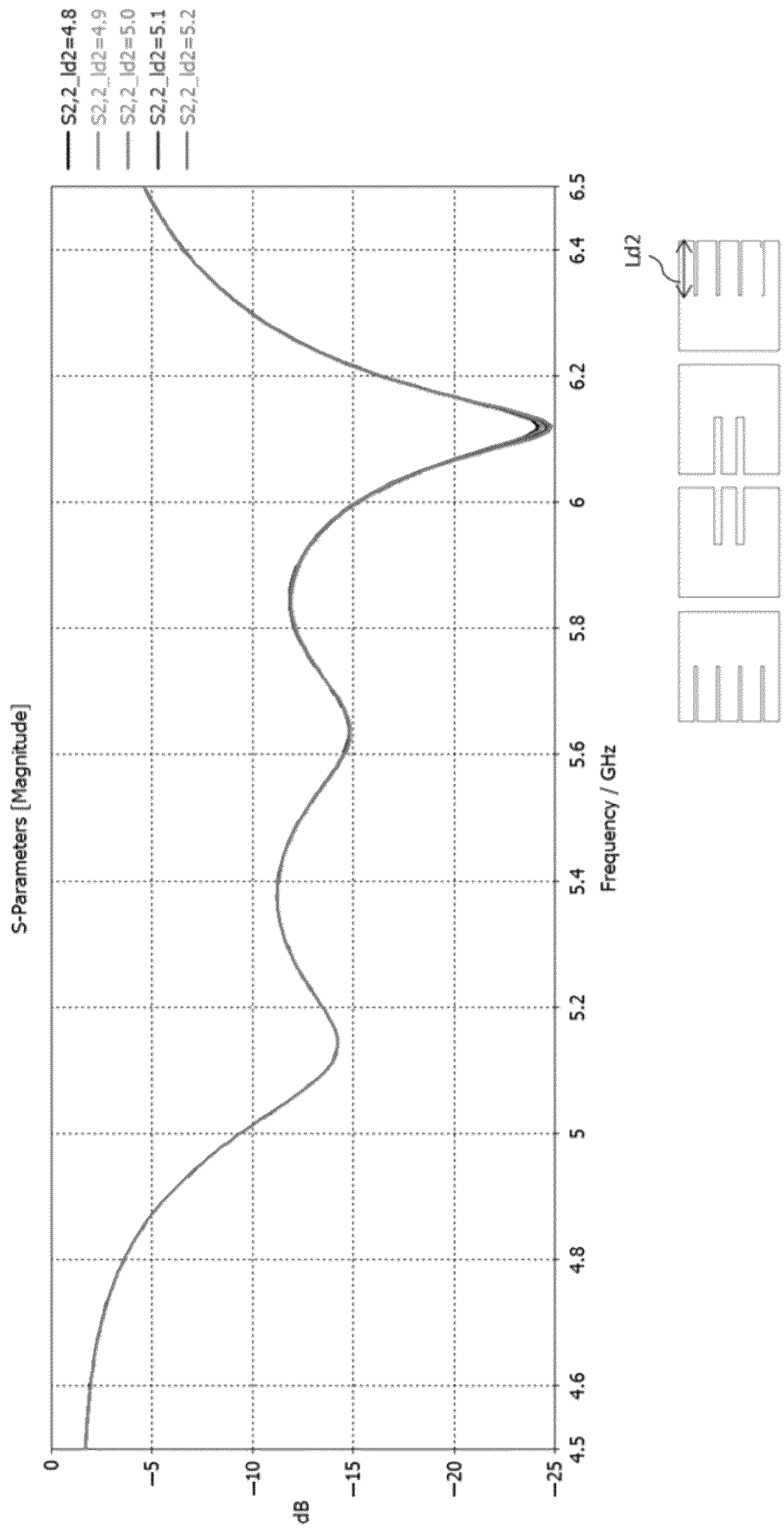

S-Parameters [Magnitude]
S2,2_ld2=4.8
S2,2_ld2=4.9
S2,2_ld2=5.0
S2,2_ld2=5.1
S2,2_ld2=5.2
dB
0
−5
−10
−15
−20
−25
4.5
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4
6.5
Frequency / GHz
Ld2

FIG. 30

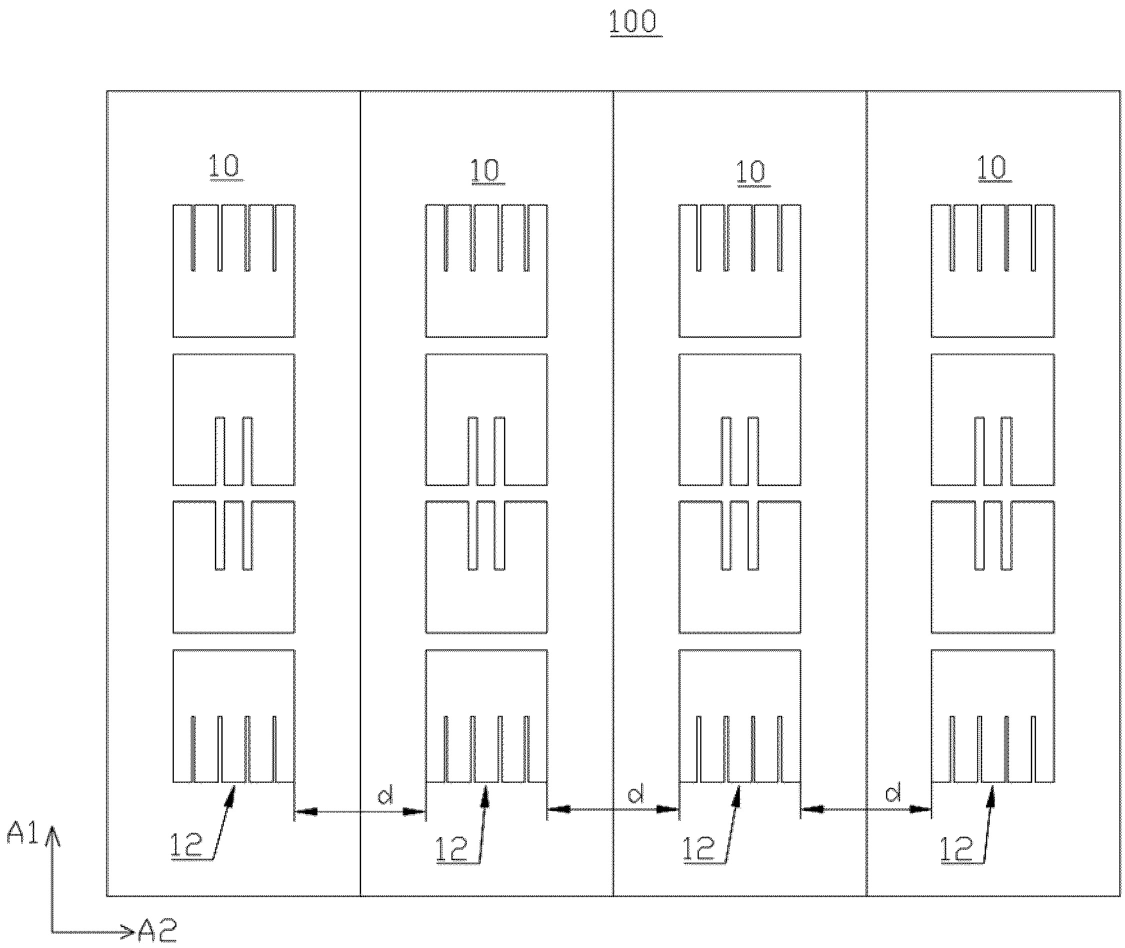


FIG. 31

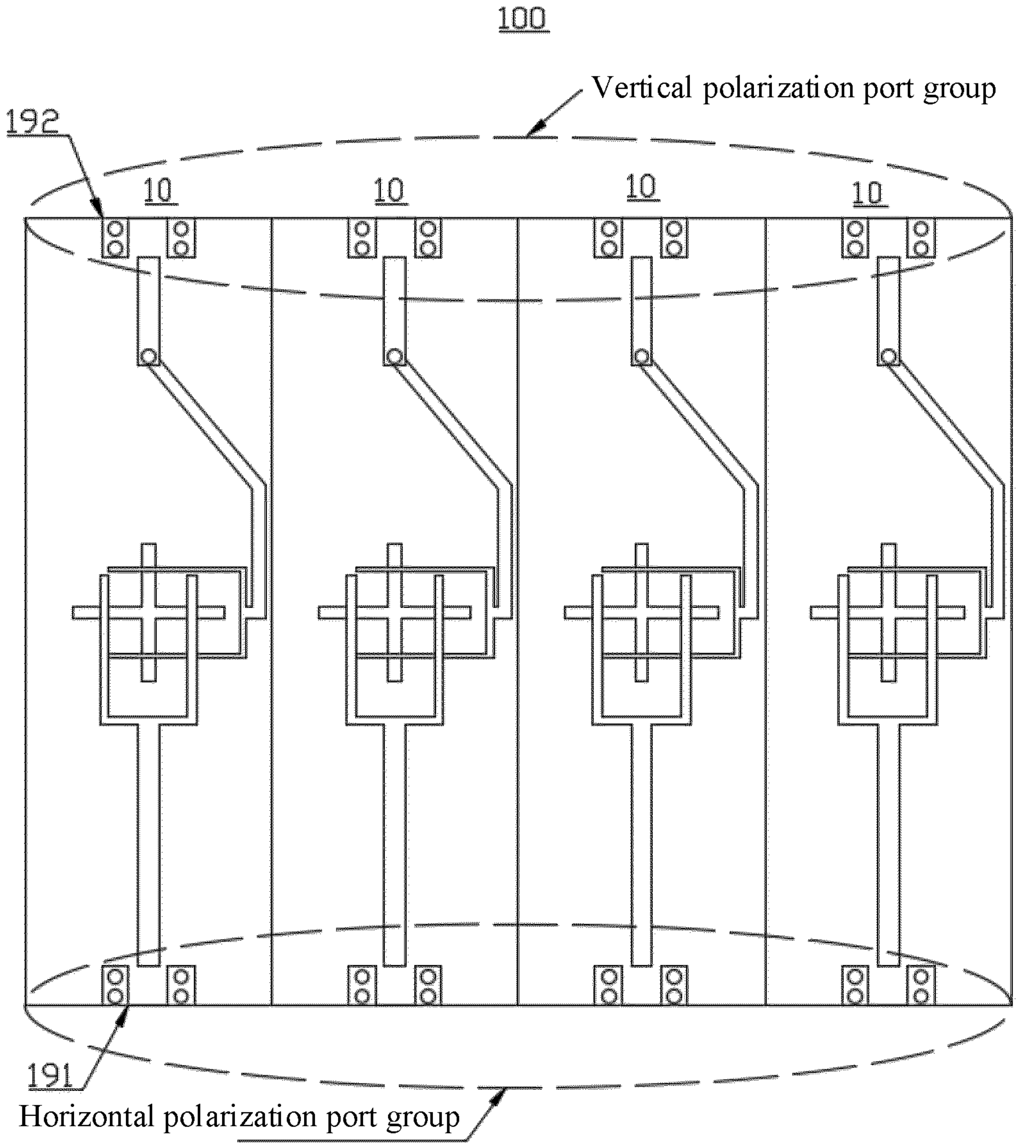

100
Vertical polarization port group
192
10
10
10
10
191
Horizontal polarization port group

FIG. 32

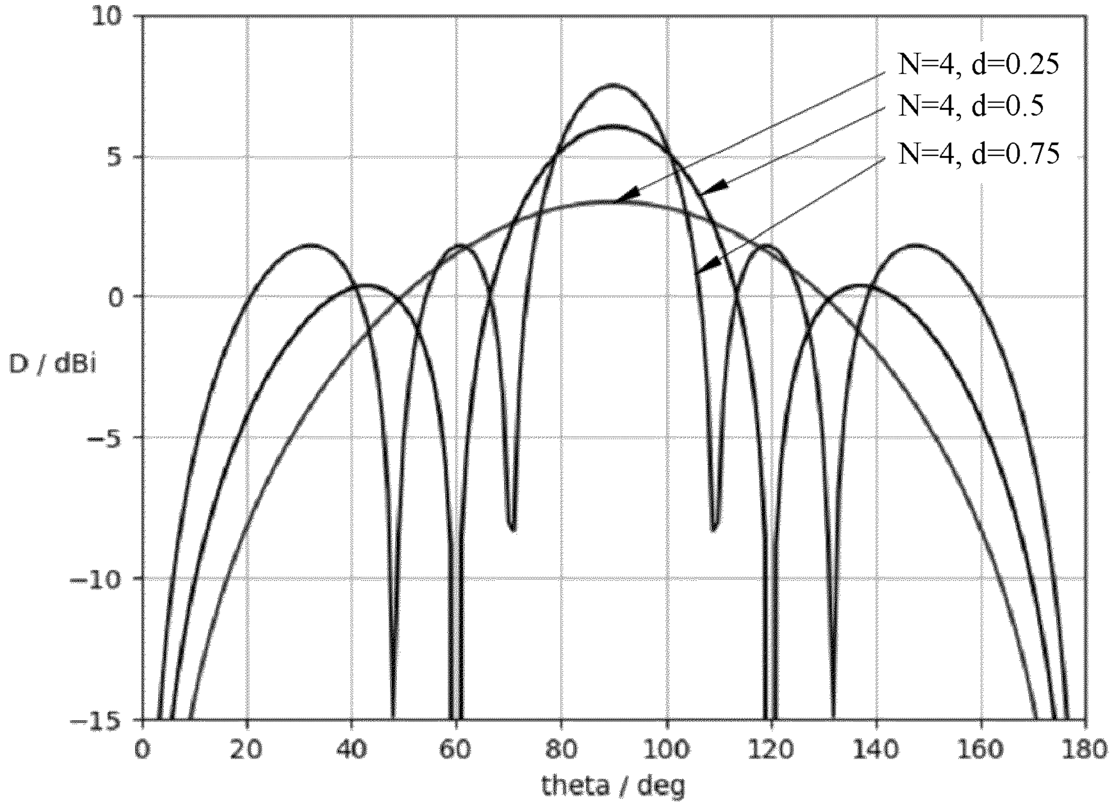

N=4, d=0.25
N=4, d=0.5
N=4, d=0.75
D / dBi
theta / deg
10
5
0
−5
−10
−15
0
20
40
60
80
100
120
140
160
180

FIG. 33

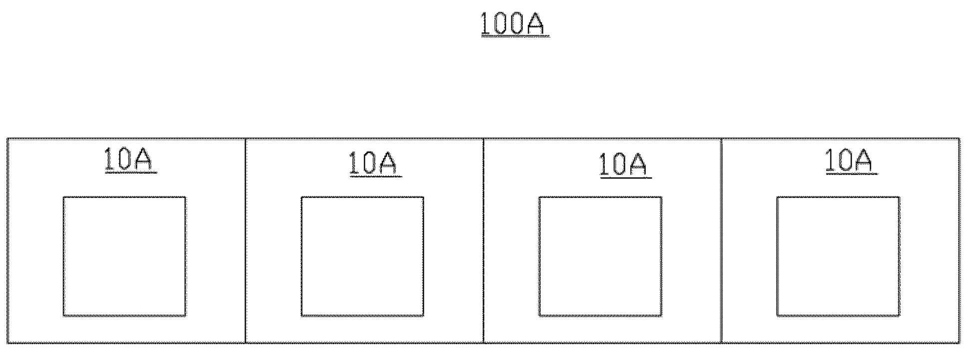

100A
10A
10A
10A
10A

FIG. 34

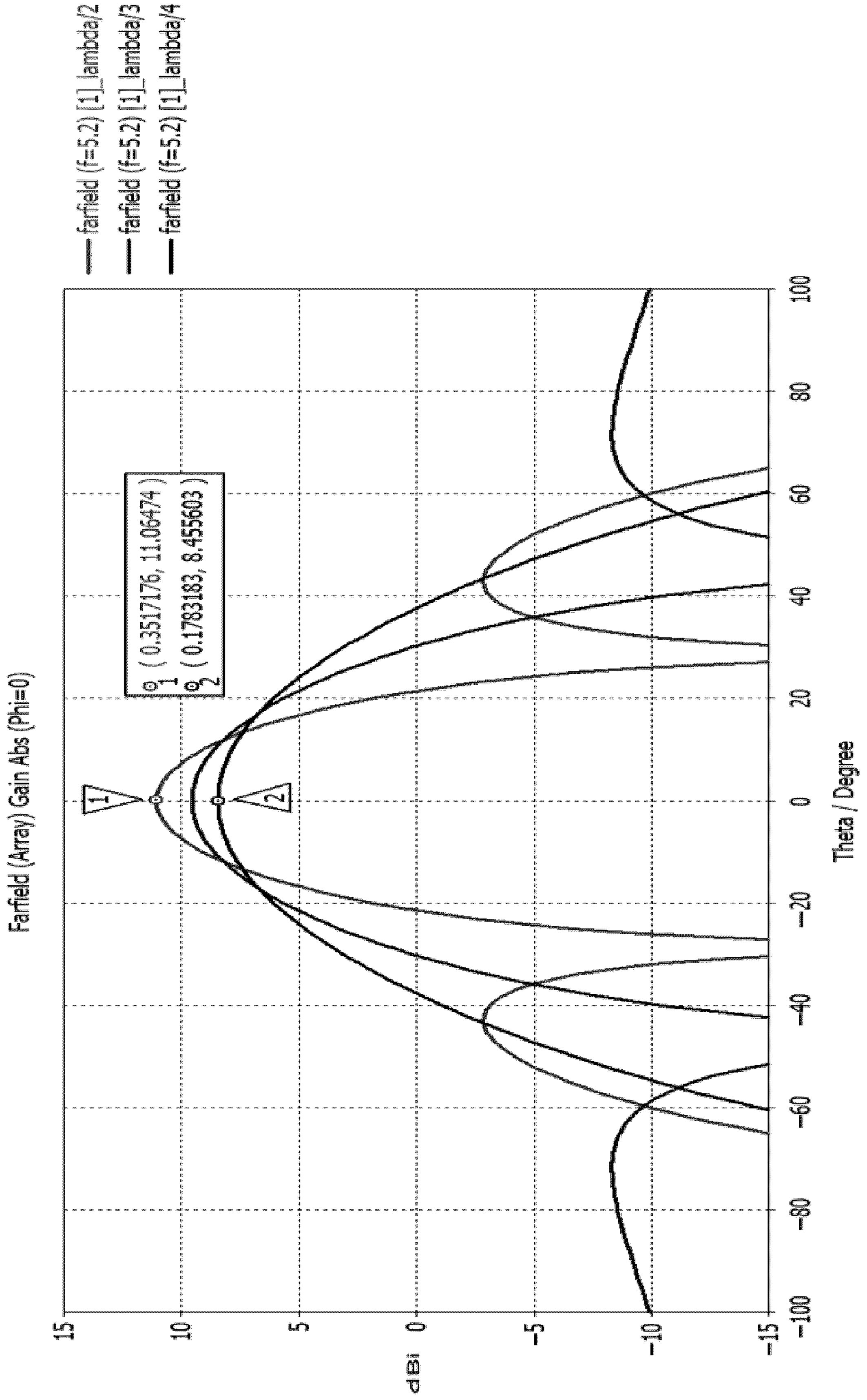
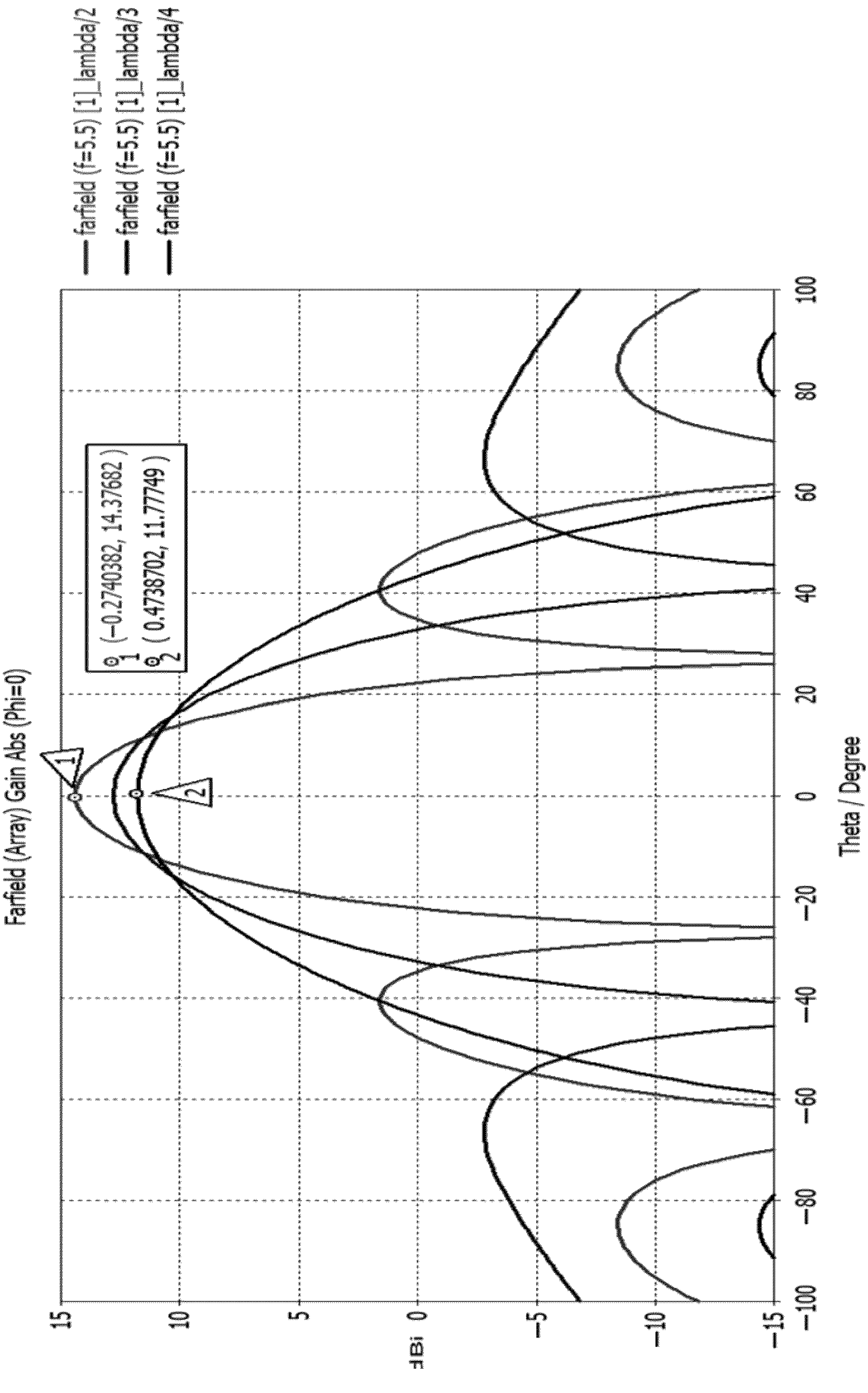

Farfield (Array) Gain Abs (Phi=0)
farfield (f=5.2) [1]_lambda/2
farfield (f=5.2) [1]_lambda/3
farfield (f=5.2) [1]_lambda/4
1 (0.3517176, 11.06474)
2 (0.1783183, 8.455603)
dBi
Theta / Degree
15
10
5
0
-5
-10
-15
-100
-80
-60
-40
-20
0
20
40
60
80
100

FIG. 35



Farfield (Array) Gain Abs (Phi=0)
farfield (f=5.5) [1]_lambda/2
farfield (f=5.5) [1]_lambda/3
farfield (f=5.5) [1]_lambda/4
1 (−0.2740382, 14.37682)
2 (0.4738702, 11.77749)
dBi
Theta / Degree

FIG. 36

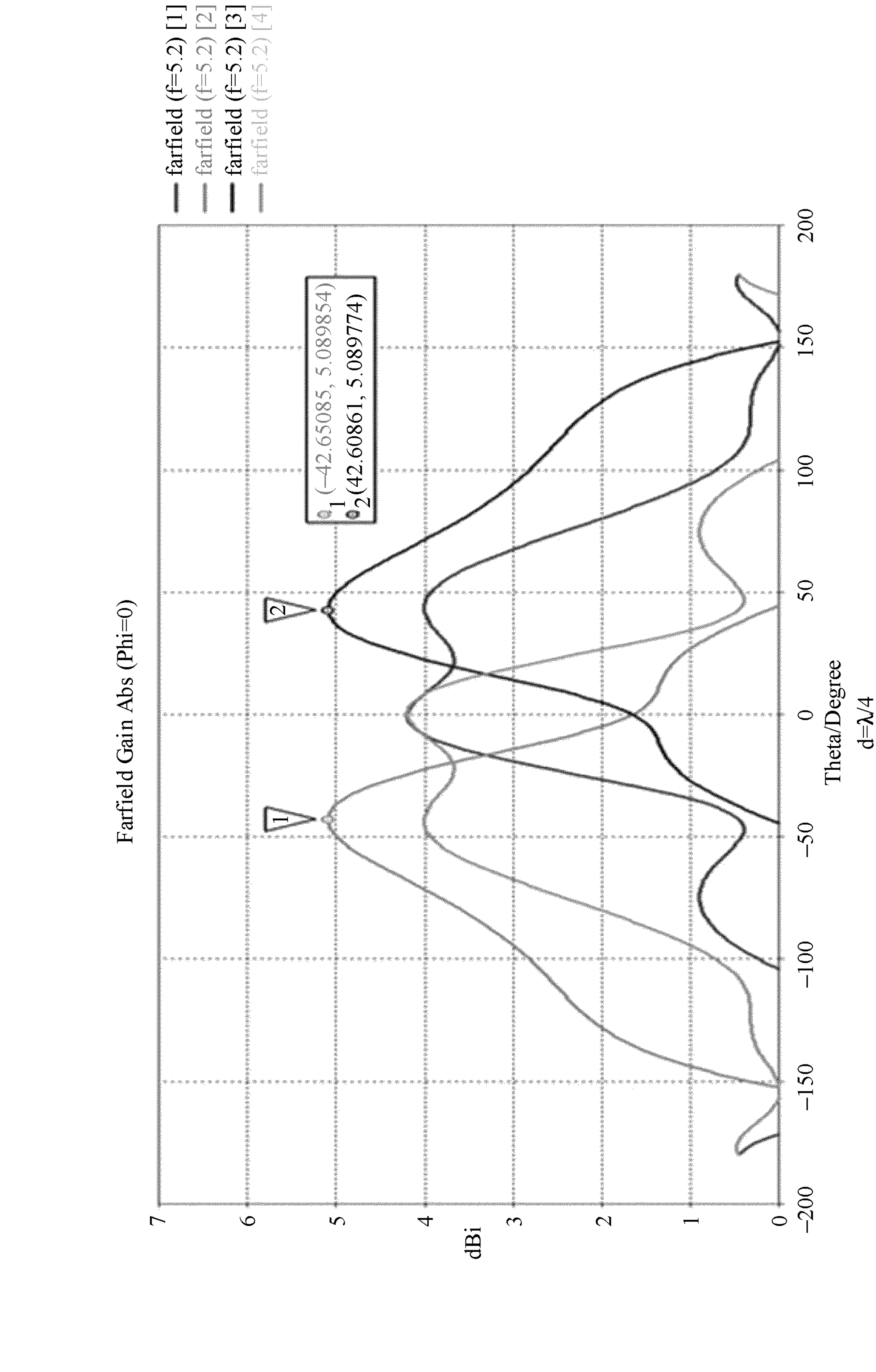

Farfield Gain Abs (Phi=0)
farfield (f=5.2) [1]
farfield (f=5.2) [2]
farfield (f=5.2) [3]
farfield (f=5.2) [4]
1 (−42.65085, 5.089854)
2 (42.60861, 5.089774)
1
2
dBi
7
6
5
4
3
2
1
0
−200
−150
−100
−50
0
50
100
150
200
Theta/Degree
d=λ/4

FIG. 37A

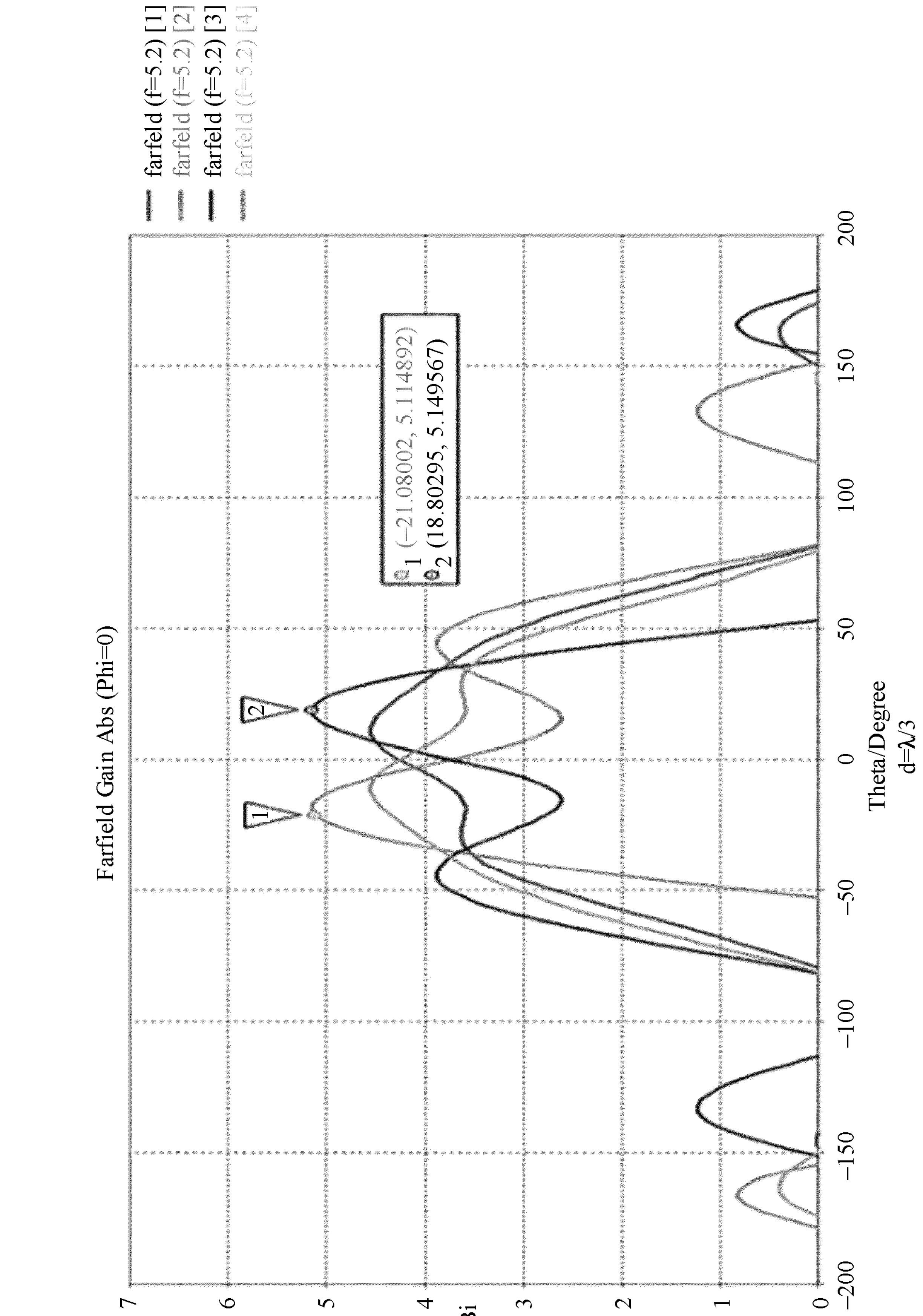

Farfield Gain Abs (Phi=0)
farfeld (f=5.2) [1]
farfeld (f=5.2) [2]
farfeld (f=5.2) [3]
farfeld (f=5.2) [4]
1 (−21.08002, 5.114892)
2 (18.80295, 5.149567)
1
2
dBi
7
6
5
4
3
2
1
0
−200
−150
−100
−50
0
50
100
150
200
Theta/Degree
d=λ/3

FIG. 37B

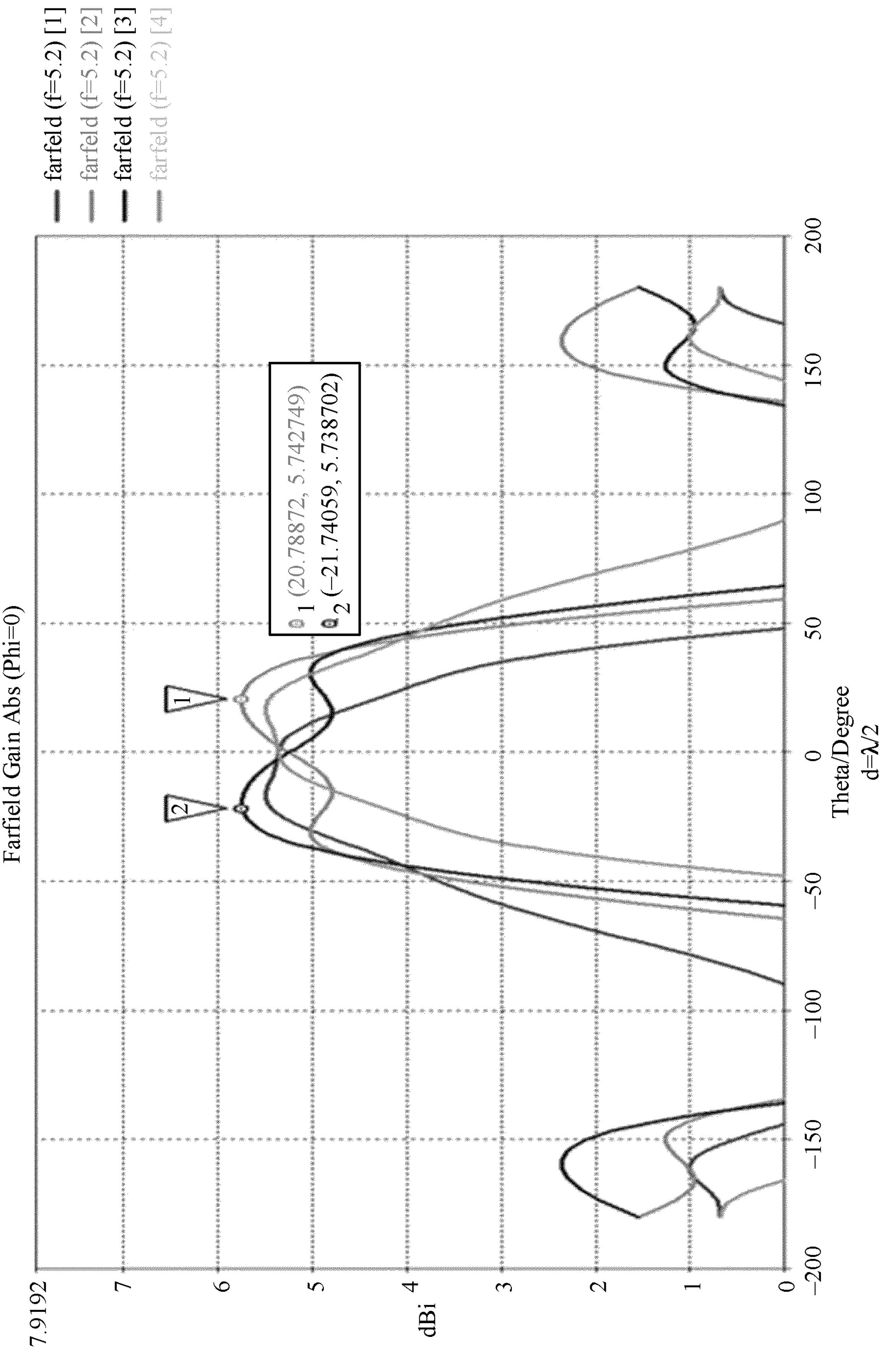

Farfield Gain Abs (Phi=0)
farfeld (f=5.2) [1]
farfeld (f=5.2) [2]
farfeld (f=5.2) [3]
farfeld (f=5.2) [4]
1 (20.78872, 5.742749)
2 (−21.74059, 5.738702)
1
2
dBi
7.9192
7
6
5
4
3
2
1
0
−200
−150
−100
−50
0
50
100
150
200
Theta/Degree
d=λ/2

FIG. 37C

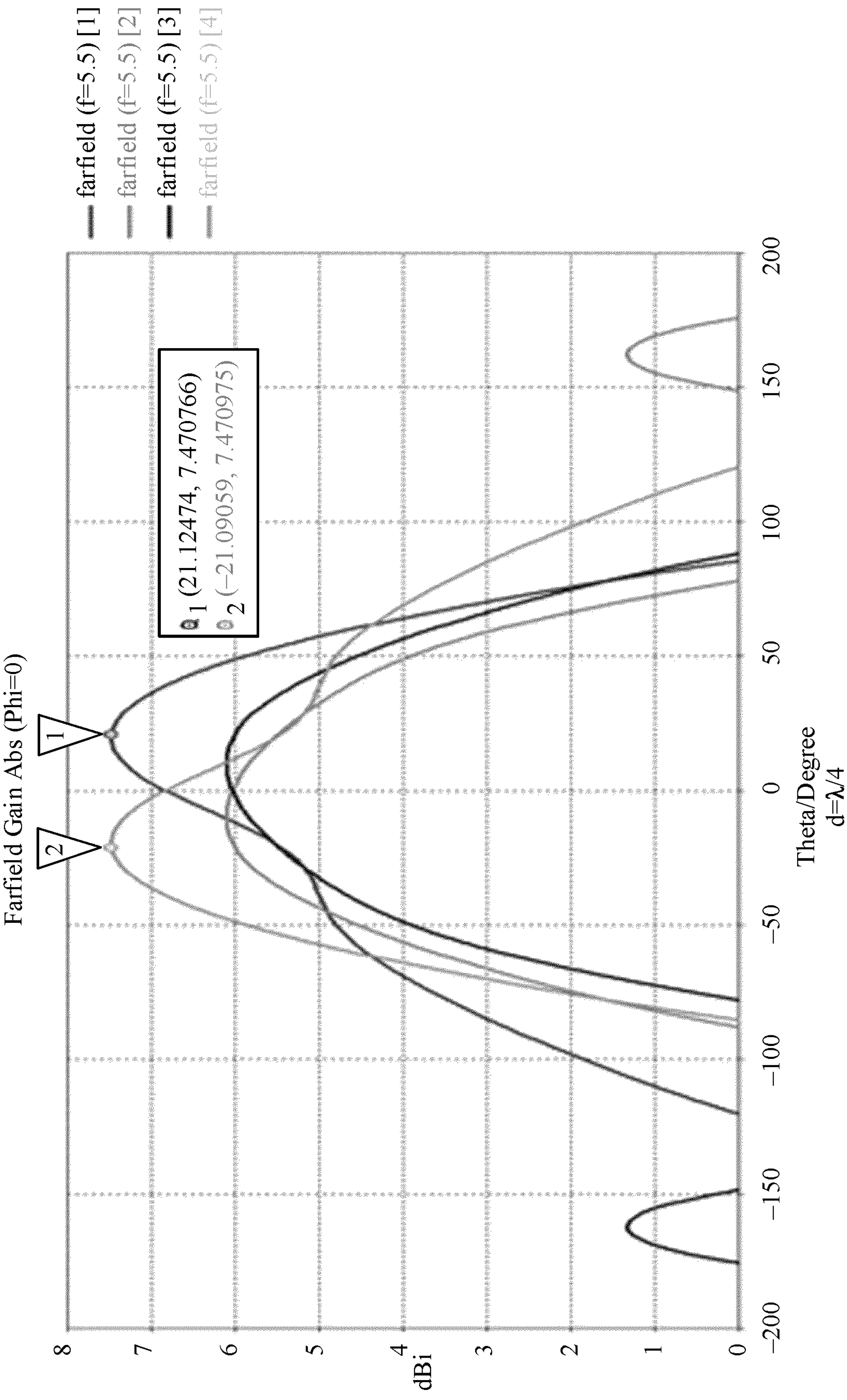

Farfield Gain Abs (Phi=0)
farfield (f=5.5) [1]
farfield (f=5.5) [2]
farfield (f=5.5) [3]
farfield (f=5.5) [4]
1 (21.12474, 7.470766)
2 (−21.09059, 7.470975)
1
2
dBi
8
7
6
5
4
3
2
1
0
−200
−150
−100
−50
0
50
100
150
200
Theta/Degree
d=λ/4

FIG. 38A

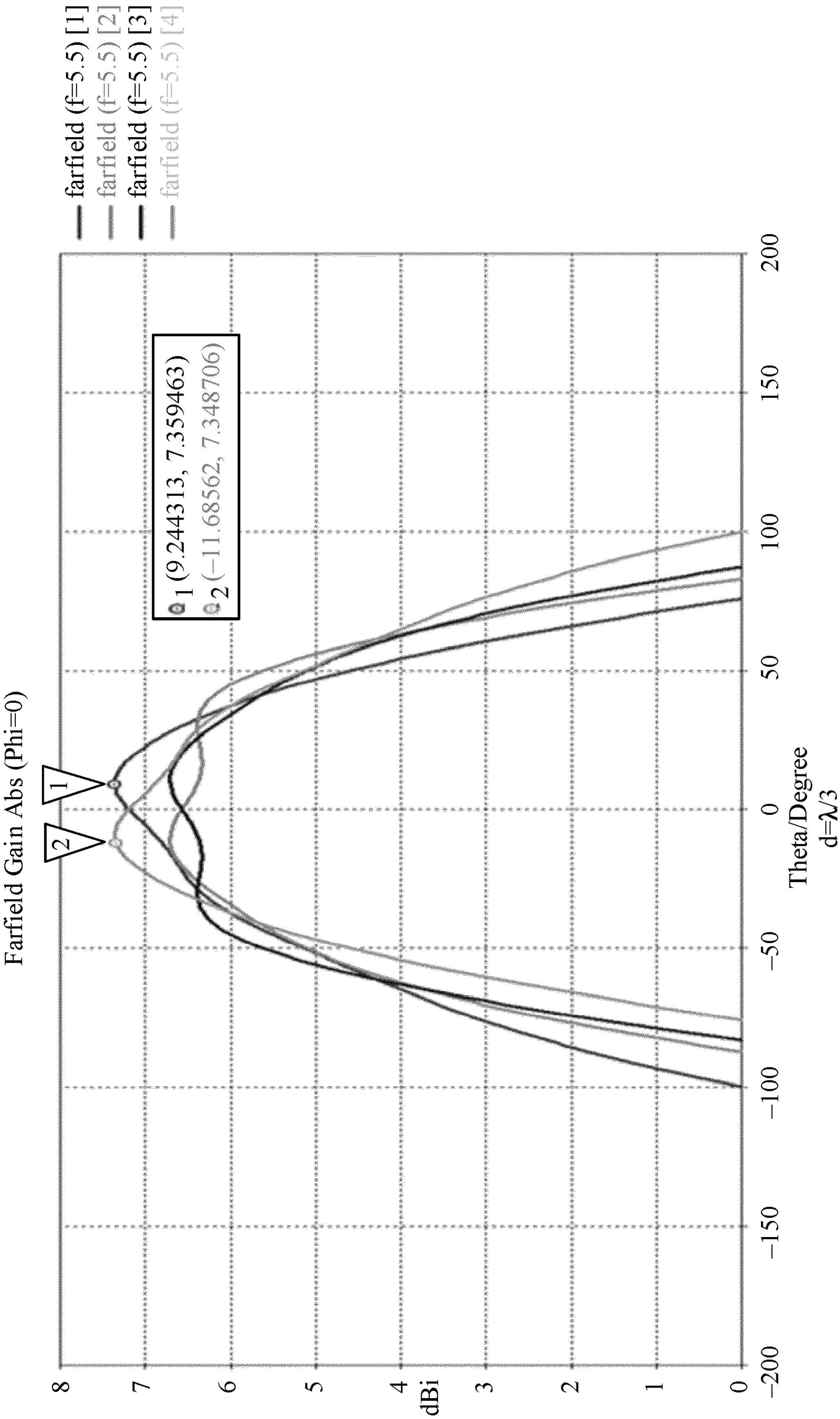

Farfield Gain Abs (Phi=0)
farfield (f=5.5) [1]
farfield (f=5.5) [2]
farfield (f=5.5) [3]
farfield (f=5.5) [4]
1 (9.244313, 7.359463)
2 (−11.68562, 7.348706)
1
2
dBi
8
7
6
5
4
3
2
1
0
−200
−150
−100
−50
0
50
100
150
200
Theta/Degree
d=λ/3

FIG. 38B

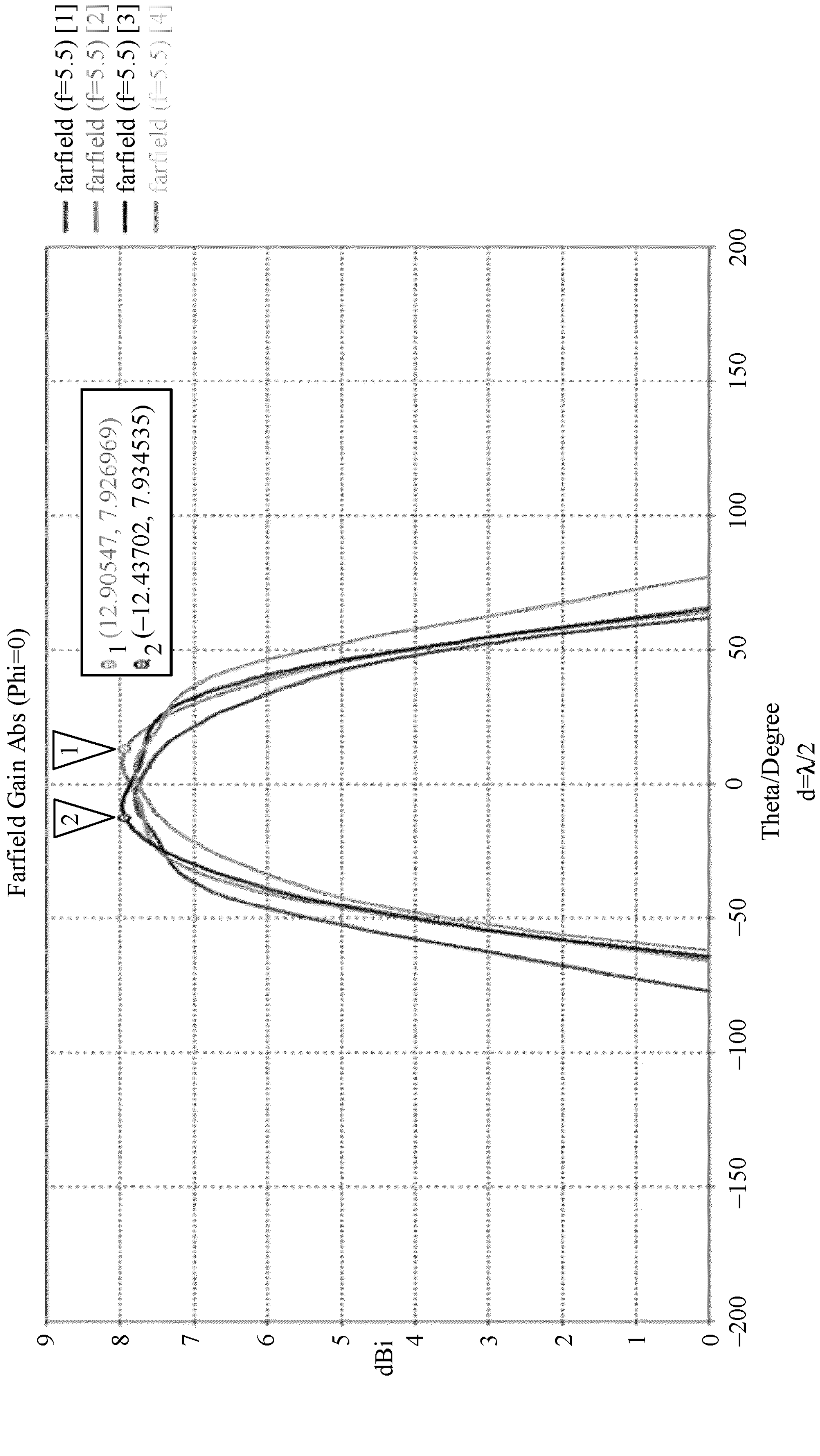

Farfield Gain Abs (Phi=0)
farfield (f=5.5) [1]
farfield (f=5.5) [2]
farfield (f=5.5) [3]
farfield (f=5.5) [4]
1 (12.90547, 7.926969)
2 (−12.43702, 7.934535)
1
2
dBi
9
8
7
6
5
4
3
2
1
0
−200
−150
−100
−50
0
50
100
150
200
Theta/Degree
d=λ/2

FIG. 38C

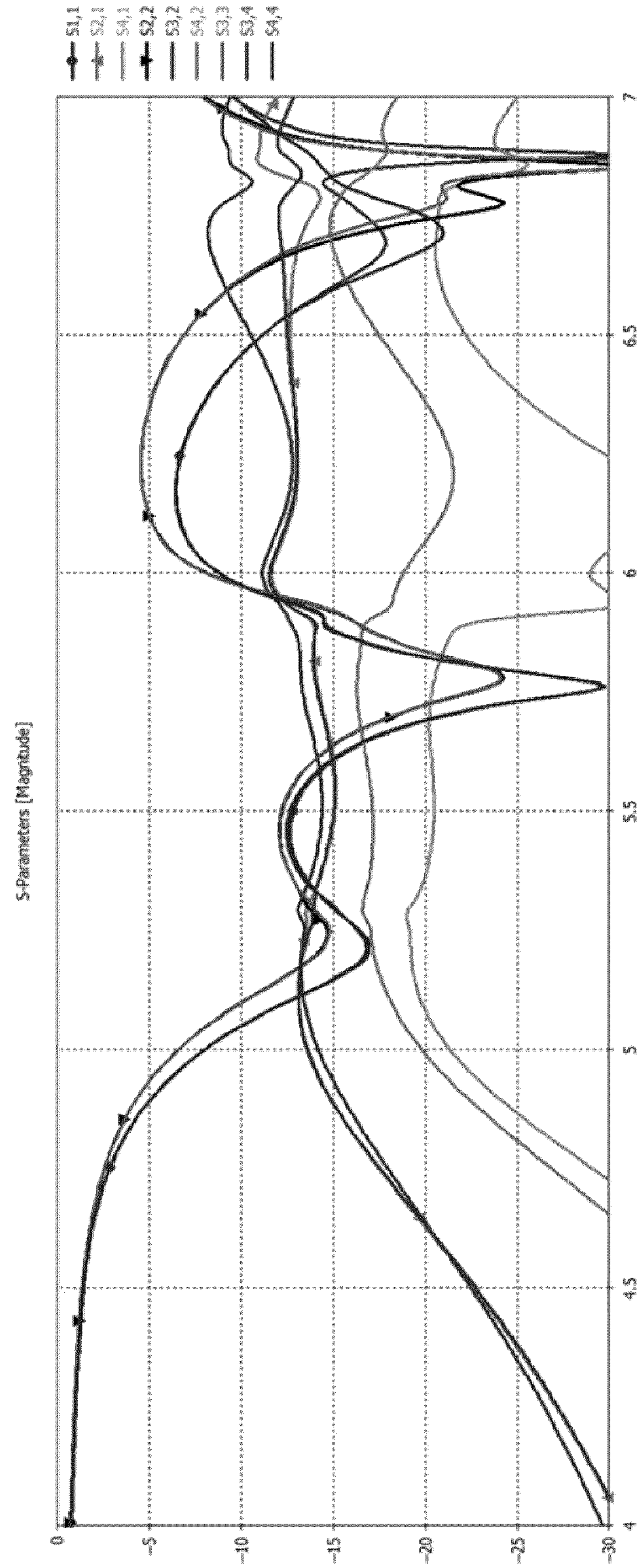


FIG. 39(a) Vertical polarization

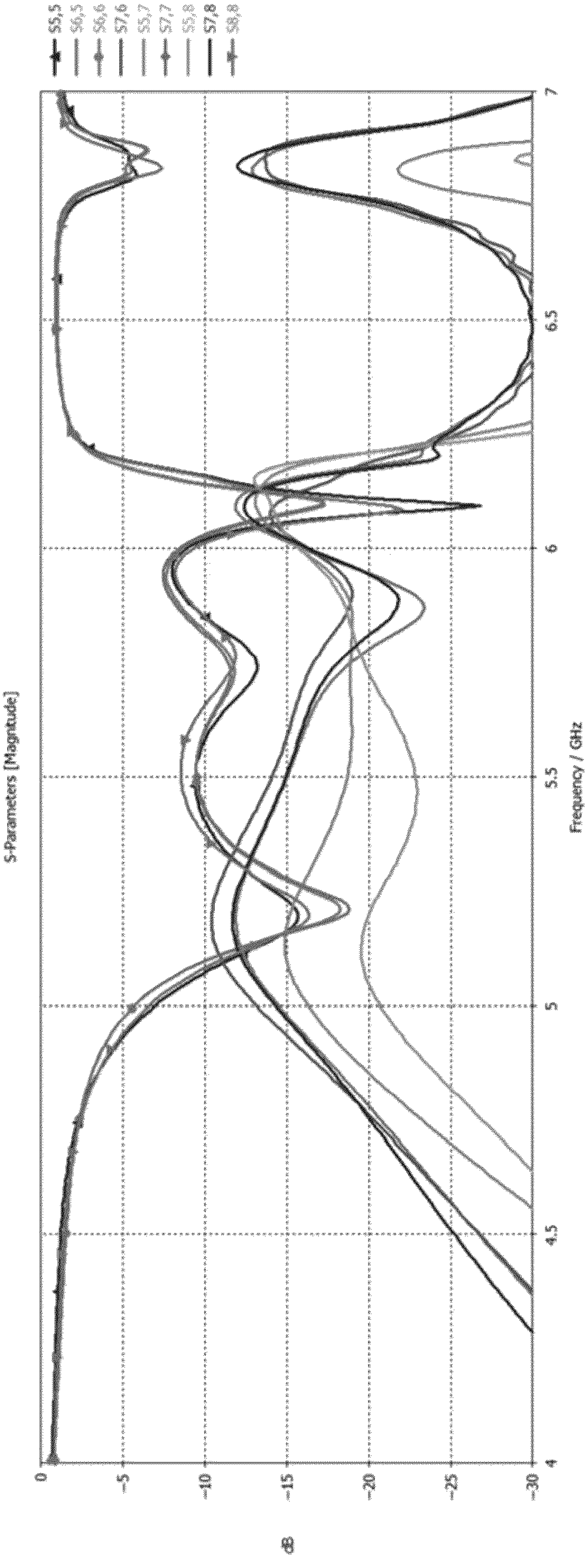


FIG. 39(b) Horizontal polarization

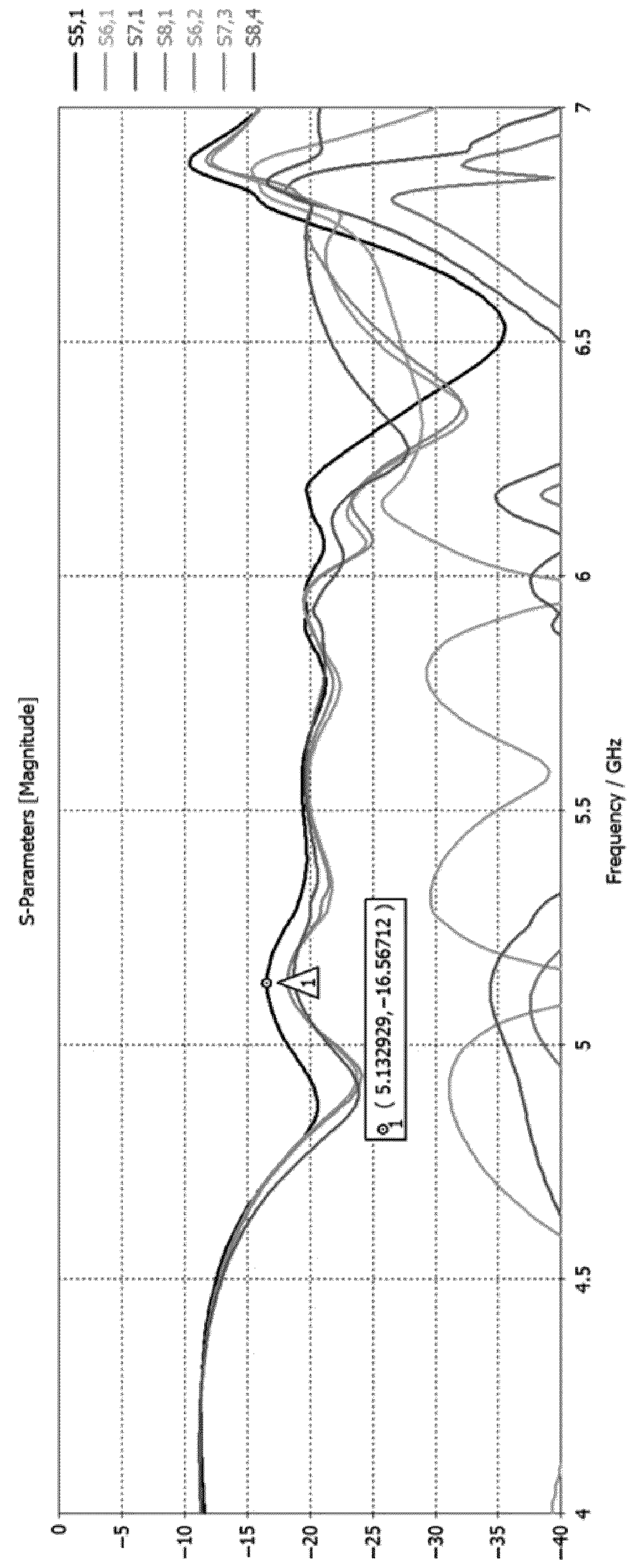
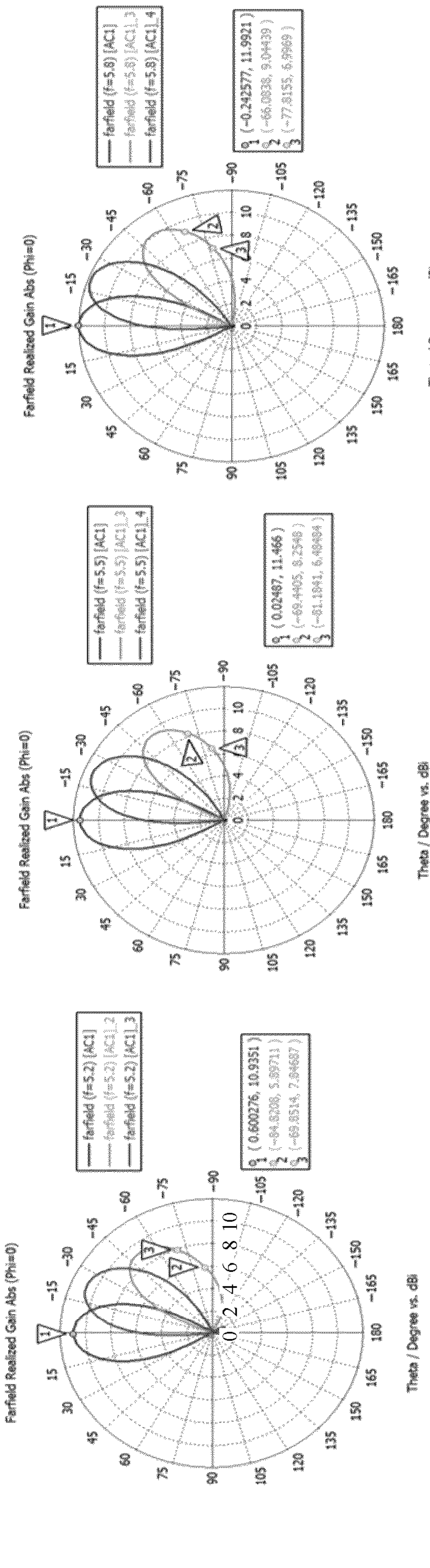


FIG. 39(c) Isolation between a vertical polarization port and a horizontal polarization port



5.2 GHz

5.5 GHz

5.8 GHz

FIG. 40(a) Vertical polarization

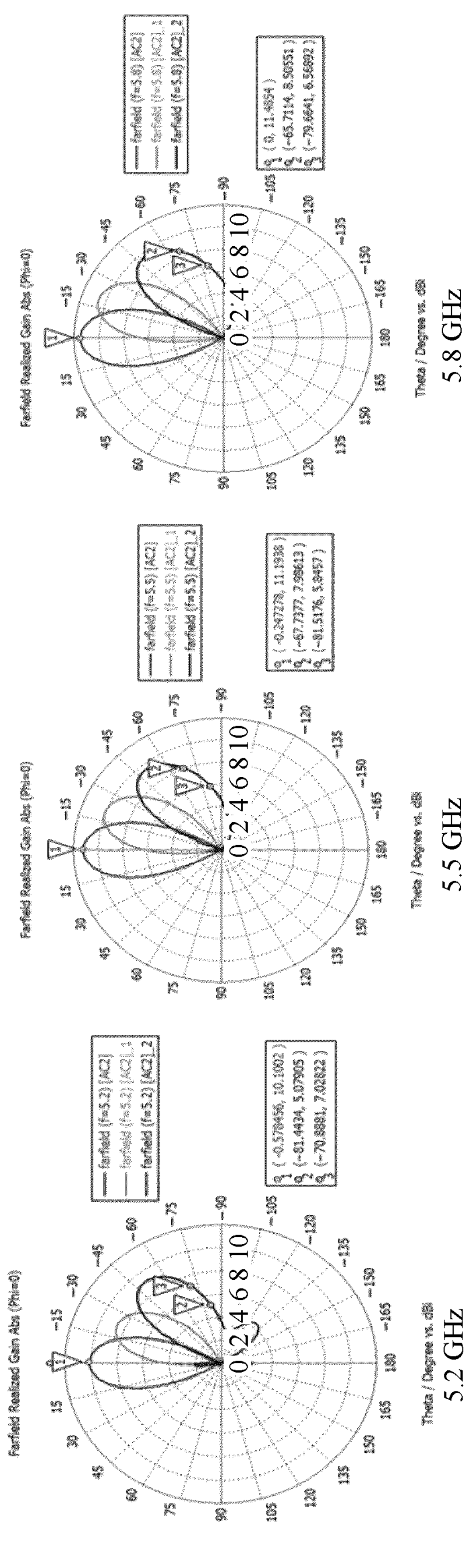


FIG. 40(b) Horizontal polarization

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2023/119355

A. CLASSIFICATION OF SUBJECT MATTER

H01Q1/38(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)

IPC: 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)

CNKI, CNTXT, ENTXTC, DWPI, IEEE: 天线, 阵列, 贴片, 寄生, 缝, 槽, 馈, 供电, 双极化, antenna, array, patch, parasitic, slot, groove, feed, dual polari+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 114976583 A (HUAWEI TECHNOLOGIES CO., LTD.) 30 August 2022 (2022-08-30) claims 1-18, description, paragraphs [0062]-[0111], and figures 2-6, 8, and 9	1-20
A	CN 113629398 A (SHENZHEN UNIVERSITY) 09 November 2021 (2021-11-09) entire document	1-20
A	CN 113097726 A (GUANGDONG UNIVERSITY OF TECHNOLOGY) 09 July 2021 (2021-07-09) entire document	1-20
A	CN 114122682 A (HUAWEI TECHNOLOGIES CO., LTD.) 01 March 2022 (2022-03-01) entire document	1-20
A	US 2018123245 A1 (BROADCOM CORP.) 03 May 2018 (2018-05-03) entire document	1-20

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

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- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 November 2023	**22 November 2023**

Name and mailing address of the ISA/CN	Authorized officer
China National Intellectual Property Administration (ISA/ CN) **China No. 6, Xitucheng Road, Jimenqiao, Haidian District, Beijing 100088**	Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2023/119355

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
CN	114976583	A	30 August 2022	WO	2022179596	A1	01 September 2022
CN	113629398	A	09 November 2021		None		
CN	113097726	A	09 July 2021		None		
CN	114122682	A	01 March 2022	WO	2022042231	A1	03 March 2022
US	2018123245	A1	03 May 2018		None		

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REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- CN 202211147258 **[0001]**