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(54) Title: DIRECTIONAL COUPLER WAVEGUIDE STRUCTURE AND METHOD

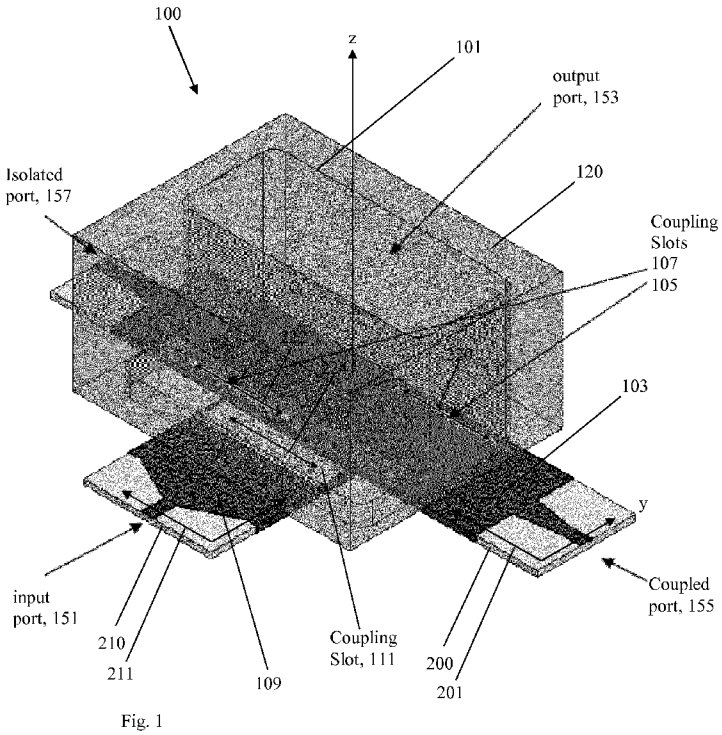


Fig. 1

(57) Abstract: A directional coupler arrangement (100), comprising an air waveguide (101) and a dielectric waveguide (109) having a coupling slot (111), wherein the air waveguide (101) and the dielectric waveguide (109) are coupled by the coupling slot (111). A method for coupling a first waveguide to a second waveguide comprising forming a coupling slot in the first waveguide and arranging the coupling slot of the first waveguide inside the second waveguide is also disclosed. The directional coupler arrangement has improved insertion loss, directivity and operational bandwidth. It is robust against manufacturing tolerances.

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DESCRIPTION

Directional Coupler Waveguide Structure and method

Technical Field

The present invention relates generally to radio technology and specifically, to directional coupler arrangements between waveguides.

BACKGROUND OF THE INVENTION

Directional couplers (DCs) are passive devices used in the field of radio technology. They couple a defined amount of the electromagnetic power in a transmission line to another port where it can be used in another circuit. A feature of directional couplers is that they only couple power flowing in one direction. Power entering the output port is not coupled. Directional couplers are most frequently constructed from two coupled transmission lines set close enough together such that energy passing through one is coupled to the other. This technique is favoured due to the microwave frequencies the devices are commonly employed with. The two transmission lines are coupled together by a gap. When applying directional couplers together with air waveguides in radio transmission devices, manufacturing tolerances limit the performance of the transition between the electrical interface and the air interface. In particular, manufacturing tolerances have a negative influence on operational bandwidth, directivity, and impedance matching of the directional coupler.

SUMMARY OF THE INVENTION

The invention provides for an interface to an air waveguide with a directional coupler which interface is robust against manufacturing tolerances.

This is achieved by the features of the independent claims. Further implementation forms are apparent from the dependent claims, the description and the figures.

The invention is based on the finding of the inventors that a dielectric waveguide may be used as a robust interface to an air waveguide when energy is transmitted by a slot in the dielectric waveguide and both waveguides are coupled by the slot. As electromagnetic energy leaves the dielectric waveguide through the slot, the slot concentrates and directs the electromagnetic energy to the air waveguide. As only a negligible amount of energy is lost when coupling the dielectric waveguide to the air waveguide by the slot, insertion loss, directivity and operational bandwidth are improved. A directional coupler arrangement based on that coupling becomes robust against manufacturing tolerances as such tolerances do not influence the amount of energy to be coupled between the dielectric waveguide and the air waveguide.

In order to describe the invention in detail, the following terms, abbreviations and notations will be used:

DC: directional coupler;

Port 1: first port of a directional coupler, e.g. the input port where the power is applied;

Port 2: second port of a directional coupler, e.g. the output port or the transmitted port where the power from “Port 1” is output;

Port 3: third port of a directional coupler, e.g. the coupled port where a portion of the power applied to “Port 1” appears;

Port 4: fourth port of a directional coupler, e.g. the isolated port where a portion of the power applied to “Port 2” is coupled to. The isolated port is usually terminated with a matched load;

PCB: printed circuit board;

DCB substrate: direct copper bonded substrate;

DPC substrate: direct copper plated substrate;

CPC substrate: copper plated ceramic substrate.

According to a first aspect, the invention relates to a directional coupler arrangement, comprising: an air waveguide; and a dielectric waveguide having a first coupling slot; wherein the air waveguide and the dielectric waveguide are coupled by the first coupling slot.

By coupling the dielectric waveguide to the air waveguide by a slot, the directional coupler arrangement exhibits lower insertion loss than a directional coupler coupling two transmission lines by a gap.

By coupling the dielectric waveguide to the air waveguide by a slot, the directional coupler arrangement requires less space on a printed circuit board (PCB) compared to an arrangement where a gap between two transmission lines has to be arranged on the PCB.

In a first possible implementation form of the directional coupler arrangement according to the first aspect, the first coupling slot of the dielectric waveguide is arranged inside the air waveguide. The coupler is therefore inside the waveguide transition.

By placing the first coupling slot of the dielectric waveguide inside the air waveguide, the directional coupler arrangement is insensitive to manufacturing tolerances of a mounting process for mounting the dielectric waveguide together with the air waveguide. The exact position of the slot inside the air waveguide is insensitive to manufacturing tolerances. By placing the first coupling slot of the dielectric waveguide inside the air waveguide, the directional coupler arrangement is space-efficiently constructed compared to placing a coupler externally.

In a second possible implementation form of the directional coupler arrangement according to the first aspect as such or according to the first implementation form of the first aspect, the dielectric waveguide comprises a dielectric material covered by a metallization, an opening in the metallization forming the first coupling slot.

The dielectric waveguide may be manufactured from a printed circuit board having a body comprising a dielectric material and a metallization covering the body. When the metallization is removed at a specified position, an opening in the metallization forms the

slot at that position. By removing the metallization from the body in a patterned manner, microstrip lines can be formed on the printed circuit board. Thus, the printed circuit board can be used as an interface from a microstrip line to a dielectric waveguide. A production method for producing the interface from a microstrip line to a dielectric waveguide may be simply performed by the steps of providing a PCB as a dielectric body covered by a metallization layer and patterning the metallization layer to form the microstrip line and the dielectric waveguide.

In a third possible implementation form of the directional coupler arrangement according to the second implementation form of the first aspect, the opening in the metallization of the dielectric waveguide extends to the dielectric material.

When the opening in the metallization of the dielectric waveguide extends to the dielectric material, electromagnetic energy leaving the dielectric waveguide is more concentrated on that opening and is emitted in the direction of the opening, substantially away from the dielectric waveguide. Thus, losses of electromagnetic energy can be minimized and the directivity of coupling is improved.

In a fourth possible implementation form of the directional coupler arrangement according to the first aspect as such or according to any of the preceding implementation forms of the first aspect, the dielectric waveguide may be formed generally planar as a plate having a main surface.

When the dielectric waveguide is formed as a plate having a main surface, the production is simplified, as a standard printed circuit board may be used as the dielectric waveguide. For smaller dimensions the plate may be the substrate layer of a chip being covered by a metallization layer, e.g. a direct copper bonded (DCB) substrate, a direct copper plated (DPC) substrate or a copper plated ceramic (CPC) substrate. The plate may be made of a dielectric material such as, e.g., Al_2O_3 (aluminum oxide), AlN (aluminum nitride) or BeO (beryllium oxide). The metallization may be made of silver (Ag), silver palladium (AgPd), silver platinum (AgPt), gold (Au), palladium gold (PdAu) or platinum gold (PtAu). The metallization may be printed on the dielectric plate or the metallization may be a paste burned on the dielectric plate. Other metallization forms are possible.

In a fifth possible implementation form of the directional coupler arrangement according to the fourth implementation form of the first aspect, a main direction of the air waveguide is substantially perpendicular to the main surface of the plate.

Electromagnetic energy leaves the dielectric waveguide through the slot and is emitted substantially perpendicular to a main surface of the plate in which the slot is formed. When the air waveguide is aligned to that emitting direction, energy losses are minimized and directivity of the directional coupler arrangement is improved.

In a sixth possible implementation form of the directional coupler arrangement according to the fourth or the sixth implementation form of the first aspect, the first coupling slot is formed in the main surface of the plate.

Electromagnetic energy leaving the dielectric waveguide is concentrated on the position of the slot in the main surface of the plate. Thus, losses are minimized and directivity of the directional coupler arrangement is improved.

In a seventh possible implementation form of the directional coupler arrangement according to the first aspect as such or according to any of the preceding implementation forms of the first aspect, the coupling slot is formed as one of the following geometrical figures: a rectangle, a circle, a cross, a larger circle beneath a smaller circle, a larger cross beneath a smaller cross.

When both, the coupling slot and the air waveguide are rectangular formed, electromagnetic waves leaving the coupling slot and entering the air waveguide experience a low transition resistance and thus coupling losses are minimized. A rectangle, a circle and a cross are symmetrical figures facilitating the transition of energy from the dielectric waveguide to the air waveguide.

In an eighth possible implementation form of the directional coupler arrangement according to the first aspect as such or according to any of the preceding implementation forms of the first aspect, the directional coupler arrangement further comprises a second dielectric waveguide having a second coupling slot; wherein the air waveguide and the second dielectric waveguide are coupled by the second coupling slot.

The second dielectric waveguide may be used for implementing an input port of the directional coupler arrangement, i.e. Port 1, where the power is applied. The output port, i.e. Port 2 where the power from Port 1 is output, is implemented by the air waveguide and the coupled port of the directional coupler arrangement, i.e. Port 3 where a portion of the power applied to Port 1 appears, may be realized by the (first) dielectric waveguide.

In a ninth possible implementation form of the directional coupler arrangement according to the eighth implementation form of the first aspect, the second dielectric waveguide is formed as a second plate having a main surface.

When the second dielectric waveguide is formed as a second plate having a main surface, the production is simplfied, as a usual printed circuit board may be used as the dielectric waveguide. A single PCB may be used for implementing both, the second dielectric waveguide and the (first) dielectric waveguide.

For smaller dimensions the second plate may be the substrate layer of a chip being covered by a metallization layer as described above. The directional coupler arrangement may be implemented in a single chip including second dielectric waveguide and (first) dielectric waveguide.

In a tenth possible implementation form of the directional coupler arrangement according to the ninth implementation form of the first aspect, the main surface of the second plate is arranged substantially parallel to the main surface of the plate.

When both main surfaces are parallel, both plates may be formed from a single plate which facilitates manufacturing and reduces manufacturing tolerances. When both main surfaces are parallel, the coupling direction of the coupling slot coincides with the coupling direction of the second coupling slot improving the directivity and thus reducing energy losses of the directional coupler arrangement.

In an eleventh possible implementation form of the directional coupler arrangement according to any of the eighth to the tenth implementation forms of the first aspect, the second coupling slot of the second dielectric waveguide is arranged inside the air waveguide.

By placing the second coupling slot of the second dielectric waveguide inside the air waveguide, the directional coupler arrangement is insensitive to manufacturing tolerances of a mounting process for mounting the second dielectric waveguide together with the air waveguide and the (first) dielectric waveguide. The exact position of the slot inside the second air waveguide is insensitive to manufacturing tolerances. By placing the second coupling slot of the second dielectric waveguide inside the air waveguide, the directional coupler arrangement is space-efficiently constructed.

In a twelfth possible implementation form of the directional coupler arrangement according to any of the eighth to the eleventh implementation forms of the first aspect, a size of the second coupling slot is larger than a size of the coupling slot. “Size” as used herein refers to at least one dimension of the slot.

The second dielectric waveguide may be used for implementing an input port of the directional coupler arrangement, i.e. Port 1, where the power is applied. The output port, i.e. Port 2 where the power from Port 1 is output, is implemented by the air waveguide and the coupled port of the directional coupler arrangement, i.e. Port 3 where a portion of the power applied to Port 1 appears, may be realized by the (first) dielectric waveguide. When a size of the second coupling slot, i.e. a size of Port 1, is larger than a size of the coupling slot, i.e. a size of Port 3, the directional coupler arrangement is able to transmit a higher amount of energy from the input port (Port 1) to the output port (Port 2) than from the input port (Port 1) to the coupled port (Port 3). Thus, energy losses and directivity of the directional coupler arrangement are improved.

In a thirteenth possible implementation form of the directional coupler arrangement according to any of the eighth to the twelfth implementation forms of the first aspect, a main direction of the second coupling slot is arranged substantially parallel to a main direction of the coupling slot.

When a main direction of the second coupling slot is arranged substantially parallel to a main direction of the coupling slot, the directivity of the directional coupler arrangement is improved and thus energy losses are minimized. The main direction of a coupling slot refers to the longer laterally extended dimension.

In a fourteenth possible implementation form of the directional coupler arrangement according to any of the eighth to the thirteenth implementation forms of the first aspect, the second dielectric waveguide comprises an input port coupled to the second coupling slot, the input port being connectable to a microstrip line.

The input port may be Port 1 of a directional coupler, i.e. the port where the power is applied. When connecting a microstrip line to the input port, the directional coupler arrangement implements directional transition of electrical energy transported by the microstrip line to electromagnetic energy transported by the second dielectric waveguide and further to electromagnetic energy transported by the air waveguide.

In a fifteenth possible implementation form of the directional coupler arrangement according to the first aspect as such or according to any of the preceding implementation forms of the first aspect, the dielectric waveguide comprises a third coupling slot, the third coupling slot being arranged inside the air waveguide.

The third coupling slot of the dielectric waveguide may be used for implementing an isolated port of the directional coupler arrangement, i.e. Port 4 where a portion of the power applied to the output port (Port 2) is coupled to. The isolated port may be terminated with a matched load. The matched load may be arranged on the dielectric waveguide or may be formed of the dielectric waveguide, thereby saving space.

By placing the third coupling slot of the dielectric waveguide inside the air waveguide, the directional coupler arrangement is insensitive to manufacturing tolerances of a mounting process for mounting the dielectric waveguide together with the air waveguide. The exact position of the third coupling slot inside the air waveguide is insensitive to manufacturing tolerances. By placing the third coupling slot of the dielectric waveguide inside the air waveguide, the directional coupler arrangement is space-efficiently constructed.

In a sixteenth possible implementation form of the directional coupler arrangement according to the fifteenth implementation form of the first aspect, a main direction of the third coupling slot is arranged substantially parallel to a main direction of the coupling slot.

When a main direction of the third coupling slot is arranged substantially parallel to a main direction of the coupling slot, the directivity of the directional coupler arrangement is

improved and thus energy losses are minimized. A matched load terminating the isolated port may be less complex.

In a seventeenth possible implementation form of the directional coupler arrangement according to the fifteenth or the sixteenth implementation form of the first aspect, a size of the third coupling slot is substantially as large as a size of the coupling slot.

By dimensioning the size of the third coupling slot substantially as large as the size of the coupling slot, symmetrical properties can be exploited, thereby improving directivity and reducing losses of the directional coupler arrangement. The dimensioning of the matched load to be connected to the isolated port is easier to design when the coupling slots are symmetrically formed and arranged on the dielectric waveguide.

In an eighteenth possible implementation form of the directional coupler arrangement according to any of the fifteenth to the seventeenth implementation forms of the first aspect, the dielectric waveguide comprises a coupled port coupled to the coupling slot, the coupled port being connectable to a microstrip line and the dielectric waveguide comprises an isolated port coupled to the third coupling slot, the isolated port being connectable to a microstrip line.

The coupled port may be Port 3 of a directional coupler, i.e. the port where a portion of the power applied to the input port (Port 1) appears. The isolated port may be Port 4 of a directional coupler,i.e. Port 4 where a portion of the power applied to the output port (Port 2) is coupled to.

When connecting a microstrip line to the coupled port or to the isolated port, energy transition from a microstrip line connected to the input port to an air waveguide connected to the output port can be efficiently measured. The whole directional coupler arrangement can be arranged on a single PCB facilitating manufacturing and improving manufacture tolerances.

According to a second aspect, the invention relates to a method of coupling a first waveguide to a second waveguide comprising: forming a coupling slot in the first waveguide; and arranging the coupling slot of the first waveguide inside the second waveguide.

By coupling the first waveguide to the second waveguide by a slot, the insertion loss is reduced compared to a conventional external coupling technique. The first waveguide may be arranged inside the second waveguide thereby saving space and avoiding energy losses. The first and second waveguides may be air waveguides or dielectric waveguides. A dielectric waveguide may be placed in an air waveguide or in a further dielectric waveguide when the slot is attached to the dielectric waveguide. Alternatively, an air waveguide may be placed in a dielectric waveguide or in a further air waveguide, when the slot is attached to the air waveguide. A directional coupler arrangement as described above may be used for coupling a first waveguide (the dielectric waveguide having a coupling slot) to a second waveguide (the air waveguide), i.e., by using the method according to the second aspect.

In a first possible implementation form of the method according to the second aspect, the first waveguide is a dielectric waveguide and the second waveguide is one of an air waveguide and a dielectric waveguide.

A dielectric waveguide placed inside another dielectric waveguide may be efficiently implemented by a multi-layer PCB or by a stacked PCB. For example, a metal coated carrier having an inner metal layer in which a slot is formed by which slot energy from an inner layer is transported to an outer layer.

The first waveguide may be a thin optical waveguide, e.g. an optical fibre, and the second waveguide a thicker optical waveguide. When a slot is attached to the thin optical waveguide and the thin optical waveguide is mounted inside the thicker optical waveguide, light is transported from the first waveguide to the second waveguide at a high degree of efficiency. The directional coupler arrangement may be used for directional coupling of light.

In a second possible implementation form of the method according to the second aspect as such or according to the first implementation form of the second aspect, the method comprises: forming a coupled port in the first waveguide, the coupled port being coupled to the coupling slot and being connectable to a microstrip line.

The coupled energy may be easily measured when connecting a measurement device to the microstrip line.

BRIEF DESCRIPTION OF THE DRAWINGS

Further illustrative embodiments of the invention will be described with respect to the following figures, in which:

Fig. 1 shows a three-dimensional representation of a directional coupler arrangement according to an implementation form;

Fig. 2 shows a cross-sectional representation of the directional coupler arrangement depicted in Fig. 1 according to an implementation form;

Fig. 3 shows a three-dimensional representation of a directional coupler arrangement according to an implementation form;

Fig. 4 shows a three-dimensional representation of a directional coupler arrangement according to an implementation form;

Fig. 5 shows a three-dimensional representation of a second dielectric waveguide according to an implementation form;

Fig. 6 shows a three-dimensional representation of a directional coupler arrangement according to an implementation form;

Fig. 7 shows a three-dimensional representation of a dielectric waveguide and a second dielectric waveguide according to an implementation form;

Fig. 8 shows a three-dimensional representation of a dielectric waveguide and a second dielectric waveguide according to an implementation form;

Fig. 9 shows a schematic diagram of a method for coupling a first waveguide to a second waveguide according to an implementation form;

Fig. 10 shows a dielectric waveguide and an air waveguide coupleable by a method according to an implementation form.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

Fig. 1 shows a three-dimensional representation of a directional coupler arrangement 100 according to an implementation form and Fig. 2 shows a cross-sectional representation of the directional coupler arrangement 100. The directional coupler arrangement 100 comprises an air waveguide 101, a first dielectric waveguide 103 and a second dielectric waveguide 109. A first coupling slot 105 is formed in a main surface 201 of the first dielectric waveguide 103. A second coupling slot 111 is formed in a main surface 211 of the second dielectric waveguide 109 and a third coupling slot 107 is formed in the main surface 201 of the first dielectric waveguide 103. The first coupling slot and third coupling slot are spaced from each other in both in-plane directions, and arranged parallel to an extended direction of the waveguide 103.

The air waveguide 101 has an internal cascaded or staircase like structure with a first stair covering a part of the main surface of the second dielectric waveguide 109 including the second coupling slot 111 and a second stair covering a part of the main surface of the first dielectric waveguide 103 including the first coupling slot 105 and the third coupling slot 107. The second stair is higher than the first stair and is open at the top while the first stair is closed at the top. The second stair forms the main body of the air waveguide 101 at which open top the output port 153 of the air waveguide 101 is located. The air waveguide 101 is embedded in a housing 120 which is mounted on the first dielectric waveguide 103 and on the second dielectric waveguide 109. The housing 120 does not fully cover both waveguides 103, 109. An input port 151 of the second dielectric waveguide 109 and a coupled port 155 and an isolated port 157 of the first dielectric waveguide 103 are not covered by the housing 120. Thus, input port 151, output port 153, coupled port 155 and isolated port 157 are accessible from the outside.

The directional coupler arrangement 100 may implement a directional coupler with a first port (Port 1) as the input port where the power is applied, a second port (Port 2) as the output port or the transmitted port where the power from “Port 1” is output, a third port (Port 3) as the coupled port where a portion of the power applied to “Port 1” appears and

a fourth port (Port 4) as the isolated port where a portion of the power applied to “Port 2” is coupled to.

The second coupling slot 111 is used to couple energy from the second dielectric waveguide 109 to the air waveguide 101. The place of coupling is below the first stair of the air waveguide. The first coupling slot 105 and the third coupling slot 107 are used to couple energy from the air waveguide 101 to the first dielectric waveguide 103. The energy, at input port 151, is coupled by means of slots 105 and 107 in order to arrive in phase at coupled port 155 and to arrive 180° out of phase at isolated port 157.

The place of coupling is below the second stair of the air waveguide, i.e. below the main body of the air waveguide 101. The air waveguide 101 extends along a main direction z describing the direction in which electromagnetic waves are transported in the air waveguide 101. The main direction z of the air waveguide 101 is substantially perpendicular to the main surface 201 of the first dielectric waveguide 103 and to the main surface 211 of the second dielectric waveguide 109. Both first dielectric waveguide 103 and second dielectric waveguide 109 are arranged in a common plane. The first coupling slot 105 is arranged along a main direction 220 which is aligned with a main direction x of the first dielectric waveguide 103. The second coupling slot 111 is arranged along a main direction 224 which is aligned with a main direction x of the first dielectric waveguide 103. The third coupling slot 107 is arranged along a main direction 222 which is aligned with a main direction x of the first dielectric waveguide 103. First coupling slot 105, second coupling slot 111 and third coupling slot 107 are rectangular formed, wherein a size of the first coupling slot 105 corresponds to a size of the third coupling slot 107 and is smaller than a size of the second coupling slot 111. In the shown embodiment, “size” refers to both x and y dimensions. Second coupling slot extends substantially across the whole width of the second dielectric waveguide.

The first dielectric waveguide 103 is a small plate 200 with the main surface 201 in which the first coupling slot 105 and the third coupling slot 107 are formed as openings. Both coupling slots 105 and 107 extend through a metallization layer (shown as dark grey) covering the first dielectric waveguide 103 to a dielectric material forming the inner body of the first dielectric waveguide 103. The second dielectric waveguide 109 is a small plate 210 with the main surface 211 in which the second coupling slot 111 is formed as an opening. The second coupling slot 111 extends through a metallization layer covering the

second dielectric waveguide 109 to a dielectric material forming the inner body of the second dielectric waveguide 109.

At a first side of the first dielectric waveguide 103 forming the coupled port 155, the metallization is nearly completely removed from the plate 200, only a small stripe of metal aligned with the main direction x of the first dielectric waveguide 103 is not removed. That small stripe of metal forms the coupled port 155 and may be connected to a microstrip line. Similarly, at a second side of the first dielectric waveguide 103 forming the isolated port 157, the metallization is nearly completely removed from the plate 200, only a small stripe of metal aligned with the main direction x of the first dielectric waveguide 103 is not removed. That small stripe of metal forms the isolated port 157 and may be connected to a microstrip line. At a first side of the second dielectric waveguide 109 forming the input port 151, the metallization is nearly completely removed from the plate 210, only a small stripe of metal aligned with the main direction y of the second dielectric waveguide 109 is not removed. That small stripe of metal forms the input port 151 and may be connected to a microstrip line. In Fig. 1, both plates 200 and 210 are separate units; in a further implementation form (not shown), a single plate is used for forming the first 103 and the second 109 dielectric waveguides.

The following implementation forms are not shown. In one, one or both of the plates 200 and 210 are printed circuit boards. In an implementation form, one or both of the plates 200 and 210 are substrate layers of a chip covered by a metallization layer. In an implementation form, one or both of the plates 200 and 210 are direct copper bonded (DCB) substrates. In an implementation form, one or both of the plates 200 and 210 are direct copper plated (DCP) substrates. In an implementation form, one or both of the plates 200 and 210 are copper plated ceramic (CPC) substrates. In an implementation form, the dielectric material forming the inner body of one or both of the plates 200 and 210 is aluminum oxide (Al2O3). In an implementation form, the dielectric material forming the inner body of one or both of the plates 200 and 210 is aluminum nitride (AlN) or beryllium oxide (BeO). In an implementation form, the metallization of one or both of the plates 200 and 210 is silver (Ag), aluminum oxide (Al2O3). silver palladium (AgPd), silver platinum (AgPt), gold (Au), palladium gold (PdAu) or platinum gold (PtAu). In an implementation form, the metallization is printed on the dielectric material of the plates 200, 210. In an implementation form, the metallization is a paste burned on the dielectric material of the plates 200, 210.

Fig. 3 shows a three-dimensional representation of a directional coupler arrangement 300 according to an implementation form. The directional coupler arrangement 300 corresponds to the directional coupler arrangement 100 as described with respect to Figures 1 and 2. The directional coupler arrangement 300, however, is not embedded in a housing 120 and its ports are shielded by shieldings. The input port 151 forming a microstrip input is shielded by a first shielding 351. The coupled port 155 forming a coupled microstrip port is shielded by a second shielding 355. The isolated port 157 forming an isolated microstrip port is shielded by a third shielding 357. The output port forming the waveguide output is shielded by the air waveguide 101. The first 351, second 355 and third 357 shieldings are formed as air waveguides covering the respective ports 151, 155 and 157 on the first 103 and second 109 dielectric waveguides.

Fig. 4 shows a three-dimensional representation of a directional coupler arrangement 400 according to an implementation form. The directional coupler arrangement 400 comprises an air waveguide 101 with an output port 153 corresponding to the air waveguide 101 as described with respect to Figures 1 and 2. The air waveguide 101 is embedded in a housing 120. The directional coupler arrangement 400 further comprises a dielectric waveguide 109 corresponding to the second dielectric waveguide 109 as described with respect to Figures 1 and 2.

The directional coupler arrangement 400 is used for realizing the microstrip to waveguide transition. The electromagnetic field comes from a microstrip line connected to the input port 151, passes through the piece of dielectric waveguide 109 and arrives at the air waveguide 101 by means of the coupling slot 111.

Fig. 5 shows a three-dimensional representation of a second dielectric waveguide 109 according to an implementation form. The second dielectric waveguide 109 corresponds to the second dielectric waveguide 109 as described with respect to Figures 1 and 2 and as described with respect to Fig. 4.

The piece of dielectric waveguide 109 is formed of a plate of dielectric material covered by a metallization layer. At a first side of the plate or piece of dielectric material on which side the input port 151 of the dielectric waveguide 109 is arranged, the metallization is nearly completely removed from the plate, only a small stripe of metal aligned with the main

direction y of the plate is not removed. That small stripe of metal forms the input port 151 and may be connected to a microstrip line. The small stripe expands under an angle of α with respect to the main direction y to a metal layer fully covering the plate 210. In a first third of the plate 210, the stripe of metal expanding to a metal layer is arranged, in a second third of the plate 210, the plate is fully covered by the metallization and in a last third of the plate 210 the metallization is removed on the main surface of the plate 210 such that a rectangular opening is formed representing the coupling slot 111.

Fig. 6 shows a three-dimensional representation of a directional coupler arrangement 600 according to an implementation form. The directional coupler arrangement 600 comprises an air waveguide 101 with an output port 153 corresponding to the air waveguide 101 as described with respect to Figures 1 and 2. The air waveguide 101 is embedded in a housing 120. The directional coupler arrangement 600 further comprises a dielectric waveguide 103 corresponding to the dielectric waveguide 103 as described with respect to Figures 1 and 2.

The directional coupler arrangement 600 is used for realizing the waveguide to microstrip transition. The electromagnetic field which is inside the air waveguide 101 can be measured by coupling a part of this field by means of two coupling slots 105 and 107. The electromagnetic field comes from the air waveguide 101, is transmitted by means of the coupling slots 105 and 107 to the inside of the dielectric waveguide 103 and arrives at the coupled port 155 and the isolated port 157 where a microstrip line can be connected for measuring the energy of the field.

Fig. 7 shows a three-dimensional representation of a dielectric waveguide 703 and a second dielectric waveguide 109 according to an implementation form. The second dielectric waveguide 109 corresponds to the second dielectric waveguide 109 as described with respect to Figures 1 and 2. The dielectric waveguide 703 corresponds to the dielectric waveguide 103 as described with respect to Figures 1 and 2 in all but the shape of the coupling slots 105 and 107. The coupling slots 705 and 707 are cross-shaped, wherein a main axis of the first cross-shaped coupling slot 705 coincides with a main axis of the second cross-shaped coupling slot 707 and is arranged in a 45-degrees angle with respect to the main direction x of the first dielectric waveguide 703.

Fig. 8 shows a three-dimensional representation of a dielectric waveguide 803 and a second dielectric waveguide 109 according to an implementation form. The second dielectric waveguide 109 corresponds to the second dielectric waveguide 109 as described with respect to Figures 1 and 2. The dielectric waveguide 803 corresponds to the dielectric waveguide 103 as described with respect to Figures 1 and 2 in all but the shape of the coupling slots 105 and 107. The coupling slots 805 and 807 are in each case formed as a large circle located beneath a smaller circle. For the first coupling slot 805 the center points of the large and the small circle are positioned on a common axis aligned with a main direction x of the first dielectric waveguide 803. For the second coupling slot 807 the center points of the large and the small circle are positioned on a common axis aligned with a main direction x of the first dielectric waveguide 803. The common axis for the large and small circle of the first coupling slot 805 is spaced apart from the common axis for the large and small circle of the second coupling slot 807. Electromagnetic energy is emitted through the four circles and so coupled from the inside of the dielectric waveguide 803 to the outside.

Fig. 9 shows a schematic diagram of a method 900 for coupling a first waveguide to a second waveguide according to an implementation form. The method 900 comprises forming 901 a coupling slot in the first waveguide and arranging 903 the coupling slot of the first waveguide inside the second waveguide.

The first waveguide may be an air waveguide 101 as described with respect to Figures 1 and 2. The second waveguide may be a dielectric waveguide 103 as described with respect to Figures 1 and 2.

The first and second waveguides may be air waveguides or dielectric waveguides. A dielectric waveguide may be placed in an air waveguide or in a further dielectric waveguide when the slot is attached to the dielectric waveguide. Alternatively, an air waveguide may be placed in a dielectric waveguide or in a further air waveguide, when the slot is attached to the air waveguide.

A dielectric waveguide placed inside another dielectric waveguide may be efficiently implemented by a multi-layer PCB or by a stacked PCB. For example, a metal coated carrier having an inner metal layer in which a slot is formed by which slot energy from an inner layer is transported to an outer layer. The first waveguide may be a thin optical

waveguide, e.g. an optical fibre, and the second waveguide a thicker optical waveguide. When a slot is attached to the thin optical waveguide and the thin optical waveguide is mounted inside the thicker optical waveguide, light is transported from the first waveguide to the second waveguide at a high degree of efficiency. The method may be used for a directional coupling of light.

In an implementation form (not shown), the method 900 further comprises: forming a coupled port in the first waveguide, the coupled port being coupled to the coupling slot and being connectable to a microstrip line. The coupled energy may be easily measured when connecting a measurement device to the microstrip line.

Fig. 10 shows a dielectric waveguide and an air waveguide coupleable by a method 900 according to an implementation form. The dielectric waveguide is produced by covering a plate of dielectric material 1003 by a metallization 1001 and removing a part of the metallization on a main surface of the plate such that a coupling slot 1005 is formed in the main surface of the plate. The plate is coupled to an air waveguide 101 such that the coupling slot 1005 is placed inside the air waveguide 101. The air waveguide 101 may be a hollow body having a metallic coating 1007. Air 1009 may flow through the air waveguide 101. The air waveguide 101 may be mounted by known means on the coupling slot 1005 of the plate such that the metallic coating 1007 of the air waveguide 101 surrounds the coupling slot 1005 and energy leaving the dielectric waveguide is transmitted through the coupling slot 1005 into the air waveguide 101. Alternatively, the dielectric waveguide may be positioned into the air waveguide 101 such that the air waveguide 101 forms a shielding for the dielectric waveguide.

Many alternatives, modifications, and variations will be apparent to those skilled in the art in light of the above teachings. Of course, those skilled in the art will readily recognize that there are numerous applications of the invention beyond those described herein. While the present invention has been described with reference to one or more particular embodiments, those skilled in the art will recognize that many changes may be made thereto without departing from the spirit and scope of the present invention. It is therefore to be understood that within the scope of the appended claims and their equivalents, the inventions may be practiced otherwise than as specifically described herein.

CLAIMS:

1. A directional coupler arrangement (100), comprising:

an air waveguide (101); and

a dielectric waveguide (103) having a coupling slot (105); wherein

the air waveguide (101) and the dielectric waveguide (103) are coupled by the coupling slot (105).

2. The directional coupler arrangement (100) of claim 1, wherein the coupling slot (105) of the dielectric waveguide (103) is arranged inside the air waveguide (101).

3. The directional coupler arrangement (100) of claim 1 or claim 2, wherein the dielectric waveguide (103) comprises a dielectric material (1003) covered by a metallization (1001), an opening (1005) in the metallization (1001) forming the coupling slot (105).

4. The directional coupler arrangement (100) of claim 3, wherein the opening (1005) in the metallization (1001) of the dielectric waveguide (103) extends to the dielectric material (1003).

5. The directional coupler arrangement (100) of any of the preceding claims, wherein the dielectric waveguide (103) is formed as a plate (200) having a main surface (201).

6. The directional coupler arrangement (100) of claim 5, wherein a main direction (z) of the air waveguide (101) is substantially perpendicular to the main surface (201) of the plate (200).

7. The directional coupler arrangement (100) of claim 5 or claim 6, wherein the coupling slot (105) is formed in the main surface (201) of the plate (200).

8. The directional coupler arrangement (100) of one of the preceding claims, wherein the coupling slot (105) is formed as one of the following geometrical figures: a rectangle, a circle, a cross, a larger circle beneath a smaller circle, a larger cross beneath a smaller cross.

9. The directional coupler arrangement (100) of any of the preceding claims, comprising a second dielectric waveguide (109) having a second coupling slot (111); wherein the air waveguide (101) and the second dielectric waveguide (109) are coupled by the second coupling slot (111).

10. The directional coupler arrangement (100) of claim 9, wherein the second dielectric waveguide (109) is formed as a second plate (210) having a main surface (211).

11. The directional coupler arrangement (100) of claim 10, wherein the main surface (211) of the second plate (210) is arranged substantially parallel to the main surface (201) of the plate (200).

12. The directional coupler arrangement (100) of any of claims 9-11, wherein the second coupling slot (111) of the second dielectric waveguide (109) is arranged inside the air waveguide (101).

13. The directional coupler arrangement (100) of any of claims 9-12, wherein a size of the second coupling slot (111) is larger than a size of the coupling slot (105).

14. The directional coupler arrangement (100) of any of claims 9-13, wherein a main direction (224) of the second coupling slot (111) is arranged substantially parallel to a main direction (220) of the coupling slot (105).

15. The directional coupler arrangement (100) of any of claims 9-14, wherein the second dielectric waveguide (109) comprises an input port (151) coupled to the second coupling slot (111), the input port (151) being connectable to a microstrip line.

16. The directional coupler arrangement (100) of any of the preceding claims, wherein the dielectric waveguide (103) comprises a third coupling slot (107), the third coupling slot (107) being arranged inside the air waveguide (101).

17. The directional coupler arrangement (100) of claim 16, wherein a main direction (222) of the third coupling slot (107) is arranged substantially parallel to a main direction (220) of the coupling slot (105).

18. The directional coupler arrangement (100) of claim 16 or claim 17, wherein a size of the third coupling slot (107) is substantially as large as a size of the coupling slot (105).

19. The directional coupler arrangement (100) of any of claims 16-18, wherein

the dielectric waveguide (103) comprises a coupled port (155) coupled to the coupling slot (105), the coupled port (155) being connectable to a microstrip line; and wherein

the dielectric waveguide (103) comprises an isolated port (157) coupled to the third coupling slot (107), the isolated port (157) being connectable to a microstrip line.

20. A method (900) of coupling a first waveguide (103) to a second waveguide (101) comprising:

forming (901) a coupling slot (105) in the first waveguide (103); and

arranging (903) the coupling slot (105) of the first waveguide (103) inside the second waveguide (101).

21. The method (900) of claim 20, wherein the first waveguide (103) is a dielectric waveguide and the second waveguide (101) is one of an air waveguide and a dielectric waveguide.

22. The method (900) of claim 20 or claim 21, comprising: forming a coupled port (155) in the first waveguide (103), the coupled port (155) being coupled to the coupling slot (105) and being connectable to a microstrip line.

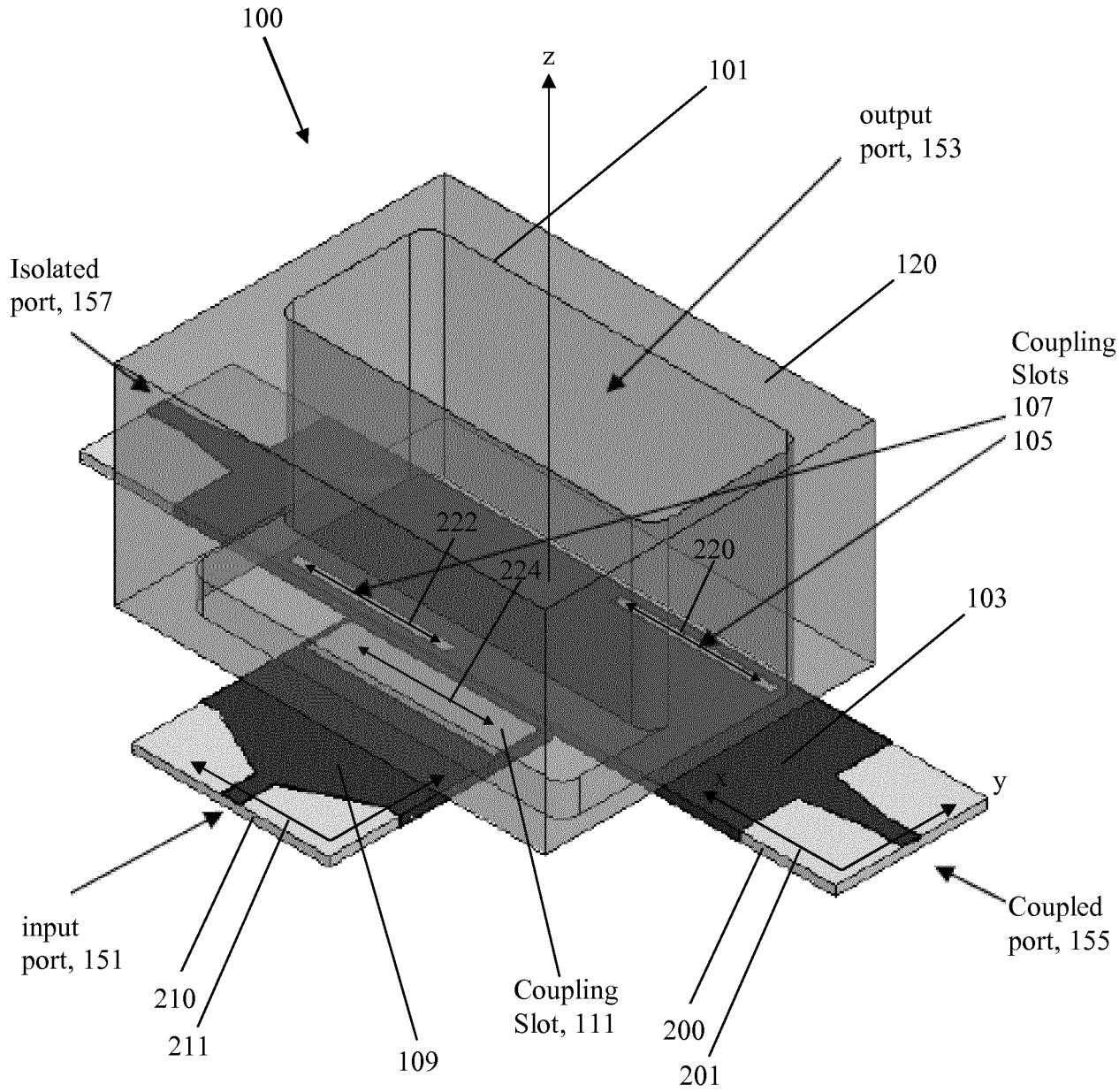

100
z
101
output
port, 153
Isolated
port, 157
120
Coupling
Slots
107
105
222
224
220
103
y
x
input
port, 151
Coupled
port, 155
210
211
109
Coupling
Slot, 111
200
201

Fig. 1

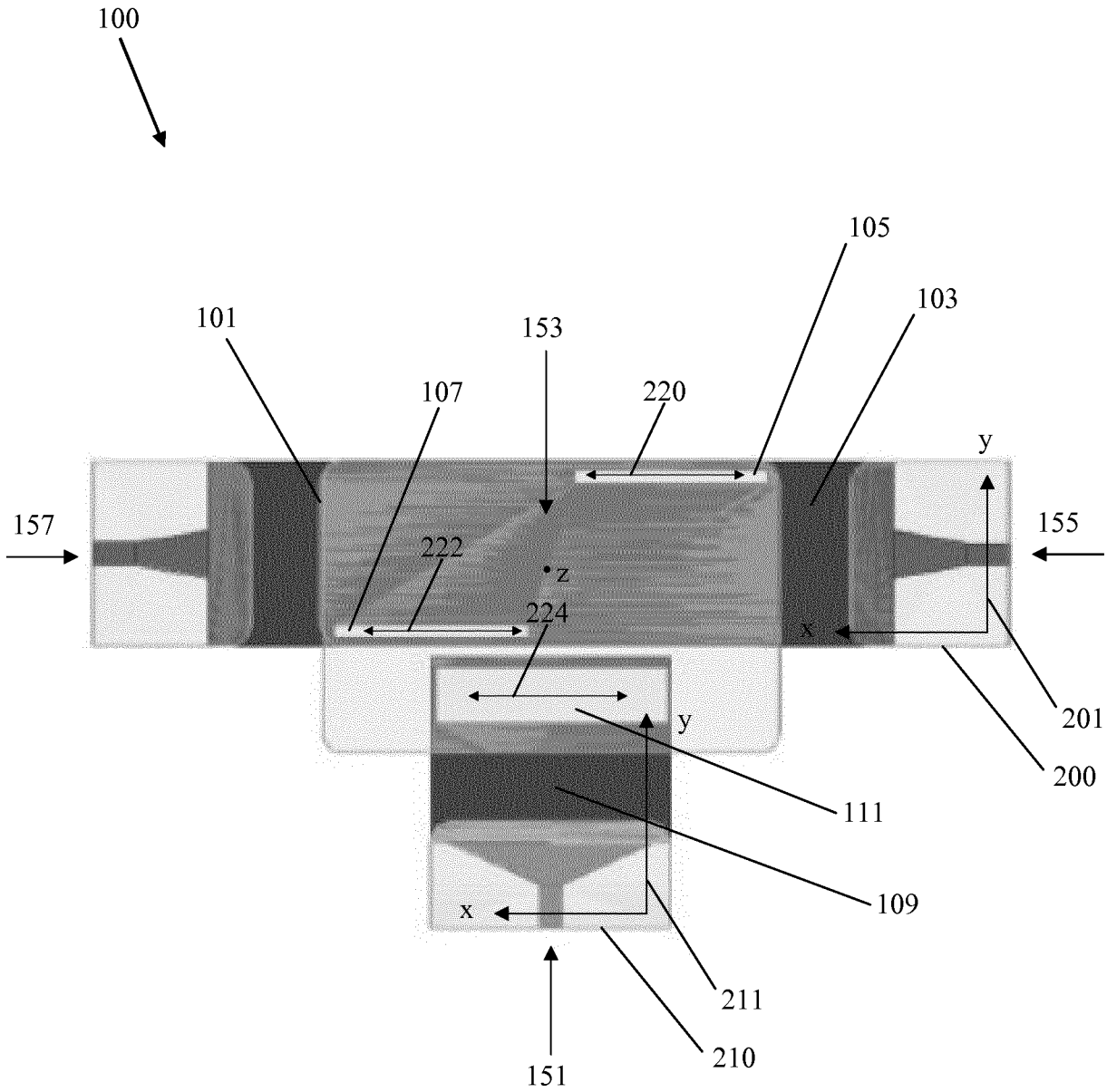

100
105
103
101
153
107
220
y
157
155
222
z
224
x
201
y
200
111
109
x
211
210
151

Fig. 2

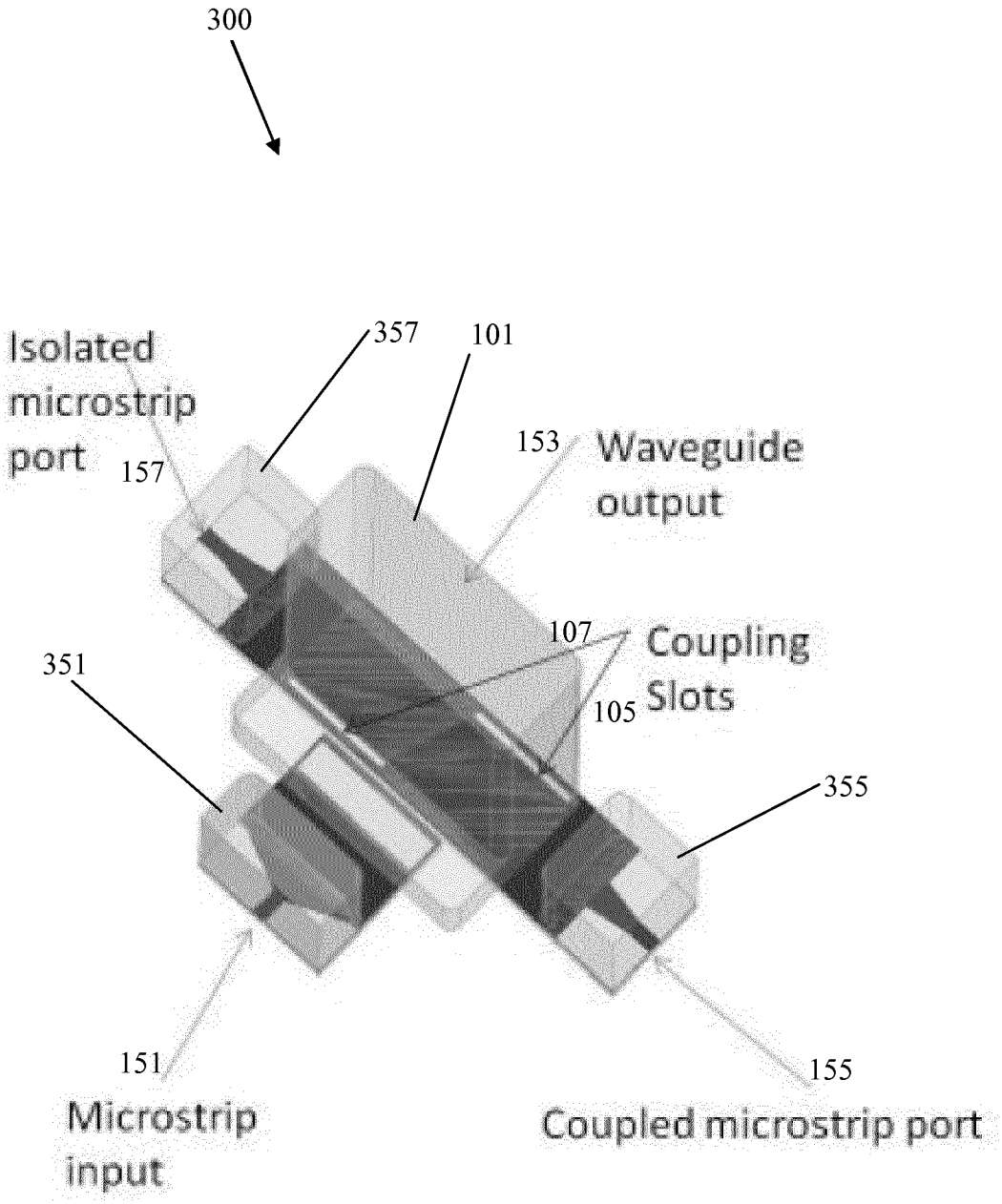

300
Isolated microstrip port
157
357
101
153
Waveguide output
107
Coupling Slots
105
351
355
151
155
Microstrip input
Coupled microstrip port

Fig. 3

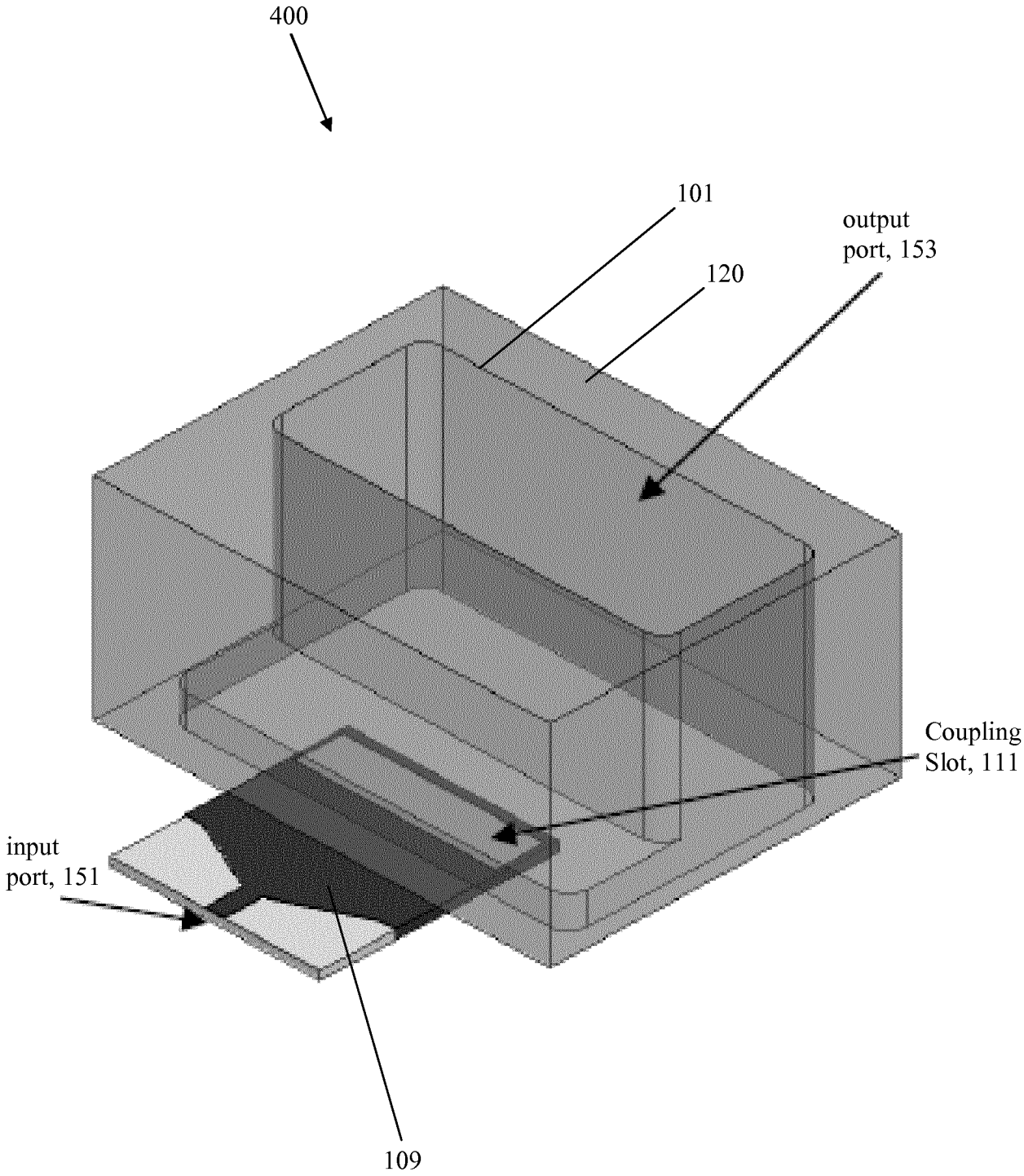

400
101
output
port, 153
120
Coupling
Slot, 111
input
port, 151
109

Fig. 4

α

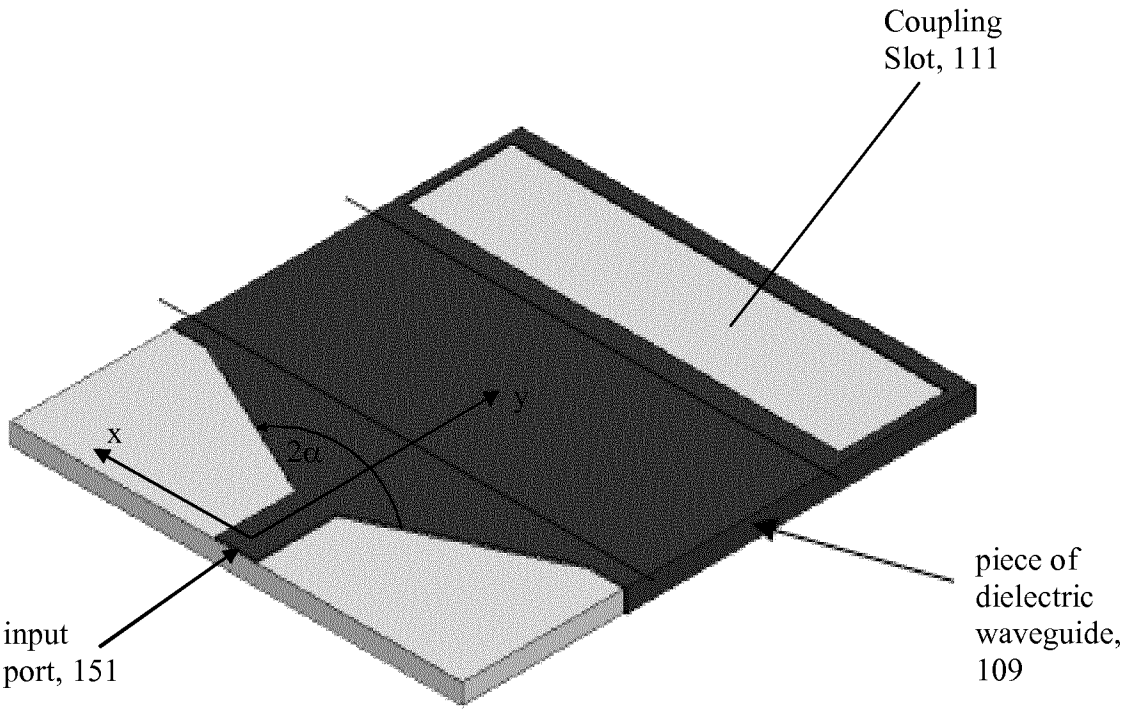

Coupling
Slot, 111
y
x
2α
input
port, 151
piece of
dielectric
waveguide,
109

Fig. 5

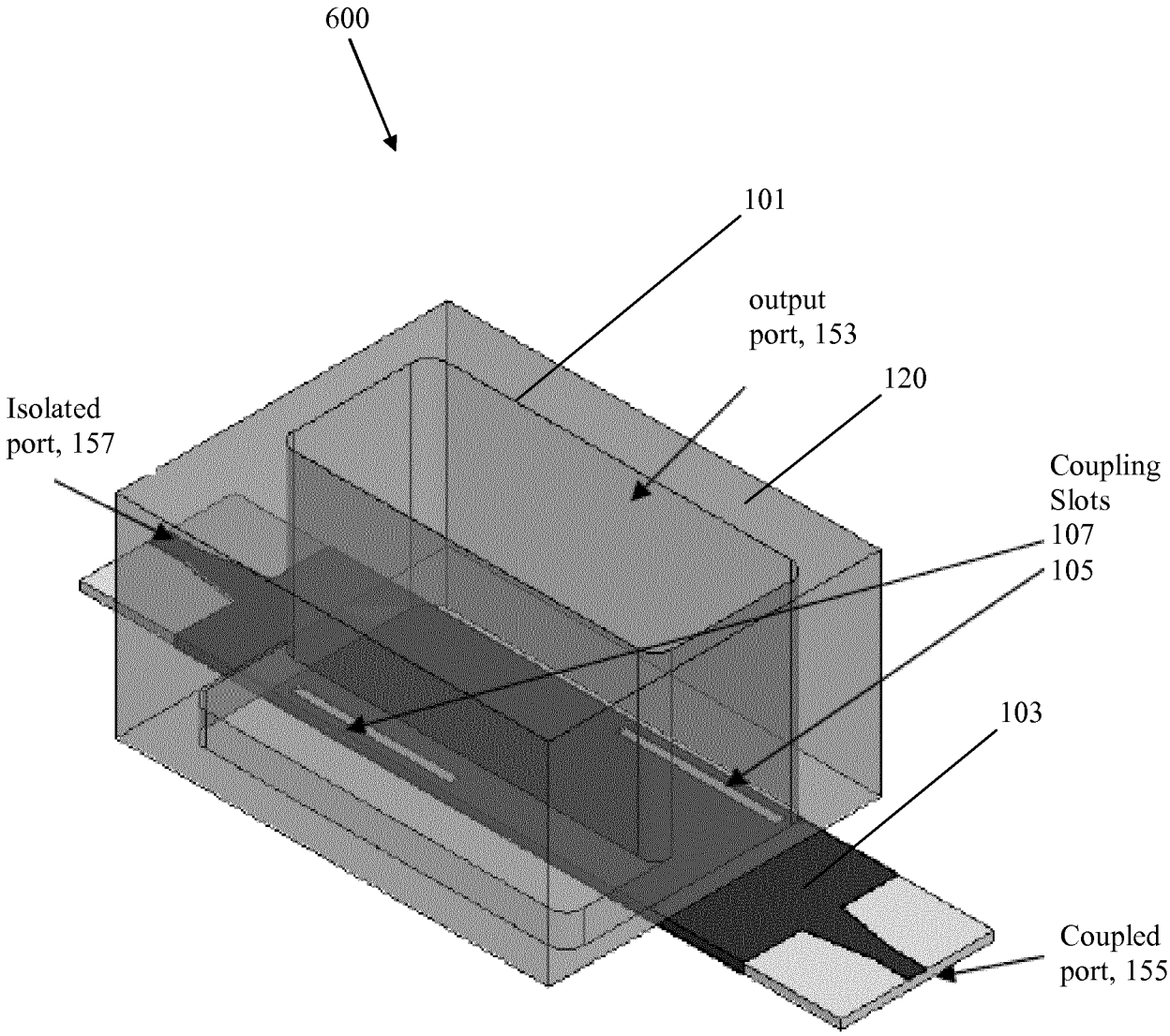

600
101
output
port, 153
120
Isolated
port, 157
Coupling
Slots
107
105
103
Coupled
port, 155

Fig. 6

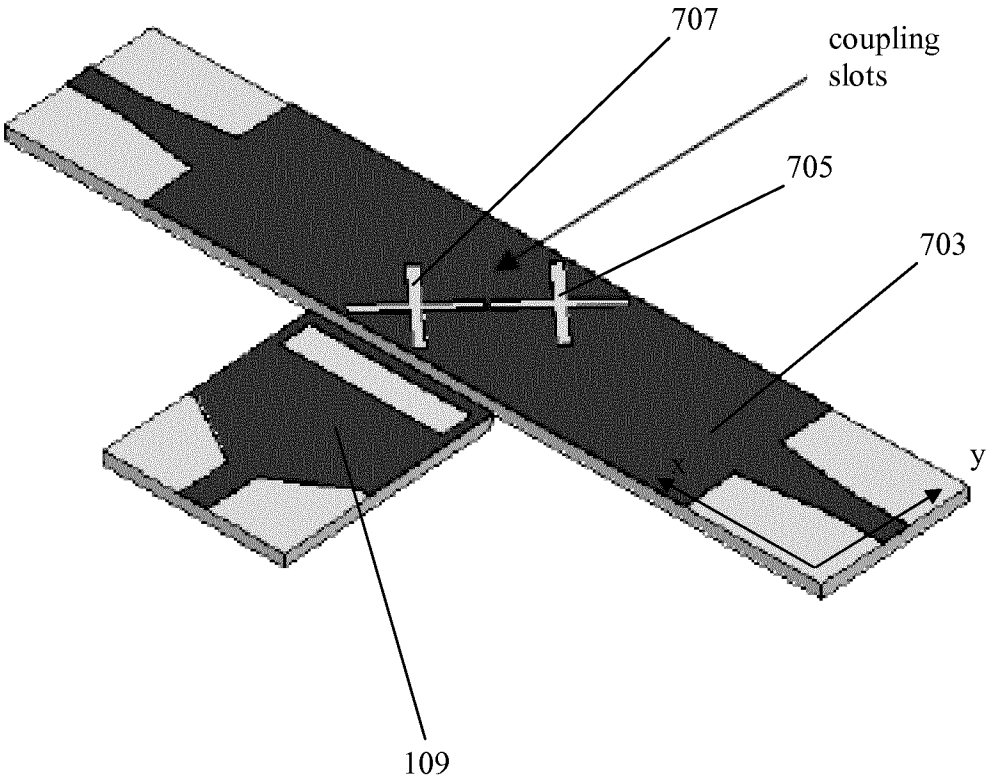


Fig. 7

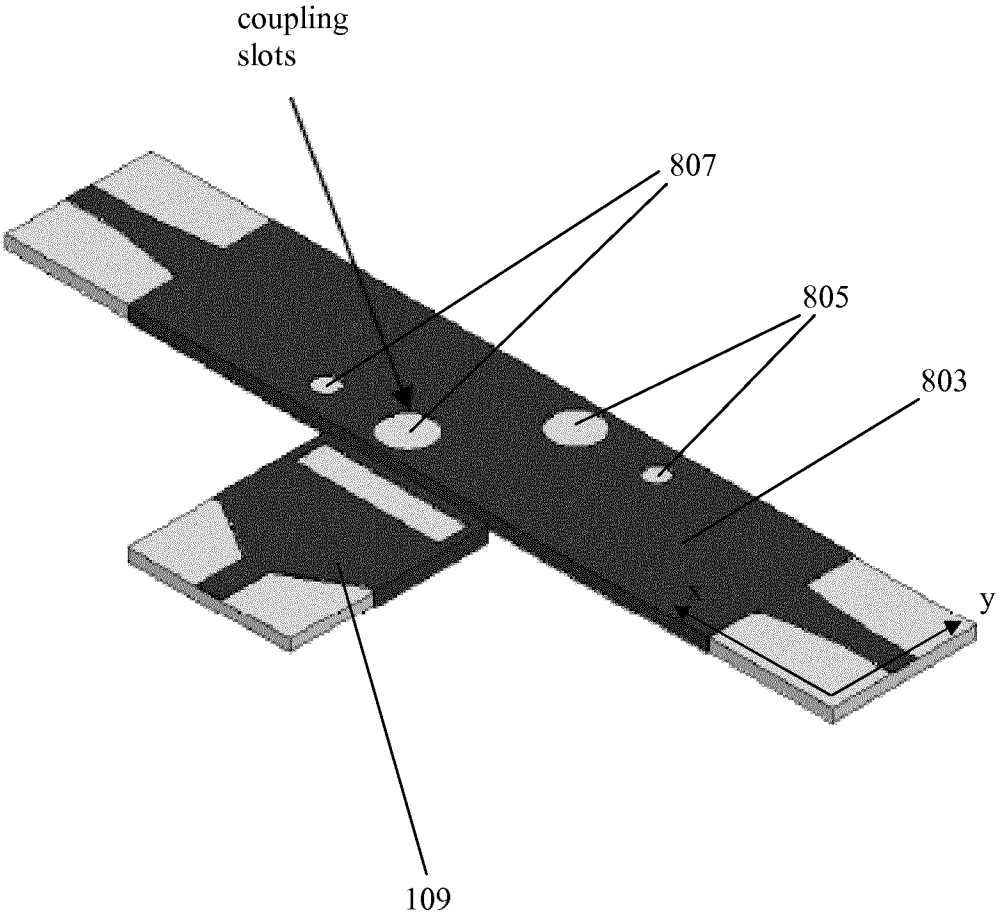


Fig. 8

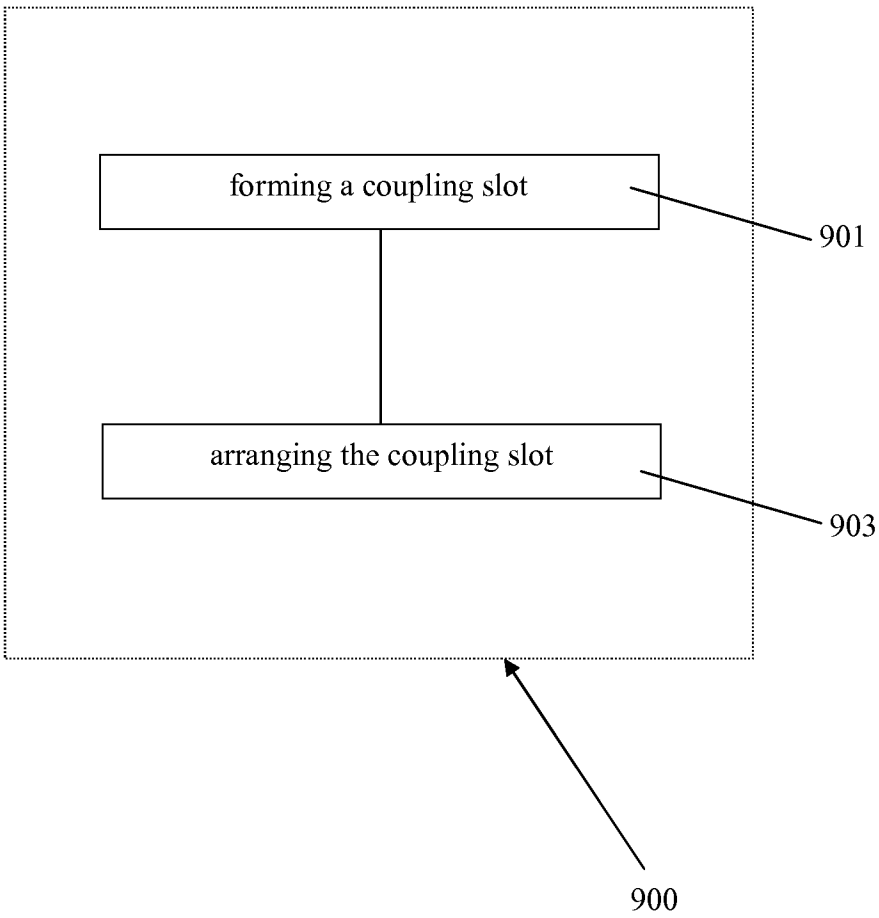
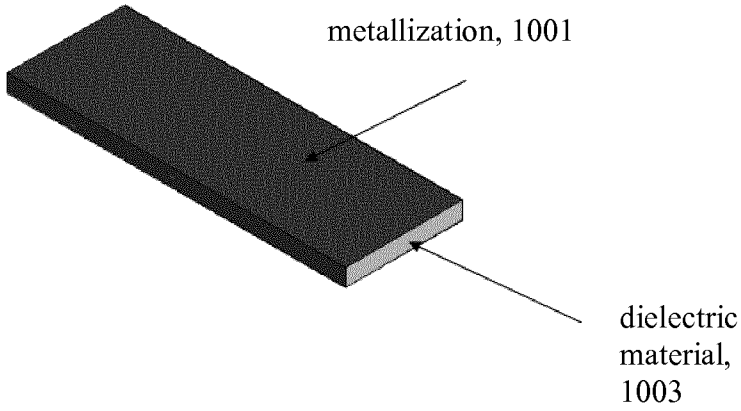
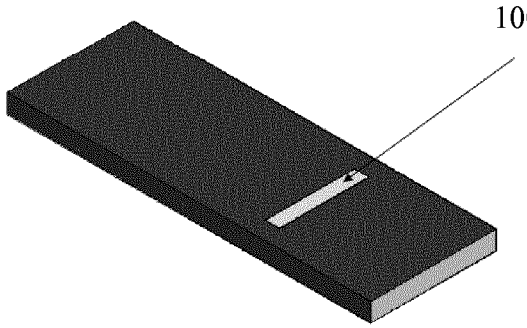

forming a coupling slot
901
arranging the coupling slot
903
900

Fig. 9


metallization, 1001
dielectric material, 1003


1005

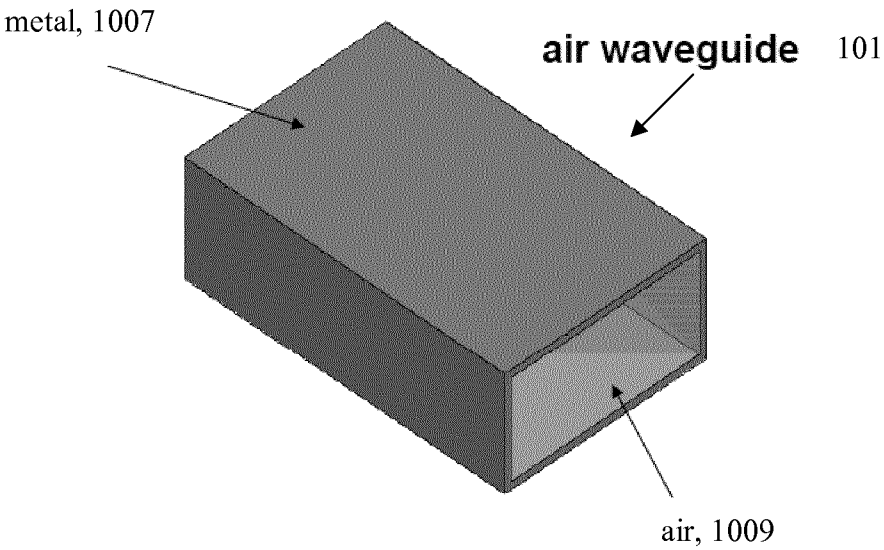

metal, 1007
air waveguide
101
air, 1009

Fig. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/061577

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01P5/107 H01P5/18
ADD.

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

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.
X	WO 2011/109939 A1 (HUAWEI TECH CO LTD [CN]; FABIO MORGIA [IT]) 15 September 2011 (2011-09-15) the whole document	1-15, 20-22
A	US 2 976 499 A (SFERRAZZA PETER J) 21 March 1961 (1961-03-21) the whole document	1,9,10, 15-19
X	LIN LI ET AL: "A transition from substrate integrated waveguide (SIW) to rectangular waveguide", MICROWAVE CONFERENCE, 2009. APMC 2009. ASIA PACIFIC, IEEE, PISCATAWAY, NJ, USA, 7 December 2009 (2009-12-07), pages 2605-2608, XP031614048, ISBN: 978-1-4244-2801-4 the whole document	1-15, 20-22

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

[X] See patent family annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 February 2013	14/02/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Köppe, Maro

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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	LABAY V A ET AL: "E-plane directional couplers in substrate-integrated waveguide technology", MICROWAVE CONFERENCE, 2008. APMC 2008. ASIA-PACIFIC, IEEE, PISCATAWAY, NJ, USA, 16 December 2008 (2008-12-16), pages 1-3, XP031636455, ISBN: 978-1-4244-2641-6	20-22
A	the whole document	16-19

X	EP 1 732 159 A1 (FUJITSU LTD [JP]) 13 December 2006 (2006-12-13) column 6, line 50 - column 10, line 31 figures 1-4	1-18, 20-22

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2012/061577

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		US 2006274992 A1	07-12-2006