(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 592 081 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
02.11.2005 Bulletin 2005/44

(51) Int Cl.[7]: **H01P 5/107**

(21) Application number: **04425300.3**

(22) Date of filing: **29.04.2004**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PL PT RO SE SI SK TR
Designated Extension States:
AL HR LT LV MK

(71) Applicant: **Siemens Mobile Communications S.p.A.**
20126 Milano (IT)

(72) Inventors:
- **Cifelli, Antonio**
  20060 Gessate (MI) (IT)
- **Milani, Angelo Giuseppe**
  20020 Magnago (MI) (IT)
- **Polini, Marco**
  20090 Vimodrone (MI) (IT)

(54) **Microstrip to waveguide transition for millimetric waves embodied in a multilayer printed circuit board**

(57) A microwave to waveguide transition is obtained in a multilayer structure comprising a 100 µm thick dielectric substrate (1) adherent to a rigid copper plate (15) 2 mm thick. The dielectric substrate is one of high-losses type suitable for PCB manufacturing techniques, such as Roger™ 4350. A metallic layout on the dielectric substrate includes a microstrip (2) terminating with a patch (3) acting as a probe inside the cavity of a rectangular waveguide WR15 (1.88 × 3.76 mm) operating in the EHF frequency range of 55-60 GHz (millimetric waves). The introduction of the probe inside the cavity (11) of the waveguide filled with air maintaining the continuity of the microstrip is a problem solved by properly working both the multilayer (1, 15) and the waveguide for a reciprocal penetration. More precisely, the multilayer is removed in correspondence of a window (5, 6) for the insertion of the waveguide (10), with the exception of a narrow central stripe (4) bearing the probe. Two opposite grooves (12, 13) are milled in the edge of the waveguide for the insertion of the stripe with the probe inside the cavity of the waveguide as far as the depth of the grooves allows it. A metallic lid (16) is screwed to the edge of the waveguide for reflecting back to the waveguide (10) the power radiated by the patch (3) in the opposite direction. The multilayer is fixed to the same metallic body which had been worked mechanically to obtain the waveguide. In order to prevent possible detachments of the thin dielectric substrate from the thick copper plate, a crown of metallized through holes is obtained around the edge of the waveguides emerging from the multilayer. The transition is part of a millimetric wave transceiver manufactured on a single multilayer accordingly to PCB, surface mount, and chip-on-board technologies (fig.5).

60 GHz MICROSTRIP TO WAVEGUIDE TRANSITION

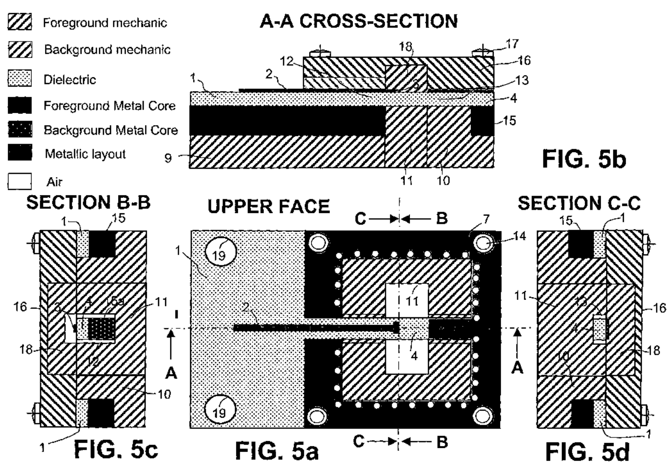

FIG. 5b FIG. 5c FIG. 5a FIG. 5d

EP 1 592 081 A1

Description

FIELD OF THE INVENTION

[0001] The present invention relates to the field of microwave circuits and apparatuses and more precisely to a microstrip to waveguide transition for millimetric waves embodied in a multilayer printed circuit board. We remind that "microwaves" is a generic term to indicate several frequency ranges for the air propagation from about 1 GHz up to roughly 3 THz, millimetric waves correspond to the EHF range from 30 to 300 GHz (λ=10 to 1 mm). The embodiment of the present invention is particularly suitable to the EHF range but there are not limitations to the application in other frequency ranges, for example the SHF one from 3 to 30 GHz (λ = 10 to 1 cm). The invention is referred both to a method for manufacturing the transition and the transition itself.

[0002] Nowadays the manufacturers of microwave transceivers are pressed by an increasing demand of apparatuses operating in the range of millimetric waves, e.g. for applications in: high/medium/low capacity radio links, point-to-multipoint networks, satellite communications, etc. Having recourse to mass manufacturing techniques oriented to achieve cost-effective products like the traditional Printed Circuit Boards (PCB) are problematic in this frequency range, due to the increased dielectric losses of the substrates and the inadequacy of the known designs to interface planar circuits with mechanical waveguides.

BACKGROUND ART

[0003] Microstrip to waveguide transitions embodied with high-loss dielectric substrates for PCB manufacturing are known in the art. The Applicant of the present invention filed on 30-5-2002 an European patent application indicated as **Ref.[1]** in the **REFERENCES** listed at the end of the description. According to **Ref.[1]** the operating frequency range of the transition was extending until to 35 GHz on fibre reinforced glass (FR4) substrates. The multilayer board made use of a thick copper layer as second layer of the build-up wafer structure to provide mechanical stiffness to the FR4 substrate for the connection of a rectangular waveguide on the bottom face. The copper layer was milled to lay bare the dielectric window of a slot transition and obtain in the meanwhile a sort of flange around it for mounting the waveguide. Disregarding the transition for the moment, the idea of making use of high-loss substrates to obtain reliable and low-cost microwave circuits suitable to the automatic or semiautomatic assembly techniques, already widely used in the manufacturing of the PCBs, had been inherited from a preceding European patent application filed by the same Applicant on 26/07/2001 and presently indicated as **Ref.[2].** This second application was describing a chip-on-board (COB) technology which allowed to integrate on the substrate many parts of the transceiver, in particular it was possible to accommodate on the substrate both the surface mounting components and those in-chip (either discrete or MMIC) with the relevant polarisation circuitry, so as the conventional waveguide transition that constituted the radio interface of the transceiver. The frequency of 80 GHz was the theoretical limit depending on the minimum width Wm of the microstrip and the thickness h of the FR4 layer allowed by the technology. Having considered Wm = 200 μm the width of the microstrip, and λ/Wm = 10 as a good design parameter, then in order to obtain 50 Ω value for the characteristic impedance of the microstrip the thickness of the FR4 layer was h = 100 μm. The optimistic value of 80 GHz had been calculated for the only wave propagation along the microstrip without taking into due consideration the effects of microstrip to waveguide transitions. Because the invention that will be disclosed is referred to an alternative embodiment to the transition of **Ref.[1]** capable to really operate up to 80 GHz, some details of the embodiment at **Ref.[1]** are needed in order to appreciate the improvements. **Figures 1a, 1b, 2a, 2b,** and **3** disclose those details.

[0004] **Fig.1a** shows a metallic layout laid down on the upper face of a dielectric FR4 substrate belonging to a multilayer structure. The layout includes a microstrip which extends along the longitudinal symmetry axis of the substrate and terminates with a metal patch. The microstrip and the remaining circuitry (not visible for simplicity) are encircled by a shielding metallic layout delimiting a rectangular unmetallized window, corresponding to a dielectric window, entered by the patched microstrip. The perimetrical metallization of the dielectric window is shaped as a rectangular frame with four unmetallized circle at the four corners in correspondence of threaded holes through the multilayer structure. **Fig.1b** shows a thick copper layer glued to the bottom face of the dielectric substrate to form a metal core giving stiffness to the multilayer structure and constituting a ground plane for the upper microstrip. The metal core is milled and completely removed to lay bare the dielectric substrate in correspondence of the dielectric window, so that the patch is visible from the rear due to the semitransparency of the FR4 layer. **Fig.2a** is a cross-section along the axis A-A of **fig.1a.** The figure shows the structure of the multilayer including three dielectric substrates, and the metal core. The upper and the lower dielectric substrates are metallized wile the interposed one is used as insulator. The end of a rectangular waveguide joins the rectangular window milled in the metal core in correspondence of the dielectric window of the upper substrate, so that the opening in the metal core is a continuation of the waveguide to the dielectric window of the substrate. A metallic lid placed upon the frame of the upper face is fixed to the multilayer structure by means of four screws at the corner of the frame penetrating into the upper dielectric substrate, the metal core (flange) and the walls of the rectangular waveguide. The metallic lid is a hollow body with a rectangular recess faced to the unmetallized window. In operation, the patched end of the microstrip which comes into the dielectric window acts as an electromagnetic probe for radiating into the closed space around it. The dimensions of the patch are calculate so as to transfer the energy from the feeding microstrip to the waveguide efficiently. The screwed metallic lid is used as a reflector to prevent propagation from the patch in the opposite direction to the waveguide. To this aim the recess of metallic lid acts as a back short for the signal. From the above considerations it can be conclude that the probe and the dielectric window in communication with the waveguide constitute a microstrip to waveguide transition that transforms the "quasi-TEM" propagation mode of the microstrip into the TE_{10} mode of the rectangular waveguide. The electromagnetic properties of the transitions are reciprocal, so that the same structure used by the RF transmitter for conveying inside the waveguide a transmission signal from the microstrip is also used by the receiver for conveying a RF reception signal from the waveguide to the microstrip.

[0005] **Fig.2b** shows a series of metallized through holes (via-holes visible in **Fig.2a)** regularly spaced along the frame. These via-holes around the transition zone have been introduced successively the filing of **Ref.[1]** to the aim of improving the performances of the transition at the higher frequencies (35.5 GHz) of the operating range. This statement is possible because the transition at **Ref.[1]** and the transition of the present invention are both developed in the laboratories of the same Applicant. The via-holes supply to the lack of continuity of the waveguide through the thickness of the dielectric substrate around the zone of the transition. Thanks to via-holes, the energy is bound inside the parallelepipedal part of the dielectric substrate adjacent to the air cavity of the waveguide, otherwise the propagation through the dielectric substrate outside the zone of the transition would constitute a cause of losses. Furthermore, the via-holes supply the upper lid with ground contacts distributed around the transition, improving the poor contact provided by the screws at the four corners of the frame. **Fig.3** is a photography of the layout of the transceiver which depicts the real arrangement of via-holes; as it can be noticed, several rows of metallized holes are needed to a satisfactory operation in the SHF range (not in the EHF).

[0006] Despite of the manufacturing simplicity of the transition illustrated in the above figures, any attempts to arrange it to the be used in the EHF range has been concluded with a failure due to unacceptable power loss and distortion introduced by the transition. From the analysis of the main causes of these failures it results that at the millimetric waves:

1. Via-holes are not more able to bound the electromagnetic field into the encircled parallelepipedal part of the dielectric substrate. The drawback is due to the fact that diameters and reciprocal distances of the holes are comparable with the used wavelength and can not be further reduced cause unavoidable technological limitations of the via-hole process.
2. The thickness of the dielectric substrate is no more completely negligible in comparison with the wavelength of the signal, as a consequence via-holes don't connect to the ground the upper lid efficiently. As a consequence the lid couldn't be considered as a continuation of the waveguide opportunely terminated at the top, and a mismatch between the two sides of the patch may generates unwanted reflections and of spurious resonating modes.
3. Losses inside the dielectric part of the transition is excessive due to the poor performances of the semi-valuable substrate.

OBJECTS OF THE INVENTION

[0007] The main object of the present invention is that to overcome the drawbacks of the known art and indicate a microstrip to waveguide transition obtainable on PCBs arranged for operating at the microwaves with good performances in the nearest EHF range (up to 80 GHz)

SUMMARY AND ADVANTAGES OF THE INVENTION

[0008] The invention achieves said object by providing a method to manufacture a microstrip to waveguide transition, as disclosed in the method claims.

[0009] Other object of the invention is a microstrip to waveguide transition obtained according to the method, as disclosed in the device claims.

[0010] The method of the invention is applied to a multilayer structure comprising, at least, a dielectric substrate of the type usable in the technology of printed circuit boards, adherent to a rigid metal plate, the dielectric substrate giving support to a metallic layout including a microstrip terminating with a patch acting as a probe for coupling the microstrip to the waveguide through the dielectric substrate, the method including the steps of:

- opening a window in the multilayer for introducing the waveguide, being the window interrupted by a central stripe bearing the probe;
- milling the edge of the waveguide to obtain two opposite grooves of given depth for accommodating said stripe;
- introducing the stripe into the opposite grooves of the waveguide as far as their depth allows it and fastening a metallic lid to the edge of the waveguide emerging from the two sides of the interruption for reflecting back to the waveguide the power radiated by the patch in the opposite direction.

[0011] According to the invention, the transition disclosed at **Ref.[1]** is now completely redesigned in order to remove almost completely the former dielectric diaphragm from the space of the transition. Prevalently air fills up the propagation space of the electromagnetic waves in the new transition; with that the drawback highlighted at point 3 is overcome. Another fundamental difference from the prior art is that the waveguide now penetrates the dielectric substrate to connect the metallic lid, without breaking the continuity of the metallic walls, except for the two grooves whose effect is completely marginal. In other words, the frame of via-holes is completely unnecessary to confine the electromagnetic field, and also the drawbacks highlighted at points 1 and 2 are overcome.

[0012] Advantageously, the waveguide part of the transition and the other mechanic part of the transceiver can be obtained by means of numerical control manufacturing techniques starting from a rough metal block. Microstrip to waveguide transitions for rectangular waveguides according to the present invention are the easiest to obtain, but the same approach is applicable to obtain transitions for circular or elliptic waveguides.

[0013] Being all causes of losses and misoperation imputable to the only transition removed, the upper frequency limit due to the microstrip on PCBs technique, for example 80 GHz, is now fully exploitable from the transceiver.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The features of the present invention which are considered to be novel are set forth with particularity in the appended claims. The invention and its advantages may be understood with reference to the following detailed description of an embodiment thereof taken in conjunction with the accompanying drawings given for purely non-limiting explanatory purposes and wherein:

- **figures 1a** to **3,** already described, show a microstrip to waveguide transition according to the prior art mentioned at **Ref.[1];**
- **figures 4a** to **4d** show some manufacturing steps of the multilayer and the waveguide according to the method of the invention;
- **figures 5a** to **5d** show a top view, a longitudinal, and transversal cross section views of the transition according to the invention;
- **figures 6a** and **6b** show a perspective simulation model and relevant parameters of the transition according to the invention;
- **figures 7** and **8** show the $\mathbf{S_{11}}$ and $\mathbf{S_{21}}$ parameters of the simulated model;
- **fig. 9a** shows a top view of two transition back-to-back used for measures;
- **fig. 9b** shows a photography of the back-to-back transition of fig.9a;
- **figures 10.** and **11** show the $\mathbf{S_{11}}$ and $\mathbf{S_{21}}$ parameters really measured at the ends of the back-to-back arrangement of fig.9a;
- **fig. 12** shows a top view of a microstrip to circular waveguide transition, without the upper lid.

DETAILED DESCRIPTION OF AN EMBODIMENT OF THE INVENTION

[0015] As a description rule, in the several figures of the drawings like referenced numerals identify like elements. Besides, the various elements represented in the figures are not a scaled reproduction of the original ones. With reference to fig.4a we see a partial upper face of a dielectric substrate 1 belonging to a known multilayer structure presently used to obtain the circuitry of a transceiver operating nearby 60 GHz (EHF range) employing traditional PCB techniques. The multilayer structure is a simpler version of the one disclosed at **Ref. [1]** limited to include a thin dielectric substrate 1, characterized by high dielectric losses in comparison with alumina or Gallium Arsenide substrates traditionally used for EHF applications, made adherent to a thick copper plate giving the needed stiffness to the planar structure. A microstrip to waveguide transition, and vice versa, used to connect both the transmitter and the receiver amplifiers to the same antenna by means of a duplexer, is the only part of the transceiver the present invention is concerned with. The substrate 1 gives support to a metallic layout including among other things a microstrip 2 placed along the axis of longitudinal symmetry of the figure. The microstrip 2 terminates with a small patch 3 nearby the centre of a stripe 4 placed between two symmetric rectangular windows 5 and 6 obtained from the removal of the multilayer by milling (or drilling and sawing) according to the known techniques. The area of the two windows 5 and 6 prevails with respect to the area of the central stripe 4 so that the space of the transition is filled prevalently with air. A metallization 7 encircles, as a frame, the two symmetric windows 5 and 6 and the central stripe 4, leaving a short passage free for the microstrip 2, but having a finger 7a covering the stripe 4 for a short tract opposite to the patch 3. Several metallized thorough holes 8 are regularly spaced along the perimeter of the frame 7. The only purpose of these holes is that of avoiding possible detachments of the upper dielectric layer from the metal core (plate) as a consequence of the milling operation for opening the windows 5 and 6, because of the not perfect physical compatibility at the interface between the two layers.

[0016] In **fig.4b** a partial top view of the mechanical part 9 of the transceiver is depicted. The mechanic is manufactured in a way to include the end of a rectangular waveguide 10. The internal cavity 11 of the metallic waveguide10 is filled up with air. Two rectangular grooves 12 and 13 are milled for all the thickness of the two longer walls at the extremity of the waveguide 10, along the symmetry axis. Four threaded holes 14 are visible at the four corners of the mechanical part 9. The dimensions of the two windows 5 and 6 and the width of the stripe 4 are set to accommodate at the same time the stripe 4 into the grooves 12 and 13 at the edge of the waveguide 10 and the edge of the waveguide 10 inside the windows 5 and 6, as far as the depth of the grooves 12 and 13 allows it. With reference to **figures 4c** and **4d**, before this accommodation takes place part of the metal core must be removed from the stripe 4. **Fig.4c** and **fig.4d** show the metal core before and after removal, respectively. An indication of the real placement of the internal cross-section 11 of the waveguide 10 is added with dashed line in **fig.4d.** It can be appreciated that the stripe 4 is free from metal in correspondence of the cavity of the microwave 10, so that the tract of the patched microstrip 2, 3 penetrating the cavity 11 is free to radiate as a probe inside the waveguide 10.

[0017] **Fig.5a** shows a top view of the assembly constituted by the multilayer of **fig.4a** superimposed to the mechanic of **fig.4b** so as they can interpenetrate. Two axes A-A and B-B are indicated in the figure as reference planes for the cross-sections reported in the successive figure. **Fig.5b** shows the cross-section along the longitudinal symmetry axis A-A of fig.5a. With reference to **fig.5b,** the edge of the waveguide 10 emerges from the openings 5 and 6 and a metallic lid 16 is leant on it. The lid 16 is fastened to the waveguide 10 by means of screws 17 penetrating the four threaded holes 14 (fig.4b). The lid 16 includes a central hollow 18 shaped as a very short tract of waveguide 10 closed at the end. By comparison with the prior art of **fig.2a,** the lid 16 is now connected to the waveguide without any interposed dielectric layer, so that the metallic continuity of the walls of the waveguide 10 is never interrupted across the transition until the lid is reached. In this way the back currents reflected from the lid reach the ground directly and, as a consequence, via-holes around the transition as in **fig.2b** are unneeded for the reasons stated before. Grooves 12 and 13 have different depths, the first one (12) is deeper than second one (13) to also include the copper finger 15a (fig.4d). The highlighted dissymmetry on the two depths is a consequence of the dissymmetric layout on the stripe 4, which bears a microstrip on the left part wile the right part is bare. More precisely, the microstrip 2 stops to be a as such only at the end of the groove 12, whose depth is calculated accordingly. Moreover the depth of both the grooves 12 and 13 shall be calculated to assure a certain free space between the end of the waveguide 10 and the microstrip 2, and considering that a certain tolerance on the width of the grooves 12 and 13 is foreseen for the insertion of the stripe 4 without problems, as visible in fig.5a, the substrate 1 has to be fixed to the mechanic 1. Two holes 19, visible in **fig.5a,** are part of a number of them drilled in the multilayer and the mechanic 9 to align the planar circuit with respect to the waveguide 10 and fasten them to the mechanic. **Figures 5c** and **5d** show the cross-sections along the transversal symmetry axis B-B and C-C of fig.5a, respectively. The observation of these figures further clarifies the arguments already developed in the description of the preceding ones and not additional description is needed.

[0018] In the operation, the transition has been designed to operate in the range of 55-60 GHz in accordance with the market request for the transceiver apparatuses. The mechanic is worked by a numerical control machine so as to obtain a WR15 (1.88 x 3.76 mm) waveguide. The planar circuitry is obtained starting form a multilayer including a dielectric substrate 0.1 mm thick glued to a copper metal plate (core) 2 mm thick is used. The selected dielectric substrate is known with its commercial name Roger™ 4350, having losses measured by a tanδ = 0.037 at 10 GHz, as declared by the manufacturer; this value clearly increases in the operating frequency range of the transition. Roger™ is similar to FR4 or "vetronite"™ used to manufacture the transition cited at **Ref.[1],** to say, a material made of glass fibres impregnated with epoxy resin having tanδ from 0,025 to 0,05. These values of tanδ are typical for PCBs but not immediately for microwave circuits where alumina imposes with a tan δ=0,0001. The electromagnetic coupling between the microstrip 2 and the waveguide 10 is obtained by means of a probe laying on the E-plane of the rectangular waveguide 10 and terminating with the small patch 3. This probe has been obtained as continuation of the microstrip 2 inside the cavity 11 of the waveguide 10 after having removed the ground plane below. The edge of the waveguide 10 emerges from the multilayer in the zone of the transition, as far as the depth of grooves 12 and 13 allows it, and joins the edge of the lid 16. The top wall of lid 16 acts as a short circuit reflecting back the signal toward the patch 3. The latter has to see an open circuit on its plane for the reflected signal in order to keep it matched to the waveguide 10. The required impedance transformation is obtained by milling the length of tract 18 in a way that the distance of the plane of the patch 3 from the short circuit plane internal to lid 16 is about $\lambda/4$. To complete the analysis of the transition, the effect of two slots delimited by lid 16 and either grooves 12 or 13 must be considered. There are not problems with these slots because their transversal dimensions are such they behave as two under-cut waveguides in the 55-60 GHz frequency range. Besides, the slots are longer than few λ and the effect of non-propagating modes is negligible, so that the electromagnetic field is completely confined in the volume of the transition, diversely from the via-holes of the prior art.

[0019] A first design of the 55-60 GHz transition has been performed roughly calculating the dimensions of its relevant parts with the help of two canonical books cited at **Ref.[3]** and **Ref.[4].** The design has been refined successively by several simulation sessions performed by means of the electromagnetic simulator 3D Agilent™ HFSS operating on the model shown in **fig. 6a.** The goal is that to optimize the probe dimensions, inclusive of patch 3, for operating in the desired band maintaining the bandwidth and matching conditions as far as possible unaffected by mechanical and assembly tolerances. With reference to **fig.6a,** we see the model including the dielectric stripe 4 leant on the edge of the waveguide 10 transversally to its rectangular cavity 11. This model also includes the slot comprised between groove 12 and lid 16, containing the relevant tract of microstrip 2. The terminal part of the probe with the patch 3 is modelled inside the cavity 11 and represented with greater details in **fig.6b.** With reference to **fig.6b,** we see the microstrip 2 and patch 3 shaped as a T. The base of the rectangular patch 3 perpendicular to the microstrip 2 has a length c greater than the height b, but this is not a general rule. Labels **w** and **h** indicate respectively the longer and the shorter dimensions of the rectangular cavity 11, while label **a** indicates the length of the microstrip 2 (without copper below) inside the cavity 11 from the internal sidewall 12 to the base of the patch 3; i.e.: the length of the line which carries the signal to the patch 3. The simulation is carried out considering a WR15 (1.88 x 3.76 mm) waveguide; with that: **h = 0.5w.** The simulation results have confirmed that the central frequency of the transition depends on the ratio (a+b)/w, while the adaptation level at the input and the output ports depends on the ratio c/b inside the considered bandwidth. Generally speaking, the greater the ratio (a+b)/w (i.e. the patch nearer to the centre of the cavity) the lower is the central frequency fo of the transition. Besides, once w (3.76 mm) is selected in accordance with standard design rules for rectangular waveguides operating in the proximity of the desired central frequency fo (58 GHz), and (a+b)/w is set to obtain the exact fo, then b (and hence a) and c are optimized in the desired frequency band independently of the exact fo previously set. For the operating band of 55-60 GHz, the values of (a+b)/w = 0,18 and c/b = 2.22 are found to be optimal. The results of simulations are reported in **figures 7** and **8** which concern the scattering parameters $\mathbf{S_{11}}$ and $\mathbf{S_{21}}$ versus frequency, respectively. With reference to **fig.7,** we see that the reflection coefficient S_{11} never falls below 20 dB in the considered band, while in **fig.8** the maximum insertion loss $\mathbf{S_{21}}$ is about 0.1 dB.

[0020] In order to check the soundness of simulations and the actual performances of the transition, a prototype with two transitions connected back-to-back by a central microstrip has been realized, as the one depicted in **fig.9a** photographed in **fig.9b.** The left part of **fig. 9a** is a mirror image of the transition of **fig.5a.** The adaptation at one input port of the double structure is measured after having closed the other port on a matched load, therefore the measure concerns the whole matching of the two transitions. The measured scattering parameters $\mathbf{S_{11}}$ and $\mathbf{S_{21}}$ versus frequency are reported in **figures 10** and **11,** respectively. With reference to **fig.10,** we see that the reflection coefficient $\mathbf{S_{11}}$ is never worse than 10 dB in the considered band. The insertion loss parameter $\mathbf{S_{21}}$ reported in **fig.11** is strongly influenced by the central microstrip which interconnect the two transitions. In fact, the 20 mm length (about 7λ) of the microstrip causes losses of about 1.5 dB, as a consequence each transition contributes to the measure with about 1.25 dB.

[0021] **Fig.12** shows a top view of a microstrip to circular waveguide transition, without the upper lid, the embodiment of which is directly achievable from the preceding description of the microstrip to rectangular waveguide transition. The same applies for a microstrip to elliptic waveguide transition (not represented in the figure).

REFERENCES

[0022]

[1] EP 02425349.4, title: "BROADBAND MICROSTRIP TO WAVEGUIDE TRANSITION ON MULTILAYER PRINTED CIRCUIT BOARDS ARRANGED FOR OPERATING IN THE MICROWAVES". (Published on 03/12/2003 with No. 1367668)

[2] EP 01830497.2, title: "PRINTED CIRCUIT BOARD AND RELEVANT MANUFACTURING METHOD FOR THE INSTALLATION OF MICROWAVE CHIPS UP TO 80 GHz ". (Published on 29/01/2003 with No. 1280392).

[3] "Microwave Filters, Impedance-Matching Networks, and Coupling Structures"; G.L.Matthaei, L. Yong and E. M. T. Jones; Artech House Books; 1980.

[4] "Foundation for Microwave Engineering"; R. E. Collin; McGraw-Hill 2nd Edition;© 1992.

Claims

1. Method to manufacture a microstrip to waveguide transition starting from a multilayer structure comprising at least, a dielectric substrate (1) of the type usable in the technology of printed circuit boards, adherent to a rigid metal plate (15), the dielectric substrate (1) giving support to a metallic layout (2, 3, 7) including a microstrip (2) terminating with a patch (3) acting as a probe for coupling the microstrip (2) to the waveguide (10) through the dielectric substrate, **characterized in that** includes the steps of:

   - opening a window (5, 6) in the multilayer (1, 15) for introducing the waveguide (10), being the window interrupted by a central stripe (4) bearing the probe (2, 3);
   - milling the edge of the waveguide (10) to obtain two opposite grooves (12, 13) of given depth for accommodating said stripe (4);
   - introducing the stripe (4) into the opposite

grooves (12, 13) of the waveguide (10) as far as their depth allows it and fastening a metallic lid (16) to the edge of the waveguide emerging from the two sides (5, 6) of the interruption (4) for reflecting back to the waveguide (10) the power radiated by the patch (3) in the opposite direction.

2. The method of claim 1, **characterized in that** the whole area of the two sub-windows (5, 6) at the two side of the interruption (4) prevails with respect to the area of the central stripe (4), so that the space of the transition is filled up prevalently with air.

3. The method of claim 1 or 2, **characterized in that** includes the step of aligning the metallic layout (2, 3, 7) with respect to the waveguide (10) and fastening the multilayer to a metallic support body (9) which has been worked to obtain the waveguide (10).

4. The method of any preceding, **characterized in that** includes the step of removing the rigid metal plate (15) from said stripe (4) at least in correspondence of the cavity (11) of the waveguide (10) crossed by the stripe (4).

5. The method of the preceding claim, **characterized in that** includes the step of milling the body of said lid (16) in order to obtain a central hollow (18) shaped as a short tract of said waveguide (10) closed at the end at a distance of about $\lambda/4$ from the plane of the patch (3).

6. The method of any preceding claim, **characterized in that** before opening the interrupted window (4, 5, 6) in the multilayer (1, 15), a drilling and a metallizing steps are performed to encircle said interrupted window (4, 5, 6) with metallized through holes (7, 8) to avoid possible detachments between the dielectric layer (1) and the rigid metal plate (15).

7. The method of any preceding claim, **characterized in that** the interrupted windows (4, 5, 6) opened in the multilayer (1, 15) has rectangular cross-section.

8. The method of claim 7, **characterized in that** includes the step of setting the central frequency of the transition by fixing a corresponding value of the ratio (a+b)/w, were: <u>w</u> is the longer cavity dimension of a rectangular waveguide whose shorter dimension holds known ratio with <u>w</u>, <u>a</u> is the length of the line which carries the signal to the patch (3), and b is the base of the patch (3) shaped as a rectangle perpendicular to the microstrip (2).

9. The method of claim 8, **characterized in that** includes the step of optimizing the adaptation at the input and the output ports inside the desired frequency band by fixing the ratio c/b, where c is the height of the rectangular patch inside the considered bandwidth.

10. The method of claim 9, **characterized in that** the desired frequency band spans 55 to 60 GHz, using a dielectric layer (1) with relative dielectric constant ε_r of approximately 3.54 and thickness of about 100 µm, the value of (a+b)/w is about 0,18 and the value of c/b is about 2.22.

11. Microwave to waveguide transition comprising:

- a multilayer structure comprising at least a dielectric substrate (1) of the type usable in the technology of printed circuit boards adherent to a rigid metal plate (15),
- a metallic layout (2, 3, 7) on the dielectric substrate (1) including a microstrip (2) terminating with a patch (3) acting as a probe for coupling the microstrip (2) to the waveguide (10) through the substrate (1),

characterized in that: the edge of the waveguide (10) has two opposite grooves (12, 13) for the insertion of a stripe (4) of dielectric substrate (1) bearing the probe (2, 3) inside the cavity of the waveguide (10) filled up prevalently with air, the edge of the waveguide (10) at the two sides of the stripe (4) being fastened to a metallic lid (16) which close the waveguide (10) opposite to the patch (3).

12. The transition of the preceding claim, **characterized in that** the two opposite grooves (12, 13) have different depths and the deeper one includes the microstrip (2) inclusive of the rigid metal plate (15).

13. The transition of the preceding claim, **characterized in that** the two opposite grooves (12, 13) have transversal dimensions such they behave as two under-cut waveguides in the desired frequency range of the transition able to confine the electromagnetic field in the volume of the transition.

14. The transition of any claim from 11 to 13, **characterized in that** said waveguide (10) is rectangular.

15. The transition of any claim from 11 to 13, **characterized in that** said waveguide (10) is circular.

16. The transition of any claim from 11 to 13, **characterized in that** said waveguide (10) is elliptic.

17. The transition of any claim from 11 to 16, **characterized in that** includes a crown of metallized through holes (7, 8) which contains the edge of the waveguide (10) at the two sides of the stripe (4) to avoid possible detachments between the dielectric layer (1) and the rigid metal plate (15).

MICROSTRIP TO WAVEGUIDE TRANSITION IDEAL LAYOUT UNTIL 33.5 GHz (KNOWN ART)

UPPER FACE

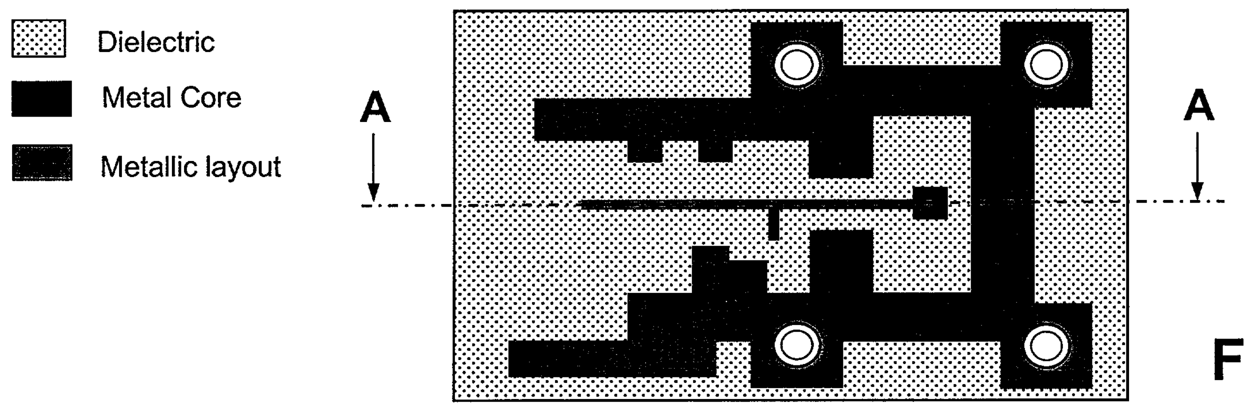

FIG. 1a

BOTTOM FACE

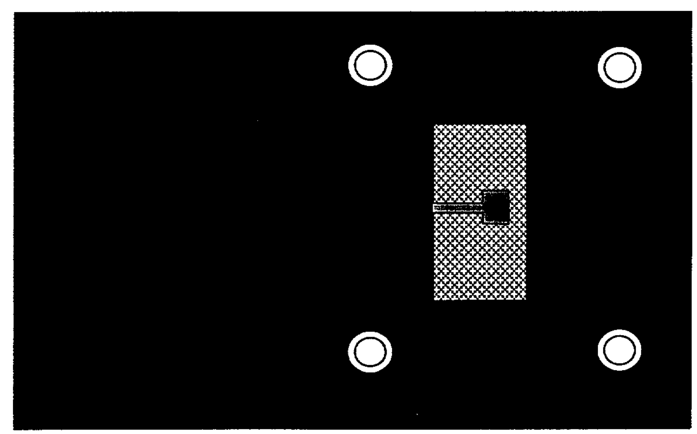

FIG. 1b

OPTIMIZED TRANSITION OF FIG.1 (KNOWN ART)

LONGITUDINAL CROSS-SECTION ALONG A-A

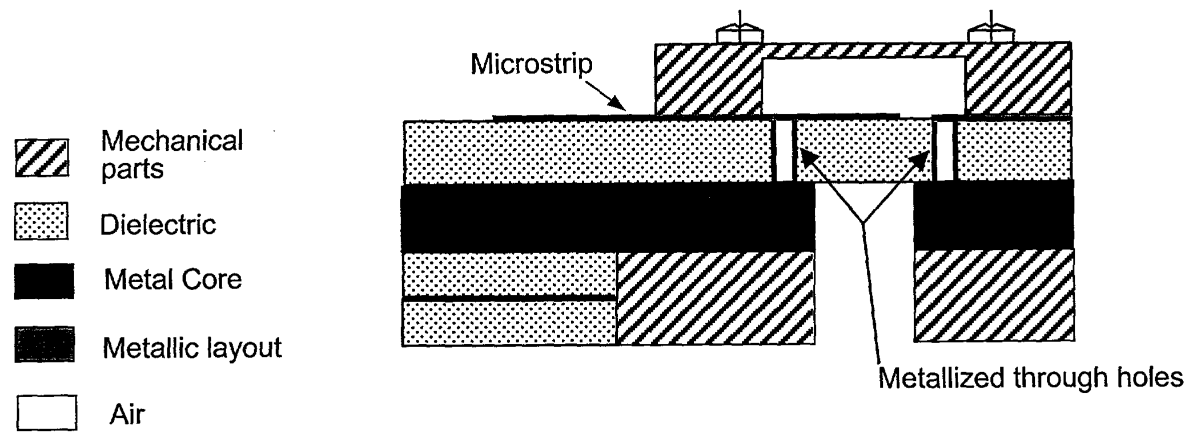

FIG. 2a

OPTIMIZED UPPER LAYOUT

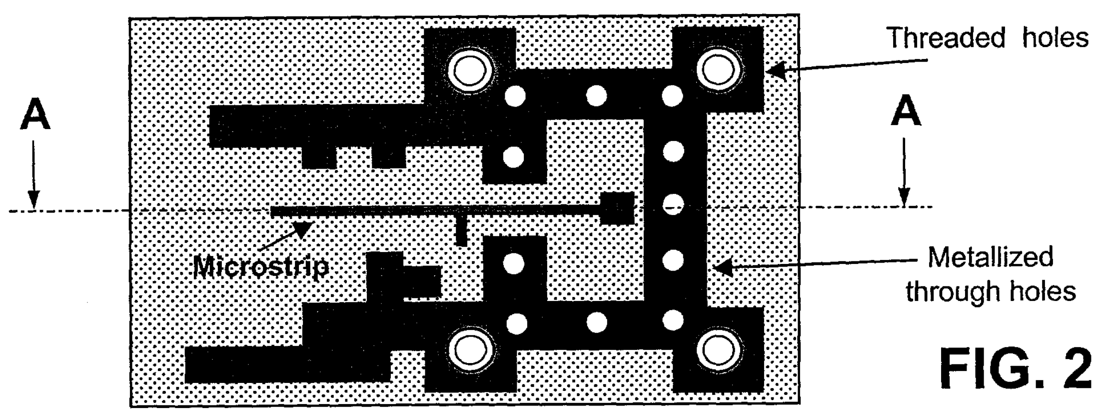

FIG. 2b

REAL CIRCUITAL LAYOUT OF FIG.2b
(PHOTOGRAPHY)

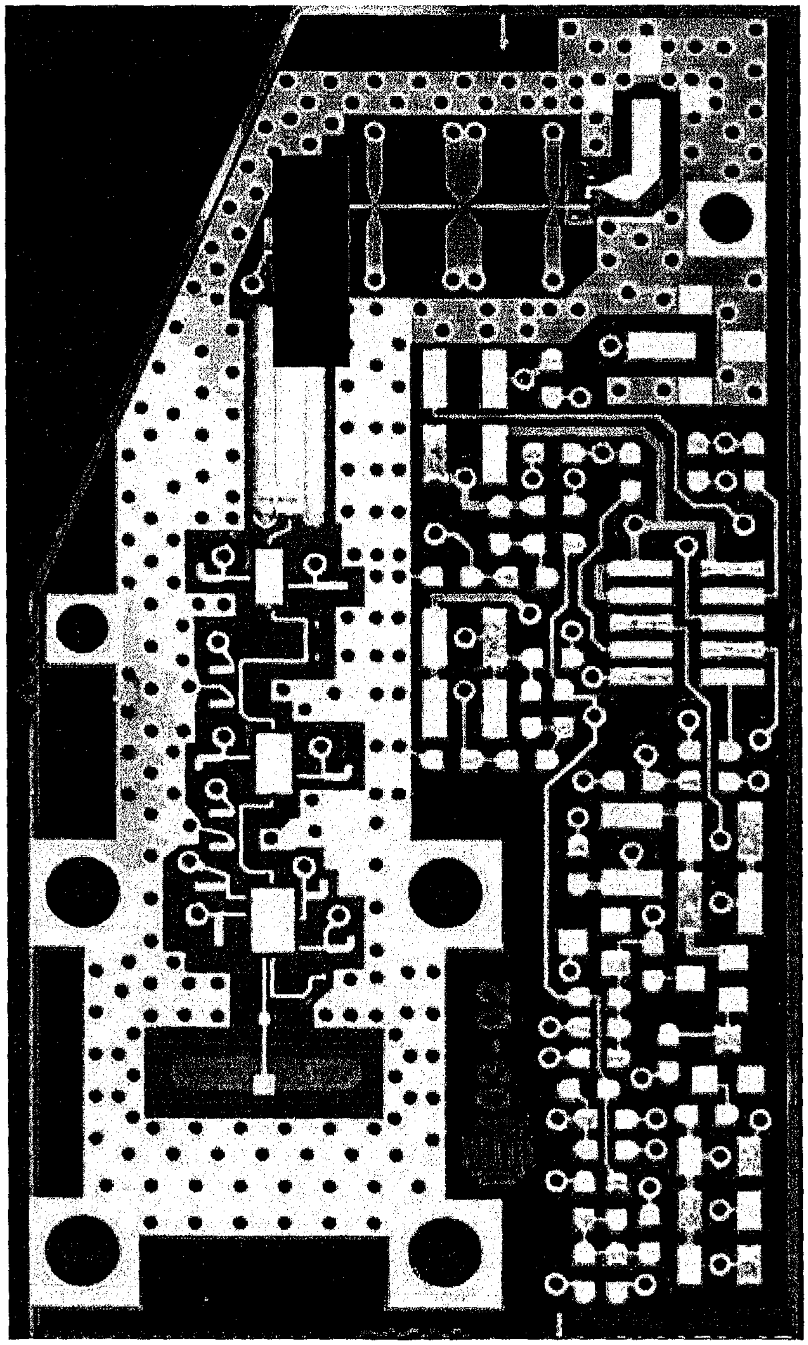

FIG. 3

60 GHz TRANSITION MANUFACTURING PROCESS

Mechanical parts | Dielectric | Metallic layout | Air

UPPER FACE

DIELECTRIC SUBSTRATE

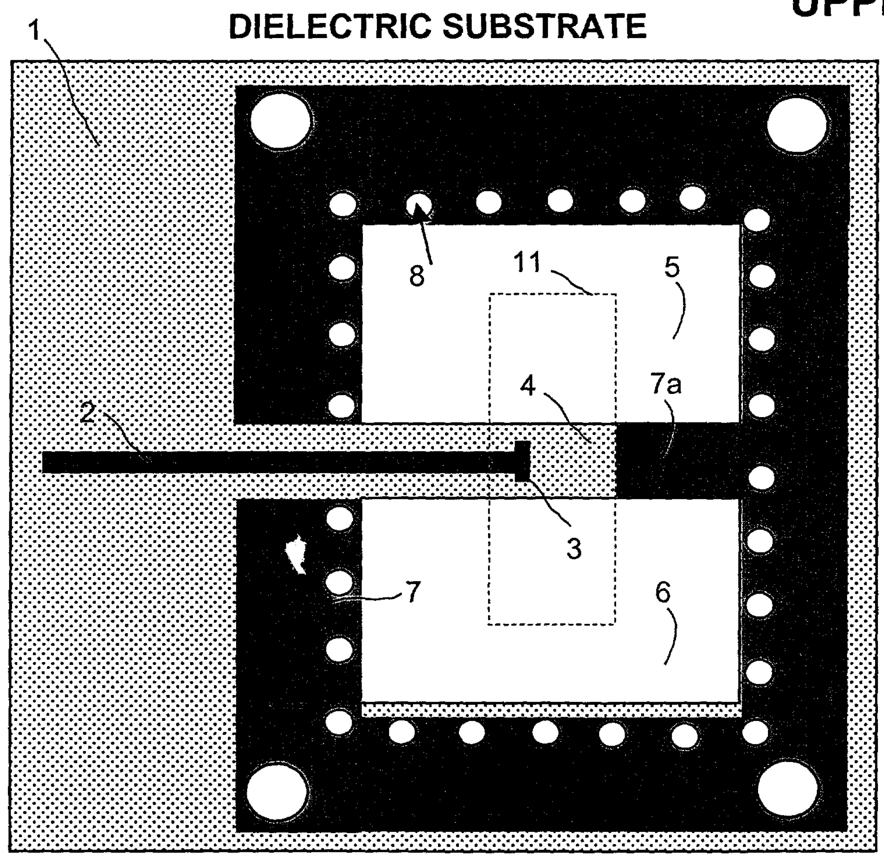

FIG. 4a

WAVEGUIDE

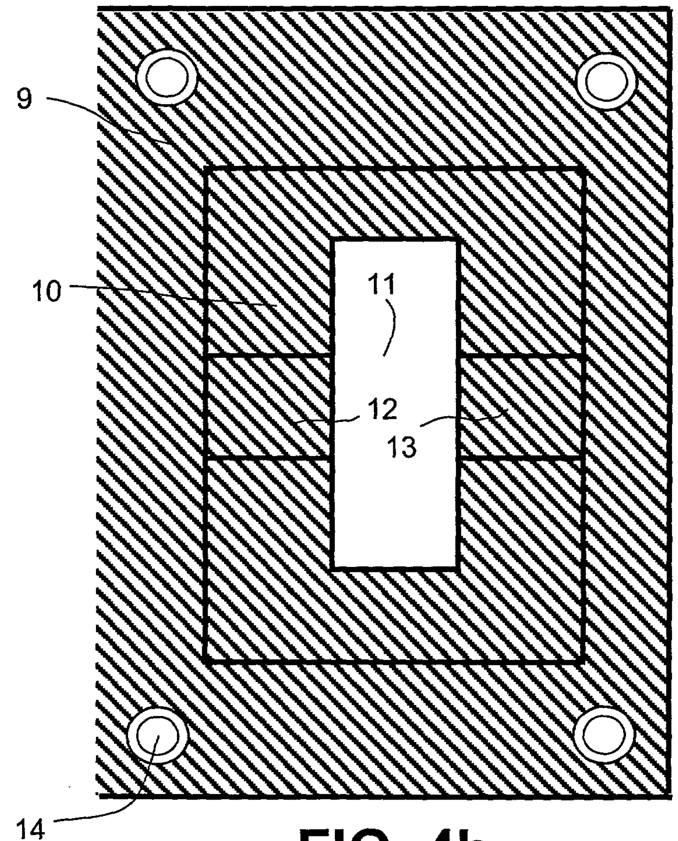

FIG. 4b

60 GHz TRANSITION MANUFACTURING PROCESS

Dielectric | Metal Core | Air

DIELECTRIC SUBSTRATE BOTTOM FACE

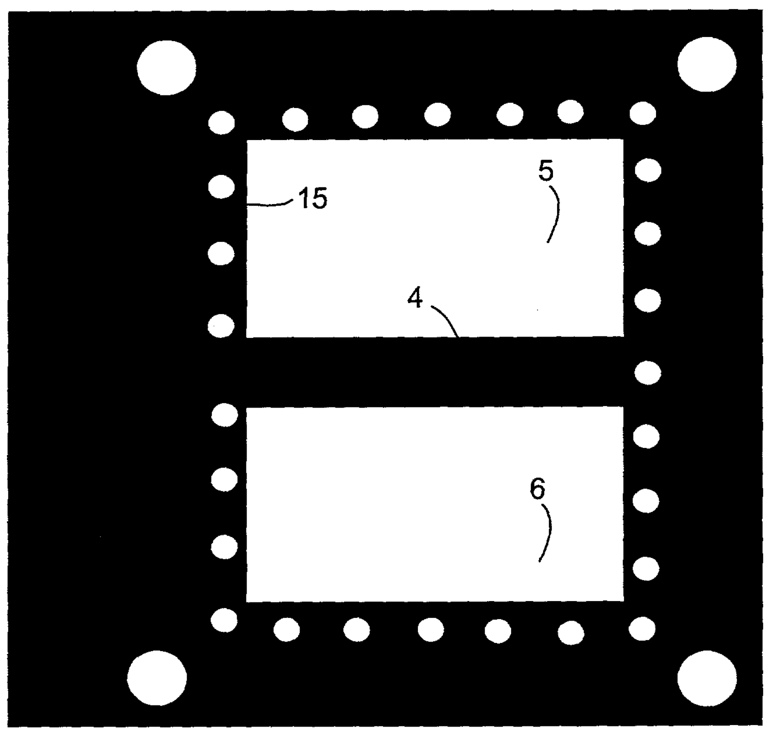

FIG. 4c

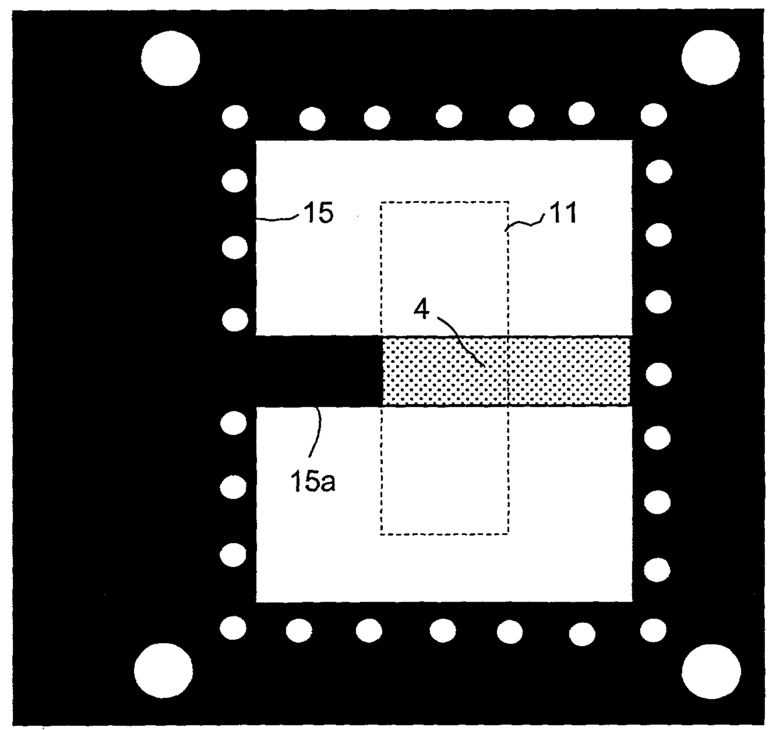

FIG. 4d

60 GHz MICROSTRIP TO WAVEGUIDE TRANSITION

A-A CROSS-SECTION

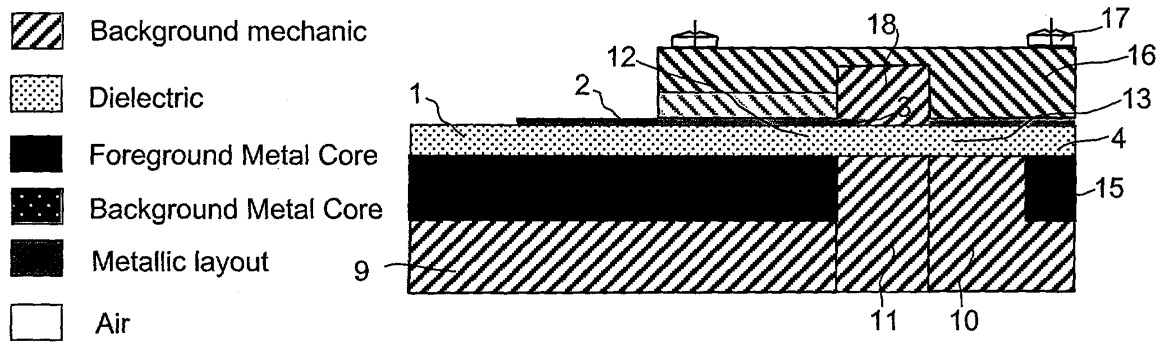

FIG. 5b

SECTION B-B

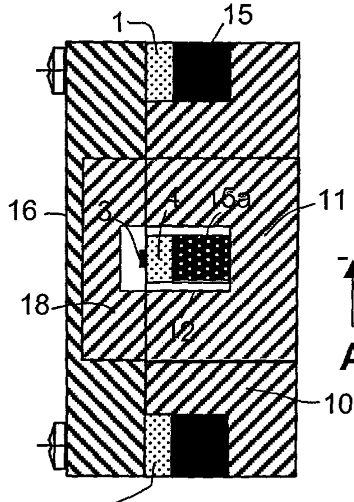

FIG. 5c

UPPER FACE

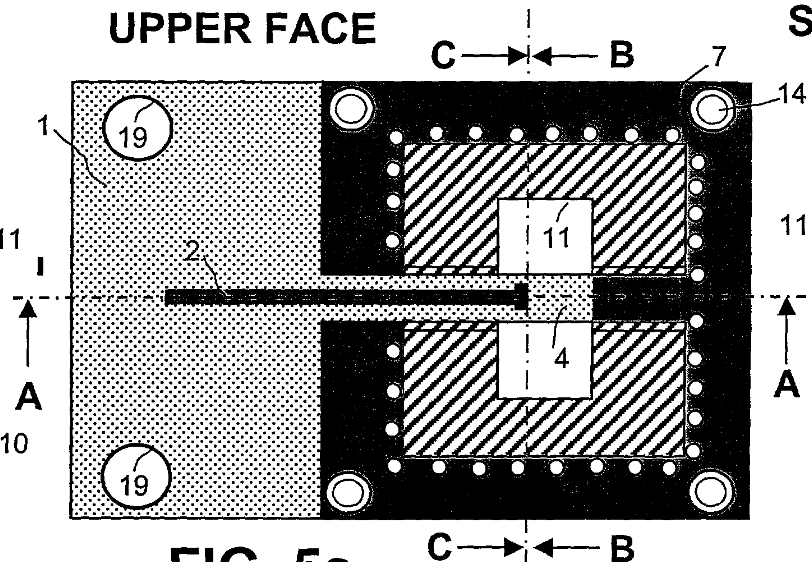

FIG. 5a

SECTION C-C

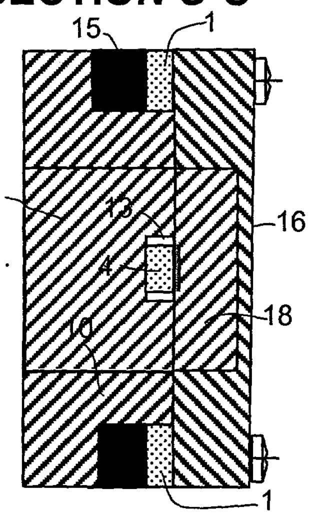

FIG. 5d

3D TRANSITION SIMULATION MODEL

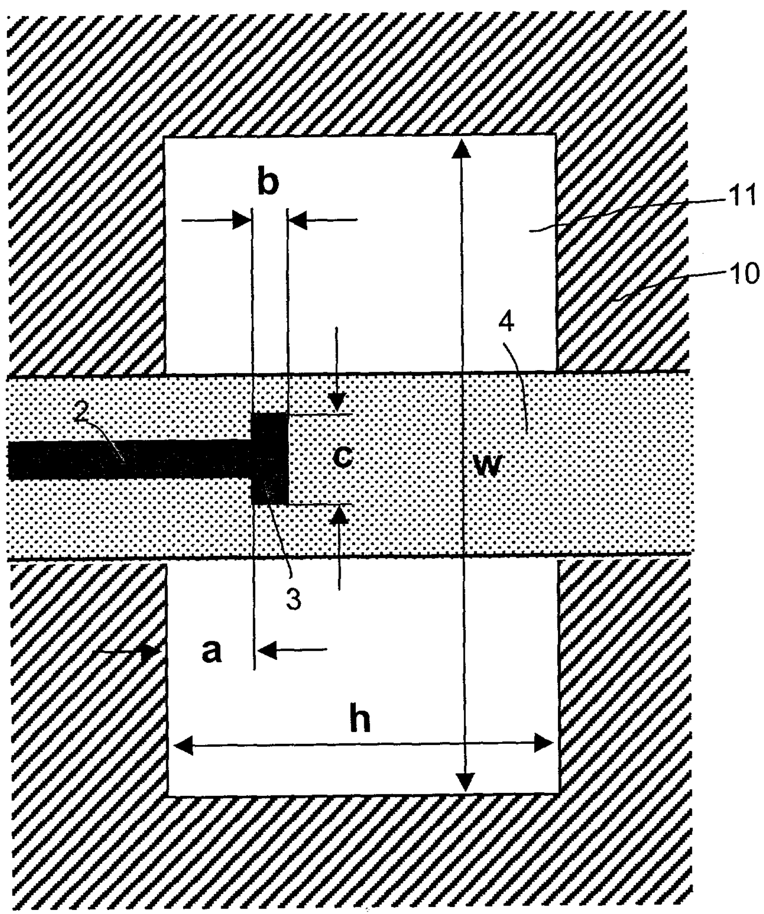

FIG. 6b

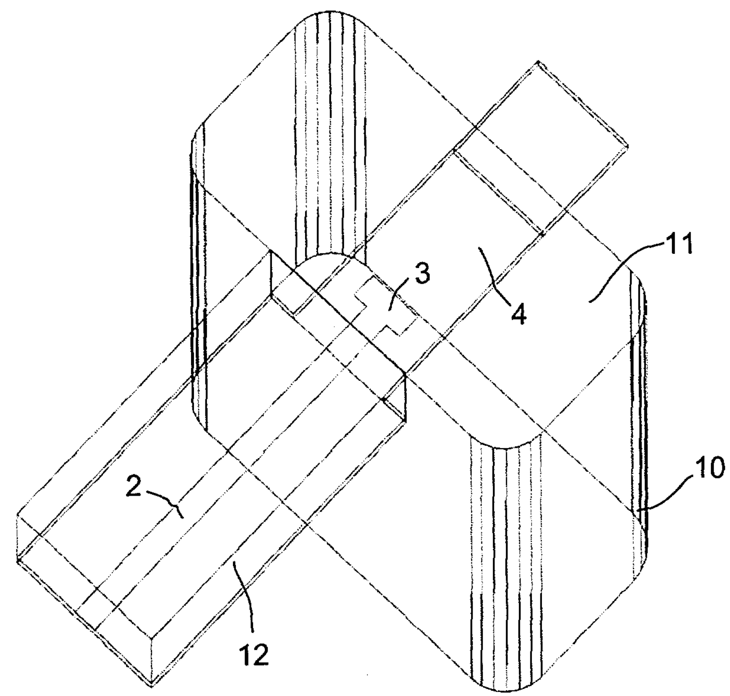

FIG. 6a

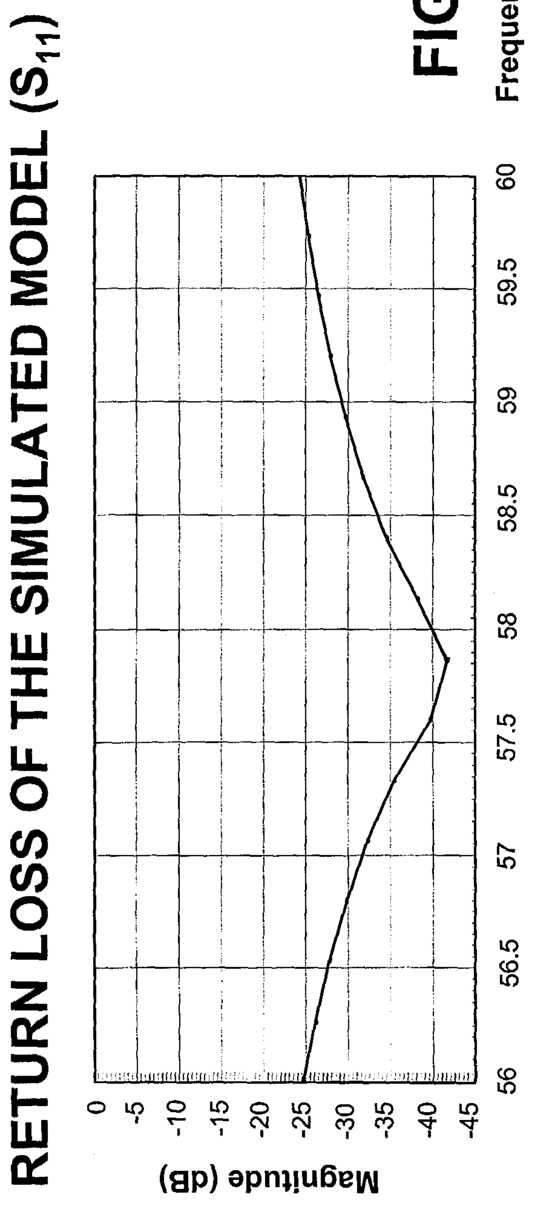
RETURN LOSS OF THE SIMULATED MODEL (S_{11})
Magnitude (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
56
56.5
57
57.5
58
58.5
59
59.5
60
Frequency (GHz)

FIG. 7

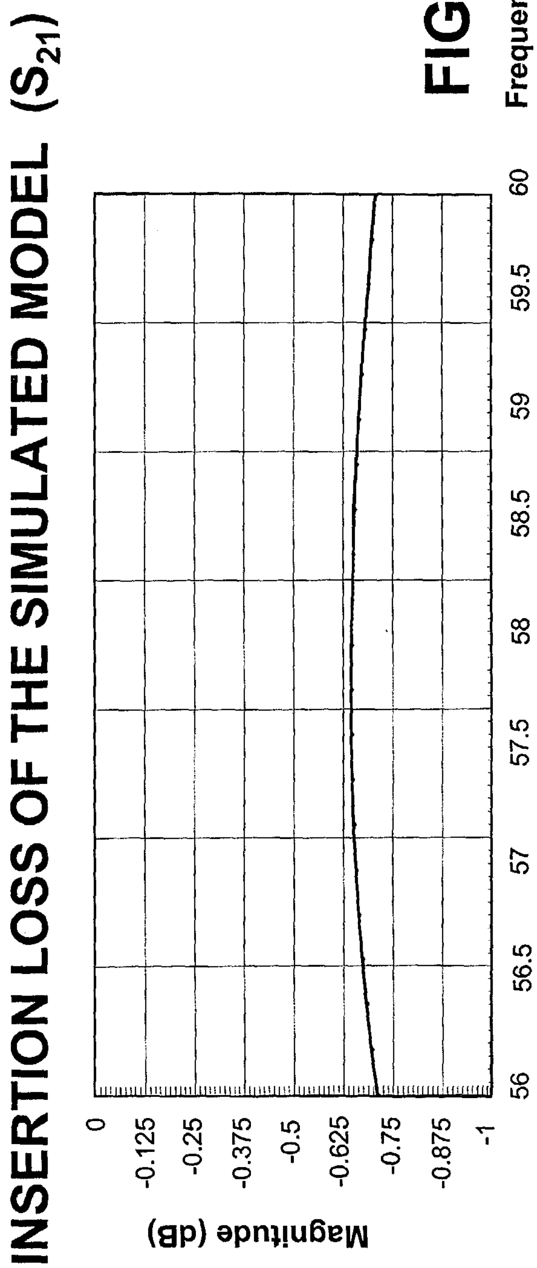
INSERTION LOSS OF THE SIMULATED MODEL (S_{21})
Magnitude (dB)
0
-0.125
-0.25
-0.375
-0.5
-0.625
-0.75
-0.875
-1
56
56.5
57
57.5
58
58.5
59
59.5
60
Frequency (GHz)

FIG. 8

BACK-TO-BACK TRANSITIONS
(UPPER FACE))

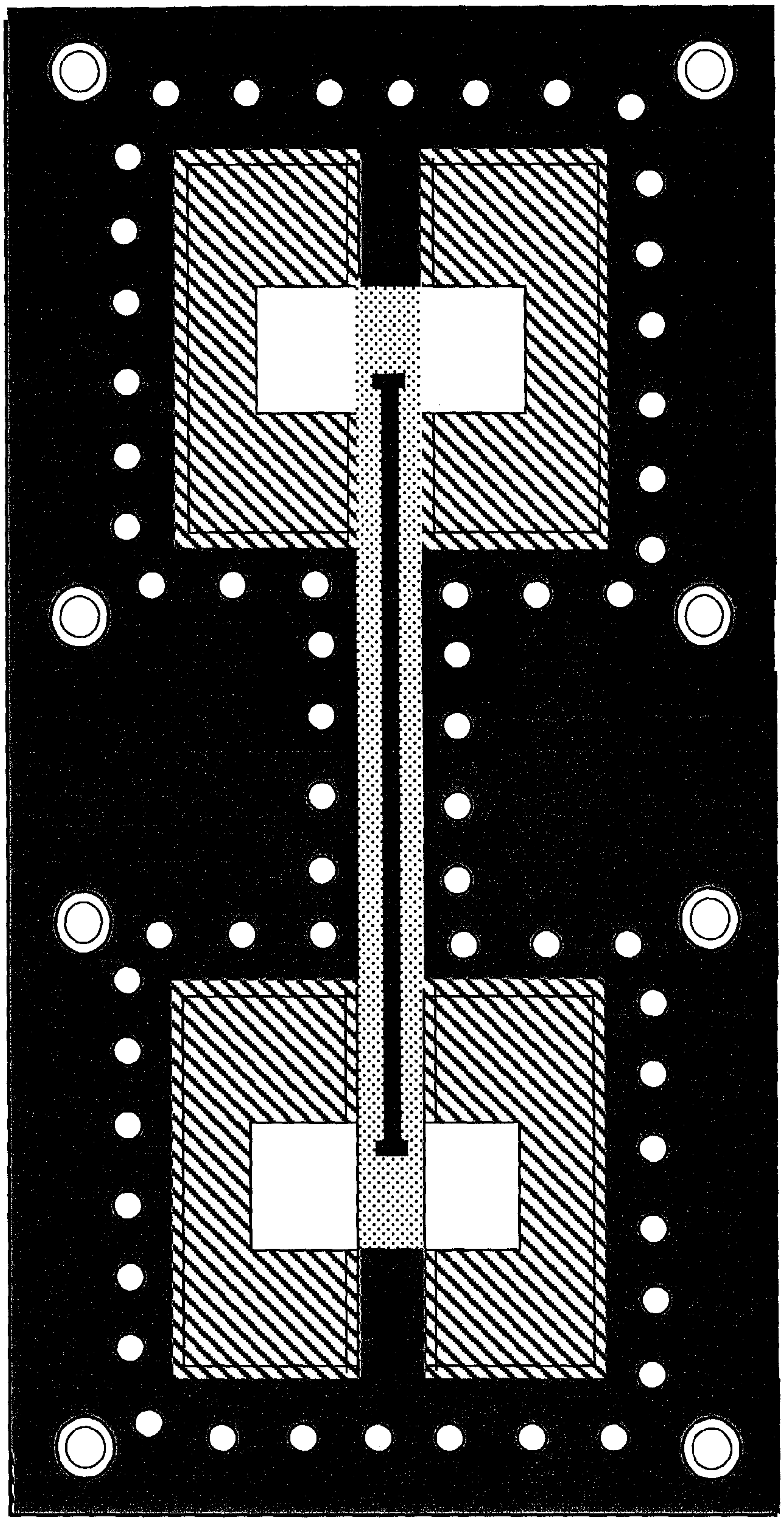

FIG. 9a

BACK-TO-BACK TRANSITIONS

(UPPER FACE))

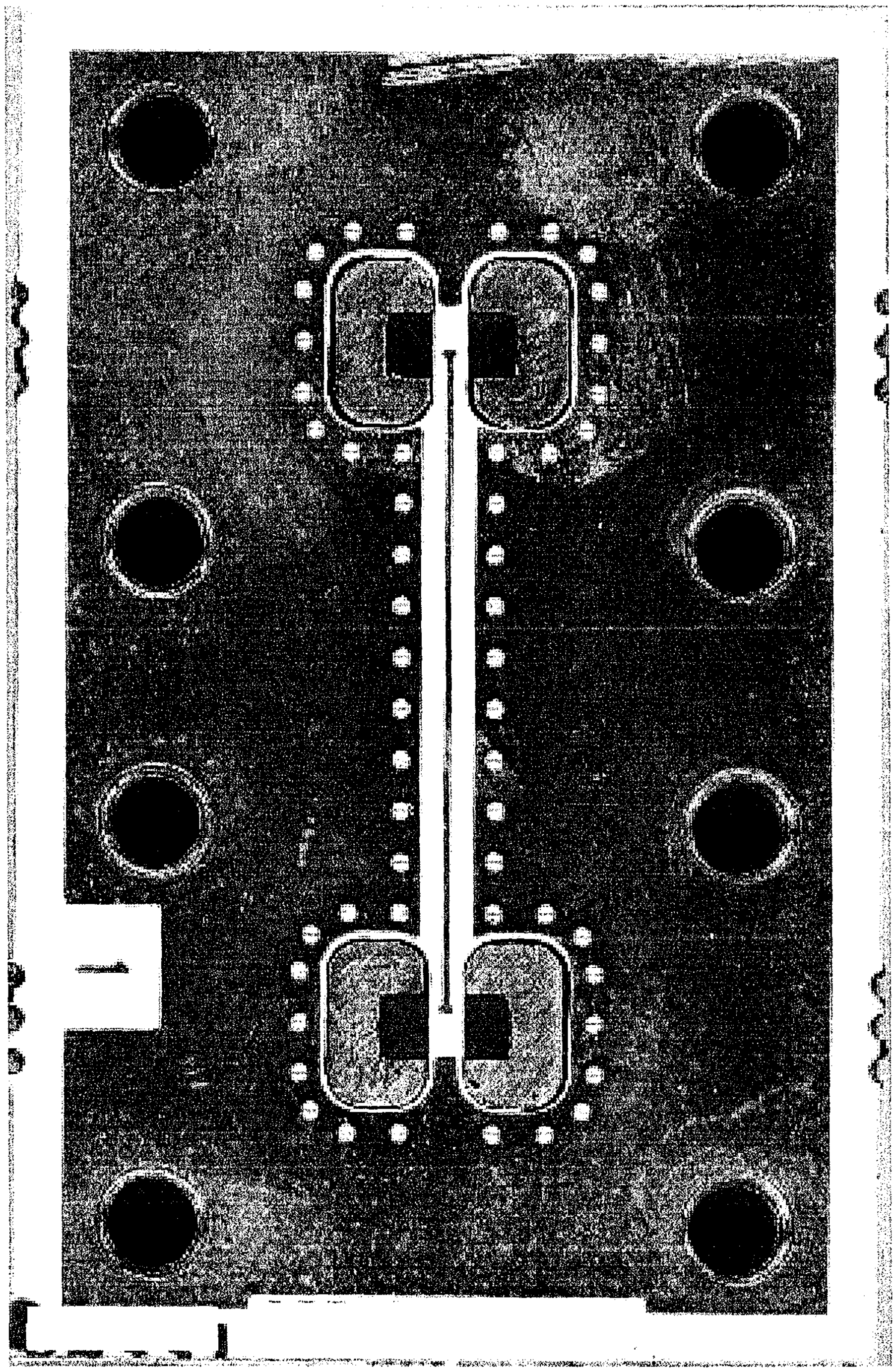

FIG. 9b

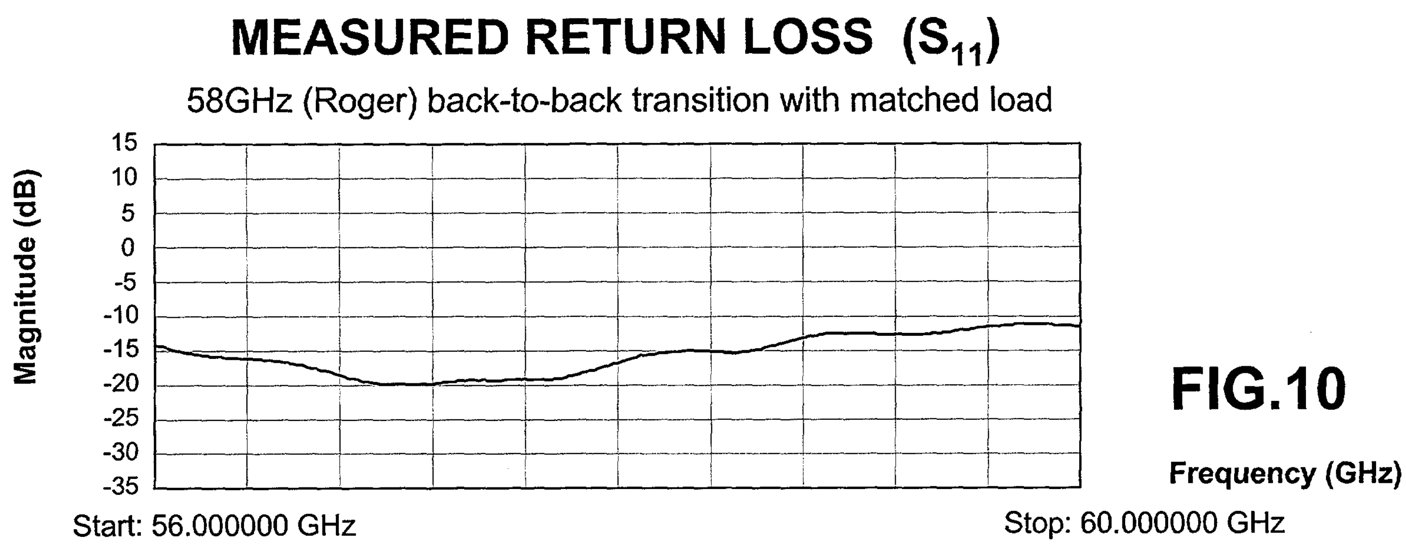
MEASURED RETURN LOSS (S11)
58GHz (Roger) back-to-back transition with matched load
Magnitude (dB)
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
Start: 56.000000 GHz
Stop: 60.000000 GHz
Frequency (GHz)

FIG.10

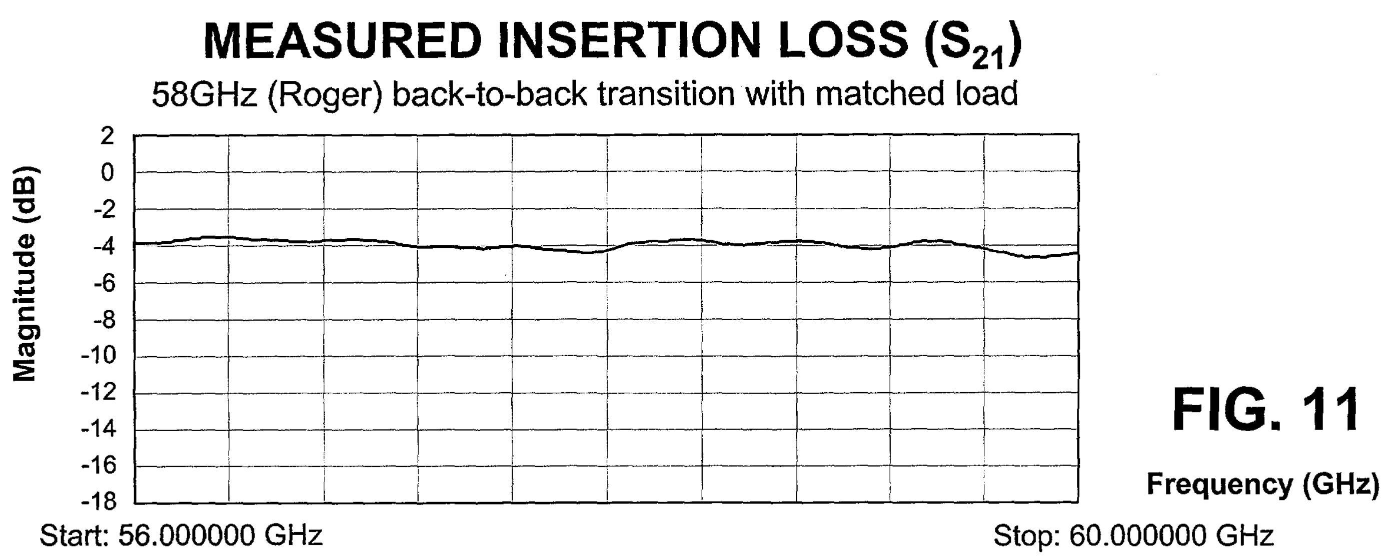
MEASURED INSERTION LOSS (S21)
58GHz (Roger) back-to-back transition with matched load
Magnitude (dB)
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
Start: 56.000000 GHz
Stop: 60.000000 GHz
Frequency (GHz)

FIG. 11

60 GHz MICROSTRIP TO CIRCULAR WAVEGUIDE TRANSITION

UPPER FACE

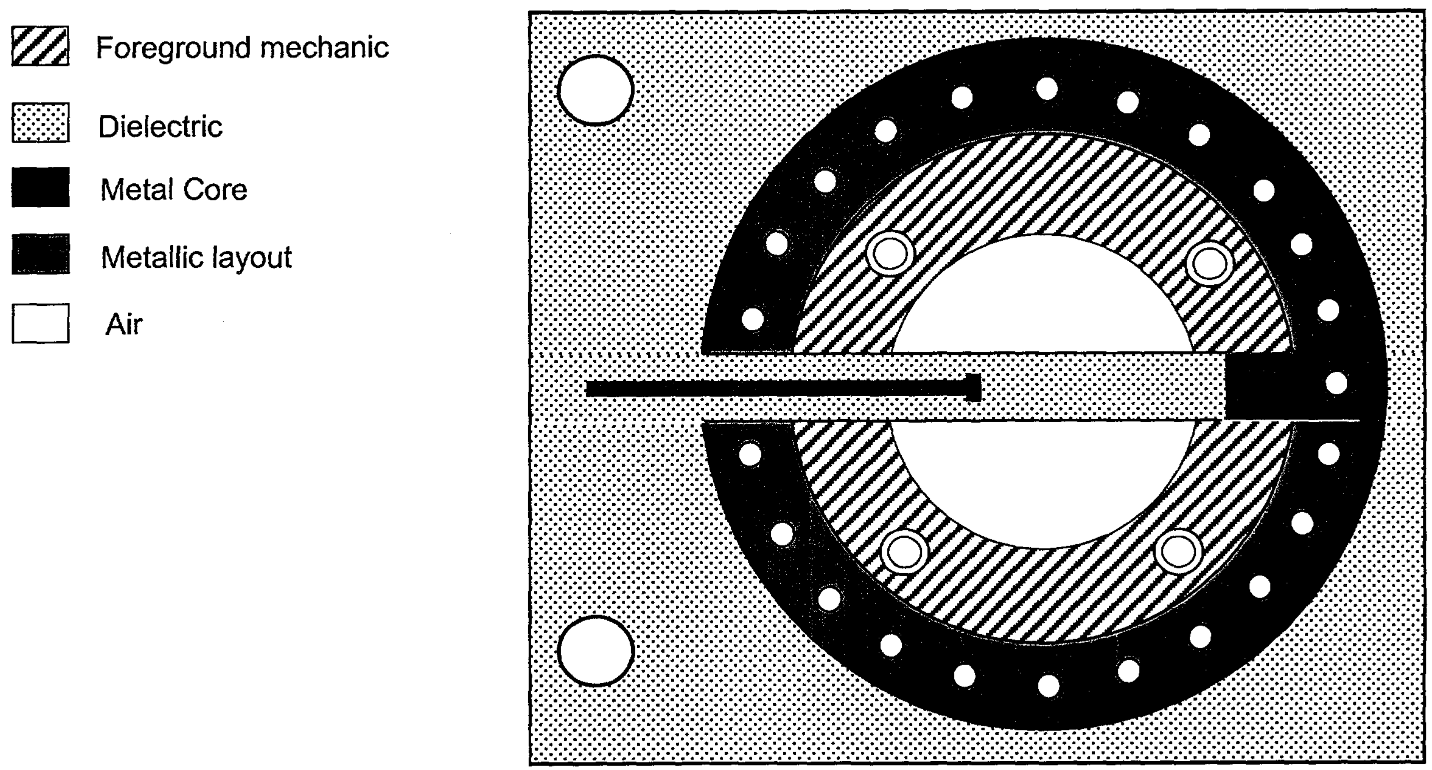

FIG. 12

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 04 42 5300

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	EP 0 874 415 A (KYOCERA CORP) 28 October 1998 (1998-10-28) * column 7, line 10 - column 8, line 19; figure 2 * * column 11, line 12 - column 12, line 12; figures 8A,8B * * column 15, line 21 - line 42; figures 14A,14B *	11,14	H01P5/107
Y		15-17	
A	-----	1-10	
Y,D	EP 1 367 668 A (SIEMENS INF & COMM NETWORKS) 3 December 2003 (2003-12-03) * paragraph [0006]; figure 1a * * paragraph [0032] * -----	15-17	
A	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 23, 10 February 2001 (2001-02-10) & JP 2001 177312 A (HITACHI KOKUSAI ELECTRIC INC), 29 June 2001 (2001-06-29) * abstract * * paragraphs [0035] - [0038]; figures 8-10 * -----	11-17	TECHNICAL FIELDS SEARCHED (Int.Cl.7) H01P
A	PATENT ABSTRACTS OF JAPAN vol. 008, no. 081 (E-238), 13 April 1984 (1984-04-13) & JP 59 002402 A (HITACHI SEISAKUSHO KK), 9 January 1984 (1984-01-09) * abstract * -----	11-17	
A	PATENT ABSTRACTS OF JAPAN vol. 1998, no. 10, 31 August 1998 (1998-08-31) & JP 10 126114 A (FURUKAWA ELECTRIC CO LTD:THE), 15 May 1998 (1998-05-15) * abstract * -----	1-17	

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
The Hague	25 October 2004	Pastor Jiménez, J-V

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
....
& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 04 42 5300

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

25-10-2004

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0874415 A	28-10-1998	JP 3464118 B2	05-11-2003
		JP 10303613 A	13-11-1998
		JP 3464119 B2	05-11-2003
		JP 10303614 A	13-11-1998
		JP 10303615 A	13-11-1998
		JP 3493278 B2	03-02-2004
		JP 10303616 A	13-11-1998
		JP 11112209 A	23-04-1999
		JP 3398314 B2	21-04-2003
		JP 11135660 A	21-05-1999
		EP 0874415 A2	28-10-1998
		US 6239669 B1	29-05-2001
EP 1367668 A	03-12-2003	EP 1367668 A1	03-12-2003
JP 2001177312 A	29-06-2001	NONE	
JP 59002402 A	09-01-1984	NONE	
JP 10126114 A	15-05-1998	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82