Device for the propagation of electromagnetic waves with modulated dielectric constant.

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

(11) EP 1 919 024 A1

(12) # EUROPEAN PATENT APPLICATION

(43) Date of publication:
07.05.2008 Bulletin 2008/19

(51) Int Cl.:
H01P 1/203 (2006.01) *H01P 3/08* (2006.01)

(21) Application number: 07021125.5

(22) Date of filing: 29.10.2007

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

(30) Priority: 03.11.2006 IT RA20060064

(71) Applicants:
- Fondazione Torino Wireless
10129 Torino (IT)
- POLITECNICO DI TORINO
10129 Torino (IT)

(72) Inventors:
- Matekovits, Landislau
10134 Turin (IT)
- Vietti Colome', Guillermo Carlos
10136 Turin (IT)
- Pirinoli, Paola
10143 Turin (IT)
- Orefice, Mario
10123 Turin (IT)

(74) Representative: Grünecker, Kinkeldey, Stockmair & Schwanhäusser
Anwaltssozietät
Maximilianstrasse 58
80538 München (DE)

(54) **Device for the propagation of electromagnetic waves with modulated dielectric constant**

(57) The propagation of electromagnetic waves in materials with electromagnetic properties, which varies along their propagation direction, presents interesting characteristics, such as the presence of frequency bands in which the propagation is allowed and of bands in which the electromagnetic waves are stopped. The present invention relates to a microstrip structure (20) comprising a conductive layer (22) whose width varies in such a way as to obtain an effective electric constant, which presents a sinusoidal shape modulation.

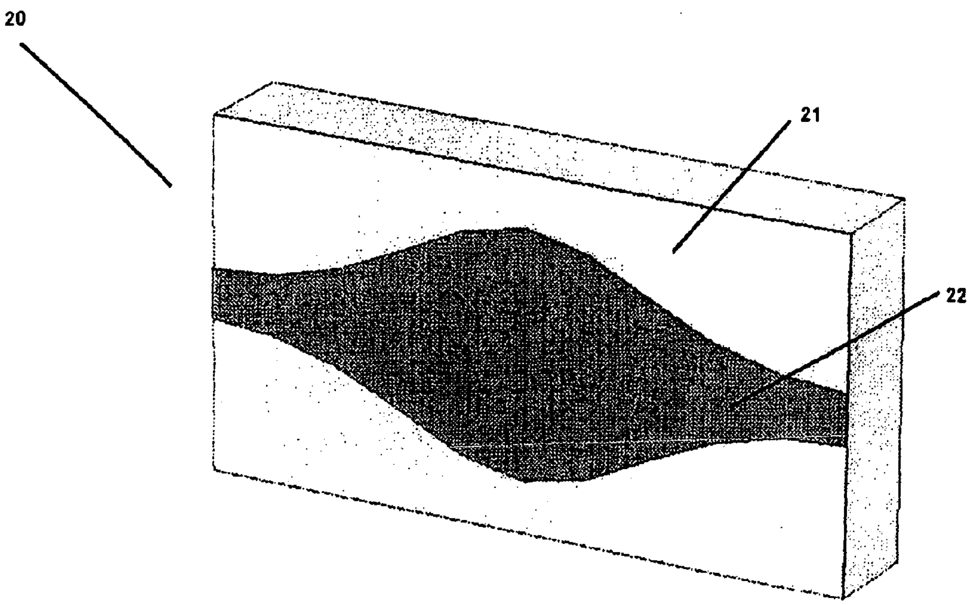

Fig. 2

EP 1 919 024 A1

Description

FIELD OF THE INVENTION

[0001] The present invention relates to the field of electromagnetic wave propagation. More in detail, the present invention relates to the propagation of electromagnetic waves through a microstrip structure with a dielectric constant which varies inside the structure. In particular, the present invention relates to a device which is used as support for the propagation of electromagnetic waves and which comprises a layer of dielectric material and at least one conductive layer or conductive track, in which the relative dielectric constant of the device is modulated by the shape of said conductive layer or conductive track. More in detail, the present invention is related to a device suited for the propagation of electromagnetic waves where the electric constant is periodically modulated along a predetermined direction by a periodic variation of the shape of said conductive layer along the same predetermined direction. More in detail, the present invention relates to a device which is suited for the propagation of electromagnetic waves whose effective dielectric constant is sinusoidally modulated along a predetermined direction by a periodic variation of the shape of said conductive layer along the same direction. Said periodic and/or sinusoidal variation can regard the width of said conductive layer, its thickness, or both of these characteristics.

DESCRIPTION OF THE STATE OF THE ART

[0002] In recent years, a large interest has been shown in materials which present an electromagnetic band gap structure (known as EBG materials), which means the materials are selective in frequency and therefore allow the propagation of electromagnetic waves of a given frequency while blocking the propagation of waves with other frequencies. This phenomenon presents strong similarities with the band structure of materials with a crystalline structure. As is known from solid-state physics, there are materials such as semiconductors which have a band energy structure such that an electron can have only energy values which correspond to an allowed energy band, while it cannot have values which correspond to a forbidden band. Similar to semiconductor materials, which allow the conduction of electrons with an energy which is comprised in a conduction band, the EBG materials allow the propagation of electromagnetic waves with frequencies comprised within given bands or intervals while they block the wave propagation of waves with frequencies outside said bands or intervals.

[0003] The EBG materials have become widely employed in antenna applications, as for example leaky wave antennas, lens antennas or also surface wave coupling reduction between antennas, etc. (see for example: Fan, Y.; Rahmat-Samii, Y.; "Microstrip antennas integrated with electromagnetic band-gap (EBG) structures: low mutual coupling design for array applications", IEEE Trans. AP, pgs 2936-2946, October 2003).

[0004] The EBG behavior can be obtained in different ways, for example by arranging reactive loads, with concentrated or distributed parameters, which are smaller than the wavelength of the wave that propagates in the device or by modulation of the media electromagnetic properties.

[0005] In particular, modulation of the electromagnetic properties of a structure can be obtained using different techniques, such as for example the modulation of its physical characteristics, that is placing materials with different dielectric constants side-by-side or one on top of another or by using electro-optic materials, materials which change their dielectric properties under the application of electromagnetic fields. Furthermore, the modulation of the parameters of the material can be achieved by drilling holes in the dielectric material. A complete characterization of EBG material can be carried out by a dispersion diagram, which represents the wavenumber in function of the frequency of the electromagnetic waves (see for example: Brillouin, L. "Wave Propagation in periodic structures", New York: Dover, 1953).

[0006] However, even though these techniques are widely used to obtain a structure with EBG behavior, they still present disadvantages and/or problems.

[0007] For example, the drilling techniques (with or without metallization) have proved not to be suited for the microstructures which are required by the demand for ever greater scale reduction of circuits and/or devices; in fact, it has proved very difficult, if not impossible, to realize microholes with dimensions suited for today's circuits such as integrated circuits or the like.

[0008] In the same way, structures with different layers have proved to be not competitive because of the costs.

[0009] Finally, the behavior of an EBG material and/or of the structure which can be realized with the known techniques has often proved to be very unstable and/or sensible to the influence of environmental factors.

[0010] It is, therefore, an object of the present invention to overcome or reduce the disadvantages of the known techniques mentioned above.

[0011] In particular, the object of the present invention is to obtain structures or materials suited to the propagation of electromagnetic waves which present a stable EBG behavior and which are not influenced by environmental factors; furthermore, said materials and/or structures can be realized at competitive costs and present dimensions suited to the demand for an always greater miniaturization of devices and/or circuits in general.

[0012] Furthermore, the proposed structure, as it does not present any holes, is easier to realize with lower costs. For the same reason, it also presents a larger mechanical resistance.

[0013] According to one embodiment of the present invention, the substrate can be multilayer, meaning that the conductive layer is located in a multilayer structure made of dielectric materials with different relative dielectric constants. According to a further embodiment, the conductive layer is located closer to the interface with the air, but not necessarily at the interface air-dielectric; this solution allows to have an M value (modulation factor) which allows control over the position and the width of the forbidden bands.

SUMMARY OF THE INVENTION

[0014] The present invention is based on the consideration that a device and/or structure suited for the propagation of electromagnetic waves and which presents an EBG behavior can be obtained by modulation of at least one of the electromagnetic properties of said structure and/or device. Furthermore, the present invention is based on the consideration that the EBG behavior can be obtained by modulation of the effective dielectric constant of the structure or device. Particularly, the present invention is based on the consideration that an appropriate modulation of the dielectric constant of the structure or device, one that provides an EBG behavior, can be obtained by realizing a conductive layer whose shape and/or dimensions are not constant but vary along a predetermined direction so as to modulate the effective dielectric constant of the structure and/or device along said direction and said predefined profile.

[0015] According to the most general embodiment, the present invention relates to a device as claimed in main claim 1. That is, a device suited for the propagation of electromagnetic waves and comprising a conductive mass plate, a substrate, and at least one other conductive layer in which at least one electromagnetic property of said device is modulated in a periodic way within said device by said conductive layer.

[0016] According to a particular embodiment as claimed in dependent claim 3, the effective dielectric constant of the device is modulated by the shape of said at least one conductive layer.

[0017] According to a further embodiment as claimed in claim 5, the width of said at least one conductive layer varies in a substantially periodic way along a predetermined direction, so that said dielectric constant is periodically modulated along said predetermined direction.

[0018] According to another embodiment as claimed in claim 6, the width of said at least one conductive layer varies substantially sinusoidally along said predetermined direction, so that said effective dielectric constant is modulated according to a substantially sinusoidal profile along said predetermined direction.

[0019] Further embodiments of the present invention are defined by the other dependent claims.

BRIEF DESCRIPTION OF THE FIGURES

[0020] Further advantages, objectives and characteristics of the present invention are defined in the claims and they will become clear from the following detailed description together with the figures in which identical or corresponding parts are identified by the same reference numerals. In particular,

- Figure 1 schematically represents a microstrip structure according to the state of the art in which the conductive layer has a constant width. The one-layer structure has a mass plate on the opposite side of the strip;
- Figure 2 schematically represents a microstrip structure according to a first embodiment of the present invention in which the conductive layer is continuous and the width is not constant;
- Figure 3 schematically represents a microstrip structure according to a further embodiment of the present invention in which the conductive layer is not continuous and the width is not constant;
- Figure 4 schematically represents the dispersion diagram of the microstrip structure according to the present invention, in which it is possible to recognize the band structure;
- Figure 5 schematically represents the dispersion diagram of a normal microstrip structure according to the state of the art with a conductive layer of constant width;
- Figure 6 schematically represents a further embodiment of the present invention, in which a plurality of parallel conductive layers are disposed on a dielectric substrate. The layers can be in phase or out of phase;
- Figure 7 schematically represents a further embodiment of the present invention, in which a plurality of conductive layers are disposed in a longitudinal and transversal way on a substrate, so that a conductive lattice is realized;

- Figure 8 schematically represents a further embodiment of the present invention in which the modulated line does not lie at the interface air-dielectric, but rather is located between two dielectrics.

DETAILED DESCRIPTION OF THE INVENTION

[0021] Even if the present invention is described with reference to the embodiments which are described in the following and represented in the figures, it should be noted that the present invention is not limited to the particular embodiments described in the following detailed description and represented in the figures, but that the described embodiments are simply examples of different aspects of the present invention, whose scope is defined in the claims.

[0022] As previously anticipated, according to the present invention one possible way to confer an EBG behavior to a structure suited for the propagation and/or transmission of electromagnetic waves is to modulate the effective dielectric constant, for example following a periodic profile, in particular a sinusoidal profile.

[0023] In fact, if one considers a microstrip structure as represented in Figure 1, which comprises a thin and flat electric conductor 1 separated from a mass plate (not shown in Figure 1) by a dielectric material 2, the following consideration may be made.

[0024] Microstrip structures of this type are widely used as transmission lines for microwaves. The electromagnetic waves which propagate in a microstrip structure of this kind diffuse in part in the dielectric material and in part in the air. The propagation velocity of the electromagnetic waves corresponds therefore to a value which is comprised between the propagation wave velocity in the dielectric and the propagation velocity in the air. The microstrip structure is therefore characterized by an effective dielectric constant ε_{eff} which is given by the formula (for details Hammerstad, E. and Jensen, O., "Accurate Models for Microstrip Computer-Aided Design", Digest of 1980 IEEE MTT-S International Symposium, Washington D. C.):

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 10\frac{h}{w}\right)^{-0.5} \qquad (1)$$

in which ε_r is the dielectric constant of the dielectric material, h is the thickness of the dielectric material and w is the width of the conductive layer. This formula is valid for the fundamental mode of the microstrip structure. Corrections to this expression are known in the literature.

[0025] By inverting the previous expression it is possible to find the value of the width of the conductive layer as a function of the dielectric constant ε_r, the effective dielectric constant ε_{eff} and the thickness *h* as shown in the formula:

$$w = 2.5h\frac{(2\varepsilon_{eff} - \varepsilon_r - 1)^2}{(\varepsilon_r - \varepsilon_{eff})(\varepsilon_{eff} - 1)} \qquad (2)$$

[0026] The inventors faced therefore the problem of determining the behavior of a microstrip structure of the type represented in Figure 2, in which the conductive layer 2 does not have a constant width along the propagation direction of the electromagnetic waves, and they arrived at the conclusion that, as previously shown, the effective dielectric constant of a microstrip structure depends on the width of the conductive layer. By varying this width it is possible to modulate the value of the effective dielectric constant along the propagation direction. The inventors arrived therefore at the unexpected conclusion that in this way it is possible to obtain a microstrip structure with new electromagnetic properties, which can bring considerable advantages in many applications. In particular, the modulation of the effective dielectric constant can allow the structure to block certain wavelengths and let others propagate through, acting therefore as a filter.

[0027] A particular case has also been considered, where an effective dielectric constant varies in a sinusoidal way along the propagation direction, as expressed by the formula:

$$\varepsilon_{eff}(u) = \varepsilon_{avg}\left(1 - M\cos\frac{2\pi u}{D}\right) \tag{3}$$

in which *u* is the position along the propagation direction of the electromagnetic wave, D is the period and M is the modulation constant that satisfies the condition that $|M| < 1$. This represents the simplest modulation scheme and as will be shown later, it confers to the structure an EBG behavior.

[0028] By substituting the value of the desired effective dielectric constant, as expressed in the equation (3), in the equation (2) of the width of the conductive layer, it is possible to determine the width along the propagation direction of the electromagnetic waves.

[0029] In a particular embodiment of the present invention, *M* is a real value, which corresponds to the case without absorption of the electromagnetic wave by the structure. When M assumes complex values, the effective dielectric constant becomes complex, which corresponds for example to the heat dissipation by the Joule effect in the dielectric material. In a further particular embodiment of the present invention, the effective dielectric constant varies only in the propagation direction of the electromagnetic waves.

[0030] To study the behavior of this structure with a modulated effective dielectric constant according to equation (3), it is necessary to insert the equation (3) in the Maxwell equation. In this way a system of equations with partial derivatives results with the necessary boundary conditions. From this system, it is possible to obtain two distinct expressions, one for the transversal electric field and one for the transversal magnetic field with respect to the modulation direction (for details: Tamir, T. et al., "Wave propagation in Sinusoidally Stratified Dielectric Media", IEEE Trans. on MTT pp. 323-335, May 1964).

[0031] Because of the diverse nature of the equations that one obtains, the transversal electric field (TE) and the transversal magnetic field (TM) can be treated separately. The transversal magnetic field can be obtained analytically by means of the Hill functions, while the transversal electric field can be obtained in terms of the Mathieu functions, which are a particular case of the Hill functions.

[0032] From the solution of the Maxwell equation for the microstrip structure of the present invention with a conductive layer with a variable width which follows an almost sinusoidal profile, as in the equation (3), it is possible to obtain the band structure as shown in Figure 4.

[0033] The limits of the bands, which allow the propagation of the electromagnetic waves or stop the electromagnetic waves, can be obtained by the intersection between the line which corresponds to the modulation parameters and the limits of the stability zones of these functions. The behavior inside the band is described by the relative functions of non-integer order.

[0034] In a particular embodiment of the present invention, a microstrip structure with a unique conductive layer in which the effective dielectric constant varies is considered.

[0035] Figure 2 schematically illustrates a period of a particular embodiment of the present invention in which the structure 20 comprises a dielectric substrate 21 on whose surface is disposed a conductive layer 22. The conductive layer 22 extends longitudinally along the entire length of the substrate 21 as shown in Figure 2. The electromagnetic waves propagate inside the structure represented in Figure 2 along the direction in which the conductive layer extends longitudinally. In the following, this propagation direction will be defined as the predetermined or predefined direction. The shape of the conductive layer and in particular its width (measured in the direction perpendicular to the propagation direction) varies periodically according to a function which results from the equation (3).

[0036] In Figure 3 a particular embodiment of the present invention is schematically shown in which the structure 30 comprises a dielectric substrate 31 on whose surface is disposed a non-continuous conductive layer 32. The conductive layer 32 extends longitudinally along the entire length of the substrate 31 and it is interrupted by non-conductive strips/zones 33 as shown in Figure 3. The conductive layer 32 is therefore made up of conductive and non-conductive strips. The length in the predefined longitudinal direction of both the conductive and non-conductive strips is constant along all the substrate. On the contrary, the width (measured in the transversal direction) of the conductive strips is variable and it describes a periodic profile as shown in Figure 3.

[0037] The length in the longitudinal direction of the non-conductive strips is identified by the reference number 33 and in a further particular embodiment of the present invention said length has a value of 0.2 mm.

[0038] Figure 6 schematically illustrates a further particular embodiment of the present invention in which the bi-dimensional structure 60 comprises a dielectric substrate 61 on whose surface are disposed a plurality of conductive layers 62. The conductive layers are parallel and there is no contact between the different conductive layers as shown in Figure 6. The conductive layer 62 extends longitudinally along the entire length of the substrate 61 as shown in Figure 6. The different conductive layers have a periodic profile which is substantially sinusoidal and are in phase with one another as shown in the upper part of Figure 6. In particular, with the expression "in phase", it should be understood that the functions of the width of the two conductive adjacent layers which are periodical along the predefined longitudinal direction are in phase between them (at a given value *u* corresponds the same value of w).

[0039] On the contrary, according to a further embodiment of the present invention the conductive layers can be out of phase, as shown in the lower part of Figure 6. In this case the functions that express the periodicity along the predefined longitudinal direction of the width of the 2 adjacent conductive layers are out of phase (at a given value of *u* correspond different values of w).

[0040] Figure 7 schematically shows a particular embodiment of the present invention in which the two dimensional structure 70 comprises a dielectric substrate 71 on whose surface are disposed conductive longitudinal layers 72 and conductive transversal layers 73. The longitudinal conductive layers are parallel and there is no contact between them, as shown in Figure 7. The same is valid for the transversal conductive layers. The longitudinal conductive layers come into contact with their respective transversal layers in the contact points 74. Both the longitudinal 72 and transversal 73 conductive layers extend respectively longitudinally and transversally for the entire length/width of the dielectric substrate 71. The conductive layers therefore form a radical structure on the dielectric surface 71. In this particular embodiment the electromagnetic waves can propagate in both the longitudinal and transversal directions.

[0041] In a particular embodiment of the present invention the dielectric material 2 is made of Arlon 350 with a thickness of 1.58 mm and the conductive layer 11 is made of copper with a thickness of 35 μm as is the mass layer behind.

[0042] In a particular embodiment of the present invention the modulation of the effective dielectric constant takes place in a continuous way in one dimension (1 D) thanks to a continuous conductive layer, as shown in Figure 2, whose width varies periodically and/or substantially sinusoidally.

[0043] In a particular embodiment of the present invention the conductive layer is not continuous and it is interrupted by non-conductive zones, that is it is made of conductive strips alternated with non-conductive zones. The width of the conductive strips is not constant.

[0044] In a particular embodiment of the present invention the width of the strips varies in a periodic way and/or sinusoidal way according to the profile of equation (3) as shown in Figure 3. The distance between the different conductive strips is smaller than the wavelength of the electromagnetic waves which propagates in the microstrip structure. This particular embodiment of the present invention has the advantage that it prevents the passage of continuous current along the conductive layer and therefore it is useful when active elements (for example for the control of the phase difference) are inserted into the system.

[0045] In a particular embodiment of the present invention the value of ε_{avg} is 2.67 and that of

$$M = \Delta\varepsilon = 0.11.$$

[0046] In a further embodiment of the present invention the frequency of the electromagnetic waves employed is within the range of 0 to 25 GHz.

[0047] In a particular embodiment of the present invention the width of the conductive layer varies between a minimum of 0.70 mm and a maximum of 3.50 mm on a period of 10 mm.

[0048] In a particular embodiment of the present invention the conductive layer is not continuous and it is interrupted by cuts which have a width of 0.2 mm.

[0049] In a further embodiment of the present invention a plurality of conductive layers are disposed on the dielectric substrate as shown in Figure 6. The different conductive layers are disposed on the same plane and are parallel to each other.

[0050] In a particular embodiment the particular shapes of the conductive layers can be in phase as shown in the upper part of Figure 6 or they can be disposed out of phase as shown in the lower part of the same figure. In a further embodiment of the present invention the conductive layers which are disposed on the dielectric substrate can come into contact forming therefore a two-dimensional conductive lattice as shown in Figure 7. These two-dimensional embodiments according to the present invention can be employed as a substrate to reduce cross-talk between data transmission lines. Actually, this is the most widely employed application. Furthermore, reducing the coupling means that the lines can be placed closer to each other and therefore the dimensions of the entire circuit can be reduced with an important advantage in terms of costs, volume, etc.

[0051] In a further embodiment of the present invention the modulation of the effective dielectric constant can be obtained by varying the thickness of the conductive layer instead of the width as mentioned in the previous embodiments. The thickness of the conductive layer is therefore not constant.

[0052] In a particular embodiment of the present invention the modulation of the dielectric constant can also be due to variation in the composition of the conductive layer or by employing different conductive materials.

[0053] Figure 8 represents a further embodiment according to the present invention in which the conductive layer is inside the dielectric material. Alternatively, the conductive layer can be disposed between two layers of different dielectric materials like in a sandwich. Also the plurality of conductive layers represented in the Figures 6 and 7 can be inside a dielectric substrate or they can be disposed between two or more layers of different dielectric material.

[0054] A particular embodiment of the present invention comprises a device which is used as support for the propagation of electromagnetic waves which comprises one layer of dielectric material with two conductive layers, one on each side, wherein one is continuous and uniform (mass layer) and the other is made of parallel strips with a width which varies periodically so that the relative effective dielectric constant of the device is periodically modulated by the shape of said conductive layer.

NUMERICAL ANALYSIS OF THE PROPERTIES OF THE SYSTEM

[0055] The microstrip structure with a conductive layer with a continuous sinusoidal shape as shown in Figure 2 and the structure with a non-continuous shape as shown in Figure 3 were analyzed in detail to better show the characteristics. In particular these two cases were examined by an eigenvector analysis and by a numerical analysis with transient solver in the time domain. The results were then represented in a dispersion diagram and they were compared also with the dispersion diagram of the structure with a constant width conductive layer as shown in Figure 1 in order to underline the differences in behavior.

[0056] For the numerical calculation by means of the transient solver analysis a structure was considered where the structure consisted of 21 unitary cells in which each cell corresponds to a modulation period for the continuous case as well as for the discrete case.

[0057] For the numerical calculation, a sinusoidal profile was taken with a width varying between a minimum of 0.70 mm and a maximum of 3.50 mm over a period of 10 mm. In the described case the interruptions have a width of 0.20 mm.

[0058] The band structure can be easily recognized in Figure 4 which shows frequency bands in which the electromagnetic radiation is propagating and bands where it is stopped.

[0059] The graph is the result of numerical calculation for a structure with a conductive layer with a continuous and not-continuous sinusoidal shape. The numerical calculations show that the behavior of these two variants is very similar with the exclusion of the fundamental mode of the continuous structure that is the transverse electromagnetic mode (TEM).

[0060] The behavior of these two variants presents clear differences if compared with the case of a microstrip structure with a conductive layer of a constant width. The respective dispersion graph is shown in Figure 5. As one can see in Figure 5 there are no forbidden frequency bands.

[0061] In the particular case shown in Figure 4 in which the frequency of the electromagnetic waves varies between 0 and 25 GHz, the limits of the band which allows the propagation and the bands which stop the propagation are: 0-7, 24-12, 905-16, 23-19, 89-24, 76 GHz.

[0062] It has therefore been shown that the present invention allows one to obtain the desired results. The EBG structure according to the present invention can be realized with a low cost, for example by realizing on a dielectric substrate one or more conductive layers or tracks using a lithography process (etching or the like).

[0063] Furthermore, as already mentioned previously, the device of the present invention can function as a filter in order to eliminate frequency bands thanks to the EBG behavior of the material. The device of the present invention is moreover adapted in order to be applied in integrated circuits. Furthermore, the surface of the device represents a high impedency surface and it is therefore an artificial magnetic conductor.

[0064] The EBG properties of the device can be used in order to reduce the coupling between radiators in the applications in which a plurality of antennas are present. Furthermore, the device can be applied in leaky antennas or for the reduction of the diffraction from the boards of a limited mass plane or more in general in all applications in which it is necessary to eliminate the surface waves.

[0065] The device of the present invention can moreover be employed in order to suppress modes in the case that it is located between two parallel metallic plates (parallel plate mode suppression).

[0066] Considering the filter behavior, the device of the present invention can be employed for noise isolations inside devices, for example it can be employed as a substrate for buses in order to reduce the ratio between the signal and the noise and to eliminate cross-talk phenomena. This has the advantage that, reducing the coupling between the lines of a bus, it is possible to dispose the lines closer to each other, so that the occupied space can be reduced, which is very important for packaging applications.

[0067] Furthermore, the periodicity of the width of said one or more conductive layers can be realized on the basis of the requested periodicity for the effective dielectric constant and/or to obtain a particular desired EBG behavior. This EBG behavior will be stable and not influenced by external factors.

Claims

1. A device (20) suited for the propagation of electromagnetic waves comprising:

a substrate (21) and at least one conductive layer (22)

characterized in that
at least one electromagnetic property of said device (20) is modulated in a periodic way inside said device (20) by said conductive layer (22).

2. The device according to claim 1
characterized in that
one of said electromagnetic properties is the effective dielectric constant.

3. The device according to claim 2
characterized in that
said effective dielectric constant is modulated by the shape of said at least one conductive layer.

4. The device according to claim 3
characterized in that
said effective dielectric constant is modulated by the width of said at least one conductive layer.

5. The device according to claim 4
characterized in that
the width of said at least one conductive layer varies substantially periodically along a predetermined direction, so that said dielectric constant is periodically modulated along said predetermined direction.

6. The device according to claim 5
characterized in that
the width of said at least one conductive layer varies substantially sinusoidally along said predetermined direction, so that said effective dielectric constant is modulated following a substantially sinusoidal profile along a predetermined direction.

7. The device according to one of claims 4 to 6
characterized in that
said effective dielectric constant is modulated by the thickness of said dielectric.

8. The device according to claim 7
characterized in that
the thickness of said dielectric varies periodically along said predetermined direction.

9. The device according to claim 8
characterized in that
the thickness of said dielectric varies substantially sinusoidally along said predetermined direction.

10. The device according to one of claims 1 to 9
characterized in that
said at least one conductive layer is continuous.

11. The device according to one of claims 1 to 9
characterized in that
said at least one conductive layer is not continuous.

12. The device according to claim 11
characterized in that
said at least one conductive layer is interrupted by non-conductive strips.

13. The device according to one of claims 1 to 12
characterized in that
said device is a microstrip structure.

14. The device according to one of claims 1 to 13

characterized in that
said device comprises a plurality of conductive layers.

15. The device according to claim 14
characterized in that
said conductive layers are disposed substantially parallel.

16. The device according to claim 15
characterized in that
the width of said conductive strips varies periodically along said predetermined direction and **in that** the periodicity of two adjacent layers is substantially in phase.

17. The device according to claim 16
characterized in that
the width of said conductive layers varies periodically along said predetermined direction and **in that** the periodicity of two adjacent layers is substantially out of phase.

18. The device according to one of claims 1 to 17
characterized in that
the device allows the propagation of electromagnetic waves with a predetermined frequency and it stops the propagation of electromagnetic waves with frequencies which are different from the predetermined frequencies.

19. The device according to one of claims 1 to 18
characterized in that
said device is suited to be part of an integrated circuit.

20. The device according to one of claims 1 to 19
characterized in that
the device is suited for the propagation of microwaves.

21. The device according to one of claims 1 to 19
characterized in that
said device is suited for the propagation of electromagnetic waves with a frequency comprised between 0 and 25 GHz.

22. The device for the propagation of electromagnetic waves according to one of claims 1 to 21
characterized in that
the width of said conductive layer is comprised between 0.70 mm and 3.50 mm.

23. The device according to one of claims 1 to 22
characterized in that
the substrate is made of dielectric material.

24. A circuit suited for the propagation of electromagnetic waves
characterized in that
said circuit comprises a device according to one of claims 1 to 23.

25. The circuit according to claim 24
characterized in that
said circuit is an integrated circuit.

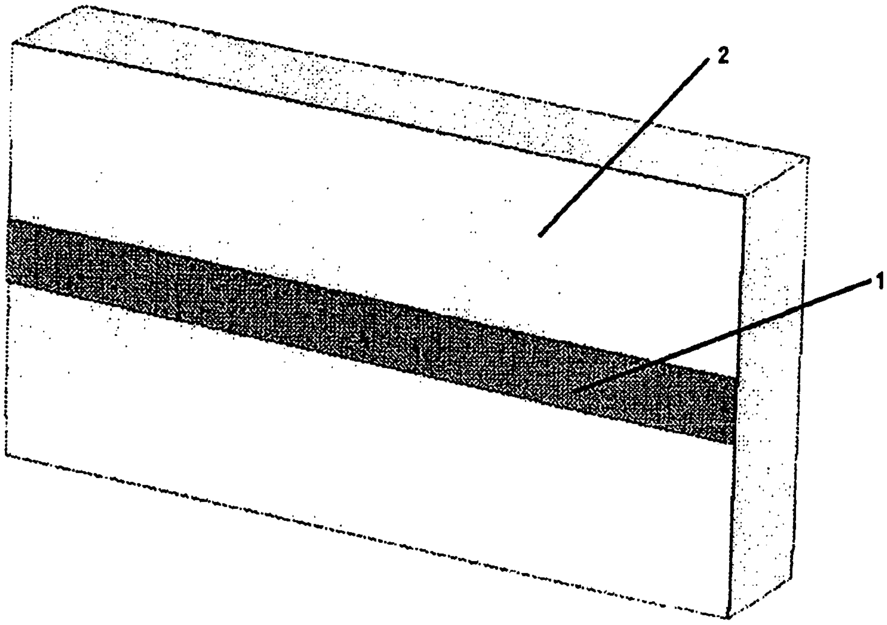

Fig. 1

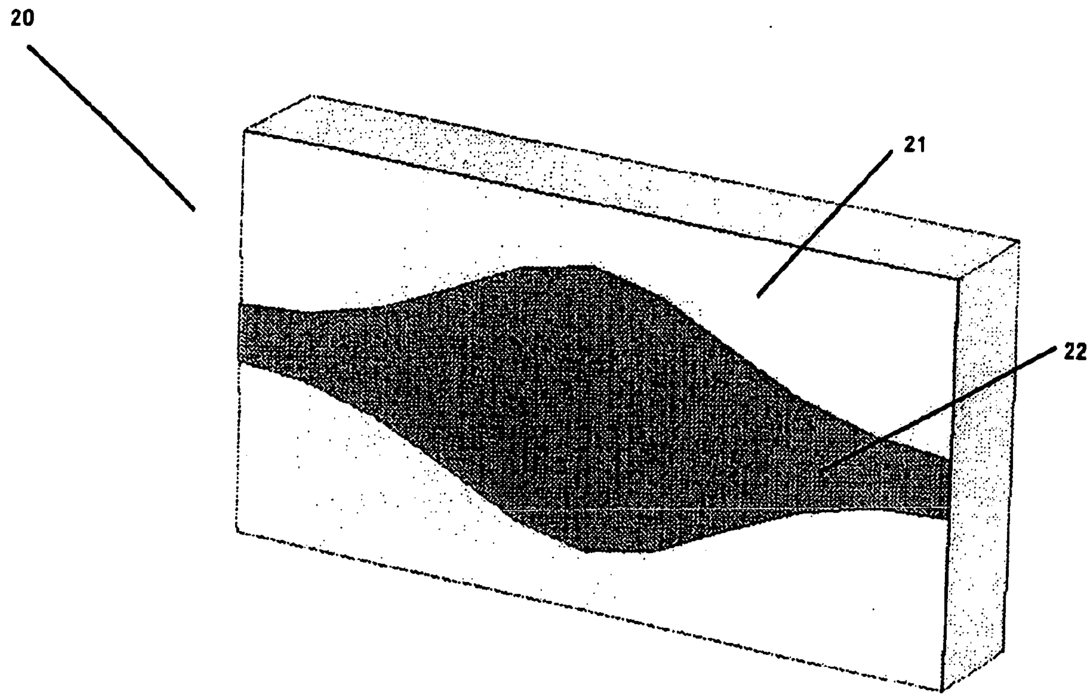

Fig. 2

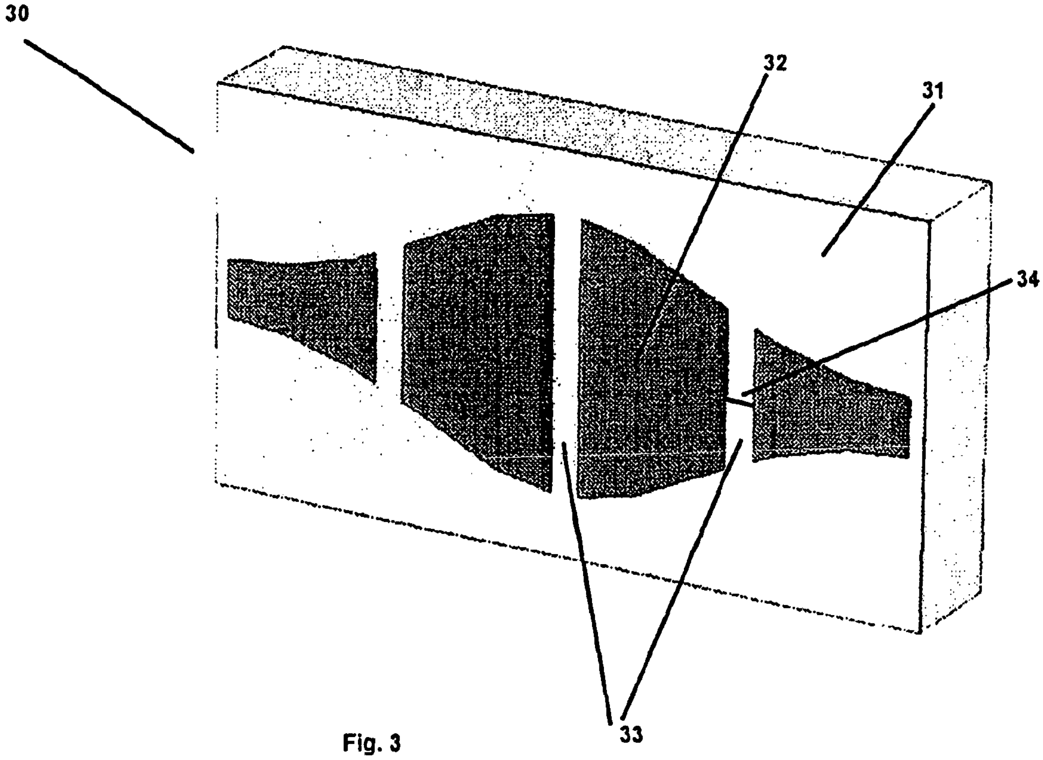

Fig. 3

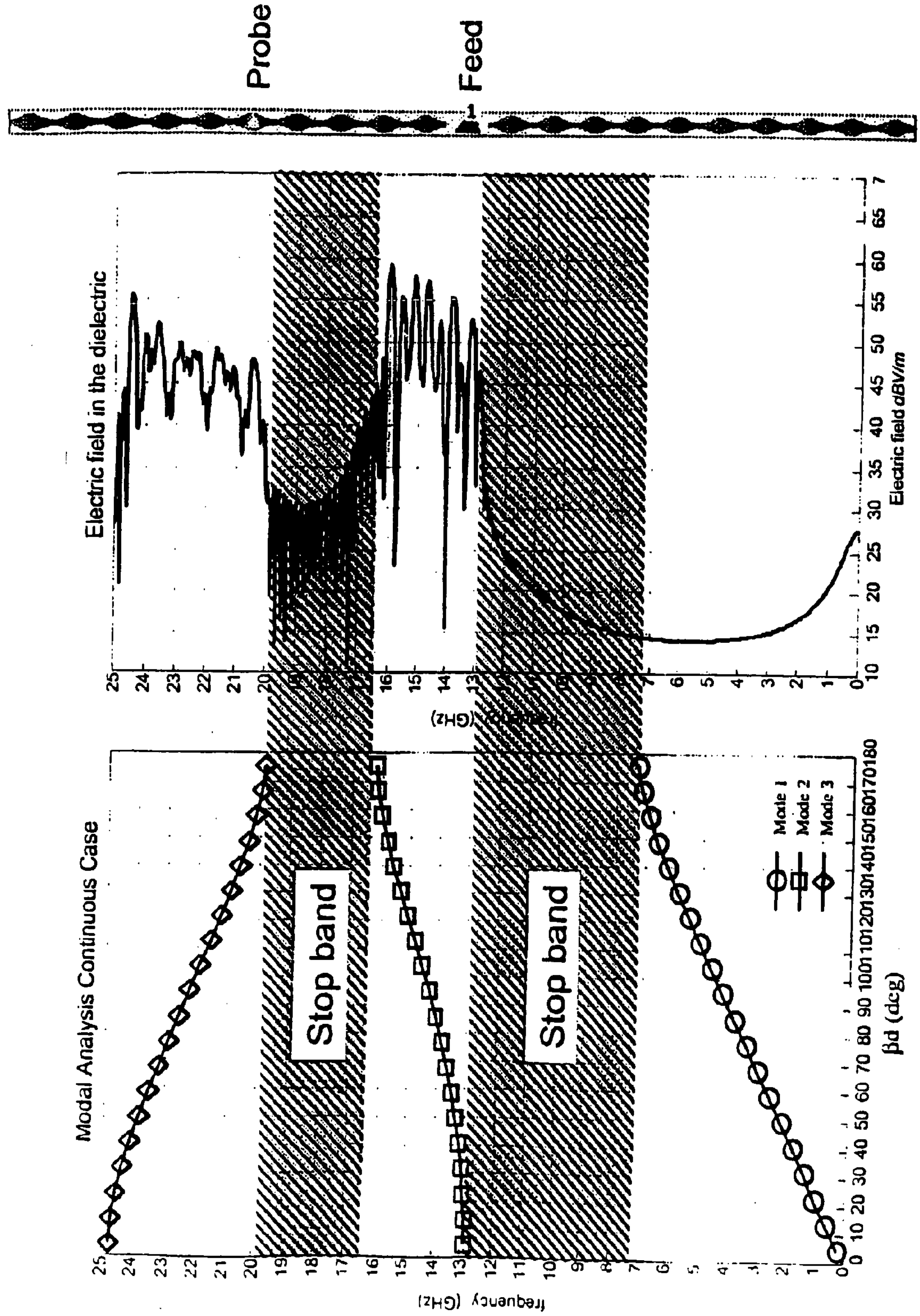
Probe
Feed
Modal Analysis Continuous Case
Electric field in the dielectric
Stop band
Stop band
frequency (GHz)
Mode 1
Mode 2
Mode 3
βd (deg)
Electric field dBV/m

Fig. 4

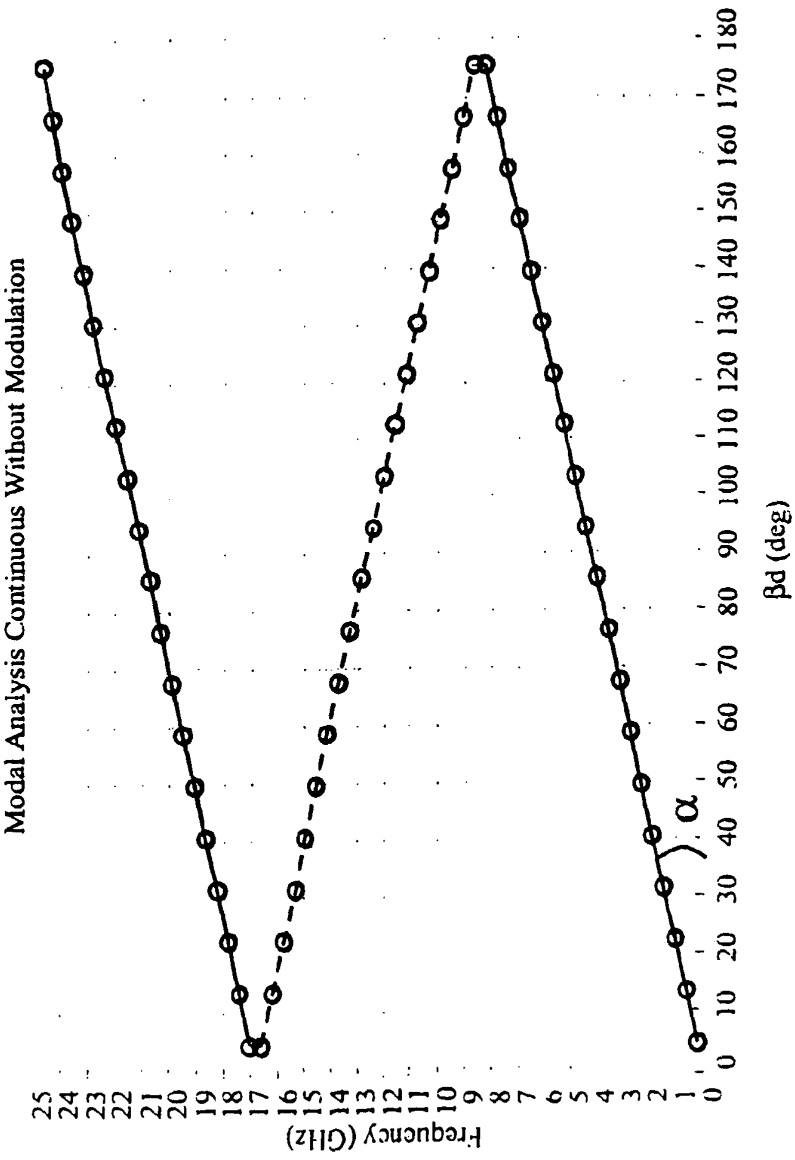
Modal Analysis Continuous Without Modulation
Frequency (GHz)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
βd (deg)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
α

Fig. 5

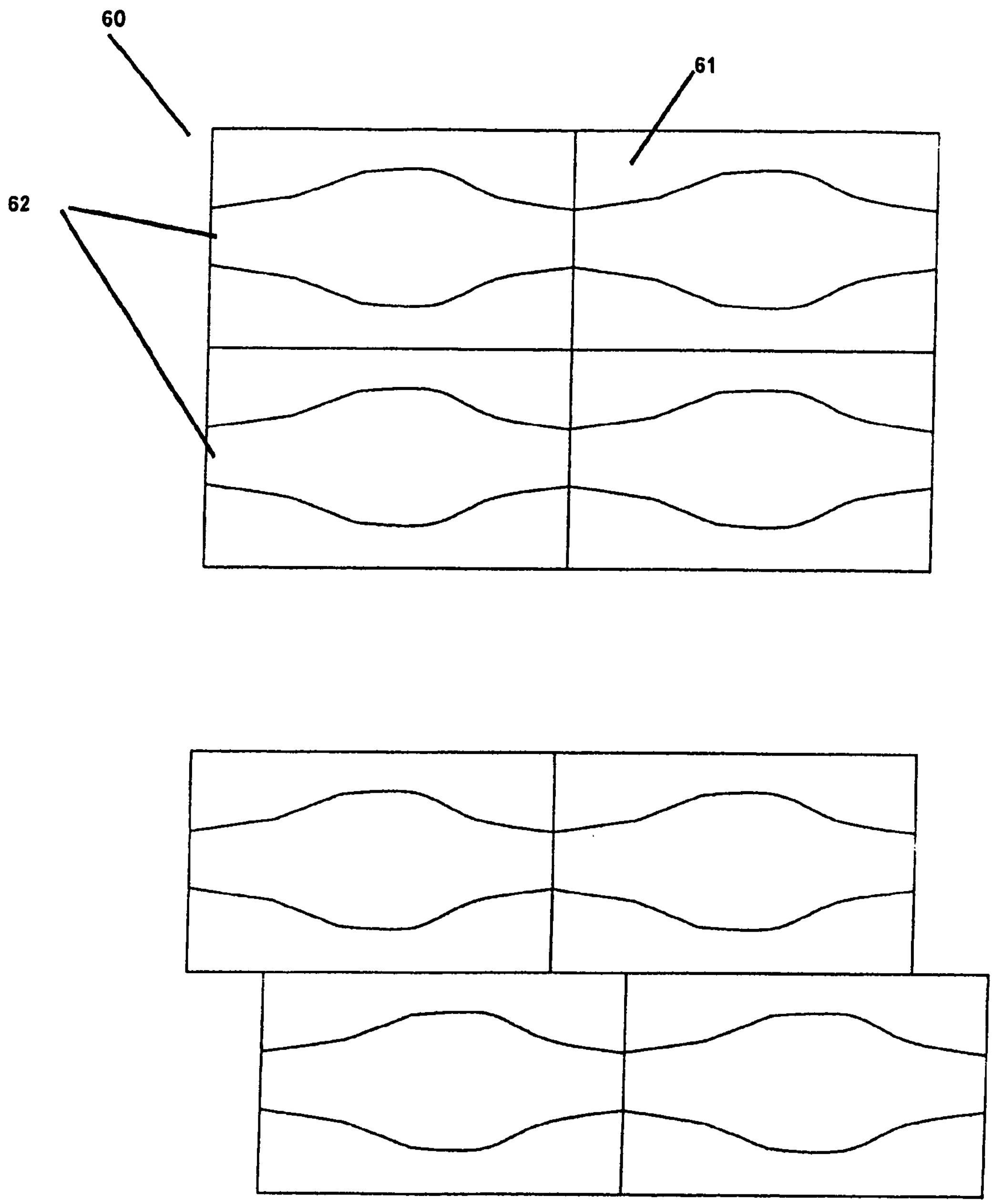

Fig. 6

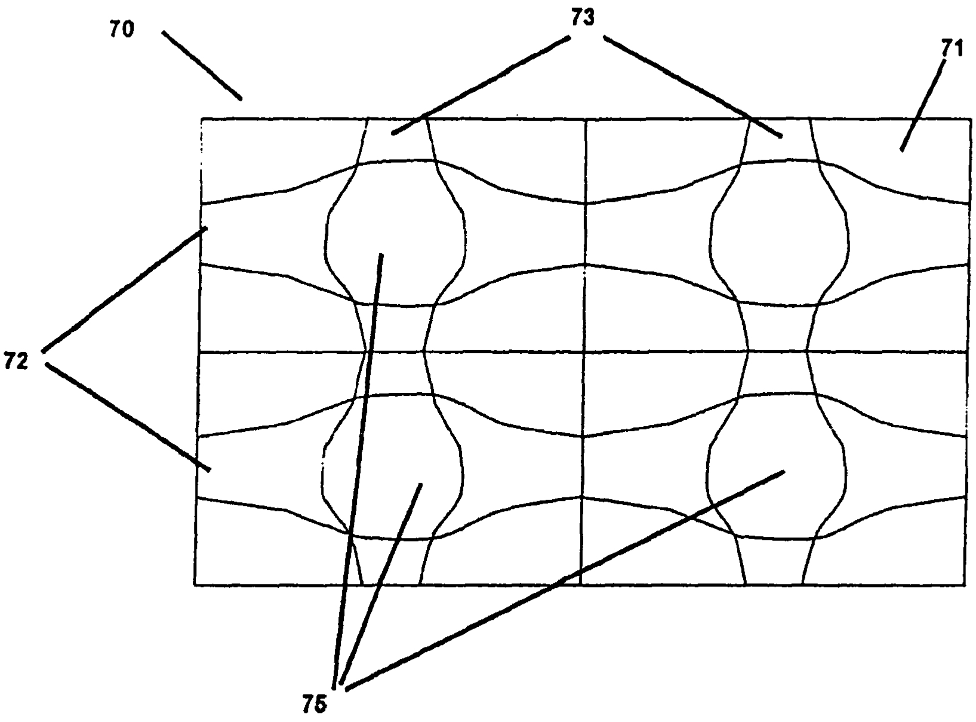

Fig. 7

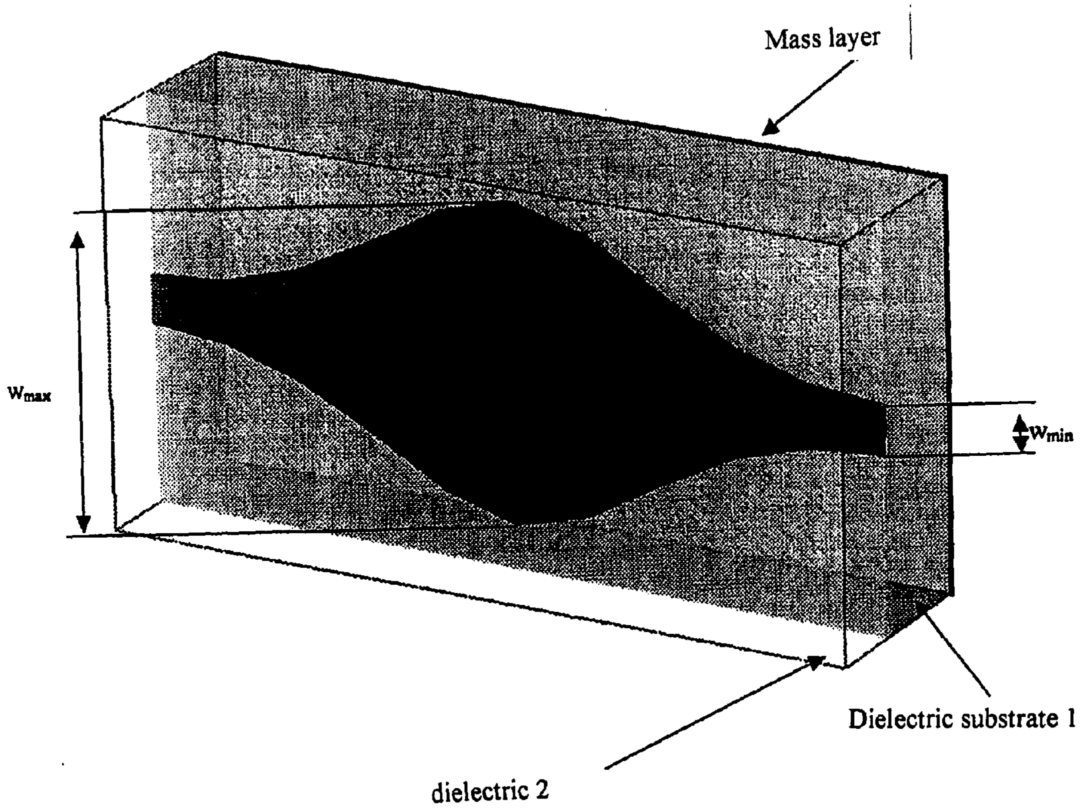

Fig. 8

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 07 02 1125

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y	LE ROY M ET AL: "Novel Circuit Models of Arbitrary-Shape Line: Application to Parallel Coupled Microstrip Filters with Suppression of Multi-Harmonic Responses" 2005 EUROPEAN MICROWAVE CONFERENCE CNIT LA DEFENSE, PARIS, FRANCE OCT. 4-6, 2005, PISCATAWAY, NJ, USA,IEEE, 4 October 2005 (2005-10-04), pages 921-924, XP010903914 ISBN: 2-9600551-2-8 * the whole document * -----	1-6, 10-17, 22-25 7-9	INV. H01P1/203 ADD. H01P3/08
Y	KIANG J-F ET AL: "Transmission properties of microstrip lines with a periodical ground plane" MICROWAVE CONFERENCE, 2001. APMC 2001. 2001 ASIA-PACIFIC DECEMBER 3-6, 201, PISCATAWAY, NJ, USA,IEEE, vol. 1, 3 December 2001 (2001-12-03), pages 67-70, XP010578889 ISBN: 0-7803-7138-0 * page 67, paragraph 2 - page 68, paragraph 4 * * figures 1-6 * * abstract * -----	7-9	TECHNICAL FIELDS SEARCHED (IPC) H01P
X	LE ROY M ET AL: "A new design of microwave filters by using continuously varying transmission lines" MICROWAVE SYMPOSIUM DIGEST, 1997., IEEE MTT-S INTERNATIONAL DENVER, CO, USA 8-13 JUNE 1997, NEW YORK, NY, USA,IEEE, US, vol. 2, 8 June 1997 (1997-06-08), pages 639-642, XP010228412 ISBN: 0-7803-3814-6 * the whole document * ----- -/--	1-6,10, 13,22-25	

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	28 January 2008	von Walter, Sven-Uwe

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

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 07 02 1125

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	NESIC D ET AL: "1-D microstrip PBG band-pass filter without etching in the ground plane and with sinusoidal variation of the characteristic impedance" TELECOMMUNICATIONS IN MODERN SATELLITE, CABLE AND BROADCASTING SERVICE, 2001. TELSIKS 2001. 5TH INTERNATIONAL CONFERENCE ON 19-21 SEPTEMBER 2001, PISCATAWAY, NJ, USA,IEEE, vol. 1, 19 September 2001 (2001-09-19), pages 181-183, XP010560918 ISBN: 0-7803-7228-X * page 181, paragraph II - page 182, paragraph III * * figures 1-5 * * abstract * -----	1-6,10, 13,22-25	
			TECHNICAL FIELDS SEARCHED (IPC)

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	28 January 2008	von Walter, Sven-Uwe

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

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Non-patent literature cited in the description

- **FAN, Y ; RAHMAT-SAMII, Y.** Microstrip antennas integrated with electromagnetic band-gap (EBG) structures: low mutual coupling design for array applications. *IEEE Trans. AP,* October 2003, 2936-2946 **[0003]**
- **BRILLOUIN, L.** Wave Propagation in periodic structures. Dover, 1953 **[0005]**
- Accurate Models for Microstrip Computer-Aided Design. **HAMMERSTAD, E. ; JENSEN, O.** Digest of 1980 IEEE MTT-S International Symposium **[0024]**
- **TAMIR, T. et al.** Wave propagation in Sinusoidally Stratified Dielectric Media. *IEEE Trans. on MTT,* May 1964, 323-335 **[0030]**