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(54) **Title**: ADAPTER PLATE AND ANTENNA ASSEMBLY

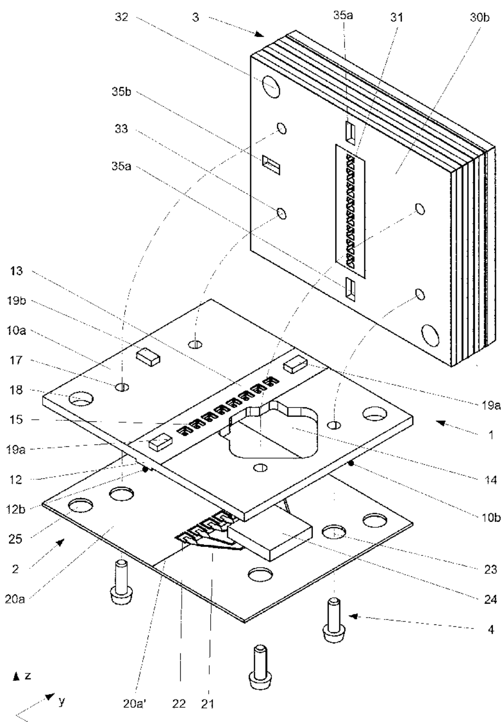

Fig. 3

(57) Abstract: Disclosed is an adapter plate (1) for high-frequency coupling a flat waveguide structure of a printed circuit board (PCB) to a waveguide coupling structure of an antenna (3), the adapter plate (1) being designed to be sandwiched between the PCB (2) and the antenna (3), the adapter plate (1) including:- an antenna-facing adapter surface (10a);- a PCB-facing adapter surface (10b), the PCB-facing adapter surface (10b) being adjacent to the antenna-facing adapter surface (10a); a number of adapter waveguide channels (15) extending inside the adapter plate (1) between the antenna-facing adapter surface (10a) and the PCB-facing adapter surface (10b), wherein a cross sectional contour of the adapter waveguide channels (15) varies along a channel length between the PCB-facing adapter surface (10b) and the antenna-facing adapter surface (10a). Disclosed is further an antenna assembly with an adapter plate and a method for manufacturing an antenna assembly.

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Adapter plate and antenna assembly

Technical field

The present invention lies in the field of high-frequency and waveguide technology. More particularly, it lies in the field of coupling an antenna and a printed circuit board (PCB) via waveguide elements.

Background

In the file of high-frequency electronics, it is generally known to use waveguides rather than wired or galvanic connections for the transmission of signals between different elements, components and assemblies. The waveguides are typically realized by tube- or channel-like elongated hollow structures with metallic or metalized sidewalls. The waveguides may, e. g. be of circular, square or rectangular cross section. It is further known to provide ridges that extend along the length of the waveguide and into its hollow area in order to influence or modify the high frequency characteristic, in particular regarding the characteristic impedance and/or frequency band.

An application where signals between different assemblies may be transmitted via waveguides to which reference is made in the following is the operative coupling between a printed circuit board (PCB) and an antenna.

Summary of invention

In high frequency electronics, matching of the characteristic impedance between the components as well as the connecting transmission lines, e. g. waveguides, is of major importance. Ideally, the specific impedance of all involved components would be identical, which, however, is hardly achievable in many practical applications due to various constraints. In any case, large steps in the characteristic impedance at the interface between different components respectively between components and waveguides should be avoided.

Furthermore, it is often desirable to couple high frequency components not only for the high frequency signal transmission, but to also to provide a robust and reliable mechanical coupling, favourably at the same time and with a small number of operations, respectively.

The US5361049 discloses a transition from double ridge waveguide to suspended substrate. However, this solution is comparatively complex and limited to suspended substrate on the PCB side.

The WO 20121123473A discloses a transition between a microstrip and a substrate integrated waveguide. The transition comprises a rectangular waveguide having a floor, side walls, a ceiling, and a transition end. The rectangular waveguide, at the transition end thereof, is coupled to the substrate integrated waveguide at a first end of the substrate integrated waveguide, wherein the microstrip is coupled to the substrate integrated waveguide at a second end thereof, and wherein the rectangular waveguide comprises a ridge attached to the ceiling, extending along a portion of the rectangular waveguide, and having a first end portion which is engaged with a portion of a top surface of the substrate integrated waveguide at its first end.

It is an overall objective to provide a waveguide transition that generally improves the state of the art regarding the coupling of high frequency components, in particular a PCB and an antenna, such as antenna. Favourably, the transition allows a compact and robust arrangement of a PCB and an antenna in a common, compact unit and/or of an antenna and a PCB with different characteristic impedances of the PCB and antenna transmission line interfaces.

The overall objective is achieved by the subject matter of the independent claims. Particularly favourable as well as general exemplary embodiments are defined by the subject matter of the dependent claims as well as the overall disclosure of the present documents. Particular advantages of the invention in general as well as of particular embodiments are discussed further below in context of the overall description.

In an aspect the overall objective is achieved by an adapter plate for high-frequency coupling of a flat waveguide structure of a printed circuit board (PCB) to a waveguide coupling structure of an antenna. The adapter plate serves as a transition between the PCB and the antenna. The adapter plate is designed to be sandwiched between the PCB and the antenna. The adapter plate includes an antenna-facing adapter surface and a PCB-facing adapter surface, the PCB-facing adapter surface being adjacent to the antenna-facing adapter surface. A number of adapter waveguide channels extends inside the adapter plate between the antenna-facing adapter surface and the PCB-facing adapter surface, wherein a cross sectional contour of the adapter waveguide channels varies along a channel length between the PCB-facing adapter surface and the antenna-facing adapter surface. Each of the adapter waveguide channel ends in a PCB-facing channel opening in the PCB-facing adapter surface. Similarly, each of the adapter waveguide channel ends in antenna-facing channel opening in the antenna-facing adapter surface.

The cross-sectional contour of the adapter waveguide channels is given by the channel footprint perpendicular to the longitudinal channel axis. While not being essential, all adapter waveguide channels are typically of identical geometry and dimensions. The adapter waveguide channels are favourably straight, i. e. spatially non-curved. Further, the adapter waveguide channels do typically not comprise branches but each establish a point-to-point connection between a PCB-facing channel-openings and the corresponding antenna-facing channel opening.

In the mounted state, an adapter-facing antenna surface contacts the antenna-facing adapter surface and an adapter-facing PCB surface contacts the PCB-facing adapter surface.

As will be explained below in more detail, the adapter plate is designed to serve, in a mounted state, as part of an antenna assembly, as intermediate element or coupling element between the antenna and the PCB and ensures proper high-frequency coupling between the antenna and the PCB. A resulting antenna assembly may especially have a flat sandwich–like structure with the PCB, the adapter plate, and the antenna each forming a sandwich layer.

Each of the adapter waveguide channels is designed and arranged to provide a one-to-one high frequency coupling (microwave coupling) between an antenna waveguide coupling opening of the waveguide coupling structure of the antenna and a corresponding PCB waveguide coupling opening of the flat waveguide structure of the PCB. The PCB waveguide coupling openings of the PCB are arranged in the adapter-facing PCB surface and the antenna waveguide coupling openings of the antenna are arranged in the adapter-facing antenna surface.

The adapter plate may be from metal and/or is metal-plated respectively metalized. The adapter plate may, for example be made from metalized respectively metal-plated plastics. The metal plating of such embodiments may cover the whole plastic surface, or may only cover functionally relevant areas, in particular the inner wall surfaces of the adapter waveguide channels and an area of each of the antenna-facing adapter surface and the PCB-facing adapter surface around the adapter waveguide channels. The plating may be made of a high-conductive and solderable metal, e. g. copper or silver. For an adapter plate that is made of metal, such metal may, e. g. be brass that is also optionally fully or partly coated or plated. In typical embodiments, the adapter plate is made from a single piece of material. Making the adapter plate from plastics is particularly favourable and economic in (large scale) series production, while making the adapter plate from metal avoids the need for moulds and is, therefore, particularly suited for small series, prototyping, and testing applications.

The adapter plate is designed to galvanically couple, in a mounted state, to the PCB and the antenna. With other words, the antenna and the PCB galvanically couple via the adapter plate as an intermediate element. Consequently, the PCB, the antenna and the adapter plate are electrically connected to a common reference potential (e. g. ground, GND). Since the adapter plate is made from metal or at least the inner wall surfaces of the adapter waveguide channels are metal coated, they galvanically couple to the reference potential, too. As will be explained further below in more detail, the galvanic electric coupling between the PCB and the adapter plate is typically achieved by soldering. The combination of a PCB and an adapter plate in the galvanically and mechanically connected state is also referred to as PCB-adapter-stack. The galvanic electric coupling between the adapter plate and the antenna is typically achieved by mechanical pressing. An adapter plate as described before and further below may be used in a wide frequency range of typically 45 GHz to 80 GHz.

In a mounted state, the galvanic coupling between the PCB and the adapter plate is such that the PCB waveguide coupling openings and the PCB-facing channel openings of the associated adapter waveguide channels are fully surrounded by a galvanic coupling in an island-like way. Similarly, the galvanic coupling between the adapter and the antenna is such that the antenna waveguide coupling openings and the antenna-facing channel openings of the associated adapter waveguide channels are fully surrounded by a galvanic coupling in an island-like way.

In addition to the general high-frequency coupling of antenna and PCB, the adapter waveguide channels provide an impedance matching between the PCB waveguide coupling openings and associated planar transmission lines of the PCB on the one hand, and the antenna waveguide coupling openings on the other hand. The course of the cross section and the footprint favourable for best matching may be numerically computed for a given antenna and PCB design. It is noted that the term "matching" does, in the context of the present disclosure, not necessarily imply an ideal matching in a strict mathematical sense, but a matching that is suited for the required signal transmission between antenna and PCB.

The adapter plate has dimensions of the PCB-facing adapter surface and the antenna-facing adapter surface that are large as compared to the distance between the PCB-facing adapter surface and the antenna-facing adapter surface or plate thickness. The waveguide adapter channels generally extend in the thickness direction of the adapter. In some typical embodiments, a footprint of the adapter, as defined by the PCB-facing adapter surface and/or the antenna-facing adapter surface, is rectangular or square. Other footprint geometries, however, may be used as well, in dependence of the PCB and/or antenna geometry.

In some embodiments, the adapter plate is designed to mechanically rigidly couple the adapter plate with the PCB and/or the antenna, e. g. via screwing, to form a common compact unit with the PCB and/or the antenna. In an exemplary embodiment of such design, through-holes are provided in the PCB and the adapter for fixing via screws with self-cutting threads in the antenna. Alternatively or additionally, coupling of the adapter plate and the antenna, the antenna and the PCB may be achieved via an additional separate fixture, frame, clamping structure, or the like.

In an embodiment, the cross sectional area of the adapter wave-guide channels increases from the PCB-facing adapter surface to the antenna-facing adapter surface.

In an embodiment, the antenna-facing adapter surface and the PCB-facing adapter surface are coplanar. This type of embodiment defines the typical plate-shaped design. Favourably, the antenna-facing adapter surface and the PCB-facing adapter surface are each generally planar. Local exceptions may be present on the PCB-facing surface and/or the antenna-facing surface in from of projections, recesses, ridges, or the like, thus deviating from a strictly planar surface geometry. In alternative embodiments, the PCB-facing surface and the antenna-facing surface are each substantially planar, but not coplanar, but angled.

A typical PCB has also adjacent coplanar surfaces. Typically, the antenna may also have adjacent planar and coplanar outer surfaces, with one of the outer surfaces being the adapter-facing antenna surface and having the antenna waveguide coupling openings, the adjacent outer surface having waveguide openings, e. g. horn-shaped waveguide openings for transmitting and/or receiving electromagnetic waves. The antenna may be realized as a stack of coplanar layers. In such embodiments, an antenna assembly with a PCB, an adapter plate in accordance with the present disclosure, and an antenna forms a stack of coplanar layers.

In an embodiment, the adapter waveguide channels extend in or parallel to a normal direction of the adapter plate. With other words, for a coplanar design as discussed before, the adapter waveguide channels are arranged traverse, in particular perpendicular, to the antenna-facing adapter surface and the PCB-facing adapter surface. With other words, the adapter waveguide channels extend in a longitudinal channel direction parallel to a normal direction of the adapter plate. Here, the PCB-facing channel openings and the antenna-facing channel openings are normal to the longitudinal channel direction. While other arrangements, e. g. with inclined waveguide channels, are possible, a traverse arrangement is assumed in the following.

In an embodiment, the adapter waveguide channels are single-ridge waveguide channels. A channel ridge of each channel extends along the length of an adapter waveguide channel thus reducing its effective surface, as generally known in the art. A channel ridge has the particular advantage of reducing the impedance of the waveguide channel. The geometry of the channel ridges generally varies along the channel length. In alternative embodiments, the adapter waveguide channels are double-ridge waveguide channels with two generally separate channel ridges at to opposite edges of the waveguide channels.

In an embodiment, the cross sectional contour of the adapter waveguide channels varies along the channel length between the PCB-facing adapter surface and the antenna-facing adapter surface continuously. This type of embodiment is particularly favourable if the adapter plate is, including the adapter waveguide channels, manufactured via injection moulding, typically from plastics.

In an embodiment, the cross sectional contour of the adapter waveguide channels varies along the channel length between the PCB-facing adapter surface and the antenna-facing adapter surface in a number of discrete steps. This type of embodiment is particularly favourable where the adapter waveguide channels, and typically the whole adapter plate, is manufactured via machining with a cutting tool. For such embodiments, the adapter plate is typically made from metal. The adapter waveguide channels may, e. g. be milled with a (miniature) end milling cutter.

In an embodiment, the adapter plate includes a PCB contact ridge, the PCB contact ridge projecting from the generally planar PCB-facing adapter surface, wherein PCB-facing channel openings of the adapter waveguide channels are arranged on a PCB-contacting ridge surface of the PCB contact ridge. The PCB contact ridge may especially have a planar or flat PCB-contacting ridge surface that is parallel to the general PCB-facing adapter surface. The PCB contact ridge and in particular the PCB-contacting ridge surface is made from metal and/or is metal-plated as explained before and ensures good electrical contact of the PCB and the adapter plate in the area or the PCB-facing channel openings respectively adapter waveguide channels, and the PCB. Via the PCB contact ridge respectively the PCB-contacting ridge surface, the PCB and the adapter plate may be galvanic coupled by soldering. The overall cross section of the PCB contact ridge, may e. g. be rectangular.

In an embodiment, the adapter plate includes contact spacers, the contact spacers projecting from the generally planar PCB-facing adapter surface. The contact spacers may, similar to a PCB contact ridge as described before, have planar or flat PCB-contacting spacer surfaces parallel to the general PCB-facing adapter surface. Further like a PCB contact ridge as described before, the contact spacers and in particular the PCB-contacting spacer surfaces may be made from metal and/or be metal-plated as explained before for soldering to the PCB. Typically, a number of, e. g. four contact spacers is present in the area of the corners respectively edges of the adapter plate. In favourable embodiments, the contact spacers are of identical height or thickness, such that all PCB-contacting spacer surfaces lay in a common plane, parallel to and spaced apart from the general PCB-facing adapter surface. In a particularly favourable embodiment with both a PCB contact ridge and contact spacers, the PCB-contacting ridge surface and the PCB-contacting spacer surfaces lay in a common plane. The contact spacers ensure that the PCB and the adapter plate are parallel and equally spaced apart over the whole area and further increase the mechanical stability. A symmetric arrangement of the contact spacers is generally favourable.

In an embodiment with a PCB contact ridge and/or contact spacers as explained before, a gap is present in an assembled state between the PCB and adapter plate, with exception of the contact ridge and/or contact spacers. The width or height of the gap corresponds to the thickness or height of the PCB contact ridge and/or contact spacers and being bridged by the PCB contact ridge and/or contact spacers. Favourably, the only coupling, in particular electrical coupling, between the PCB and the adapter plate is via the PCB contact ridge and/or contact spacers.

In an embodiment, the adapter plate includes through-going screw holes, the screw holes extending through the contact spacers. In such embodiments, the contact spacers additionally serve as mechanical supports via which a contact force –typically a pressing force – is transferred between the PCB, the adapter plate, and the antenna. By the screw holes extending through the contact spacers, a mechanical bending or deformation of the adapter plate and/or the PCB, which may otherwise result from the force that is exerted by the screws, is avoided. In a mounted state, the screws rigidly connect all three of the PCB, adapter plate and the antenna and also provide the contact force that is required between the adapter plate and the antenna for good electrical and waveguide high-frequency coupling.

In an embodiment, the adapter plate includes an antenna contact ridge, the antenna contact ridge projecting from the generally planar antenna-facing adapter surface, wherein an antenna-facing channel opening of the adapter waveguide channels is arranged on an antenna-contacting ridge surface of the antenna contact ridge.

An antenna contact ridge may be designed in the same way as a before-explained PCB contact ridge and have a corresponding shape. In an embodiment with an adapter contact ridge, the only contact between the antenna and the adapter is via the antenna contact ridge, while a gap is otherwise present between the adapter and the antenna. The height by which the antenna contact ridge projects beyond the antenna-facing adapter surface is typically smaller than the height of the PCB contact ridge since no further components are typically arranged on the antenna-facing adapter surface. In a typical setup, the antenna is coupled with the adapter plate by a pressing force, e. g. via screws, clamps or the like. The reduced contact surface between the adapter and the antenna that results from the antenna contact ridge favourably increases the contact pressure.

In an embodiment, the adapter plate includes alignment members for mechanical alignment of the adapter plate with the PCB and/or the antenna.

In an embodiment, the alignment members include alignment protrusions or alignment openings. The alignment protrusions or alignment openings are designed to mechanically engage counter alignment openings or counter alignment protrusions of the PCB or the antenna. Alignment openings may be through-going or may be recesses. Alternatively or additionally, the alignment members include through-going alignment bores to receive alignment pins.

The alignment members ensure that, in a mounted state and/or during mounting, the antenna waveguide coupling openings of the antenna, the adapter waveguide channels, and the PCB waveguide coupling opening of the PCB are in correct mutual alignment.

Alignment protrusions respectively alignment openings may be integrally formed into the adapter plate e. g. during injection moulding or milling as manufacturing process. While a variety of geometries may be used, alignment protrusions and/or alignment openings are of rectangular footprint in a typical exemplary embodiment. Alignment openings may be through-going or may be recesses.

Alignment bores may be provided as a number of, e. g. two fitting bores that may also be present in the PCB and/or the antenna. In this way, the adapter plate may be aligned with the PCB and/or the antenna via corresponding e. g. cylindrical alignment pins.

In an embodiment, the adapter plate includes a component recess or component cut-out. The component recess or component cut-out is arranged to receive at least part of a component that is mounted on and projects from the PCB in direction of the adapter plate. A cut-out may be through-going and extend between the PCB-facing adapter surface and the antenna-facing adapter surface. A recess may not be through-going (i. e. blind) and extend from the PCB-facing adapter side.

In another aspect, the overall objective is achieved by an antenna assembly. The antenna assembly includes an antenna, in particular an array antenna, the antenna having an adapter-facing antenna surface, the adapter-facing antenna surface having a waveguide coupling structure with number of antenna waveguide coupling openings. The antenna assembly further includes an adapter plate. The antenna assembly further includes a PCB, the PCB having flat waveguide structure with a number of PCB waveguide coupling openings. The adapter plate is sandwiched between the PCB and the antenna, such that each of the adapter waveguide channels is aligned with a corresponding antenna waveguide coupling opening and a corresponding PCB waveguide coupling opening. The adapter plate is an adapter plate according to an embodiment as described before and/or further below with reference to the figures. The PCB-facing adapter surface and the antenna-facing adapter surface may contact the adapter-facing PCB surface respectively the adapter-facing antenna surface over their whole surface areas. Alternatively, a PCB contact ridge and optional contact spacers may project from the PCB-facing adapter surface as explained before and a gap may, with exception of the PCB contact ridge and the contact spacers, be present between the PCB-facing adapter surface and the adapter-facing PCB surface. Likewise, an antenna contact ridge may project from the antenna-facing adapter surface and a gap may, with exception of the antenna-contact ridge, be present between the antenna-facing adapter surface and the adapter-facing antenna surface, as explained before.

The flat waveguide structure of the PCB comprises a number of flat waveguide elements. Each of the flat waveguide elements is typically not branched but provides a one-to-one coupling between a waveguide coupling element of a component, such as a microwave semiconductor component, on the PCB, and a corresponding PCB waveguide coupling opening.

The adapter plate of the antenna assembly may be an adapter plate according to any embodiment as described before and/or further below in the framework of exemplary embodiments. Likewise, the PCB respectively the antenna may be designed according to any PCB respectively antenna embodiment as described before and/or further below.

In another aspect, the overall objective is achieved by a method for manufacturing an antenna assembly as described before and/or further below. The method includes aligning the adapter plate and the PCB with respect to each other such that each of the adapter waveguide channels is aligned with a corresponding PCB waveguide coupling opening and the PCB-facing adapter surface is parallel to and faces the adapter-facing PCB surface.

The method further includes connecting, in the aligned state, the adapter plate and the PCB galvanically and mechanically, favourably by way of soldering, thus forming a PCB-adapter-stack.

The method further includes aligning the antenna and the PCB-adapter-stack with respect to each other such that each of the adapter waveguide channels is aligned with a corresponding antenna waveguide coupling opening and the antenna-facing adapter surface is parallel to and faces the adapter-facing antenna-surface.

The method further includes connecting, in the aligned state, the PCB-adapter-stack and the antenna galvanically and mechanically by establishing a pressing force between the antenna-facing adapter surface and the adapter-facing antenna surface. In an embodiment with an antenna contact ridge as explained before, the pressing force favourably acts between the antenna-contacting ridge surface and a corresponding counter section of the adapter-facing antenna surface only.

Exemplary and/or particularly favourable embodiments of the method are further defined by and disclosed in the context of embodiments of the PCB, the antenna and the adapter plate.

Brief description of figures

Fig. 1 shows an exemplary antenna assembly in a schematic antenna assembly in a perspective top view;

Fig. 2 shows the exemplary antenna assembly in a schematic antenna assembly in a perspective bottom view;

Fig. 3 shows the antenna assembly in an exploded view;

Fig. 4 shows a top view of the antenna-facing adapter surface;

Fig. 5 shows a cross sectional view of the adapter plate the area of a through-hole;

Fig. 6 shows a cross sectional view of the adapter plate 1 and an adapter waveguide channel 15.

Exemplary embodiments

In the following description of exemplary embodiments, directional terms such as "top", "bottom", "left", "right", are referred to with respect to the viewing directions according to the drawings and are only given to improve the reader's understanding. They do not refer to any particular directions or orientations in use. Furthermore, a plane that is span by the x-y directions of the shown coordinate systems (normal to the z-direction) is referred to as "lateral". The term "footprint" is used with reference to the z-direction as viewing direction.

In the following, reference is first made to Fig. 1, showing an exemplary antenna assembly in accordance with the present invention in a perspective top view. The antenna assembly includes an adapter plate 1, a printed circuit board 2, and an array antenna 3 in a mounted state. The PCB 2, the adapter plate 1 and the antenna 3 form, in combination, a stack of coplanar layers, with the adapter plate 1 being sandwiched between the PCB 2 and the antenna 3. By way of example, all layers have identical rectangular footprints and are arranged in a congruent way one above the other in the z-direction, with the layer surfaces extending normal to the z-direction. By way of example, the antenna 3 is itself realized by a stack of four coplanar layers 3a, 3b, 3c, 3d. Layer 3a (bottom layer) is closest to the adapter plate 1 and the PCB 2 and comprises an adapter-facing antenna surface 30b with a waveguide coupling structure as will be discussed further below in more detail. Layer 3d (top layer) comprises e. g. horn-shaped waveguide openings 34 for transmitting and/or receiving electromagnetic waves. By way of example, it is assumed that the shown antenna assembly is a receiver assembly and the waveguide openings 34 are designed for receiving electromagnetic waves that are transferred through the lower layers 3c, 3b, 3a and the adapter plate 1 to the PCB 2 which comprises corresponding receiver circuitry. This configuration, however, as well as shown stacked layer design of the antenna 3, is not essential.

In the following, reference is additionally made to Fig. 2, showing the antenna assembly in perspective bottom view. All layers of the antenna assembly, namely the layers 3a, 3b, 3c, 3d of the antenna 3, the PCB 2, and the adapter plate 1, each have two optional through-going alignment bores as alignment members in two diagonal corners, wherein the alignment bores in all layers coincide, thus forming a common through-going alignment bore. In the view of Fig. 1, the alignment bores 32 in the top plate 3d is visible, while the alignment bores 25 of the PCB 2 are visible in Fig. 2. While the shown arrangement is particularly suitable, neither the number nor the specific arrangement of the alignment bores is mandatory.

By way of example, the PCB 1, the adapter plate 2 and the antenna 3 are mounted via exemplarily four screws 4 with self-cutting threads (not visible) that cut into layers of the antenna 3. The screws 4 mechanically connect the PCB 2, the adapter 1 and the antenna 3, and further ensure the required pressing force for galvanic coupling of the antenna 3 and the adapter plate 2. Alternatively or additionally to the screws 4, clamps, fixtures or the like may be used. Furthermore, screws with non-self-cutting threads, e. g. machine threads, and additional nuts may be used.

In the following, reference is additionally made to Fig. 3, showing the antenna assembly in an exploded view. The PCB 2 includes electronics components as generally known in the art. For exemplary purposes and clarity reasons, only a single electronics component in form of microwave semiconductor component 24 is present. The top PCB surface onto which the chip 24 is mounted is the adapter-facing PCB surface 20a. The microwave semiconductor component 24 (also referred to as chip) operatively couples for high frequency signal transmission purposes to a number of PCB waveguide coupling openings 22 via a flat waveguide structure with flat waveguide elements 21. The flat waveguide elements 21 may, as such, be realized as known in the art for example Substrate Integrated Waveguides, Coplanar Waveguides (CPWG), Grounded Coplanar Waveguides (GCPWG), microstrip lines, striplines, or suspended striplines. In the example embodiment, the waveguide elements 21 are realized using microstrip lines which are connected to a short sections of Substrate Integrated Waveguides which end in PCB waveguide coupling opening 22 for coupling with the adapter waveguide channels 15. The area of the adapter-facing PCB surface 20a in which the PCB waveguide coupling openings 22 are arranged (left part in Fig. 3) is fully metallized, as indicated by metallization edge 20a' between the metallized and the non-metallized area.

The PCB waveguide coupling openings 22 are arranged in the adapter-facing PCB surface 20a. In this example, the PCB waveguide coupling openings 22 are designed with a U-shaped cross section which corresponds to the cross section of the adapter waveguide channel 15. By way of example, the centre distance between adjacent PCB waveguide coupling openings is in a range of 1mm to 19mm depending on the frequency range, such as 2.9 mm in a specific example. With increasing frequency, the centre distance generally decreases.

By way of example, the adapter plate 1 has a rectangular outer contour or footprint that is identical to the outer contour of the PCB 2 and is made from metal, e. g. brass, in a single piece by machining. By way of example, the thickness of the adapter plate 1 is 1 mm to 10mm, such as 1.8 mm in a specific example. The top adapter surface or antenna facing adapter surface 10a and the bottom adapter surface or PCB-facing adapter surface 10b are coplanar. The antenna-facing adapter surface 10a is further coplanar with the adapter-facing antenna surface 30b and the PCB-facing adapter surface 10b is coplanar with the adapter-facing PCB surface 20a. The antenna-facing adapter surface 10a and the PCB-facing adapter surface 10b are each generally planar or flat. The antenna-facing adapter surface 10a, however, includes a PCB contact ridge 12 that is positioned to cover, in a mounted state, the PCB waveguide coupling openings 22. Similarly, the antenna-facing adapter surface 10a includes an antenna contact ridge 13 with an antenna-contacting ridge surface 13a. The height (dimension in z-direction) of the antenna contact ridge surface 13, however, is considerably smaller as compared to the PCB contact ridge 12 (see also Fig. 6).

Through-going adapter waveguide channels 15 as discussed further below extend in z-direction between the PCB-facing adapter surface 10b and the antenna-facing adapter surface 10a. On the top side of the adapter plate 1, the adapter waveguide channels 15 end in antenna-facing channel openings on the antenna-contacting ridge surface 13a (see Fig. 6) of the antenna contact ridge 13. On the bottom side, the adapter waveguide channels 15 end in PCB-facing channel openings on the PCB-contacting ridge surface 12b (see Fig. 4, 6) of the PCB contact ridge 12.

The adapter plate 1 further includes a through-going component recess 14. The component recess 14 is sized and shaped to receive the chip 24. In this way, the required distance or gap between the PCB 2 and the adapter plate 1 is significantly reduced. The thickness of the adapter plate 1 is such that the top side of the chip 24 does not project above and preferably stands back behind the antenna-facing adapter surface 10a.

The waveguide coupling structure of the antenna 3 comprises a number of antenna waveguide coupling openings 31 that corresponds in number and location with the number of adapter waveguide channels 15 and PCB waveguide coupling openings 22. In the aligned and mounted state, each of the PCB waveguide coupling openings 22 is aligned with a corresponding adapter waveguide channel 15 and a corresponding antenna waveguide coupling opening 31.

In the shown exemplary embodiment, the PCB waveguide coupling openings 22, the adapter waveguide channels 15 and the antenna waveguide coupling openings 31 are arranged along a single straight line (along the y-direction). Alternative arrangements, however, may also be used. For example, the arrangement may be in a curved line, in a matrix of several rows and columns, or without any particularly geometrical order, provided, that the alignment between PCB waveguide coupling openings, adapter waveguide channels and antenna waveguide coupling openings is maintained.

In the shown example, exemplarily cuboid-shaped alignment protrusions 19a, 19b project from the antenna-facing adapter surface 10a. Two alignment protrusions 19a are arranged in line with the adapter waveguide channels 15 and spaced apart from each other as far as possible in order to minimize tolerance-caused alignment errors. In a state of proper alignment, the alignment protrusions 19a engage corresponding alignment openings 35a in the adapter-facing antenna surface 30b. The alignment protrusions 19a and alignment openings 35a ensure alignment between the antenna 3 and the adapter plate 1 along the first axis. For alignment along the second axis perpendicular to the first axis, a third alignment protrusion 19b and a corresponding alignment opening 35b are provided. Exemplarily the alignment protrusions 19a, 19b and the alignment openings 35a, 35b each form an isosceles triangle.

Exemplarily, the adapter plate 1 further includes two alignment bores 18 that are, in a situation of correct alignment, aligned with the alignment bores 25 of the PCB 2 and the alignment bores 32 of the antenna 3. In this example, the alignment bores 25, 18, 32 serve for process alignment during assembly via alignment pins (not shown) which are subsequently removed in order to avoid positioning redundancies. Alternatively however alignment bores and alignment pins may also be used for permanent alignment, while omitting the alignment projections 19a, 19b, and the alignment openings 35a, 35b. Such embodiment may especially be favourable for machined adapter plates since the machining of the alignment protrusions 19a, 19b is time consuming and involves the cutting of a significant amount of material.

For the mechanical connection via the screws 4, the PCB 2 and the adapter plate 1 comprise aligned through-holes 23, 17. The antenna 3 respectively antenna layer 3a comprises corresponding (exemplarily blind) holes 33 of smaller diameter to allow thread-cutting by the screws 4. In the mounted state, the antenna-facing adapter surface 10a and the adapter-facing antenna surface 30b contact lay on and contact each other via a small ridges in both adapter plate as well as antenna in order to increase the contact pressure.

In the following, reference is additionally made to Fig. 5, showing a cross sectional view of the adapter plate 1 in the area of a through-holes 17. Contact spacers 11 of e. g. disk-shaped cylindrical shape are arranged around the through-holes 17, with PCB-contacting spacer surfaces 11b laying in a common plane with the PCB-contacting ridge surface 12b, parallel to and spaced apart from the general PCB-facing adapter surface 10b.

In the following, reference is additionally made to Fig. 4 and Fig. 6. Fig. 4 shows a top view of the antenna-facing adapter surface 10a and a detailed view of an adapter waveguide channel 15. Fig. 6 shows a cross sectional view of the adapter plate 1 and an adapter waveguide channel 15.

The adapter waveguide channels 15 have a varying cross –sectional contour (given by the x-y-plane) along the channel length (given by the z-direction). The adapter waveguide channels 15 are narrower at the PCB-facing adapter surface 10b and wider at the antenna-facing adapter surface 10a. Along their length, the cross section of the adapter waveguide channels varies in a number of discrete steps. As best visible in Fig. 4, a single channel ridge 16 extends into the adapter waveguide channels 15, resulting in the cross sectional geometry of the adapter waveguide channels 15 being generally U-shaped. Like the adapter waveguide channels 15, the geometry of the channel ridges 16 varies with the length. At the PCB-facing adapter surface 10b, the channel ridge 16 projects deeper into the adapter waveguide channel 15 and projects less deep into the adapter waveguide channel 15 at the antenna-facing adapter surface 10a, i. e. their height (dimension in x-direction) is larger at the PCB-facing adapter surface 10b and smaller at the antenna-facing adapter surface 10a. Further the width (i. e. dimension in y-direction) of the channel ridges 16 is larger at the PCB-facing adapter surface 10b and smaller at the antenna-facing adapter surface 10a. Between the PCB-facing adapter surface 10b respectively the PCB-contacting ridge surface 12b and the antenna-facing adapter surface 10a respectively the antenna-contacting ridge surface 11a, the width and height of the channel ridges 16 varies, like the contour of the adapter waveguide channels 15, in a number of discrete steps.

By way of example, the characteristic impedance of the flat waveguides 21 with the single-ridge PCB waveguide coupling openings 22 is an in a range of 50 Ohm ... 150 Ohm. The double-ridge antenna waveguide coupling openings 31 have a characteristic impedance of exemplarily about 400 Ohm. Via the design of the adapter waveguide channels 15 and channel ridges 16 with varying geometry along the channel length, proper impedance matching is achieved. At the same time, the design allows smaller adapter waveguide cross-section (in y direction) on the PCB-facing side 10b of the adapter plate 1 which facilitates the design of the PCB waveguide coupling openings 22 as well as PCB flat waveguide elements 21 and increases the isolation between PCB flat waveguide elements 21. The cross-sectional geometry of the adapter waveguide channels 15 for each of the stepped is favourably determined via numerical/computational optimization methods as generally known in the art.

In the discussed example, the adapter plate 1 is made from metal by machining, as mentioned before. In an alternative embodiment, the adapter plate 1 may be made from metal-plated plastics without requiring substantive modifications. For such embodiments, however, the cross sectional geometry of the adapter waveguide channels 15 and the channel ridges 16 varies favourably continuously along the channel length rather than in discrete steps.

Reference signs

1	adapter plate
10a	antenna-facing adapter surface
10b	PCB-facing adapter surface
11	contact spacer
11b	PCB-contacting spacer surface
12	PCB contact ridge
12b	PCB-contacting ridge surface
13	antenna contact ridge
13a	antenna contacting ridge surface
14	component cut-out
15	adapter waveguide channel
16	channel ridge
17	through-hole
18	alignment bore
19a, 19b	alignment protrusion
2	printed circuit board (PCB)
20a	adapter-facing PCB surface
20a'	metallization edge
21	flat waveguide element
22	PCB waveguide coupling opening
23	through-hole
24	chip
25	alignment bore
3	array antenna
3a, 3b, 3c	antenna layer
30b	adapter-facing antenna surface
31	antenna waveguide coupling opening
32	alignment bore
4	screw
33	screw hole
34	waveguide opening
35a, 35b	alignment opening

Claims

1. Adapter plate (1) for high-frequency coupling a flat waveguide structure of a printed circuit board (PCB) to a waveguide coupling structure of an antenna (3), the adapter plate (1) being designed to be sandwiched between the PCB (2) and the antenna (3), the adapter plate (1) including:

   - an antenna-facing adapter surface (10a);
   - a PCB-facing adapter surface (10b), the PCB-facing adapter surface (10b) being adjacent to the antenna-facing adapter surface (10a);
   - a number of adapter waveguide channels (15) extending inside the adapter plate (1) between the antenna-facing adapter surface (10a) and the PCB-facing adapter surface (10b), wherein a cross sectional contour of the adapter waveguide channels (15) varies along a channel length between the PCB-facing adapter surface (10b) and the antenna-facing adapter surface (10a).

2. Adapter plate (1) according to claim 1, wherein a cross sectional area of the adapter waveguide channels (15) increases from the PCB-facing adapter surface (10b) to the antenna-facing adapter surface (10a).

3. Adapter plate (1) according to either of the preceding claims, wherein the antenna-facing adapter surface and the PCB-facing adapter surface (10b) are coplanar.

4. Adapter plate (1) according to claim 3, wherein the adapter waveguide channels (15) extend in or parallel to a normal direction of the adapter plate (1).

5. Adapter plate (1) according to either of the preceding claims, wherein the adapter waveguide channels (15) are single-ridge waveguide channels.

6. Adapter plate (1) according to either of the preceding claims, wherein the cross sectional contour of the adapter waveguide channels varies along the channel length between the PCB-facing adapter surface (10b) and the antenna-facing adapter surface continuously.

7. Adapter plate (1) according to either of claim 1 to claim 5, wherein the cross sectional contour of the adapter waveguide channels (15) varies along the channel length between the PCB-facing adapter surface (10b) and the antenna-facing adapter surface in a number of discrete steps.

8. Adapter plate (1) according to either of the preceding claims, wherein the adapter plate (1) includes a PCB contact ridge (12), the PCB contact ridge (12) projecting from the PCB-facing adapter surface (10b), wherein a PCB-facing channel opening of the adapter waveguide channels (15) is arranged on a PCB-contacting ridge surface (12b) of the PCB contact ridge (12).

9. Adapter plate (1) according to either of the preceding claims, wherein the adapter plate (1) includes contact spacers (11), the contact spacers (11) projecting from the PCB-facing adapter surface (10b).

10. Adapter plate (1) according to either of the preceding claims, wherein the adapter plate (1) includes an antenna contact ridge (13), the adapter contact ridge (13) projecting from the antenna-facing adapter surface (10a), wherein an antenna-facing channel opening of the adapter waveguide channels (13) is arranged on an antenna-contacting ridge surface (13) of the antenna contact ridge (13).

11. Adapter plate (1) according either of the preceding claims, wherein the adapter plate (1) includes alignment members for mechanical alignment of the adapter plate (1) with the PCB (2) and/or the antenna (3).

12. Adapter plate (1) according to claim 11, wherein the alignment members include alignment protrusions (19a, 19b) or alignment openings, the alignment protrusions (19a, 19b) or alignment openings being designed to mechanically engage counter alignment openings (35a, 35b) or counter alignment protrusions of the PCB (2) or the antenna (3), and/or the alignment members include through-going alignment bores (18) to receive alignment pins.

13. Adapter plate according to either of the preceding claims, wherein the adapter plate (1) includes a component recess or component cut-out (14), the component recess or component cut-out (14) being arranged to receive at least part of a component (24) that is mounted on and projects from the PCB (2) in direction of the adapter plate.

14. Antenna assembly, including:

- an antenna (3), in particular an array antenna, the antenna (3) having an adapter-facing antenna surface (30b), the adapter-facing antenna surface (30b) having a waveguide coupling structure with a number of antenna waveguide coupling openings (31);
- an adapter plate (1) according to either of the preceding claims;
- a PCB (2), the PCB (2) having a flat waveguide structure with a number of PCB waveguide coupling openings (22);

wherein the adapter plate (1) is sandwiched between the PCB (2) and the antenna (3), such that each of the adapter waveguide channels (15) is aligned with a corresponding antenna waveguide coupling opening (31) and a corresponding PCB waveguide coupling opening (22).

15. Method for manufacturing an antenna assembly according to claim 14, the method including:

- aligning the adapter plate (1) and the PCB (2) with respect to each other such that each of the adapter waveguide channels (15) is aligned with a corresponding PCB waveguide coupling opening (22) and the PCB-facing adapter surface (10b) is parallel to and faces the adapter-facing PCB surface (20a);
- connecting, in the aligned state, the adapter plate (1) and the PCB (2) galvanically and mechanically, favourably by way of soldering, thus forming a PCB-adapter-stack;
- aligning the antenna (3) and the PCB-adapter-stack with respect to each other such that each of the adapter waveguide channels (15) is aligned with a corresponding antenna waveguide coupling opening (31) and the antenna-facing adapter surface (10a) is parallel to and faces the adapter-facing antenna-surface (30b);
- connecting, in the aligned state, the PCB-adapter-stack and the antenna galvanically and mechanically by establishing a pressing force between the antenna-facing adapter surface (10a) and the adapter-facing antenna surface (30b).

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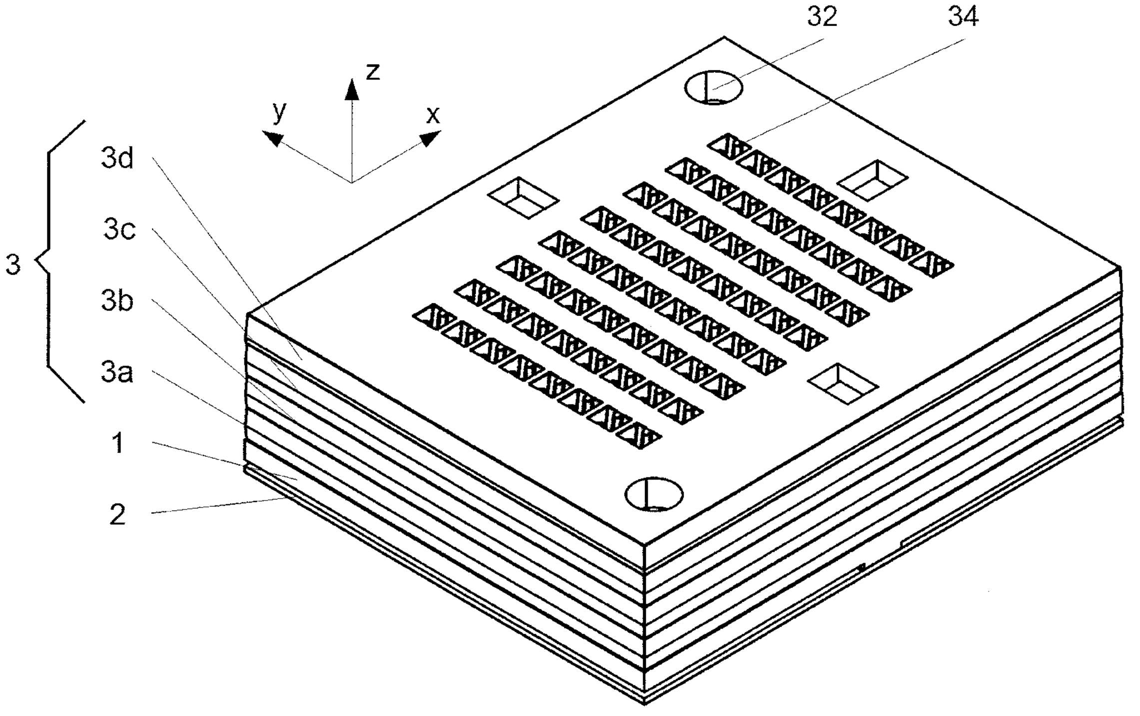


Fig. 1

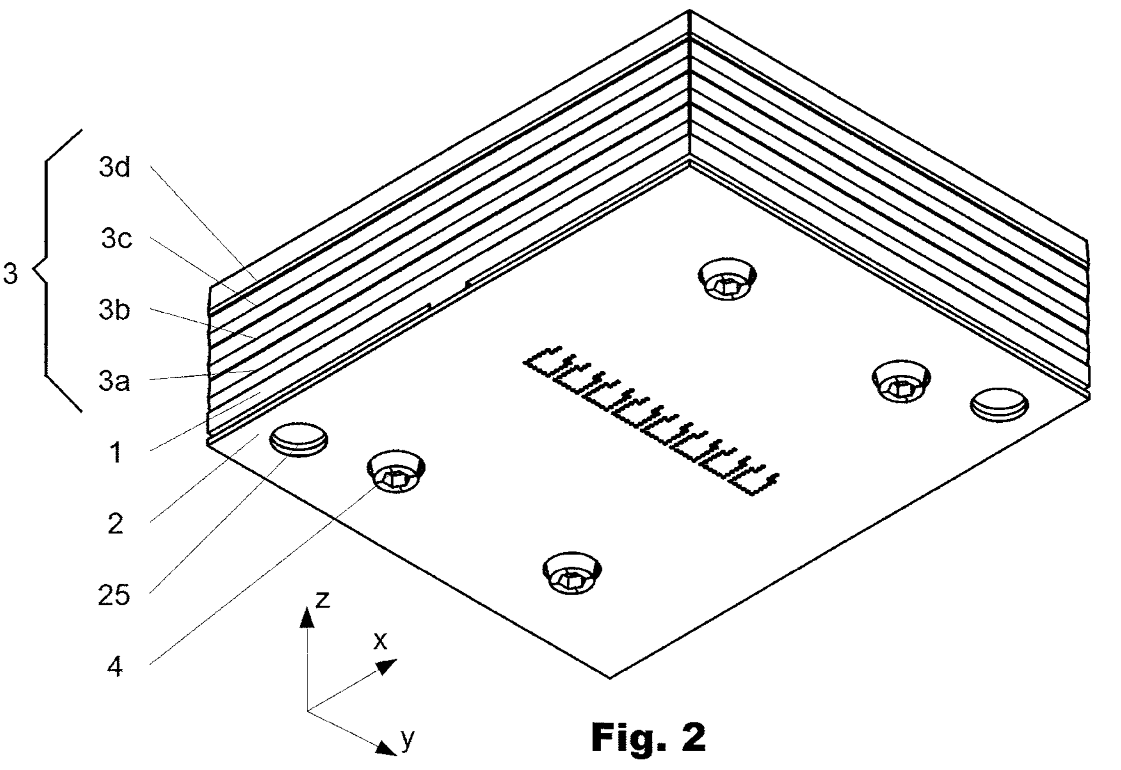
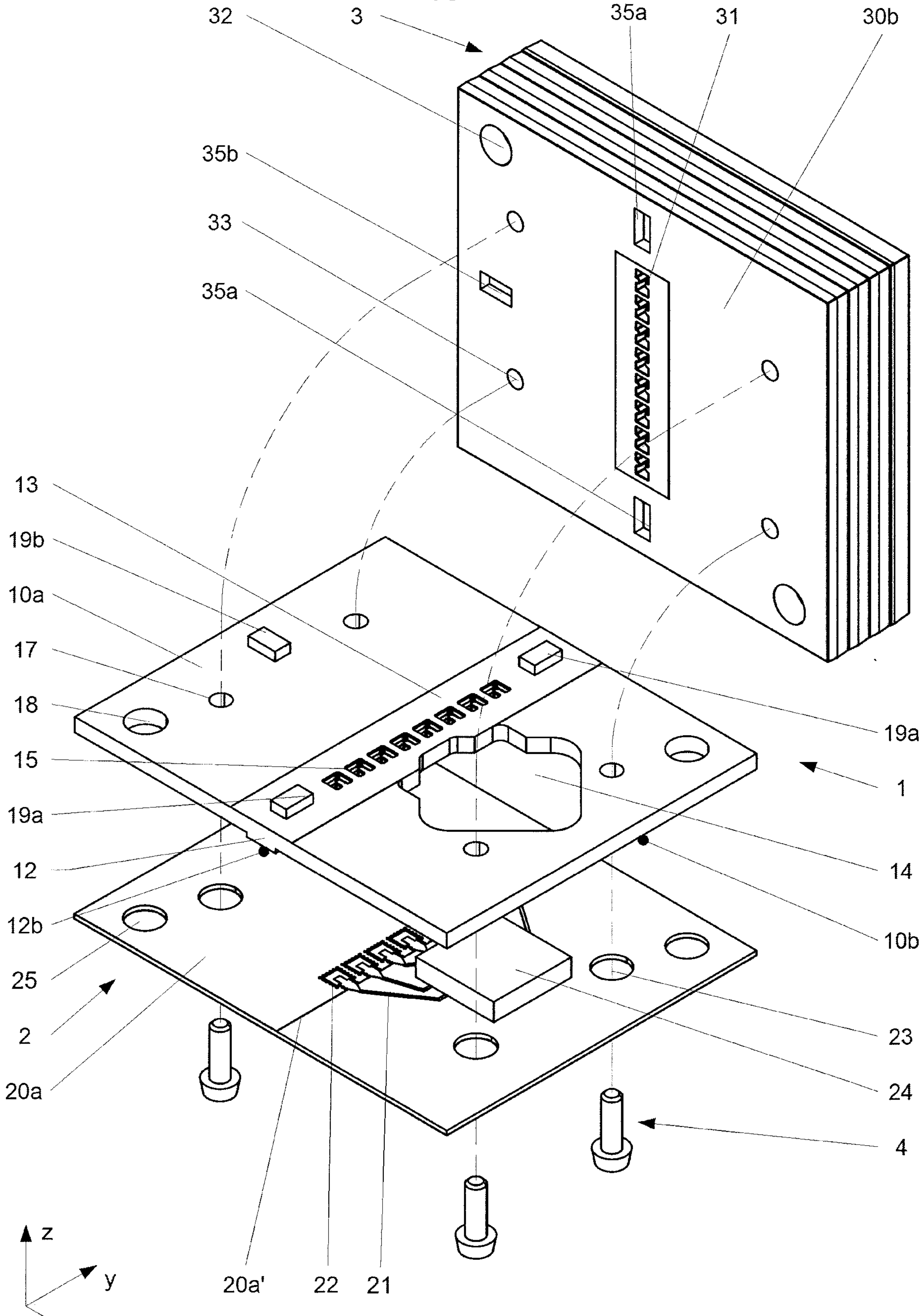


Fig. 2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10b
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20a'
22
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Fig. 3

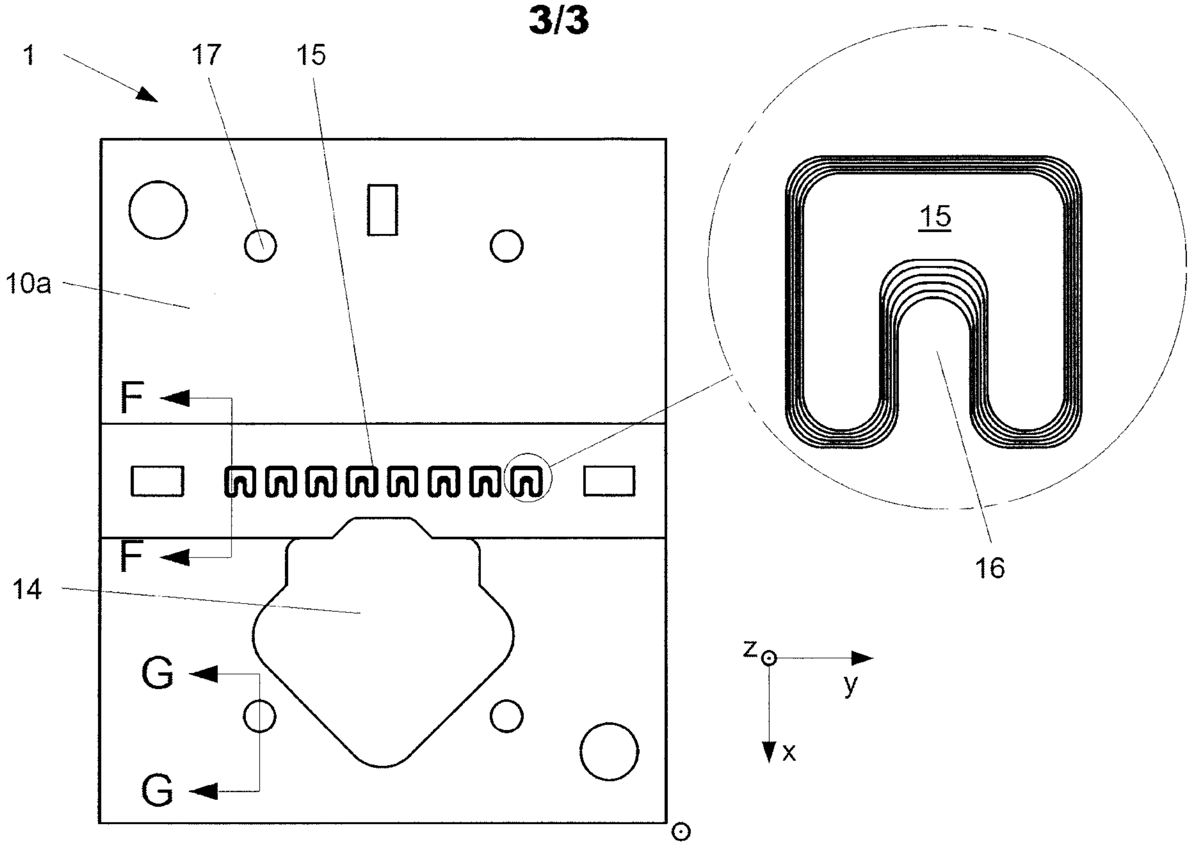

Fig. 4

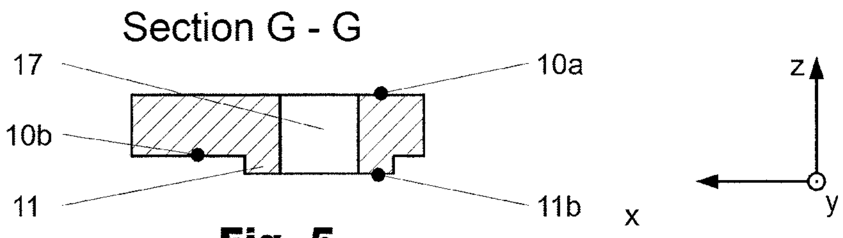

Fig. 5

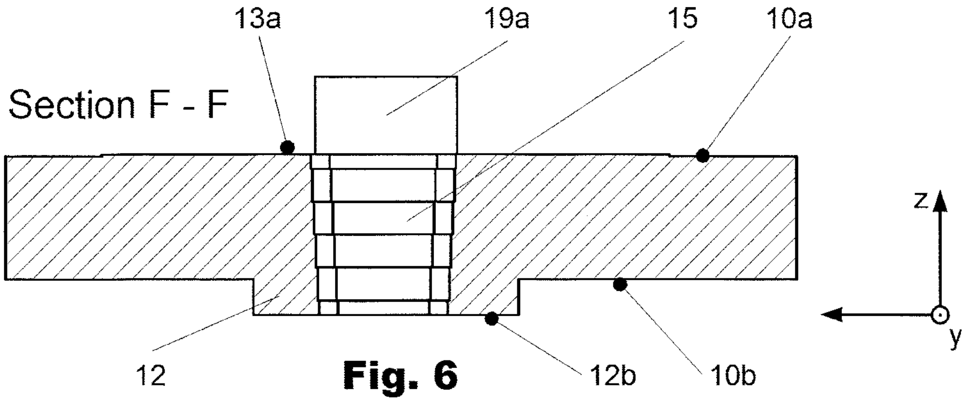

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/057605

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01P5/107 H01Q21/06
ADD. H01Q13/02 H01Q21/00

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)
H01P 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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	column 5, line 1 - column 7, line 55; figures 1C,2	5,7,8,13
X	US 2012/032750 A1 (FEIL PETER [DE]) 9 February 2012 (2012-02-09)	1-4,7-15
A	paragraph [0035] - paragraph [0038]; figures 1,2	5,6
X	EP 1 367 668 A1 (SIEMENS INF & COMM NETWORKS [IT]) 3 December 2003 (2003-12-03)	1-4,7, 9-15
A	paragraph [0018] - paragraph [0025]; figure 5c	5,6,8

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 June 2017	20/06/2017

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/057605

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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X A	XIAOBO HUANG ET AL: "A Broadband U-Slot Coupled Microstrip-to-Waveguide Transition", IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 60, no. 5, 1 May 2012 (2012-05-01), pages 1210-1217, XP011442413, ISSN: 0018-9480, DOI: 10.1109/TMTT.2012.2187677 Section II, Section IV; figures 1b,5,10 -----	1,5-7, 9-12,14, 15 2-4,8,13
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