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(73) Patenthaver: **Naval Group, 40-42 rue du Docteur Finlay, 75015 Paris, Frankrig**
Centre National de la Recherche Scientifique, 3, rue Michel-Ange, 75016 Paris, Frankrig
Université de Rennes I, 2, rue du Thabor, CS 46510, 35065 Rennes Cedex, Frankrig

(72) Opfinder: **RUBRICE, Kevin, DCNS Research-Technocampus Océan, 5 rue de l'Halbrane, 44340 Bouguenais, Frankrig**
CASTEL, Xavier, IUT de Saint-Brieuc/IETR UMR-6164/ Université de, Rennes, 1 18 rue Henri Wallon, 22004 Saint-Brieuc, Frankrig
HIMDI, Mohammed, IETR UMR-6164 / Université de Rennes 1 Campus de, Beaulieu-bât. 11D 263 avenue du Général Leclerc-CS, 74205, 35042 Rennes Cedex, Frankrig
PARNEIX, Patrick, DCNS Research-Technocampus Océan, 5 rue de l'Halbrane, 44340 Bouguenais, Frankrig

(74) Fuldmægtig i Danmark: **Zacco Denmark A/S, Arne Jacobsens Allé 15, 2300 København S, Danmark**

(54) Benævnelse: **Flerlagsstruktur med rekonfigurerbare, dielektriske egenskaber og enhed, omfattende en sådan flerlagsstruktur**

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Description

The present invention relates to a composite structure having reconfigurable dielectric characteristics.

Such structures are known from US 2004/184752 and US 5739796.

The invention relates in particular to multifunctional active composite structures having both a structural function and one or more functionalities in the field of hyperfrequency applications, for example in terms of stealth, shielding, antenna integration or decoupling, or a radome function.

Substrates of composite materials, whether they be monolithic or sandwich, have complex dielectric characteristics (real part + imaginary part) that are defined for a given composition of the structure and at a given working frequency. These dielectric characteristics are fixed and not reconfigurable at present.

Such substrates can be integrated into a hyperfrequency system composed, for example, of a radome of composite materials and the accommodated antenna, or of a printed circuit on a substrate of composite material, or of an antenna integrated into a structural wall of composite material.

For example, a hyperfrequency system can be composed of an antenna and a wall formed of a substrate of a composite material, which is, for example, the wall carrying the antenna or a radome. The reconfigurability of such a hyperfrequency system is generally provided by the antenna, *via* the use of active, electrically controllable components such as PIN diodes, varicap diodes, transistors and/or MEMS, the substrate of composite material having an entirely passive function.

It has been proposed to use, in the wall, reconfigurable active materials, for example by depositing thin layers of versatile materials, the dielectric parameters of which are controllable, on a specific passive substrate. The reconfigurability of the hyperfrequency system is then no longer provided by the antenna itself but by the active wall.

Such a solution is not entirely satisfactory. In particular, the use of such walls is reserved to a local scale, owing to the numerous constraints associated with such walls, which limit their use on a larger scale. In particular, such walls are unsuitable for the production of large structures such as naval structures.

An object of the invention is therefore to propose a composite structure having reconfigurable dielectric properties, which is adapted both for use as a wall carrying an antenna or as a radome, and for use on a large scale as a structural panel, especially of a naval, terrestrial or aerial carrier.

To that end, the invention provides a composite structure according to claim 1.

The structure according to the invention may have one or more of the features of claims 2 to 9.

The invention additionally provides an assembly according to claim 10.

The invention will be better understood from reading the following description, which is given solely by way of example and with reference to the accompanying drawings, in which:

- Figure 1 is a diagram of a composite structure according to a first embodiment, comprising a composite substrate made of a monolithic composite material;
- Figure 2 is a diagram of a composite structure according to a second embodiment, comprising a sandwich composite substrate;
- Figure 3 shows, in schematic form, a honeycomb core of a sandwich composite substrate according to the second embodiment;
- Figure 4 shows, in schematic form, a composite structure according to the first embodiment equipped with a microstrip line and a stub;
- Figure 5 is a graph showing the variation of the coefficient of transmission S_{21} of the composite structure of Figure 4 as a function of frequency and of temperature;
- Figure 6 is an enlargement of Figure 5, centred on a first frequency peak;
- Figure 7 is an enlargement of Figure 5, centred on a second frequency peak;
- Figure 8 shows, in schematic form, a core of cellular structure of the honeycomb type of a sandwich composite substrate according to the second embodiment, provided with heating resistors;

- Figure 9 is a graph showing the variation of the coefficient of reflection S_{11} of the core of Figure 8 as a function of frequency and of temperature.

In all the embodiments described with reference to Figures 1 to 3, the composite structure comprises a composite substrate and a plurality of active fillers dispersed in the composite substrate.

The active fillers are formed of a piezoelectric material, the dielectric characteristics of which are modifiable by application of a command to said composite structure, therefore to the active fillers. The piezoelectric material is, for example, also pyroelectric, i.e. piezoelectric and pyroelectric. The piezoelectric material can further be ferroelectric, i.e. can be piezoelectric, pyroelectric and ferroelectric.

Accordingly, the dielectric characteristics of the composite structure including those fillers are themselves modifiable, and therefore reconfigurable, by application of that command.

In particular, the active fillers are characterised by a complex dielectric permittivity $\varepsilon^* = \varepsilon' + j\varepsilon''$, where ε' and ε'' are, respectively, the real component and the imaginary component of the complex electric permittivity ε^* of the material constituting the active fillers.

The loss factor or tangent δ of those active fillers is defined as: $tan\delta = \varepsilon''/\varepsilon'$.

The complex dielectric permittivity of the active fillers, and therefore of the structure in which they are integrated, can be modified by application of a suitable command, so as to vary the properties of absorption and reflection by the composite structure of electromagnetic waves incident on the composite substrate.

In particular, the complex electric permittivity of the active fillers depends on the command applied to the fillers. The complex dielectric permittivity of the active fillers is therefore modifiable by application of a command.

If the material is piezoelectric only, i.e. does not have pyroelectric properties, and therefore does not have ferroelectric properties, the complex dielectric permittivity of the active fillers is modifiable by application of a mechanical command.

If the material is additionally pyroelectric, the complex dielectric permittivity of the active fillers is modifiable by application of a mechanical, thermal or optical command.

If the material is additionally ferroelectric, the complex dielectric permittivity of the active fillers is modifiable by application of a mechanical, thermal, optical or electrical command.

Preferably, the active fillers are made of a ferroelectric material, which therefore also has piezoelectric and pyroelectric properties.

Thus, the complex electric permittivity of the active fillers is modifiable by application of an electrical command, a thermal command, an optical command and/or a mechanical command.

The active fillers are, for example, dispersed in the substrate as a whole. In this case, the dielectric characteristics of the composite structure as a whole are reconfigurable. In particular, the active fillers are, for example, dispersed uniformly in the substrate.

In a variant, the active fillers are dispersed locally, in a localised portion or a plurality of localised portions of the composite substrate. In this case, the dielectric characteristics of the portion(s) of the composite structure that comprise active fillers are reconfigurable. In that portion or in each of those portions, the active fillers are, for example, dispersed uniformly.

The active fillers are, for example, formed of a ferroelectric material, which is preferably chosen from the family of the perovskites, the family of the ilmenites, the family of the pyrochlores, the family of the quadratic bronzes, the family of the Aurivilius phases, the chosen material being optionally doped.

In particular, the ferroelectric material is, for example, a material of the family of the perovskites, for example $BaTiO_3$, $CaTiO_3$, $KTaO_3$, $YMnO_3$, $PbTiO_3$, etc.

The ferroelectric material may also be:
- an ilmenite, for example $LiNbO_3$,
- a pyrochlore, especially $Cd_2Nb_2O_7$,
- a quadratic bronze, especially $PbNb_2O_6$,
- an Aurivilius phase, especially $BiTi_3O_{12}$ or $SrBi_2Ta_2O_9$, etc.

The ferroelectric material may be a phase doped with one of the following materials, for example $Ba_{1-x}SrTiO_3$, $KTa_{1-x}Nb_xTiO_3$, $AgTa_{1-x}Nb_xO_3$, $Sr_{1-x}Bi_xTiO_3$, $Pb_{1-x}Sr_xTiO_3$, $BaZr_{1-x}Ti_xO_3$, etc.

The value of the coefficient x may be chosen between 0 and 1, as a function especially of the Curie temperature desired for the material.

The ferroelectric material may also be a multiferroic material, for example $BiFeO_3$, having a plurality of ferroic properties. For example, the material is both ferroelectric, ferroelastic and ferromagnetic.

A plurality of ferroelectric materials can be combined. The active fillers are then composed of a mixture of at least two ferroelectric materials.

Moreover, a plurality of pyroelectric materials, or a plurality of piezoelectric materials, can be combined.

The command, especially electrical, thermal, optical or mechanical, can be applied to the composite structure as a whole, so as to control the dielectric characteristics uniformly in the composite structure as a whole, or to a only portion of the composite structure, so as to control the dielectric characteristics of that portion of the composite structure independently of the remainder of the composite structure. A different command can of course be applied to the remainder of the composite structure.

In particular, an electrical command comprises the application of an electric potential difference to at least a portion of the composite structure, for example a potential difference imposed between the two faces of the composite structure, resulting in a modification of the complex electric permittivity of the active fillers, and therefore of the selected portion of the composite structure or of the composite structure as a whole.

A thermal command is carried out by imposing a given temperature on at least a portion of the composite structure, resulting in a modification of the complex electric permittivity of the active fillers in that portion. In order to permit such a thermal command, the composite structure may be associated, for example, with one or more resistors arranged on the periphery of the composite structure.

An optical command is carried out, for example, by directing an optical source, for example a laser source, at a localised portion of the composite structure or at the composite structure as a whole, so as to generate a rise in temperature in the localised portion, or in the structure as a whole, resulting in a modification of the complex electric permittivity of the active fillers in that localised portion or in the composite structure as a whole.

A mechanical command comprises the application of a mechanical stress, compression or tensile stress, to a localised portion of the composite structure or to the composite structure as a whole, resulting in a modification of the complex electric permittivity of the active fillers in that localised portion or in the composite structure as a whole.

If the ferroelectric material is also ferromagnetic (multiferroic material), the magnetic characteristics of the composite structure are also modifiable by application of a magnetic command.

Generally, the command is applied by a control device, which is configured to apply an electrical, thermal, mechanical, optical and/or magnetic command to the structure, to the portion of the composite structure containing the active fillers, or to a selected part of the composite structure.

The use of a thermal command is more particularly adapted for controlling the overall dielectric characteristics of the composite structure, while the use of an optical or electrical command is in particular adapted for locally varying the dielectric characteristics of the composite structure.

According to a first embodiment, shown schematically in Figure 1, the composite structure 1 comprises a composite substrate 3 made of a monolithic composite material.

This monolithic composite material comprises an impregnation resin 5, which forms the matrix of the composite material, and a set of fibrous reinforcements 7, which serve to mechanically reinforce the composite substrate.

The resin 5 is preferably a thermosetting or thermoplastic organic resin, for example a polymer resin such as an epoxy resin, a polyester resin, a vinyl ester resin, etc.

The reinforcements 7 are made of an organic or inorganic material. The material is, for example, glass fibres or carbon fibres.

The composite structure 1 additionally comprises a plurality of active fillers 9 which are dispersed in the composite substrate 3. Preferably, the active fillers 9 are dispersed, in powder form, in the impregnation resin 5. The active fillers 9 are, for example, introduced by being mixed into the resin before it cures.

The content of dispersed active fillers is chosen so as to optimise the reconfigurability of the composite structure 1, that is to say in a quantity sufficient to permit a significant modification of the dielectric characteristics of the composite structure 1 while maintaining the mechanical performance of the resin and especially its ability to serve as the impregnation matrix for the fibrous reinforcements 7.

Preferably, the filler content, expressed in percent by mass in the resin matrix, is between 50% and 90%.

A reduction in the filler content of active fillers induces a fall in the reconfigurability properties of the composite structure comprising the fillers, while an increase in the filler content can induce embrittlement of the composite structure and render it more difficult to produce.

In a variant, the active fillers are dispersed in powder form on the reinforcements 7.

According to a second embodiment, shown generally in Figure 2, the composite structure 11 comprises a sandwich composite substrate 13.

The sandwich composite substrate 13 comprises a core 15 interposed between two skins 17.

The core 15 is, for example, made of an expanded or foam material, which is, for example, a polyethersulfone foam, a polyvinyl chloride foam, a polyurethane foam, a polyethylene foam, a polystyrene foam or a polymethacrylimide foam.

According to another example, the core 15 is made of a material having a cellular structure of the honeycomb type, this cellular structure comprising transverse walls delimiting a plurality of cells. The cells are, for example, through-cells, that is to say they open transversely on either side of the core 15. The cellular structure is, for example, made of aluminium or of a thermosetting or thermoplastic material such as polypropylene, or of aramid paper.

Each skin 17 is made of a rigid material, for example of a monolithic composite material as described with reference to the first embodiment, comprising an impregnation resin and a set of fibrous reinforcements.

The composite structure 11 comprises a plurality of active fillers which are dispersed in the core 15 and/or in at least one of the skins 17.

In a first variant of this second embodiment, the core 15 is made of a material having a cellular structure of the honeycomb type, and the active fillers are dispersed in the core 15, in particular in at least a portion of the cells.

Thus, at least a first set of cells, i.e. a portion of the cells, comprises active fillers.

For example, the active fillers are introduced into the cells in the form of ferroelectric material powder. In this case, the powder formed of active fillers is introduced directly into the cells.

Alternatively, the active fillers are introduced into the cells in powder form after sintering (ceramics).

The active fillers may also be dispersed in an organic resin or in an expanded material introduced into the cells. In particular, when the active fillers are dispersed in an organic resin, as described hereinbefore, the filler content of active fillers in the resin is chosen so as to optimise the reconfigurability of the composite structure 11.

The cells comprising such active fillers are selected as a function of the intended application.

There is thus illustrated in Figure 3, by way of example, a core 15 of a sandwich composite substrate comprising a plurality of cells 19, active fillers 21 being dispersed in only a first set of cells, designated by the reference numeral 19*, a second set of cells, designated by the reference numeral 19', not comprising active fillers. The insertion of active fillers into only a first set of cells permits controllability of the structure only in precise zones of the structure.

In a second variant of this second embodiment, the core 15 is made of an expanded or foam material and the active fillers are dispersed within the expanded material.

The active fillers are, for example, dispersed in the foam forming the core 15 as a whole. In this case, the dielectric characteristics of the composite structure 11 as a whole can be configured by modifying the dielectric characteristics of the active fillers. According to this example, the active fillers are, for example, introduced into the foam during the production thereof, or introduced subsequently into openings formed beforehand.

According to another example, the active fillers are dispersed in only a portion of the foam, so that only the dielectric characteristics of the corresponding portion of the composite structure 11 can be reconfigured.

According to this example, the active fillers are, for example, introduced into the core 15 into openings formed beforehand.

The active fillers are, for example, introduced in the form of compact or sintered powder.

In a third variant of this second embodiment, at least one of the skins 17 is made of a monolithic composite material comprising an impregnation resin and a set of fibrous reinforcements.

As described hereinbefore with reference to the first embodiment, the resin is, for example, a thermosetting or thermoplastic organic resin, for example a polymer resin such as an epoxy resin, a polyester resin, a vinyl ester resin, etc., and the reinforcements are, for example, glass fibres or carbon fibres.

In this third variant, the composite structure 11 comprises a plurality of active fillers which are dispersed in the skin(s) 17 made of a monolithic composite material, especially in the impregnation resin and/or on the reinforcements of the skin(s), as described hereinbefore with reference to the first embodiment.

The embodiments and variants described hereinbefore may further be combined.

In particular, if the composite substrate is monolithic, a first portion of the active fillers may be dispersed in the resin and a second portion on the reinforcements.

Furthermore, if the substrate is a sandwich composite substrate, a portion of the active fillers may be dispersed in the core of the substrate and another portion may be dispersed in one of the skins or in both skins, especially in the resin and/or on the reinforcements of the skin(s).

By way of example, a composite structure 23 comprising a monolithic composite substrate formed of an epoxy resin and of reinforcements (not shown), and active fillers composed of barium strontium titanate $Ba_xSr_{1-x}TiO_3$ where $x = 0.6$ (BST) has been produced.

$Ba_xSr_{1-x}TiO_3$, also called BST, has a Curie temperature Tc, which delimits the boundary between the ferroelectric state of BST ($T < Tc$) and its paraelectric state ($T > Tc$), of approximately 270 K. The composition x will be selected in such a manner as to place the value of Tc at the average use temperature of the composite material, i.e. where the variation of the complex dielectric permittivity will be greatest. The real part of the dielectric permittivity of BST, ε', is maximum at temperature T = Tc. Thus, an evolution of the temperature experienced by the material around that temperature will bring about a considerable evolution of the real and imaginary parts of its dielectric permittivity, ε', ε'', and also of the loss tangent tanδ.

In order to produce the composite structure, a BST ceramics material in the powdered state was mixed with epoxy resin of grade PRIME®27 and its associated curing agent PRIME®20, in the following proportions by mass: 35.512 g of BST / 6.661 g of epoxy resin / 1.865 g of curing agent. Such proportions correspond to a proportion by mass of active fillers in the composite substrate of 80.6%, which corresponds to the maximum amount of powder which can be introduced into the mixture while retaining an optimum distribution of BST within the organic matrix.

The resin was first mixed with the curing agent, and then the BST powder was introduced into the mixture. After homogenisation, the mixture was moulded in the form of a square sheet measuring 50 mm x 50 mm x 2 mm. The mixture, once moulded, was left at ambient temperature for a period of 12 hours, inducing polymerisation of the epoxy resin. The resin was then baked at 65°C for a period of 7 hours in an oven.

In order to test the thermal controllability of the structure so obtained, a strip line 25 and a stub 27 were printed on a surface of the composite structure, as shown schematically in Figure 4.

The hyperfrequency characteristics of the composite structure were measured by means of a network analyser, the temperature being varied from 30°C to 200°C, for example by means of an oven or other means allowing the temperature to be brought to the required level.

The coefficient of transmission S_{21} so measured as a function of the temperature and of the frequency, denoted F (in GHz), expressed in decibels (dB), has been shown in Figure 5 and in Figures 6 and 7, which show more precisely the frequency ranges centred on the first resonance peak and the second resonance peak, respectively.

In those figures, the coefficient of transmission S_{21} measured at 30°C, 40°C, 50°C, 60°C, 70°C, 80°C, 90°C, 100°C, 110°C, 130°C, 160°C and 200°C is shown. Generally, the coefficient of transmission S_{21}, expressed in dB, at the first and second peaks is a decreasing function of the temperature.

As shown in those figures, a variation of the attenuation between 30°C and 200°C which can reach 12.43 dB at 4.5 GHz, and a frequency agility of +/- 60 MHz around the frequency of 4.5 GHz were measured.

These tests therefore show that a significant modification of the hyperfrequency characteristics of the composite structure, resulting from a modification of its dielectric characteristics, is effectively obtained by applying a thermal command to the composite structure.

The thermal evolution of the dielectric characteristics, especially of the real part ε' of the dielectric permittivity, and of the loss tangent were determined by retro-simulation. In particular, by simulating the microstrip line on its controllable substrate by means of electromagnetic simulation software (for example of the CST Studio type), it is possible to obtain the parameters S_{ij}. By modifying the dielectric characteristics of the substrate used in the simulation, we are able to compare the parameters S_{ij} obtained in simulation with those of the measurement. This comparison thus makes it possible to trace back the dielectric permittivity and the loss tangent of the controllable composite, for different temperatures. In particular, it has been determined that the real part ε' of the dielectric permittivity varies from $\varepsilon' = 14$ at 30°C to $\varepsilon' = 15$ at 80°C and then $\varepsilon' = 14$ again at 200°C. The loss tangent $\tan\delta$ varies from $\tan\delta = 0.04$ at 30°C to $\tan\delta = 0.09$ at 80°C and then to $\tan\delta = 0.14$ at 200°C.

The curves of variation of the coefficient of transmission S_{21} at 30°C, 80°C and 200°C, determined from those values, correspond to the measured curves as shown in Figures 5 to 7.

According to a second example, a composite structure comprising a sandwich composite substrate comprising a cellular structure of the honeycomb type and active fillers composed of epoxy resin loaded with barium strontium titanate powder $Ba_xSr_{1-x}TiO_3$, where x = 0.6, was produced.

The cellular structure 31, shown in Figure 8, is composed of 12 x 12 circular cells with a diameter of 13.4 mm. One cell in 4 was filled with an epoxy resin previously loaded with 80.6% by mass of $Ba_{0.6}Sr_{0.4}TiO_3$. The cells filled with resin loaded with BST, which are designated by reference numeral 33 in Figure 8, are separated in pairs.

The cellular structure so filled is intended to be associated with two skins made of a monolithic composite material. However, the hyperfrequency characteristics of the filled cellular structure were studied in the absence of the monolithic skins, in order to determine those characteristics and their evolution more precisely.

In the first instance, the hyperfrequency characteristics of a cellular structure without active filler were determined, by way of comparison, by interposing the cellular structure without filler between two horns (a horn transmitting electromagnetic waves and a receiving horn) and measuring the coefficient of reflection S_{11}. The coefficient of reflection S_{11}, expressed in decibels, is zero, the electromagnetic waves being totally reflected by the cellular structure without filler.

In order to test the thermal controllability of the structure so obtained, four heating resistors 35 were arranged on the frame of the cellular structure.

The hyperfrequency characteristics of the filled cellular structure were additionally determined at 25°C and then at 75°C (the cellular structure being heated by means of the heating resistors 35), by interposing the filled cellular structure between two horns (a horn transmitting electromagnetic waves and a receiving horn) and measuring the coefficient of reflection S_{11} of the electromagnetic waves between 2 GHz and 6 GHz.

The coefficient of reflection S_{11} so measured is shown in Figure 9. In that figure, curve A shows the coefficient of reflection S_{11} of the cellular structure without filler, curve B shows the coefficient of reflection S_{11} of the filled cellular structure at a temperature of 25°C, while curve C shows the coefficient of reflection S_{11} of the filled cellular structure at a temperature of 75°C.

It is noted that, when the cellular structure comprises active fillers, the electromagnetic waves are partially transmitted through the cellular structure.

It is especially noted that a frequency window centred at 4.05 GHz, with $S_{11} = -7.3$ dB, appears when the filled cellular structure is at a temperature of 25°C.

When the temperature of the cellular structure is raised to 75°C, the frequency window is displaced to a lower frequency, centred at 3.94 GHz, and the coefficient of reflection S_{11} increases ($S_{11} = -4.7$ dB).

This test thus shows that the inclusion in some cells of the cellular structure make it possible to obtain dielectric characteristics of that structure that can be modified by application of a thermal command.

Such a cellular structure, when it is associated with two skins to form a composite structure, may therefore be used as an active structure that is reconfigurable as a function of the desired hyperfrequency characteristics.

Such reconfigurability could of course also be obtained by applying an electrical, optical or mechanical command to the structure.

The composite structures according to the invention thus have dielectric characteristics that are controllable and reconfigurable as a function of the intended application, while being suitable for use on a large scale, for example as a structural panel, especially of a naval, terrestrial or aerial carrier, and on a smaller scale.

Moreover, the additional cost associated with integrating active fillers into the composite substrate is moderate, which makes it possible to confer reconfigurable dielectric characteristics on a system including such a structure at low cost.

Furthermore, the composite structure according to the invention retains the primary characteristics of the composite substrate in which the fillers are dispersed, in particular in terms of lightness, mechanical rigidity, corrosion resistance, etc.

The composite structures according to the invention provide the electromagnetic performances of the systems in which they are integrated with a modulable nature.

In particular, the composite structures having reconfigurable dielectric characteristics according to the invention, associated with a suitable control device, can be integrated into various systems, such as antenna systems dedicated to communication applications, especially the naval (in surface craft, masts) or terrestrial (within vehicles, buildings) or aeronautical or space field.

Such composite structures can also be used:
- as an active radome wall, associated with an antenna, and/or as a carrying structure, for example a carrying structure of an antenna,
- as a structural wall of a naval, terrestrial or aerial carrier in which an antenna is integrated,
- in a scrambler, an electronic board, a phase shifter, a filter, in a radar or a goniometer,
- as a substrate of a printed circuit in the electronics field.

The use of composite structures according to the invention whose dielectric characteristics are reconfigurable, and which are therefore active, unlike the composite structures generally used, allows the systems in which they are integrated to be provided with new functionalities and allows the service life of those systems to be extended, especially by allowing the systems to be adapted to new requirements.

Patentkrav

1. Flerlagsstruktur (1; 11) med rekonfigurerbare, dielektriske egenskaber, hvor flerlagsstrukturen (1; 11) omfatter et kompositsubstrat (3; 13) og en flerhed af aktive fyldstoffer (9; 21), der er dispergeret i kompositsubstratet (3; 13), hvor hvert aktive fyldstof (9; 21) består af et materiale med dielektriske egenskaber, som kan ændres ved anvendelse af en styring til kompositstrukturen (1; 11),
hvor kompositsubstratet (13) er et sandwichkompositsubstrat, omfattende mindst én kerne (15), der er anbragt imellem to hudlag (17), hvor mindst en del af de aktive fyldstoffer (21) er dispergeret i kernen (15), hvor kernen (15) omfatter et lag af materiale med en hulrumsstruktur, som omfatter tværgående vægge, der afgrænser en flerhed af hulrum (19),
hvor flerlagsstrukturen (1; 11) er **kendetegnet ved, at**mindst en del af de aktive fyldstoffer er dispergeret i mindst én første enhed af hulrum (19), hvor en anden enhed af hulrum er fri for aktive fyldstoffer.

2. Flerlagsstruktur (1; 11) ifølge krav 1, **kendetegnet ved, at** materialet er udvalgt blandt:
- familien af piezoelektriske materialer, hvor de dielektriske egenskaber af materialet kan ændres ved anvendelse af en mekanisk styring,
- familien af pyroelektriske materialer, hvor de dielektriske egenskaber af materialet kan ændres ved anvendelse af en mekanisk, termisk og/eller optisk styring,
- familien af ferroelektriske materialer, hvor de dielektriske egenskaber af materialet kan ændres ved anvendelse af en mekanisk, termisk, optisk og/eller elektrisk styring.

3. Flerlagsstruktur (1; 11) ifølge krav 2, **kendetegnet ved, at** materialet er udvalgt blandt familien af multiferroiske materialer.

4. Flerlagsstruktur (1; 11) ifølge et hvilket som helst af kravene 1 til 3, **kendetegnet ved, at** flerlagsstrukturen (3; 13) omfatter mindst ét lag (3 ; 17) i et monolitisk kompositmateriale, hvor det monolitiske kompositmateriale indeholder en harpiks (5) og et sæt forstærkninger (7).

5. Flerlagsstruktur (1; 11) ifølge krav 4, **kendetegnet ved, at** de aktive fyldstoffer (9; 21) er dispergeret i harpiksen (5) og/eller på forstærkningerne (7) af det mindst ét lag (3; 17).

6. Flerlagsstruktur (11) ifølge et hvilket som helst af kravene 1 til 5, **kendetegnet ved, at** mindst ét af hudlagene (17) er udført i et monolitisk kompositmateriale, hvor det monolitiske kompositmateriale omfatter en harpiks og et sæt forstærkninger, hvor mindst en del af de aktive fyldstoffer er dispergeret i harpiksen og/eller på forstærkningerne.

7. Flerlagsstruktur (11) ifølge et hvilket som helst af kravene 1 til 6, **kendetegnet ved, at** kernen (15) omfatter et lag, der er udført i et ekspanderet materiale.

8. Flerlagsstruktur (11) ifølge krav 7, **kendetegnet ved, at** mindst en del af de aktive fyldstoffer er dispergeret i det ekspanderede materiale.

9. Flerlagsstruktur (1; 11) ifølge et hvilket som helst af de foregående krav, **kendetegnet ved, at** materialet er udvalgt blandt familien af perovskiter, familien af ilmeniter, familien af pyroklorforbindelser, familien af kvadratiske bronzer, familien af Aurivilius-faser, hvor materialet eventuelt er doteret.

10. Enhed, omfattende en flerlagsstruktur (1; 11) ifølge et hvilket som helst af kravene 1 til 9 og en styreindretning, der er konfigureret til at anvende en styring, især en elektrisk, termisk, mekanisk, optisk og/eller magnetisk styring, til flerlagsstrukturen (1; 11) for at ændre materialets dielektriske egenskaber.

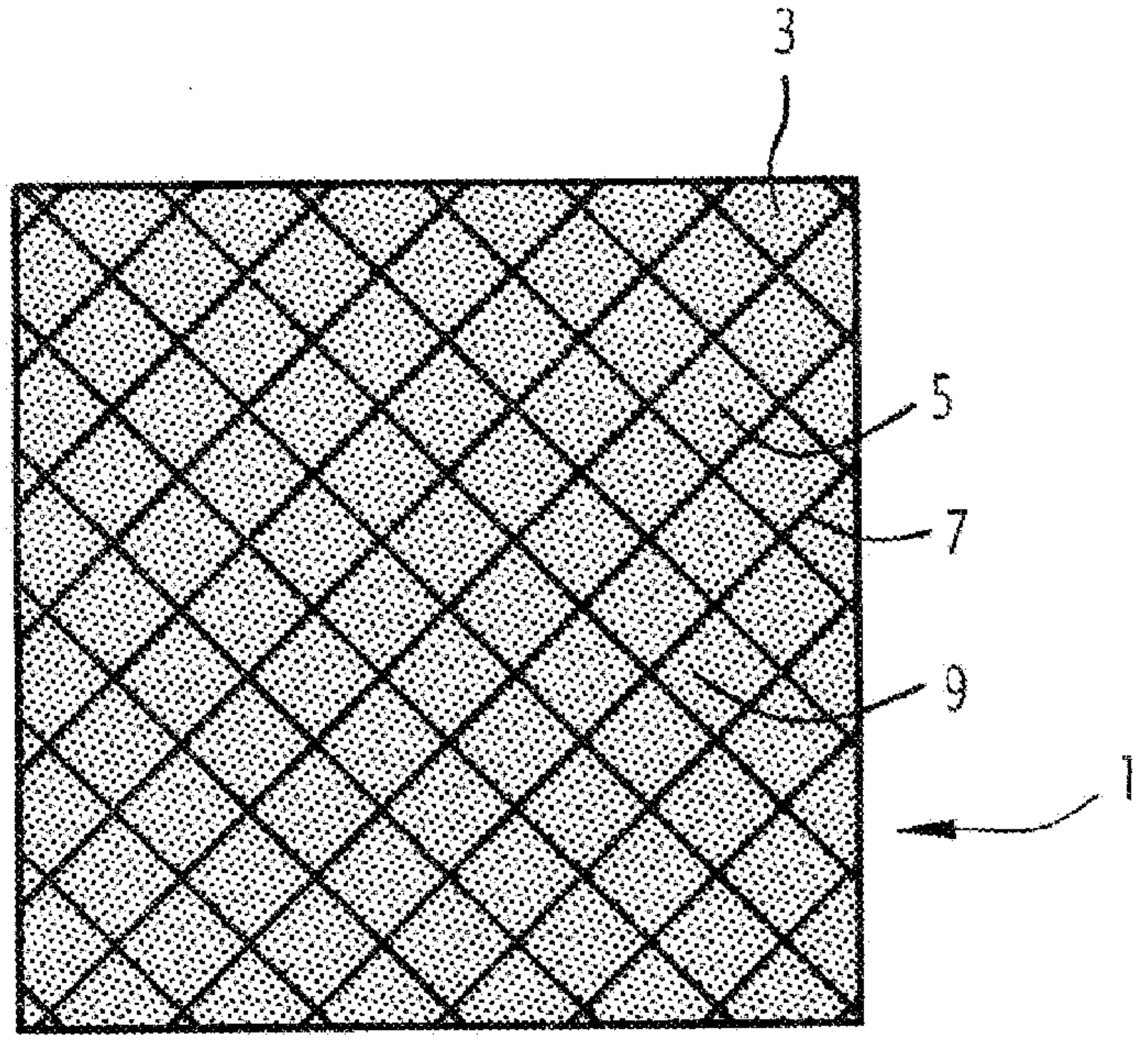

FIG.1

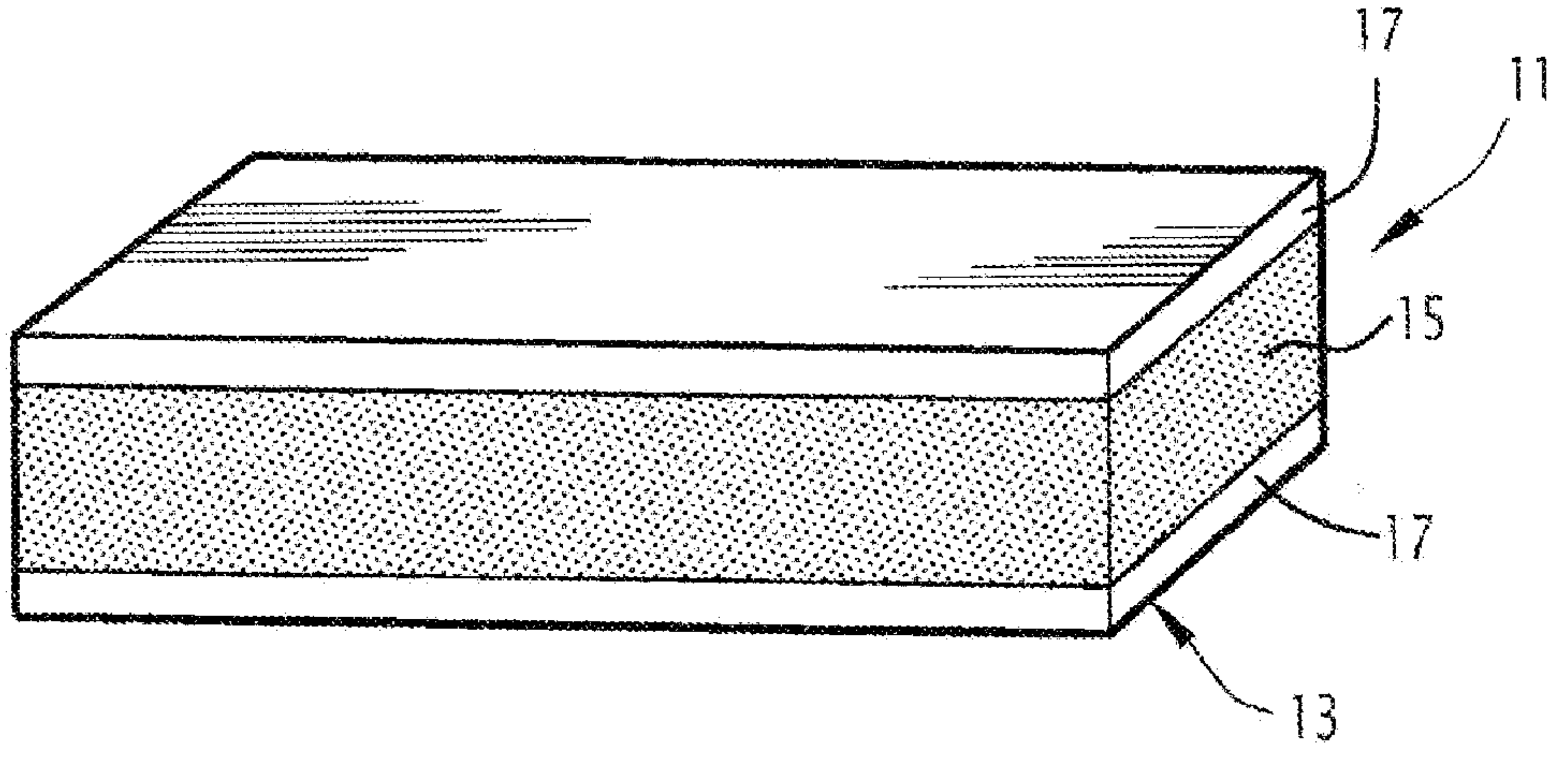

FIG.2

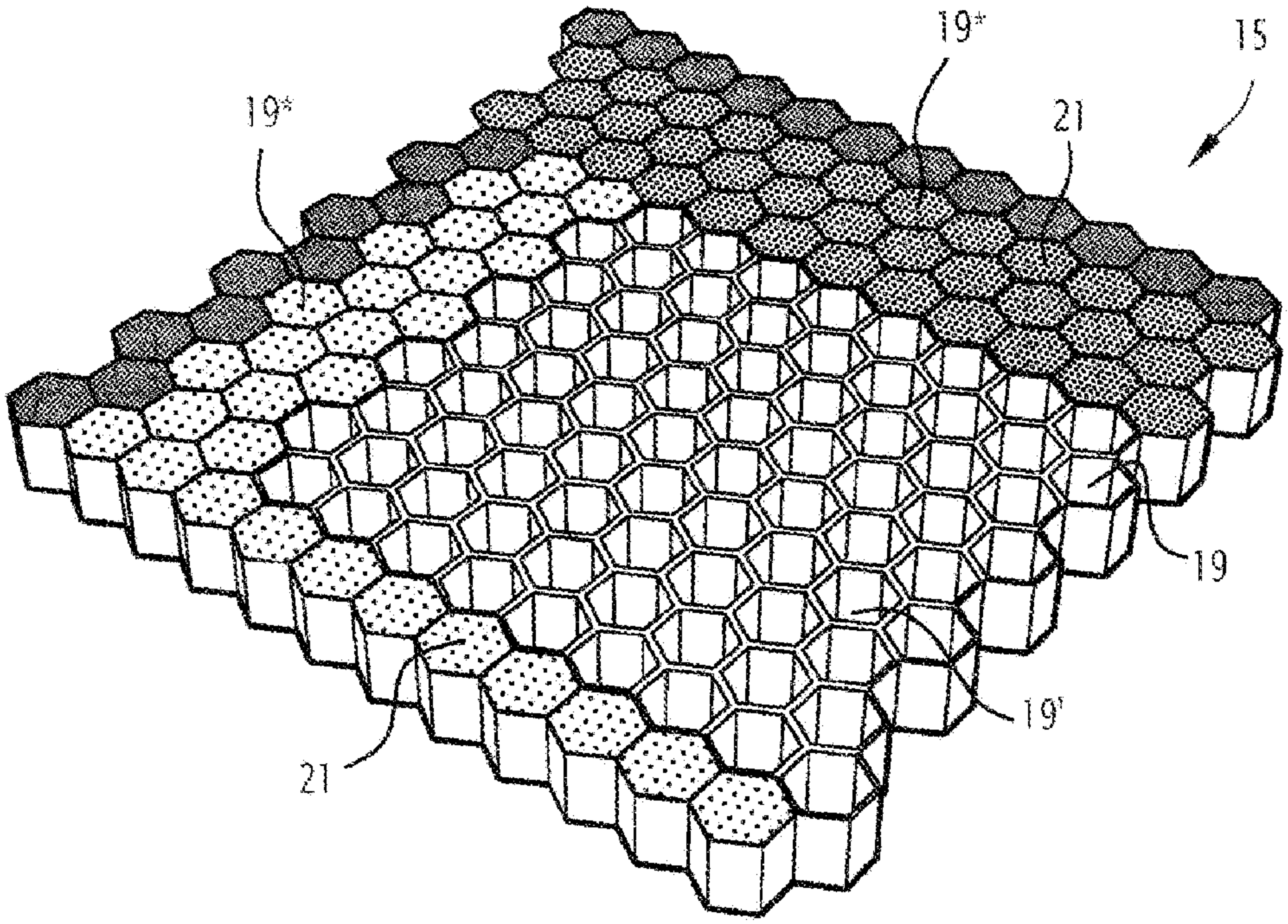

FIG.3

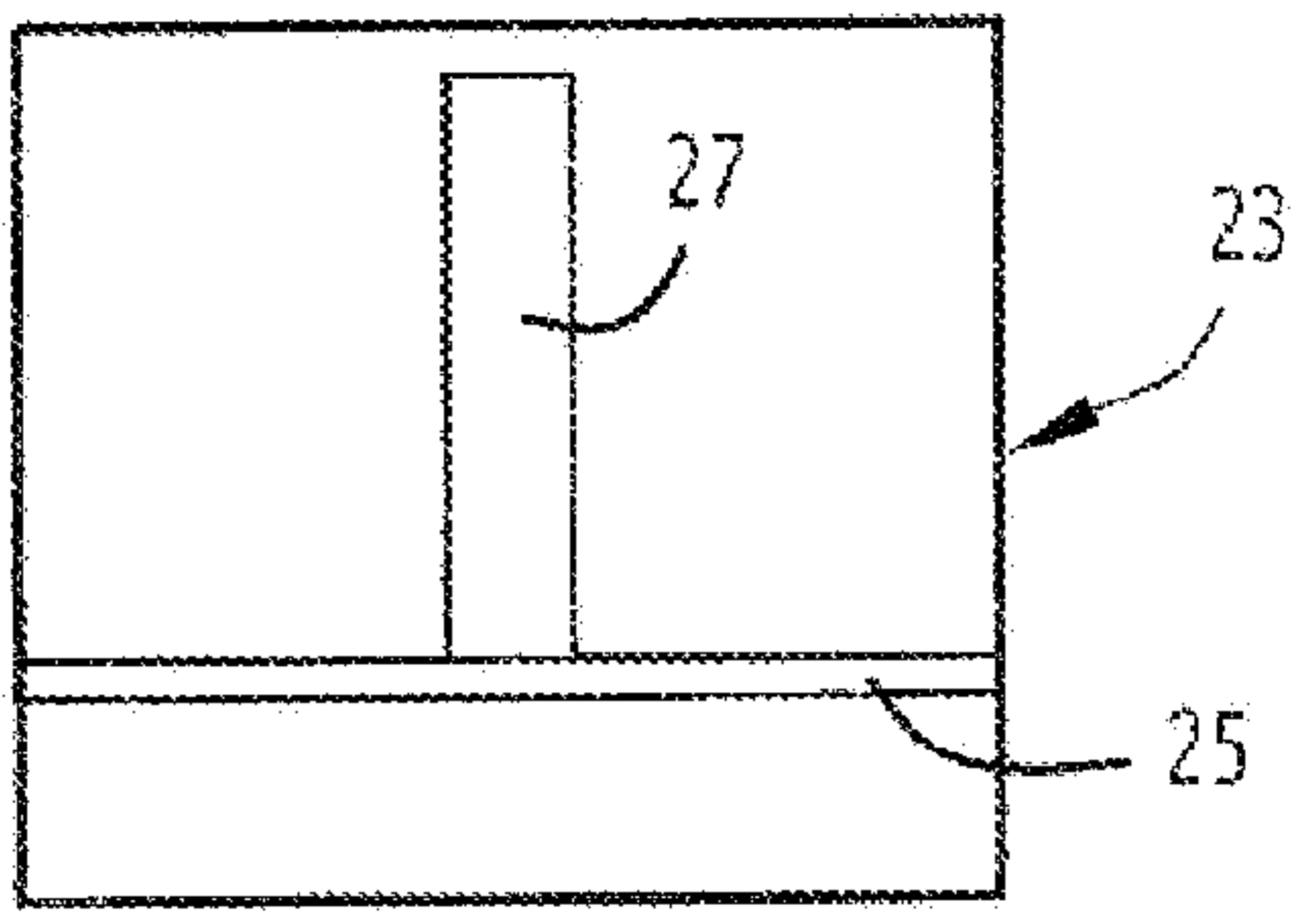

FIG.4

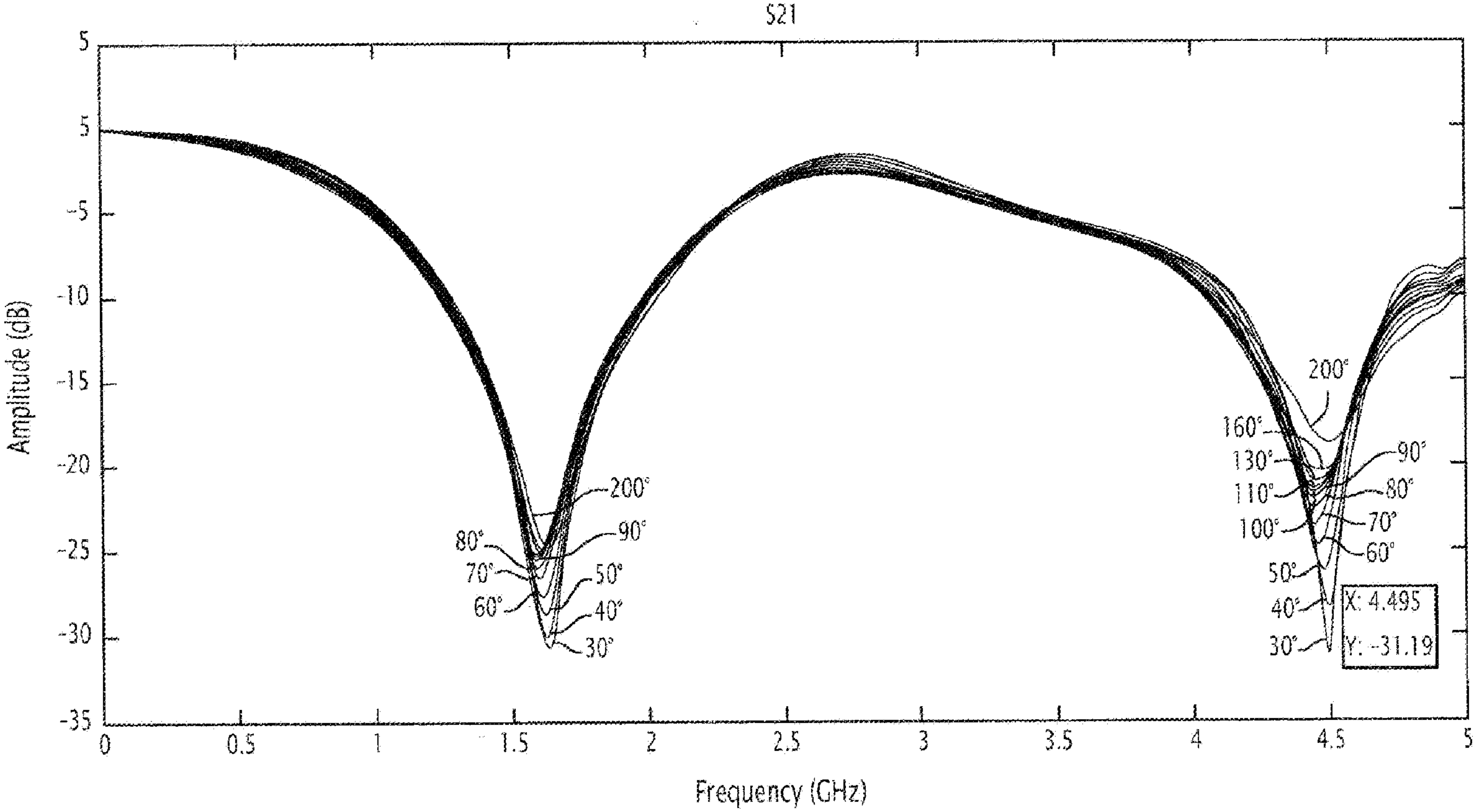
S21
Amplitude (dB)
5
5
-5
-10
-15
-20
-25
-30
-35
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Frequency (GHz)
200°
90°
80°
70°
60°
50°
40°
30°
200°
160°
130°
110°
100°
90°
80°
70°
60°
50°
40°
30°
X: 4.495
Y: -31.19

FIG.5

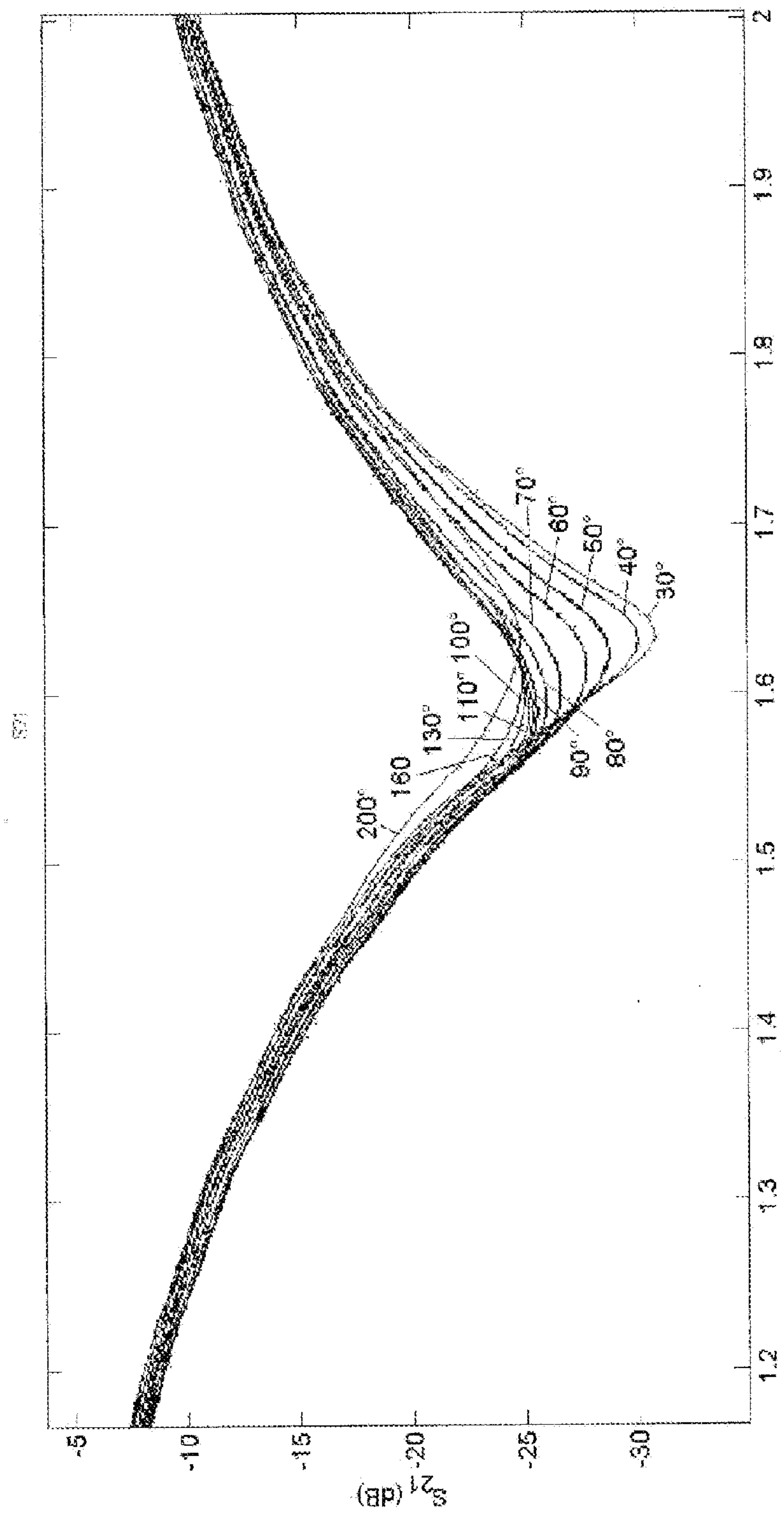
S21
S21 (dB)
-5
-10
-15
-20
-25
-30
F(GHz)
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
70°
60°
50°
40°
30°
100°
110°
130°
160
200°
90°
80°

FIG.6

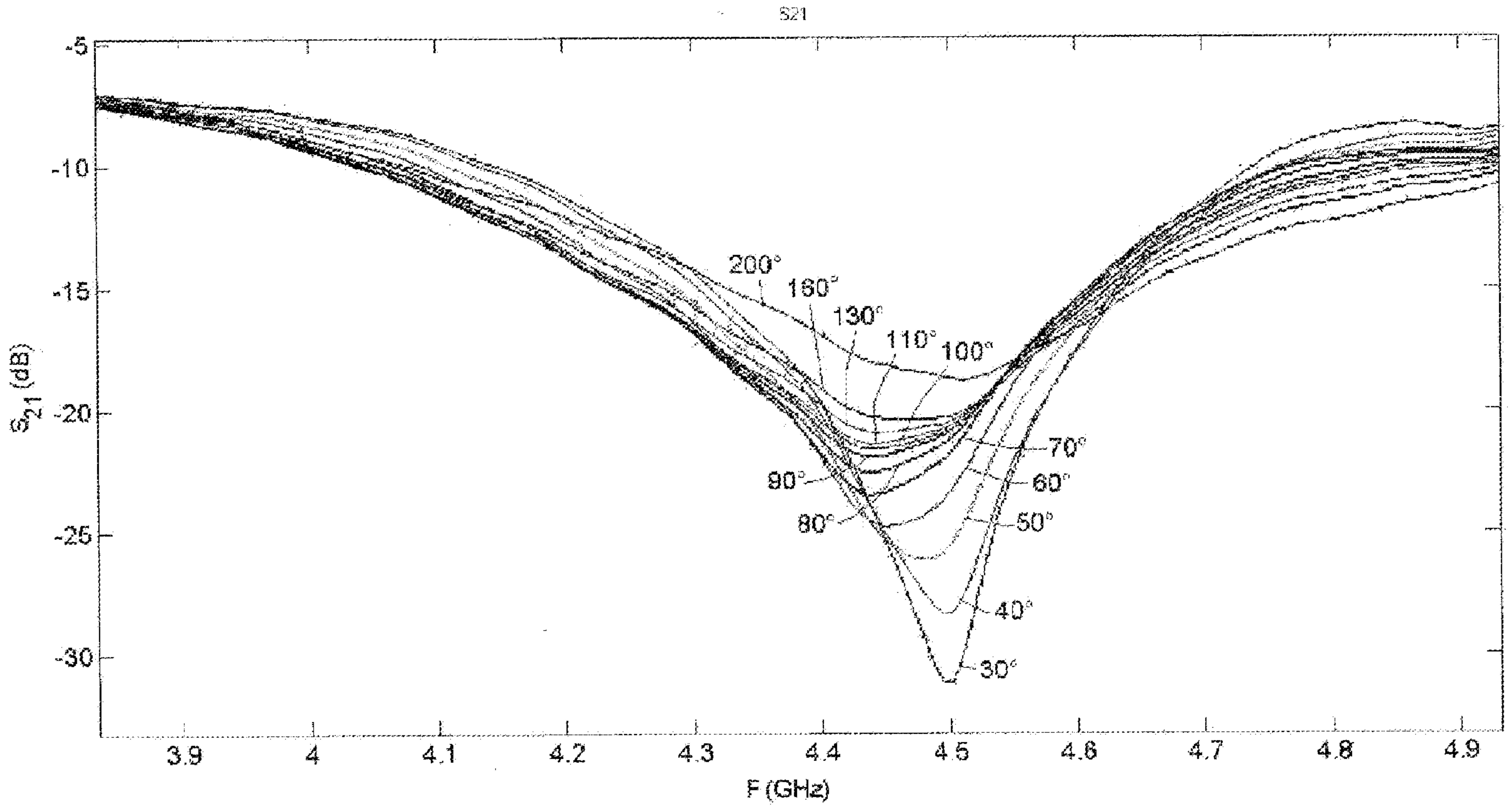
S21
-5
-10
-15
-20
-25
-30
S_{21} (dB)
3.9
4
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
F (GHz)
200°
160°
130°
110°
100°
90°
80°
70°
60°
50°
40°
30°

FIG.7

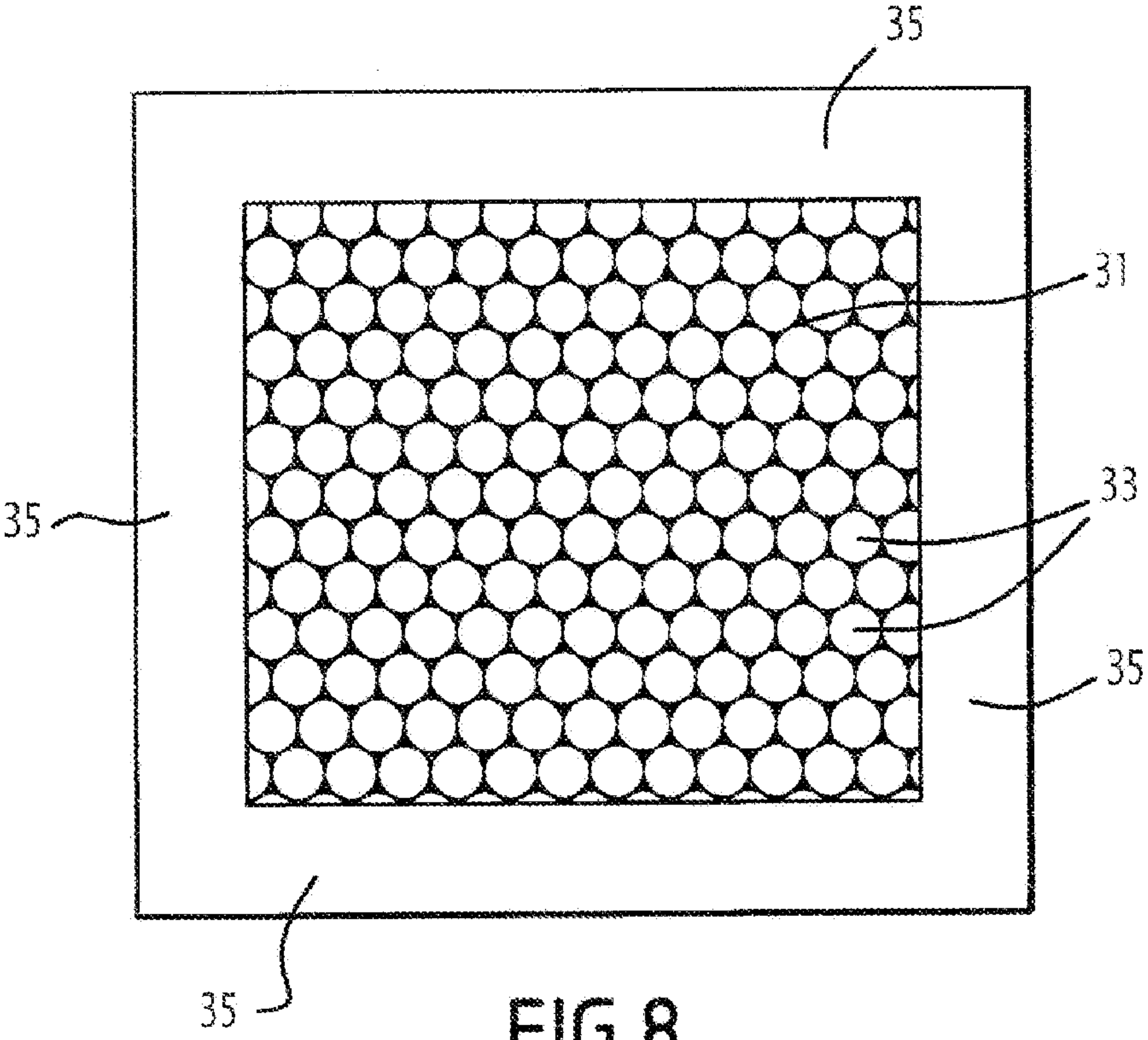
35
31
35
33
35
35

FIG.8

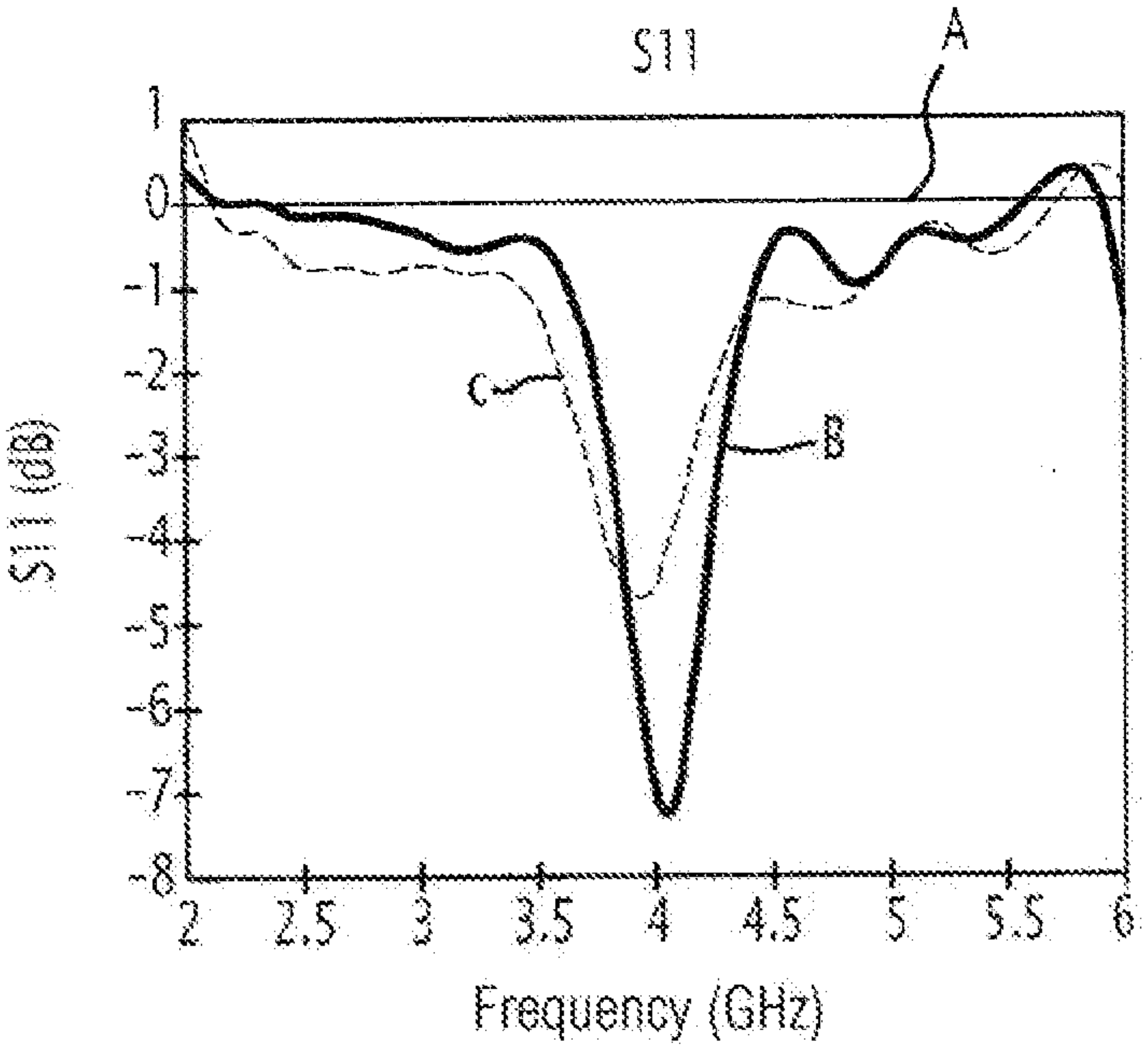
S11
A
1
0
-1
-2
-3
-4
-5
-6
-7
-8
S11 (dB)
C
B
2
2.5
3
3.5
4
4.5
5
5.5
6
Frequency (GHz)

FIG.9