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(54) **WEARABLE DEVICE**

(57) This application provides a wearable device, including an antenna, and a pattern of the antenna may be switched, so that an anti-interference capability of the wearable device can be improved. The wearable device includes a casing, the antenna, and a ground plane. The antenna includes a feed unit, a switch, a first electronic element, a first radiator, and a second radiator that are disposed in the casing. An end of the first radiator and an end of the second radiator are opposite to each other and are not in contact with each other. A first end of the first radiator includes a feed point. The feed unit is electrically connected to the first radiator at the feed point. A first end of the second radiator includes a ground point. The switch is electrically connected between the second radiator and the ground plane at the ground point. The first electronic element is electrically connected between the switch and the ground plane.

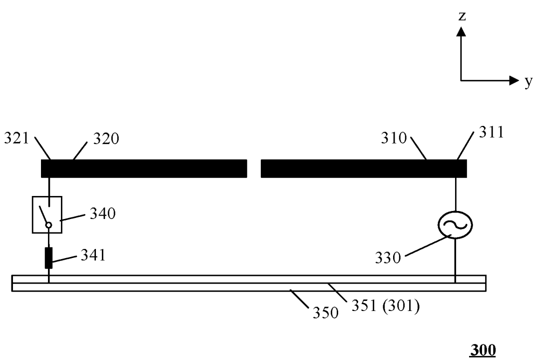

FIG. 9

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Description

[0001] This application claims priority to Chinese Patent Application No. 202211114401.0, filed with the China National Intellectual Property Administration on September 14, 2022 and entitled "WEARABLE 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 a wearable device.

BACKGROUND

[0003] Wireless earphones, especially true wireless stereo (true wireless stereo, TWS) Bluetooth (Bluetooth, BT) earphones, are increasingly popular with users because of convenience and miniaturization. However, because a TWS earphone is directly worn on an ear of a user, antenna performance of the TWS earphone is easily affected by a head of the user. Consequently, it is difficult to implement excellent antenna performance. In addition, when interference occurs around the user when the TWS earphone is worn on the ear of the user, for example, when another electronic device sends an electrical signal in a Bluetooth frequency band or a 2.4 GHz Wi-Fi signal in a same frequency as the Bluetooth frequency band, interference on user using the TWS earphone is caused.

[0004] The same problem may also occur on other wearable devices such as a smartwatch and smart glasses worn by the user. Due to the foregoing problem, an antenna of a wearable device has an urgent requirement for pattern switching.

SUMMARY

[0005] This application provides a wearable device, including an antenna. The antenna has a simple structure, and can switch a pattern while ensuring a good radiation characteristic of the antenna, to improve an anti-interference capability of the wearable device.

[0006] According to a first aspect, a wearable device is provided, including: a casing; an antenna, including a feed unit, a switch, a first electronic element, a first radiator, and a second radiator, where the feed unit, the switch, the first radiator, and the second radiator are located in the casing; a ground plane, where a first end of the second radiator is electrically connected to the ground plane via the switch; an end of the first radiator and an end of the second radiator are opposite to each other and are not in contact with each other; a first end of the first radiator includes a feed point, and the feed unit is electrically connected to the first radiator at the feed point; the first end of the second radiator includes a ground point, the switch is electrically connected between the second radiator and the ground plane at the ground point, and the first electronic element is electrically connected between the switch and the ground plane; when the switch is in a first switch state, an operating frequency band of the antenna includes a first frequency band, and the antenna generates a first pattern; and when the switch is in a second switch state, the operating frequency band of the antenna includes the first frequency band, and the antenna generates a second pattern, where the first pattern and the second pattern are complementary to each other.

[0007] According to the technical solution in this embodiment of this application, an electrical connection state of the switch is adjusted to control an electrical connection state between the first end of the second radiator and the ground plane, to change an operating mode of the antenna, so that switching between two complementary patterns is implemented in different operating modes of the antenna.

[0008] With reference to the first aspect, in some implementations of the first aspect, when the switch is in the first switch state, the first end of the second radiator is grounded via the switch; and when the switch is in the second switch state, the first end of the second radiator is not grounded via the switch.

[0009] According to the technical solution in this embodiment of this application, a state of the first switch may be controlled, to control switching of the operating mode of the antenna between a first antenna element and a second antenna element.

[0010] With reference to the first aspect, in some implementations of the first aspect, the antenna further includes a second electronic element, where the second electronic element is electrically connected between the end of the first radiator and the end of the second radiator that are disposed opposite to each other.

[0011] According to the technical solution in this embodiment of this application, the second electronic element is controlled, so that an electrical signal transmitted on the second radiator through the second electronic element and an electrical signal spatially coupled on the second radiator are opposite in phase (for example, a phase difference is 180°). In this way, the two signals may cancel each other, to reduce coupling between the first radiator and the second radiator.

[0012] With reference to the first aspect, in some implementations of the first aspect, the second electronic element is an inductor, and an inductance is greater than or equal to 10 nH.

[0013] According to the technical solution in this embodiment of this application, the inductance of the second electronic element may be adjusted based on an actual design. This is not limited in this application.

[0014] With reference to the first aspect, in some implementations of the first aspect, the antenna further includes a neutralization line; and a first end of the neutralization line is electrically connected to the first radiator at a first position, and a second end of the neutralization line is electrically connected to the second radiator at a second position.

[0015] According to the technical solution in this embodiment of this application, when the neutralization line is electrically connected between the first radiator and the second radiator, an electrical length of the neutralization line may be controlled, so that an electrical signal transmitted on the second radiator through the neutralization line and an electrical signal spatially coupled on the second radiator are opposite in phase (for example, a phase difference is 180°). In this way, the two signals may cancel each other, to reduce coupling between the first radiator and the second radiator.

[0016] With reference to the first aspect, in some implementations of the first aspect, a distance between the first position and the feed point is less than one sixteenth of a first wavelength, and/or a distance between the second position and the ground point is less than one sixteenth of the first wavelength. The first wavelength is a wavelength corresponding to the first frequency band.

[0017] With reference to the first aspect, in some implementations of the first aspect, the antenna further includes a third electronic element; and the neutralization line includes a slot, and the third electronic element is electrically connected between two sides of the slot of the neutralization line.

[0018] According to the technical solution in this embodiment of this application, the third electronic element may be adjusted to control the electrical length of the neutralization line, so that the electrical signal transmitted by the neutralization line on the second radiator and the electrical signal spatially coupled on the second radiator are opposite in phase (for example, the phase difference is 180°). In this way, the two signals may cancel each other.

[0019] With reference to the first aspect, in some implementations of the first aspect, the third electronic element is an inductor, and an inductance is greater than or equal to 5 nH.

[0020] According to the technical solution in this embodiment of this application, the inductance of the third electronic element may be adjusted based on an actual design. This is not limited in this application.

[0021] With reference to the first aspect, in some implementations of the first aspect, a distance between the first radiator and the ground plane is greater than or equal to 0.5 mm and less than or equal to 3 mm.

[0022] According to the technical solution in this embodiment of this application, the distance between the first radiator and the ground plane may be understood as a minimum value of a line segment distance between a point on the first radiator and a point on the ground plane, or may be understood as a distance between the first radiator and the ground plane in a first direction. The first direction may be a direction perpendicular to a plane on which the first radiator is located.

[0023] With reference to the first aspect, in some implementations of the first aspect, a distance between the end of the first radiator and the end of the second radiator that are disposed opposite to each other is less than or equal to 1 mm.

[0024] According to the technical solution in this embodiment of this application, the distance between the end of the first radiator and the end of the second radiator that are disposed opposite to each other may be 0.6 mm. The distance between the end of the first radiator and the end of the second radiator may be understood as a width of a slot formed between the end of the first radiator and the end of the second radiator.

[0025] With reference to the first aspect, in some implementations of the first aspect, a length L1 of the first radiator and a length L2 of the second radiator satisfy: $L1\times 60\%\leq L2$, or $L2\times 60\%\leq L1$.

[0026] According to the technical solution in this embodiment of this application, electrical lengths of the first radiator and the second radiator may be the same (for example, a difference between the electrical lengths is $\pm 10\%$). Due to a spatial layout inside the wearable device, an electronic element (for example, a capacitor or an inductor) may be disposed between a radiator and the ground plane, to shorten a physical length of the radiator without changing the electrical length.

[0027] With reference to the first aspect, in some implementations of the first aspect, projections of the first radiator and the second radiator on a plane on which the ground plane is located are parallel to each other in a first direction, and a spacing in a second direction is less than a quarter of the first wavelength. The first direction is an extension direction of the first radiator and the second radiator, the second direction is perpendicular to the first direction, and the first wavelength is the wavelength corresponding to the first frequency band.

[0028] According to the technical solution in this embodiment of this application, the first radiator and the second radiator may be arranged in parallel. The first radiator and the second radiator may be arranged along a same straight line, or the first radiator and the second radiator may be arranged in a staggered manner.

[0029] With reference to the first aspect, in some implementations of the first aspect, a second end of the first radiator and a second end of the second radiator are opposite to each other and are not in contact with each other; and the second end of the first radiator and the second end of the second radiator are open ends.

[0030] With reference to the first aspect, in some implementations of the first aspect, the first end of the first radiator and a second end of the second radiator are opposite to each other and are not in contact with each other; and a second end of the first radiator and the second end of the second radiator are open ends.

[0031] With reference to the first aspect, in some implementations of the first aspect, a second end of the first radiator and a second end of the first radiator are opposite to each other and are not in contact with each other; and the second end of the first radiator and a second end of the second radiator are open ends.

[0032] With reference to the first aspect, in some implementations of the first aspect, the first end of the first radiator and a second end of the first radiator are opposite to each other and are not in contact with each other; and a second end of the first radiator and a second end of the second radiator are open ends.

[0033] With reference to the first aspect, in some implementations of the first aspect, the wearable device is a true wireless stereo TWS earphone; the wearable device includes an earbud portion and an earbud stem portion, and the antenna is disposed on the earbud stem portion; and a distance between the first radiator and the earbud portion is less than a distance between the second radiator and the earbud portion.

[0034] According to the technical solution in this embodiment of this application, the first radiator may be disposed in a region that is of the earbud stem portion and that is close to the earbud portion, and the first radiator may be used as a main radiator (a feed point is provided). In this way, radiation is generated via a metal component that is in the earbud portion and that is electrically connected to the ground plane, to improve a radiation characteristic of the antenna.

[0035] With reference to the first aspect, in some implementations of the first aspect, the first radiator and the second radiator are sheet-shaped; and the wearable device further includes a printed circuit board PCB, the PCB includes a metal layer, and the metal layer is disposed opposite to the first radiator and the second radiator.

[0036] With reference to the first aspect, in some implementations of the first aspect, no switch is included between the feed unit and the first radiator or between the feed unit and the ground plane.

[0037] According to the technical solution in this embodiment of this application, no switch is disposed between the feed unit and the first radiator or between the feed unit and the ground plane. Because no switch is disposed at the feed unit to switch a matching network, no additional insertion loss is caused, so that radiation performance of the antenna is not lost.

[0038] With reference to the first aspect, in some implementations of the first aspect, the first frequency band includes a Bluetooth frequency band of 2.4-2.485 GHz.

BRIEF DESCRIPTION OF DRAWINGS

[0039]

FIG. 1(a) to FIG. 1(c) are diagrams of a structure of a wearable device according to an embodiment of this application;

FIG. 2 is a diagram of comparison between patterns of an antenna structure of a TWS earphone in different cases;

FIG. 3 is a diagram of switching between patterns of an antenna structure according to an embodiment of this application;

FIG. 4 is a diagram of an antenna 201 according to an embodiment of this application;

FIG. 5 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. 6 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. 7 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. 8 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. 9 is a diagram of a structure of an antenna 300 according to an embodiment of this application;

FIG. 10 is a top view of an antenna 300 according to an embodiment of this application;

FIG. 11 shows S-parameters of the antenna shown in FIG. 9;

FIG. 12 is a distribution diagram of currents of the antenna shown in FIG. 9;

FIG. 13 shows simulation results of S-parameters and total efficiency of the antenna shown in FIG. 9;

FIG. 14 shows a pattern of the antenna shown in FIG. 9 on a yoz plane;

FIG. 15 shows a pattern of the antenna shown in FIG. 9 in a head model;

FIG. 16 shows a pattern of the antenna shown in FIG. 9 in a human body model;

FIG. 17 is a diagram of another antenna 300 according to an embodiment of this application;

FIG. 18 shows isolation between a first radiator and a second radiator in the antenna shown in FIG. 17;

FIG. 19 shows a simulation result of the antenna shown in FIG. 17;

FIG. 20 is a diagram of another antenna 300 according to an embodiment of this application;

FIG. 21 shows isolation between a first radiator and a second radiator in the antenna shown in FIG. 20;

FIG. 22 shows a simulation result of the antenna shown in FIG. 20;

FIG. 23 is a diagram of another antenna 300 according to an embodiment of this application;

FIG. 24 shows a simulation result of total efficiency of the antenna shown in FIG. 23;

FIG. 25 is a distribution diagram of currents of the antenna shown in FIG. 23;

FIG. 26 shows a pattern of the antenna shown in FIG. 23;

FIG. 27 is a diagram of another antenna 300 according to an embodiment of this application;

FIG. 28 shows a simulation result of total efficiency of the antenna shown in FIG. 31;

FIG. 29 is a distribution diagram of currents of the antenna shown in FIG. 31;

FIG. 30 shows a pattern of the antenna shown in FIG. 33;

FIG. 31 is a diagram of another antenna 300 according to an embodiment of this application;

FIG. 32 shows a simulation result of total efficiency of the antenna shown in FIG. 31;

FIG. 33 is a distribution diagram of currents of the antenna shown in FIG. 31;

FIG. 34 shows a pattern of the antenna shown in FIG. 31;

FIG. 35 shows another wearable device according to an embodiment of this application; and

FIG. 36 shows still another wearable device according to an embodiment of this application.

DESCRIPTION OF EMBODIMENTS

[0040] The following describes the technical solutions in this application with reference to the accompanying drawings.

[0041] The following describes possible terms in embodiments of this application.

[0042] 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.

[0043] 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.

[0044] Connection: That two or more components are conducted or connected in the "electrical connection" or "indirect coupling" manner to perform signal/energy transmission may be referred to as the connection.

[0045] 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 a distributed capacitor) is an equivalent capacitor formed due to a gap between two electric-conductors.

[0046] Resonance/Resonance frequency: The resonance frequency is also referred to as a resonant frequency. The resonance frequency may be a frequency 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.

[0047] 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.

[0048] 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:

$$\overline{L} = \frac{L}{\lambda}.$$

[0049] In the formula, L is a physical length, and λ is a wavelength of an electromagnetic wave.

[0050] 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.

[0051] 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:

$$\lambda_{\varepsilon} = \frac{\lambda_c}{\sqrt{\varepsilon_r}}.$$

[0052] In the formula, λ_ε 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.

[0053] A limitation on a position or a distance, such as middle or a middle position, mentioned in embodiments of this application, depends on a current process, and is not absolutely and strictly defined in a mathematical sense. 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).

[0054] Total efficiency (total efficiency) of an antenna: The total efficiency is a ratio of input power to output power at an antenna port.

[0055] 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.

[0056] 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.

[0057] Antenna pattern: The antenna pattern is also referred to as a radiation pattern. The antenna pattern is a pattern in which a relative field strength (normalized modulus value) of an antenna radiation field changes with a direction at a specific distance from an antenna. The antenna pattern is usually represented by two plane patterns that are perpendicular to each other in a maximum radiation direction of the antenna.

[0058] The antenna pattern usually includes a plurality of radiation beams. A radiation beam with a maximum radiation strength is referred to as a main lobe, and other radiation beams are referred to as minor lobes or side lobes. In the minor lobes, a minor lobe in an opposite direction of the main lobe is also referred to as a back lobe.

[0059] 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.

[0060] 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.

[0061] 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.

[0062] 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. In an embodiment, the circuit board includes a dielectric substrate, a grounding plane, and a cable layer, where the cable layer and the grounding plane may be electrically connected through a via.

[0063] 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.

[0064] 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.

[0065] The technical solution provided in this application is applicable to wearable devices using one or more of the following communication technologies: a BT communication technology, a global positioning system (global positioning system, GPS) communication technology, a wireless fidelity (wireless fidelity, Wi-Fi) communication technology, a global system for mobile communications (global system for mobile communications, GSM) communication technology, a wideband code division multiple access (wideband code division multiple access, WCDMA) communication technology, a long term evolution (long term evolution, LTE) communication technology, a 5th generation (5th generation, 5G) communication technology, or other future communication technologies.

[0066] FIG. 1(a) to FIG. 1(c) are diagrams of a structure of a wearable device according to an embodiment of this application. An example of a wireless earphone is used for description.

[0067] FIG. 1(a) to FIG. 1(c) are diagrams of a structure of a wireless earphone 100. The wireless earphone 100 may be, for example, a TWS Bluetooth earphone. The wireless earphone 100 may be divided into an earbud portion 1 and an earbud stem portion 2. The earbud portion 1 is connected to one end of the earbud stem portion 2. The earbud 1 may be accommodated or embedded in an auricle of a user. The earbud stem portion 2 may be mounted at an edge of the auricle of the user, and is located at a periphery of the auricle of the user.

[0068] As shown in FIG. 1(a) and FIG. 1(c), the earbud stem portion 2 may be further divided into a connection segment 21 connected to the earbud portion 1, and a top segment 22 and a bottom segment 23 located on two sides of the connection segment 21. The top segment 22, the connection segment 21, and the bottom segment 23 of the earbud stem portion 2 are sequentially arranged in a longitudinal direction of the wireless earphone. In this application, the longitudinal direction may be an extension direction of the earbud stem portion 2 (a Y axis shown in FIG. 1(a)) or a length direction of the earbud stem portion 2. Two ends in the longitudinal direction may be a top end and the bottom end respectively. The top segment 22, the connection segment 21, and the bottom segment 23 may be an integrated structure or a split structure.

[0069] As shown in FIG. 1(b), the earbud stem portion 2 may be further divided into the connection segment 21 connected to the earbud portion 1, and the bottom segment 23 located on one side of the connection segment 21. The connection segment 21 is connected between the earbud portion 1 and the bottom segment 23. The connection segment 21 and the bottom segment 23 are distributed in a longitudinal direction of the wireless earphone 100. In other words, in this application, the wireless earphone 100 may or may not have the top segment 22 shown in FIG. 1(a) and FIG. 1(c).

[0070] As shown in FIG. 1(a) and FIG. 1(b), the wireless earphone 100 may include a casing 10. The casing 10 may be configured to accommodate various components of the wireless earphone 100. The casing 10 may include a main housing 101, a bottom housing 102, and a side housing 103.

[0071] The main housing 101 may cover a part of the bottom segment 23 of the earbud stem portion 2, the connection segment 21 of the earbud stem portion 2, the top segment 22 of the earbud stem portion 2, and a part that is of the earbud portion 1 and that is connected to the connection segment 21. The main housing 101 may form a first opening 1011 at the bottom segment 23 of the earbud stem portion 2, and may form a second opening 1012 at the earbud portion 1. The first opening 1011 and the second opening 1012 may be used to mount components in the wireless earphone 100.

[0072] The bottom housing 102 may be located at the bottommost of the bottom segment 23 of the earbud stem portion 2. The bottom housing 102 may be fastened to the main housing 101 through the first opening 1011. In a possible implementation, a connection between the bottom housing 102 and the main housing 101 is a detachable connection (for example, a snap-fit connection or a threaded connection), to facilitate subsequent repair (or maintenance) of the wireless earphone 100. In another possible implementation, a connection between the bottom housing 102 and the main housing 101 may be a non-detachable connection (for example, gluing), to reduce a risk of accidental falling of the bottom housing 102, and therefore help improve reliability of the wireless earphone 100.

[0073] The side housing 103 may be located on a side that is of the earbud portion 1 and that is away from the earbud stem portion 2. The side housing 103 may be fastened to the main housing 101 through the second opening 1012. In a possible implementation, a connection between the side housing 103 and the main housing 101 is a detachable connection (for example, a snap-fit connection or a threaded connection), to facilitate subsequent repair (or maintenance) of the wireless earphone 100. In another possible implementation, a connection between the side housing 103 and the main housing 101 may alternatively be a non-detachable connection (for example, gluing), to reduce a risk of accidental falling of the side housing 103, and therefore help improve reliability of the wireless earphone 100.

[0074] The side housing 103 is provided with one or more sound outlet holes 1031, so that sound inside the casing 10 can be transmitted to outside of the casing 10 through the sound outlet hole 1031. A shape, a position, a quantity, and the like of the sound outlet hole 1031 may not be limited in this application.

[0075] It should be understood that a quantity of openings on the casing 10 and opening positions may not be limited in this application. Different wireless earphones 100 may have different quantities of openings and/or different opening positions. For example, as shown in FIG. 1(c), the casing 10 may include a first housing 104 and a second housing 105. A third opening 1041 may be formed on the first housing 104. The first housing 104 may be fastened to the second housing 105 through the third opening 1041. In the example shown in FIG. 1(c), the wireless earphone 100 may have a smaller quantity of openings.

[0076] It should be understood that structures of the wireless earphone 100 shown in FIG. 1(a) to FIG. 1(c) are only some examples, and the wireless earphone 100 may have other different embodiments. The following uses the wireless earphone 100 shown in FIG. 1(a) to FIG. 1(c) only as an example for detailed description.

[0077] FIG. 2 is a diagram of comparison between patterns of an antenna structure of a TWS earphone in different cases. (a) in FIG. 2 shows a pattern of an antenna structure of the TWS earphone in a case in which a user does not wear the TWS earphone, and (b) in FIG. 2 shows a pattern of the antenna structure of the TWS earphone in a case in which the user wears the TWS earphone.

[0078] Because the TWS earphone is worn on an ear of the user and close to a head of the user, a human body greatly absorbs energy radiated from the antenna structure of the earphone, and a pattern of the antenna structure changes. In addition, due to reflection effect, the antenna structure of the earphone generates, on a side close to the human head, a node with very poor radiation performance, as shown in (b) in FIG. 2, which causes a stuttering problem during use of the user and reduces user experience. It should be understood that a node of a pattern of the antenna structure may be considered as a smaller value of a gain in the pattern of the antenna structure, or may be considered as a region in which a gain in the pattern of the antenna structure is less than a threshold, and the pattern of the antenna structure may have a plurality of nodes due to different antenna structures and different environments in which the antenna structure is located.

[0079] In addition, when interference occurs around the user after the TWS earphone is worn on the ear of the user, for example, when another electronic device sends an electrical signal in a Bluetooth frequency band or a 2.4 GHz Wi-Fi signal that has a same frequency as the Bluetooth frequency band, interference is caused to use of the TWS earphone by the user. The same problem is also encountered in other wearable devices such as a smartwatch and smart glasses worn by the user.

[0080] Due to the foregoing problem, an antenna of a wearable device has an urgent requirement for pattern switching.

[0081] The antenna structure provided in embodiments of this application may include an antenna element 1 and an antenna element 2. A pattern, of the antenna element 1, generated when the user wears the earphone is a pattern 1 in FIG. 3, a pattern, of the antenna element 2, generated when the user wears the earphone is a pattern 2 in FIG. 3, and the pattern 1 and the pattern 2 are two complementary patterns. The earphone can switch between the antenna element 1 and the antenna element 2 based on sensitivity of the antenna elements when a packet loss ratio is lower than a threshold, so as to switch between the two complementary patterns. A position of a node of an original single antenna pattern is complemented, and a combined dual antenna pattern compensates for a small gain of either single antenna pattern at a node. This improves overall over-the-air (over the air, OTA) performance of the antenna structure. It should be understood that two complementary patterns may be understood as that nodes of the two patterns are not in an identical direction, that is, the nodes do not overlap. The packet loss ratio may be understood as a ratio of lost data packets in a process in which an electronic device receives data packets. When the packet loss ratio is greater than the threshold, it may be determined that the current antenna structure is greatly affected by an environment and radiation characteristics of the antenna structure are poor. The combined pattern is formed by combining at least two patterns for ease of understanding, and the combined pattern may be understood as that a gain at any angle is a larger value of gains corresponding to the angle in the at least two patterns. It should be understood that a combined pattern of two complementary patterns may increase at least a gain of either pattern at a node.

[0082] FIG. 4 is a diagram of an antenna 201 (which may also be referred to as the antenna 201).

[0083] As shown in FIG. 4, the antenna 201 may include a radiator 211, a PCB 220, a feed unit 230, and a switch 240.

[0084] The radiator 211 may be formed by using a metal part of a casing of the wearable device. The radiator 211 may be disposed opposite to the PCB 220. That the radiator 211 is disposed opposite to the PCB 220 may be understood as that the radiator 211 and the PCB 220 face each other. The feed unit 230 is electrically connected between a first end of the radiator 211 and a ground plane (for example, a metal layer 211 in the PCB 220). The switch 240 is electrically connected between a second end of the radiator 211 and the ground plane.

[0085] In the antenna 201 shown in FIG. 4, an electrical connection state between the metal layer 221 and the second end of the radiator 211 is switched via the switch 240, so that different operating modes of the antenna radiator in a same frequency band can be implemented. The radiator 211 in different operating modes may be considered as corresponding different antenna elements, for example, including a first antenna element and a second antenna element. The first antenna element and the second antenna element share the radiator 211. When the switch 240 is in a first switch state (for example, a turned-on state), the second end of the radiator 211 and the metal layer 221 are in a first connection state (for example, an electrical connection state), and a second end of the metal part is grounded via a first switch, a part of the metal part 211 or the entire metal part 211 is used as a radiator of the first antenna element. In this case, the first element may be a left-handed antenna or a loop (loop) antenna. When the switch 240 is in a second switch state (for example, a turned-off state), the second end of the radiator 211 and the metal layer 221 are in a second connection state (for example, a second end of the metal part 211 and the metal layer 221 are not connected, that is, no electrical connection is formed, and no electrical signal is transmitted), the second end of the radiator 211 is not grounded via the switch 240, and a part of the radiator 211 or the entire radiator 211 is used as a radiator of the second antenna element. In this case, the second element may be a monopole antenna.

[0086] Therefore, a state of the switch 240 may be controlled, so that the antenna 201 can be controlled to switch between the first antenna element and the second antenna element. The first antenna element and the second antenna element each use the radiator 211 as a radiator to generate radiation. Patterns of the first antenna element and the second antenna element are complementary to each other.

[0087] However, in the antenna structure, when the switch 240 switches between the first switch state and the second switch state, a mode difference between the first antenna element and the second antenna element is large (the first element is a left-handed antenna or a loop (loop) antenna, and the second antenna element is a monopole antenna). Therefore, to ensure a good radiation characteristic of the antenna structure, a switch 241 further needs to be disposed between the feed unit 230 and the radiator 211, to switch between different matching corresponding to the first antenna element and the second antenna element.

[0088] Because space in the wearable device is compact, it is difficult to lay out a plurality of switches in the limited space. Therefore, it is difficult to implement the antenna shown in FIG. 4 in the wearable device.

[0089] This application provides a wearable device that may include an antenna. The antenna has a simple structure, and can switch a pattern while ensuring a good radiation characteristic of the antenna, to improve an anti-interference capability of the wearable device.

[0090] First, FIG. 5 to FIG. 8 describe four antenna modes in this application. FIG. 5 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. 6 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. 7 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. 8 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

[0091] (a) in FIG. 5 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).

[0092] 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.

[0093] (b) in FIG. 5 shows distribution of currents and electric fields of the wire antenna 40. As shown in (b) in FIG. 5, 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. 5, 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. 5 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. 5 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. 5 may be referred to as a CM mode current and a CM mode electric field of the wire antenna.

[0094] 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

[0095] (a) in FIG. 6 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.

[0096] 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°±10°.

[0097] (b) in FIG. 6 shows distribution of currents and electric fields of the wire antenna 50. As shown in (b) in FIG. 6, currents are asymmetrically distributed, for example, 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. 6, 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. 6 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. 6 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. 6 may be referred to as a DM mode current and a DM mode electric field of the wire antenna.

[0098] 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.

[0099] 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. 5, or may be two, as shown in FIG. 6, 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. 6, two ends of the two radiators are disposed opposite to each other and are 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. 5 may also be achieved. Correspondingly, in the DM mode of the wire antenna, one radiator may also be used as shown in FIG. 5, 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. 6 may also be achieved.

3. CM mode of a slot antenna

[0100] A slot antenna 60 shown in (a) in FIG. 7 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°±10°.

[0101] (b) in FIG. 7 shows distribution of currents, electric fields, and magnetic currents of the slot antenna 60. As shown in (b) in FIG. 7, currents are codirectionally distributed around the slit 61 on a conductor (for example, a ground plane and/or a radiator 60) around the slit 61i. 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. 7, 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. 7 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. 7 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. 7 may be referred to as a CM mode electric field, a CM mode current, and a CM mode magnetic current of the slot antenna.

[0102] 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

[0103] A slot antenna 70 shown in (a) in FIG. 8 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/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.

[0104] (b) in FIG. 8 shows distribution of currents, electric fields, and magnetic currents of the slot antenna 70. As shown in (b) in FIG. 8, 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. 8 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. 8 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. 8 may be referred to as a DM mode electric field, a DM mode current, and a DM mode magnetic current of the slot antenna.

[0105] 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.

[0106] 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. 7 or may be a complete loop shown in FIG. 8, 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. 8, 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. 7 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. 7, 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. 8 may also be achieved.

[0107] FIG. 9 is a diagram of a structure of an antenna

300 according to an embodiment of this application. The antenna may be used in the electronic device shown in FIG. 1(a) to FIG. 1(c).

[0108] As shown in FIG. 9, the antenna 300 includes a first radiator 310, a second radiator 320, a first electronic element 341, a feed unit 330, and a switch 340.

[0109] The first radiator 310, the second radiator 320, the feed unit 330, and the switch 340 may be disposed in the casing 10 of the wearable device shown in FIG. 1(a) to FIG. 1(c). In an embodiment, the first radiator 310, the second radiator 320, the feed unit 330, and the switch 340 may be disposed on the earbud stem portion 2 of the wearable device shown in FIG. 1(a) to FIG. 1(c).

[0110] An end of the first radiator 310 and an end of the second radiator 320 are opposite to each other and are not in contact with each other. In an embodiment, a second end of the first radiator 310 and a second end of the second radiator 320 are opposite to each other and are not in contact with each other. The second end of the first radiator 310 and the second end of the second radiator 320 are open ends. The open ends may be understood as that an end of the radiator is not connected to another conductor. For brevity of description, in an embodiment, an example in which the second end of the first radiator 310 and the second end of the second radiator 320 face each other is merely used for description.

[0111] A first end of the first radiator 310 includes a feed point 311, and the feed unit 330 is electrically connected to the first radiator 310 at the feed point 311. A first end of the second radiator 320 includes a ground point 321, and the switch 340 is electrically connected between the second radiator 320 and a ground plane 301 at the ground point 321. The first electronic element 341 is electrically connected between the switch 340 and the ground plane 301.

[0112] When the switch 340 is in a first switch state, an operating frequency band of the antenna 300 includes a first frequency band, and the antenna 300 generates a first pattern. When the switch 340 is in a second switch state, an operating frequency band of the antenna 300 includes a first frequency band, and the antenna generates a second pattern. The first pattern and the second pattern are complementary to each other.

[0113] In an embodiment, when the switch 340 is in the first switch state (for example, a turned-on state), the first end of the second radiator 320 is grounded via the switch 340. When the switch 340 is in the second switch state (for example, a turned-off state), the first end of the second radiator 320 is not grounded via the switch 340.

[0114] According to the technical solution provided in this embodiment of this application, an electrical connection state of the switch 340 is adjusted to control an electrical connection state between the first end of the second radiator 320 and the ground plane 301, to change an operating mode of the antenna 300, so that switching between two complementary patterns is implemented in different operating modes of the antenna 300. In an embodiment, as shown in FIG. 9, when the switch 340 is in the second switch state (for example, the turned-off state), the antenna 300 may be used as the first antenna element, and an operating mode of the antenna 300 is the CM mode of the wire antenna. When the switch 340 is in the first switch state (for example, the turned-on state), the antenna 300 may be used as the second antenna element, and an operating mode of the antenna 300 is a hybrid mode of the CM mode and the DM mode of the slot antenna. Both a resonance generated by the first antenna element and a resonance generated by the second antenna element can support the wearable device in performing communication in the first frequency band, the first pattern generated by the first antenna element in the CM mode and the complementary second pattern generated by the second antenna element in a hybrid mode may implement switching of patterns of the antenna.

[0115] In an embodiment, no switch is disposed between the feed unit 330 and the first radiator 310, or no switch is disposed between the feed unit 330 and the ground plane 301. In the technical solution provided in this embodiment of this application, the first antenna element and the second antenna element are switched by adjusting the electrical connection state of the switch 340. Because the operating modes of the first antenna element and the second antenna element are close, an additional switch does not need to be disposed at the feed unit 330 to switch matching networks corresponding to operating modes of different antenna elements (for example, a capacitor is connected in series between the feed unit 330 and the first radiator 310, and an inductor is connected in parallel), so that layout space occupied by the antenna 300 can be reduced. In addition, because no switch is disposed at the feed unit 330 to switch a matching network, no additional insertion loss is caused, so that radiation performance of the antenna is not lost.

[0116] In an embodiment, the first end of the first radiator 310 cannot be understood as a point in a narrow sense, but may further be considered as a radiator segment that is of the first radiator 310 and that includes an endpoint (the endpoint of the first radiator 310 may be any point on an edge of the first radiator 310). For example, the first end may be considered as a radiator whose distance from the endpoint is within one-sixteenth of the first wavelength, or may be considered as a radiator whose distance from a first endpoint is within 2 mm. The first end or the second end of the radiator in this embodiment of this application may also be correspondingly understood. The first wavelength may be a wavelength corresponding to the first frequency band. For example, the first wavelength may be a wavelength corresponding to a resonance point in the first frequency band, or may be a wavelength corresponding to a center frequency of the first frequency band.

[0117] In an embodiment, the antenna 300 may be disposed on the earbud stem portion 2 of the wearable device shown in FIG. 1(a) to FIG. 1(c).

[0118] In an embodiment, a distance between the first radiator 310 and the earbud portion 1 of the wearable device shown in FIG. 1(a) to FIG. 1(c) is less than a distance between the second radiator 320 and the earbud portion 1. The first radiator 310 may be disposed in a region that is of the earbud stem portion 2 and that is close to the earbud portion 1, and the first radiator 310 may be used as a main radiator (a feed point is provided). In this way, radiation is generated by using a metal component that is in the earbud portion 1 and that is electrically connected to the ground plane 301, to improve a radiation characteristic of the antenna 300.

[0119] In an embodiment, the ground plane 301 may be a metal layer 351 of a PCB 350 in the wearable device, and the metal layer 351 is used as a ground plane of the antenna, or a conductor electrically connected to the metal layer 351 may be used as a ground plane of the antenna.

[0120] In an embodiment, the first radiator 310 and the second radiator 320 may be sheet-shaped. The metal layer 351 may be disposed opposite to (face to face) the first radiator 310 and the second radiator 320.

[0121] In an embodiment, the feed unit 330 and the switch 340 may be disposed on a same substrate (for example, the PCB 350), or may be disposed on two or more different substrates based on a layout requirement, for example, disposed on another PCB different from the PCB 350 and/or a flexible printed circuit (flexible printed circuit, FPC). This is not limited in this application, and may be adjusted based on an actual design.

[0122] In an embodiment, a distance between the first radiator 310 and the ground plane 301 is greater than or equal to 0.5 mm and less than or equal to 3 mm. In an embodiment, the distance between the first radiator 310 and the ground plane 301 may be 1.6 mm. The distance between the first radiator 310 and the ground plane 301 may be understood as a minimum value of a line segment distance between a point on the first radiator 310 and a point on the ground plane 301, or may be understood as a distance between the first radiator 310 and the ground plane 301 in a first direction. The first direction may be a direction (for example, a z direction) perpendicular to a plane on which the first radiator 310 is located.

[0123] In an embodiment, a distance between the end (second end) of the first radiator 310 and the end (second end) of the second radiator 320 that are disposed opposite to each other is less than or equal to 1 mm. In an embodiment, the distance between the end (second end) of the first radiator 310 and the end (second end) of the second radiator 320 may be 0.6 mm. The distance between the end (second end) of the first radiator 310 and the end (second end) of the second radiator 320 may be understood as a width of a slot formed between the end (second end) of the first radiator 310 and the end (second end) of the second radiator 320.

[0124] In an embodiment, a length L1 of the first radiator 310 and a length L2 of the second radiator 320 satisfy: $L1 \times 60\% \leq L2$, or $L2 \times 60\% \leq L1$. In an embodiment, electrical lengths of the first radiator 310 and the second radiator 320 may be the same (for example, a difference between the electrical lengths is $\pm 10\%$). Due to a spatial layout inside the wearable device, an electronic element (for example, a capacitor or an inductor) may be disposed between a radiator and the ground plane, to shorten a physical length of the radiator without changing the electrical length.

[0125] In an embodiment, the first radiator 310 and the second radiator 320 may be arranged in parallel. In an embodiment, the first radiator 310 and the second radiator 320 may be arranged along a same straight line, and projections of the first radiator 310 and the second radiator 320 on a plane on which the ground plane is located are arranged along a same straight line. Alternatively, in an embodiment, the first radiator 310 and the second radiator 320 may be arranged in a staggered manner, and projections of the first radiator 310 and the second radiator 320 on a plane on which the ground plane is located are parallel to each other in a first direction, and are spaced in a second direction. The first direction is an extension direction (for example, a y direction) of the first radiator 310 and the second radiator 320, and the second direction (for example, an x direction) is perpendicular to the first direction.

[0126] In an embodiment, projections of the first radiator 310 and the second radiator 320 on a plane on which the ground plane is located are parallel to each other in a first direction, and a spacing in a second direction is less than a quarter of the first wavelength, where the first wavelength is the wavelength corresponding to the first frequency band; or it may also be considered that a spacing in a second direction is less than 5 mm.

[0127] In an embodiment, the first frequency band includes a Bluetooth frequency band (2.4-2.485 GHz).

[0128] In an embodiment, when the first radiator 310 and the second radiator 320 are disposed or formed on an inner surface of the casing, the first radiator 310 and the second radiator 320 may be disposed on a surface (an inner surface or an outer surface) of the casing of the wearable device by using a patch or a laser-direct-structuring (laser-direct-structuring, LDS) technology.

[0129] When the first radiator 310 and the second radiator 320 are disposed in internal space enclosed by the casing, the first radiator 310 and the second radiator 320 may be implemented by using a metal layer or a metal patch, for example, floating metal (floating metal, FLM), an FPC, an internal conductive/mechanical part, a PCB onboard, or the like. This is not limited in this application.

[0130] In an embodiment, the switch 340 may be a single-pole single-throw switch, or a switch of another type, for example, a single-pole double-throw switch, a single-pole four-throw switch, or a four-pole single-throw switch that may achieve same technical effect, or an element of another type, for example, a variable capacitor (an adjustable capacitor), where a capacitance of the variable capacitor is changed to switch an electrical connection state between the metal layer 351 and the second radiator 320. The variable capacitor may include a first capacitance state and a second capacitance state that correspond to the first switch state and to the second switch state of the switch 340 respectively. The first capacitance state corresponds to a first capacitance, and the second capacitance state corresponds to a second capacitance. Settings of the first capacitance and the second capacitance are related to an operating frequency of the antenna structure. For a Bluetooth frequency band (2.4-2.485 GHz), when the first capacitance of the variable capacitor in the first capacitance state is less than or equal to 0.2 pF, it may be considered that the first end of the second radiator 320 is not connected to the metal layer 351. When the second capacitance of the variable capacitor in the second capacitance state is greater than or equal to 10 pF, it may be considered that the first end of the second radiator 320 is electrically connected to the metal layer 351. It should be understood that capacitances corresponding to electrical connection states (a turned-off state or a turned-on state) between the metal layer 351 and the second radiator 320 are different in different frequency bands. Therefore, for another frequency band, same effect may also be achieved by adjusting a capacitance of the variable capacitor. This is not limited in this application.

[0131] The variable capacitor is a variable capacitor whose capacitance can be adjusted within a specific range. The capacitance of the capacitor is calculated as follows:

$$C = \frac{\varepsilon S}{4\pi k d}.$$

[0132] In the formula, ε is a dielectric constant between two plates; δ is an absolute permittivity in a vacuum; k is an electrostatic force constant; S is an area in which the two plates are directly opposite to each other; and d is a vertical distance between the two plates.

[0133] Therefore, a principle of the variable capacitor is generally to change the area in which the two plates of the capacitor are directly opposite to each other or the vertical distance between the two plates, so as to change the capacitance accordingly.

[0134] FIG. 11 shows S-parameters of the antenna shown in FIG. 9.

[0135] As shown in FIG. 11, when the switch is in the second switch state (for example, the turned-off state), the first end of the second radiator is not grounded via the switch. In this case, the antenna may be used as the first antenna element, and a resonance may be generated by the first antenna element in the CM mode.

[0136] When the switch is in the first switch state (for example, the turned-on state), the first end of the second radiator is grounded via the switch. In this case, the antenna may be used as the second antenna element. An electrical length of the radiator is determined by a frequency of a resonance generated by the first antenna element when the switch is in the second switch state.

[0137] Because an electrical length of the radiator cannot be adjusted when no electronic element is electrically connected between the switch and the radiator, a boundary condition of the hybrid mode of the CM mode and the DM mode of the slot antenna cannot be met. In this case, only one resonance can be generated, the operating mode is similar to the CM mode of the first antenna element, and the second pattern generated by the second antenna element is similar to the first pattern generated by the first antenna element. Because the first pattern and the second pattern are not complementary to each other, pattern switching cannot be implemented.

[0138] When an electronic element is electrically connected between the switch and the radiator, an electrical length of the radiator may be adjusted by using different values (a capacitance or an inductance) of the electronic element (an example in which the electronic element is an inductor and an inductance is 2.2 nH is used for description in this embodiment of this application), so that the CM mode and the DM mode are excited to generate two resonances (a low-frequency resonance may correspond to the CM mode, and a high-frequency resonance may correspond to the DM mode). In addition, in this case, the second pattern generated by the second antenna element and the first pattern generated by the first antenna element are complementary to each other, so that pattern switching can be implemented.

[0139] FIG. 12 is a distribution diagram of currents of the antenna shown in FIG. 9.

[0140] (a) in FIG. 12 is a distribution diagram of currents of the first antenna element in a case in which the switch is in the second switch state (for example, the turned-off state) and the first end of the second radiator is not grounded via the switch. In a current path, directions of currents are not reversed, which may correspond to a half-wavelength mode.

[0141] (b) in FIG. 12 is a distribution diagram of currents of the second antenna element in the CM mode of the slot antenna in a case in which the switch is in the first switch state (for example, the turned-on state) and the first end of the second radiator is grounded via the switch. In a current path, directions of currents are not reversed, which may correspond to a half-wavelength mode.

[0142] (c) in FIG. 12 is a distribution diagram of currents of the second antenna element in the DM mode of the slot antenna in a case in which the switch is in the first switch state (for example, the turned-on state) and the first end of the second radiator is grounded via the switch. In a current path, directions of currents are sequentially reversed, which may correspond to the one-wavelength mode.

[0143] FIG. 13 and FIG. 14 show simulation results of the antenna shown in FIG. 9. FIG. 13 shows simulation results of S-parameters and total efficiency of the antenna shown in FIG. 9. FIG. 14 shows a pattern of the antenna shown in FIG. 9 on a yoz plane.

[0144] As shown in FIG. 13, a value of an electronic element may be adjusted, so that resonances generated by the slot antenna in the CM mode and the DM mode may be made close to each other, to form a resonant frequency band. An operating frequency band of the first antenna element and an operating frequency band of the second antenna element each include a Bluetooth frequency band (2.4-2.485 GHz).

[0145] Only an example in which an operating mode corresponding to the second antenna element in the Bluetooth frequency band (2.4-2.485 GHz) is the CM mode of the slot antenna is used for description in this embodiment of this application.

[0146] As shown in FIG. 13, at 2.44 GHz, total efficiency of the first antenna element and total efficiency of the second antenna element are approximately the same, and are flat in an operating frequency range. This meets a basic communication requirement of an antenna in a Bluetooth frequency band.

[0147] As shown in FIG. 14, nodes of a pattern generated by the first antenna element are in directions of about 60° and 120°. Nodes of a pattern generated by the second antenna element are in directions of about 95° and 70°. The pattern generated by the first antenna element and the pattern generated by the second antenna element are complementary to each other.

[0148] FIG. 15 shows a pattern of the antenna shown in FIG. 9 in a head model and FIG. 16 shows a pattern of the antenna shown in FIG. 9 in a human body model.

[0149] It should be understood that FIG. 15 and FIG. 16 show patterns corresponding to different angles of view at 2.44 GHz in a case in which the wearable device is worn on a left ear of a model.

[0150] (a) in FIG. 15 and (a) in FIG. 16 each are a pattern on an xoy plane (a horizontal plane) in a case in which the model wears the wearable device. A gain of the first antenna element is greater than a gain (greater than 5 dB) of the second antenna element at 0° to 150°. When an interference signal is emitted at the angle, the antenna element may be switched to the second antenna element, so that the weak interference signal is received; or when an audio signal is emitted at the angle, the antenna element may be switched to the first antenna element, so that the strong audio signal is received. This improves performance of the wearable device. A gain of the second antenna element is greater than a gain of the first antenna element at 150° to 360°. In this case, switching may be performed based on an interference signal or an audio signal.

[0151] (b) in FIG. 15 and (b) in FIG. 16 each are a pattern on an xoz plane in a case in which the model wears the wearable device. In a pattern on a side away from the model, a gain of the first antenna element is approximately the same as a gain of the second antenna element.

[0152] (c) in FIG. 15 and (c) in FIG. 16 each are a pattern on a yoz plane in a case in which the model wears the wearable device. In a pattern on a side away from the model, a gain of the first antenna element is greater than a gain of the second antenna element.

[0153] FIG. 17 is a diagram of another antenna 300 according to an embodiment of this application.

[0154] As shown in FIG. 17, the antenna 300 may further include a neutralization line 360. A first end of the neutralization line 360 is electrically connected to the first radiator 310 at a first position 361, and a second end is electrically connected to the second radiator 320 at a second position 362.

[0155] It should be understood that a difference between the antenna 300 shown in FIG. 17 and the antenna 300 shown in FIG. 9 lies only in the neutralization line 360 electrically connected between the first radiator 310 and the second radiator 320.

[0156] Because a plurality of electronic elements are disposed in space inside the wearable device and affect the antenna 300, coupling between the first radiator 310 and the second radiator 320 may be affected. When the first radiator 310 and the second radiator 320 are weakly coupled, the first electronic element 341 electrically connected between the switch 340 and the ground plane 301 may be adjusted to control a frequency difference between resonances generated by the second antenna element in the CM mode and the DM mode, so that a resonant frequency band generated by the second antenna element includes the first frequency band. When the first radiator 310 and the second radiator 320 are strongly coupled, resonance points at which resonances are generated by the second antenna element in the CM mode and the DM mode are respectively located on two sides of the first frequency band. In this case, the first electronic element 341 cannot be adjusted to control a frequency difference between resonances generated by the second antenna element in the CM mode and the DM mode, and therefore a resonant frequency band generated by the second antenna element does not include the first frequency band.

[0157] Therefore, when the neutralization line 360 is electrically connected between the first radiator 310 and the second radiator 320, an electrical length of the neutralization line 360 may be controlled, so that an electrical signal transmitted on the second radiator 320 through the neutralization line 360 and an electrical signal spatially coupled on the second radiator 320 are opposite in phase (for example, a phase difference is 180°). In this way, the two signals may cancel each other, to reduce coupling between the first radiator 310 and the second radiator 320.

[0158] In an embodiment, a distance between the first position 361 and the feed point 311 is less than one sixteenth of a first wavelength, and/or a distance between the second position 362 and the ground point 321 is less than one sixteenth of the first wavelength. The first wavelength is a wavelength corresponding to the first frequency band. Alternatively, in an embodiment, a distance between the first position 361 and the feed point 311 is less than 3 mm, and/or a distance between the second position 362 and the ground point 321 is less than 3 mm.

[0159] In an embodiment, the neutralization line 360 may further include a slot. The second electronic element 342 of the antenna 300 may be electrically connected between two sides of the slot of the neutralization line. The second electronic element 342 may be adjusted to control the electrical length of the neutralization line 360, so that the electrical signal transmitted on the second radiator 320 through the neutralization line 360 and the electrical signal spatially coupled on the second radiator 320 (for example, the phase difference of 180°) are in opposite phases. In this way, the two signals may cancel each other.

[0160] In an embodiment, the second electronic element 342 may be an inductor, and an inductance may be greater than or equal to 5 nH. It should be understood that the inductance of the second electronic element 342 may be adjusted based on an actual design. This is not limited in this application.

[0161] FIG. 18 and FIG. 19 each are a diagram of a simulation result of the antenna structure shown in FIG. 17. FIG. 18 shows isolation between the first radiator and the second radiator in the antenna shown in FIG. 17. FIG. 19 shows the simulation result of the antenna shown in FIG. 17.

[0162] It should be understood that, for brevity of description, in this embodiment of this application, an example in which the second electronic element 342 is an inductor and an inductance is 5 nH is merely used for description. In an actual application, adjustment may be performed based on a design. This is not limited in this application.

[0163] As shown in FIG. 18, because the neutralization line 360 is electrically connected between the first radiator 310 and the second radiator 320, the isolation between the first radiator 310 and the second radiator 320 has a dent near a Bluetooth frequency band (2.4-2.485 GHz). Therefore, in the Bluetooth frequency band, good isolation can be maintained between the first radiator 310 and the second radiator 320.

[0164] As shown in FIG. 19, because good isolation may be maintained between the first radiator 310 and the second radiator 320, the frequency difference between the resonances generated by the second antenna element in the CM mode and the DM mode may be reduced, so that the resonances generated by the second antenna element in the CM mode and the DM mode may form a resonant frequency band. The resonant frequency band includes a Bluetooth frequency band (2.4-2.485 GHz).

[0165] FIG. 20 is a diagram of another antenna 300 according to an embodiment of this application.

[0166] As shown in FIG. 20, the antenna 300 may further include a third electronic element 343, and the third electronic element 343 may be electrically connected between the end of the first radiator 310 and the end of the second radiator 320 that are disposed opposite to each other (for example, electrically connected between a second end of the first radiator 310 and a second end of the second radiator 320).

[0167] It should be understood that a difference between the antenna 300 shown in FIG. 17 and the antenna 300 shown in FIG. 9 lies only in the third electronic element 343 electrically connected between the end of the first radiator 310 and the end of the second radiator 320 that are disposed opposite to each other.

[0168] When the antenna 300 includes the third electronic element 343, the third electronic element 343 may be controlled, so that an electrical signal transmitted on the second radiator 320 through the third electronic element 343 and an electrical signal spatially coupled on the second radiator 320 are opposite in phase (for example, a phase difference is 180°). In this way, the two signals may cancel each other, to reduce coupling between the first radiator 310 and the second radiator 320.

[0169] In an embodiment, the third electronic element 343 is an inductor, and an inductance is greater than or equal to 10 nH. It should be understood that the inductance of the third electronic element 343 may be adjusted based on an actual design. This is not limited in this application.

[0170] FIG. 21 and FIG. 22 each are a diagram of a simulation result of the antenna structure shown in FIG. 20. FIG. 21 shows isolation between the first radiator and the second radiator in the antenna shown in FIG. 20. FIG. 22 shows the simulation result of the antenna shown in FIG. 20.

[0171] It should be understood that, for brevity of description, in this embodiment of this application, an example in which the third electronic element 343 is an inductor and an inductance is 24 nH is merely used for description. In an actual application, adjustment may be performed based on a design. This is not limited in this application.

[0172] As shown in FIG. 21, because the third electronic element 343 is electrically connected between the first radiator 310 and the second radiator 320, the isolation between the first radiator 310 and the second radiator 320 has a dent near a Bluetooth frequency band (2.4-2.485 GHz). Therefore, in the Bluetooth frequency band, good isolation can be maintained between the first radiator 310 and the second radiator 320.

[0173] As shown in FIG. 22, because good isolation may be maintained between the first radiator 310 and the second radiator 320, a frequency difference between resonances generated by the second antenna element in the CM mode and the DM mode may be reduced, so that the resonances generated by the second antenna element in the CM mode and the DM mode may form a resonant frequency band. The resonant frequency band includes a Bluetooth frequency band (2.4-2.485 GHz).

[0174] In the foregoing embodiments, an example in which an open end (a second end) of the first radiator and an open end (a second end) of the second radiator are close to each other, and a ground end (an end electrically connected to the feed unit) of the first radiator and a ground end (an end electrically connected to the switch) of the second radiator are far away from each other is used for description. The technical solution provided in embodiments of this application may also be applied to another dual-radiator layout manner, and are described in the following embodiments.

[0175] FIG. 23 is a diagram of another antenna 300 according to an embodiment of this application.

[0176] As shown in FIG. 23, an end of the first radiator 310 and an end of the second radiator 320 are opposite to each other and are not in contact with each other. In an embodiment, a first end of the first radiator 310 and a second end of the second radiator 320 are opposite to each other and are not in contact with each other. A second end of the first radiator 310 and the second end of the second radiator 320 are open ends. The first end of the first radiator 310 includes a feed point, and the feed unit 330 is electrically connected to the first radiator 310 at the feed point. A first end of the second radiator 320 includes a ground point, and the switch 340 is electrically connected between the second radiator 320 and the ground plane 301 at the ground point. The first electronic element 341 is electrically connected between the switch 340 and the ground plane 301.

[0177] It should be understood that a difference between the antenna 300 shown in FIG. 23 and the antenna 300 shown in FIG. 17 lies only in a layout manner of the first radiator 310 and the second radiator 320. In the antenna 300 shown in FIG. 17, the open end (second end) of the first radiator and the open end (second end) of the second radiator are close to each other, and the ground end (the end electrically connected to the feed unit) of the first radiator and the ground end of the second radiator (the end electrically connected to the switch) are away from each other. However, in the antenna 300 shown in FIG. 23, a ground end of the first radiator and an open end of the second radiator are close to each other.

[0178] FIG. 24 shows a simulation result of total efficiency of the antenna shown in FIG. 23.

[0179] It should be understood that values of the first electronic element (in this embodiment, an inductance of 4 nH is used as an example for description) and the second electronic element in a slot of a neutralization line (in this embodiment, an inductance of 10 nH is used as an example for description) that are electrically connected between the switch and the ground plane are adjusted, so that two resonances generated by the second antenna element in a hybrid operating mode (an operating mode of the slot antenna and an operating mode of the wire antenna) may be made close to each other, to form a resonant frequency band. An operating frequency band of the first antenna element and an operating frequency band of the second antenna element each include a Bluetooth frequency band (2.4-2.485 GHz).

[0180] As shown in FIG. 24, at 2.44 GHz, total efficiency of the first antenna element and total efficiency of the second antenna element are approximately the same, and are flat in an operating frequency range. This meets a basic communication requirement of an antenna in a Bluetooth frequency band.

[0181] FIG. 25 and FIG. 26 show simulation results of the antenna shown in FIG. 23. FIG. 25 is a distribution diagram of currents of the antenna shown in FIG. 23. FIG. 26 shows a pattern of the antenna shown in FIG. 23.

[0182] (a) in FIG. 25 is a distribution diagram of currents of the first antenna element in the CM mode of the wire antenna in a case in which the switch is in the second switch state (for example, the turned-off state) and the first end of the second radiator is not grounded via the switch. In a current path, directions of currents are not reversed, which may correspond to a half-wavelength mode. A first pattern generated by the first antenna element at 2.44 GHz is shown in (a) in FIG. 26.

[0183] (b) in FIG. 25 is a distribution diagram of currents of the second antenna element in the hybrid mode in a case in which the switch is in the first switch state (for example, the turned-on state) and the first end of the second radiator is grounded via the switch. A first pattern generated by the second antenna element at 2.44 GHz is shown in (b) in FIG. 26.

[0184] As shown in FIG. 26, the first pattern generated by the first antenna element and the second pattern generated by the second antenna element are complementary to each other, and the antenna may switch between the first pattern and the second pattern via the switch, to improve performance of the wearable device.

[0185] FIG. 27 is a diagram of another antenna 300 according to an embodiment of this application.

[0186] As shown in FIG. 27, an end of the first radiator 310 and an end of the second radiator 320 are opposite to each other and are not in contact with each other. In an embodiment, a second end of the first radiator 310 and a first end of the second radiator 320 are opposite to each other and are not in contact with each other. The second end of the first radiator 310 and a second end of the second radiator 320 are open ends. A first end of the first radiator 310 includes a feed point, and the feed unit 330 is electrically connected to the first radiator 310 at the feed point. The first end of the second radiator 320 includes a ground point, and the switch 340 is electrically connected between the second radiator 320 and the ground plane 301 at the ground point. The first electronic element 341 is electrically connected between the switch 340 and the ground plane 301.

[0187] It should be understood that a difference between the antenna 300 shown in FIG. 27 and the antenna 300 shown in FIG. 17 lies only in a layout manner of the first radiator 310 and the second radiator 320. In the antenna 300 shown in FIG. 17, the open end (second end) of the first radiator and the open end (second end) of the second radiator are close to each other, and the ground end (the end electrically connected to the feed unit) of the first radiator and the ground end of the second radiator (the end electrically connected to the switch) are away from each other. However, in the antenna 300 shown in FIG. 27, an open end of the first radiator and a ground end of the second radiator are close to each other.

[0188] FIG. 28 shows a simulation result of total efficiency of the antenna shown in FIG. 27.

[0189] It should be understood that values of the first electronic element (in this embodiment, an inductance of 3.5 nH is used as an example for description) and the second electronic element in a slot of a neutralization line (in this embodiment, an inductance of 12 nH is used as an example for description) that are electrically connected between the switch and the ground plane are adjusted, so that two resonances generated by the second antenna element in a hybrid operating mode (an operating mode of the slot antenna and an operating mode of the wire antenna) may be made close to each other, to form a resonant frequency band. An operating frequency band of the first antenna element and an operating frequency band of the second antenna element each include a Bluetooth frequency band (2.4-2.485 GHz).

[0190] As shown in FIG. 28, at 2.44 GHz, total efficiency of the first antenna element and total efficiency of the second antenna element are approximately the same, and are flat in an operating frequency range. This meets a basic communication requirement of an antenna in a Bluetooth frequency band.

[0191] FIG. 29 and FIG. 30 show simulation results of the antenna shown in FIG. 27. FIG. 29 is a distribution diagram of currents of the antenna shown in FIG. 27. FIG. 30 shows a pattern of the antenna shown in FIG. 27.

[0192] (a) in FIG. 29 is a distribution diagram of currents of the first antenna element in the CM mode of the wire antenna in a case in which the switch is in the second switch state (for example, the turned-off state) and the first end of the second radiator is not grounded via the switch. In a current path, directions of currents are not reversed, which may correspond to a half-wavelength mode. A first pattern generated by the first antenna element at 2.44 GHz is shown in (a) in FIG. 30.

[0193] (b) in FIG. 29 is a distribution diagram of currents of the second antenna element in the hybrid mode in a case in which the switch is in the first switch state (for example, the turned-on state) and the first end of the second radiator is grounded via the switch. A first pattern generated by the second antenna element at 2.44 GHz is shown in (b) in FIG. 30.

[0194] As shown in FIG. 30, the first pattern generated by the first antenna element and the second pattern generated by the second antenna element are complementary to each other, and the antenna may switch between the first pattern and the second pattern via the switch, to improve performance of the wearable device.

[0195] FIG. 31 is a diagram of another antenna 300 according to an embodiment of this application.

[0196] As shown in FIG. 31, an end of the first radiator 310 and an end of the second radiator 320 are opposite to each other and are not in contact with each other. In an embodiment, a first end of the first radiator 310 and a first end of the second radiator 320 are opposite to each other and are not in contact with each other. A second end of the first radiator 310 and a second end of the second radiator 320 are open ends. The first end of the first radiator 310 includes a feed point, and the feed unit 330 is electrically connected to the first radiator 310 at the feed point. The first end of the second radiator 320 includes a ground point, and the switch 340 is electrically connected between the second radiator 320 and the ground plane 301 at the ground point. The first electronic element 341 is electrically connected between the switch 340 and the ground plane 301.

[0197] It should be understood that a difference between the antenna 300 shown in FIG. 31 and the antenna 300 shown in FIG. 9 lies only in a layout manner of the first radiator 310 and the second radiator 320. In the antenna 300 shown in FIG. 9, the open end (second end) of the first radiator and the open end (second end) of the second radiator are close to each other, and the ground end (the end electrically connected to the feed unit) of the first radiator and the ground end of the second radiator (the end electrically connected to the switch) are away from each other. However, in the antenna 300 shown in FIG. 31, a ground end of the first radiator and a ground end of the second radiator are close to each other.

[0198] FIG. 32 shows a simulation result of total efficiency of the antenna shown in FIG. 31.

[0199] It should be understood that a value of the first electronic element electrically connected between the switch and the ground plane may be adjusted, so that two resonances generated by the second antenna element of the wire antenna in the DM mode may be made close to each other, to form a resonant frequency band. An operating frequency band of the first antenna element and an operating frequency band of the second antenna element each include a Bluetooth frequency band (2.4-2.485 GHz).

[0200] As shown in FIG. 32, at 2.44 GHz, total efficiency of the first antenna element and total efficiency of the second antenna element are approximately the same, and are flat in an operating frequency range. This meets a basic communication requirement of an antenna in a Bluetooth frequency band.

[0201] FIG. 33 and FIG. 34 show simulation results of the antenna shown in FIG. 31. FIG. 33 is a distribution diagram of currents of the antenna shown in FIG. 31. FIG. 34 shows a pattern of the antenna shown in FIG. 31.

[0202] (a) in FIG. 33 is a distribution diagram of currents of the first antenna element in the CM mode of the wire antenna in a case in which the switch is in the second switch state (for example, the turned-off state) and the first end of the second radiator is not grounded via the switch. In a current path, directions of currents are not reversed, which may correspond to a half-wavelength mode. A first pattern generated by the first antenna element at 2.44 GHz is shown in (a) in FIG. 34.

[0203] (b) in FIG. 33 is a distribution diagram of currents of the second antenna element in the DM mode of the wire antenna in a case in which the switch is in the first switch state (for example, the turned-on state) and the first end of the second radiator is grounded via the switch. In a current path, directions of currents are not reversed, which may correspond to a half-wavelength mode. A first pattern generated by the second antenna element at 2.44 GHz is shown in (b) in FIG. 34.

[0204] As shown in FIG. 34, the first pattern generated by the first antenna element and the second pattern generated by the second antenna element are complementary to each other, and the antenna may switch between the first pattern and the second pattern via the switch, to improve performance of the wearable device.

[0205] This application provides a wearable device. The wearable device may include an antenna. The antenna may be disposed in a casing of the wearable device. An operating frequency of the antenna may support a communication connection between the wearable device and another electronic device. Regardless of whether the electronic device connected to the wearable device is placed in a bag or a pocket, or a user is located in a place with strong signal interference such as an airport, an operating mode of the antenna structure is switched via a switch of the antenna, so that a stable communication connection between the wearable device and the electronic device can be implemented. Specifically, the wearable device having the antenna structure may implement a stable signal connection by switching the switch of the antenna structure. The communication connection may be a Bluetooth connection.

[0206] FIG. 35 and FIG. 36 each show another wearable device according to an embodiment of this application.

[0207] It should be understood that the antenna structure provided in embodiments of this application may be applied to wearable devices other than TWS earphones, for example, a smart watch or smart glasses.

[0208] As shown in FIG. 35, the antenna structure in the foregoing embodiment may be applied to a smartwatch. A specific position of the antenna structure is not limited in this application, and is used only as an example. For example, a radiator of the antenna may be disposed in a bezel, a PCB may be disposed in space enclo sed by a metal casing, a feed unit may be disposed on the PCB, and the switch may also be disposed on the PCB. A designed position may be shown in FIG. 35. It should be understood that the radiator of the antenna may alternatively be disposed on an inner surface of the casing of the smartwatch.

[0209] As shown in FIG. 36, the antenna structure may be designed by using a temple of the smart glasses, and a design position is shown in the figure. Alternatively, the antenna structure may be designed by using a frame of the smart glasses, or may be adjusted based on an actual production design requirement. For example, an antenna radiator may be disposed in internal space of the temple or the frame of the smart glasses, a PCB may be disposed in the temple, a feed unit may be disposed on the PCB, and a switch may be disposed on the PCB. A designed position is shown in FIG. 36.

[0210] A person skilled in the art may use different methods to implement the described functions for each specific application, but such implementation should not be considered beyond the scope of this application.

[0211] It may be clearly understood by a person skilled in the art that, for the purpose of convenient and brief description, for a detailed operating process of the foregoing system, apparatus, and unit, refer to a corresponding process in the foregoing method embodiments. Details are not described herein again.

[0212] 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 embodiment is merely an example. For example, division into the units is merely logical function division and may be other division in 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 an electrical form or another form.

[0213] 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. A wearable device, comprising:

   a casing;
   an antenna, comprising a feed unit, a switch, a first electronic element, a first radiator, and a second radiator, wherein the feed unit, the switch, the first radiator, and the second radiator are located in the casing; and
   a ground plane, wherein a first end of the second radiator is electrically connected to the ground plane via the switch, wherein
   an end of the first radiator and an end of the second radiator are opposite to each other and are not in contact with each other;
   a first end of the first radiator comprises a feed

point, and the feed unit is electrically connected to the first radiator at the feed point;
the first end of the second radiator comprises a ground point, the switch is electrically connected between the second radiator and the ground plane at the ground point, and the first electronic element is electrically connected between the switch and the ground plane;
when the switch is in a first switch state, an operating frequency band of the antenna comprises a first frequency band, and the antenna generates a first pattern; and
when the switch is in a second switch state, the operating frequency band of the antenna comprises the first frequency band, and the antenna generates a second pattern, wherein the first pattern and the second pattern are complementary to each other.

2. The wearable device according to claim 1, wherein

when the switch is in the first switch state, the first end of the second radiator is grounded via the switch; and
when the switch is in the second switch state, the first end of the second radiator is not grounded via the switch.

3. The wearable device according to claim 1 or 2, wherein

the antenna further comprises a second electronic element; and
the second electronic element is electrically connected between the end of the first radiator and the end of the second radiator that are disposed opposite to each other.

4. The wearable device according to claim 1, wherein the second electronic element is an inductor, and an inductance is greater than or equal to 10 nH.

5. The wearable device according to claim 1 or 2, wherein

the antenna further comprises a neutralization line; and
a first end of the neutralization line is electrically connected to the first radiator at a first position, and a second end of the neutralization line is electrically connected to the second radiator at a second position.

6. The wearable device according to claim 5, wherein

a distance between the first position and the feed point is less than one sixteenth of a first wavelength; and/or
a distance between the second position and the ground point is less than one sixteenth of the first wavelength, wherein the first wavelength is a wavelength corresponding to the first frequency band.

7. The wearable device according to claim 5 or 6, wherein

the antenna further comprises a third electronic element; and
the neutralization line comprises a slot, and the third electronic element is electrically connected between two sides of the slot of the neutralization line.

8. The wearable device according to claim 7, wherein the third electronic element is an inductor, and an inductance is greater than or equal to 5 nH.

9. The wearable device according to any one of claims 1 to 8, wherein
a distance between the first radiator and the ground plane is greater than or equal to 0.5 mm and less than or equal to 3 mm.

10. The wearable device according to any one of claims 1 to 9, wherein
a distance between the end of the first radiator and the end of the second radiator that are disposed opposite to each other is less than or equal to 1 mm.

11. The wearable device according to any one of claims 1 to 10, wherein
a length L1 of the first radiator and a length L2 of the second radiator satisfy: $L1\times 60\%\leq L2$, or $L2\times 60\%\leq L1$.

12. The wearable device according to any one of claims 1 to 11, wherein
projections of the first radiator and the second radiator on a plane on which the ground plane is located are parallel to each other in a first direction, and a spacing in a second direction is less than a quarter of the first wavelength, wherein the first direction is an extension direction of the first radiator and the second radiator, the second direction is perpendicular to the first direction, and the first wavelength is the wavelength corresponding to the first frequency band.

13. The wearable device according to any one of claims 1 to 12, wherein

a second end of the first radiator and a second end of the second radiator are opposite to each other and are not in contact with each other; and
the second end of the first radiator and the

second end of the second radiator are open ends.

14. The wearable device according to any one of claims 1 to 12, wherein

the first end of the first radiator and a second end of the second radiator are opposite to each other and are not in contact with each other; and
a second end of the first radiator and the second end of the second radiator are open ends.

15. The wearable device according to any one of claims 1 to 12, wherein

a second end of the first radiator and a second end of the first radiator are opposite to each other and are not in contact with each other; and
the second end of the first radiator and a second end of the second radiator are open ends.

16. The wearable device according to any one of claims 1 to 12, wherein

the first end of the first radiator and a second end of the first radiator are opposite to each other and are not in contact with each other; and
a second end of the first radiator and a second end of the second radiator are open ends.

17. The wearable device according to any one of claims 1 to 16, wherein

the wearable device is a true wireless stereo TWS earphone;
the wearable device comprises an earbud portion and an earbud stem portion, and the antenna is disposed on the earbud stem portion; and
a distance between the first radiator and the earbud portion is less than a distance between the second radiator and the earbud portion.

18. The wearable device according to any one of claims 1 to 17, wherein

the first radiator and the second radiator are sheet-shaped; and
the wearable device further comprises a printed circuit board PCB, the PCB comprises a metal layer, and the metal layer is disposed opposite to the first radiator and the second radiator.

19. The wearable device according to any one of claims 1 to 18, wherein no switch is comprised between the feed unit and the first radiator or between the feed unit and the ground plane.

20. The wearable device according to any one of claims 1 to 19, wherein the first frequency band comprises a Bluetooth frequency band of 2.4-2.485 GHz.

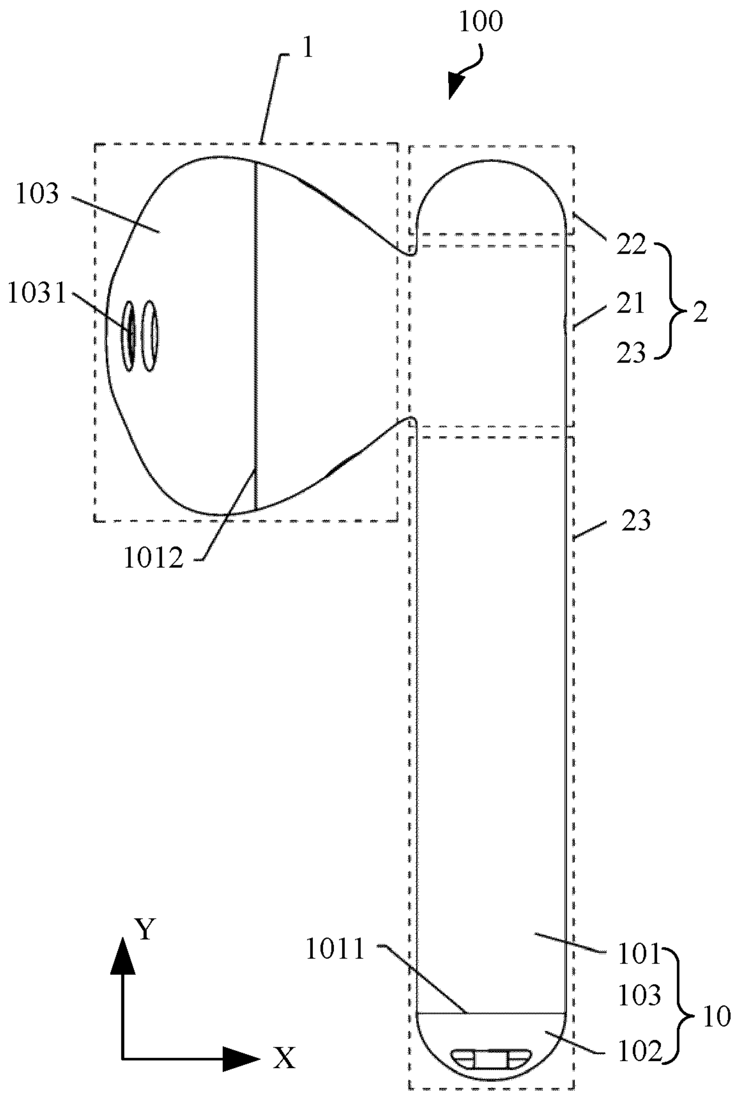


FIG. 1(a)

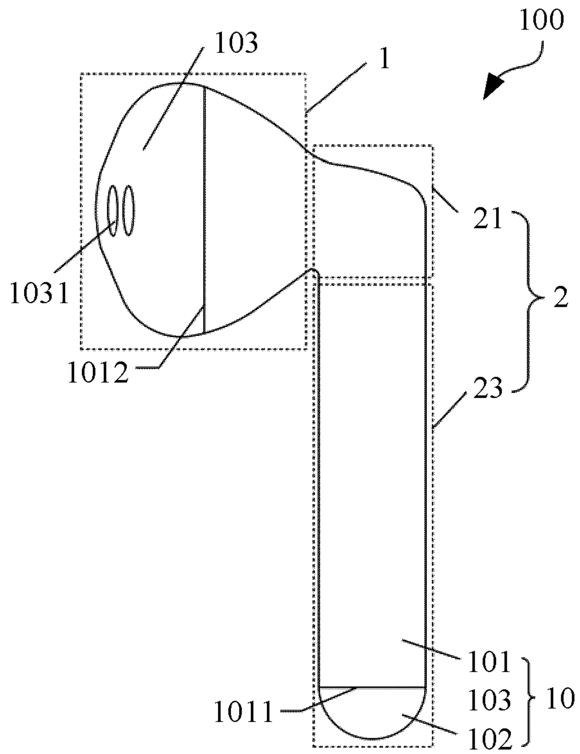

100
103
1
21
2
23
1031
1012
101
103
10
1011
102

FIG. 1(b)

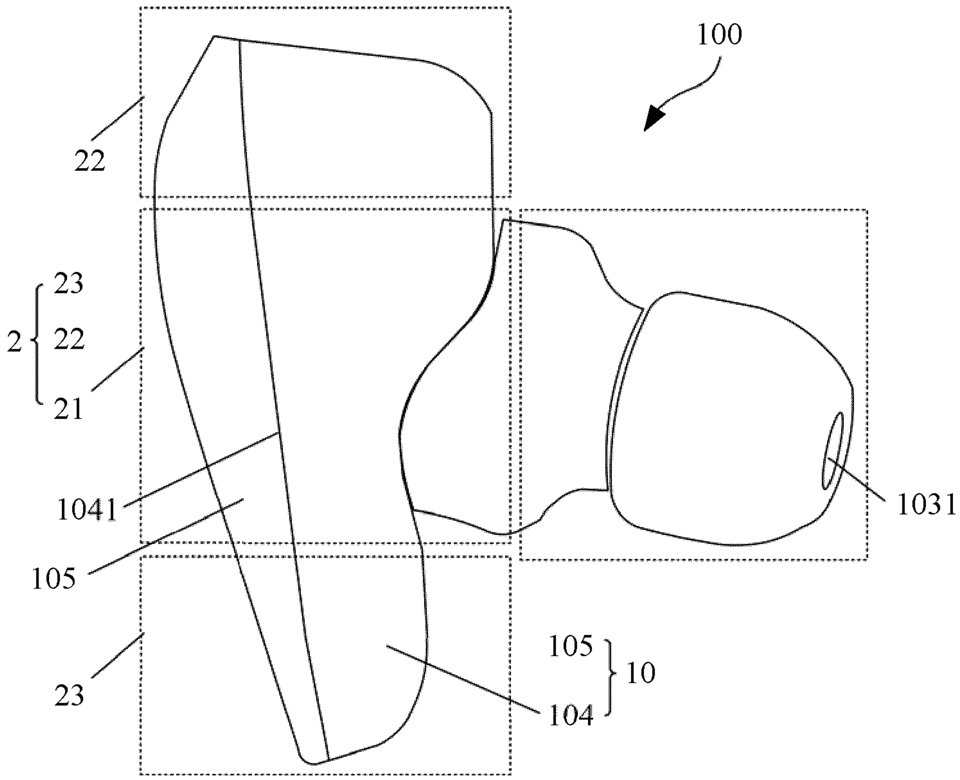

100
22
23
2
22
21
1041
105
1031
23
105
10
104

FIG. 1(c)

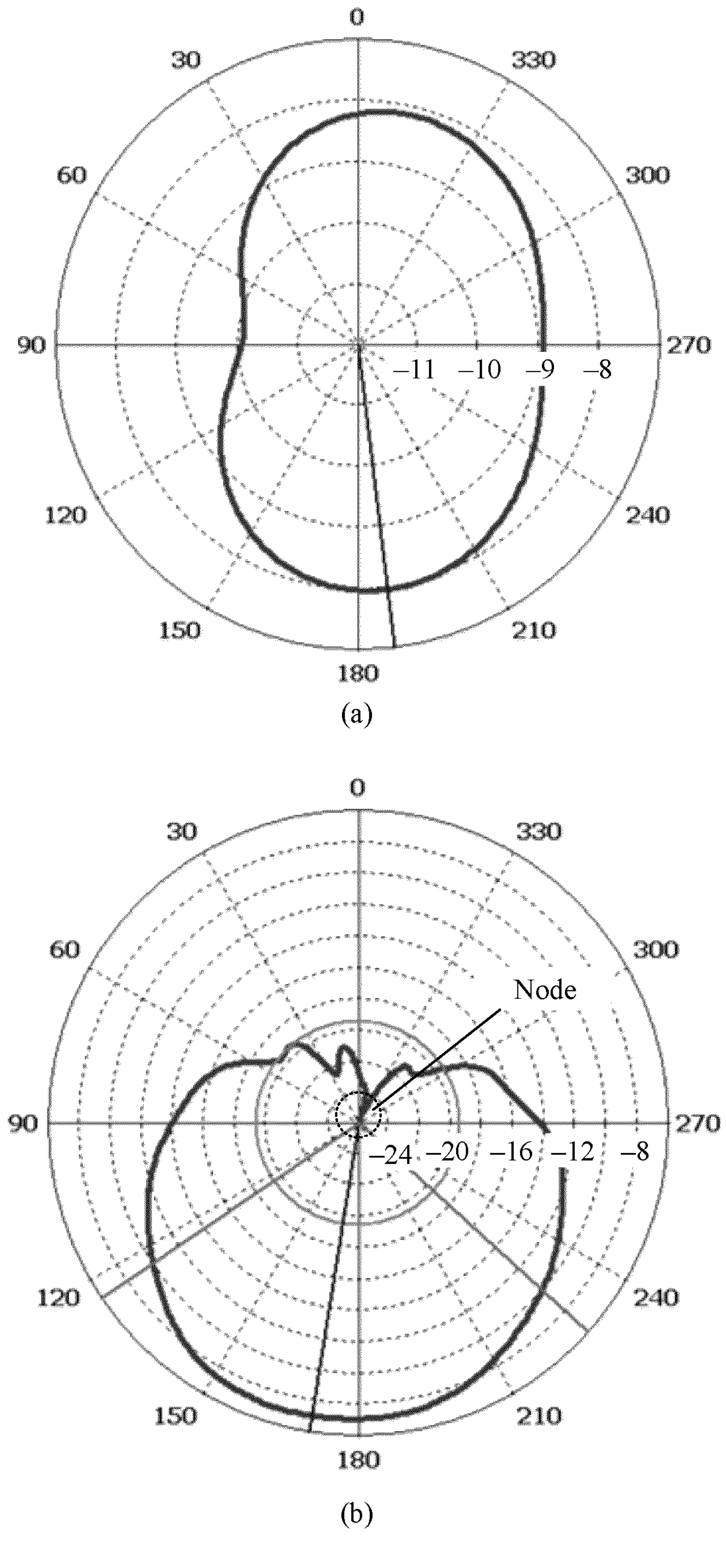

0
30
330
60
300
90
270
−11
−10
−9
−8
120
240
150
210
180
(a)
0
30
330
60
300
Node
90
270
−24
−20
−16
−12
−8
120
240
150
210
180
(b)

FIG. 2

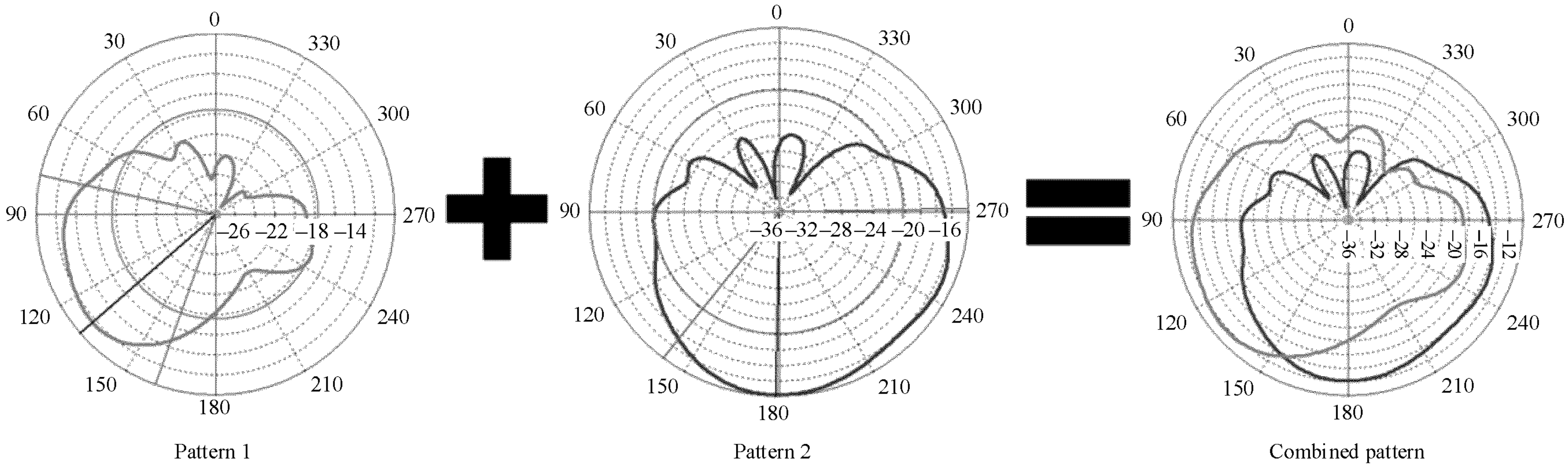

0
30
60
90
120
150
180
210
240
270
300
330
−26 −22 −18 −14
Pattern 1
−36 −32 −28 −24 −20 −16
Pattern 2
−36
−32
−28
−24
−20
−16
−12
Combined pattern

FIG. 3

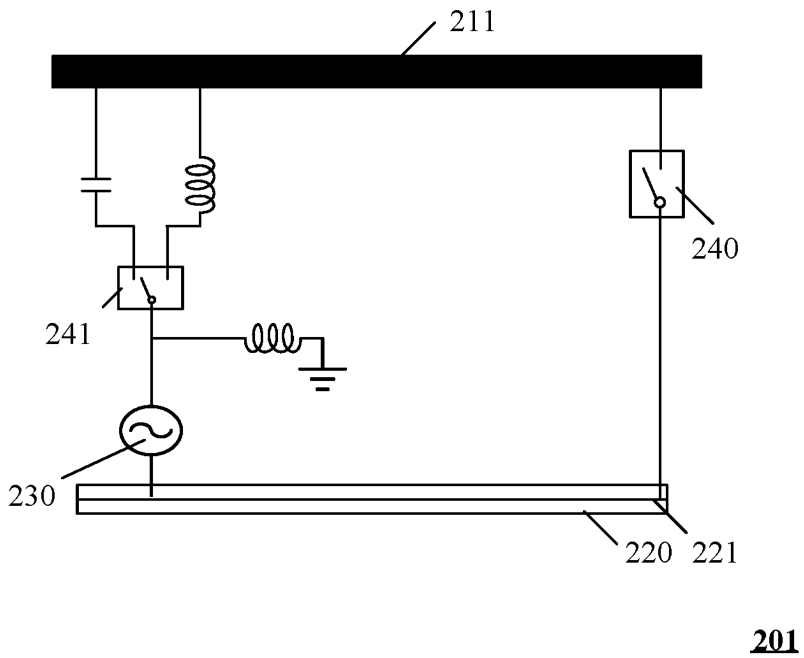


FIG. 4

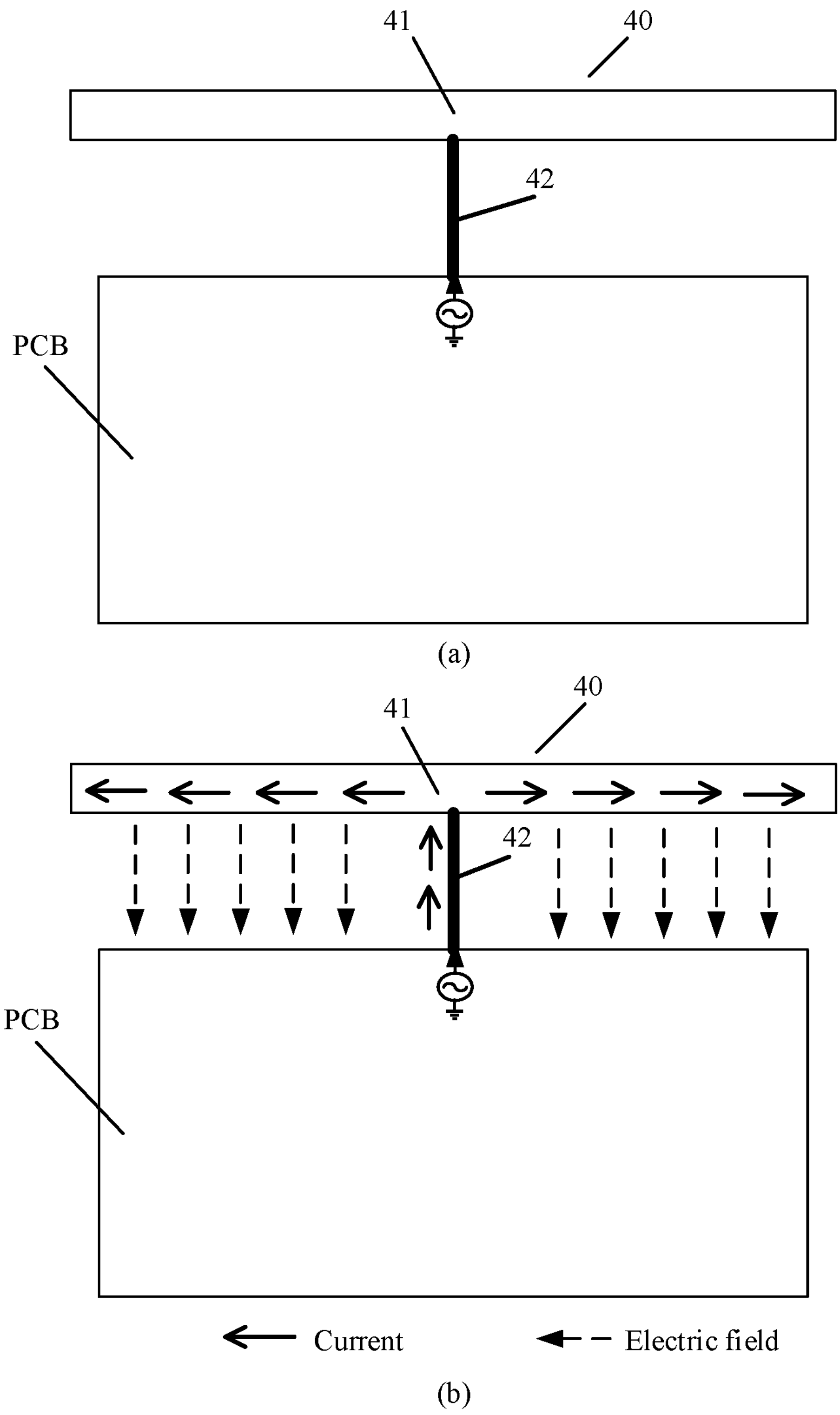


FIG. 5

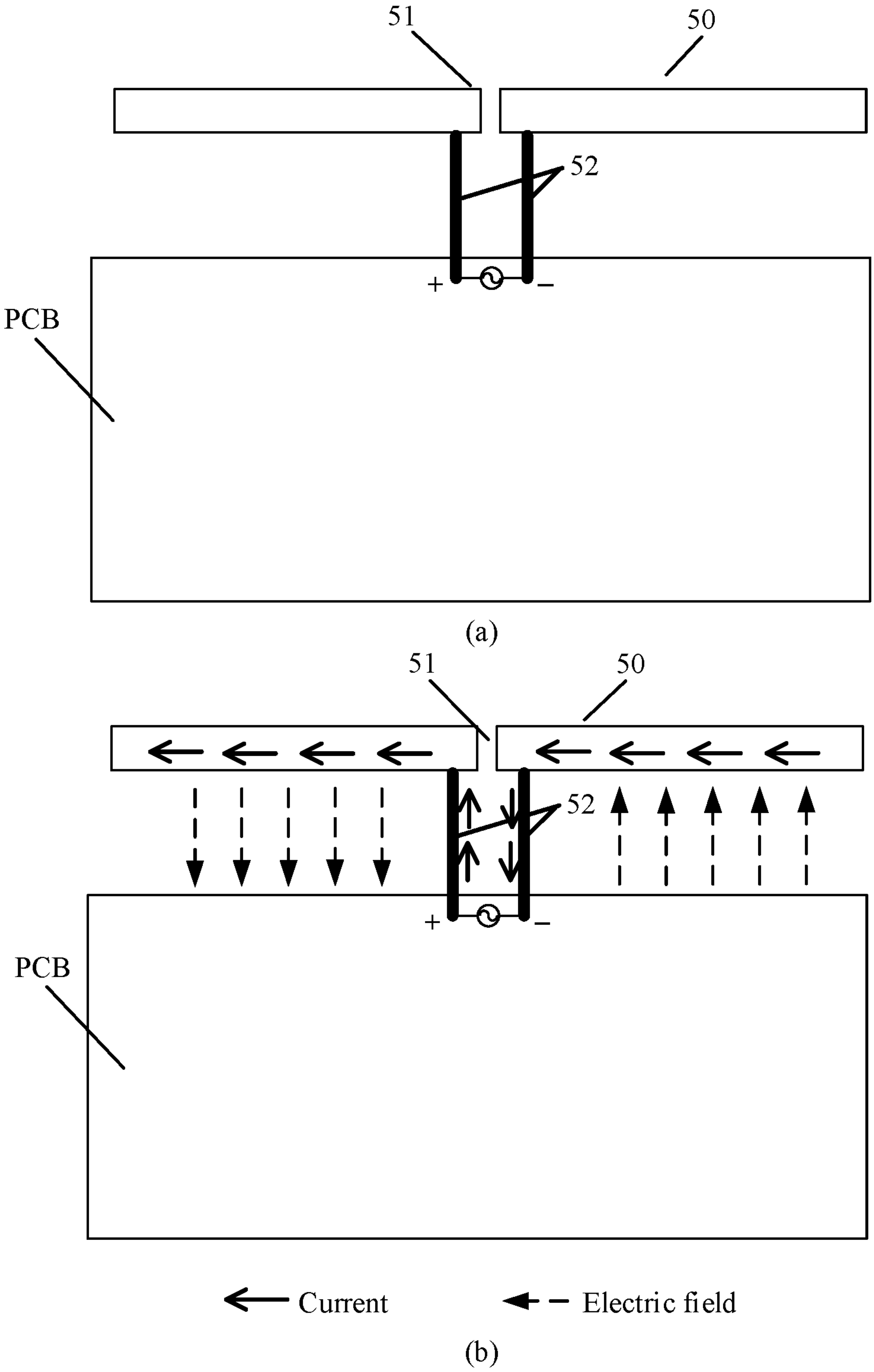
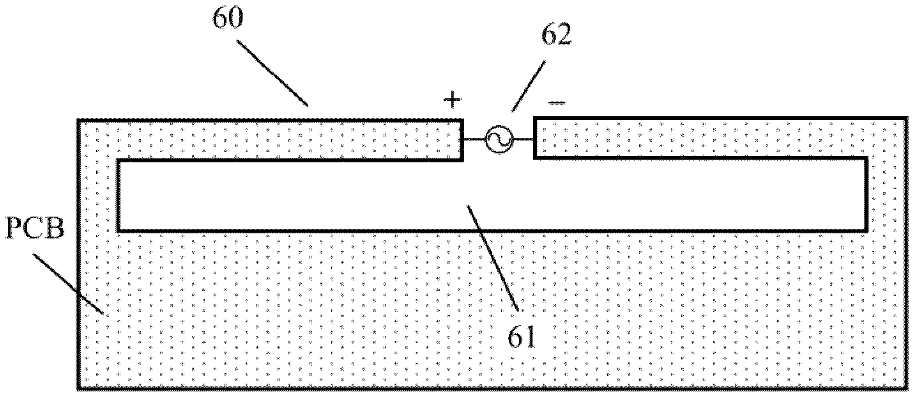
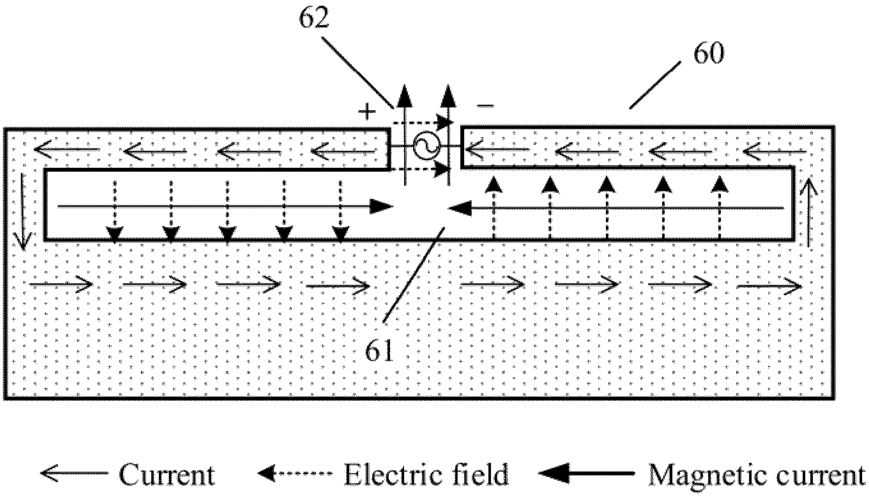


FIG. 6

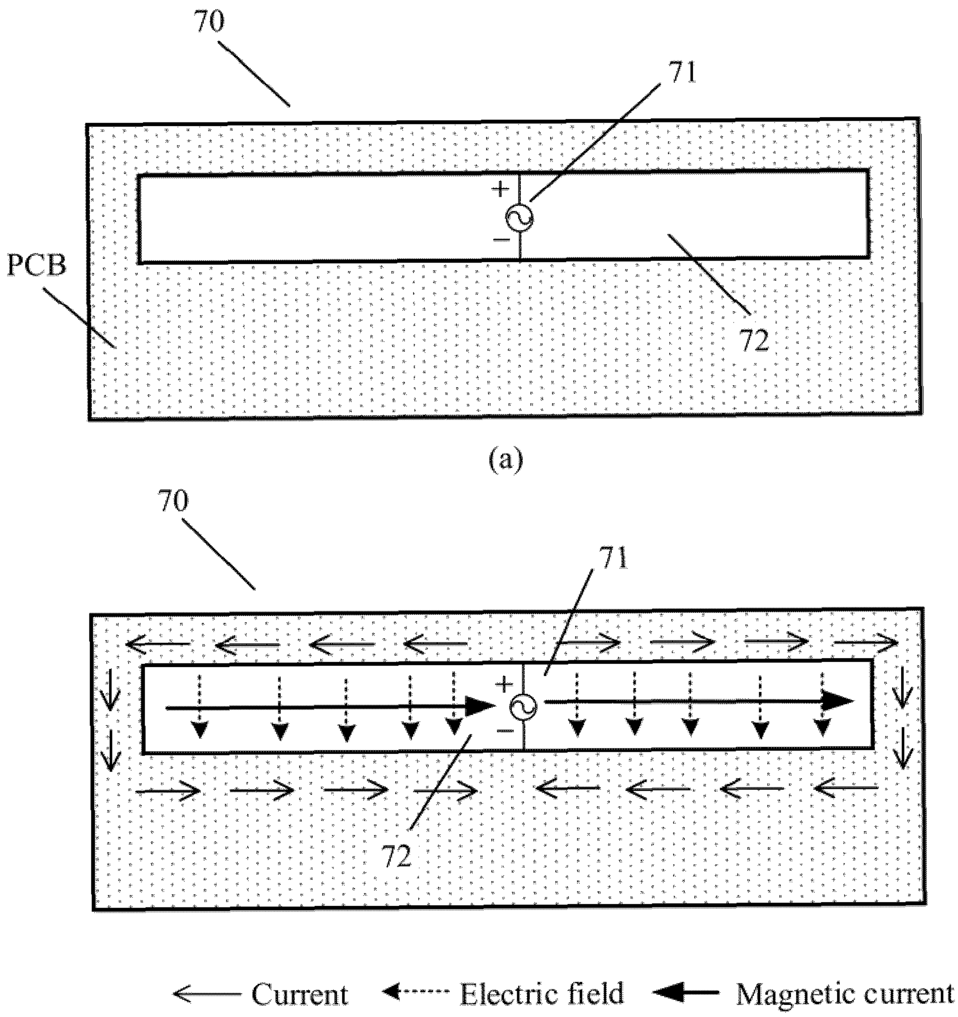

60
62
+
−
PCB
61

(a)


62
60
+
−
61
Current
Electric field
Magnetic current

(b)

FIG. 7


70
71
PCB
72
70
71
72
Current
Electric field
Magnetic current

(a)

(b)

FIG. 8

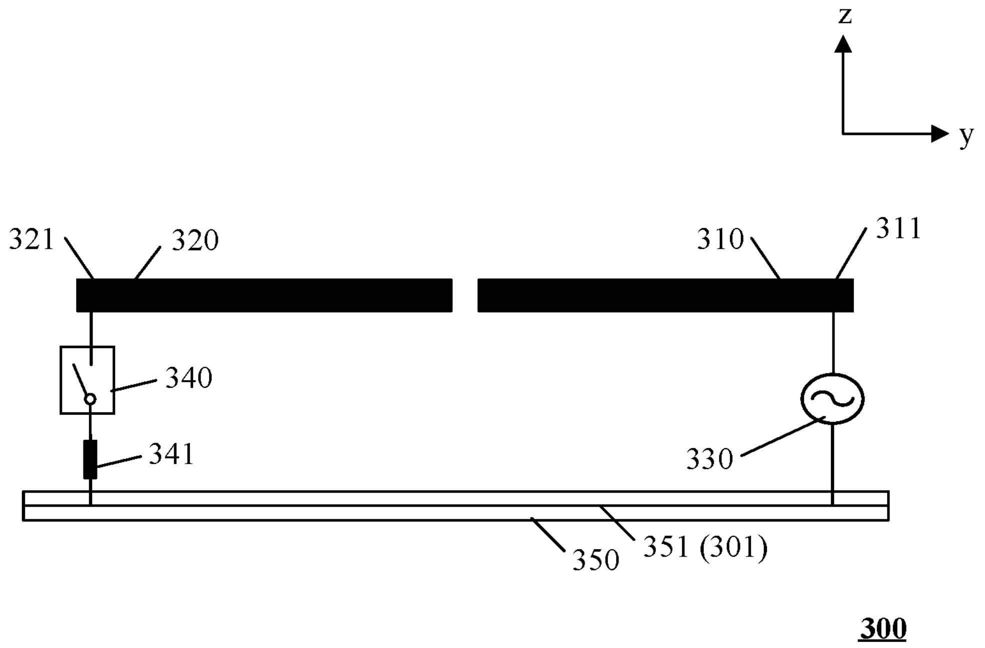

z
y
321
320
310
311
340
341
330
350
351 (301)
300

FIG. 9

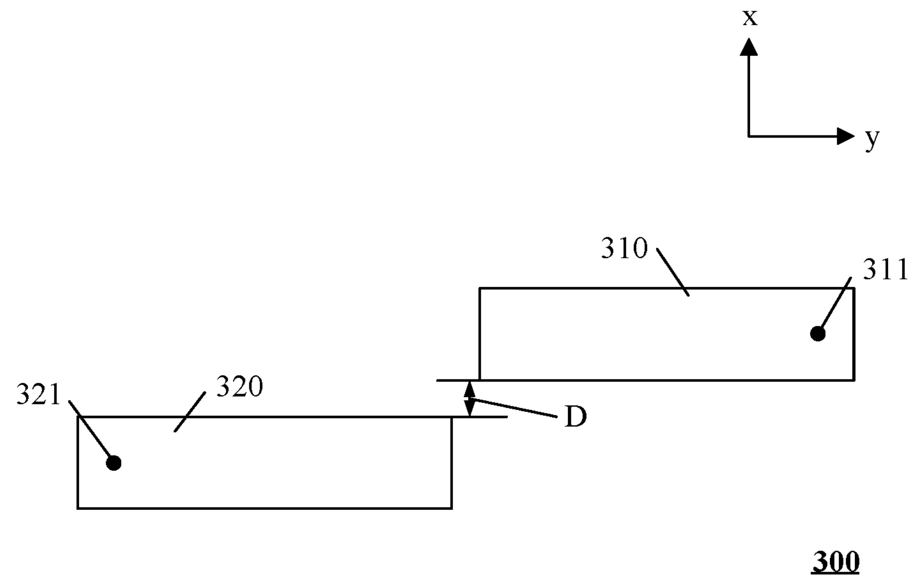

x
y
310
311
321
320
D
300

FIG. 10

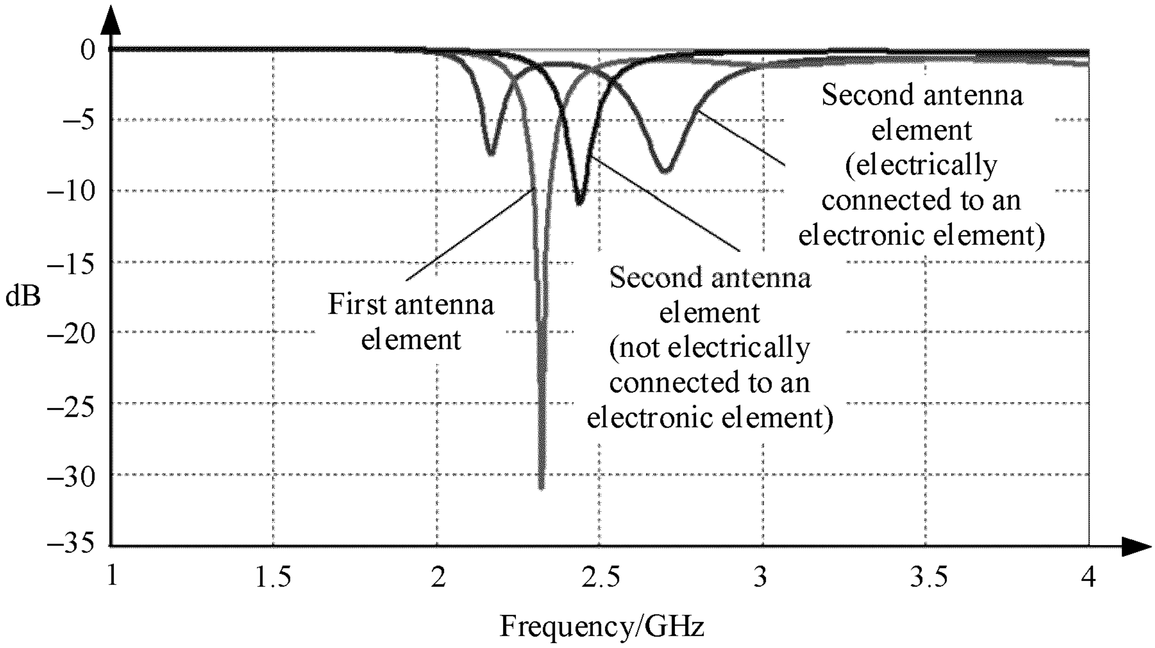

0
−5
−10
−15
dB
−20
−25
−30
−35
1
1.5
2
2.5
3
3.5
4
Frequency/GHz
Second antenna element (electrically connected to an electronic element)
First antenna element
Second antenna element (not electrically connected to an electronic element)

FIG. 11

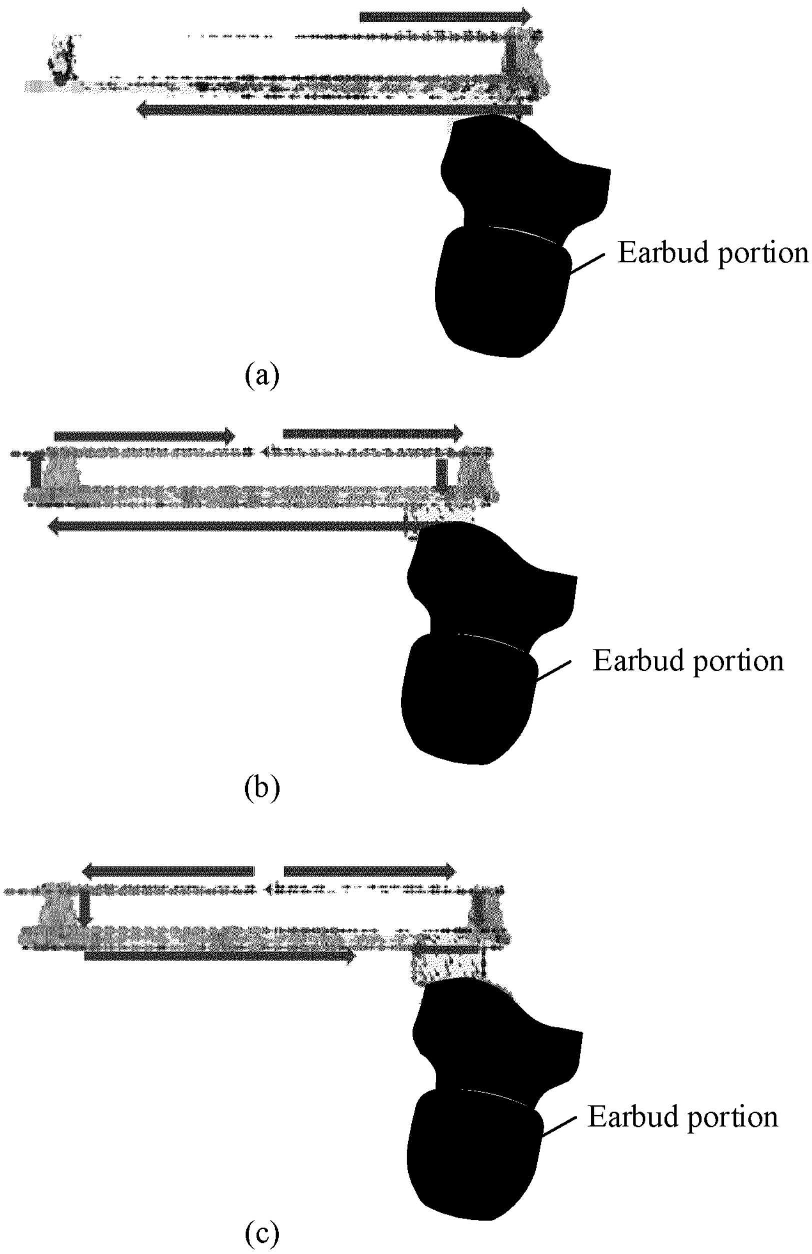


FIG. 12

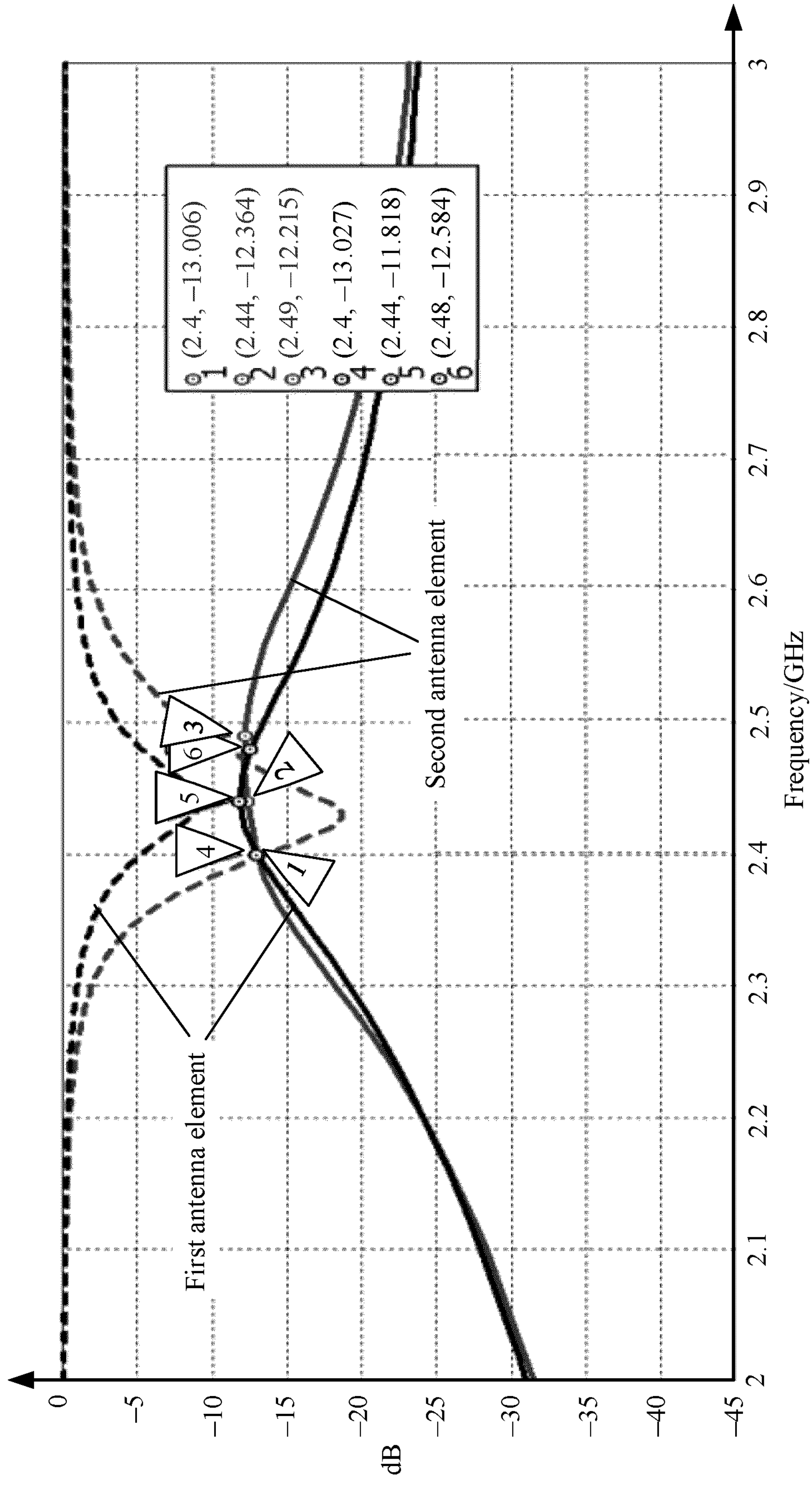
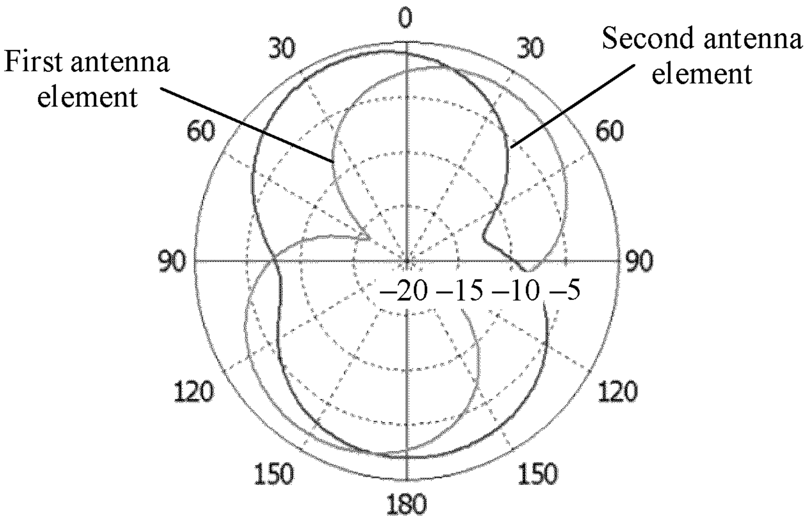

dB
0
−5
−10
−15
−20
−25
−30
−35
−40
−45
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
Frequency/GHz
First antenna element
Second antenna element
1 (2.4, −13.006)
2 (2.44, −12.364)
3 (2.49, −12.215)
4 (2.4, −13.027)
5 (2.44, −11.818)
6 (2.48, −12.584)
1
2
3
4
5
6

FIG. 13



0
30
30
First antenna element
Second antenna element
60
60
90
90
−20 −15 −10 −5
120
120
150
150
180

FIG. 14

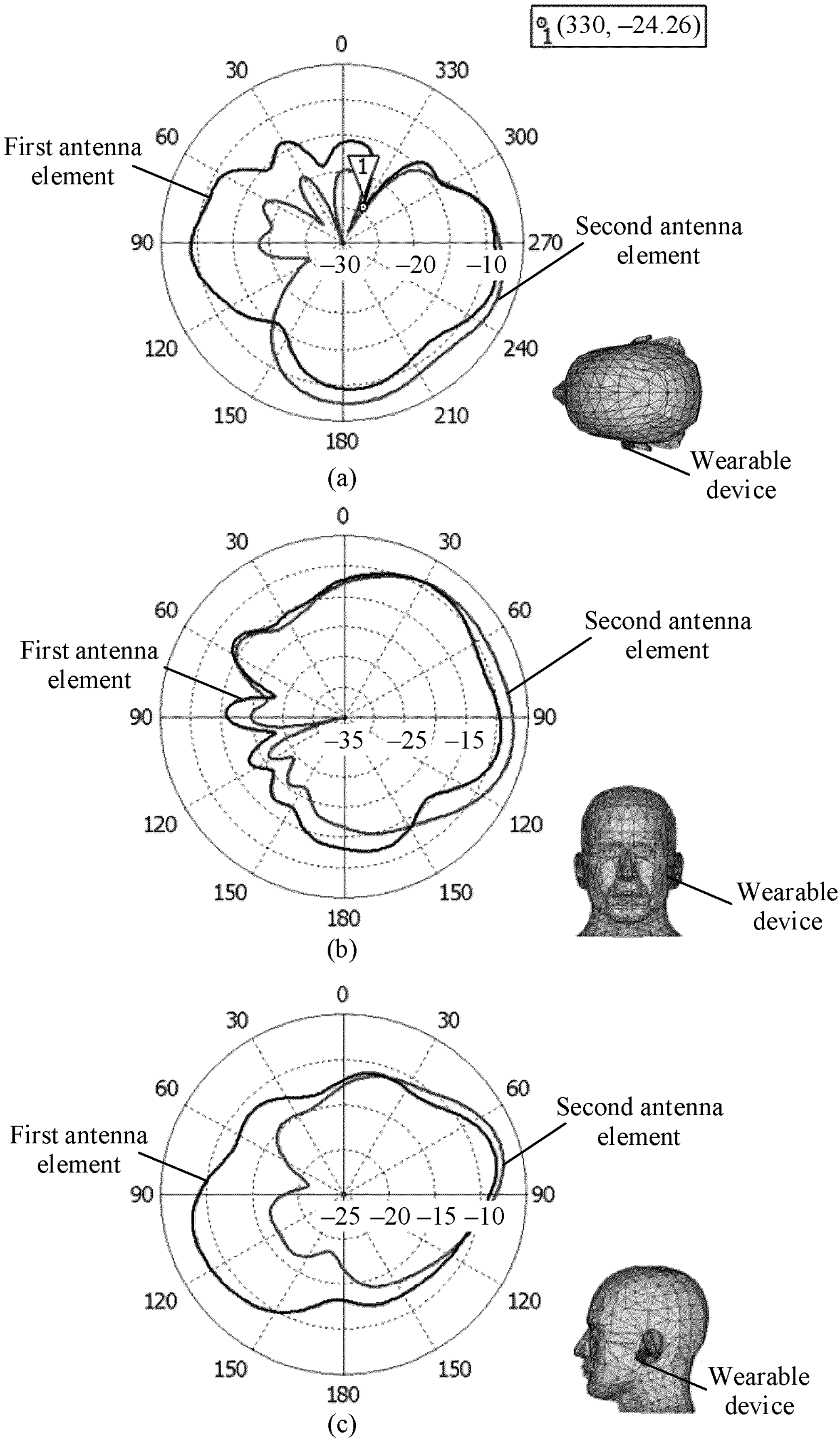

1 (330, –24.26)
0
30
330
60
300
90
270
120
240
150
210
180
–30
–20
–10
First antenna element
Second antenna element
Wearable device
(a)
0
30
30
60
60
90
90
120
120
150
150
180
–35
–25
–15
First antenna element
Second antenna element
Wearable device
(b)
0
30
30
60
60
90
90
120
120
150
150
180
–25
–20
–15
–10
First antenna element
Second antenna element
Wearable device
(c)

FIG. 15

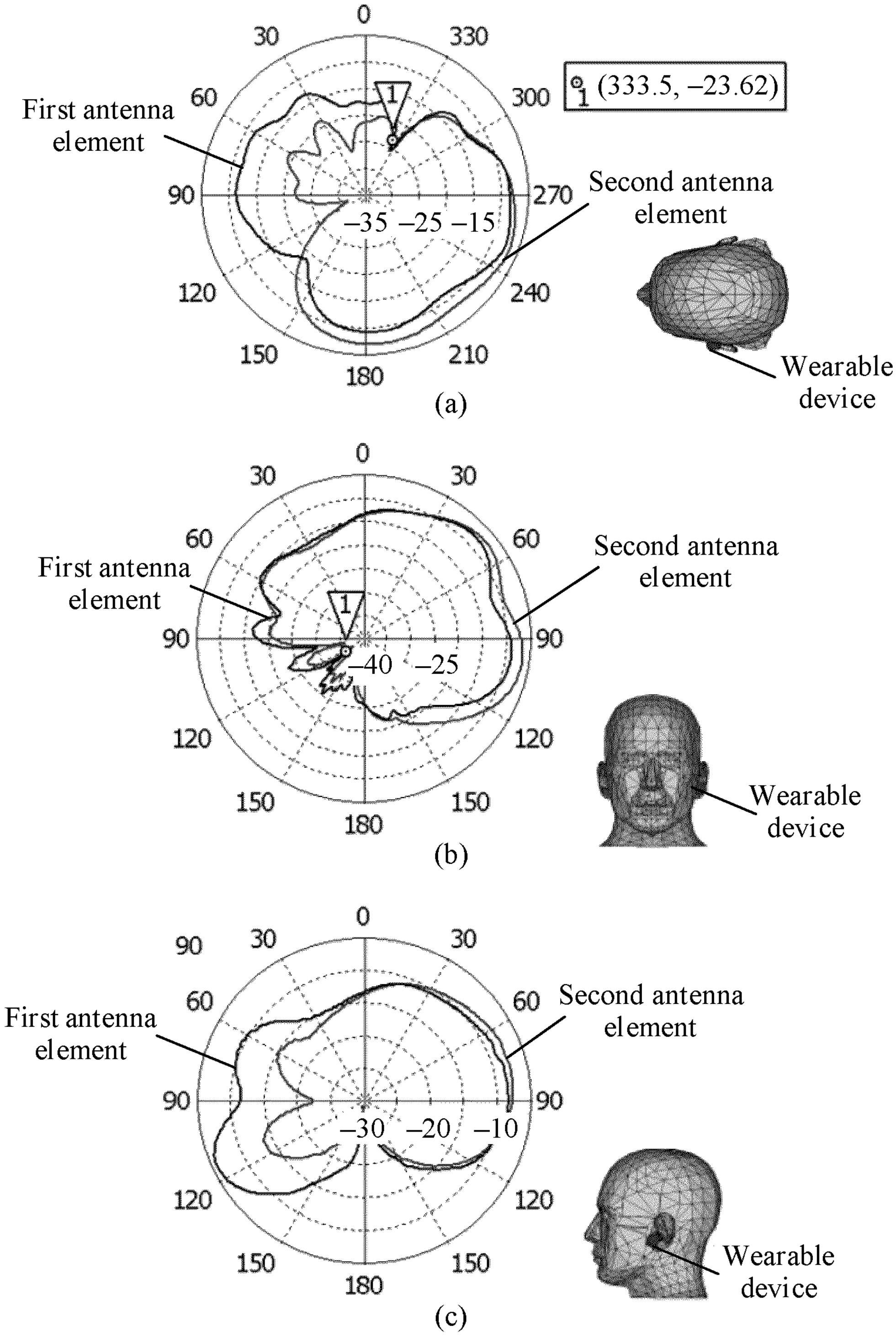

0
30
330
60
300
90
270
120
240
150
210
180
1
(333.5, −23.62)
First antenna element
Second antenna element
−35 −25 −15
Wearable device
(a)
0
30
30
60
60
90
90
120
120
150
150
180
1
First antenna element
Second antenna element
−40 −25
Wearable device
(b)
0
30
30
90
60
60
90
90
120
120
150
150
180
First antenna element
Second antenna element
−30 −20 −10
Wearable device
(c)

FIG. 16

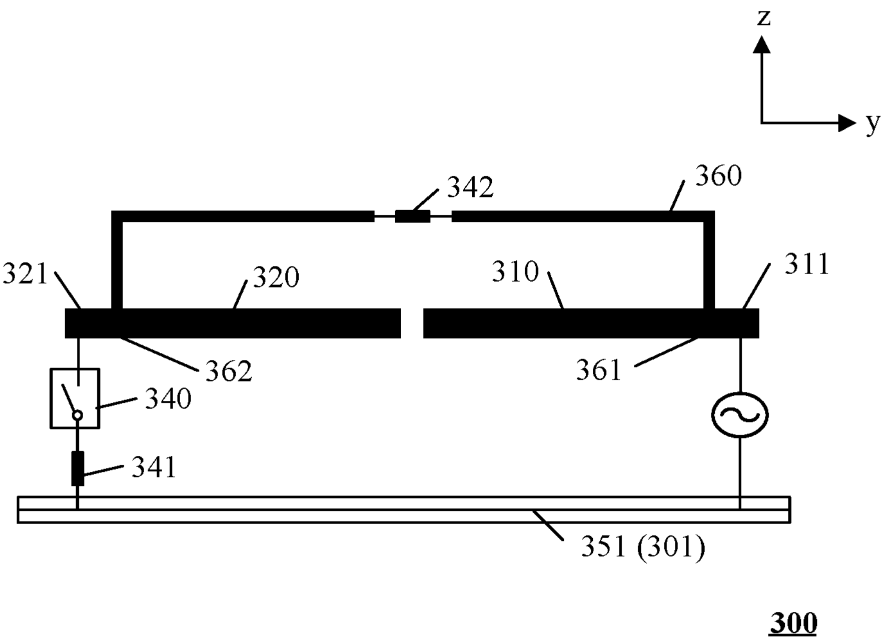

z
y
342
360
321
320
310
311
362
361
340
341
351 (301)
300

FIG. 17

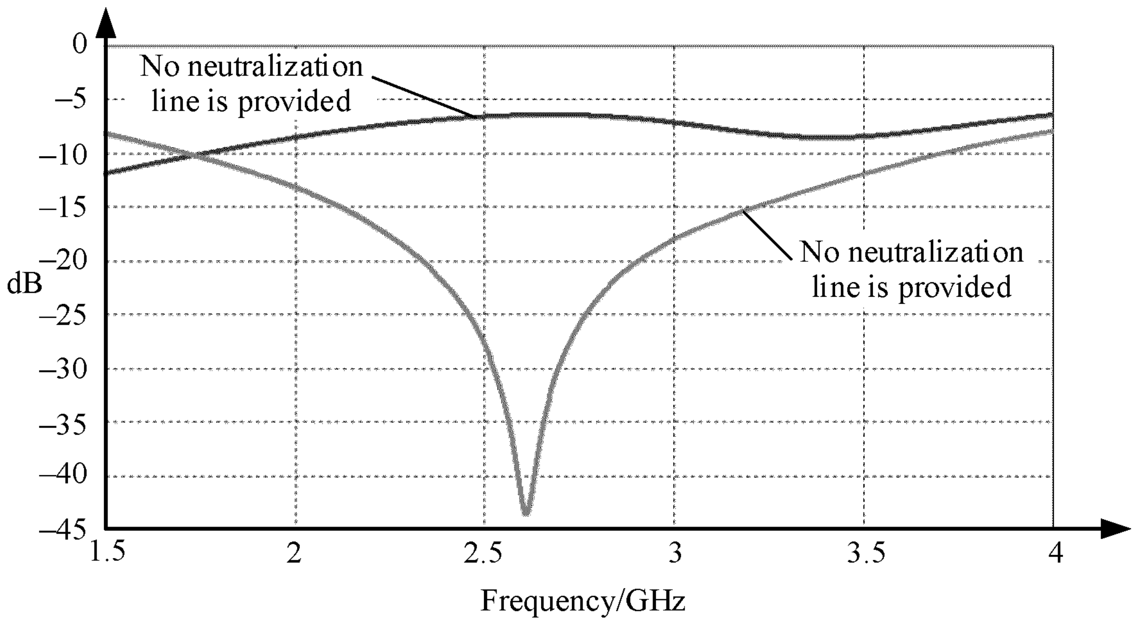

0
–5
–10
–15
–20
dB
–25
–30
–35
–40
–45
1.5
2
2.5
3
3.5
4
Frequency/GHz
No neutralization line is provided
No neutralization line is provided

FIG. 18

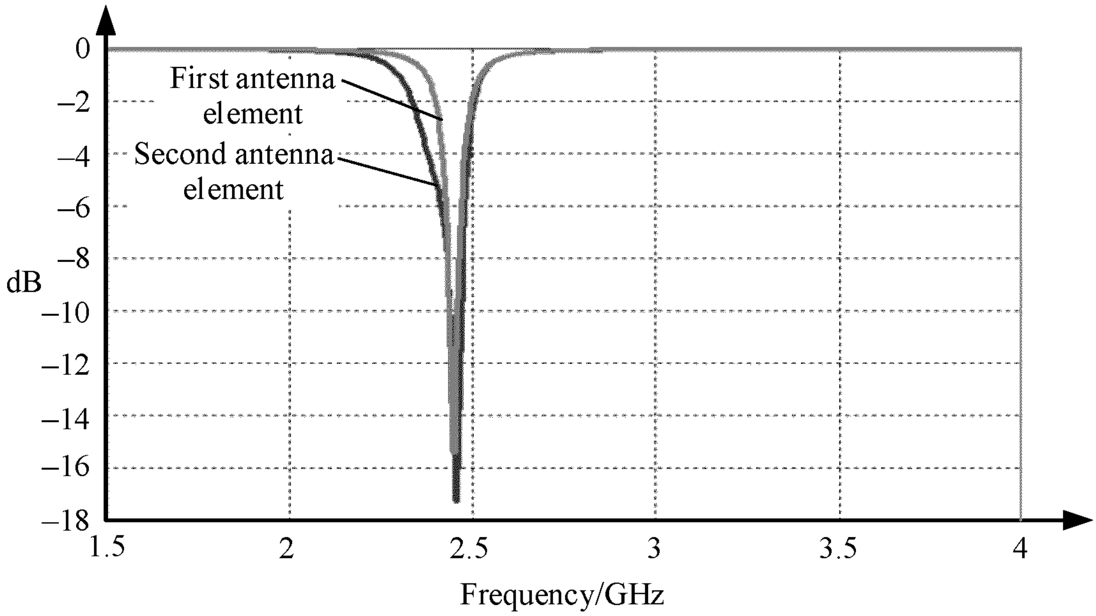

0
–2
–4
–6
–8
–10
–12
–14
–16
–18
dB
First antenna element
Second antenna element
1.5
2
2.5
3
3.5
4
Frequency/GHz

FIG. 19

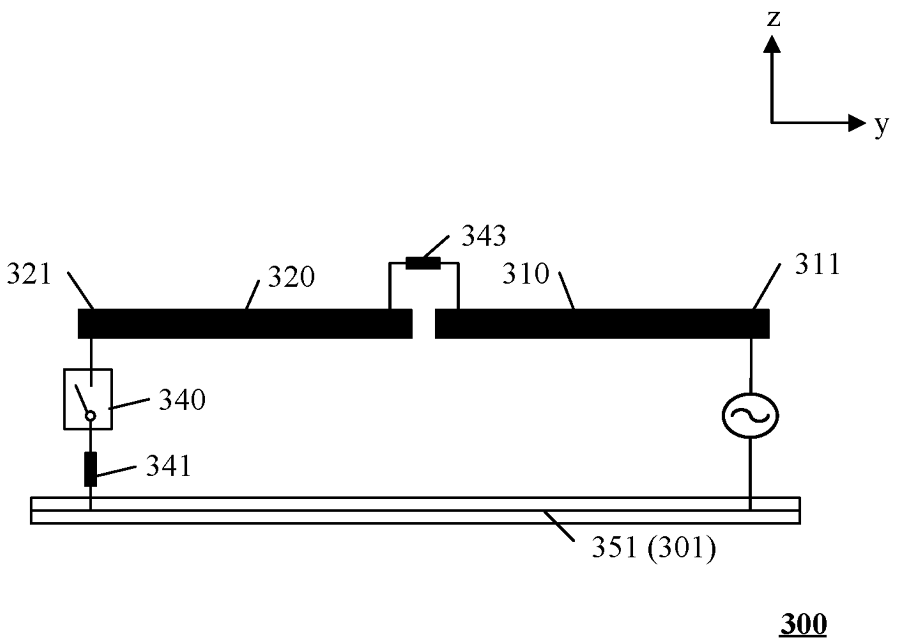

z
y
343
321
320
310
311
340
341
351 (301)
300

FIG. 20

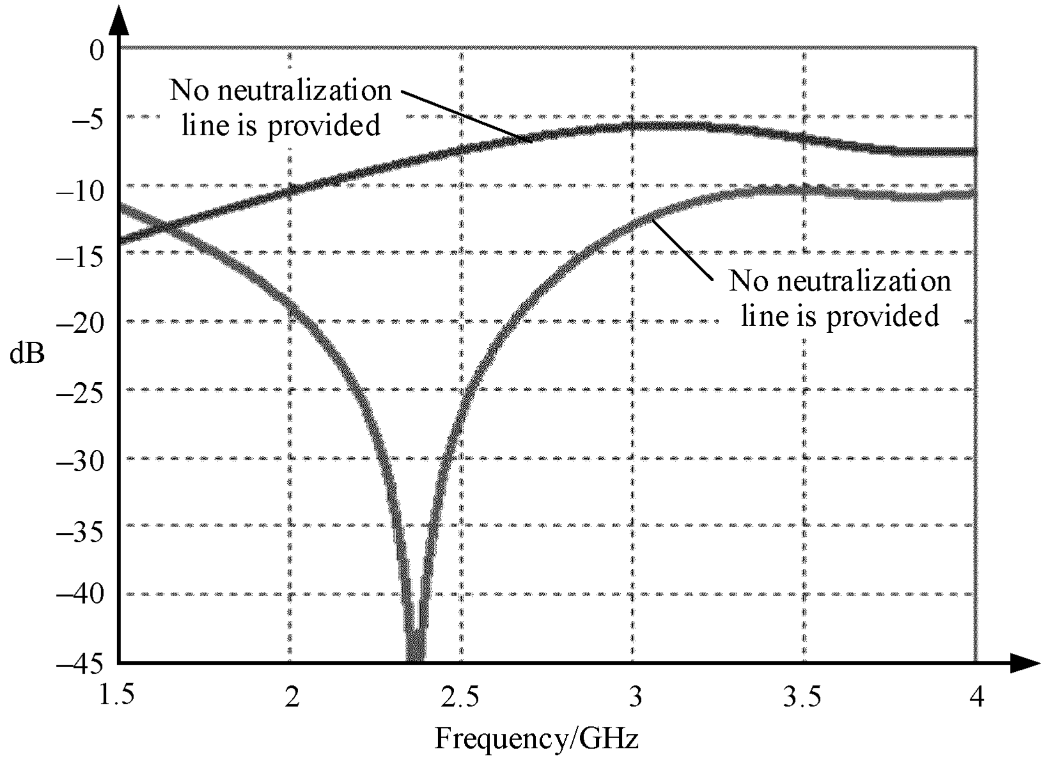

0
–5
–10
–15
–20
–25
–30
–35
–40
–45
dB
No neutralization line is provided
No neutralization line is provided
1.5
2
2.5
3
3.5
4
Frequency/GHz

FIG. 21

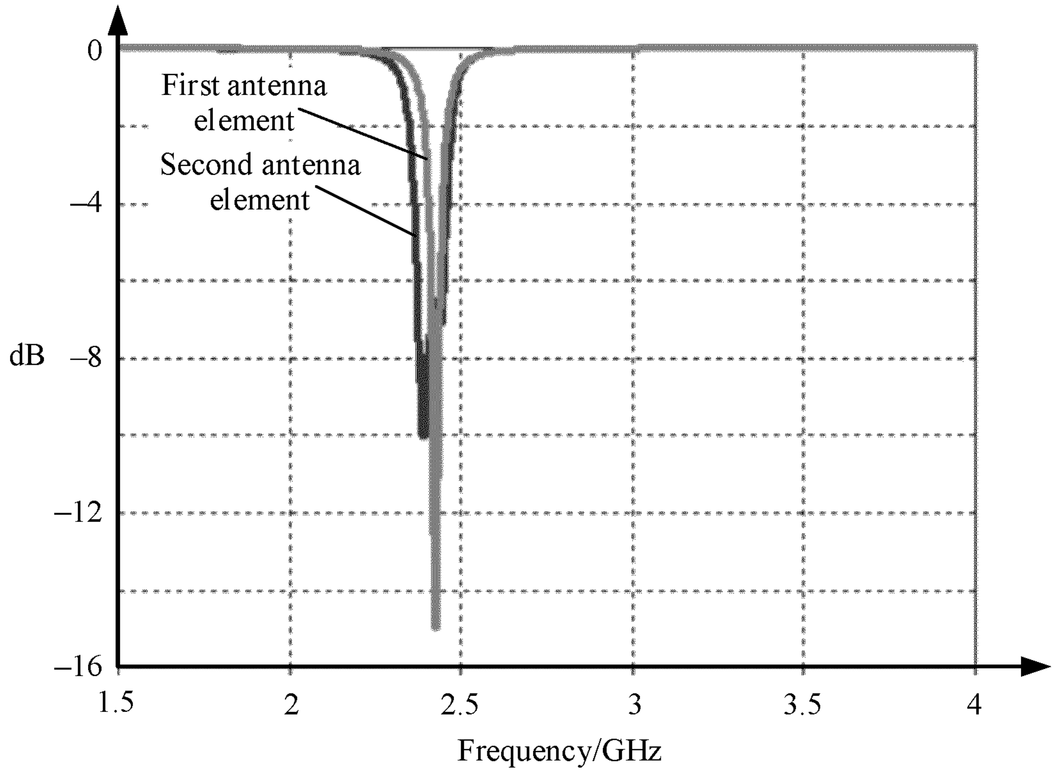

0
–4
–8
–12
–16
dB
First antenna element
Second antenna element
1.5
2
2.5
3
3.5
4
Frequency/GHz

FIG. 22

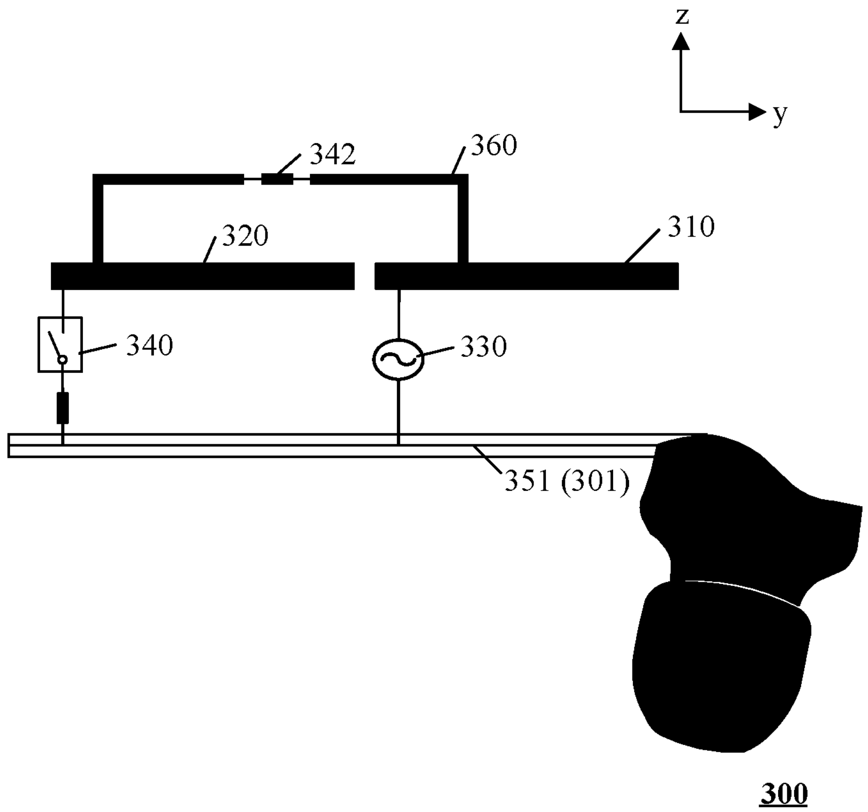

z
y
342
360
320
310
340
330
351 (301)
300

FIG. 23

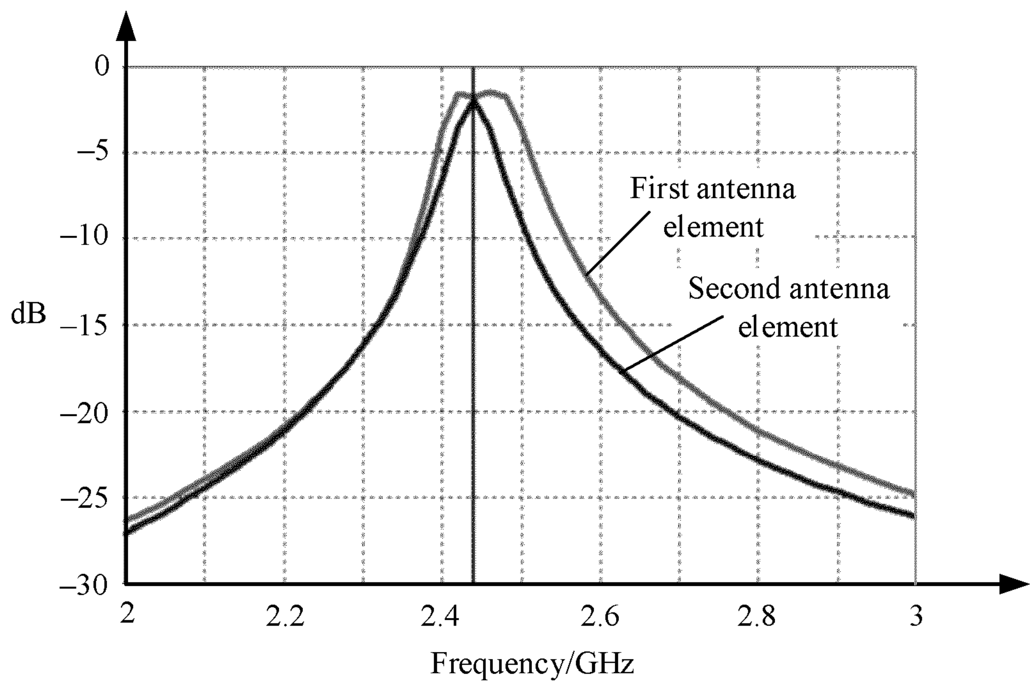
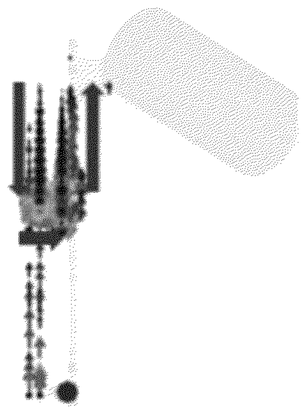
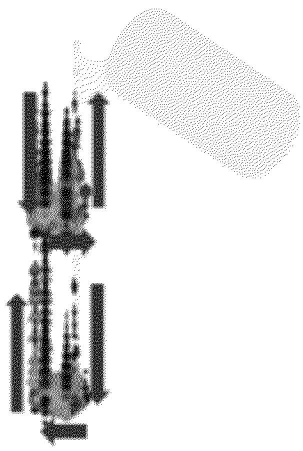

0
−5
−10
dB
−15
−20
−25
−30
2
2.2
2.4
2.6
2.8
3
Frequency/GHz
First antenna element
Second antenna element

FIG. 24



(a)



(b)

FIG. 25

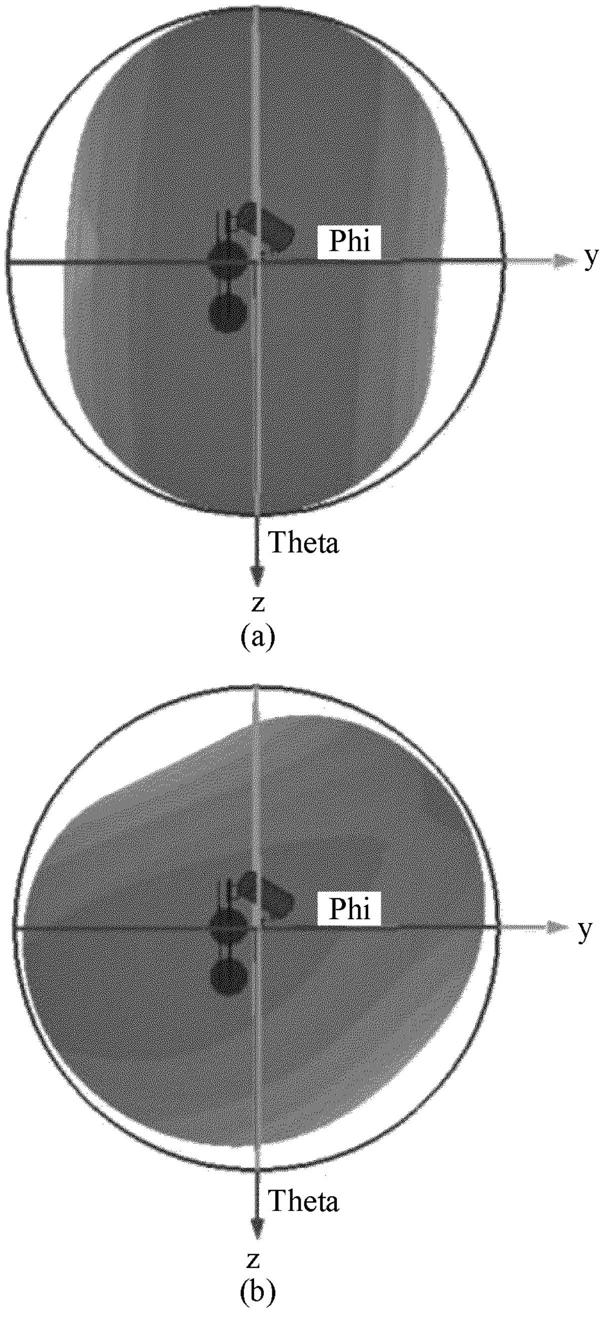


FIG. 26

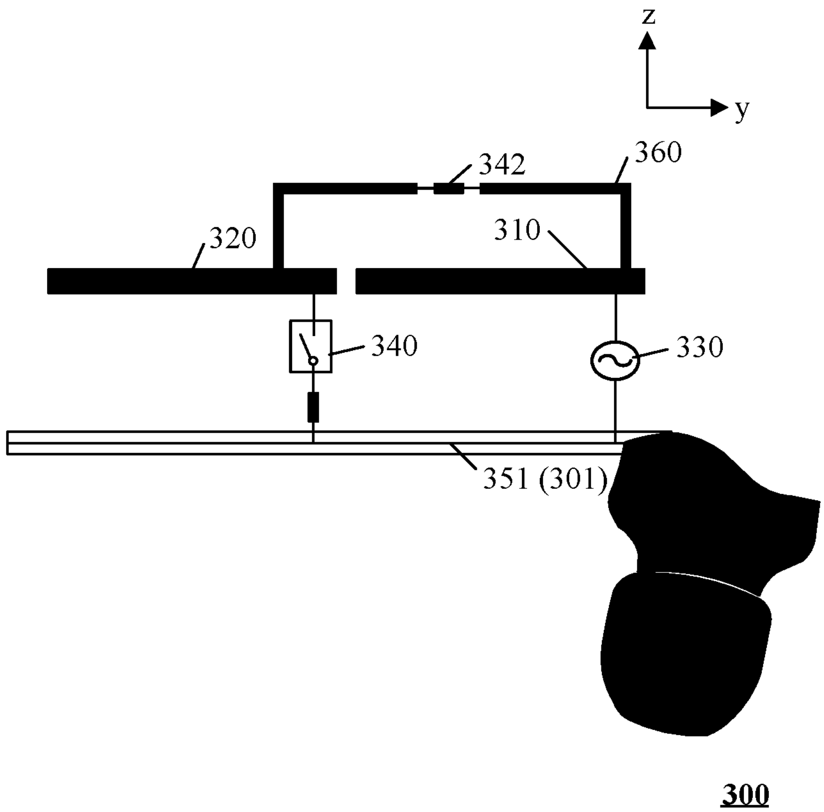

z
y
342
360
320
310
340
330
351 (301)
300

FIG. 27

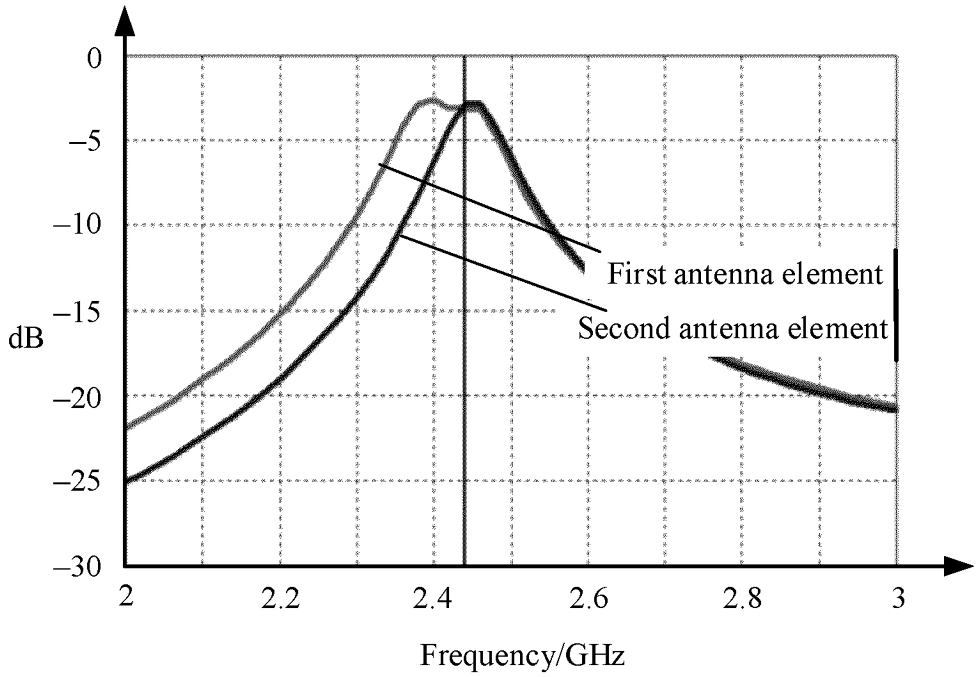
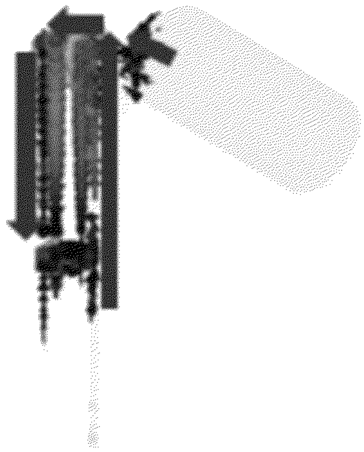
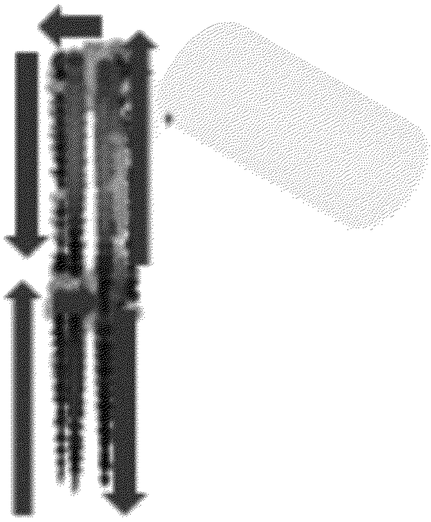

0
–5
–10
–15
–20
–25
–30
dB
First antenna element
Second antenna element
2
2.2
2.4
2.6
2.8
3
Frequency/GHz

FIG. 28

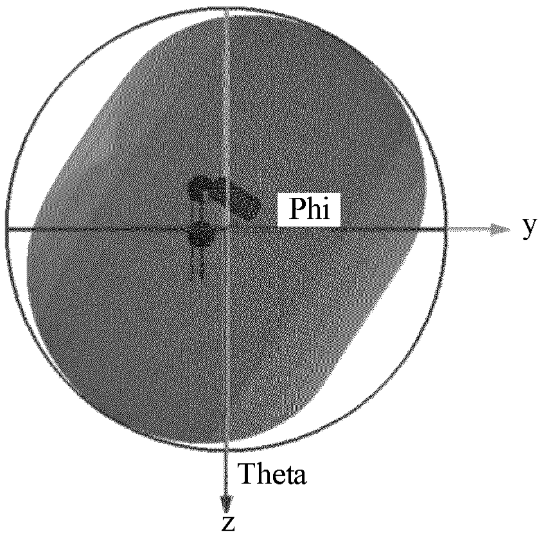


(a)

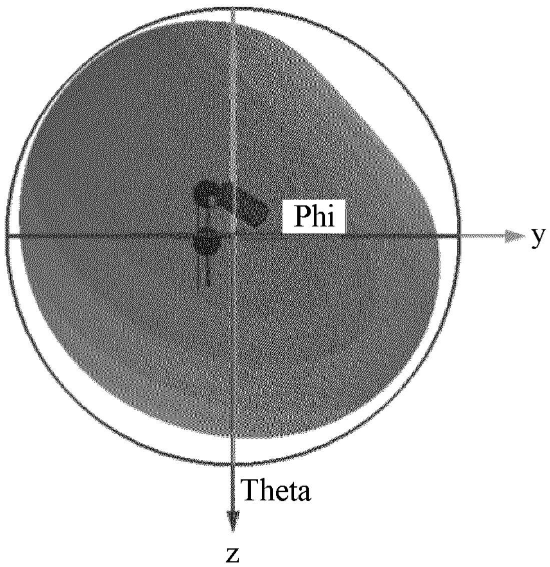


(b)

FIG. 29



(a)



(b)

FIG. 30

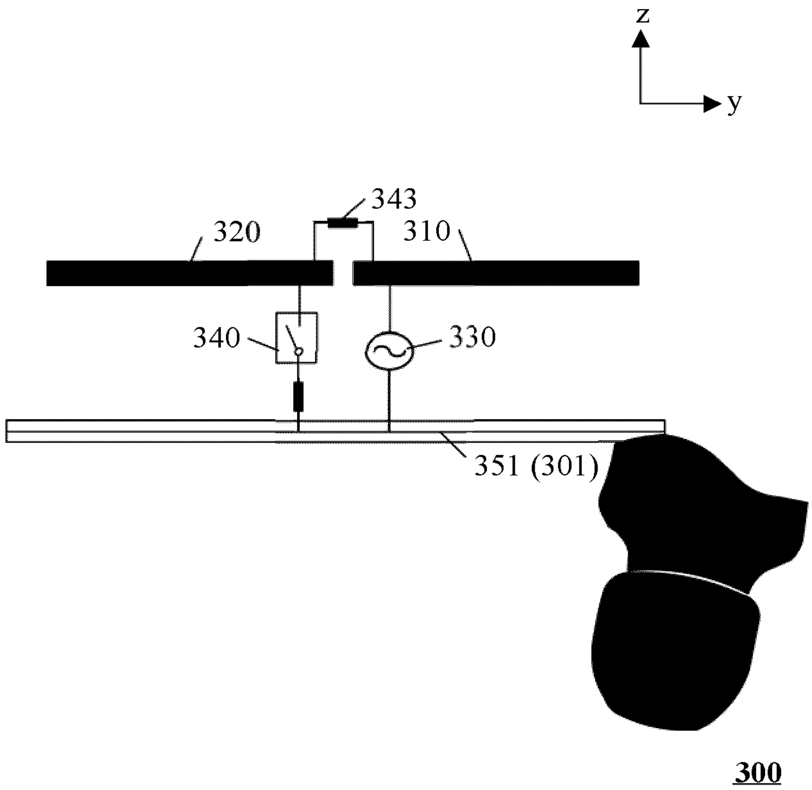

z
y
343
320
310
340
330
351 (301)
300

FIG. 31

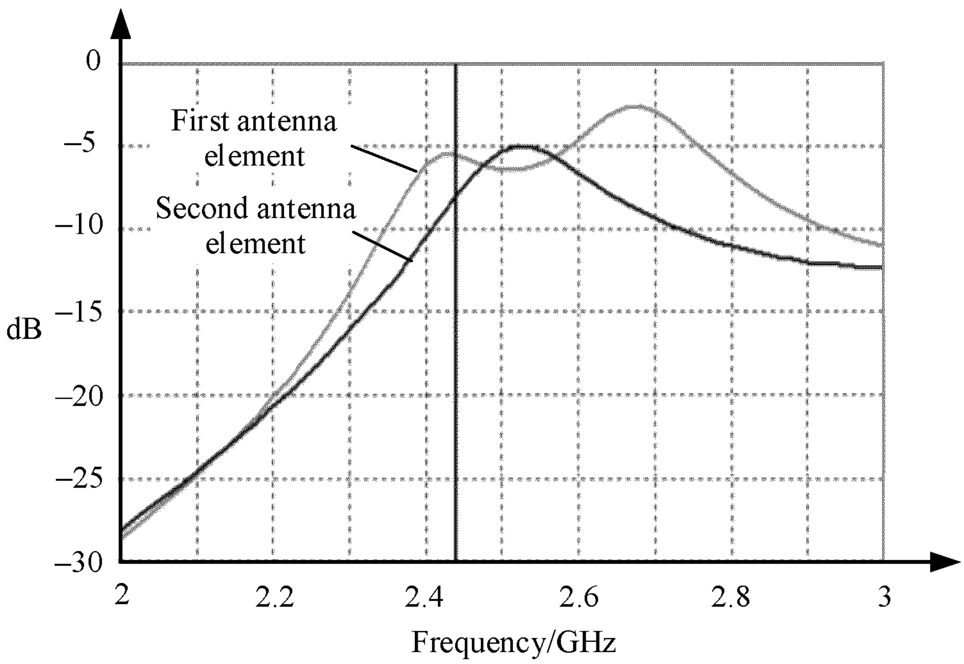
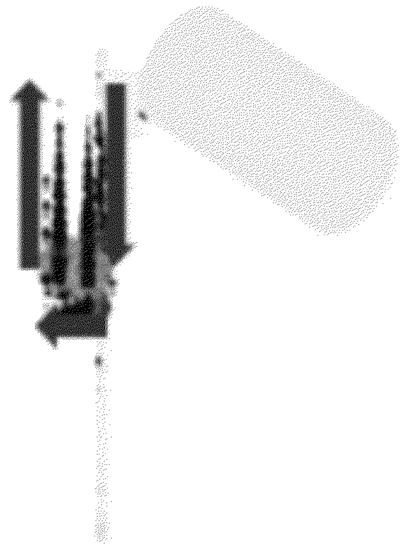
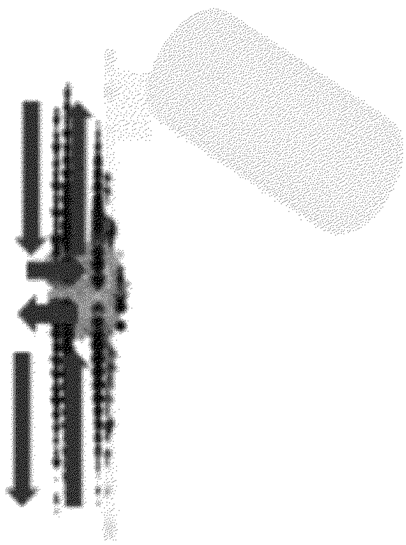

0
–5
–10
–15
–20
–25
–30
dB
First antenna
element
Second antenna
element
2
2.2
2.4
2.6
2.8
3
Frequency/GHz

FIG. 32

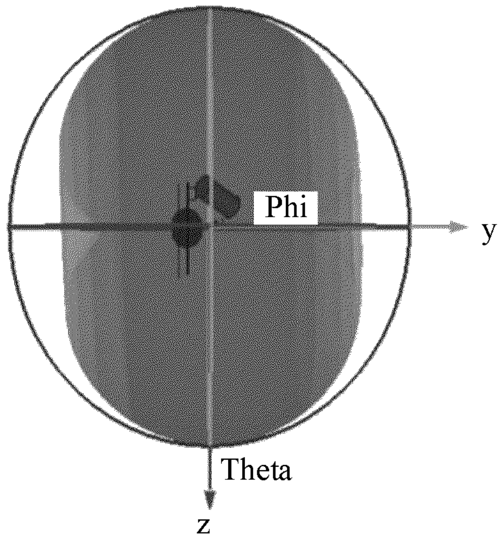


(a)

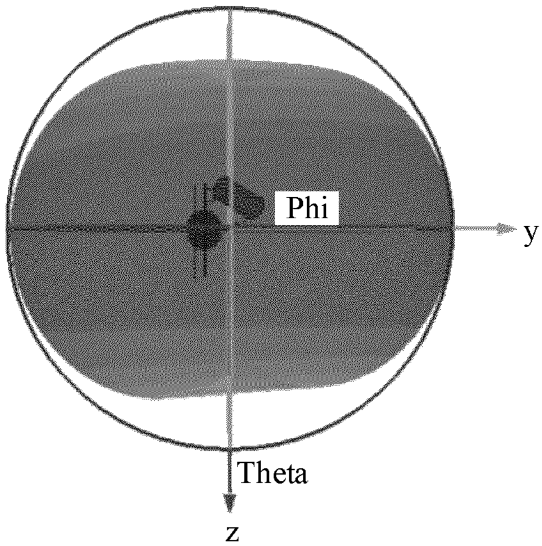


(b)

FIG. 33



(a)



(b)

FIG. 34

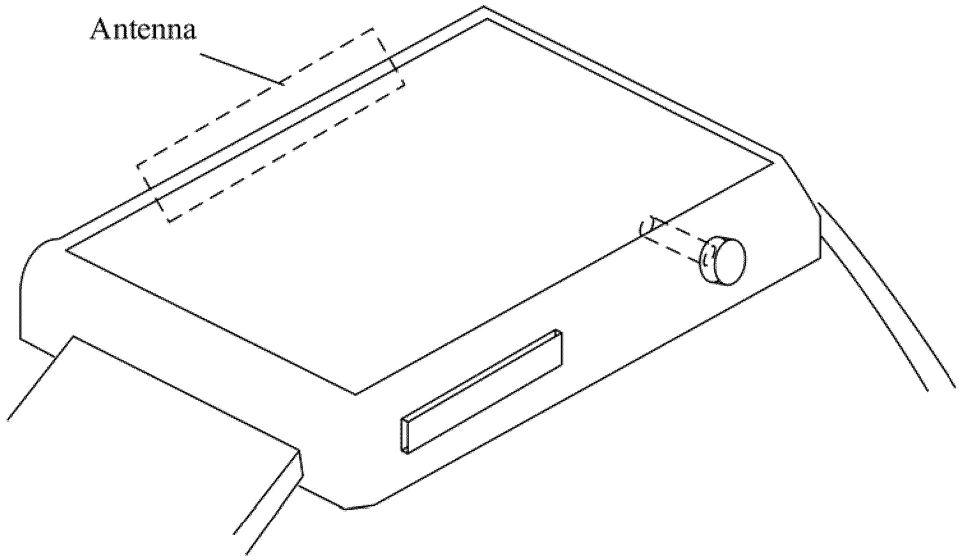


FIG. 35

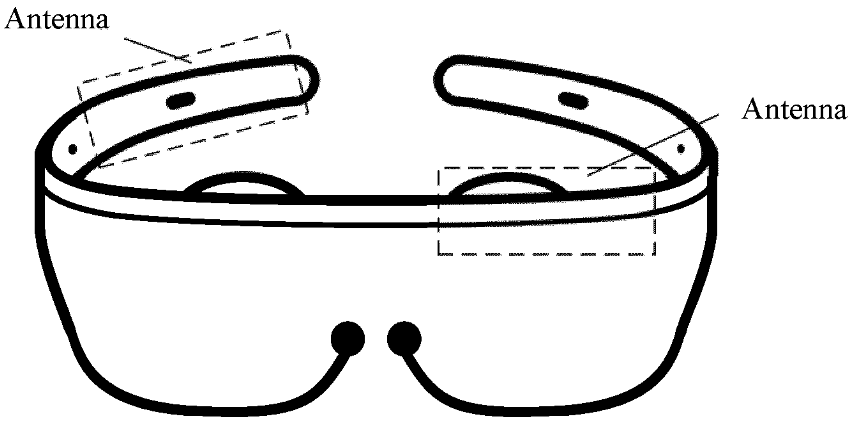


FIG. 36

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2023/116944

A. CLASSIFICATION OF SUBJECT MATTER

H01Q1/27(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; CNKI; VEN; USTXT; WOTXT; EPTXT: 华为, 天线, 开关, 切换, 辐射, 地板, 金属层, 金属板, 接地, 馈电, 馈源, 馈入, 射频源, 互补, 频段, 频带, antenna, switch, radiat+, GND, ground+, metal, feeder, frequenc+, band

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 113140889 A (WISTRON NEWEB CORP.) 20 July 2021 (2021-07-20) description, paragraphs 65-103, and figures 1-16	1-20
A	CN 109449569 A (VIVO MOBILE COMMUNICATION CO., LTD.) 08 March 2019 (2019-03-08) entire document	1-20
A	CN 113708093 A (BEIJING XIAOMI MOBILE SOFTWARE CO., LTD.) 26 November 2021 (2021-11-26) entire document	1-20
A	CN 213905595 U (VIVO MOBILE COMMUNICATION CO., LTD.) 06 August 2021 (2021-08-06) entire document	1-20
A	WO 2020005477 A1 (GOOGLE LLC) 02 January 2020 (2020-01-02) entire document	1-20

☐ Further documents are listed in the continuation of Box C.

☑ See patent family annex.

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "D" document cited by the applicant in the international application
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
01 November 2023	**21 November 2023**

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2023/116944

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
CN	113140889	A	20 July 2021	US	2021226318	A1	22 July 2021
				TW	I723744	B	01 April 2021
CN	109449569	A	08 March 2019	None			
CN	113708093	A	26 November 2021	None			
CN	213905595	U	06 August 2021	None			
WO	2020005477	A1	02 January 2020	None			

Form PCT/ISA/210 (patent family annex) (July 2022)

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- CN 202211114401 **[0001]**