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(54) **ANTENNA, ANTENNA ARRANGEMENT, AND ELECTRONIC DEVICE**

ANTENNE, ANTENNENANORDNUNG UND ELEKTRONISCHE VORRICHTUNG

ANTENNE, AGENCEMENT D'ANTENNE ET DISPOSITIF ÉLECTRONIQUE

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EP 3 718 168 B1

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Description

TECHNICAL FIELD

[0001] The present invention relates to the field of antennas used for wireless communications, and particularly to antennas that fit into tight spaces in electronic devices built with electrically conductive frames. Furthermore the invention relates to antenna arrangements that comprise a plurality of antennas, and to electronic devices that comprise an antenna or antenna arrangement.

BACKGROUND

[0002] Antennas are needed in all electronic devices that communicate using radio waves. Many such devices are meant to be portable, easily usable, and aesthetically appealing to users. As a consequence their size, design, overall appearance, mechanical robustness, and efficiency in radio communications may pose difficult and possibly mutually contradicting requirements to antenna design.

[0003] One example of such an electronic device is a portable communications and/or computing device such as a smartphone, a tablet computer, or a laptop computer. Such a device may be relatively flat and somewhat elongated in form and have two ends, two side edges, as well as a front side and a back side. A large majority portion of the front side is often reserved for a touch-sensitive display. The back side may be covered by a layer of glass and/or metal. The circumference along said ends and side edges may also comprise a metallic frame. The device may be only some millimeters thick, and the ends and side edges may measure from a few centimeters to some decimeters. The physical dimensions of an antenna have certain relation to the wavelength of communications, which means that if an antenna is to be used for communications at wavelengths below 6 GHz, it must have physical dimensions in the order of some centimeters. It is difficult to design an antenna of that size so that on one hand it would enable efficient communications and high data throughput but on the other hand it would fit easily within a portable communications device.

[0004] Prior art suggests various antenna structures that usually necessitate making openings in the metallic plate that covers the back side of the device, and/or gaps in the metallic frame along the circumference of the device. Such gaps may have an unfavorable effect on the overall design of the device. Additionally an antenna with such a gap is prone to the so-called death grip phenomenon, which means that the user's finger or palm loads the electric field where it is strongest next to the gap, which dramatically weakens antenna performance.

[0005] Document GB 2 438 292 A relates to an antenna formed by a metal plate and a dielectric printed board and, more particularly, to a small-sized broadband antenna element and a method of using the same. The fold-

able broadband antenna comprises a plate conductor having a slit, a back conductor that is electrically connected with the plate conductor and is disposed parallel to the plate conductor with space, wherein one of a pair of conductors composing a line spans the slit and is electrically connected with the plate conductor on a conductive route from the slit to the back conductor.

[0006] US 2009/153407 A1 provides handheld electronic devices and antennas for handheld electronic devices. A handheld electronic device may have conductive structures that form an antenna ground plane element. The ground plane element may have portions that define a slot antenna resonating element. Another antenna resonating element may be electromagnetically coupled to the slot antenna resonating element through electromagnetic near-field coupling. During operation, a coaxial cable or other transmission line in a handheld electronic device may directly feed the slot antenna resonating element and may indirectly feed the near-field-coupled antenna resonating element through the slot antenna resonating element.

[0007] JP 2003 101334 A provides a plate antenna that saves space in such a way as capable of being incorporated in a mobile terminal, an electric appliance, or a wall at a low cost and assured performance, and that is capable of sufficiently withstanding the effect caused by a metal box inside a product or a user's hand and the like.

SUMMARY

[0008] It is an object of the invention to provide an antenna that is compact in size, applicable in portable electronic devices, robust against many kinds of operating conditions, and combinable with other antennas into an antenna arrangement. Another object of the invention is to provide an antenna arrangement that includes at least one antenna of said kind. Yet another object of the invention is to provide an electronic device that includes at least one antenna of said kind.

[0009] The foregoing and other objects are achieved by the features of the independent claims. Further implementation forms and advantages are apparent from the depending claims, the description and the figures.

[0010] According to a first aspect, an antenna is provided. The antenna comprises an electrically conductive ground plane that defines a first plane and has a first edge. The antenna comprises also an electrically conductive first ground plate located on a second plane essentially parallel to said first plane and displaced by a first distance from said first plane, said first ground plate having a second edge essentially parallel to said first edge of the ground plane. The antenna comprises also an electrically conductive bridge connecting said second edge of the first ground plate to said first edge of the ground plane. The antenna comprises also an elongated first slot delimited by at least one of said ground plane and said bridge, the longitudinal direction of said first slot being essentially parallel to said first edge. Said first slot

is essentially coincident with said ground plate seen from said direction perpendicular to said first and second planes. The antenna comprises also a first antenna feed point on the distal side of said slot seen from the center of said ground plane. The dimensions of said first ground plate are such that its length in said longitudinal direction is essentially equal to at least one of: a half wavelength of electromagnetic radiation at an operational frequency of said antenna, the length of said first slot in said longitudinal direction; and its width in a direction perpendicular to said longitudinal direction is between 3 and 10 millimetres.

[0011] In a first possible implementation form of the antenna, said first slot is delimited by said ground plane on one side and by said bridge on the other side.

[0012] In a further possible implementation form of the antenna, said first antenna feed point is a part of said bridge.

[0013] In a further possible implementation form of the antenna, the width of said first slot in the direction perpendicular to its longitudinal direction is between 0.3 and 1.5 millimeters, preferably between 0.5 and 1.0 millimeters.

[0014] In a further possible implementation form of the antenna, the antenna comprises a first dielectric support between said ground plane and said first ground plate for supporting said first ground plate.

[0015] In a further possible implementation form of the antenna, the antenna comprises a first opening in said first dielectric support coincident with a central portion of said first ground plate.

[0016] In a further possible implementation form of the antenna, the antenna comprises a second opening in said first ground plate on the bridge side of the central portion of said first ground plate.

[0017] According to an example, an antenna arrangement is provided. The antenna arrangement comprises at least one antenna of the kind described above. The antenna arrangement comprises also an electrically conductive second ground plate located on said second plane, said second ground plate having a third edge parallel to said first edge of the ground plane. The antenna arrangement comprises also an elongated second slot delimited by at least one of said ground plane and said bridge. The longitudinal direction of said second slot is essentially parallel to said first edge, said second slot being essentially coincident with said second ground plate seen from said direction perpendicular to said first and second planes. The antenna arrangement comprises also a second antenna feed point on the distal side of said second slot seen from the center of said ground plane. Said electrically conductive bridge connects said third edge of said second ground plate to said first edge of the ground plane.

[0018] In a first implementation form of the antenna arrangement, proximal ends of said first slot and said second slot are separated from each other in the direction of said first edge by a first isthmus of the ground plane

material. Said first ground plate and said second ground plate are separated from each other in the direction of said first edge by a first gap.

[0019] In a further implementation form of the antenna arrangement, the antenna arrangement comprises a capacitor coupled electrically in parallel with said first isthmus of the ground plane material.

[0020] In a further implementation form of the antenna arrangement, the antenna arrangement comprises at least one further antenna displaced from said first and second slots in the direction of said first edge.

[0021] In a further implementation form of the antenna arrangement, the antenna arrangement comprises a first open slot antenna displaced from the distal end of said first slot in the direction of said first edge, and a second open slot antenna displaced from the distal end of said second slot in the direction of said first edge.

[0022] In a further implementation form of the antenna arrangement, said bridge extends as a continuous piece of conductive material in the direction of said first edge from a slit of said first open slot antenna past said first and second ground plates to a slit of said second open slot antenna.

[0023] According to a second aspect, an electronic device is provided. The electronic device comprises at least one antenna of the kind described above.

[0024] In a first implementation form of the electronic device, the electronic device comprises an electrically conductive second ground plate located on said second plane, said second ground plate having a third edge parallel to said first edge of the ground plane. The electronic device comprises also an elongated second slot delimited by at least one of said ground plane and said bridge. The longitudinal direction of said second slot is essentially parallel to said first edge, said second slot being essentially coincident with said second ground plate seen from said direction perpendicular to said first and second planes. The electronic device comprises also a second antenna feed point on the distal side of said second slot seen from the center of said ground plane. Said electrically conductive bridge connects said third edge of said second ground plate to said first edge of the ground plane.

[0025] In a further implementation form of the electronic device, the electronic device comprises a first open slot antenna displaced from the distal end of said first slot in the direction of said first edge, and a second open slot antenna displaced from the distal end of said second slot in the direction of said first edge.

[0026] In a further implementation form of the electronic device, a continuous piece of conductive material extends in the direction of said first edge from a slit of said first open slot antenna past said first and second ground plates to a slit of said second open slot antenna.

[0027] In a further implementation form of the electronic device, the electronic device is flat in shape, comprising two ends, two side edges, a front side, and a back side; and the electronic device comprises a metallic ring along

said two ends and said two side edges, said metallic ring essentially defining the dimensions of said front side and said back side. Said bridge or an edge of said ground plane is a portion of said ring.

[0028] In a further implementation form of the electronic device, the electronic device comprises a first group of four antennas along a first side edge of said two side edges, said first group comprising, in this order: a first open slot antenna, a first closed slot antenna, a second closed slot antenna, and a second open slot antenna. The electronic device comprises also a second group of four antennas along a second side edge of said two side edges, said second group comprising, in this order: a third open slot antenna, a third closed slot antenna, a fourth closed slot antenna, and a fourth open slot antenna.

[0029] In a further implementation form of the electronic device, the electronic device comprises at least one further antenna at at least one end of said two ends.

BRIEF DESCRIPTION OF DRAWINGS

[0030]

Figure 1 illustrates a principle of a slot antenna.

Figure 2 illustrates a principle of a slot antenna with an extended ground plane.

Figure 3 illustrates a principle of a slot antenna with a folded extended ground plane.

Figures 4a to 4d illustrate a slot antenna structure.

Figure 5 illustrates examples of slot antenna structures.

Figure 6 illustrates examples of slot antenna structures.

Figure 7 illustrates a cross section of a part of an electronic device.

Figure 8 illustrates a slot antenna structure of an electronic device in an exploded view.

Figure 9 illustrates a principle of a slot antenna with a folded extended ground plane.

Figure 10 illustrates the same principle as Figure 9 but with a different cross-sectional plane.

Figure 11 illustrates a cross section of a slot antenna structure along a first cross-sectional plane.

Figure 12 illustrates a cross section of the same slot antenna structure as Figure 11 but along a second cross-sectional plane.

Figure 13 illustrates a cross section of a part of an electronic device along a first cross-sectional plane.

Figure 14 illustrate a cross section of the same part of an electronic device as Figure 13 but along a second cross-sectional plane.

Figure 15 illustrates a slot antenna structure of an electronic device in an exploded view.

Figure 16 illustrates an electronic device with multiple antennas.

DETAILED DESCRIPTION

[0031] In the present document geometrical relations between several elements shall be understood to cover the mentioned geometrical relationship but also a range around this within manufacturing tolerances. Hence, the term essentially used in the following shall make clear that also manufacturing tolerances are covered.

[0032] Figure 1 illustrates a principle of a slot antenna. An elongated slot 101 is made in an electrically conductive ground plane 102. In this example the longitudinal direction of the slot 101 is essentially parallel to an edge 103 of the ground plane. An antenna feed point 104 is located on the distal side of the slot 101 seen from the center of the ground plane 102. A coaxial cable is used to feed the antenna; only a small portion of the very end of the coaxial cable is shown in fig. 1. Other kinds of transmission lines could be used as well for feeding the antenna. The center wire of 104 the coaxial cable is connected to the antenna feed point 104, while the conductive shield 106 of the coaxial cable is connected to the ground plane 102 on the proximal side of the slot 101. It has been observed that the efficiency of this kind of a slot antenna is not always optimal. The reason may be the relatively narrow width of the piece of electrically conductive material on the distal side of the slot 101, i.e. between the slot 101 and the edge 103.

[0033] Figure 2 illustrates an improved slot antenna. The structure is otherwise similar to that in fig. 1, but there is an extension 201 of the ground plane 102 on the distal side of the slot 101. The efficiency of such an improved slot antenna has been found to be significantly better than that of the antenna in fig. 1. However, it may prove problematic trying to fit an improved slot antenna according to fig. 2 into a portable electronic device, unless the design of the electronic device allows for a protrusion or other kind of outline feature that houses the extension 201.

[0034] Fig. 3 illustrates an antenna that exhibits both the compact outline of the antenna of fig. 1 and the efficiency of the antenna of fig. 2. The antenna is seen from the same direction in fig. 3 as in figs. 1 and 2. The slot 101 and feed point 104 are drawn with dashed lines in fig. 3, because looking from this direction they are hidden under a ground plate 301 that resembles the extension

201 of fig. 2, folded back over that portion of the ground plane 102 that comprises the slot 101 and feed point 104.

[0035] Figs. 4a to 4d illustrate an antenna similar to that of fig. 3 in more detail. Figs. 4a to 4d all show the same antenna seen from four different directions: from below (fig. 4a), from an end (fig. 4b), from a side (fig. 4c), and from above (fig. 4d).

[0036] The antenna comprises an electrically conductive ground plane 401 that - geometrically considered - defines a first plane and has an edge, which here is called the first edge 402. The expression "first plane" refers to a virtual plane that is not a tangible thing but a geometrical concept. Saying that the ground plane 401 defines a first plane means that the ground plane 401 has a generally planar form, so that in a three-dimensional Cartesian coordinate system the points (x, y, z) of the ground plane 401 can be said to obey an equation $a(x-x_0) + b(y-y_0) + c(z-z_0) = 0$, where a, b, and c are constants and (x₀, y₀, z₀) is a fixed point of the ground plane 401. The ground plane 401 does not need to be strictly planar, so the "equal to" sign in said equation can be replaced with "approximately equal to". Some ways in which the form of the ground plane 401 can differ from strictly planar form are described later in this text.

[0037] The edge 402 is a straight edge in figs 4a - 4d. This is not a requirement of the invention, but the edge 402 can be curved or meandering, or it may comprise bends or corners. However, many electronic devices have straight edges, so that a ground plane that constitutes a part of an electronic device may have a straight edge that follows closely a straight edge of the electronic device.

[0038] The antenna comprises an electrically conductive ground plate 403 that in the three-dimensional geometry of the antenna is located on a second plane that is essentially parallel to the first plane described above. Also the second plane is a geometrical concept rather than any tangible thing. If the equation of said first plane is like that given above, and the second plane is displayed from the first plane by a distance given by the square root of $(a^2+b^2+c^2)$, the points (x, y, z) of the second plane obey the equation $a(x+a-x_0) + b(y+b-y_0) + c(z+c-z_0) = 0$.

[0039] The ground plate 403 does not need to be strictly planar, and the two planes do not need to be strictly parallel. However, in an electronic device that has a generally flat form the two planes may be parallel with the flat front and back sides of the electronic device, which involves the advantage that the structure of the electronic device may be more straightforward to design. In such a case the second plane may be displaced from the first plane by a distance that is dictated by two structural parts of the electronic device that follow the generally flat outline of the device. One possible characterization is that if an antenna of the kind described here is implemented in an electronic device that is flat and/or rectangular in form, the ground plane 401 and the ground plate 403 are said to be planar and parallel to each other if both of them conform to one or more of those structural parts of the

electronic device that make it appear as flat and/or rectangular.

[0040] The ground plate 403 has an edge 404 that is essentially parallel with the edge 402 of the ground plane 401. If an antenna of the kind described here is implemented in an electronic device that has an edge, the two edges 404 and 402 can be said to be essentially parallel for example if both of them conform to one or more of those structural parts of an electronic device that define said edge of the electronic device.

[0041] For clarity, the edge 402 of the ground plane 401 can be called the first edge, and the edge 404 of the ground plate 403 can be called the second edge. Seen from a direction 405 that is perpendicular to the first and second planes, the second edge 404 is essentially coincident with the first edge 402. In other words, in the bottom view (fig. 4a) and top view (fig. 4d) the first and second edges 402 and 404 are on top of each other. The first and second edges being coincident with each other seen from the direction 405 is not an essential requirement of the invention, but merely a consequence of the generally right-angled structure in figs. 4a to 4d.

[0042] The antenna comprises an electrically conductive bridge 406 connecting the second edge 404 of the ground plate 403 to the first edge 402 of the ground plane 401. The end view of fig. 4b shows how the ground plane 401, the bridge 406, and the ground plate 403 may all be portions of a single sheet of conductive material, so that the structure may have been obtained by bending an extension of such a sheet of conductive material first up at edge 402 and then backwards at edge 404 (compare to figs. 2 and 3 earlier). However, it is not a requirement of the invention that these three parts would be portions of a single, continuous sheet of electrically conductive material. Embodiments in which they are originally different structural pieces are explained later in this description. The example structure in figs. 4a to 4d is generally right-angled, but in an alternative embodiment the bend between the ground plane 401 and the bridge 406, and/or the bend between the bridge 406 and the ground plate 403, could be at an oblique angle.

[0043] The antenna comprises an elongated slot 407 that is delimited by at least one of the ground plane 401 and the bridge 406. In the embodiment of figs. 4a to 4d the slot 407 is delimited solely by the ground plane 401. The longitudinal direction of the slot 407 is essentially parallel to the first edge 402. Seen from the direction 405 perpendicular to the first and second planes, the slot 407 is essentially coincident with the ground plate 403. In other words, in the bottom view of fig. 4a and the top view of fig. 4d the outline of the slot 407 fits at least mostly inside the outline of the ground plate 403.

[0044] The antenna comprises an antenna feed point 408 on the distal side of the slot 407 seen from the center of the ground plane 401. In the embodiment of figs. 4a to 4d the feed point 408 is essentially half way between the ends of the slot 407, but this is not a requirement of the invention. Considering the symmetric distribution of

electric currents in the electrically conductive parts of the antenna it may be advantageous to place the feed point 408 closer to the midpoint of the slot 407 than towards any of its ends.

[0045] In some cases it may be advantageous to place the feed point in a different way than in figs. 4a to 4d. For example, if the other structures of the electronic device are asymmetric with relation to the midpoint of the antenna in the environment of the antenna, the optimal distribution of electric currents may be achieved with an asymmetric location of the feed point. According to another example the antenna may be designed to operate at multiple non-adjacent frequency bands, in which the optimal location for the feed point may be other than the midpoint.

[0046] The center wire 409 of a coaxial cable is connected to the feed point 408 in figs. 4a to 4d. The conductive shield 410 of the coaxial cable is connected to the ground plane 401 at or close to the proximal side of the slot 407. The other end of the coaxial cable is not shown in figs. 4a to 4d, but it is assumed to go to a radio transceiver.

[0047] The operation of the antenna in transmission mode can be briefly considered. According to the known principle, its operation in reception mode is essentially an inverse of its operation in transmission mode.

[0048] In transmission mode a radio frequency signal is coupled from the coaxial cable to the feed point 408. It excites oscillating currents in the electrically conductive material at the frequency of the radio frequency signal. Due to the geometry, the currents flow around the slot between the feed point 408 and the point 411 at which the conductive shield 410 of the coaxial cable is coupled to the opposite edge of the slot. For the antenna to be most efficient in the so-called half wavelength mode, the shortest distance available for the currents conducted between said two points should be equal to one half wavelength of electromagnetic radiation at an operational frequency of the antenna.

[0049] The ground plate 403 is parallel to that part of the ground plane 401 in which said currents flow, displaced from it by only a short distance in comparison to the wavelength of the electromagnetic radiation on said operational frequency. The ground plate 403 enhances the efficiency of the antenna by offering a path for currents that become induced to it, mirroring the currents that flow around the slot. Thus advantageous dimensions of the ground plate 403 are such that its length in the longitudinal direction is essentially equal to a half wavelength of electromagnetic radiation at an operational frequency of the antenna, and/or essentially equal to the length of the slot 407 in the longitudinal direction. This kind of an exemplary length of the ground plate involves the advantage that there is optimal space for the induced currents in the longitudinal direction of the ground plate, without having to reserve too much space for the ground plate. The ground plate 403 may also be somewhat longer than the length of the slot 407 in the longitudinal di-

rection.

[0050] According to an example not forming part of the scope of the claims, the length of the ground plate 403 may be also slightly less than a half wavelength of electromagnetic radiation at said operational frequency, because the width of the ground plate 403 offers some additional space for said electric currents, lengthening their path. In figs. 4a - 4d the ground plate 403 has been drawn longer than the slot 407 for reasons of graphical clarity.

[0051] The width of the slot 407 in the direction perpendicular to its longitudinal direction may be for example between 0.3 and 1.5 millimeters, preferably between 0.5 and 1.0 millimeters, if the operational frequencies of the antenna are in the order of a couple of gigahertz. As such, antenna efficiency may advocate making the slot wider, while other consideration like the limited available space in the structure of the electronic device may drive the design towards narrower slot widths.

[0052] The width of the ground plate 403 should be larger than the width of the slot. The width of the ground plate 403 in the direction perpendicular to its longitudinal direction is between 3 and 10 millimeters. This kind of an exemplary width of the ground plate involves the advantage of being sufficiently large for efficient antenna operation, while simultaneously being sufficiently small to only reserve a relatively small proportion of the space available inside a portable electronic device. Advantageously the width of the ground plate 403 is smaller than a quarter wavelength on the operational frequency. The operational (self-resonance) frequency of the antenna can be optimized by optimizing the width and the length of the ground plate 403 and the length of the slot 407.

[0053] The structure of the electronic device, as well as the space available for the parts of the antenna, may have a significant influence on how the dimensions of the ground plate 403 are selected. Basically the lower the frequencies on which the antenna is to be used, the larger the dimensions. Similarly if the electronic device is relatively large, more space can be allocated for antenna structures. Therefore the numeric examples given above should be considered as examples only, and different numeric values could be given to the dimensions described therein.

[0054] Fig. 5 illustrates an antenna arrangement that comprises two antennas, each of which follows the general principle described earlier with reference to figs. 4a - 4d. The antenna arrangement of fig. 5 comprises an electrically conductive ground plane 505 that defines a first plane and has a first edge 507. It comprises an electrically conductive first ground plate 501 and an electrically conductive second ground plate 502. These are both located on a second plane that is essentially parallel to the first plane and displaced by a first distance from said first plane. It is not a requirement of the invention that the first and second ground plates must be located on the same "second" plane, but each of them may be located on a plane of its own, i.e. displaced by a different distance from the first plane.

[0055] The first ground plate 501 has a second edge that is essentially parallel to the first edge 507 of the ground plane, and here also essentially coincident with said first edge 507 seen from a direction perpendicular to said first and second planes because the structure is generally right-angled. The second ground plate 502 has a third edge that is parallel to said first edge 507 of the ground plane 505 and essentially coincident with said first edge seen from said direction perpendicular to said first and second planes for the same reason as the second edge. In this respect said second and third edges resemble closely the second edge 404 that was described above with reference to fig. 4b.

[0056] The antenna arrangement of fig. 5 comprises a first electrically conductive bridge connecting the second edge of the first ground plate 501 to the first edge 507 of the ground plane 505, and a second electrically conductive bridge connecting the third edge of the second ground plate 502 to the first edge 507 of the ground plane 505. The first and second bridges could also be the same part. That kind of embodiments are described in more detail later in this description.

[0057] The antenna arrangement of fig. 5 comprises an elongated first slot 503 and an elongated second slot 504, both of which are delimited by at least one of the ground plane 505 and the (respective) bridge. The longitudinal directions of both the first slot 503 and the second slot 504 is essentially parallel to the first edge 507 of the ground plane 505. The first slot 503 is essentially coincident with the first ground plate 501 seen from the direction perpendicular to said first and second planes. The second slot 504 is essentially coincident with the second ground plate 502 seen from said direction perpendicular to said first and second planes.

[0058] The antenna arrangement of fig. 5 comprises a first antenna feed point 508 on the distal side of the first slot 503 seen from the center of the ground plane 505. The antenna arrangement comprises also a second antenna feed point 509 on the distal side of the second slot 504 seen from the center of the ground plane 505. Of these, the second antenna feed point 509 is located on a protruding portion 510 of the ground plane 505 that protrudes across the generally elongated form of the second slot 504.

[0059] The protruding portion 510 is long enough so that its tip is actually on (or even beyond) the imaginary line defined by the proximal side of the second slot 504 seen from the center of the ground plane 505 (a cut 511 in said proximal side of the second slot 504 ensures that the tip of the protruding portion 510 does not touch the material of the ground plane 505 on said proximal side). However, electrically the second antenna feed point 509 is on the distal side of the second slot 504 seen from the center of the ground plane 505. This can be shown for example by examining, what kind of an electric current would result from a positive potential of the center wire of the coaxial cable with respect to its conductive shield: the electric current would flow from the center wire of the

coaxial cable to the second antenna feed point 509 and then first along the distal side of the second slot 504 before looping back towards the grounding point of the conductive shield on the proximal side of the second slot 504.

[0060] The proximal ends (i.e. the ends closest to each other) of the first slot 503 and the second slot 504 are separated from each other in the direction of the first edge 507 by an isthmus 506 of the ground plane material. That is, the electrically conductive material of the ground plane 505 is essentially continuous around the first 503 and second 504 slots. This is not a requirement of the invention, but in some embodiments there could be a slit in the ground plane material between the proximal ends of the slots in order to enhance isolation between adjacent antennas. Providing an isthmus of the ground plane material between the proximal ends of the slots involves the advantage of offering space for the installation of additional components, as will be explained in more detail later in this description.

[0061] The first ground plate 501 and the second ground plate 502 are separated from each other in the direction of the first edge by a gap. The provision of a gap, as opposed to using a continuous ground plate that would cover both the first slot 503 and the second slot 504, involves the advantage that it enhances isolation between adjacent antennas.

[0062] Fig. 5 illustrates also the possibility that the first 503 and second 504 slots may be differently dimensioned. Also the first 501 and second 502 ground plates may be differently dimensioned. Unique dimensioning of various parts of the antenna arrangement involves the advantage that each antenna can be made to work optimally at a particular operational frequency or frequency range. Unique dimensioning may also be of advantage in cases where the operating frequencies and other parameters are the same for both antennas, but the loading effects caused by nearby other parts of the electronic device are not the same for both antennas.

[0063] Fig. 6 illustrates another antenna arrangement that comprises two antennas, each of which follows the general principle described above with reference to figs. 4a - 4d, however with certain modifications compared to fig. 5.

[0064] In the embodiment of fig. 6 the first slot 601 and the second slot 602 are both delimited by the ground plane on one side and by the bridge 607 on the other side. This involves a number of advantages. First, the ground plane 608 may be easier to manufacture than one in which the slots would be through-holes, because only the outline of the ground plane needs to be cut in a particular way, without having to make any through-holes. Second, in particular if the bridge 607 is at or very close to an outer edge of the electronic device, the slots 601 and 602 can be also made to appear at or very close to an outer edge of the electronic device. Thus they do not restrict using continuous areas of the side surfaces of the electronic device for e.g. a display, a continuous back plate, or other part that requires a large proportion

of a side surface.

[0065] In the embodiment of fig. 6 the first antenna feed point 603 and the second antenna feed point 604 are parts of the bridge 607. This involves the advantage that if the transmission line that connects the antenna to the transceiver is designed correspondingly, connecting the antenna may be made automatically in the course of assembling the device, without requiring any dedicated manufacturing step such as soldering. In fig. 6 the first antenna feed point 603 is right on the bridge 607, while the second antenna feed point 604 is located on a protruding portion of the bridge 607.

[0066] In the embodiment of fig. 6 the bridge 607 extends as a continuous piece of conductive material in the direction of the (first) edge of the ground plane 608 from one antenna to another. This involves advantages both in the structural viewpoint and the aesthetical viewpoint. The structure can be more robust, because a continuous bridge may offer more structural support than two separate bridges. If, as will be described later in this text, the part that constitutes the bridge is also at least partly visible from the outside of the electronic device, a continuous bridge may enable making the device aesthetically more appealing than one with a (number of) break(s).

[0067] Fig. 7 is a partial cross section of an edge of certain parts of an electronic device that comprises at least one antenna of the kind described above. The electronic device comprises an electrically conductive ground plane 701, which may be a dedicated ground plane for the antennas of the electronic device. Alternatively the ground plane 701 may have other functions: for example, if a front side surface of the electronic device comprises a large display, the ground plane 701 may be a ground plane of the display. Following the mostly flat form of the electronic device, the ground plane 701 is essentially planar. The outer appearance of the electronic device may involve certain rounding and/or thinning towards its outer edges. Correspondingly also the ground plane 701 may be slightly curved by cross section towards its edges, as is seen in fig. 7.

[0068] The electronic device of fig. 7 comprises an electrically conductive ground plate 702 that is essentially planar and located parallel to the ground plane 701, displaced from it by a first distance. The outer appearance of the electronic device may dictate also some exceptions from a strictly planar form of the ground plate 702. In fig. 7 the ground plate 702 is slightly inwards curved towards that edge that is on the left in fig. 7. Thus the distance between the ground plane 701 and the ground plate 702 is smaller towards their edge than more to the right in fig. 7. However, for the purposes of this description they can still be said to be essentially planar and located on two adjacent, parallel virtual planes.

[0069] The electronic device of fig. 7 comprises an electrically conductive bridge 703 that connects the edge (in fig. 7: the left-hand edge) of the ground plate 702 to the edge (in fig. 7: the left-hand edge) of the ground plane 701. The bridge 703 has also other functions in the struc-

ture of the electronic device. These functions will be described in more detail later with reference to fig. 8. An electrically conductive connection between the edge of the ground plane 701 and the bridge 703, as well as between the edge of the ground plate 702 and the bridge 703, can be enhanced by using an electrically conductive gasket, some electrically conductive adhesive, or some other means that are known as such on the field of enhancing the electrical conductivity of a mechanical connection.

[0070] The electronic device of fig. 7 comprises an elongated slot 704 delimited by the ground plane 701 on one side and by the bridge 703 on the other side. This feature of the slot 704 makes it resemble the slots 601 and 602 in fig. 6. Because fig. 7 is a cross section along a plane that is perpendicular to the longitudinal direction of the slot 704, the slot 704 appears only as a small gap in fig. 7.

[0071] The electronic device of fig. 7 comprises an antenna feed point 705, which is a part of the bridge 703. More particularly, a protrusion extends inwards (i.e. towards the inside of the electronic device) from the bridge 703, and the end of the protrusion constitutes the antenna feed point 705. A transmission line connects the antenna feed point 705 to a transceiver (not shown) of the electronic device. In the embodiment of fig. 7 the transmission line is implemented on a multilayer flexible printed circuit board 706. An electrically conductive patch on the surface of the multilayer flexible printed circuit board 706 comes into contact with the antenna feed point 705 when the structure is assembled. Further structures of the electronic device, which may support the multilayer flexible printed circuit board 706, are shown only schematically with reference designator 707 in fig. 7.

[0072] One part of the antenna of the electronic device of fig. 7 is a dielectric support 708 between the ground plane 701 and the ground plate 702. The invention does not mandatorily require the use of such a dielectric support in other cases, but one is shown in fig. 7 as an example. The dielectric support 708 is, as its name indicates, a supporting structure for at least supporting the ground plate 702. It may also have other structural functions, such as supporting the bridge 703 and/or supporting some portion(s) of the side surface(s) of the electronic device, or supporting a dielectric (plastic, glass, or other) outer cover of the electronic device that would come above the ground plate 702. The use of a dielectric support involves the advantage that the structure can be made more robust against structural loads that may originate e.g. from a user's hand holding the electronic device.

[0073] Fig. 8 is a partial exploded view of certain parts of an electronic device that comprises an antenna arrangement that comprises at least two antennas of the kind described earlier with reference to figs. 4a - 4d. The electronic device comprises an electrically conductive ground plane 801, as well as a first electrically conductive ground plate 802 and a second electrically conductive

ground plate 803. The form and location with reference to each other of the ground plane 801 and the ground plates 802 and 803 are similar as those explained above with reference to e.g. the ground plane 701 and the ground plate 702 in fig. 7.

[0074] The electronic device of fig. 8 comprises an elongated first slot and an elongated second slot, each delimited by the ground plane 801 on one side. The respective, cut portions of the edge of the ground plane 801 are marked with reference designators 804 and 805.

[0075] The electronic device of fig. 8 is flat in shape, comprising two ends, two side edges, a front side, and a back side. This shape of the electronic device can be seen in fig. 8, with the ends pointing to the right and to the left, and the side edges being the two edges connecting the ends to each other. The front side is the one not visible in the drawing, and the back side is the one best visible in the drawing.

[0076] The electronic device of fig. 8 comprises a metallic ring 806 along said two ends and said two side edges. The ring 806 essentially defines the dimensions of the front side and back side of the electronic device. In other words, the ring 806 constitutes the outer perimeter of the flat-shaped electronic device.

[0077] The electrically conductive bridge 807 that connects the respective edges of the ground plates 802 and 803 to the edge of ground plane 801 is a portion of the ring 806 in fig. 8. This involves an advantage of simplifying the mechanical structure of the electronic device, because a single mechanical part can be used for two functions. This structural solution can be compared to the partial cross section in fig. 7, where the bridge 703 can also be a portion of a ring that defines an outer perimeter of the electronic device.

[0078] Antenna feed points of the electronic device are not directly visible in fig. 8, because they are on the inner side of the bridge 807. However, fig. 8 illustrates a multilayer flexible printed circuit board 808, on the surface of which are conductive patches 809 and 810. These come against the respective antenna feed points when the electronic device is assembled. The use of a multilayer flexible printed circuit board 808 for implementing the transmission lines to the antennas involves also the advantage that impedance matching components can be placed very close to the antenna feed points. Examples of such impedance matching components are shown in fig. 8 with reference designators 811 and 812.

[0079] The electronic device of fig. 8 comprises a first dielectric support 813 for supporting the first ground plate 802 and a second dielectric support 814 for supporting the second ground plate 803. There is an opening 815 in the first dielectric support 813, and a corresponding opening 816 in the second dielectric support 814. Each of the openings is coincident with a central portion of the respective ground plate 802 or 803. The use of such openings involves the advantage of minimizing loading caused by the dielectric support material. Placing the openings 815 and 816 coincident with the central portion

of the respective ground plate 802 or 803 emphasizes this advantage, because the electric fields involved in the operation of the antenna are the strongest close to the center of the respective ground plate. The triangular form of the openings 815 and 816 is just one example, and other forms could be used, such as rectangular, oval, or the like. The rectangular cuts in the downwards pointing portions of the dielectric supports 813 and 814 in fig. 8 are for accommodating the antenna feed connections and impedance matching components.

[0080] Each of the first ground plate 802 and the second ground plate 803 also comprises an opening, marked with the reference designators 817 and 818 respectively. These openings may be used for providing more space for example for possibly protruding portions of the feed contact (e.g. screw) or impedance matching components 811 and 812. If such openings are made to the ground plates, it is advisable to make them on the bridge side of the central portion of the respective ground plate, in order not to take away too much of the electrically conductive material. The size of the opening(s) should also be minimized. If any of the ground plates 802 or 803 comprises such an opening, it may be a through-hole type opening such as those seen in fig. 8 or it may be a cut in an edge of the respective ground plate, so that an edge of the ground plate consists of two separate portions, each of which is independently connected to the bridge 807.

[0081] The proximal ends of the first slot and second slot are separated from each other in the direction of the edge of the ground plane 801 by an isthmus of the ground plane material in fig. 8. The electronic device may comprise a capacitor 819 coupled electrically in parallel with the isthmus of the ground plane material. This involves the advantage of enhancing antenna efficiency and isolation between adjacent antennas. At radio frequencies, narrow portions of electrically conductive material (like the isthmus of ground plane material) are essentially inductances. The capacitor 819 coupled electrically in parallel with the isthmus of ground plane material then constitutes, together with the inductance-type operation of the isthmus, a kind of an additional decoupling filtering circuit.

[0082] The electronic device may comprise a lot more parts and components in addition to those shown in the simplified view of fig. 8. These have been omitted to provide an easier view to those parts that have been described above. However, structural features of such other parts can be used in various combinations with the features that are shown in fig. 8. For example, the one or both of the ground plates 802 and 803 can be metallic foils or metallized areas on the inner surface of a (dielectric) cover plate of the electronic device. Additionally or alternatively the electronic device may comprise another flexible printed circuit board in addition to that shown in fig. 8, and at least one of the ground plates 802 and 803 can be a portion of such another flexible printed circuit board.

[0083] The embodiments described above have con-

sidered the ground plane as a relatively thin, almost two-dimensional structural part. This is not an essential requirement of the invention. The ground plane, as well as many other parts of the antenna structure, can have significant three-dimensional character. An example of this kind is described next with reference to figs. 9 to 15.

[0084] Fig. 9 is a simplified graphical representation of an antenna. It comprises an electrically conductive ground plane 901 that has a generally planar form so that it defines a first plane 902. The ground plane 901 (or, like in fig. 9, at least a portion of it) has also a significant thickness in the direction perpendicular to said first plane 902. In fig. 9 the first plane 902 is drawn coincident with the lower planar surface of the ground plane 901. The ground plane has a first edge 903.

[0085] The antenna of fig. 9 comprises an electrically conductive first ground plate 904 located on a second plane 905 that is essentially parallel to the first plane 902 and displaced by a first distance from the first plane 902. This distance is shown exaggerated in fig. 9 compared to the assembled configuration of the antenna: in the assembled configuration the first ground plate 904 will come closer to the upper planar surface of the ground plane 901, as shown by the dashed lines. The first ground plate 904 has a second edge 906 that is essentially parallel to the first edge 903 of the ground plane 901.

[0086] An electrically conductive bridge 907 connects (in the assembled configuration) the second edge 906 of the first ground plate 904 to the first edge 903 of the ground plane 901. For graphical clarity the bridge 907 is shown at a right angle against the first plane 902 and the second plane 905, but this is not an essential requirement of the invention; the bridge 907 could be at an oblique angle against said planes.

[0087] An elongated first slot 908 is delimited by a portion of the thick part of the ground plane 901. If the relative dimensions of the ground plane 901 and the bridge 907 were arranged differently, the first slot 908 could be also at least partly delimited by the bridge. The longitudinal dimension of the first slot 908 is essentially parallel to the first edge 903. The first slot 908 is essentially coincident with the first ground plate 904 seen from the direction 909 perpendicular to the first plane 902 and the second plane 905. The operational (self-resonance) frequency of the antenna can be optimized by optimizing the width and the length of the ground plate 904 and the length of the slot 908.

[0088] A first antenna feed point 910 is located on the distal side of the first slot 908 seen from the center of the ground plane 901. Resembling the feed point 509 in fig. 5 and the feed point 604 in fig. 6, the first antenna feed point 910 is located at the tip of a protrusion that protrudes from the distal side of the first slot 908 towards - or even beyond - the imaginary line defined by the proximal side of the first slot 908. However, considering the electrical operation of the slot antenna, electrically the first antenna feed point 910 is located on the distal side of the first slot 908.

[0089] Fig. 9 illustrates also a first cross-sectional plane 911. Fig. 10 illustrates the same antenna, and a second cross-sectional plane 1001. The cross-sectional planes 911 and 1001 are drawn to make it easier to understand how figs. 11, 12, 13, and 14 describe various parts of the antenna structure.

[0090] Fig. 11 is a cross-sectional view of an antenna, the structural principle of which generally resembles that shown in figs. 9 and 10. The cross-sectional view of fig. 11 is taken along the first cross-sectional plane 911. As a difference to fig. 9, the first ground plate 904 and the bridge 907 do not constitute a right-angled combination of two planar portions. In fig. 11 the bridge 907 is a curved portion that joins smoothly with the second edge 906 of the first ground plate 904. Also the first edge 903 of the ground plane 901 and the edges of the first elongated slot 908 may have some three-dimensional forms like steps, beveled surfaces, and the like.

[0091] Fig. 11 shows how the thick part of the ground plane 901 may comprise additional forms, like a groove 1101 for a flexible printed circuit board or some other kinds of electric conductors.

[0092] Fig. 12 is a cross-sectional view of an antenna generally resembling that shown in figs. 9 and 10 along the second cross-sectional plane 1001. Fig. 12 shows how the first antenna feed point 910 is located at the tip of a protrusion 1201.

[0093] Figs. 13 and 14 show examples of how other parts of an electronic device may come around an antenna like that described above with reference to figs. 9 to 12. Fig. 13 is a cross section along a similar plane as fig. 11, and fig. 14 is a cross section along a similar plane as fig. 12.

[0094] In fig. 13 a front cover 1301 covers a front side of the electronic device, and a back cover 1302 covers a back side of the electronic device. A layered component like a display 1303 fills the space between the ground plane 901 and the front cover 1301. The display 1303 may contain electrically conductive layers; if the display 1303 extended all the way to the side edge of the electronic device (on the left in fig. 13), effective operation of the antenna would suffer significantly. Therefore it is advantageous to leave a gap 1304 between the outer edge of the display 1303 and any conductive parts at the outer edge of the electronic device. The width of the gap 1304 is advantageously of the same order of magnitude as the width of the first elongated slot 908.

[0095] The cross section of a (flexible) printed circuit board 1305, fitted in the groove shown as 1101 in fig. 11, is also seen in fig. 13. Those parts of the structure that appear empty in fig. 13 may be left empty, or - for example if needed for mechanical stiffness - they can be partly or completely filled with a suitable dielectric material like an electrically nonconducting plastic. In order not to cause unwanted loading and attenuation, the plastic - if any - that fills the first elongated slot 908 should be selected considering particularly its suitability for the immediate vicinity of an antenna operating at the frequencies in

question.

[0096] Fig. 14 shows an example of how the antenna feed can be implemented. Close to the first antenna feed point a connector part 1401 is attached to the flexible printed circuit board 1305. A screw 1402 goes through a hole in the connector part 1401 and a threaded hole in the protrusion 1201.

[0097] Fig. 15 is a partial exploded view of certain parts of an electronic device that comprises an antenna arrangement that comprises at least two antennas of the kind described earlier with reference to figs. 9 - 14, and additional antennas. Parts that resemble closely the corresponding parts in the previous figures have the same reference designators, so their appropriate description can be read above with reference to the respective previous figures.

[0098] As a difference to fig. 8, the edge 1505 of the ground plane that constitutes a part of the antennas of the electronic device is a portion of the ring 806 that essentially defines the dimensions of the front side and the back side of the electronic device.

[0099] The antenna arrangement in the electronic device of fig. 15 comprises at least one further antenna displaced from the first 1501 and second 1502 slots in the direction of the (first) edge of the ground plane. This involves the advantage of providing the electronic device with further wireless communications capability, for example with further wireless frequency ranges and/or with further MIMO (multiple input multiple output) capability that enhances data rates and robustness against attenuation and interference.

[0100] In particular the antenna arrangement of the electronic device of fig. 15 comprises a first open slot antenna 1503 displaced from the distal end of the first slot 1501 in the direction of the (first) edge 1505 of the ground plane. Additionally the antenna arrangement comprises a second open slot antenna 1504 displaced from the distal end of the second slot 1502 in the direction of said (first) edge 1505 of the ground plane. This kind of selection and placing of additional antennas involves for example the advantage that the slits in the surrounding electrically conductive material that are necessitated by the open slot antennas can be placed close to the ends of the electronic device. Open slot antennas are typically quarter wavelength structures at the frequency of operation.

[0101] The edge 1505 of the ground plane that is part of the first and second closed-slot antennas (compare to bridge 807 in fig. 8) extends as a continuous piece of conductive material from a slit 1506 of the first open slot antenna past the first 802 and second 803 ground plates to a slit 1507 of the second open slot antenna. The slits 1506 and 1507 are close to the ends of the electronic device, which is aesthetically appealing and may also involve technical advantages.

[0102] The second open slot antenna is fed with a similar feeding point arrangement as the middle two (closed-slot) antennas in fig. 15. In other words there is a con-

ductive patch 1508 on the surface of a flexible printed circuit board 1509, against which a corresponding protrusion on the inner side of the edge 1501 will come when the device is assembled. The first open slot antenna, however, has a so-called capacitive feed in the antenna arrangement seen in fig. 15. The capacitive feed involves a portion of the flexible printed circuit board 1509 extending as a flap 1510 to a suitable position close to a particular part of the slot of the open slot antenna. This kind of a feeding arrangement involves the advantage that free space can be left for other structural features, such as an opening for a SIM (subscriber identity module) tray, a volume key that can be pressed, or the like.

[0103] The feeding arrangements of fig. 15 are examples, and could be interchanged in many ways. For example, capacitive feeds could be used for one or both of the closed slot antennas, and any or both of the open slot antennas could have either a capacitive or conductive feeds.

[0104] The planar structure shown under the other parts in fig. 15 is an example of an electrically conductive (ground) plane 1511 that may be part of another component of the electronic device, like a display for example. In the embodiment of fig. 15 the planar (electrically conductive) structure is slightly narrower than the largest width of the electronic device. This ensures that a gap (compare to gap 1304 in fig. 13) will be left between the edge of the electrically conductive plane 1511 and the electrically conductive structure that is a part of the ground plane of the antennas. Reference designator 1512 shows how for example the first slit 1506 will remain isolated from the electrically conductive plane 1511 in the assembled configuration.

[0105] An alternative of making the electrically conductive plane 1511 consistently narrower than the available space would be to provide its edge with protrusions that coincided with the isthmuses of conductive material between antennas in the ground plane. This could further improve the isolation between adjacent antennas.

[0106] An electronic device that has an antenna arrangement of the kind shown in fig. 15 along a first side edge can have antennas in its other parts also. The provision of additional antennas involves the advantage of enhancing further the wireless communications capability of the electronic device, as well as the data throughput and robustness against interference and attenuation.

[0107] Fig. 16 illustrates schematically an electronic device that comprises a first group 1601 of four antennas along a first side edge. The first group 1601 comprises, in this order, a first open slot antenna 1602, a first closed slot antenna 1603, a second closed slot antenna 1604, and a second open slot antenna 1605. The electronic device comprises a second group 1606 of four antennas along a second side edge. The second group 1606 comprises, in this order, a third open slot antenna 1607, a third closed slot antenna 1608, a fourth closed slot antenna 1609, and a fourth open slot antenna 1610. This composition of antenna groups and antenna elements

involves the advantage that at least 4 times the LTE B41 (2500-2690 MHz) frequency bands and 8 times the LTE B42/43 (3400-3800 MHz) frequency bands can be covered.

[0108] Each of the first group 1601 and second group 1606 thus resembles fig. 15 in that there are two closed slot antennas in the middle, flanked by open slot antennas on both sides. In an alternative embodiment any or all of the open slot antennas 1602, 1605, 1607, or 1610 could be closed slot antennas, and/or any or all of the closed slot antennas 1603, 1604, 1608, or 1609 could be open slot antennas.

[0109] The electronic device of fig. 16 comprises at least one further antenna at at least one of its ends. In particular, the electronic device shown in fig. 16 comprises four additional antennas, of which two antennas 1611 and 1612 are located in one end and two other antennas 1613 and 1614 are located in the other end. This kind of antenna composition involves the advantage that a full 8x8 MIMO antenna system can be provided for the electronic device. The additional antennas 1611 to 1614 can be closed-slot antennas, open slot antennas, inverted-F antennas, monopoles, loops, coupling elements, or any other applicable types of antennas.

[0110] Additionally or alternatively the electronic device may comprise one or more further antennas elsewhere, i.e. not only at its ends. For example PIFA (planar inverted-F antennas) can be produced on top of a ground plane at any suitable location of the electronic device.

[0111] The invention has been described in conjunction with various embodiments herein. However, other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the description and claims the word "comprising" does not exclude other elements and steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or other unit may fulfil the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these Z measures cannot be used to advantage.

Claims

1. An antenna, comprising:

an electrically conductive ground plane (401, 505, 608, 701, 801, 901) that defines a first plane and has a first edge (402, 507, 903, 1505),
an electrically conductive first ground plate (403, 501, 502, 605, 606, 702, 802, 803, 904) located on a second plane parallel to said first plane and displaced by a first distance from said first plane, said first ground plate having a second edge (404, 906) parallel to said first edge (402, 507,

903, 1505) of the ground plane (401, 505, 608, 701, 801, 901),

an electrically conductive bridge (406, 607, 703, 807, 907) connecting said second edge (404, 906) of the first ground plate (403, 501, 502, 605, 606, 702, 802, 803, 904) to said first edge (402, 507, 903, 1505) of the ground plane (401, 505, 608, 701, 801, 901),

an elongated first slot (407, 503, 504, 601, 602, 704, 908, 1501) delimited by at least one of said ground plane (401, 505, 608, 701, 801, 901) and said bridge (406, 607, 703, 807, 907), the longitudinal direction of said first slot (407, 503, 504, 601, 602, 704, 908, 1501) being parallel to said first edge (402, 507, 903, 1505), said first slot (407, 503, 504, 601, 602, 704, 908, 1501) being coincident with said first ground plate (403, 501, 502, 605, 606, 702, 802, 904) seen from a direction (405, 909) perpendicular to said first and second planes, and

a first antenna feed point (408, 603, 604, 705, 910) on the distal side of said first slot (407, 503, 504, 601, 602, 704, 908, 1501) seen from the center of said ground plane (401, 505, 608, 701, 801, 901),

wherein the dimensions of said first ground plate (403, 501, 502, 605, 606, 802) are such that its length in said longitudinal direction is equal to at least one of: a half wavelength of electromagnetic radiation at an operational frequency of said antenna, the length of said first slot (407, 503, 504, 601, 602, 704, 1501) in said longitudinal direction, and

its width in a direction perpendicular to said longitudinal direction is between 3 and 10 millimeters.

2. The antenna according to claim 1, wherein:

said first slot (601, 602, 704) is delimited by said ground plane (608, 701) on one side and by said bridge (607, 703, 807) on the other side.

3. The antenna according to claim 1 or 2, wherein said

first antenna feed point (603, 604, 705) is a part of said bridge (607, 703, 807).

4. The antenna according to any of the preceding

claims, wherein the width of said first slot (407, 503, 504, 601, 602, 704, 1501) in the direction perpendicular to its longitudinal direction is between 0.3 and 1.5 millimeters, preferably between 0.5 and 1.0 millimeters.

5. The antenna according to any of the preceding

claims, comprising a first dielectric support (708, 813) between said ground plane (701, 801) and said first ground plate (702, 802) for supporting said first ground plate.

6. The antenna according to claim 5, comprising a first opening (815) in said first dielectric support (813) coincident with a central portion of said first ground plate (802).

7. The antenna according to any of the preceding claims, comprising a second opening (817) in said first ground plate (802) on the bridge side of the central portion of said first ground plate.

8. An electronic device, comprising an antenna according to any of claims 1 to 7.

9. The electronic device according to claim 8, comprising:

an electrically conductive second ground plate (502, 606, 803) located on said second plane, said second ground plate (502, 606, 803) having a third edge parallel to said first edge of the ground plane (505, 608, 701, 801),
an elongated second slot (504, 602, 805, 1502) delimited by at least one of said ground plane (505, 608, 701, 801) and said bridge (607, 703, 807), the longitudinal direction of said second slot (504, 602, 805, 1502) being parallel to said first edge, said second slot (504, 602, 805, 1502) being coincident with said second ground plate (502, 606, 803) seen from said direction perpendicular to said first and second planes, and
a second antenna feed point (604) on the distal side of said second slot (504, 602, 805, 1502) seen from the center of said ground plane (505, 608, 701, 801);
wherein said electrically conductive bridge (607, 807) connects said third edge of said second ground plate (502, 606, 803) to said first edge of the ground plane (505, 608, 801).

10. The electronic device according to claim 9, wherein proximal ends of said first slot (503, 601, 804, 1501) and said second slot (504, 602, 805, 1502) are separated from each other in the direction of said first edge by a first isthmus (506, 609) of the ground plane material, and wherein said first ground plate (503, 605, 802) and said second ground plate (504, 606, 803) are separated from each other in the direction of said first edge by a first gap.

11. The electronic device according to claim 10, further comprising a capacitor (819) coupled electrically in parallel with said first isthmus of the ground plane material.

12. The electronic device according to claim 9, comprising:

a first open slot antenna (1503) displaced from

the distal end of said first slot (1501) in the direction of said first edge (1505), and
a second open slot antenna (1504) displaced from the distal end of said second slot (1502) in the direction of said first edge (1505).

13. The electronic device according to claim 12, wherein a continuous piece of conductive material extends in the direction of said first edge (1505) from a slit (1506) of said first open slot antenna (1503) past said first (802) and second (803) ground plates to a slit (1507) of said second open slot antenna (1504).

14. The electronic device according to claim 13, wherein:

the electronic device is flat in shape, comprising two ends, two side edges, a front side, and a back side,
the electronic device comprises a metallic ring (806) along said two ends and said two side edges, said ring (806) defining the dimensions of said front side and said back side, and
said bridge (807) or an edge (1505) of said ground plane is a portion of said ring (806).

15. The electronic device according to claim 14, comprising:

a first group (1601) of four antennas along a first side edge of said two side edges, said first group comprising, in this order: a first open slot antenna (1602), a first closed slot antenna (1603), a second closed slot antenna (1604), and a second open slot antenna (1605), and
a second group (1606) of four antennas along a second side edge of said two side edges, said second group comprising, in this order: a third open slot antenna (1607), a third closed slot antenna (1608), a fourth closed slot antenna (1609), and a fourth open slot antenna (1610).

Patentansprüche

1. Antenne, die Folgendes umfasst:

eine elektrisch leitfähige Erdungsebene (401, 505, 608, 701, 801, 901), die eine erste Ebene definiert und eine erste Kante (402, 507, 903, 1505) aufweist,
eine elektrisch leitfähige erste Erdungsplatte (403, 501, 502, 605, 606, 702, 802, 803, 904), die sich auf einer zweiten Ebene parallel zu der ersten Ebene befindet und durch einen ersten Abstand von der ersten Ebene versetzt ist, wobei die erste Erdungsplatte eine zweite Kante (404, 906) parallel zu der ersten Kante (402, 507, 903, 1505) der Erdungsebene (401, 505,

- 608, 701, 801, 901) aufweist,
eine elektrisch leitfähige Brücke (406, 607, 703, 807, 907), die die zweite Kante (404, 906) der ersten Erdungsplatte (403, 501, 502, 605, 606, 702, 802, 803, 904) mit der ersten Kante (402, 507, 903, 1505) der Erdungsebene (401, 505, 608, 701, 801, 901) verbindet,
einen länglichen ersten Schlitz (407, 503, 504, 601, 602, 704, 908, 1501), der durch die Erdungsebene (401, 505, 608, 701, 801, 901) und/oder die Brücke (406, 607, 703, 807, 907) begrenzt wird, wobei die Längsrichtung des ersten Schlitzes (407, 503, 504, 601, 602, 704, 908, 1501) parallel zu der ersten Kante (402, 507, 903, 1505) ist, wobei der erste Schlitz (407, 503, 504, 601, 602, 704, 908, 1501) mit der ersten Erdungsplatte (403, 501, 502, 605, 606, 702, 802, 904) zusammenfällt, die von einer Richtung (405, 909) senkrecht zu der ersten und der zweiten Ebene gesehen wird, und
einen ersten Antennenspeisepunkt (408, 603, 604, 705, 910) auf der distalen Seite des ersten Schlitzes (407, 503, 504, 601, 602, 704, 908, 1501), der von der Mitte der Erdungsebene (401, 505, 608, 701, 801, 901) gesehen wird, wobei die Abmessungen der ersten Erdungsplatte (403, 501, 502, 605, 606, 802) derart sind, dass
ihre Länge in der Längsrichtung gleich zu Folgendem ist: einer halben Wellenlänge elektromagnetischer Strahlung bei einer Betriebsfrequenz der Antenne und/oder der Länge des ersten Schlitzes (407, 503, 504, 601, 602, 704, 1501) in der Längsrichtung, und
ihre Breite in einer Richtung senkrecht zu der Längsrichtung zwischen 3 und 10 Millimetern ist.
2. Antenne nach Anspruch 1, wobei:
der erste Schlitz (601, 602, 704) durch die Erdungsebene (608, 701) auf einer Seite und durch die Brücke (607, 703, 807) auf der anderen Seite begrenzt ist.
 3. Antenne nach Anspruch 1 oder 2, wobei der erste Antennenspeisepunkt (603, 604, 705) ein Teil der Brücke (607, 703, 807) ist.
 4. Antenne nach einem der vorhergehenden Ansprüche, wobei die Breite des ersten Schlitzes (407, 503, 504, 601, 602, 704, 1501) in der Richtung senkrecht zu seiner Längsrichtung zwischen 0,3 und 1,5 Millimeter, vorzugsweise zwischen 0,5, und 1,0 Millimeter ist.
 5. Antenne nach einem der vorhergehenden Ansprüche, die einen ersten dielektrischen Träger (708, 813) zwischen der Erdungsebene (701, 801) und der ersten Erdungsplatte (702, 802) zum Tragen der ersten Erdungsplatte umfasst.
 6. Antenne nach Anspruch 5, die eine erste Öffnung (815) in dem ersten dielektrischen Träger (813) umfasst, die mit einem zentralen Abschnitt der ersten Erdungsplatte (802) zusammenfällt.
 7. Antenne nach einem der vorhergehenden Ansprüche, die eine zweite Öffnung (817) in der ersten Erdungsplatte (802) auf der Brückenseite des zentralen Abschnitts der ersten Erdungsplatte umfasst.
 8. Elektronische Vorrichtung, die eine Antenne nach einem der Ansprüche 1 bis 7 umfasst.
 9. Elektronische Vorrichtung nach Anspruch 8, die Folgendes umfasst:
eine elektrisch leitfähige zweite Erdungsplatte (502, 606, 803), die sich auf der zweiten Ebene befindet, wobei die zweite Erdungsplatte (502, 606, 803) eine dritte Kante parallel zu der ersten Kante der Erdungsebene (505, 608, 701, 801) aufweist,
einen länglichen zweiten Schlitz (504, 602, 805, 1502), der durch die Erdungsebene (505, 608, 701, 801) und/oder die Brücke (607, 703, 807) begrenzt ist, wobei die Längsrichtung des zweiten Schlitzes (504, 602, 805, 1502) parallel zu der ersten Kante ist, wobei der zweite Schlitz (504, 602, 805, 1502) mit der zweiten Erdungsplatte (502, 606, 803) zusammenfällt, die von der Richtung senkrecht zu der ersten und der zweiten Ebene gesehen wird, und
einen zweiten Antennenspeisepunkt (604) auf der distalen Seite des zweiten Schlitzes (504, 602, 805, 1502), der von der Mitte der Erdungsebene (505, 608, 701, 801) gesehen wird;
wobei die elektrisch leitfähige Brücke (607, 807) die dritte Kante der zweiten Erdungsplatte (502, 606, 803) mit der ersten Kante der Erdungsebene (505, 608, 801) verbindet.
 10. Elektronische Vorrichtung nach Anspruch 9, wobei die proximalen Enden des ersten Schlitzes (503, 601, 804, 1501) und des zweiten Schlitzes (504, 602, 805, 1502) in der Richtung der ersten Kante durch einen ersten Isthmus (506, 609) des Erdungsebenematerials voneinander getrennt sind, und wobei die erste Erdungsplatte (503, 605, 802) und die zweite Erdungsplatte (504, 606, 803) in der Richtung der ersten Kante durch eine erste Lücke voneinander getrennt sind.
 11. Elektronische Vorrichtung nach Anspruch 10, die ferner einen Kondensator (819) umfasst, der mit dem ersten Isthmus des Erdungsebenematerials parallel

elektrisch gekoppelt ist.

12. Elektronische Vorrichtung nach Anspruch 9, die Folgendes umfasst:

eine erste Antenne mit offenem Schlitz (1503), die von dem distalen Ende des ersten Schlitzes (1501) in die Richtung der ersten Kante (1505) versetzt ist, und
eine zweite Antenne mit offenem Schlitz (1504), die von dem distalen Ende des zweiten Schlitzes (1502) in die Richtung der ersten Kante (1505) versetzt ist.

13. Elektronische Vorrichtung nach Anspruch 12, wobei sich ein fortlaufendes Stück leitfähigen Materials in die Richtung der ersten Kante (1505) von einem Schlitz (1506) der ersten Antenne mit offenem Schlitz (1503) vorbei an der ersten (802) und der zweiten (803) Erdungsplatte zu einem Schlitz (1507) der zweiten Antenne mit offenem Schlitz (1504) erstreckt.

14. Elektronische Vorrichtung nach Anspruch 13, wobei:

die elektronische Vorrichtung eine flache Form hat und zwei Enden, zwei Seitenkanten, eine Vorderseite und eine Rückseite umfasst, die elektronische Vorrichtung einen metallischen Ring (806) entlang der zwei Enden und der zwei Seitenkanten umfasst, wobei der Ring (806) die Abmessungen der Vorderseite und der Rückseite definiert, und
die Brücke (807) oder eine Kante (1505) der Erdoberfläche ein Abschnitt des Rings (806) ist.

15. Elektronische Vorrichtung nach Anspruch 14, die Folgendes umfasst:

eine erste Gruppe (1601) von vier Antennen entlang einer ersten Seitenkante der zwei Seitenkanten, wobei die erste Gruppe in dieser Reihenfolge Folgendes umfasst: eine erste Antenne mit offenem Schlitz (1602), eine erste Antenne mit geschlossenem Schlitz (1603), eine zweite Antenne mit geschlossenem Schlitz (1604) und eine zweite Antenne mit offenem Schlitz (1605), und
eine zweite Gruppe (1606) von vier Antennen entlang einer zweiten Seitenkante der zwei Seitenkanten, wobei die zweite Gruppe in dieser Reihenfolge Folgendes umfasst: eine dritte Antenne mit offenem Schlitz (1607), eine dritte Antenne mit geschlossenem Schlitz (1608), eine vierte Antenne mit geschlossenem Schlitz (1609) und eine vierte Antenne mit offenem Schlitz (1610).

Revendications

1. Antenne, comprenant :

un plan de masse électriquement conducteur (401, 505, 608, 701, 801, 901) qui définit un premier plan et présente un premier bord (402, 507, 903, 1505),
une première plaque de masse électriquement conductrice (403, 501, 502, 605, 606, 702, 802, 803, 904) située sur un second plan parallèle audit premier plan et déplacée d'une première distance dudit premier plan, ladite première plaque de masse présentant un deuxième bord (404, 906) parallèle audit premier bord (402, 507, 903, 1505) du plan de masse (401, 505, 608, 701, 801, 901),
un pont électriquement conducteur (406, 607, 703, 807, 907) connectant ledit deuxième bord (404, 906) de la première plaque de masse (403, 501, 502, 605, 606, 702, 802, 803, 904) audit premier bord (402, 507, 903, 1505) du plan de masse (401, 505, 608, 701, 801, 901),
une première fente allongée (407, 503, 504, 601, 602, 704, 908, 1501) délimitée par ledit plan de masse (401, 505, 608, 701, 801, 901) et/ou ledit pont (406, 607, 703, 807, 907), la direction longitudinale de ladite première fente (407, 503, 504, 601, 602, 704, 908, 1501) étant parallèle audit premier bord (402, 507, 903, 1505), ladite première fente (407, 503, 504, 601, 602, 704, 908, 1501) coïncidant avec ladite première plaque de masse (403, 501, 502, 605, 606, 702, 802, 904) vue depuis une direction (405, 909) perpendiculaire auxdits premier et second plans, et
un premier point d'alimentation d'antenne (408, 603, 604, 705, 910) sur le côté distal de ladite première fente (407, 503, 504, 601, 602, 704, 908, 1501) vu depuis le centre dudit plan de masse (401, 505, 608, 701, 801, 901),
les dimensions de ladite première plaque de masse (403, 501, 502, 605, 606, 802) étant telles que
sa longueur dans ladite direction longitudinale est égale à : une demi-longueur d'onde de rayonnement électromagnétique à une fréquence de fonctionnement de ladite antenne, et/ou la longueur de ladite première fente (407, 503, 504, 601, 602, 704, 1501) dans ladite direction longitudinale, et
sa largeur dans une direction perpendiculaire à ladite direction longitudinale est comprise entre 3 et 10 millimètres.

2. Antenne selon la revendication 1 :
ladite première fente (601, 602, 704) étant délimitée par ledit plan de masse (608, 701) d'un côté et par

ledit pont (607, 703, 807) de l'autre côté.

3. Antenne selon la revendication 1 ou 2, ledit premier point d'alimentation d'antenne (603, 604, 705) faisant partie dudit pont (607, 703, 807).

4. Antenne selon l'une quelconque des revendications précédentes, la largeur de ladite première fente (407, 503, 504, 601, 602, 704, 1501) dans la direction perpendiculaire à sa direction longitudinale étant comprise entre 0,3 et 1,5 millimètre, de préférence entre 0,5 et 1,0 millimètre.

5. Antenne selon l'une quelconque des revendications précédentes, comprenant un premier support diélectrique (708, 813) entre ledit plan de masse (701, 801) et ladite première plaque de masse (702, 802) pour soutenir ladite première plaque de masse.

6. Antenne selon la revendication 5, comprenant une première ouverture (815) dans ledit premier support diélectrique (813) coïncidant avec une partie centrale de ladite première plaque de masse (802).

7. Antenne selon l'une quelconque des revendications précédentes, comprenant une seconde ouverture (817) dans ladite première plaque de masse (802) du côté pont de la partie centrale de ladite première plaque de masse.

8. Dispositif électronique, comprenant une antenne selon l'une quelconque des revendications 1 à 7.

9. Dispositif électronique selon la revendication 8, comprenant :

une seconde plaque de masse électriquement conductrice (502, 606, 803) située sur ledit second plan, ladite seconde plaque de masse (502, 606, 803) présentant un troisième bord parallèle audit premier bord du plan de masse (505, 608, 701, 801),

une seconde fente allongée (504, 602, 805, 1502) délimitée par ledit plan de masse (505, 608, 701, 801) et/ou ledit pont (607, 703, 807), la direction longitudinale de ladite seconde fente (504, 602, 805, 1502) étant parallèle audit premier bord, ladite seconde fente (504, 602, 805, 1502) coïncidant avec ladite seconde plaque de masse (502, 606, 803) vue depuis ladite direction perpendiculaire auxdits premier et second plans, et

un second point d'alimentation d'antenne (604) sur le côté distal de ladite seconde fente (504, 602, 805, 1502) vu depuis le centre dudit plan de masse (505, 608, 701, 801) ;
ledit pont électriquement conducteur (607, 807) connectant ledit troisième bord de ladite secon-

de plaque de masse (502, 606, 803) audit premier bord du plan de masse (505, 608, 801).

10. Dispositif électronique selon la revendication 9, les extrémités proximales de ladite première fente (503, 601, 804, 1501) et de ladite seconde fente (504, 602, 805, 1502) étant séparées l'une de l'autre dans la direction dudit premier bord par un premier isthme (506, 609) du matériau de plan de masse, et ladite première plaque de masse (503, 605, 802) et ladite seconde plaque de masse (504, 606, 803) étant séparées l'une de l'autre en direction dudit première bord par un premier espace.

11. Dispositif électronique selon la revendication 10, comprenant en outre un condensateur (819) couplé électriquement en parallèle avec ledit premier isthme du matériau de plan de masse.

12. Dispositif électronique selon la revendication 9, comprenant :

une première antenne à fente ouverte (1503) déplacée de l'extrémité distale de ladite première fente (1501) dans la direction dudit premier bord (1505), et

une deuxième antenne à fente ouverte (1504) déplacée de l'extrémité distale de ladite seconde fente (1502) dans la direction dudit premier bord (1505).

13. Dispositif électronique selon la revendication 12, un morceau continu de matériau conducteur s'étendant dans la direction dudit premier bord (1505) à partir d'une entaille (1506) de ladite première antenne à fente ouverte (1503) au-delà desdites première (802) et seconde (803) plaques de masse sur une entaille (1507) de ladite deuxième antenne à fente ouverte (1504).

14. Dispositif électronique selon la revendication 13 :

le dispositif électronique étant de forme plate, comprenant deux extrémités, deux bords latéraux, un côté avant et un côté arrière, le dispositif électronique comprenant un anneau métallique (806) le long desdites deux extrémités et desdits deux bords latéraux, ledit anneau (806) définissant les dimensions dudit côté avant et dudit côté arrière, et ledit pont (807) ou un bord (1505) dudit plan de masse étant une partie dudit anneau (806).

15. Dispositif électronique selon la revendication 14, comprenant :

un premier groupe (1601) de quatre antennes le long d'un premier bord latéral desdits deux

bords latéraux, ledit premier groupe comprenant, dans cet ordre : une première antenne à fente ouverte (1602), une première antenne à fente fermée (1603), une deuxième antenne à fente fermée (1604), et une deuxième antenne à fente ouverte (1605), et
un second groupe (1606) de quatre antennes le long d'un second bord latéral desdits deux bords latéraux, ledit second groupe comprenant, dans cet ordre : une troisième antenne à fente ouverte (1607), une troisième antenne à fente fermée (1608), une quatrième antenne à fente fermée (1609), et une quatrième antenne à fente ouverte (1610).

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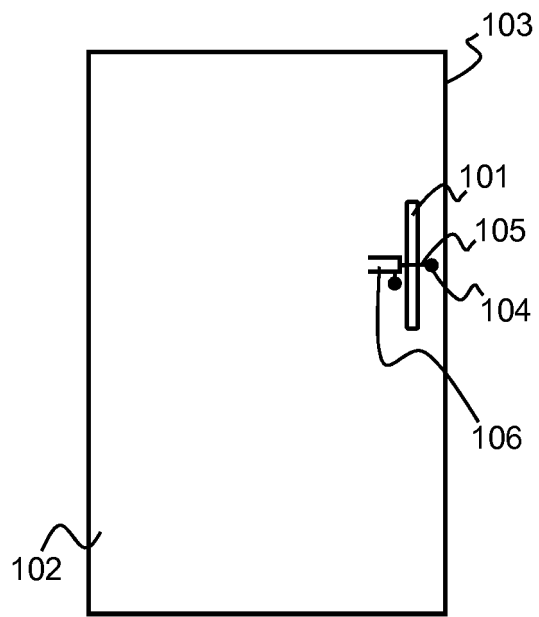


Fig. 1

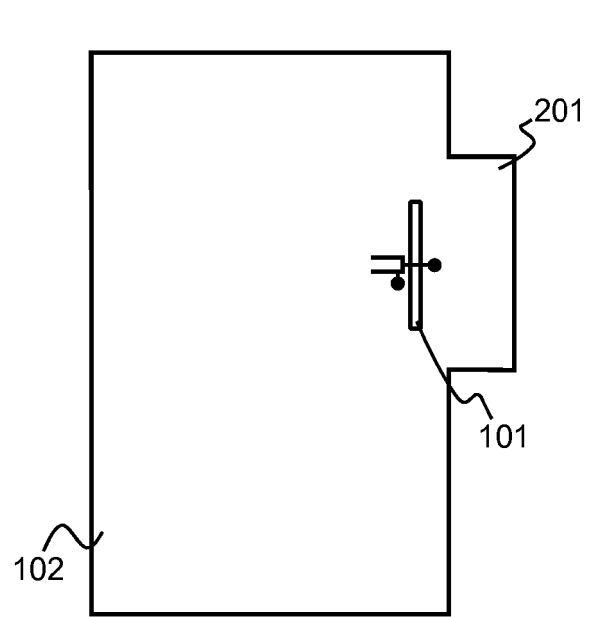


Fig. 2

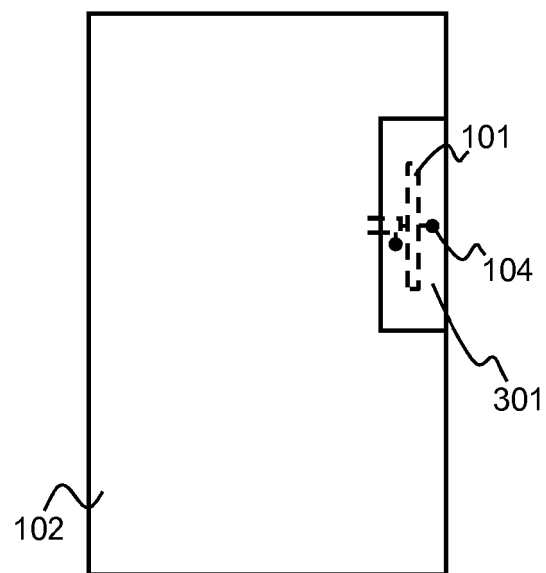


Fig. 3

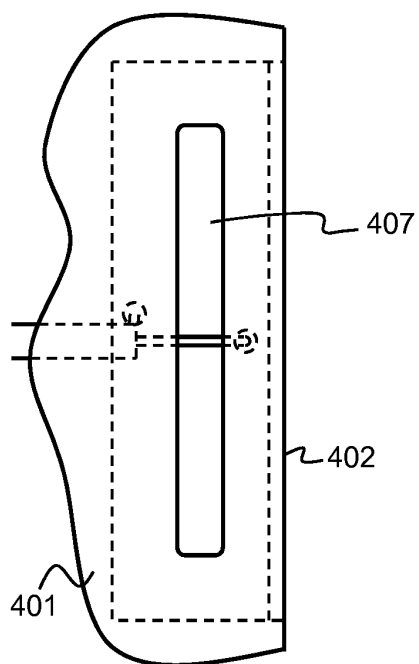


Fig. 4a

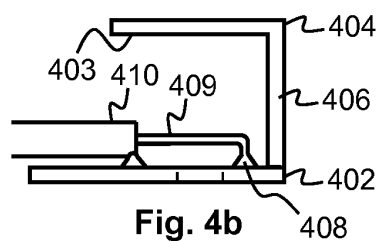


Fig. 4b

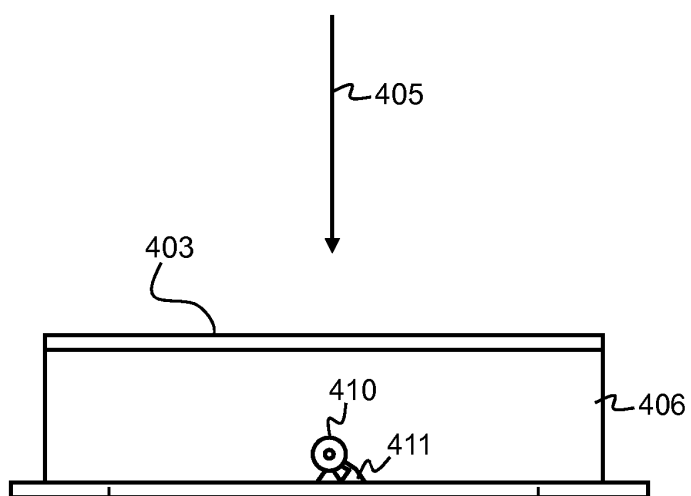


Fig. 4c

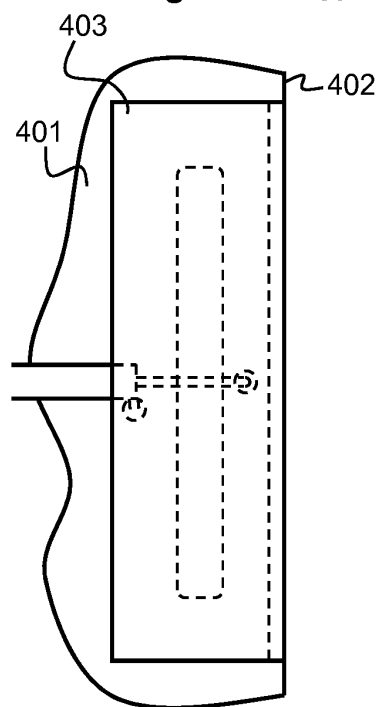


Fig. 4d

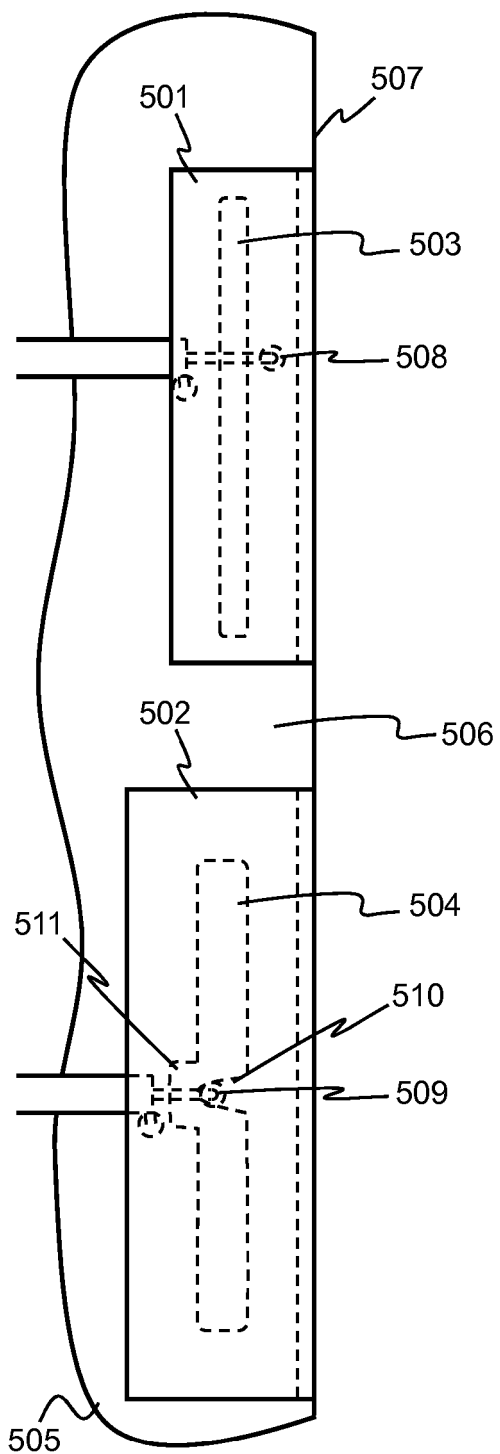


Fig. 5

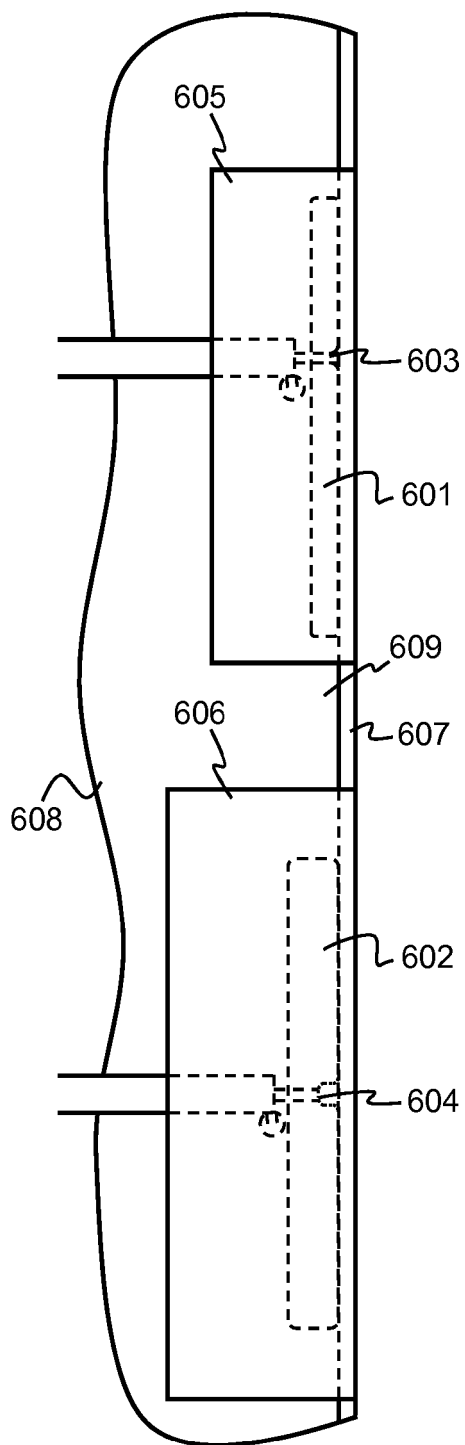
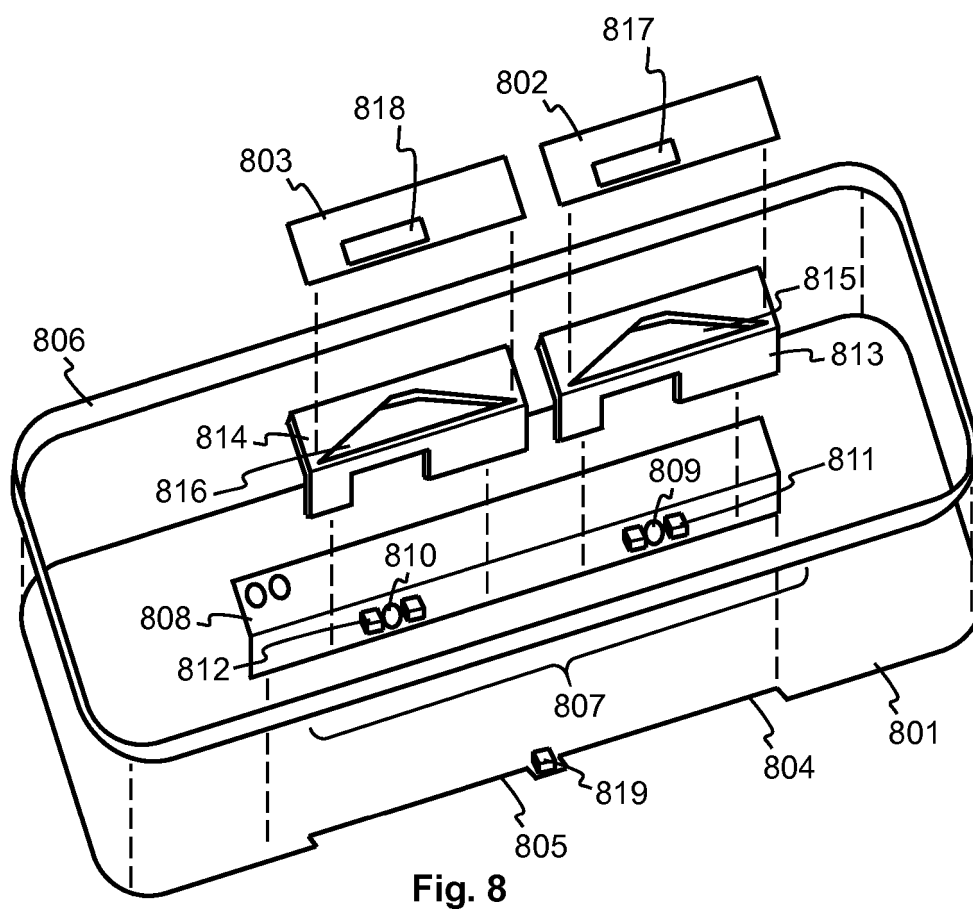
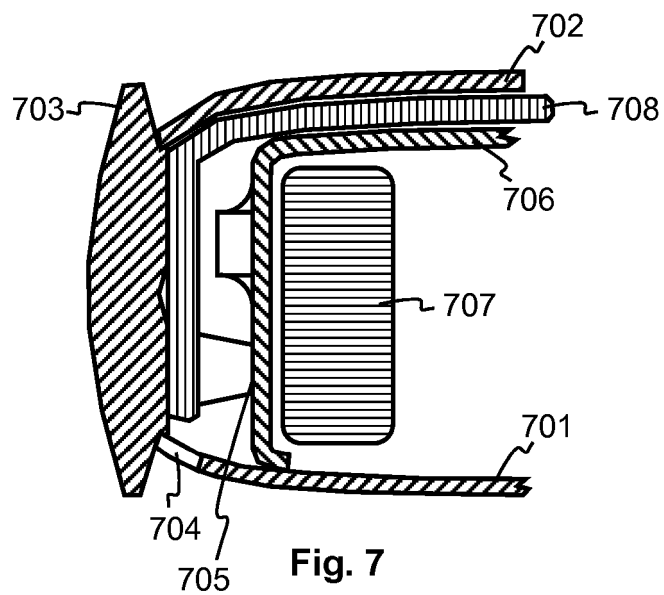


Fig. 6



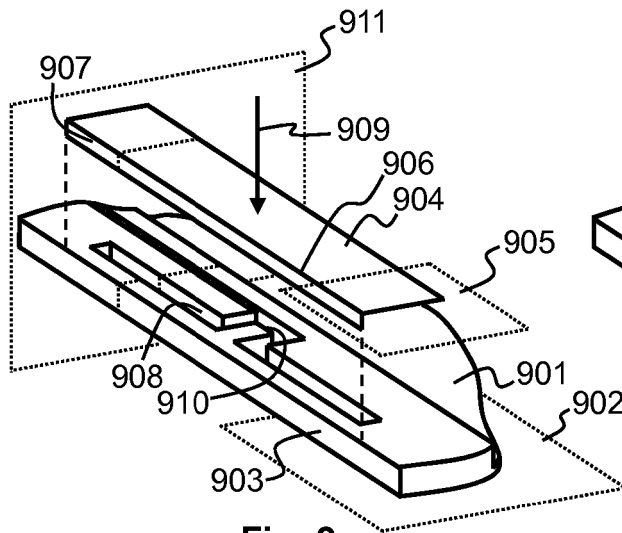


Fig. 9

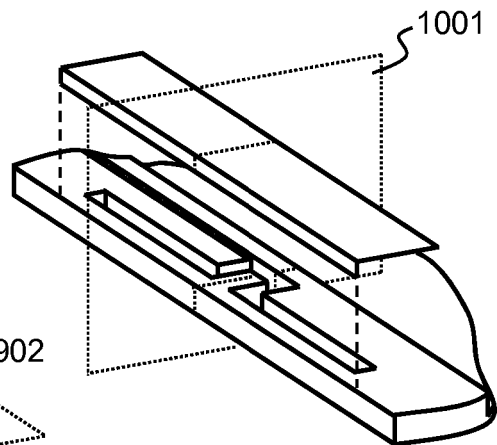


Fig. 10

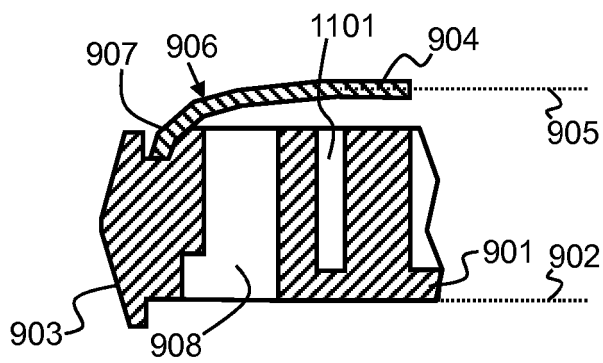


Fig. 11

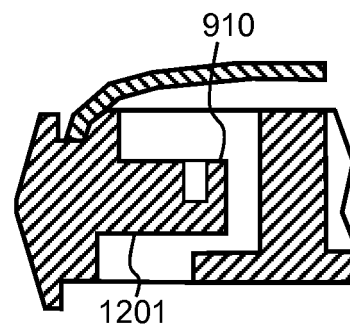


Fig. 12

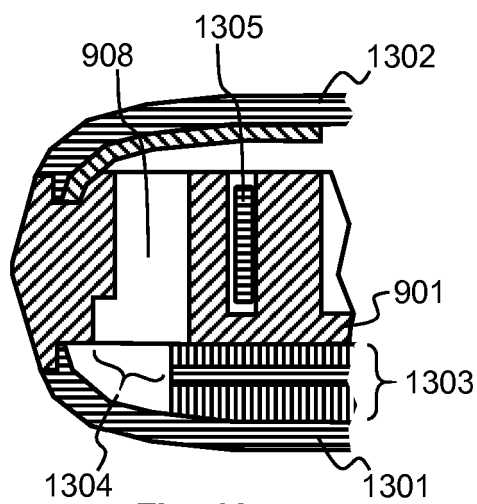


Fig. 13

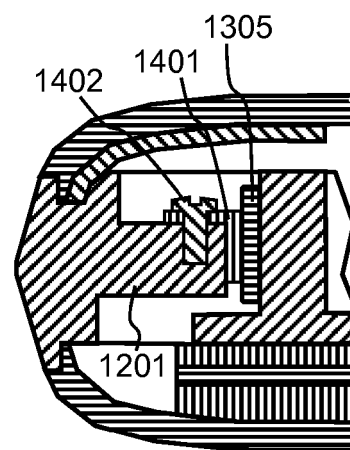


Fig. 14

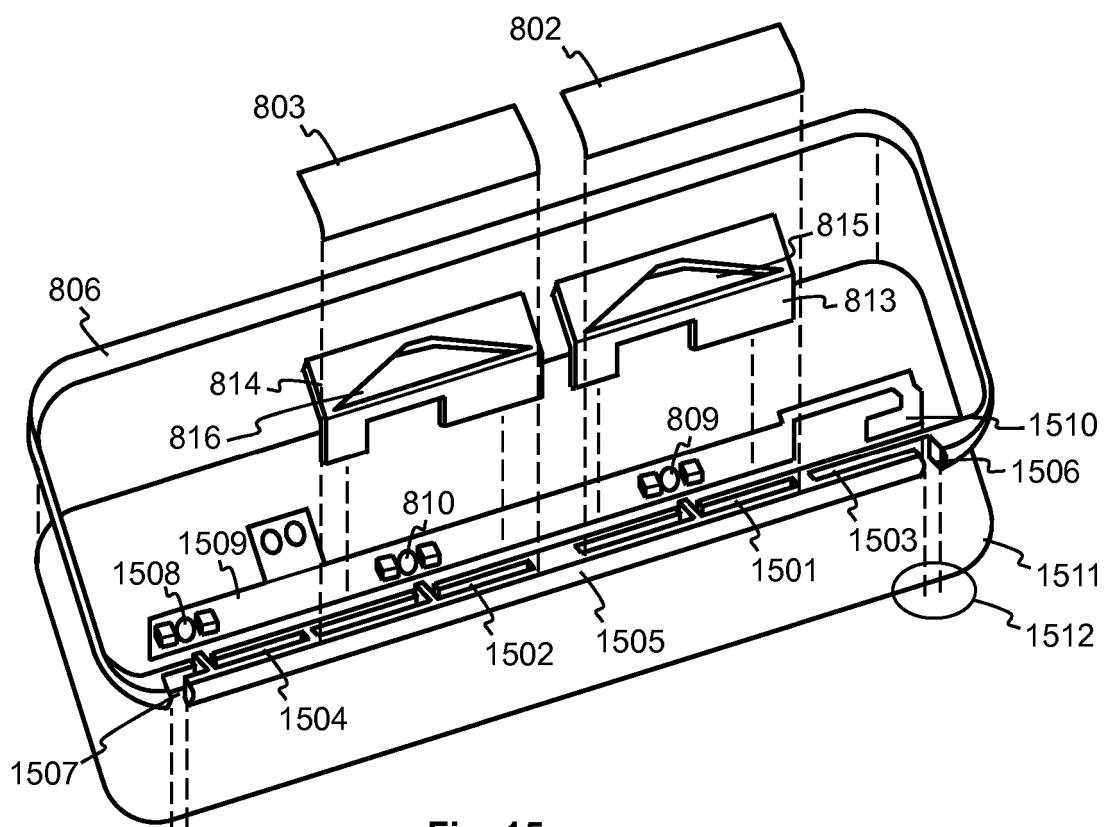


Fig. 15

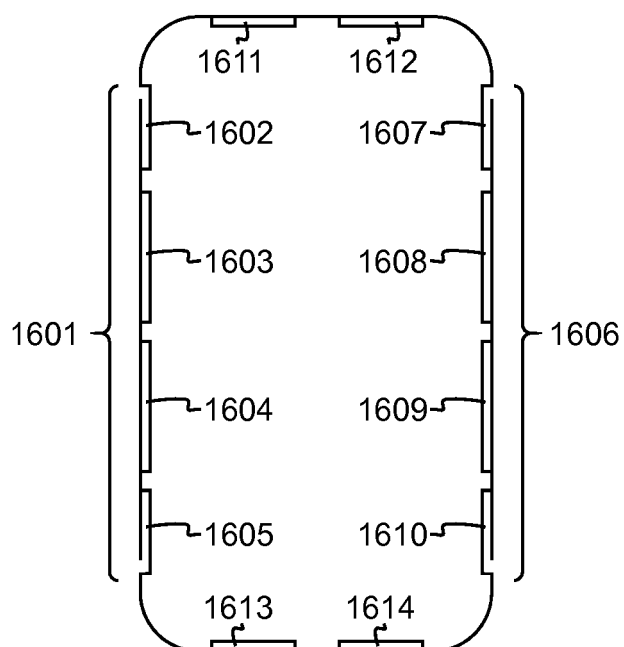


Fig. 16

REFERENCES CITED IN THE DESCRIPTION

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