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(54) **ANTENNA STRUCTURE AND ELECTRONIC DEVICE**

(57) Embodiments of this application provide an antenna structure and an electronic device. An electronic element is loaded in a predetermined current region of a radiator, so that the radiator is connected to a ground plane in the region. Then, a boundary condition is adjusted, and an operating mode of the antenna structure is changed, so that a low-frequency resonant frequency band is adjusted to be close to a high-frequency resonant frequency band. In this way, an operating bandwidth of the antenna structure is expanded.

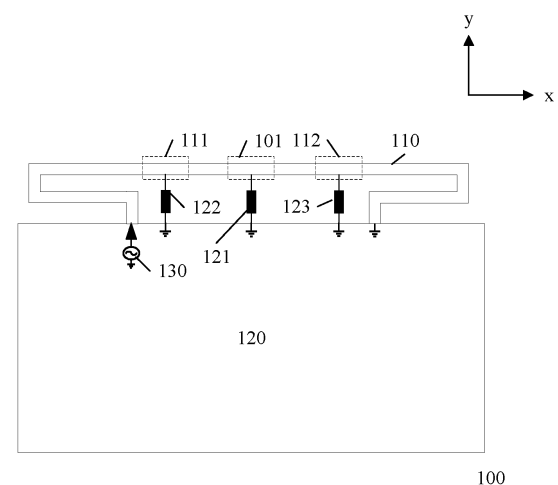


FIG. 7

Description

[0001] This application claims priority to Chinese Patent Application No. 202211114439.8, filed with the China National Intellectual Property Administration on September 14, 2022 and entitled "ANTENNA STRUCTURE AND ELECTRONIC DEVICE", which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] This application relates to the field of wireless communication, and in particular, to an antenna structure and an electronic device.

BACKGROUND

[0003] As people's demands for high-speed data transmission increase, a development trend of an industrial design (industrial design, ID) of an electronic device is to have a large screen-to-body ratio and a plurality of cameras. Consequently, antenna clearance is greatly reduced, and space for layout is increasingly limited.

[0004] In a current state, in terms of a communication frequency band of the electronic device, a third-generation mobile communication technology (3rd generation wireless system, 3G), a fourth-generation mobile communication technology (4th generation wireless system, 4G), and a fifth-generation mobile communication technology (5th generation wireless system, 5G) may coexist for a long time, and frequency band coverage is increasingly wide. Based on these changes, it is urgent to expand an operating bandwidth of an antenna of the electronic device.

SUMMARY

[0005] Embodiments of this application provide an antenna structure and an electronic device. An electronic element is loaded in a current region of a radiator, so that the radiator is connected to a ground plane in the region. Then, a boundary condition is adjusted, and an operating mode of the antenna structure is changed, so that a low-frequency resonant frequency band is adjusted to be close to a high-frequency resonant frequency band. In this way, an operating bandwidth of the antenna structure is expanded.

[0006] According to a first aspect, an antenna structure is provided, including: a ground plane, where the antenna structure is grounded through the ground plane; a radiator, where a first end and a second end of the radiator are grounded; and a first electronic element and a second electronic element, where a central region of the radiator includes a slot, or the antenna structure further includes a ground element and the ground element is electrically connected between the central region and the ground plane. The radiator includes a first current region and a second current region, the central region is between the

first current region and the second current region, the first current region includes an electric field node generated by the antenna structure, and the second current region includes an electric field node generated by the antenna structure; the first electronic element is electrically connected between the first current region and the ground plane; and the second electronic element is electrically connected between the second current region and the ground plane.

[0007] According to this embodiment of this application, the ground element is electrically connected between the ground plane and the central region of the radiator, so that an operating mode of the antenna structure can include two one-wavelength modes (in a CM mode and a DM mode) and two two-wavelength modes (in the CM mode and the DM mode). In addition, the first electronic element and the second electronic element are respectively electrically connected between the first current region of the radiator and the ground plane and between the second current region of the radiator and the ground plane, so that current nodes (electric field strong points) in the first current region and the second current region in the one-wavelength mode may be changed into electric field nodes (current strong points), and the operating mode may be changed from the one-wavelength mode to the two-wavelength mode, to form a new two-wavelength mode pair. In this case, the operating mode of the antenna structure may be increased to adjust a low-frequency resonant frequency band to a high-frequency resonant frequency band, so that the operating mode of the antenna structure includes two two-wavelength modes in the CM mode and two two-wavelength modes in the DM mode. In this way, four resonances with close frequencies may be generated, to expand an operating bandwidth of the antenna structure.

[0008] With reference to the first aspect, in some implementations of the first aspect, at least a part of the radiator from the first end to the second end is configured to generate a first resonance. The first electronic element is an inductor, the second electronic element is an inductor, and inductances of the first electronic element and the second electronic element are both less than or equal to a first threshold. When a frequency of the first resonance is less than or equal to 1.7 GHz, the first threshold is 5 nH. When a frequency of the first resonance is greater than 1.7 GHz and less than or equal to 3 GHz, the first threshold is 3 nH. When a frequency of the first resonance is greater than 3 GHz, the first threshold is 2 nH.

[0009] According to this embodiment of this application, the inductance of the electronic element may be understood as an equivalent inductance between the current region and the ground plane. For example, when only a single electronic element is electrically connected between the first current region and the ground plane, an inductance of the electronic element may be 3 nH. However, when only two electronic elements are electrically connected between the first current region and the

ground plane, inductances of the two electronic elements may be both 6 nH, and an equivalent inductance between the first current region and the ground plane is also 3 nH, so that same technical effect can be achieved. Alternatively, it may be understood that the threshold accordingly changes as more electronic elements are electrically connected between the current region and the ground plane.

[0010] With reference to the first aspect, in some implementations of the first aspect, a distance between the first end and the second end is equal to a length of the radiator.

[0011] According to this embodiment of this application, the antenna structure may be a slot antenna.

[0012] With reference to the first aspect, in some implementations of the first aspect, the antenna structure is used in an electronic device. The electronic device further includes a conductive bezel. The bezel has a first position and a second position. The first position and the second position of the bezel are continuous with a remaining part of the bezel. The bezel between the first position and the second position is used as the radiator.

[0013] With reference to the first aspect, in some implementations of the first aspect, a distance between the first end and the second end is less than a length of the radiator.

[0014] According to this embodiment of this application, the antenna structure may be a loop antenna.

[0015] With reference to the first aspect, in some implementations of the first aspect, the antenna structure includes a first filter and a second filter. The first filter is electrically connected between the first electronic element and the first current region. The second filter is electrically connected between the second electronic element and the second current region. The first filter and the second filter are in a turned-on state in a first frequency band, and are in a turned-off state in a second frequency band. A frequency of the first frequency band is higher than a frequency of the second frequency band.

[0016] With reference to the first aspect, in some implementations of the first aspect, a part of the radiator from the first end to the second end is configured to generate a first resonance, a second resonance, a third resonance, a fourth resonance, a fifth resonance, and a sixth resonance. The first frequency band includes a resonant frequency band of the first resonance, a resonant frequency band of the second resonance, a resonant frequency band of the third resonance, and a resonant frequency band of the fourth resonance. The second frequency band includes a resonant frequency band of the fifth resonance and a resonant frequency band of the sixth resonance.

[0017] According to this embodiment of this application, when the first frequency band includes the resonant frequency band of the first resonance, the resonant frequency band of the second resonance, the resonant frequency band of the third resonance, and the resonant frequency band of the fourth resonance, the second

frequency band includes the resonant frequency band of the fifth resonance and the resonant frequency band of the sixth resonance. The first filter and the second filter are in the turned-on state in the first frequency band. In this case, the first electronic element and the second electronic element are electrically connected to the radiator, and the antenna structure may generate the first resonance, the second resonance, the third resonance, and the fourth resonance. The first filter and the second filter are in the turned-off state in the second frequency band. In this case, the first electronic element and the second electronic element are disconnected from and are not electrically connected to the radiator, and the antenna structure may additionally generate the fifth resonance and the sixth resonance.

[0018] With reference to the first aspect, in some implementations of the first aspect, the central region of the radiator includes the slot, an electrical length of the radiator is three halves of a first wavelength, and the first wavelength is a wavelength corresponding to a resonance generated by the antenna structure.

[0019] With reference to the first aspect, in some implementations of the first aspect, the ground element is electrically connected between the central region and the ground plane, an electrical length of the radiator is twice a first wavelength, and the first wavelength is a wavelength corresponding to a resonance generated by the antenna structure.

[0020] According to a second aspect, an electronic device is provided, including the antenna structure according to any implementation of the first aspect.

[0021] According to a third aspect, an antenna structure is provided, including: a ground plane, where the antenna structure is grounded through the ground plane; a radiator, where a first end of the radiator is grounded, and a second end of the radiator is an open end; and a first electronic element, where the radiator includes a first current region, the first current region includes an electric field node generated by the antenna structure, and the first electronic element is electrically connected between the first current region and the ground plane.

[0022] With reference to the third aspect, in some implementations of the third aspect, at least a part of the radiator from the first end to the second end is configured to generate a first resonance. The first electronic element is an inductor, and an inductance of the first electronic element is less than or equal to a first threshold. When a frequency of the first resonance is less than or equal to 1.7 GHz, the first threshold is 5 nH. When a frequency of the first resonance is greater than 1.7 GHz and less than or equal to 3 GHz, the first threshold is 3 nH. When a frequency of the first resonance is greater than 3 GHz, the first threshold is 2 nH.

[0023] With reference to the third aspect, in some implementations of the third aspect, the antenna structure further includes a second electronic element; and the first electronic element is electrically connected to the radiator at a first position, the second electronic element

is electrically connected to the radiator at a second position, the second position is between the first position and a third position, and a distance between the third position and the first position is the same as a distance between the third position and the second end.

[0024] With reference to the third aspect, in some implementations of the third aspect, the antenna structure further includes a feed unit; the radiator includes an electric field region, and the electric field region includes a current node generated by the antenna structure; and the electric field region includes a feed point, and the feed unit is electrically connected to the radiator at the feed point.

[0025] With reference to the third aspect, in some implementations of the third aspect, the antenna structure further includes the feed unit; and the first current region includes a feed point, and the feed unit is electrically connected to the radiator at the feed point.

[0026] With reference to the third aspect, in some implementations of the third aspect, the antenna structure further includes a resonant stub; and a third end of the resonant stub is connected to the first end, and a fourth end of the resonant stub is an open end.

[0027] With reference to the third aspect, in some implementations of the third aspect, a length L1 of the resonant stub and a length L2 of the radiator satisfy: $0.2 \times L2 \leq L1 \leq 0.3 \times L2$.

[0028] With reference to the third aspect, in some implementations of the third aspect, the antenna structure further includes a third electronic element; and the third electronic element is electrically connected between the first end and the ground plane.

[0029] With reference to the third aspect, in some implementations of the third aspect, the antenna structure includes a filter. The first filter is electrically connected between the first electronic element and the first current region. The first filter is in a turned-on state in a first frequency band, and is in a turned-off state in a second frequency band. A frequency of the first frequency band is higher than a frequency of the second frequency band.

[0030] With reference to the third aspect, in some implementations of the third aspect, a part of the radiator from the first end to the second end is configured to generate a first resonance, a second resonance, and a third resonance; the first frequency band includes a resonant frequency band of the first resonance and a resonant frequency band of the second resonance; and the second frequency band includes a resonant frequency band of the third resonance.

[0031] With reference to the third aspect, in some implementations of the third aspect, the antenna structure further includes a fourth electronic element; the radiator includes a second current region, and the second current region includes an electric field node generated by the antenna structure; and the fourth electronic element is electrically connected between the second current region and the ground plane.

[0032] According to a fourth aspect, an electronic device is provided, including the antenna structure according to any implementation of the third aspect.

5 BRIEF DESCRIPTION OF DRAWINGS

[0033]

FIG. 1 is a diagram of an electronic device according to an embodiment of this application;

FIG. 2 is a diagram of a common-mode structure of a wire antenna and corresponding distribution of currents and electric fields according to this application; FIG. 3 is a diagram of a differential-mode structure of a wire antenna and corresponding distribution of currents and electric fields according to this application;

FIG. 4 is a diagram of a common-mode structure of a slot antenna and corresponding distribution of currents, electric fields, and magnetic currents according to this application;

FIG. 5 is a diagram of a differential-mode structure of a slot antenna and corresponding distribution of currents, electric fields, and magnetic currents according to this application;

FIG. 6 is a distribution diagram of currents of a slot antenna according to an embodiment of this application;

FIG. 7 is a diagram of an antenna structure according to an embodiment of this application;

FIG. 8 is a distribution diagram of currents of the antenna structure, as shown in FIG. 7, in which an electronic element and a ground element are not disposed;

FIG. 9 is a distribution diagram of currents of the antenna structure, as shown in FIG. 7, in which only a ground element is disposed;

FIG. 10 is a distribution diagram of currents of the antenna structure shown in FIG. 7;

FIG. 11 shows S-parameters of the antenna structure shown in FIG. 7;

FIG. 12 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 7;

FIG. 13 shows corresponding S-parameters of the antenna structure, as shown in FIG. 7, in which a first electronic element and a second electronic element are changed;

FIG. 14 shows corresponding simulation results of radiation efficiency and total efficiency of the antenna structure, as shown in FIG. 7, in which a first electronic element and a second electronic element are changed;

FIG. 15 is a distribution diagram of currents in a case in which a ground element, a first electronic element, and a second electronic element are not disposed;

FIG. 16 is a distribution diagram of currents in a case in which only a ground element is disposed;

FIG. 17 is a distribution diagram of currents in a case in which a ground element, a first electronic element, and a second electronic element are disposed;
 FIG. 18 is a diagram of another antenna structure 100 according to an embodiment of this application;
 FIG. 19 is a diagram of an electronic device according to an embodiment of this application;
 FIG. 20 shows S-parameters of the antenna structure shown in FIG. 18;
 FIG. 21 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 18;
 FIG. 22 is a distribution diagram of electric fields/magnetic currents in a case in which a ground element, a first electronic element, and a second electronic element are not disposed;
 FIG. 23 is a distribution diagram of electric fields/magnetic currents in a case in which only a ground element is disposed;
 FIG. 24 is a distribution diagram of electric fields/magnetic currents in a case in which a ground element, a first electronic element, and a second electronic element are disposed;
 FIG. 25 is a diagram of still another antenna structure 100 according to an embodiment of this application;
 FIG. 26 shows S-parameters of the antenna structure shown in FIG. 25;
 FIG. 27 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 25;
 FIG. 28 is a diagram of still another antenna structure 100 according to an embodiment of this application;
 FIG. 29 is a distribution diagram of currents of the antenna structure, as shown in FIG. 28, in which an electronic element and a slot are not provided;
 FIG. 30 is a distribution diagram of currents of the antenna structure, as shown in FIG. 28, in which only a slot is provided;
 FIG. 31 is a distribution diagram of currents of the antenna structure shown in FIG. 28;
 FIG. 32 shows S-parameters of the antenna structure shown in FIG. 28;
 FIG. 33 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 28;
 FIG. 34 is a diagram of still another antenna structure 100 according to an embodiment of this application;
 FIG. 35 shows S-parameters of the antenna structure shown in FIG. 34;
 FIG. 36 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 34;
 FIG. 37 is a distribution diagram of electric fields/magnetic currents in a case in which a first electronic element and a second electronic element are not disposed;
 FIG. 38 is a distribution diagram of electric fields/magnetic currents in a case in which a first electronic

element and a second electronic element are disposed;
 FIG. 39 is a diagram of still another antenna structure 100 according to an embodiment of this application;
 FIG. 40 shows S-parameters of the antenna structure shown in FIG. 39;
 FIG. 41 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 39;
 FIG. 42 is a diagram of an antenna structure 200 according to an embodiment of this application;
 FIG. 43 is a distribution diagram of currents and electric fields of the antenna structure, as shown in FIG. 42, in which an electronic element is not disposed;
 FIG. 44 is a distribution diagram of currents and electric fields, corresponding to a quarter-wavelength mode, of the antenna structure shown in FIG. 42;
 FIG. 45 is a distribution diagram of currents and electric fields, corresponding to a three-quarters-wavelength mode, of the antenna structure shown in FIG. 42;
 FIG. 46 shows S-parameters of the antenna structure shown in FIG. 42;
 FIG. 47 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 42;
 FIG. 48 is a diagram of another antenna structure 200 according to an embodiment of this application;
 FIG. 49 is a diagram of still another antenna structure 200 according to an embodiment of this application;
 FIG. 50 is a distribution diagram of electric fields and currents of the antenna structure 200 shown in FIG. 49;
 FIG. 51 shows S-parameters of the antenna structure shown in FIG. 49;
 FIG. 52 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 49;
 FIG. 53 is a diagram of still another antenna structure 200 according to an embodiment of this application;
 FIG. 54 is a distribution diagram of electric fields and currents of the antenna structure 200 shown in FIG. 53;
 FIG. 55 shows S-parameters of the antenna structure shown in FIG. 53;
 FIG. 56 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 53;
 FIG. 57 is a diagram of still another antenna structure 200 according to an embodiment of this application;
 FIG. 58 shows S-parameters of the antenna structure, as shown in FIG. 57, in which a first electronic element is electrically connected and a second electronic element is not electrically connected;
 FIG. 59 shows simulation results of radiation efficiency and total efficiency of the antenna structure,

as shown in FIG. 57, in which a first electronic element is electrically connected and a second electronic element is not electrically connected;

FIG. 60 is a distribution diagram of currents of the antenna structure, as shown in FIG. 57, in which a first electronic element is electrically connected and a second electronic element is not electrically connected;

FIG. 61 shows S-parameters of the antenna structure shown in FIG. 57;

FIG. 62 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 57;

FIG. 63 is a distribution diagram of currents of the antenna structure shown in FIG. 57;

FIG. 64 is a diagram of still another antenna structure 200 according to an embodiment of this application;

FIG. 65 shows S-parameters of the antenna structure shown in FIG. 64;

FIG. 66 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 64;

FIG. 67 is a distribution diagram of currents of the antenna structure shown in FIG. 64;

FIG. 68 shows S-parameters of the antenna structure (excluding a resonant stub) shown in FIG. 64 in different models;

FIG. 69 shows simulation results of radiation efficiency and total efficiency of the antenna structure (excluding a resonant stub) shown in FIG. 64 in different models;

FIG. 70 shows S-parameters of the antenna structure shown in FIG. 64 in different models;

FIG. 71 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 64 in different models;

FIG. 72 shows S-parameters of the antenna structure shown in FIG. 64;

FIG. 73 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 64;

FIG. 74 is a distribution diagram of currents of the antenna structure shown in FIG. 64;

FIG. 75 is a diagram of still another antenna structure 200 according to an embodiment of this application;

FIG. 76 shows S-parameters of the antenna structure shown in FIG. 75;

FIG. 77 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 75;

FIG. 78 is a distribution diagram of electric fields and currents of the antenna structure shown in FIG. 75;

FIG. 79 is a pattern of the antenna structure shown in FIG. 75;

FIG. 80 shows S-parameters of the antenna structure shown in FIG. 75 that includes a second electronic element;

FIG. 81 shows simulation results of radiation effi-

ciency and total efficiency of the antenna structure shown in FIG. 75 that includes a second electronic element;

FIG. 82 shows S-parameters of the antenna structure shown in FIG. 75 in a left/right-handed model;

FIG. 83 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 75 in a left/right-handed model;

FIG. 84 is a diagram of still another antenna structure 200 according to an embodiment of this application;

FIG. 85 is a distribution diagram of electric fields and currents of the antenna structure shown in FIG. 84;

FIG. 86 is a pattern of the antenna structure shown in FIG. 84;

FIG. 87 shows S-parameters of the antenna structure shown in FIG. 84 in a left/right-handed model;

FIG. 88 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 84 in a left/right-handed model;

FIG. 89 is a diagram of still another antenna structure 200 according to an embodiment of this application;

FIG. 90 shows S-parameters of the antenna structure shown in FIG. 89;

FIG. 91 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 89;

FIG. 92 is a distribution diagram of currents of the antenna structure shown in FIG. 89;

FIG. 93 is a pattern of the antenna structure shown in FIG. 89;

FIG. 94 is a diagram of still another antenna structure 200 according to an embodiment of this application;

FIG. 95 shows S-parameters of the antenna structure shown in FIG. 94;

FIG. 96 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 94;

FIG. 97 is a distribution diagram of electric fields and currents of the antenna structure shown in FIG. 94 that does not include a second electronic element;

FIG. 98 is a distribution diagram of electric fields and currents of the antenna structure shown in FIG. 94 that includes a second electronic element;

FIG. 99 shows S-parameters of the antenna structure shown in FIG. 94 in a left/right-handed model; and

FIG. 100 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 94 in a left/right-handed model.

DESCRIPTION OF EMBODIMENTS

[0034] The following describes possible terms in embodiments of this application.

[0035] 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 in a gap between two electric-conductors.

[0036] Connection/Connected: The connection may indicate a mechanical connection relationship or a physical connection relationship. For example, a connection between A and B or A being connected to B may mean that there is a fastening component (for example, a screw, a bolt, or a rivet) between A and B, or mean that A and B are in contact with each other and A and B are difficult to be separated.

[0037] Connection: That two or more components are turned on or connected in the "electrical connection" or "indirect coupling" manner to perform signal/energy transmission may be referred to as the connection.

[0038] Capacitor: The capacitor may be understood as a lumped capacitor and/or a distributed capacitor. The lumped capacitor is a capacitive component, for example, a capacitive element, and the distributed capacitor (or distributed capacitor) is an equivalent capacitor formed due to a gap between two electric-conductors.

[0039] Inductor: The inductor may be understood as a lumped inductor and/or a distributed inductor. The lumped inductor is an inductive component, for example, a capacitive element, and the distributed inductor (or distributed inductor) is an equivalent inductor formed due to curling or rotation of a conductor.

[0040] Resonance/Resonance frequency: The resonance frequency is also referred to as a resonant frequency. The resonance frequency may be a frequency of a position at which an imaginary part of an antenna input impedance is zero. The resonance frequency may have a frequency range, namely, a frequency range in which resonance occurs. A frequency corresponding to a strongest resonance point is a center frequency. A return loss of the center frequency may be less than -20 dB. It should be understood that, unless otherwise specified, in "the first resonance generated by the antenna/radiator" mentioned in this application, the first resonance should mean a fundamental resonance generated by the antenna/radiator, or a resonance with a lowest frequency generated by the antenna/radiator.

[0041] Resonant frequency band/Communication frequency band/Operating frequency band: Regardless of a type of an antenna, the antenna operates in a specific frequency range (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.

[0042] Electrical length: The electrical length may be a ratio of a physical length (namely, a mechanical length or a geometric length) to a wavelength of a transmitted electromagnetic wave. The electrical length may satisfy the following formula:

$$\bar{L} = \frac{L}{\lambda}$$

[0043] In the formula, L is a physical length, and λ is a wavelength of an electromagnetic wave.

[0044] Wavelength: The wavelength, or an operating wavelength, may be a wavelength corresponding to a center frequency of a resonance frequency or a center frequency of an operating frequency band supported by an antenna. For example, it is assumed that a center frequency of a B1 uplink frequency band (with a resonance frequency ranging from 1920 MHz to 1980 MHz) is 1955 MHz. In this case, the operating wavelength may be a wavelength calculated by using the frequency of 1955 MHz. The operating wavelength is not limited to the center frequency, and may alternatively be a wavelength corresponding to a resonance frequency or a frequency of an operating frequency band other than a center frequency.

[0045] It should be understood that, the wavelength (operating wavelength) may be understood as a wavelength of an electromagnetic wave in a dielectric. For example, a wavelength of an electromagnetic wave generated by a radiator and transmitted in a dielectric and a wavelength of the electromagnetic wave transmitted in a vacuum satisfy the following formula:

$$\lambda_e = \frac{\lambda_c}{\sqrt{\epsilon_r}}$$

[0046] In the formula, λ_e is the wavelength of the electromagnetic wave in the dielectric, λ_c is a wavelength of the electromagnetic wave in a vacuum, and ϵ_r is a relative dielectric constant of the dielectric in a dielectric layer. The wavelength in embodiments of this application is usually a dielectric wavelength, and may be a dielectric wavelength corresponding to the center frequency of the resonance frequency, or a dielectric wavelength corresponding to the center frequency of the operating frequency band supported by the antenna. For example, it is assumed that a center frequency of a B1 uplink frequency band (with a resonance frequency ranging from 1920 MHz to 1980 MHz) is 1955 MHz. In this case, the wavelength may be a dielectric wavelength calculated by using the frequency of 1955 MHz. The dielectric wavelength is

not limited to the center frequency, and may alternatively be a dielectric wavelength corresponding to a resonance frequency or a frequency of an operating frequency band other than a center frequency. For ease of understanding, the dielectric wavelength mentioned in embodiments of this application may be simply calculated by using a relative dielectric constant of the dielectric filled on one or more sides of the radiator.

[0047] End: A first end (second end) of an antenna radiator, a ground end, or an open end cannot be understood as a point in a narrow sense, but may further be considered as a radiator segment that is of the antenna radiator and that includes a first endpoint. The first endpoint is an endpoint of the antenna radiator in a first slot. For example, the first end of the antenna radiator may be considered as a radiator segment within a range of one-sixteenth of a first wavelength from the first endpoint. The first wavelength may be a wavelength corresponding to an operating frequency band of an antenna structure, a wavelength corresponding to a center frequency of an operating frequency band, or a wavelength corresponding to a resonance point.

[0048] A limitation on a position or a distance, such as middle or a middle position, mentioned in embodiments of this application all represent a specific range. For example, a middle (position) of a conductor may be a segment that is of a conductor and that includes a midpoint on the conductor, for example, the middle (position) of the conductor may be a segment that is of the conductor and whose distance from the midpoint on the conductor is less than a predetermined threshold (for example, 1 mm, 2 mm, or 2.5 mm).

[0049] Total efficiency (total efficiency) of an antenna: The total efficiency is a ratio of input power to output power at an antenna port.

[0050] Radiation efficiency (radiation efficiency) of an antenna: The radiation efficiency is a ratio of power radiated by an antenna to space (namely, power for effectively converting an electromagnetic wave) to active power input to the antenna. Active power input to the antenna=Input power of the antenna-Loss power. The loss power mainly includes return loss power and metal ohmic loss power and/or dielectric loss power. The radiation efficiency is a value for measuring a radiation capability of an antenna. The metal loss and dielectric loss are both factors that affect the radiation efficiency.

[0051] A person skilled in the art may understand that the efficiency is usually indicated by a percentage, and there is a corresponding conversion relationship between the efficiency and dB. Efficiency closer to 0 dB indicates better antenna efficiency.

[0052] 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 the 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.

[0053] The antenna return loss may be represented by an S11 parameter, and S11 is one of S-parameters. S11 indicates a reflection coefficient, and the parameter indicates transmit efficiency of the antenna. The S11 parameter is usually a negative number. A smaller value of the S11 parameter indicates a smaller return loss of the antenna and less energy reflected back through the antenna, in other words, more energy actually enters the antenna and total efficiency of the antenna is higher. A larger value of the S11 parameter indicates a larger return loss of the antenna and lower total efficiency of the antenna.

[0054] It should be noted that, -6 dB is usually used as a standard value of S11 in engineering. When the value of S11 of the antenna is less than -6 dB, it may be considered that the antenna can operate normally, or it may be considered that transmit efficiency of the antenna is good.

[0055] Ground, or ground plane: The ground may generally mean at least a part of any grounding plane, any grounding plate, any grounding metal layer, or the like of an electronic device (for example, a mobile phone), or at least a part of any combination of the grounding plane, the grounding plate, a grounding component, or the like. "Ground" may be used for grounding of a component of the electronic device. In an embodiment, "ground" may be a grounding plane of a circuit board of an electronic device, or may be a grounding plate formed by a middle frame of the electronic device or a grounding metal layer formed by a metal film below a screen of the electronic device. 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.

[0056] Any one of the grounding plane, the grounding plate, or the grounding 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/grounding metal layer may alternatively be made of another conductive material.

[0057] The following describes technical solutions of embodiments in this application with reference to accom-

panying drawings.

[0058] As shown in FIG. 1, an electronic device 10 may include a cover (cover) 13, a display/display module (display) 15, a printed circuit board (printed circuit board, PCB) 17, a middle frame (middle frame) 19, and a rear cover (rear cover) 21. It should be understood that, in some embodiments, the cover 13 may be a glass cover (cover glass), or may be replaced with a cover of another material, for example, a PET (Polyethylene terephthalate, polyethylene terephthalate) material cover.

[0059] The cover 13 may be disposed close to the display module 15, and may be mainly configured to protect and prevent dust on the display module 15.

[0060] In an embodiment, the display module 15 may include a liquid crystal display (liquid crystal display, LCD), a light-emitting diode (light-emitting diode, LED) display panel, an organic light-emitting semiconductor (organic light-emitting diode, OLED) display panel, or the like. This is not limited in embodiments of this application.

[0061] The middle frame 19 is mainly used to support the entire electronic device. FIG. 1 shows that the PCB 17 is disposed between the middle frame 19 and the rear cover 21. It should be understood that, in an embodiment, the PCB 17 may alternatively be disposed between the middle frame 19 and the display module 15. This is not limited in embodiments of this application. The printed circuit board PCB 17 may be a flame-resistant material (FR-4) dielectric board, or may be a Rogers (Rogers) dielectric board, or may be a Rogers and FR-4 mixed dielectric board, or the like. Herein, FR-4 is a grade designation for a flame-resistant material, and the Rogers dielectric board is a high-frequency board. An electronic element, for example, a radio frequency chip, is carried on the PCB 17. In an embodiment, a metal layer may be disposed on the printed circuit board PCB 17. The metal layer may be used for grounding an electronic element carried on the printed circuit board PCB 17, or may be used for grounding another element, for example, a bracketed antenna or a bezel antenna. The metal layer may be referred to as a ground plane, a grounding plate, or a grounding plane. In an embodiment, the metal layer may be formed by etching metal on a surface of any layer of dielectric boards in the PCB 17. In an embodiment, the metal layer used for grounding may be disposed on a side that is of the printed circuit board PCB 17 that is close to the middle frame 19. In an embodiment, an edge of the printed circuit board PCB 17 may be considered as an edge of the grounding plane of the PCB 17. In an embodiment, the metal middle frame 19 may also be used for grounding the foregoing elements. The electronic device 10 may further have another ground plane/grounding plate/grounding plane. As described above, details are not described herein again.

[0062] The electronic device 10 may further include a battery (not shown in the figure). The battery may be disposed between the middle frame 19 and the rear cover 21, or may be disposed between the middle frame 19 and the display module 15. This is not limited in embodiments

of this application. In some embodiments, the PCB 17 is divided into a motherboard and a daughter board. The battery may be disposed between the motherboard and the daughter board. The motherboard may be disposed between the middle frame 19 and an upper edge of the battery, and the daughter board may be disposed between the middle frame 19 and a lower edge of the battery.

[0063] The electronic device 10 may further include a bezel 11. The bezel 11 may be formed of a conductive material like metal. The bezel 11 may be disposed between the display module 15 and the rear cover 21, and extends circumferentially around a periphery of the electronic device 10. The bezel 11 may have four side edges surrounding the display module 15, to help fasten the display module 15. In an implementation, the bezel 11 made of a metal material may be directly used as a metal frame of the electronic device 10 to form an appearance of the metal frame, and is applicable to a metal industrial design (industrial design, ID). In another implementation, an outer surface of the bezel 11 may alternatively be made of a material other than metal, for example, a plastic frame, to form an appearance of a non-metal frame, and is applicable to a non-metal ID.

[0064] The middle frame 19 may include the bezel 11, and the middle frame 19 including the bezel 11 is used as an integral part, and may support electronic elements in the entire electronic device. The cover 13 and the rear cover 21 are respectively covered along an upper edge and a lower edge of the bezel, to form a shell or a housing (housing) of the electronic device. In an embodiment, the cover 13, the rear cover 21, the bezel 11, and/or the middle frame 19 may be collectively referred to as the shell or the housing of the electronic device 10. It should be understood that the "shell or housing" may be used to indicate a part or all of any one of the cover 13, the rear cover 21, the bezel 11, or the middle frame 19, or indicate a part or all of any combination of the cover 13, the rear cover 21, the bezel 11, or the middle frame 19.

[0065] The bezel 11 on the middle frame 19 may be at least partially used as an antenna radiator to transmit/receive a radio frequency signal. There may be a gap between the bezel that is used as the radiator and another part of the middle frame 19, to ensure that the antenna radiator has a good radiation environment. In an embodiment, an aperture of the middle frame 19 may be disposed at the bezel that is used as the radiator, to facilitate radiation of the antenna.

[0066] Alternatively, the bezel 11 may not be considered as a part of the middle frame 19. In an embodiment, the bezel 11 and the middle frame 19 may be connected and integrally formed. In another embodiment, the bezel 11 may include a protrusion extending inward, to be connected to the middle frame 19, for example, connected by using a spring or a screw, or connected through welding. The protrusion of the bezel 11 may be further configured to receive a feed signal, so that at least a part of the bezel 11 is used as the antenna radiator to trans-

mit/receive a radio frequency signal. There is a gap 42 between the bezel that is used as the radiator and the middle frame 30, to ensure that the antenna radiator has a good radiation environment, so that the antenna has a good signal transmission function.

[0067] The rear cover 21 may be a rear cover made of a metal material, or a rear cover made of a non-conductive material, such as a glass rear cover or a plastic rear cover; or a rear cover made of both a conductive material and a non-conductive material. In an embodiment, the rear cover 21 including the conductive material may replace the middle frame 19, and is integrated with the bezel 11 to support electronic elements in the entire system.

[0068] In an embodiment, the middle frame 19 and/or a conductive part of the rear cover 21 may be used as a reference ground of the electronic device 10. The bezel 11, the PCB 17, and the like of the electronic device may be electrically connected to the middle frame for grounding.

[0069] Alternatively, the antenna of the electronic device 10 may be disposed in the bezel 11. When the bezel 11 of the electronic device 10 is made of a non-conductive material, the antenna radiator may be positioned in the electronic device 10 and disposed along the bezel 11. For example, the antenna radiator is disposed adjacent to the bezel 11, to minimize a size occupied by the antenna radiator, and is closer to outside of the electronic device 10, to achieve better signal transmission effect. It should be noted that, that the antenna radiator is disposed adjacent to the bezel 11 means that the antenna radiator may be disposed in close contact with the bezel 11, or may be disposed close to the bezel 11. For example, there may be a small slot between the antenna radiator and the bezel 11.

[0070] Alternatively, the antenna of the electronic device 10 may be disposed in the shell, for example, a bracketed antenna or a millimeter wave antenna (not shown in FIG. 1). Clearance of the antenna disposed in the housing may be obtained by a slot/hole in any one of the middle frame, and/or the bezel, and/or the rear cover, and/or the display, or by a non-conductive slot/aperture formed between any several of the middle frame, the bezel, the rear cover, and the display. The setting of the clearance of the antenna may ensure radiation performance of the antenna. It should be understood that, the clearance of the antenna may be a non-conductive region formed by any conductive component in the electronic device 10, and the antenna radiates a signal to external space through the non-conductive region. In an embodiment, the antenna 40 may be a flexible printed circuit (flexible printed circuit, FPC)-based antenna, a laser-direct-structuring (laser-direct-structuring, LDS)-based antenna, a microstrip disk antenna (microstrip disk antenna, MDA)-based antenna, or another antenna. In an embodiment, the antenna may alternatively be in a transparent structure embedded in the screen of the electronic device 10, so that the antenna

is a transparent antenna element embedded in the screen of the electronic device 10.

[0071] FIG. 1 shows only an example of some components included in the electronic device 10. An actual shape, an actual size, and an actual configuration of the components are not limited to those in FIG. 1.

[0072] It should be understood that, in this embodiment of this application, it may be considered that a surface on which the display of the electronic device is positioned is a front surface, a surface on which the rear cover is positioned is a rear surface, and a surface on which the bezel is positioned is a side surface.

[0073] It should be understood that, in this embodiment of this application, it is considered that when a user holds (usually holding the electronic device vertically and facing the screen), an orientation of the electronic device includes top, bottom, left, and right. It should be understood that, in this embodiment of this application, it is considered that when a user holds (usually holding the electronic device vertically and facing the screen), an orientation of the electronic device includes top, bottom, left, and right.

[0074] First, FIG. 2 to FIG. 5 describe four antenna modes in this application. FIG. 2 is a diagram of a common-mode structure of a wire antenna and corresponding distribution of currents and electric fields according to this application. FIG. 3 is a diagram of a differential-mode structure of another wire antenna and corresponding distribution of currents and electric fields according to this application. FIG. 4 is a diagram of a common-mode structure of a slot antenna and corresponding distribution of currents, electric fields, and magnetic currents according to this application. FIG. 5 is a diagram of a differential-mode structure of another slot antenna and corresponding distribution of currents, electric fields, and magnetic currents according to this application.

1. Common mode (common mode, CM) of a wire antenna

[0075] (a) in FIG. 2 shows a case in which a radiator of a wire antenna 40 is connected to a ground (for example, a ground plane, which may be a PCB) through a feed line 42. The wire antenna 40 is connected to a feed unit (not shown) at a middle position 41, and symmetrical feed (symmetrical feed) is used. The feed unit may be connected to the middle position 41 of the wire antenna 40 through the feed line 42. It should be understood that the symmetrical feed may be understood as that one end of the feed unit is connected to the radiator and the other end is grounded. A joint (feed point) between the feed unit and the radiator is in a center of the radiator. The center of the radiator may be, for example, a midpoint of an integrated structure, or a midpoint of an electrical length (or a region within a specific range near the midpoint).

[0076] The middle position 41 of the wire antenna 40, for example, the middle position 41, may be a geometric center of the wire antenna, or a midpoint of an electrical

length of the radiator, for example, a joint between the feed line 42 and the wire antenna 40 covers the middle position 41.

[0077] (b) in FIG. 2 shows distribution of currents and electric fields of the wire antenna 40. As shown in (b) in FIG. 2, currents are symmetrically distributed, for example, reversely distributed, on two sides of the middle position 41. The electric fields are codirectionally distributed on two sides of the middle position 41. As shown in (b) in FIG. 2, currents are codirectionally distributed at the feed line 42. Based on codirectional distribution of the currents at the feed line 42, the feeding shown in (a) in FIG. 2 may be referred to as CM feeding for the wire antenna. Based on symmetrical distribution of currents on two sides of a joint between the radiator and the feed line 42, the wire antenna mode shown in (b) in FIG. 2 may be referred to as a CM mode of the wire antenna (or may be referred to as a CM mode for short, for example, for the wire antenna, the CM mode is a CM mode of the wire antenna). The current and the electric field shown in (b) in FIG. 2 may be referred to as a CM mode current and a CM mode electric field of the wire antenna.

[0078] The CM mode current and the CM mode electric field of the wire antenna are generated by using two stubs (for example, two horizontal stubs) on two sides of the middle position 41 of the wire antenna 40 as an antenna operating in a quarter-wavelength mode. The current is strong at the middle position 41 of the wire antenna 40 and weak at two ends of the wire antenna 40. The electric field is weak at the middle position 41 of the wire antenna 40 and strong at two ends of the wire antenna 40.

2. Differential mode (differential mode, DM) of a wire antenna

[0079] (a) in FIG. 3 shows a case in which two radiators of a wire antenna 50 are connected to a ground (for example, a ground plane, which may be a PCB) through a feed line 52. The wire antenna 50 is connected to a feed unit at a middle position 51 between the two radiators, and anti-symmetrical feed (anti-symmetrical feed) is used. One end of the feed unit is connected to one of the radiators through the feed line 52, and the other end of the feed unit is connected to the other of the radiators through the feed line 52. The middle position 51 may be a geometric center of the wire antenna, or a slot between the radiators.

[0080] It should be understood that, "central anti-symmetrical feed" mentioned in this application may be understood as that a positive electrode and a negative electrode of the feed unit are respectively connected to two joints near the midpoint of the radiator. Signals output from the positive electrode and the negative electrode of the feed unit are same in amplitude and are opposite in phase. For example, a phase difference is $180^\circ \pm 10^\circ$.

[0081] (b) in FIG. 3 shows distribution of currents and electric fields of the wire antenna 50. As shown in (b) in FIG. 3, currents are asymmetrically distributed, for ex-

ample, codirectionally distributed, on two sides of the middle position 51 of the wire antenna 50. The electric fields are reversely distributed on two sides of the middle position 51. As shown in (b) in FIG. 3, currents are reversely distributed at the feed line 52. Based on reverse distribution of the currents at the feed line 52, the feeding shown in (a) in FIG. 3 may be referred to as DM feeding for the wire antenna. Based on asymmetrical distribution (for example, codirectional distribution) of currents on two sides of a joint between the radiator and the feed line 52, the wire antenna mode shown in (b) in FIG. 3 may be referred to as a DM mode of the wire antenna (or may be referred to as a DM mode for short, for example, for the wire antenna, the DM mode is a DM mode of the wire antenna). The current and the electric field shown in (b) in FIG. 3 may be referred to as a DM mode current and a DM mode electric field of the wire antenna.

[0082] The DM mode current and the DM mode electric field of the wire antenna are generated by using the entire wire antenna 50 as an antenna operating in a half-wavelength mode. The current is strong at the middle position 51 of the wire antenna 50 and weak at two ends of the wire antenna 50. The electric field is weak at the middle position 51 of the wire antenna 50 and strong at two ends of the wire antenna 50.

[0083] It should be understood that the radiator of the wire antenna may be understood as a metal mechanical part that generates radiation, and a quantity of the radiator may be one, as shown in FIG. 2, or may be two, as shown in FIG. 3, and may be adjusted according to an actual design or a production requirement. For example, in the CM mode of the wire antenna, two radiators may also be used as shown in FIG. 3, two ends of the two radiators are oppositely disposed and spaced by a slot, and symmetrical feed is used for two ends that are close to each other, for example, a same feeding source signal is fed into each of two ends of the two radiators that are close to each other, so that effect similar to that of the antenna structure shown in FIG. 2 may also be achieved. Correspondingly, in the DM mode of the wire antenna, one radiator may also be used as shown in FIG. 2, two feed points are provided at the middle position of the radiator, and anti-symmetrical feed is used, for example, signals in a same amplitude and opposite phases are respectively fed at two symmetrical feed points on the radiator, so that effect similar to that of the antenna structure shown in FIG. 3 may also be achieved.

3. CM mode of a slot antenna

[0084] A slot antenna 60 shown in (a) in FIG. 4 may be formed by a hollowed-out slit or slot 61 in a radiator of the slot antenna, or formed by a radiator of the slot antenna and a ground (for example, a ground plane, which may be a PCB) enclosing the slit or slot 61. The slit 61 may be formed by slitting on the ground plane. An opening 62 is disposed on one side of the slit 61, and the opening 62 may be specifically disposed in a middle position of the

side. The middle position of the side of the slit 61 may be, for example, a geometric midpoint of the slot antenna, or a midpoint of an electrical length of the radiator. For example, a region of the opening 62 on the radiator covers the middle position of the side. A feed unit may be connected to the opening 62, and anti-symmetrical feed is used. It should be understood that the anti-symmetrical feed may be understood as that a positive electrode and a negative electrode of the feed unit are respectively connected to two ends of the radiator. Signals output from the positive electrode and the negative electrode of the feed unit are same in amplitude and are opposite in phase. For example, a phase difference is $180^\circ \pm 10^\circ$.

[0085] (b) in FIG. 4 shows distribution of currents, electric fields, and magnetic currents of the slot antenna 60. As shown in (b) in FIG. 4, currents are codirectionally distributed around the slit 61 on a conductor (for example, a ground plane and/or a radiator 60) around the slit 61. Electric fields are reversely distributed on two sides of a middle position of the slit 61. Magnetic currents are reversely distributed on two sides of the middle position of the slit 61. As shown in (b) in FIG. 4, electric fields are codirectional at the opening 62 (for example, a feeding position), and magnetic currents are codirectional at the opening 62 (for example, the feeding position). Based on codirectional magnetic currents at the opening 62 (the feeding position), the feeding shown in (a) in FIG. 4 may be referred to as CM feeding for the slot antenna. Based on asymmetrical distribution of currents on the radiator on two sides of the opening 62 (for example, codirectional distribution), or based on codirectional distribution of currents around the slit 61 on the conductor around the slit 61, the slot antenna mode shown in (b) in FIG. 4 may be referred to as a CM mode of the slot antenna (or may be referred to as a CM mode for short, for example, for the slot antenna, the CM mode is a CM mode of the slot antenna). Distribution of the electric fields, the currents, and the magnetic currents shown in (b) in FIG. 4 may be referred to as a CM mode electric field, a CM mode current, and a CM mode magnetic current of the slot antenna.

[0086] The CM mode current and the CM mode electric field of the slot antenna are generated by using the slot antenna on two sides of the middle position of the slot antenna 60 as an antenna operating in a half-wavelength mode. The magnetic field is weak at the middle position of the slot antenna 60 and strong at two ends of the slot antenna 60. The electric field is strong at the middle position of the slot antenna 60 and weak at two ends of the slot antenna 60.

4. DM mode of a slot antenna

[0087] A slot antenna 70 shown in (a) in FIG. 5 may be formed by a hollowed-out slit or slot 72 in a radiator of the slot antenna, or formed by a radiator of the slot antenna and a ground (for example, a ground plane, which may be

a PCB) enclosing the slit or slot 72. The slit 72 may be formed by slitting on the ground plane. A feed unit is connected to a middle position 71 of the slit 72, and symmetrical feed is used. It should be understood that the symmetrical feed may be understood as that one end of the feed unit is connected to the radiator and the other end is grounded. A joint (feed point) between the feed unit and the radiator is in a center of the radiator. The center of the radiator may be, for example, a midpoint of an integrated structure, or a midpoint of an electrical length (or a region within a specific range near the midpoint). A middle position of one side edge of the slit 72 is connected to a positive electrode of the feed unit, and a middle position of the other side edge of the slit 72 is connected to a negative electrode of the feed unit. The middle position of the side edge of the slit 72 may be, for example, a middle position of the slot antenna 60/a middle position of the ground, for example, a geometric midpoint of the slot antenna, or a midpoint of an electrical length of the radiator. For example, a joint between the feed unit and the radiator covers the middle position 51 of the side.

[0088] (b) in FIG. 5 shows distribution of currents, electric fields, and magnetic currents of the slot antenna 70. As shown in (b) in FIG. 5, on a conductor (for example, a ground plane and/or a radiator 60) around the slit 72, currents are distributed around the slit 72, and are reversely distributed on two sides of the middle position of the slit 72. Electric fields are codirectionally distributed on two sides of the middle position 71. Magnetic currents are codirectionally distributed on two sides of the middle position 71. Magnetic currents are reversely distributed at the feed unit (not shown). Based on reverse distribution of the magnetic currents at the feed unit, the feeding shown in (a) in FIG. 5 may be referred to as DM feeding for the slot antenna. Based on symmetrical distribution (for example, reverse distribution) of currents on two sides of the joint between the feed unit and the radiator, or based on symmetrical distribution (for example, reverse distribution) of currents around a slot 71, the slot antenna mode shown in (b) in FIG. 5 may be referred to as a DM mode of the slot antenna (or may be referred to as a DM mode for short, for example, for the slot antenna, the DM mode is a DM mode of the slot antenna). Distribution of the electric fields, the currents, and the magnetic currents shown in (b) in FIG. 5 may be referred to as a DM mode electric field, a DM mode current, and a DM mode magnetic current of the slot antenna.

[0089] The DM mode current and the DM mode electric field of the slot antenna are generated by using the entire slot antenna 70 as an antenna operating in a one-wavelength mode. The current is weak at the middle position of the slot antenna 70 and strong at two ends of the slot antenna 70. The electric field is strong at the middle position of the slot antenna 70 and weak at two ends of the slot antenna 70.

[0090] In the field of antennas, an antenna operating in a CM mode and an antenna operating in a DM mode generally show high isolation. In addition, frequency

bands of the antenna operating in the CM mode and the antenna operating in the DM mode are usually in single-mode resonance, and it is difficult to cover a plurality of frequency bands required for communication. In particular, space left by an electronic device for an antenna structure is increasingly decreased. For a MIMO system, a single antenna structure is required to implement coverage of the plurality of frequency bands. Therefore, an antenna with multi-mode resonance and high isolation is of high research and practical value.

[0091] It should be understood that the radiator of the slot antenna may be understood as a metal mechanical part (for example, including a part of the ground plane) that generates radiation, may include an opening shown in FIG. 4 or may be a complete loop shown in FIG. 5, and may be adjusted based on an actual design or a production requirement. For example, in the CM mode of the slot antenna, the complete loop radiator may also be used as shown in FIG. 5, two feed points are provided at the middle position of the radiator on one side of the slit 61, and anti-symmetrical feed is used, for example, signals in a same amplitude and opposite phases are respectively fed into two ends of an original opening position, so that effect similar to that of the antenna structure shown in FIG. 4 may also be achieved. Correspondingly, in the DM mode of the slot antenna, a radiator including an opening may also be used as shown in FIG. 4, and symmetrical feed is used at two ends of the opening position, for example, a same feeding source signal is separately fed into two ends of the radiator on two sides of the opening, so that effect similar to that of the antenna structure shown in FIG. 5 may also be achieved.

[0092] Because the foregoing antenna structure may have two operating modes (the electric fields are symmetrically distributed or anti-symmetrically distributed) in which the electric field is orthogonal (an inner product of the electric field is zero in the far field (integral quadrature)), the antenna structure has good isolation between the two operating modes, and may be used in a multi-input multi-output (multi-input multi-output, MIMO) antenna system in an electronic device.

[0093] FIG. 6 is a distribution diagram of currents of a slot antenna according to an embodiment of this application.

[0094] (a) in FIG. 6 is a distribution diagram of currents in a case in which the slot antenna operates in a half-wavelength mode, anti-symmetrical feed is used in the slot antenna, and a current strong point of the slot antenna is in a region of the feed unit, and may correspond to the CM mode.

[0095] A radiator itself has a plurality of modes that can be obtained through excitation, and a corresponding mode can be obtained through excitation as long as an input impedance of the radiator is consistent with an impedance of an excitation source. Therefore, when an input impedance corresponding to the current distribution shown in (a) in FIG. 6 is used for the excitation source, the half-wavelength mode of the slot antenna can

be excited, and an $(N-1/2)$ wavelength mode of the slot antenna can be excited, where N is a positive integer. For the slot antenna or the wire antenna, the $(N-1/2)$ wavelength mode may be considered as follows: A wavelength corresponding to a resonance generated by the antenna structure in this mode is approximately $(N-1/2)$ times of an electrical length of a radiator in the antenna structure.

[0096] It should be understood that being approximately $(N-1/2)$ times means that due to an operating environment of the antenna structure and settings of a matching circuit and the like, a relationship between the wavelength corresponding to the resonance generated in the $(N-1/2)$ wavelength mode and the electrical length of the radiator may not be strictly $(N-1/2)$ times, but a specific error is allowed. In addition, the antenna structure has $(N-1/2)/(1/2)$ current nodes in the $(N-1/2)$ wavelength mode.

[0097] (b) in FIG. 6 is a distribution diagram of currents in a case in which the slot antenna operates in a one-wavelength mode, symmetrical feed is used in the slot antenna, and current strong points of the slot antenna are on two sides of the slot, and may correspond to the DM mode.

[0098] When an input impedance corresponding to the current distribution shown in (b) in FIG. 6 is used for the excitation source, the one-wavelength mode of the slot antenna can be excited, and an N -wavelength mode of the slot antenna can be excited, where N is a positive integer. For the slot antenna or the wire antenna, the N -wavelength mode may be considered as follows: A wavelength corresponding to a resonance generated by the antenna structure in this mode is approximately N times of an electrical length of a radiator in the antenna structure.

[0099] It should be understood that being approximately N times means that due to an operating environment of the antenna structure and settings of a matching circuit and the like, a relationship between the wavelength corresponding to the resonance generated in the N -wavelength mode and the electrical length of the radiator may not be strictly N times, but a specific error is allowed. In addition, the antenna structure has $N/(1/2)$ current nodes in the N -wavelength mode.

[0100] Therefore, when an electrical length of the slot antenna shown in FIG. 6 is twice an operating wavelength, side feed (or referred to as "offset feed", where a feed point deviates from a central region of the radiator) is used in the slot antenna, and both a CM mode and a DM mode of the slot antenna can be excited. The CM mode of the slot antenna may include a half-wavelength mode and a three-halves-wavelength mode, and the DM mode of the slot antenna may include a one-wavelength mode and a two-wavelength mode.

[0101] However, frequencies of resonances generated in a low frequency multiplication mode (for example, the one-wavelength mode) and a high frequency multiplication mode (for example, a two-wavelength mode) generally have a frequency multiplication characteristic.

Therefore, it is difficult to make a resonant frequency band generated in the low frequency multiplication mode close to a resonant frequency band generated in the high frequency multiplication mode, and a wide operating bandwidth cannot be generated by using the low frequency multiplication mode and the high frequency multiplication mode.

[0102] Embodiments of this application provide an antenna structure. An electronic element is loaded in a current region of a radiator, so that the radiator is connected to a ground plane in the region. Then, a boundary condition is adjusted, and an operating mode of the antenna structure is changed, so that a low-frequency resonant frequency band is adjusted to be close to a high-frequency resonant frequency band. In this way, an operating bandwidth of the antenna structure is expanded.

[0103] FIG. 7 is a diagram of an antenna structure 100 according to an embodiment of this application.

[0104] As shown in FIG. 7, the antenna structure 100 may include a radiator 110, a ground plane 120, a ground element 121, a first electronic element 122, and a second electronic element 123.

[0105] The antenna structure 100 is grounded through the ground plane 120. A first end of the radiator 110 is electrically connected to the ground plane 120 for grounding, and a second end of the radiator 110 is electrically connected to the ground plane 120 for grounding.

[0106] A first end of the ground element 121 is electrically connected to a central region 101 of the radiator 110, a second end of the ground element 121 is electrically connected to the ground plane 120 for grounding, and the ground element 121 is electrically connected between the central region 101 of the radiator 110 and the ground plane 120. It should be understood that the central region 101 may be understood as a local region within a specific range of a geometric center (physical lengths of the radiator 110 on two sides of the center are the same) or an electrical length center (electrical lengths of the radiator 110 on two sides of the center are the same) of the radiator 110, for example, a region within 5 mm from the center.

[0107] The radiator 110 includes a first current region 111 and a second current region 112. The central region 101 is between the first current region 111 and the second current region 112. The first current region 111 includes an electric field node generated by the antenna structure 100, and the second current region 112 includes an electric field node generated by the antenna structure 100. It should be understood that the electric field node may be understood as that when an electrical signal is fed into the antenna structure 100, directions of electric fields are reversed on two sides of the electric field node. The electric field node corresponds to a current strong point. The first current region 111 and the second current region 112 may be understood as regions within a specific range from the electric field node or the current strong point. For example, the first current region 111 and the second

current region 112 may be understood as regions within 5 mm from the electric field node or the current strong point.

[0108] The first electronic element 122 and the second electronic element 123 are respectively electrically connected between the first current region 111 of the radiator 110 and the ground plane 120 and between the second current region 112 of the radiator 110 and the ground plane 120. A first end of the first electronic element 122 is electrically connected to the first current region 111 of the radiator 110, and a second end of the first electronic element 122 is electrically connected to the ground plane 120 for grounding. A first end of the second electronic element 123 is electrically connected to the second current region 112 of the radiator 110, and a second end of the second electronic element 123 is electrically connected to the ground plane 120 for grounding.

[0109] In an embodiment, at least a part of the radiator 110 from the first end to the second end is configured to generate a first resonance.

[0110] In an embodiment, an electrical length of the radiator 110 may be twice a first wavelength. The antenna structure 100 is an antenna structure designed based on a two-wavelength. The first wavelength is a wavelength corresponding to the first resonance. For example, the first wavelength may be a wavelength corresponding to a resonance point of the first resonance or may be a wavelength corresponding to a center frequency corresponding to a resonant frequency band generated by the first resonance.

[0111] It should be understood that the ground element may be configured to change a current and an electric field of an original antenna structure in a CM mode, so as to adjust an operating mode of the antenna structure.

[0112] When the ground element 121, the first electronic element 122, and the second electronic element 123 are not disposed, the operating mode of the antenna structure 100 may include a half-wavelength mode and a three-halves-wavelength mode in the CM mode, and a one-wavelength mode and a two-wavelength mode in a DM mode. Corresponding distribution of currents and electric fields is shown in FIG. 8.

[0113] It should be understood that the electric field nodes (current strong points) that are generated by the antenna structure 100 and that are included in the foregoing current regions may be understood as current nodes included in distribution of currents and electric fields corresponding to a highest-order mode in the antenna structure. In an embodiment, the electrical length of the radiator 110 is twice the first wavelength, and correspondingly, an electric field node (a current strong point) generated by the antenna structure 100 may be understood as an electric field node (a current strong point) generated in the two-wavelength mode.

[0114] (a) and (c) in FIG. 8 are distribution diagrams of electric fields and currents corresponding to the half-wavelength mode and the three-halves-wavelength mode in the CM mode. (b) and (d) in FIG. 8 are distribution

diagrams of electric fields and currents corresponding to the one-wavelength mode and the two-wavelength mode in the DM mode. In the distribution diagrams shown as (a) and (c) in FIG. 8, the central region of the radiator includes a current node (an electric field strong point). In the distribution diagrams shown as (b) and (d) in FIG. 8, the central region of the radiator includes an electric field node (a current strong point).

[0115] Therefore, when the ground element is electrically connected between the central region and the ground plane, the central region of the radiator is short-circuited to the ground plane, and a boundary condition of the central region is changed in the half-wavelength mode and the three-halves-wavelength mode in the CM mode, that is, the current node (electric field strong point) is changed into the electric field node (current strong point). (a) and (b) in FIG. 9 show distribution of currents and electric fields of the radiator in a case in which the boundary condition of the central region is changed, where the half-wavelength mode in the CM mode is changed into the one-wavelength mode, and the three-halves-wavelength mode in the CM mode is changed into the two-wavelength mode.

[0116] However, in the one-wavelength mode and the two-wavelength mode in the DM mode, an electric field node (a current strong point) is in the central region of the radiator, which is equivalent to a short circuit. In this case, the ground element being electrically connected between the central region and the ground plane does not change the boundary condition. Therefore, the one-wavelength mode and the two-wavelength mode in the DM mode do not change.

[0117] The first electronic element 122 and the second electronic element 123 may be configured to change a current and an electric field of the antenna structure 100 in the one-wavelength mode, so as to adjust the operating mode of the antenna structure 100.

[0118] When only the ground element 121 is disposed, (b) in FIG. 8 and (a) in FIG. 9 are distribution diagrams of electric fields and currents corresponding to the one-wavelength modes in the CM mode and the DM mode. The first current region 111 and the second current region 112 that separately include a current node (an electric field strong point) exist between the central region of the radiator and a first end (second end) of the radiator. In the one-wavelength modes in the CM mode and the DM mode, when electronic elements are respectively electrically connected between the first current region 111 and the ground plane and between the second current region 112 and the ground plane, because the regions are electrically connected to the ground plane 120 through the electronic elements, boundary conditions of the regions may be changed, and current nodes (electric field strong points) are changed into electric field nodes (current strong points) in the regions. Because the boundary conditions of the regions are changed, distribution of electric fields and currents corresponding to the one-wavelength modes in the CM mode and the

DM mode is changed correspondingly. (a) and (b) in FIG. 10 show distribution of currents and electric fields of the radiator, where the one-wavelength mode is changed into the two-wavelength mode.

[0119] However, in the two-wavelength modes in the CM mode and the DM mode, the regions (the first current region 111 and the second current region 112) that are respectively connected to the first electronic element 122 and the second electronic element 123 each include an electric field node (a current strong point), which is equivalent to a short circuit. In this case, electronic elements being electrically connected between the regions of the radiator and the ground plane does not change the boundary conditions. Therefore, the two-wavelength modes in the CM mode and the DM mode are not changed.

[0120] In view of this, the ground element is electrically connected between the ground plane 120 and the central region of the radiator 110, so that the operating mode of the antenna structure can include two one-wavelength modes (in the CM mode and the DM mode) and two two-wavelength modes (in the CM mode and the DM mode). In addition, the first electronic element and the second electronic element are respectively electrically connected between the first current region 111 of the radiator 110 and the ground plane 120 and between the second current region 112 of the radiator 110 and the ground plane 120, so that current nodes (electric field strong points) in the first current region 111 and the second current region 112 in the one-wavelength mode may be changed into electric field nodes (current strong points), and the operating mode may be changed from the one-wavelength mode to the two-wavelength mode, to form a new two-wavelength mode pair. In this case, the operating mode of the antenna structure may be increased to adjust a low-frequency resonant frequency band to a high-frequency resonant frequency band, so that the operating mode of the antenna structure includes two two-wavelength modes in the CM mode and two two-wavelength modes in the DM mode. In this way, four resonances with close frequencies may be generated, to expand an operating bandwidth of the antenna structure.

[0121] In an embodiment, the first electronic element 122 or the second electronic element 123 may be an inductor, and an inductance of the first electronic element 122 or the second electronic element 123 is less than or equal to a first threshold. For example, when a frequency of the first resonance is less than or equal to 1.7 GHz, the first threshold is 5 nH. When a frequency of the first resonance is greater than 1.7 GHz and less than or equal to 3 GHz, the first threshold is 3 nH. When a frequency of the first resonance is greater than 3 GHz, the first threshold is 2 nH.

[0122] It should be understood that the inductance of the electronic element may be understood as an equivalent inductance between the current region and the ground plane. For example, when only a single electronic element is electrically connected between the first cur-

rent region 111 and the ground plane 120, an inductance of the electronic element may be 3 nH. However, when only two electronic elements are electrically connected between the first current region 111 and the ground plane 120, inductances of the two electronic elements may be both 6 nH, and an equivalent inductance between the first current region 111 and the ground plane 120 is also 3 nH, so that same technical effect can be achieved. Alternatively, it may be understood that the threshold accordingly changes as more electronic elements are electrically connected between the current region and the ground plane. For brevity of description, in the following embodiments, descriptions of a threshold of an electronic element may be understood with reference.

[0123] In an embodiment, the first electronic element 122 or the second electronic element 123 may be a capacitor, and a capacitance of the first electronic element 122 or the second electronic element 123 is less than or equal to a second threshold. For example, the second threshold may be 50 pF.

[0124] In an embodiment, the first electronic element 122 or the second electronic element 123 may be a resistor. For example, a resistance of the first electronic element 122 or the second electronic element 123 may be 0 ohm.

[0125] It should be understood that the first electronic element 122 and the second electronic element 123 are respectively electrically connected between the first current region 111 and the ground plane 120 and between the second current region 112 and the ground plane 120, so that the regions of the radiator 110 are short-circuited to the ground plane 120, to change boundary conditions of the first current region 111 and the second current region 112. The first electronic element 122 and the second electronic element 123 each may be an inductor with a small inductance, a capacitor with a large capacitance, a resistor with a small resistance, or a circuit including a capacitor or an inductor. This is not limited in this application.

[0126] In an embodiment, the ground element 121 may be an inductor, and all inductances of the ground element 121 are less than or equal to a third threshold. For example, when a frequency of the first resonance is less than or equal to 1.7 GHz, the third threshold is 5 nH. When a frequency of the first resonance is greater than 1.7 GHz and less than or equal to 3 GHz, the third threshold is 3 nH. When a frequency of the first resonance is greater than 3 GHz, the third threshold is 2 nH.

[0127] In an embodiment, the ground element 121 may be a capacitor, and all capacitances of the ground element 121 are less than or equal to a fourth threshold. For example, the fourth threshold may be 50 pF.

[0128] In an embodiment, the ground element 121 may be a resistor. For example, a resistance of the ground element 121 may be 0 ohm.

[0129] In an embodiment, the antenna structure 100 may include a feed unit 130. The antenna structure 100 may perform feeding through edge feeding (a joint (a feed

point) between the feed unit 130 and the radiator 220 deviates from the central region of the radiator), so that both the CM mode and the DM mode may be excited. In an embodiment, the feed unit 130 may be electrically connected to one end of the radiator 110, to feed an electrical signal and excite a plurality of operating modes.

[0130] FIG. 11 to FIG. 14 are diagrams of simulation results of the antenna structure shown in FIG. 7. FIG. 11 shows S-parameters of the antenna structure shown in FIG. 7. FIG. 12 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 7. FIG. 13 shows corresponding S-parameters of the antenna structure, as shown in FIG. 7, in which a first electronic element and a second electronic element are changed. FIG. 14 shows corresponding simulation results of radiation efficiency and total efficiency of the antenna structure, as shown in FIG. 7, in which the first electronic element and the second electronic element are changed.

[0131] It should be understood that, for brevity of description, in this embodiment, an example in which the first electronic element and the second electronic element are inductors, an inductance L1 of the first electronic element is 4 nH, an inductance L2 of the second electronic element is 2 nH, a length of the radiator in an extension direction (in an x direction) is 62.8 mm, a width (in a y direction) of the radiator is 4 mm, and a distance (in the x direction) between two ends of the radiator is 12.4 mm is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement.

[0132] As shown in FIG. 11, when the first electronic element and the second electronic element are not electrically connected between the radiator and the ground plane, and only the ground element (the ground element is a resistor) (a resistance L0=0 ohm) is electrically connected between the central region of the radiator and the ground plane, in the CM mode, the half-wavelength mode is changed into the one-wavelength mode, and the three-halves-wavelength mode is changed into the two-wavelength mode, and in the DM mode, the one-wavelength mode and the two-wavelength mode are not changed.

[0133] When the ground element is electrically connected between the central region and the ground plane, and the first electronic element and the second electronic element are electrically connected between the radiator and the ground plane, the one-wavelength modes in the CM mode and the DM mode are changed into new two-wavelength modes to form a new two-wavelength mode pair, and the original two-wavelength modes in the CM mode and the DM mode are not changed.

[0134] The antenna structure includes the new two-wavelength mode pair and the original two-wavelength mode pair, namely, four two-wavelength modes in total, so that an operating frequency band (with S11<-4 dB as a boundary) of the antenna structure may include 1.8 GHz to 3.2 GHz.

[0135] As shown in FIG. 12, the antenna structure has

good efficiency (total efficiency and radiation efficiency) in a frequency band corresponding to a resonance generated in each mode.

[0136] As shown in FIG. 13, a frequency difference between the new two-wavelength mode pair (two two-wavelength modes formed by the one-wavelength modes in the CM mode and the DM mode) and the original two-wavelength mode pair (two-wavelength modes formed in the CM mode and the DM mode after the ground element is electrically connected between the central region and the ground plane) may be adjusted when the inductance L1 of the first electronic element electrically connected between the radiator and the ground plane and the inductance L2 of the second electronic element electrically connected between the radiator and the ground plane are changed. For example, when the inductance L1 of the first electronic element and the inductance L2 of the second electronic element decrease, the frequency difference between the new two-wavelength mode pair and the original two-wavelength mode pair decreases, and the new two-wavelength mode pair is close to the original two-wavelength mode pair.

[0137] As shown in FIG. 14, when the inductance L1 of the first electronic element electrically connected between the radiator and the ground plane and the inductance L2 of the second electronic element electrically connected between the radiator and the ground plane are changed, efficiency (total efficiency and radiation efficiency) is good in a frequency band corresponding to a resonance generated in the new two-wavelength mode pair.

[0138] FIG. 15 to FIG. 17 are distribution diagrams of currents of the antenna structure 100 shown in FIG. 7. FIG. 15 is a distribution diagram of currents in a case in which the ground element, the first electronic element, and the second electronic element are not disposed. FIG. 16 is a distribution diagram of currents in a case in which only the ground element is disposed. FIG. 17 is a distribution diagram of currents in a case in which the ground element, the first electronic element, and the second electronic element are disposed.

[0139] Distribution of currents in FIG. 15 may correspond to distribution of currents at different frequencies in an S11 curve shown in FIG. 11 in a case in which the ground element, the first electronic element, and the second electronic element are not disposed.

[0140] (a) in FIG. 15 is a distribution diagram of currents at 1.1 GHz, and may correspond to the half-wavelength mode in the CM mode. (b) in FIG. 15 is a distribution diagram of currents at 1.65 GHz, and may correspond to the one-wavelength mode in the DM mode. (c) in FIG. 15 is a distribution diagram of currents at 2.05 GHz, and may correspond to the three-halves-wavelength mode in the CM mode. (d) in FIG. 15 is a distribution diagram of currents at 2.65 GHz, and may correspond to the two-wavelength mode in the DM mode.

[0141] Distribution of currents in FIG. 16 may corre-

spond to distribution of currents at different frequencies in an S11 curve shown in FIG. 11 in a case in which the ground element is disposed, and the first electronic element and the second electronic element are not disposed.

[0142] (a) in FIG. 16 is a distribution diagram of currents at 1.45 GHz, and may correspond to the one-wavelength mode in the CM mode, where the central region (ground element connection region) of the radiator includes an electric field node (a current strong point). (b) in FIG. 16 is a distribution diagram of currents at 1.7 GHz, and may correspond to the one-wavelength mode in the DM mode. Distribution of the currents in (b) in FIG. 16 is the same as the distribution of the currents in the one-wavelength mode in the DM mode in (b) in FIG. 15. (c) in FIG. 16 is a distribution diagram of currents at 2.5 GHz, and may correspond to the two-wavelength mode in the CM mode, where the central region (ground element connection region) of the radiator includes an electric field node (a current strong point). (d) in FIG. 16 is a distribution diagram of currents at 2.7 GHz, and may correspond to the two-wavelength mode in the DM mode. Distribution of the currents in (d) in FIG. 16 is the same as the distribution of the currents in the two-wavelength mode in the DM mode in (d) in FIG. 15.

[0143] The ground element is electrically connected between the central region of the radiator and the ground plane, so that the radiator is short-circuited in the central region, to change a boundary condition of the region in the CM mode. In this case, an operating mode in the CM mode can be increased, so that a resonance generated in the CM mode is close to a resonance generated in the DM mode.

[0144] Distribution of currents in FIG. 17 may correspond to distribution of currents at different frequencies in an S11 curve shown in FIG. 11 in a case in which the ground element, the first electronic element, and the second electronic element are disposed.

[0145] (a) in FIG. 17 is a distribution diagram of currents at 2 GHz, and may correspond to the two-wavelength mode in the CM mode, where the first current region (first electronic element connection region) and the second current region (second electronic element) of the radiator each include an electric field node (a current strong point). (b) in FIG. 17 is a distribution diagram of currents at 2.25 GHz, and may correspond to the two-wavelength mode in the DM mode, where the first current region (first electronic element connection region) and the second current region (second electronic element) of the radiator each include an electric field node (a current strong point). (c) in FIG. 17 is a distribution diagram of currents at 2.7 GHz, and may correspond to the two-wavelength mode in the CM mode. Distribution of the currents in (c) in FIG. 17 is the same as the distribution of the currents in the two-wavelength mode in the CM mode in (c) in FIG. 16. (d) in FIG. 17 is a distribution diagram of currents at 3.1 GHz, and may correspond to the two-wavelength mode in the DM mode. Distribution of the

currents in (d) in FIG. 17 is the same as the distribution of the currents in the two-wavelength mode in the DM mode in (d) in FIG. 16.

[0146] Electronic elements are respectively electrically connected between the first current region of the radiator and the ground plane and between the second current region of the radiator and the ground plane, so that the radiator is short-circuited in the first current region and the second current region, to change a boundary conditions of the region in the one-wavelength mode. In this case, the one-wavelength mode is increased to the new two-wavelength mode, and the original two-wavelength mode remains unchanged, so that a resonance generated in the new two-wavelength mode is close to a high-frequency resonance (a resonance generated in the original two-wavelength mode).

[0147] FIG. 18 is a diagram of another antenna structure 100 according to an embodiment of this application.

[0148] As shown in FIG. 18, the antenna structure 100 may include a radiator 110, a ground plane 120, a ground element 121, a first electronic element 122, and a second electronic element 123.

[0149] The antenna structure 100 is grounded through the ground plane 120. A first end of the radiator 110 is electrically connected to the ground plane 120 for grounding, and a second end of the radiator 110 is electrically connected to the ground plane 120 for grounding.

[0150] A first end of the ground element 121 is electrically connected to a central region 101 of the radiator 110, a second end of the ground element 121 is electrically connected to the ground plane 120 for grounding, and the ground element 121 is electrically connected between the central region 101 of the radiator 110 and the ground plane 120.

[0151] The radiator 110 includes a first current region 111 and a second current region 112. The central region 101 is between the first current region 111 and the second current region 112. The first current region 111 includes an electric field node generated by the antenna structure 100, and the second current region 112 includes an electric field node generated by the antenna structure 100.

[0152] The first electronic element 122 and the second electronic element 123 are respectively electrically connected between the first current region 111 of the radiator 110 and the ground plane 120 and between the second current region 112 of the radiator 110 and the ground plane 120. A first end of the first electronic element 122 is electrically connected to the first current region 111 of the radiator 110, and a second end of the first electronic element 122 is electrically connected to the ground plane 120 for grounding. A first end of the second electronic element 123 is electrically connected to the second current region 112 of the radiator 110, and a second end of the second electronic element 123 is electrically connected to the ground plane 120 for grounding.

[0153] It should be understood that the ground element

may be configured to change a current and an electric field of the original antenna structure in a DM mode, so as to adjust an operating mode of the antenna structure.

[0154] A difference between the antenna structure 100 shown in FIG. 18 and the antenna structure 100 shown in FIG. 7 lies in that a length of the radiator 110 in the antenna structure 100 shown in FIG. 18 is equal to a distance between the first end and the second end, and the radiator 110 and the ground plane 120 enclose a linear (for example, a strip) slot; while a length of the radiator 110 in the antenna structure 100 shown in FIG. 7 is far greater than a distance between the first end and the second end, and the radiator 110 and the ground plane 120 enclose a non-linear (T-shaped or bent) slot. In an embodiment, the antenna structure 100 shown in FIG. 18 is a slot antenna (slot antenna). In an embodiment, the antenna structure 100 shown in FIG. 7 is a loop antenna (loop antenna). In an embodiment, that the distance L1 between the first end and the second end is approximately the same as the length L2 of the radiator may be understood as $L2 \times 80\% \leq L1 \leq L2 \times 120\%$, for example, $L2 \times 90\% \leq L1 \leq L2 \times 110\%$. In an embodiment, that the length L2 of the radiator is far greater than the distance L1 between the first end and the second end may be understood that $L1 \leq L2 \times 50\%$, for example, $L1 < L2 \times 30\%$. It should be understood that, when a ratio of the distance L1 between the first end and the second end to the length L2 of the radiator is between ratios for forming a loop antenna and a slot antenna (for example, $L2 \times 30\% \leq L1 \leq L2 \times 80\%$), the antenna structure may have characteristics of both the slot antenna and the loop antenna.

[0155] In an embodiment, an electronic device with the antenna structure further includes a part of a conductive bezel 11. The bezel 11 has a first position 141 and a second position 142, and a first bezel between the first position 141 and the second position 142 is used as the radiator 110, as shown in FIG. 19. It should be understood that the first position 141 and the second position 142 of the bezel 11 are continuous with a remaining part of the bezel 11. In addition, the first position 141 and the second position 142 may respectively correspond to the first end and the second end of the radiator 110.

[0156] It should be understood that the bezel (for example, the first bezel) may be a conductive bezel, or a non-conductive bezel that may have a conductive patch (disposed on an inner surface or disposed in an embedded manner), and in this case, a conductive part of the first bezel is used as the radiator 110 of the antenna structure 100. It should be understood that, in this embodiment of this application, the first bezel at a grounding position (for example, the first position 141 and the second position 142) is continuous with another part of the bezel, and actually, a slot may be provided between the first bezel and the another part of the bezel. For a non-conductive bezel, a conductive patch may include only a part that is shown in FIG. 18 and that is used as a radiator and a parasitic radiator, or may be continuously or dis-

continuously disposed near another conductive patch.

[0157] FIG. 20 and FIG. 21 are diagrams of simulation results of the antenna structure shown in FIG. 18. FIG. 20 shows S-parameters of the antenna structure shown in FIG. 18. FIG. 21 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 18.

[0158] It should be understood that, for brevity of description, in this embodiment, an example in which the first electronic element and the second electronic element are inductors, an inductance L1 of the first electronic element is 1 nH, an inductance L2 of the second electronic element is 1 nH, a length of the radiator in an extension direction (in an x direction) is 76 mm, and a width (in a y direction) of the radiator is 32 mm is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement.

[0159] As shown in FIG. 20, when the first electronic element and the second electronic element are not electrically connected between the radiator and the ground plane, and only the ground element (the ground element is an inductor) (an inductance L0=0.8 nH) is electrically connected between the central region of the radiator and the ground plane, in a CM mode, a half-wavelength mode is changed into a one-wavelength mode, and a three-halves-wavelength mode is changed into a two-wavelength mode, and in a DM mode, a one-wavelength mode and a two-wavelength mode are not changed.

[0160] When the ground element is electrically connected between the central region and the ground plane, and the first electronic element and the second electronic element are electrically connected between the radiator and the ground plane, the one-wavelength modes in the CM mode and the DM mode are changed into two-wavelength modes to form a new two-wavelength mode pair, and the original two-wavelength modes in the CM mode and the DM mode are not changed.

[0161] The antenna structure includes the new two-wavelength mode pair and the original two-wavelength mode pair, namely, four two-wavelength modes in total, so that an operating frequency band (with S11<-4 dB as a boundary) of the antenna structure may include 1.8 GHz to 2.7 GHz.

[0162] As shown in FIG. 21, the antenna structure has good efficiency (total efficiency and radiation efficiency) in a frequency band corresponding to a resonance generated in each mode.

[0163] FIG. 22 to FIG. 24 are distribution diagrams of electric fields/magnetic currents of the antenna structure 100 shown in FIG. 18. FIG. 22 is a distribution diagram of electric fields/magnetic currents in a case in which the ground element, the first electronic element, and the second electronic element are not disposed. FIG. 23 is a distribution diagram of electric fields/magnetic currents in a case in which only the ground element is disposed. FIG. 24 is a distribution diagram of electric fields/magnetic currents in a case in which the ground element, the

first electronic element, and the second electronic element are disposed.

[0164] FIG. 22 may correspond to distribution of electric fields/magnetic currents at different frequencies in an S11 curve shown in FIG. 20 in a case in which the ground element, the first electronic element, and the second electronic element are not disposed.

[0165] (a) in FIG. 22 is a distribution diagram of electric fields/magnetic currents at 0.67 GHz, and may correspond to a half-wavelength mode in the DM mode. (b) in FIG. 22 is a distribution diagram of electric fields/magnetic currents at 1.35 GHz, and may correspond to the one-wavelength mode in the CM mode. (c) in FIG. 22 is a distribution diagram of electric fields/magnetic currents at 2.05 GHz, and may correspond to a three-halves-wavelength mode in the DM mode. (d) in FIG. 23 is a distribution diagram of electric fields/magnetic currents at 2.7 GHz, and may correspond to the two-wavelength mode in the CM mode.

[0166] FIG. 23 may correspond to distribution of currents at different frequencies in an S11 curve shown in FIG. 20 in a case in which the ground element is disposed, and the first electronic element and the second electronic element are not disposed.

[0167] (a) in FIG. 23 is a distribution diagram of currents at 1.15 GHz, and may correspond to the one-wavelength mode in the DM mode, where the central region (ground element connection region) of the radiator includes an electric field node (a current strong point). (b) in FIG. 23 is a distribution diagram of currents at 1.35 GHz, and may correspond to the one-wavelength mode in the CM mode. Distribution of the currents in (b) in FIG. 23 is the same as the distribution of the currents in the one-wavelength mode in the CM mode in (b) in FIG. 22. (c) in FIG. 23 is a distribution diagram of currents at 2.4 GHz, and may correspond to the two-wavelength mode in the DM mode, where the central region (ground element connection region) of the radiator includes an electric field node (a current strong point), and there are electric field nodes (current strong points) between the central region and two ends of the radiator. (d) in FIG. 23 is a distribution diagram of currents at 2.7 GHz, and may correspond to the two-wavelength mode in the CM mode. Distribution of the currents in (d) in FIG. 23 is the same as the distribution of the currents in the two-wavelength mode in the CM mode in (d) in FIG. 22.

[0168] The ground element is electrically connected between the central region of the radiator and the ground plane, so that the radiator is short-circuited in the central region, to change a boundary condition of the region in the DM mode. In this case, an operating mode in the DM mode can be increased, so that a resonance generated in the DM mode is close to a resonance generated in the CM mode.

[0169] FIG. 24 may correspond to distribution of currents at different frequencies in an S11 curve shown in FIG. 20 in a case in which the ground element, the first electronic element, and the second electronic element

are disposed.

[0170] (a) in FIG. 24 is a distribution diagram of currents at 1.85 GHz, and may correspond to the two-wavelength mode in the DM mode, where the first current region (first electronic element connection region) and the second current region (second electronic element) of the radiator each include an electric field node (a current strong point). (b) in FIG. 24 is a distribution diagram of currents at 2.15 GHz, and may correspond to the two-wavelength mode in the CM mode, where the first current region (first electronic element connection region) and the second current region (second electronic element) of the radiator each include an electric field node (a current strong point). (c) in FIG. 24 is a distribution diagram of currents at 2.45 GHz, and may correspond to the two-wavelength mode in the DM mode. Distribution of the currents in (c) in FIG. 24 is the same as the distribution of the currents in the two-wavelength mode in the DM mode in (c) in FIG. 23. (d) in FIG. 24 is a distribution diagram of currents at 2.7 GHz, and may correspond to the two-wavelength mode in the CM mode. Distribution of the currents in (d) in FIG. 24 is the same as the distribution of the currents in the two-wavelength mode in the CM mode in (d) in FIG. 23.

[0171] Electronic elements are respectively electrically connected between the first current region of the radiator and the ground plane and between the second current region of the radiator and the ground plane, so that the radiator is short-circuited in the first current region and the second current region, to change boundary conditions of the regions in the one-wavelength mode. In this case, the one-wavelength mode is increased to the new two-wavelength mode, and the original two-wavelength mode remains unchanged, so that a resonance generated in the new two-wavelength mode is close to a high-frequency resonance (a resonance generated in the original two-wavelength mode).

[0172] FIG. 25 is a diagram of still another antenna structure 100 according to an embodiment of this application.

[0173] It should be understood that, for brevity of description, the antenna structure 100 shown in FIG. 25 may be any one of the foregoing antenna structures (for example, the loop antenna shown in FIG. 7 or the slot antenna shown in FIG. 20), or may be any one of antenna structures in the following embodiments. In this embodiment, an example in which the antenna structure 100 is the slot antenna shown in FIG. 20 is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement. This is not limited in embodiments of this application.

[0174] As shown in FIG. 25, the antenna structure 100 may further include a first filter 131 and a second filter 132.

[0175] The first filter 131 is electrically connected between a first current region 111 and a first electronic element 122, and the second filter 132 is electrically

connected between a second current region 112 and a second electronic element 123. The first filter 131 and the second filter 132 are in a turned-on state (a low impedance, a low insertion loss, and a short-circuit state) in a first frequency band, and are in a turned-off state (a high impedance, a high insertion loss, and an open-circuit state) in a second frequency band. A frequency of the first frequency band is higher than a frequency of the second frequency band.

[0176] In an embodiment, the first filter 131 and the second filter 132 may be high-pass filters. For example, each of the first filter 131 and the second filter 132 may include a capacitor and an inductor to form an LC oscillation structure. It should be understood that types of the first filter 131 and the second filter 132 are not limited in embodiments of this application, and may be adjusted based on an actual production or design requirement.

[0177] It should be understood that when the first filter 131 and the second filter 132 are not disposed, the antenna structure 100 may generate a first resonance (a new two-wavelength mode in a DM mode), a second resonance (a new two-wavelength mode in a CM mode), a third resonance (an original two-wavelength mode in the DM mode), and a fourth resonance (an original two-wavelength mode in the CM mode). When the first electronic element 122 and the second electronic element 123 are not disposed, the antenna structure 100 may generate a fifth resonance (a one-wavelength mode in a DM mode), a sixth resonance (a one-wavelength mode in a CM mode), a third resonance, and a fourth resonance.

[0178] Therefore, when the first frequency band includes a resonant frequency band of the first resonance, a resonant frequency band of the second resonance, a resonant frequency band of the third resonance, and a resonant frequency band of the fourth resonance, the second frequency band includes a resonant frequency band of the fifth resonance and a resonant frequency band of the sixth resonance. The first filter 131 and the second filter 132 are in the turned-on state in the first frequency band. In this case, the first electronic element 122 and the second electronic element 123 are electrically connected to the radiator 110, and the antenna structure 100 may generate the first resonance, the second resonance, the third resonance, and the fourth resonance. The first filter 131 and the second filter 132 are in the turned-off state in the second frequency band. In this case, the first electronic element 122 and the second electronic element 123 are disconnected from and are not electrically connected to the radiator 110, and the antenna structure 100 may additionally generate the fifth resonance and the sixth resonance.

[0179] The first filter 131 and the second filter 132 are electrically connected between the radiator and the electronic element, so that an electrical connection state (a short circuit state or an open circuit state) between the electronic element and the radiator can be adjusted by using an impedance characteristic, and an operating bandwidth of the antenna structure 100 can be further

expanded by using the one-wavelength mode in the DM mode and the one-wavelength mode in the CM mode.

[0180] FIG. 26 and FIG. 27 are diagrams of simulation results of the antenna structure shown in FIG. 25. FIG. 26 shows S-parameters of the antenna structure shown in FIG. 25. FIG. 27 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 25.

[0181] It should be understood that, for brevity of description, in this embodiment of this application, an example in which an LC filter with the first filter 131 and the second filter 132 being connected in parallel is merely used for description. In the filter, a capacitance of a capacitor is 3 pF, an inductance of an inductor is 5 nH, an inductance of the first electronic element is 4 nH, and an inductance of the second electronic element is 3 nH.

[0182] FIG. 26 shows an S11 curve in a case in which the first electronic element and the second electronic element are electrically connected between the radiator and the ground plane (the electronic elements are connected), the first electronic element and the second electronic element are not disposed between the radiator and the ground plane (the electronic elements are disconnected), and the filter is electrically connected between the electronic element and the radiator.

[0183] The antenna structure can generate six resonant frequency bands at a low frequency and a high frequency by using a high-resistance characteristic (equivalent to a case in which the electronic element is disconnected from the radiator) of the filter at the low frequency (a frequency band corresponding to the one-wavelength mode) and a low-resistance characteristic (equivalent to a case in which the electronic element is short-circuited to the radiator) of the filter at the high frequency (a frequency band corresponding to the two-wavelength mode), to expand the operating bandwidth of the antenna structure.

[0184] As shown in FIG. 27, the antenna structure has good efficiency (total efficiency and radiation efficiency) in a frequency band corresponding to a resonance generated in each mode.

[0185] FIG. 28 is a diagram of still another antenna structure 100 according to an embodiment of this application.

[0186] As shown in FIG. 28, the antenna structure 100 may include a radiator 110, a ground plane 120, a first electronic element 122, and a second electronic element 123.

[0187] The antenna structure 100 is grounded through the ground plane 120. A first end of the radiator 110 is electrically connected to the ground plane 120 for grounding, and a second end of the radiator 110 is electrically connected to the ground plane 120 for grounding.

[0188] A slot 121 is provided in a central region 101 of the radiator 110. The radiator 110 includes a first current region 111 and a second current region 112. The central region 101 is between the first current region 111 and the

second current region 112. The first current region 111 includes an electric field node generated by the antenna structure 100, and the second current region 112 includes an electric field node generated by the antenna structure 100.

[0189] The first electronic element 122 and the second electronic element 123 are respectively electrically connected between the first current region 111 of the radiator 110 and the ground plane 120 and between the second current region 112 of the radiator 110 and the ground plane 120. A first end of the first electronic element 122 is electrically connected to the first current region 111 of the radiator 110, and a second end of the first electronic element 122 is electrically connected to the ground plane 120 for grounding. A first end of the second electronic element 123 is electrically connected to the second current region 112 of the radiator 110, and a second end of the second electronic element 123 is electrically connected to the ground plane 120 for grounding.

[0190] In the antenna structure 100 shown in FIG. 28 and the antenna structure 100 shown in FIG. 7, the radiator 110 and the ground plane 120 enclose a non-linear (T-shaped or bent) slot to form a loop antenna. A difference between the antenna structure 100 shown in FIG. 28 and the antenna structure 100 shown in FIG. 7 lies in that an electrical length of the radiator 110 in the antenna structure 100 shown in FIG. 28 is three halves of a first wavelength, and an electrical length of the radiator 110 in the antenna structure 100 shown in FIG. 7 is twice the first wavelength.

[0191] It should be understood that the slot 121 provided in the central region 101 may be used to change an original current and electric field of the antenna structure in a DM mode, and increase the DM mode of the antenna structure.

[0192] When the slot 121, the first electronic element 122, and the second electronic element 123 are not disposed, an operating mode of the antenna structure 100 may include a half-wavelength mode and a three-halves-wavelength mode in a CM mode, and a one-wavelength mode in the DM mode. FIG. 29 shows corresponding distribution of currents and electric fields. Compared with the antenna structure 100 shown in FIG. 7, in the antenna structure 100 shown in FIG. 28, the electrical length of the radiator 110 is reduced from twice the first wavelength to three halves of the first wavelength. Therefore, the two-wavelength mode in the DM mode cannot be excited.

[0193] It should be understood that the electric field nodes (current strong points) that are generated by the antenna structure 100 and that are included in the foregoing current regions may be understood as current nodes included in distribution of currents and electric fields corresponding to a highest-order mode in the antenna structure. In an embodiment, the electrical length of the radiator 110 is three halves of the first wavelength, and correspondingly, an electric field node (a current strong point) generated by the antenna structure 100

may be understood as an electric field node (a current strong point) generated in the three-halves-wavelength mode.

[0194] (a) and (c) in FIG. 29 are distribution diagrams of electric fields and currents corresponding to the half-wavelength mode and the three-halves-wavelength mode in the CM mode. (b) and (d) in FIG. 29 are distribution diagrams of electric fields and currents corresponding to the one-wavelength mode and the two-wavelength mode in the DM mode. In the distribution diagrams shown as (a) and (c) in FIG. 29, the central region of the radiator includes a current node (an electric field strong point). In the distribution diagram shown as (b) in FIG. 29, the central region of the radiator includes an electric field node (a current strong point).

[0195] Therefore, when the slot 121 is provided in the central region, a current on the radiator is cut off in the central region, to form a current node (an electric field strong point). In the one-wavelength mode in the DM mode, a boundary condition of the central region is changed, that is, the electric field node (current strong point) is changed into the current node (electric field strong point). (a) and (c) in FIG. 30 show distribution of currents and electric fields of the radiator in a case in which the boundary condition of the central region is changed, where in the DM mode, the one-wavelength mode disappears, distribution of generated currents and electric fields may correspond to the half-wavelength mode and the three-halves-wavelength mode.

[0196] (b) and (d) in FIG. 30 show distribution of currents and electric fields of the radiator in the half-wavelength mode and the three-halves-wavelength mode in the CM mode. A current node (an electric field strong point) is in the central region of the radiator, indicating that a current is cut off in the central region, and the slot provided in the central region does not change the boundary condition. Therefore, the half-wavelength mode and the three-halves-wavelength mode in the CM mode are not changed.

[0197] The first electronic element 122 and the second electronic element 123 may be configured to change a current and an electric field of the antenna structure 100 in the half-wavelength mode, so as to adjust the operating mode of the antenna structure 100.

[0198] When the slot 121 is provided in the central region, (c) and (d) in FIG. 30 are distribution diagrams of electric fields and currents corresponding to the three-halves-wavelength modes in the CM mode and the DM mode. The first current region 111 and the second current region 112 that separately include an electric field node (a current strong point) exist between the central region of the radiator and the first end (second end) of the radiator. In the half-wavelength modes in the CM mode and the DM mode, when electronic elements are respectively electrically connected between the first current region 111 and the ground plane and between the second current region 112 and the ground plane, because the regions are electrically connected to the ground plane 120

through the electronic elements, the radiator is short-circuited between the regions and the ground plane, boundary conditions of the regions may be changed, and electric field nodes (current strong points) appear in the regions. Because the boundary conditions of the regions are changed, distribution of electric fields and currents corresponding to the half-wavelength modes in the CM mode and the DM mode is changed correspondingly. (a) and (b) in FIG. 31 show distribution of currents and electric fields of the radiator, where the half-wavelength mode is changed into the three-halves-wavelength mode.

[0199] (c) and (d) in FIG. 31 are distribution diagrams of electric fields and currents corresponding to the three-halves-wavelength mode in the CM mode and the DM mode. The regions (the first current region 111 and the second current region 112) that are respectively connected to the first electronic element 122 and the second electronic element 123 each include an electric field node (a current strong point), which is equivalent to a short circuit. In this case, electronic elements being electrically connected between the regions of the radiator and the ground plane does not change the boundary conditions. Therefore, the three-halves-wavelength modes in the CM mode and the DM mode are not changed.

[0200] In view of this, the slot 121 is provided in the central region of the radiator 110, so that the operating mode of the antenna structure can include two half-wavelength modes (in the CM mode and the DM mode) and two three-halves-wavelength modes (in the CM mode and the DM mode). In addition, the first electronic element and the second electronic element are respectively electrically connected between the first current region 111 of the radiator 110 and the ground plane 120 and between the second current region 112 of the radiator 110 and the ground plane 120, so that electric field nodes (current strong points) may appear in the first current region 111 and the second current region 112 in the half-wavelength mode, and the operating mode may be changed from the half-wavelength mode to the three-halves-wavelength mode, to form a new three-halves-wavelength mode pair. In this case, the operating mode of the antenna structure may be increased to adjust a low-frequency resonant frequency band to a high-frequency resonant frequency band, so that the operating mode of the antenna structure includes two three-halves-wavelength modes in the CM mode and two three-halves-wavelength modes in the DM mode. In this way, four resonances with close frequencies may be generated, to expand an operating bandwidth of the antenna structure.

[0201] In an embodiment, the antenna structure 100 may further include a third electronic element 124, and the third electronic element 124 may be electrically connected between radiators on two sides of the slot 121. It should be understood that the third electronic element 124 may be configured to adjust a frequency of a resonance generated in the DM mode. In an embodiment, the third electronic element 124 may be a capacitor, and a

capacitance of the third electronic element 124 may be adjusted based on actual production or design.

[0202] FIG. 32 and FIG. 33 are diagrams of simulation results of the antenna structure shown in FIG. 28. FIG. 32 shows S-parameters of the antenna structure shown in FIG. 28. FIG. 33 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 28.

[0203] It should be understood that, for brevity of description, in this embodiment, an example in which the first electronic element and the second electronic element are inductors, an inductance L1 of the first electronic element is 1.5 nH, an inductance L2 of the second electronic element is 2 nH, a capacitance C0 of the third electronic element is 0.06 pF, a length of the radiator in an extension direction (in an x direction) is 62.8 mm, a width (in a y direction) of the radiator is 4 mm, and a distance (in the x direction) between two ends of the radiator is 12.4 mm is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement.

[0204] As shown in FIG. 32, when no slot is provided in the central region of the radiator, the antenna structure may sequentially generate three resonant frequency bands in the half-wavelength mode in the CM mode, the one-wavelength mode in the DM mode, and the three-halves-wavelength mode in the CM mode.

[0205] When a slot is provided in the central region of the radiator, the one-wavelength mode in the DM mode disappears. In this case, resonant frequency bands generated in the half-wavelength mode in the CM mode and the half-wavelength mode in the DM mode are combined into one resonant frequency band due to a short frequency distance, and resonant frequency bands generated in the three-halves-wavelength mode in the CM mode and the three-halves-wavelength mode in the DM mode are combined into one resonant frequency band due to a short frequency distance.

[0206] When the slot is provided in the central region, and the first electronic element and the second electronic element are electrically connected between the radiator and the ground plane, the half-wavelength modes in the CM mode and the DM mode are changed into new three-halves-wavelength modes to form a new three-halves-wavelength mode pair, and the original three-halves-wavelength modes in the CM mode and the DM mode are not changed.

[0207] The antenna structure includes the new three-halves-wavelength mode pair and the original three-halves-wavelength mode pair, namely, four two-wavelength modes in total, so that an operating frequency band (with $S_{11} < -4$ dB as a boundary) of the antenna structure may include 1.6 GHz to 2.3 GHz.

[0208] Therefore, compared with the antenna structure 100 shown in FIG. 7, in the antenna structure shown in FIG. 28, when four resonances are generated, a size of the radiator is reduced from twice the first wavelength to three halves of the first wavelength, so that a size of the

antenna structure is reduced.

[0209] As shown in FIG. 33, the antenna structure has good efficiency (total efficiency and radiation efficiency) in a frequency band corresponding to a resonance generated in each mode.

[0210] FIG. 34 is a diagram of still another antenna structure 100 according to an embodiment of this application.

[0211] As shown in FIG. 34, the antenna structure 100 may include a radiator 110, a ground plane 120, a first electronic element 122, and a second electronic element 123.

[0212] The antenna structure 100 is grounded through the ground plane 120. A first end of the radiator 110 is electrically connected to the ground plane 120 for grounding, and a second end of the radiator 110 is electrically connected to the ground plane 120 for grounding.

[0213] A slot 121 is provided in a central region 101 of the radiator 110. The radiator 110 includes a first current region 111 and a second current region 112. The central region 101 is between the first current region 111 and the second current region 112. The first current region 111 includes an electric field node generated by the antenna structure 100, and the second current region 112 includes an electric field node generated by the antenna structure 100.

[0214] The first electronic element 122 and the second electronic element 123 are respectively electrically connected between the first current region 111 of the radiator 110 and the ground plane 120 and between the second current region 112 of the radiator 110 and the ground plane 120. A first end of the first electronic element 122 is electrically connected to the first current region 111 of the radiator 110, and a second end of the first electronic element 122 is electrically connected to the ground plane 120 for grounding. A first end of the second electronic element 123 is electrically connected to the second current region 112 of the radiator 110, and a second end of the second electronic element 123 is electrically connected to the ground plane 120 for grounding.

[0215] In the antenna structure 100 shown in FIG. 34 and the antenna structure 100 shown in FIG. 18, the radiator 110 and the ground plane 120 enclose a straight (for example, a strip) slot to form a slot antenna. A difference between the antenna structure 100 shown in FIG. 34 and the antenna structure 100 shown in FIG. 18 lies in that an electrical length of the radiator 110 in the antenna structure 100 shown in FIG. 34 is three halves of a first wavelength, and an electrical length of the radiator 110 in the antenna structure 100 shown in FIG. 18 is twice the first wavelength.

[0216] FIG. 35 and FIG. 36 are diagrams of simulation results of the antenna structure shown in FIG. 34. FIG. 35 shows S-parameters of the antenna structure shown in FIG. 34. FIG. 36 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 34.

[0217] It should be understood that, for brevity of description, in this embodiment, an example in which the first electronic element and the second electronic element are inductors, an inductance L1 of the first electronic element is 1 nH, an inductance L2 of the second electronic element is 1 nH, a length of the radiator in an extension direction (in an x direction) is 76 mm, and a width (in a y direction) of the radiator is 32 mm is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement.

[0218] As shown in FIG. 35, when the first electronic element and the second electronic element are not electrically connected between the radiator and the ground plane, and the slot is provided only in the central region of the radiator, an operating mode of the antenna structure includes half-wavelength modes in a CM mode and a DM mode, and three-halves-wavelength modes in the CM mode and the DM mode.

[0219] When the slot is provided in the central region, and the first electronic element and the second electronic element are electrically connected between the radiator and the ground plane, the half-wavelength modes in the CM mode and the DM mode are changed into the three-halves-wavelength modes to form a new three-halves-wavelength mode pair, and the original three-halves-wavelength modes in the CM mode and the DM mode are not changed.

[0220] The antenna structure includes the new three-halves-wavelength mode pair and the original three-halves-wavelength mode pair, namely, four three-halves-wavelength modes in total, so that an operating frequency band (with $S_{11} < -4$ dB as a boundary) of the antenna structure may include 1.25 GHz to 2.05 GHz.

[0221] Therefore, compared with the antenna structure 100 shown in FIG. 18, in the antenna structure shown in FIG. 34, when four resonances are generated, a size of the radiator is reduced from twice the first wavelength to three halves of the first wavelength, so that a size of the antenna structure is reduced.

[0222] As shown in FIG. 36, the antenna structure has good efficiency (total efficiency and radiation efficiency) in a frequency band corresponding to a resonance generated in each mode.

[0223] FIG. 37 and FIG. 38 are distribution diagrams of electric fields/magnetic currents of the antenna structure 100 shown in FIG. 34. FIG. 37 is a distribution diagram of electric fields/magnetic currents in a case in which the first electronic element and the second electronic element are not disposed. FIG. 38 is a distribution diagram of electric fields/magnetic currents in a case in which the first electronic element and the second electronic element are disposed.

[0224] Distribution of the currents in FIG. 37 may correspond to distribution of currents at different frequencies in an S11 curve shown in FIG. 35 in a case in which the slot is provided, and the first electronic element and the second electronic element are not disposed.

[0225] (a) in FIG. 37 is a distribution diagram of currents at 0.58 GHz, and may correspond to the half-wavelength mode in the CM mode, where the central region of the radiator includes a current node (an electric field strong point). (b) in FIG. 37 is a distribution diagram of currents at 0.65 GHz, and may correspond to the half-wavelength mode in the DM mode. (c) in FIG. 37 is a distribution diagram of currents at 1.8 GHz, and may correspond to the three-halves-wavelength mode in the CM mode, where the central region of the radiator includes a current node (an electric field strong point), and there are current nodes (electric field strong points) between the central region and two ends of the radiator. (d) in FIG. 37 is a distribution diagram of currents at 1.9 GHz, and may correspond to the three-halves-wavelength mode in the DM mode.

[0226] The slot is provided in the central region of the radiator, so that a current on the radiator is cut off in the central region. In this way, a boundary condition of the region in the DM mode may be changed, to change a one-wavelength mode in the DM mode into a half-wavelength mode and a three-halves-wavelength mode.

[0227] Distribution of the currents in FIG. 38 may correspond to distribution of currents at different frequencies in an S11 curve shown in FIG. 35 in a case in which the slot, the first electronic element, and the second electronic element are disposed.

[0228] (a) in FIG. 38 is a distribution diagram of currents at 1.45 GHz, and may correspond to the three-halves-wavelength mode in the CM mode, where the first current region (first electronic element connection region) and a second current region (second electronic element) of the radiator each include an electric field node (a current strong point). (b) in FIG. 38 is a distribution diagram of currents at 1.6 GHz, and may correspond to the three-halves-wavelength mode in the DM mode, where the first current region (first electronic element connection region) and a second current region (second electronic element) of the radiator each include an electric field node (a current strong point). (c) in FIG. 38 is a distribution diagram of currents at 1.8 GHz, and may correspond to the three-halves-wavelength mode in the CM mode. Distribution of the currents in (c) in FIG. 38 is the same as the distribution of the currents in the three-halves-wavelength mode in the CM mode in (c) in FIG. 37. (d) in FIG. 38 is a distribution diagram of currents at 1.9 GHz, and may correspond to the three-halves-wavelength mode in the DM mode. Distribution of the currents in (d) in FIG. 38 is the same as the distribution of the currents in the three-halves-wavelength mode in the CM mode in (d) in FIG. 37.

[0229] Electronic elements are respectively electrically connected between the first current region of the radiator and the ground plane and between the second current region of the radiator and the ground plane, so that the radiator is short-circuited in the first current region and the second current region, to change boundary conditions of the regions in the half-wavelength mode. In this case, the

half-wavelength mode is increased to the new three-halves-wavelength mode, and the original three-halves-wavelength mode remains unchanged, so that a resonance generated in the new three-halves-wavelength mode is close to a high-frequency resonance (a resonance generated in the original two-wavelength mode).

[0230] FIG. 39 is a diagram of still another antenna structure 100 according to an embodiment of this application.

[0231] It should be understood that the antenna structure 100 shown in FIG. 25 may alternatively be a loop antenna shown in FIG. 28 with an electrical length of the radiator being three halves a wavelength, or a slot antenna shown in FIG. 34 with an electrical length of the radiator being three halves a wavelength. In this embodiment, an example in which the antenna structure 100 is the slot antenna shown in FIG. 34 is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement. This is not limited in embodiments of this application.

[0232] FIG. 40 and FIG. 41 are diagrams of simulation results of the antenna structure shown in FIG. 39. FIG. 40 shows S-parameters of the antenna structure shown in FIG. 39. FIG. 41 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 39.

[0233] It should be understood that, for brevity of description, in this embodiment of this application, an example in which an LC filter with a first filter 131 and a second filter 132 being connected in parallel is merely used for description. In the first filter 131, a capacitance of a capacitor is 4 pF, and an inductance of an inductor is 19 nH. In the second filter 132, a capacitance of a capacitor is 3 pF, an inductance of an inductor is 20 nH, an inductance L1 of a first electronic element is 4 nH, and an inductance L2 of a second electronic element is 4.5 nH.

[0234] FIG. 40 shows an S11 curve in a case in which the first electronic element and the second electronic element are electrically connected between the radiator and the ground plane (the electronic elements are connected), the first electronic element and the second electronic element are not disposed between the radiator and the ground plane (the electronic elements are disconnected), and the filter is electrically connected between the electronic element and the radiator.

[0235] The antenna structure can generate six resonant frequency bands at a low frequency and a high frequency by using a high-resistance characteristic (equivalent to a case in which the electronic element is disconnected from the radiator) of the filter at the low frequency (a frequency band corresponding to a half-wavelength mode) and a low-resistance characteristic (equivalent to a case in which the electronic element is short-circuited to the radiator) of the filter at the high frequency (a frequency band corresponding to a three-halves-wavelength mode), to expand an operating band-

width of the antenna structure.

[0236] As shown in FIG. 41, the antenna structure has good efficiency (total efficiency and radiation efficiency) in a frequency band corresponding to a resonance generated in each mode.

[0237] It should be understood that, in the foregoing embodiments, an example in which the antenna structure is a slot antenna or a loop antenna is used for description. The technical solutions provided in embodiments of this application may also be applied to a structure of a wire antenna.

[0238] FIG. 42 is a diagram of an antenna structure 200 according to an embodiment of this application.

[0239] As shown in FIG. 42, the antenna structure 200 may include a radiator 210, a ground plane 220, and a first electronic element 221.

[0240] A first end of the radiator 210 is grounded, and a second end of the radiator 210 is an open end (the second end of the radiator 210 is not directly connected to another conductor). The radiator 210 includes a first current region 211, and the first current region 211 includes an electric field node generated by the antenna structure 200. The first electronic element 221 is electrically connected between the first current region 211 and the ground plane 220.

[0241] In an embodiment, the antenna structure 200 may further include a feed unit 230, and the feed unit 230 may be electrically connected to the radiator 210 at a feed point, to feed an electrical signal, so that the antenna structure generates a resonance.

[0242] In an embodiment, at least a part of the radiator 210 from the first end to the second end is configured to generate a first resonance.

[0243] In an embodiment, an electrical length of the radiator 210 may be three quarters of a first wavelength, the antenna structure 200 is an antenna structure designed based on a three-quarters wavelength, and the first wavelength is a wavelength corresponding to the first resonance.

[0244] It should be understood that, when the first electronic element is not disposed, and the electrical length of the radiator 210 is three quarters of the first wavelength, an operating mode of the antenna structure may include a quarter-wavelength mode and a three-quarters-wavelength mode. FIG. 43 shows corresponding distribution of currents and electric fields in a case in which the feed unit 230 performs feeding at the second end.

[0245] It should be understood that the electric field node (current strong point) that is generated by the antenna structure 200 and that is included in the foregoing current region may be understood as a current node included in distribution of currents and electric fields corresponding to a highest-order mode in the antenna structure. In an embodiment, the electrical length of the radiator 210 is three quarters of the first wavelength, and correspondingly, the electric field node (current strong point) generated by the antenna structure 200 may be

understood as an electric field node (a current strong point) generated in the three-quarters-wavelength mode.

[0246] (a) in FIG. 43 shows distribution of currents and electric fields corresponding to the quarter-wavelength mode, where the radiator does not include an electric field node (a current strong point). (b) in FIG. 43 shows distribution of currents and electric fields corresponding to the three-quarters-wavelength mode, where the radiator includes an electric field node (a current strong point).

[0247] The first electronic element 221 may be configured to change a current and an electric field of the antenna structure 200 in the quarter-wavelength mode, so as to adjust the operating mode of the antenna structure 200.

[0248] In the quarter-wavelength mode, when an electronic element is electrically connected between the first current region 211 and the ground plane, because the region is electrically connected to the ground plane 220 through the electronic element, a boundary condition of the region may be changed, so that a current node (an electric field strong point) is changed into an electric field node (a current strong point) in the region. Because the boundary condition of the region is changed, distribution of electric fields and currents corresponding to the quarter-wavelength mode is changed correspondingly. (a) in FIG. 44 shows distribution of currents of the radiator, and (b) in FIG. 44 shows distribution of electric fields of the radiator, where the quarter-wavelength mode is changed into a new three-quarters-wavelength mode.

[0249] In the three-quarters-wavelength mode, an electric field node (a current strong point) is included in the region (the first current region 211) connected to the first electronic element 221. (a) in FIG. 45 shows distribution of currents of the radiator, and (b) in FIG. 45 shows distribution of electric fields of the radiator, which is equivalent to a short circuit. Because the electronic element being electrically connected between the region of the radiator and the ground plane does not change the boundary condition, the three-quarters-wavelength mode is not changed.

[0250] Therefore, the first electronic element is electrically connected between the ground plane 220 and the first current region 211 of the radiator 210, so that the electric field node (current strong point) may be generated in the first current region 211 in the quarter-wavelength mode, and the operating mode may be changed from the quarter-wavelength mode to the three-quarters-wavelength mode, to form the new three-quarters-wavelength mode. In this case, the operating mode of the antenna structure is increased to adjust a low-frequency resonant frequency band to a high-frequency resonant frequency band, so that the operating mode of the antenna structure includes two three-quarters-wavelength modes. In this way, two resonances with close frequencies may be generated, to expand an operating bandwidth of the antenna structure.

[0251] In an embodiment, the first electronic element 221 may be an inductor, and an inductance of the first

electronic element 221 is less than or equal to a first threshold. For example, when a frequency of the first resonance is less than or equal to 1.7 GHz, the first threshold is 5 nH. When a frequency of the first resonance is greater than 1.7 GHz and less than or equal to 3 GHz, the first threshold is 3 nH. When a frequency of the first resonance is greater than 3 GHz, the first threshold is 2 nH.

[0252] In an embodiment, the first electronic element 221 may be a capacitor, and a capacitance of the first electronic element 221 is less than or equal to a second threshold. For example, the second threshold may be 50 pF.

[0253] In an embodiment, the first electronic element 221 may be a resistor. For example, a resistance of the first electronic element 221 may be 0 ohm.

[0254] In an embodiment, an electronic device with the antenna structure further includes a part of a conductive bezel 11. The bezel 11 has a first position 201 and a second position 202. The bezel 11 is grounded at the first position 201, and is provided with a slot at the second position. A first bezel between the first position 201 and the second position 202 is used as the radiator 210. It should be understood that the first position 201 of the bezel 11 is continuous with a remaining part of the bezel 11. In addition, the first position 201 and the second position 202 may respectively correspond to the first end and the second end of the radiator 210.

[0255] In an embodiment, the filtering structure in the foregoing embodiments may also be used in FIG. 42 and the following antenna structures. The antenna structure 200 may further include a filter, and the filter may be electrically connected between the first electronic element 221 and the first current region 211. The filter is in a turned-on state in a first frequency band, and is in a turned-off state in a second frequency band, and a frequency of the first frequency band is higher than a frequency of the second frequency band. In an embodiment, a part of the radiator 210 from the first end to the second end is configured to generate the first resonance, a second resonance, and a third resonance. The first frequency band includes a resonant frequency band of the first resonance and a resonant frequency band of the second resonance, and the second frequency band includes a resonant frequency band of the third resonance. The resonant frequency band of the first resonance may correspond to a resonant frequency band of a resonance generated in the new three-quarters-wavelength mode. The resonant frequency band of the second resonance may correspond to a resonant frequency band of a resonance generated in the original three-quarters-wavelength mode. The resonant frequency band of the third resonance may correspond to a resonant frequency band of a resonance generated in the quarter-wavelength mode when the first electronic element 211 is not electrically connected.

[0256] FIG. 46 and FIG. 47 are diagrams of simulation results of the antenna structure shown in FIG. 42. FIG. 46

shows S-parameters of the antenna structure shown in FIG. 42. FIG. 47 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 42.

[0257] It should be understood that, for brevity of description, in this embodiment, an example in which a length of the radiator is 54 mm is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement.

[0258] As shown in FIG. 46, when the first electronic element is not electrically connected between the radiator and the ground plane, the antenna structure may generate two resonances in the quarter-wavelength mode and the three-quarters-wavelength mode.

[0259] When the first electronic element is electrically connected between the radiator and the ground plane, the quarter-wavelength mode is changed into the new three-quarters-wavelength mode, so that a resonance generated in the new three-quarters-wavelength mode is close to a resonance generated in the original three-quarters-wavelength mode.

[0260] In addition, the first electronic element (for example, the first electronic element may be an inductor, a capacitor, or a resistor) is adjusted, so that a frequency of a resonance generated in the new quarter-wavelength mode is changed, and a frequency of a resonance generated in the original three-quarters-wavelength mode is almost not shifted.

[0261] As shown in FIG. 47, the antenna structure has good efficiency (total efficiency and radiation efficiency) in a frequency band corresponding to a resonance generated in each mode.

[0262] FIG. 48 is a diagram of another antenna structure 200 according to an embodiment of this application.

[0263] It should be understood that a difference between the antenna structure 200 shown in FIG. 48 and the antenna structure 200 shown in FIG. 42 lies in that the feed unit 230 is disposed at a different position.

[0264] In the antenna structure 200 shown in FIG. 42, the feed unit 230 is electrically connected to the radiator 210 at the second end of the radiator 210. As shown in (b) in FIG. 45, in this antenna structure, a strong binding electric field is generated in a closed slit formed between the ground plane and the radiator between two ground points (the first end of the radiator and a joint between the first electronic element and the radiator). This part of electric field cannot form radiation in a far field, but is converted into thermal energy in a dielectric or a conductor around the closed slit and then is consumed. This deteriorates radiation performance (for example, far-field radiation efficiency) of the antenna structure.

[0265] In an embodiment, the feed unit 230 may be electrically connected to the radiator 210 in a first current region 211, to feed an electrical signal.

[0266] Alternatively, in an embodiment, the feed unit 230 may be electrically connected to the radiator 210 in an electric field region 212, to feed an electrical signal.

The electric field region 212 includes a current node generated by the antenna structure 200. It should be understood that the current node may be understood as that when an electrical signal is fed into the antenna structure 200, directions of currents are reversed on two sides of the current node. The current node corresponds to an electric field strong point. The electric field region 212 may be understood as a region within a specific range from a current strong point or an electric field node. For example, the electric field region 212 may be understood as a region within 5 mm from the current node or the electric field strong point.

[0267] Alternatively, in an embodiment, the feed unit 230 may be electrically connected to the radiator 210 at the first end of the radiator 210, to feed an electrical signal.

[0268] It should be understood that a position of the joint between the feed unit 230 and the radiator 210 is not limited in embodiments of this application, and may be flexibly adjusted based on an internal layout of the electronic device in actual production or design, to reduce the strong binding electric field generated in the closed slit formed between the ground plane and the radiator between the two ground points, so as to reduce a loss of converted thermal energy in the dielectric or the conductor around the closed slit. This improves radiation performance of the antenna structure.

[0269] FIG. 49 is a diagram of still another antenna structure 200 according to an embodiment of this application.

[0270] As shown in FIG. 49, the antenna structure 200 may further include a second electronic element 222.

[0271] A first electronic element 221 is electrically connected to a radiator 210 at a first position 231. The second electronic element 222 is electrically connected to the radiator at a second position 232. The second position 232 is between the first position 231 and a third position 233. The third position 233 is between the first position 232 and a second end (an open end) of the radiator 210. A distance between the third position 233 and the first position 231 is the same as a distance between the third position 233 and the second end of the radiator 210.

[0272] It should be understood that the second electronic element 222 may be configured to reduce a strong binding electric field generated in a closed slit formed between the ground plane and the radiator between two ground points in an original three-quarters-wavelength mode, so as to reduce a loss of converted thermal energy in a dielectric or a conductor around the closed slit. This improves radiation performance of the antenna structure.

[0273] In an embodiment, the second electronic element 222 may be an inductor, a capacitor, or a resistor. This is not limited in embodiments of this application, and selection may be performed based on an actual design.

[0274] In an embodiment, the feed unit 230 may be electrically connected to the radiator 210 in the electric field region 212, to feed an electrical signal.

[0275] It should be understood that a difference be-

tween the antenna structure 200 shown in FIG. 49 and the antenna structure 200 shown in FIG. 42 lies in that the second electronic element 222 is electrically connected between the radiator 210 and the ground plane 220, and the feed unit 230 is disposed at a different position.

[0276] FIG. 50 is a distribution diagram of electric fields and currents of the antenna structure 200 shown in FIG. 49.

[0277] (a) in FIG. 50 is a distribution diagram of electric fields and currents, corresponding to a new three-quarters-wavelength mode changed from a quarter-wavelength mode, in which the first electronic element 211 is electrically connected between the radiator 210 and the ground plane 220. Distribution of electric fields and currents corresponding to a new three-quarters-wavelength mode in a case in which a second electronic element 222 is electrically connected between the radiator 210 and the ground plane 220 is approximately the same as that in (a) in FIG. 50.

[0278] (b) and (c) in FIG. 50 are distribution diagrams of electric fields and currents, corresponding to an original three-quarters-wavelength mode, in which the second electronic element 212 is not electrically connected between the radiator 210 and the ground plane 220, and the second electronic element 212 is electrically connected between the radiator 210 and the ground plane 220 respectively. In this case, an electric field generated in the closed slit formed between the ground plane and the radiator between the two ground points (a first end of the radiator and a joint between the first electronic element and the radiator) is weakened, to reduce a loss of converted thermal energy in the dielectric or the conductor around the closed slit. This improves radiation performance of the antenna structure.

[0279] FIG. 51 and FIG. 52 are diagrams of simulation results of the antenna structure shown in FIG. 49. FIG. 51 shows S-parameters of the antenna structure shown in FIG. 49. FIG. 52 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 49.

[0280] It should be understood that, for brevity of description, in this embodiment, an example in which the second electronic element is an inductor and an inductance L_2 is 3 nH is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement.

[0281] As shown in FIG. 51, when the first electronic element and the second electronic element are not electrically connected between the radiator and the ground plane, the antenna structure may generate two resonances in a quarter-wavelength mode and a three-quarters-wavelength mode.

[0282] When the second electronic element, instead of the first electronic element, is electrically connected between the radiator and the ground plane, the quarter-wavelength mode of the antenna structure may also be changed into the three-quarters-wavelength mode, and a frequency of a generated resonant frequency band is

shifted toward a high frequency.

[0283] When the first electronic element and the second electronic element are electrically connected between the radiator and the ground plane, the quarter-wavelength mode of the antenna structure may also be changed into the three-quarters-wavelength mode, and a frequency of a generated resonant frequency band is shifted toward a high frequency. The first electronic element may be adjusted (for example, $L_1=0.5$ nH or 2 nH), to control a difference between a frequency of a resonance generated in a new three-quarters-wavelength mode and a frequency of a resonance generated in an original three-quarters-wavelength mode, so that the frequency of the resonance generated in the new three-quarters-wavelength mode is close to the frequency of the resonance generated in the original three-quarters-wavelength mode.

[0284] In addition, after the second electronic element is added, an operating bandwidth ($S_{11}<-4$ dB) of the antenna structure is widened.

[0285] Compared with a case in which the second electronic element is not electrically connected between the radiator and the ground plane, as shown in FIG. 52, in a case in which the second electronic element is electrically connected, efficiency of the antenna structure is improved by about 1 dB at a resonance point (about 2.1 GHz) of the resonance generated in the original three-quarters-wavelength mode.

[0286] FIG. 53 is a diagram of still another antenna structure 200 according to an embodiment of this application.

[0287] It should be understood that a difference between the antenna structure 200 shown in FIG. 53 and the antenna structure 200 shown in FIG. 49 lies in that a feed unit 230 is disposed at a different position. In the antenna structure 200 shown in FIG. 53, a feed point on a radiator 210 is disposed in a first current region 211, and the feed unit 230 is electrically connected to the radiator 210 at the feed point.

[0288] FIG. 54 is a distribution diagram of electric fields and currents of the antenna structure 200 shown in FIG. 53.

[0289] (a) in FIG. 54 is a distribution diagram of electric fields and currents, corresponding to a new three-quarters-wavelength mode changed from the quarter-wavelength mode, in which a first electronic element 211 is electrically connected between the radiator 210 and a ground plane 220. Distribution of electric fields and currents corresponding to a new three-quarters-wavelength mode in a case in which the second electronic element 222 is electrically connected between the radiator 210 and the ground plane 220 is approximately the same as that in (a) in FIG. 54.

[0290] (b) and (c) in FIG. 54 are distribution diagrams of electric fields and currents, corresponding to an original three-quarters-wavelength mode, in which a second electronic element 212 is not electrically connected between the radiator 210 and the ground plane 220, and the

second electronic element 212 is electrically connected between the radiator 210 and the ground plane 220. In this case, an electric field generated in a closed slit formed between the ground plane and the radiator between two ground points (a first end of the radiator and a joint between the first electronic element and the radiator) is weakened, to reduce a loss of converted thermal energy in a dielectric or a conductor around the closed slit. This improves radiation performance of the antenna structure.

[0291] FIG. 55 and FIG. 56 are diagrams of simulation results of the antenna structure shown in FIG. 53. FIG. 55 shows S-parameters of the antenna structure shown in FIG. 53. FIG. 56 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 53.

[0292] It should be understood that, for brevity of description, in this embodiment, an example in which the second electronic element is an inductor and an inductance L2 is 3 nH is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement.

[0293] As shown in FIG. 55, when the first electronic element and the second electronic element are not electrically connected between the radiator and the ground plane, the antenna structure may generate two resonances in a quarter-wavelength mode and a three-quarters-wavelength mode.

[0294] When the second electronic element, instead of the first electronic element, is electrically connected between the radiator and the ground plane, a frequency of a resonant frequency band generated by the antenna structure in a quarter-wavelength mode is shifted toward a high frequency with a limited amplitude.

[0295] When the first electronic element and the second electronic element are electrically connected between the radiator and the ground plane, the quarter-wavelength mode of the antenna structure is changed into the three-quarters-wavelength mode, and a frequency of a generated resonant frequency band is shifted toward a high frequency. The first electronic element may be adjusted (for example, $L1=0.5$ nH or 2 nH), to control a difference between a frequency of a resonance generated in a new three-quarters-wavelength mode and a frequency of a resonance generated in an original three-quarters-wavelength mode, so that the frequency of the resonance generated in the new three-quarters-wavelength mode is close to the frequency of the resonance generated in the original three-quarters-wavelength mode.

[0296] In addition, after the second electronic element is added, an operating bandwidth ($S_{11}<-4$ dB) of the antenna structure is widened.

[0297] Compared with a case in which the second electronic element is not electrically connected between the radiator and the ground plane, as shown in FIG. 56, in a case in which the second electronic element is electrically connected, efficiency of the antenna structure is

improved by about 1 dB at a resonance point (about 2.3 GHz) of the resonance generated in the original three-quarters-wavelength mode.

[0298] FIG. 57 is a diagram of still another antenna structure 200 according to an embodiment of this application.

[0299] It should be understood that a difference between the antenna structure 200 shown in FIG. 57 and the antenna structure 200 shown in FIG. 53 lies in that the antenna structure has a different operating frequency band. An operating frequency band of the antenna structure 200 shown in FIG. 53 is an intermediate frequency band (for example, the operating frequency band is greater than 1.7 GHz and less than or equal to 3 GHz), and an operating frequency band of the antenna structure 200 shown in FIG. 57 is a low frequency band (for example, the operating frequency band is less than or equal to 1.7 GHz).

[0300] As shown in FIG. 57, in the antenna structure 200, a part of the bezel 11 of the electronic device is used as a radiator 210. Because an electrical length of the radiator is three quarters of a first wavelength, when a first resonance corresponding to the first wavelength is in a low frequency band, a physical length of the radiator is large and the radiator 210 may be positioned on three adjacent edges of the bezel, to meet a requirement for the physical length of the radiator 210.

[0301] FIG. 58 to FIG. 63 are diagrams of simulation results of the antenna structure shown in FIG. 57. FIG. 58 shows S-parameters of the antenna structure, as shown in FIG. 57, in which a first electronic element is electrically connected and a second electronic element is not electrically connected. FIG. 59 shows simulation results of radiation efficiency and total efficiency of the antenna structure, as shown in FIG. 57, in which a first electronic element is electrically connected and a second electronic element is not electrically connected. FIG. 60 is a distribution diagram of currents of the antenna structure, as shown in FIG. 57, in which a first electronic element is electrically connected and a second electronic element is not electrically connected. FIG. 61 shows S-parameters of the antenna structure shown in FIG. 57. FIG. 62 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 57. FIG. 63 is a distribution diagram of currents of the antenna structure shown in FIG. 57.

[0302] It should be understood that, for brevity of description, lengths of the radiator 210 on a first side, a second side, and a third side of the bezel 11 are 63 mm, 76 mm, and 16 mm respectively, where the radiator sequentially intersects with the first side, the second side, and the third side at an angle. The foregoing parameters are merely used as an example for description. In an actual application, adjustment may be performed based on a design. This is not limited in this application.

[0303] As shown in FIG. 58, when the first electronic element and the second electronic element are not electrically connected between the radiator and the ground

plane, the antenna structure may generate two resonances in a quarter-wavelength mode and a three-quarters-wavelength mode.

[0304] When the first electronic element, instead of the second electronic element, is electrically connected between the radiator and the ground plane, a quarter-wavelength mode of the antenna structure is changed into a three-quarters-wavelength mode, and a frequency of a generated resonant frequency band is shifted toward a high frequency. The first electronic element may be adjusted (for example, $L1=0.5$ nH or 2 nH), to control a difference between a frequency of a resonance generated in a new three-quarters-wavelength mode and a frequency of a resonance generated in an original three-quarters-wavelength mode, so that the frequency of the resonance generated in the new three-quarters-wavelength mode is close to the frequency of the resonance generated in the original three-quarters-wavelength mode.

[0305] As shown in FIG. 59, at a resonance point (about 0.89 GHz) of the resonance generated in the original three-quarters-wavelength mode, a strong bonding electric field is generated in a closed slit formed between the ground plane and the radiator between two ground points (a first end of the radiator and a joint between the first electronic element and the radiator). Therefore, efficiency of the antenna structure is low.

[0306] (a) in FIG. 60 is a distribution diagram of currents corresponding to a new three-quarters-wavelength mode formed by electrically connecting the first electronic element between the radiator and the ground plane when $L1$ is 1 nH. (b) in FIG. 60 is a distribution diagram of currents corresponding to an original three-quarters-wavelength mode when $L1$ is 1 nH.

[0307] As shown in FIG. 61, when the second electronic element, instead of the first electronic element, is electrically connected between the radiator and the ground plane, a frequency of a resonant frequency band generated by the antenna structure in a quarter-wavelength mode is shifted toward a high frequency with a limited amplitude.

[0308] When the first electronic element and the second electronic element (an inductance $L2$ of the second electronic element is 2.5 nH) are electrically connected between the radiator and the ground plane, the first electronic element may be adjusted, to control a difference between a frequency of a resonance generated in a new three-quarters-wavelength mode and a frequency of a resonance generated in an original three-quarters-wavelength mode, so that the frequency of the resonance generated in the new three-quarters-wavelength mode is close to the frequency of the resonance generated in the original three-quarters-wavelength mode.

[0309] Compared with an efficiency simulation result shown in FIG. 59, efficiency, as shown in FIG. 62, of the antenna structure in which the second electronic element is electrically connected is improved by about 4 dB at a resonance point (about 0.89 GHz) of the resonance

generated in the original three-quarters-wavelength mode.

[0310] (a) in FIG. 63 is a distribution diagram of currents corresponding to a new three-quarters-wavelength mode. That a current on the ground plane flows along a long side (a length in a y direction is greater than a length in an x direction) of the ground plane in this operating mode may be understood as that the ground plane forms a monopole-like structure in a longitudinal mode of the ground plane, and an electrical length of the ground plane may be half of an operating wavelength (a wavelength corresponding to a current resonance) of the antenna structure, to improve radiation efficiency of the antenna structure.

[0311] (b) in FIG. 63 is a distribution diagram of currents corresponding to an original three-quarters-wavelength mode. That a current on the ground plane includes a component flowing along a long side (a length in a y direction is greater than a length in an x direction) of the ground plane and a component flowing along a short side of the ground plane in this operating mode may be understood as that, in a mixed longitudinal and transverse mode of the ground plane, because a length of the short side of the ground plane is less than half of an operating wavelength (a wavelength corresponding to a current resonance) of the antenna structure, the transverse mode cannot improve radiation efficiency of the antenna structure, and only a component generated on the ground plane in the longitudinal mode can improve efficiency of the antenna structure.

[0312] FIG. 64 is a diagram of still another antenna structure 200 according to an embodiment of this application.

[0313] It should be understood that a difference between the antenna structure 200 shown in FIG. 64 and the antenna structure 200 shown in FIG. 57 lies in that the antenna structure 200 includes a resonant stub 250. Based on the antenna structure 200 shown in FIG. 57, in the antenna structure 200 shown in FIG. 64, the resonant stub 250 whose electrical length is a quarter of a first wavelength is added to a first end of a radiator 210, a first end of the resonant stub 250 is connected to the first end of the radiator 210 (a bezel 11 is continuous at the position), and a second end of the resonant stub 250 is an open end (the bezel 11 is provided with a slot at the position, and the resonant stub 250 is not electrically connected to another bezel at the position), so that a radiation aperture of the antenna structure is increased from three quarters of the first wavelength to twice the first wavelength.

[0314] In an embodiment, a length $L1$ of the resonant stub 250 and a length $L2$ of the radiator 210 satisfy: $0.2 \times L2 \leq L1 \leq 0.3 \times L2$.

[0315] In one embodiment, a third electronic element 223 is electrically connected between the first end of the radiator 210 and a ground plane 220. The third electronic element 223 may be configured to adjust a frequency of a resonance generated by the antenna structure, so that

resonant frequency bands of a plurality of resonances generated by the antenna structure are close to each other, to expand an operating bandwidth of the antenna structure.

[0316] FIG. 65 to FIG. 74 are diagrams of simulation results of the antenna structure shown in FIG. 64. FIG. 65 shows S-parameters of the antenna structure shown in FIG. 64. FIG. 66 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 64. FIG. 67 is a distribution diagram of currents of the antenna structure shown in FIG. 64. FIG. 68 shows S-parameters of the antenna structure (excluding a resonant stub) shown in FIG. 64 in different models. FIG. 69 shows simulation results of radiation efficiency and total efficiency of the antenna structure (excluding a resonant stub) shown in FIG. 64 in different models. FIG. 70 shows S-parameters of the antenna structure shown in FIG. 64 in different models. FIG. 71 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 64 in different models. FIG. 72 shows S-parameters of the antenna structure shown in FIG. 64. FIG. 73 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 64. FIG. 74 is a distribution diagram of currents of the antenna structure shown in FIG. 64.

[0317] It should be understood that, for brevity of description, an example in which an inductance L1 of a first electronic element is 2 nH, an inductance L2 of a second electronic element is 2.5 nH, a third electronic element is a resistor, and a resistance of the third electronic element is 0 ohm. The foregoing parameters are merely used as an example for description. In an actual application, adjustment may be performed based on a design. This is not limited in this application.

[0318] As shown in FIG. 65, when the antenna structure includes a resonant stub, the antenna structure may generate three resonant frequency bands.

[0319] As shown in FIG. 66, an efficiency dent occurs between a second resonance and a third resonance (near 0.9 GHz). However, because a frequency of a resonant frequency band corresponding to the third resonance is close to the dent, efficiency at the dent can be effectively improved by using the resonance.

[0320] (a) in FIG. 67 is a distribution diagram of currents corresponding to a resonance point of the first resonance, and may correspond to a one-wavelength mode in a CM mode. (b) in FIG. 67 is a distribution diagram of currents corresponding to a resonance point of the second resonance, and may correspond to the one-wavelength mode in the CM mode. (c) in FIG. 67 is a distribution diagram of currents corresponding to a resonance point of the third resonance, and may correspond to the one-wavelength mode in the CM mode.

[0321] In the distribution diagrams of the currents corresponding to the resonance point of the first resonance and the resonance point of the third resonance, currents on two sides of the radiator and currents on the ground

plane are codirectional, so that a longitudinal mode of the ground plane can be better excited, and the entire ground plane participates in radiation as a radiator. This provides good radiation efficiency and a good bandwidth. In the distribution diagram of the currents corresponding to the resonance point of the second resonance, directions of currents on two sides of the radiator and currents on the ground plane are reversed; and consequently, a longitudinal current mode of the ground plane cannot be effectively excited, and currents and electric fields are concentrated near the radiator of the antenna structure. In this case, efficiency is poor, and there is an obvious efficiency dent.

[0322] In addition, when no resonant stub is added, the antenna structure has two resonant frequency bands. FIG. 68 shows S-parameters in a hand-held model (a left-handed model or a right-handed model). As shown in FIG. 63, currents on two sides of the ground plane are unbalanced, and a current on the left side of the ground plane is definitely greater than that on the right side of the ground plane. Radiation absorption of the antenna structure is different in the hand-held model, resulting in unbalanced efficiency reduction of the antenna structure in the left/right-handed model. Compared with efficiency in free space (free space, FS), radiation efficiency is reduced by about 2.5 dB in the left-handed mode, and radiation efficiency is reduced by about 4.2 dB in the right-handed mode, as shown in FIG. 69.

[0323] A resonant stub may be added, to introduce a new resonance. FIG. 70 shows S-parameters in a hand-held model. Because a current on the right side of the ground plane increases significantly, efficiency reduction of the right-handed model is greatly improved. Compared with efficiency of free space, efficiency reduction of a left-handed model is basically the same as that of the right-handed model, and radiation efficiency reduction is about 3.2 dB, as shown in FIG. 71.

[0324] Because the second resonance cannot effectively excite the longitudinal current mode of the ground plane, currents and electric fields are concentrated near the radiator of the antenna structure. In this case, efficiency is poor, and there is an obvious efficiency dent. Therefore, the first electronic element, the second electronic element, the third electronic element, and a matching network between a feed unit and the radiator may be adjusted, so that the second resonance is not excited when an electrical signal is fed. For example, L1 of the first electronic element is 15 nH, L2 of the second electronic element is 3 nH, L3 of the third electronic element is 0.9 nH, and a matching network is provided between the feed unit and the radiator, and includes a 5 nH inductor connected in series and a 4 pF capacitor connected in parallel.

[0325] FIG. 72 shows S-parameters generated by the antenna structure in the hand-held model. FIG. 73 shows corresponding efficiency in the hand-held model. Because the second resonance is not excited, no dent exists in an efficiency curve.

[0326] (a) in FIG. 74 is a distribution diagram of currents of a resonance generated by the ground plane at 0.65 GHz. In this case, efficiency of a low frequency in a resonant frequency band of the first resonance can be improved. (b) in FIG. 74 is a distribution diagram of currents corresponding to a resonance point of a first resonance at 0.8 GHz. (c) in FIG. 74 is a distribution diagram of currents corresponding to a resonance point of a first resonance at 0.96 GHz.

[0327] FIG. 75 is a diagram of still another antenna structure 200 according to an embodiment of this application.

[0328] As shown in FIG. 75, the antenna structure 200 may include a radiator 210, a ground plane 220, a first electronic element 221, and a fourth electronic element 224.

[0329] A first end of the radiator 210 is grounded, and a second end of the radiator 210 is an open end (the second end of the radiator 210 is not directly connected to another conductor). The radiator 210 includes a first current region 211 and a second current region 212. The first current region 211 and the second current region 212 each include an electric field node generated by the antenna structure 200. The first electronic element 221 is electrically connected between the first current region 211 and the ground plane 220, and the fourth electronic element 224 is electrically connected between the second current region 212 and the ground plane 220.

[0330] In an embodiment, the antenna structure 200 is a bezel antenna, and may be disposed on a long edge of a bezel.

[0331] It should be understood that a difference between the antenna structure 200 shown in FIG. 75 and the antenna structure 200 in the foregoing embodiments lies in that an electrical length of the radiator 210 in the antenna structure 200 shown in FIG. 75 is five quarters of a first wavelength.

[0332] Because the electrical length of the radiator 210 in the antenna structure 200 is five quarters of the first wavelength, an operating mode of the antenna structure 200 may include a quarter-wavelength mode, a three-quarters-wavelength mode, and a five-quarters-wavelength mode. Therefore, during operation of the antenna structure 200, two electric field nodes (current strong points) may be generated on the radiator 210. Loading an electronic element in the regions can increase the quarter-wavelength mode and the three-quarters-wavelength mode to new five-quarters-wavelength modes. The antenna structure 200 may include three five-quarters-wavelength modes to expand an operating bandwidth of the antenna structure.

[0333] It should be understood that the electric field nodes (current strong points) that are generated by the antenna structure 200 and that are included in the foregoing current regions may be understood as current nodes included in distribution of currents and electric fields corresponding to a highest-order mode in the antenna structure. In an embodiment, the electrical length

of the radiator 210 is five quarters of the first wavelength, and correspondingly, an electric field node (a current strong point) generated by the antenna structure 200 may be understood as an electric field node (a current strong point) generated in the five-quarters-wavelength mode.

[0334] In an embodiment, the antenna structure 200 may further include a second electronic element 222. The first electronic element 221 is electrically connected to the radiator 210 at a first position 231. The second electronic element 222 is electrically connected to the radiator 210 at a second position. The second position is between the first position and a third position. The third position is between the first position and the second end (the open end) of the radiator. A distance between the third position and the first position is the same as a distance between the third position and the second end of the radiator. A distance between the first electronic element 221 and the second end of the radiator 210 is less than a distance between the fourth electronic element 224 and the second end of the radiator 210.

[0335] It should be understood that the second electronic element 222 may be configured to reduce a strong binding electric field generated in a closed slit formed between the ground plane and the radiator between two adjacent ground points (for example, the first electronic element 221 and the fourth electronic element 224) in the original three-quarters-wavelength mode and five-quarters-wavelength mode, so as to reduce a loss of converted thermal energy in a dielectric or a conductor around the closed slit. This improves efficiency of the antenna structure.

[0336] In an embodiment, the antenna structure 200 may further include a feed unit 230. The feed unit 230 and the radiator 210 may be electrically connected between the first end of the radiator 210 and an electrical joint between the fourth electronic element 224 and the radiator.

[0337] FIG. 76 and FIG. 77 are diagrams of simulation results of the antenna structure shown in FIG. 75. FIG. 76 shows S-parameters of the antenna structure shown in FIG. 75. FIG. 77 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 75.

[0338] It should be understood that, for brevity of description, in this embodiment, an example in which a length of the radiator is 80 mm is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement.

[0339] As shown in FIG. 76, when the first electronic element and the fourth electronic element are not electrically connected between the radiator and the ground plane, the antenna structure may generate three resonances in the quarter-wavelength mode, the three-quarters-wavelength mode, and the five-quarters-wavelength mode (a frequency of a resonance generated in the quarter-wavelength mode is excessively low and is not

shown).

[0340] When the first electronic element and the fourth electronic element are electrically connected between the radiator and the ground plane (the first electronic element is an inductor ($L_1=1$ nH), and the fourth electronic element is a resistor ($L_4=0$ ohm)), an electric field node (a current strong point) is generated in regions (the first current region and the second current region) near electrical joints between the electronic elements and the radiator. In this case, the quarter-wavelength mode and the three-quarters-wavelength mode are changed into new five-quarters-wavelength modes, so that resonances generated in the new five-quarters-wavelength modes are close to a resonance generated in the original five-quarters-wavelength mode, to obtain a wide operating bandwidth.

[0341] As shown in FIG. 77, the antenna structure has good efficiency (total efficiency and radiation efficiency) in a frequency band corresponding to a resonance generated in each mode.

[0342] FIG. 78 and FIG. 79 are diagrams of simulation results of the antenna structure shown in FIG. 75 that does not include the second electronic element. FIG. 78 is a distribution diagram of electric fields and currents of the antenna structure shown in FIG. 75. FIG. 79 is a pattern of the antenna structure shown in FIG. 75.

[0343] As shown in (a) in FIG. 78, the first electronic element and the fourth electronic element are electrically connected between the radiator and the ground plane, the electronic element is electrically connected to the ground plane in the current region to generate an electric field node (a current strong point), and the operating mode is changed from the quarter-wavelength mode to a new five-quarters-wavelength mode. (a) in FIG. 79 is a pattern corresponding to the mode.

[0344] As shown in (b) in FIG. 78, the first electronic element and the fourth electronic element are electrically connected between the radiator and the ground plane, the electronic element is electrically connected to the ground plane in the current region to generate an electric field node (a current strong point), and the operating mode is changed from the three-quarters-wavelength mode to a new five-quarters-wavelength mode. (b) in FIG. 79 is a pattern corresponding to the mode.

[0345] As shown in (c) in FIG. 78, the first electronic element and the fourth electronic element are electrically connected between the radiator and the ground plane, the electronic element is electrically connected to the ground plane in the current region, a region of an electric field node (a current strong point) is the same as that of the electric field node (current strong point) generated in the original five-quarters-wavelength mode, a boundary condition is not changed, and the original five-quarters-wavelength mode is not changed. (c) in FIG. 79 is a pattern corresponding to the mode.

[0346] It should be understood that, when the electronic elements are respectively electrically connected to the first current region and the second current region,

because the regions are electrically connected to the ground plane through the electronic elements, boundary conditions of the regions may be changed, and electric field nodes (current strong points) are generated in the regions. Because the boundary conditions of the regions are changed, distribution of currents corresponding to the quarter-wavelength mode and the three-quarters-wavelength mode is changed accordingly, and the quarter-wavelength mode and the three-quarters-wavelength mode are changed into new five-quarters-wavelength modes.

[0347] FIG. 80 to FIG. 83 are diagrams of simulation results of the antenna structure shown in FIG. 75 that includes the second electronic element. FIG. 80 shows S-parameters of the antenna structure shown in FIG. 75 that includes the second electronic element. FIG. 81 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 75 that includes the second electronic element. FIG. 82 shows S-parameters of the antenna structure shown in FIG. 75 in a left/right-handed model. FIG. 83 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 75 in the left/right-handed model.

[0348] It should be understood that, for brevity of description, in this embodiment, an example in which the first electronic element is a resistor ($L_1=0$ ohm), the second electronic element is an inductor ($L_2=6$ nH), and the fourth electronic element is an inductor ($L_4=1$ nH) is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement.

[0349] As shown in FIG. 80, after the second electronic element is electrically connected between the radiator and the ground plane, S-parameters of the antenna structure are approximately the same, and resonance points of resonances slightly deviate.

[0350] As shown in FIG. 81, in a resonant frequency band of a resonance generated in the new five-quarters-wavelength mode, efficiency of the antenna structure is approximately the same. In a resonant frequency band of a resonance generated in the original five-quarters-wavelength mode, efficiency of the antenna structure is improved by about 1 dB after the second electronic element is electrically connected between the radiator and the ground plane.

[0351] FIG. 82 shows S-parameters in a hand-held model (a left-handed model or a right-handed model). Because the antenna structure is disposed on the left side of the ground plane, currents on two sides of the ground plane are unbalanced during radiation, and a current on the left side of the ground plane is definitely greater than that on the right side of the ground plane. Radiation absorption of the antenna structure is different in the hand-held model, resulting in unbalanced efficiency reduction of the antenna structure in the left/right-handed model. Compared with efficiency in free space, radiation efficiency is reduced by about 3.3 dB

in the left-handed mode, and radiation efficiency is reduced by about 6.3 dB in the right-handed mode, as shown in FIG. 83.

[0352] FIG. 84 is a diagram of still another antenna structure 200 according to an embodiment of this application.

[0353] It should be understood that a difference between the antenna structure 200 shown in FIG. 84 and the antenna structure 200 shown in FIG. 75 lies in that a radiator 210 is disposed at a different position of a bezel of an electronic device. The radiator 210 in the antenna structure 200 shown in FIG. 75 is on a long side of a bezel, and the radiator 210 in the antenna structure 200 shown in FIG. 84 is partially on a long side of a bezel, and partially on a short side of the bezel.

[0354] FIG. 85 and FIG. 86 are diagrams of simulation results of the antenna structure shown in FIG. 84 that does not include a second electronic element. FIG. 85 is a distribution diagram of electric fields and currents of the antenna structure shown in FIG. 84. FIG. 86 is a pattern of the antenna structure shown in FIG. 84.

[0355] It should be understood that, for brevity of description, in this embodiment, an example in which a length of the radiator is 88 mm, a first electronic element is a resistor ($L1=0$ ohm), and a fourth electronic element is an inductor ($L4=1$ nH) is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement.

[0356] As shown in (a) in FIG. 85, the first electronic element and the fourth electronic element are electrically connected between the radiator and the ground plane, the electronic element is electrically connected to the ground plane in the current region to generate an electric field node (a current strong point), and the operating mode is changed from the quarter-wavelength mode to a new five-quarters-wavelength mode. (a) in FIG. 86 is a pattern corresponding to the mode.

[0357] As shown in (b) in FIG. 85, the first electronic element and the fourth electronic element are electrically connected between the radiator and the ground plane, the electronic element is electrically connected to the ground plane in the current region to generate an electric field node (a current strong point), and the operating mode is changed from the three-quarters-wavelength mode to a new five-quarters-wavelength mode. (b) in FIG. 86 is a pattern corresponding to the mode.

[0358] As shown in (c) in FIG. 85, the first electronic element and the fourth electronic element are electrically connected between the radiator and the ground plane, the electronic element is electrically connected to the ground plane in a current region, a region of an electric field node (a current strong point) is the same as that of the electric field node (current strong point) generated in the original five-quarters-wavelength mode, a boundary condition is not changed, and the original five-quarters-wavelength mode is not changed. (c) in FIG. 86 is a pattern corresponding to the mode.

[0359] FIG. 87 and FIG. 88 are diagrams of simulation

results of the antenna structure shown in FIG. 84 that includes the second electronic element. FIG. 87 shows S-parameters of the antenna structure shown in FIG. 84 in a left/right-handed model. FIG. 88 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 84 in the left/right-handed model.

[0360] It should be understood that, for brevity of description, in this embodiment, an example in which the first electronic element is an inductor ($L1=3$ nH), the second electronic element is an inductor ($L2=1$ nH), and the fourth electronic element is an inductor ($L4=1.5$ nH) is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement.

[0361] FIG. 87 shows S-parameters in a hand-held model (a left-handed model or a right-handed model). Because the antenna structure is disposed in a lower right corner of the ground plane, compared with the antenna structure 200 shown in FIG. 75 in which the radiator 210 is on the long side of the bezel, in the antenna structure 200 shown in FIG. 84, currents on two sides of the ground plane are improved during radiation but are still unbalanced, and a current on the right side of the ground plane is definitely greater than that on the left side of the ground plane. Radiation absorption of the antenna structure is different in the hand-held model, resulting in unbalanced efficiency reduction of the antenna structure in the left/right-handed model. Compared with efficiency in free space, radiation efficiency is reduced by a maximum of about 8 dB in the left-handed mode, and radiation efficiency is reduced by about 4 dB in the right-handed mode, as shown in FIG. 88.

[0362] It should be understood that a technical solution of a resonant stub may also be applied to the antenna structure 200 (for example, the antenna structure shown in FIG. 75 and FIG. 84). For example, the resonant stub is connected to a first end (ground end) of the radiator, to improve efficiency of the antenna structure in the left/right-handed model.

[0363] FIG. 89 is a diagram of still another antenna structure 200 according to an embodiment of this application.

[0364] As shown in FIG. 89, the antenna structure 200 may further include a fifth electronic element 225. A radiator 210 may further include an electric field region. The electric field region includes a current node generated by the antenna structure 200. The fifth electronic element 225 is electrically connected between the electric field region and a ground plane 220. It should be understood that the fifth electronic elements 225 may be configured to improve efficiency of the antenna structure.

[0365] It should be understood that a difference between the antenna structure 200 shown in FIG. 89 and the antenna structure 200 shown in FIG. 84 lies in that operating frequency bands of the antenna structure are different, and a second electronic element 222 is replaced with the fifth electronic element 225 to improve

efficiency of the antenna structure. An operating frequency band of the antenna structure 200 shown in FIG. 84 is an intermediate frequency band (for example, the operating frequency band is greater than 1.7 GHz and less than or equal to 3 GHz), and an operating frequency band of the antenna structure 200 shown in FIG. 88 is a low frequency band (for example, the operating frequency band is less than or equal to 1.7 GHz).

[0366] As shown in FIG. 89, in the antenna structure 200, a part of a bezel of an electronic device is used as the radiator 210. Because an electrical length of the radiator is five quarters of a first wavelength, when a first resonance corresponding to a first wavelength is in a low frequency band, a physical length of the radiator is large and the radiator 210 may be positioned on three adjacent edges of the bezel, to meet a requirement for the physical length of the radiator 210.

[0367] FIG. 90 and FIG. 91 are diagrams of simulation results of the antenna structure shown in FIG. 89. FIG. 90 shows S-parameters of the antenna structure shown in FIG. 89. FIG. 91 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 89.

[0368] It should be understood that, for brevity of description, in this embodiment, an example in which a first electronic element is an inductor ($L_1=0.7$ nH), a fourth electronic element is an inductor ($L_4=3$ nH), and the fifth electronic element is a capacitor ($L_5=1$ pF) is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement.

[0369] As shown in FIG. 90, when the first electronic element and the fourth electronic element are electrically connected between the radiator and the ground plane, an electric field node (a current strong point) is generated in regions (a first current region and a second current region) near an electrical joint between the electronic element and the radiator. In this case, a quarter-wavelength mode and a three-quarters-wavelength mode are changed into new five-quarters-wavelength modes, so that a resonance generated in the new five-quarters-wavelength mode is close to a resonance generated in the original five-quarters-wavelength mode, to obtain a wide operating bandwidth.

[0370] As shown in FIG. 91, the fifth electronic element is electrically connected in the electric field region, so that efficiency of the antenna structure in an operating frequency band (with $S_{11}<-4$ dB as a boundary) can be improved.

[0371] FIG. 92 and FIG. 93 are diagrams of simulation results of the antenna structure shown in FIG. 89. FIG. 92 is a distribution diagram of currents of the antenna structure shown in FIG. 89. FIG. 93 is a pattern of the antenna structure shown in FIG. 89.

[0372] (a) in FIG. 92 is distribution diagram of electric fields and currents, corresponding to an operating mode of a new five-quarters-wavelength mode changed from the quarter-wavelength mode, in which the first electronic

element and the fourth electronic element are electrically connected between the radiator and the ground plane, and the electronic element is electrically connected to the ground plane in a current region to generate an electric field node (a current strong point). (a) in FIG. 93 is a pattern corresponding to the mode.

[0373] (b) in FIG. 92 is a distribution diagram of electric fields and currents, corresponding to an operating mode of a new five-quarters-wavelength mode changed from the three-quarters-wavelength mode, in which the first electronic element and the fourth electronic element are electrically connected between the radiator and the ground plane, and the electronic element is electrically connected to the ground plane in a current region to generate an electric field node (a current strong point). (b) in FIG. 93 is a pattern corresponding to the mode.

[0374] As shown in (c) in FIG. 92, the first electronic element and the fourth electronic element are electrically connected between the radiator and the ground plane, the electronic element is electrically connected to the ground plane in a current region, a region of an electric field node (a current strong point) is the same as that of the electric field node (current strong point) generated in the original five-quarters-wavelength mode, and the original five-quarters-wavelength mode is not changed. (c) in FIG. 93 is a pattern corresponding to the mode.

[0375] FIG. 94 is a diagram of still another antenna structure 200 according to an embodiment of this application.

[0376] As shown in FIG. 94, the antenna structure 200 may include a radiator 210, a ground plane 220, a first electronic element 221, a fourth electronic element 224, and a sixth electronic element 226.

[0377] A first end of the radiator 210 is grounded, and a second end of the radiator 210 is an open end (the second end of the radiator 210 is not directly connected to another conductor). The radiator 210 includes a first current region 211, a second current region 212, and a third current region 213. The first current region 211, the second current region 212, and the third current region 213 each include an electric field node generated by the antenna structure 200. The second current region 212 is between the first current region 212 and the third current region 213. The first electronic element 221 is electrically connected between the first current region 211 and the ground plane 220. The fourth electronic element 224 is electrically connected between the second current region 212 and the ground plane 220. The sixth electronic element 226 is electrically connected between the third current region 213 and the ground plane 220.

[0378] In an embodiment, the antenna structure 200 is a bezel antenna, and may be disposed on a long edge of a bezel.

[0379] It should be understood that a difference between the antenna structure 200 shown in FIG. 94 and the antenna structure 200 in the foregoing embodiments lies in that an electrical length of the radiator 210 in the antenna structure 200 shown in FIG. 94 is seven quarters

of a first wavelength.

[0380] Because the electrical length of the radiator 210 in the antenna structure 200 is seven quarters of the first wavelength, an operating mode of the antenna structure 200 may include a quarter-wavelength mode, a three-quarters-wavelength mode, a five-quarters-wavelength mode, and a seven-quarters-wavelength mode. Therefore, during operation of the antenna structure 200, three electric field nodes (current strong points) may be generated on the radiator 210. Loading an electronic element in the regions can increase the quarter-wavelength mode, the three-quarters-wavelength mode, and the five-quarters-wavelength mode to a new seven-quarters-wavelength mode. The antenna structure 200 may include four seven-quarters-wavelength modes to expand an operating bandwidth of the antenna structure.

[0381] It should be understood that the electric field nodes (current strong points) that are generated by the antenna structure 200 and that are included in the foregoing current regions may be understood as current nodes included in distribution of currents and electric fields corresponding to a highest-order mode in the antenna structure. In an embodiment, the electrical length of the radiator 210 is seven quarters of the first wavelength, and correspondingly, an electric field node (a current strong point) generated by the antenna structure 200 may be understood as an electric field node (a current strong point) generated in the seven-quarters-wavelength mode.

[0382] In an embodiment, the antenna structure 200 may further include a second electronic element 222. The first electronic element 221 is electrically connected to the radiator 210 at a first position 231. The second electronic element 222 is electrically connected to the radiator 210 at a second position. The second position is between the first position and a third position. The third position is between the first position and the second end (an open end) of the radiator. A distance between the third position and the first position is the same as a distance between the third position and the second end of the radiator. A distance between the first electronic element 221 and the second end of the radiator 210 is less than a distance between the fourth electronic element 224 or the sixth electronic element 226 and the second end of the radiator 210.

[0383] It should be understood that the second electronic element 222 may be configured to reduce a strong binding electric field generated in a closed slit formed between the ground plane and the radiator between two adjacent ground points (for example, the first electronic element 221 and the fourth electronic element 224) in the original seven-quarters-wavelength mode, so as to reduce a loss of converted thermal energy in a dielectric or a conductor around the closed slit. This improves efficiency of the antenna structure.

[0384] In an embodiment, the antenna structure 200 may further include a feed unit 230. The feed unit 230 and the radiator 210 may be electrically connected between

the first end of the radiator 210 and an electrical joint between the sixth electronic element 226 and the radiator.

[0385] FIG. 95 and FIG. 96 are diagrams of simulation results of the antenna structure shown in FIG. 94. FIG. 95 shows S-parameters of the antenna structure shown in FIG. 94. FIG. 96 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 94.

[0386] It should be understood that, for brevity of description, in this embodiment, an example in which a length of the radiator is 112 mm is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement.

[0387] As shown in FIG. 95, when the first electronic element 221, the fourth electronic element 224, and the sixth electronic element 226 are not electrically connected between the radiator and the ground plane, the antenna structure may generate four resonances in the quarter-wavelength mode, the three-quarters-wavelength mode, the five-quarters-wavelength mode, and the seven-quarters-wavelength mode (a frequency of a resonance generated in the quarter-wavelength mode is excessively low and is not shown).

[0388] When the first electronic element 221, the fourth electronic element 224, and the sixth electronic element 226 are electrically connected between the radiator and the ground plane (the first electronic element is a resistor ($L1=0$ ohm), the fourth electronic element is an inductor ($L4=1$ nH), and the sixth electronic element is an inductor ($L6=2$ nH)), an electric field node (a current strong point) is generated in a region near an electronic joint between the electronic element and the radiator. In this case, the quarter-wavelength mode, the three-quarters-wavelength mode, and the five-quarters-wavelength mode are changed into new seven-quarters-wavelength modes, so that a resonance generated in the new seven-quarters-wavelength mode is close to a resonance generated in the original seven-quarters-wavelength mode, to obtain a wide operating bandwidth.

[0389] As shown in FIG. 96, the antenna structure has good efficiency (total efficiency and radiation efficiency) in a frequency band corresponding to a resonance generated in each mode.

[0390] FIG. 97 and FIG. 98 are distribution diagrams of electric fields and currents of the antenna structure shown in FIG. 94. FIG. 97 is a distribution diagram of electric fields and currents of the antenna structure shown in FIG. 94 that does not include the second electronic element. FIG. 98 is a distribution diagram of electric fields and currents of the antenna structure shown in FIG. 94 that includes the second electronic element.

[0391] As shown in (a) in FIG. 97, the first electronic element, the fourth electronic element, and the sixth electronic element are electrically connected between the radiator and the ground plane, the electronic element

is electrically connected to the ground plane in the current region to generate an electric field node (a current strong point), and the operating mode is changed from the quarter-wavelength mode to a new seven-quarters-wavelength mode. (a) in FIG. 98 shows distribution of electric fields and currents corresponding to the new five-quarters-wavelength mode in a case in which the antenna structure includes the second electronic element. Distribution of the electric fields is approximately the same.

[0392] (b) in FIG. 97 is a distribution diagram of electric fields and currents, corresponding to an operating mode of a new seven-quarters-wavelength mode changed from the three-quarters-wavelength mode, in which the first electronic element, the fourth electronic element, and the sixth electronic element are electrically connected between the radiator and the ground plane, and the electronic element is electrically connected to the ground plane in the current region to generate an electric field node (a current strong point).

[0393] (c) in FIG. 97 is a distribution diagram of electric fields and currents, corresponding to an operating mode of a new seven-quarters-wavelength mode changed from the five-quarters-wavelength mode, in which the first electronic element, the fourth electronic element, and the sixth electronic element are electrically connected between the radiator and the ground plane, and the electronic element is electrically connected to the ground plane in the current region to generate an electric field node (a current strong point).

[0394] As shown in (d) in FIG. 97, the first electronic element, the fourth electronic element, and the sixth electronic element are electrically connected between the radiator and the ground plane, the electronic element is electrically connected to the ground plane in a current region, a region of an electric field node (a current strong point) is the same as that of the electric field node (current strong point) generated in the original seven-quarters-wavelength mode, a boundary condition is not changed, and the original seven-quarters-wavelength mode is not changed. (d) in FIG. 98 shows distribution of electric fields and currents corresponding to a case in which the antenna structure includes the second electronic element. Because the second electronic element is added, to reduce the strong binding electric field generated in the closed slit formed between the ground plane and the radiator between two adjacent ground points (for example, the first electronic element and the fourth electronic element).

[0395] It should be understood that, when electronic elements are respectively electrically connected to the first current region, the second current region, and the third current region, because the regions are electrically connected to the ground plane through the electronic elements, boundary conditions of the regions may be changed, and electric field nodes (current strong points) are generated in the regions. Because the boundary conditions of the regions are changed, distribution of

the electric fields and currents corresponding to the quarter-wavelength mode, the three-quarters-wavelength mode, and the five-quarters-wavelength mode is changed accordingly, and the quarter-wavelength mode, the three-quarters-wavelength mode, and the five-quarters-wavelength mode are changed into new seven-quarters-wavelength modes.

[0396] FIG. 99 and FIG. 100 are diagrams of simulation results of the antenna structure shown in FIG. 94 that includes the second electronic element. FIG. 99 shows S-parameters of the antenna structure shown in FIG. 94 in a left/right-handed model. FIG. 100 shows simulation results of radiation efficiency and total efficiency of the antenna structure shown in FIG. 94 in a left/right-handed model.

[0397] It should be understood that, for brevity of description, in this embodiment, an example in which the first electronic element is an inductor ($L_1=0.3$ nH), the second electronic element is an inductor ($L_2=6$ nH), the fourth electronic element is an inductor ($L_4=1.2$ nH), and the sixth electronic element is an inductor ($L_6=2$ nH) is merely used for description. In an actual application, adjustment may be performed based on an actual production or design requirement.

[0398] FIG. 99 shows S-parameters in a hand-held model (a left-handed model or a right-handed model). Because the antenna structure is disposed on the left side of the ground plane, currents on two sides of the ground plane are unbalanced during radiation, and a current on the left side of the ground plane is definitely greater than that on the right side of the ground plane. Radiation absorption of the antenna structure is different in the hand-held model, resulting in unbalanced efficiency reduction of the antenna structure in the left/right-handed model. Compared with efficiency in free space, radiation efficiency is reduced by about 4.5 dB in the left-handed mode, and radiation efficiency is reduced by about 6.5 dB in the right-handed mode, as shown in FIG. 83.

[0399] It should be understood that a technical solution of a resonant stub may also be applied to the antenna structure 200 shown in FIG. 94. For example, the resonant stub is connected to the first end (ground end) of the radiator, to improve efficiency of the antenna structure in the left/right-handed model.

[0400] It may be clearly understood by a person skilled in the art that, for the purpose of convenient and brief description, for a detailed working process of the foregoing system, apparatus, and unit, refer to a corresponding process in the foregoing method embodiments. Details are not described herein again.

[0401] In the several embodiments provided in this application, it should be understood that the disclosed system, apparatus, and method may be implemented in other manners. For example, the described apparatus embodiments are merely examples. For example, the unit division is merely logical function division and may be other division in an actual implementation. For example,

a plurality of units or components may be combined or integrated into another system, or some features may be ignored or not performed. In addition, the displayed or discussed mutual couplings or direct couplings or communication connections may be implemented through some interfaces. The indirect couplings or communication connections between the apparatuses or units may be implemented in electronic, mechanical, or another form.

[0402] The foregoing descriptions are merely specific implementations of this application, but are not intended to limit the protection scope of this application. Any variation or replacement readily figured out by a person skilled in the art within the technical scope disclosed in this application shall fall within the protection scope of this application. Therefore, the protection scope of this application shall be subject to the protection scope of the claims.

Claims

1. An antenna structure, comprising:

a ground plane, wherein the antenna structure is grounded through the ground plane;
 a radiator, wherein a first end and a second end of the radiator are grounded; and
 a first electronic element and a second electronic element, wherein
 a central region of the radiator comprises a slot, or the antenna structure further comprises a ground element and the ground element is electrically connected between the central region and the ground plane;
 the radiator comprises a first current region and a second current region, the central region is between the first current region and the second current region, the first current region comprises an electric field node generated by the antenna structure, and the second current region comprises an electric field node generated by the antenna structure;
 the first electronic element is electrically connected between the first current region and the ground plane; and
 the second electronic element is electrically connected between the second current region and the ground plane.

2. The antenna structure according to claim 1, wherein a distance between the first end and the second end is equal to a length of the radiator.

3. The antenna structure according to claim 2, wherein
 the antenna structure is used in an electronic device; and

the electronic device further comprises a conductive bezel, the bezel has a first position and a second position, the first position and the second position of the bezel are continuous with a remaining part of the bezel, and the bezel between the first position and the second position is used as the radiator.

4. The antenna structure according to claim 1, wherein a distance between the first end and the second end is less than a length of the radiator.

5. The antenna structure according to any one of claims 1 to 4, wherein

the antenna structure comprises a first filter and a second filter;
 the first filter is electrically connected between the first electronic element and the first current region;
 the second filter is electrically connected between the second electronic element and the second current region; and
 the first filter and the second filter are in a turned-on state in a first frequency band, and are in a turned-off state in a second frequency band, and a frequency of the first frequency band is higher than a frequency of the second frequency band.

6. The antenna structure according to claim 5, wherein

a part of the radiator from the first end to the second end is configured to generate a first resonance, a second resonance, a third resonance, a fourth resonance, a fifth resonance, and a sixth resonance;
 the first frequency band comprises a resonant frequency band of the first resonance, a resonant frequency band of the second resonance, a resonant frequency band of the third resonance, and a resonant frequency band of the fourth resonance; and
 the second frequency band comprises a resonant frequency band of the fifth resonance and a resonant frequency band of the sixth resonance.

7. The antenna structure according to any one of claims 1 to 6, wherein the central region of the radiator comprises the slot, an electrical length of the radiator is three halves of a first wavelength, and the first wavelength is a wavelength corresponding to a resonance generated by the antenna structure.

8. The antenna structure according to any one of claims 1 to 6, wherein the ground element is electrically connected between the central region and the ground plane, an electrical length of the radiator is twice a first wavelength, and the first wavelength is a

wavelength corresponding to a resonance generated by the antenna structure.

9. An electronic device, comprising the antenna structure according to any one of claims 1 to 8.

10. An antenna structure, comprising:

a ground plane, wherein the antenna structure is grounded through the ground plane;
a radiator, wherein a first end of the radiator is grounded, and a second end of the radiator is an open end; and
a first electronic element, wherein the radiator comprises a first current region, and the first current region comprises an electric field node generated by the antenna structure; and the first electronic element is electrically connected between the first current region and the ground plane.

11. The antenna structure according to claim 10, wherein

the antenna structure further comprises a second electronic element; and
the first electronic element is electrically connected to the radiator at a first position, the second electronic element is electrically connected to the radiator at a second position, the second position is between the first position and a third position, and a distance between the third position and the first position is the same as a distance between the third position and the second end.

12. The antenna structure according to claim 10 or 11, wherein

the antenna structure further comprises a feed unit;
the radiator comprises an electric field region, and the electric field region comprises a current node generated by the antenna structure; and
the electric field region comprises a feed point, and the feed unit is electrically connected to the radiator at the feed point.

13. The antenna structure according to any one of claims 10 to 12, wherein

the antenna structure further comprises the feed unit; and
the first current region comprises a feed point, and the feed unit is electrically connected to the radiator at the feed point.

14. The antenna structure according to any one of claims

10 to 13, wherein

the antenna structure further comprises a resonant stub; and
a third end of the resonant stub is connected to the first end, and a fourth end of the resonant stub is an open end.

15. The antenna structure according to claim 14, wherein
a length L_1 of the resonant stub and a length L_2 of the radiator satisfy: $0.2 \times L_2 \leq L_1 \leq 0.3 \times L_2$.

16. The antenna structure according to claim 14, wherein

the antenna structure further comprises a third electronic element; and
the third electronic element is electrically connected between the first end and the ground plane.

17. The antenna structure according to any one of claims 10 to 16, wherein

the antenna structure comprises a filter;
the first filter is electrically connected between the first electronic element and the first current region; and
the first filter is in a turned-on state in a first frequency band, and is in a turned-off state in a second frequency band, and a frequency of the first frequency band is higher than a frequency of the second frequency band.

18. The antenna structure according to claim 17, wherein

a part of the radiator from the first end to the second end is configured to generate a first resonance, a second resonance, and a third resonance;
the first frequency band comprises a resonant frequency band of the first resonance and a resonant frequency band of the second resonance; and
the second frequency band comprises a resonant frequency band of the third resonance.

19. The antenna structure according to any one of claims 10 to 18, wherein

the antenna structure further comprises a fourth electronic element;
the radiator comprises a second current region, and the second current region comprises an electric field node generated by the antenna structure; and

the fourth electronic element is electrically connected between the second current region and the ground plane.

20. An electronic device, comprising the antenna structure according to any one of claims 10 to 19. 5

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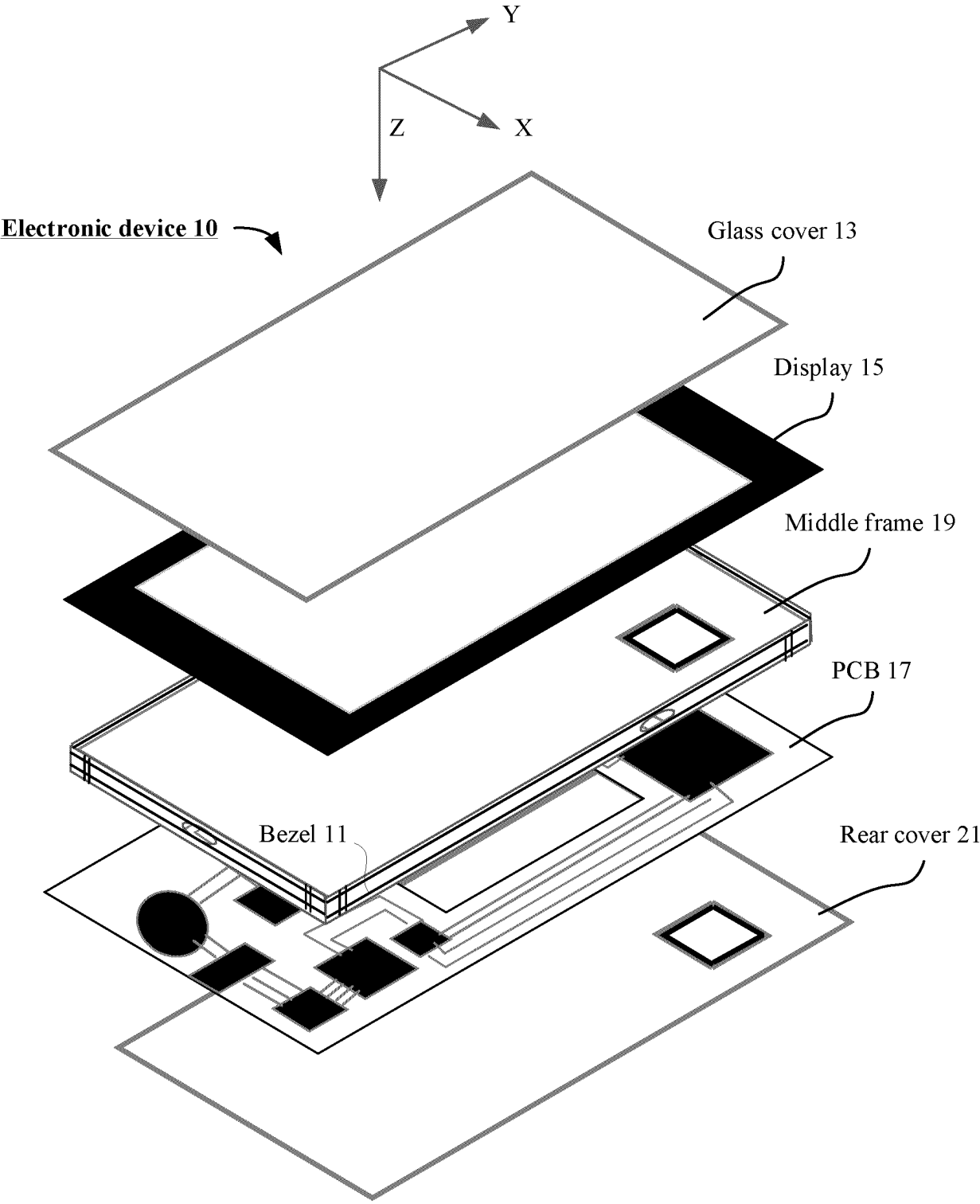
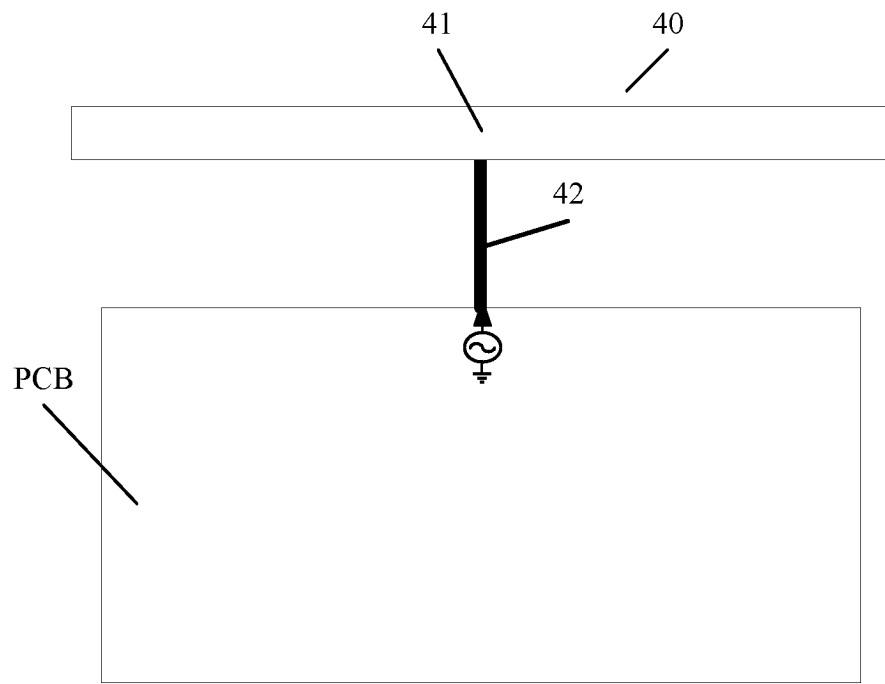
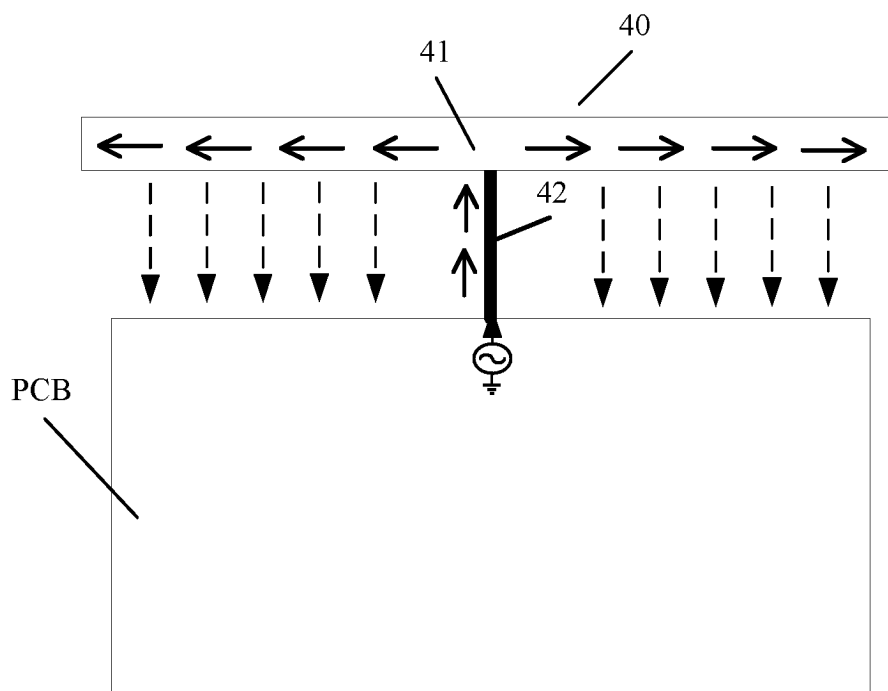


FIG. 1



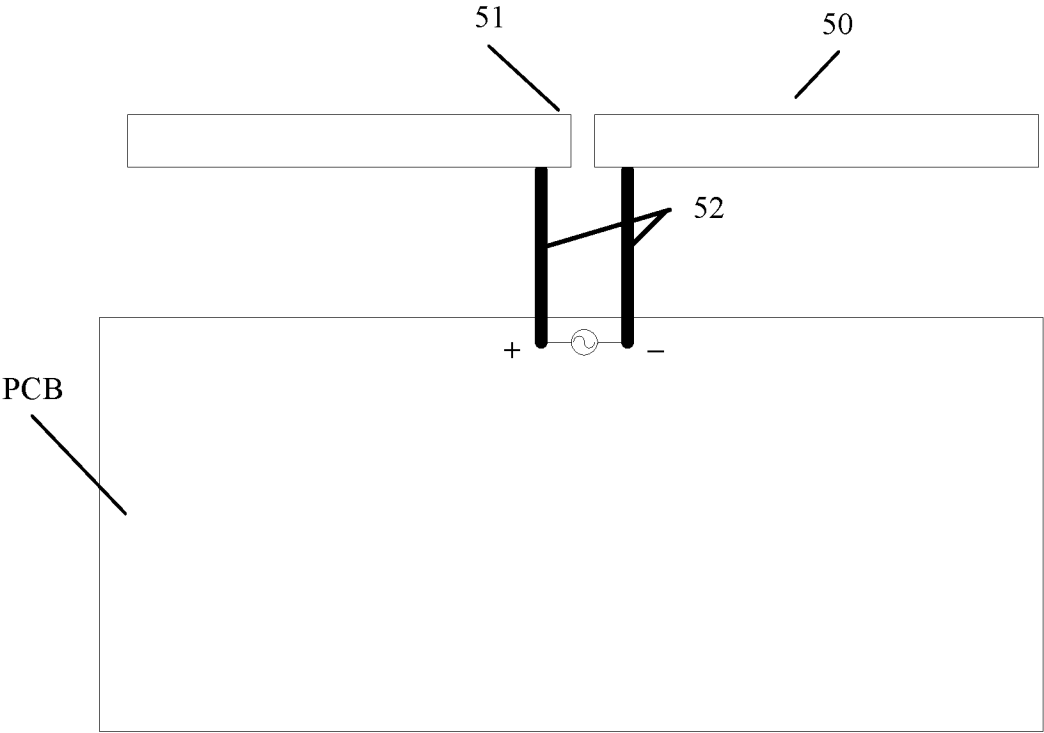
(a)



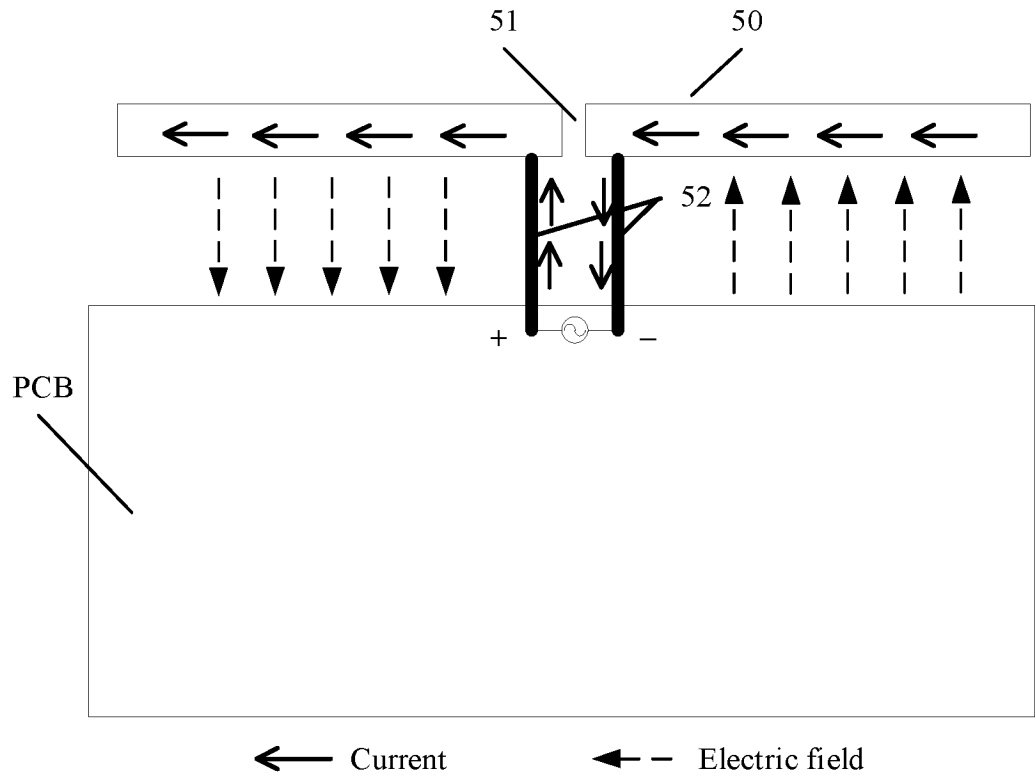
← Current ← - Electric field

(b)

FIG. 2

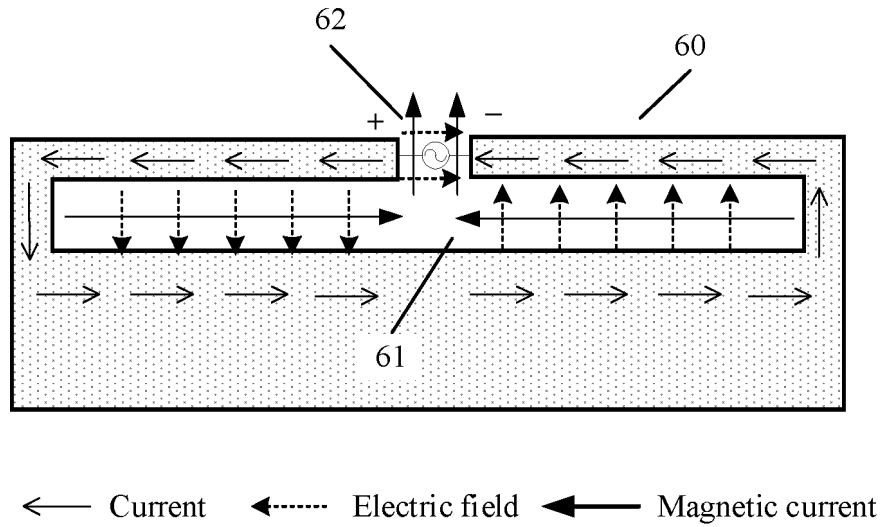
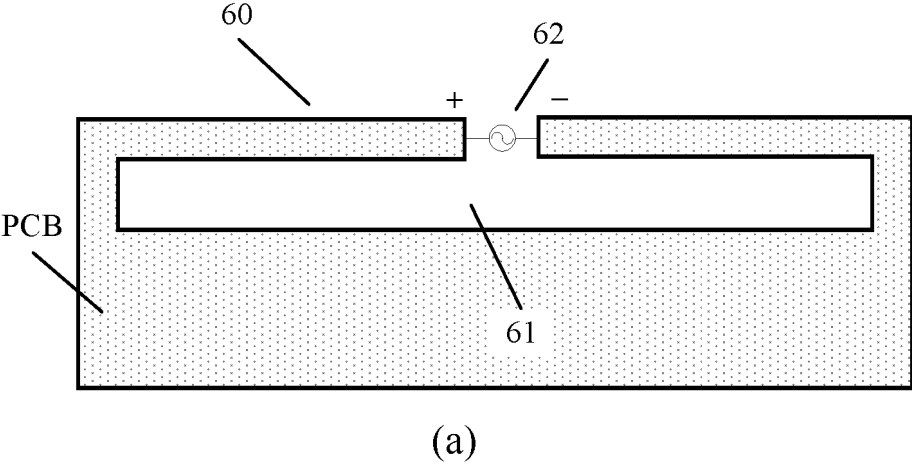


(a)

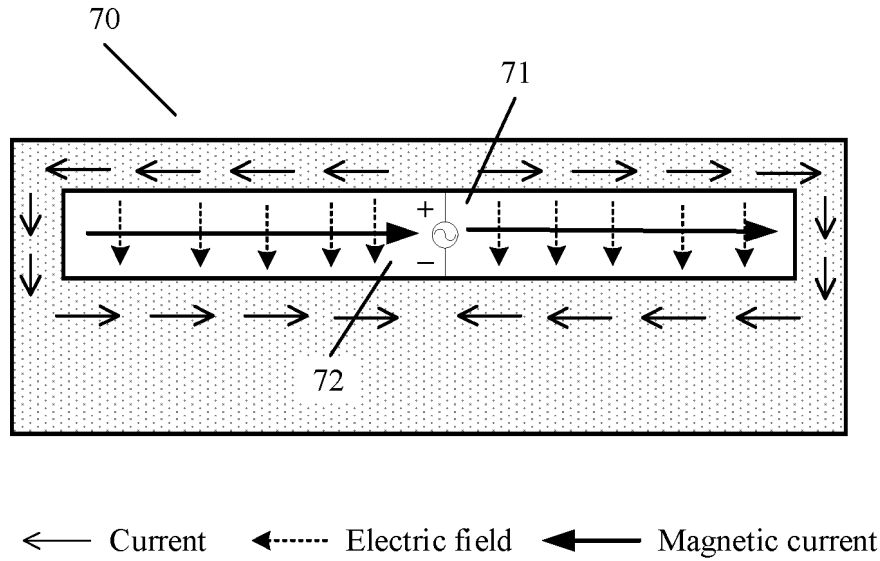
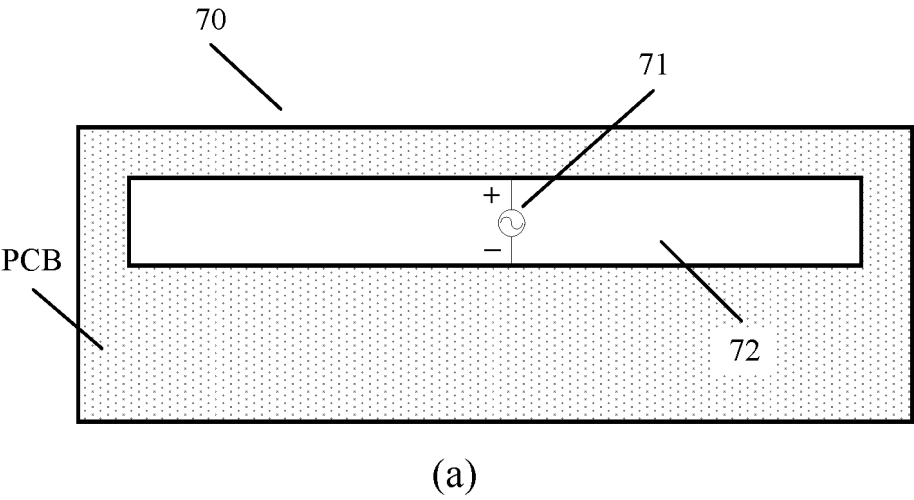


(b)

FIG. 3

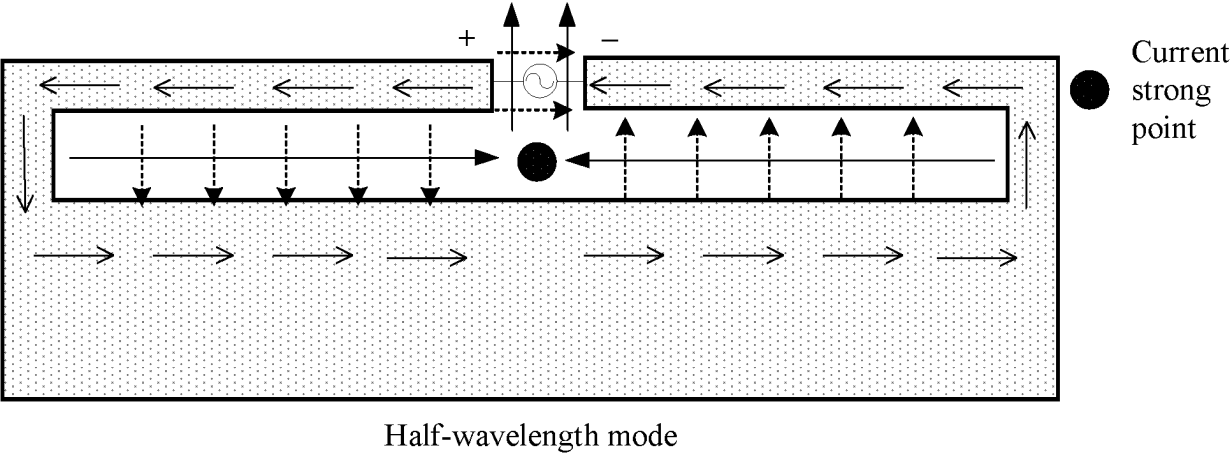


(b)
FIG. 4

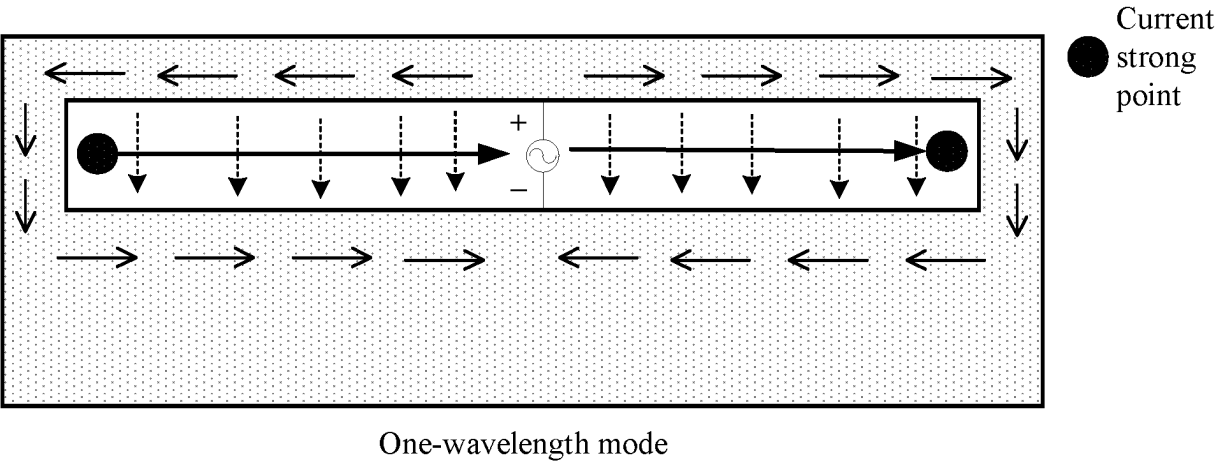


(b)

FIG. 5



(a)



(b)

FIG. 6

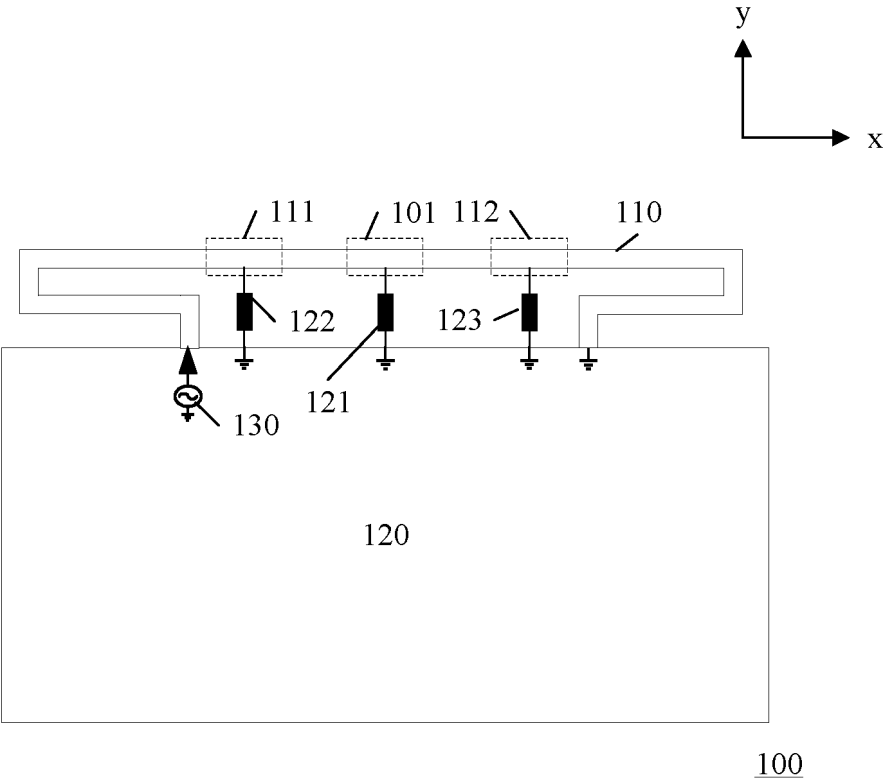


FIG. 7

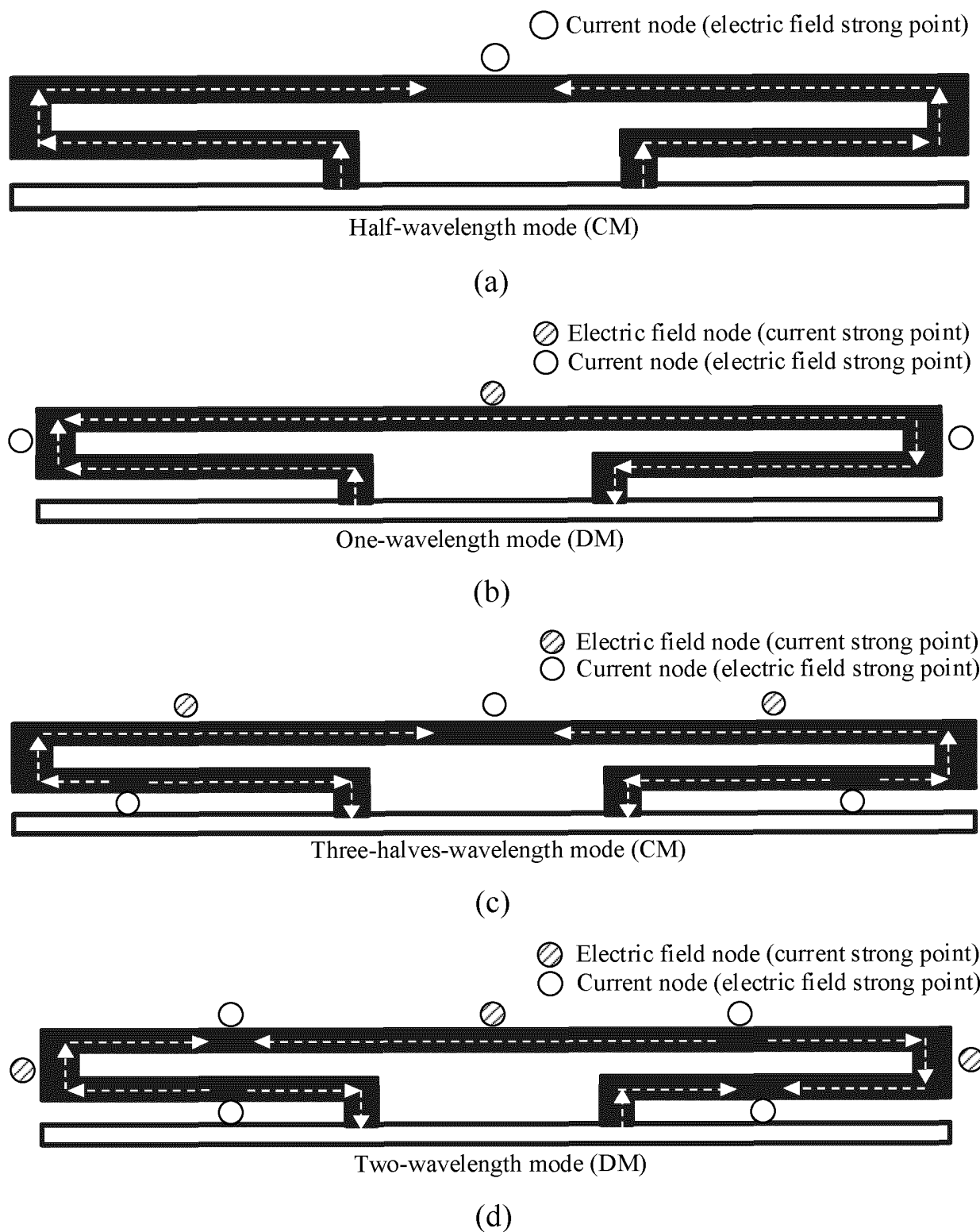
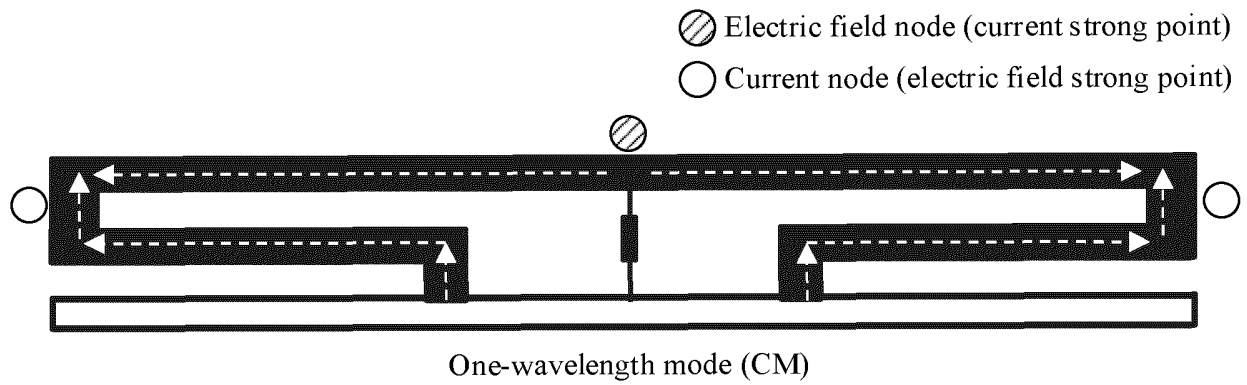
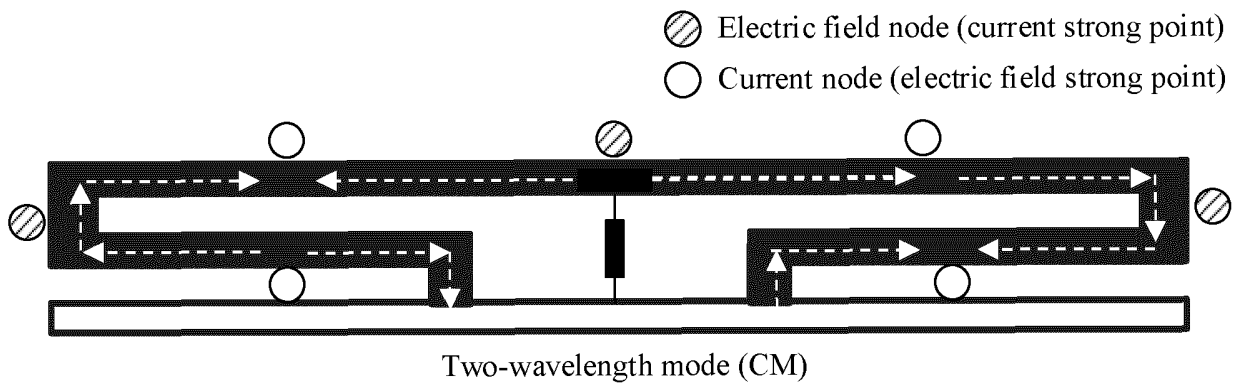


FIG. 8

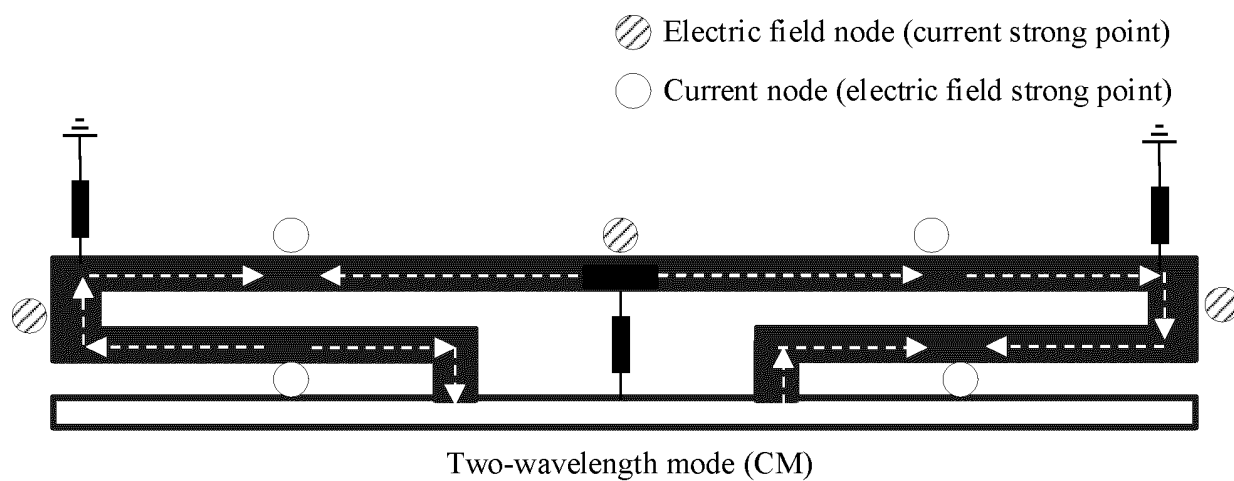


(a)

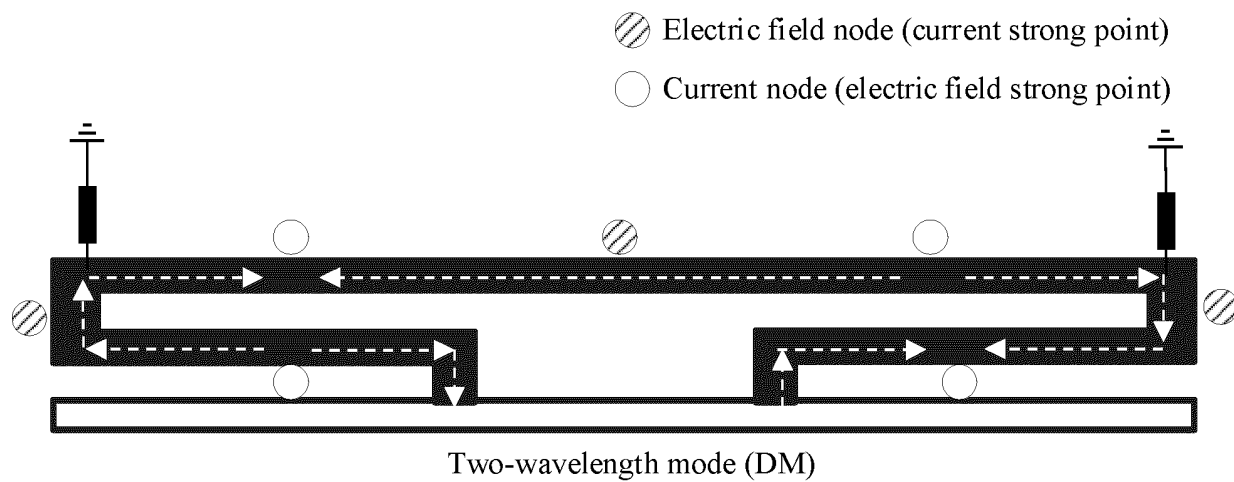


(b)

FIG. 9



(a)



(b)

FIG. 10

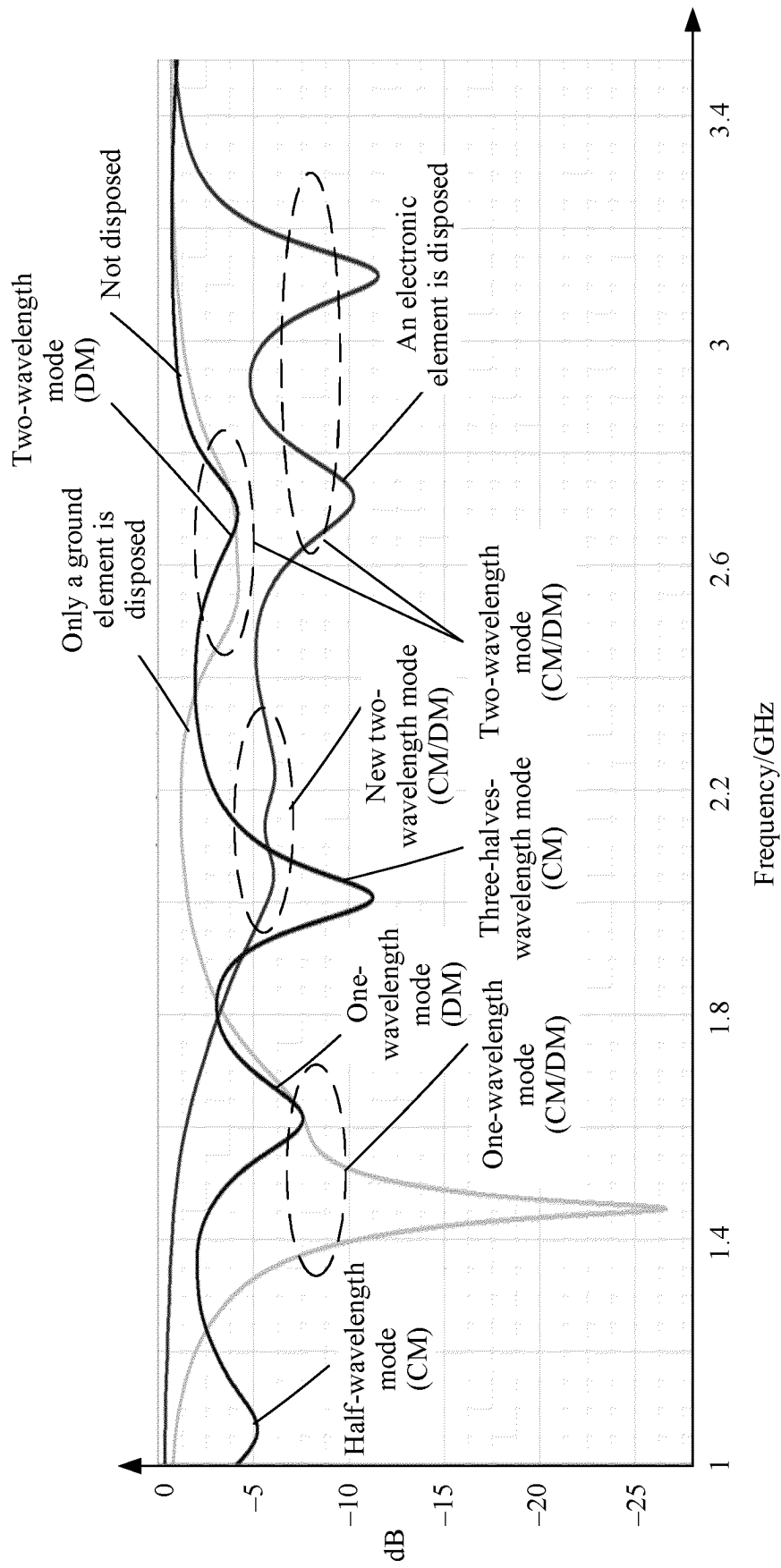


FIG. 11

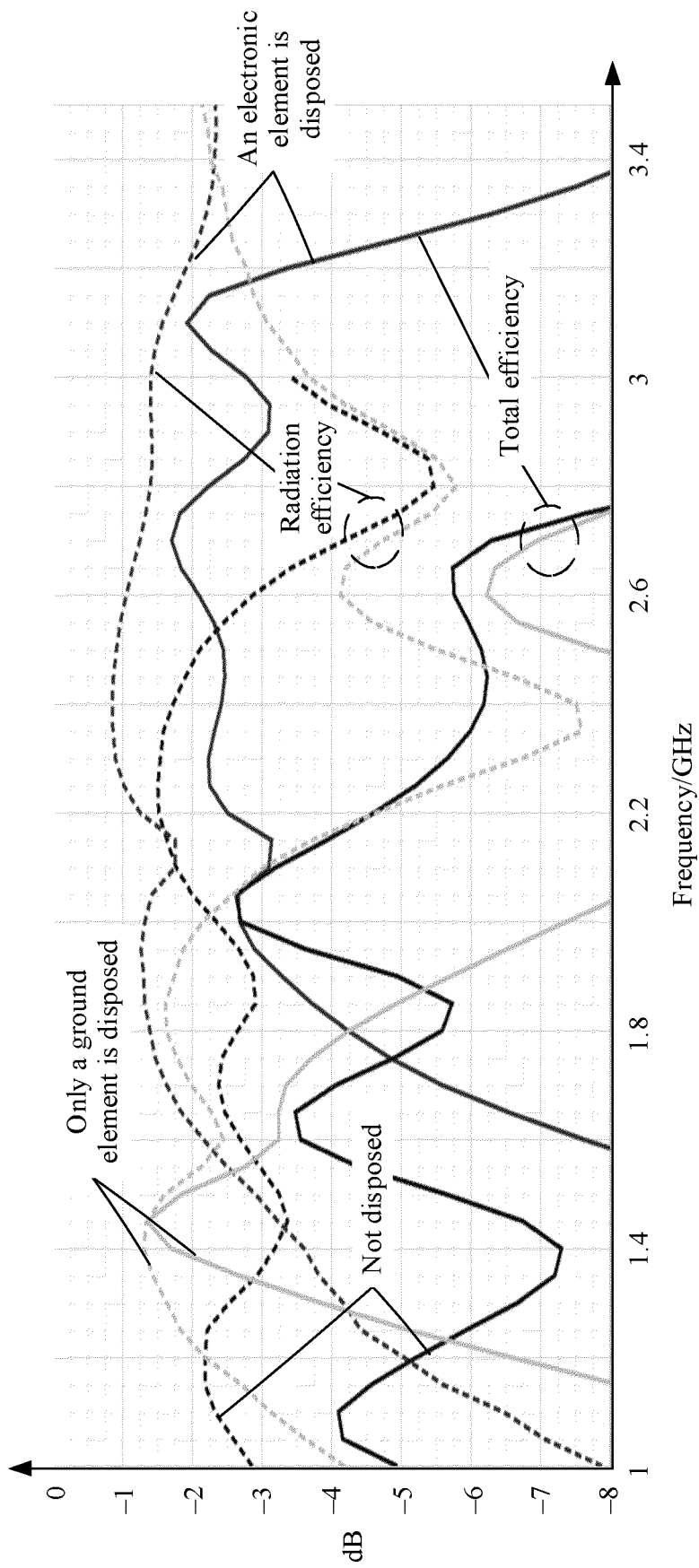


FIG. 12

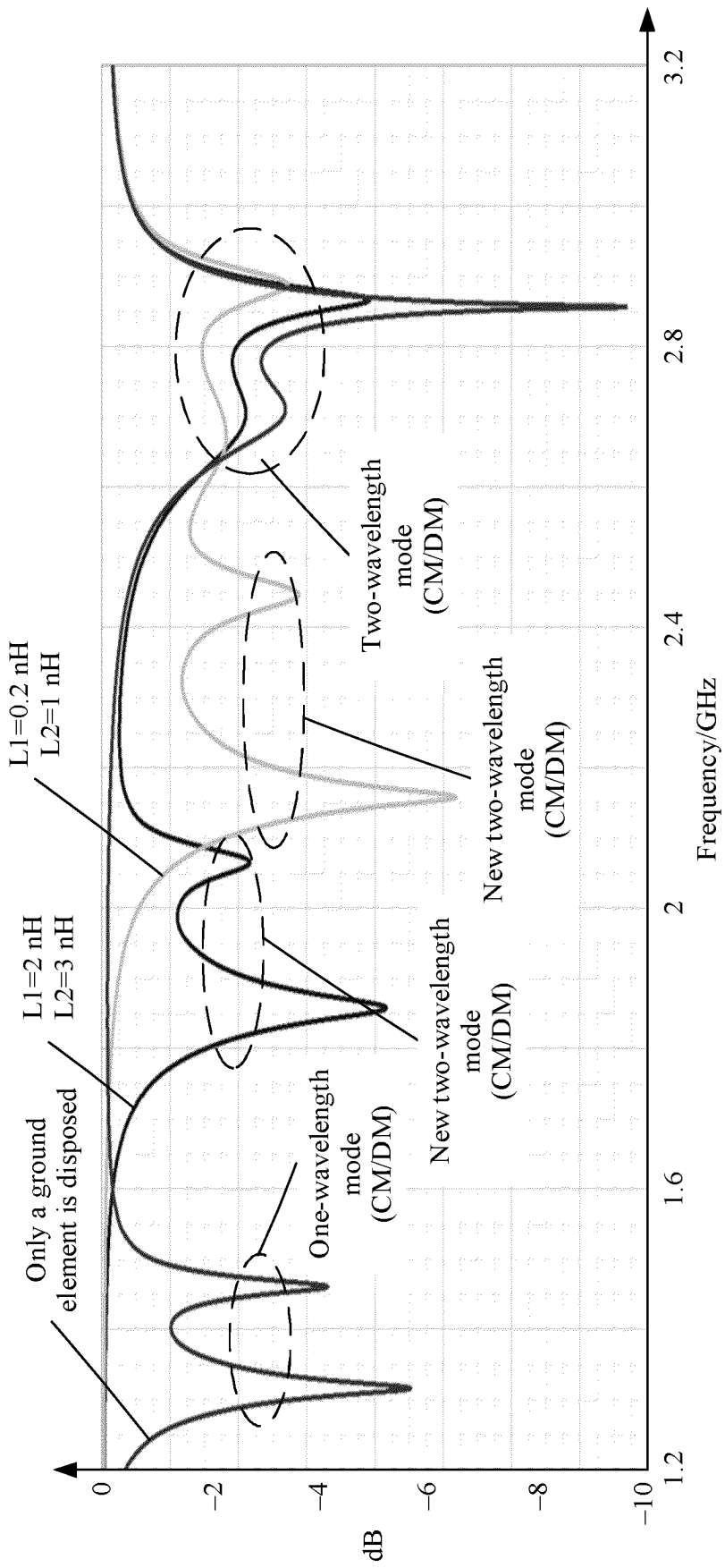


FIG. 13

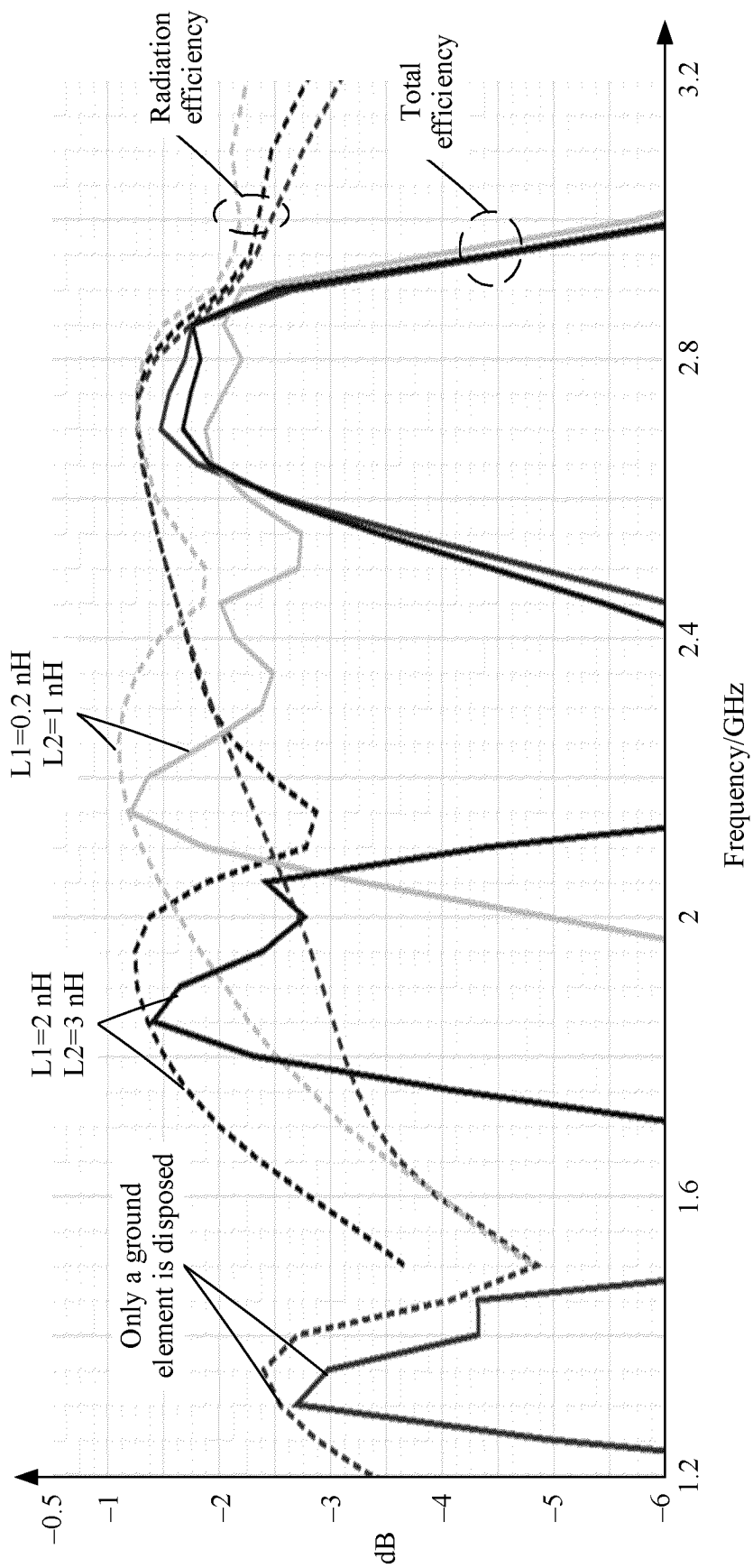


FIG. 14

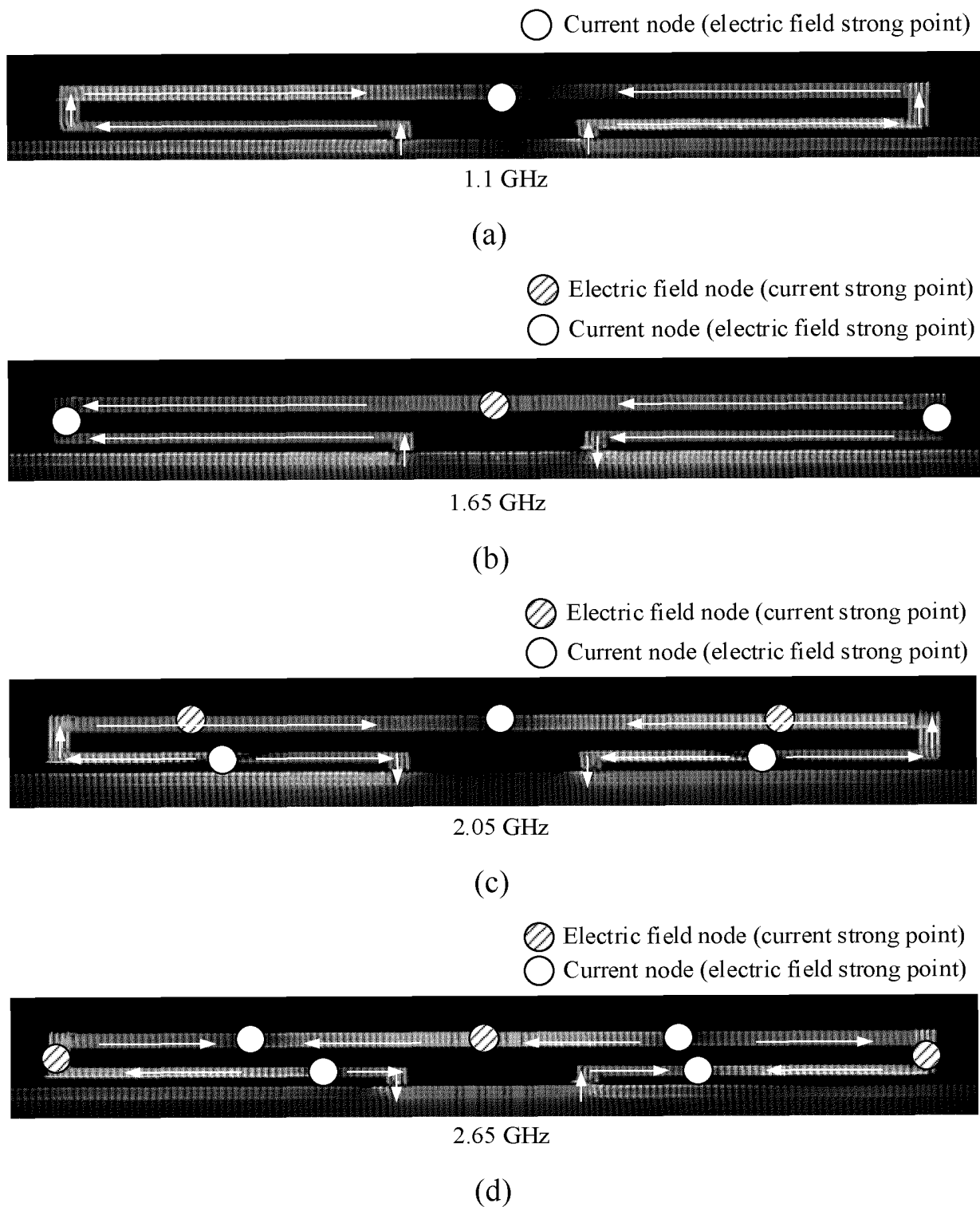


FIG. 15

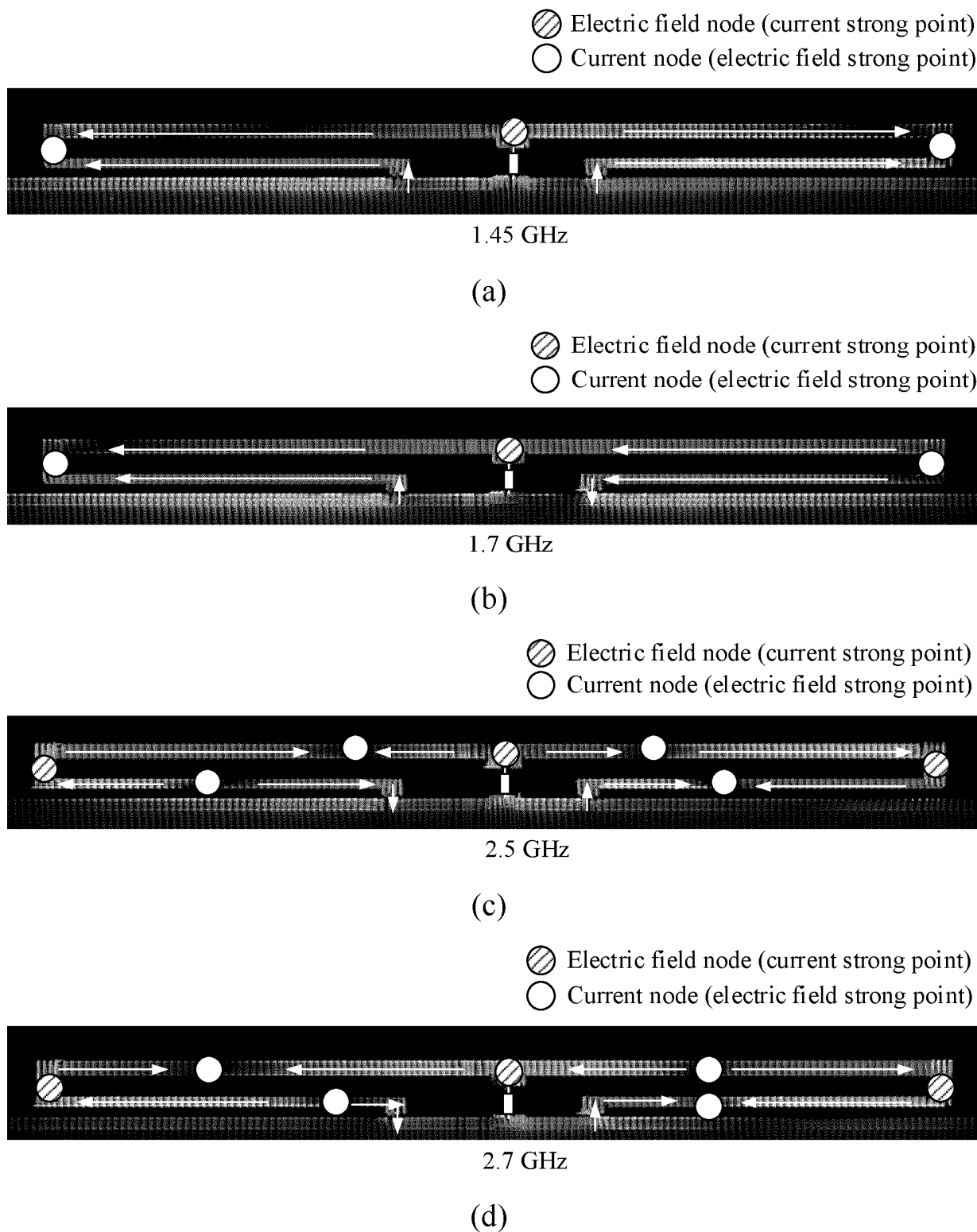


FIG. 16

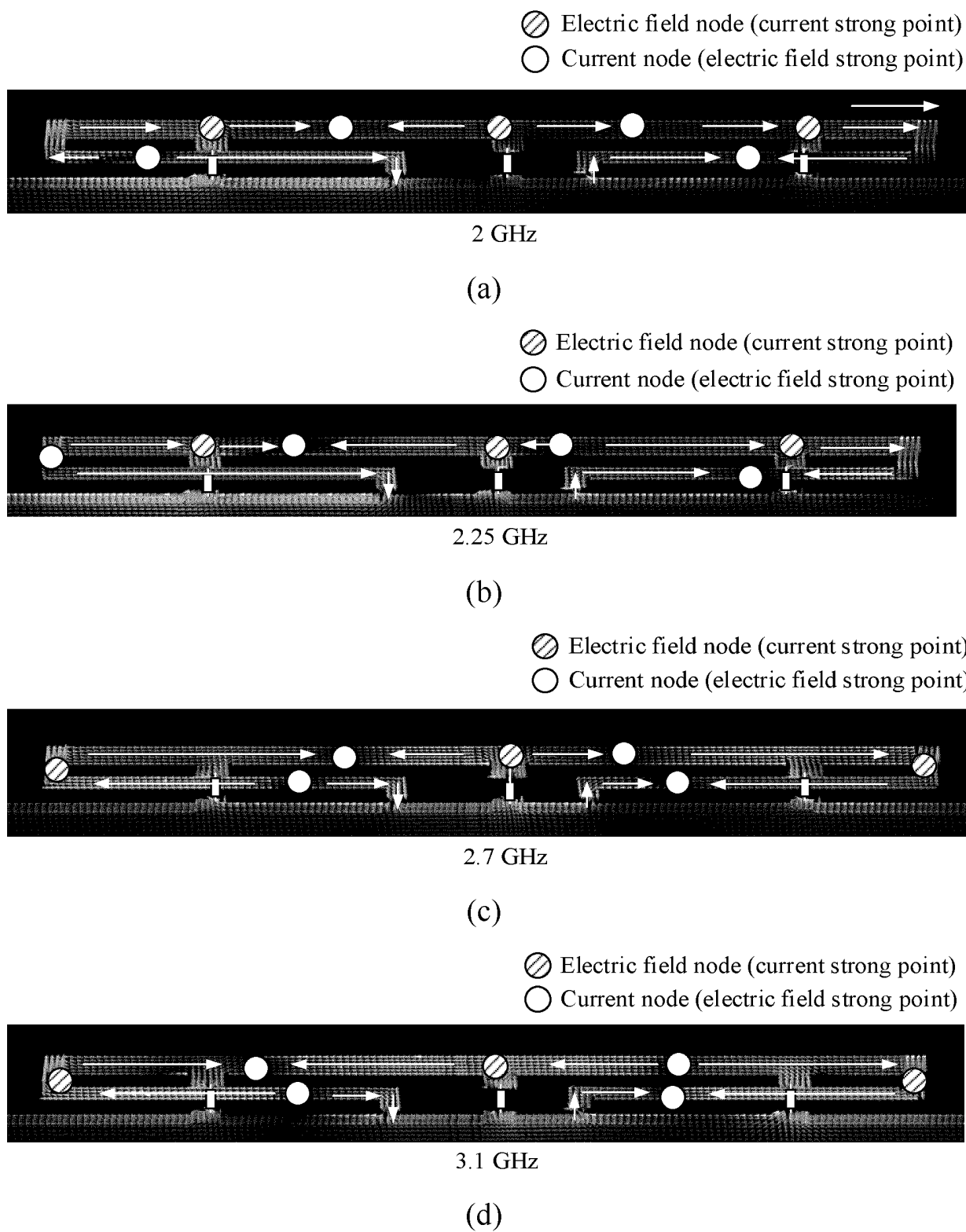


FIG. 17

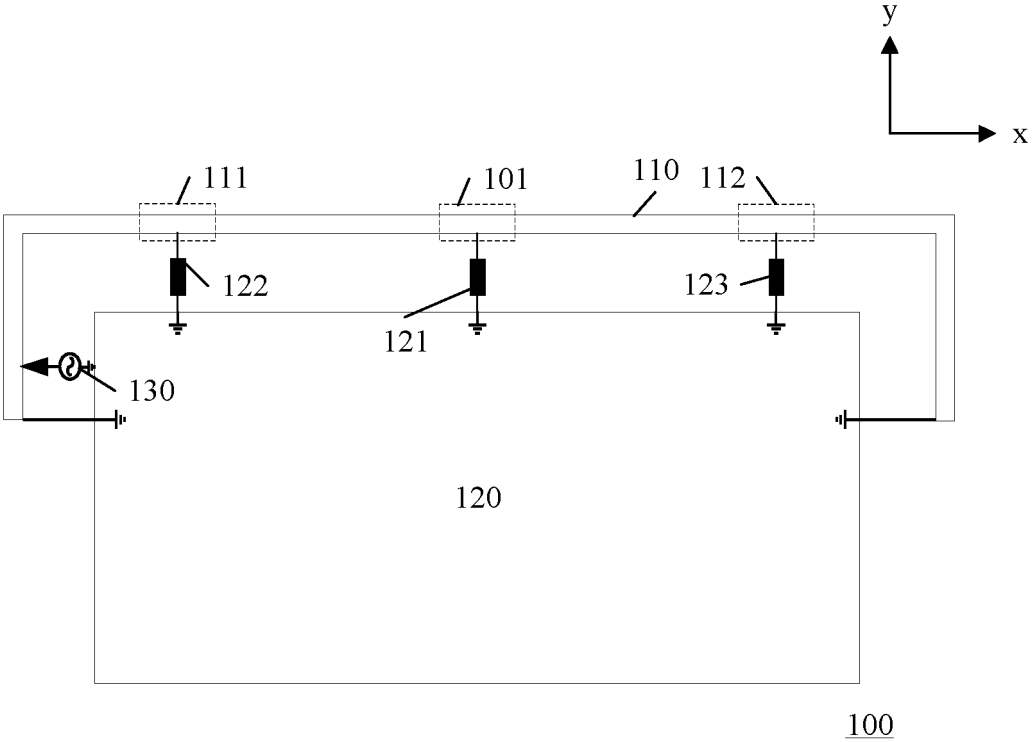


FIG. 18

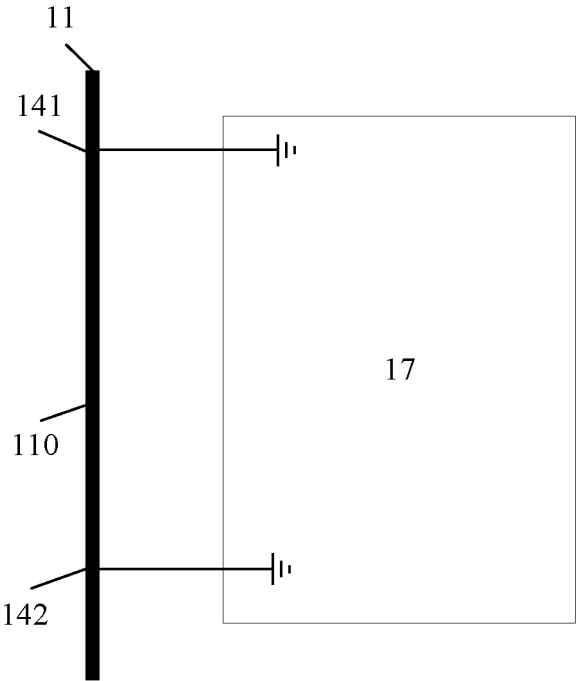


FIG. 19

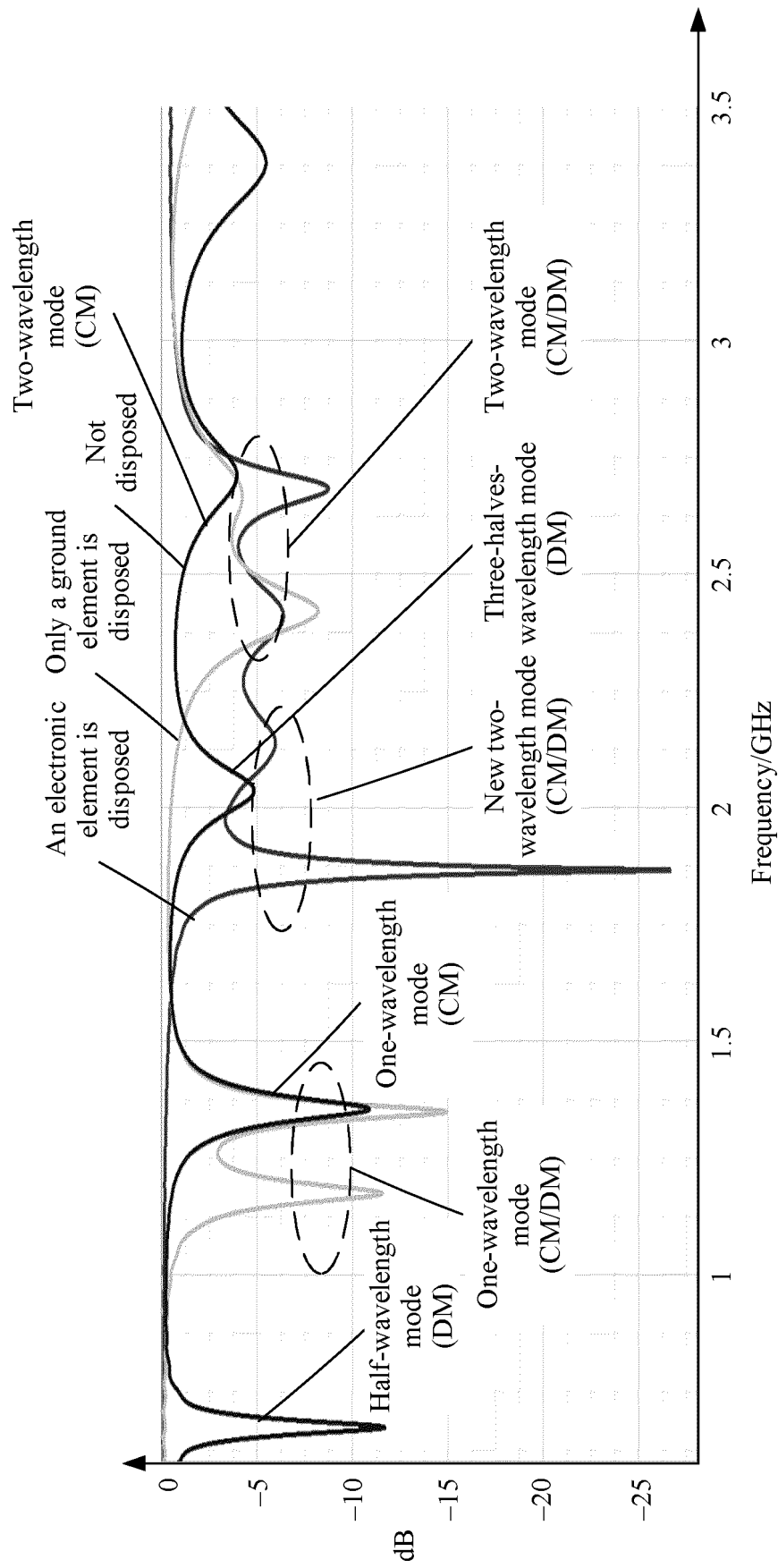


FIG. 20

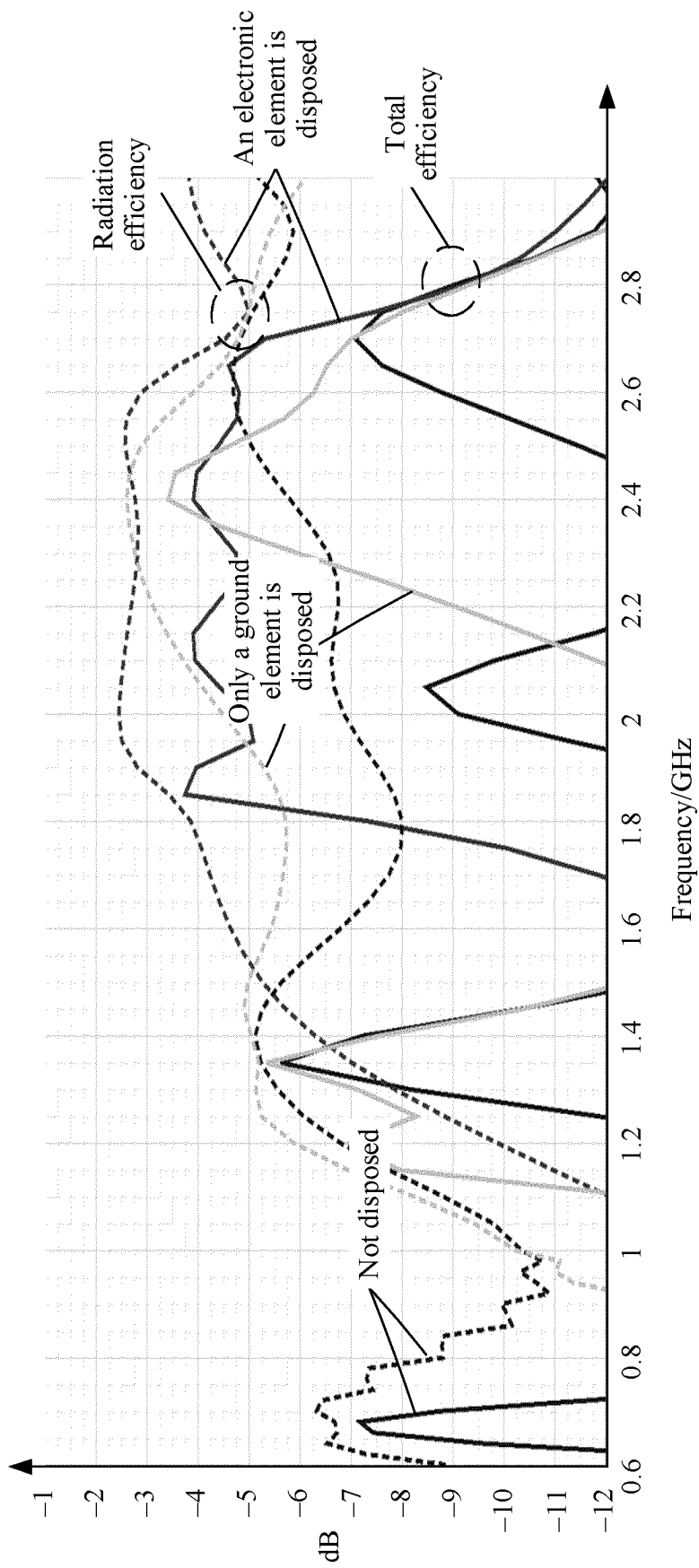
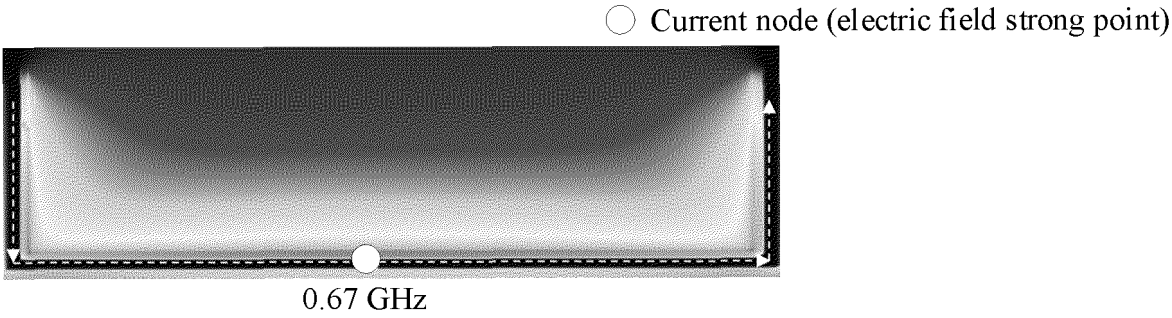
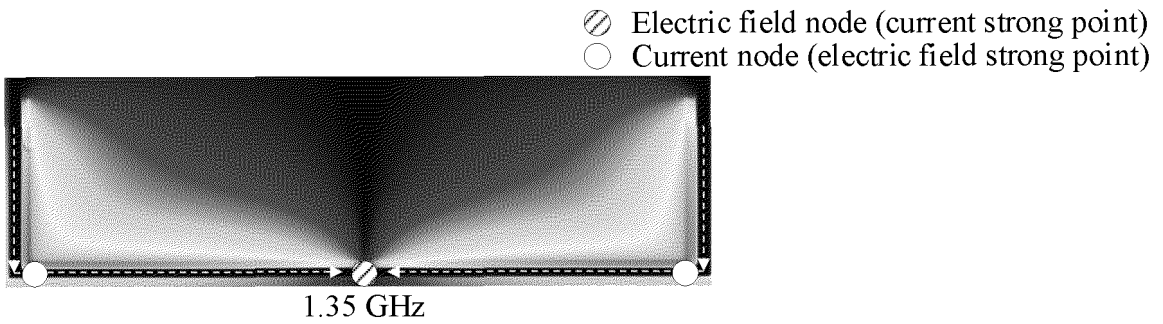


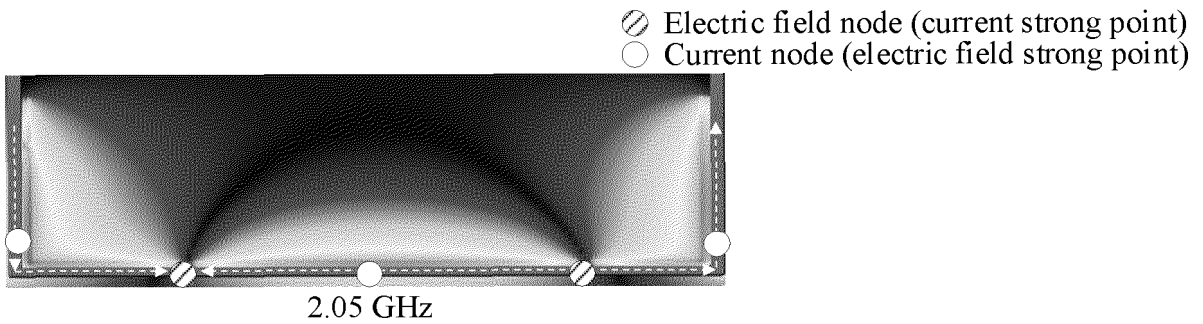
FIG. 21



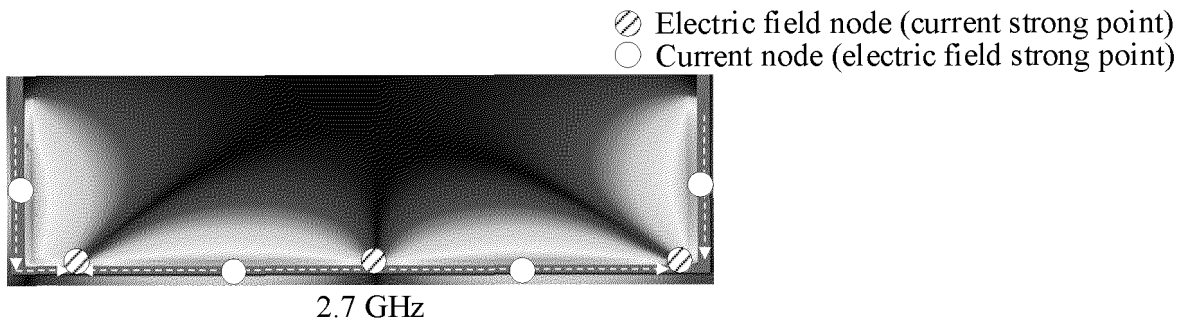
(a)



(b)

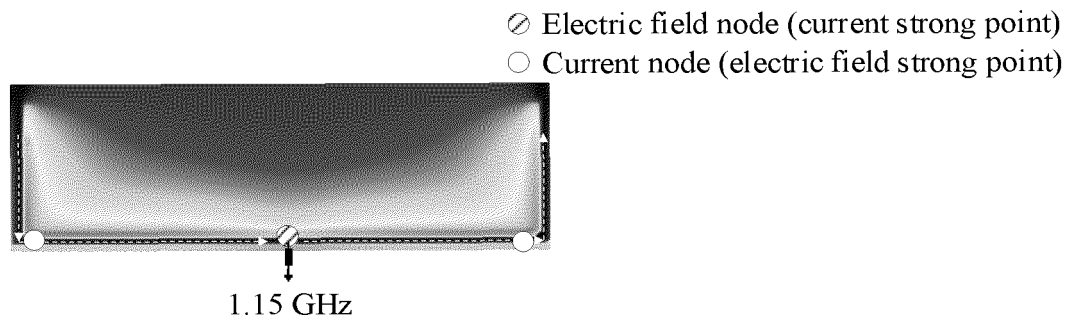


(c)

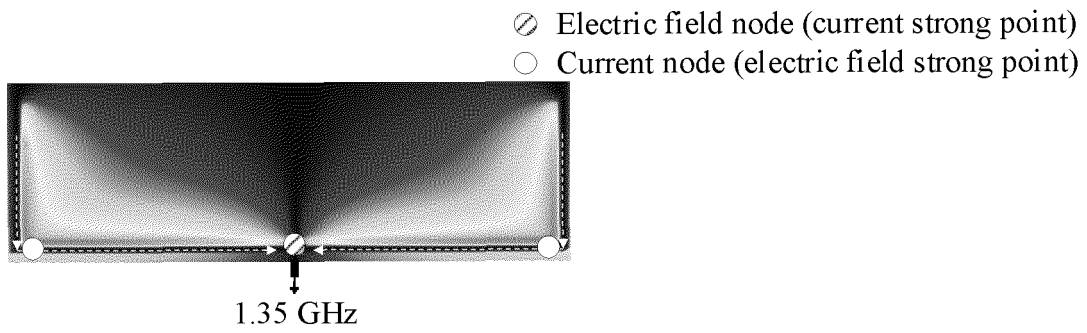


(d)

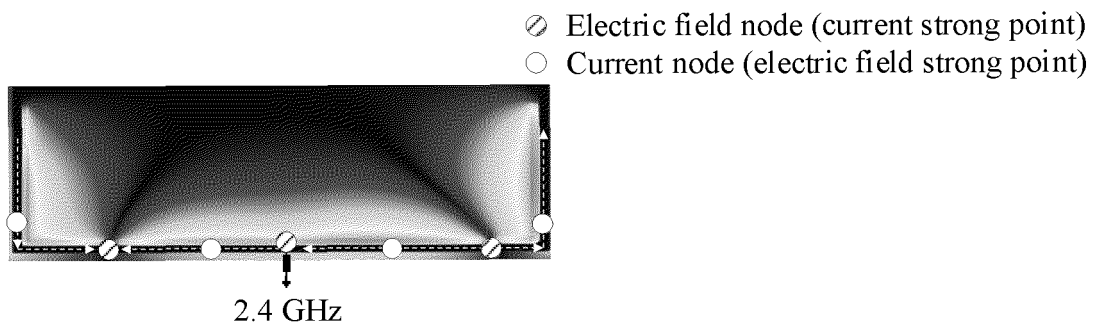
FIG. 22



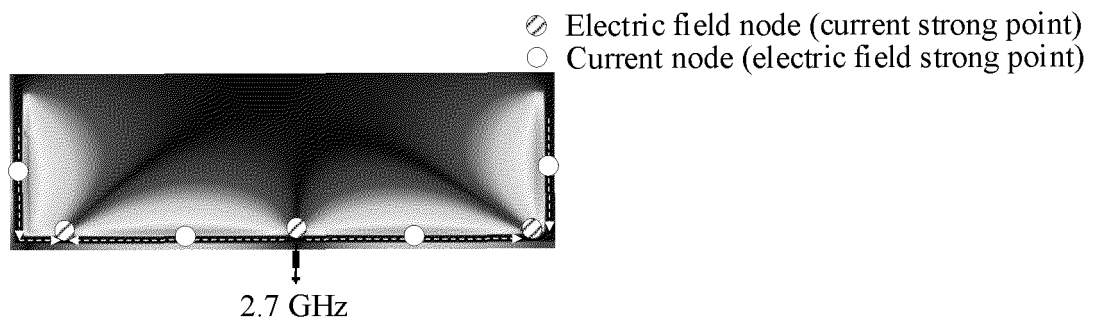
(a)



(b)

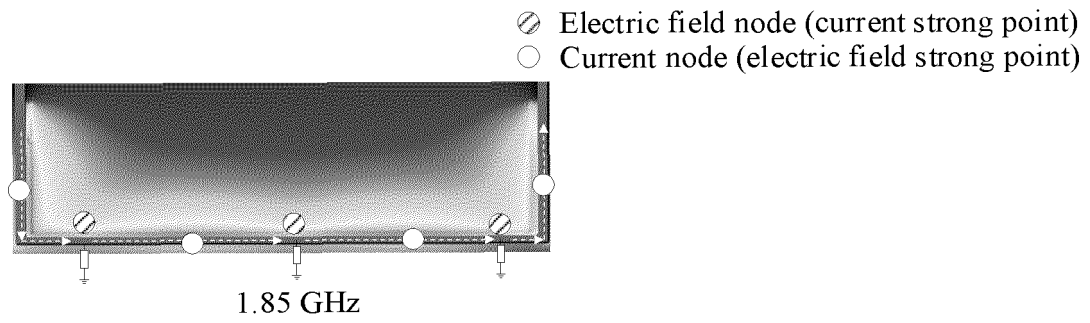


(c)

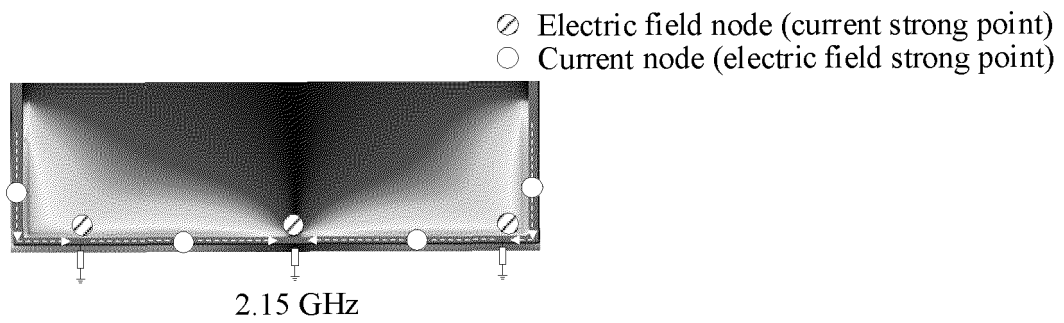


(d)

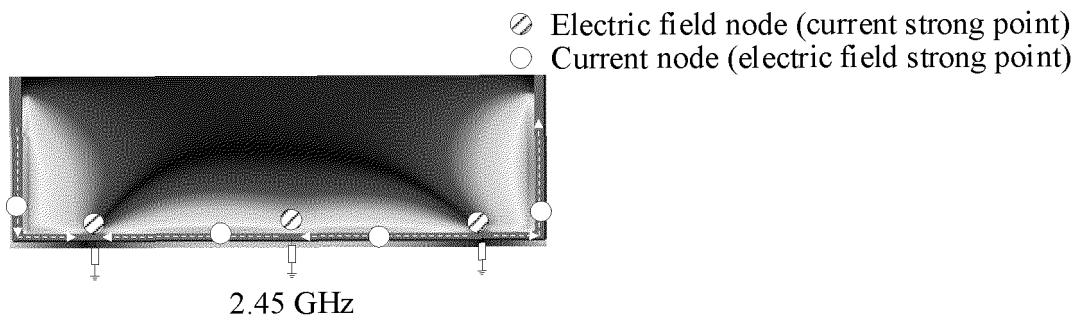
FIG. 23



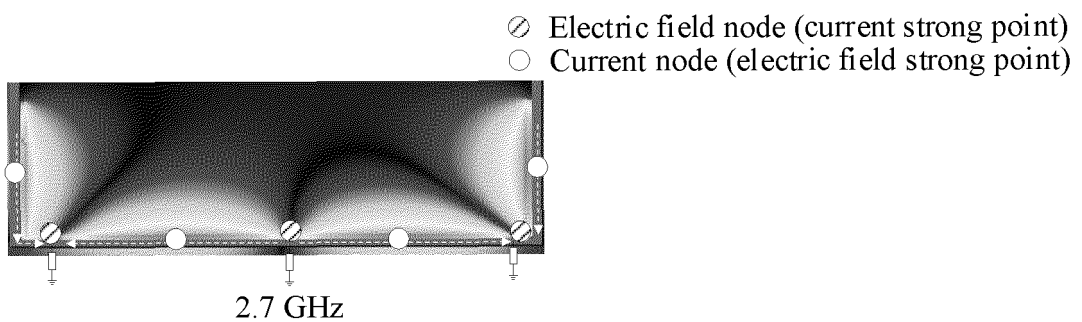
(a)



(b)



(c)



(d)

FIG. 24

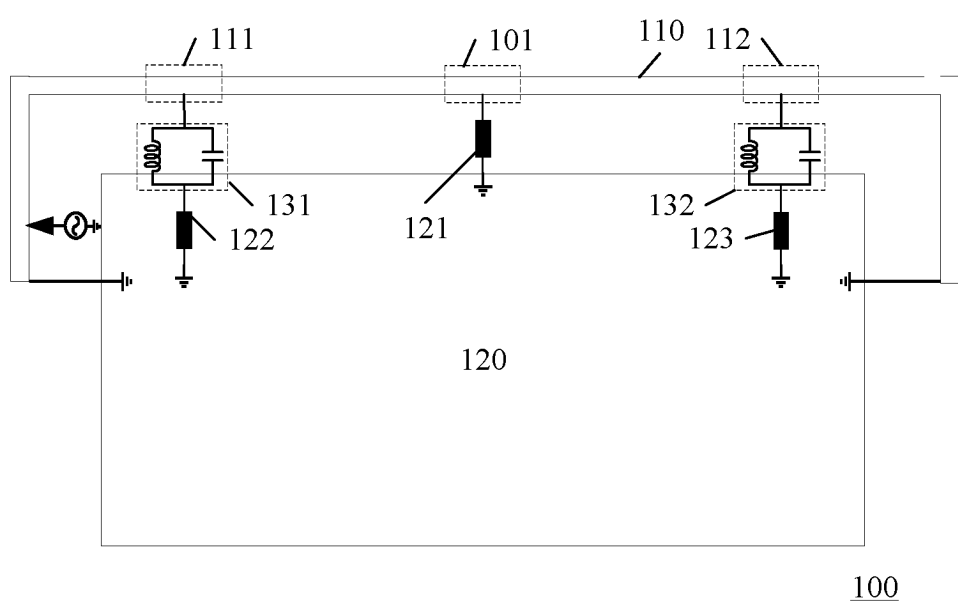


FIG. 25

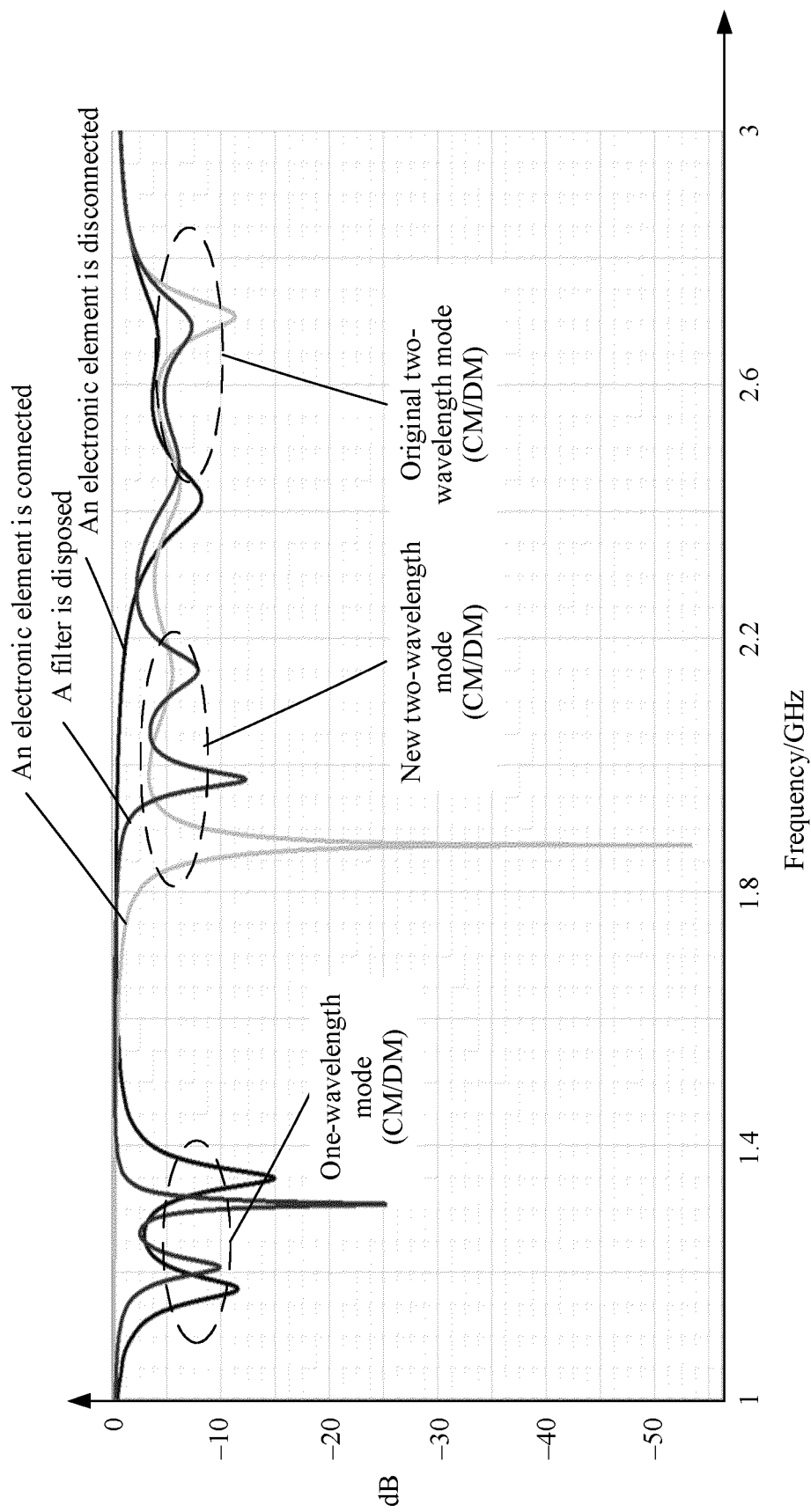


FIG. 26

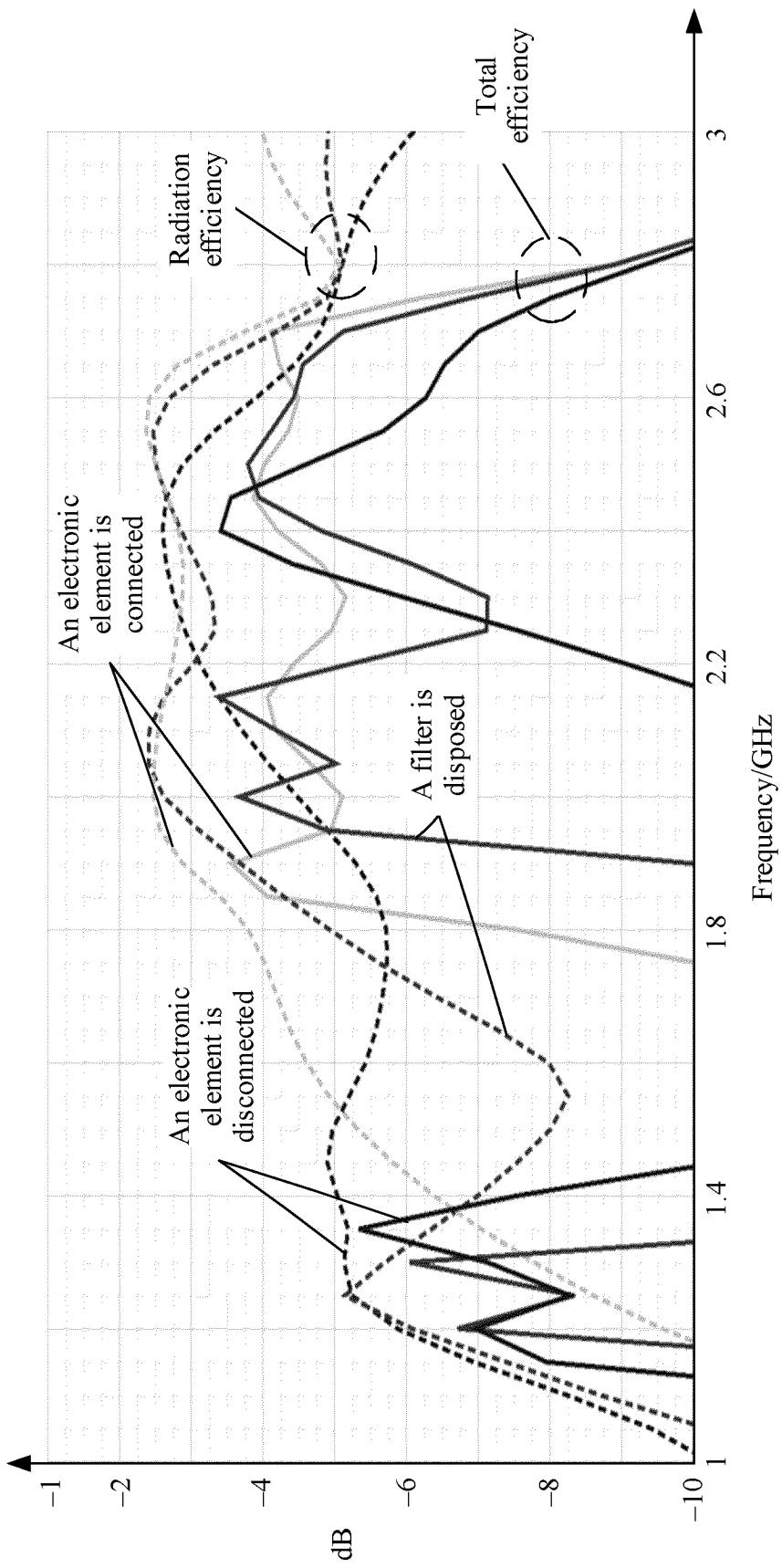


FIG. 27

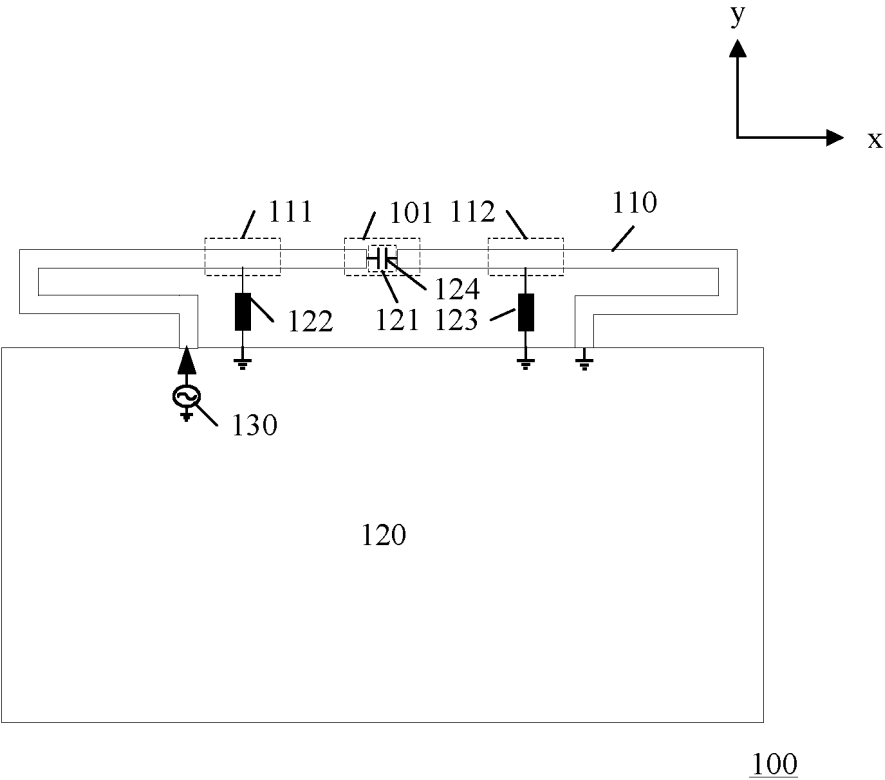


FIG. 28

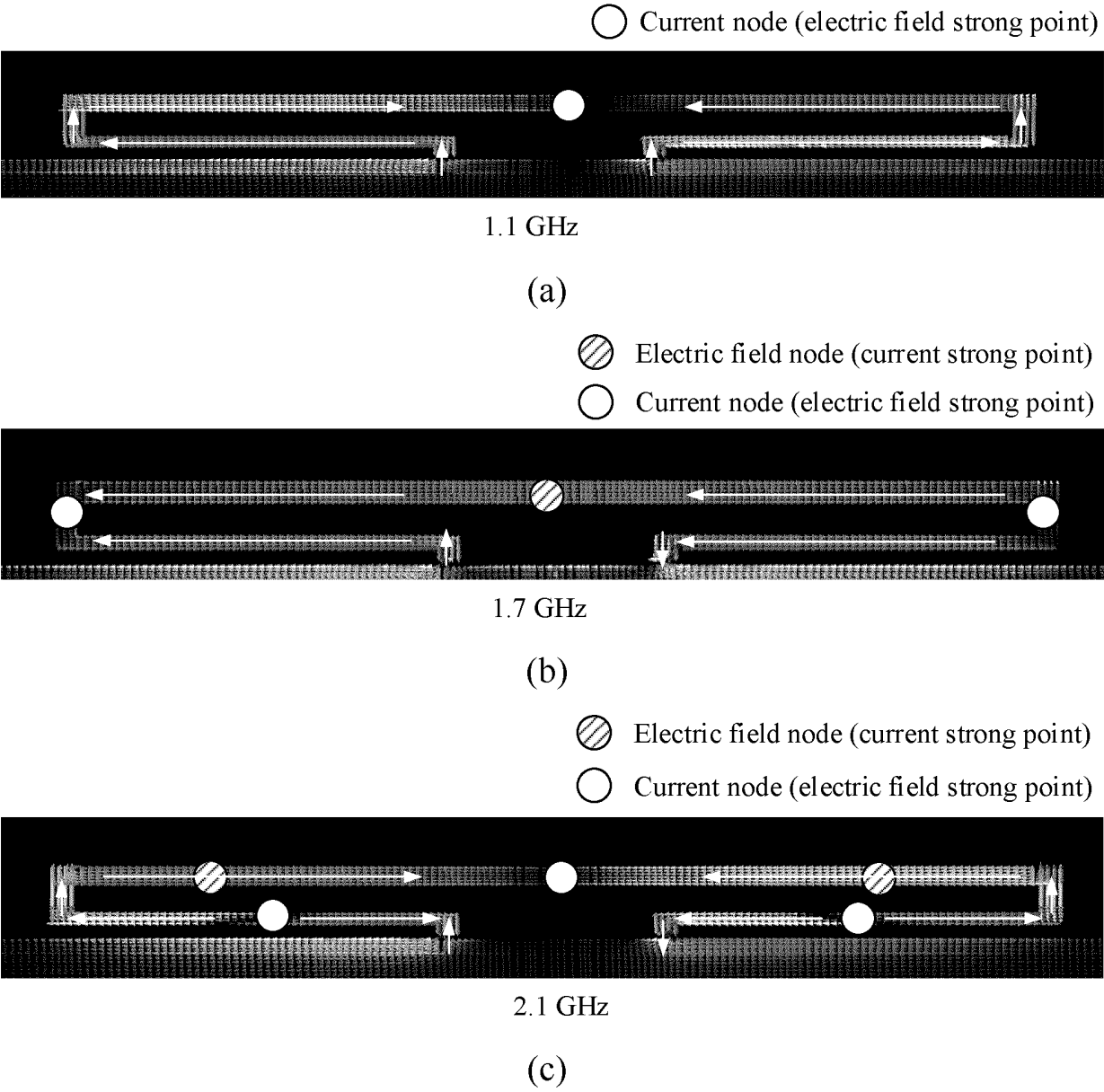
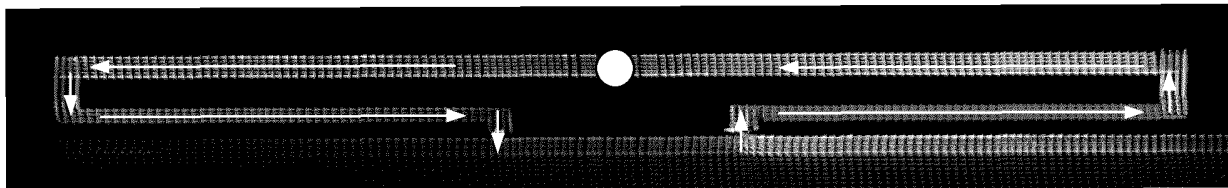


FIG. 29

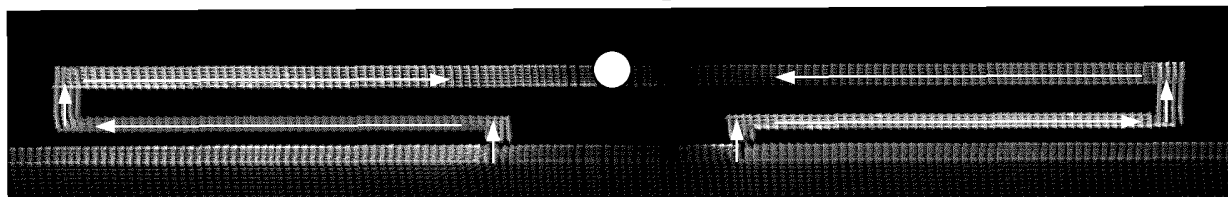
○ Current node (electric field strong point)



0.97 GHz

(a)

○ Current node (electric field strong point)

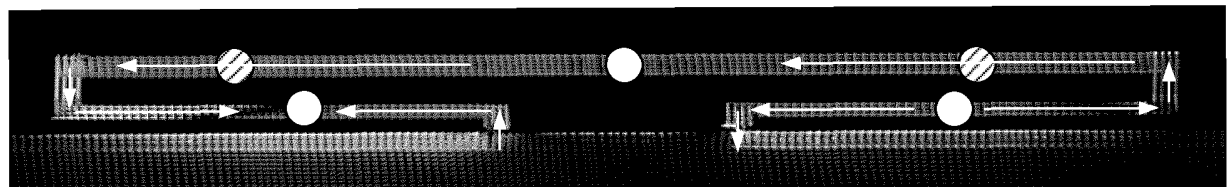


1.1 GHz

(b)

⊗ Electric field node (current strong point)

○ Current node (electric field strong point)

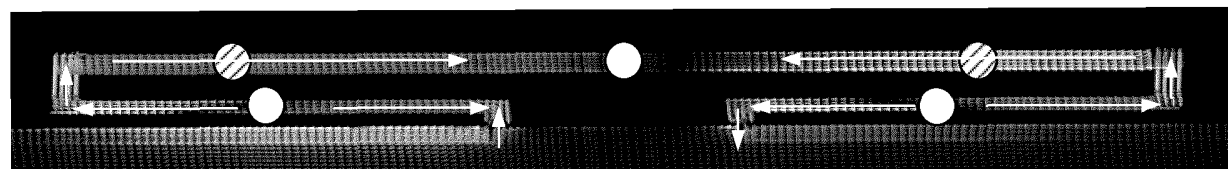


1.95 GHz

(c)

⊗ Electric field node (current strong point)

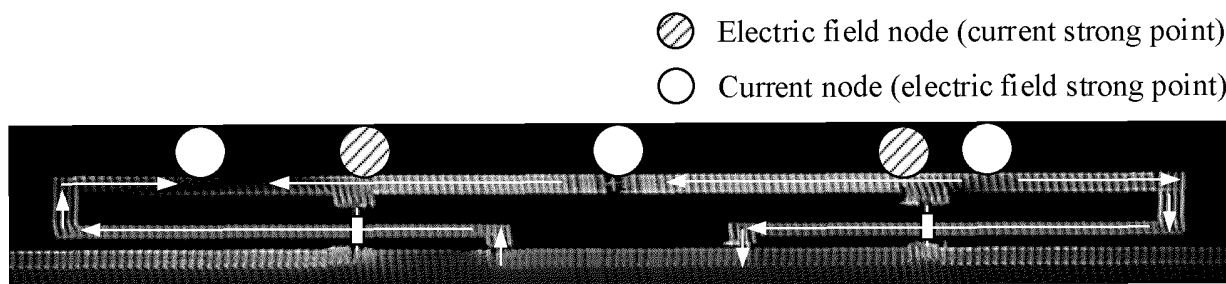
○ Current node (electric field strong point)



2.1 GHz

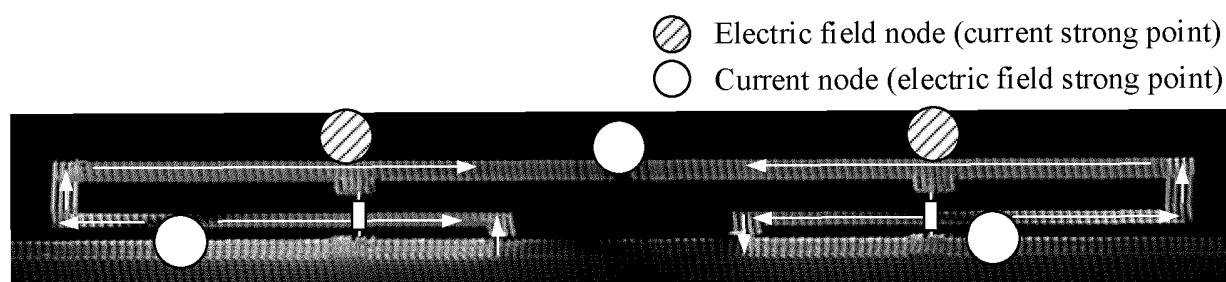
(d)

FIG. 30



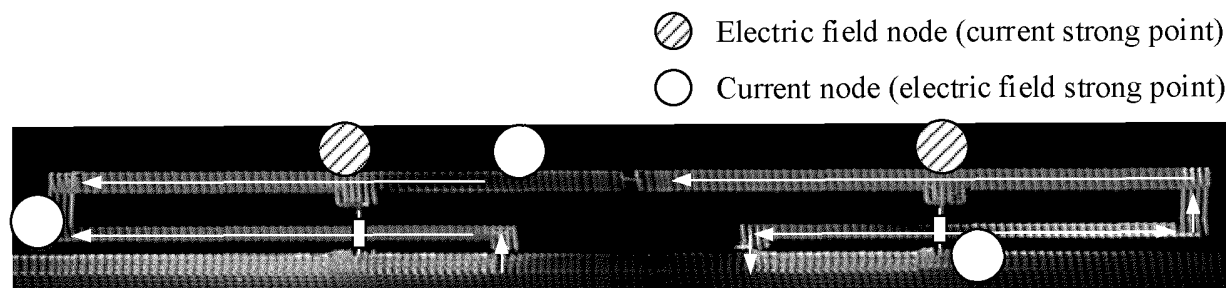
1.6 GHz

(a)



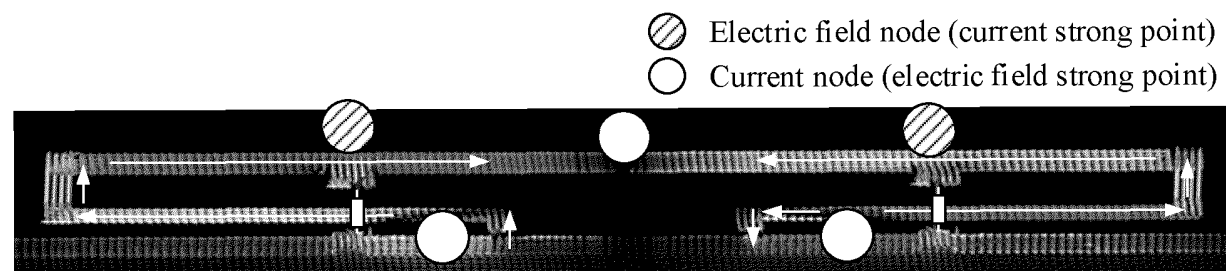
1.9 GHz

(b)



2.05 GHz

(c)



2.25 GHz

(d)

FIG. 31

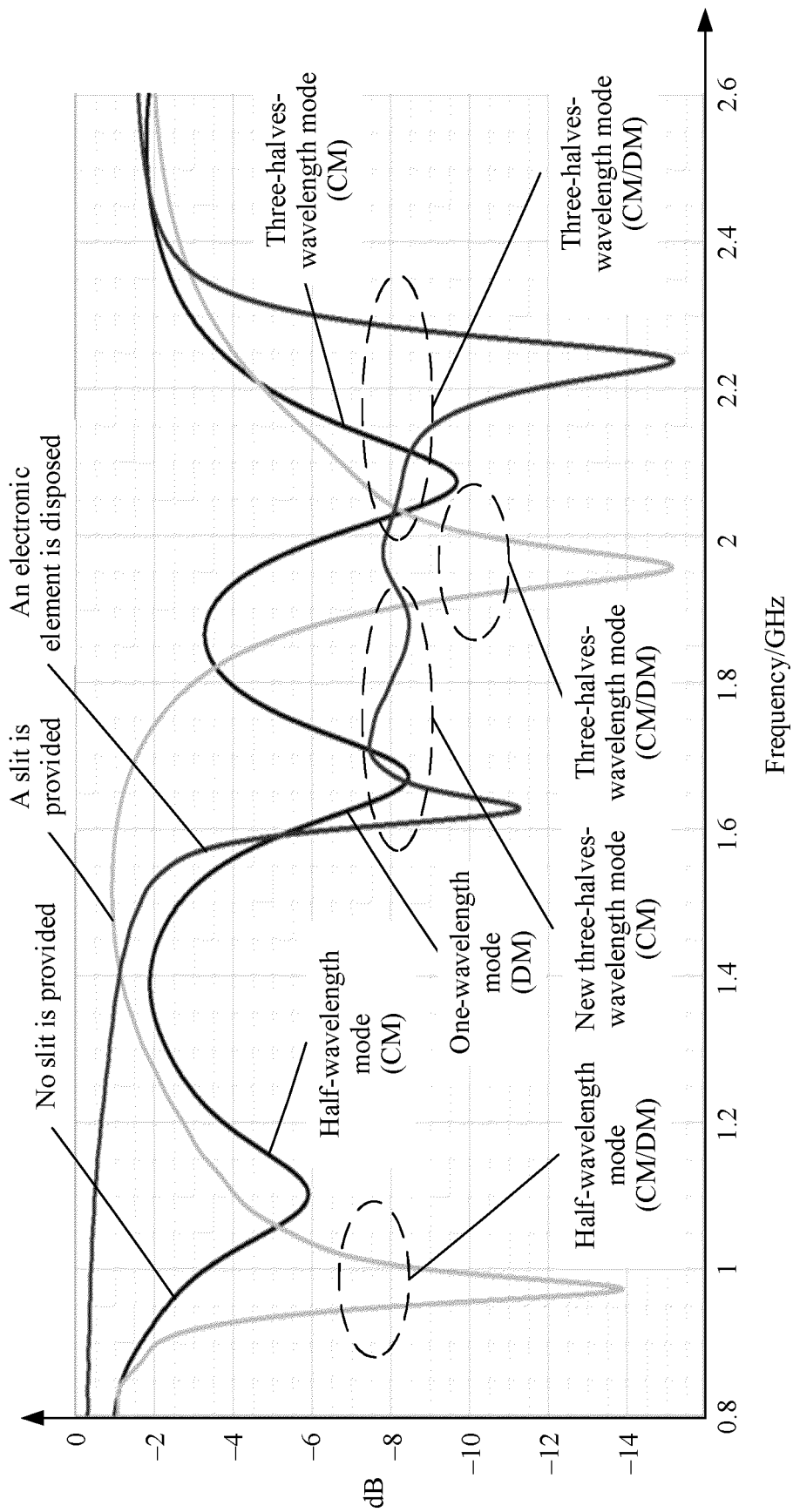


FIG. 32

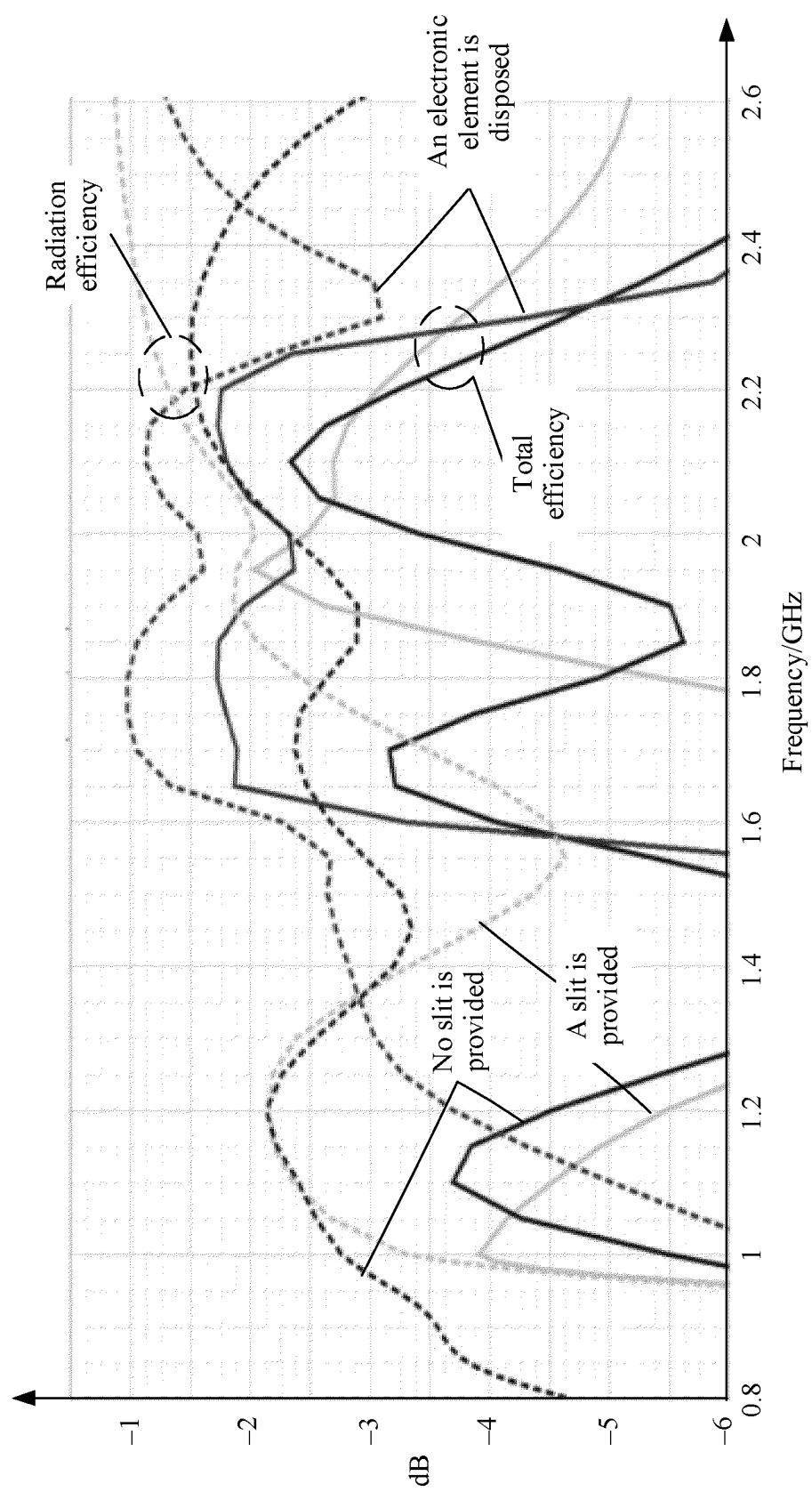


FIG. 33

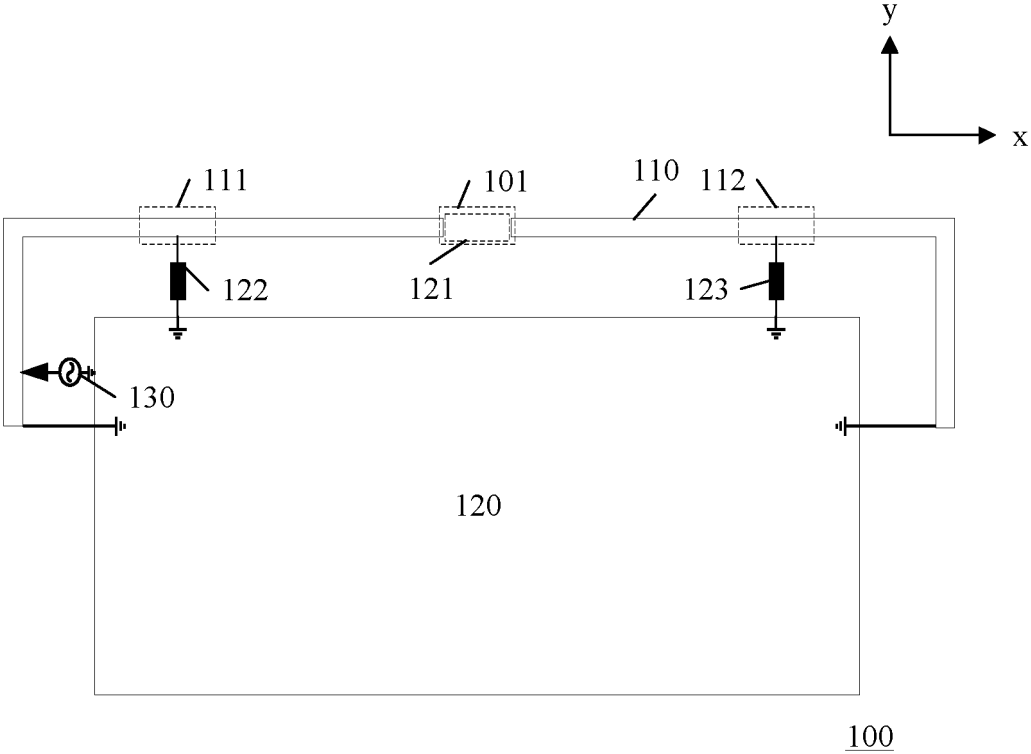


FIG. 34

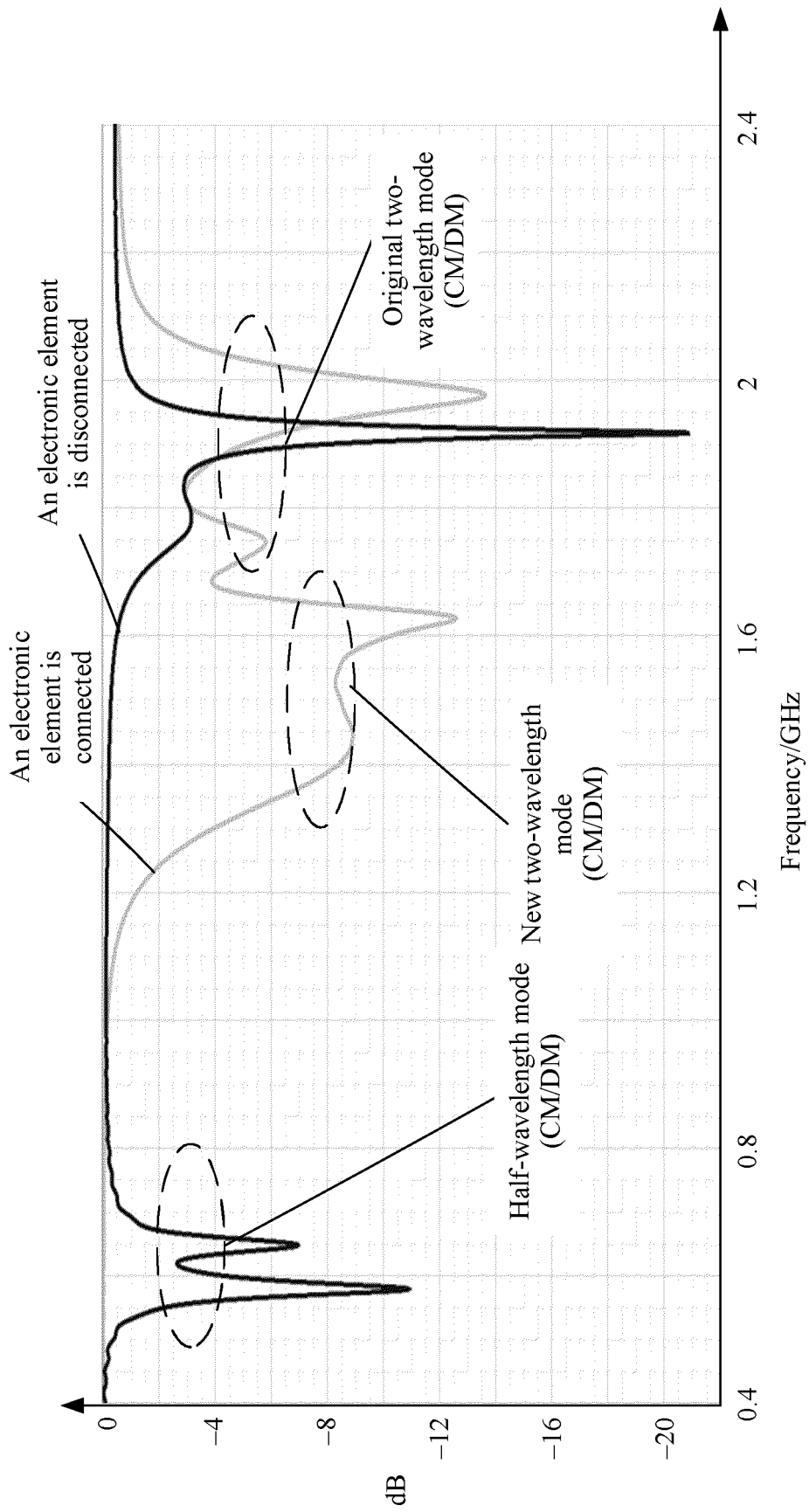


FIG. 35

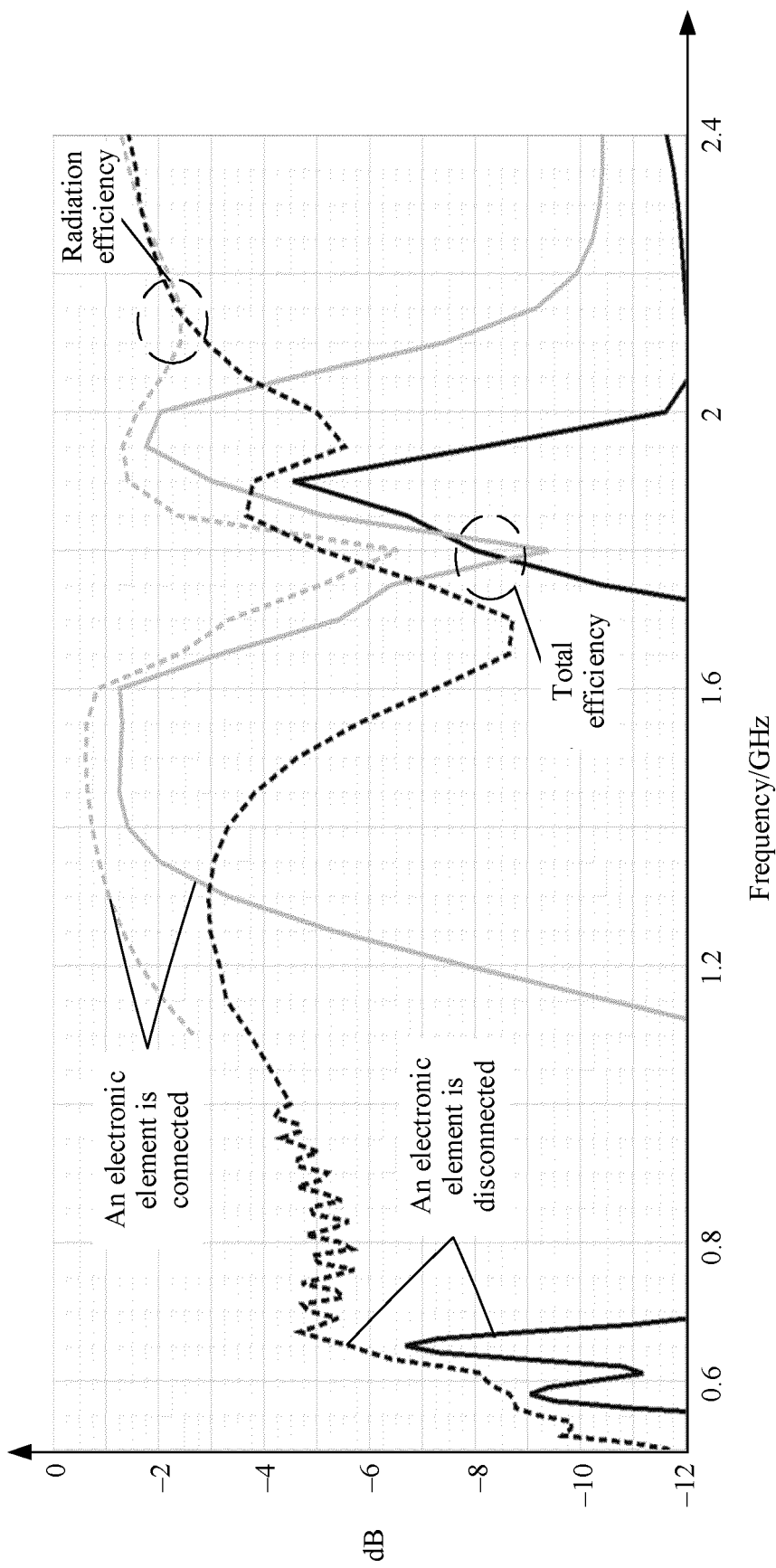
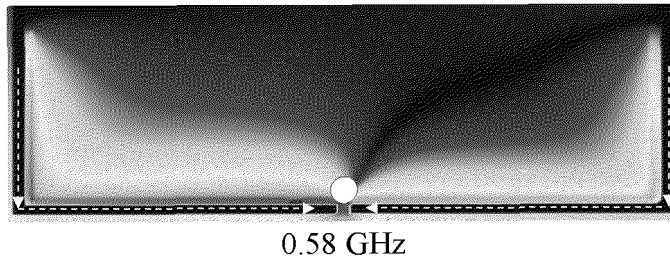


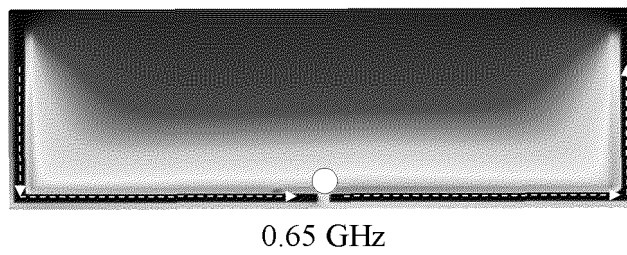
FIG. 36

○ Current node (electric field strong point)



(a)

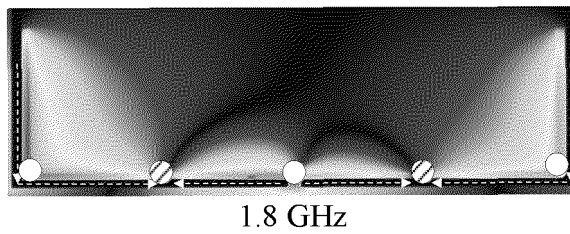
○ Current node (electric field strong point)



(b)

⊗ Electric field node (current strong point)

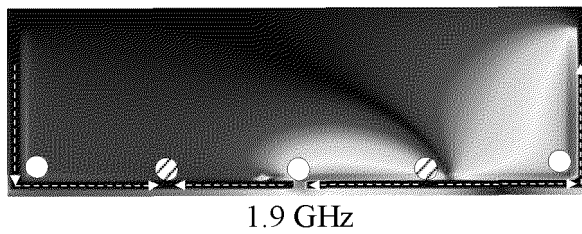
○ Current node (electric field strong point)



(c)

⊗ Electric field node (current strong point)

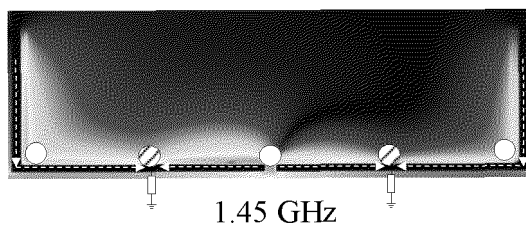
○ Current node (electric field strong point)



(d)

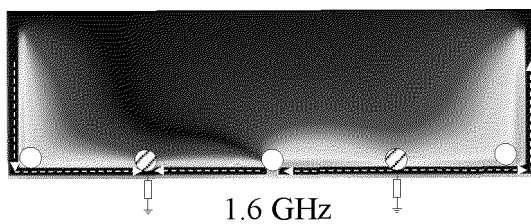
FIG. 37

- ⊗ Electric field node (current strong point)
- Current node (electric field strong point)



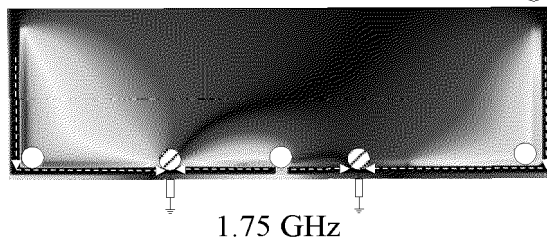
(a)

- ⊗ Electric field node (current strong point)
- Current node (electric field strong point)



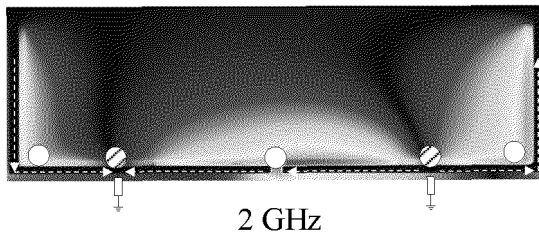
(b)

- ⊗ Electric field node (current strong point)
- Current node (electric field strong point)



(c)

- ⊗ Electric field node (current strong point)
- Current node (electric field strong point)



(d)

FIG. 38

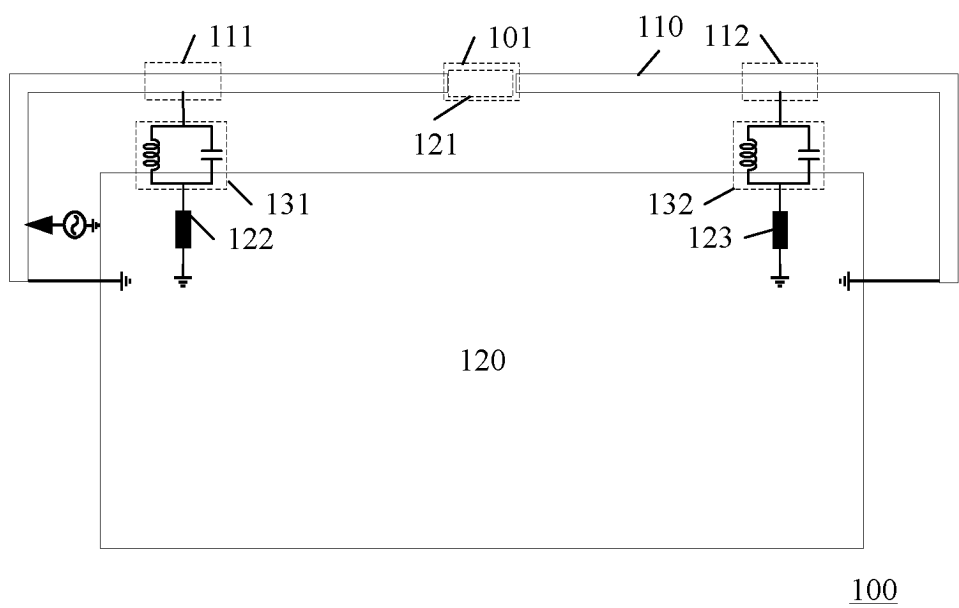


FIG. 39

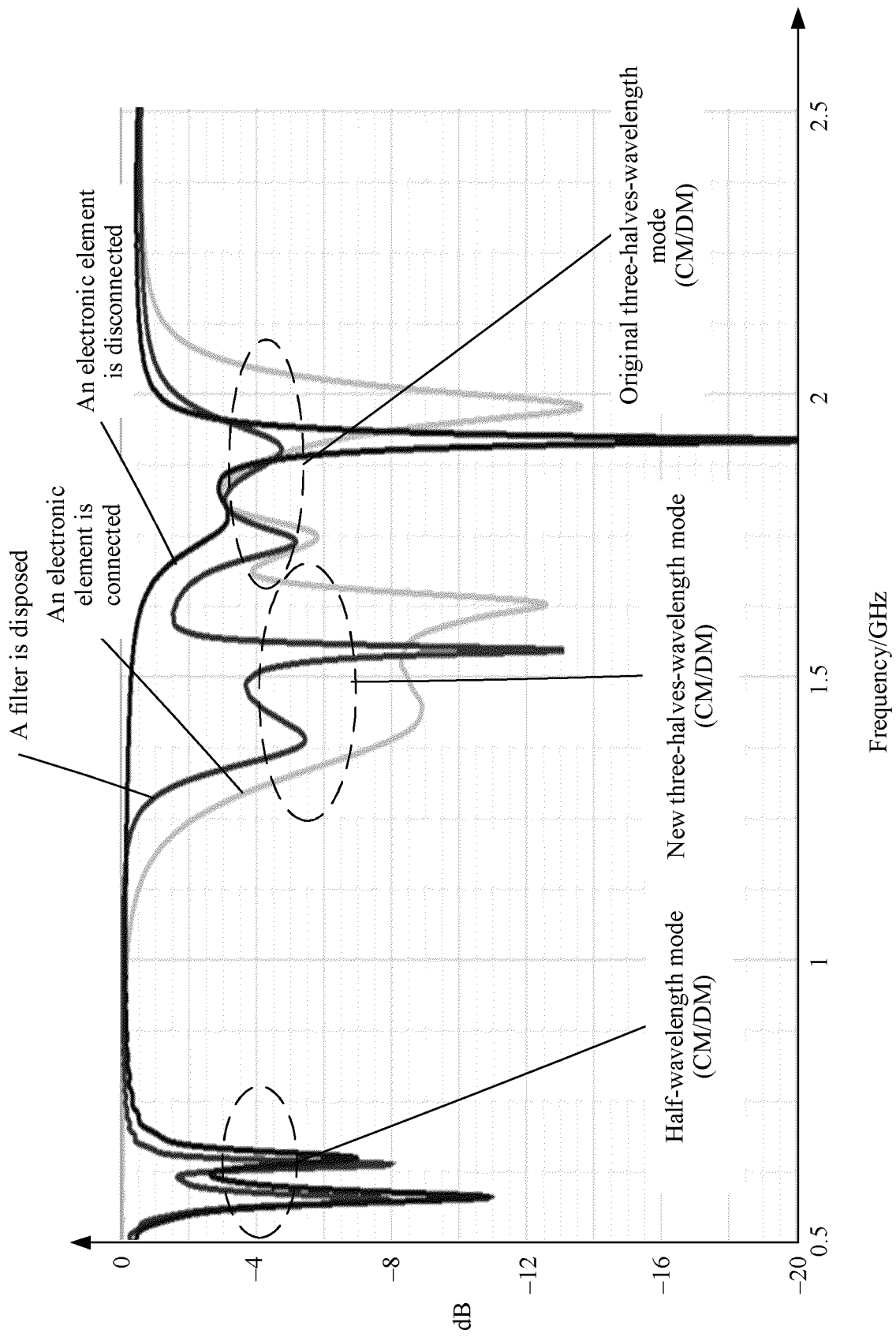


FIG. 40

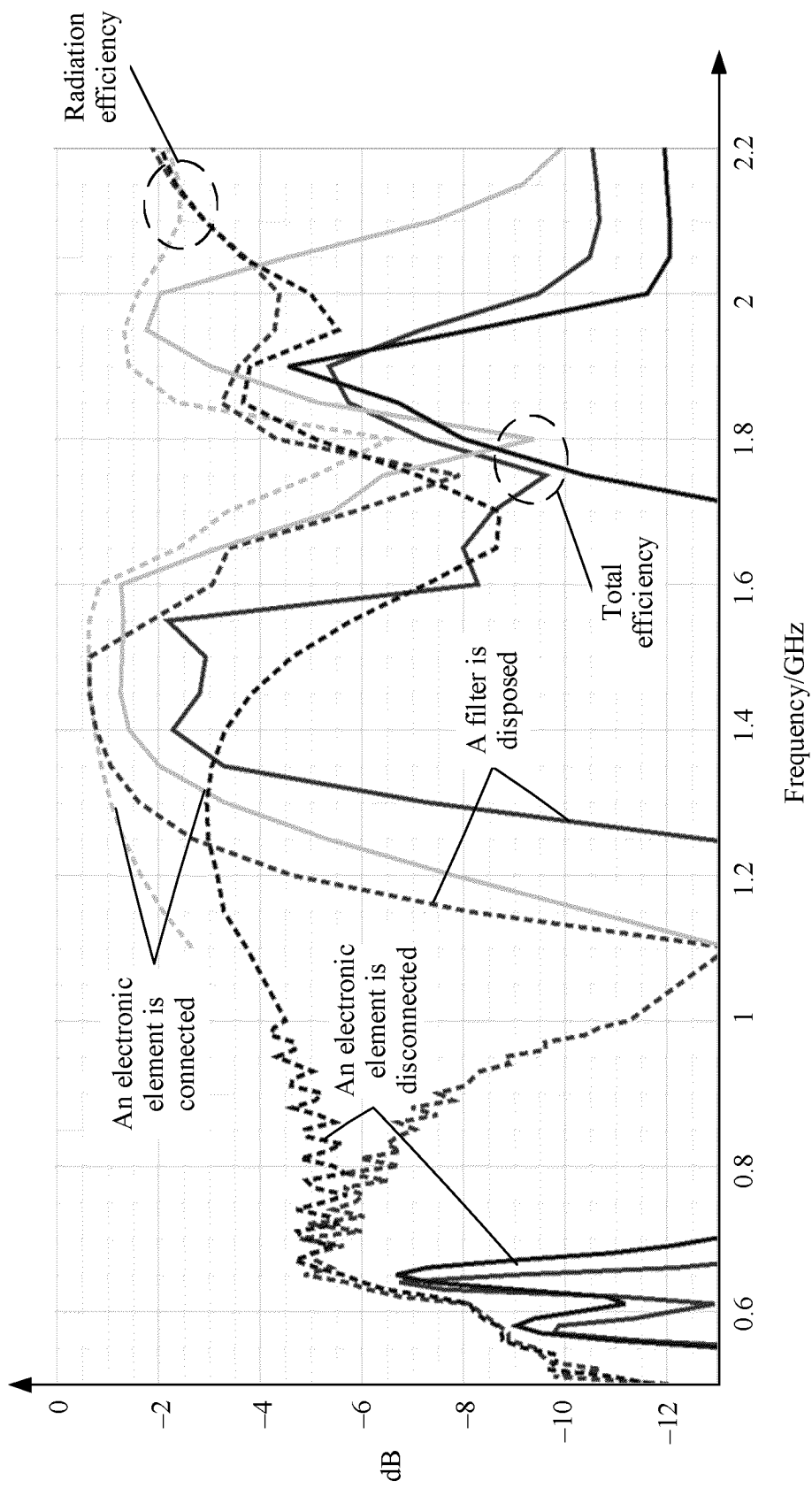


FIG. 41

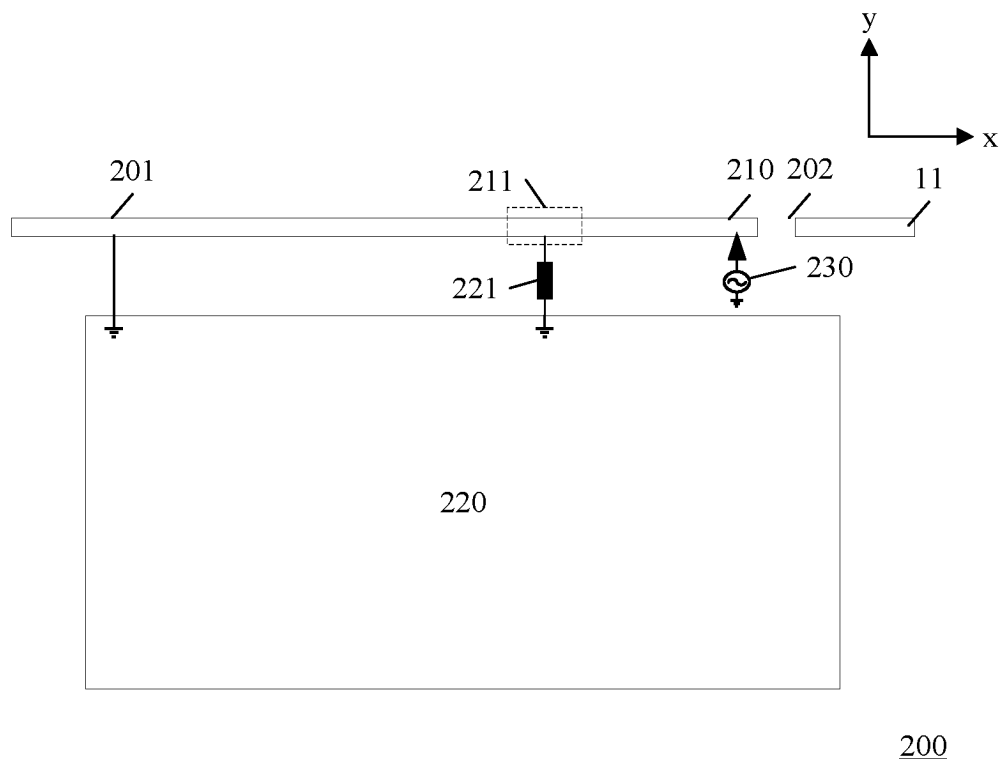
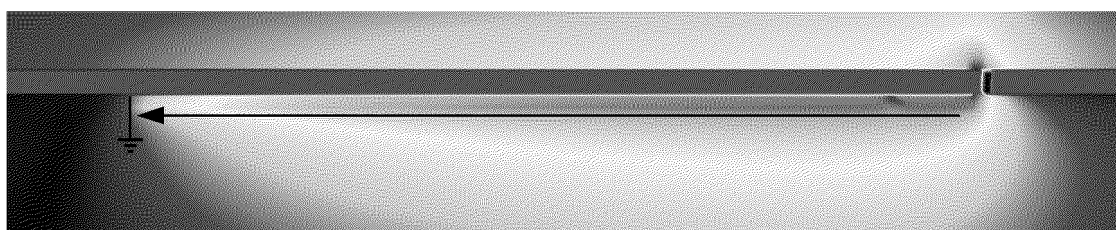


FIG. 42



(a)

 Electric field node (current strong point)



(b)

FIG. 43

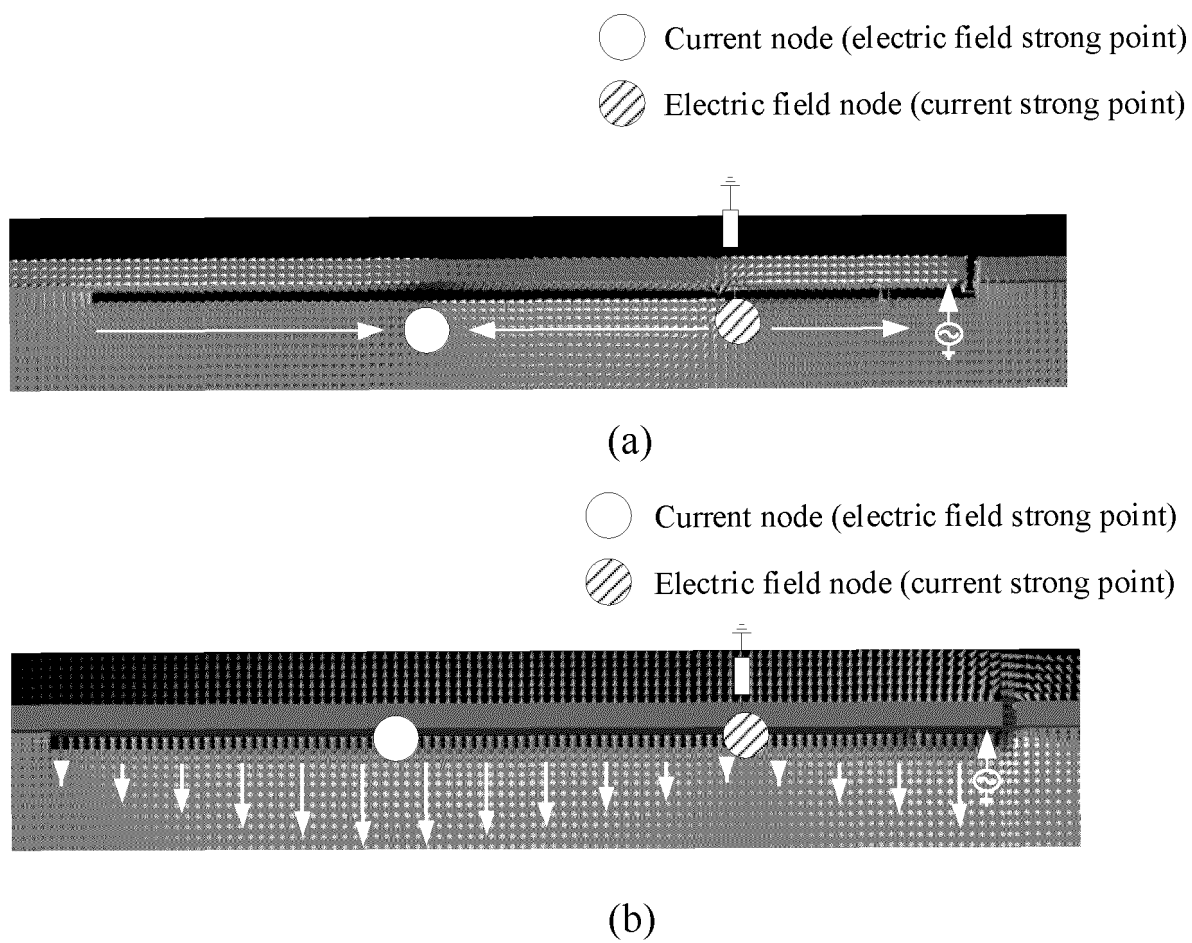
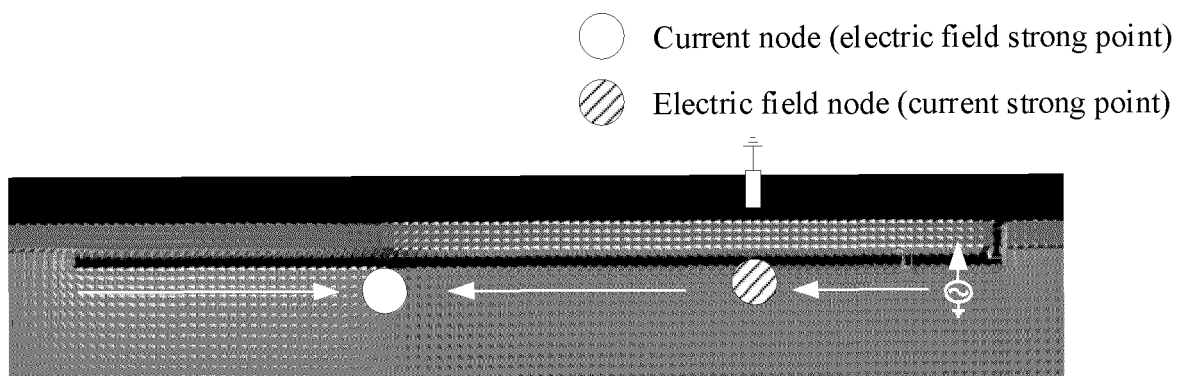
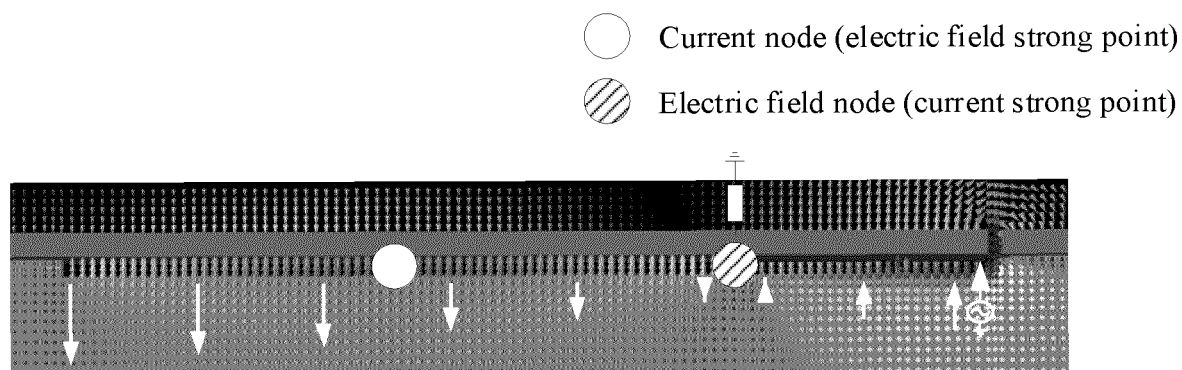


FIG. 44



(a)



(b)

FIG. 45

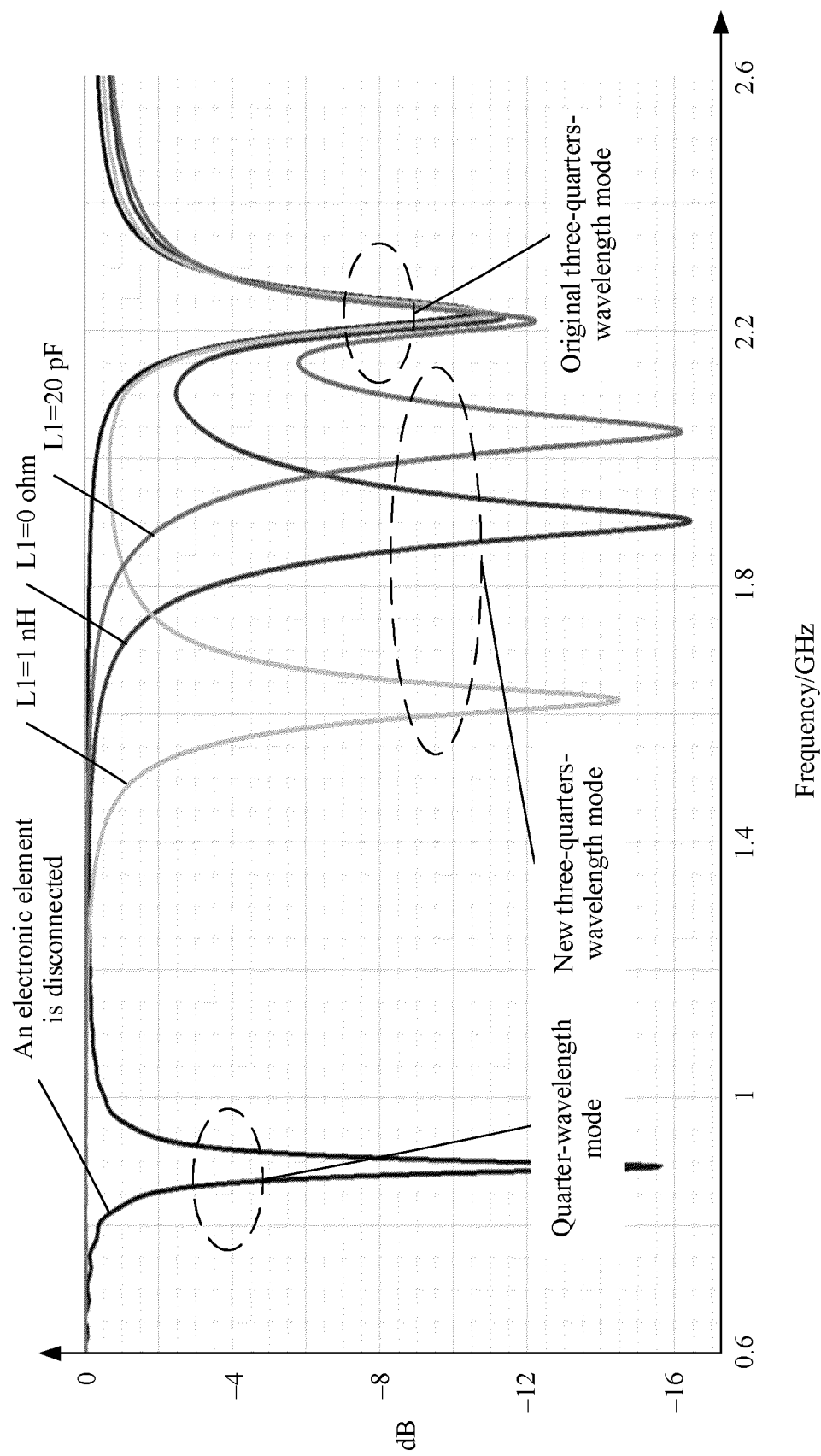


FIG. 46

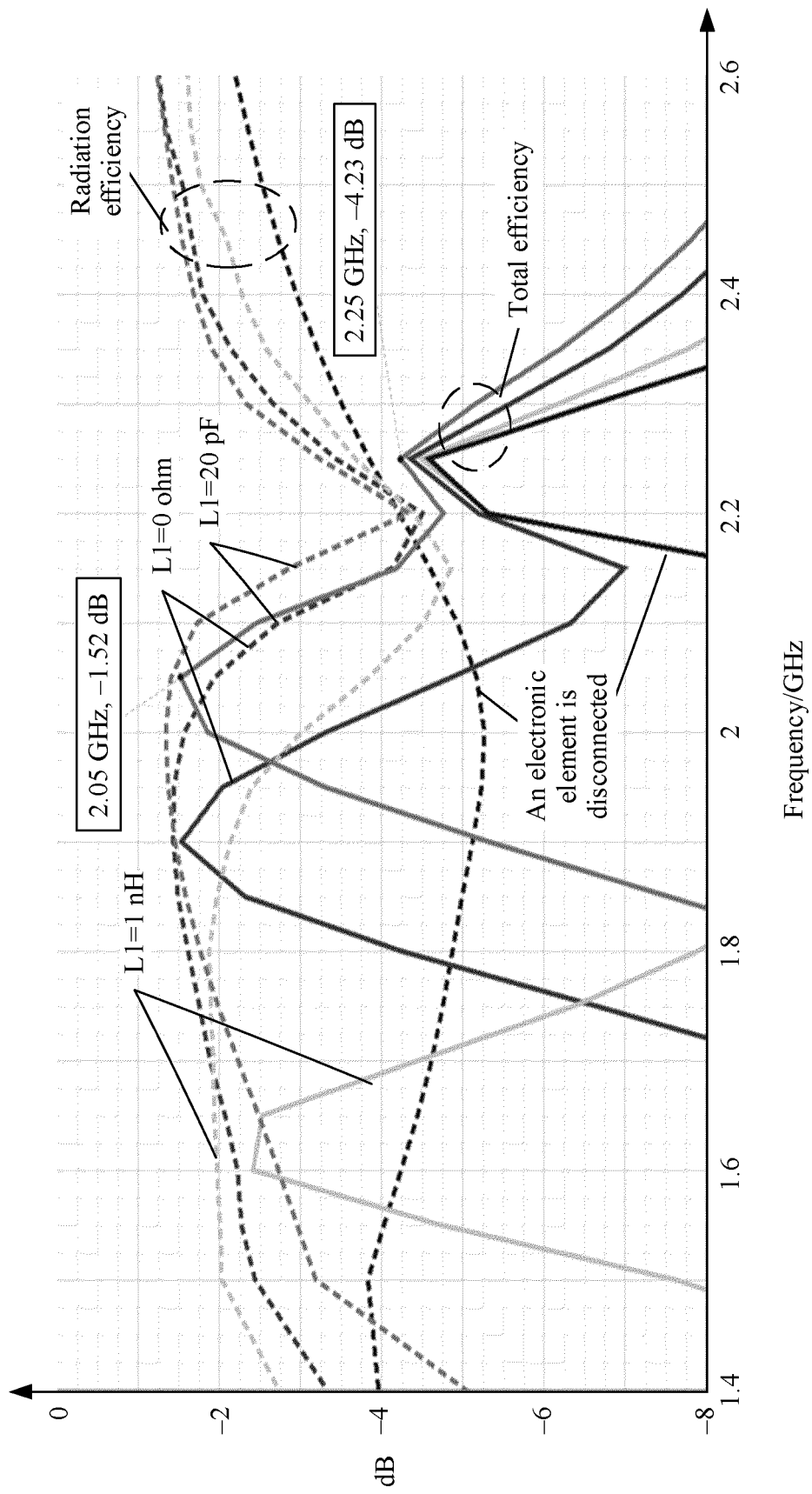


FIG. 47

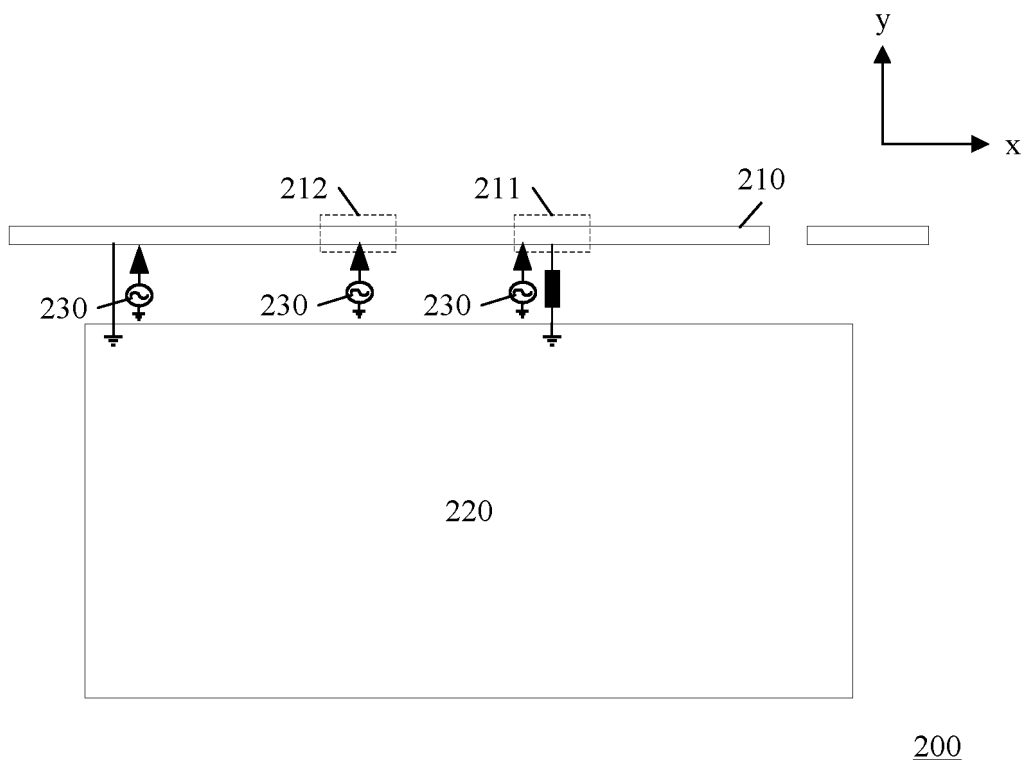


FIG. 48

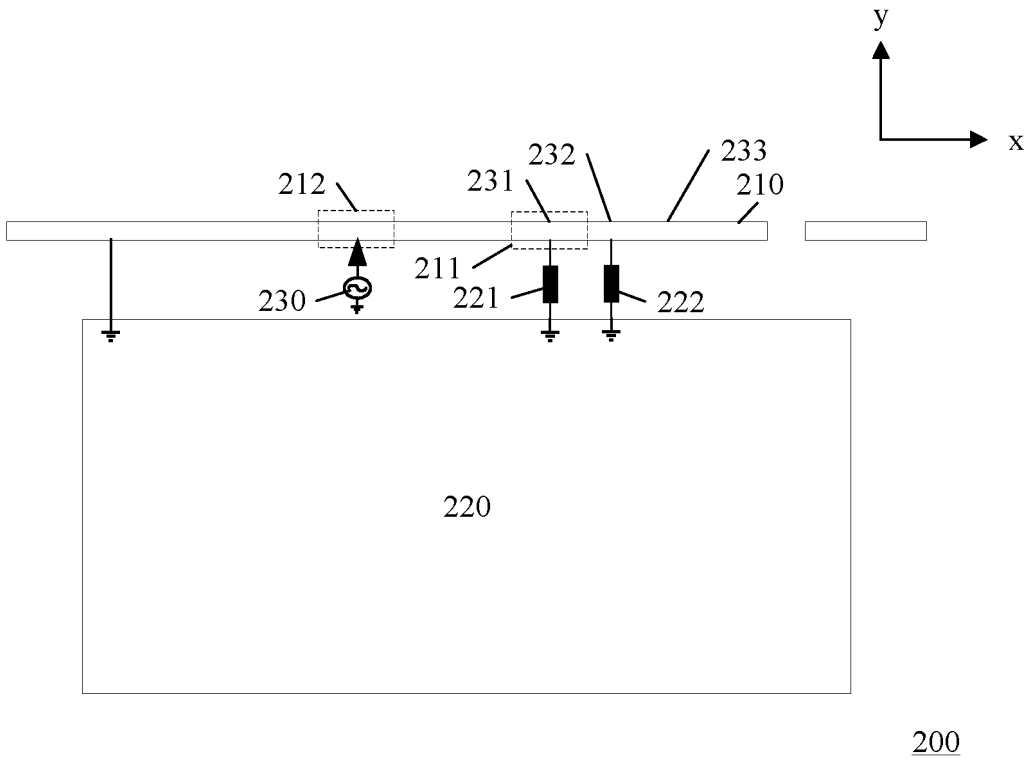
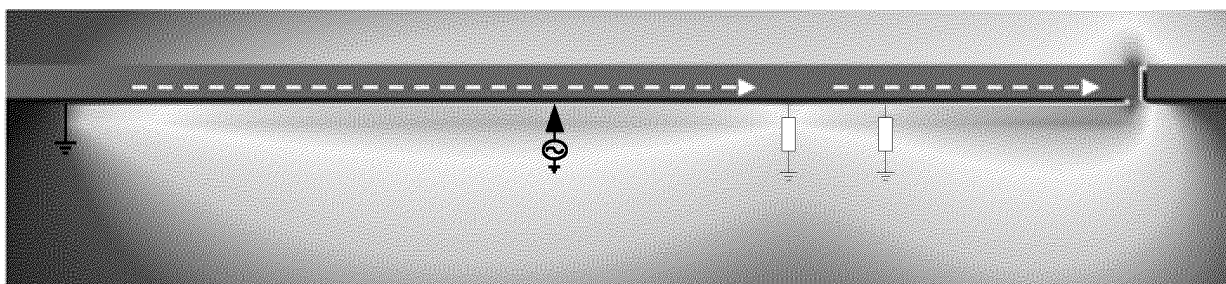
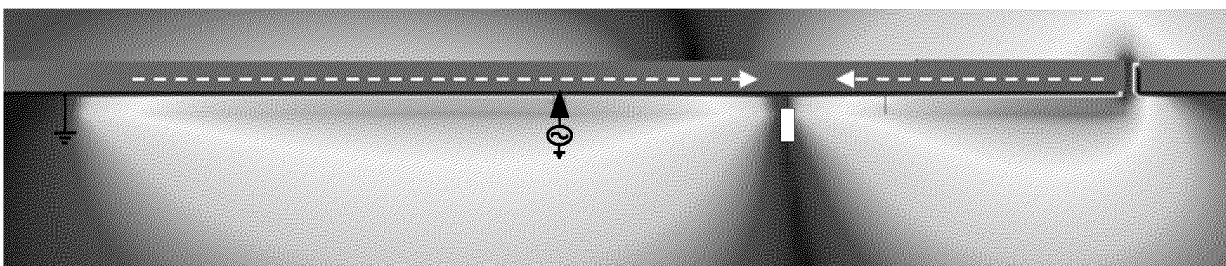


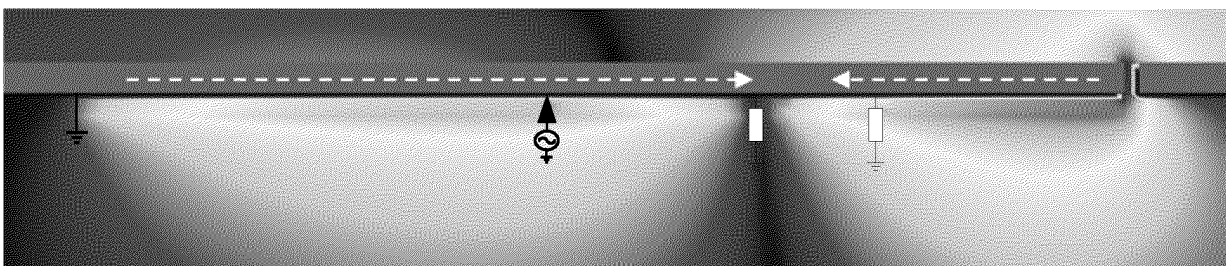
FIG. 49



(a)



(b)



(c)

FIG. 50

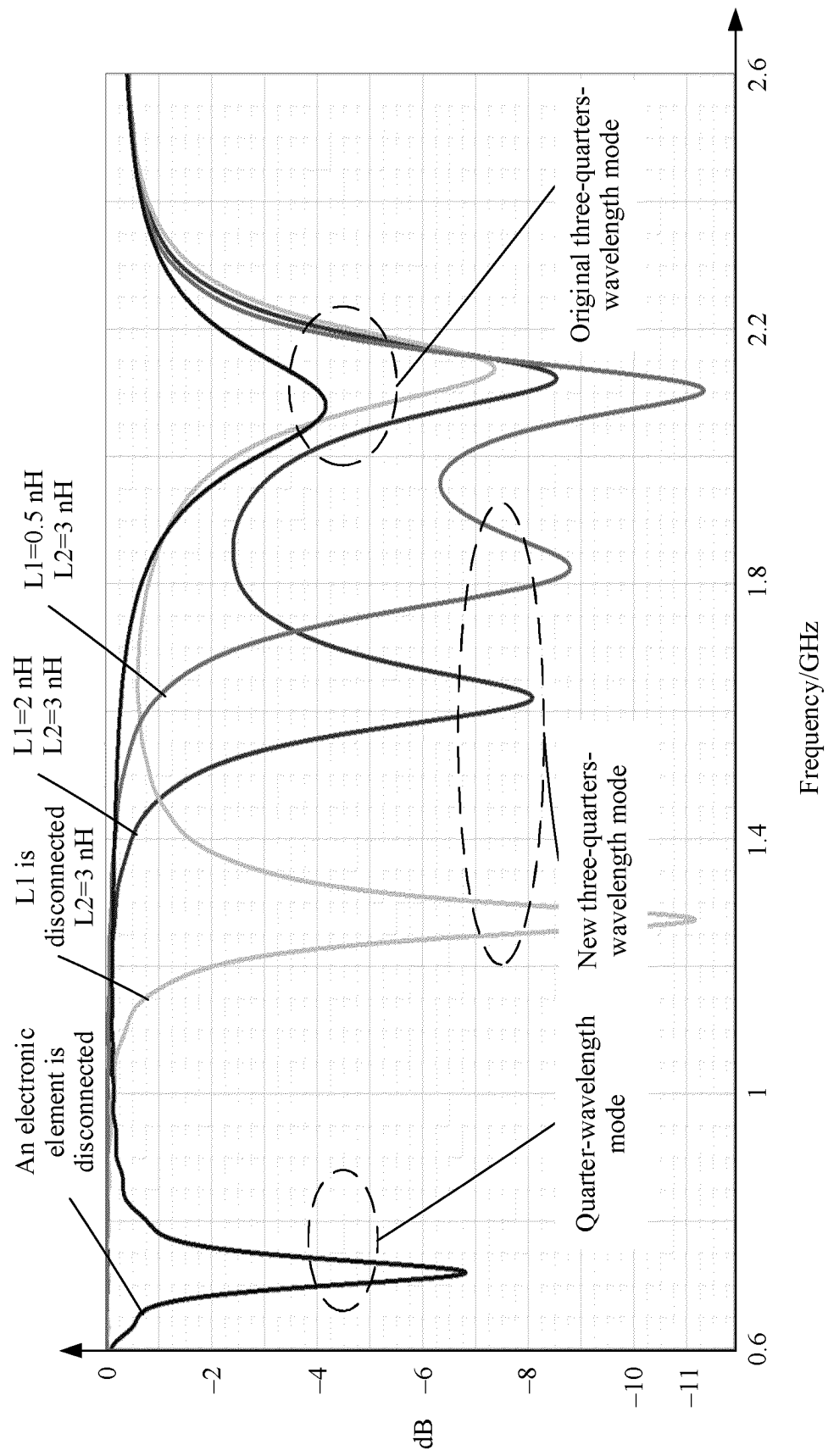
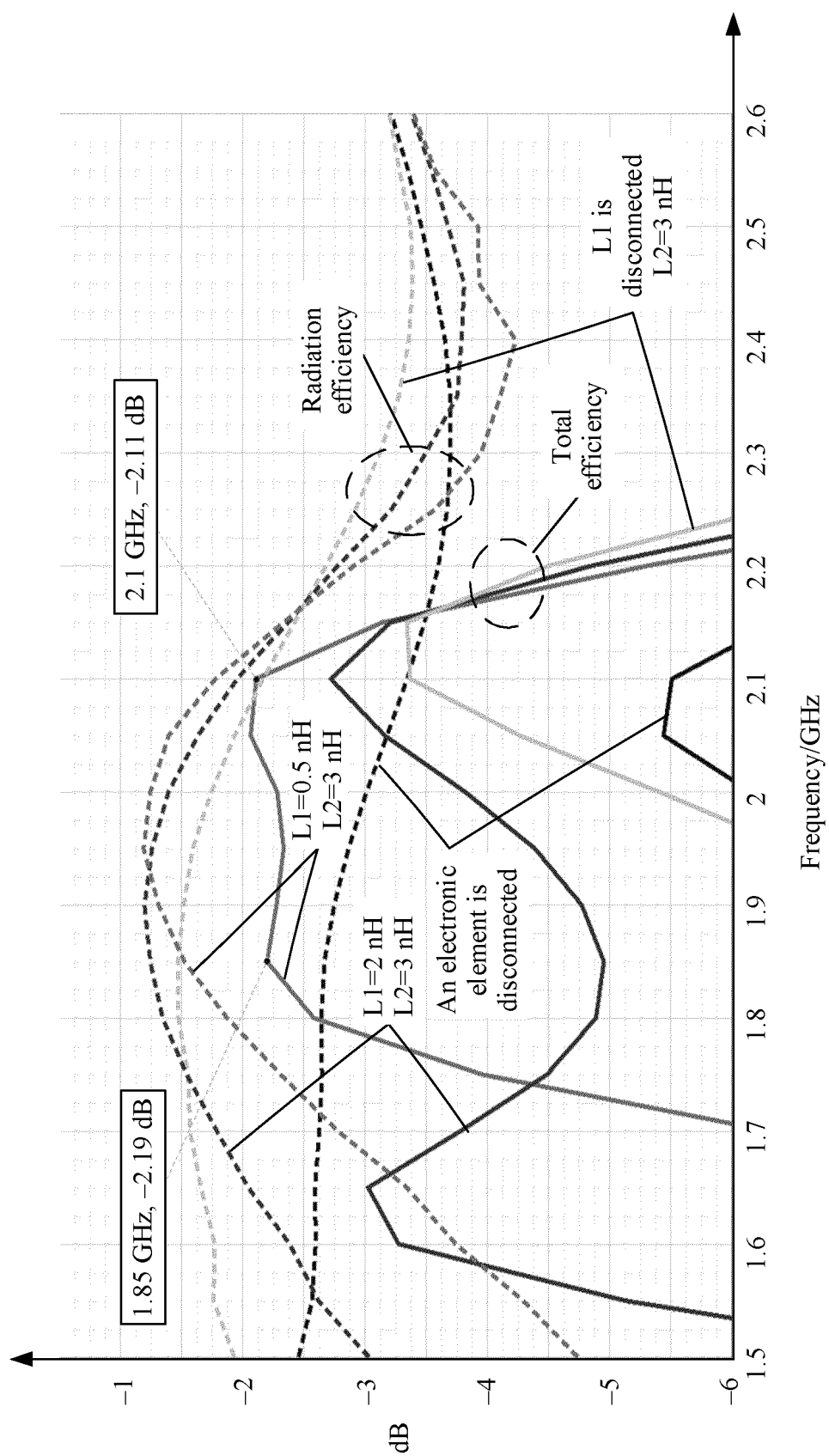


FIG. 51



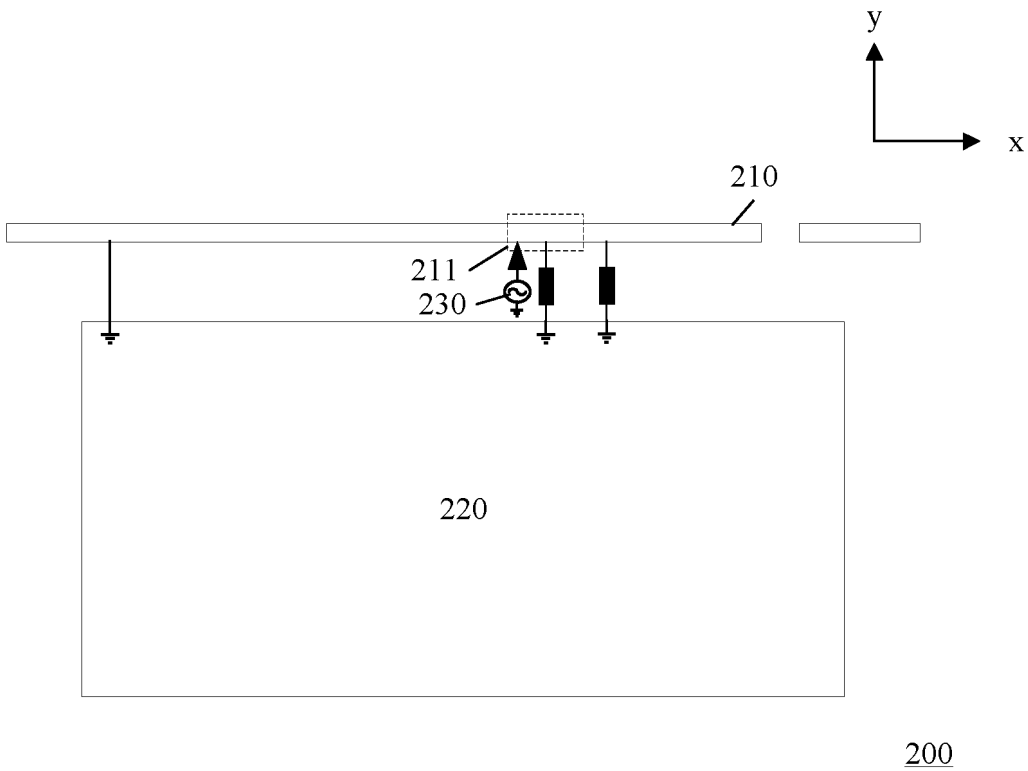
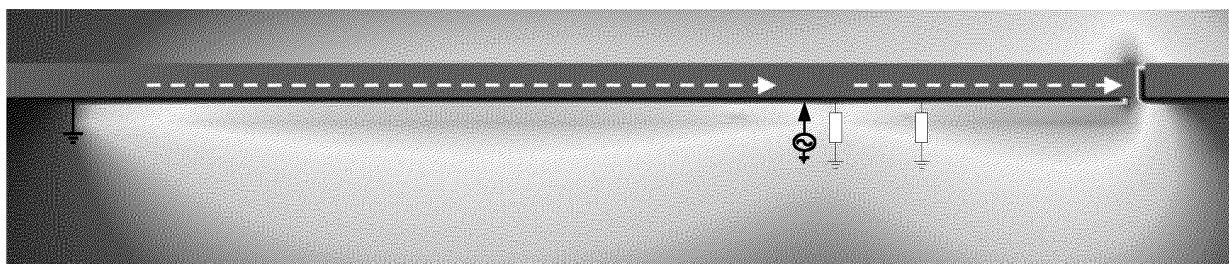
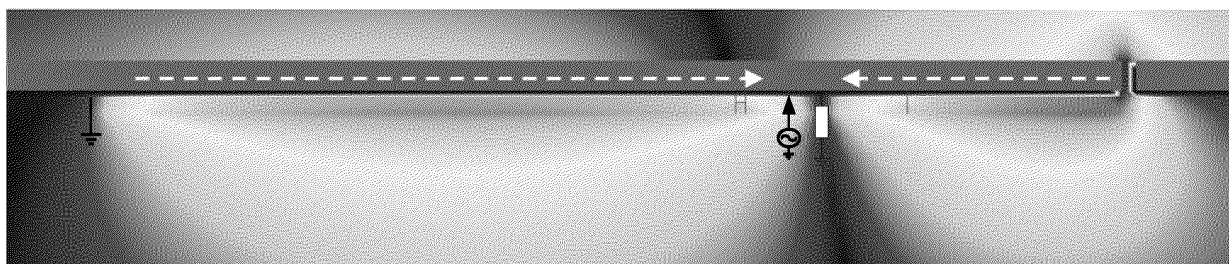


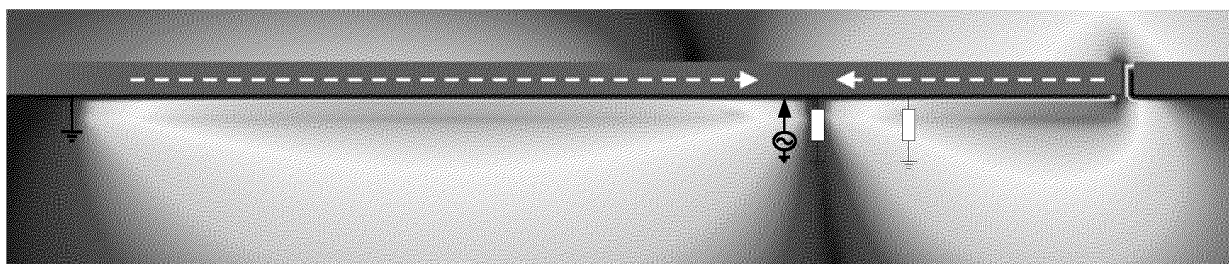
FIG. 53



(a)



(b)



(c)

FIG. 54

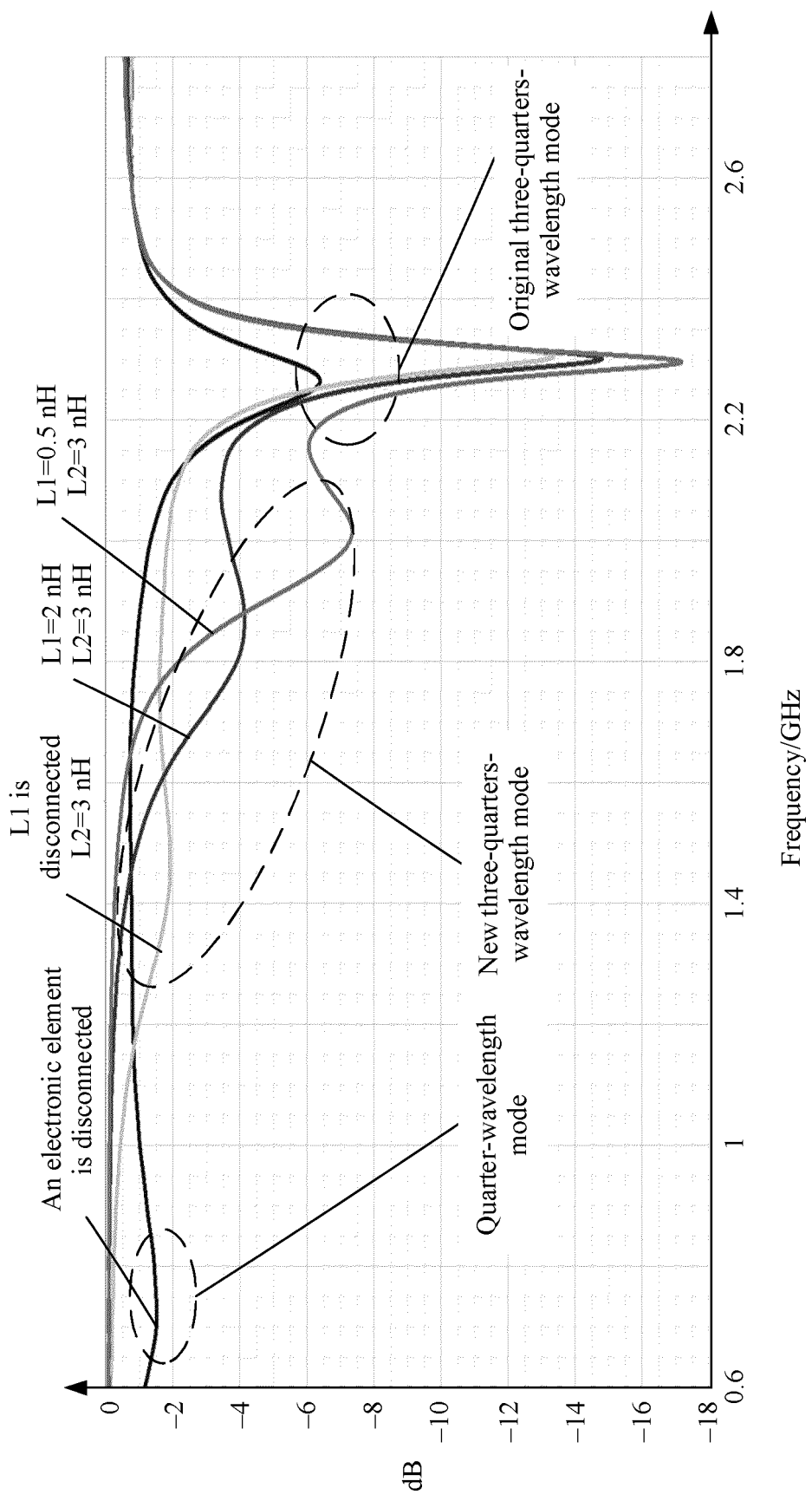


FIG. 55

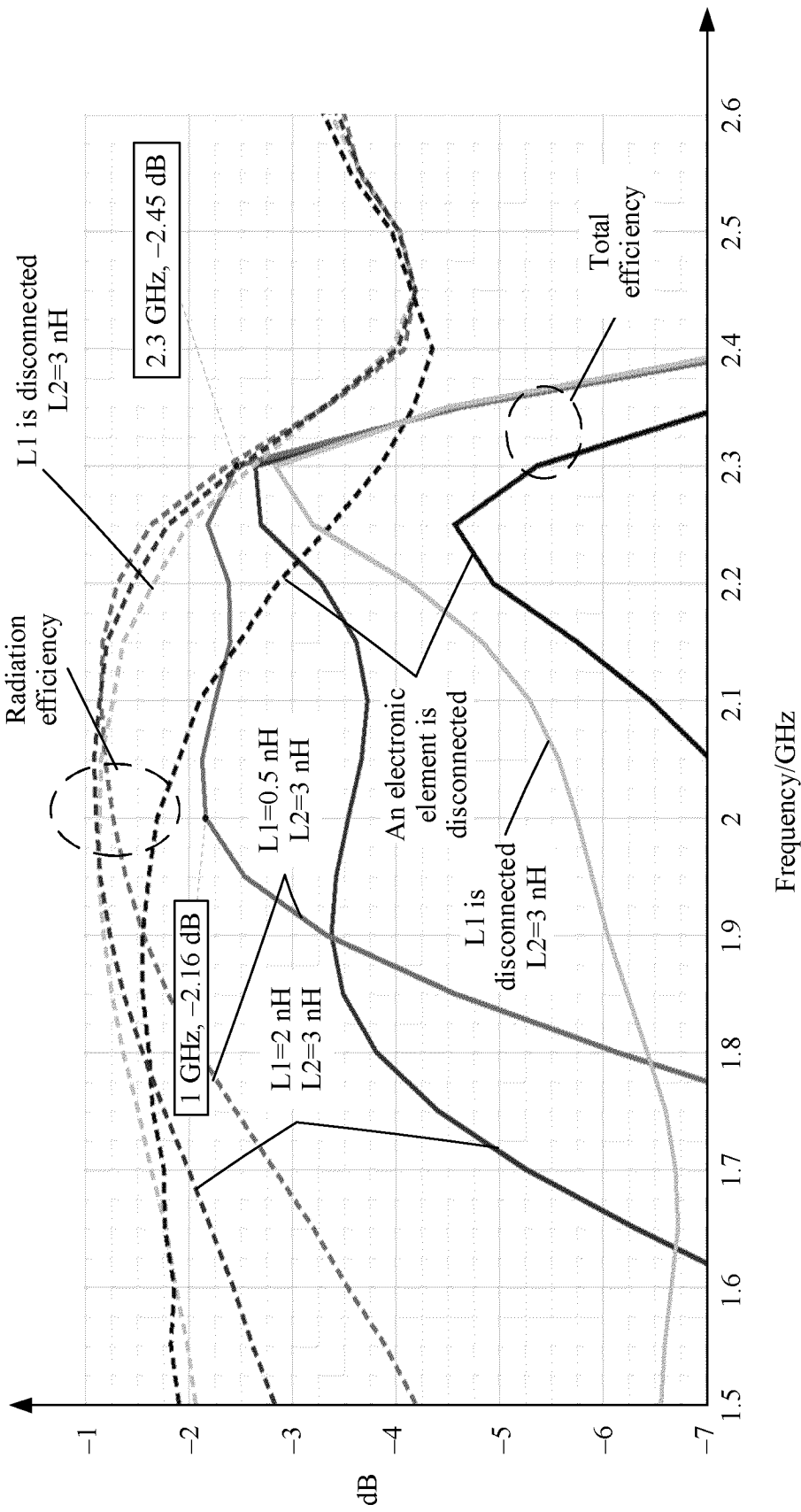


FIG. 56

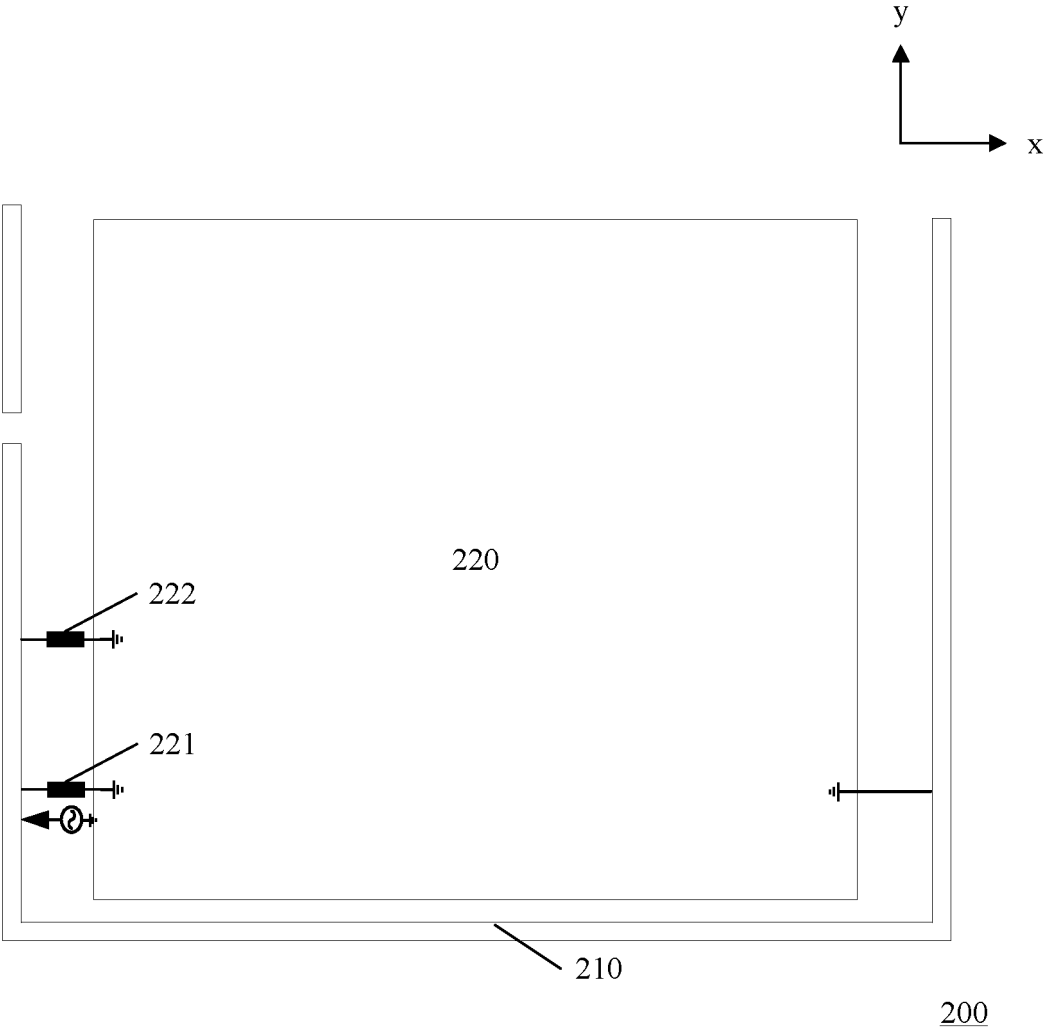


FIG. 57

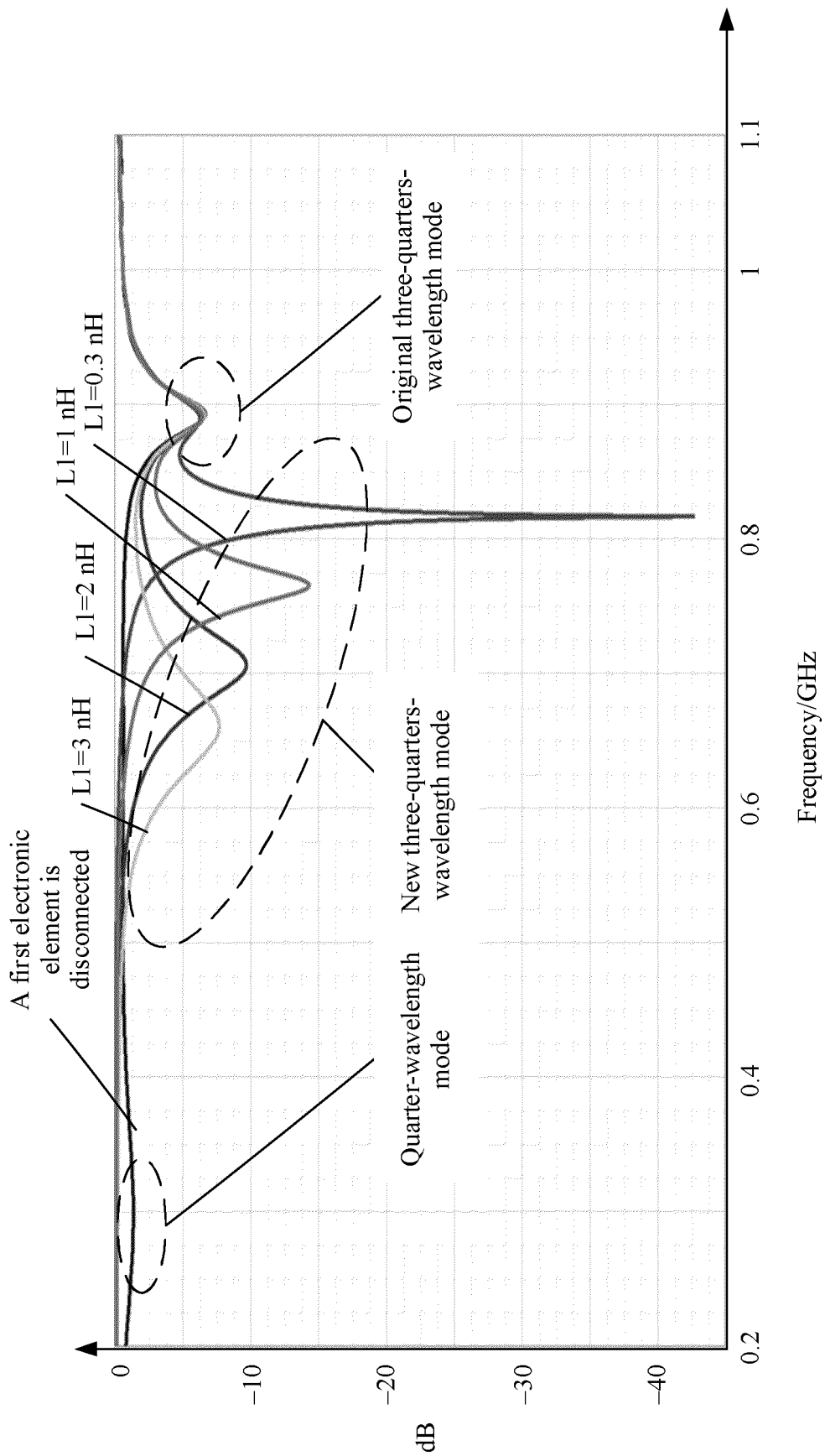


FIG. 58

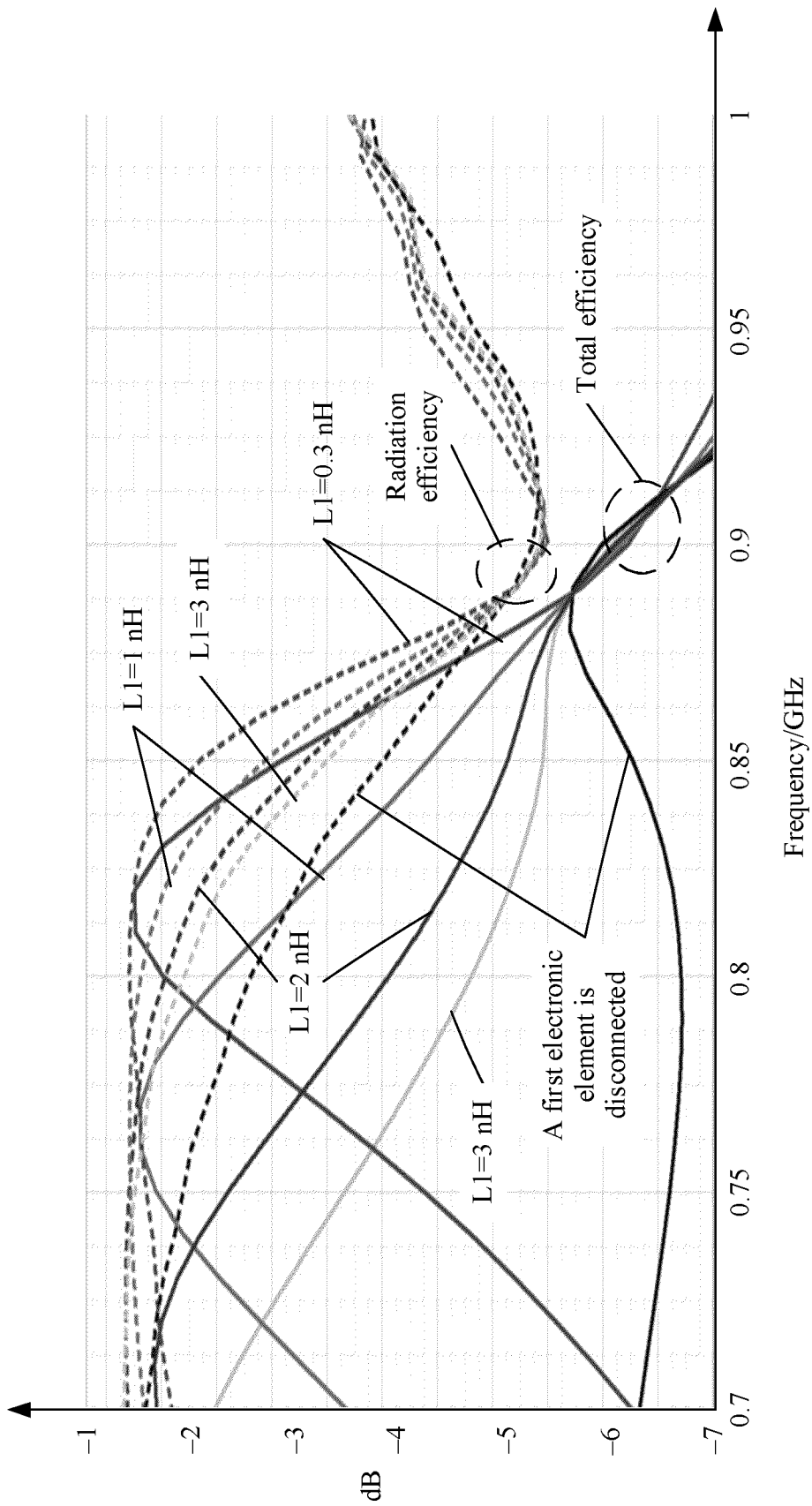
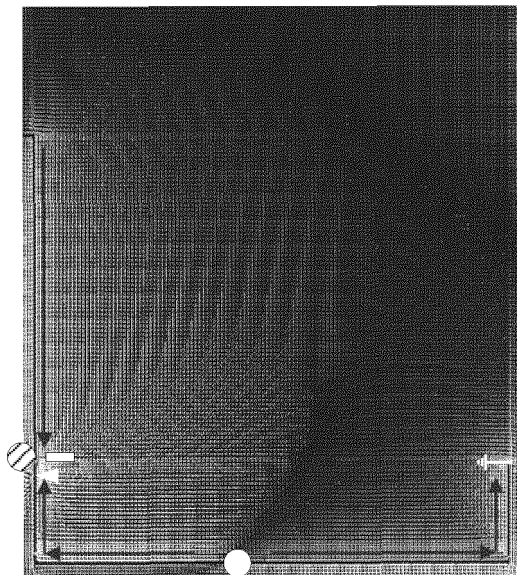


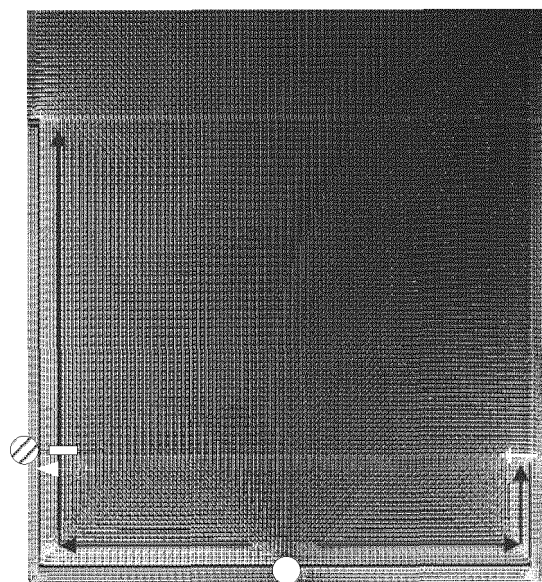
FIG. 59

- Current node (electric field strong point)
- ⊗ Electric field node (current strong point)



(a)

- Current node (electric field strong point)
- ⊗ Electric field node (current strong point)



(b)

FIG. 60

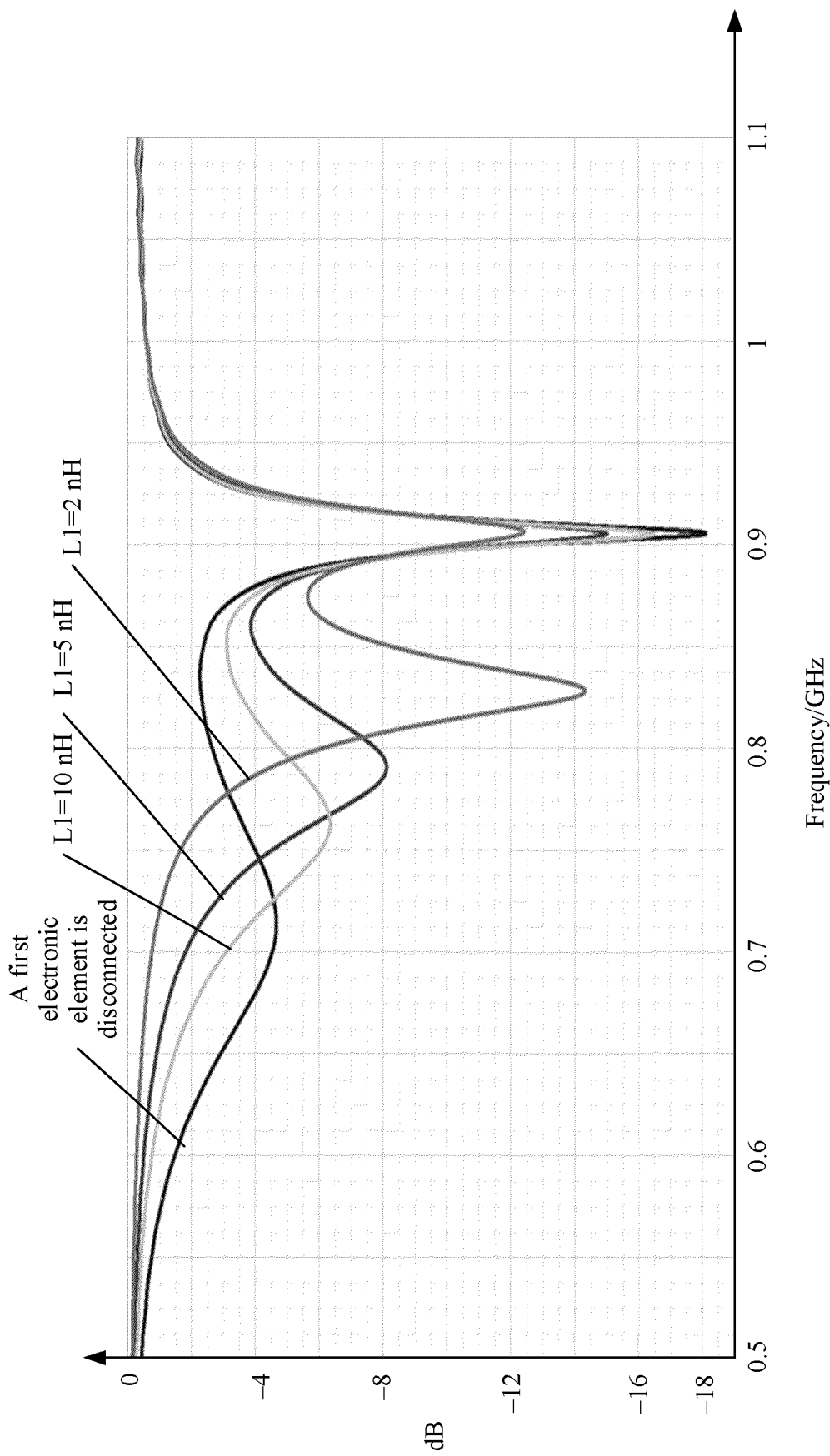


FIG. 61

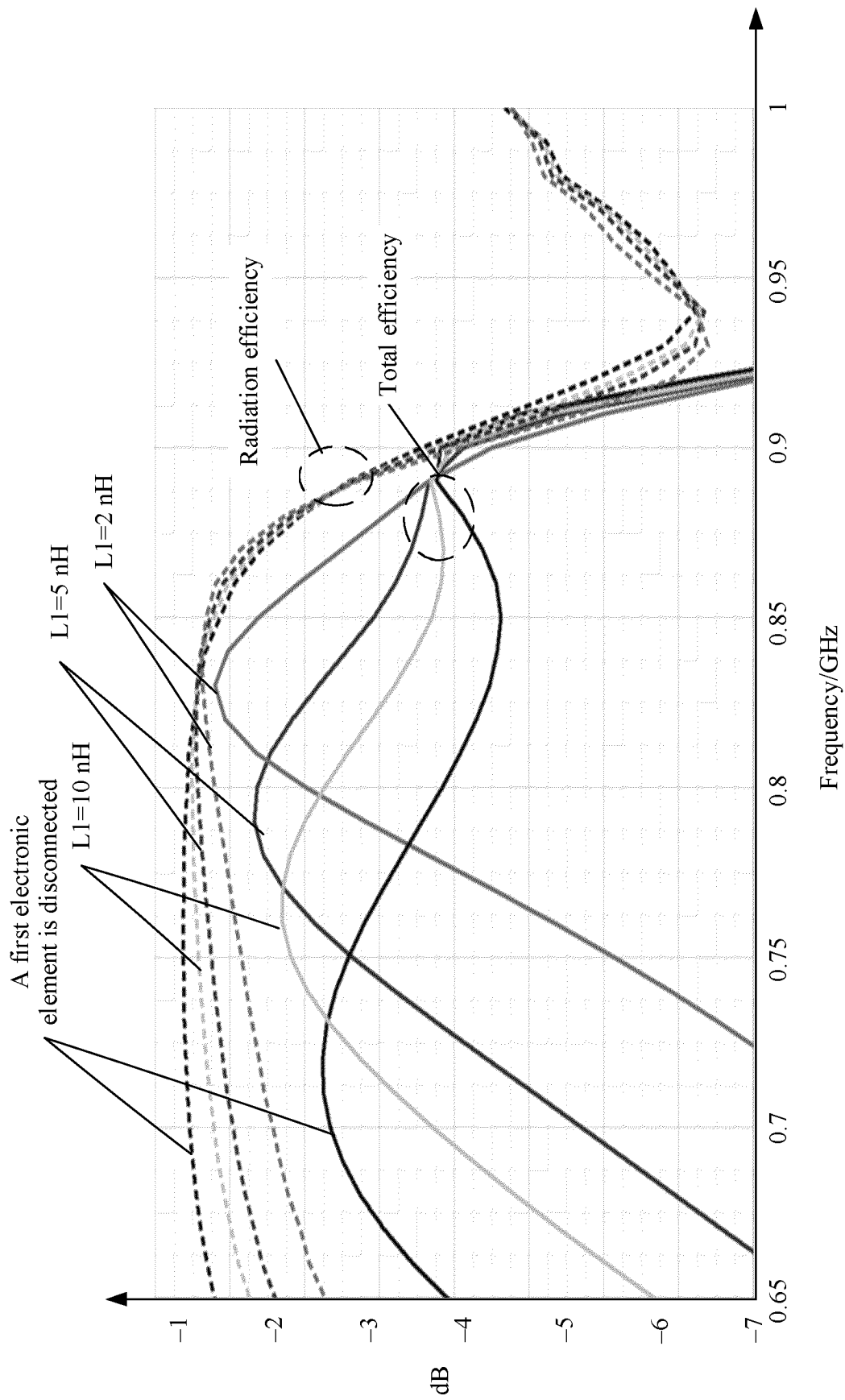


FIG. 62

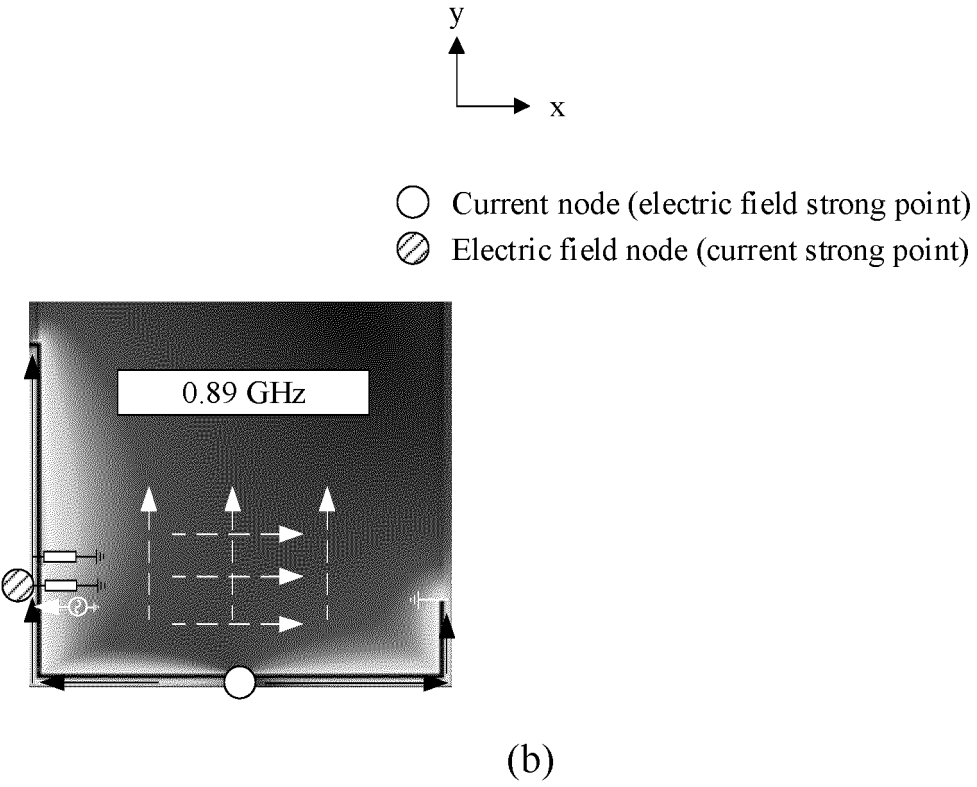
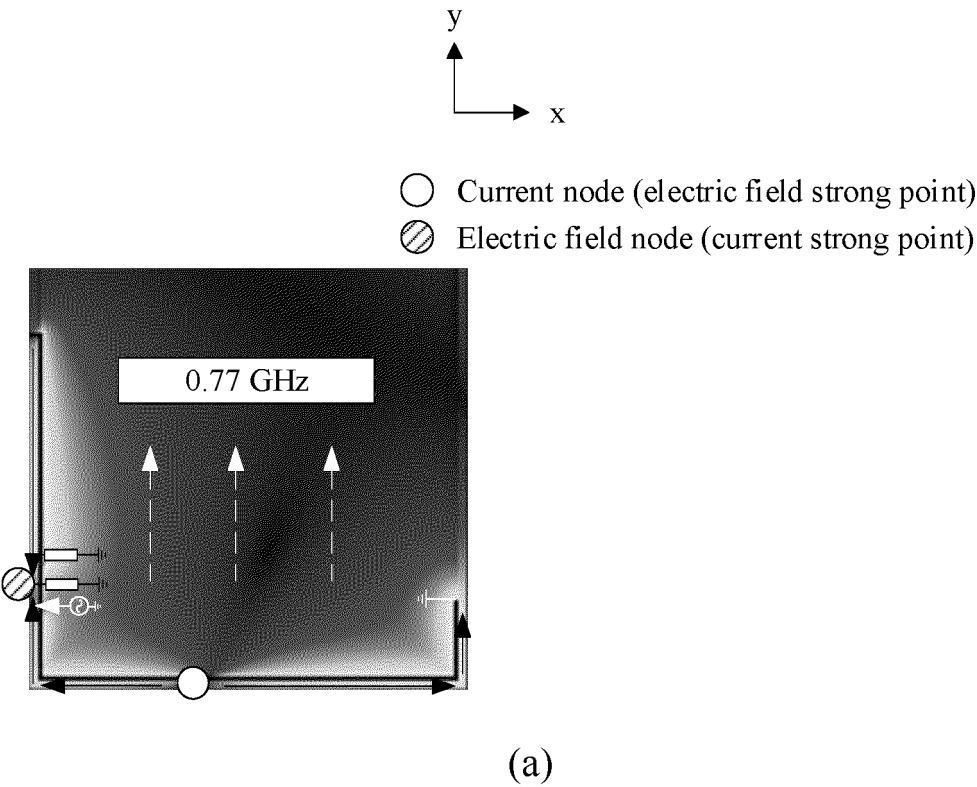


FIG. 63

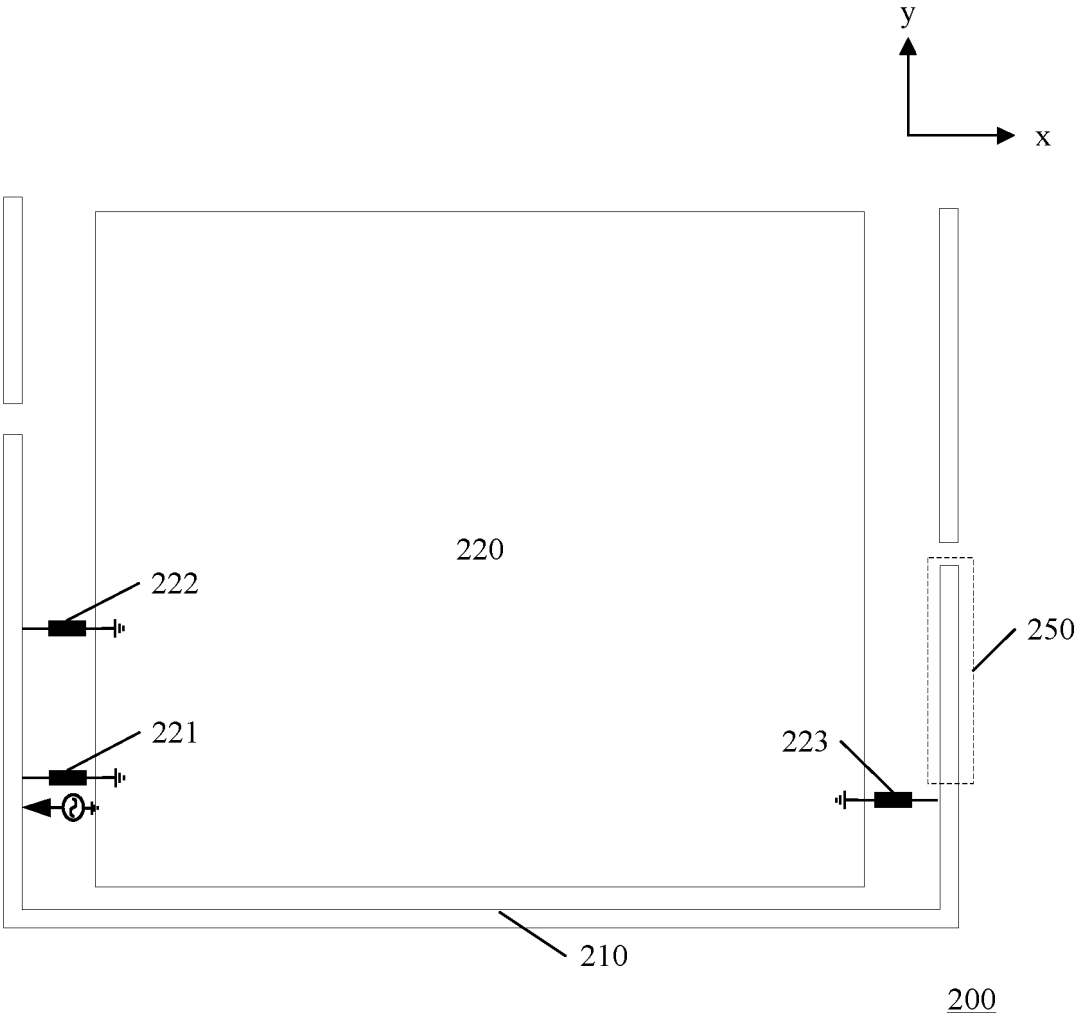


FIG. 64

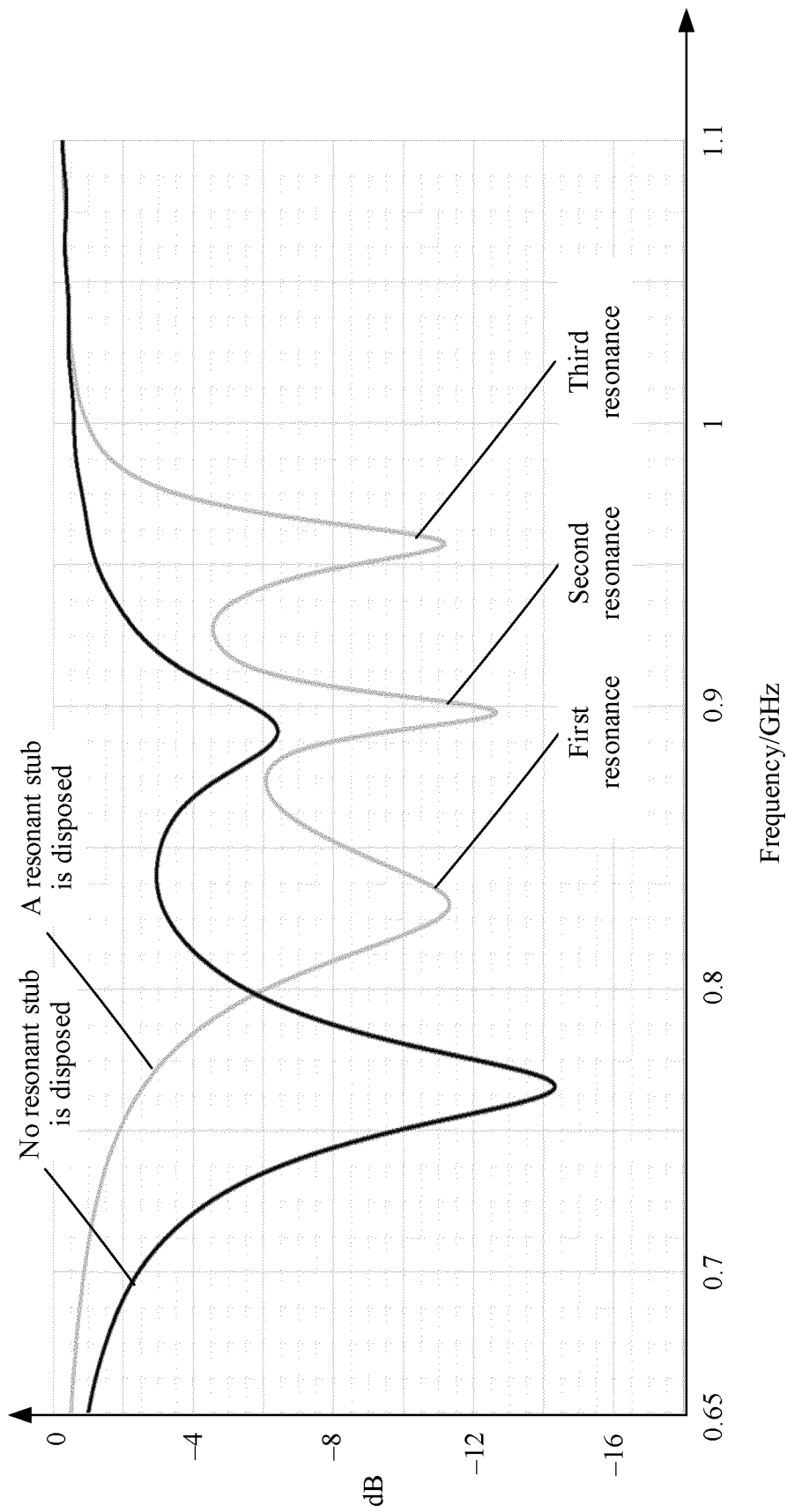


FIG. 65

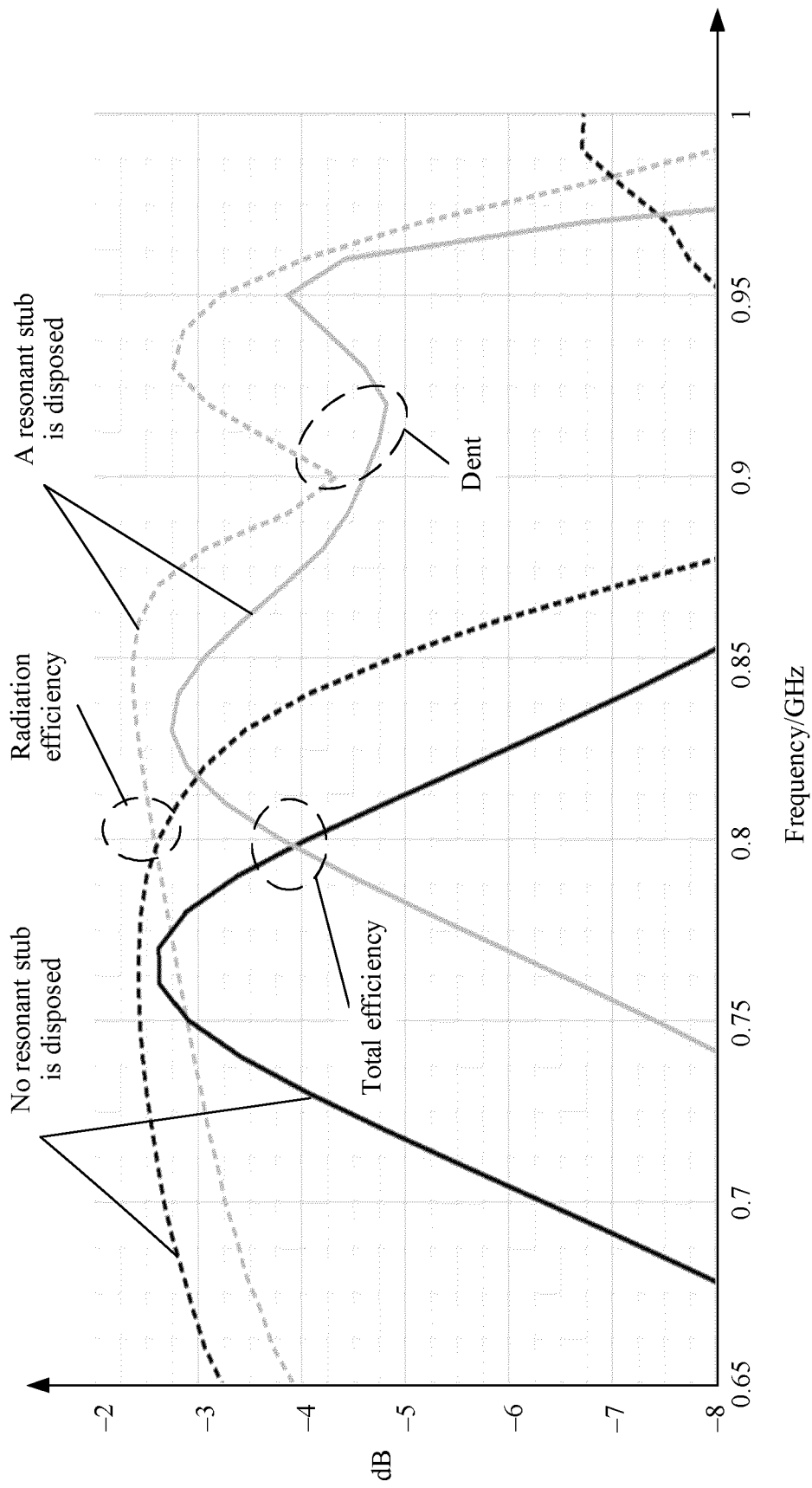
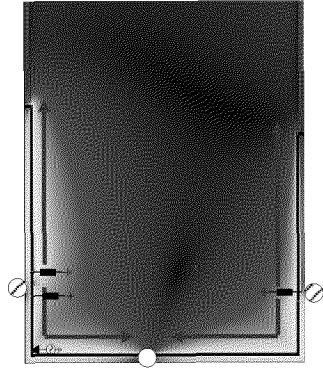


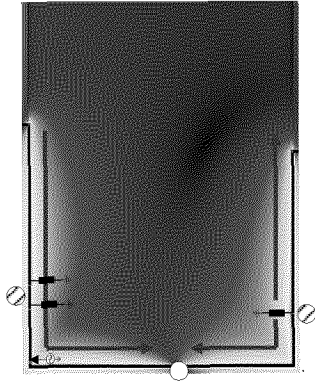
FIG. 66

- Current node (electric field strong point)
- ⊗ Electric field node (current strong point)



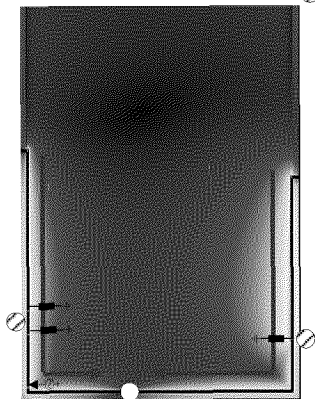
(a)

- Current node (electric field strong point)
- ⊗ Electric field node (current strong point)



(b)

- Current node (electric field strong point)
- ⊗ Electric field node (current strong point)



(c)

FIG. 67

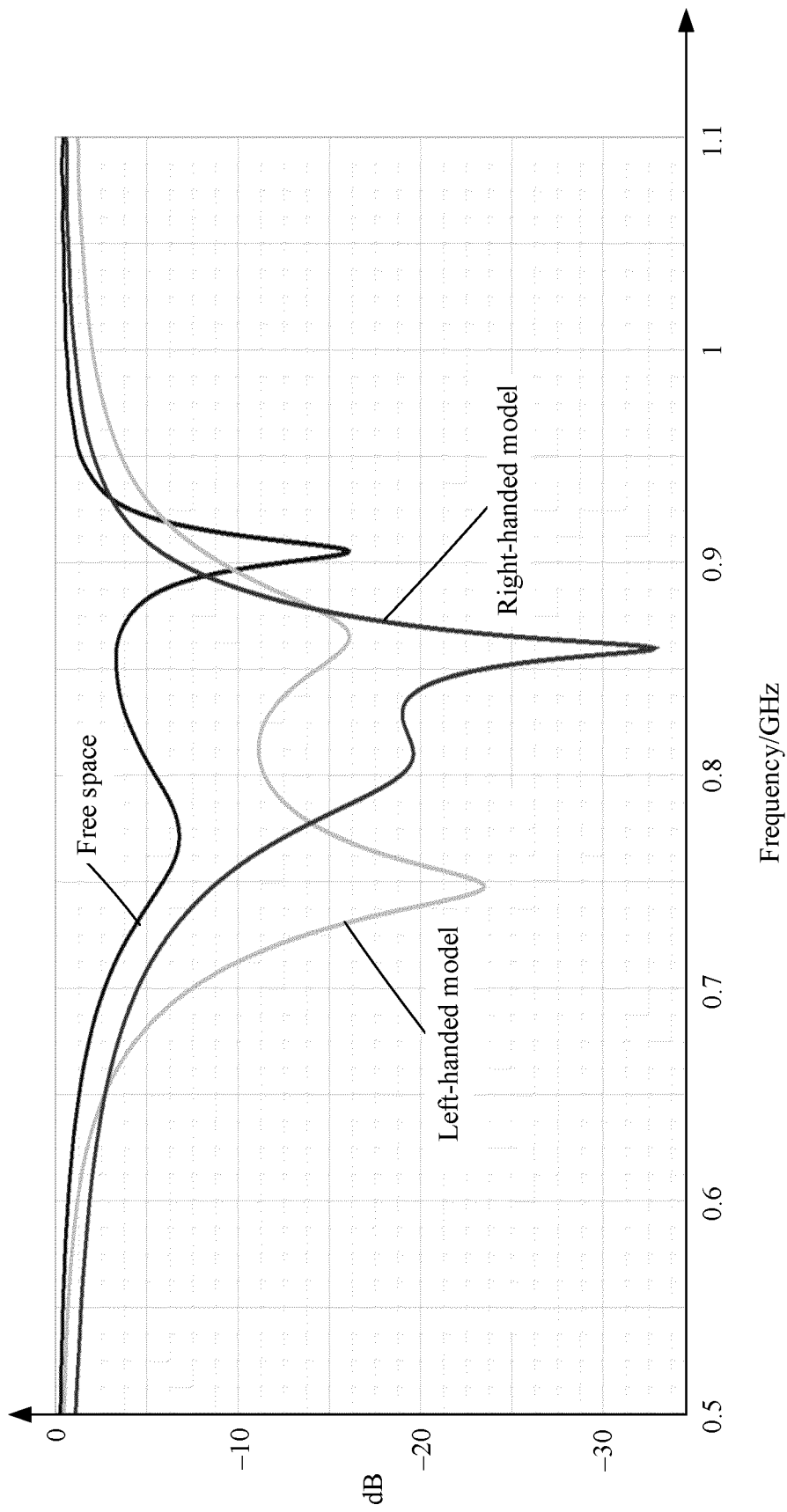


FIG. 68

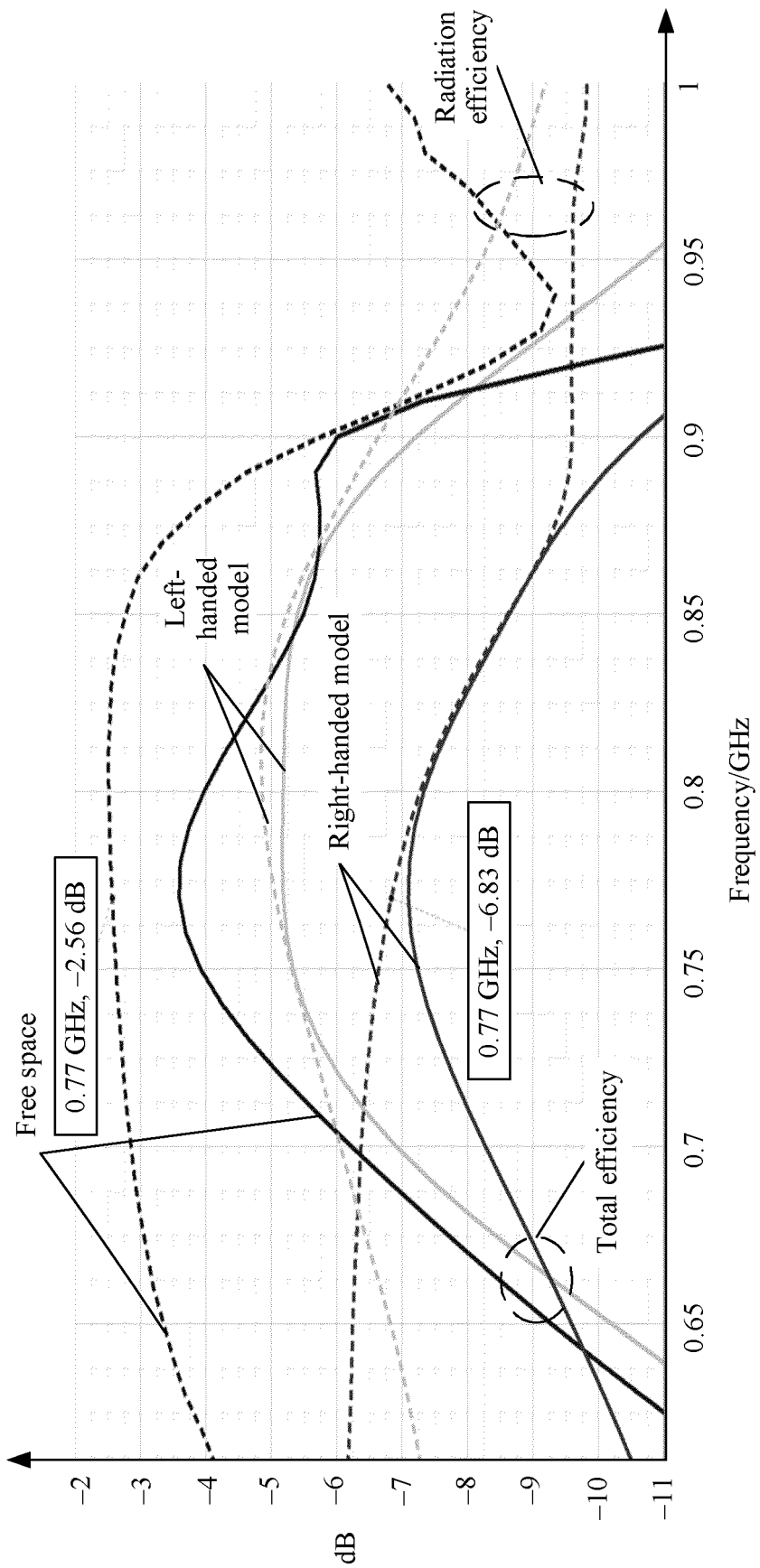


FIG. 69

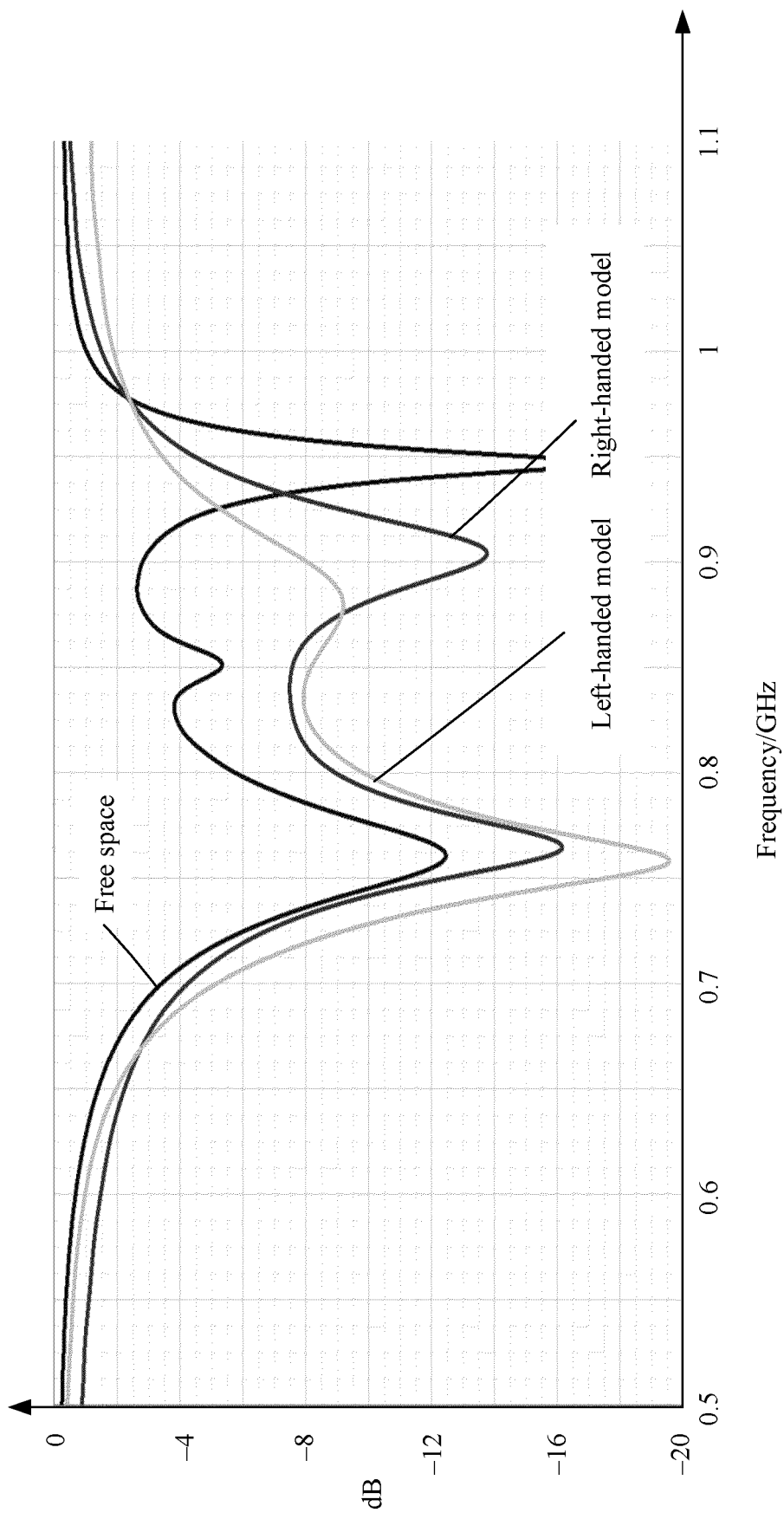


FIG. 70

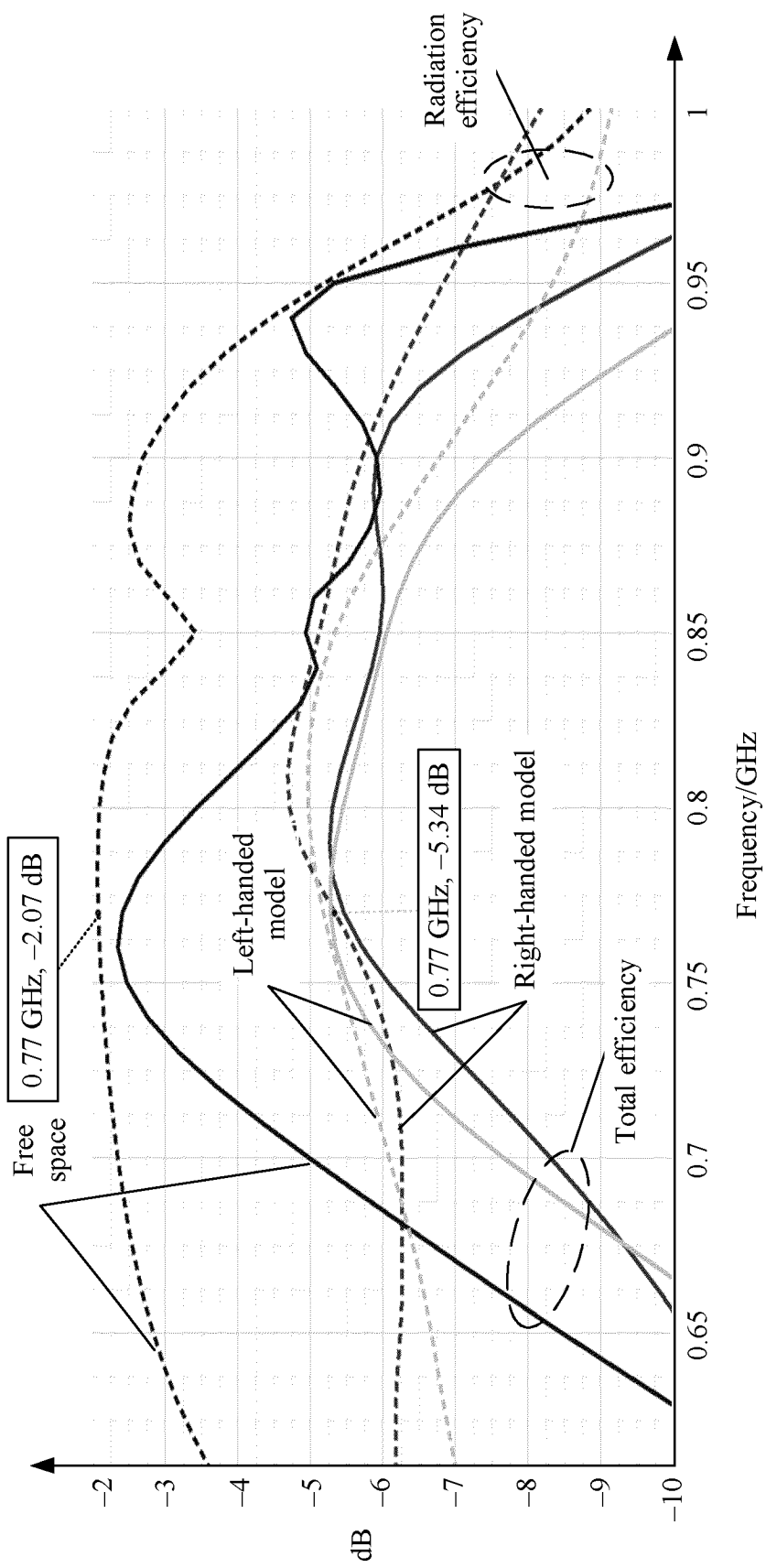


FIG. 71

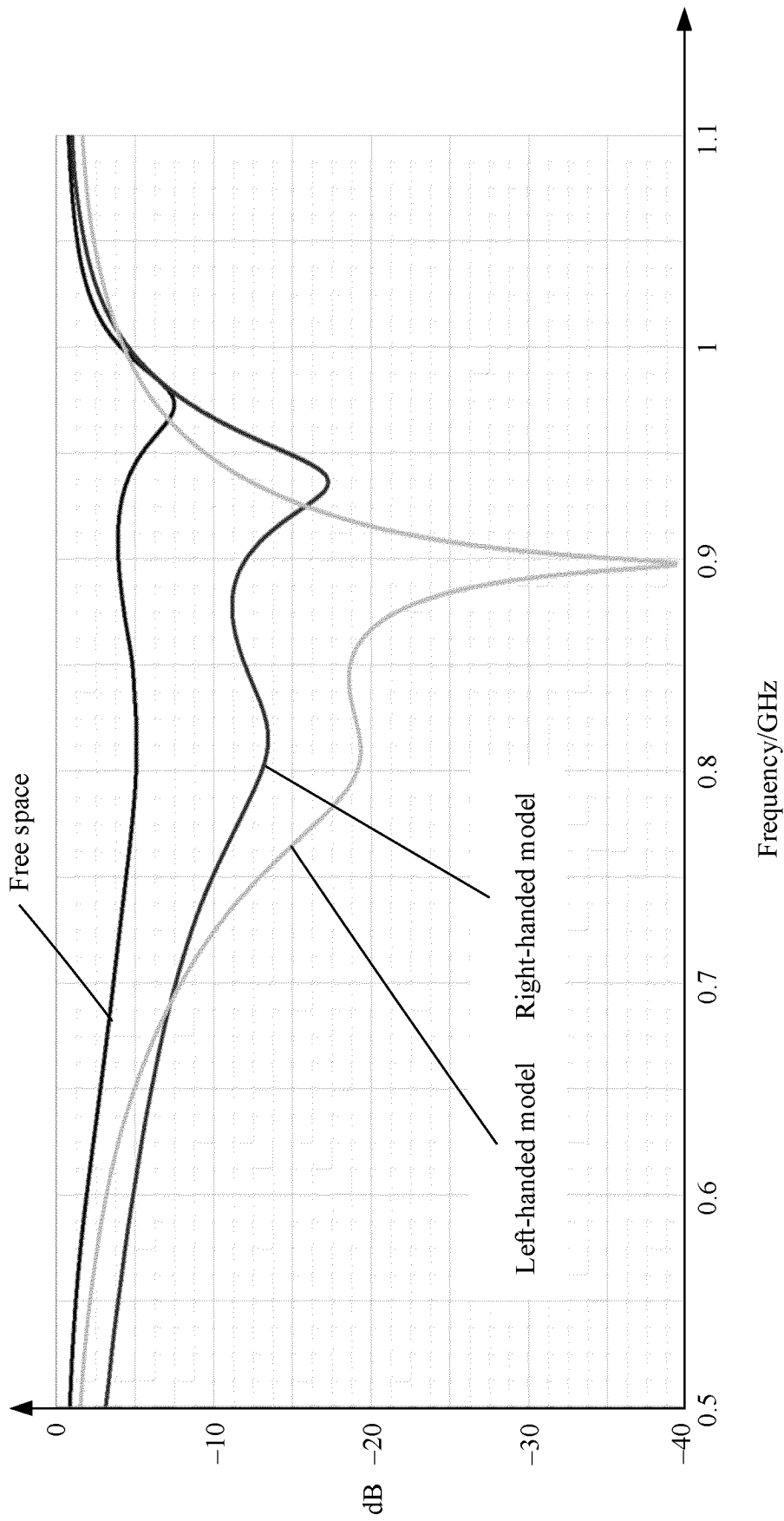


FIG. 72

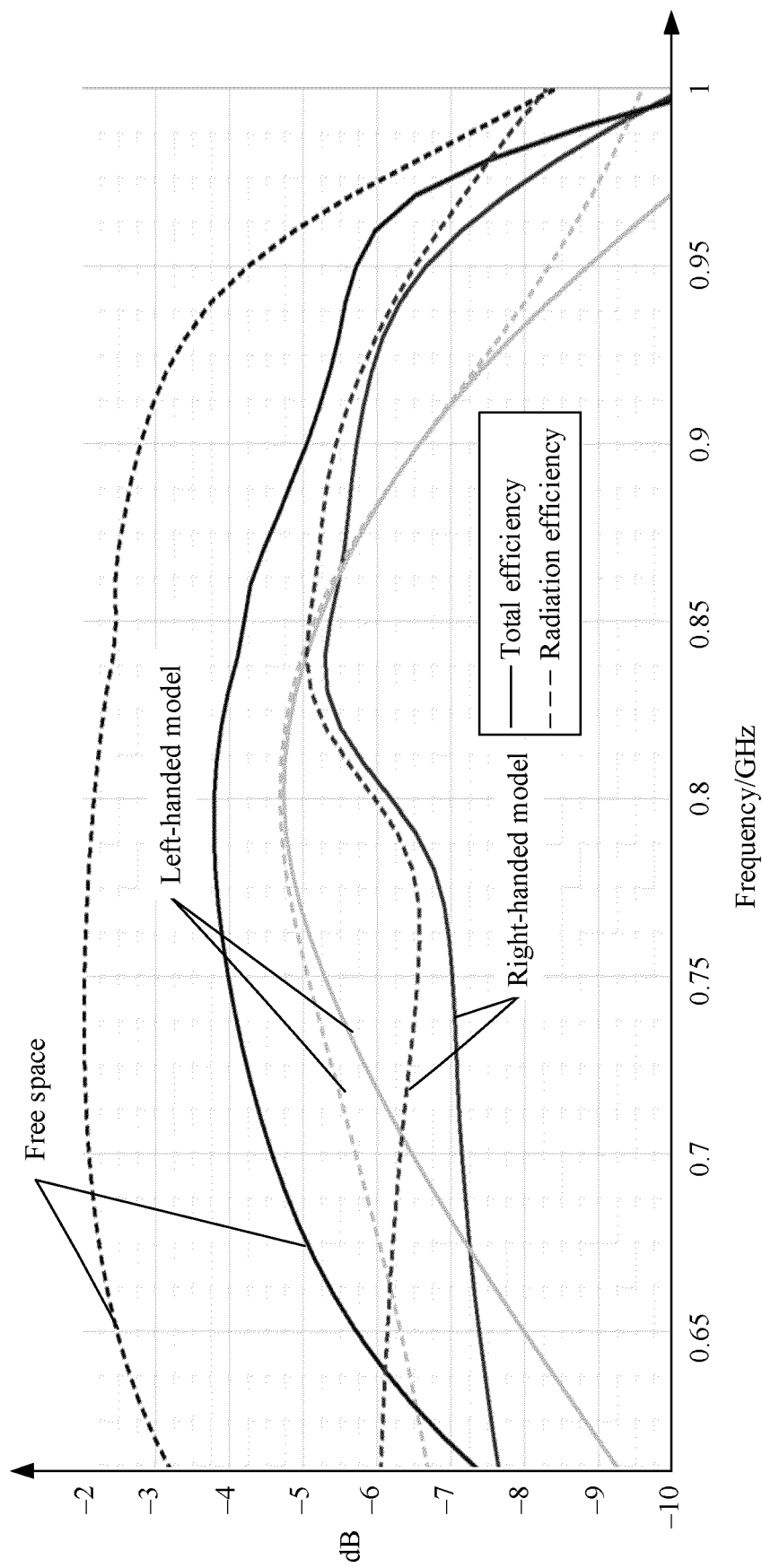
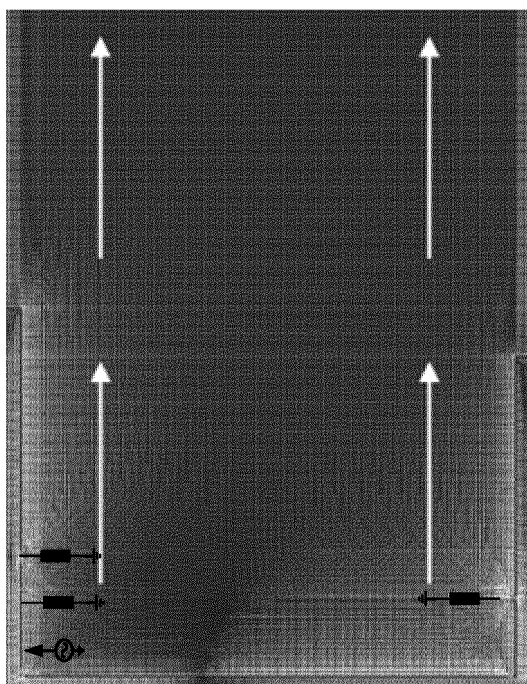
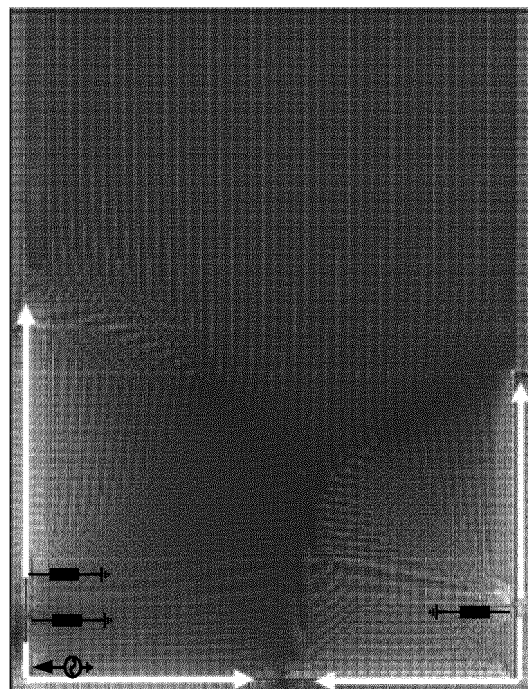


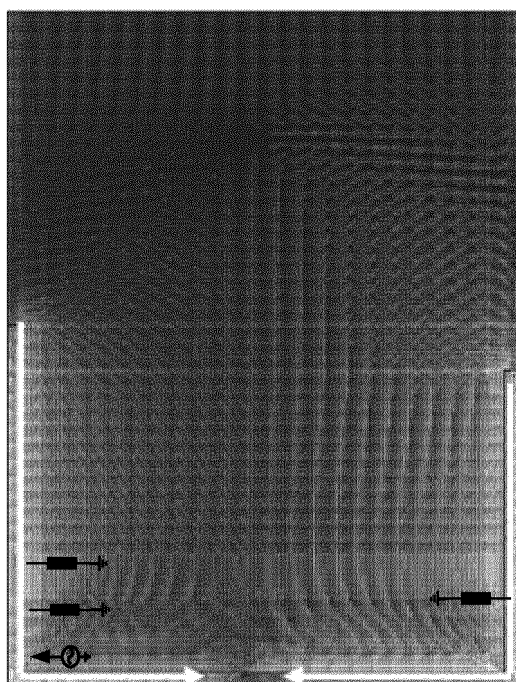
FIG. 73



(a)



(b)



(c)

FIG. 74

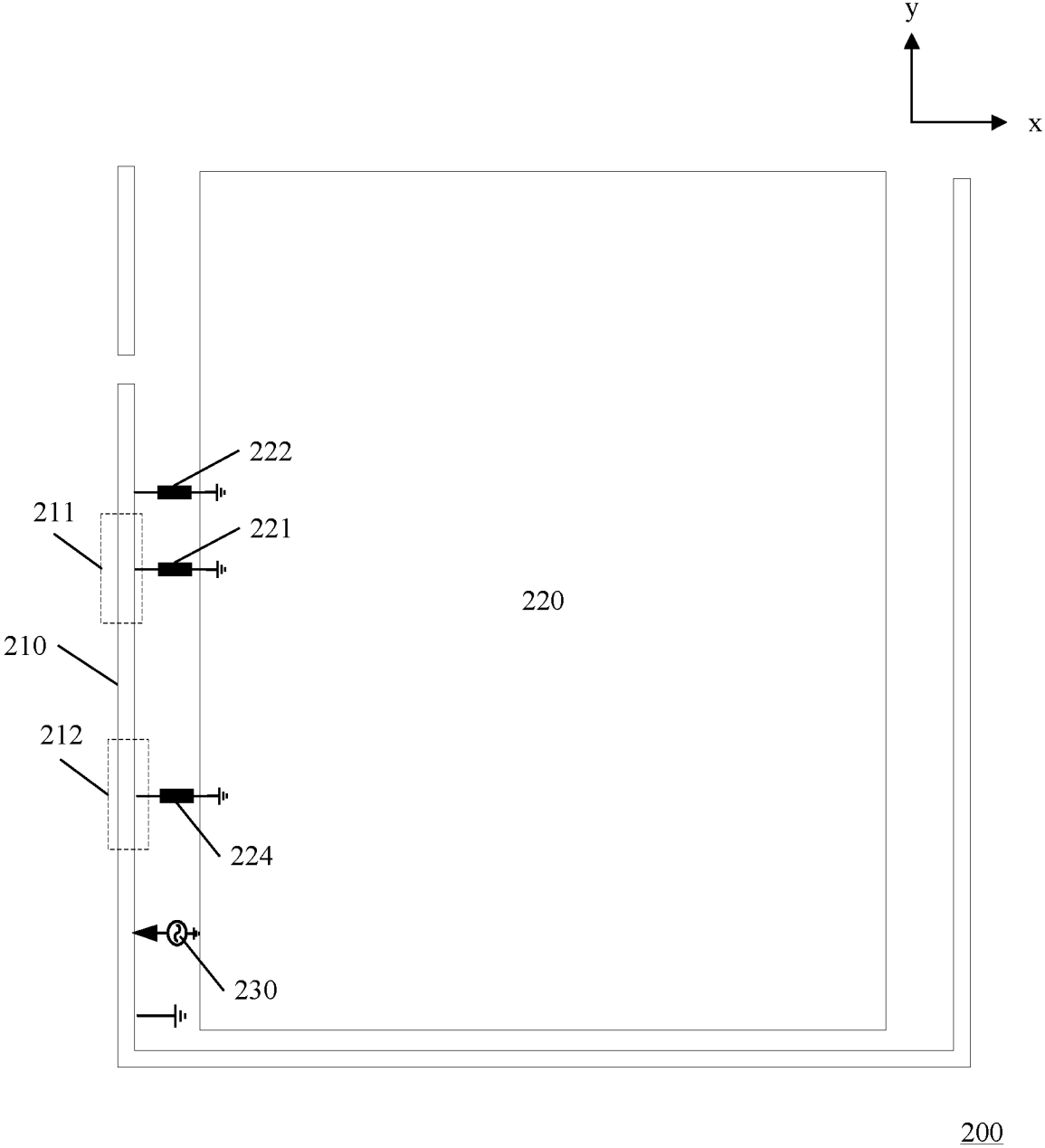


FIG. 75

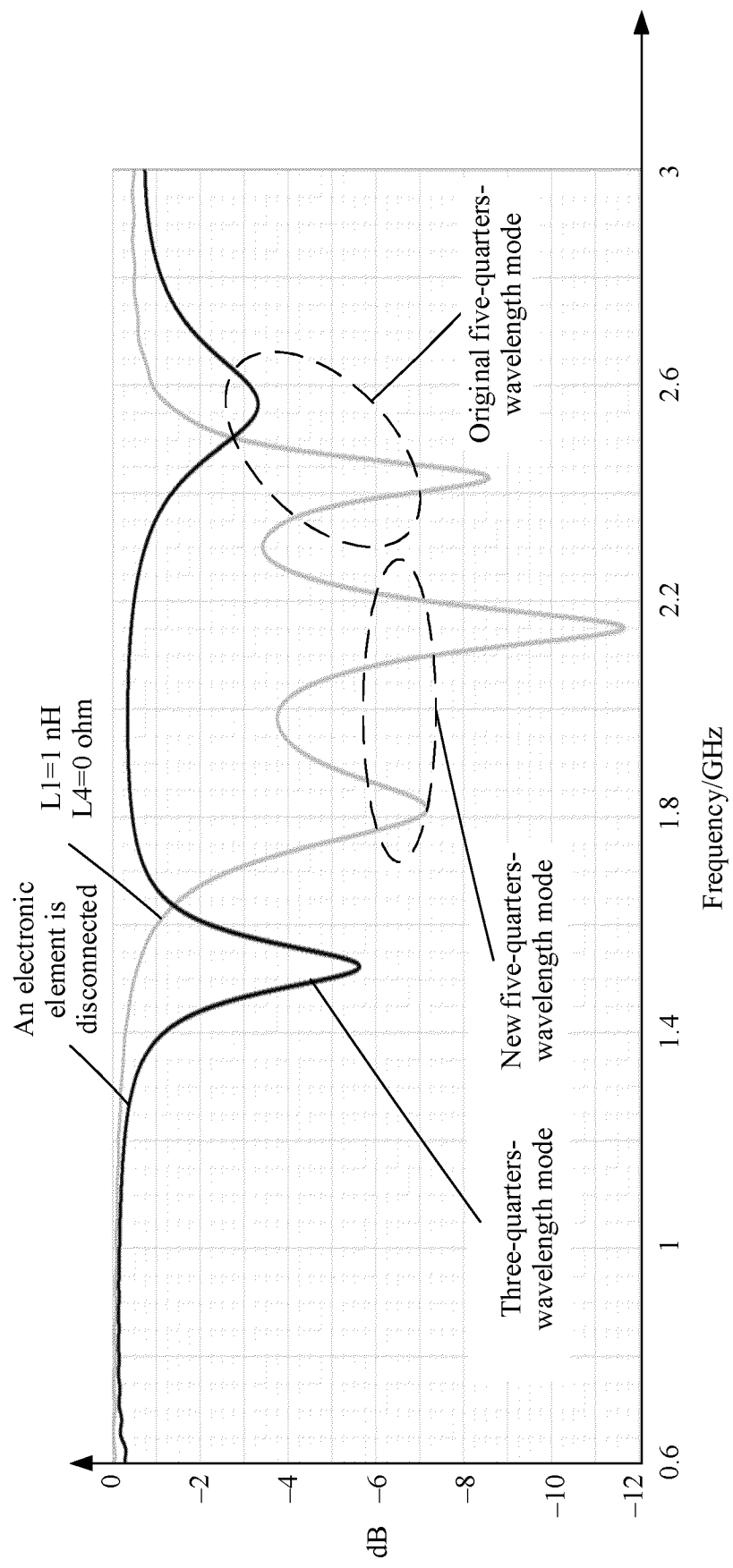


FIG. 76

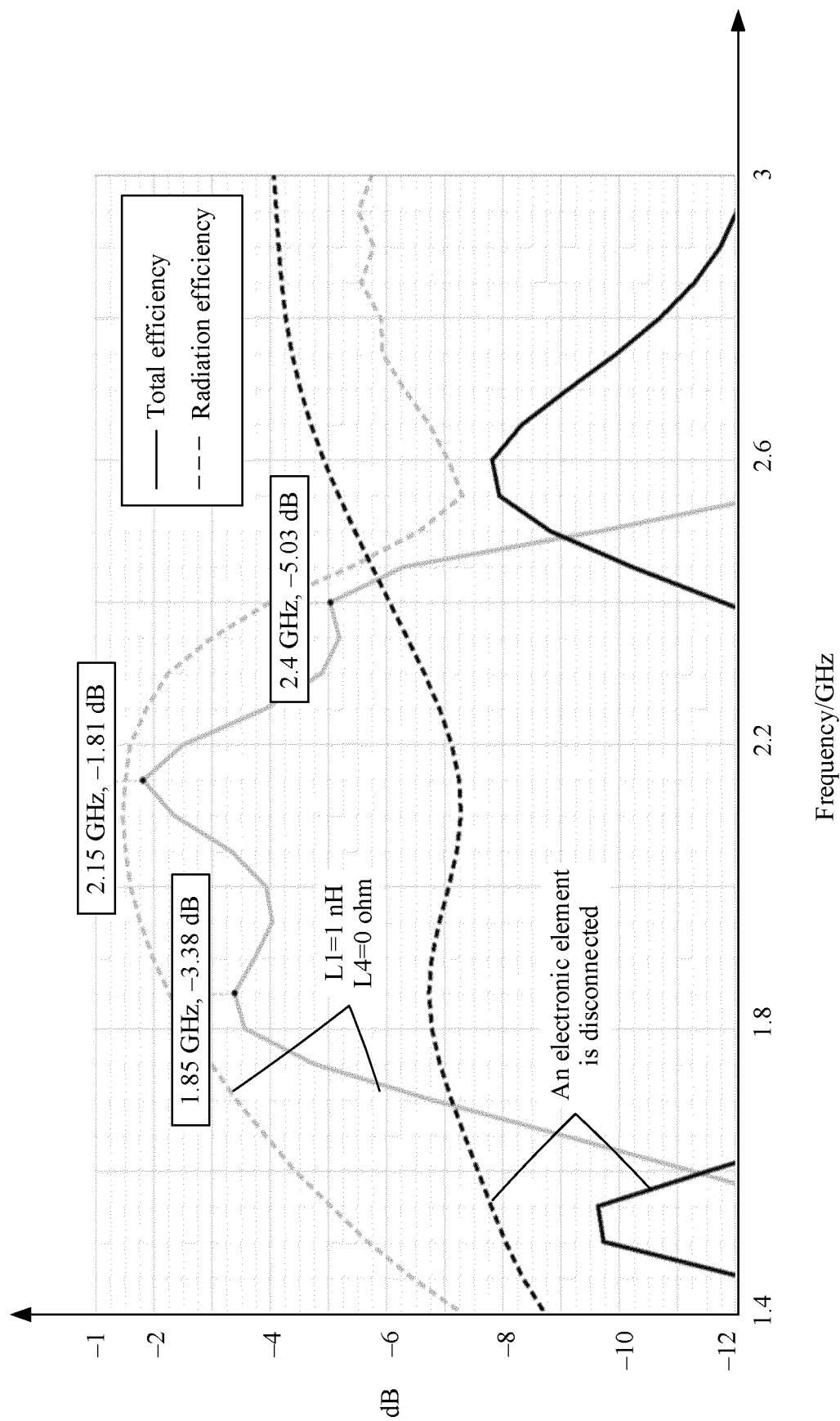
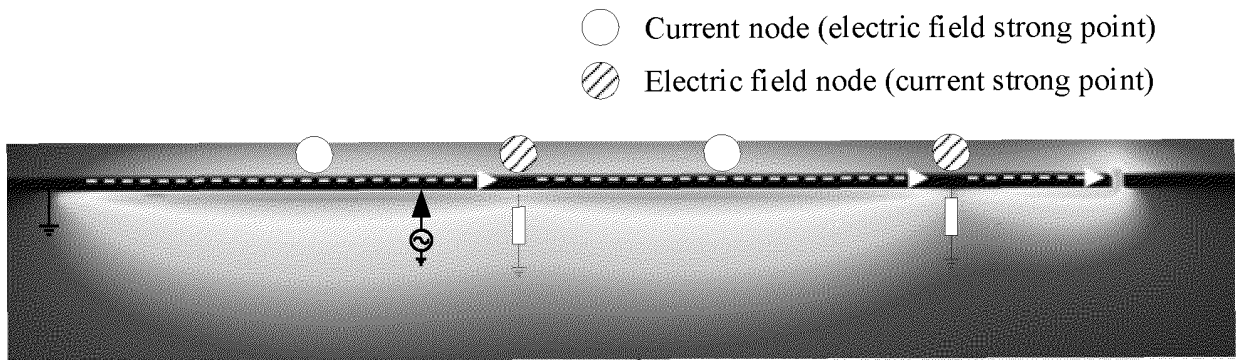
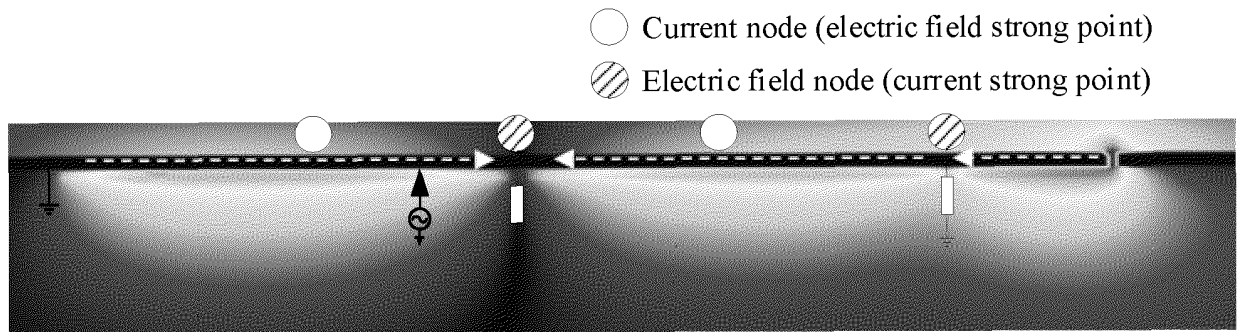


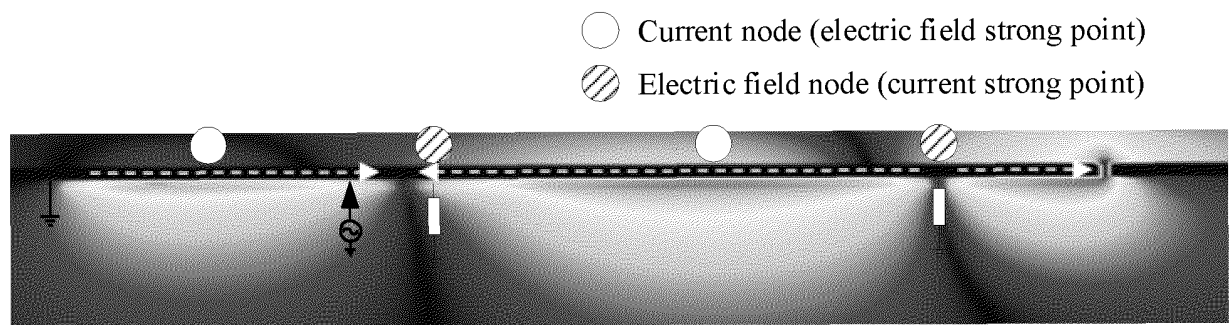
FIG. 77



(a)

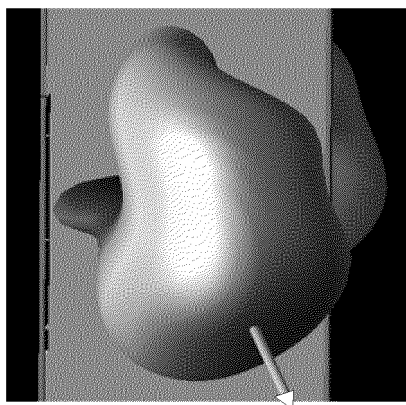


(b)



(c)

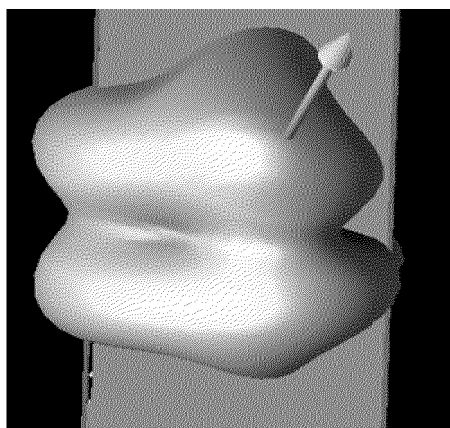
FIG. 78



Direction of maximum radiation

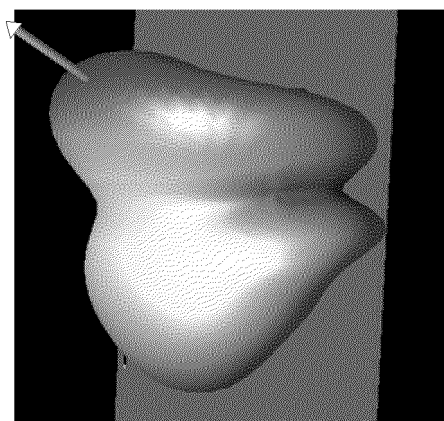
(a)

Direction of maximum radiation



(b)

Direction of maximum radiation



(c)

FIG. 79

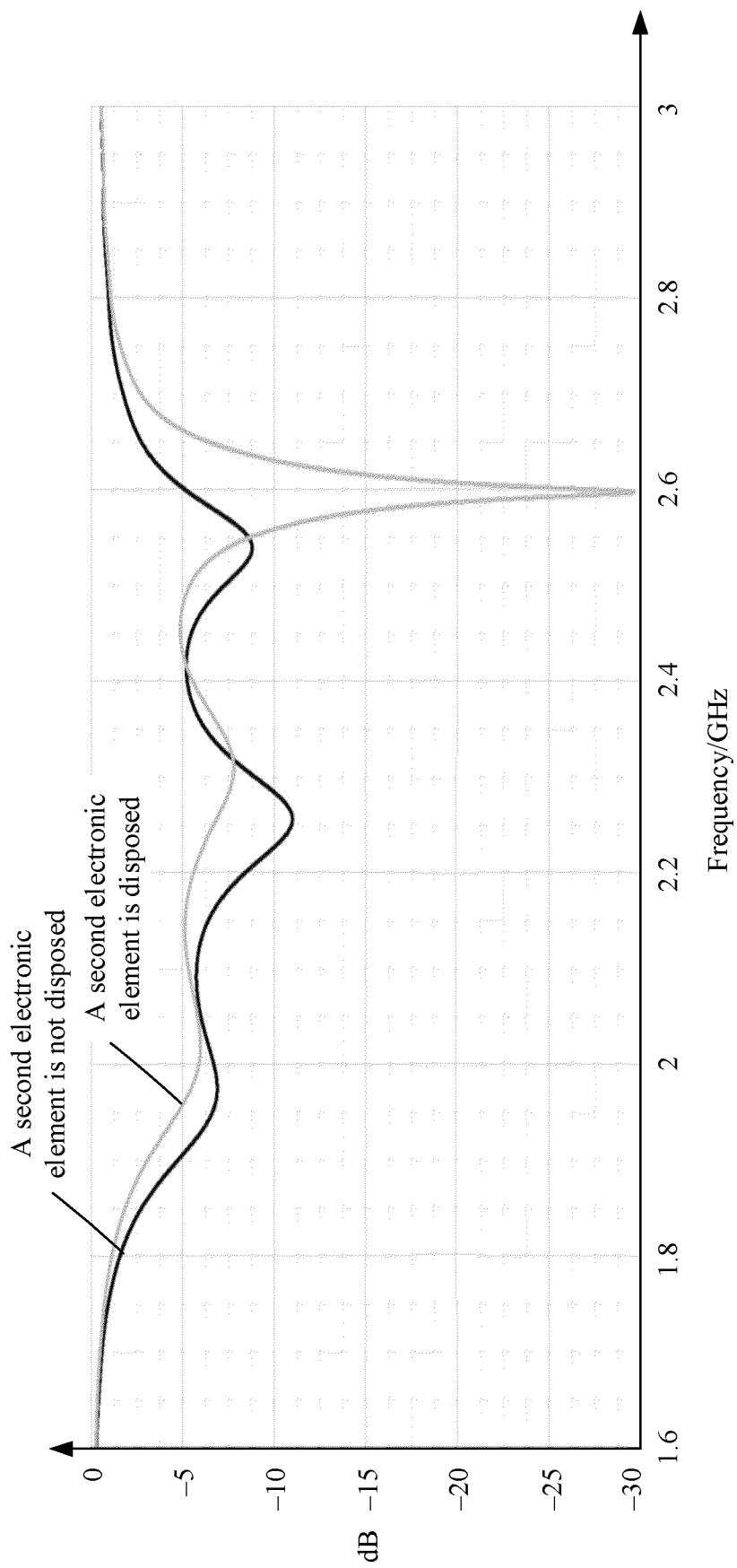


FIG. 80

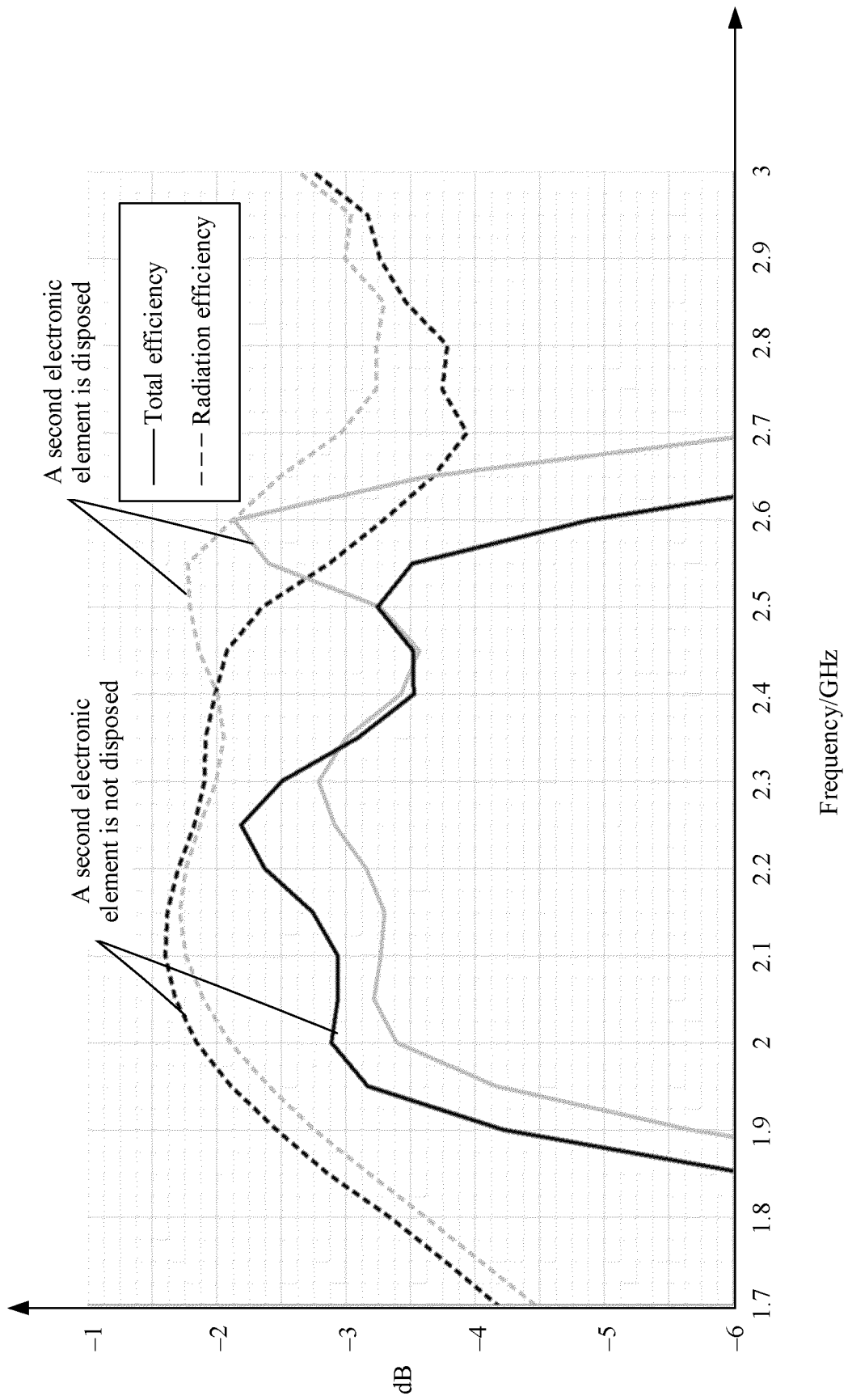


FIG. 81

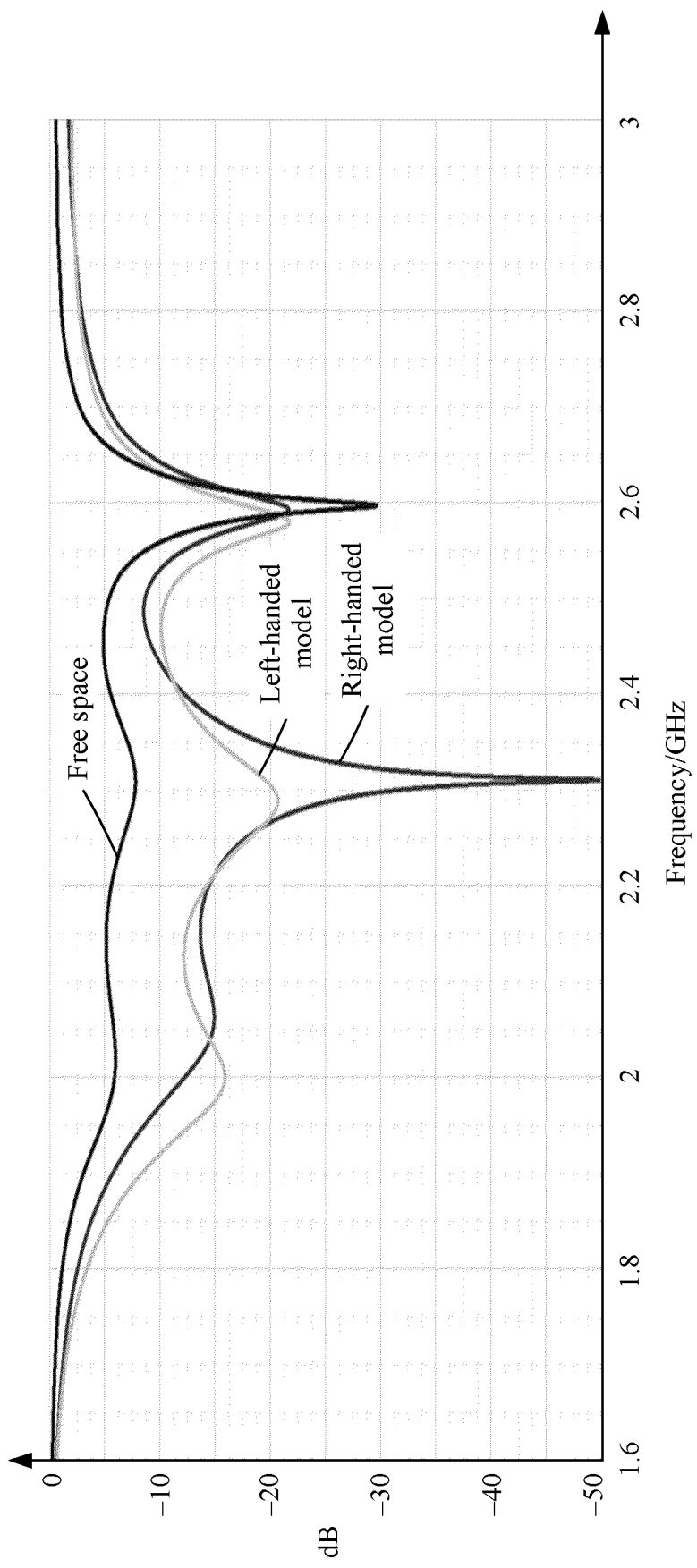


FIG. 82

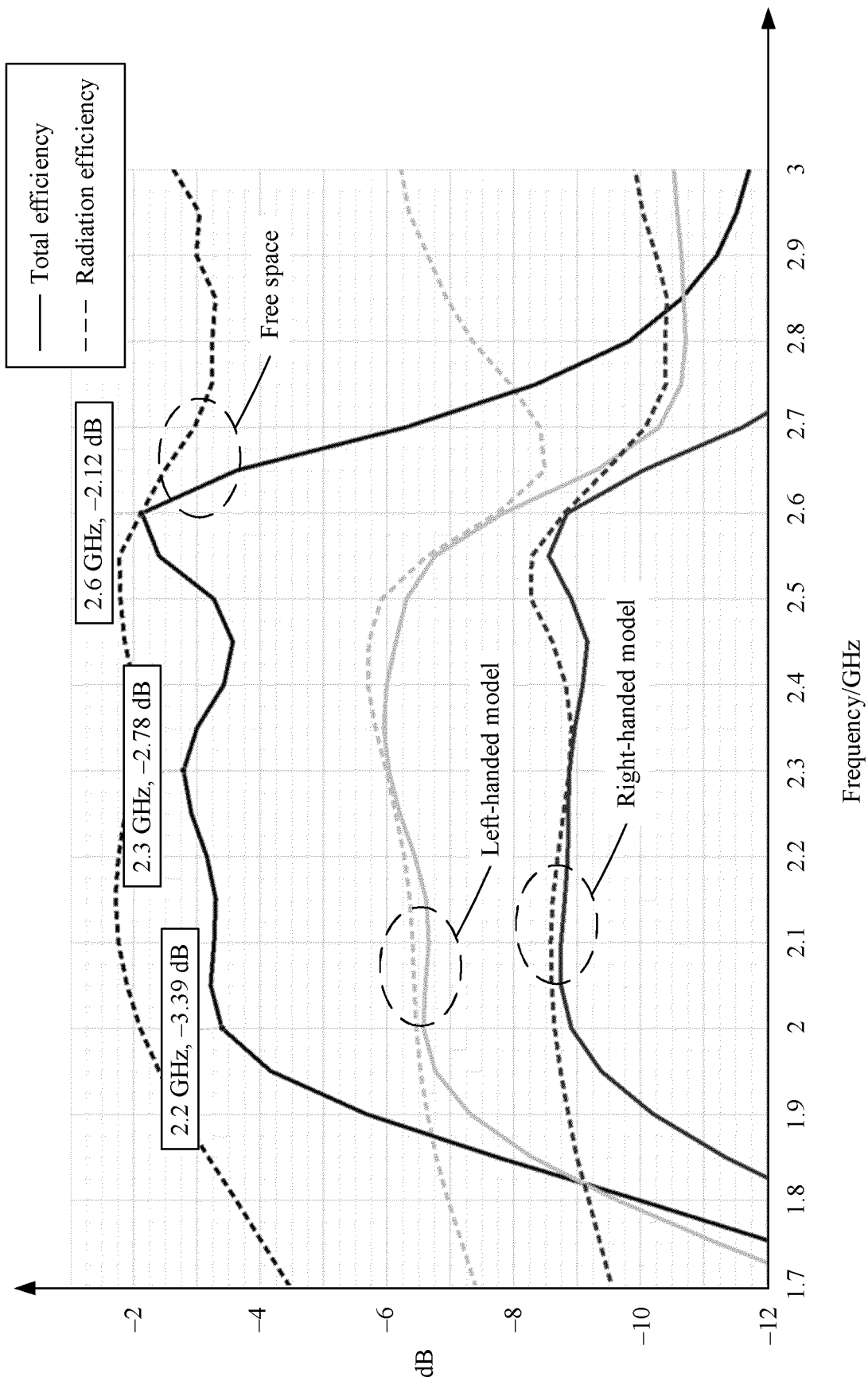


FIG. 83

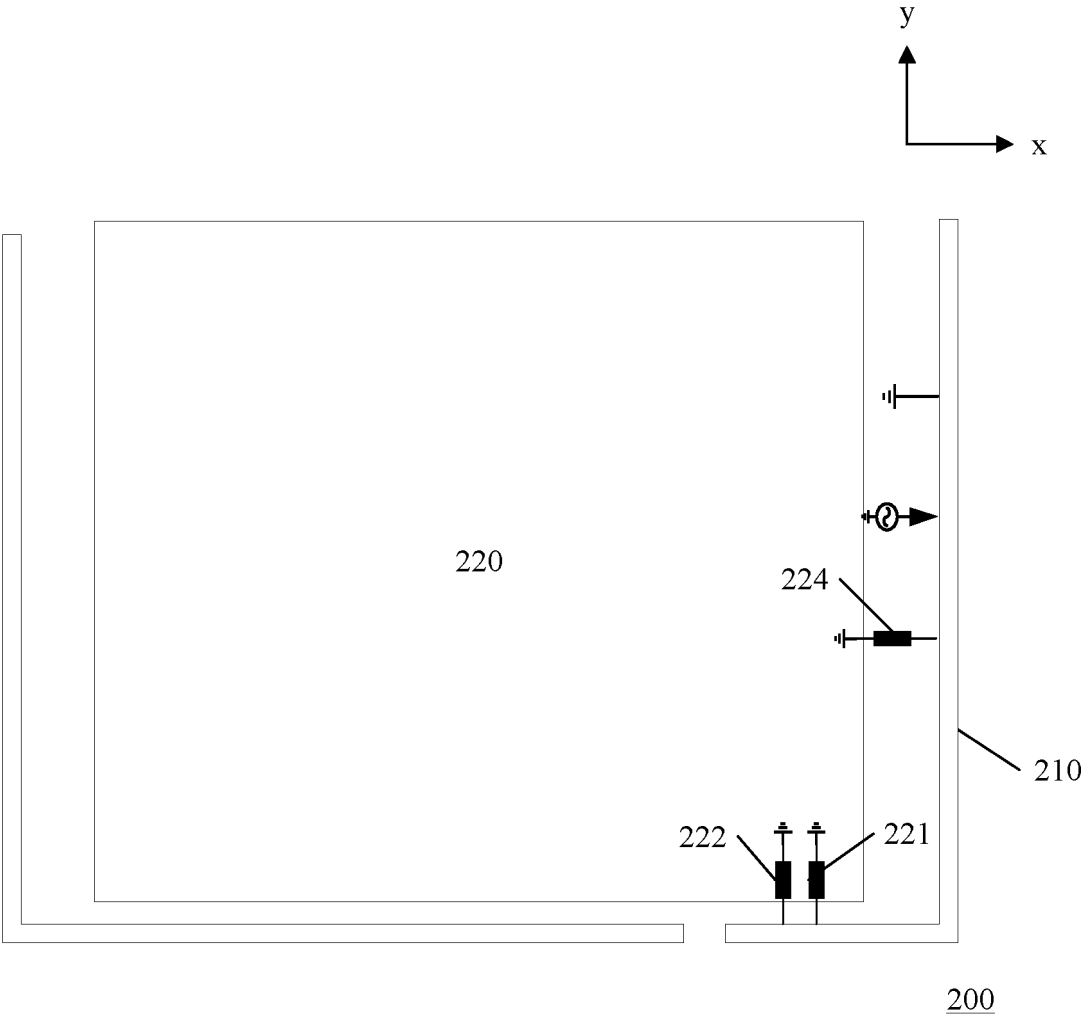
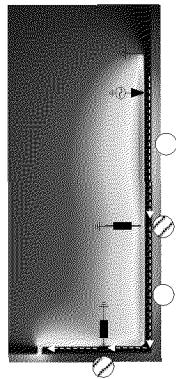


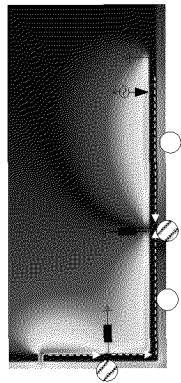
FIG. 84

- Current node (electric field strong point)
- ⊗ Electric field node (current strong point)



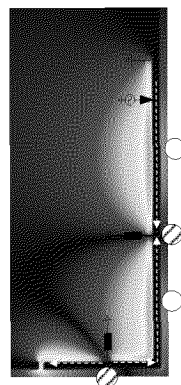
(a)

- Current node (electric field strong point)
- ⊗ Electric field node (current strong point)



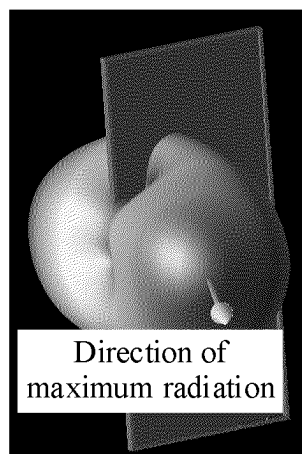
(b)

- Current node (electric field strong point)
- ⊗ Electric field node (current strong point)

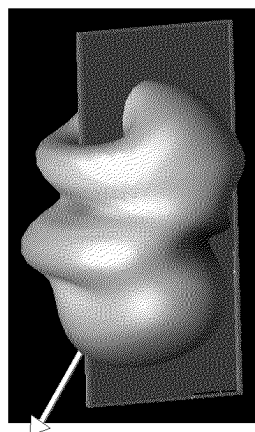


(c)

FIG. 85

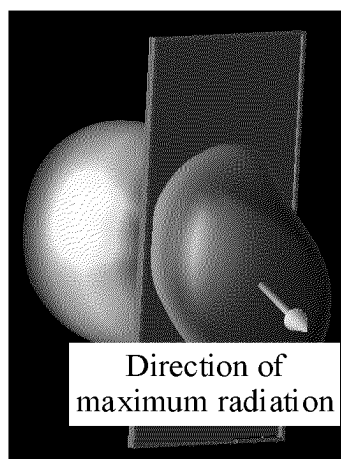


(a)



Direction of maximum radiation

(b)



(c)

FIG. 86

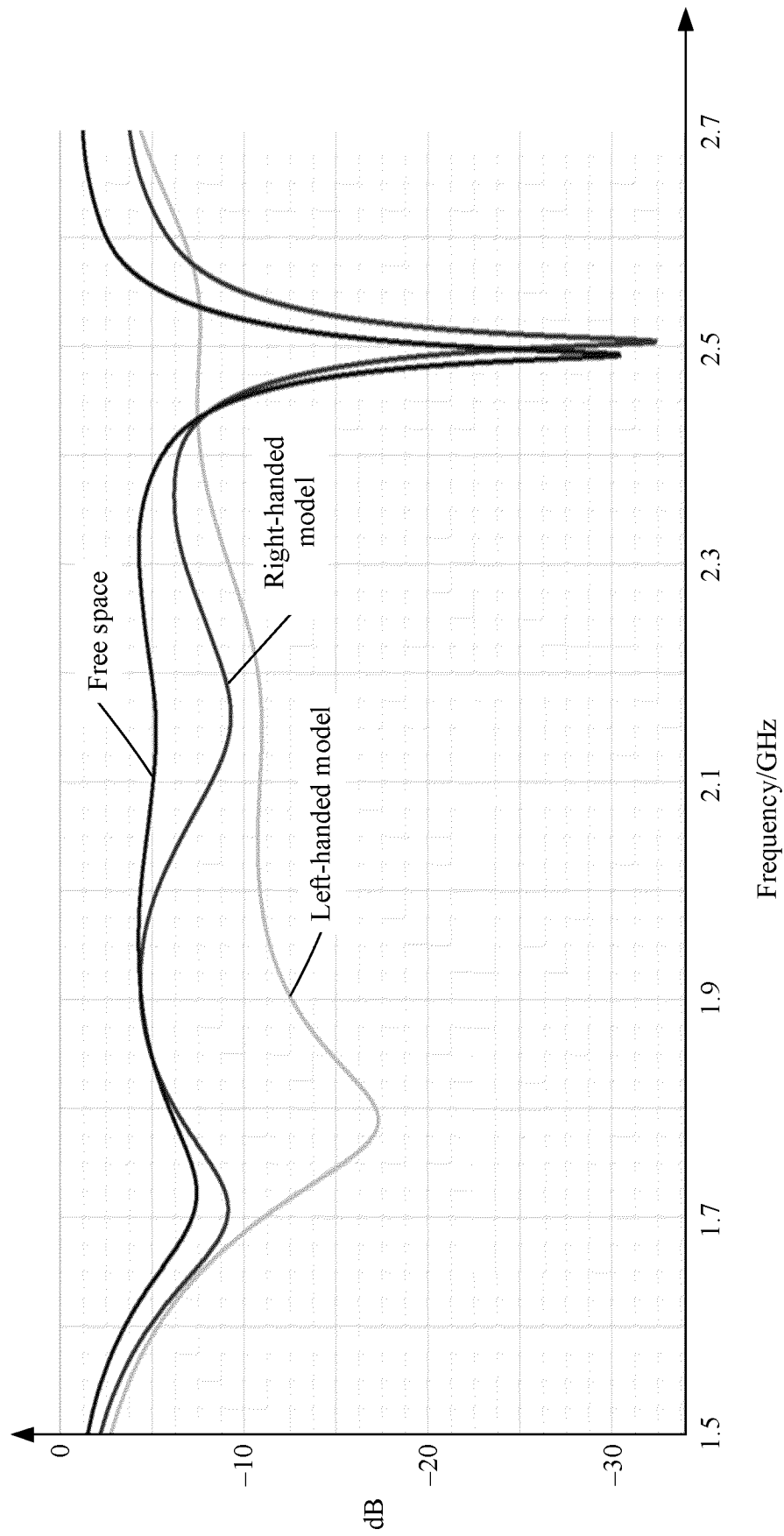


FIG. 87

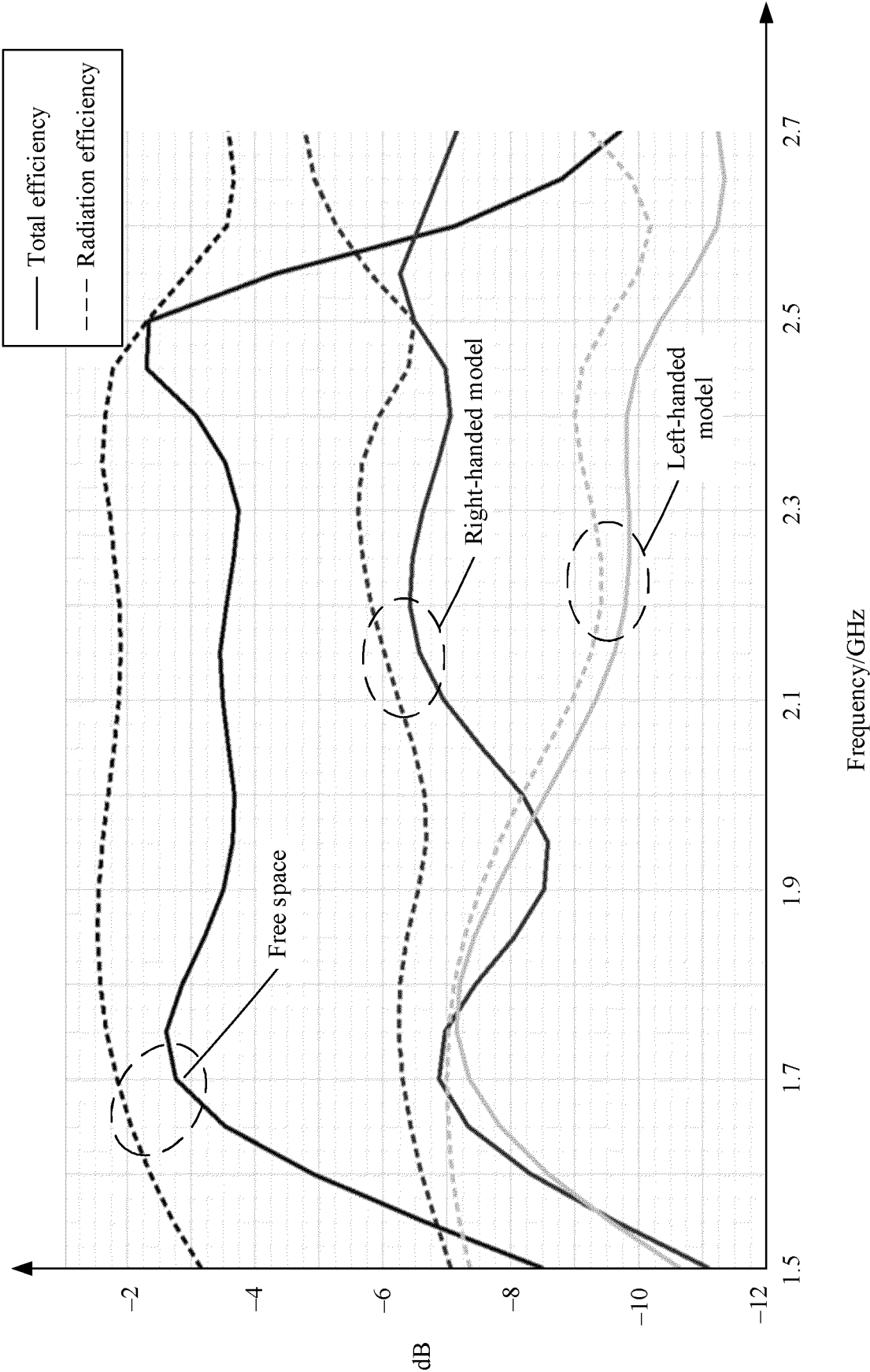


FIG. 88

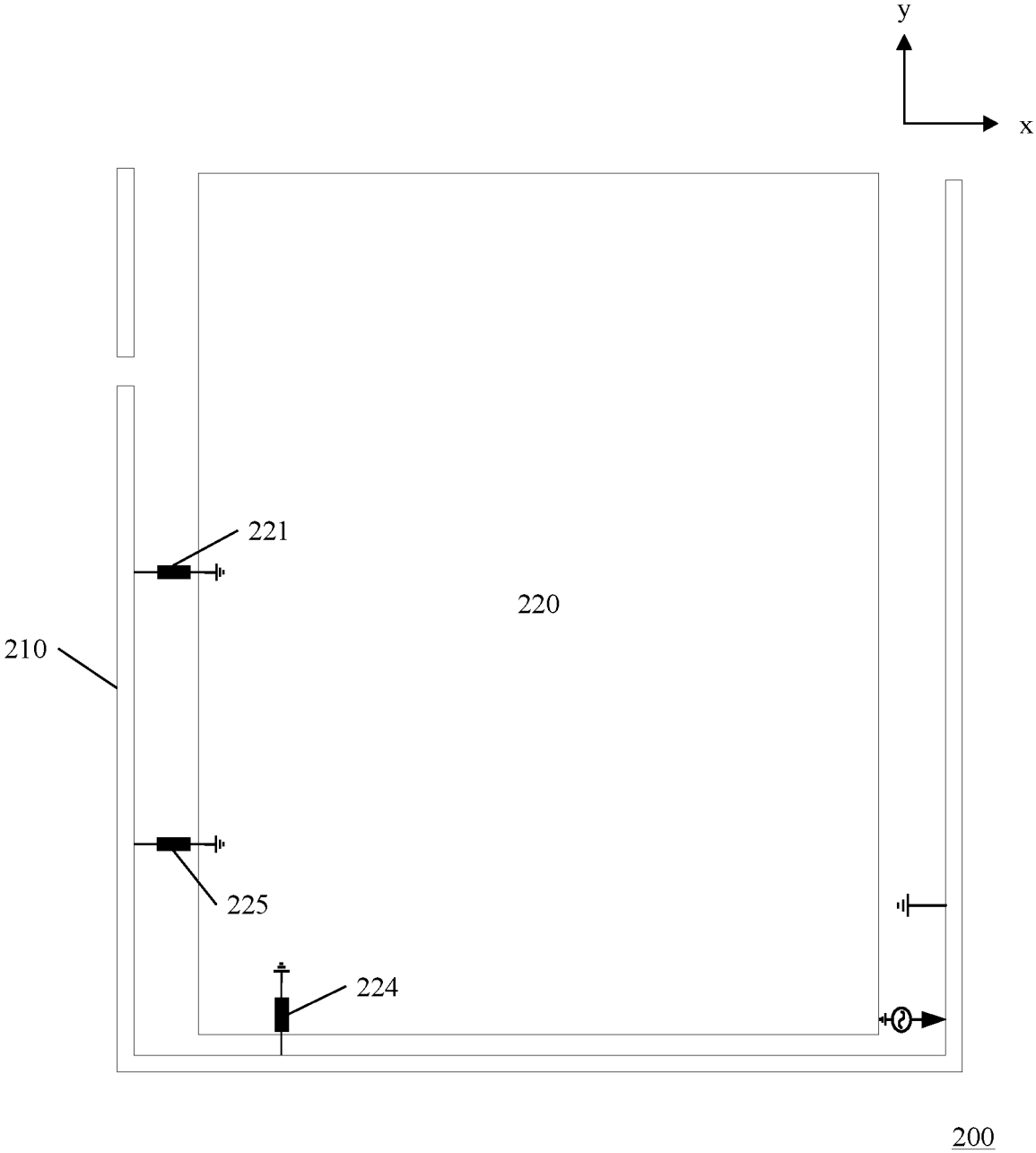


FIG. 89

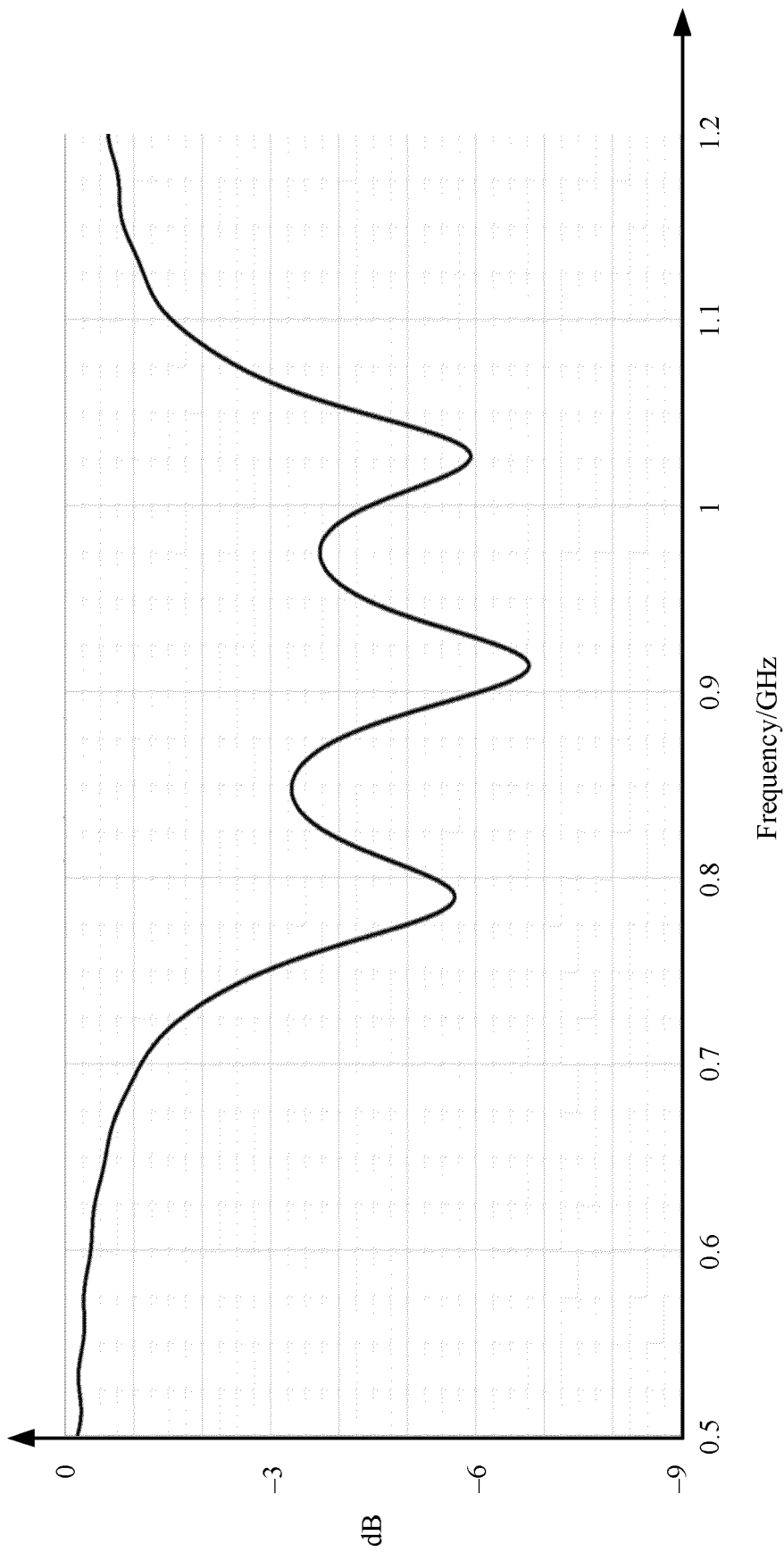


FIG. 90

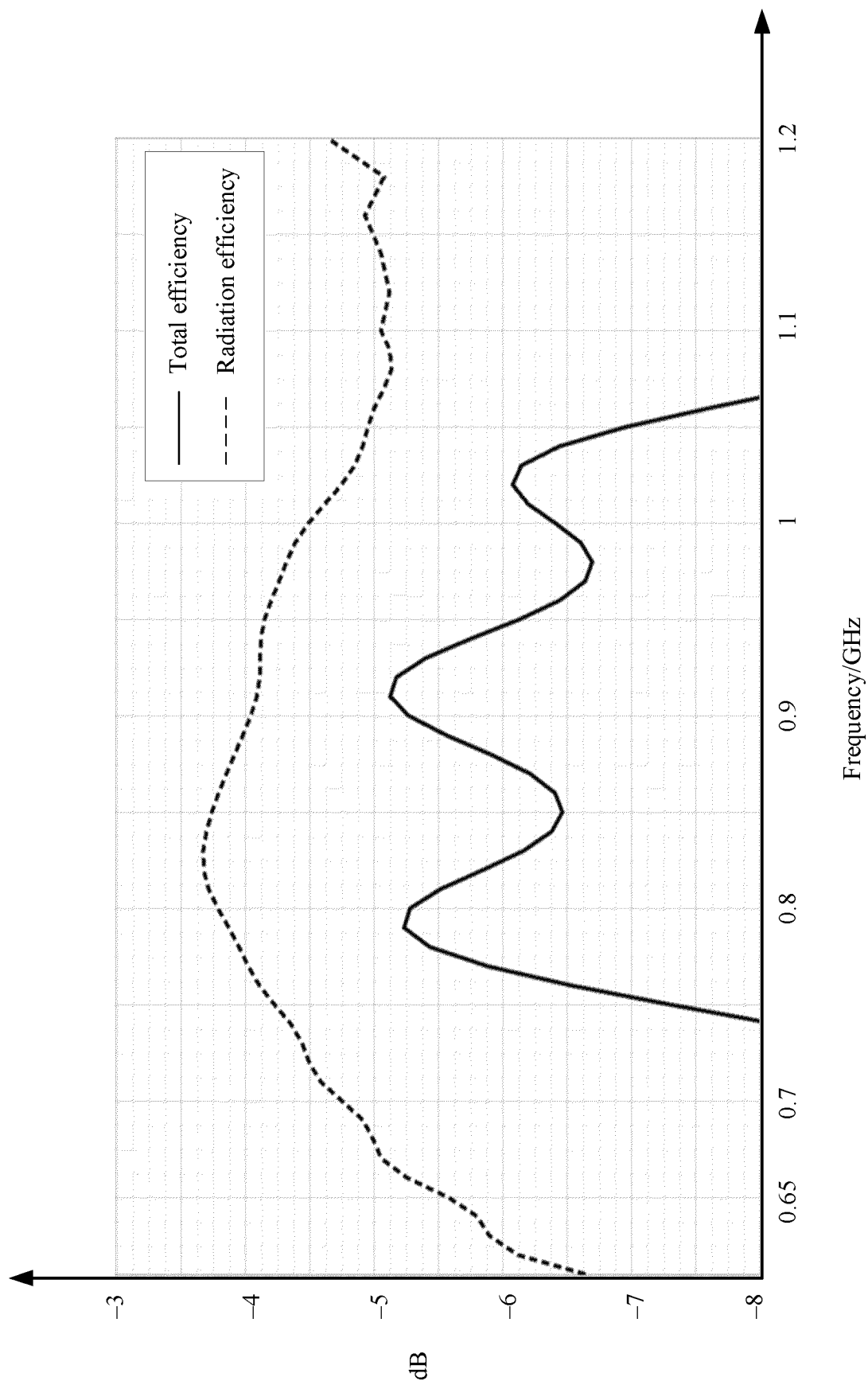
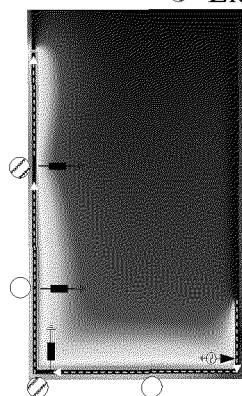


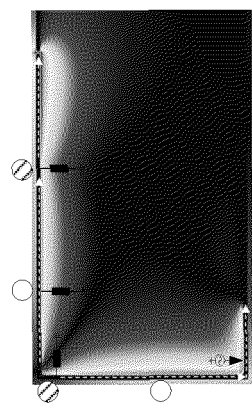
FIG. 91

- Current node (electric field strong point)
- ⊗ Electric field node (current strong point)



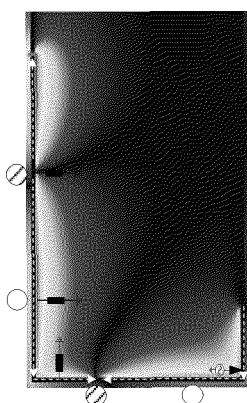
(a)

- Current node (electric field strong point)
- ⊗ Electric field node (current strong point)



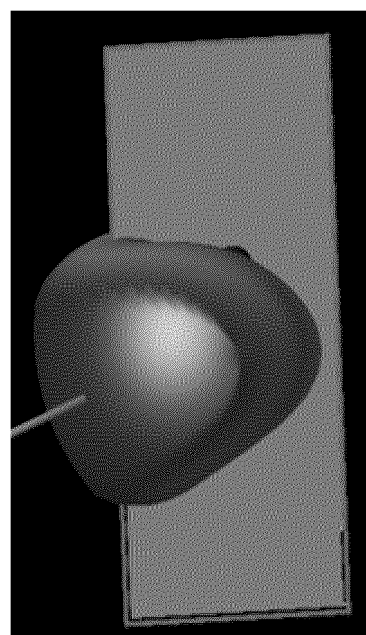
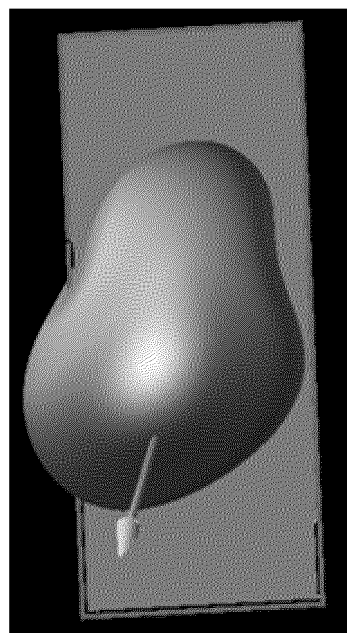
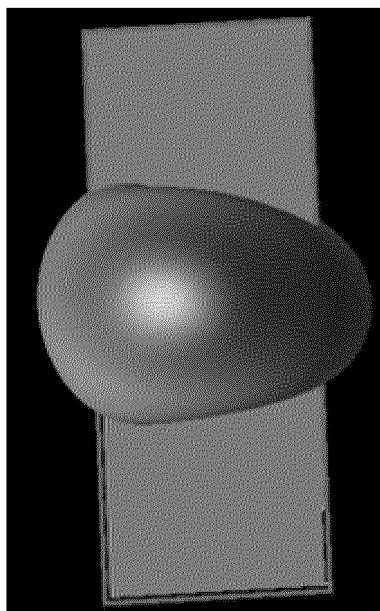
(b)

- Current node (electric field strong point)
- ⊗ Electric field node (current strong point)



(c)

FIG. 92



(a)

(b)

(c)

FIG. 93

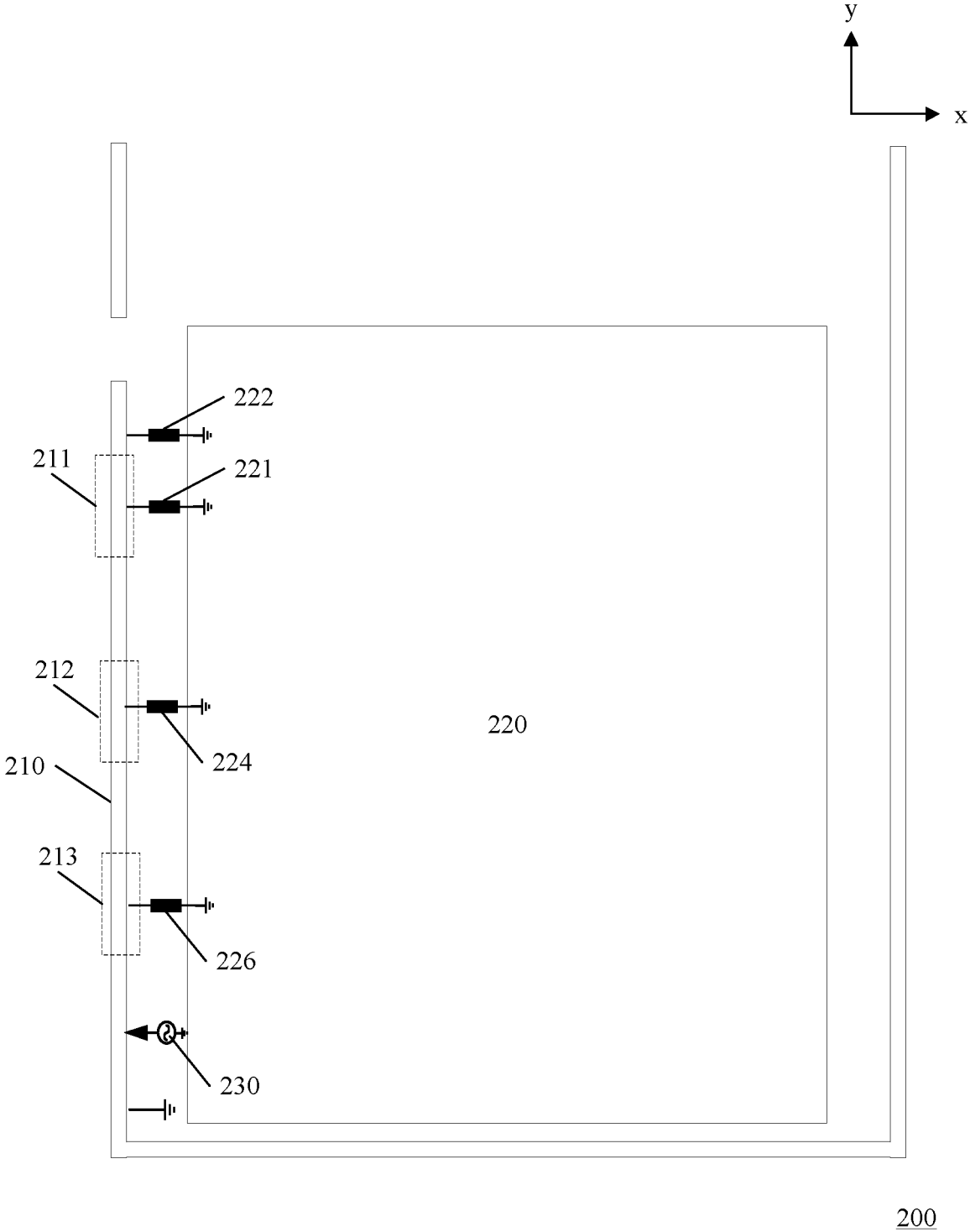


FIG. 94

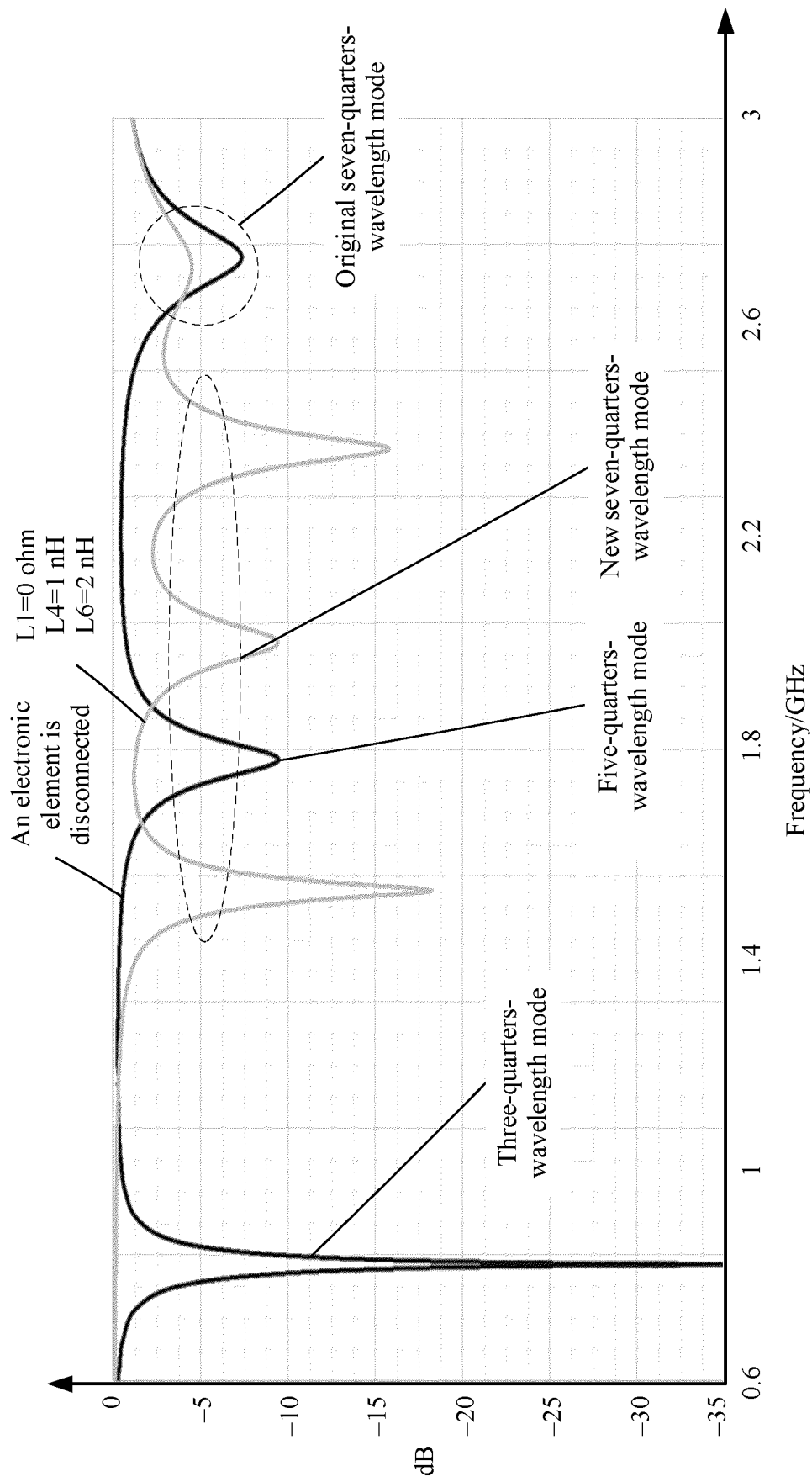


FIG. 95

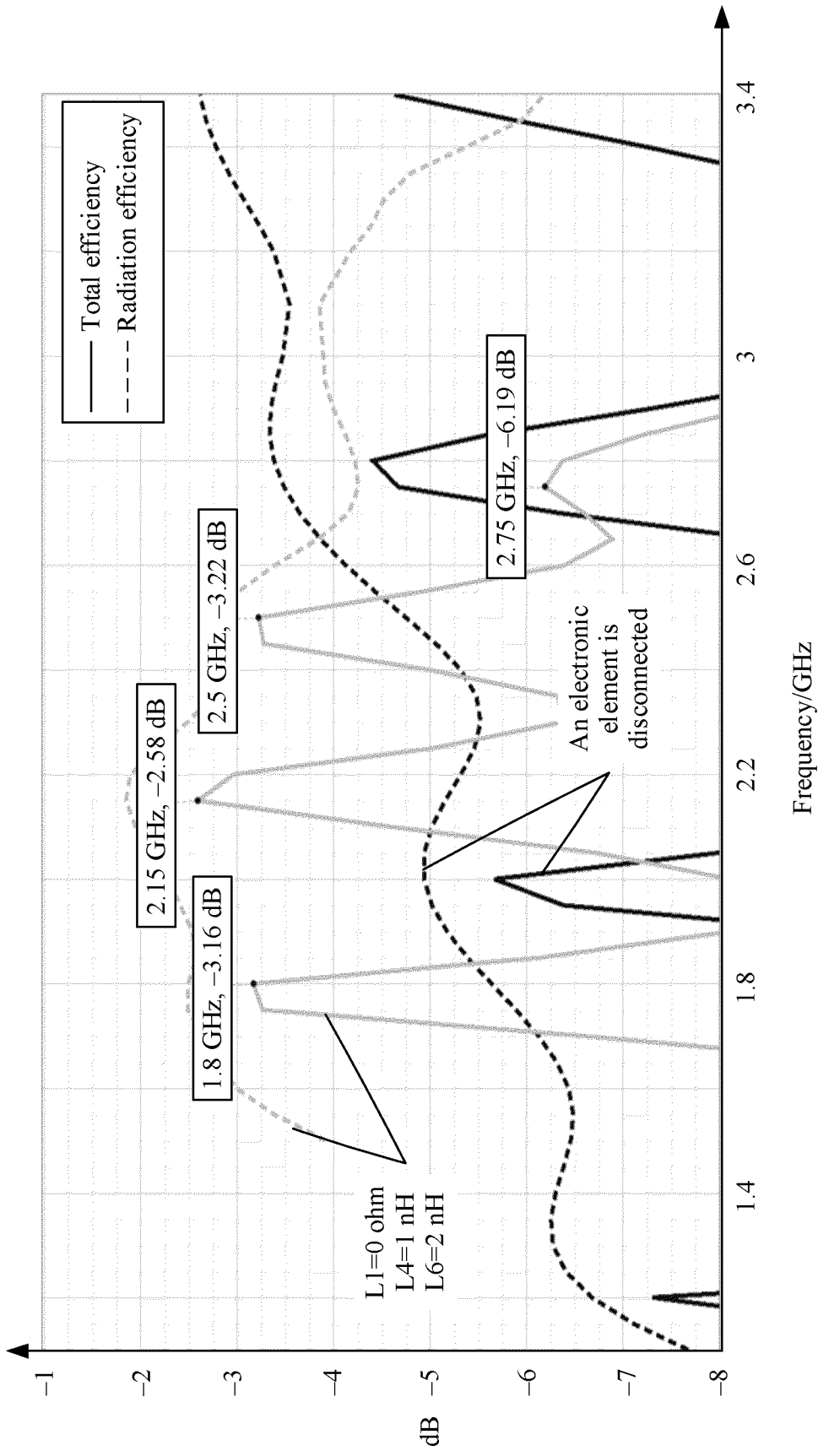
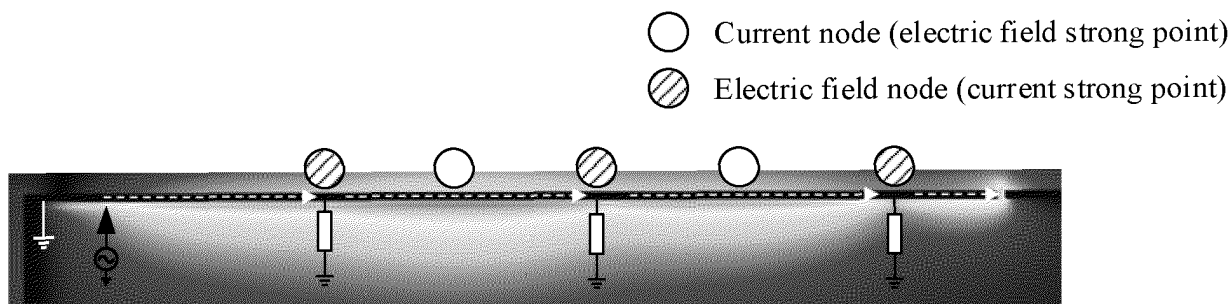
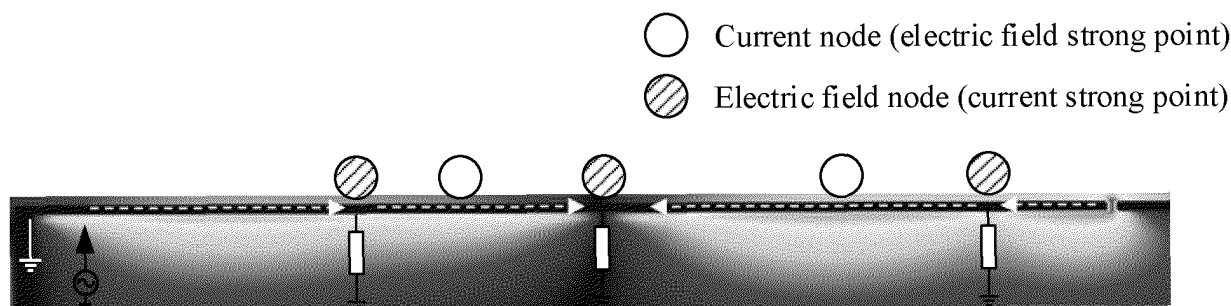


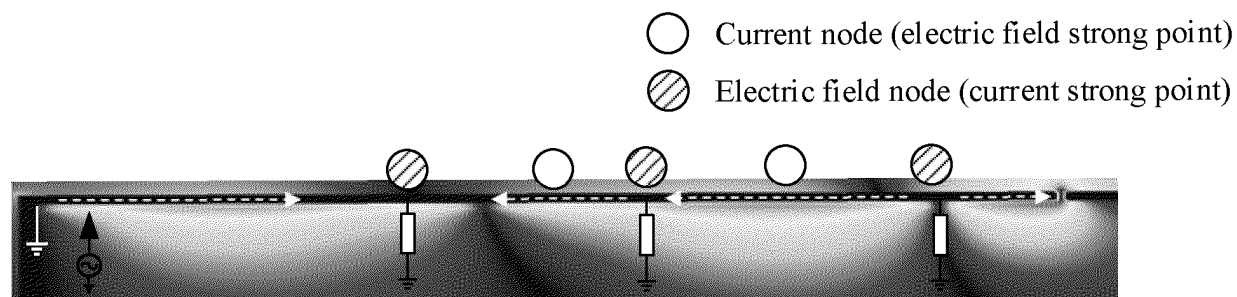
FIG. 96



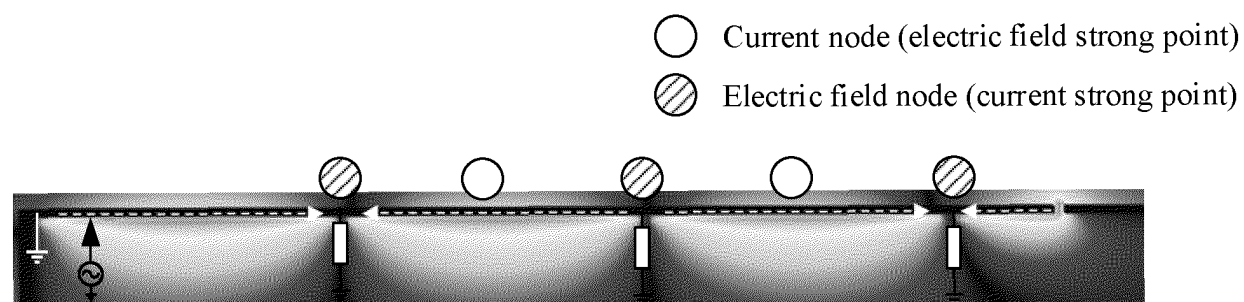
(a)



(b)

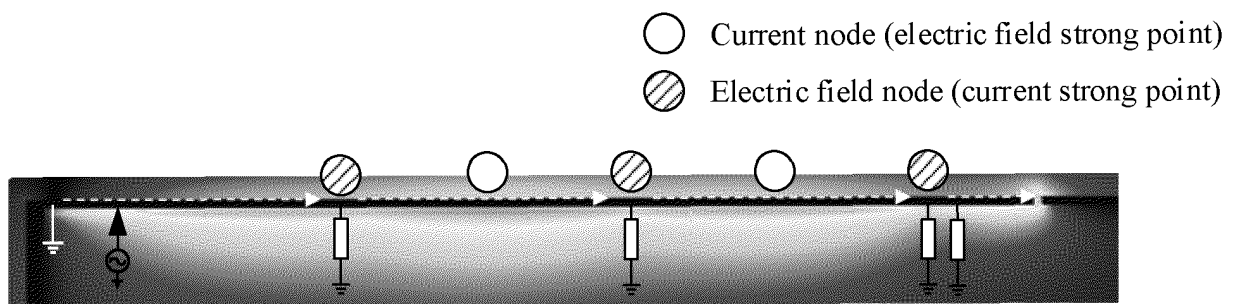


(c)

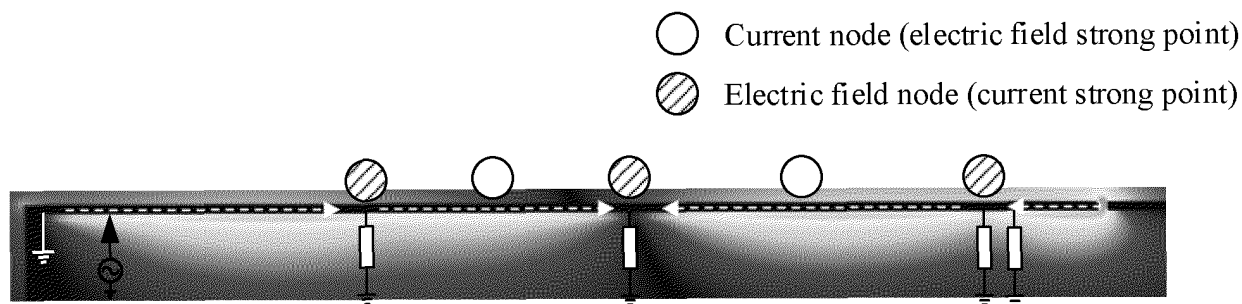


(d)

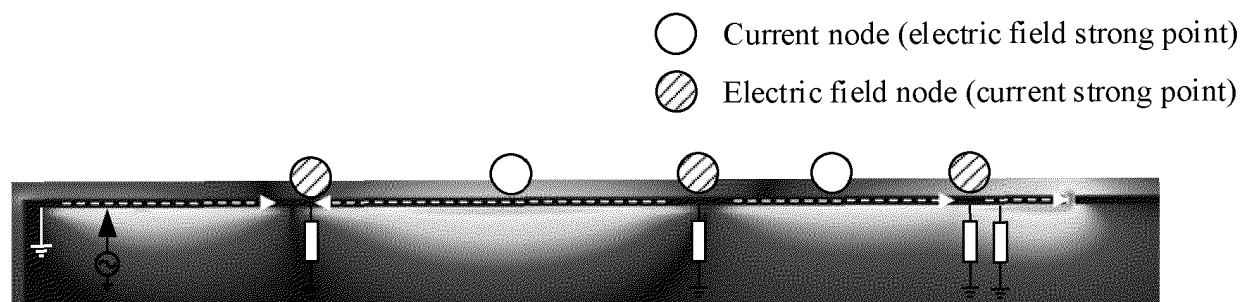
FIG. 97



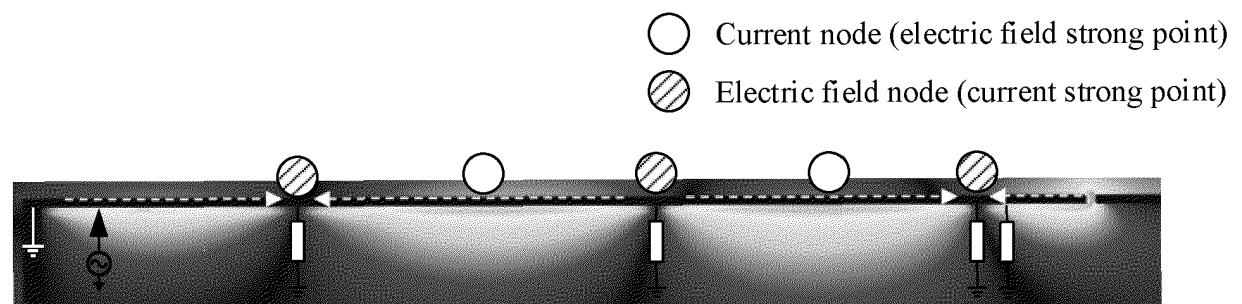
(a)



(b)



(c)



(d)

FIG. 98

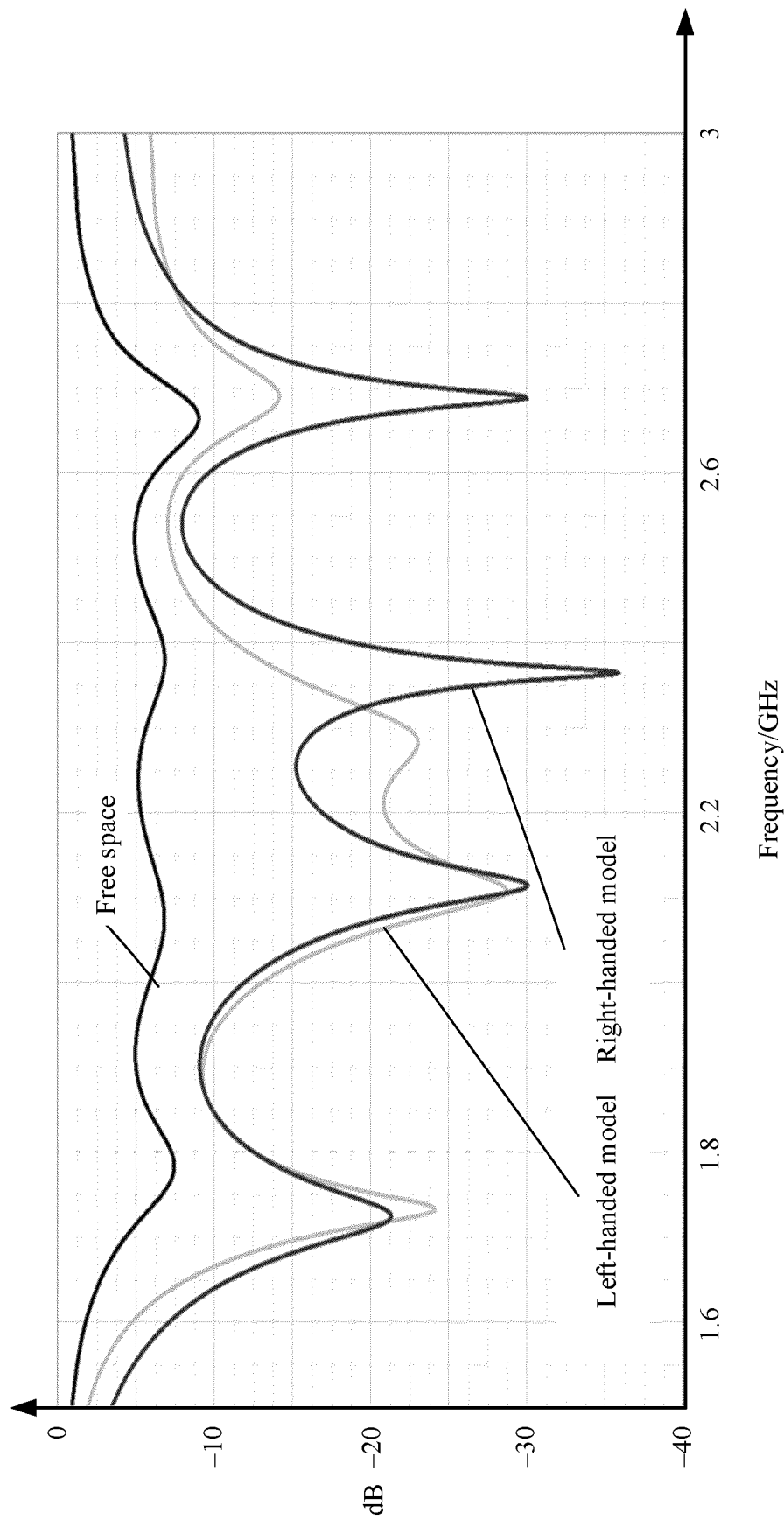


FIG. 99

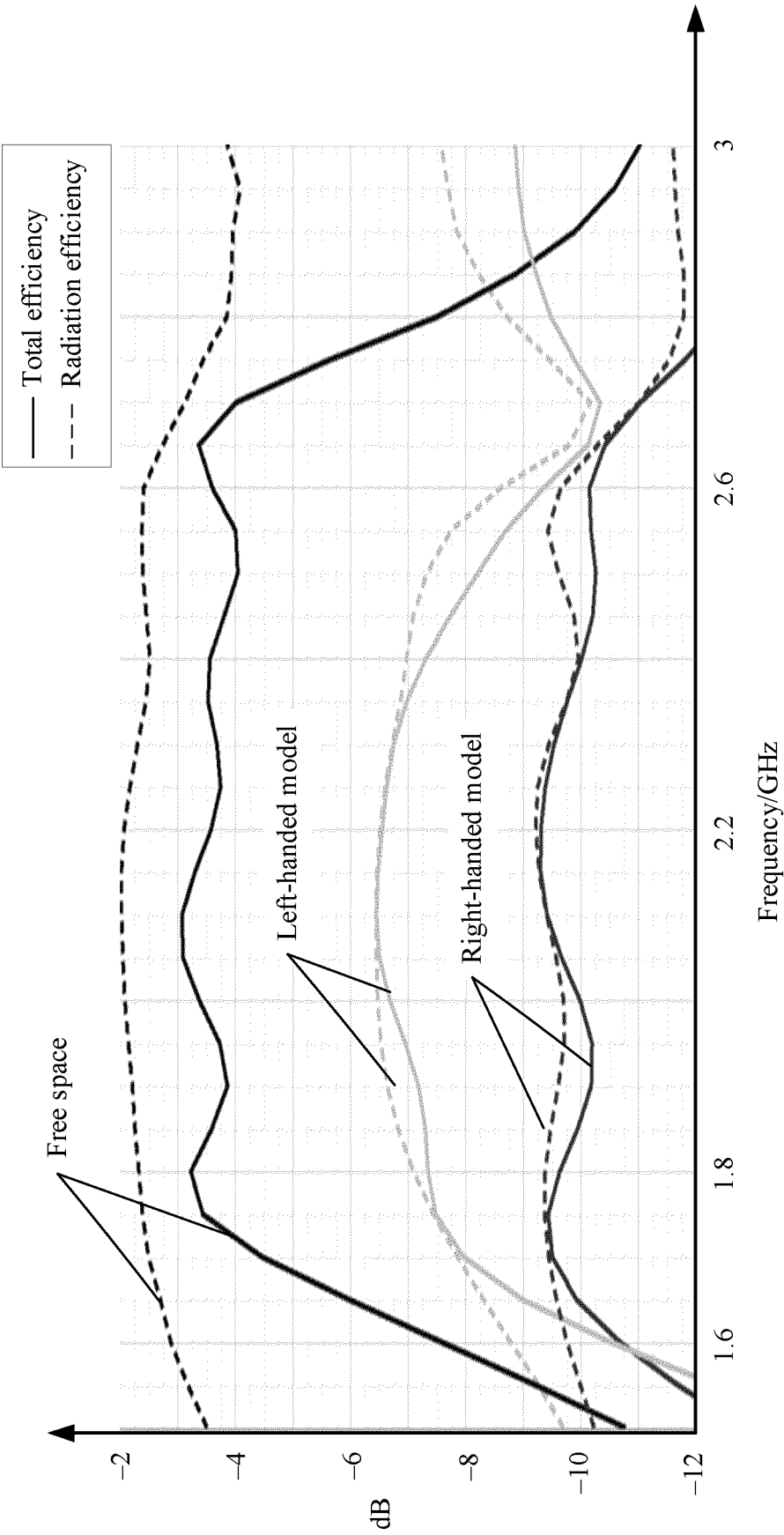


FIG. 100

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2023/116964

A. CLASSIFICATION OF SUBJECT MATTER

H01Q1/36(2006.01)i; H01Q1/24(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)

CNABS, CNTXT, VEN, USTXT, WOTXT, EPTXT, CNKI, IEEE, 百度学术, BAIDU SCHOLAR: 天线, 电场, 零点, 电流, 强点, 接地, 短路, 框, 带宽, 增加, antenna, electric field, zero point, current, intensity point, ground, short circuit, frame, bandwidth, increase

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CN 108767499 A (HUAQIN TELECOM TECHNOLOGY CO., LTD.) 06 November 2018 (2018-11-06) description, paragraphs [0005]-[0047], and figures 1-9	1-9
Y	杨梦妮 (YANG, Mengni). "基于SIW 加载的方形贴片谐振器理论分析与应用 (Non-official translation: Theoretical Analysis And Application of SIW-backed Square Patch Resonator)" 中国优秀硕士学位论文全文数据库 (China Master's Theses Full-text Database), No. 06, 15 June 2020 (2020-06-15), these, pages 16-18	1-9
Y	CN 112310663 A (XIDIAN UNIVERSITY) 02 February 2021 (2021-02-02) description, paragraphs [0005]-[0050], and figures 1-5	1-9
X	CN 113745809 A (HUAWEI TECHNOLOGIES CO., LTD.) 03 December 2021 (2021-12-03) description, paragraphs [0004]-[0136], and figures 1-17	10-20
A	CN 101997938 A (HTC CORP.) 30 March 2011 (2011-03-30) entire document	1-20

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

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2023/116964

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	CN 114284721 A (REALME INC.) 05 April 2022 (2022-04-05) entire document	1-20
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REFERENCES CITED IN THE DESCRIPTION

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