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

(11) EP 1 376 746 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
23.08.2006 Bulletin 2006/34

(51) Int Cl.:
H01P 1/208 *(2006.01)* ***H01P 5/107*** *(2006.01)*
H01P 11/00 *(2006.01)*

(21) Application number: **03007045.2**

(22) Date of filing: **27.03.2003**

(54) **Tuneless rectangular dielectric waveguide filter**

Nicht-abstimmbares rechteckiges dielektrisches Wellenleiterfilter

Filtre non accordable en guide d'ondes rectangulaire diélectrique

(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 PT RO SE SI SK TR

(30) Priority: **27.06.2002 IT MI20021415**

(43) Date of publication of application:
02.01.2004 Bulletin 2004/01

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Description

Field of application

[0001] The present invention relates to the sector of the technique concerning the implementation of microwave filters, and specifically to a no-tuning filter in rectangular dielectric wave guide.

Background art

[0002] Canonical texts for the design of microwave filters are:

- "Microwave Filters, Impedance-Matching Networks, and Coupling Structures", authors G.L.Matthaei, L. Yong and E. M. T. Jones, published by Artech House Books, 1980.
- "Waveguide Handbook", author N. Marcuvitz, published by McGraw-Hill Book Company, 1951.
- "Foundation for Microwave Engineering", by R. E. Collin, published by McGraw-Hill 2nd Edition, © 1992.

[0003] From the conspicuous teaching offered by the mentioned works, it results that a typical band pass filter operating at the microwave frequencies includes a resonant hollow cavity consisting of metallic waveguide having rectangular cross section, delimited at its ends by metallic walls. The cavity has a predetermined length, generally half wavelength λ_G at resonance or its multiples. Input and output couplings are also obtained by appropriate means, similar to probes, to excite the right standing mode in the hollow cavity . The signal to be filtered is inlet in the cavity through the first probe and the filtered signal is collected by the second probe . To obtain higher selectivity, more adjacent resonant hollow cavities can be employed; these cavities are separated by metal walls with an opening along one of the transverse axis ("iris"), for instance the shorter axis, to obtain an inductive coupling. An alternative implementation, similar from the electrical point of view, foresees the use of one sole waveguide containing cylindrical conductors of appropriate diameter, arranged transversally to the waveguide, along the longitudinal axis and $\lambda_G/2$ apart. Said conductors are called "inductive post" , they act as impedance inverters and enable the synthesis of the selected desired bandpass response . The mentioned filters, generally have a large size and allow to obtain high values for the unloaded quality coefficient Q_o and therefore low insertion losses in the desired bandpass frequency range, but require manufacturing techniques complex and expensive from a mechanical point of view. Said filters are also difficult to integrate with the circuits of microwave transceivers, manufactured nowadays in planar technique; therefore additional electrical and mechanical interconnection elements become necessary. Very often, the filters in metallic waveguide require also a fine tuning to be made manually by a skilled operator, through appropriate regulation elements.

[0004] A traditional way to reduce the overall dimensions of filters based on hollow waveguide is to fill the cavities with a material having high dielectric constant ε_r and low dielectric losses, that is with a material having small tan δ values, where δ is the loss angle appropriately defined. The filling with dielectric material partially reduces the value of the quality factor Q_o, therefore a compromise criterion shall be defined between the reduction of the overall dimensions of the cavity and the major insertion losses that can be tolerated for the filter. A filter implemented as just mentioned still shows, the drawbacks of the previous air filled filter, mainly relating to the cost of the mechanical working and subsequent calibration.

[0005] A considerable progress in the manufacturing of filters employing dielectric material in the resonant cavity can be obtained employing the same technologies already used for the manufacturing of circuits in thin metal films on ceramic substrates. Through the above-mentioned technologies, metallic surfaces are deposited on the desired parts of the ceramic substrate to obtain a waveguide. Cylindrical "inductive post " elements can be easily realized through metallized via-holes. The use of the planar technology enables to considerably reduce the overall dimensions of microwave filters facilitating the integration with the remaining circuits. Furthermore, thanks to the higher accuracy and yield of thin film production processes compared to the mechanical ones, the filter calibration step could be completely avoided. However, the different solutions proposed on this matter in the known technique are not completely satisfactory up to now, for the reasons described below.

[0006] In the article by Arun Chandra Kundu and Kenji Endou, under the title "TEM-Mode Planar Dielectric Waveguide Resonator BPF for W-CDMA", published in the "2000 IEEE" collection, a two-pole band pass filter is described, including two identical resonators in dielectric waveguide having size 4,25 $\times$ 3 $\times$ 1 mm each. Each resonator consisting of a parallelepiped in high dielectric constant material (ε_r = 93) whose upper and lower face, as well as a side face, are completely covered with a thin silver layer, while the remaining three side faces are open on air. Denoted λ_G the wavelength characteristic of the resonant mode, the dimensions indicated are those of a $\lambda_G/4$ resonator operating at 2 GHz in the fundamental TEM mode, with a quality factor Q_o = 240. The two $\lambda_G/4$ resonators are inductively coupled through interposition of an appropriate segment of reduced cross section dielectric waveguide along the longitudinal axis, in which an H mode of evanescent type (that damps at a short distance) propagates. Two rectangular shaped

metal electrodes are required on two side faces without metal coating, to realize the input/output ports. The filter thus obtained, despite its compactness and reduced dimensions, has some drawbacks. A first drawback is that very high dielectric constant material must be used to confine the electrical field mainly inside the filtering structure, because non metal coated walls would otherwise irradiate the power. This involves a low value of the quality factor Q_0 limiting the frequency range in which this solution is applicable. A second disadvantage is due to the difficulty in realizing the connections between the I/O electrodes of the filter and the conductive lines of the remaining circuits employing it. In fact, said connections foresee welds on orthogonal plans requiring accurate manual operations that do not fit an automatic "surface mounting" manufacturing process.

[0007] The European patent application EP-A1-1024548 (Sano et al.) discloses a dielectric filter in which three or more resonators are integrally formed in a rectangular parallelepiped dielectric block completely metallized on its surfaces with exception of two unmetallized dielectric crowns around respective metal patches constituting the input/output electrodes at the two end resonators. Through holes are formed for adjusting the coupling between adjacent resonators. The unmetallized dielectric crowns constitute two dielectric windows; a first one for injecting an input signal on the metal patch into the dielectric cavity, and a second one for extracting a filtered signal from the cavity and making available it on the metal patch. Due to the particular embodiment of the I/O electrodes, this filter is not suitable to be integrated with a different layout on the same surface of a common dielectric surface, in particular a microstrip layout. In fact, the connection to the I/O electrodes shall be performed by wire bonding or equivalent means.

[0008] A different implementation method of bandpass filters in dielectric waveguide is described in the paper by Masaharu Ito, Kenichi Maruhashi, Kazuhiro Ikuina, Takeya Hashiguchi, Shunichi Iwanaga and Keiichi Ohata, under the title "A 60 GHz-BAND PLANAR DIELECTRIC WAVEGUIDE FILTER FOR FLIP-CHIP MODULES", published in "2001 IEEE" collection. As shown in **figure 1**, referred to such a filter, a plurality of metal coated holes delimits the filter profile as a crown. Said holes are separated one from the other for less than $\lambda_G/2$ to drastically reduce the power irradiation out of the dielectric guide. In this way it was possible to use an alumina substrate SUB having a relative dielectric constant ε_r = 9,7. The filter in **fig. 1** includes a segment of dielectric waveguide made of four contiguous $\lambda_G/2$ resonators. The waveguide is delimited by a metal coating MET deposited on the upper face of the sub-layer SUB, by a ground plan deposited on the opposite face, and at its longitudinal sides by the crown of peripheral metal coated holes. Inside the guide, three couples of metallized via-holes regularly arranged along the longitudinal axis are visible, the holes of each couple being symmetrically arranged at the two sides of said axis and appropriately spaced. From an electrical point of view, the couples of holes form "inductive post" elements that shape the filter frequency response. The transverse spacing among the holes is calculated to obtain the desired inductive coupling between adjacent sections. On the shorter sides of the dielectric guide two identical input/output sections CPW can be seen, each consisting, of a coplanar line ending in a transition TRA towards the rectangular dielectric waveguide. Coplanar lines and relative transitions are obtained removing the metal coating MET from the substrate SUB, as shown in the figure, each transition corresponding to the two shorter segments of coplanar line, which terminate on the metal coating MET and are arranged at right angle versus the segment of longitudinal coplanar line. This kind of filter has been specifically developed for connections to coplanar line circuits, generally used only for millimetre wave applications, a narrow range of microwaves.

[0009] The analysis made up to now, highlighted some lack of the known art concerning both the realization of planar filters and the connection with the remaining circuits. Additional limitations are considered below. Concerning the filters of the first (Kundu and Endou) and the second (Sano et al.) citations, these filters do not fit at all the requirement of integration with other circuits on the same substrate, because, due to the electrodes placed on the side faces of the dielectric waveguide, in the first filter, or configured as insulated patches, in the second filter, these electrodes are separated from the layout of the remaining circuits and welding (wire bonding) is needed.

[0010] On the contrary, concerning the filter of the third reference (Ito et al), it has been specifically designed to be coupled with circuits in coplanar line, therefore the type of transition developed is specific for the above mentioned scope, actually inhibiting the use of the filter by the numerous cases of microstrip circuits developed up to date that can operate also in the field of millimetre waves.

[0011] The next three cited documents overcome the drawbacks of the previous references. Two quite identical examples of how connecting a microstrip layout to a metallic rectangular waveguide obtained on a common dielectric substrate without breaking the continuity of the metallic layout, are disclosed in the following documents:

- US 6,268,781 B1 patent, titled: "PLANAR WAVEGUIDE-TO-STRIPLINE ADAPTER"; and
- the paper by Dominic Deslands and Ke Wu, titled: "Integrated Microstrip and Rectangular Waveguide in Planar Form", IEEE Service Center, Piscataway, NJ, US, vol. 11. No. 2, 1 February 2001, pages 68-70, XP001006819, ISSN: 1531-1309.

[0012] Both solutions implement a tapered microstrip to obtain a microstrip-to-waveguide transition. The transition is used broadband and no indications are given of how obtaining a bandpass filter. An indication in this direction is given

in the paper by:

- Tzuang C-K et al., titled: "H-PLANE MODE CONVERSION AND APPLICATION IN PRINTED MICROWAVE INTEGRATED CIRCUIT", 30th European Microwave Conference Proceedings, Paris, October 3-5, 2000; Proceedings of the European Microwave Conference, London: CMP, GB, Vol. 2 of 3 Conf. 30, 4 October 2000, pages 37-40, XP001060868, ISBN: 0-86213-212-6.

[0013] This paper presents a novel MIC (microwave integrated circuit) design methodology, which consistently applies the H-plane discontinuity structures to integrate a multi-function PCB (printed-circuit board) fabrication process. Two distinct types of waveguide, namely: microstrip and metallic rectangular waveguide, are simultaneously integrated on the same substrate(s) through the interface mode converters. The specific design is directed to embody an X-band bandpass filter prototype of the fifth-order (five waveguide sections). The filter includes two tapered microstrips at the two sides of the rectangular metallic waveguide filled with the dielectric of the substrate either constituting a microstrip-to-waveguide transition or vice versa. Six H-plane slits are milled at each side of the rectangular waveguide, symmetrically in respect of the longitudinal axis. Each couple of slits faced at the two sides of the rectangular waveguide behaves as an inductive element (impedance inverter) which controls the coupling between the delimited waveguide sections, for obtaining the desired frequency response.

Object of the invention

[0014] Therefore, scope of the present invention is to overcome the drawbacks of the known art and to propose a filter in dielectric waveguide that could be completely integrated in microstrip circuits, realized on the same substrate of the waveguide, eliminating the parasitic effects of additional connections. Particular scope of the invention is that to provide an alternative solution to the planar filter disclosed in the lastly cited paper (Tzuang), which constitutes the nearest prior art.

Summary of the invention

[0015] To attain said objects, scope of the present invention is a microwave filter in metallized dielectric rectangular waveguide, as described in claim 1.

[0016] The filter outstanding aspects resulting from claim 1 are as follows:

- The filter is made on the same dielectric substrate that can also be used for the circuits in microstrip connected to the filter.
- The metal coating on the longitudinal sides of the resonant dielectric guide is obtained through metal coating of two hollows obtained in parallel on the guide sides.
- The structures for the access to the resonant dielectric guide segment are obtained duly modifying the geometrical shape of the microstrips connected to the guide ends. The transition between the microstrip and the dielectric waveguide is similar to a "taper" that, in the context of the invention, is used to the double purpose of transforming the "quasi-TEM" mode of the microstrip into the TE_{10} mode propagating into the dielectric waveguide and of adjusting the microstrip impedance to that of the dielectric guide. The transition between the dielectric waveguide and the microstrip behaves, as well known, in a reciprocal way.
- The inductive elements delimiting the waveguide sections and setting the 3 dB bandwidth of the frequency response of the filter are through holes spaced $\lambda_G/2$ apart, drilled along the longitudinal symmetry axis of the rectangular waveguide,

where λ_G is the wavelength of the fundamental propagation mode.

Advantages of the invention

[0017] The filter implemented according to the subject invention has:

- The advantage to use the same design typology both for the integration with electrical parts developed on the same substrate and for the realization of single filters to be then installed according to "flip-chip" techniques (overturned) on other supports, either alumina or glass-fibre substrates, FR4 type, for printed circuits. The electrical connection being made through direct welding between the microstrips of the two substrates (without "bumps" or "vias"), thus avoiding the parasitic effects that would affect the input/output connections.
- The advantage that does not require accurate masking process along the vertical axis, to be necessarily implemented

on single filters rather than on the whole dielectric wafer , contrarily to the filter described in the first paper mentioned above (Kundu and Endou)

- The advantage to use low cost metal deposition techniques of serigraphic type, contrarily to the second example mentioned above (Ito et al), foreseeing "gaps" to be made with absolute accuracy just on the input/output lines. Said serigraphic techniques enable also silver metallization that additionally lowers the insertion losses.

Brief description of figures

[0018] The invention, together with further objects and advantages thereof may be understood from the following detailed description of an embodiment of the same, taken in conjunction with the accompanying drawings, and in which:

- **Figure 1** (already described) shows a microwave filter in dielectric guide made according to the known art;
- **Figure 2** shows a 3D view of a microwave filter in dielectric waveguide implemented according to the present invention;
- **Figure 3** shows a top view of the filter of fig.2 before the separation from the substrate ;
- **Figure 4** is similar to **Figure 3** with the indication of the relevant dimensions;
- **Figures 5** and **6** show the patterns of the transverse electrical field within the dielectric guide and the microstrip, respectively, of the filter in fig.2;
- **Figure 7** shows a measurement of the scattering parameters $\mathbf{S}_{11}$ and $\mathbf{S}_{21}$ relevant to an embodiment of the filter shown in fig. 2.

Detailed description of a preferred embodiment of the invention

[0019] **Figure 2** shows the dielectric waveguide filter of the present invention. With reference to the figure, a rectangular shaped central metal coating can be seen on the front side of the dielectric substrate, that extends for the whole width of the substrate up to reaching the two edges, where it continues connecting to a metal coating completely covering the rear face of the substrate (not shown in the figure) to form a resonant dielectric waveguide GDL-RIS. Two metal coatings, isosceles triangle shaped with the vertexes in a relevant short micro-strip for the input/output signals, extend from the shorter sides of the metal coating towards the edges of the substrate. Inside the guide GDL-RIS two metallized holes arranged along the longitudinal axis in central position are visible, other two holes of lower diameter are aligned to the previous ones in a more external position. Since the invention is focused on the filter, the figure shows only the filter and not a possible microstrip circuit that can also be obtained on the same substrate . As it can be noticed, the filter has a symmetrical structure along the two axis of the front side of the dielectric substrate. The first striking thing is the compactness and elegance of the filter object of the invention and the fact that it has no tuning devices.

[0020] **Figure 3** shows the front view of a dielectric substrate 1 duly metal coated in such a way as to include the filter of the previous figure not yet separated from the rest of the substrate including other copies of the same filter. As it can be noticed, the front side metallization includes the two short microstrips 2 and 2' whose length continuously widens to form the triangular metal shapes 3 and 3' connected to the opposite sides of the central metal coating 4, having rectangular shape, corresponding to the upper wall of the dielectric guide GDL-RIS. Two metal-coated grooves 5 and 5' delimit the dielectric waveguide guide GDL-RIS at the sides for all its length and over, if preferred for technological purposes .

[0021] **Figure 4** shows the upper face of the filter of **figure 2**, maintaining the same description of the previous **figure 3** for the different elements. The scope of this figure is to highlight the dimensions having a functional value. The structure of **figure 4** has length Lfil = 44 mm, width a = 10 mm, and thickness b = 0,635 mm (visible in fig.5). The filter is made on an alumina substrate (ε_r = 9,8) in which the thickness of the metallization layers is 7 μm. Microstrips 2 and 2' have width w = 0,60 mm and 50 Ohm characteristic impedance. The metal coating 4 has length Lgdl-ris = 28,70 mm, enabling the realization of 3 $\lambda_G/2$ resonators . The two metallized via-holes F1 and F2, visible at centre of the metal coating 4, have diameter D = 1,75 mm and are $\lambda_G/2$ apart. The two smaller external holes F3 and F4 have 0,5 mm diameter and are placed close to the two longitudinal ends of the metal coating 4. Triangular metal coatings 3 and 3' have size TL = 4,70 mm and T = 2,77 mm.

[0022] **Figures 5** and **6** show the pattern of the transverse electrical fields along two cross sections of the substrate of **fig.2** matching the dielectric waveguide GDL-RIS and the micro-strip 2 (or 2'), respectively. The two figures highlight the ground plan 6, common to the micro-strip 2 (or 2') and to the dielectric waveguide GDL-RIS, which completely covers the rear side of the substrate 1 wich is continuously connected to the front side metallization visible in **figure 4**. Referring to the two figures, the lines of the electrical field have trends coinciding with a "quasi-TEM" propagation mode in microstrips 2 and 2' and TE_{10} in the dielectric guide GDL-RIS. Of course, the two different modes must be well coupled between each other. The triangular metal coatings 3 and 3' attain the double purpose of transforming the "quasi-TEM" mode of the microstrips 2 and 2' into the TE_{10} mode of the waveguide GDL-RIS, simultaneously adjusting the impedance seen at the common ends of the two structures. As it can be noticed, the lines of the transverse electrical field in the

different structures represented in figures 5 and 6 are approximately oriented in the same direction and share a same profile, therefore the microstrip appears a suitable way to excite the dielectric waveguide. The metal coatings 3 and 3' improve the above-mentioned suitability, making the two profiles of the electrical field more compatible between them in the filter operating frequency band. Due to the above, the mentioned metal coatings have the additional characteristic to operate a mode transition, distinguishing from the simple "tapers" that perform the sole impedance adjustment. It is known that the propagation constant β of the TE_{10} mode of the rectangular guide depends only on the width a (**fig.4**) and not on the thickness b (**fig.5**) of the guide, therefore the guide GDL-RIS thickness can be reduced without affecting the propagation constant, thus enabling to implement dielectric waveguide and microstrip circuits on the same substrate reducing the losses due to interconnections.

[0023] The filter of the example is a bandpass of the Chebyshev type, having 7,6 GHz central frequency and bandwidth at 20dB Return Loss of approximately 200 MHz. The frequency response we wanted to realize is represented by the measurement of the scattering parameter $\mathbf{S_{21}}$ and $\mathbf{S_{11}}$ shown in **figure 7**.

[0024] The design of the filter takes place in three steps: firstly **A)** the dimensions of the dielectric waveguide GDL-RIS and the first confidence level of the via-holes' diameters are calculated ; afterwards, **B)** the dimensions of transitions 3 and 3' are calculated; finally **C)** the filter as a whole is optimised. The background for the design of the two steps **A)** and **B)** is largely supplied in the three volumes mentioned in the introduction.

[0025] Concerning step **A)**, the width a is such that the waveguide allows the propagation of the fundamental mode TE_{10} for the frequencies included in the passband of the filter. The length Lgdl-ris of the guide GDL-RIS depends on the shape and selectivity of the band pass filtering function we want to synthesize. The problem of the synthesis of a lumped elements bandpass filter is to calculate the parameters of a prototype filter made of a cascade of concentrated constant resonant sections, each section consisting of a branch L_s, C_s, series, connected to a branch L_p, C_p, parallel; the cascade being supplied by the signal generator and ending on the matched load. Choosing a canonical filtering functions (Butterworth, Chebyshev, etc.) we have the advantage that the parameters of the prototype filter are already known. The structure of the prototype filter is generally simplified using corresponding impedance inverter elements in each section; this enables to eliminate the series branch and transforms the inductance and capacity values of the parallel branch to equal values for all the resonators. The "distributed" physical filter corresponding to the lumped elements prototype filter is realized selecting a waveguide length Lgdl-ris n-times $\lambda_G/2$ long for an "n" resonator prototype filter, and drilling n+1 "inductive post" acting as many inductive impedance inverters: these metallized via-holes are placed among adjacent $\lambda_G/2$ resonators . The diameter of the metal coated holes is calculated based on the inductance value needed for a correct impedance inversion. This method leads to a first approximation project of the filter, which can be immediately verified through a generic linear simulation "tool" for a first design optimisation.

[0026] Concerning step **B)**, the problem is to obtain the dimensions TL and T of the metal coatings 3 and 3' such that the impedance adjustment is optimised in the whole band of the filter. Since said metal coatings correspond to "taper" transitions, their dimensioning can avail of the teachings relevant to the same developed, for instance, in the corresponding sections of the third volume mentioned above (Collins) and of the relevant formula. From the theory we notice that the reflection factor Γ_i at the "taper" input closed on a load (that in this case is the input impedance of the waveguide GDL-RIS) is expressed through a complex mathematical equation of the integral type evaluated on the "taper" profile. What we must know for the calculation of Γ_i is the function expressing the variation of the normalized impedance *Z* according to the size TL considered variable (see **figure 4**). Such a function will clearly depend on the profile selected for the "taper" and on the type of line used. Any profile of the transition 3 and 3', provided that it increases as the guide GDL-RIS approaches, can be considered as a progressive widening of the microstrips 2 and 2'. For the linear microstrip profile in of **figure 4** the function *Z(TL)* is well known. An aspect having great importance in the design of a "taper" is to summarize the function *Z(TL)* that supplies the desired trend in frequency for the reflection factor Γ_i. For some trends of the function *Z(TL)*, for instance increasing exponential, the expression of Γ_i is known and its module shows band-pass behaviour. In the more general case, the problem leads to the solution of the Riccati equation. The result of the considerations made on transitions with "taper" is that they too contribute to the total band pass response of the filter.

[0027] Step **C)** is required by the complexity of the filtering structure and by the need to eliminate any manual tuning after the manufacturing of the filters themselves. To this purpose a linear simulation tool is inadequate, while it is profitable to have the optimisation made by an electromagnetic simulator for tri-dimensional structures (3-D) such as for instance, that corresponding to the version 5.6 of "Agilent HFSS" developed by Agilent Technologies Inc., located at Palo Alto, California.

[0028] **Figure 7** shows two superimposed diagrams with the measured frequency response of the transmission ($\mathbf{S_{21}}$) and reflection ($\mathbf{S_{11}}$) scattering parameters $\mathbf{S_{21}}$ of the filter shown in **figure 2**. These measures have been obtained employing a vectorial networks analyser, like HP8510C , equipped with Wiltron "Universal Test Fixture" calibrated with "Calibration kit - 36804" using a TRL technique, and 25 mils alumina reference standards. The diagrams show that insertion losses are only 0,9dB at 7,6 GHz band centre frequency and the return losses are higher than 20dB in the 200 MHz band around the central frequency. The filter of the example fits to the following generalizations:

- Metal coatings 3 and 3' can deviate from the triangular shape and assume a profile having not a fixed but an increasing slope , for instance parabolic or exponential.
- The dielectric waveguide GDL-RIS can have one single or more than one via-hole in the internal part, , acting as impedance inverter, depending on the requested selectivity an bandwidth.

[0029] From studies conducted by the Applicant, it resulted that what described before with reference to the mentioned "tapered" transitions is perfectly valid when the filter operates at frequencies lower than 38 GHz. On the contrary, when the filter operates at higher frequencies (38 GHz or higher):

- The width w of the microstrip 2 remains unchanged, while
- The width of the waveguide GDL-RIS 4 reduces, therefore it was observed that the "taper" tends to nullify, that is, T≅w therefore TL=0.

[0030] The manufacturing method of the filter of **figure 2** avails of the usual deposit techniques of thin metal layers on dielectric substrates . The election technique is the one availing of the cathode deposit, or sputtering, of a metal multi-layer over an alumina substrate , on which multi-layer, a gold layer is then added according to galvanic or chemical method, after masking with fotoresist and subsequent removal. The sputtering and the subsequent deposit of gold enables also to coat inside the holes F1, F2, F3, and F4 and the longitudinal grooves 5 and 5', the Applicant holds some patents in this respect. A more economic technique avails of the silver serigraphic deposit on the top and bottom sides of the substrate ; the same operation enables the simultaneous deposit of silver in the mentioned holes and grooves. Thanks to the two metal coated grooves 5 and 5', contrarily to the filter of the second article mentioned above (Ito et al), a crown of holes is no more necessary along the contour of the filter to limit the power irradiation through the lateral sides of the dielectric waveguide. The edges, completely metal coated of the guide GDL-RIS enable therefore to raise the unloaded quality factor Q_o of the filter compared to known implementations. The separation of the filter from the rest of the alumina substrate occurs cutting with a diamond saw the substrate 1 along the centreline of the metal coated grooves 5 and 5'. The above-mentioned process enables to obtain more filters at the same time, starting from one sole substrate , highly reducing the manufacturing costs. An additional advantage deriving from the considerable accuracy and yield characteristic of the manufacturing process is to make useless the tuning of the frequency of the single filters of the production lot ("no-tuning"). A confirmation in this sense is given by the fact that the dispersion of design characteristics of the filter over 10 measured filters proved to be very low.

[0031] It is now described in due detail the manufacturing process of microwave filters in dielectric waveguide having the characteristics of the subject invention. The process is referred to the multiplexed and includes the following steps:

- Drilling of the dielectric substrate 1 matching the positions of the inductive elements F1, F2, F3, and F4 to obtain in the thickness as many segments of dielectric waveguide GDL-RIS as are the filters intended to be worked in parallel on the same sub-layer;
- drilling of the dielectric sub-layer 1 to obtain couples of parallel grooves 5, 5' longitudinally,delimiting on both sides each segment of waveguide GDL-RIS;
- deposit of metal on the bottom side 6 of the substrate 1, matching the surfaces assigned to each filter and on the internal walls of the holes F1, F2, F3, and F4 and the grooves 5 and 5';
- repetition of the previous step matching the top side of the substrate 1, obtaining a good metal contact through said holes and grooves;
- deposit of negative fotoresist on the front side of the substrate 1 and masking of each segment of waveguide inclusive of its own input/output structures in microstrip 2, 3; 3', and 2', exposure and development to obtain metal coated areas without fotoresist matching the masked areas;
- addition of gold on the metal surfaces without fotoresist;
- removal of the residual fotoresist and engraving of the steel multi-layer not protected with gold;
- cutting of the substrate 1 along the centreline of each metal coated groove 5, 5' for the separation of the single filters.

Claims

1. Microwave filter including a dielectric substrate (1) supporting a metallization (2, 3, 4, 3', 2', 5, 5', 6) suitable to form a metallic rectangular waveguide (GDL-RIS) filled with the dielectric of the substrate and resonating in its fundamental mode and two tapered microstrip-to-waveguide transitions as input/output structures (2, 3; 3', 2') at the two ends of said rectangular waveguide which includes a predetermined number of contiguous waveguide sections coupled with each other by coupling means (F1, F2, F3, F4) operating as inductive elements for obtaining the desired 3 dB bandwidth,

said metallization completely covering the side walls (5, 5') of said rectangular waveguide (GDL-RIS) **characterized in that:**

- said coupling means are metallized via-holes (F1, F2, F3, F4) spaced $\lambda_G/2$ apart along the longitudinal symmetry axis of the dielectric waveguide (GDL-RIS), where λ_G is the wavelength of said fundamental propagation mode.

2. Microwave filter, according to claim 1, **characterized in that** the width of said tapered microstrip-to-waveguide transitions (3, 3') increases with linear trend.

3. Microwave filter, according to claim 1, **characterized in that** the width of said tapered microstrip-to-waveguide transitions (3, 3') increases with parabolic trend.

4. Microwave filter, according to claim 1, **characterized in that** the width of said tapered microstrip-to-waveguide transitions (3, 3') increases with exponential trend.

5. Microwave filter according to any of the previous claims, **characterized in that** it forms part of a multi-layer structure including a second dielectric substrate supporting its own microstrip circuits and connected to the microstrip structure (2, 3; 3', 2') of said filter, assembled overturned on the second substrate.

Patentansprüche

1. Mikrowellenfilter, das ein dielektrisches Substrat (1) umfasst, das eine Metallisierung (2, 3, 4, 3', 2', 5, 5', 6) trägt, die geeignet ist, einen metallischen rechteckigen Wellenleiter (GDL-RIS), der mit dem Dielektrikum des Substrats gefüllt ist und in seiner Grundmode in Resonanz schwingt, und zwei sich verjüngende Mikrostreifen-Wellenleiter-Übergänge als Ein-/Ausgangsstrukturen (2, 3; 3', 2') an den zwei Enden des besagten rechteckigen Wellenleiters zu bilden, welches eine vorgegebene Anzahl von aneinander angrenzenden Wellenleiterabschnitten aufweist, die miteinander durch Kopplungsmittel (F1, F2, F3, F4) gekoppelt sind, die als induktive Element wirken, um die gewünschte Bandbreite von 3 dB zu erhalten, wobei die besagte Metallisierung die Seitenwände (5, 5') des besagten rechteckigen Wellenleiters (GDL-RIS) vollständig bedeckt,
dadurch gekennzeichnet, dass:

- die besagten Kopplungsmittel metallisierte Kontaktlöcher (F1, F2, F3, F4) sind, die in Abständen von $\lambda_G/2$ voneinander entlang der längs verlaufenden Symmetrieachse des dielektrischen Wellenleiters (GDL-RIS) angeordnet sind, wobei λ_G die Wellenlänge der besagten Grundmode ist.

2. Mikrowellenfilter nach Anspruch 1, **dadurch gekennzeichnet, dass** sich die Breite der besagten sich verjüngenden Mikrostreifen-Wellenleiter-Übergänge (3, 3') linear vergrößert.

3. Mikrowellenfilter nach Anspruch 1, **dadurch gekennzeichnet, dass** sich die Breite der besagten sich verjüngenden Mikrostreifen-Wellenleiter-Übergänge (3, 3') entsprechend einer parabolischen Funktion vergrößert.

4. Mikrowellenfilter nach Anspruch 1, **dadurch gekennzeichnet, dass** sich die Breite der besagten sich verjüngenden Mikrostreifen-Wellenleiter-Übergänge (3, 3') entsprechend einer exponentiellen Funktion vergrößert.

5. Mikrowellenfilter nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** es einen Teil einer Mehrschichtstruktur bildet, die ein zweites dielektrisches Substrat aufweist, das seine eigenen Mikrostreifen-Schaltungen trägt und mit der Mikrostreifen-Struktur (2, 3; 3', 2') des besagten Filters verbunden ist, die auf dem zweite Substrat umgedreht montiert wird.

Revendications

1. Filtre micro-onde comprenant un substrat diélectrique (1) supportant une métallisation (2, 3, 4, 3', 2', 5, 5', 6) adéquate pour former un guide d'ondes rectangulaire métallique (GDL-RIS) rempli du diélectrique du substrat et résonant dans son mode fondamental et deux transitions s'amincissantes de micro-bande à guide d'ondes comme structures d'entrée / de sortie (2, 3 ; 3', 2') aux deux extrémités dudit guide d'ondes rectangulaire qui comprend un nombre prédéterminé de sections de guide d'ondes contiguës couplées les unes aux autres par des moyens de couplage

(F1, F2, F3, F4) fonctionnant comme des éléments inductifs pour obtenir la largeur de bande de 3 dB désirée, ladite métallisation recouvrant complètement les parois latérales (5, 5') dudit guide d'ondes rectangulaire (GDL-RIS), **caractérisé en ce que** :

- lesdits moyens de couplage sont des trous de passage métallisés (F1, F2, F3, F4) espacés de $\lambda_G/2$ le long de l'axe de symétrie longitudinal du guide d'ondes diélectrique (GDL-RIS), où λ_G est la longueur d'onde dudit mode de propagation fondamental.

2. Filtre micro-ondes selon la revendication 1, **caractérisé en ce que** la largeur desdites transitions s'amincissantes de micro-bande à guide d'ondes (3, 3') augmente selon une tendance linéaire.

3. Filtre micro-ondes selon la revendication 1, **caractérisé en ce que** la largeur desdites transitions s'amincissantes de micro-bande à guide d'ondes (3, 3') augmente selon une tendance parabolique.

4. Filtre micro-ondes selon la revendication 1, **caractérisé en ce que** la largeur desdites transitions s'amincissantes de micro-bande à guide d'ondes (3, 3') augmente selon une tendance exponentielle.

5. Filtre micro-ondes selon l'une quelconque des revendications précédentes, **caractérisé en ce qu'**il forme une structure multicouche comprenant un deuxième substrat diélectrique supportant ses propres circuits à microbande et relié à la structure à microbande (2, 3, 3', 2') dudit filtre, assemblée en étant renversée sur le deuxième substrat.

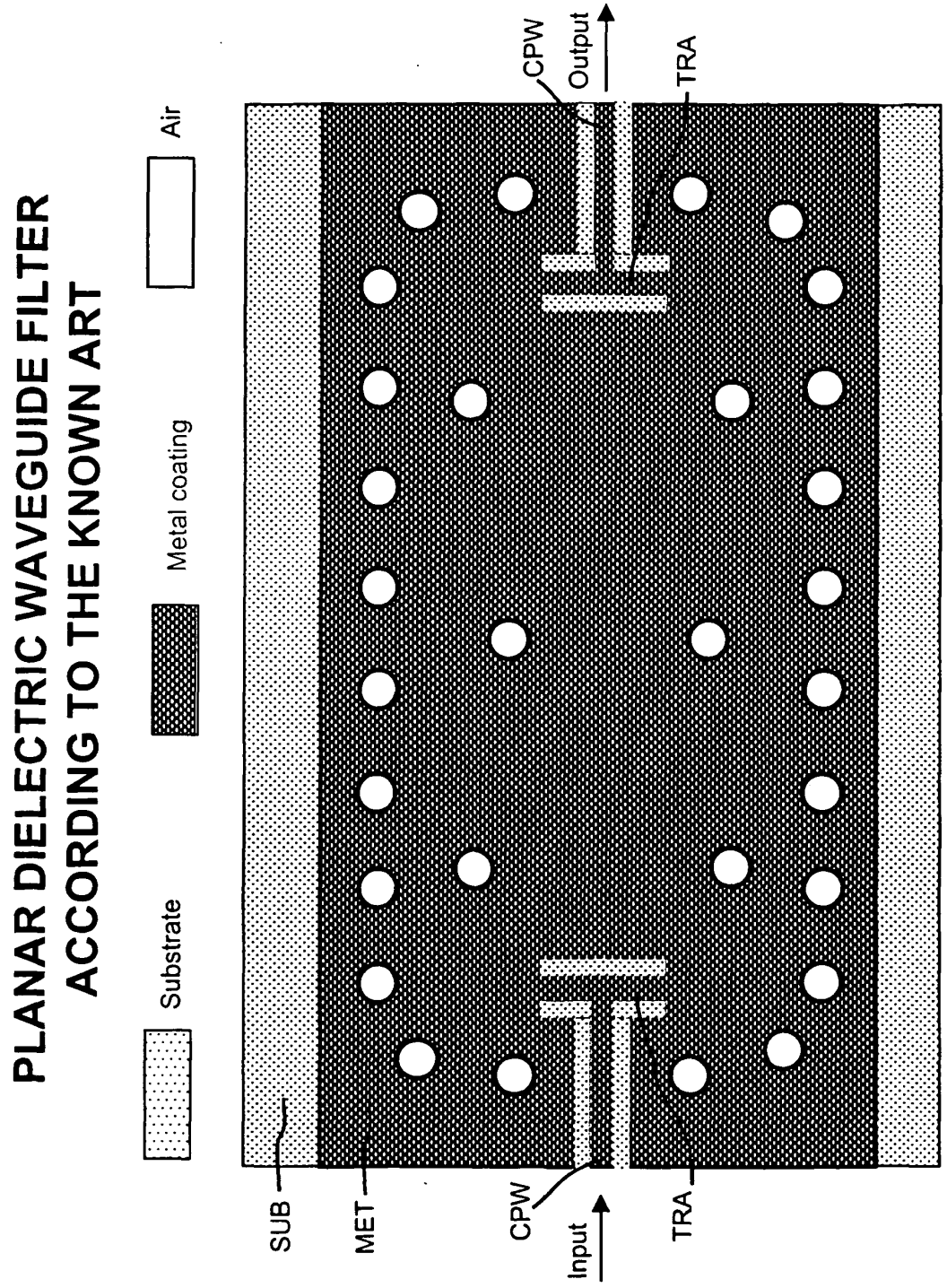

PLANAR DIELECTRIC WAVEGUIDE FILTER
ACCORDING TO THE KNOWN ART
Substrate
Metal coating
Air
SUB
MET
CPW
Input
TRA
CPW
Output
TRA

FIG. 1

3D VIEW OF THE PLANAR FILTER

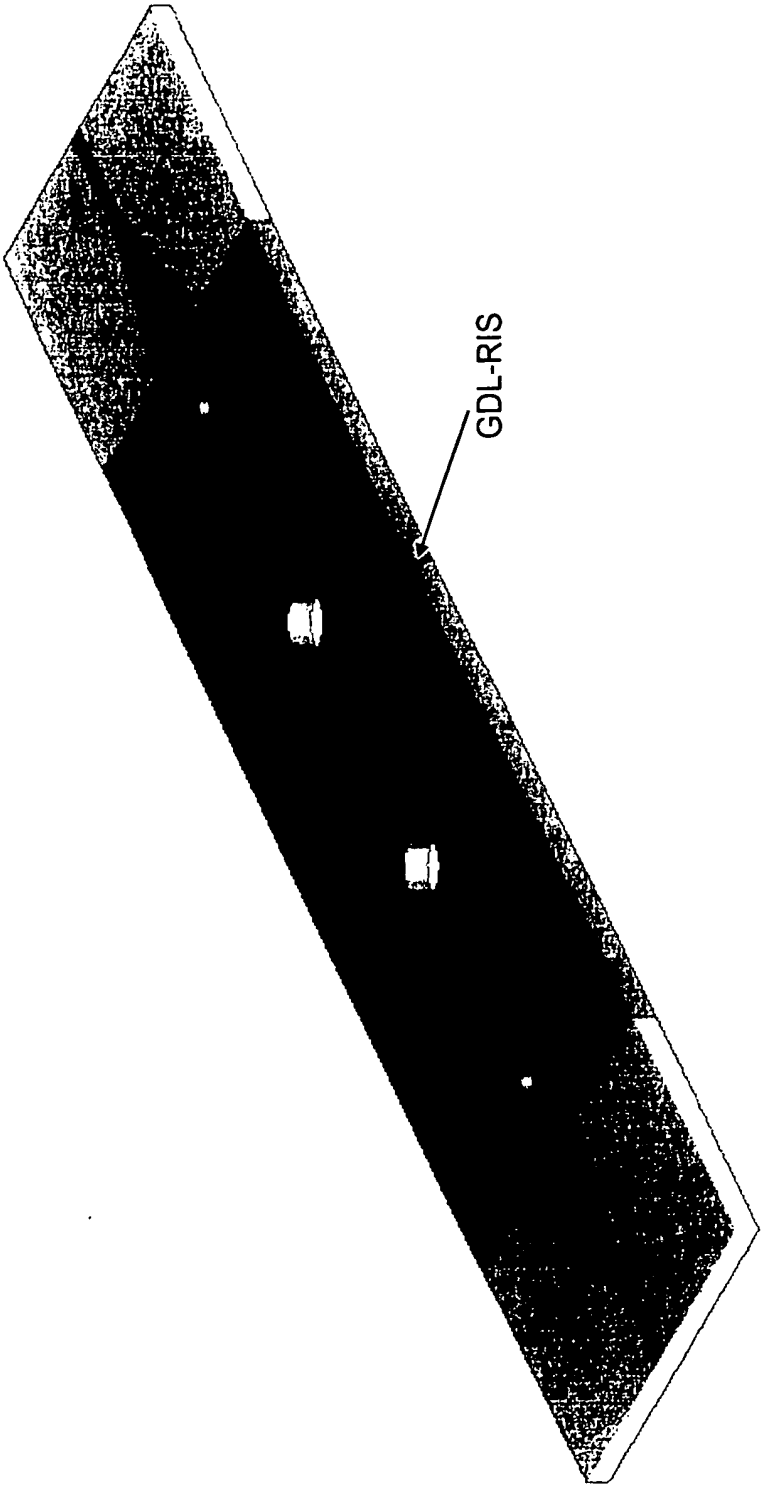


FIG. 2

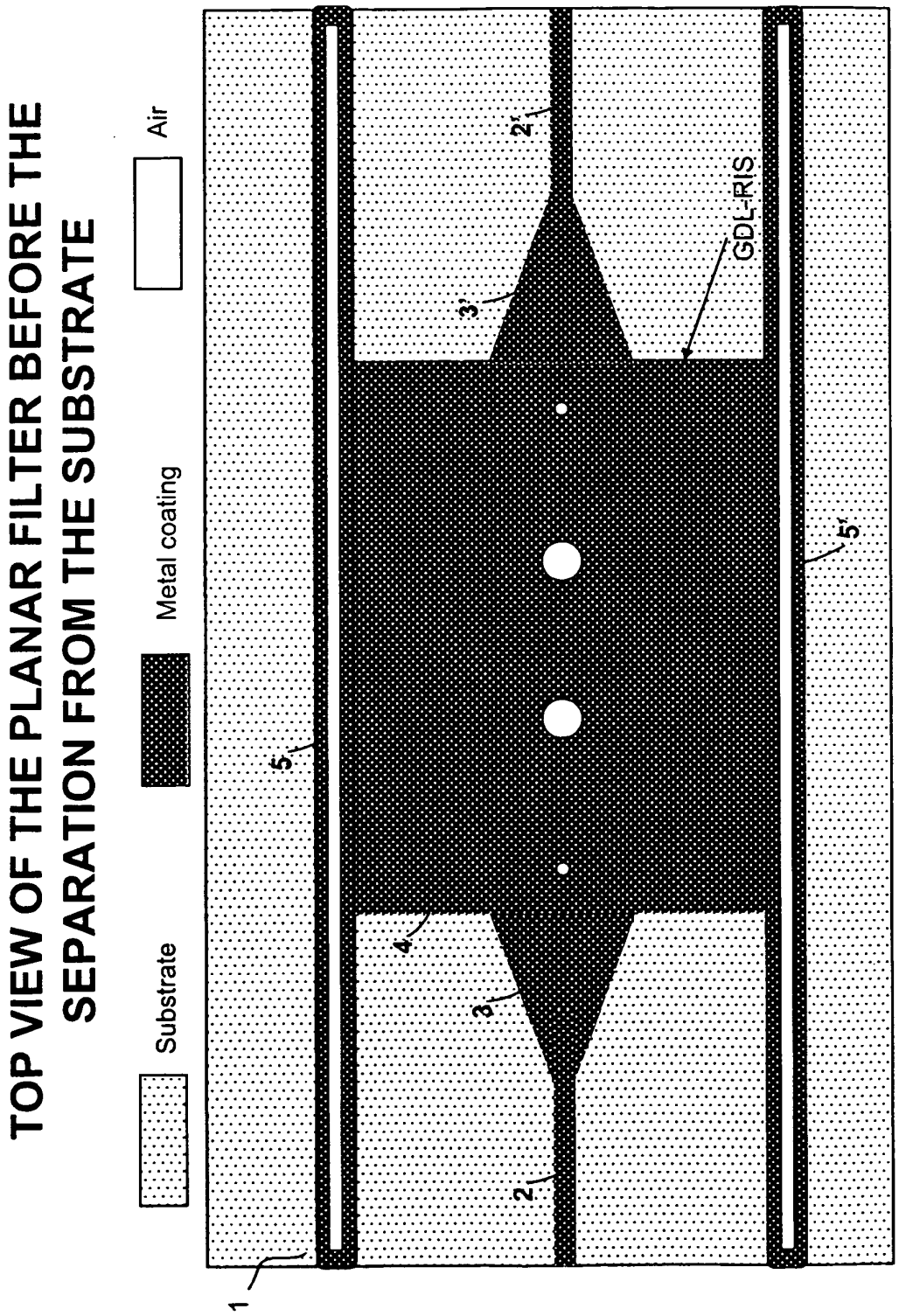

TOP VIEW OF THE PLANAR FILTER BEFORE THE SEPARATION FROM THE SUBSTRATE
Substrate
Metal coating
Air
GDL-RIS
1
2
2'
3
3'
4
5
5'

FIG. 3

TOP VIEW OF THE PLANAR FILTER

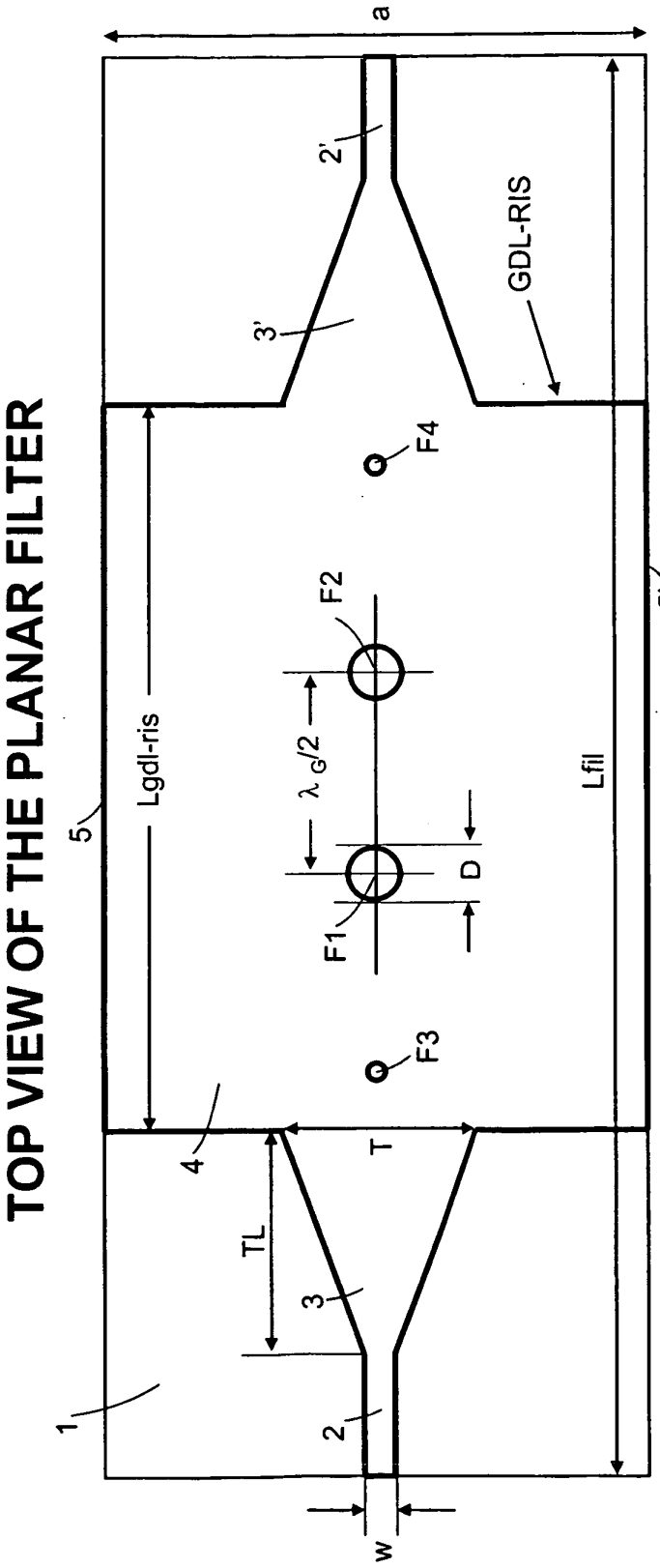


FIG. 4

PATTERN OF THE TRANSVERSE ELECTRICAL FIELD IN THE WAVEGUIDE AND THE MICROSTRIP

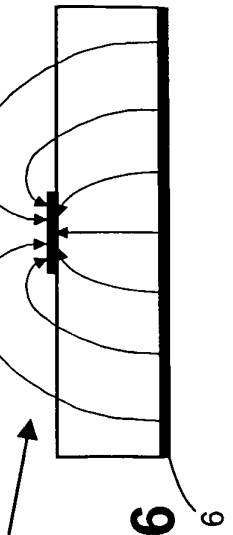


FIG. 6

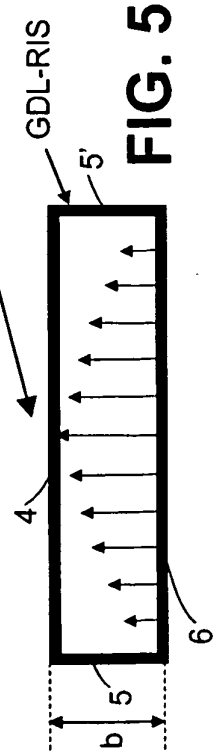
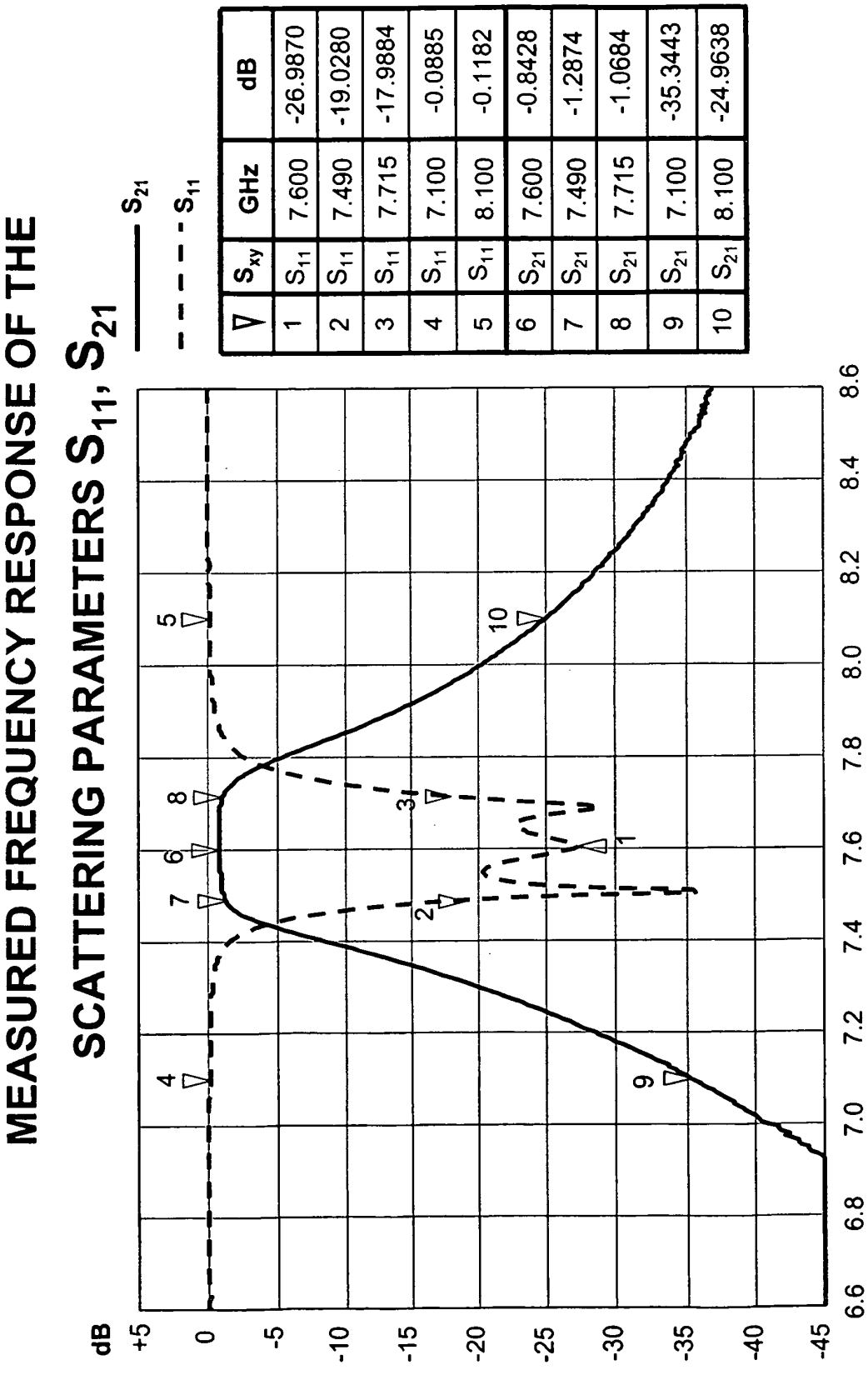


FIG. 5



▽	S_{xy}	GHz	dB
1	S_{11}	7.600	-26.9870
2	S_{11}	7.490	-19.0280
3	S_{11}	7.715	-17.9884
4	S_{11}	7.100	-0.0885
5	S_{11}	8.100	-0.1182
6	S_{21}	7.600	-0.8428
7	S_{21}	7.490	-1.2874
8	S_{21}	7.715	-1.0684
9	S_{21}	7.100	-35.3443
10	S_{21}	8.100	-24.9638

FIG. 7