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H1Q QEJ

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GB 2253519 A	**EP 0187437 A1**
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INT CL^7 **H01Q** 15/00
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(54) Abstract Title
Electromagnetic filter

(57) A device substantially transparent to electromagnetic radiation of a certain frequency band is presented. The device comprises at least one dielectric structure formed with a predetermined substantially periodic inner pattern composed of a two-dimensional array of spaced-apart substantially identical elements made of an electrically conducting material and capable of scattering said electromagnetic radiation. The elements are disconnected from each other, each having a size smaller than that of a resonance condition of the array of such elements - typically less than half the wavelength of the radiation to be passed. The device may be sandwiched between layers of dielectric sheets, or between ferroelectric layers. If ferroelectric layers are used, application of an electric field allows the pass-band to be changed.

The device may be used in radomes.

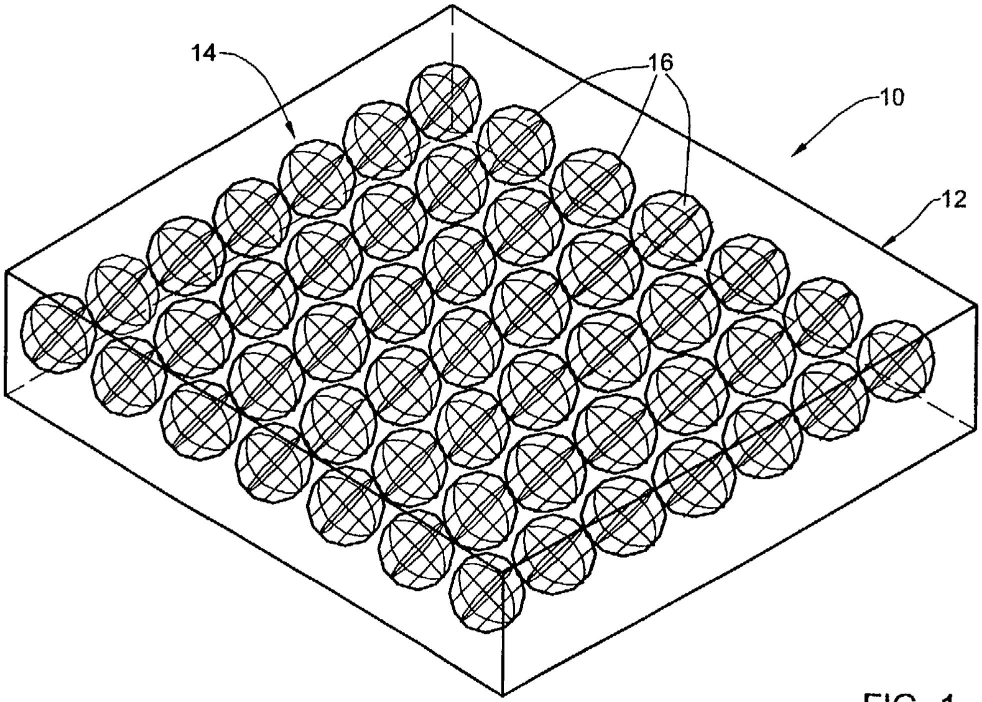


FIG. 1

GB 2 378 820 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

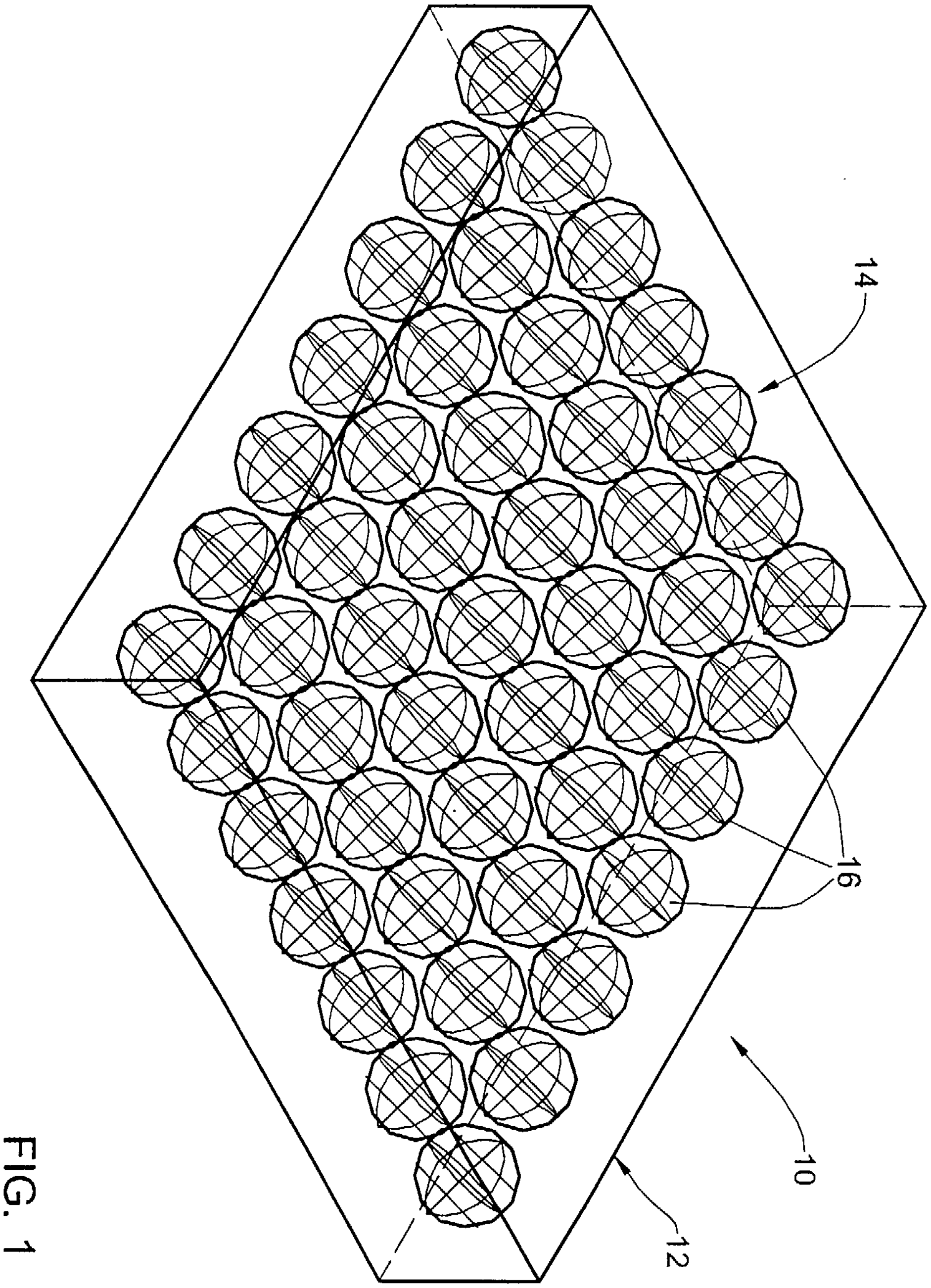


FIG. 1

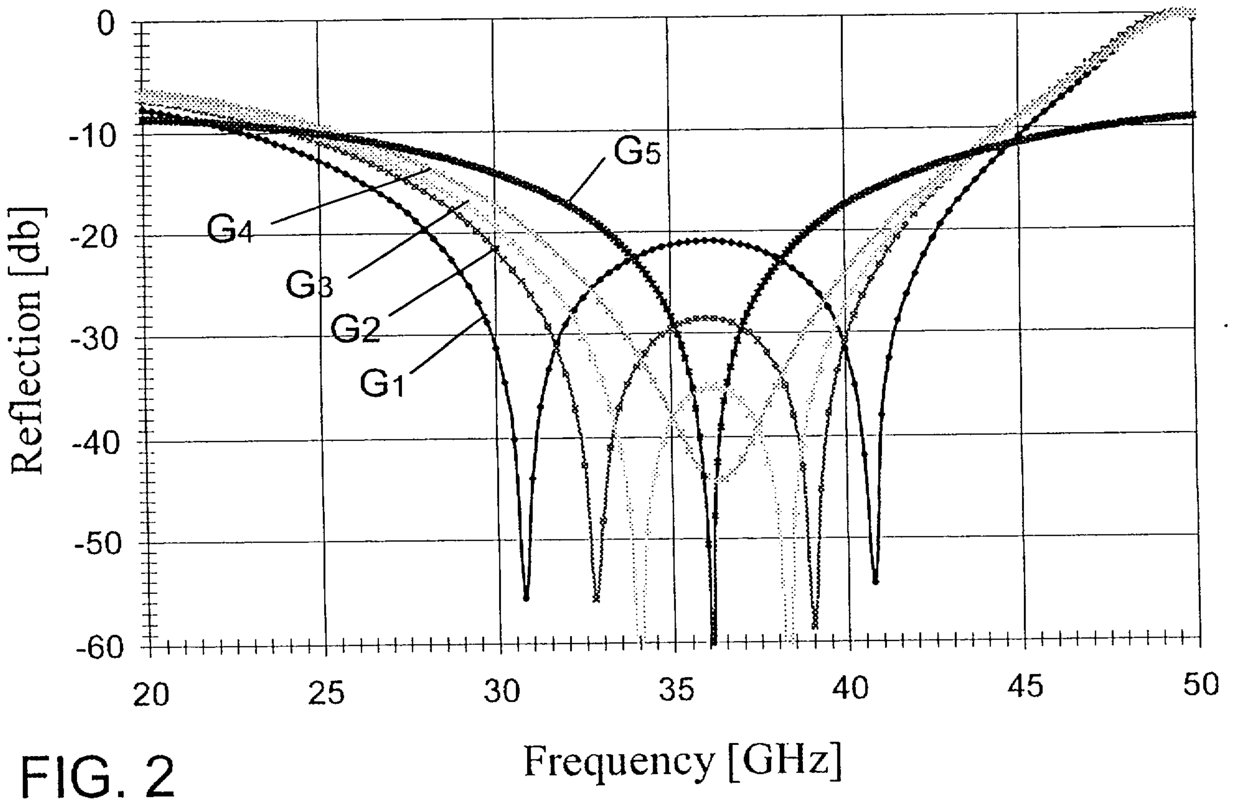

Reflection [db]
0
-10
-20
-30
-40
-50
-60
20
25
30
35
40
45
50
Frequency [GHz]
G_5
G_4
G_3
G_2
G_1

FIG. 2

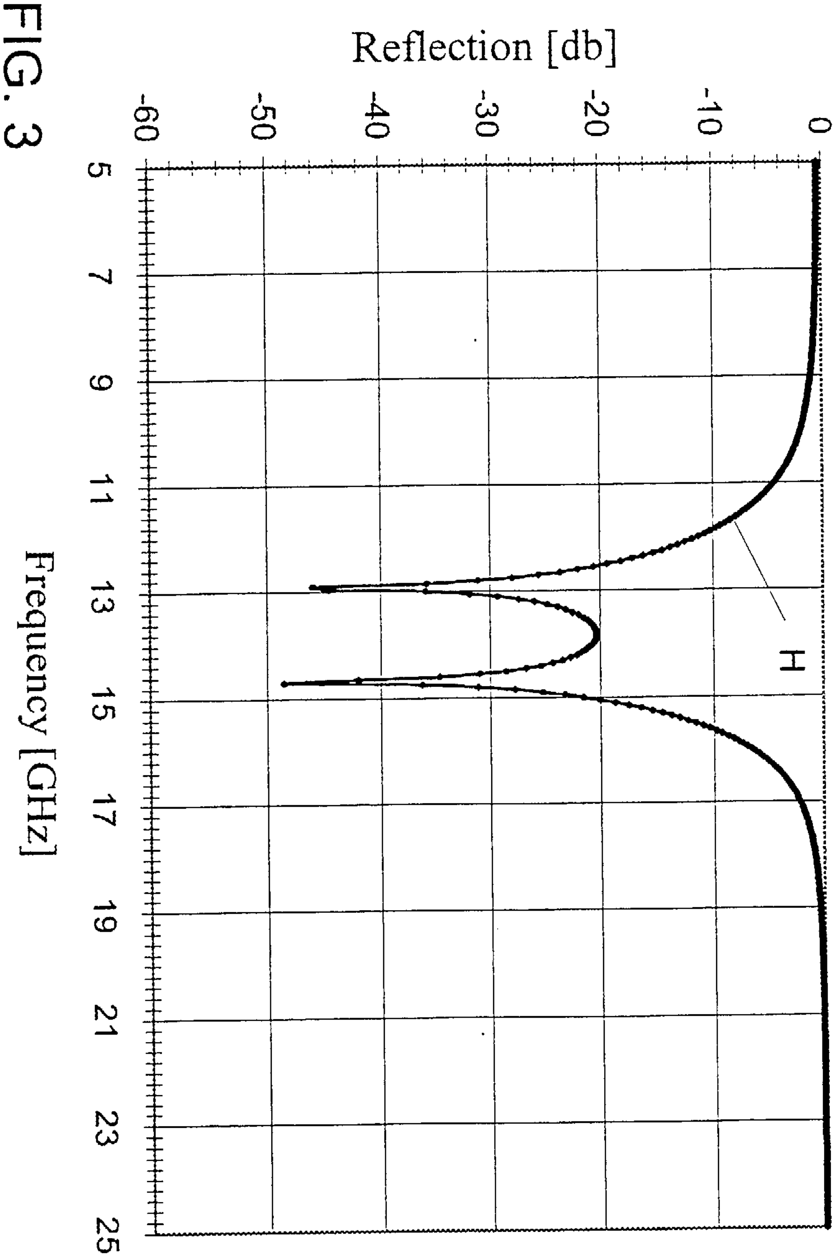

Reflection [db]
0
-10
-20
-30
-40
-50
-60
5
7
9
11
13
15
17
19
21
23
25
Frequency [GHz]
H

FIG. 3

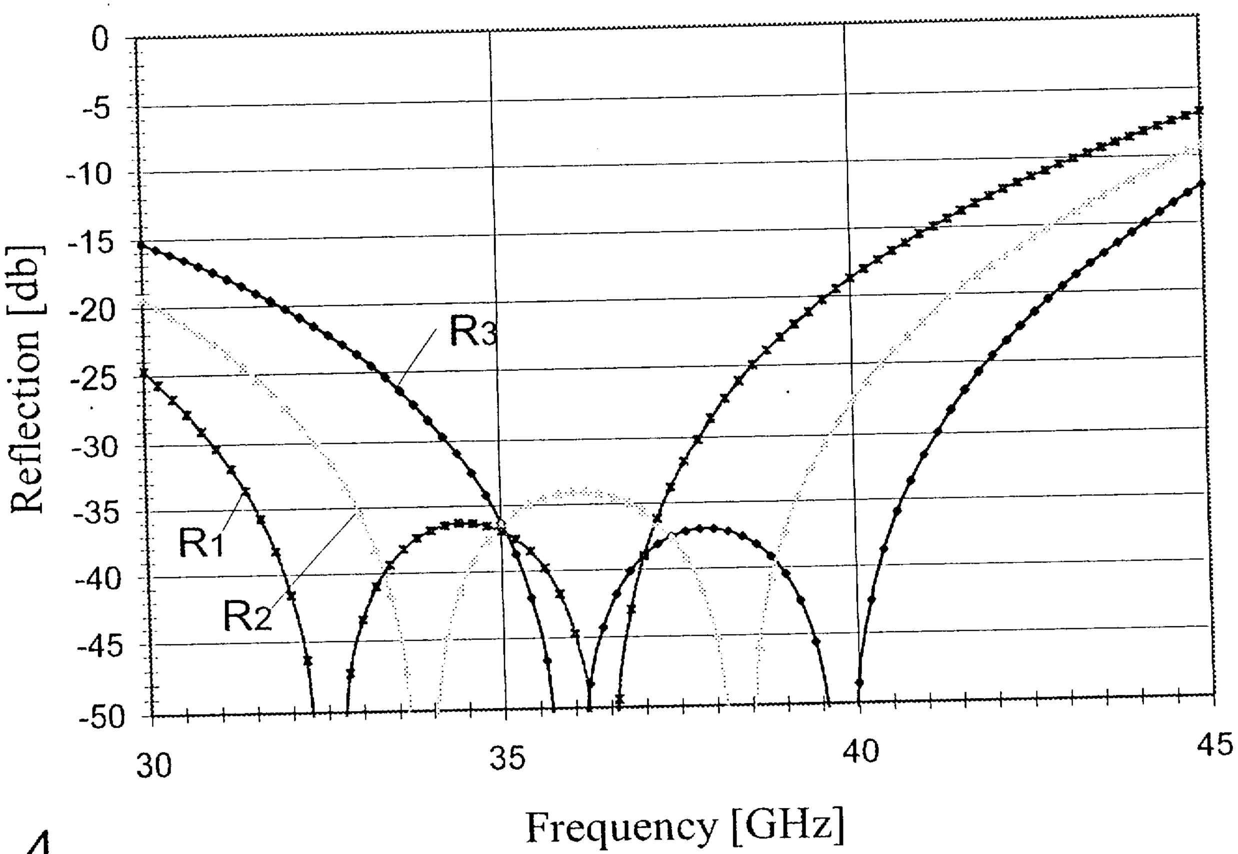

Reflection [db]
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
30
35
40
45
Frequency [GHz]
R1
R2
R3

FIG. 4

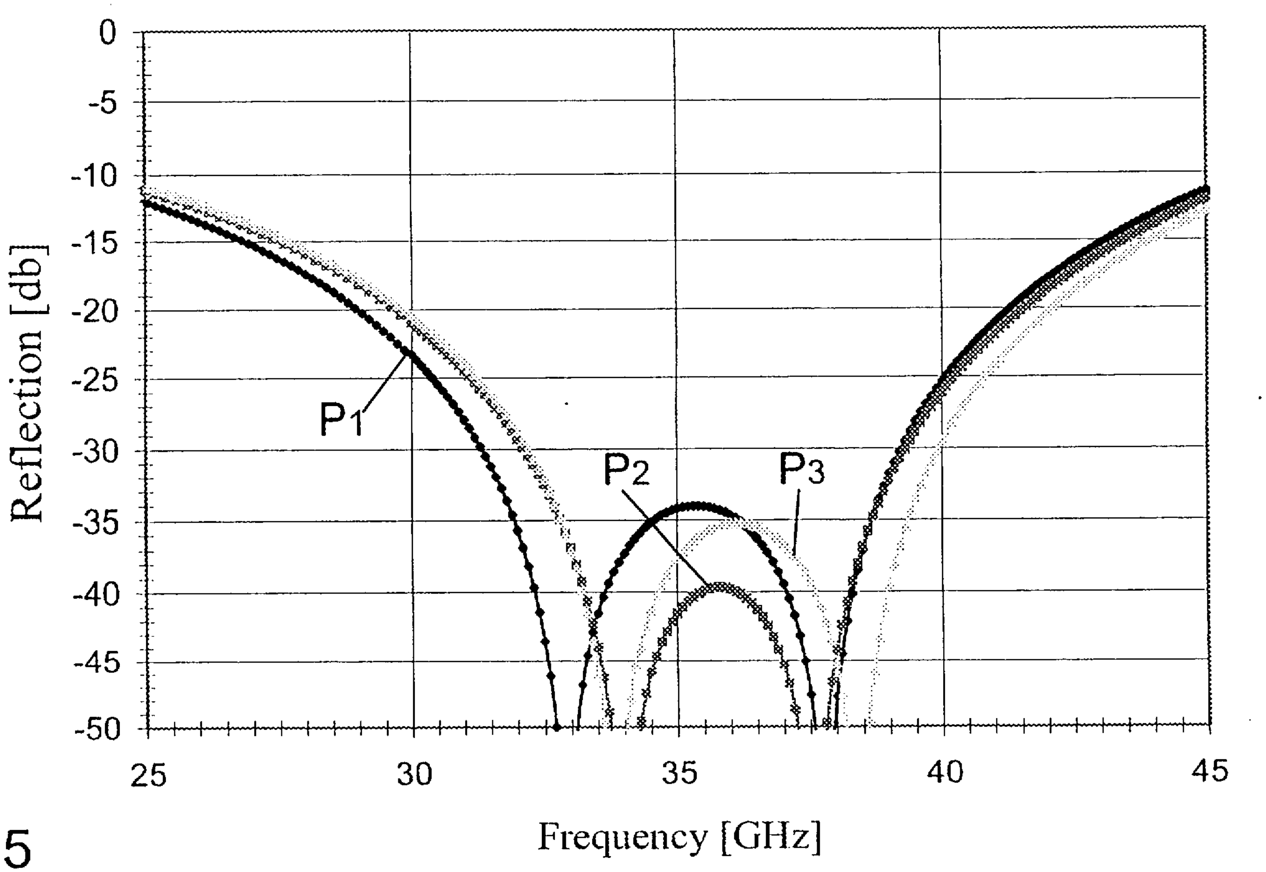

0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
Reflection [db]
25
30
35
40
45
Frequency [GHz]
P1
P2
P3

FIG. 5

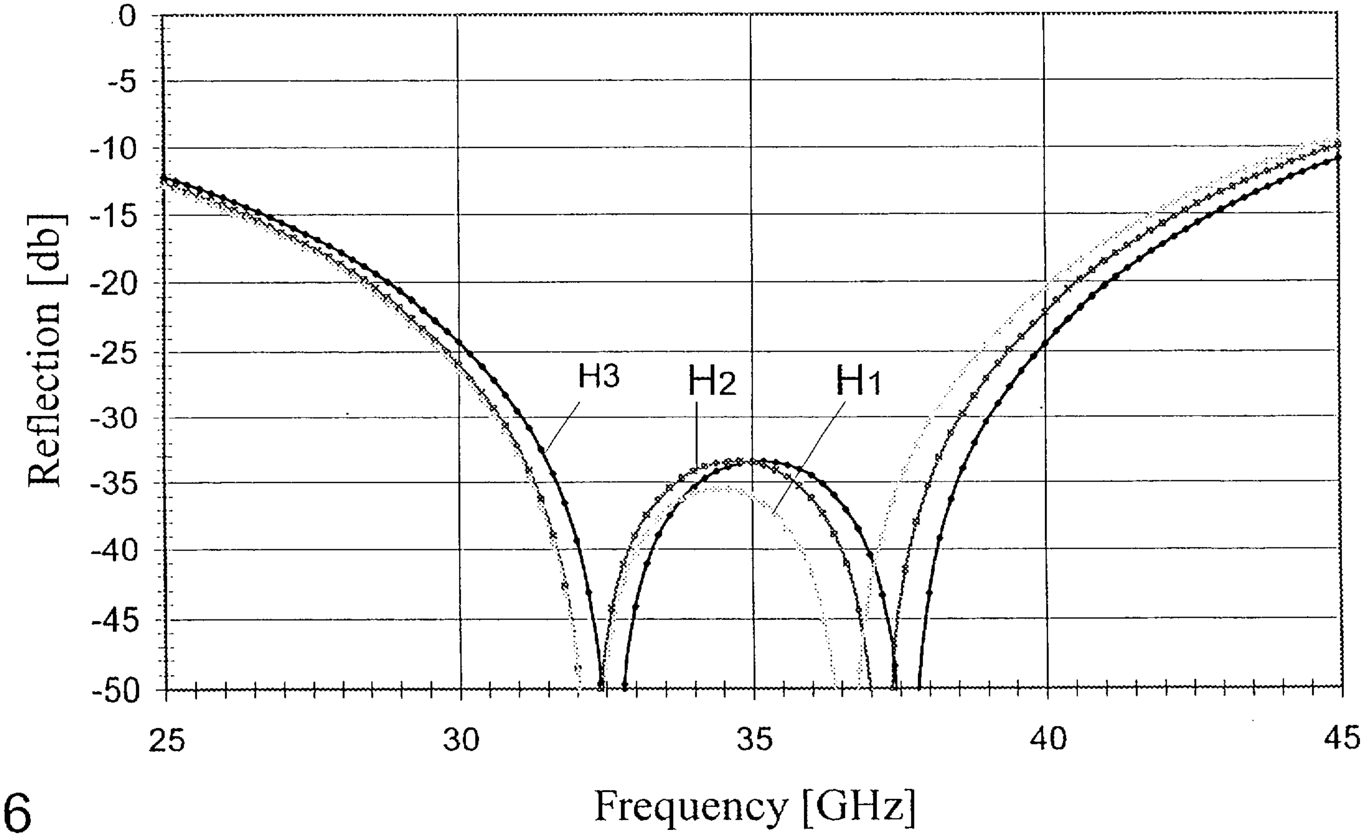
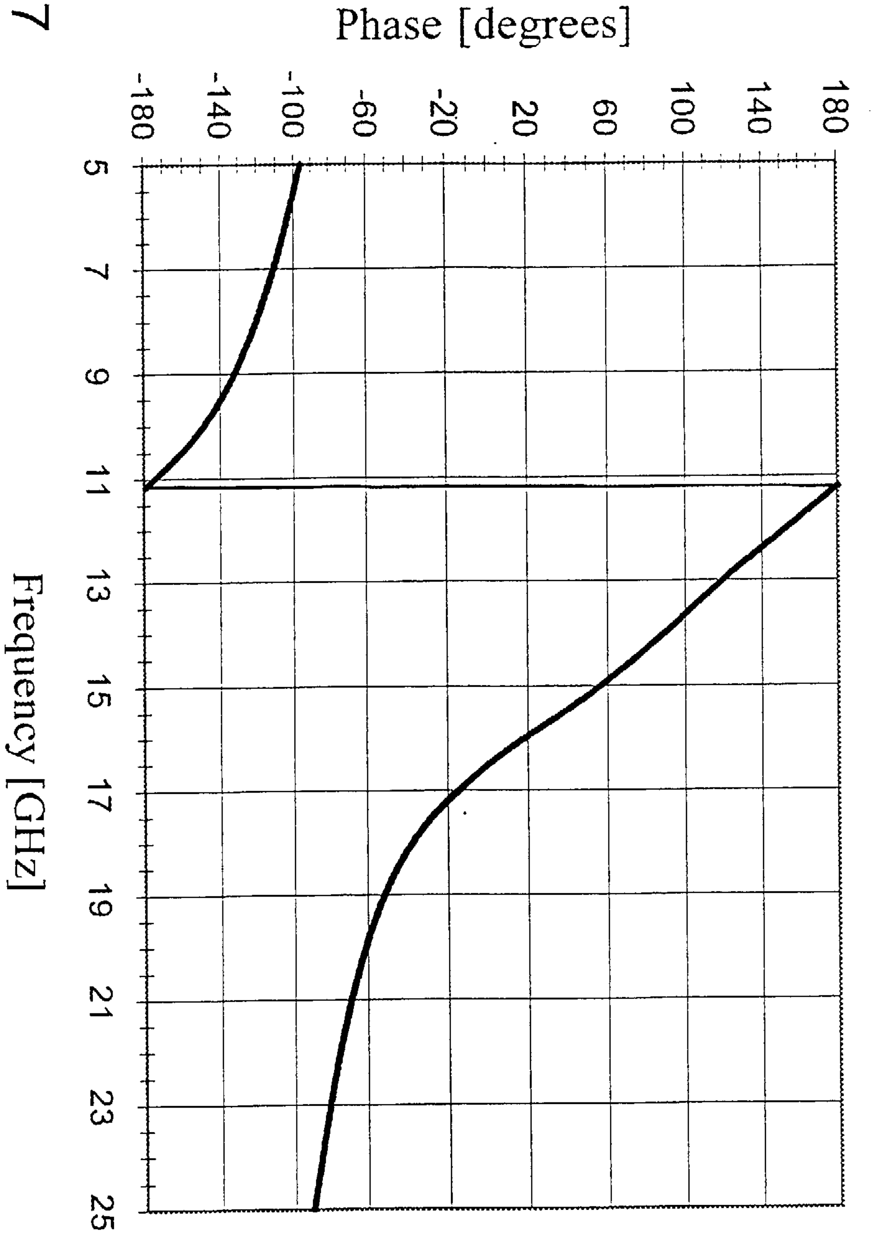

Reflection [db]
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
25
30
35
40
45
Frequency [GHz]
H3
H2
H1

FIG. 6

FIG. 7


Phase [degrees]
-180
-140
-100
-60
-20
20
60
100
140
180
Frequency [GHz]
5
7
9
11
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15
17
19
21
23
25

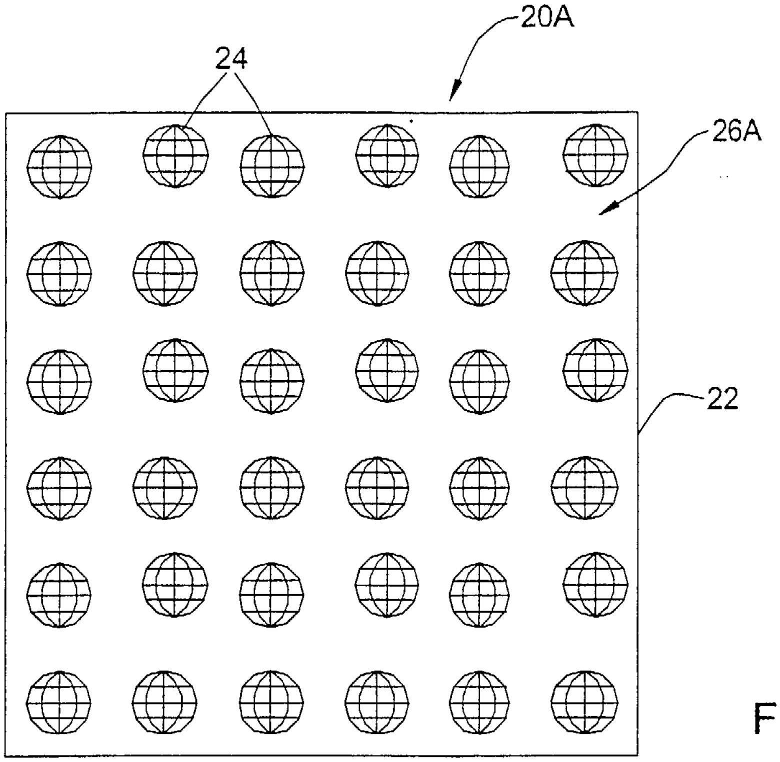


FIG. 8A

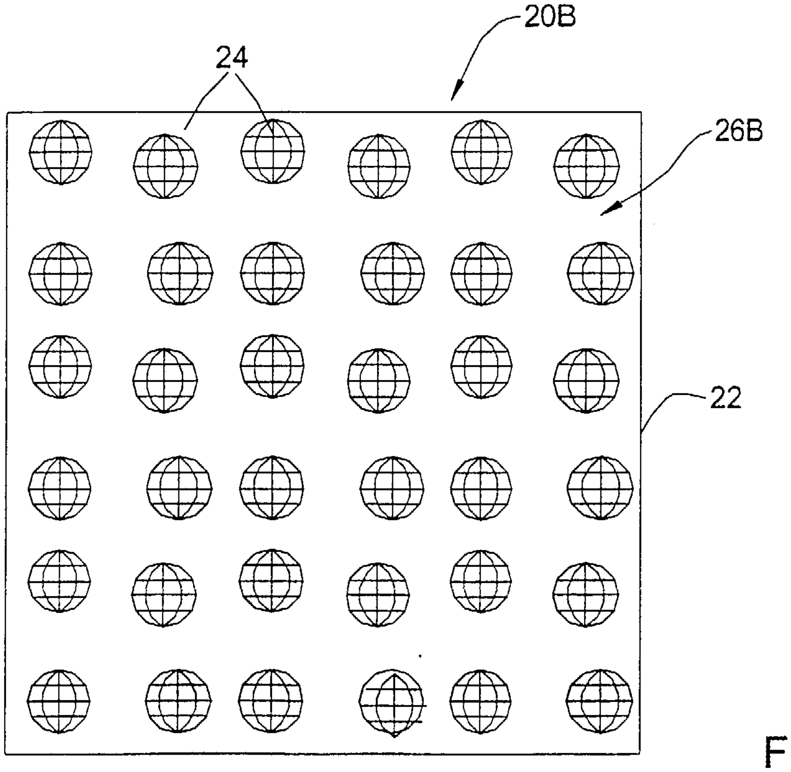


FIG. 8B

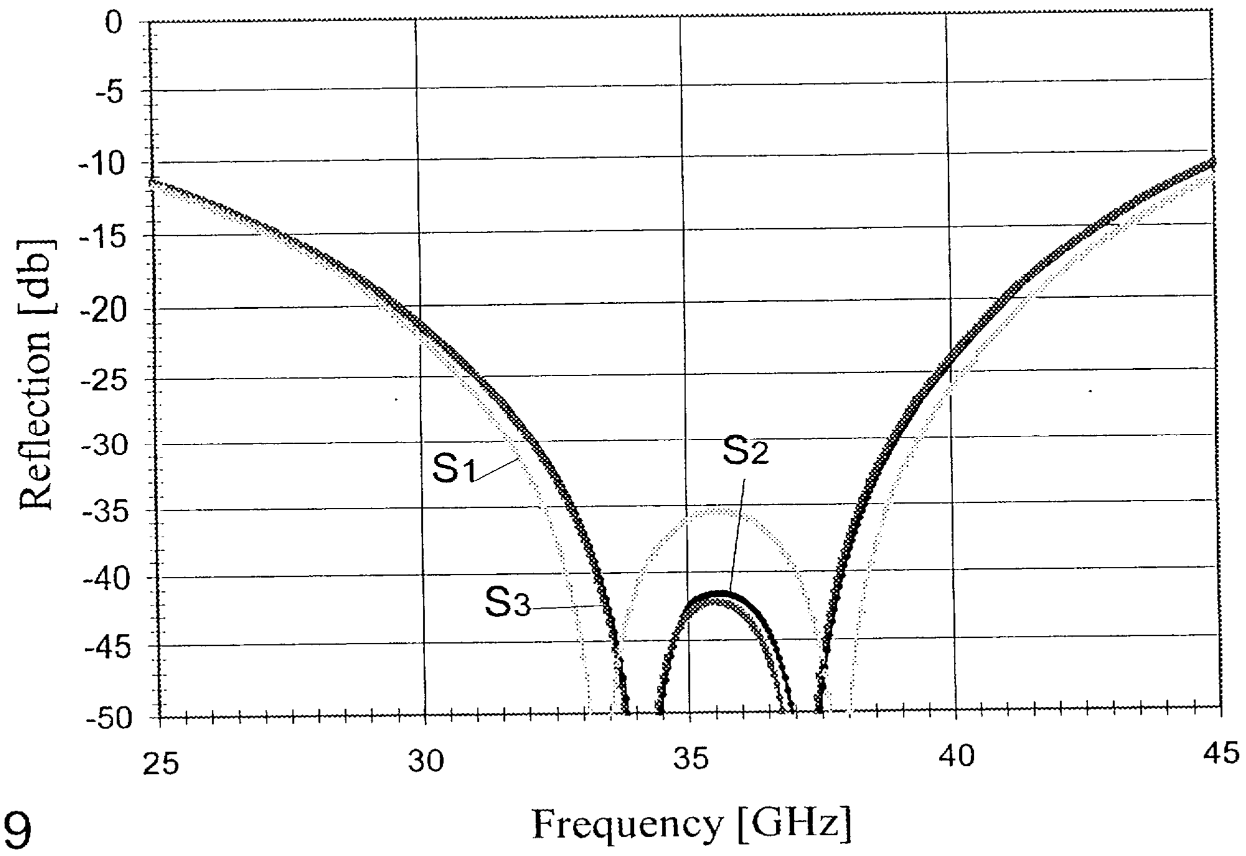
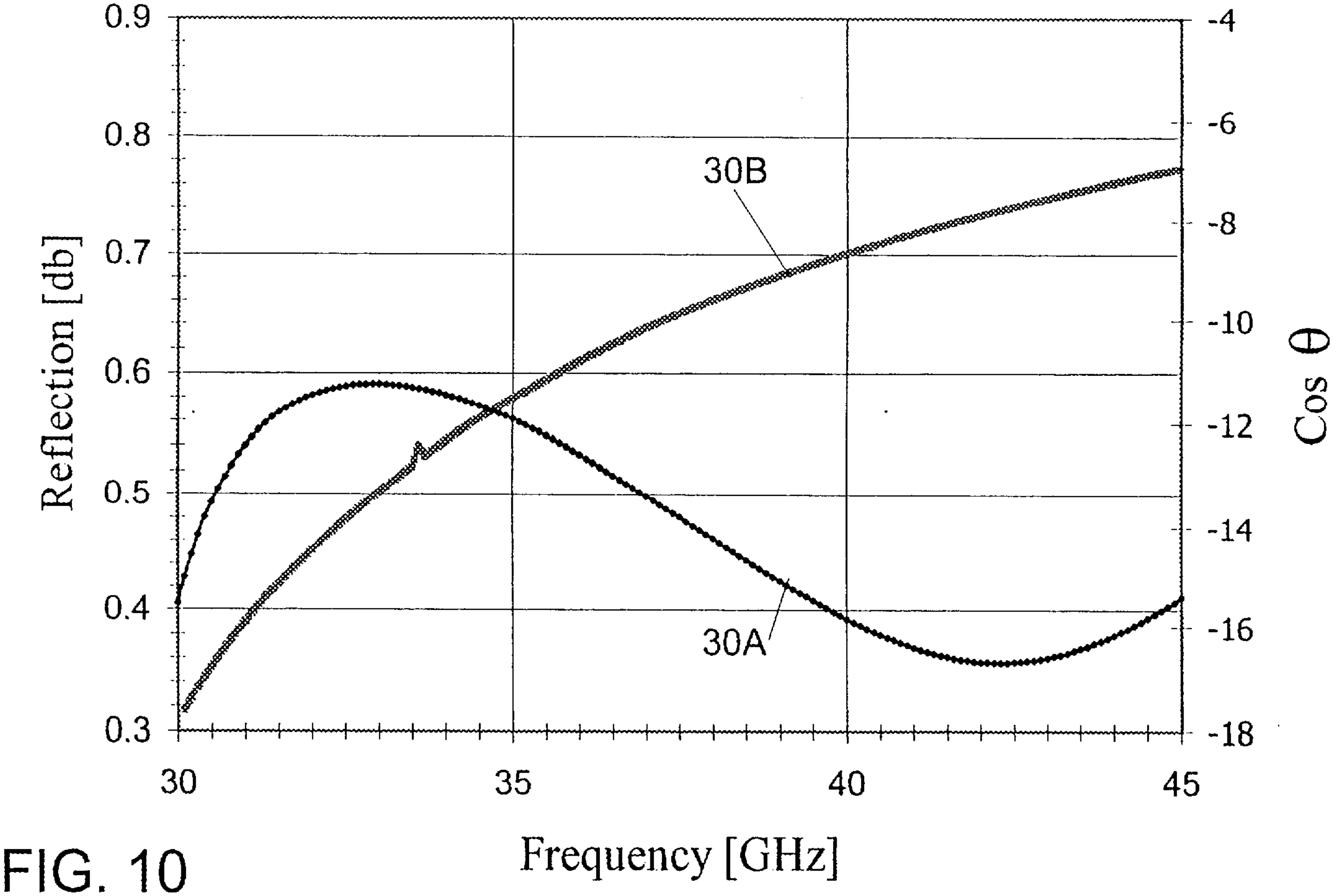

0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
Reflection [db]
25
30
35
40
45
Frequency [GHz]
S1
S2
S3

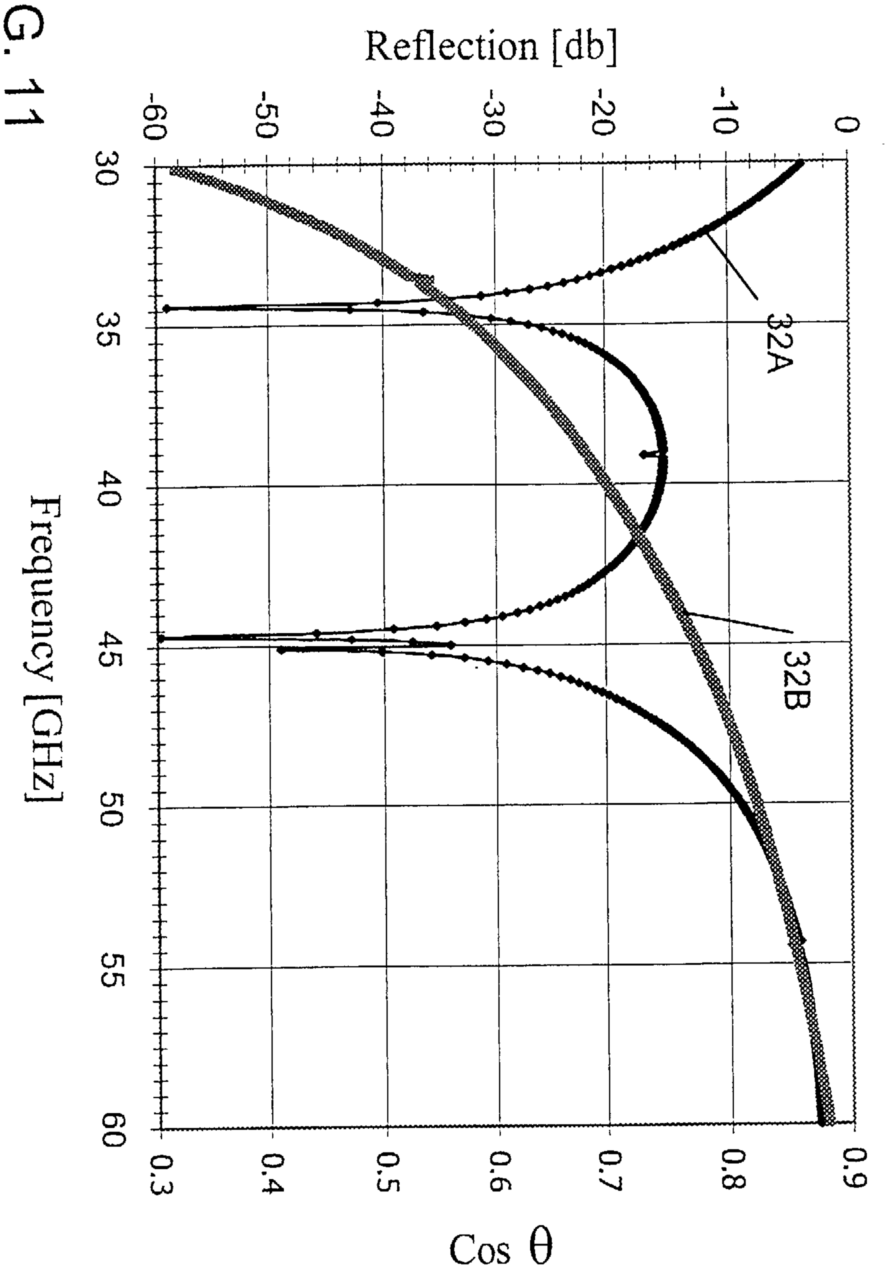
FIG. 9



0.9
0.8
0.7
0.6
0.5
0.4
0.3
Reflection [db]
-4
-6
-8
-10
-12
-14
-16
-18
Cos θ
30
35
40
45
Frequency [GHz]
30B
30A

FIG. 10

FIG. 11


Reflection [db]
0
-10
-20
-30
-40
-50
-60
32A
32B
30
35
40
45
50
55
60
Frequency [GHz]
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Cos θ

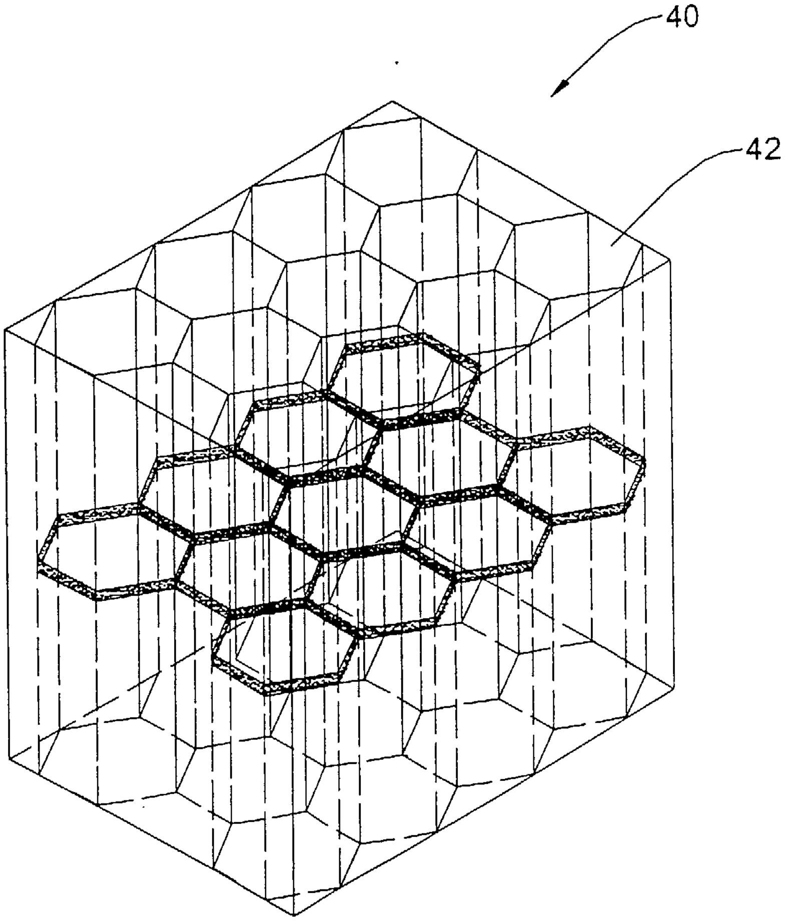


FIG. 12

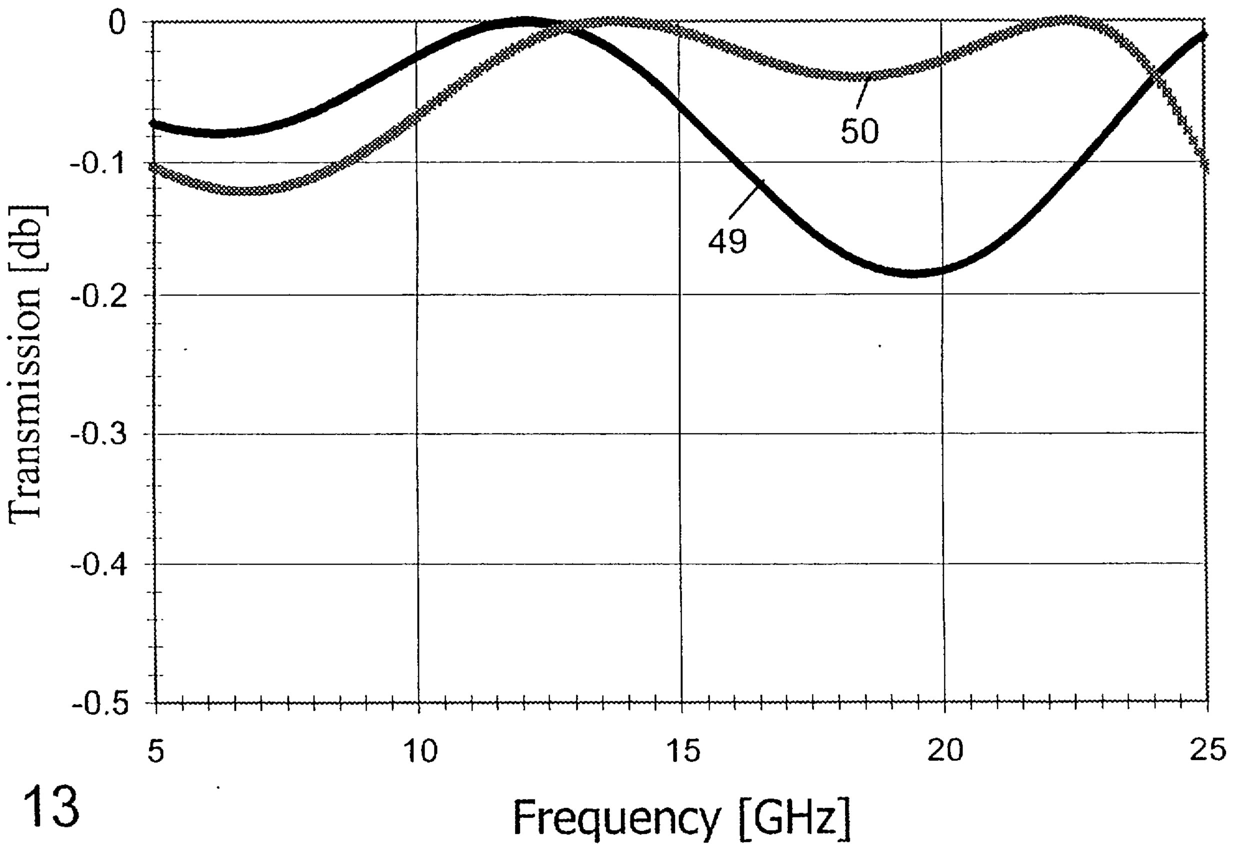

0
-0.1
-0.2
-0.3
-0.4
-0.5
Transmission [db]
5
10
15
20
25
Frequency [GHz]
49
50

FIG. 13

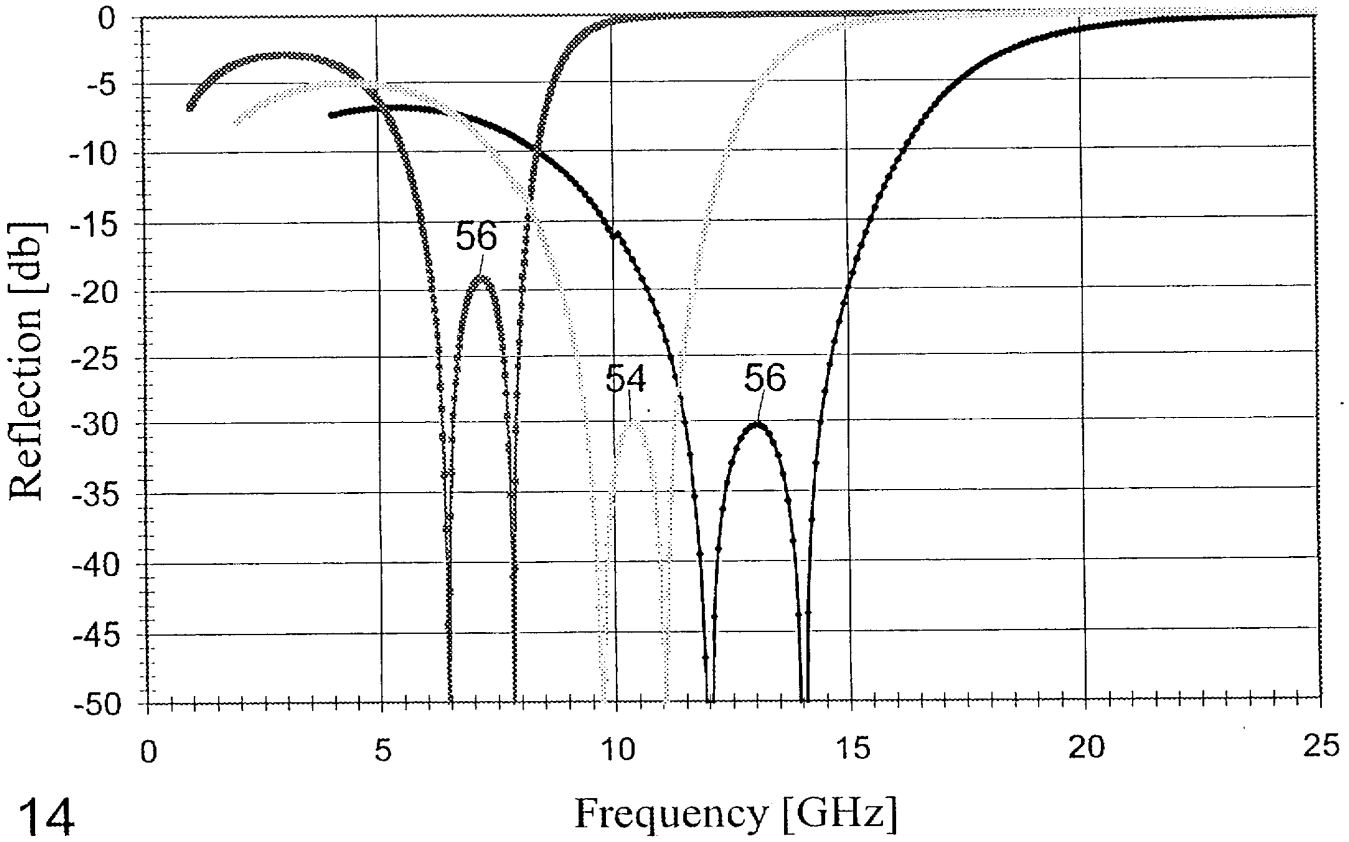
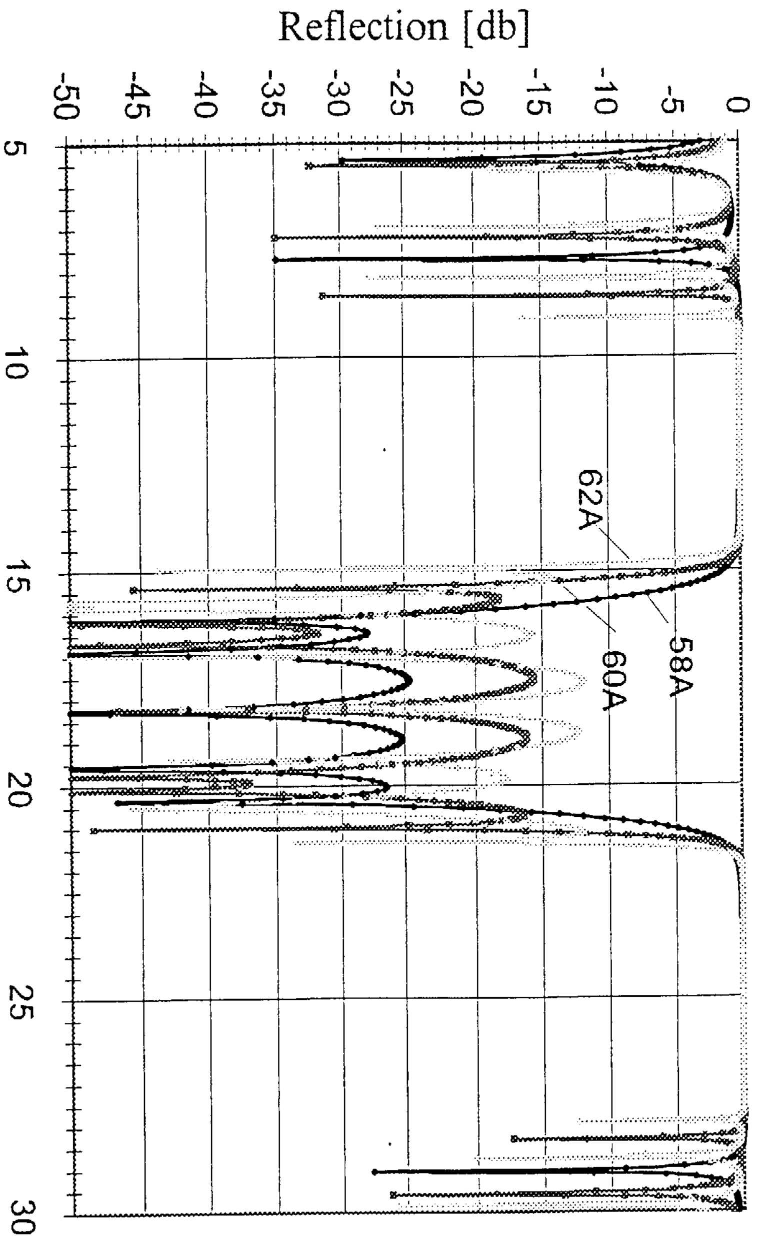

Reflection [db]
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
Frequency [GHz]
0
5
10
15
20
25
56
54
56

FIG. 14

FIG. 15


Reflection [db]
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
Frequency [GHz]
5
10
15
20
25
30
62A
58A
60A

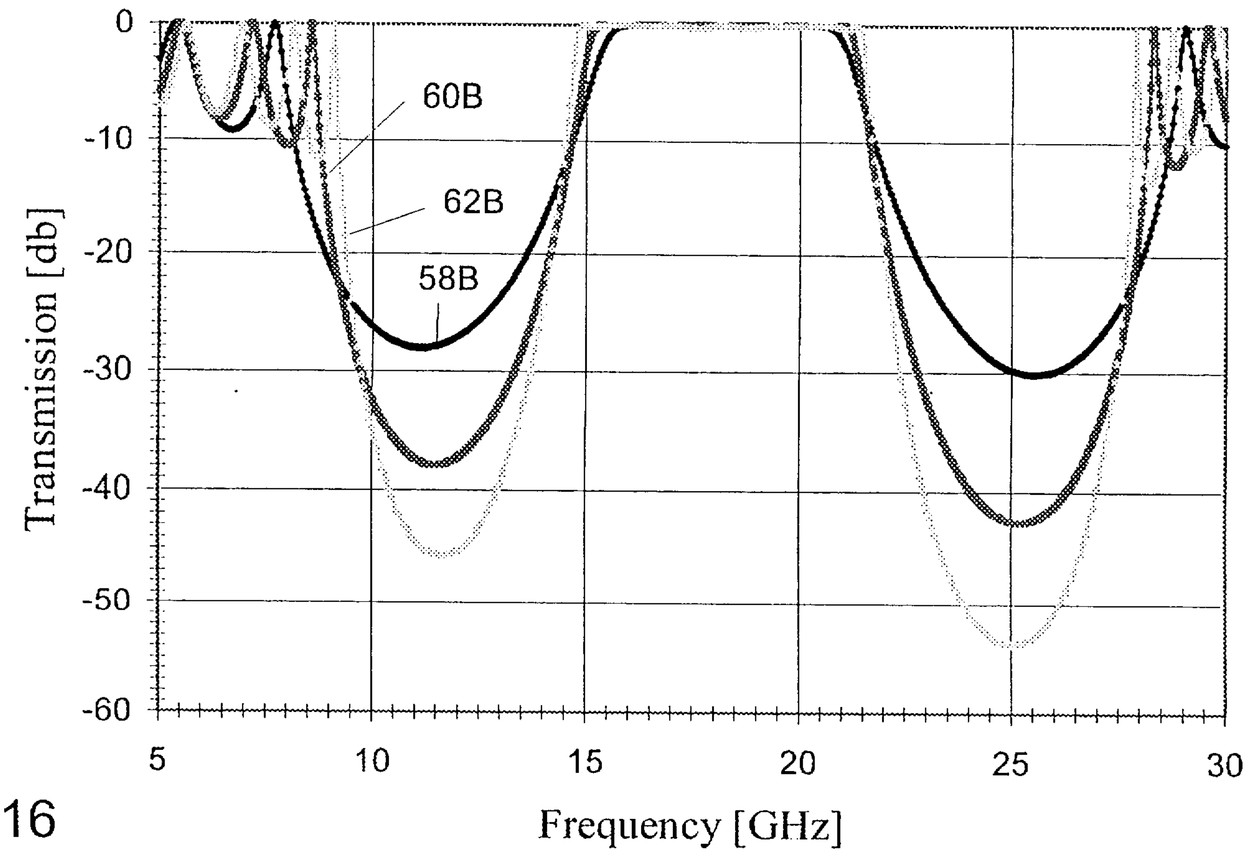

0
-10
-20
-30
-40
-50
-60
Transmission [db]
5
10
15
20
25
30
Frequency [GHz]
60B
62B
58B

FIG. 16

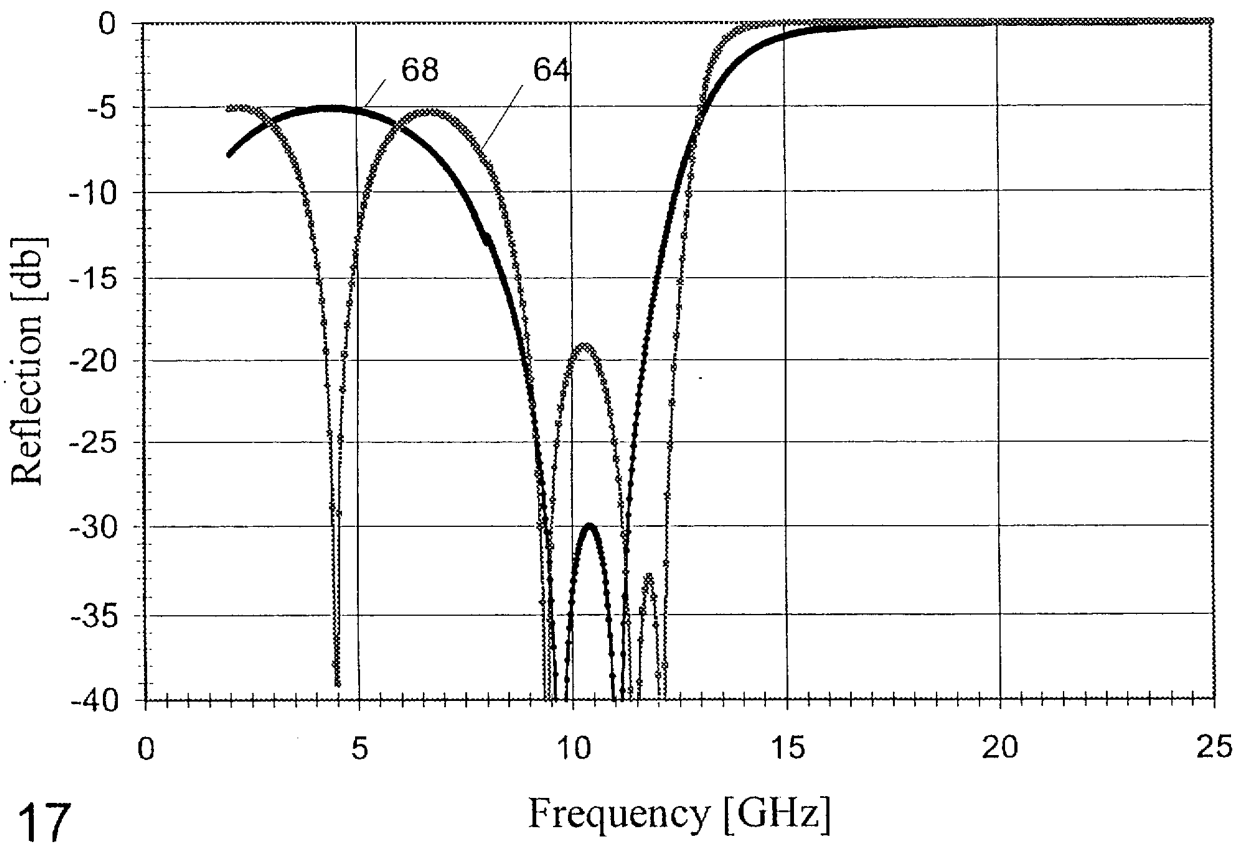

0
-5
-10
-15
-20
-25
-30
-35
-40
Reflection [db]
0
5
10
15
20
25
Frequency [GHz]
68
64

FIG. 17

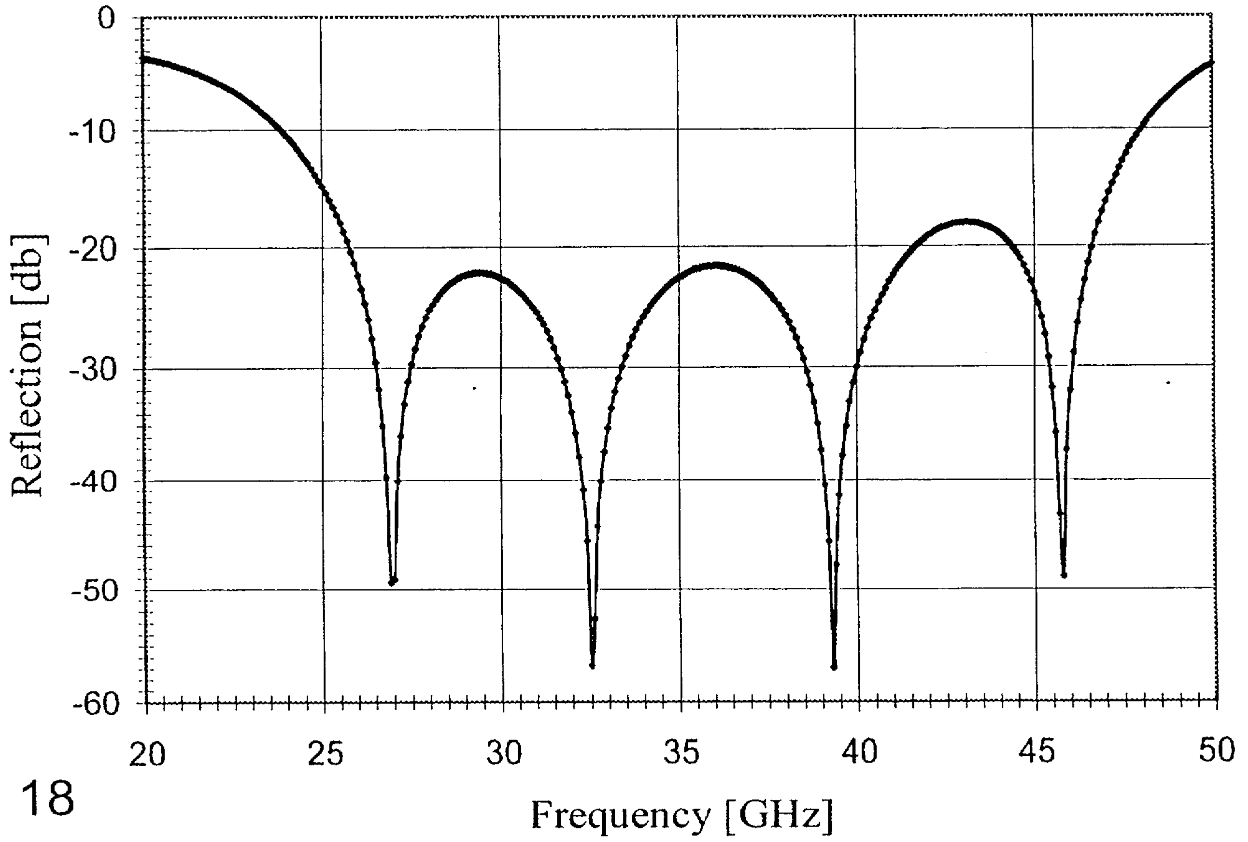

0
-10
-20
-30
-40
-50
-60
Reflection [db]
20
25
30
35
40
45
50
Frequency [GHz]

FIG. 18

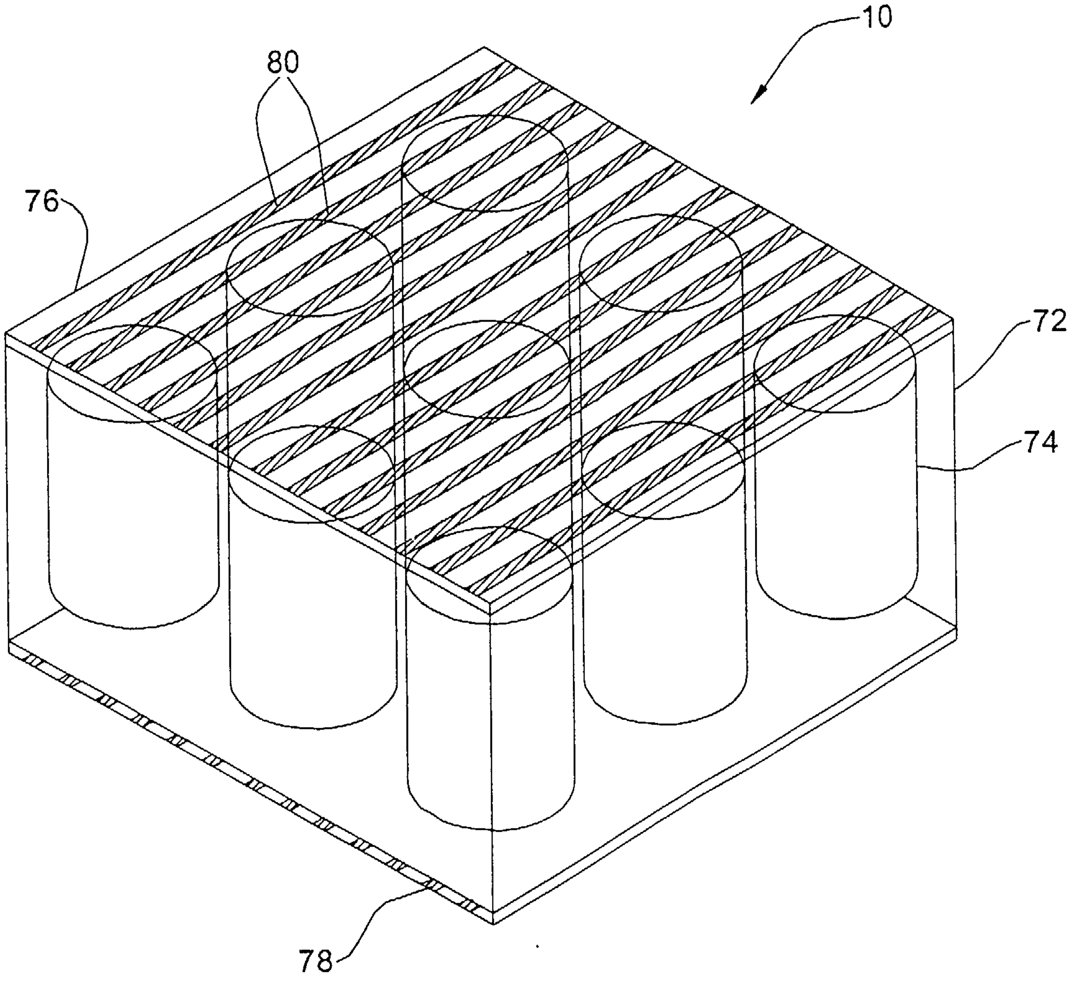


FIG. 19

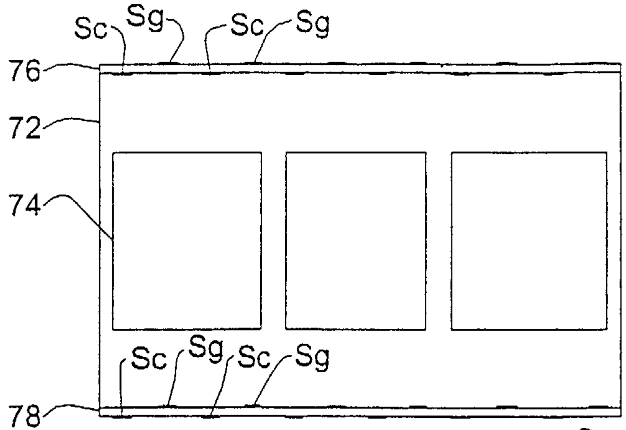


FIG. 20A

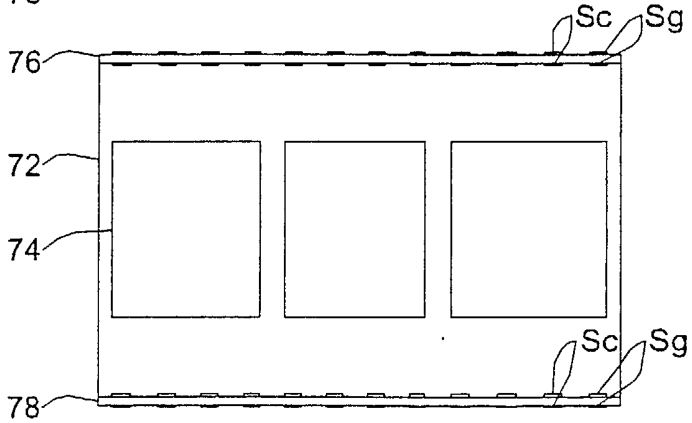


FIG. 20B

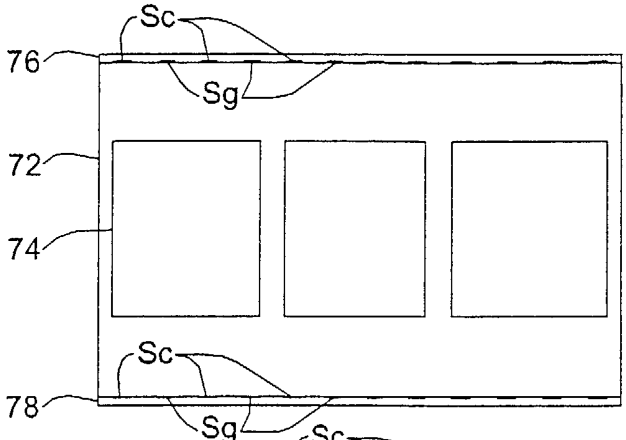


FIG. 20C

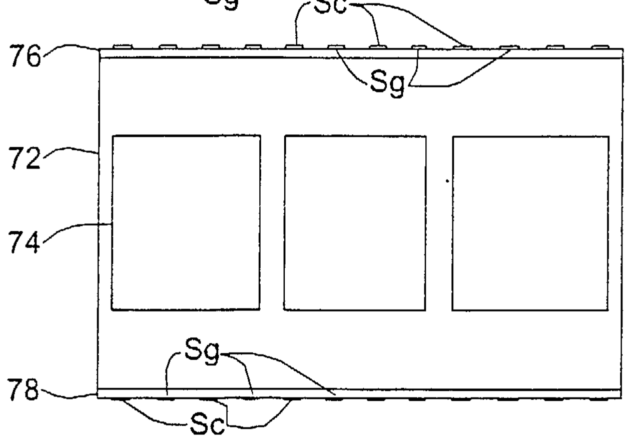


FIG. 20D

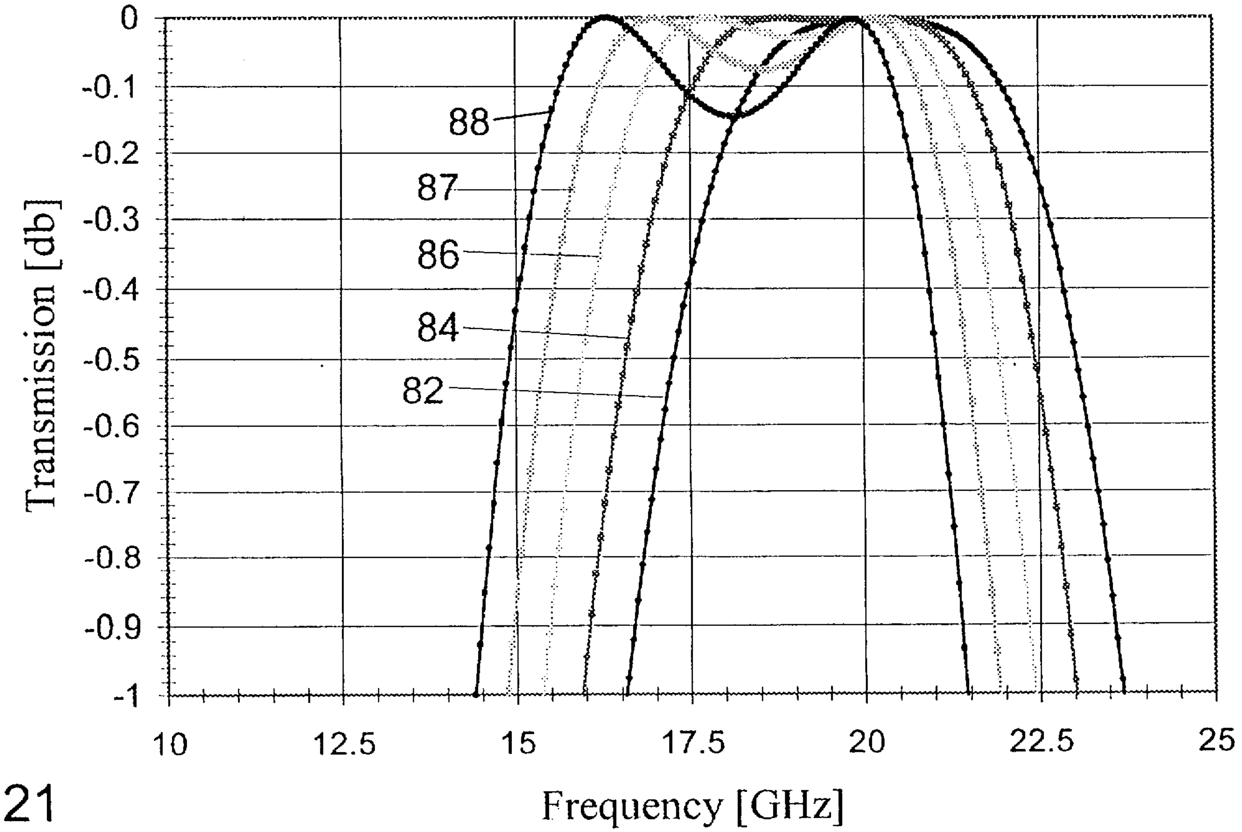

0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
Transmission [db]
10
12.5
15
17.5
20
22.5
25
Frequency [GHz]
88
87
86
84
82

FIG. 21

An Electromagnetic Window

FIELD OF THE INVENTION

This invention is generally in the field of electromagnetics, and relates to a device that presents an electromagnetic window allowing electromagnetic radiation of various wavelengths to pass therethrough. The invention is particularly useful in radomes that cover antennas in the RF, microwaves, millimeter waves and sub-millimeter waves frequency bands; and in optical devices where the transmission of infrared, visible and ultraviolet frequency bands is required.

BACKGROUND OF THE INVENTION

Electromagnetic windows are designed to cover and protect a radiation source while maintaining high transmission of the radiation generated thereby, and are typically based on one or more planar or shaped dielectric layer. It is known that the use of a thin dielectric layer (of a thickness significantly smaller than a wavelength to be transmitted) enables to provide broadband low-loss transmission.

U.S. Patent No. 5,958,557 discloses an electromagnetic window having a half-wavelength thickness (i.e., relatively thick). This window is characterized by narrow frequency band (just around a certain frequency value), due to its resonant character. When dealing with optical frequencies, which are relatively high, thick windows can be used.

In systems operating with RF, microwave and millimeter-wave frequencies, in order to achieve a larger frequency bandwidth of a window-device, one or more rigid-foam or honeycomb cores with two or more dielectric coatings are used. This is disclosed, for example in US Patents Nos. 3,780,374 and 4,358,772. A similar multi-layer design of the window-device is also used in optical applications, where the provision of different coating layers enables to reduce reflection at the air-window interface.

Window-devices utilizing a metal-dielectric combination have been developed, aimed at improving or augmenting device performance. US Patent No. 4,467330 discloses the use of an inductive screen incorporated inside a solid dielectric window having a thickness smaller than a half-wavelength. The inductive screen is a metal or metal-coated sheet of a connected-loop structure, thereby defining conducting loops and allowing the passage of an induced current all around the screen. The operation of such a metal-dielectric window is based on the cancellation of the capacitive loading of the dielectric layer against the inductive loading of the conducting loops.

Metal-dielectric windows of another type utilize a transparent Frequency Selective Surface (FSS) incorporated inside the window. The transparent FSS is a metal or metal-coated sheet with a periodic array of resonant slots cut in the metal surface. Such a window may include several dielectric layers and one or more FSSs. The operation of this metal-dielectric window is based on the resonance condition of the slots. The resonance frequencies strongly depend on the geometry of the slot, which may be rectangular, shaped like a cross, Jerusalem cross, circular ring, etc. As disclosed in US Patent No. 4,785,310, FSS layers in the form of reflective dipole type elements can be added to the slot type layers, thereby enabling to block radiation of a frequency band different from the transmission band.

Controllable windows enabling to tune the transmission band of the window have been developed, and are disclosed, for example in US Patent No. 5,600,325. Such windows utilize ferroelectric materials capable of changing their dielectric constant in response to the application of DC voltage thereto. The main problem with these devices is associated with the supply of DC voltage without destroying the window transparency. According to US 5,600,325, the FSS has complete electrical conductivity, and therefore DC voltage can be directly applied to the FSS.

SUMMARY OF THE INVENTION

There is accordingly a need in the art to facilitate the transmission of electromagnetic radiation by providing a novel broadband window device having no thickness and voltage supply limitations of the conventional devices of the kind specified.

The present invention provides a metal-dielectric based window device for transmitting electromagnetic radiation of a predetermined frequency band (in the case of a passive device), or a selected frequency band (in the case of an electrically controllable device). This device is based on the inclusion of an array of spaced-apart disconnected metal-containing elements into a dielectric layer. It should be understood that for the purposes of the present invention, such an inner pattern inside the dielectric layer is formed by spaced-apart elements made of an electrically conductive material capable of scattering incident radiation. In most cases, such elements are metallic (made of a metal containing material), but other conducting materials, such as superconductors or conducting polymers, can be used as well. The array of conducting elements may be periodic or quasi-periodic (i.e., the average density of the inclusions being approximately the same). The periodicity type of the array can be a rectangular grid, a hexagonal grid or any other type of two-dimensional periodic grid.

There is thus provided according to one broad aspect of the present invention, a device substantially transparent to electromagnetic radiation of a certain frequency band, the device comprising at least one dielectric structure having a predetermined substantially periodic inner pattern formed by a two-dimensional array of spaced-apart substantially identical elements made of an electrically conducting material and capable of scattering the electromagnetic radiation, said elements being disconnected from each other, and each having a size smaller than that of a resonance condition of the array of elements.

It should be understood that the conductive element's size (cross section) is such as not to cause the resonance of the element, and is typically smaller than a half-wavelength of propagation of said electromagnetic radiation in said dielectric structure.

The term *"substantially periodic pattern"* signifies the pattern formed by spaced-apart elements, the average density of the elements being approximately the same all along a pattern-containing area.

The term *"dielectric structure"* signifies a single dielectric layer structure, or a symmetrical structure formed by a stack of dielectric layers, that may be made of isotropic or anisotropic dielectric materials (i.e., the dielectric constant ε being a 3x3 symmetric tensor). In the case of a multiple dielectric layer structure, the wavelength of propagation changes from layer to layer, and is the smallest in the layer of the highest dielectric constant at all the frequencies of incident radiation. At the central frequency of the window device, the total thickness of the dielectric structure lies between the three quarters of the minimal wavelength and the three quarters of the maximal wavelength (i.e., between $3/4\lambda_{min}$ and $3/4\lambda_{max}$).

The present invention provides for using a symmetric multi-layer window (e.g., a conventional A-type radome with a core and two skins, or a C-type radome with two cores and three skins) with the periodic array of inclusions according to the invention located at the central plane of the window to thereby interfere destructively with the reflections from dielectric interfaces.

According to another aspect of the present invention, there is provided a radiation source for generating electromagnetic radiation of a certain frequency band utilizing the above-described window device for transmitting at least a predetermined frequency range of said certain frequency band of the generated radiation.

Owing to the fact that the elements are small in size, relative to the wavelength (or wavelengths) of the radiation propagating in the dielectric structure, no self-resonance of the individual inclusion is excited with the frequency band to be transmitted. The dimensions of the radiation scattering elements and spaces between them are chosen such that the scattering from the elements compensates for the reflection from the dielectric discontinuities (e.g., the air-dielectric interfaces), thereby causing the formation of a double-resonance transmission band. More specifically, in the case of a single dielectric layer, two transmission resonance profiles at frequencies related to the half-wavelength and one-wavelength of the electromagnetic radiation are both brought close to the three-quarter-wavelength point, and generate together a deep and wide transmission band. For example, a typical bandwidth at the -20dB level is 5 times wider than that of the conventional half-wavelength window.

Thus, according to yet another aspect of the present invention, there is provided a method for constructing the above-described window device to be substantially transparent to electromagnetic radiation of the certain frequency band, wherein at least one dielectric material of a predetermined dielectric constant is selected for the fabrication of the at least one dielectric structure, and dimensions of the electrically conductive scattering elements and the spaces between them are selected to form the inner pattern inside said dielectric structure, so as to ensure that the scattering from said elements compensates for reflection effects from the dielectric discontinuities.

For a single dielectric layer structure, its thickness is preferably about .75λ, wherein λ is the wavelength of propagation of said radiation in the dielectric layer. It should be understood that for a multiple dielectric layer structure, there is no single wavelength that characterizes the radiation propagation in the entire structure. Practically, the thickness of such a multiple dielectric layer structure is defined by the minimal and maximal dielectric constants of the layers in the structure.

The array of conductive elements is preferably positioned in a plane located at the middle of the dielectric structure thickness, parallel to the planes defined by upper and lower surfaces of the dielectric structure. The present invention allows for using a planar window device, i.e., of a constant thickness all along the window, as well as a device of varying window thickness.

The conductive elements of various shapes can be used, such as voluminous elements (e.g., spheres, cylinders, boxes) or substantially flat elements (e.g., circular or rectangular patches). Such electrically conductive inclusions may be formed by coating conductive elements with one or more dielectric layers, coating dielectric elements by at least one conducting layer, conductive coating of through-holes or selective conductive coating of honeycomb cores.

The device according to the invention may include parallel strips made of a highly reflective or scattering material (e.g., electrically conductive material). This makes the device reflective to electromagnetic radiation polarized in a direction parallel to the longitudinal axes of strips, while maintaining the desired transmission for radiation polarized in a direction perpendicular to the strips' axes. Hence, when using the device with a linearly polarized radiation source, various configurations of parallel conducting strips can be used.

The device may also utilize thin layers of ferroelectric materials of very high dielectric constant controlled by an external voltage source (in a symmetrical position relative to the layer(s) of metal objects). This allows a gradual change of the average dielectric constant, and the dynamic shift of the location of the pass-band according to the applied voltage. The above-indicated strips made of an electrically conductive material may be used, being printed on one or two sides of these ferroelectric layers to thereby enable application of a DC voltage to the ferroelectric layers.

The window structure according to the invention is weakly dependent on the angle of incidence at angles up to 60 degrees, for both parallel and perpendicular polarizations. Hence, the device is characterized by improved transmission, as compared to that of the conventional half-wavelength window. This is especially pronounced when high dielectric (with a dielectric constant higher than 4) materials are used. This is achieved by controlling both the array grid parameters and the size of the conductive inclusions. The use of different combinations of grid parameters and inclusions' size result in the same transmission curve at normal incidence, while differing appreciably in their oblique incidence transmission (i.e., the denser the grid, the weaker the effects of oblique incidence).

The device according to the invention may be a multi-stage structure, where dielectric structures, each with the two-dimensional array of metal-containing inclusions, are placed on top of each other. Several structures constructed as described above can be combined to generate a thick multi-stage window structure with very sharp transitions at the frequency edges of the transmission band, at the expense of higher transmission loss.

The performance of the multi-stage structure may be improved by varying the layers' thicknesses (in a symmetric layer structure) and dimensions of the conducting solids, wherein the transmission response curve is tuned as a function of frequency. The stages (each in the form of the above-described structure) can be shifted by half the grid constants to generate new three-dimensional grids out of the same two-dimensional grids.

Moreover, with high dielectric constant material, the multi-stage window leads to almost complete blockage at two frequency bands below and above the transmission band. Alternatively, two stages can be combined with a low dielectric spacer between them to generate a wideband window with a bandwidth of almost an octave.

According to yet another aspect of the present invention, there is provided a tunable device for transmitting electromagnetic radiation of a selected frequency band, the device comprising:

- at least one dielectric structure;
- an inner pattern formed by inclusions inside said at least one dielectric structure, the pattern being in the form of an array of spaced-apart substantially identical electrically conductive elements capable of scattering said electromagnetic radiation, said elements being disconnected from each other and each having a size smaller than that of a resonance condition of the array; and
- at least two ferroelectric layers located at opposite sides of said at least one dielectric structure, the application of an

electric field to said ferroelectric layer effecting a change in a dielectric constant of said ferroelectric layer, thereby enabling the transmission of said selected frequency band.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 is a schematic illustration of a device according to the present invention;

Fig. 2 illustrates simulation results showing the dependency of the frequency variations of the reflection coefficient of the device of Fig. 2 on the radius of sphere inclusions, and also compared to a standard half-wavelength thick window;

Fig. 3 illustrates the reflection coefficient as a function of frequency for a specific example of the single layer device according to the invention with high relative permittivity of a dielectric layer;

Fig. 4 illustrates simulation results showing how the change in the dielectric layer thickness affects the center frequency of the transmission band;

Fig. 5 illustrates simulation results showing how the scattering from the metal inclusions, defined by the dimension of the inclusion and the grid constant, affect the device performance;

Fig. 6 illustrates the reflection coefficients as functions of frequency at normal incidence for a specific example of the device according to the invention;

Fig. 7 illustrates frequency dependence of the phase delay generated by a single layer window device according to a specific example of the invention;

Figs. 8A and 8B illustrate window devices according to two different examples, respectively, according to the invention, with the inner patterns being obtained by shifting some of the electrically conductive elements from positions in a two-dimensional array with ideal periodicity;

Fig. 9 illustrates variations of the reflection coefficient with the frequency of electromagnetic radiation for a window device with the ideal array, and the devices of Figs. 8A and 8B;

Figs. 10 and 11 illustrate the reflection coefficient at oblique incidence and cosθ as functions of frequency for, respectively, the case of perpendicular polarization of the incident radiation, and the case of parallel polarization direction;

Fig. 12 illustrates a multi-dielectric single array structure according a specific example of the invention utilizing a hexagonal honeycomb layer with upper and lower supporting dielectric skins;

Fig. 13 illustrates the frequency variations of the transmission coefficient for the structure of Fig. 12 with and without the conductive inclusions;

Fig. 14 illustrates the frequency variations of the reflection coefficient for window devices of three different examples of the present invention characterized by the different thickness of the skins;

Figs. 15 and 16 illustrate, respectively, the frequency variations of the reflection coefficient and the transmission coefficient, for four-, six- and eight-layers structures;

Fig. 17 illustrates the frequency variation of the reflection coefficient of both the "double-stage" and "single-stage" designs according to the invention;

Fig. 18 illustrates how the transmission band is broadened with the use of a multi-stage design according to the invention (at normal incidence of electromagnetic radiation);

Fig. 19 illustrates an example of the controllable (tunable) window device according to the invention;

Figs. 20A-20D illustrate, respectively, different strips arrangements suitable to be used in the device of Fig. 19; and

Fig. 21 illustrates the principles of tuning the device of Fig. 19, wherein different transmission curves of the device are obtained for different values of the dielectric constant of ferroelectric layers.

DETAILED DESCRIPTION OF THE INVENTION

Referring to **Fig. 1**, there is illustrated a device **10** according to the invention, presenting a single layer window for transmitting therethrough electromagnetic radiation of the wavelength λ_0 (or a wavelength band with the mean wavelength λ_0). The device **10** comprises a dielectric structure (slab) **12** and an inner two-dimensional periodic pattern **14** (grid) located inside the slab defining a patterned area. In the present example, the structure **12** is composed of a single dielectric layer. The pattern **14** is formed by metal inclusions **16** (constituting elements capable of scattering incident radiation), which are aligned in a spaced-apart parallel relationship in a central plane of the slab with a grid constant *a*. In the present example, such inclusions are spheres with a radius *r*.

Considering the thickness *d* of the dielectric slab, relative permittivity ε_r of the dielectric material, and relative permeability μ_r radiated by normally incident electromagnetic radiation of the wavelength λ_0 in vacuum, the wavelength λ of the radiation propagation inside the slab is as follows: $\lambda=\lambda_0/\mathrm{sqrt}(\varepsilon_r\mu_r)$. It is known that for this slab to be transparent for this radiation, it either should be much thinner than the wavelength λ of radiation propagation (i.e., $d<<\lambda$), or should have a resonant thickness of one or more half-wavelengths (i.e., $d=n\lambda/2$, *n* being an integer). It is evident that the resonant transmission bandwidth is narrow, especially for dielectric materials with high values of relative permittivity ε_r. In the device **10**, the thickness of the dielectric layer **12** is about 0.75λ.

Reference is made to **Fig. 2**, illustrating simulation results of variations of the reflection coefficient with the frequency of the electromagnetic radiation for normal incidence thereof onto the window device **10**.

Generally, the reflection coefficient *R* measures the ratio between the amplitudes of reflected and incident waves, and the transmission coefficient *T* measures the ratio between the amplitudes of the transmitted and incident waves. These ratios are complex numbers determined as follows:

$$T = |T| \cdot e^{j\varphi}$$

$$R = |R| \cdot e^{j\varphi_r}$$

wherein |R| is the ratio between the amplitudes of the reflected and incident plane waves; |T| is the ratio between the amplitudes of the transmitted and incident plane waves; φ_r and φ_t are phase delays of, respectively, the reflected and transmitted plane waves, relative to the incident plane wave, and are defined as follows. $-\varphi=\omega \cdot t_{delay}$ ($\omega=2\pi f$, f being the frequency of the incident radiation).

In this specific example of Fig. 2, the following parameters of the window device are used: d=4mm, ε_r=2.2, and a=4mm. Different graphs **G$_1$**, **G$_2$**, **G$_3$** and **G$_4$** correspond, respectively, to different values of the spheres' radius r_1=0.88mm, r_2=0.96mm, r_3=1mm and r_4=1.04mm, and graph **G$_5$** corresponds to the behavior of a dielectric-only slab with thickness of d'=2.67mm as a reference. As shown, enlarging the spheres' radius *r* results in that λ/2- and λ-resonance curves couple, the lower resonance moves up in frequency, and the upper resonance moves down in frequency, with the level of reflection at the central frequency lowering dramatically. At the radius value r_4 (critical value), the two resonance curves coalesce, and a single dip is obtained. Enlarging the radius *r* beyond the critical value causes an increase of the reflection, and fills in the transmission band. In this specific example, the first resonance of the spheres occurs at 49.7GHz. This is the peak of total reflection (0dB reflection coefficient) which characterizes all the grids of resonating conducting objects. The dielectric-only reference window has no such resonance. At the resonance frequency, the wavelength inside the dielectric slab is 4.07mm, and the sphere's diameter (about 2mm) is close to the half-wavelength value.

The above performance of the single layer window device **10** is based on the interference of three scattering processes occurring in the device during the propagation of the electromagnetic radiation therethrough:

(1) reflection of the radiation from the first air-dielectric interface (defined by the upper surface of the dielectric layer),

(2) reflection of the radiation from the second air dielectric interface (defined by the lower surface of the dielectric layer), and

(3) radiation scattering from the array of metal inclusions.

The above effect takes place when using dielectric materials with high values of relative permittivity ε_r. **Fig. 3** illustrates a graph **H** presenting the reflection coefficient at normal incidence of the electromagnetic radiation as a function of frequency, for a specific example of the single layer device with the following parameters: ε_r=13.2, d=4mm, a=1mm, and r=0.48mm. Considering the transmission band as the ratio between the frequency difference of the (–20)dB reflection points and the central frequency, it is shown that with a larger value of dielectric constant (13.2 compared to 2.2 of the example of Fig. 2), sharpening of the transmission band is observed. The simulation results have shown that the transmission bands of 35%, 23%, 20.5% and 18% can be obtained with the relative permittivity values 2.2; 4.4; 8.8 and 13.2, respectively.

The transmission window of the present invention can be easily shifted in frequency by modifying the thickness *d* of the dielectric slab (12 in Fig. 1) without changing the radius and grid constant values *r* and *a*. **Fig. 4** illustrates similar graphs $\mathbf{R_1}$, $\mathbf{R_2}$ and $\mathbf{R_3}$ for a specific example of ε_r =2.2, a=4mm, r=1mm, and the thickness values d_1=4.2mm, d_2=4mm and d_3=3.8mm, respectively. As shown, the change in the dielectric layer thickness affects the frequency of the transmission band, while substantially not affecting the level of reflection inside the transmission band.

It should be noted that the inclusions can be made of metal elements, metal-coated dielectric elements, or dielectric-coated metal element. In cases where the inclusions are closely packed, the use of dielectric coating enables to avoid any direct contact of the conducting elements. Other realization of the conducting inclusions could be metal-coated through-holes in a dielectric slab, thus avoiding the necessity to implant solid inclusions. These metal-coated through-holes scatter effectively the incident radiation even if the through-hole is hollow. Yet another realization of the conducting inclusions is a selective metal coating of a dielectric honeycomb structure, where the selectivity of metal coating means that the coating is not necessarily applied to all the holes in the honeycomb, and that the metal coating may cover only a central portion of the hole.

For a specific dielectric slab (with certain values of thickness *d* and relative permittivity ε_r), different transparent windows can be constructed by controlling the scattering from the metal inclusions, namely selecting the sphere radius r (generally, the dimension of the inclusion) and the grid constant *a*. For example, a dielectric slab with the thickness d=4mm and relative permittivity $\varepsilon_r = 2.2$ is used, the grid constant *a* is changed and the sphere radius *r* is optimized for each grid constant to obtain a transmission frequency band. This is illustrated in **Fig. 5** showing three graphs $\mathbf{P}_1$, $\mathbf{P}_2$ and $\mathbf{P}_3$ corresponding, respectively, to the following grid and radius values: a_1=1mm, r_1=0.33mm; a_2=2mm, r_2=0.56mm, and a_3=3mm, r_3=0.77mm. Almost identical transmission windows are obtained for these three different implementations. The optimum radius decreases monotonically with the grid constant *a*, and does not follow the constant filling-factor rule. Simulation results have shown that the equivalence between the above-described different implementations is not only in the reflected/transmitted amplitude, but also in the reflected/transmitted phase.

The inclusions **16** in Fig. 1 may be cylinders or boxes. **Fig. 6** illustrates the reflection coefficients at normal incidence as functions of frequency for a specific example where ε_r =2.2, d=4mm, a=1.5mm. Three graphs $\mathbf{H}_1$, $\mathbf{H}_2$ and $\mathbf{H}_3$ correspond, respectively, to the following height *h* and radius *r* values of the cylinders: r_1=0.48mm, h_1=0.27mm; r_2=0.45mm, h_2=0.35mm; and r_3=0.42mm, h_3=0.5mm. As shown, substantially the same transparent frequency band is obtained.

It is important to note that contrary to the capacitance-inductance cancellation of the conventional approach used in windows of a thickness smaller than $\lambda/2$, the metal inclusions of the present invention are separated from each other and do not allow large current loops to occur. Moreover, if the inclusions in the array are connected (e.g., by short wire segments) to generate a connected mesh, the structure is not transparent any more.

In the example of Fig. 1, the periodic grid of the metal inclusions is square. It should, however, be noted that, for the purposes of the present invention, the grid may be rectangular, triangular or hexagonal, as well. Generally, for each grid type and constants, the size of the inclusions can be selected to obtain a desired transparent window.

The following should be noted: Enlarging the grid constant beyond $\lambda/2$, generates grating lobes inside the dielectric slab and can result in undesirable reflection. Reducing the grid constant to less than $\lambda/20$, the inclusions may intersect with each other prior to obtaining the optimal point of low reflection level. In the example of Fig. 6, the smallest grid that could be used with non-touching conducting balls is a=0.28mm. Below this grid size, an optimized transparent window with metal ball inclusions cannot be obtained.

Turning now to **Fig.** 7, there is shown that the phase delay generated by the single layer transparent window of the present invention has linear frequency dependence inside the transmission band. In the present example, the phase of the wave transmitted by the window of Fig.3 (ε_r=13.2, d=4mm, a=1mm, and r=0.48mm) is presented.

Comparing the effective optical thickness *L* of the window (as calculated from the phase delay, which is equal to $2\pi L/\lambda$) with the thickness *d* of the dielectric slab, the effective optical thickness of the window device of the present invention is larger. Depending on the dielectric constant and thickness of the dielectric layer, and the grid constant of the inclusions' array, the increase of 15-80% in the effective optical thickness has been observed in various examples. The larger delay of the wave inside the window device according to the invention, presumably because of the multiple scattering with the inclusions, provides an important design parameter for both microwaves and optical designs.

With regard to the periodicity of the array of inclusions, the following should be understood. Although a perfect periodic array of metal inclusions has been assumed so far, only quasi-periodicity is important, i.e., a short-range order and not a long-range order.

Figs. 8A and 8B illustrate two devices **20A** and **20B**, respectively, both with the thickness *d* and relative permittivity e_r of a dielectric slab **22** being d=4mm and ε_r=2.2, and with the 1.5mm grid constant of a quasi-periodic array of spheres **24** (inclusions). Array **26A** of the device **20A** is obtained by shifting about 25% of the entire number of spheres of an ideal (periodic) array a distance 1.414δ diagonally off the center of their unit-cell. Array **26B** of the device **20B** is formed by shifting 25% of the entire number of spheres of an ideal array a distance δ along the X-axis, and sifting 25% of spheres the distance δ along the Y-axis.

Fig. 9 illustrates the variations of the reflection coefficient with the frequency of electromagnetic radiation, wherein three graphs S_1, S_2 and S_3 correspond to, respectively, a window device with the ideal array, device **20A**, and device **20B**. As shown, the reflection coefficient of these windows confirms the sufficiency of the quasi-periodicity of the arrays.

Another important aspect of the performance of a window device is associated with dependency of the reflection coefficient on angle of incidence and on the polarization of the electromagnetic radiation. A solid window with a $\lambda/2$-thickness has a rather poor performance in this regard.

Considering the above-described simulation results of Fig. 5 and the equivalence in the reflected/transmitted phase of the different grid implementations, the following results would be expected: the lower the grid constant, the lower the sensitivity of the window to oblique incidence.

The performance of the window with ε_r =2.2, d=4mm, a=1.5mm and r=0.45mm has been investigated for oblique incidence within a range of incident angles θ up to 60 degrees to the Z-axis, and for both linear polarizations of the incident radiation (parallel and normal to the plane of incidence). The oblique incidence performance has been simulated by analyzing different "waveguide simulators".

Fig. 10 illustrates two graphs **30A** and **30B** corresponding, respectively, to the reflection coefficient as a function of frequency, and cosθ as a function of frequency, both for the case of perpendicular polarization of the incident radiation. **Fig. 11** illustrates two graphs **32A** and **32B** of the reflection coefficient and cosθ as functions of frequency, for the case of parallel polarization direction. The two figures show that the window mildly shifts in frequency at large oblique incidence, and that the reflection coefficient is lower than -10dB for both polarizations. Further simulations have confirmed that the window with ε_r=8.8 shows similar behavior. Hence, the performance of the single layer window design of the present invention is comparable to that of the conventional multi-layer hybrid FSS radomes, and can be obtained with high dielectric materials, where the FSS design is severely limited.

A window device of the present invention may comprise multiple dielectric layers (constituting a dielectric structure) and a single array of metallic inclusions. The additional layers are either part of the basic design of the window due to, say, mechanical demands; or result from such manufacturing processes as coating, painting, glazing or impregnation. According to the present invention, the geometry of the metal inclusions can be re-tuned (selected) to account for these external dielectric layers.

The most popular window structures are multi-layer all-dielectric windows like an optical window with two tuning layers of a $\lambda/4$-thickness, or an A-type composite radome with one core layer (inclusions containing layer) and two external skin layers (dielectric layers without metal inclusions). A device according to the present invention is based on a symmetric multi-dielectric layer structure with a single array of metallic (generally, conductive) inclusions at the center of the multi-dielectric structure.

Fig. 12 illustrates such a multi-dielectric single array structure **40** according to the invention utilizing a hexagonal honeycomb layer **42** with upper and lower supporting dielectric skins each having a thickness of t=0.3mm (skin dielectric constant is equal to 2.6). The honeycomb is a heterogeneous structure made of two materials: air and a dielectric foil (with the foil thickness of 0.17mm, and foil dielectric constant of 4.3), and has a hexagonal unit-cell diameter of 3mm and honeycomb layer thickness of d=8mm. The metal inclusions are realized by selected metal coating at the central plane of the structure, thus generating an array of hexagonal open conducting cylinders of a 0.4mm height. The metal inclusion thus has the cross-section of the hexagon of a size defined by the honeycomb unit-cell.

Fig. 13 illustrates the transmission coefficient for the cases of all-dielectric radome (graph **49**) and metal-dielectric radome **40** (graph **50**). As shown, the transmission of the conventional radome structure has broadband characteristics with the degradation of the device performance towards the higher frequencies. By selective metalization of the honeycomb, the transmission at the frequency band of 14-23GHz is improved with a little sacrifice at lower frequencies. The metal-dielectric radome is characterized by a sharp degradation beyond 25GHz, which is not observed in the conventional all-dielectric radome. Similar results could also be obtained by using the C-type radomes formed of two cores and three skin layers. In order to further compensate for the mismatch at the outer skins, an array of metallic patches could be printed on the inner skin.

The present invention provides for using high dielectric constant skins and for compensating for their mismatch by the provision of a layer of metallic inclusions. It should, however, be noted that, if the use of thick low dielectric constant skins is required for a specific application (to withstand the environment condition like hailstone impact), the present invention provides for the compensation of the mismatch of such skins as well.

Fig. 14 illustrates three graphs **52**, **54** and **56** in the form of the reflection coefficient as functions of frequency, for three different examples, respectively. In all the examples, a foam core (thickness d=8mm) and two identical Duroid skins with $\varepsilon=10$ are used, with one central plane of metallic inclusions. The thickness of the skins for these three examples are, respectively $t_1=0.25$mm, $t_2=0.5$mm and $t_3=1.25$mm. As shown, in the three examples, low reflection window (at the –20dB level) is observed at frequency ranges 10.5-15GHz, 9-11.5GHz and 6-8GHZ, respectively.

The multi-dielectric, single metallic array design according to the present invention enables to obtain high reflection at frequencies above the transmission band. This very low transmission band can block interference effects, thereby providing a system filtration load on the electromagnetic window to enable a simpler and cheaper communication system. Such a window can also be used as a sub-reflector in dichroic multi-reflector systems, requiring that the sub-reflector is transparent for some frequencies and is totally reflective for other frequencies. Such dichroic reflectors are capable of efficiently using the common main reflector aperture for various frequency bands, and are therefore used in satellite systems.

The above-described metal-dielectric windows (single layer design or multi-dielectric single inclusions' array design) can be used as a basic stage (or building block) in more complex designs of multi-stage windows. The design of the multi-stage window is preferably such as to keep the symmetry of the entire structure. To achieve this, the stages may and may not be identical.

Figs. 15 and 16 illustrate, respectively, the reflection coefficient as a function of frequency and the transmission coefficient as a function of frequency, characterizing the performance of three devices of different designs. Graphs **58A** and **58B** in Figs. 15 and 16, respectively, correspond to the four-stage design of the window device, graphs **60A** and **60B** correspond to the six-stage design, and graphs **62A** and **62B** correspond to the eight-stage design.

It should be understood that here the word *"stage"* refers to a structure with a single metallic inclusions containing layer, whereas such a structure may include one dielectric layer or may be formed of a stack of dielectric layers. Hence, the multi-stage design is a stack of spaced-apart metallic inclusions (arrays) containing layers. Although multi-stage windows can be prohibitively thick at low microwave frequencies, at higher frequencies, they provide an additional degree of freedom for optimizing the device.

In this specific example, such a building block is a slab with the following parameters: ε_r=8.8, d=4mm, a=2mm, r=0.85mm. For each metal inclusion containing structure, the radii of all spheres were tuned to obtain the optimal response. The reflection and transmission of the window devices with the number *n* of stages being equal to 4, 6 and 8, respectively, demonstrate that the windows have the same central frequency. The advantage of employing a larger number of stages lies in sharpening the edges of the transmission band (Fig. 16). Additionally, as shown in the figures, the peak level of reflection inside the passband grows with the number of stages: (-25dB) for 4-layer design, (-17dB) for 6-layer design, and (-12dB) for 8-layer design, thus increasing the transmission loss inside the transmission band.

The simulation results have shown that two broad stop-bands take place, one below the passband and the other above it. In this specific example of Figs. 16 and 17, the lower stop-band is 9-15GHz, and the upper stop-band is 22-28GHz. If the same results are presented by plotting the transmission coefficient (Fig. 16), they show that the blockage in the stop bands deepens with the number of stages. These results are typical only for designs with high dielectric constant materials. For low dielectric constant devices, there are no real stop-bands, but rather a moderate level of reflection is observed in the range of (-1dB)-(-6 dB).

Another important parameter is the slope of the transmission curve of Fig. 14 at the edges of the band. Considering two frequencies, one at –0.5dB point and the other at –20dB point at the higher edge, the ratios of the two frequencies for 4-, 6- and 8-stage designs are, respectively 1.09, 1.05 and 1.03. These results meet the requirements of satellite borne radiometers and sounders in the frequency range of 100GHz-1THZ (C. Antonopoulos et al., "Multilayer frequency selective surface for millimeter and submillimeter wave applications", Proc. IEE Microwaves Antennas and Propagation, Vol. 144, pp. 415-420, 1997).

In another example, two multi-layer windows each with a foam core of thickness d=8mm, and two identical Duroid skins with ε=10, t=0.50mm and one central plane of metallic inclusions, were stacked together. As shown in **Fig. 17,** comparing the frequency variation of the reflection coefficient of this "double-stage" window (graph **64**) to that of the "single-stage" window (graph **68**), the double-stage window presents a steeper transition into the transmission band, a wider transmission band, and better blockage at the frequency above the transmission band. In the present example of double-stage window, the edge frequency ratio is equal to 1.19.

If more than two stages (metal inclusion containing structures) are stacked with each other, a three dimensional grid is obtained. A four-stage device was tested, where inclusion layers 2 and 4 were shifted by half the grid constant along both the X- and the Y-axis. The performance of the window device was very little affected by this change.

Simulations were also carried out with respect to oblique incidence of the electromagnetic radiation onto the 4-layer, ε_r=8.8 window. The results show that for both polarizations and for incidence angles up to 60 degrees, the reflection level is lower than -10dB.

The multi-stage radomes improve the bandwidth of the window just by sharpening the transition regions. In order to provide significant improvement of the single-stage bandwidth, the stages have to be separated by low dielectric spacers, and the window device should be tuned by controlling the thickness of the spacer. A window device composed of two stages each of ε_r=2.2, a=1.5mm, d=4mm, r=0.43 mm, and a spacer of ε_r=1.1 and thickness of 2mm between them, was designed. Hence, such a composite window device has the 10mm thickness. As shown in **Fig. 18**, at normal incidence of electromagnetic radiation, a transmission band in the range of 25-47GHz with reflection lower than -15dB (almost an octave bandwidth) was obtained.

As known, the ferroelectric materials are characterized by a change in their dielectric constant in response to the application of a DC voltage. The known ferroelectric materials are of ceramic nature, for example, $BaTiO_3$ and $SiTiO_3$.

Fig. 19 illustrates an experimental controllable window device **70** according to the present invention based on a ceramic core (MgO or SiO_2) formed of a dielectric layer **72** with cylindrical metal inclusions (inner pattern) **74**, and two external ferroelectric layers **76** and **78** of dielectric constant about 33. The DC voltage was supplied via a grid of parallel metal strips, generally at **80**, printed on the ferroelectric layers. To this end, the high voltage strips and the grounded strips are interlaced, so as to generate high DC electric fields at the openings between the strips. The window was tuned by the inclusions **74** (i.e., the size of the cylinders and spaces between them were optimized) to compensate for both the reflection from the ferroelectric layers and the metal strips.

As shown in **Figs. 20A-20D**, various strips' arrangements can be used, namely various ways of charging and grounding the strips, provided that a strong electric field is generated in the ferroelectric layers especially between the strips, where the electromagnetic radiation has the highest energy density. As shown, in all the arrangements the charged strips S_c and the grounded strips S_g are interlaced, irrespective of the surface the strips are printed on. In the examples of Figs.20A and 20B, the strips S_c and S_g are printed on the outer surfaces of the ferroelectric layers **76** and **78** and on the outer surfaces of the central dielectric layer **72**. In the examples of Figs. 20C and 20D, the strips S_c and S_g are printed on the outer surfaces of, respectively, the dielectric layer, and the ferroelectric layers.

Fig. 21 illustrates the transmission curves of the window **70** simulated while varying the dielectric constant of the ferroelectric layers between 27 to 39. Four graphs **82**, **84**, **86** and **88** correspond to, respectively, the following values of dielectric constant: $\varepsilon_1=27$, $\varepsilon_2=30$, $\varepsilon_3=33$, $\varepsilon_4=36$ and $\varepsilon_5=39$. It is clear from the figure that the window keeps its high transparency, while the center frequency of the window is shifted from 20GHZ to 18GHz.

It should be noted that in the case of non-linear polarization of the incident radiation, e.g., circular polarization, the electric field component parallel to the strips (**80** in Fig. 19) is strongly reflected, and the window device is not transparent any more. In order to reduce this reflection, high resistivity strips (e.g., with 1000-2000Ohm/sq) can be used, thereby allowing the transmission of both polarizations at the expense of 1-2dB transmission loss.

Those skilled in the art will readily appreciate that various modifications and changes can be applied to the embodiments of the invention as hereinbefore exemplified without departing from its scope defined in and by the appended claims.

CLAIMS

1. A device substantially transparent to electromagnetic radiation of a certain frequency band, the device comprising at least one dielectric structure and having a predetermined substantially periodic inner pattern formed by a two-dimensional array of spaced-apart substantially identical elements made of an electrically conducting material and capable of scattering said electromagnetic radiation, said elements being disconnected from each other, and each having a size smaller than that of a resonance condition of the array.

2. The device according to Claim 1, wherein the periodicity of said inner pattern is such that average density of the elements is approximately the same all along a patterned area.

3. The device according to Claim 1, wherein the dielectric structure comprises a single dielectric layer formed with said inner pattern.

4. The device according to Claim 3, wherein the electrically conductive element has the size smaller than the half-wavelength of propagation of said electromagnetic radiation in said dielectric structure.

5. The device according to Claim 3, wherein a thickness of the dielectric layer is about 0.75λ, wherein λ is the wavelength of propagation of said radiation in the dielectric layer.

6. The device according to Claim 1, wherein said at least one structure is a substantially symmetrical structure formed by a stack of dielectric layers, wherein the central dielectric layer is formed with said inner pattern.

7. The device according to Claim 5, wherein the dielectric layers are made of different dielectric materials characterized by different wavelengths of propagation of said electromagnetic radiation.

8. The device according to Claim 6, wherein the electrically conductive element has the size smaller than the half of at least maximal wavelength of propagation of said electromagnetic radiation in said dielectric structure.

9. The device according to Claim 6, wherein a thickness of the device is in the range from three quarters of the shortest wavelength and three quarters of the longest wavelength of radiation propagation in the different dielectric layers at the central frequency of said frequency band.

10. The device according to Claim 1, wherein said elements are made of a metal-containing material.

11. The device according to Claim 1, wherein said elements are formed by coating conductive elements with one or more dielectric layers.

12. The device according to Claim 1, wherein said elements are formed by coating dielectric elements by at least one conducting layer.

13. The device according to Claim 1, wherein said elements are formed by selective coating of through-holes or honeycomb cores.

14. The device according to Claim 1, wherein dimensions of the radiation scattering elements and spaces between them are selected such that the scattering from said elements substantially compensates for reflection effects from discontinuities at and inside the device.

15. The device according to Claim 1, wherein the array of said elements is positioned in a plane located at the middle of the dielectric structure parallel to planes defined by upper and lower surfaces of the dielectric structure.

16. The device according to Claim 1, having a constant thickness all along the device.

17. The device according to Claim 1, having a varying thickness all along the device.

18. The device according to Claim 1, wherein said elements have circular or polygonal cross-section.

19. The device according to Claim 18, wherein said elements are voluminous.

20. The device according to Claim 18, wherein said elements are substantially flat.

21. The device according to Claim 1, and also comprising electrically conductive strips arranged in a spaced-apart parallel relationship on opposite surfaces of said at least one dielectric structure.

22. The device according to Claim 1, and also comprising at least two layers made of a ferroelectric material at opposite sides of said at least one dielectric structure.

23. The device according to Claim 22, wherein said ferroelectric layers are formed with conductive strips arranged in a spaced-apart parallel relationship to be charged and grounded during an application of an electric field to the ferroelectric layers.

24. The device according to Claim 1, capable of transmitting the electromagnetic radiation impinging thereon at an angle of incidence up to 60 degrees.

25. The device according to Claim 1, and also comprising at least one additional dielectric structure with a predetermined substantially periodic inner pattern formed by a two-dimensional array of spaced-apart substantially identical elements made of an electrically conducting material and capable of scattering said electromagnetic radiation, said elements being disconnected from each other, and each having a size smaller than that of a resonance condition of the array, the at least two structures being located one on top of the other.

26. A radiation source for generating electromagnetic radiation of a certain frequency band, the radiation source comprising the device constructed according to Claim 1, accommodated adjacent to an emitter of the electromagnetic radiation.

27. A controllable device for transmitting electromagnetic radiation of a selected frequency band, the device comprising:

- at least one dielectric structure;
- an inner pattern formed by inclusions inside said at least one dielectric structure, the pattern being in the form of a two-dimensional array of spaced-apart substantially identical elements made of an electrically conducting material and

capable of scattering said electromagnetic radiation, said elements being disconnected from each other, each having a size smaller than that of a resonance condition of the array; and

- at least two ferroelectric layer located at either side of said at least one dielectric structure, application of an electric field to said ferroelectric layer effecting a change in a dielectric constant of said ferroelectric layer, thereby enabling transmission of said selected wavelength band.

28. A method for constructing the device of Claim 1 to be substantially transparent to electromagnetic radiation of the certain frequency band, the method comprising the steps of:

- selecting at least one dielectric material of a predetermined dielectric constant to fabricate said at least one dielectric structure, and selecting dimensions of said elements and the spaces between the elements for the inner pattern inside said dielectric structure, so as to ensure that the scattering from said elements compensates for reflection effects at and inside the dielectric structure;
- fabricating said at least one dielectric structure with said inner pattern of the spaced-apart electrically conductive elements.

CLAIMS

1. A device substantially transparent to electromagnetic radiation of a certain frequency band, the device comprising at least one dielectric structure having a predetermined inner pattern formed by a two-dimensional array of elements made of an electrically conducting material and capable of scattering said electromagnetic radiation, the device being characterized in that:

said at least one dielectric structure has a predetermined thickness defined by the central frequency of said certain frequency band;

said inner pattern is substantially periodic;

said elements are substantially identical, sub-resonant, capacitive elements arranged in a spaced-apart disconnected from each other relationship.

2. The device according to claim 1, wherein the periodicity of said inner pattern is such that average density of the elements is approximately the same all along a patterned area.

3. The device according to claim 1, wherein the dielectric structure comprises a single dielectric layer formed with said inner pattern.

4. The device according to claim 3, wherein the electrically conductive element has the size smaller than the half-wavelength of propagation of said electromagnetic radiation in said dielectric structure.

5. The device according to claim 3, wherein a thickness of the dielectric layer is about 0.75λ, wherein λ is the wavelength of propagation of said radiation in the dielectric layer.

6. The device according to claim 1, wherein said at least one structure is a substantially symmetrical structure formed by a stack of dielectric layers, wherein the central dielectric layer is formed with said inner pattern.

7. The device according to claim 5, wherein the dielectric layers are made of different dielectric materials characterized by different wavelengths of propagation of said electromagnetic radiation.

8. The device according to claim 6, wherein the electrically conductive element has the size smaller than the half of at least maximal wavelength of propagation of said electromagnetic radiation in said dielectric structure.

9. The device according to claim 6, wherein a thickness of the device is in the range from three quarters of the shortest wavelength and three quarters of the longest wavelength of radiation propagation in the different dielectric layers at the central frequency of said frequency band.

10. The device according to claim 1, wherein said elements are made of a metal-containing material.

11. The device according to claim 1, wherein said elements are formed by coating conductive elements with one or more dielectric layers.

12. The device according to claim 1, wherein said elements are formed by coating dielectric elements by at least one conducting layer.

13. The device according to claim 1, wherein said elements are formed by selective coating of through-holes or honeycomb cores.

14. The device according to claim 1, wherein dimensions of the radiation scattering elements and spaces between them are selected such that the scattering from said elements substantially compensates for reflection effects from discontinuities at and inside the device.

15. The device according to claim 1, wherein the array of said elements is positioned in a plane located at the middle of the dielectric structure parallel to planes defined by upper and lower surfaces of the dielectric structure.

16. The device according to claim 1, having a constant thickness all along the device.

17. The device according to claim 1, having a varying thickness all along the device.

18. The device according to claim 1, wherein said elements have circular or polygonal cross-section.

19. The device according to claim 18, wherein said elements are voluminous.

20. The device according to claim 18, wherein said elements are substantially flat.

21. The device according to claim 1, and also comprising electrically conductive strips arranged in a spaced-apart parallel relationship on opposite surfaces of said at least one dielectric structure.

22. The device according to claim 1, and also comprising at least two layers made of a ferroelectric material at opposite sides of said at least one dielectric structure.

23. The device according to claim 22, wherein said ferroelectric layers are formed with conductive strips arranged in a spaced-apart parallel relationship to be charged and grounded during an application of an electric field to the ferroelectric layers.

24. The device according to claim 1, capable of transmitting the electromagnetic radiation impinging thereon at an angle of incidence up to 60 degrees.

25. The device according to claim 1, and also comprising at least one additional dielectric structure with a predetermined substantially periodic inner pattern formed by a two-dimensional array of spaced-apart substantially identical elements made of an electrically conducting material and capable of scattering said electromagnetic radiation, said elements being disconnected from each other, and each having a size smaller than that of a resonance condition of the array, the at least two structures being located one on top of the other.

26. A radiation source for generating electromagnetic radiation of a certain frequency band, the radiation source comprising the device constructed according to claim 1, accommodated adjacent to an emitter of the electromagnetic radiation.

27. A controllable device for transmitting electromagnetic radiation of a selected frequency band, the device comprising: at least one dielectric structure having an inner pattern formed by inclusions inside said at least one dielectric structure, the pattern being in the form of a two-dimensional array of elements made of an electrically conducting material and capable of scattering said electromagnetic radiation; and at least two ferroelectric layers located at opposite sides of said at least one dielectric structure, application of

an electric field to said ferroelectric layer effecting a change in a dielectric constant of said ferroelectric layer, the device being characterized in that:

said at least one dielectric structure has a predetermined thickness defined by the central frequency of said certain frequency band;

said inner pattern is substantially periodic;

said elements are substantially identical, sub-resonant, capacitive elements arranged in a spaced-apart disconnected from each other relationship.

28. A method for constructing the device of claim 1 to be substantially transparent to electromagnetic radiation of the certain frequency band, the method comprising the steps of:

selecting at least one dielectric material of a predetermined dielectric constant to fabricate said at least one dielectric structure of the predetermined thickness, and selecting dimensions of said elements and the spaces between the elements for the inner pattern inside said dielectric structure, so as to ensure that the scattering from said elements compensates for reflection effects at and inside the dielectric structure;

fabricating said at least one dielectric structure with said inner pattern of the spaced-apart electrically conductive elements.

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Application No: GB 0120075.7
Claims searched: all

Examiner: Dr E.P. Plummer
Date of search: 9 May 2002

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): H1Q (QEX, QEJ,)

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Other: Online: WPI, INSPEC, PAJ

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB2337860A	TRW whole document	1,2,3,4, 10,14,16, 18,19,20, 24,25,26, 28
X	GB2328319A	BRITISH AEROSPACE whole document	1,2,4,10, 14,15,16, 18,19,20, 24,25,28
X	GB2325784A	TRW whole document	1,2,3,4, 10,14,16, 18,19,20, 24,25,26, 28
X	GB2294813A	MMS SPACE SYSTEMS whole document	1,2,3,4,5, 10,14,15, 16,18,19, 20,21,24, 25,26,28
X	GB2253519A	LOUGHBOROUGH UNIVERSITY whole document	1,2,3,4, 10,14,15, 16,18,19, 20,21,24, 25,26,28

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Category	Identity of document and relevant passage		Relevant to claims
X	EP0187437A1	HAZELTINE CORP whole document	1,2,3,8, 10,14,16, 18,19,20, 24,28
X	EP0096529A1	KENT SCIENTIFIC INDUSTRIAL whole document	1,2,3,4, 10,16,18, 19,20,26, 28

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