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(54) **Title:** ANTENNA DEVICE WITH CURVED RIDGES

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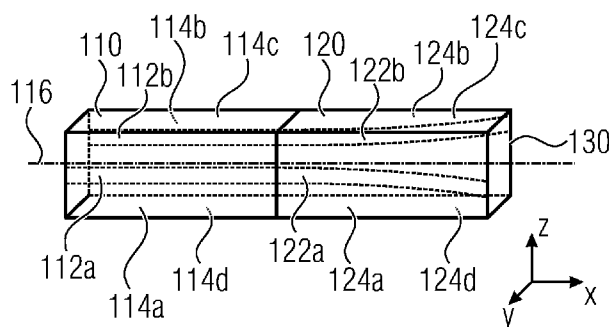


Fig. 1A

(57) **Abstract:** The invention relates to an antenna device and an automated test equipment comprising a double-ridged waveguide structure with a first and a second ridge and a circular polarization antenna structure coupled to the double-ridged waveguide and extending between the double-ridged waveguide structure and a radiating aperture of the antenna device. The circular polarization antenna structure comprises a third ridge having a first curved extension and transitioning into the first ridge and a fourth ridge having a second curved extension different from the first curved extension and transitioning into the second ridge.

Antenna device with curved ridges

Technical field

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Embodiments according to the invention relate to an antenna device and an automated test equipment.

10 Embodiments relate to an antenna device and an automated test equipment comprising a circular polarization antenna structure with curved ridges.

Embodiments according to the invention relate to a Circular Polarized Wideband Waveguide Antenna for an over the air (OTA) socket.

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Background of the invention

An antenna device with a circular polarization antenna structure allows generating and/or receiving circularly polarized electromagnetic waves and can be used in various applica-
20 tions that may include satellites, radar, and mobile phones (e.g., in the 5G standard).

Moreover, an antenna device with a circular polarization antenna structure is also well-use-able in test arrangements for testing components.

25 However, it has been recognized that such antenna device may suffer from resonances (e.g., cavity resonances), which may bring distortions to return loss and antenna radiation performance (e.g., gain drop) and limit available frequency bandwidth of operation.

Furthermore, it has been recognized there is a desire to improve a bandwidth of such a
30 device.

It has also been recognized that another problem common for circular polarization antenna structures is axial ratio performance.

Therefore, there is a need for an antenna device that improves a compromise between reduction (or prevention) of cavity resonances, increasing bandwidth, and improving axial ratio performance.

5 Summary of the invention

An embodiment of the invention is directed at an antenna device comprising a double-ridged waveguide structure (e.g., with a rectangular cross section) with a first and a second ridge (wherein, for example, the double-ridged waveguide structure forms a feed structure, and
10 wherein, for example, the first ridge and the second ridge are arranged in parallel along a symmetry plane of the double-ridged waveguide structure, e.g., a symmetry plane oriented parallel to narrow sides of a rectangular frame of the double-ridged waveguide structure). The antenna device further comprises a circular polarization antenna structure coupled to the double-ridged waveguide and extending between the double-ridged waveguide struc-
15 ture and a radiating aperture of the antenna device (wherein, for example, the circular polarization antenna structure may be tapered, e.g. in a sense that there is a widening of the aperture between the double-ridged waveguide structure and the radiating aperture), wherein the circular polarization antenna structure comprises a third ridge having a first curved extension and transitioning into the first ridge and a fourth ridge having a second
20 curved extension different from the first curved extension and transitioning into the second ridge (wherein, for example, the third ridge bends away towards a first half-space (or area) at a first side of the symmetry plane of the double-ridged waveguide structure, e.g., symmetry plane oriented parallel to narrow sides of a rectangular frame of the double-ridged waveguide structure, and wherein, for example, the fourth ridge bends away towards a sec-
25 ond half-space (or area) at a second side of the symmetry plane of the double-ridged waveguide structure) (wherein, for example, there is a tapering, e.g. in a sense that the distance between the third ridge and the fourth ridge increases in a direction towards the radiating aperture).

30 It has been recognized that the double-ridged waveguide structure allows excitation over an wide bandwidth (e.g., covering an octave or more), wherein the transition of the ridges of the double-ridged waveguide structure into the ridges of the circular polarization antenna structure increases a bandwidth of the circular polarization antenna structure. Therefore, the antenna device is capable of receiving and/or transmitting circular polarized radiation
35 over an improved bandwidth, wherein the double-ridged waveguide structure is capable of feeding electromagnetic waves of such an increased bandwidth to the circular polarization

antenna structure and/or exciting electromagnetic waves of such an increased bandwidth received at the circular polarization antenna structure. Furthermore it has been recognized that the transitioning ridges improve the axial ratio performance of the antenna device. Furthermore, it has been recognized that a usage of ridges having a curved extension allows for an excitation and/or reception of circularly polarized waves. For example, the curvature (curved extension) of the third ridge and of the fourth ridge allows to smoothly rotate electric and magnetic field vectors of an electromagnetic wave propagating from an aperture of the waveguide, in which typically a single mode is propagating, to the radiating aperture of the antenna device, where a circular polarization (which can be seen as a combination of two linear polarized waves with polarization planes at right angles relative to each other, wherein a phase difference between the two linear polarized waves is 90°) is present. The curvature of the third ridge and of the fourth ridge may also allow to smoothly guide a circularly polarized wave incoming at the aperture of the antenna towards the double-ridged waveguide. Thus, the curved design of the third ridge and of the fourth ridge may help to achieve a desired axial ratio performance.

To conclude, the combination of the double-ridged waveguide structure and of the circular polarization antenna structure comprising curved ridges allows for a broadband operation of the antenna device with a good axial ratio performance and good matching.

According to an embodiment, at least one of the third and fourth ridge extends only along a part of a way from the double-ridged waveguide structure towards the radiating aperture (and ends before the respective ridge reaches the radiating aperture). For example, a length of an extension of at least one of the third and fourth ridge may be shorter than a length of the circular polarization antenna structure (e.g., a length from a border between the double-ridged waveguide structure to the radiating aperture). In other words, the length of the third and the fourth ridge extension is less than the radiating aperture height (or length)

The third and fourth ridges therefore are trimmed (e.g., shortened), which may result in an improved axial ratio performance at the lower frequencies of interest. Furthermore, an operational band of the antenna device may be shifted towards lower frequencies.

According to an embodiment, the antenna device comprises a main body, wherein the circular polarization antenna structure is arranged partially inside the main body and wherein

the circular polarization antenna structure (e.g., a rectangular frame thereof) extends partially (e.g., by at least essentially 3.65 mm) beyond a surface (e.g. a surface on a radiating side of the antenna device) of the main body (or beyond one or more corrugations arranged on a surface of the main body).

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Since the circular polarization antenna structure extends beyond the surface, resonance effects (e.g., situated at the bottom of the circular polarization antenna structure and/or the waveguide) that may occur (e.g., in interaction with the main body) may be reduced or prevented. Moreover, it has been recognized that, in some cases, an antenna matching may be better (e.g. at a lower edge of the band) using such a structure.

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According to an embodiment, the first curved extension (of the third ridge) and the second curved extension (of the fourth ridge) are arranged along different parallel and spaced apart (virtual) planes, and the first curved extension and the second curved extension bend away towards opposite directions from the (common) direction of the first ridge and of the second ridge (when extending outwardly from the double-ridged waveguide structure).

15

This arrangement of the first curved extension and of the second curved extension may allow for an smooth transition of electromagnetic wave between the (radiating) aperture of the antenna device and the double-ridged waveguide (or vice versa). The fact that the first curved extension and the second curved extension bend away towards opposite directions from the (common) direction of the first ridge and of the second ridge may contribute to a rotation of an electromagnetic field, which in turn supports a formation of a circularly polarized wave (e.g. on the basis of an electromagnetic wave travelling along the double-ridged waveguide structure, in other words, the circular polarized wave is formed from a linear polarized wave that propagates in the feeding double-ridged waveguide or structure) or the transformation of an incoming circularly-polarized wave into a waveguide mode which can propagate inward along the double-ridged waveguide structure. In other words, the first curved extension and the second curved extension may, for example, be formed in such a manner that a direction of a straight line connecting the third ridge and the fourth ridge smoothly changes with increasing distance from the double-ridged waveguide structure, which may cause a rotation of an electric field.

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To conclude, the described arrangement of the third ridge and of the fourth ridge allows to achieve a good axial ratio performance over a wide frequency range, wherein a good matching can be achieved.

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According to an embodiment, the first curved extension of the third ridge is arranged along a plane which is defined by a (e.g. first) sidewall of the double-ridged waveguide structure (e.g. by a first wide sidewall (or by a first wider sidewall, e.g. when compared to a narrower sidewall) or by a first broad sidewall (or a first broader sidewall, e.g. when compared to a narrower sidewall) of a rectangular frame of the double-ridged waveguide) on which the first ridge is arranged (for example, such that the third ridge lies between a plane defining a sidewall of the double-ridged waveguide carrying the first ridge and a plane defining an inner surface of the first ridge), and wherein the second curved extension of the fourth ridge is arranged along a plane which is defined by a (e.g. second) sidewall of the double-ridged waveguide structure (e.g. by a second wide sidewall (or by a second wider sidewall, e.g. when compared to a narrower sidewall) or by a second broad sidewall (or a second broader sidewall, e.g. when compared to a narrower sidewall) of a rectangular frame of the double-ridged waveguide) on which the second ridge is arranged (for example, such that the fourth ridge lies between a plane defining a sidewall of the double-ridged waveguide structure carrying the second ridge and a plane defining an inner surface of the second ridge).

The sidewalls may define (electrically conductive) surfaces for guiding electromagnetic waves, wherein the third and fourth ridge extending along these sidewalls can improve reception and/or emission of circular polarization. Furthermore, axial ratio performance may be improved. In addition, it should be noted that, for example, the arrangement of the first curved extension of the third ridge along a plane which is defined by a (e.g. first) sidewall of the double-ridged waveguide structure (and the corresponding arrangement of the second curved extension of the fourth ridge) helps to avoid a significant discontinuity, which results in a good matching over a wide frequency range.

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According to an embodiment, the first curved extension and the second curved extension are axially symmetric to an axis of the double-ridged waveguide structure and the circular polarization antenna structure (e.g., point symmetric relative to the axis) (e.g., symmetric according to a reflection by two mirror planes that are arranged perpendicular to each other, wherein each mirror plane comprises the axis). For example, the first curved extension has

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a rotational symmetry of 180 degrees (e.g., within a tolerance of -10 degrees and +10 degrees) around the axis of the double-ridged waveguide structure relative to the second curved extension. In other words, for example, one curved extension (e.g. the second curved extension) is provided by 180 degrees rotation of another one (e.g. of the first curved extension), around the double ridged waveguide's axis.

The axial symmetry of the first and second curved extensions may improve reception and/or emission of circular polarization and may improve axial ratio performance.

According to an embodiment, the third ridge and the fourth ridge are configured to rotate (e.g., configured to contribute to rotate) a direction of electric and magnetic fields, which are present between the first ridge and the second ridge, when a wave is traveling from the double ridged waveguide structure toward a radiating aperture of the antenna device (and, e.g., vice versa; e.g., the third ridge and the fourth ridge are configured to transform a wave received at the radiating aperture of the antenna device, e.g., such that during and after transformation, the wave is travelling toward and along the double ridged waveguide (e.g. with an electrical field between the first ridge and the second ridge), e.g., due to the reciprocity principle of passive devices).

Using such a design, the third ridge and the fourth ridge therefore cause or facilitate reception and/or emission of radiation with circular polarization. Geometric details or profile of the third ridge and of the fourth ridge may, for example, be used to tune an axial ratio performance. In addition, by gradually rotating the direction of the electrical field, a good broadband matching of the antenna device may be achieved.

According to an embodiment, the circular polarization antenna structure comprises a rectangular frame with a first (wide) sidewall structure and a second (wide) sidewall structure (e.g., that are wider than a first and second narrow sidewall structure) (and, for example, a third (narrow) sidewall structure and a fourth (narrow) sidewall structure, wherein, for example, the third (narrow) sidewall structure and the fourth (narrow) sidewall structure are closed structures without any openings), wherein the third ridge and the fourth ridge are arranged in the rectangular frame (wherein, for example, the third ridge is arranged along the first sidewall structure, and wherein, for example, the fourth ridge is arranged along the second sidewall structure) (wherein, for example, the rectangular frame may act as a polarizer).

The rectangular frame of the circular polarization antenna structure has a high compatibility with the double-ridged waveguide at least in regards to excitable electric fields. In case the first and second sidewalls are wide sidewalls, the transition between the first, second, third, and fourth ridge can be realized with low complexity. Moreover, the transition between a waveguide mode and a circularly polarized mode can take place in a well-defined structure (which can, for example, be manufactured with comparatively low tolerances), e.g. insensitive to an external environment, which helps to achieve a good axial ratio.

According to an embodiment, the antenna device or a component thereof (e.g., at least one of the double-ridged waveguide and the circular polarization antenna structure) comprises (or is formed entirely out of) metal (e.g., aluminium and/or steel). At least a portion of the antenna device may comprise non-metallic materials (e.g., a polymer or a ceramic).

Accordingly, the antenna device exhibits robustness in many uses such as in a testing environment.

According to an embodiment, the rectangular frame comprises (or forms) a widened (or widening) continuation of the double-ridged waveguide structure (e.g., wherein the frame is widened along a width direction of the first and second (wide) sidewall structures).

Accordingly, a discontinuity between the double-ridged waveguide and the rectangular frame can be kept small, resulting in a good broadband matching of the antenna device. Furthermore, a well-defined and smooth transition between the waveguide mode and the desired circular polarization wave can be achieved in this manner, resulting in well-defined polarization characteristics.

According to an embodiment, the first (wide) sidewall structure has a first opening (slot) and the second wide sidewall structure has a second opening (slot), wherein the first opening extends (e.g. in a (continuously) broadening manner) (e.g. from an associated starting point) towards the radiating aperture (e.g. fully to the radiating aperture), and wherein the second opening extends (e.g. in a (continuously) broadening manner) (e.g. from an associated starting point) towards the radiating aperture (e.g. fully to the radiating aperture) (e.g.,

wherein the first and second opening are arranged offset relative to each other in a direction parallel to the first and/or second (wide) sidewall structure) (e.g., wherein at least one of the first and second openings are formed by cuts in the rectangular frame).

5 The first and second openings may further improve reception and/or emission of circular polarization. For example, the first and second openings may allow for a gradually increasing coupling between an inside of the rectangular frame and a (typically hollow) portion of the antenna structure (or a portion of a circular waveguide) surrounding the rectangular frame. Accordingly, the coupling between the double-ridged waveguide and a relatively
10 large radiating aperture of the antenna device (which may, for example, have an area which is at least two times larger or at least 5 times larger or even at least ten times larger than an aperture area of the double-ridged waveguide) can be achieved via the first and second openings, without introducing an excessive discontinuity. Consequently, a good matching and a good broadband characteristic of the antenna device can be achieved.

15 According to an embodiment, the first opening and the second opening are axially symmetric or at least essentially axially symmetric (e.g., within a tolerance of -20% and +20%, or with a tolerance of -10% and +10%, or with a tolerance that is determined by manufacturing tolerances, wherein the tolerance may, for example, relate to dimensions of the opening)
20 with respect to an axis of the double-ridged waveguide structure and an axis of the circular polarization antenna structure (e.g., point symmetric relative to the axis) (e.g., symmetric according to a reflection by two mirror planes that are arranged perpendicular to each, wherein each mirror plane comprises the axis). For example, the first opening has a rotational symmetry of 180 degrees (e.g., within a tolerance of -10 degrees and +10 degrees)
25 around the axis of the double-ridged waveguide structure relative to the second opening. In other words, for example, one opening (e.g. the second opening) is provided by 180 degrees rotation of another one (e.g. of the first opening), around the double-ridged waveguide's axis.

30 The axial symmetry may improve axial ratio performance and the bandwidth of the antenna device.

According to an embodiment, the third ridge extends at least partly along an edge of the first opening, and the fourth ridge extends at least partly along an edge of the second opening (e.g., such that a part of a side surface of the third ridge is arranged flush with a surface of the first opening and such that a part of a side surface of the fourth ridge is arranged flush with a surface of the second opening).

It has been found that the extension of the third ridge along the edge of the first opening and the extension of the fourth ridge along the edge of the second opening may reduce return loss and may improve reception and/or emission of circular polarization.

According to an embodiment, at least one of the first and second openings has a shape that broadens towards the radiating aperture (or, equivalently, a shape that narrows towards the double-ridged waveguide structure) (e.g. a shape bounded by two converging lines wherein at least one of the converging lines is curved, e.g. a shape bounded by two converging curved lines, e.g. converging lines that converge along an extension from the radiating surface towards the double-ridged waveguide structure) (e.g., in a shape bounded by a V; e.g. in a shape bounded by a V having curved lines; e.g. in a shape bounded by a V having curved lines, wherein the curved lines of the V are curved in the same direction) (extending parallel to the respective first and/or second wide sidewall).

It has been found that the broadening shape of the one or more openings may improve reception and/or emission of circular polarization. Furthermore, a broadening forms a gradual change in shape, which may reduce return loss and widen the frequency bandwidth.

According to an embodiment, the first opening has a convex shape (e.g., according to a hyperbolic formula or equation or according to an elliptic formula or equation or according to an exponential formula or equation) at one side and a concave shape (e.g., according to an elliptical formula or according to a hyperbolic formula or according to an exponential formula or equation) at another side, and/or the second opening has a convex shape (e.g., according to a hyperbolic formula or according to an elliptic formula) at one side and a concave shape (e.g., according to an elliptical formula or according to a hyperbolic formula) at another side (e.g., in a (virtual) plane parallel the corresponding opening).

It has been recognized that the convex and concave shape of the one or more openings may improve axial ratio performance (in particular with an elliptical and hyperbolic formula) and contribute to a good broadband matching of the antenna device.

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According to an embodiment, the main body comprises a rounded (e.g. cylindrical or conical) recess (wherein the rounded recess may, for example, form a circular waveguide or a circular horn, except for the presence of the rectangular frame), wherein the rectangular frame with the first sidewall structure and the second sidewall structure is arranged in a central region of the rounded recess, and wherein there is an electromagnetic coupling between an inner region of the rectangular frame and a first outer rounded region of the rounded recess through a first opening in the first sidewall structure, and wherein there is an electromagnetic coupling between the inner region of the rectangular frame and a second outer rounded region of the rounded recess through a second opening in the second sidewall structure.

The rounded recess may form a space that allows excitation of electromagnetic fields. As such the rounded recess may act as a circular waveguide or horn that may contribute to the emission and/or reception of electromagnetic fields. Accordingly, the rounded recess may allow for a transition between the rectangular frame and sufficiently large radiating aperture. For example, an excitation of a circularly polarized wave may be effected by the structure of the rectangular frame and within the rectangular frame, and a widening of electromagnetic field may be effected by the circular recess. Accordingly, the structure may provide good radiation characteristics over a large frequency range.

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According to an embodiment, the first opening in the first sidewall structure widens towards a radiating aperture of the antenna device, such that a width (e.g. diameter oriented parallel to a width direction of the first sidewall) of the first opening reaches at least 60 percent or at least 70 percent of a diameter of the rounded recess in a proximity (e.g., at an end) of the radiating aperture.

It has been recognized that a coupling of electromagnetic fields between the circular polarization antenna structure and the double-ridged waveguide may be improved by such a geometry of the first opening, so as to improve emission and/or reception of electromagnetic fields.

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According to an embodiment, the rectangular frame (which is preferably configured to act as a polarizer), is longer than a circular waveguide which is formed by the rounded recess.

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With a rectangular frame that is longer than the circular waveguide, cavity resonances caused by the circular waveguide may be reduced or prevented. Also, a comparatively long rectangular frame may support a wideband operation of the antenna device.

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According to an embodiment, the rectangular frame is a separate workpiece, which inserted (or insertable) into a body of the antenna device.

As a separate workpiece, the rectangular frame allows for easier fabrication and/or enables finer and/or more complex structures. Furthermore, in some cases, different rectangular frames (which may largely define the bandwidth) can be combined with the same main body.

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According to an embodiment, the rectangular frame is assembled using a plurality of slices (e.g. layer structures) (e.g. metallic parts) (e.g. using three to four slices).

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Manufacturing of the third and fourth ridge (and optionally first and second openings) may be facilitated when formed in the plurality of slices.

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According to an embodiment, the rectangular frame protrudes over a surface of a body of the antenna device (e.g. over a surface of a main body of the antenna device surrounding an aperture of the circular polarization antenna structure).

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With the rectangular frame protruding over the surface of the body, resonances caused by the main body may be reduced or prevented. Also, a comparatively long rectangular frame may support a wideband operation of the antenna device.

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According to an embodiment, the rectangular frame protrudes over one or more corrugations arranged on a surface (e.g., of the main body) surrounding (e.g. located adjacent to) an aperture of the circular polarization antenna structure.

- 5 The corrugations may reduce surfaces waves at the radiation aperture and consequently improve axial ratio performance. Furthermore, the extension of the rectangular frame, protruding over one or more corrugations, may further help to reduce surface waves and also improve a broadband characteristic of the antenna device.

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According to an embodiment, one or more (e.g., periodic) corrugations (e.g. periodical structures formed by corrugations) (e.g., optionally, including corrugations of various depths or dimensions) are arranged on a surface (e.g., of the main body) surrounding (e.g. located adjacent to) an aperture of the circular polarization antenna structure, wherein the one or
15 more corrugations extend at least partly (e.g., entirely) around the circular polarization antenna structure (e.g., in a circular shape) (such that, for example, surface waves in the surface surrounding the aperture of the circular polarization antenna structure are at least partly suppressed). The corrugations may have a depth of at least essentially $\lambda_0/4$ and/or a width smaller than $\lambda_0/10$, wherein λ_0 defines a largest wavelength, or a center wavelength,
20 or (in some cases) a smallest wavelength of an operating bandwidth of the antenna device (e.g., λ_0 may, for example, be at least essentially 12.5mm, 7.8 mm or 5.7mm corresponding to 24 GHz, 38.5GHz, and 53GHz).

The plurality of corrugations further reduce surfaces waves, in particular when arranged
25 periodically.

According to an embodiment, at least one corrugation has a height in a range of 2.5mm to 3.5mm, or in a range of 2.9mm to 3.1mm (e.g., at least essentially 3.0mm), a wall thickness
30 in a range of 0.5mm to 1.0mm, or in a range of 0.6mm to 0.8mm (e.g., at least essentially 0.7mm).

It has been recognized that such dimensions reduce surface waves particularly well and provide good antenna characteristics within a 5G FR2 frequency bandwidth (e.g., 24GHz
35 to 53Ghz).

According to an embodiment, the antenna device comprises a plurality of corrugations, and a radial distance (e.g., perpendicular to an axial direction of the double-ridged waveguide structure and/or the circular polarization antenna structure) between two corrugations in a range of 0.5mm to 1.5mm, or in a range of 0.9mm to 1.1mm (e.g., at least essentially 1.0mm).

It has been recognized that for a plurality of corrugations, such dimensions may further reduce surface waves (e.g. over a 5G frequency range).

According to an embodiment, at least one of the third and fourth ridges comprises a first tapering (e.g. a tapering in the plane of waveguide/polarizer narrow wall, or a tapering in the plane orthogonal to the waveguide/polarizer broad wall)(e.g., a stepped tapering), wherein a thickness (e.g., in a direction perpendicular to a surface from which the respective ridge extends) (e.g., in a direction perpendicular to a wide sidewall of a rectangular frame of the double-ridged waveguide structure) of the at least one of the third and fourth ridges decreases along its extension towards the radiating aperture (e.g., wherein at least one of the third and fourth ridges terminates at the elevation tapering). In other words, the third and fourth ridges may be tapered in the plane of waveguide/polarizer narrow wall.

It has been recognized that such tapering of the third and fourth ridge may improve impedance matching and radiation characteristics.

According to an embodiment, at least one of the third and fourth ridges comprises a second tapering (e.g., a continuous tapering) wherein a width (e.g., in a direction parallel to a width of the corresponding wide sidewall, or in a direction that is perpendicular to a middle line of the respective ridge) of the at least one of the third and fourth ridges decreases along its extension towards the radiating aperture.

It has been recognized that such tapering of the third and fourth ridge may improve impedance matching and radiation characteristics.

According to an embodiment, the double-ridged waveguide structure comprises a bend at which an extension direction of the double-ridged waveguide structure changes at least essentially by 90° (e.g., within a range of $\pm 5^\circ$) (e.g., wherein the bend comprises a stepwise tapering).

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The bend may allow for a more compact routing and easy fabrication of the double-ridged waveguide and low profile (or height) of the antenna body.

10 According to an embodiment, the antenna device comprises an insert structure (e.g., comprising or formed from aluminium) (e.g., a separate workpiece) comprising the circular polarization antenna structure (and also the rectangular frame), and at least a first housing portion (e.g., comprising or formed from aluminium) (e.g., with a height (e.g., parallel to the axis of the double-ridged waveguide structure) of 10.5mm) in which at least a portion of the
15 double-ridged waveguide structure is formed, wherein the first housing portion comprises an (e.g., cylindrical) opening configured to receive the insert structure (e.g., wherein the insert structure is attached or attachable to the first housing, e.g., by screws).

The insert structure and the first housing portion can be fabricated separately, which may
20 facilitate fabrication and/or allow more complex structures. Furthermore, different designs of insert structures (e.g., with different radiation characteristics) and first housing portions may be combined more easily, which may facilitate adapting to different operation requirements.

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According to an aspect of the invention, an automated test equipment is provided, comprising the antenna device as described herein, wherein the automated test equipment is configured to test (e.g., in a near field of) a device under test (e.g., in a test socket) using the antenna device.

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The automated test equipment benefits from the aforementioned advantages such as increased bandwidth and improved axial ratio performance and may therefore have improved testing accuracy. The automated test equipment may optionally be supplemented by any of the features, functionalities and details

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Brief Description of the Drawings

The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, various embodiments of the invention are described with reference to the following drawings, in which:

Fig. 1A shows a schematic view of an example of an antenna device;

10 Fig. 1B shows a perspective view of an example of a ridge structure;

Fig. 2A shows a perspective view of another example of an antenna device;

15 Fig. 2B shows a cross-sectional view of the antenna device shown in Fig. 2A;

Fig. 3A shows a perspective view of another example of an antenna device;

Fig. 3B shows a cross-sectional view of the antenna device shown in Fig. 3A;

20 Fig. 4A shows a schematic cross section of an example of a plurality of corrugations, which can be used in embodiments of the invention;

Fig. 4B shows results of a simulation of an axial ratio (in dB) for different antenna devices;

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Fig. 5A shows a simulation result of an electric field pattern at the radiating aperture of an antenna device without corrugations at an operation frequency of 24 GHz;

30 Fig. 5B shows a simulation result of an electric field pattern at the radiating aperture of the antenna device of Fig. 5A at an operation frequency of 53 GHz;

Fig. 6A shows a simulation result of an electric field pattern at the radiating aperture of an antenna device with corrugations at an operation frequency of 24 GHz;

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- Fig. 6B shows a simulation result of an electric field pattern at the radiating aperture the antenna device of Fig. 6A at an operation frequency of 53 GHz;
- 5 Fig. 7A shows a perspective view of another example of an antenna device;
- Fig. 7B shows results of a simulation of a reflection coefficient in dB of the antenna device shown in Fig. 7A over a frequency bandwidth of 20 to 60 GHz;
- 10 Fig. 8A shows results of a simulation of an electric field pattern in the antenna device shown in Fig. 7A at an operation frequency of 24 GHz;
- Fig. 8B shows results of a simulation of an electric field pattern in the antenna device shown in Fig. 7A at an operation frequency of 29.5 GHz;
- 15 Fig. 8C shows results of a simulation of an electric field pattern in the antenna device shown in Fig. 7A at an operation frequency of 37 GHz;
- Fig. 9 shows an exploded-view drawing of an example of an antenna device;
- 20 Fig. 10 shows an exploded-view drawing of the antenna device from a different viewing angle than Fig. 9;
- Fig. 11A shows a perspective view of an opening of the antenna device shown in Fig. 9;
- 25 Fig. 11B shows a perspective view of an insert structure of the antenna device shown in Fig. 9;
- Fig. 12A shows a perspective view of an example of an antenna device;
- 30 Fig. 12B shows a perspective view of the antenna device from a different perspective than Fig. 12A;
- Fig. 13A shows a perspective view of the antenna device from a different perspective;
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- Fig. 13B shows a schematic view of a wireframe model of the antenna device that shows inner structures of the antenna device;
- 5 Fig. 14A shows results of simulations of a gain and return loss of the antenna device for the reception of differently polarized radiation;
- Fig. 14B shows results of a simulation of a far-field pattern of the antenna device;
- 10 Fig. 15A shows results of a simulation of a far-field pattern of the antenna device at a frequency of 24Gz;
- Fig. 15B shows results of a simulation of a far-field pattern of the antenna device at a frequency of 37GHz;
- 15 Fig. 15C shows results of a simulation of a far-field pattern of the antenna device at a frequency of 53Gz;
- Fig. 15D shows results of a simulation of axial ratio performances of two antenna devices;
- 20 Fig. 16A shows a perspective view of a first housing and an example of dimensions that may be particularly relevant for fabrication tolerances;
- Fig. 16B shows a perspective view of an insert structure and an example of dimensions that may be particularly relevant for fabrication tolerances;
- 25 Fig. 16C shows a result of simulations of a scattering parameter S_{11} deviation over fabrication tolerances shown in Figs. 16A, B;
- 30 Fig. 16D shows a result of simulations of an axial ratio deviation over fabrication tolerances shown in Figs. 16A, B;
- Fig. 17A shows a perspective view of an example of an antenna device with an adapter device;
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- Fig. 17B shows results of a simulation of return loss of the antenna device shown in Fig. 17A with and without adapter device;
- 5 Fig. 18 shows a schematic cross section of an example of an automated test equipment;
- Fig. 19 shows a perspective view of an automated test equipment with a carrier structure a signal receiver and/or signal generator;
- 10 Fig. 20 shows a close-up view of the automated test equipment shown in Fig. 19 in an assembled configuration;
- Fig. 21 shows a close-up view of the automated test equipment in a disassembled configuration, wherein an antenna device is detached from an device-under-test socket;
- 15 Fig. 22 shows a close-up view of the automated test equipment of Fig. 21, wherein an antenna cover is attached to the antenna device; and
- 20 Fig. 23 shows a perspective view of an example of an insert structure.

Detailed Description of the Embodiments

- 25 Equal or equivalent elements or elements with equal or equivalent functionality are denoted in the following description by equal or equivalent reference numerals even if occurring in different figures.

In the following description, a plurality of details is set forth to provide a more throughout
30 explanation of embodiments of the present invention. However, it will be apparent to those skilled in the art that embodiments of the present invention may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form rather than in detail in order to avoid obscuring embodiments of the present invention. In addition, features of the different embodiments described herein may optionally
35 be combined with each other, unless specifically noted otherwise.

In the drawings, dashed lines indicate lines that would be obscured by other structures features such as lines within a cavity (e.g., a waveguide).

Fig. 1A shows a schematic view of an example of an antenna device 100.

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The antenna device 100 comprises a double-ridged waveguide structure 110 with a first ridge 112a and a second ridge 112b and a circular polarization antenna structure 120 coupled to the double-ridged waveguide 110 and extending between the double-ridged waveguide structure and a radiating aperture 130 of the antenna device 100. It should be noted that the circular polarization antenna structure is shown very schematically in Fig. 1A, and that the circular polarization antenna structure may actually comprise a significantly different physical shape (e.g. a rounded shape or a round shape). Also, it should be noted that a rounded cavity, which may optionally surround the antenna structure shown in Fig.1, is intentionally omitted in Fig. 1A for the sake of simplicity.

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The circular polarization antenna structure 120 (e.g., an antenna polarizer) comprises a third ridge 122a having a first curved extension and transitioning into the first ridge 112a and a fourth ridge 122b having a second curved extension different from the first curved extension and transitioning into the second ridge 122b.

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In the example shown in Fig. 1A, the first curved extension of the third ridge 122a and the second curved extension of the fourth ridge 122b are arranged along different parallel and spaced apart (imaginary or virtual) planes (e.g., planes parallel to the x-direction and z-direction or, worded differently, planes parallel to an x-z-plane), wherein the first curved extension and the second curved extension bend away towards opposite directions from the (common) direction of the first ridge 112a and of the second ridge 112b (when extending outwardly from the double-ridged waveguide structure). In the example shown in Fig. 1A, the first and second ridges 112a, b extend in x-direction. The first and second ridges 112a, b transition into the third and fourth ridges 122a, b, which initially (also) extend in the x-direction. However, the third ridge 122a gradually bends (at least partially) towards a negative z-direction, whereas the fourth ridge 122b gradually bends (at least partially) towards a positive z-direction.

In the example shown in Fig. 1A, the double-ridged waveguide has a rectangular frame with a first wide sidewall 114a (e.g. parallel to an x-z-plane) and a second wide sidewall 114b (e.g. parallel to the x-z-plane and parallel to the first wide sidewall) that are wider than a first

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narrow sidewall 114c (e.g. parallel to an x-y-plane) and a second narrow sidewall 114d (e.g. parallel to the x-y-plane and parallel to the first narrow sidewall) .

5 The first curved extension of the third ridge 122a may be arranged along a plane which is parallel to the first wide sidewall 114a of the double-ridged waveguide structure 110 (or by a first “broad” sidewall of the double-ridged waveguide structure 110) on which the first ridge 112a is arranged (such that the third ridge 122a lies between a plane defining the first wide sidewall 114a of the double-ridged waveguide 110 carrying the first ridge 112a and a plane defining an inner surface of the first ridge 112a), and the second curved extension of the
10 fourth ridge 122b may be arranged along a plane which is defined by second wide sidewall 114b of the double-ridged waveguide structure 110 (or by a second “broad” sidewall of the double-ridged waveguide structure 110) on which the second ridge 112b is arranged (such that the fourth ridge 122b lies between a plane defining a second wide sidewall 114b of the double-ridged waveguide structure 110 carrying the second ridge 112b and a plane defining
15 an inner surface of the second ridge 112b).

The rectangular frame of the double-ridged waveguide structure 110 may preferably have an oblong rectangular shape or (e.g. in some special cases) a square shape. Alternatively, (e.g. in some special cases) the double-ridged waveguide may have a different frame
20 shape, for example with a circular, elliptical, or polygonal cross-section.

The circular polarization antenna structure 120, or a part thereof, may, for example, comprise a rectangular frame (e.g., as seen in Fig. 1A) with a first wide sidewall structure 124a and a second wide sidewall structure 124b, wherein the first wide sidewall structure 124a
25 and the second wide sidewall structure 124b are wider than a first and second narrow sidewall structure 124c, d. The third ridge 122a and the fourth ridge 122b are, for example, arranged in the rectangular frame. In the example shown in Fig. 1A, the third ridge 122a is arranged along the first sidewall structure 124a and the fourth ridge 122b is arranged along the second sidewall structure 124b. The rectangular frame of the circular polarization antenna structure 120 may, for example, act as a polarizer. The first narrow sidewall structure 124c and the second narrow sidewall structure 124d may, for example, be closed structures without any openings. Alternatively, the circular polarization antenna structure 120 may have a different frame shape with a circular, elliptical, or polygonal cross-section. The rectangular frame may, for example, be assembled using a plurality of slices (e.g. layer structures)
30 (e.g. metallic parts) (e.g. using three to four slices).

In the example shown in Fig. 1A, the frame of the double-ridged waveguide structure 110 and the frame of the circular polarization antenna structure 120 have (at least essentially) an identical cross-section. Alternatively, frames may have different cross-sections. For example, the rectangular frame of the circular polarization antenna structure 120 may comprise (or form) a widened (or widening) continuation of the double-ridged waveguide structure 120 (e.g., wherein the frame is widened or widening along a width direction of the first and second wide sidewall structures 124a, b and/or a width direction of the first and second narrow sidewall structure 124c, d).

In the example shown in Fig. 1A, the first curved extension and the second curved extension are axially symmetric to an axis 116 of the double-ridged waveguide structure 110 and of the circular polarization antenna structure 120 (e.g., point symmetric relative to the axis; e.g., symmetric according to a reflection by two mirror planes that are arranged perpendicular to each other, wherein each mirror plane comprises the axis). For example, the first curved extension has a rotational symmetry of 180 degrees (e.g., within a tolerance of -10 degrees and +10 degrees) around the axis of the double-ridged waveguide structure relative to the second curved extension. In other words, for example, one curved extension (e.g. the second curved extension) is provided by a 180 degrees rotation of another one (e.g. of the first curved extension), around the double ridged waveguide's axis.

Therefore, for example, the first curved extension in Fig. 1A bends in the negative z-direction to the same degree as the second curved extension bends in the positive z-direction.

Alternatively, in some implementations, the first and second curved extensions are not axially symmetric. For example, the first curved extension may have a more pronounced bending behaviour than the second curved extension (or vice versa).

The third ridge 122a and the fourth ridge 122b may be configured to rotate a direction of an electrical field, which is present between the first ridge and the second ridge, when a wave is traveling from the double ridged waveguide structure 110 toward a radiating aperture 130 of the antenna device 100 (and or vice versa). Consequently, a circular polarization electromagnetic wave may be excited.

The antenna device 100 (optionally including a main body that may comprise two or more housing portions) may, for example, be formed entirely from metal (e.g., aluminium and/or

steel). However, different implementations are also possible, e.g. using plastic or any other synthetic material, wherein one or more surfaces may be metallized.

However, it should be noted that the antenna device of Fig. 1A may optionally be supplemented by any of the features, functionalities and details disclosed herein.

Fig. 1B shows a perspective view of an example of a ridge structure 121. The ridge structure 121 shown in Fig. 1B (or alternative embodiments) may be implemented in any antenna device 100 disclosed herein. A double-ridged waveguide 110 and a circular polarization structure 120 are indicated in dashed lines so as to not obstruct a view to the ridge structure 121.

The ridge structure 121 comprises the first ridge 112a, the second ridge 112b, the third ridge 122a, and the fourth ridge 122b. In the example shown in Fig. 1B, the third and fourth ridges 122a, b have a first tapering 123b (e.g. a tapering in the plane of waveguide/polarizer narrow wall, or a tapering in the plane orthogonal to the waveguide/polarizer broad wall, in Fig. 1B parallel to the y-axis), wherein a thickness (e.g., in a direction perpendicular to a surface from which the respective ridge extends, e.g., in a direction perpendicular to a wide sidewall of a rectangular frame of the double-ridged waveguide structure, e.g., in the y-direction) of each of the third and fourth ridges 122a, b decreases along its extension towards the radiating aperture 130. The third and fourth ridges 122a, b have second tapering 123a wherein a width (e.g., in a direction parallel to a width of the corresponding wide sidewall, or in a direction that is perpendicular to a middle line of the respective ridge; e.g., parallel to the z-direction) of each of the third and fourth ridges 122a, b decreases along its extension towards the radiating aperture 130. Alternatively, at least one of the third and fourth ridge 122a, b has only one of the first and second tapering 123a, b. Further alternatively, the at least one of the third and fourth ridge 122a, b has no tapering.

Fig. 2A shows a perspective view of another example of an antenna device 200. The antenna device 200 comprises a double-ridged waveguide structure (not shown in Fig. 2A) and a circular polarization antenna structure 220 (e.g., polarizer) with a third and fourth ridge 222a, b.

The circular polarization antenna structure 220 has a rectangular frame with a first wide sidewall structure 224a and a second wide sidewall structure 224b, wherein the third ridge

222a and the fourth ridge 224b are respectively arranged on the first and second wide sidewall structure 224a, b in the rectangular frame.

5 The first wide sidewall structure 224a has a first opening 226a (e.g., slot or an opening widening/broadening towards the radiating aperture of the antenna device), and the second wide sidewall structure 224b has a second opening 226b (e.g., slot or an opening widening/broadening towards the radiating aperture of the antenna device), wherein the first opening 226a extends (e.g. in a continuously broadening manner) fully towards the radiating aperture 230, and wherein the second opening 226b extends (e.g. in a continuously broadening manner) fully towards the radiating aperture 230. The first and second openings 226a, b may be arranged offset relative to each other in a direction parallel to the first and second wide sidewall structure 224a, b (and perpendicular to an axis of the double-ridged waveguide) (e.g., as shown in Fig. 2A). The first and second openings 226a, b may be formed by cuts or by cutouts in the rectangular frame of the circular polarization antenna structure 220.

15 In the example shown in Fig. 2A, the first opening 226a and the second opening 226b are axially symmetric or at least essentially axially symmetric (e.g., within a tolerance of -20% and +20%, or with a tolerance of -10% and +10%, or with a tolerance that is determined by manufacturing tolerances, wherein the tolerance may, for example, relate to dimensions of the opening) with respect to an axis of the double-ridged waveguide structure and/or with respect to an axis of the circular polarization antenna structure 220 (e.g., point symmetric relative to the axis) (wherein the axis of the double-ridged waveguide structure and the axis of the circular polarization antenna structure may, in some embodiments, coincide).

25 Alternatively, in some embodiments, the first and second openings 226a, b are not axially symmetric. For example, the first opening 226a may be larger than the second opening 226b (or vice versa).

30 The third ridge 222a extends at least partly along an edge of the first opening 226a, and the fourth ridge 222b extends at least partly along an edge of the second opening 226b (e.g., such that a part of a side surface of the third ridge is arranged flush with a surface of the first opening and such that a part of a side surface of the fourth ridge is arranged flush with a surface of the second opening). Alternatively, at least one of the ridges 222a, b may be arranged spatially separate from its respective opening 226a, b.

The antenna device 200 comprises a main body 240 and an insert structure 242. The insert structure 242 comprises or is formed by the rectangular frame of the circular polarization antenna structure 220 such that the rectangular frame (or the insert structure 242) is a separate workpiece. The insert structure 242 is inserted or configured to be inserted into the main body 240 such that the circular polarization antenna structure 220 is arranged partially inside the main body 240. The circular polarization antenna structure 220 (e.g., a rectangular frame thereof) extends partially (e.g., by at least essentially 3.65 mm) beyond a surface 246 (e.g. a surface on a radiating side of the antenna device 200) of the main body 240.

The main body 240 comprises a rounded recess 248. The rounded recess 248 may generally comprise a cylindrical or conical shape. However, as shown in Fig. 2A, the rounded recess 248 may have additional structural features such as a further recesses with a rectangular shape configured to receive the insert structure 242. The circular or conical portion of the rounded recess 248 may, for example, have a diameter of 9.6mm or may, for example, have a diameter between 7mm and 12mm or between 9 mm and 10mm. The main body may, for example, have a depth (e.g., in x-direction) of 10.5mm or may, for example, have a depth between 8mm and 13mm or between 10mm and 11mm.

The rectangular frame with the first sidewall structure and the second sidewall structure 224a, b is arranged in a central region of the rounded recess 248. There is an electromagnetic coupling between an inner region of the rectangular frame and a first outer rounded region 249a of the rounded recess 248 through the first opening 226a in the first sidewall structure 224a, and there is an electromagnetic coupling between the inner region of the rectangular frame and a second outer rounded region 249b of the rounded recess 248 through the second opening 226b in the second sidewall structure 224b. Due to the widening of the first and second openings 226a, b, the coupling (or the strength of the coupling) may increase towards the radiating aperture 230.

For example, the first and second opening 226a, b in the first and second sidewall structure 224a, b widen towards the radiating aperture 230 of the antenna device 200, for example such that a width of the first and second openings 226a, b reaches at least 60 percent or at least 70 percent of a diameter of the rounded recess 248 in a proximity of the radiating aperture 230.

Fig. 2B shows a cross-sectional view of the antenna device 200 shown in Fig. 2A. The cross-section intersects the double-ridged waveguide structure 210 and the circular polarization antenna structure 220 (wherein a sectional plane of the cross-section is arranged parallel to the wide sidewalls of the double-ridged waveguide structure 210 and the circular polarization antenna structure 220).

The double-ridged waveguide structure 210 comprises a second ridge 212b and the circular polarization antenna structure 220 comprises a fourth ridge 222b, wherein the second ridge 212b transitions into the fourth ridge 222b. Similarly, the double-ridged waveguide structure 210 comprises a first ridge that transitions into a third ridge of the circular polarization antenna structure 220, but the first and third ridge are not depicted in Fig. 2B.

In the example shown in Fig. 2B, the rectangular frame of the circular polarization antenna structure 220 comprises a widened continuation of the double-ridged waveguide structure 210. To this end, the frame of the circular polarization antenna structure 220 comprises a widening 234, where a cross-sectional area of circular polarization antenna structure increases when compared to a cross-sectional area of the double-ridged waveguide structure. The widening 234 is arranged along the extension of the circular polarization antenna structure 220. Alternatively, the widening 234 may be arranged at an interface between the double-ridged waveguide structure 210 and the circular polarization antenna structure 220 or along an extension of the double-ridged waveguide structure 210. The widening 234 shown in Fig. 2B comprises a step. Alternatively or additionally, the widening 234 may comprise a continuous tapering. The extension of the frame may increase only in a direction parallel to the wide sidewalls (as shown in Fig. 2B). Alternatively or additionally the frame may increase in a direction parallel to the narrow sidewalls or in both directions.

The first and/or second opening 226b extends through a part of the extension of the circular polarization antenna structure 220. Alternatively, the first and/or second opening 226b may extend through the entire length of the circular polarization antenna structure 220 and optionally extend into the double-ridged waveguide structure 210.

For example, the second opening 226b (and optionally also the first opening) has a convex shape at one side 228a and a concave shape at another side 228b (e.g., in an imaginary (virtual) plane parallel the corresponding opening). The convex shape may, for example, be formed according to a hyperbolic formula or equation or according to an elliptic formula or equation (e.g., according to an elliptical formula or according to a hyperbolic formula). In

the example shown in Fig. 2B, the concave shape is, for example, shaped according to an exponential formula (e.g., $z=e^{ax+b}+c$ with coordinates x and z and parameters a , b , and c) and the convex shape is shaped according to a hyperbolic formula (e.g., $z=a/(x+b)+c$ with coordinates x and z and parameters a , b and c). Alternatively, the convex shape may be
5 shaped according to exponential formula and the concave shape may be shaped according to a hyperbolic formula. The convex and concave shapes may, for example, be connected by a straight edge (as shown in Fig. 2B), by a rounded edge or intersect at an angle.

The third ridge 222a may, for example, extend at least partly along an edge of the first
10 opening 226a, and the fourth ridge 222b may, for example, extend at least partly along an edge of the second opening 226b (e.g., such that a part of a side surface of the third and fourth ridge 222a, b is arranged flush with a surface of the first and second opening 226a, b, respectively). Alternatively, the third and fourth ridges 222a, b may be arranged separate from the first and second openings 226a, b.

15 Fig. 23 shows a perspective view of an example of an insert structure 2342.

The insert structure 2342 has a first opening 2326a and a second opening 2326b. The first opening 2326a has convex shape at one side 2328c and a concave shape at another side
20 2328d. The second opening 2326a has convex shape at one side 2328a and a concave shape at another side 2328b. The convex shape of the one side 2328c of the first opening 2326a is shaped according to a hyperbolic formula $y=a/(x+b)+c$ with y being a function dependent on x (e.g., the convex side is shaped in hyperbola). The concave shape of the other side 2328d of the first opening 2326a is shaped according to an exponential formula
25 $y=e^{ax+b}+c$ with y being a function dependent on x (e.g., the concave is shaped in exponential profile).

In the example shown in Fig. 23, the one side 2328c of the first opening 2326a and the one side 2328a of the second opening 2326b have the same shape (e.g., a convex shape according to a hyperbolic formula $y=a/(x+b)+c$ with y being a function dependent on x) that is
30 mirrored along a plane parallel to narrow sides of the insert structure 2342. The other side 2328d of the first opening 2326a and the other side 2328b of the second opening 2326a have the same shape (e.g., a concave shape according to an exponential formula $y=e^{ax+b}+c$ with y being a function dependent on x) that is mirrored along a plane parallel to narrow
35 sides of the insert structure 2342. As a result, the first and second openings 2326a, b may

be axially symmetric with respect to an (common) axis 2316 of the double-ridged waveguide structure and of the circular polarization antenna structure.

Alternatively, the insert structure 2342 may have a mirrored structure (e.g., mirrored along a plane parallel to narrow sides of the insert structure 2342) compared to the one shown in Fig. 23, wherein sides with the convex shapes described above are concave shapes and the concave shapes described above have convex shapes. Further alternatively, the one sides 2328a, c may have different shapes and/or the other sides 2328b, d may have different shapes.

The insert structure 2342 (e.g., at least the sides 2328a-d described herein) may be implemented in any antenna device described herein (e.g., in any of the antenna devices 100, 200, 300, 700, 900, 1200, 1700, or 1800 described herein).

It should be noted that the antenna device 200 according to Fig. 2 may optionally be supplemented by any of the features, functionalities and details disclosed herein, both individually and taken in combination.

Fig. 3A shows a perspective view of another example of an antenna device 300. The antenna device 300 comprises a double-ridged waveguide structure (not shown in Fig. 3A) and a circular polarization antenna structure 320 (e.g., polarizer) with a third and fourth ridge 322a, b. The double-ridged waveguide structure and the circular polarization antenna structure 320 of the antenna device 300 may, for example, be similar to the respective double-ridged waveguide structure and circular polarization antenna structure of the antenna devices 100, 200. However, in addition to the features of the antenna devices 100, 200, the antenna device may 300 further comprise corrugations.

Fig. 3B shows a cross-sectional view of the antenna device 300 shown in Fig. 3A. The cross-section intersects the double-ridged waveguide structure 310 and the circular polarization antenna structure 320 (wherein a sectional plane of the cross-section is arranged parallel to the wide sidewalls of the double-ridged waveguide structure 310 and the circular polarization antenna structure 320).

Fig. 3B only shows the fourth ridge 322b and a second opening 326b. However, the antenna device 300 also comprises a third ridge 322a and a first opening, wherein the third ridge 322a and the fourth ridge 322b are, for example, axially symmetric with respect to an (common) axis of the double-ridged waveguide structure 310 and of the circular polarization antenna structure 320. Therefore, the third ridge 322a and the first opening may be shaped similar or identical (taking into account the axial symmetry) when compared to the fourth ridge 322b and the second opening. Alternatively, the third and fourth ridges may be shaped differently.

The fourth ridge 322b extends only along a part of a way from the double-ridged waveguide structure 310 towards the radiating aperture 330 (and ends before the respective ridge reaches the radiating aperture 330). In the example shown in Fig. 3B, the fourth ridge 322b extends only along approximately 65% of the way from the double-ridged waveguide structure 310 towards the radiating aperture 330. Alternatively, the fourth ridge 322b may extend any other portion such as 33%, 50%, 75%, or 90% of the way towards the radiating aperture 330 (e.g. with a tolerance of +/-10%).

The fourth ridge 322b comprise a first tapering 323b (e.g. a tapering in the plane of waveguide/polarizer narrow wall, or a tapering in the plane orthogonal to the waveguide/polarizer broad wall), wherein a thickness (e.g., in a direction perpendicular to a surface from which the respective ridge extends) (e.g., in a direction perpendicular to a wide sidewall of a rectangular frame of the double-ridged waveguide structure) (e.g., in the y-direction) of the fourth ridge 322b decreases along its extension towards the radiating aperture 330. The fourth ridge 322b terminates at the first tapering 323b. Alternatively, the fourth ridge 322b may continue extending beyond the first tapering 323b.

The first tapering 323b may be or may comprise a stepped tapering. In the example shown in Fig. 3B, the first tapering 323b comprises two steps. Alternatively, the first tapering 323b may comprise any other number of steps such as one, three, four, five, or more steps. The steps may comprise surfaces that are arranged at least essentially parallel to the radiating aperture 330 (e.g. perpendicular to an (common) axis of the double-ridged waveguide structure 310 and of the circular polarization antenna structure 320).

The fourth ridge 322b comprises a second tapering wherein a width (e.g., in a direction parallel to a width of the corresponding wide sidewall, or in a direction that is perpendicular

to a middle line of the respective ridge; e.g., parallel to the z-direction) of the fourth ridge 322b decreases along its extension towards the radiating aperture 330.

In the example shown in Fig. 3B the fourth ridge 322b has a continuous second tapering along its (entire) extension in the circular polarization antenna structure 320. Alternatively, the fourth ridge 322b may have a continuous second tapering along a part of its extension (e.g., a first or second half of its extension). Alternatively or additionally, the second tapering may have a step wise tapering. In the example shown in Fig. 3B, the width of the forth ridge 322b within the circular polarization antenna structure 320 is reduced by approximately 50%. However, the width may be reduced by any other amount such as 33%, 50%, 75%, or 90% of its initial width (e.g., at the transition between the double-ridged waveguide structure 310 and the circular polarization antenna structure 320)(e.g. with a tolerance of +/- 10%).

The antenna device 300 comprises three corrugations 350a, b, c, which may, for example, circularly surround the rounded recess. Alternatively, the antenna device 300 may comprise any other number of corrugations 350 such as one, two, four, five, or more. The corrugations 350a, b, c may be periodic (e.g., having at least essentially equal dimensions and/or at least essentially equal distances). The corrugations 350a, b, c may, for example, have a circular shape. Alternatively, the corrugations 350a, b, c may have other shapes such as an elliptical, rectangular, square, or polygonal shape. For example, in some embodiments, at least one of the corrugations 350a, b, c may extend only partially around the circular polarization antenna structure 320. Alternatively, at least one of the corrugations 350a, b, c may fully extend around the circular polarization antenna structure 320 (as shown in Fig. 3A), or even all corrugations may fully extend around the circular polarization antenna structure 320 .

The corrugations (or at least a part of the corrugations) may be formed on a surface 346 of a main body 340 of the antenna device 300. The corrugations (or at least a part of the corrugations) may be formed by elevations on and/or by recesses in the surface 346 of the main body 340. In the example shown in Fig. 3A, a part of the corrugations 350a, c, b is part of an insert structure 342 that comprises the circular polarization antenna structure 320. The insert structure 342 may have (at least essentially) a rectangular shape (e.g., with a lateral extension (in a direction perpendicular to the axis of the insert structure) that is equal to the diameter of the largest corrugation of the insert structure 342) However, the insert structure 342 may have a different shape and may, for example, comprise the corrugations in their entirety.

The rectangular frame of the circular polarization antenna structure 320 protrudes over the corrugations 350a, b, c arranged on the surface (e.g., of the main body 340 and/or the insert structure 342) surrounding (e.g. located adjacent to) an aperture (e.g. a radiating aperture) 330 of the circular polarization antenna structure 320. Alternatively, the rectangular frame of the circular polarization antenna structure 320 may be arranged recessed under the corrugations 350a, b, c arranged on the surface.

In the example shown in Figs. 3A, B, an inner surface of the (innermost) corrugation 350a is arranged flush with an inner surface of a rounded recess 348. Furthermore, an outer surface of the (innermost) corrugation 350a is arranged flush with an outer surface of the frame of the circular polarization antenna structure 320. Thus, for example, a recess between the outer surface of the innermost corrugation 350a and an inner surface of a next corrugation 350b may have a circular shape with a (substantially) constant gap width. As a result, return loss may be improved. Alternatively, at least one of the inner and outer surface of the (innermost) corrugation 350a is arranged spatially separate from the rounded recess 348 and/or the frame of the circular polarization antenna structure 320.

It should be noted that the antenna device 300 according to Fig. 3 may optionally be supplemented by any of the features, functionalities and details disclosed herein, both individually and taken in combination.

Fig. 4A shows a schematic cross section of an example of a plurality of corrugations 450 (disregarding a rounded recess and/or surface of a main body for the sake of simplicity), which can be used in embodiments of the invention. For example, the corrugations 450 may be used in combination with any of the antenna devices disclosed herein. As an example, the corrugations 450a, 450b, 450c may correspond to (or take the place of) the corrugations 350a, 350b, 350c.

Antenna devices with corrugations 450 may form “aperture matched horns” (or an aperture horn) or “choke horns” (or a choke horn) and may be used, for example in satellite communications and other applications as excellent circularly polarized radiators. Moreover, the corrugations also improve antenna radiation characteristics when used in combination with the antenna devices disclosed herein. The corrugations may, for example, provide

good antenna characteristics that are desired in testing applications. Accordingly, the corrugations are well suited for application in antennas used in combination with automated test equipment.

- 5 The corrugations may, for example, be formed by a milling process. For example grooves of the corrugations may be milled with a tool with a diameter of 1mm in a main body (e.g., top housing) of the antenna device.

10 The corrugations 450a, b, c may, for example, have a depth of at least essentially $\lambda_0/4$ (e.g. with a tolerance of +/-20% or +/-10%) and/or a width smaller than $\lambda_0/10$, wherein λ_0 defines a largest wavelength (e.g. a largest free space wavelength at a lowest frequency within a bandwidth of the antenna device), or a centre wavelength (e.g. a free space wavelength at a center frequency of an antenna bandwidth of the antenna device), a smallest wavelength of an operating bandwidth of the antenna device wavelength (e.g. a free space wavelength at a highest frequency of an antenna bandwidth of the antenna device) (e.g., λ_0 may be at
15 at least essentially 12.5mm, 7.8 mm or 5.7mm, corresponding to 24 Ghz, 38.5GHz, and 53GHz).

20 In the example shown in Fig. 4A, the corrugations 450a, b, c have a height d of at least essentially 3.0mm (e.g. with a tolerance of +/-20% or +/-10%), a wall thickness of at least essentially 0.7mm (e.g. with a tolerance of +/-20% or +/-10%), and a radial interval w (e.g., perpendicular to an axial direction of the double-ridged waveguide structure 310 and/or the circular polarization antenna structure 320) between two corrugations 350a, b, c of at least essentially 1.0mm (e.g. with a tolerance of +/-20% or +/-10%). Alternatively, at least one of
25 these three dimensions may be different as described herein.

Fig. 4B shows results of a simulation of an axial ratio (in dB) for an antenna device (e.g. according to Fig. 1A or according to Fig. 2A or according to Fig 3A) according to a first
30 antenna design with two corrugations (dark continuous line 476), an antenna device according to a second antenna design without corrugations (dark dashed line 477), and an antenna device according to a third antenna design without corrugations (bright continuous line 478). A horizontal abscissa shows a frequency in Gigahertz, and a vertical ordinate 456 shows an axial ratio (e.g. in decibel).

The simulations have been performed predominantly in a bandwidth between 24GHz (lower boundary of an antenna bandwidth) and 53GHz (upper boundary of the antenna bandwidth) as indicated by vertical lines. However, as can be seen in Fig 4B, the simulated values extend past said range.

5

When comparing the results of the antenna devices with and without corrugations, it can be seen that the corrugations result in a 3-dB axial ratio band being widened so as to better cover the desired frequency band of 24GHz to 53GHz. The antenna device with corrugations has a lower axial ratio at the lower and upper end of the bandwidth. The minimum axial ratio of the antenna device without corrugations (height of 17mm) is 4-5-dB.

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It can be seen that the usage of corrugations in combination with the antenna device is advantageous, but not essential.

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Fig. 5A shows a simulation result of an electric field pattern in the radiating aperture at an antenna device without corrugations at an operation frequency of 24 GHz.

Fig. 5B shows a simulation result of an electric field pattern at the radiating aperture of the antenna device of Fig. 5A at an operation frequency of 53 GHz.

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Fig. 6A shows a simulation result of an electric field pattern at the radiating aperture of an antenna device with corrugations at an operation frequency of 24 GHz.

Fig. 6B shows a simulation result of an electric field pattern at the radiating aperture of the antenna device of Fig. 6A at an operation frequency of 53 GHz.

25

It has been recognized that a radiation performance of antenna apertures or antenna elements placed on a relatively large metal plane may suffer from surface waves effects. These surface waves may, for example, propagate along E-plane direction, e.g., for linearly polarized antennas. In general, the surface waves may bring oscillations to a main lobe of a far field pattern, may increase sidelobes, back-fire radiation, and mutual coupling with adjacent antennas. In addition, cross-polarization performance and RL may degrade.

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In the simulations of circular polarization antenna structures, it has been found that surface waves may have a significant impact on axial ratio performance. Simulated field distributions at an antenna aperture plane are shown in Figs. 5A to 6B. Two period of (e.g., quarter-wave) corrugations are implemented in an antenna device (e.g. in an antenna device according to Fig. 1A, or in an antenna device according to Fig.2, or in an antenna device according to Fig. 3), which suppress surface waves as can be seen in Figs. 6A and B. It has been recognized that these corrugations (e.g., grooves) may, for example, reduce diffraction effects at edges of the aperture device (e.g., at the radiating aperture and/or the rounded recess) and associated cross-polarization components, so a symmetrical radiation pattern may be achieved with lower cross-polarization which may affect axial ratio parameter. When comparing the surface waves of the antenna device without and with corrugations, it can be seen that the surface waves are reduced for the antenna device with corrugations.

Fig. 7A shows a perspective view of another example of an antenna device 700. The antenna device 700 comprises a double-ridged waveguide structure (not shown in Fig. 7A) and a circular polarization antenna structure 720 (e.g., polarizer), for example with a third and fourth ridge (not shown in Fig. 7A).

The circular polarization antenna structure 720 and the double-ridged waveguide structure of the antenna device 700 may be implemented in the same manner like the corresponding components of the antenna devices 100, 200, 300

The antenna device 700 comprises a main body 740 with a surface 746. The circular polarization antenna structure 720 and its radiating aperture 730 are arranged such as to be recessed relative to the surface 746 of the main body 740. For example, the main body 740 may have a height of 17mm (e.g. with a tolerance of $\pm 20\%$ or $\pm 10\%$), the circular polarization antenna structure 720 may have a height of 16mm (e.g. with a tolerance of $\pm 20\%$ or $\pm 10\%$), and the double-ridged waveguide structure (or at least a portion of it that is arranged within the main body 740) may have a height of 0.5mm (e.g. with a tolerance of $\pm 20\%$ or $\pm 10\%$). As a result, the radiating aperture 730 of the circular polarization antenna structure 720 is recessed by 0.5mm (e.g. with a tolerance of $\pm 50\%$ or $\pm 20\%$ or $\pm 10\%$) (e.g., $17\text{mm} - 16\text{mm} - 0.5\text{mm} = 0.5\text{mm}$) relative to the surface 746 of the main body 740. However, the radiating aperture 730 (and/or the circular polarization antenna structure 720) may be recessed relative to the surface 746 of the main body 740 by any other height

difference such as 0.3mm, 0.75mm, 1.0mm, or 1.5mm (e.g. with a tolerance of +/-50% or +/-20% or +/-10%) (or, generally speaking, by any height in a range between 0.2mm and 2mm).

5 It is noted that in the example shown in Fig. 7A, the third and fourth ridges may, for example, extend only along a part of a way from the double-ridged waveguide structure towards the radiating aperture 740 (e.g., in a way as shown in Figs. 3A and B). As a result, the third and fourth ridges are, for example, not visible in Fig. 7A.

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It should be noted that the antenna device 700 according to Fig. 7 may optionally be supplemented by any of the features, functionalities and details disclosed herein.

Fig. 7B shows results of a simulation of a reflection coefficient in dB (antenna RL) of the
15 antenna device 700 shown in Fig. 7A over a frequency bandwidth of 20 to 60 GHz.

Fig. 8A shows results of a simulation of an electric field pattern in the antenna device 700 shown in Fig. 7A at an operation frequency of 24 GHz.

20 Fig. 8B shows results of a simulation of an electric field pattern in the antenna device 700 shown in Fig. 7A at an operation frequency of 29.5 GHz.

Fig. 8C shows results of a simulation of an electric field pattern in the antenna device 700 shown in Fig. 7A at an operation frequency of 37 GHz.

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Fig. 8B shows the formation of a cavity resonance. As a result, the reflection coefficient is increased, which can be observed as a peak at a frequency of 29.5 GHz in Fig. 7B. Depending on a size of a waveguide cavity (e.g., if a waveguide cavity size is appropriate), further resonances may occur, e.g., at frequencies 24 GHz and 37GHz shown in Fig. 8A
30 and C.

During the simulations it was observed that a cavity resonance may occur, whereas the frequency of the resonance may be determined by a waveguide size. A cavity resonance may cause distortions to a return loss and antenna radiation performance (e.g., a gain local
35 minimum). Such resonances should be avoided, especially in view of fabrication tolerances impact. It has been recognized that such resonances may be reduced by arranging the

circular polarization antenna structure such that it extends (at least) partially beyond the surface of the main body (e.g., as shown in Fig. 3A and B).

5 Fig. 9 shows an exploded-view drawing of an example of an antenna device 900, according to an embodiment of the present invention. The antenna device comprises an insert structure 942 comprising the circular polarization antenna structure 920. For example, the insert structure 942 may correspond to the insert structure 242 according to Fig. 2A, or the insert structure 942 may correspond to the insert structure 342 according to Fig. 3B. The circular polarization antenna structure 920 may, for example, correspond to the circular polarization antenna structure 120 of Fig. 1A, to circular polarization antenna structure 220 of Fig. 2A, to circular polarization antenna structure 320 of Fig. 3A, or to circular polarization antenna structure 720 of Fig. 7A.

15 The antenna device 900 comprises a first housing portion 944a in which, for example, at least a first portion of a double-ridged waveguide structure (not shown in Fig. 9) is formed, wherein the first housing portion 944a comprises an opening 945 configured to receive the insert structure 942 (and connected to the first portion of the double-ridged waveguide structure). The first housing portion 944 comprises a first waveguide part (not shown in Fig. 9 but shown at reference numeral 947a in Fig. 10) formed at a side opposite of the opening 945.

The antenna device 900 comprises a second housing portion 944b with a second waveguide part 947b complementing the first waveguide part 947a of the first housing portion 944a. The first and second housing portions 944a, b are configured to be connected into a combined configuration. In the combined configuration, the first waveguide part 947a and the second waveguide part 947b form a second portion 910b of the double-ridged waveguide structure. It should be noted that, for example, the first housing portion 944 (optionally together with the second housing portion 944b) may comprise the functionality of the main bodies 240, 340, of 740 shown in Figs. 2A, 3A, and 7A.

35 The double-ridged waveguide structure 910 comprises a bend (waveguide bend) 915 at which an extension direction of the double-ridged waveguide structure 910 changes at least essentially by 90° (e.g., within a range of $\pm 5^\circ$). The bend 915 may, for example, comprise a stepwise tapering (e.g., with two, three, four, or more steps).

The first housing portion 944a further comprises a third double-ridged waveguide portion 910c. In the combined configuration, the first, second and third double-ridged waveguide portions form the double-ridged waveguide of the antenna device 900. For example, the third waveguide portion 910c may end in a waveguide flange (e.g. a blind-mating waveguide flange), wherein said waveguide flange may be arranged on a same side (or surface) of the first housing portion like a radiating aperture of the antenna device. Such a configuration comprises a good manufacturability and is well-suited for a usage in a test equipment (e.g. an automated test equipment).

The first housing portion may comprise a plurality of screw holes, e.g. three first screw holes 960a-c, and the second housing portions 944a, b may optionally also comprise a plurality of screw holes, e.g. three first screw holes 960d-f. For example, the first screw holes 960a-f are configured to receive first screws 962a-c. To this end, at least one of the first screw holes 960a-f may be threaded. Alternatively, at least one of the first screws 962a-c may be tightened by nuts. In the example shown in Fig. 9, the antenna device 900 comprises six first screw holes 960a-f and three first screws 962a-c. Alternatively, the antenna device 900 may comprise any other number of first screw holes 960a-f and first screws 962a-c (e.g., with a ratio of two to one). For example, when the first screws 962a-c are inserted into the first screw holes 960, the first screws 962a-c may be configured to fasten the first housing portion 944a to the second housing portion 944b, thereby effectively mainlining the combined configuration. However, alternatively, different fastening means may be used to fix the first housing portion and the second housing portion together. Moreover, optionally, one or more alignment structures (alignment pins, mating surface structures, or the like) may be used to align the first housing portion and the second housing portion.

For example, the second housing portion 944b further comprises two second screw holes 964a, b. The first housing portion 944a comprises two second screw holes (not shown in Fig. 9) that align with the second screw holes 964a, b in the combined configuration.

For example, the first housing portion 944a further comprises third screw holes 968a, b configured to receive alignment pins (e.g. for aligning with a blind-mating waveguide flange) or third screws 969a, b. For example, the alignment pins or third screws 969a, b may allow aligning with a blind mating waveguide flange or fastening further attachments to the antenna device such as an adapter device configured to connect the double-ridged waveguide to a coaxial connector.

It is noted that, for example, at least one of the fastenings involving the first, second, third screws 962a-c, 966a, b, 969a, b may alternatively or additionally comprise other fastening elements (e.g., a clamp, a snap-in connection, a welding connection, an adhesive connection, or a magnet).

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It should be noted that the antenna device 900 may optionally be supplemented by any of the features, functionalities and details disclosed herein, both individually and taken in combination.

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Fig. 10 shows an exploded-view drawing of the antenna device 900 from a different viewing angle than Fig. 9A.

15 Fig. 10 shows an underside of the insert structure 942 and shows, for example, the first portion 910a of the double ridged waveguide structure (if the first portion 910a is a part of the insert structure 942). The insert structure 942 may comprise a portion of at least one of the first and second ridges 912a, b, which extend into the first housing portion 944a when the insert structure 942 is inserted into the first housing portion 942. As a result, for example,
20 the first and second ridges may be formed (only) partly in the first housing portion 944a or may not be formed at all in the first housing portion 944a.

For example, the first housing portion 944a comprises the first waveguide part 947a of the second waveguide portion 910b of the double ridged waveguide structure. The first waveguide part 947a is formed at a side opposite of the opening (not shown in Fig. 10) and
25 formed at a side facing the second housing portion 944b. Thus, the second waveguide portion 910b may, for example, extend along an interface between the first housing portion 944a and the second housing portion 944b and may, for example, be limited by the first waveguide part 947a and the second waveguide part 947b. In the example shown in Fig.
30 10, the first housing portion 944a comprises a bottom (surface), wherein the first waveguide part 947a comprises a ridge extending from a flat surface, which forms a top wall and ridge of the second waveguide portion 910b. In other words, the bottom of the first housing portion 944a serves as a top wall and the ridge of a feeding waveguide (e.g., the second waveguide portion 910b).

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In the examples shown in Fig. 9 and 10, the first waveguide part 947a is, for example, formed by (or comprises) a ridge extending from a flat surface and the second waveguide portion 947b is, for example, formed by (or comprises) a recess having a ridge. However, the second waveguide portion 910b may be separated differently into the first and second waveguide portions 947a, b (e.g., into two equal halves).

To conclude, any of the antenna devices 100, 200, 300 may, for example, be implemented using a structure as shown in Figs. 9 and 10 (or may be embedded in a structure as shown in Figs. 9 and 10). The structure of Figs. 9 and 10 allows for a cost-efficient manufacture and is well-useable in an automated test equipment.

Fig. 11A shows a perspective view of the opening 945 of the antenna device 900, which is arranged in a main body structure 940 (e.g., comprising or in form of the first housing portion 944a) which may, for example, correspond to the main body 240, 340, or 740 of the antenna devices 200, 300, or 700 of Figs. 1A, 2A, and 7A. The opening has a rounded (or round) recess 948 and a cuboid shaped recess 941. The rounded recess 948 and the cuboid shaped recess 941 may form or be a part of the opening 945. The rounded recess 948 and the cuboid shaped recess 941 intersect, for example such that an axis of symmetry of the rounded recess 948 and an axis of symmetry of the cuboid shaped recess 941 align (e.g. coincide). Furthermore the two axis of symmetry may, for example, align (e.g. coincide) with an axis of the first waveguide portion 910a.

The first portion 910a of the double-ridged waveguide structure may, for example, extend towards a bottom of the rounded recess 948 (or even through the bottom of the rounded recess 948, e.g. through an aperture in the main body structure). In the example shown in Fig. 11A, an aperture 979 in a bottom portion of the main body structure, through which the double-ridged waveguide structure extends, does not comprise ridges. Instead, the insert structure 942 comprises at least portions of the first and second ridge 912a, b of the first portion 910a of the double-ridged waveguide structure, when the insert structure 942 is arranged inside the opening 945 (e.g., the cuboid shaped recess 941). For example, the portions of the first and second ridge 912a,b, which are attached to the insert structure 942, reach into the aperture, for example, such that the aperture and the ridges 912a,b together form the double-ridged waveguide. Alternatively, at least a part of the first and second ridges 912a, b may be formed in the main body (or in the aperture).

The first housing portion 944a comprises, for example, two second screw holes 964c, d, which are arranged at a bottom of the opening 945 and extending through the first housing portion 944a. For example, the second screw holes 964c, d of the first housing portion 944a align with the second screw holes 964a, b of the second housing portion 944b when in the combined configuration (e.g. when the first housing portion 944a and the second housing portion 944b are aligned together). The insert structure 942 comprises, for example, two second screw holes 964e, f (see Fig. 10) that align with the second screw holes 964c, d of the first housing portion 944a, when the insert structure 942 is inserted into the opening 945. The second screw holes 964a, b of the second housing portion 944b are configured to receive two second screws 966a, b. Therefore, the second screws 966a, b are configured to fasten the insert structure 942 in the opening 945, when the insert structure 942 is inserted in the opening 945 and the first and second housing portions 944a, b are in the combined configuration. However, it should be noted that other solutions for a fastening of the insert structure 942 are also possible, such that the holes 964a,b,c,d,e,f and the screws 966amb may be fully or partly replaced.

The antenna device 900 comprises corrugations 950 that include corrugations 950a, b, c. The corrugations 950a, b, c are formed on or in a surface 912 of the first housing portion 944a. Alternatively, at least one of the corrugations 950a, b, c (or a part thereof) may be formed in a further insert structure that is inserted into an opening of the first housing structure 944a. In the example shown in Fig. 9 to 12B, the corrugations 950a, b, c are partly formed in or on the surface 912 of the first housing portion 944a and on or in the insert structure 942. Alternatively, at least one of the corrugations 950a, b, c may be formed entirely on or in the surface 912 of the first housing portion 944a or on or in the insert structure 942 (or a further insert structure).

The corrugations 950a, b, c may, for example, be realized (e.g., in regard to amount, shape, dimensions) as described herein (e.g., with reference to Figs. 3A to 6B).

Fig. 11B shows a perspective view of the insert structure 942 of the antenna device 900 shown in Fig. 9. The insert structure 942 is dimensioned such as to be insertable into the opening 945 (e.g., the cuboid shaped recess 941).

The insert structure 942 comprises (at least part of) the circular polarization antenna structure 920 with a radiating aperture 930 thereof. The circular polarization antenna structure

comprises a third ridge 922a having a first curved extension and transitioning into the first ridge 912a and a fourth ridge 922b having a second curved extension different from the first curved extension and transitioning into the second ridge 912b.

- 5 The circular polarization antenna structure 920 comprises a rectangular (or substantially rectangular) frame with a first (wide) sidewall structure 924a and a second sidewall structure 924b, wherein the first (wide) sidewall structure 924a has a first opening 926a and the second (wide) sidewall structure 924b has a second opening 926b. The first and second openings 926a, b extend towards the radiating aperture. The first and second sidewalls 924a, b
10 and the first and second openings 926a, b may be formed as described herein (e.g., with reference to Fig. 3A).

Fig. 12A shows a perspective view of an example of an antenna device 1200. The antenna
15 device 1200 may correspond to an assembled version of the antenna device 900.

The antenna device 1200 comprises a double-ridged waveguide structure 1210 (which may, for example, correspond to the double-ridged waveguide structure 910) with a first and a second ridge 1212a, b and a circular polarization antenna structure 1220 (which may, for
20 example, correspond to the circular polarization antenna structure 120, 220, 320, 720, or 920 of Figs. 1A, 2A, 3A, 7A, and 9A) coupled to the double-ridged waveguide 1210 and extending between the double-ridged waveguide structure 1210 and a radiating aperture 1230 of the antenna device 1200. The circular polarization antenna structure 1220 comprises a third ridge 1222a (which may, for example, correspond to the third ridge 922a)
25 having a first curved extension and transitioning into the first ridge 1212a and a fourth ridge (not shown in Fig. 12A) (which may, for example, correspond to the fourth ridge 922b) having a second curved extension different from the first curved extension and transitioning into the second ridge 1212b.

30 The antenna device 1200 comprises a first housing portion 1244a (which may, for example, correspond to the first housing portion 944a) and a second housing portion 1244b (which may, for example, correspond to the first housing portion 944b). The antenna device 1200 further comprises an insert structure 1242 (which may, for example, correspond to the insert structure 942) comprising the circular polarization antenna structure 1220.

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Fig. 12B shows a perspective view of the antenna device 1200 from a different perspective than Fig. 12A.

The antenna device 1200 comprises, for example, first screws 1262a-c, which are configured to attach the first housing portion 1244a to the second housing portion 1244b. In the example shown in Fig. 12, the antenna device 1200 comprises three first screws 1262a-c. However, the antenna device 1200 may comprise any other amount of first screws 1262a-c.

The antenna device 1200 comprises, for example, second screws 1266a, b configured to engage and fasten the insert structure 1242 inserted into the first housing portion 1244b.

As can be seen in Figs. 12A, B, the antenna device 1200 may, for example, comprise further openings. The further openings may be used for receiving further screws, and/or shafts (e.g., alignment shafts) and/or additional components and/or devices.

Fig. 13A shows a perspective view of the antenna device 1200 from a different perspective. From the viewing angle, the third and fourth ridges 1222a, b of the circular polarization antenna structure 1220 can be seen.

Fig. 13B shows a schematic view of a wireframe model of the antenna device 1200 that shows inner structures of the antenna device 1200.

The double-ridged waveguide structure 1210 has a first, second, and third portion 1210a, b, c.

The first portion 1210a of the double-ridged waveguide structure 1210 is coupled with the circular polarization antenna structure 1220. The first portion 1210a is coupled to the second portion 1210b at a 90° bend. The second portion 1210b extends in a plane perpendicular (e.g. with a tolerance of +/- 10 degree) to an axis of the first portion 1210a and to an axis of the frame of the circular polarization antenna structure 1220. The second portion 1210b may be routed within this plane. In the example shown in Fig. 13B, the second portions 1210b includes two bends. However, the second portion 1210b may be routed in any other way. The second portion 1210b is coupled to the third portion 1210c at a 90° bend. As a result, the first and third portion 1210c extend parallel relative to each other.

However, it should be noted that the antenna device shown in Figs. 9 to 13B may optionally be supplemented by any of the features, functionalities and details disclosed herein, both individually and taken in combination.

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Fig. 14A shows results of simulations of a gain and of a return loss of the antenna device 1200 for the transmission or reception of differently polarized radiation. It is noted that the performance is uniform in reception/transmission modes due to the reciprocity principle of a passive device.

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In the example shown in Fig. 14A, antenna gain, shown at reference numerals 1491a, varies in a 7-12 dBi range for left-hand (LH) circular polarization, whereas its cross polarization component (right-hand circular polarization, RHCP) does not (or not significantly) exceed -5 dBi (e.g., -12...-18 dB relative to cross polarization). Radiation with a right handed circular polarization (RHCPol, thin dashed line, shown at reference numeral 1491b) shows a gain between approximately -4 and -20 dBi.

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The geometry of the circular polarization antenna structure 1220 therefore is configured to predominantly receive and/or emit radiation with a left handed circular polarization. A circular polarization antenna structure 1220 with a mirrored arrangement of the third and fourth ridges (and the first and second openings, if provided) may be configured to predominantly receive and/or emit radiation with a right handed circular polarization. For example, the circular polarization antenna structure 1220 may be mirrored by a symmetry plane through the wide or narrow sidewall of the circular polarization antenna structure 1220. To conclude, a polarization characteristic of the antenna device can easily be adjusted.

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Return loss performance is >15 dB over a 24.25-53 GHz band. The simulations further show a gain between 0 and 10 dB for linear polarizations, in particular with a horizontal polarization (Hpol), a vertical polarization (Vpol), a first linear polarization rotated by +45° (+45pol) and a second linear polarization rotated by -45° (-45pol). Thus, the antenna device can also be used for transmission or reception of linearly polarized waves (e.g. of unknown orientation of the polarization). Naturally, a polarization loss factor occurs (e.g., -3 dB) when a circular polarized wave is received/transmitted by/to a linear polarization antenna. If, for example, both antennas are collinear CP, polarization loss factor is, for example, 0dB (no loss). If one antenna is RHCP, another LHCP than polarization loss will be -infinity, in theory.

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In other words, the antenna device can also be applied if the reception of linearly polarized waves with arbitrary polarization is desired and no separation of these polarizations is required. Accordingly, the antenna device is well-useable in several different testing applications.

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Fig. 14B shows results of a simulation of a far-field pattern of the antenna device 1200. At a lower frequency F1 (e.g., 24 GHz), a far-field pattern in a ZX plane (e.g., parallel to the wide sidewalls of the frame of the circular polarization antenna structure 1220) is essentially identical to a far-field pattern in a YX plane (e.g., parallel to the narrow sidewalls of the frame of the circular polarization antenna structure 1220). At a higher frequency F5 (e.g., 53 GHz), a far-field pattern in the XZ plane differs more from the far-field pattern in a YX plane (compared to F1). The radiation pattern of the antenna device 1200 may be mostly symmetrical at low/mid-frequencies compared to frequencies at the higher band edge. However, the radiation characteristic of the antenna device is considered as very good in view of the relatively small dimensions of the antenna device and wide frequency band.

Fig. 15A shows results of a simulation of a far-field pattern of the antenna device 1200 at a frequency of 24GHz.

Fig. 15B shows results of a simulation of a far-field pattern of the antenna device 1200 at a frequency of 37GHz.

Fig. 15C shows results of a simulation of a far-field pattern of the antenna device 1200 at a frequency of 53GHz.

As can be seen in Figs. 15A-C, the far-field pattern of the antenna device 1200 shows a symmetric behaviour at 24GHz, wherein the symmetry decreases towards higher frequencies from 37GHz to 53GHz. Radiation pattern asymmetry (at least in E/H-planes) is natural for the vast majority of antennas (except, e.g., corrugated conical horns). Moreover, in the CP antenna development there is not such a strict requirement for a symmetrical beam shape.

Therefore, beam symmetry at low and mid frequencies is a benefit of the antenna device described herein.

Fig. 15D shows results of a simulation of axial ratio performances of two antenna devices.

Antenna #1 (bright line or line 1593a) is an antenna device, wherein the radiating aperture of the circular polarization antenna structure is arranged flush (or recessed) relative to a surface of a main body (or first housing portion thereof). For example, antenna #1 may be realized by antenna device 200 (see Fig. 2A) or antenna device 700 (see Fig. 7A). Antenna #2 (dark line or line 1593b) is an antenna device with corrugations, wherein the circular polarization antenna structure extends partially beyond a surface of the main body (or first housing portion thereof). For example, antenna #2 may be realized by antenna device 900 (see Fig. 9A) or antenna device 1200 (see Fig. 12A).

In regard to antenna #1, the axial ratio performance of antenna #2 has been significantly improved, so the antenna #2 may be closer to a typical (or ideal) circular-polarization antenna. The antenna #2 has shown in improved relative bandwidth (e.g., 75%) versus an antenna without ridges (e.g., with a relative bandwidth of 40%).

Fig. 16A shows a perspective view of a first housing 1644a (e.g., of a main body) (which may, for example, correspond to the first housing 944a) and an example of dimensions that may be particularly relevant for fabrication tolerances. The dimension $\Delta w_{\text{opening}}$ defines a fabrication tolerance for a diameter of the rounded recess 1648 (i.e. not the absolute value of the diameter itself). The dimension $\Delta w_{\text{corrugations}}$ defines fabrication tolerance for a width of corrugations 1650 and/or a radial distance between two corrugations 1650.

Fig. 16B shows a perspective view of an insert structure 1642 (which may, for example, correspond to the insert structure 942) and an example of dimensions that may be particularly relevant for fabrication tolerances. The dimension $\Delta h_{\text{polarizer}}$ defines a fabrication tolerance of a height of a frame of a circular polarization antenna structure 1620 and/or a length of a first tapering 1623b of a (third and/or) fourth ridge 1622b. The dimension $\Delta w_{\text{polarizer}}$ defines a fabrication tolerance of a width of a radiating aperture 1630 and/or a width of a (first and/or) second opening 1626b of the circular polarization antenna structure 1620.

Fig. 16C shows a result of simulations of a reflection coefficient S_{11} for different fabrication tolerances shown in Figs. 16A, B.

Fig. 16D shows a result of simulations of an axial ratio for different fabrication tolerances shown in Figs. 16A, B.

For an investigation of an impact of fabrication tolerances, a parameterized antenna model has been stressed with maximum $\pm 50\mu\text{m}$ (e.g., a range of -0.05 to $+0.05\text{mm}$) deviations for both, width of milled slots (e.g., $\Delta w_{\text{opening}}$, $\Delta w_{\text{corrugations}}$, and $\Delta w_{\text{polarizer}}$) and height of parts (e.g., $\Delta h_{\text{polarizer}}$). According to twenty seven parametric sweeps, the results of the simulations show that a return loss and axial ratio performance is robust and that the impact of tolerances is minimal.

The presented analysis in Figs. 16C, D is made with the assumptions that the insert structure 1642 (e.g. polarizer insert) is a single part. However, the insert structure 1642 may be formed by an assembly of several metal parts (e.g., slices) which may require precise assembly. Misalignments and small gaps within this assembly may lead to comparable deviations. In such a case, tolerance analysis by simulations may be much more sophisticated.

However, it can be expected that the antenna device is sufficiently insensitive to expected fabrication tolerances.

Fig. 17A shows a perspective view of an example of an antenna device 1700 with a double-ridged waveguide adapter 1770. The antenna device 1700 may, for example, correspond to the antenna device 900, or to any other antenna device disclosed herein.

The double-ridged waveguide adapter 1770 comprise a double-ridged waveguide flange (not shown in Fig. 17A) and a coaxial connector 1772 (electromagnetically) coupled to the double-ridged waveguide flange. For example, the waveguide flange may be a standard waveguide flange, and may use four mounting screws. Accordingly, it may, in some cases, be obligatory to use all four screws when mounting an adapter. In the test equipment a custom flange may, for example, be used, that is not standard and the mounting may, for example, be different.

The double-ridged waveguide adapter 1770 is coupled (or coupleable) to a first housing portion 1744a (which may, for example, correspond to the first housing 944a), for example using screws). The double-ridged waveguide flange is coupled to the third portion of the

double ridged waveguide structure of the first housing portion 1744a. As a result, electromagnetic radiation received at the radiating aperture 1730 can be transmitted via the double-ridged waveguide structure and the double-ridged waveguide adapter 1770 to the coaxial connector 1772. Vice versa, a signal received at the coaxial connector 1772 can be transmitted to the radiating aperture 1730. The coaxial connector 1772 can be connected to a instrumentation, e.g., of a test arrangement for evaluating electromagnetic radiation received by the antenna device 1700.

In the example shown in Fig. 17A, the double-ridged waveguide adapter 1770 is attached to the first housing portion 1744a by screws. Alternatively, the first housing portion 1744a and the double-ridged waveguide adapter 1770 may be coupled using a blind mating interface, or using any other mounting technique.

Fig. 17B shows results of a simulation of return loss of the antenna device shown in Fig. 17A with and without double-ridged waveguide adapter 1770.

The adapter device (e.g. dual ridged waveguide-to-coaxial adapter) and a waveguide feeding network may bring distortions to a reflection coefficient of the circular polarization antenna structure, for example, due to an extra standing wave. For this reason, an antenna circuit comprising the antenna device may be optimized to reach, for example, more than 15 dB return loss (see, for example, the dashed line 1795a in Fig. 17B) in a desired band (e.g., 24GHz to 64GHz). An overall return loss of the antenna device 1700 with the double-ridged waveguide adapter 1770 (e.g., see the black curve 1795b in Fig. 17B) may not be worse than 10 dB.

Fig. 18 shows a schematic cross section of an example of an automated test equipment (or test arrangement) 1880. The automated test equipment comprises an antenna device 1800. The antenna device 1800 may be any antenna device described herein. The automated test equipment 1880 is configured to test (e.g. using a wireless testing or over-the-air testing) a device 1882 under test using the antenna device 1800.

The automated test equipment 1880 may further comprise a device-under-test socket 1884 for insertion of the device under test 1882. In other words, the device-under-test socket 1884 may be configured to receive the device under test 1882. The device-under-test

socket 1884 may, for example, be arranged on (and optionally attached to) a carrier structure 1886 (e.g., a loadboard). The antenna device 1800 may be coupled to a signal receiver and/or signal generator 1888, for example via an adapter device 1870 (e.g., using a coaxial cable). The signal receiver and/or signal generator 1888 may be configured to receive a
5 signal from the antenna device 1800 (e.g., for at least one of analysing, logging, storing, and processing) and/or to generate signals that can be transmitted by a radiating aperture of the antenna device 1800 .

Thus, the test arrangement 1880, which may be used as a part of an automated test equipment or in combination with an automated test equipment allows to efficiently perform a
10 testing of the device under test. The antenna device may help to improve testing results, e.g. by providing a good axial ratio performance over a wide frequency range. Moreover, a relatively small size of the antenna device allows for an efficient integration of the antenna device in a test environment.

Fig. 19 shows a perspective view of an automated test equipment 1980 with a carrier structure 1986 a signal receiver and/or signal generator 1988. The automated test equipment 1980 comprises an antenna device 1900 (e.g., as any antenna device disclosed herein such as antenna device 100, 200, 300, 700, 900, 1200, 1700, or 1800), wherein the automated
15 test equipment 1980 is configured to test a device under test (not shown in Fig. 19) using the antenna device 1900. The carrier structure 1986 may comprise or be formed by a printed circuit board, PCB.

Fig. 20 shows a close-up view of the automated test equipment 1980 shown in Fig. 19 in
25 an assembled configuration. The automated test equipment 1980 comprises a device-under-test socket 1984 for insertion of the device under test. The antenna device 1900 comprises an attachment mechanism 1981 (e.g., a clamping device) configured to releasably attach the antenna device 1900 to the device-under-test socket 1984. The device-under-test socket 1984 is attached to the carrier structure 1986 such that the attachment mechanism 1981 is configured to (indirectly) attach antenna device 1900 to the carrier structure
30 1986.

Fig. 21 shows a close-up view of the automated test equipment 1980 in a disassembled configuration, wherein the antenna device 1900 is detached from the device-under-test
35 socket 1984. The antenna device 1900 comprises a double-ridged waveguide structure 1910 that is coupled at one end to a circular polarization antenna structure 1920 and at

another end to a first double-ridged waveguide flange 1983a. The automated test equipment 1980 comprises a second double-ridged waveguide flange 1983b (e.g., extending through an opening in the carrier structure 1986) that is coupled to the signal receiver and/or signal generator 1988. The antenna device 1900, the device-under-test socket 1984, and the first and second double-ridged waveguide flanges 1983a, b are arranged such that when the antenna device 1900 is mounted onto the device-under-test socket 1984, the first double-ridged waveguide flange 1983a connects to the second double-ridged waveguide flanges 1983b. To this end, the first and second double-ridged waveguide flanges 1983a, b may be blind mating flanges.

The antenna device 1900 and the device-under-test socket 1984 are configured such that when a device under test is inserted into the device-under-test socket 1984 and the antenna device 1900 is mounted on the device-under-test socket 1984, the circular polarization antenna structure of the antenna device 1900 is arranged in a near field or far field of the device under test. As a result, an electromagnetic wave emitted by the device under test can be received by the circular polarization antenna structure of the antenna device 1900 and transmitted via the double-ridged waveguide structure 1910 and the first and second double-ridged waveguide flanges 1983a, b to the signal receiver and/or signal generator 1988. Vice versa, an electromagnetic wave emitted by the signal receiver and/or signal generator 1988 can be received by the device under test.

The automated test equipment 1980 shown in Fig. 21 further comprises an antenna cover 1985 that is configured to be (releasably) attached to the antenna device 1900 such as to cover the circular polarization antenna structure 1920 of the antenna device 1900. For example, the antenna cover 1985 may be attached to the antenna device 1900 using screws that are screwed into openings in a main body 1940 of the antenna device 1900. The antenna cover 1985 is partly or fully transparent at least for a frequency bandwidth of operation (e.g., 24GHz to 53GHz). To this end, the antenna cover may be formed partly or fully from a dielectric material.

Fig. 22 shows a close-up view of the automated test equipment 1980 of Fig. 21, wherein antenna cover 1985 is attached to the antenna device 1900. The antenna cover 1985 comprises an end face 1987 that is dimensioned such that as to abut against a device under test 1982 inside the device-under-test socket 1984, when the antenna device 1900 is attached to the device-under-test socket 1984. The antenna cover 1985 allows securing the device under test 1982 in the device-under-test socket 1984. Furthermore, the antenna

cover 1985 may facilitate establishing a reproducible distance between the antenna device 1900 and the device under test 1982, e.g., for testing a plurality of devices under test.

5 Implementation alternatives

Although some aspects have been described in the context of an apparatus, it is clear that these aspects also represent a description of the corresponding method, where a block or device corresponds to a method step or a feature of a method step. Analogously, aspects described in the context of a method step also represent a description of a corresponding block or item or feature of a corresponding apparatus.

The above described embodiments are merely illustrative for the principles of the present invention. It is understood that modifications and variations of the arrangements and the details described herein will be apparent to others skilled in the art. It is the intent, therefore, to be limited only by the scope of the impending patent claims and not by the specific details presented by way of description and explanation of the embodiments herein.

Claims

1. An antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) comprising

5 a double-ridged waveguide structure (110; 210; 310; 910; 1210; 1910) with a first and a second ridge (112a, b; 212a, b; 912a, b; 1212a, b);

a circular polarization antenna structure (120; 220; 320; 720; 920; 1220; 1920) coupled to the double-ridged waveguide (110; 210; 310; 910; 1210; 1910) and extending between the double-ridged waveguide structure (110; 210; 310; 910; 1210; 1910) and a radiating aperture (130; 230; 330; 730; 930; 1230; 1730) of the antenna device,

wherein the circular polarization antenna structure (120; 220; 320; 720; 920; 1220; 1920) comprises a third ridge (122a; 222a; 322a; 922a; 1222a) having a first curved extension and transitioning into the first ridge (112a; 212a; 912a; 1212a) and a fourth ridge (122b; 222b; 322b; 922b; 1222b; 1622b) having a second curved extension different from the first curved extension and transitioning into the second ridge (112b; 212b; 912b; 1212b).

2. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to claim 1,

wherein at least one of the third and fourth ridge (122a, b; 222a, b; 322a, b; 922a, b; 1222a, b; 1622b) extends only along a part of a way from the double-ridged waveguide structure (110; 210; 310; 910; 1210; 1910) towards the radiating aperture (130; 230; 330; 730; 930; 1230; 1730).

3. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to claim 1 or 2, further comprising

30 a main body (240; 340; 740; 1940), wherein the circular polarization antenna structure (120; 220; 320; 720; 920; 1220; 1920) is arranged partially inside the main body (240; 340; 740; 1940) and wherein the circular polarization antenna structure (120; 220; 320; 720; 920; 1220; 1920) extends partially beyond a surface (246; 346; 746) of the main body (240; 340; 740; 1940).

35

4. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the preceding claims,

wherein the first curved extension and the second curved extension are arranged along different parallel and spaced apart planes, and

wherein the first curved extension and the second curved extension bend away towards opposite directions from the direction of the first ridge and of the second ridge (112a, b; 212a, b; 912a, b; 1212a, b).

5. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the preceding claims,

wherein the first curved extension of the third ridge (122a; 222a; 322a; 922a; 1222a) is arranged along a plane which is defined by a sidewall (114a) of the double-ridged waveguide structure (110; 210; 310; 910; 1210; 1910) on which the first ridge (112a; 212a; 912a; 1212a) is arranged, and

wherein the second curved extension of the fourth ridge (122b; 222b; 322b; 922b; 1222b; 1622b) is arranged along a plane which is defined by a sidewall (114b) of the double-ridged waveguide structure (110; 210; 310; 910; 1210; 1910) on which the second ridge (112b; 212b; 912b; 1212b) is arranged .

6. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the preceding claims,

wherein the first curved extension and the second curved extension are axially symmetric to an axis of the double-ridged waveguide structure (110; 210; 310; 910; 1210; 1910) and the circular polarization antenna structure (120; 220; 320; 720; 920; 1220; 1920).

7. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the preceding claims,

wherein the third ridge and the fourth ridge (122a, b; 222a, b; 322a, b; 922a, b; 1222a, b; 1622b) are configured to rotate a direction of an electrical field, which is present between the first ridge and the second ridge (112a, b; 212a, b; 912a, b; 1212a, b), when a

wave is traveling from the double-ridged waveguide structure (110; 210; 310; 910; 1210; 1910) toward a radiating aperture (130; 230; 330; 730; 930; 1230; 1730) of the antenna device.

- 5 8. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the preceding claims,

 wherein the circular polarization antenna structure (120; 220; 320; 720; 920; 1220; 1920) comprises a rectangular frame with a first sidewall structure (124a; 224a; 924a) and
10 a second sidewall structure (124b; 224b; 924b),

 wherein the third ridge and the fourth ridge (122a, b; 222a, b; 322a, b; 922a, b; 1222a, b; 1622b) are arranged in the rectangular frame.

- 15 9. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to claim 8,

 wherein the rectangular frame comprises a widened continuation of the double-ridged waveguide structure (110; 210; 310; 910; 1210; 1910).

20

10. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to claim 8 or 9,

 wherein the first sidewall structure (124a; 224a; 924a) has a first opening (226a; 926a) and the second sidewall structure (124b; 224b; 924b) has a second opening (226b; 326b; 926b; 1626b),
25

 wherein the first opening (226a; 926a) extends towards the radiating aperture (130; 230; 330; 730; 930; 1230; 1730), and
30

 wherein the second opening (226b; 326b; 926b; 1626b) extends towards the radiating aperture (130; 230; 330; 730; 930; 1230; 1730).

11. The antenna device according to claim 10,

35

wherein the first opening (226a; 926a) and the second opening (226b; 326b; 926b; 1626b) are axially symmetric or at least essentially axially symmetric with respect to an axis (116) of the double-ridged waveguide structure (110; 210; 310; 910; 1210; 1910) and an axis (116) of the circular polarization antenna structure (120; 220; 320; 720; 920; 1220; 1920).

12. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to claim 11,

wherein the third ridge (122a; 222a; 322a; 922a; 1222a) extends at least partly along an edge of the first opening (226a; 926a), and

wherein the fourth ridge (122b; 222b; 322b; 922b; 1222b; 1622b) extends at least partly along an edge of the second opening (226b; 326b; 926b; 1626b).

13. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the claims 10 to 12,

wherein at least one of the first and second openings (226a, b; 326b; 926a, b; 1626b) has a shape that broadens towards the radiating aperture (130; 230; 330; 730; 930; 1230; 1730).

14. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to claim 13,

wherein the first opening (226a; 926a) has a convex shape at one side and a concave shape at another side, and/or

wherein the second opening (226b; 326b; 926b; 1626b) has a convex shape at one side and a concave shape at another side.

15. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the claims 8 to 14, when dependent at least on claim 3,

wherein the main body (240; 340; 740; 1940) comprises a rounded recess (248; 348; 948; 1648),

wherein the rectangular frame with the first sidewall structure (124a; 224a; 924a) and the second sidewall structure (124b; 224b; 924b) is arranged in a central region of the rounded recess (248; 348; 948; 1648), and

5

wherein there is an electromagnetic coupling between an inner region of the rectangular frame and a first outer rounded region (249a) of the rounded recess (248; 348; 948; 1648) through a first opening (226a; 926a) in the first sidewall structure (124a; 224a; 924a), and

10

wherein there is an electromagnetic coupling between the inner region of the rectangular frame and a second outer rounded region (249b) of the rounded recess (248; 348; 948; 1648) through a second opening (226b; 326b; 926b; 1626b) in the second sidewall structure (124b; 224b; 924b).

15

16. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to claim 15,

wherein the first opening (226a; 926a) in the first sidewall structure (124a; 224a; 924a) widens towards a radiating aperture (130; 230; 330; 730; 930; 1230; 1730) of the antenna device, such that a width of the first opening (226a; 926a) reaches at least 60 percent or at least 70 percent of a diameter of the rounded recess (248; 348; 948; 1648) in a proximity of the radiating aperture (130; 230; 330; 730; 930; 1230; 1730).

25 17. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to claim 15 or 16,

wherein the rectangular frame, is longer than a circular waveguide which is formed by the rounded recess (248; 348; 948; 1648).

30

18. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the claims 8 to 17,

wherein the rectangular frame is a separate workpiece, which inserted into a main body of the antenna device.

35

19. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800) according to any of the claims 8 to 18,

wherein the rectangular frame is assembled using a plurality of slices.

5

20. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the claims 8 to 19,

wherein the rectangular frame protrudes over a surface (246; 346; 746) of a main body of the antenna device.

10

21. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the claims 8 to 20,

wherein the rectangular frame protrudes over one or more corrugations (350; 950; 1650) arranged on a surface (246; 346; 746) surrounding a radiating aperture (130; 230; 330; 730; 930; 1230; 1730) of the circular polarization antenna structure (120; 220; 320; 720; 920; 1220; 1920).

15

22. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the preceding claims, further comprising

20

one or more corrugations (350; 950; 1650) arranged on a surface (246; 346; 746) surrounding a radiating aperture (130; 230; 330; 730; 930; 1230; 1730) of the circular polarization antenna structure (120; 220; 320; 720; 920; 1220; 1920), wherein the one or more corrugations (350; 950; 1650) extend at least partly around the circular polarization antenna structure (120; 220; 320; 720; 920; 1220; 1920).

25

23. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to claim 22,

30

wherein at least one corrugation (350; 950; 1650) has a height in a range of 2.5mm to 3.5mm, or in a range of 2.9mm to 3.1mm, a wall thickness in a range of 0.5mm to 1.0mm, or in a range of 0.6mm to 0.8mm.

35

24. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800) according to claim 22 or 23,

wherein the antenna device comprises a plurality of corrugations (350; 950; 1650),
5 and

wherein a radial distance between two corrugations (350; 950; 1650) in a range of 0.5mm to 1.5mm, or in a range of 0.9mm to 1.1mm.

10 25. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the preceding claims,

wherein at least one of the third and fourth ridges (122a, b; 222a, b; 322a, b; 922a, b; 1222a, b; 1622b) comprises a first tapering (323b; 1623b),

15 wherein a thickness of the at least one of the third and fourth ridges (122a, b; 222a, b; 322a, b; 922a, b; 1222a, b; 1622b) decreases along its extension towards the radiating aperture (130; 230; 330; 730; 930; 1230; 1730).

20 26. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the preceding claims, wherein at least one of the third and fourth ridges (122a, b; 222a, b; 322a, b; 922a, b; 1222a, b; 1622b) comprises a second tapering wherein a width of the at least one of the third and fourth ridges (122a, b; 222a, b; 322a, b; 922a, b; 1222a, b; 1622b) decreases along its extension towards the radiating aperture (130; 230; 330; 730; 930; 1230; 1730).
25

27. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the preceding claims, wherein the double-ridged waveguide structure (110; 210; 310; 910; 1210; 1910) comprises a bend at which an extension direction of the double-ridged waveguide structure (110; 210; 310; 910; 1210; 1910) changes at least essentially by 90°.
30

28. The antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the preceding claims, further comprising
35 an insert structure (242; 342; 942; 1242) comprising the circular polarization antenna structure (120; 220; 320; 720; 920; 1220; 1920); and

at least a first housing portion in which at least a portion of the double-ridged waveguide structure (110; 210; 310; 910; 1210; 1910) is formed, wherein the first housing portion comprises an opening configured to receive the insert structure (242; 342; 942; 1242).

- 5 29. An automated test equipment (1880; 1980), comprising
the antenna device (100; 200; 300; 700; 900; 1200; 1700; 1800; 1900) according to any of the preceding claims, wherein the automated test equipment is configured to test a device under test (1882) using the antenna device.

100

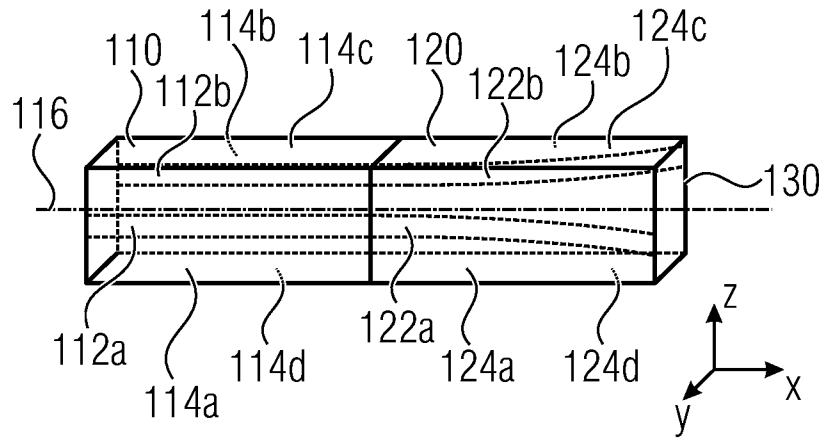


Fig. 1A

121

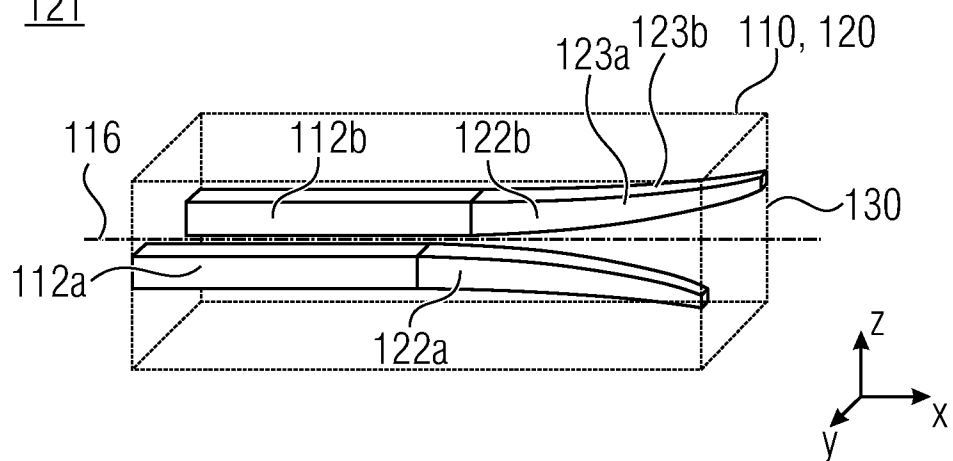


Fig. 1B

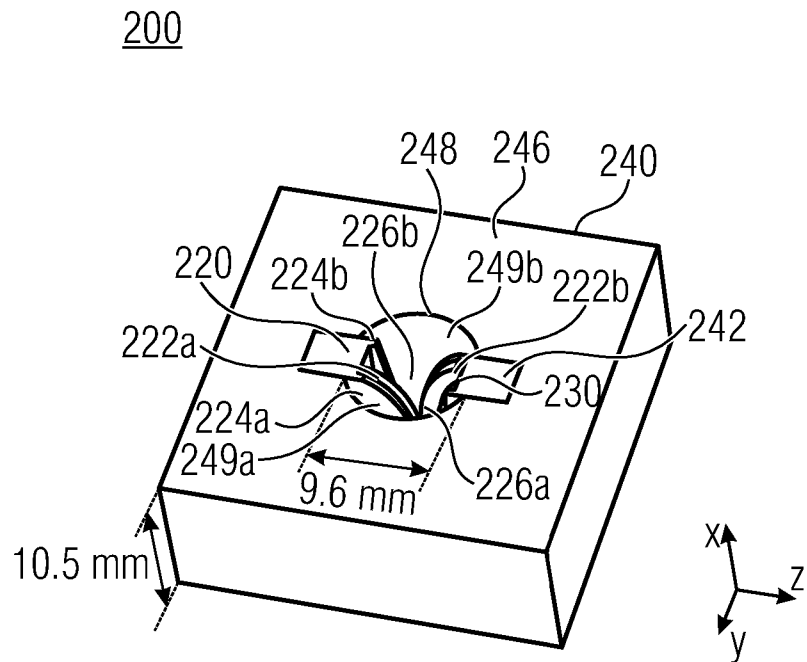


Fig. 2A

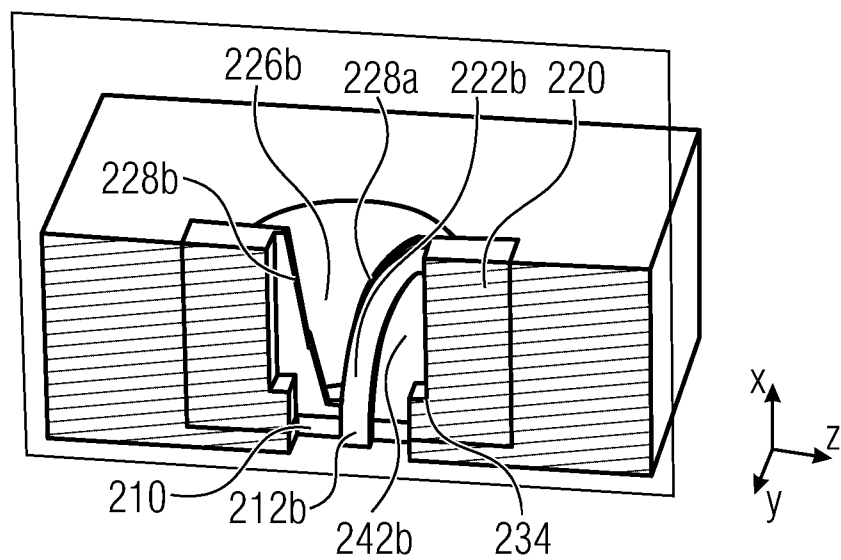


Fig. 2B

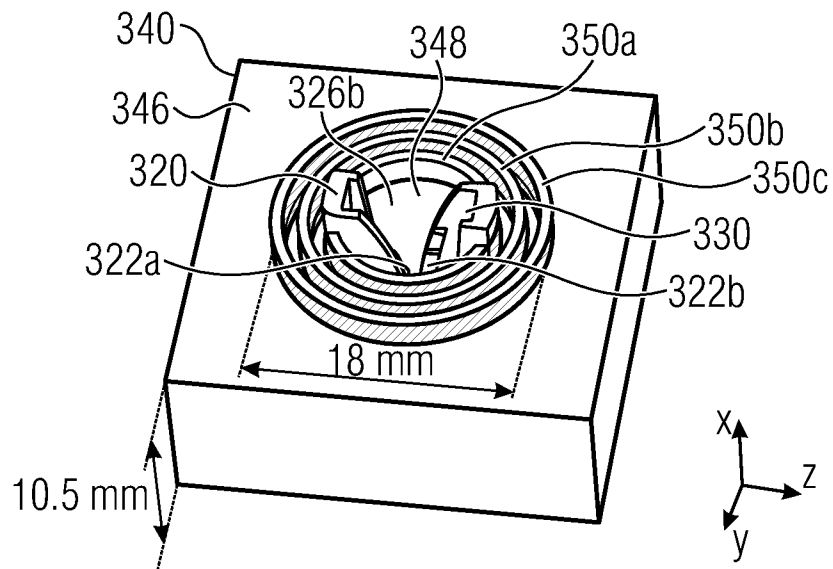
300

Fig. 3A

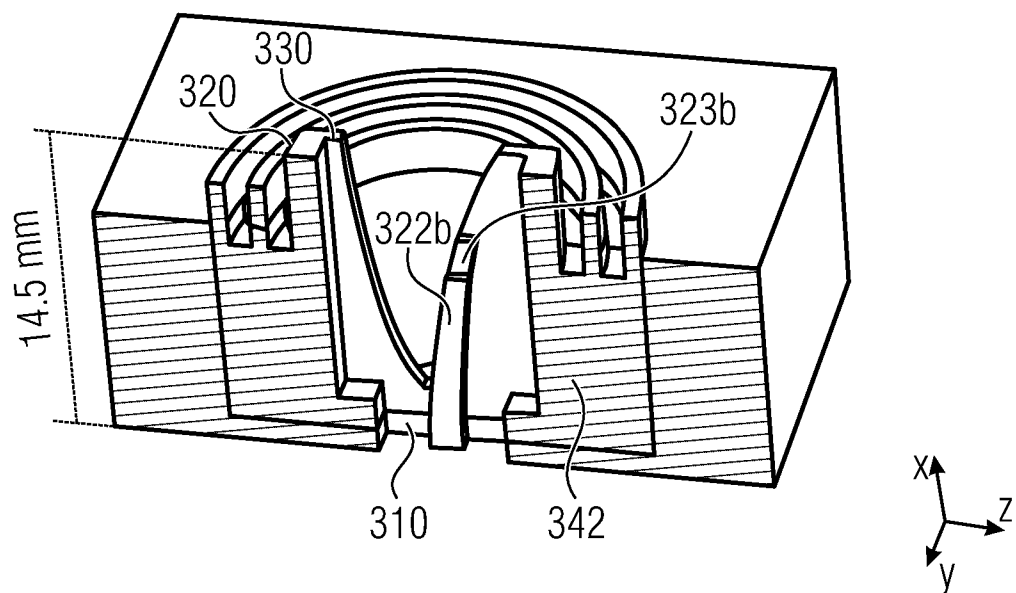


Fig. 3B

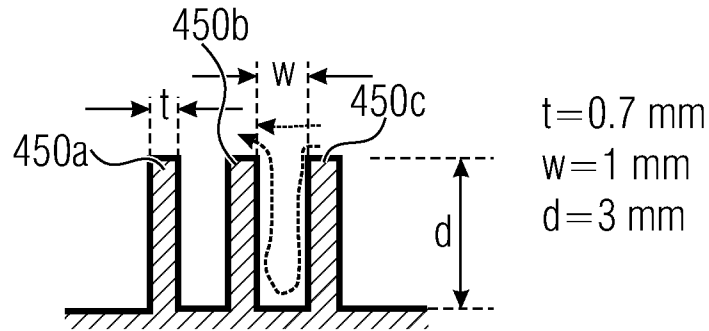
450

Fig. 4A

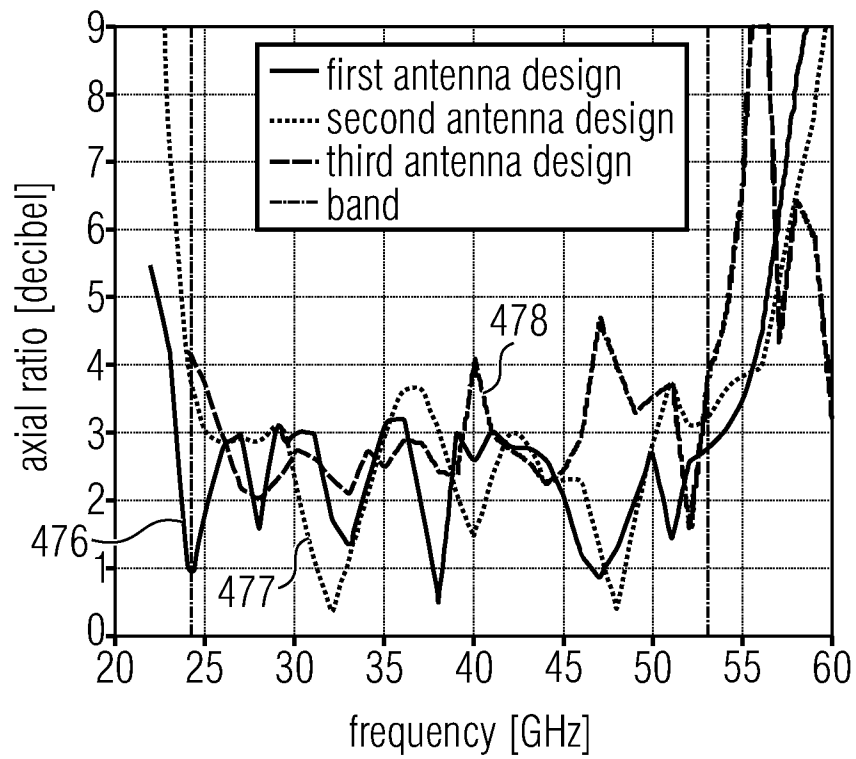


Fig. 4B

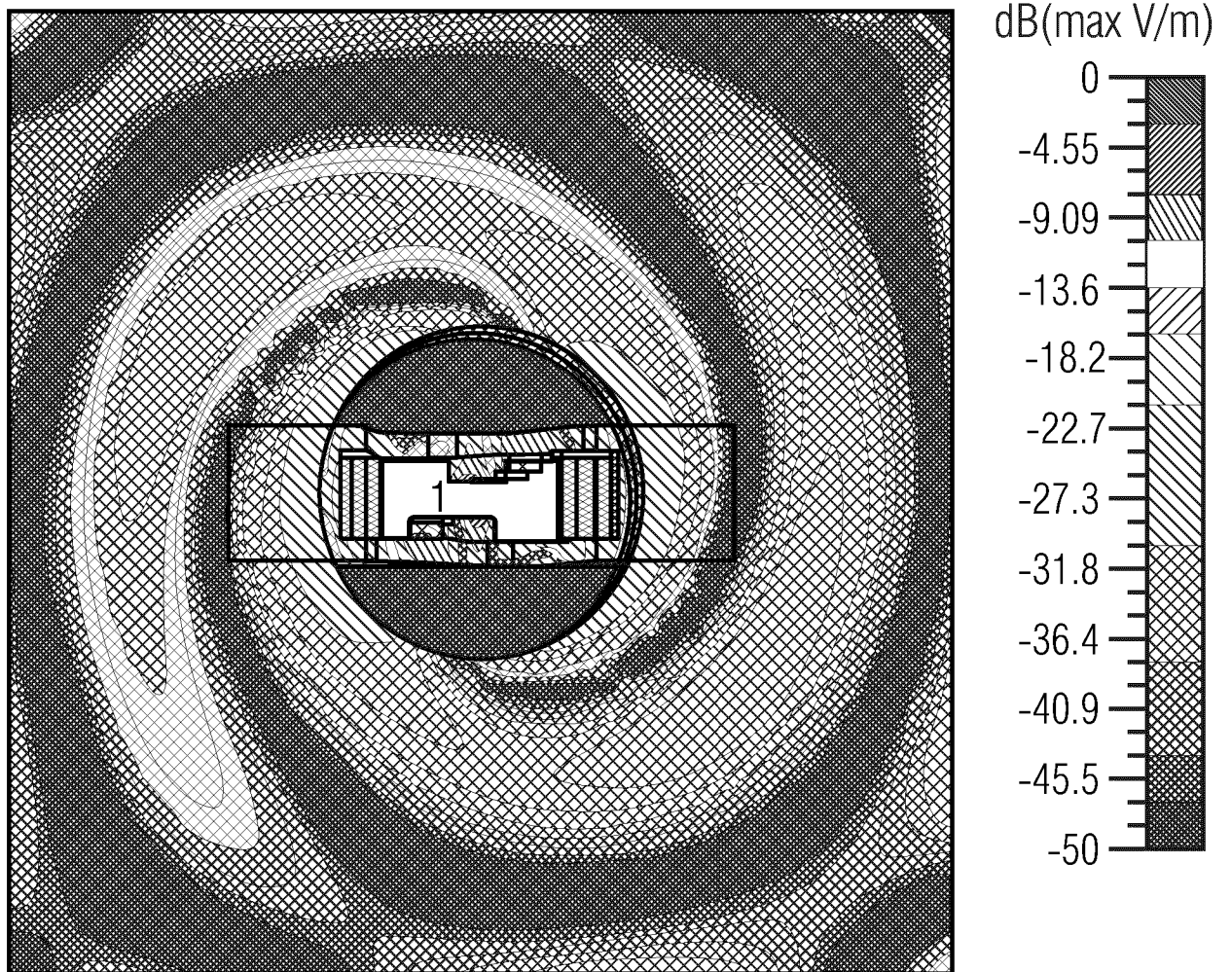


Fig. 5A

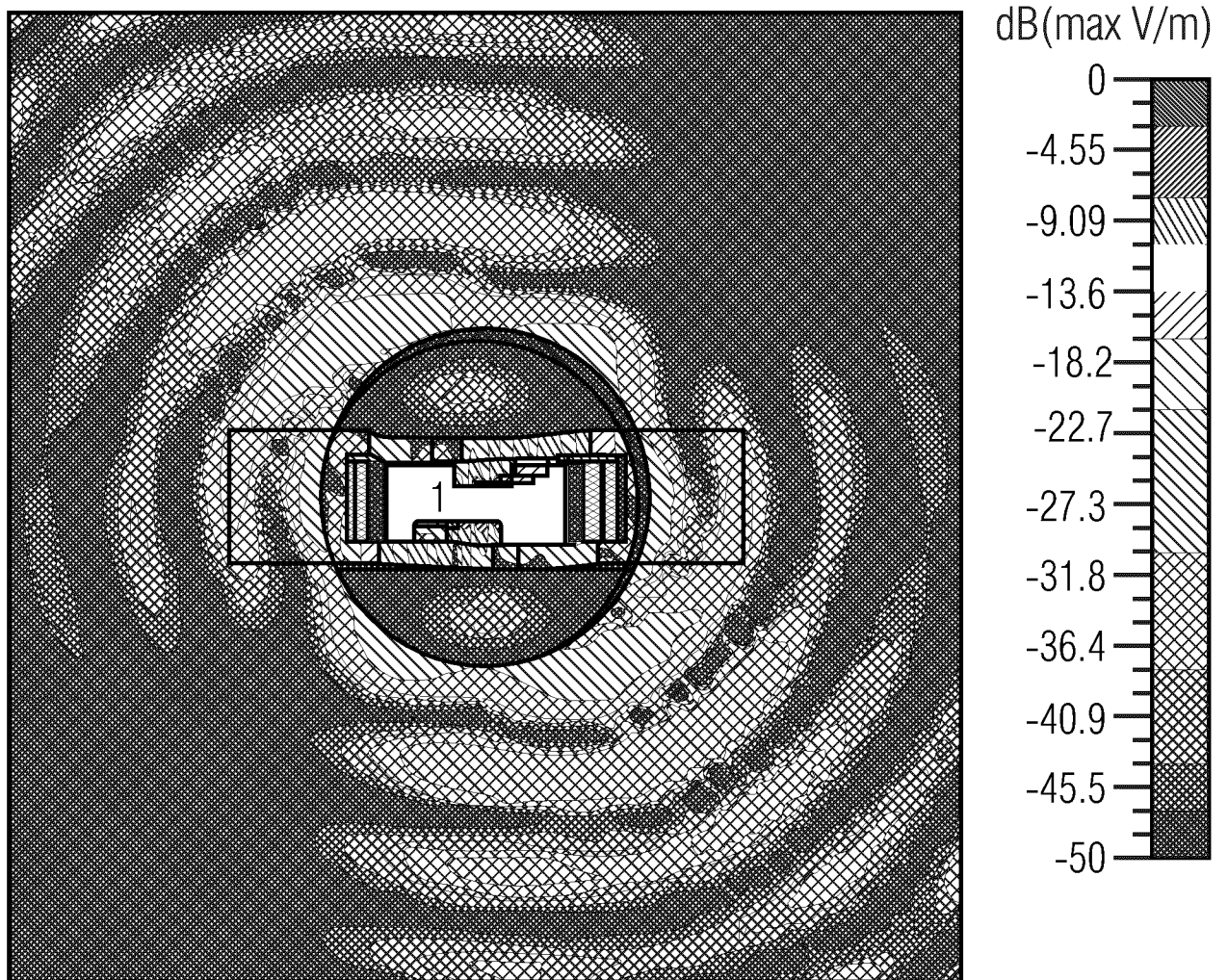


Fig. 5B

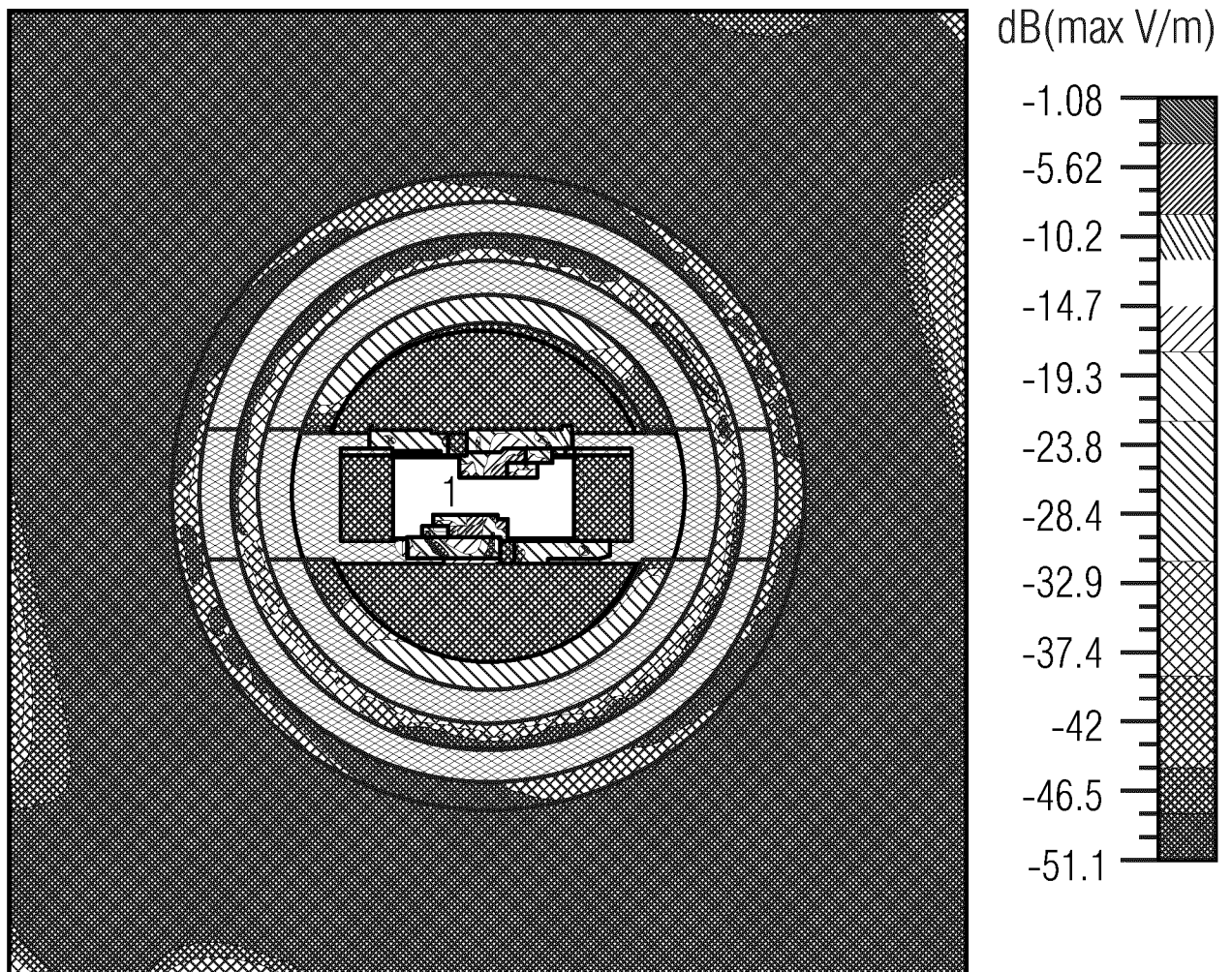


Fig. 6A

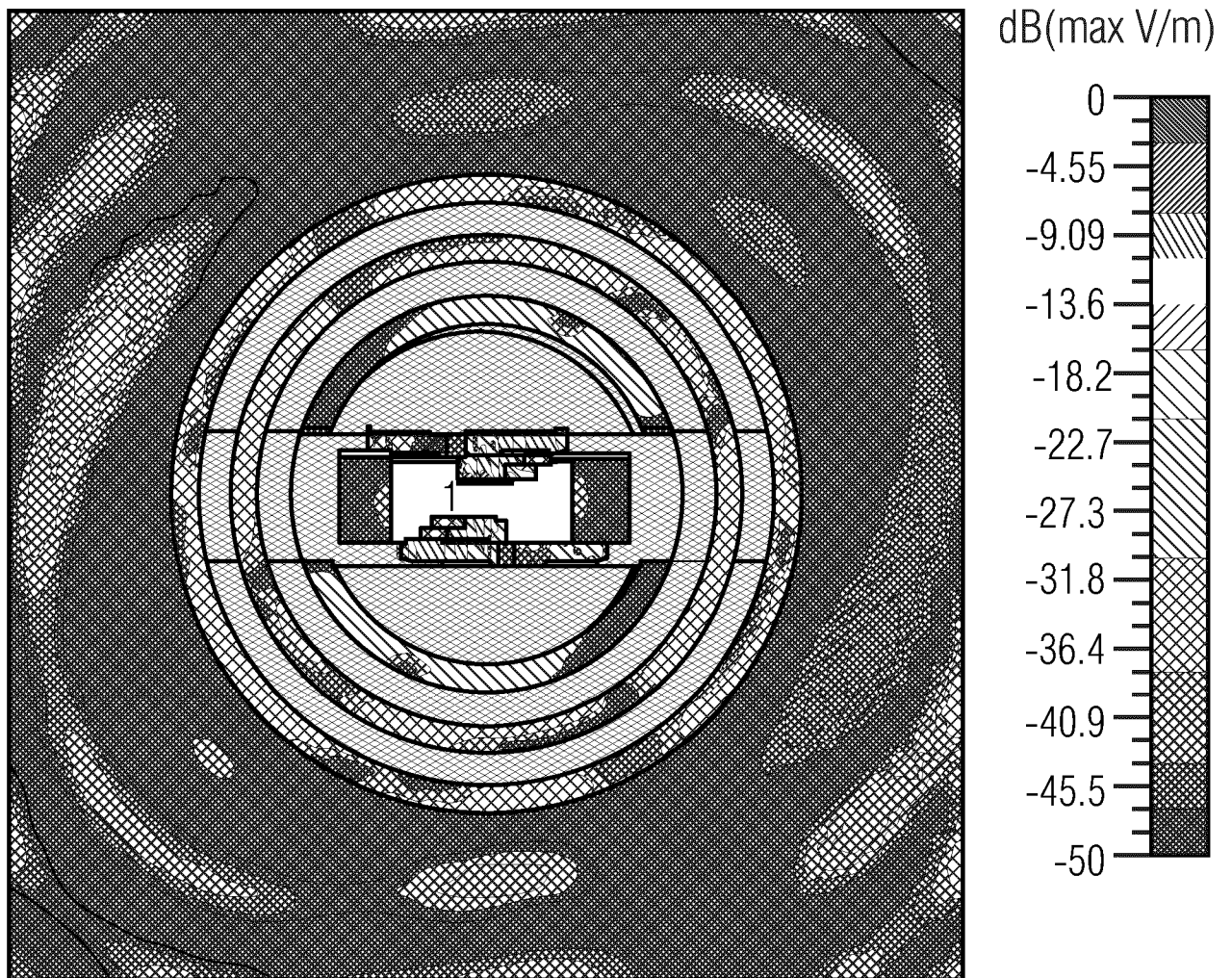


Fig. 6B

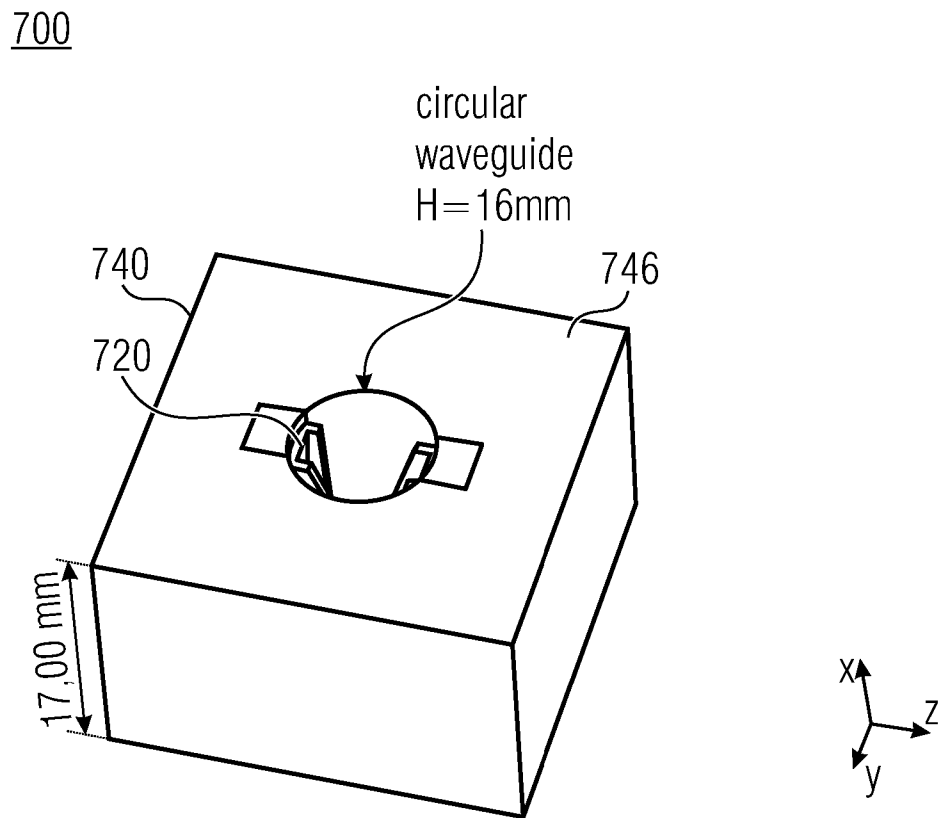


Fig. 7A

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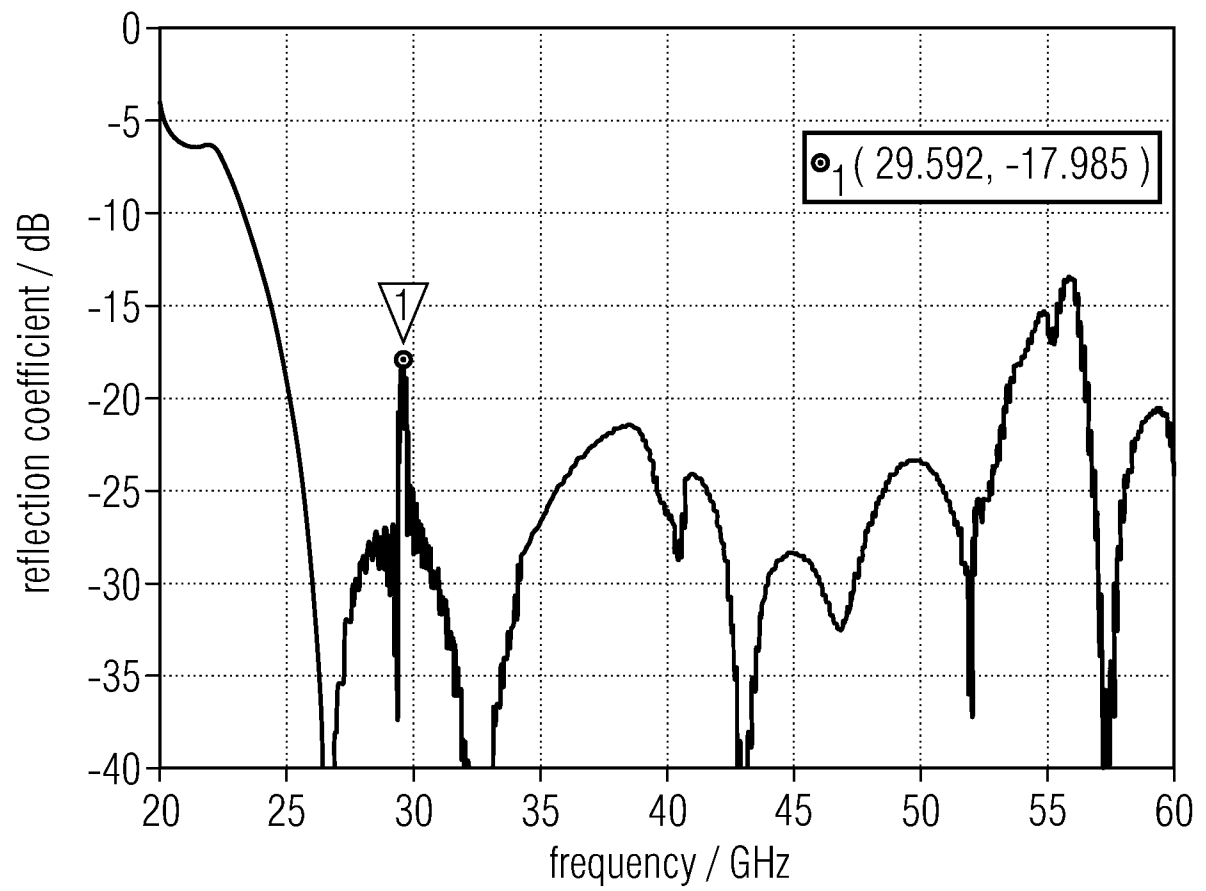


Fig. 7B

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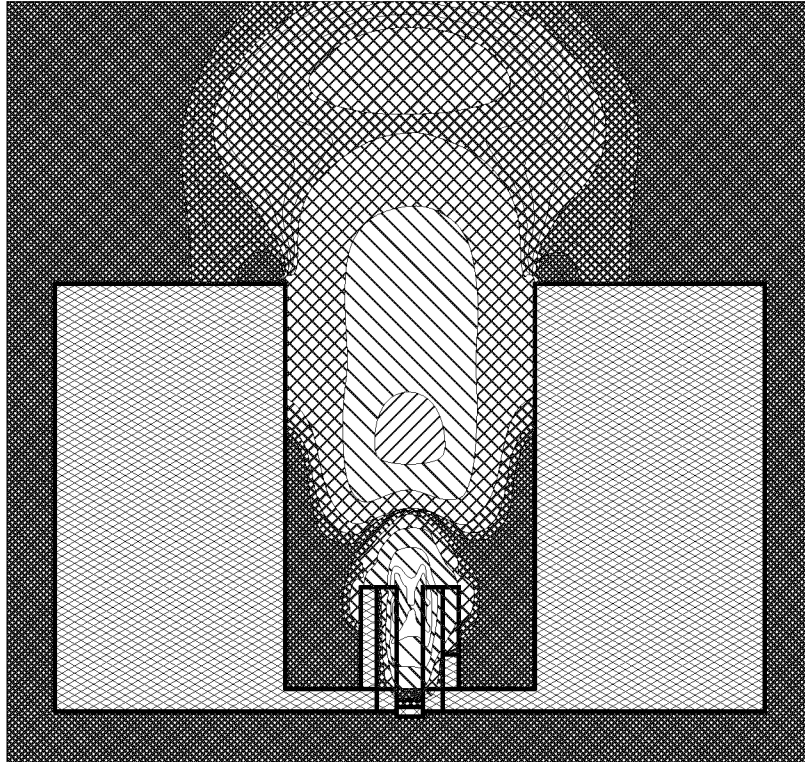


Fig. 8A

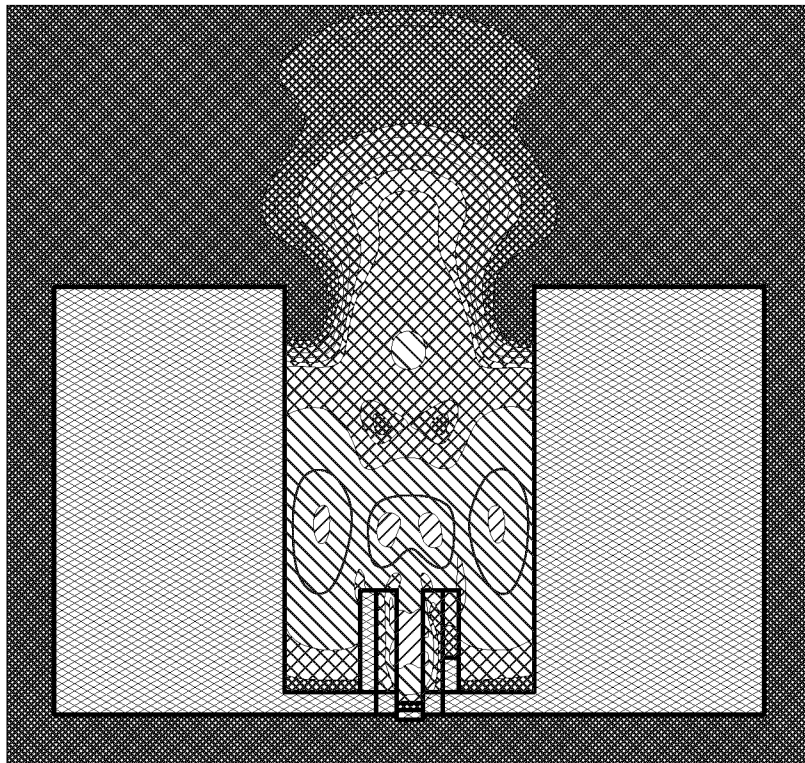


Fig. 8B

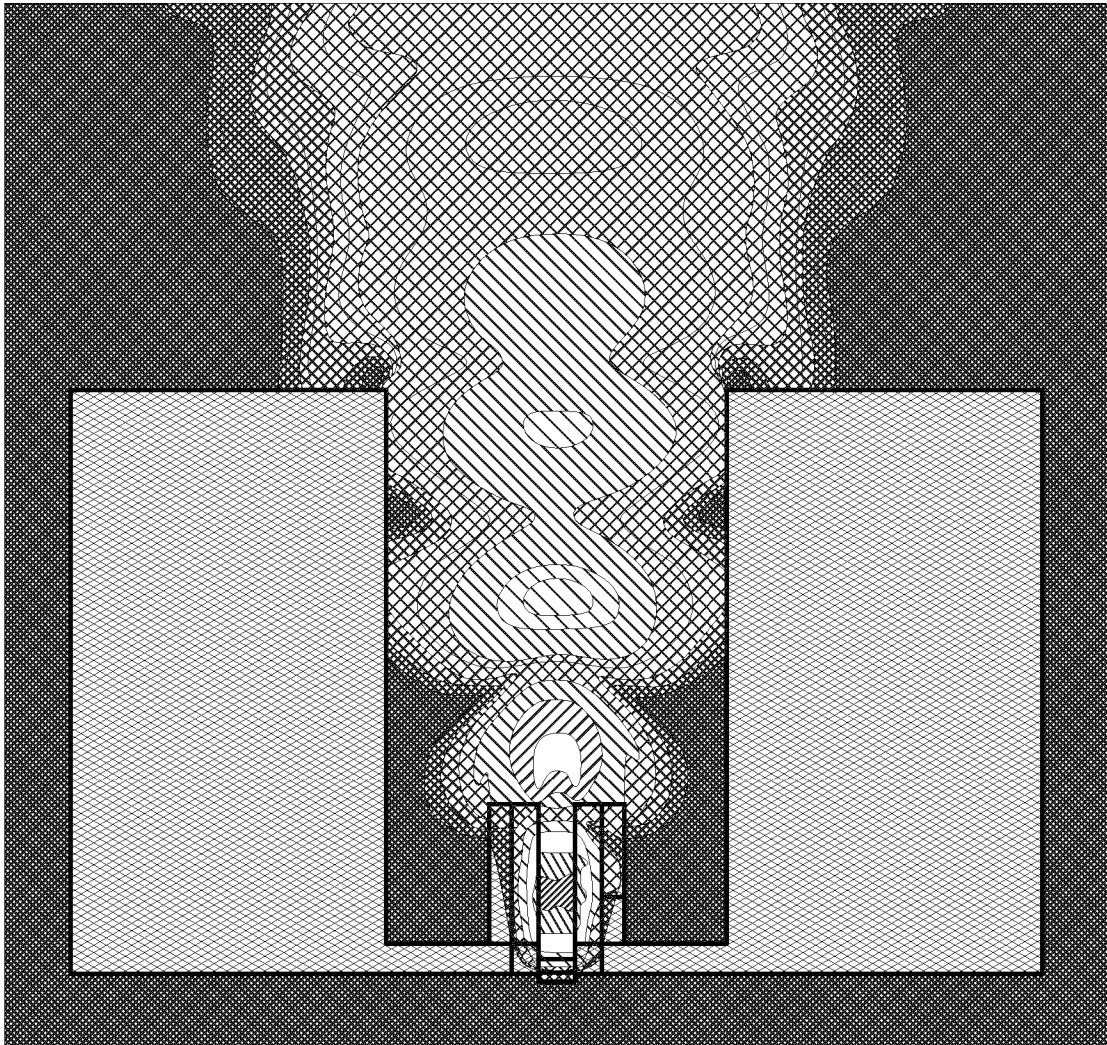


Fig. 8C

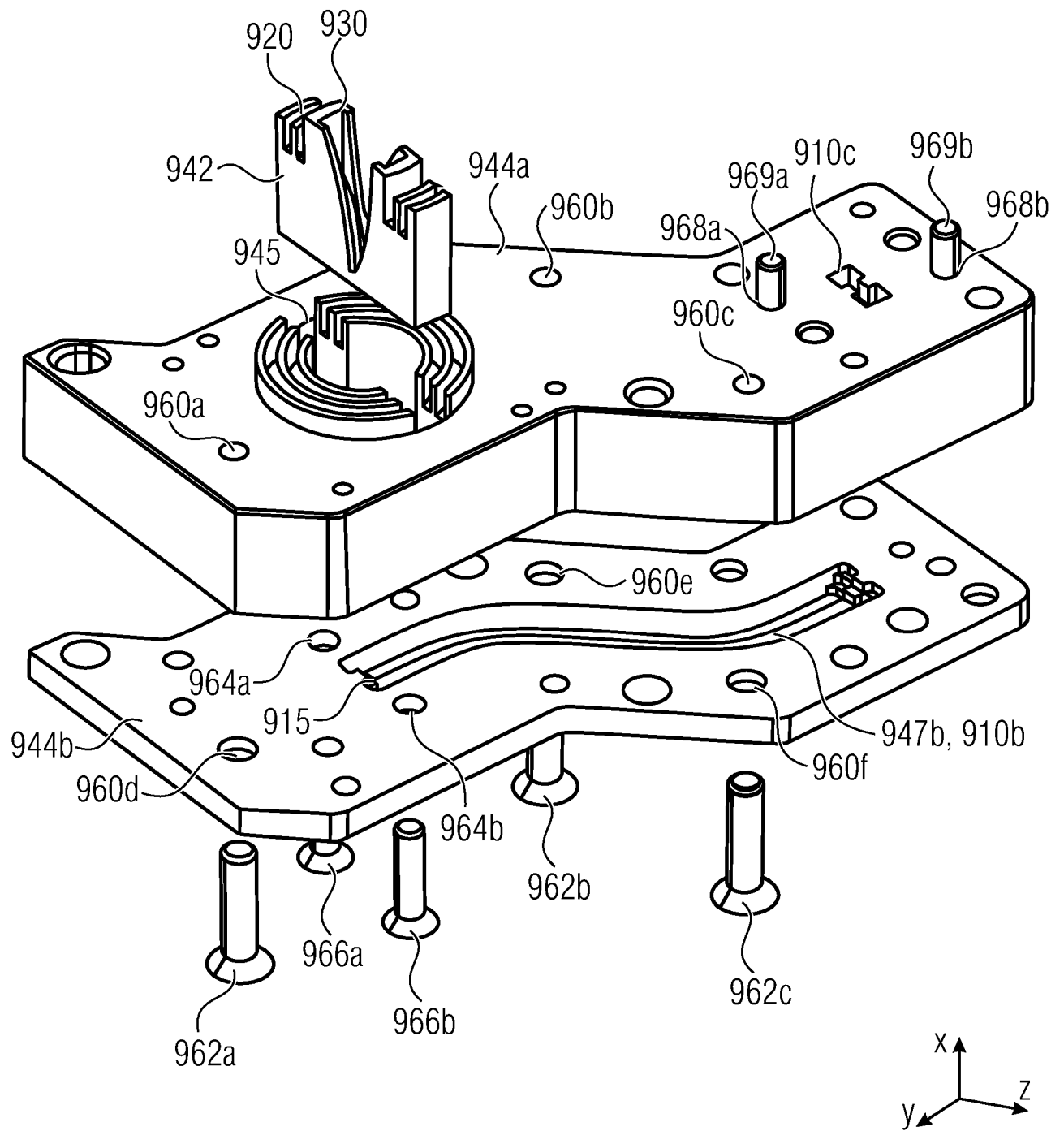
900

Fig. 9

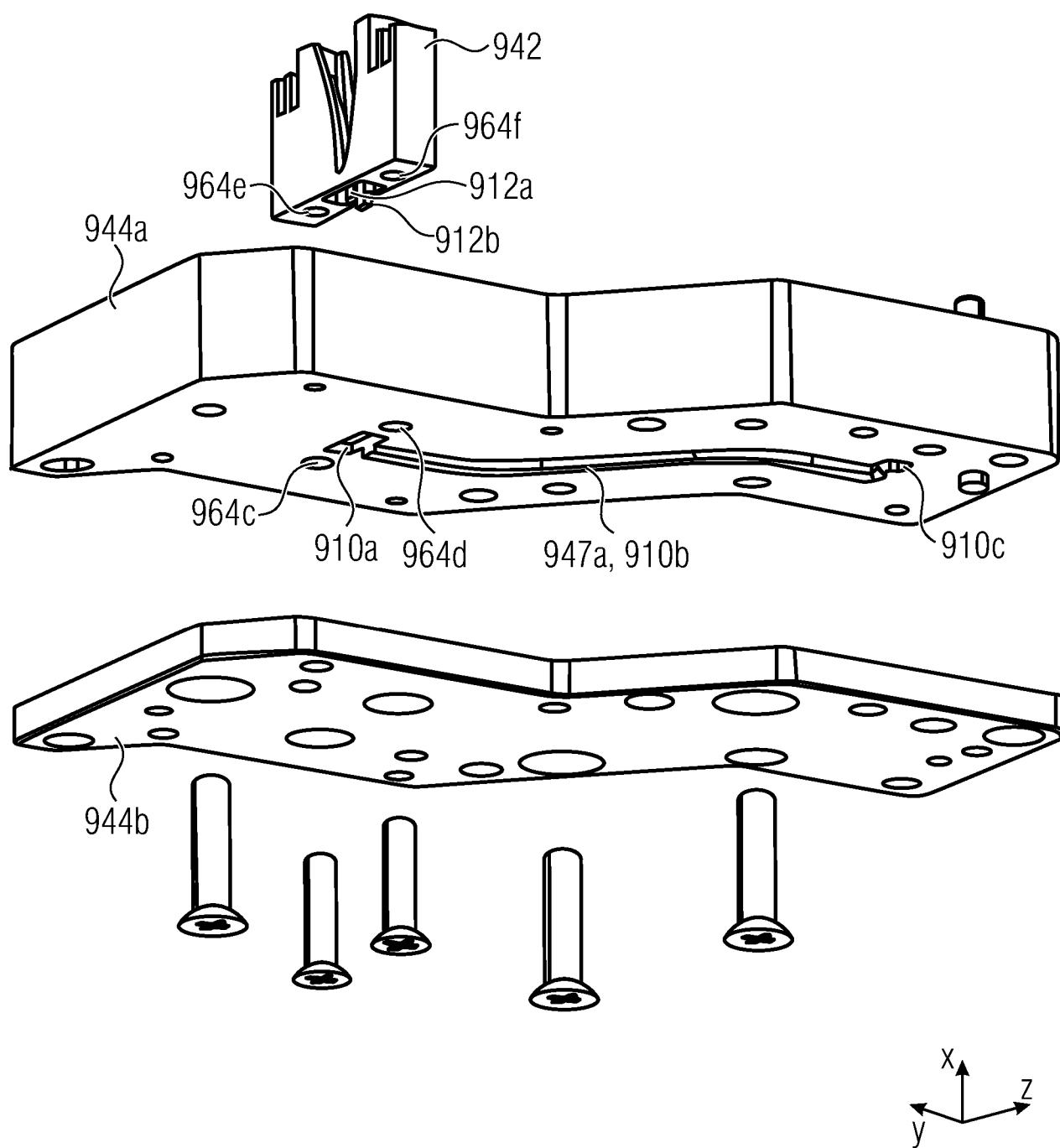
900

Fig. 10

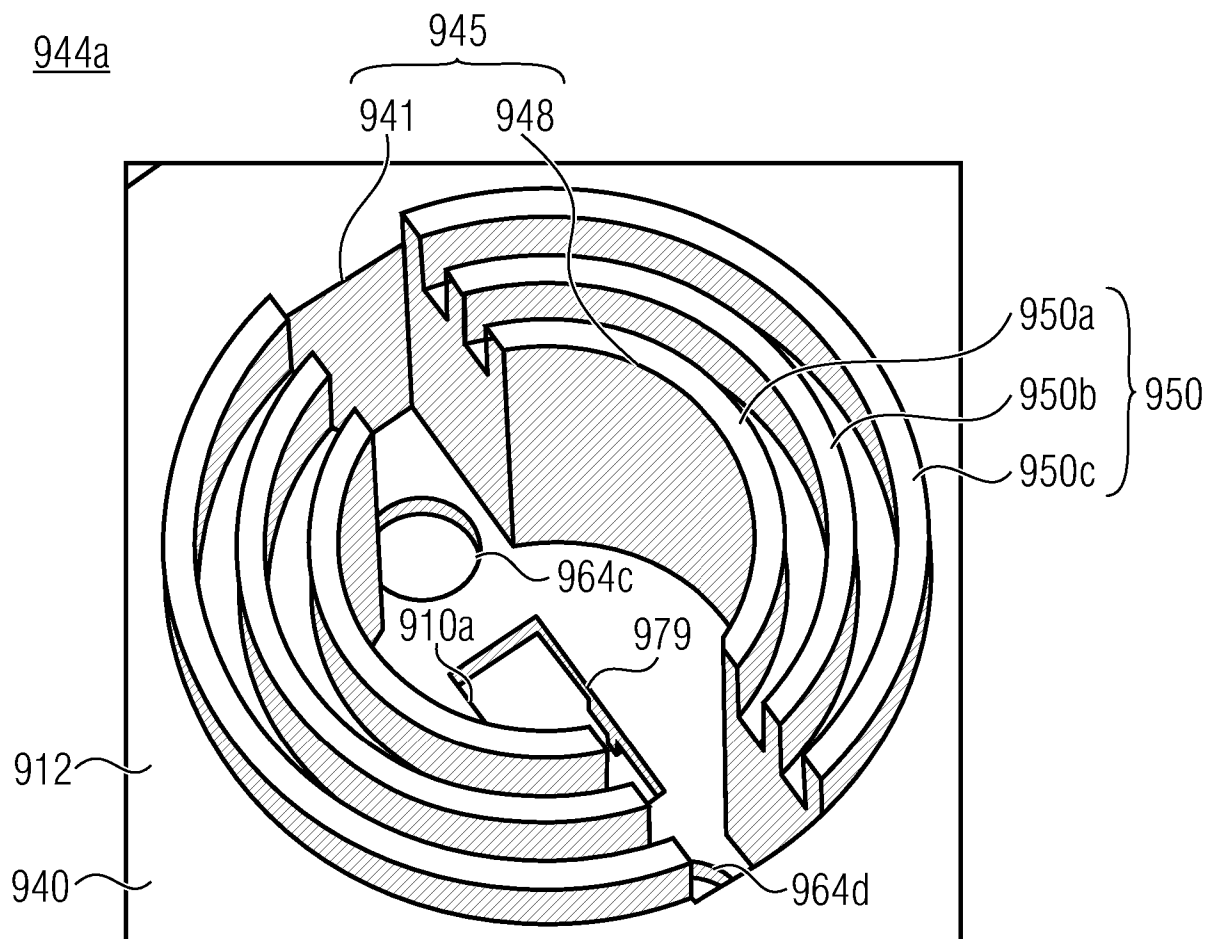


Fig. 11A

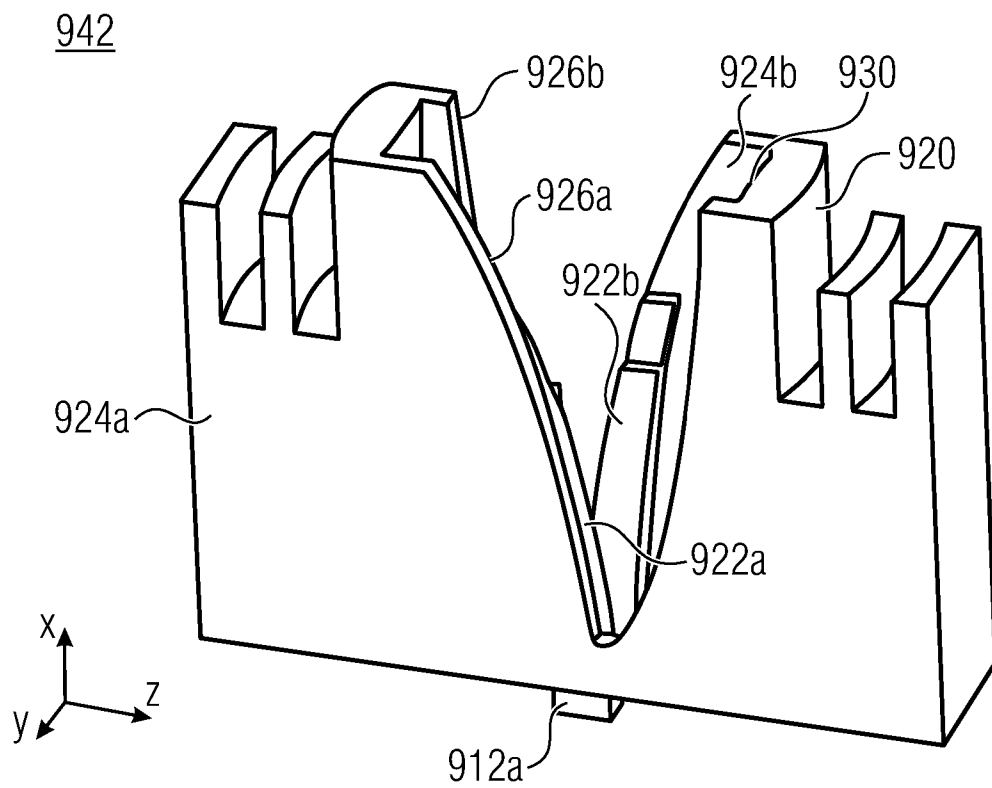


Fig. 11B

1200

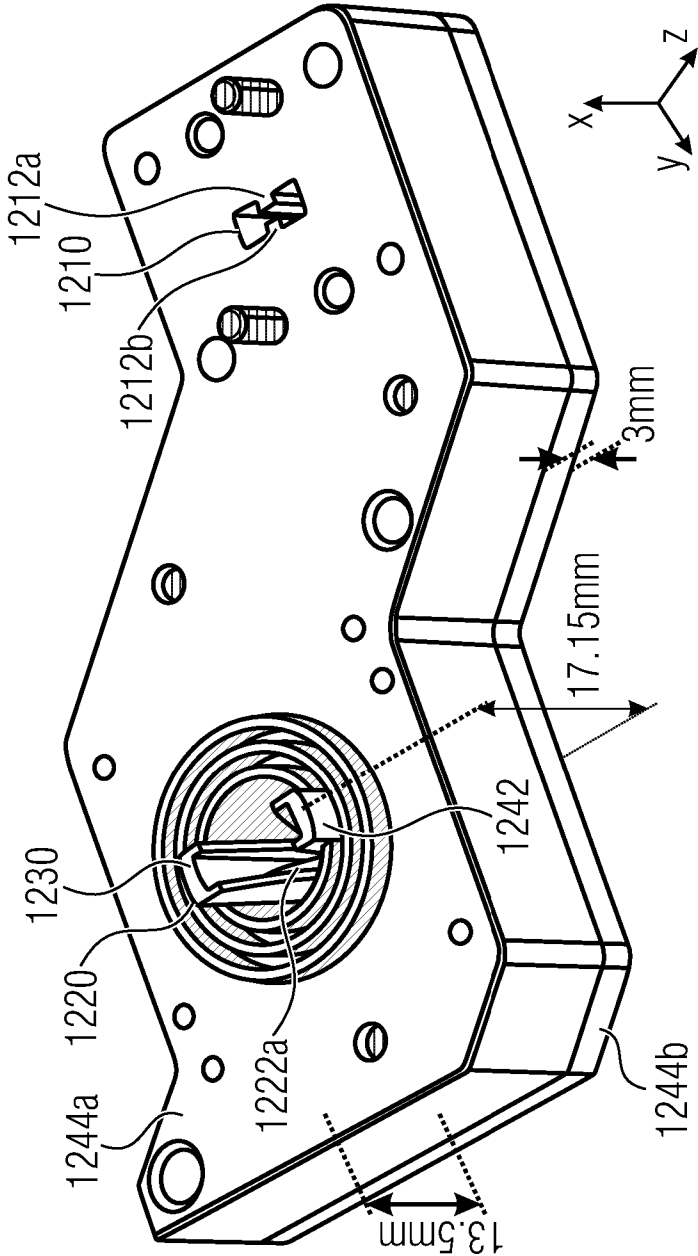


Fig. 12A

1200

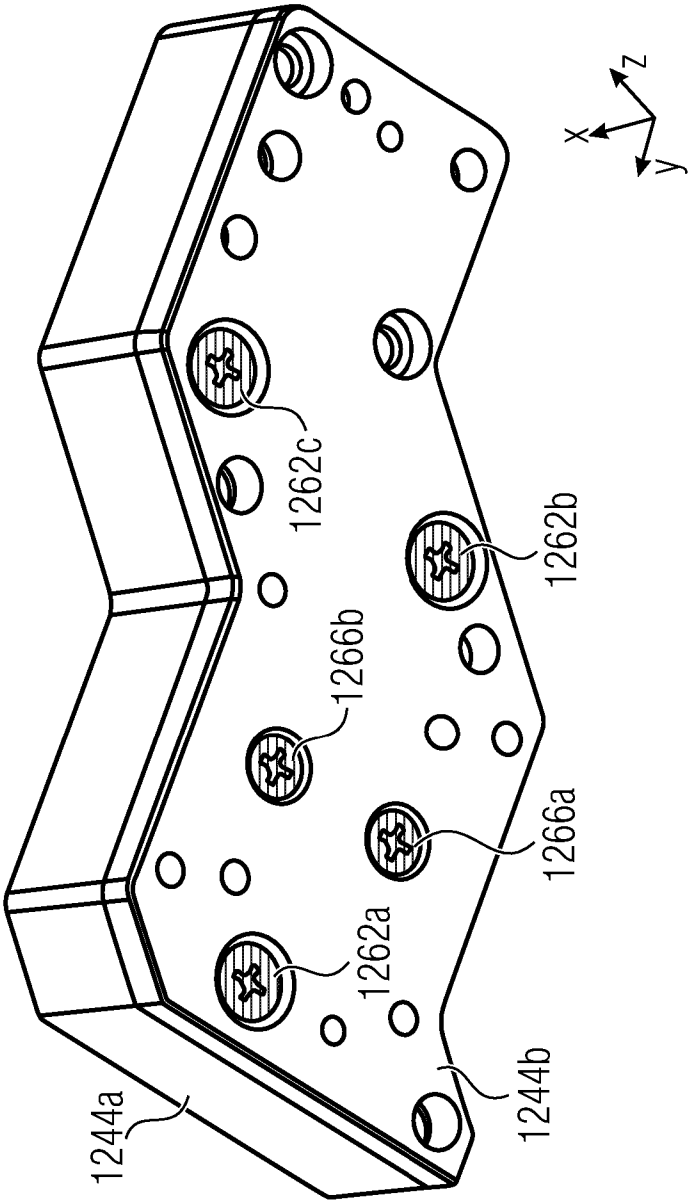


Fig. 12B

1200

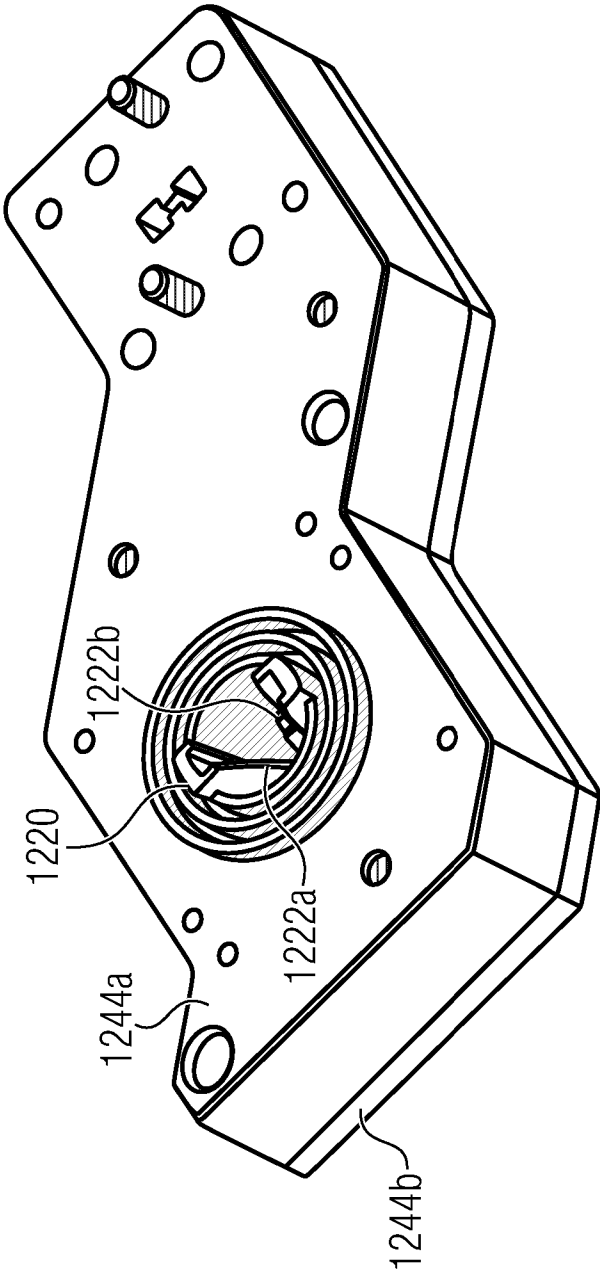


Fig. 13A

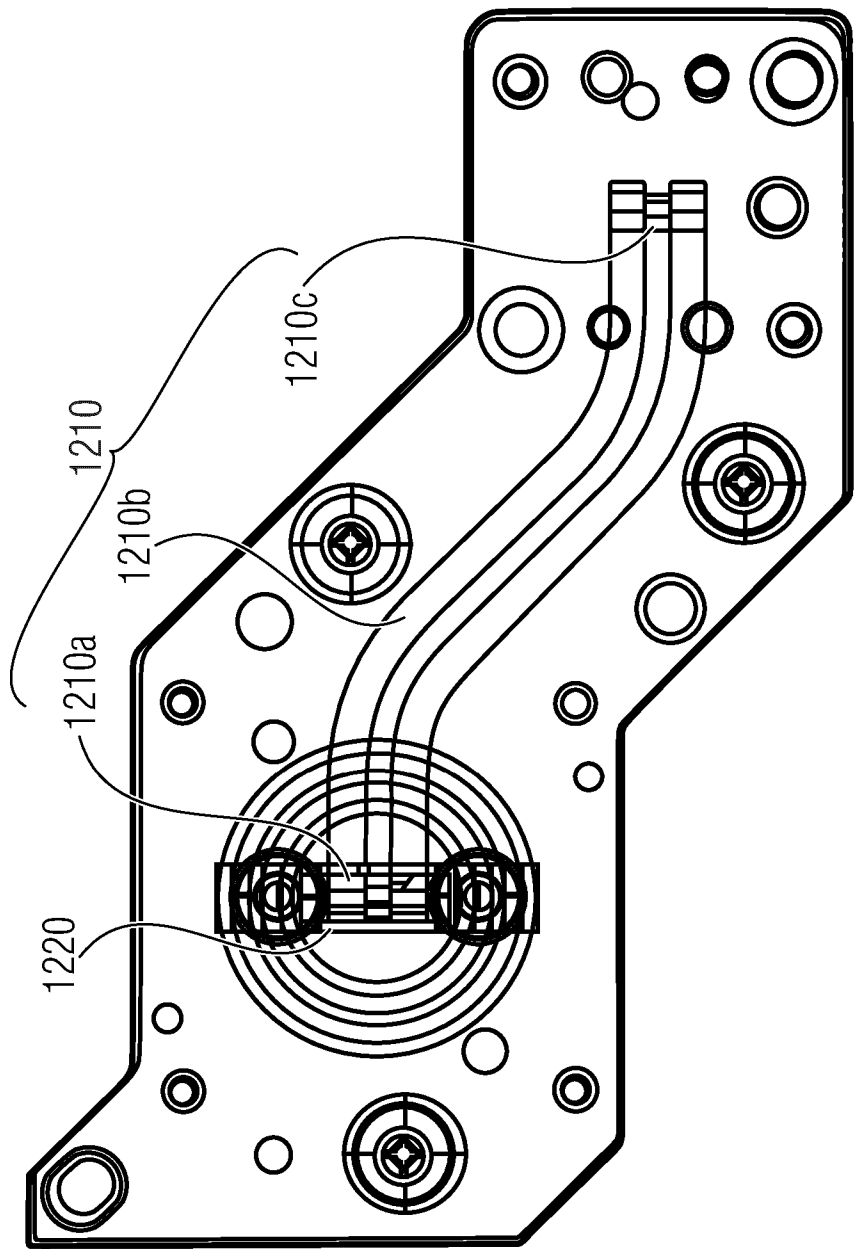


Fig. 13B

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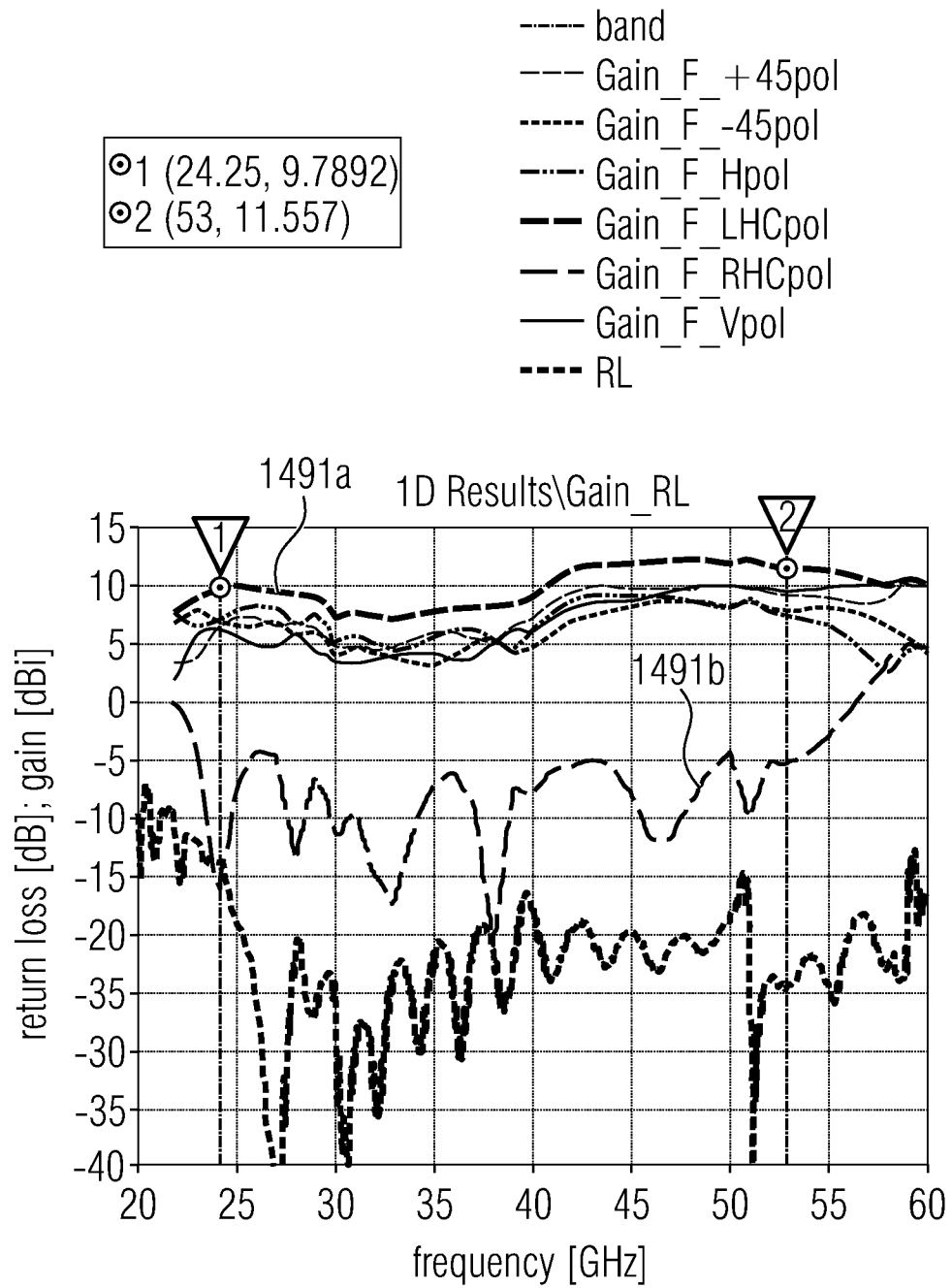


Fig. 14A

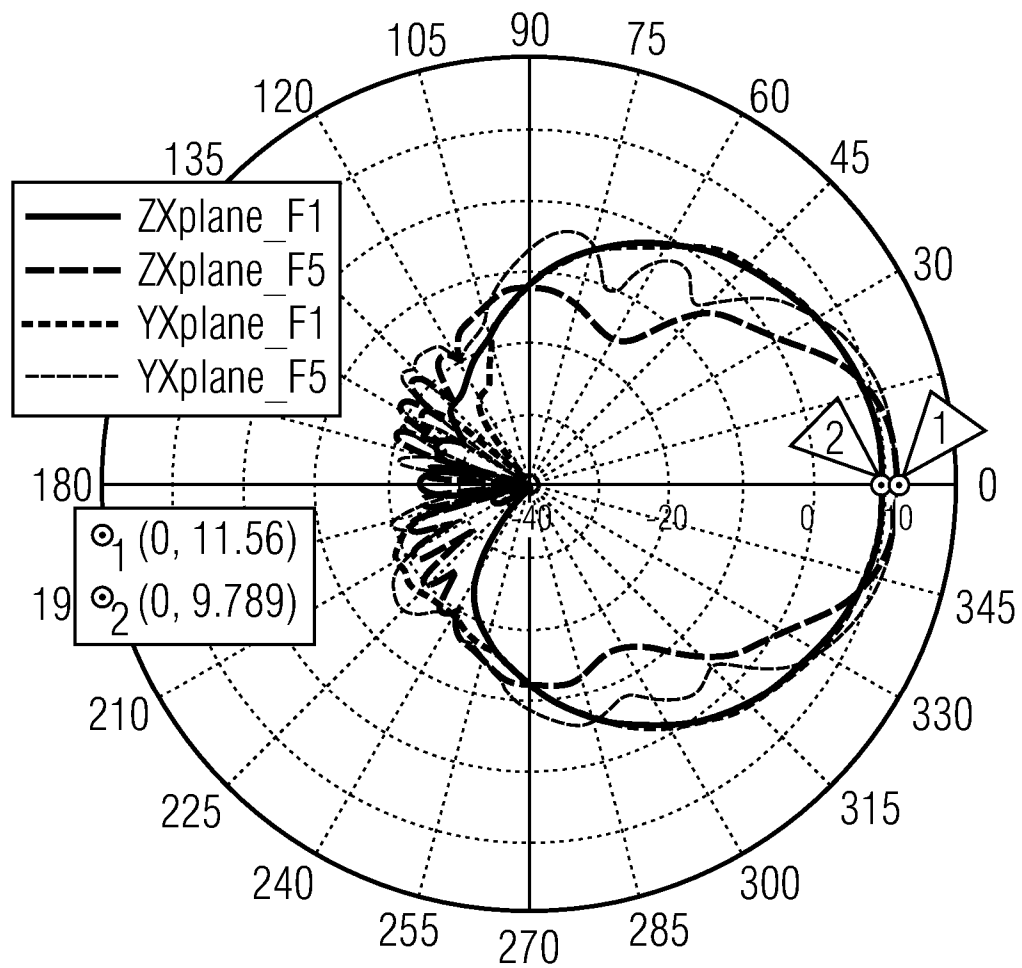


Fig. 14B

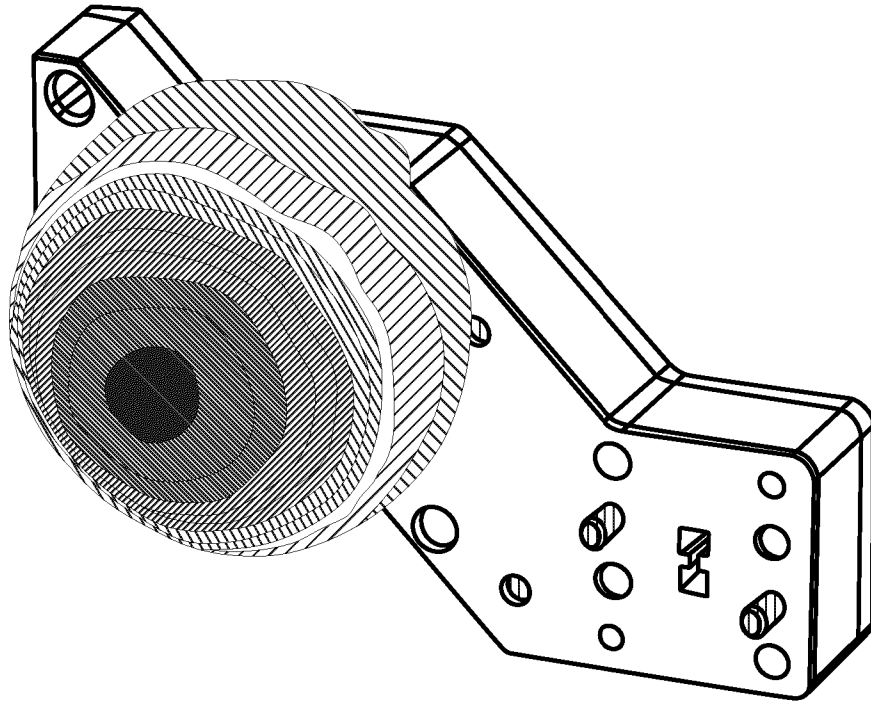


Fig. 15A

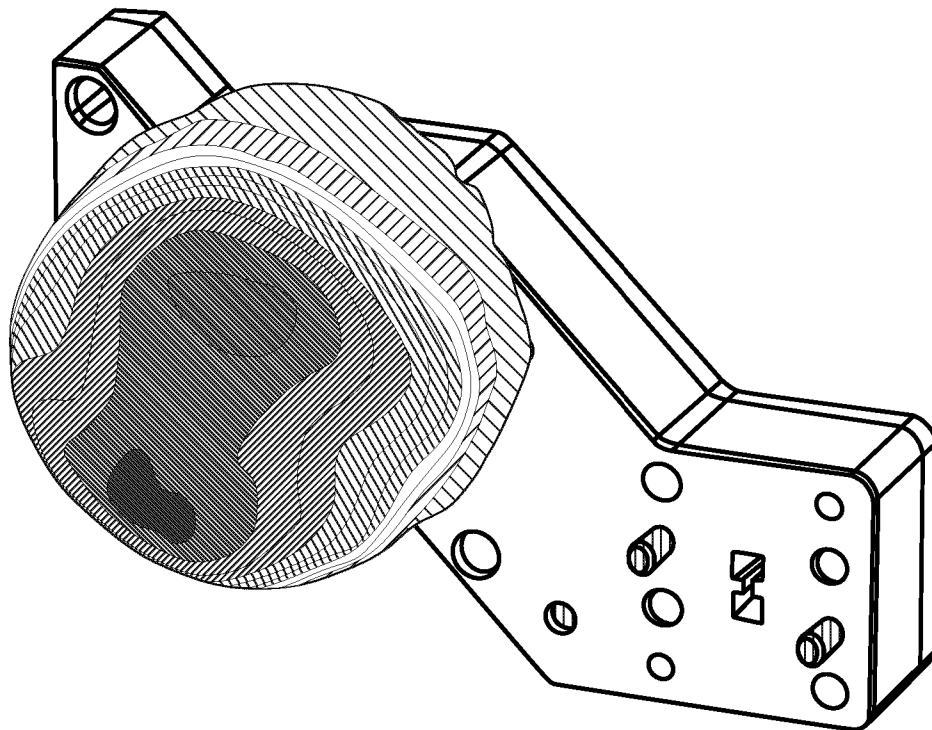


Fig. 15B

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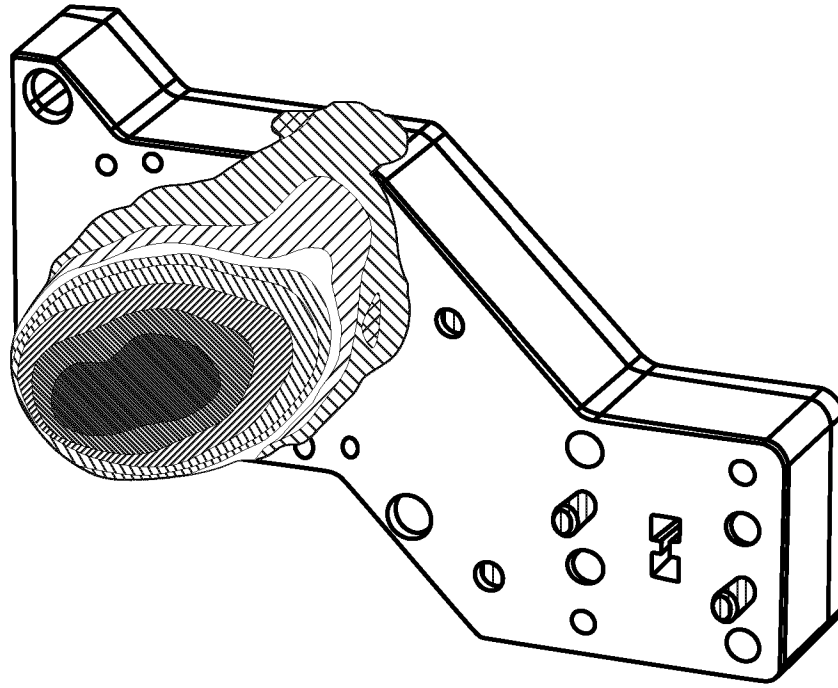


Fig. 15C

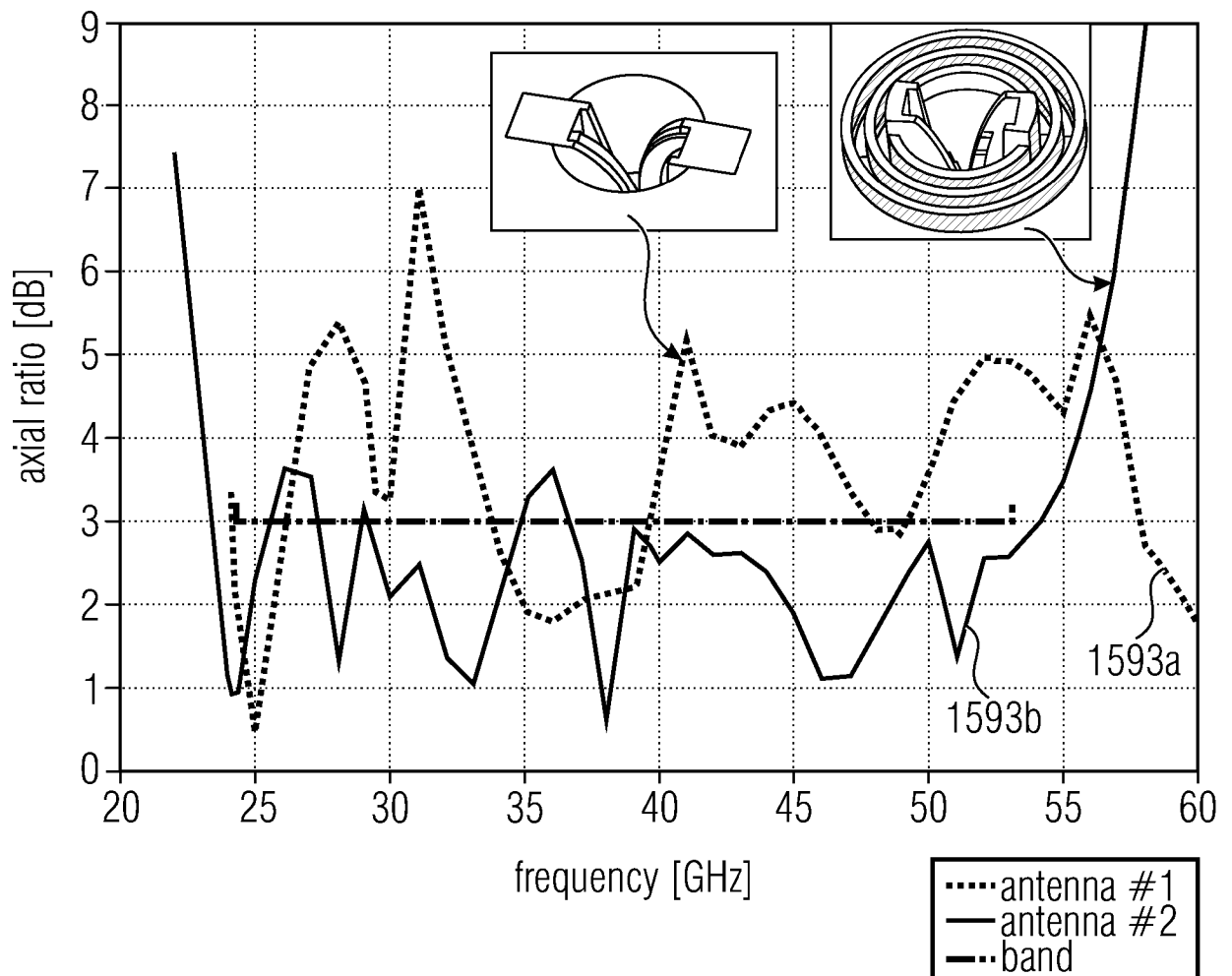


Fig. 15D

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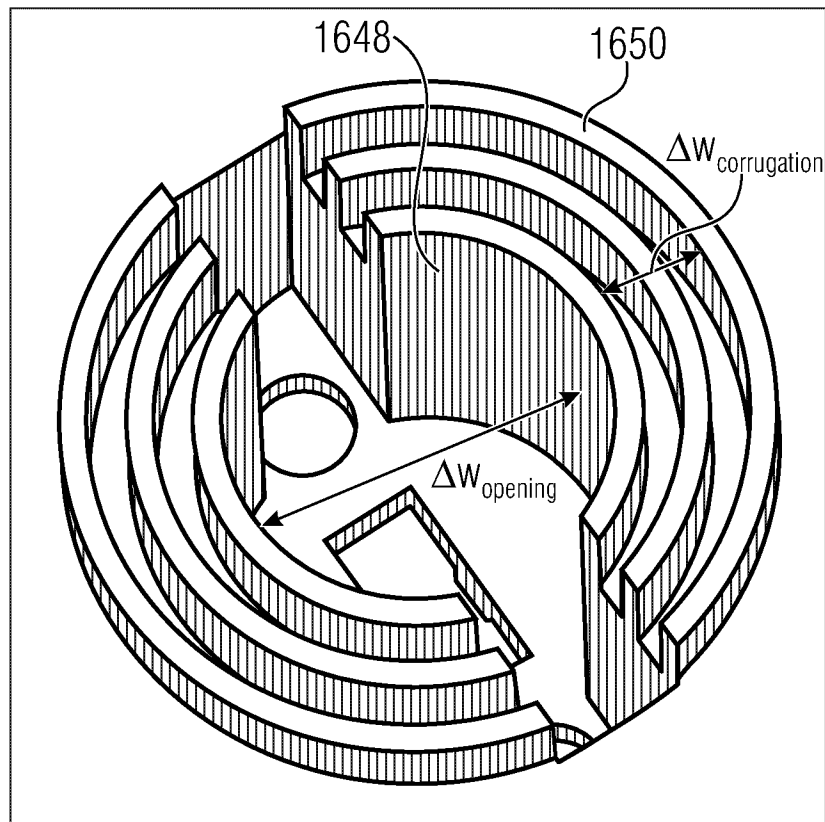
1600

Fig. 16A

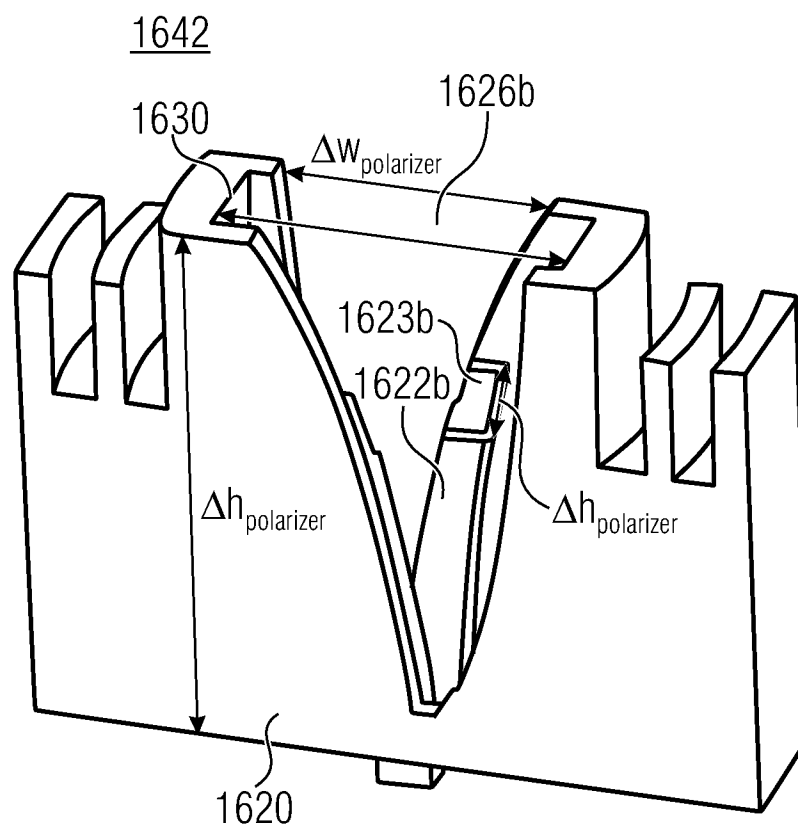


Fig. 16B

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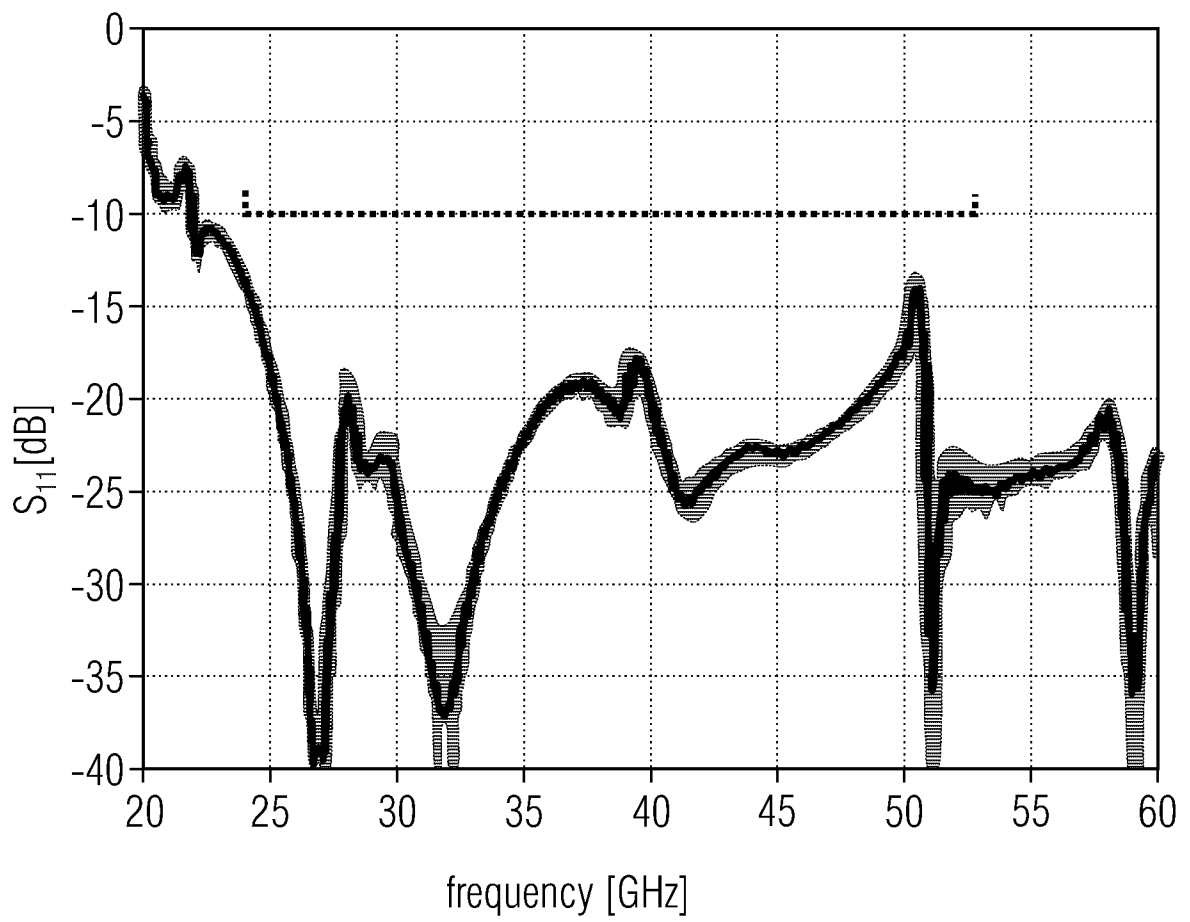


Fig. 16C

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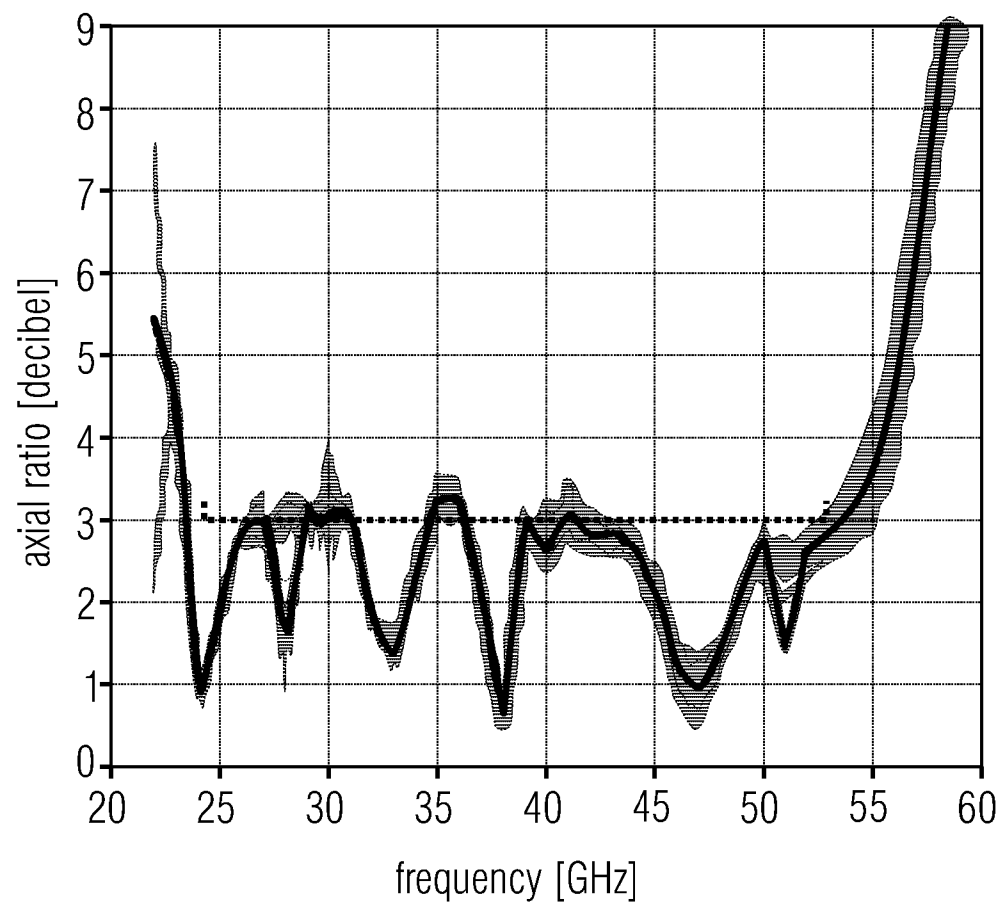


Fig. 16D

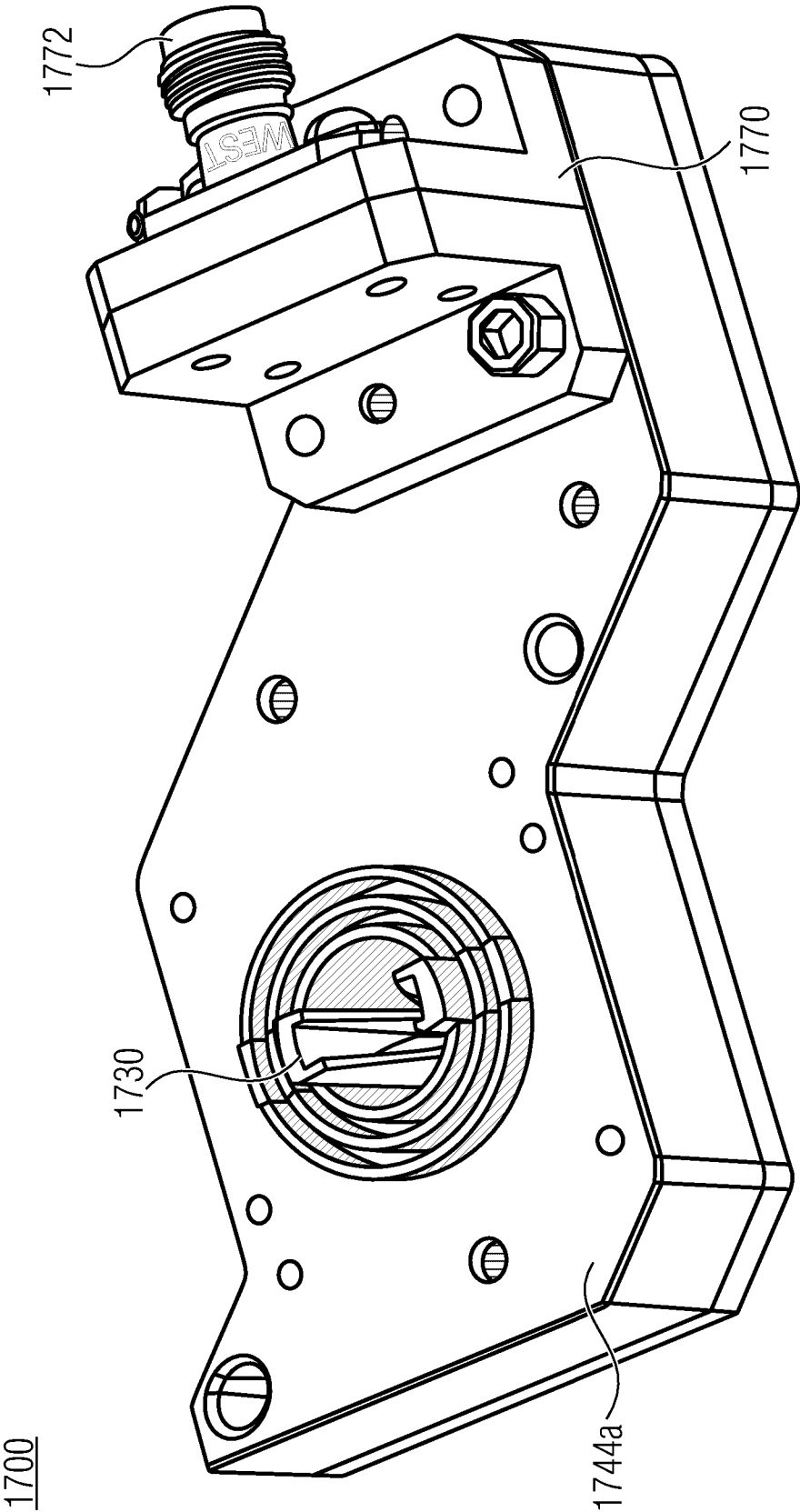


Fig. 17A

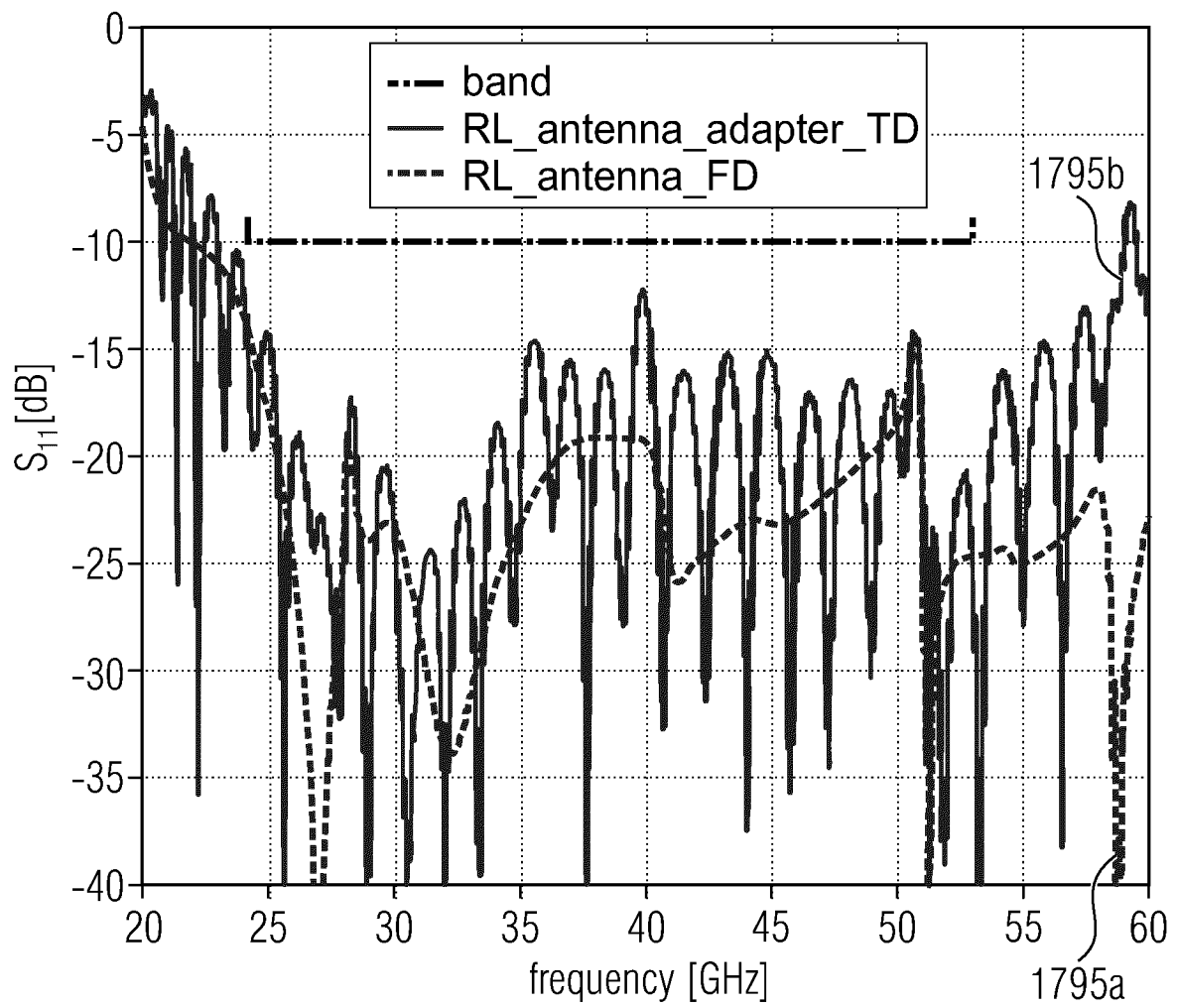


Fig. 17B

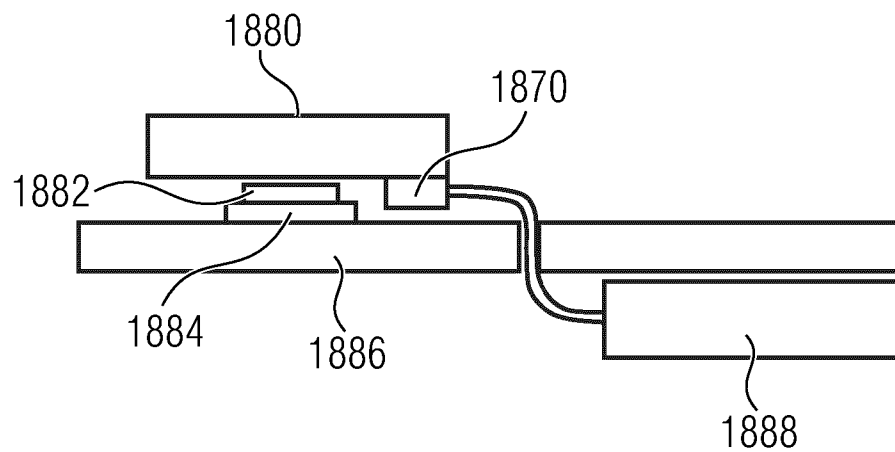


Fig. 18

1980

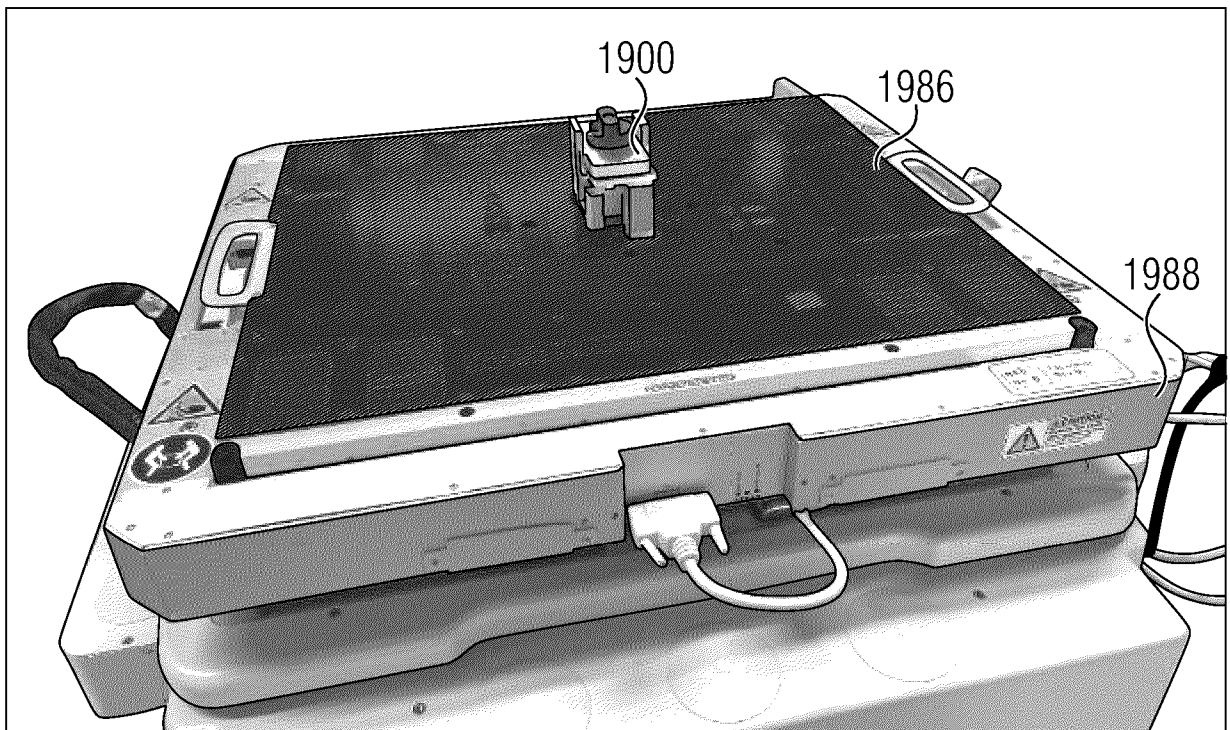


Fig. 19

1980

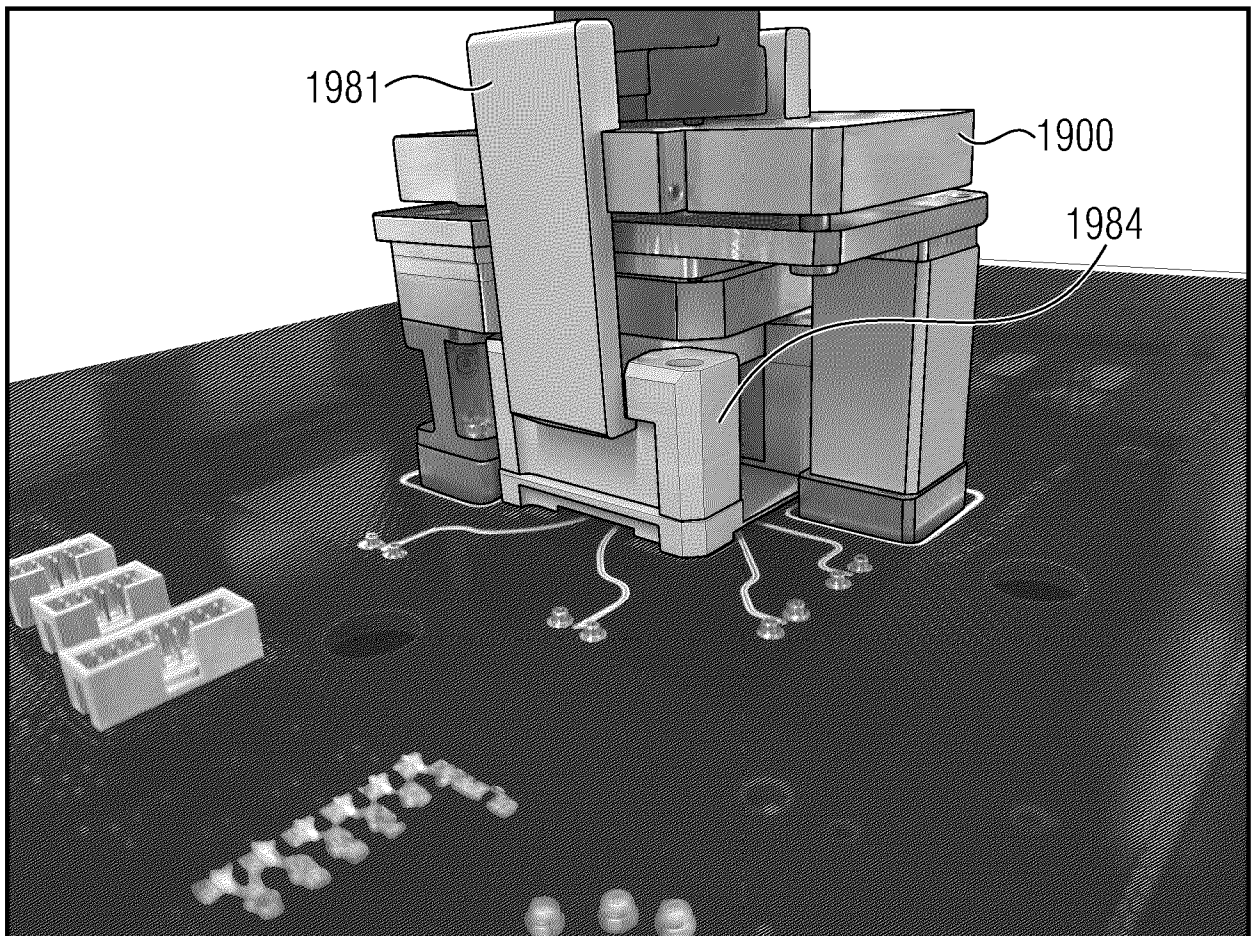


Fig. 20

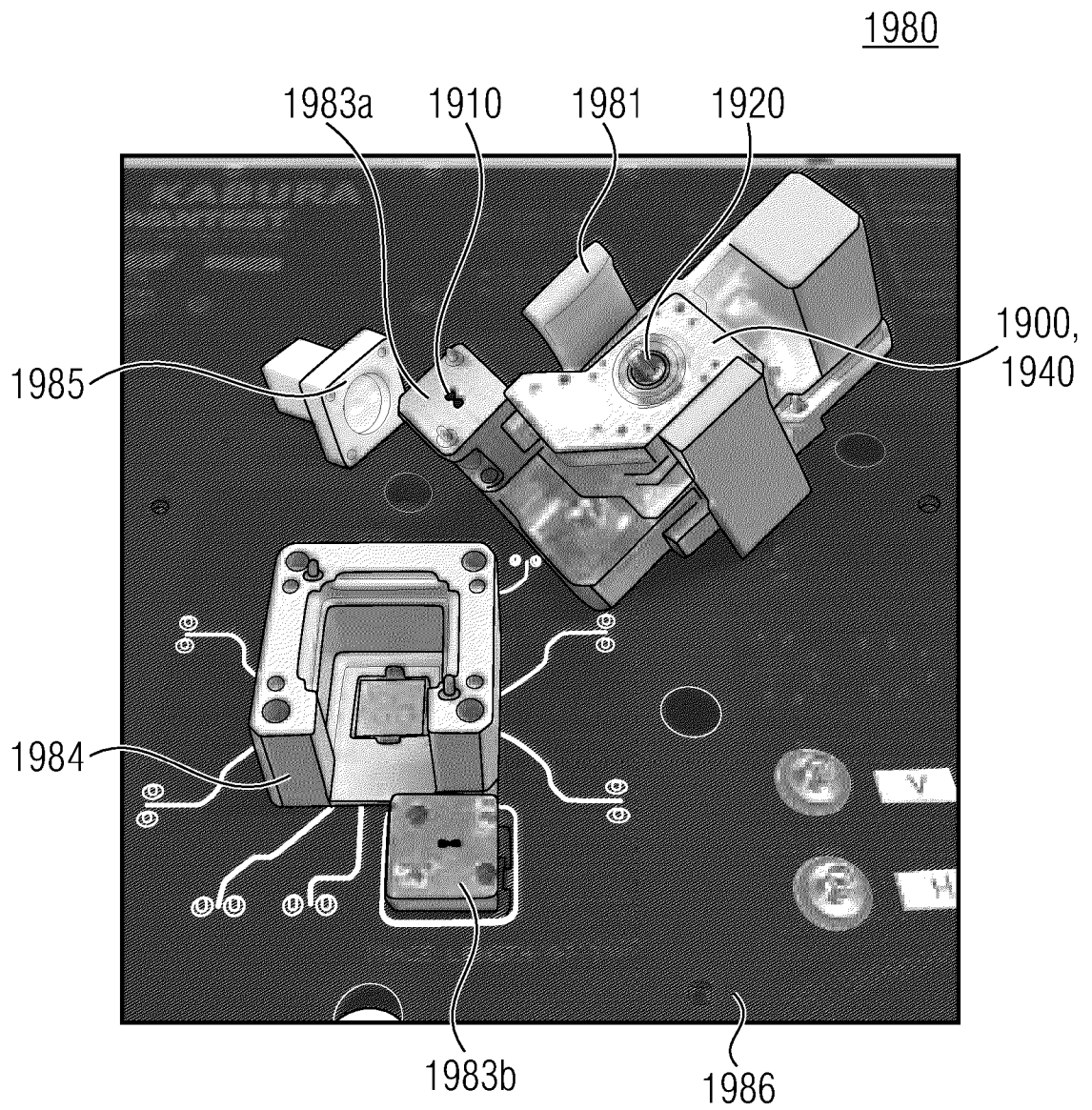


Fig. 21

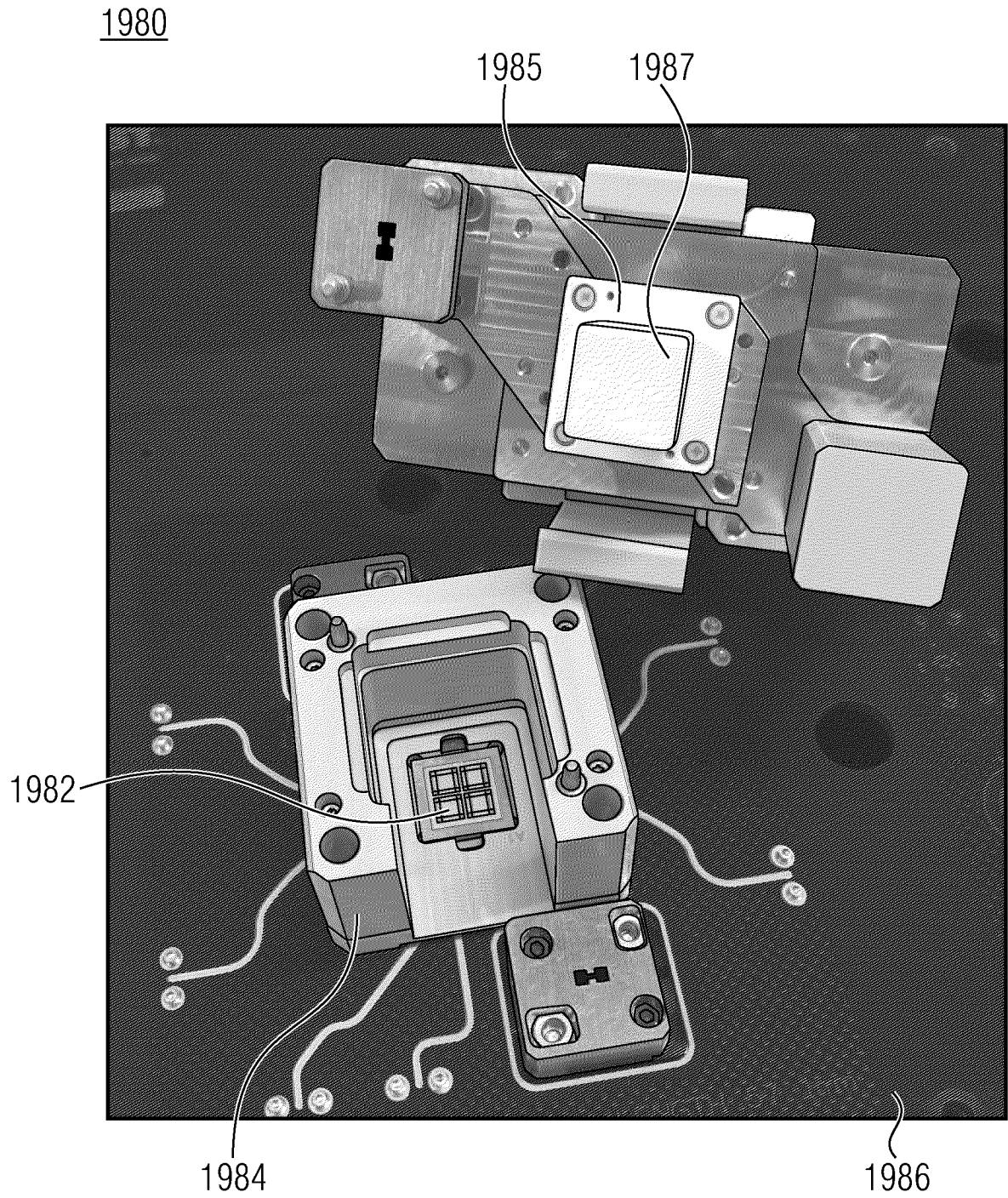


Fig. 22

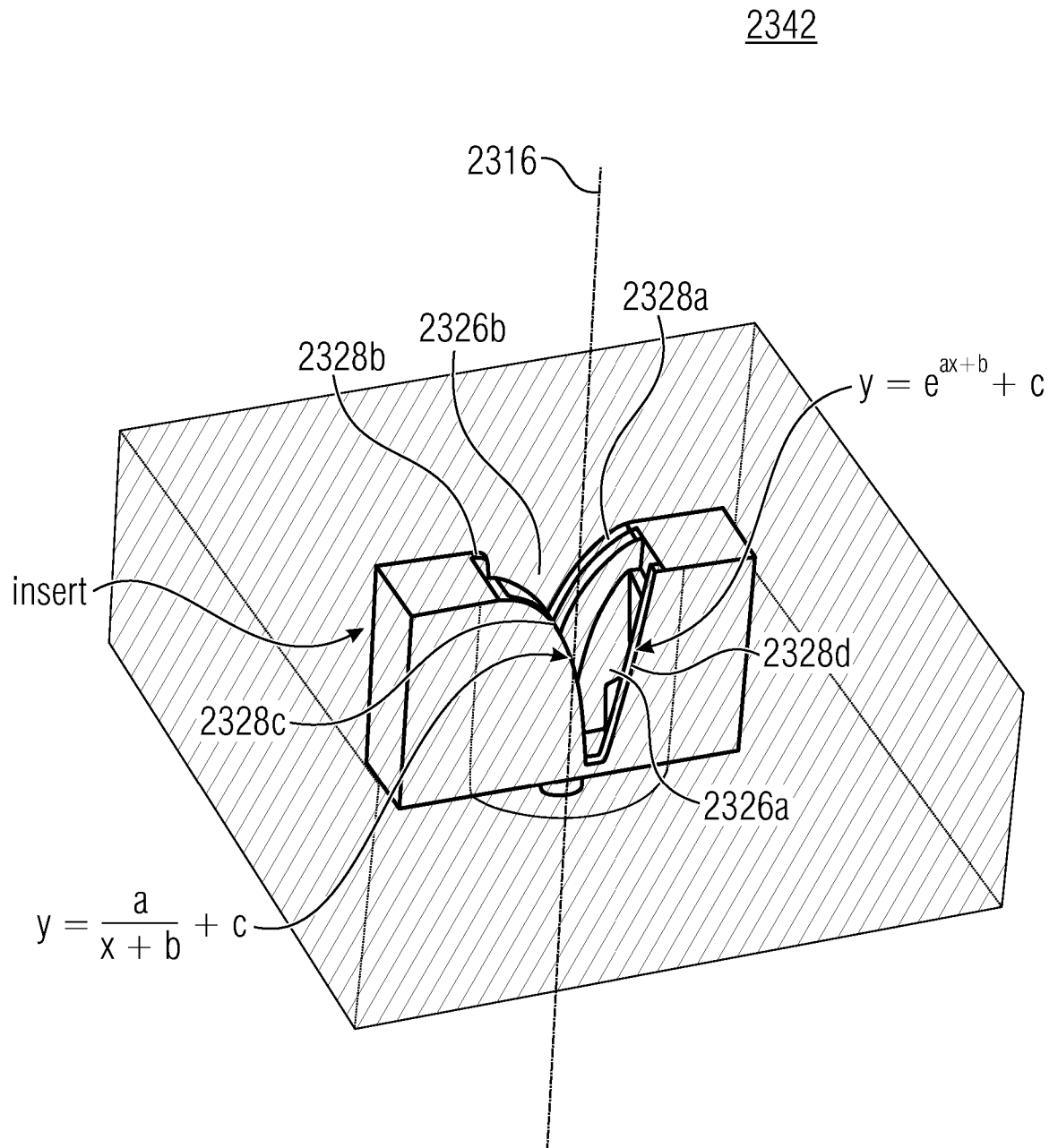


Fig. 23

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2023/068801

A. CLASSIFICATION OF SUBJECT MATTER INV. H01Q13/02 ADD. H01Q13/08		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) H01Q		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	LU KAI ET AL: "3-D-Printed Circularly Polarized Twisted-Ridge Horn Antenna", IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, IEEE, USA, vol. 69, no. 3, 22 October 2020 (2020-10-22), pages 1746-1750, XP011842531, ISSN: 0018-926X, DOI: 10.1109/TAP.2020.3031764 [retrieved on 2021-03-02] pages 1-5; figures 1-9 -----	1, 2, 6, 7, 22-26, 29
X	CN 115 117 632 A (CHENGDU XINMANG ELECTRONIC TECH CO LTD) 27 September 2022 (2022-09-27) pages 1-6; figures 1-4 ----- --/--	1, 6, 7, 22-26, 29
☒ 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 "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 18 January 2024		Date of mailing of the international search report 31/01/2024
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer El-Shaarawy, Heba

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2023/068801

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CHENG XIAOHE ET AL: "Analysis and Design of a Low-Cost Circularly Polarized Horn Antenna", IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, IEEE, USA, vol. 66, no. 12, 1 December 2018 (2018-12-01), pages 7363-7367, XP011702312, ISSN: 0018-926X, DOI: 10.1109/TAP.2018.2867024 [retrieved on 2018-11-29]	1, 2, 4-13, 18, 19, 22-29
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X	----- LIU YONG ET AL: "Millimeterwave and Terahertz Waveguide-Fed Circularly Polarized Antipodal Curvedly Tapered Slot Antennas", IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, IEEE, USA, vol. 64, no. 5, 1 May 2016 (2016-05-01), pages 1607-1614, XP011611504, ISSN: 0018-926X, DOI: 10.1109/TAP.2016.2536174 [retrieved on 2016-05-03] pages 1-7; figures 1-15	1, 4-14, 19, 25-27, 29
A	----- US 6 489 931 B2 (EMC TEST SYSTEMS LP [US]) 3 December 2002 (2002-12-03) columns 1-9; figures 1-7	29
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Information on patent family members

International application No

PCT/EP2023/068801

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