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(54) **ANTENNA ISOLATION USING METAMATERIAL**

ANTENNENISOLIERUNG MITTELS METAMATERIAL

ISOLATION D'ANTENNE AU MOYEN D'UN MÉTAMATÉRIAU

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Description

[0001] This invention relates to techniques for improving isolation between antennas by using metamaterials, to the metamaterials themselves, and to antenna devices comprising such metamaterials.

BACKGROUND

[0002] A metamaterial is an artificial material engineered to have properties that are not found in nature. Naturally occurring materials exhibit electromagnetic behaviour determined by their atomic and molecular structures. With metamaterials, the electromagnetic behaviour is modified by introducing structural features into the material that are smaller than the wavelength electromagnetic wave propagating through the material. Typically these features will have a size $\lambda/10$ to $\lambda/20$. In their simplest form, these structural features are distributed capacitive and inductive elements fabricated on a dielectric substrate such as FR4 (commonly used in printed circuit boards (PCBs)). More complex structures are possible and the use of discrete components, such as commercial capacitors, has also been explored.

[0003] From the antenna designer's perspective, one of the potentially most useful properties of metamaterials is the engineering of a structure having a negative refractive index. Negative refractive index materials are not naturally occurring because all natural materials have positive values for both permittivity ϵ and permeability μ . There are many interesting properties of negative refractive index materials including changes to the normal geometric rules of diffraction, reversal of the Doppler shift, etc. However, the property usually of most interest to the radio and antenna engineer is that a material having either negative ϵ or negative μ (but not both) is opaque to electromagnetic radiation. The electromagnetic properties of a transparent material are fully specified by the parameters ϵ and μ , but it is common practice to refer to the refractive index n determined from $n = \pm\sqrt{\epsilon\mu}$. When n becomes negative, a common dielectric substrate material such as FR4 (which is naturally translucent at microwave radio frequencies) can be made opaque to radio waves. This can have applications for shielding an antenna from nearby conducting surfaces and for improving the isolation between antennas.

[0004] Negative refractive index metamaterials can be constructed at microwave frequencies using arrays of electrically conductive elements engineered to have a suitable capacitance **C** and inductance **L**. One of the earliest and most commonly used elements is the Split Ring Resonator (SRR) [Pendry, J B.; AJ Holden, DJ Robbins, and WJ Stewart. "Magnetism from Conductors and Enhanced Nonlinear Phenomena" IEEE Trans. Microwave Theory Tech 47 (11): 2075-2084, 1999]. Each SRR element comprises two or more concentric rings, each having a split. The capacitance of each element arises from the close spacing between the concentric rings and the

inductance from the thin printed traces used to create the rings.

[0005] It is known to provide a left-handed metamaterial with double L-shaped resonator inclusions [J. H. Lv, X. W. Hu, M.H. Liu, B. R. Yan and L. H. Kong.: "Negative refraction of a double L-shaped metamaterial", J. Opt. A: Pure Appl. Opt. 11 085101, 2009]. Here, the L-shaped resonators are formed of copper wire on an FR4 substrate, with each unit cell comprising a pair of L-shaped resonators arranged with one rotated by 180° to the other.

[0006] It is also known from Hsu, C-C et al. ["Design of MIMO Antennas with Strong Isolation for Portable Applications"; IEEE Antennas and Propagation Society International Symposium, 2009, pp 1-4] to provide a metamaterial with back-to-back L-shaped conductive members surrounded by a perimetral track. The metamaterial may be placed between a MIMO antenna pair to improve isolation.

[0007] Other metamaterials include those with splitting resonator unit cells, as described, for example, in Moser, H O et al. ["Electromagnetic metamaterials over the whole THz range - achievements and perspectives"; ELECTROMAGNETIC MATERIALS Proceedings of the Symposium R, ICMAT 2005 (World Scientific Publishing Co.): 18].

[0008] A commonly used microwave radio frequency is 2.4 GHz, which is employed for Bluetooth™ links, wireless local area networks (WLAN), etc. The wavelength at 2.4 GHz is around 120 mm and so each **LC** element in the array might be expected to have a size typically in the order of 6-12 mm.

[0009] SU H-L et al. "Dual-band insulator design by stacking capacitively loaded loops for MIMO antennas" in the Institution of Engineering and Technology Journal, vol. 46, no. 20, 30 September 2010 pages 1364 to 1365 describes a compact dual-band insulator for MIMO antennas. Capacitively loaded loops are designed for different operating frequencies and printed on both sides of the substrate of the MIMO antenna of the portable devices.

BRIEF SUMMARY OF THE DISCLOSURE

[0010] Modern radio communication systems often make use of antenna diversity or MIMO (Multiple Input, Multiple Output) antenna technology. Both diversity and MIMO systems require more than one antenna operating at the same time and on the same frequency and so good isolation between the antennas becomes important. Poor isolation leads to a loss of antenna efficiency because power from one antenna ends up in other antennas instead of being radiated. Poor isolation also leads to a loss of diversity and MIMO performance because the coupling between the antennas means they are not receiving sufficiently independent samples of the radio multipath environment.

[0011] The invention provides a metamaterial as defined in claim 1 and an antenna system as defined in

claim 13.

[0012] In an example, there is provided a metamaterial comprising an array of unit cells each formed by at least one conductive track, wherein the at least one conductive track of at least one of the unit cells has a different length or width or thickness to the at least one conductive track of the other unit cells.

[0013] The metamaterial may comprise a 2D array of unit cells formed on or in a dielectric substrate.

[0014] In some examples, the metamaterial may comprise a stack of 2D arrays of unit cells, each 2D array of unit cells formed on or in a respective dielectric substrate. At least one of the dielectric substrates in the stack may be made of a material having a different dielectric constant to at least one other of the dielectric substrates in the stack. This can help to improve the bandwidth over which the metamaterial provides isolation between two or more antennas.

[0015] The metamaterial may comprise a first 2D array of unit cells on a first surface of a dielectric substrate, and a second 2D array of unit cells on an opposed, second surface of the dielectric substrate. At least one further 2D array of unit cells may be formed as an interstitial layer within the dielectric substrate between the first and second 2D arrays.

[0016] The unit cells of at least one 2D array may each be formed by at least one conductive track having a different length or width or thickness to the at least one conductive track of the unit cells in at least one other 2D array. This can help to improve the bandwidth over which the metamaterial provides isolation between two or more antennas.

[0017] At least one and generally each unit cell may comprise at least one conductive track configured as a split-ring resonator. The split-ring resonator may be symmetrical about a mirror plane, or may be asymmetrical in accordance with the invention. In the present context, asymmetrical denotes a split-ring resonator that does not have a mirror symmetry plane perpendicular to the plane of the conductive track. Asymmetrical arrangements may provide isolation over a wider bandwidth than symmetrical arrangements.

[0018] According to the invention at least one unit cell comprises first and second L-shaped conductive members disposed back-to-back in a plane with a gap between the members, and connected together by a perimetral conductive track that runs from an arm of the first L-shaped conductive member to an arm of the second L-shaped conductive member so as substantially to surround both L-shaped conductive members in the plane.

[0019] In examples, the L-shaped conductive members, the split-ring resonators and/or the perimetral conductive track are formed on a dielectric substrate, for example a printed circuit board (PCB) substrate such as Duroid® or FR4, or on a flexible plastics substrate such as that used for flexi-circuits. In some embodiments, the L-shaped conductive members, the split-ring resonators and/or the perimetral conductive track may be printed or

formed on a dielectric substrate in the form of an adhesive tape, which can then be applied to a PCB substrate as required.

[0020] In some examples, the perimetral conductive track may be generally rectangular in outline. Alternatively, generally circular, elliptical, oval or other polygonal outlines may be employed.

[0021] A gap may be defined in the perimetral conductive track corresponding to the gap between the back-to-back L-shaped conductive members. In other words, the perimetral conductive track may be split between the two L-shaped members.

[0022] Alternatively, the perimetral conductive track is not split between the two L-shaped members, but forms a continuous perimeter.

[0023] The array of elements may be configured as an $n \times m$ array having a generally 2-D configuration. Alternatively, the array of elements may be configured as an $l \times n \times m$ array having a generally 3-D configuration. In yet further embodiments, several layers of metamaterial may be stacked on top of each other, with each layer having the same or different 2-D arrays of elements formed thereon.

[0024] The elements within any given array may be generally of the same shape and size. Alternatively, one or more elements within any given array may have slightly different sizes or shapes so that the elements are resonant at slightly different frequencies. According to the invention, one of the L-shaped conductive members in at least one of the elements is differently sized and/or shaped than the other L-shaped conductive member. These arrangements may help to improve bandwidth.

[0025] It is not necessary for each array of elements to be a filled array. Indeed, one or more elements may be omitted from an array, and this has been found to improve the degree of isolation across a wider bandwidth. Moreover, it is possible to provide a degree of tuning by altering a position of one or more elements where space is made available through not filling the array. For example, an incompletely filled array may comprise a left hand column of two elements, a right hand column of two elements, and a middle column with only one element. By moving the element in the middle column up or down the column, the bandwidth of the metamaterial can be fine-tuned as required.

[0026] The metamaterial may be used to improve isolation between two or more antennas. This is of particular advantage in antenna systems using antenna diversity or MIMO technology, since these employ several antennas operating simultaneously within a small space.

[0027] Examples provide an antenna system comprising at least two antennas disposed on a substrate and a portion of metamaterial of the examples disposed between the at least two antennas.

[0028] It is also possible to use a metamaterial comprising a dielectric substrate with first and second opposed surfaces, with a first pattern of elements formed on the first surface and a second pattern of elements

formed on the second surface. The first and second patterns of elements may be tuned to different frequencies or frequency bands, and the dual surface metamaterial, when disposed between a pair of dual-band antennas, can improve antenna isolation on both bands.

[0029] A similar result may be achieved by forming a first metamaterial comprising a dielectric substrate with a first pattern of elements, forming a second metamaterial comprising a dielectric substrate with a second pattern of elements, and then positioning the second metamaterial on top of the first metamaterial between a pair of antennas.

[0030] This principle may be extended to multiple metamaterial layers or surfaces so as to improve isolation between two antennas in several bands.

[0031] The metamaterial can also be used to improve isolation between several (more than two) antennas, including several antennas disposed in a co-planar fashion and in geometries other than co-planar.

[0032] In some examples, the conductive structures of the metamaterial are printed or otherwise formed on one or both surfaces of a dielectric substrate material, for example FR4. In other examples, the conductive structures are printed or otherwise formed on an interstitial layer of dielectric substrate material, such as FR4. It will be appreciated that other common PCB substrate materials, including Duroid®, may also be used. Multiple layers of dielectric substrate with the same or different dielectric constant may be used.

[0033] Other low or high dielectric constant materials (typically in the range of 1 to 90) may be used as substrates for the metamaterial.

[0034] The novel metamaterial structure of certain embodiments can be used to increase the isolation between a pair of closely spaced antennas. The metamaterial structure of some examples may be low cost as it can be printed on a layer of FR4, a low cost substrate material often used in the radio industry. Some examples have a further advantage that, for dual band antennas and antenna arrangement, the metamaterial can be engineered to improve the isolation between both bands. This can be achieved by introducing an additional layer of dielectric substrate, printed with a different array of LC elements, above or below the first layer. Indeed, isolation between more bands is possible by introducing more layers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] Examples are further described hereinafter with reference to the accompanying drawings, in which:

Figure 1 shows a prior art arrangement comprising a pair of closely spaced dual-band WLAN antennas on a PCB;

Figure 2 is a plot showing the isolation between the two WLAN antennas of the Figure 1 arrangement;

Figure 3 shows a first example comprising a meta-

material on a PCB;

Figure 4 shows a second example comprising a metamaterial on a PCB;

Figure 5 shows a third example comprising a dual-band composite metamaterial comprising a first layer of the Figure 3 example and a second layer of the Figure 4 example;

Figure 6 shows the metamaterial of Figure 5 disposed between a pair of WLAN antennas similar to those shown in Figure 1;

Figure 7 is a plot showing the isolation between the two WLAN antennas of the Figure 6 arrangement;

Figure 8 shows how the metamaterial of the Figure 5 example can be tuned by moving a middle element on one layer of metamaterial;

Figure 9 is a plot showing the isolation between the two WLAN antennas of the Figure 6 arrangement when a middle element on one layer of metamaterial is moved;

Figure 10 shows a metamaterial comprising a 2D array of split-ring resonators on a dielectric substrate with one or more of the split-ring resonators having a different size to the others;

Figure 11 shows a metamaterial comprising a 2D array of split-ring resonators on a dielectric substrate with one or more of the split-ring resonators having a different shape to the others;

Figure 12 shows a metamaterial comprising a 2D array of split-ring resonators having a first configuration on one surface of a dielectric substrate, and a 2D array of split-ring resonators having a second, different configuration on the other surface of the dielectric substrate; and

Figure 13 shows a metamaterial comprising a 2D array of split-ring resonators having a first configuration on one surface of a dielectric substrate, a 2D array of split-ring resonators having a second, different configuration on the other surface of the dielectric substrate, and an interstitial 2D array of split-ring resonators having a third, different configuration between the surfaces of the dielectric substrate.

DETAILED DESCRIPTION

[0036] Figure 1 shows two coplanar 2.4/5 GHz dual-band quarter-wave monopole antennas 1, 2 are closely spaced in a generally parallel arrangement on a PCB 3 comprising a dielectric substrate 4 with a conductive groundplane 5 over part of the substrate 4, and an area 6 free of groundplane 5 where the antennas 1, 2 are located. It will be appreciated that this is just an exemplary arrangement, and that other types of antenna and other frequency bands may be used with examples of the present application given suitable adjustments of the metamaterial design. In Figure 1, the width of the PCB 3 is 20 mm and the antenna area 6 clear of groundplane 5 is 15 mm long. The long lower portion 7 of the antenna is generally responsible for the radiation of 2.4 GHz and

the elevated portions 1, 2 for the 5 GHz radiation. The height of the antenna at its tallest part is 3.2 mm.

[0037] In the 2.40 - 2.48 GHz WLAN band, the monopole antennas 1, 2 are spaced only about $\lambda/6$ apart and so the isolation between them is poor at around -6 dB, see Figure 2. In the 4.9 - 5.9 GHz WLAN band, the monopole antennas 1, 2 are electrically further apart, but even so, the worst-case the isolation remains poor at around -8 dB.

[0038] A metamaterial structure of an example of the present application is shown in Figure 3. A plurality of conductive **LC** (inductive capacitive) elements 8 are printed on a single surface of FR4 substrate 9 and require no vias to ground (used in some metamaterial structures). In the illustrated example, the elements 8 are not conductively connected to each other. The inductance of each element 8 arises from the narrow conductive tracks 10 and the capacitance primarily from the closely spaced back-to-back L-shaped elements 11. The use of double L-shaped metamaterials has been described in the literature [J. H. Lv, X. W. Hu, M.H. Liu, B. R. Yan and L. H. Kong.: "Negative refraction of a double L-shaped metamaterial", J. Opt. A: Pure Appl. Opt. 11 085101, 2009], but here one L-shape is inverted with respect to the other and not back-to-back as described in the present application. It has been found advantageous to use an unfilled array of elements 8, as shown in Figure 3, where an element 8 is absent at location 12. Removing an element has been found to improve bandwidth and moving the remaining centre element 13 (in this example) up and down may be used to tune the bandwidth to a particular application. The metamaterial structure of Figure 3 provides good electromagnetic isolation at around 2.4 GHz.

[0039] An alternative metamaterial design is shown in Figure 4, and is tuned to the 5 GHz band. As with the Figure 3 example, a plurality of conductive **LC** elements 8' are printed on a single surface of FR4 substrate 9, but in the Figure 4 example, the elements 8' are conductively linked to each other and arranged as a pair of closely spaced columns. Other arrangements are possible.

[0040] In order to achieve a practical dual-band device, two different metamaterial surfaces can be combined. For example, a 5 GHz surface of the Figure 4 example can be mounted on top of and appropriately registered or aligned with a 2.4 GHz surface of the Figure 3 example, as shown in Figure 5, to provide a dual-band metamaterial 14.

[0041] Figure 6 shows a complete structure of a pair of monopole antennas 1, 2 on a PCB 3, with a dual-band combined metamaterial 14 of Figure 5 disposed between the monopole antennas 1, 2.

[0042] With the dual-band metamaterial 14 in place, the isolation between the antennas 1, 2 is improved in both bands, as shown in Figure 7. In the lower 2.4 GHz band the isolation has a very deep null and even at the band edges it is around -12 dB. This could be improved by careful tuning of the metamaterial 14 to put the null

exactly in the centre of the band. In the high frequency band the isolation around 5 GHz is -20 dB. This notch may be moved to any part of the 4.9 - 5.9 GHz band by retuning the metamaterial 14.

[0043] The lower layer of the dual-band metamaterial 14 is an unfilled array and has one element missing in the centre column (see Figure 3). Moving the position of the element within the column, see Figure 8, can be used to change the bandwidth of isolation in the 5GHz band without much affecting the isolation frequency of the 2.4 GHz. This effect is shown in Figure 9.

[0044] In this exemplary arrangement the 2.4 GHz metamaterial has been shown as a 3x2 element array, whereas the 5 GHz metamaterial has been shown as a 2x3 array. It will be appreciated that other array configurations are possible with greater or smaller number of elements. It will also be appreciated that more than one array element may be removed to tune the bandwidth of the isolation effect.

[0045] In the exemplary arrangement described above, FR4 has been used as the substrate material. Many other types of substrate materials may be used including low and high dielectric materials. Generally the beneficial characteristics of a metamaterial improve with increasing numbers of elements in the array. For a given platform size, the use of a high dielectric substrate may be used to shrink the element size and allow more elements to be used in the array.

[0046] The exemplary arrangement above describes a dual-band metamaterial comprising two layers. In general, n-band metamaterials can be created using n-layer substrates.

[0047] Although isolation between two antennas has been described in the exemplary arrangement above, isolation between greater numbers is possible by suitably disposing metamaterial elements between all the pairs.

[0048] The exemplary arrangement above describes two coplanar antennas, but the metamaterial described may also be used to improve isolation between antennas disposed using other geometries.

[0049] Figure 10 shows a metamaterial comprising a 2D array of split-ring resonators 8 on a dielectric substrate 9 with one or more of the split-ring resonators 8 having a different size to the others. This may help to provide isolation over a wider bandwidth.

[0050] Figure 11 shows a metamaterial comprising a 2D array of split-ring resonators 8 on a dielectric substrate 9 with one or more of the split-ring resonators 8 having a different shape to the others. This may help to provide isolation over a wider bandwidth.

[0051] Figure 12 shows a metamaterial comprising a 2D array of split-ring resonators 8 having a first configuration on one surface of a dielectric substrate 9, and a 2D array of split-ring resonators 8' having a second, different configuration on the other surface of the dielectric substrate 9. This may help to provide isolation over a wider bandwidth.

[0052] Figure 13 shows a metamaterial comprising a

2D array of split-ring resonators 8 having a first configuration on one surface of a dielectric substrate 9, a 2D array of split-ring resonators 8' having a second, different configuration on the other surface of the dielectric substrate 9, and an interstitial 2D array of split-ring resonators 8" having a third, different configuration between the surfaces of the dielectric substrate 9. This may help to provide isolation over a wider bandwidth.

[0053] Throughout the description and claims of this specification, the words "comprise" and "contain" and variations of them mean "including but not limited to", and they are not intended to (and do not) exclude other moieties, additives, components, integers or steps. Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

[0054] Features, integers, characteristics, compounds, chemical moieties or groups described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The invention is not restricted to the details of any foregoing embodiments. The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Claims

1. A metamaterial comprising an array of unit cells each formed by at least one conductive track (10), wherein the at least one conductive track (10) of at least one of the unit cells is configured as an asymmetrical split-ring resonator which does not have a mirror symmetry plane perpendicular to a plane of the conductive track (10), wherein the at least one unit cell comprises first and second L-shaped conductive members (11) disposed back-to-back in a plane with a gap between the members (11), and connected together by a perimetral conductive track that runs from an arm of the first L-shaped conductive member (11) to an arm of the second L-shaped conductive member (11) so as substantially to surround both L-shaped conductive members (11) in the plane, and wherein the first and second L-shaped conductive members (11) in at least one of the unit cells are

differently sized and/or shaped to each other.

2. A metamaterial as claimed in claim 1, comprising a stack of 2D arrays of unit cells, each 2D array of unit cells formed on or in a respective dielectric substrate (9).
3. A metamaterial as claimed in claim 2, wherein at least one of the dielectric substrates (9) in the stack is made of a material having a different dielectric constant to at least one other of the dielectric substrates (9) in the stack.
4. A metamaterial as claimed in claim 1, comprising a first 2D array of unit cells on a first surface of a dielectric substrate (9), and a second 2D array of unit cells on an opposed, second surface of the dielectric substrate (9) and further comprising at least one further 2D array of unit cells formed as in interstitial layer within the dielectric substrate (9) between the first and second 2D arrays.
5. A metamaterial as claimed in any one of claims 2 to 4, wherein the unit cells of at least one 2D array are each formed by at least one conductive track (10) having a different length or width or thickness to the at least one conductive track (10) of the unit cells in at least one other 2D array.
6. A metamaterial as claimed in any preceding claim, wherein each unit cell comprises at least one conductive track (10) configured as a split-ring resonator.
7. A metamaterial as claimed in claim 1, wherein the perimetral conductive track (10) of the at least one unit cell is either generally rectangular in outline or is generally circular, elliptical, oval or polygonal in outline.
8. A metamaterial as claimed in claim 1, wherein for the at least one unit cell, a gap is defined in the perimetral conductive track (10) corresponding to the gap between the back-to-back L-shaped conductive members (11).
9. A metamaterial as claimed in claim 1, wherein for the at least one unit cell, the perimetral conductive track (10) is not split between the two L-shaped members (11), but forms a continuous perimeter.
10. A metamaterial of any one of claims 1 to 9, wherein one or more unit cells have different sizes or shapes so that the unit cells are resonant at different frequencies.
11. A metamaterial as claimed in any preceding claim, wherein the array of unit cells is not a filled array,

one or more elements having been omitted therefrom.

12. A metamaterial as claimed in claim 1, wherein the at least one conductive track of at least one unit cell has a different length or width or thickness to the at least one conductive track (10) of the other unit cells.
13. An antenna system comprising at least two antennas (1,2) disposed on a substrate (4) and a portion of metamaterial as claimed in any one of claims 1 to 12 disposed between the at least two antennas (1,2).

Patentansprüche

1. Metamaterial, umfassend eine Anordnung von Elementarzellen, die jeweils durch mindestens eine Leiterbahn (10) ausgebildet sind, wobei die mindestens eine Leiterbahn (10) mindestens einer der Elementarzellen als asymmetrischer Spaltring-Resonator konfiguriert ist, der keine Spiegelsymmetrieebene senkrecht zu einer Ebene der Leiterbahn (10) aufweist, wobei die mindestens eine Elementarzelle erste und zweite L-förmige leitende Elemente (11) umfasst, die hintereinander in einer Ebene mit einem Spalt zwischen den Elementen (11) angeordnet sind, und durch eine umlaufende Leiterbahn miteinander verbunden ist, die von einem Arm des ersten L-förmigen leitenden Elements (11) zu einem Arm des zweiten L-förmigen leitenden Elements (11) verläuft, um im Wesentlichen beide L-förmigen leitenden Elemente (11) in der Ebene zu umgeben, und wobei das erste und zweite L-förmige leitende Element (11) in mindestens einer der Elementarzellen unterschiedlich groß und/oder geformt sind.
2. Metamaterial nach Anspruch 1, umfassend einen Stapel von 2D-Anordnungen von Elementarzellen, wobei jede 2D-Anordnung von Elementarzellen auf oder in einem jeweiligen dielektrischen Substrat (9) ausgebildet ist.
3. Metamaterial nach Anspruch 2, wobei mindestens eines der dielektrischen Substrate (9) im Stapel aus einem Material mit einer unterschiedlichen Dielektrizitätskonstante als mindestens eines anderen der dielektrischen Substrate (9) im Stapel hergestellt ist.
4. Metamaterial nach Anspruch 1, umfassend eine erste 2D-Anordnung von Elementarzellen auf einer ersten Oberfläche eines dielektrischen Substrats (9) und eine zweite 2D-Anordnung von Elementarzellen auf einer gegenüberliegenden, zweiten Oberfläche des dielektrischen Substrats (9) und weiter umfassend mindestens eine weitere 2D-Anordnung von Elementarzellen, die als Zwischenschicht innerhalb des dielektrischen Substrats (9) zwischen der ersten

und zweiten 2D-Anordnung ausgebildet sind.

5. Metamaterial nach einem der Ansprüche 2 bis 4, wobei die Elementarzellen mindestens einer 2D-Anordnung jeweils durch mindestens eine Leiterbahn (10) mit einer unterschiedlichen Länge oder Breite oder Dicke als die mindestens eine Leiterbahn (10) der Elementarzellen in mindestens einer anderen 2D-Anordnung ausgebildet sind.
6. Metamaterial nach einem der vorstehenden Ansprüche, wobei jede Elementarzelle mindestens eine Leiterbahn (10) umfasst, die als Spaltring-Resonator konfiguriert ist.
7. Metamaterial nach Anspruch 1, wobei die umlaufende Leiterbahn (10) der mindestens einen Elementarzelle entweder im Allgemeinen rechteckig im Umriss oder im Allgemeinen kreisförmig, elliptisch, oval oder polygonal im Umriss ist.
8. Metamaterial nach Anspruch 1, wobei für die mindestens eine Elementarzelle ein Spalt in der umlaufenden Leiterbahn (10) definiert ist, der dem Spalt zwischen den hintereinander angeordneten L-förmigen leitenden Elementen (11) entspricht.
9. Metamaterial nach Anspruch 1, wobei für die mindestens eine Elementarzelle die umlaufende Leiterbahn (10) nicht zwischen den beiden L-förmigen Elementen (11) aufgeteilt ist, sondern eine kontinuierliche Umfangslinie bildet.
10. Metamaterial nach einem der Ansprüche 1 bis 9, wobei eine oder mehrere Elementarzellen unterschiedliche Größen oder Formen aufweisen, so dass die Elementarzellen bei verschiedenen Frequenzen resonant sind.
11. Metamaterial nach einem der vorstehenden Ansprüche, wobei die Anordnung von Elementarzellen keine gefüllte Anordnung ist, wobei ein oder mehrere Elemente davon weggelassen wurden.
12. Metamaterial nach Anspruch 1, wobei die mindestens eine Leiterbahn mindestens einer Elementarzelle eine unterschiedliche Länge, Breite oder Dicke aufweist als die mindestens eine Leiterbahn (10) der anderen Elementarzellen.
13. Antennensystem, umfassend mindestens zwei Antennen (1,2), die auf einem Substrat (4) angeordnet sind, und einen Abschnitt aus Metamaterial nach einem der Ansprüche 1 bis 12, der zwischen den mindestens zwei Antennen (1,2) angeordnet ist.

Revendications

1. Métamatériau comprenant un groupement de cellules unitaires formées chacune par au moins une piste conductrice (10), dans lequel l'au moins une piste conductrice (10) d'au moins une des cellules unitaires est configurée comme un résonateur à bague fendue asymétrique qui n'a pas de plan de symétrie miroir perpendiculaire à un plan de la piste conductrice (10), dans lequel l'au moins une cellule unitaire comprend des premier et second éléments conducteurs en forme de L (11) disposés dos à dos dans un plan avec un espacement entre les éléments (11), et reliés ensemble par une piste conductrice périmétrique qui court à partir d'un bras du premier élément conducteur en forme de L (11) jusqu'à un bras du second élément conducteur en forme de L (11) afin de sensiblement entourer les deux éléments conducteurs en forme de L (11) dans le plan, et dans lequel les premier et second éléments conducteurs en forme de L (11) dans au moins une des cellules unitaires ont une taille et/ou une forme différentes l'un par rapport à l'autre. 5
2. Métamatériau selon la revendication 1, comprenant un empilement de groupements 2D de cellules unitaires, chaque groupement 2D de cellules unitaires formées sur ou dans un substrat diélectrique respectif (9). 10
3. Métamatériau selon la revendication 2, dans lequel au moins un des substrats diélectriques (9) dans l'empilement est fait d'une matière ayant une constante diélectrique différente d'au moins un autre des substrats diélectriques (9) dans l'empilement. 15
4. Métamatériau selon la revendication 1, comprenant un premier groupement 2D de cellules unitaires sur une première surface d'un substrat diélectrique (9) et un deuxième groupement 2D de cellules unitaires sur une seconde surface opposée du substrat diélectrique (9) et comprenant en outre au moins un groupement 2D supplémentaire de cellules unitaires formées comme une couche interstitielle à l'intérieur du substrat diélectrique (9) entre les premier et deuxième groupements 2D. 20
5. Métamatériau selon l'une quelconque des revendications 2 à 4, dans lequel les cellules unitaires d'au moins un groupement 2D sont formées chacune par au moins une piste conductrice (10) ayant une longueur ou largeur ou épaisseur différente d'au moins une piste conductrice (10) des cellules unitaires dans au moins un autre groupement 2D. 25
6. Métamatériau selon l'une quelconque des revendications précédentes, dans lequel chaque cellule unitaire comprend au moins une piste conductrice (10) 30
7. Métamatériau selon la revendication 1, dans lequel la piste conductrice périmétrique (10) de l'au moins une cellule unitaire est soit globalement rectangulaire dans le contour soit est globalement circulaire, elliptique, ovale ou polygonale dans le contour. 35
8. Métamatériau selon la revendication 1, dans lequel pour l'au moins une cellule unitaire, un espacement est défini dans la piste conductrice périmétrique (10) correspondant à l'espacement entre les éléments conducteurs en forme de L dos à dos (11). 40
9. Métamatériau selon la revendication 1, dans lequel pour l'au moins une cellule unitaire, la piste conductrice périmétrique (10) n'est pas divisée entre les deux éléments en forme de L (11), mais forme un périmètre continu. 45
10. Métamatériau selon l'une quelconque des revendications 1 à 9, dans lequel une ou plusieurs cellules unitaires ont des tailles ou des formes différentes de sorte que les cellules unitaires sont résonantes à des fréquences différentes. 50
11. Métamatériau selon l'une quelconque des revendications précédentes, dans lequel le groupement de cellules unitaires n'est pas un groupement rempli, un ou plusieurs éléments ayant été omis de celui-ci. 55
12. Métamatériau selon la revendication 1, dans lequel au moins une piste conductrice d'au moins une cellule unitaire a une longueur ou largeur ou épaisseur différente d'au moins une piste conductrice (10) des autres cellules unitaires.
13. Système d'antenne comprenant au moins deux antennes (1, 2) disposées sur un substrat (4) et une portion de métamatériau selon l'une quelconque des revendications 1 à 12 disposée entre les au moins deux antennes (1, 2).

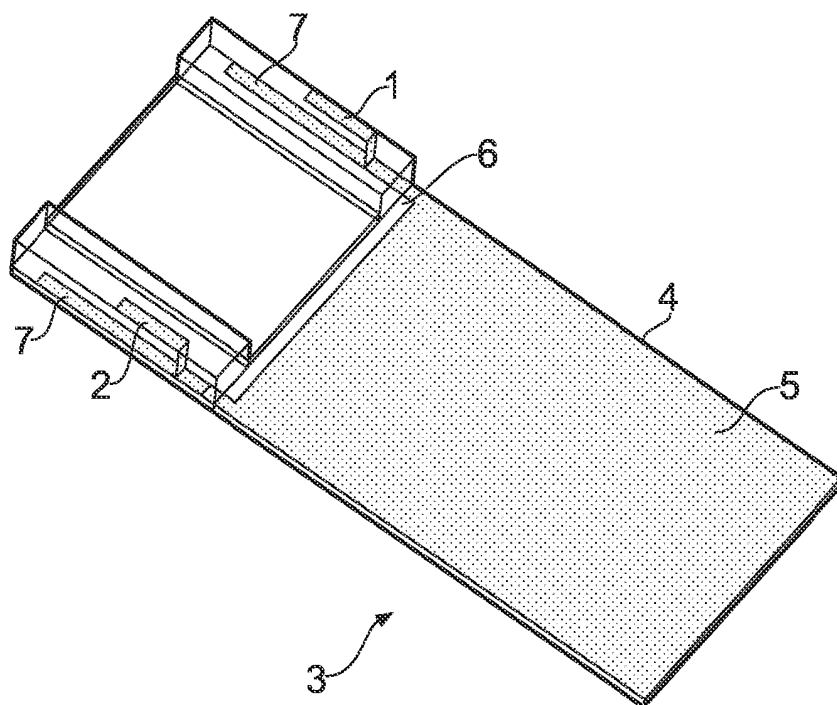


FIG. 1

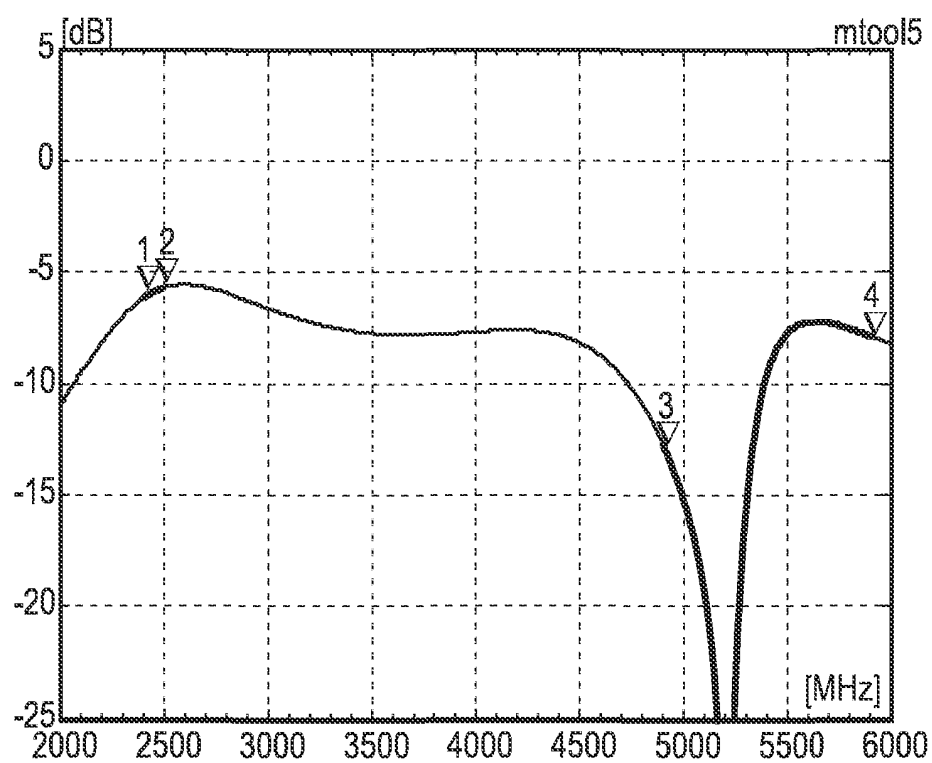


FIG. 2

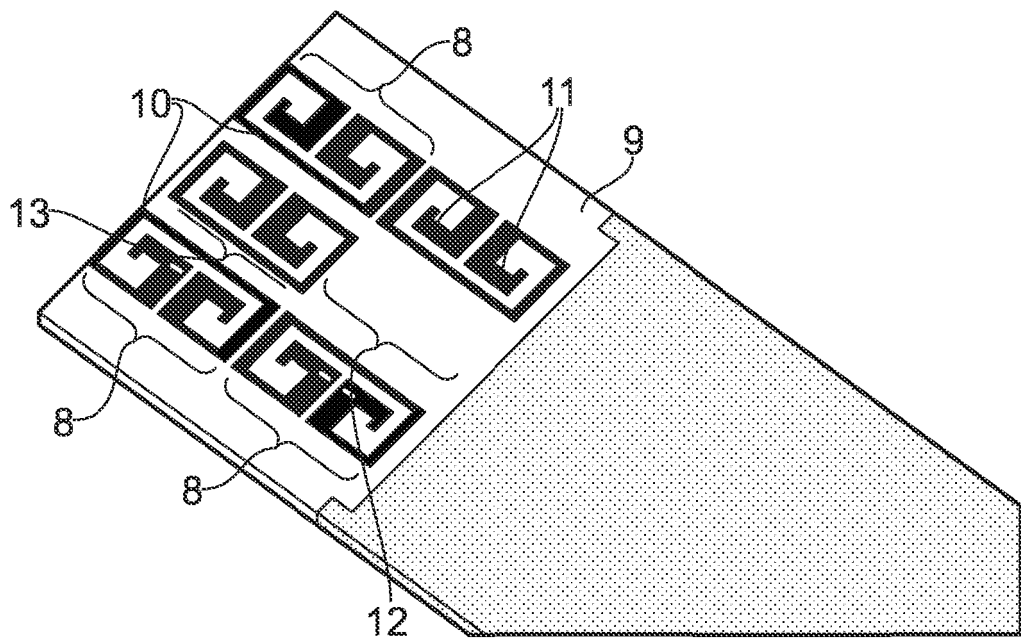


FIG. 3

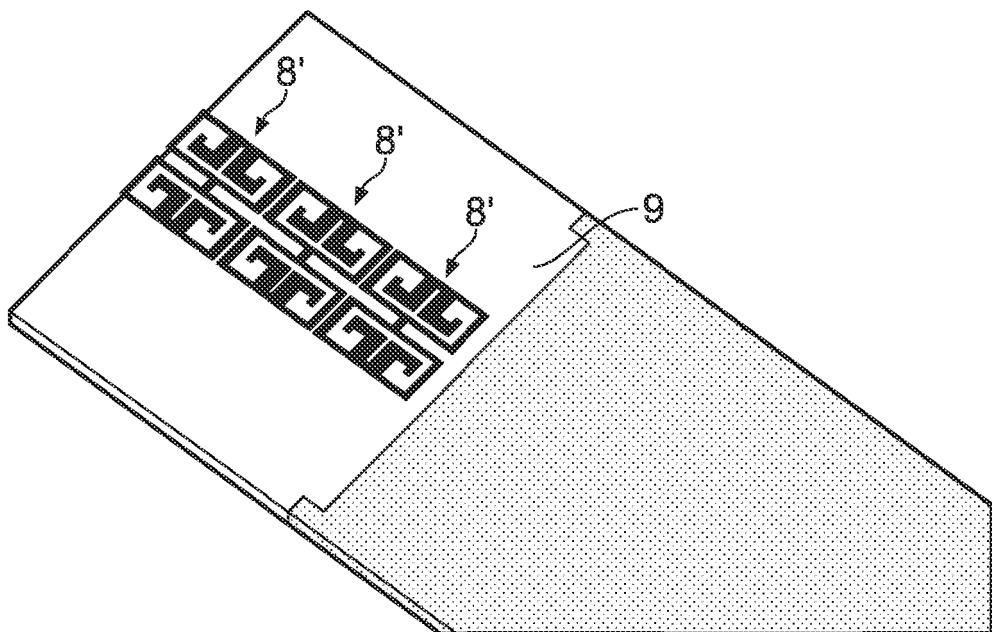


FIG. 4

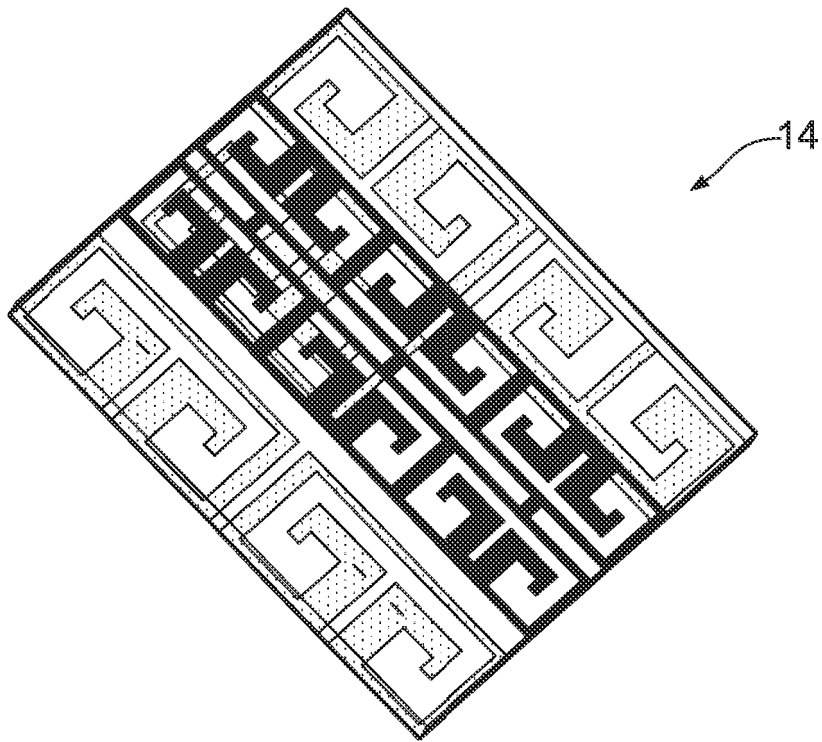


FIG. 5

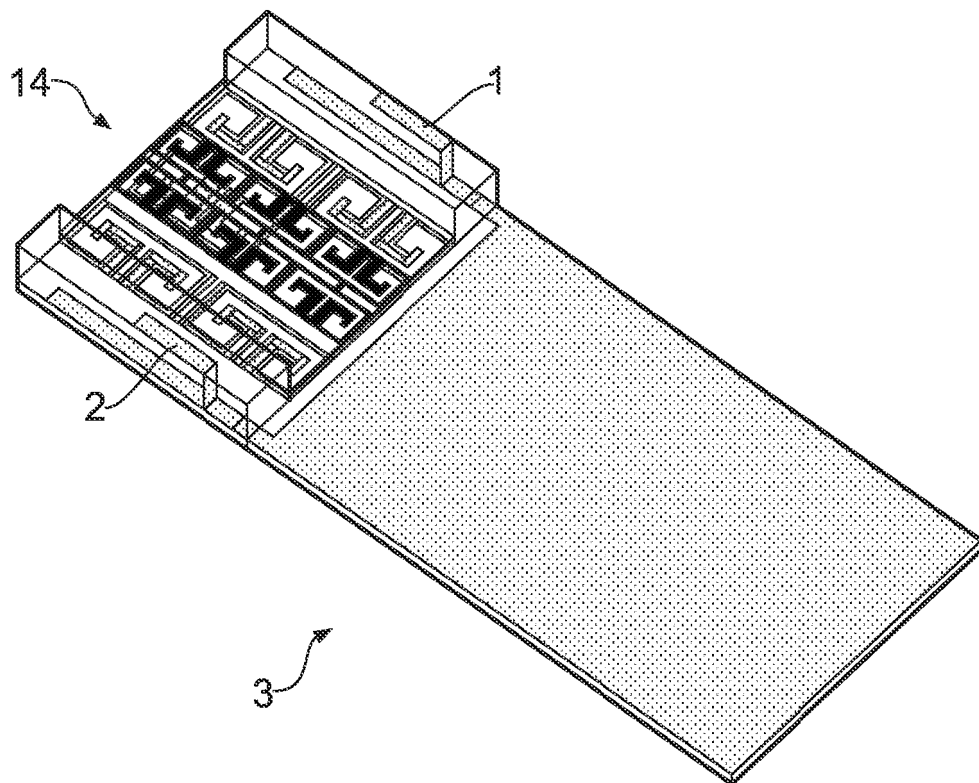


FIG. 6

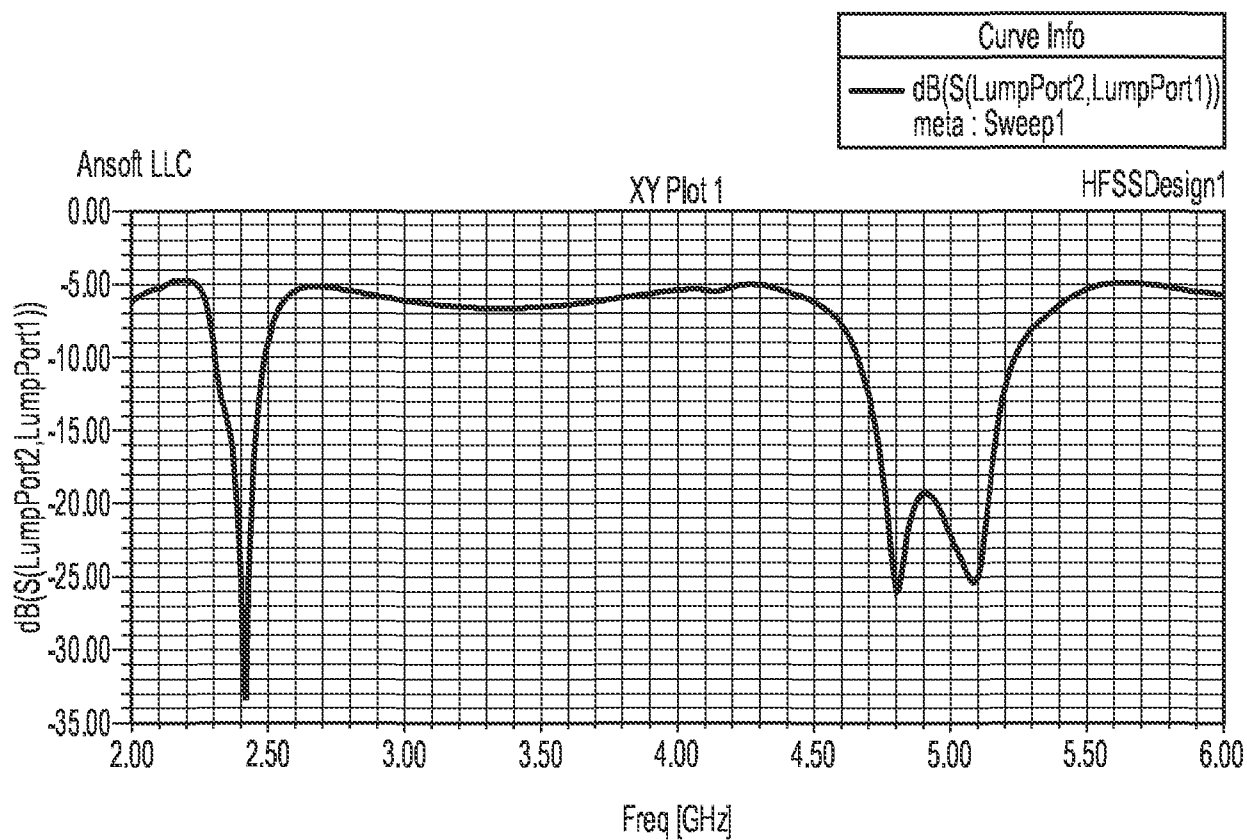


FIG. 7

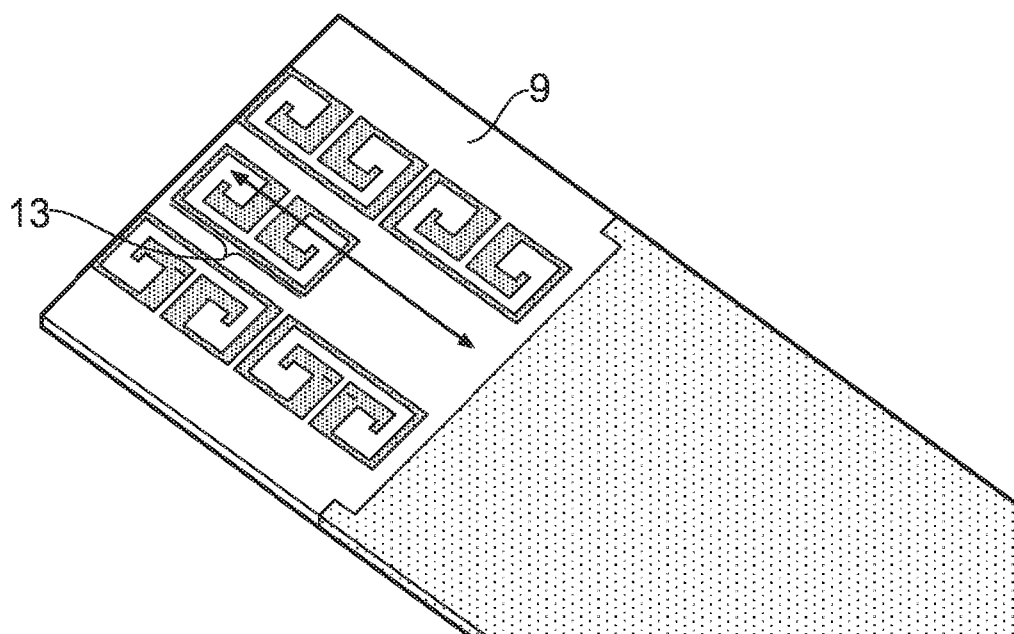


FIG. 8

Curve Info	
---- dB(S(LumpPort2,LumpPort1)) meta : Sweep1 a=0mm'	---- dB(S(LumpPort2,LumpPort1)) meta : Sweep1 a=6mm'
..... dB(S(LumpPort2,LumpPort1)) meta : Sweep1 a=2mm'	---- dB(S(LumpPort2,LumpPort1)) meta : Sweep1 a=8mm'
..... dB(S(LumpPort2,LumpPort1)) meta : Sweep1 a=4mm'	

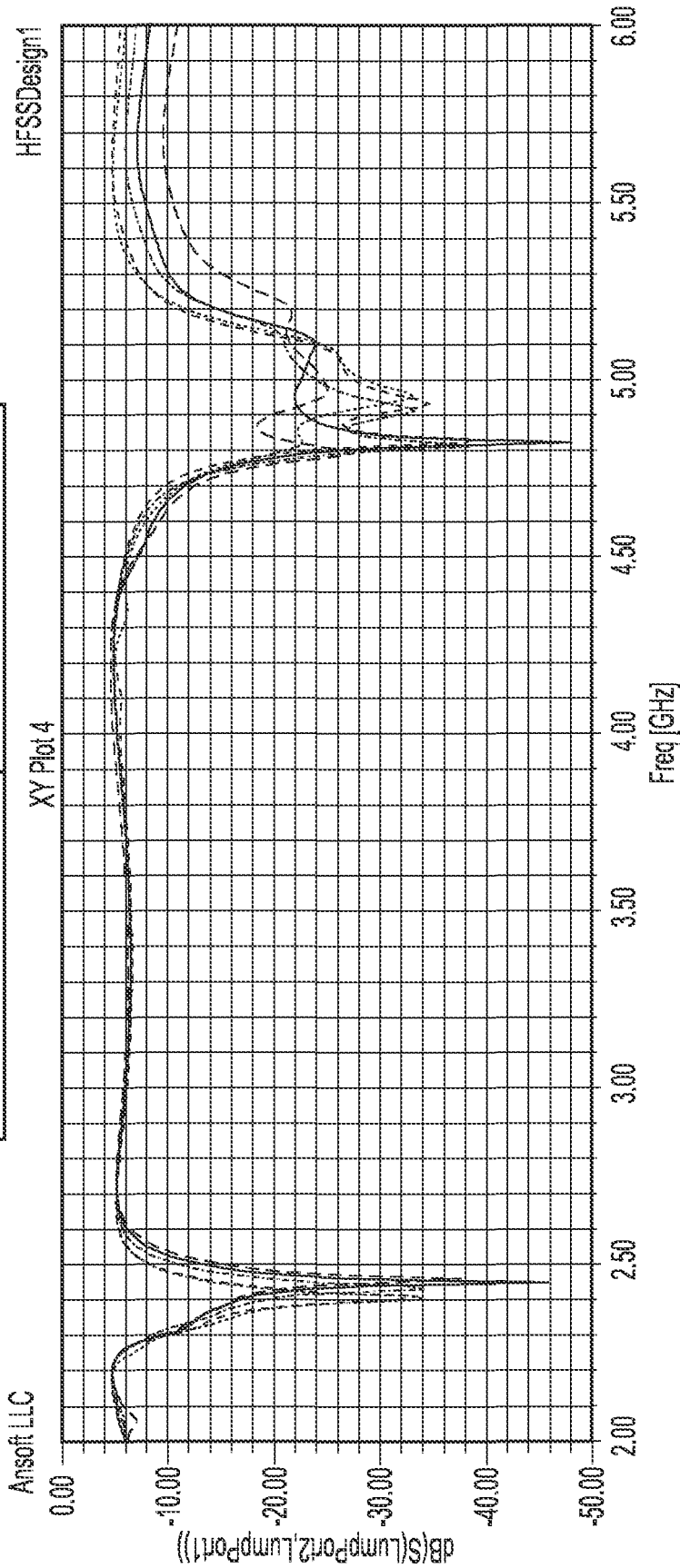


FIG. 9

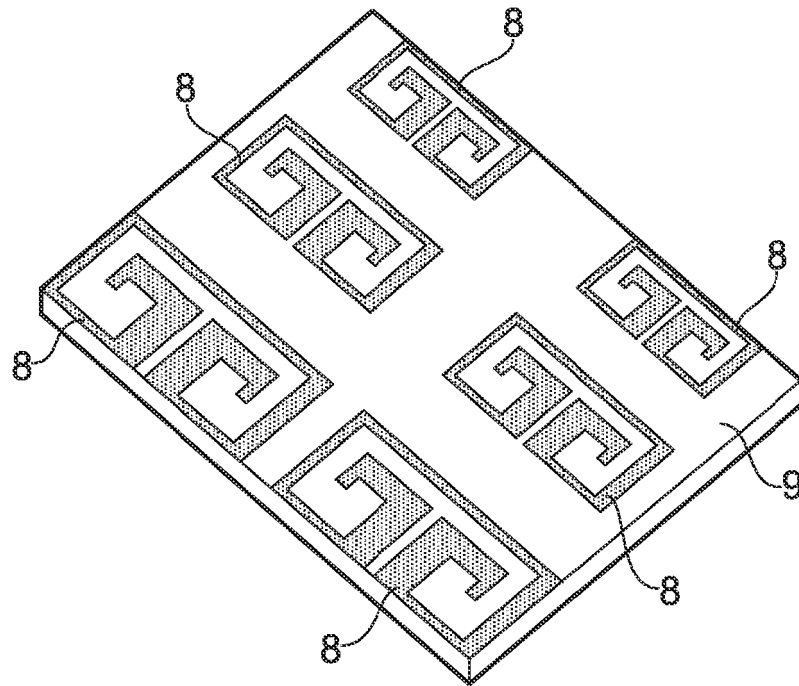


FIG. 10

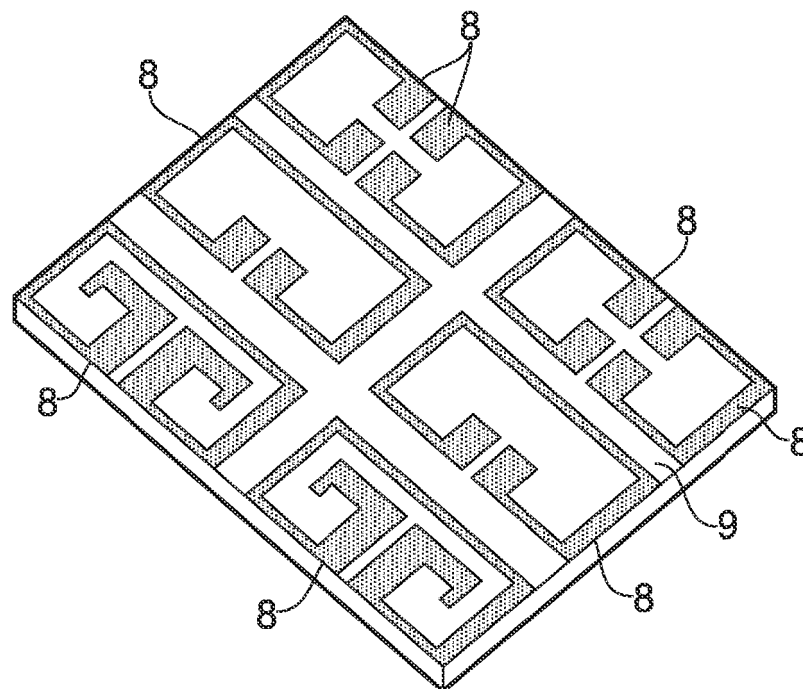


FIG. 11

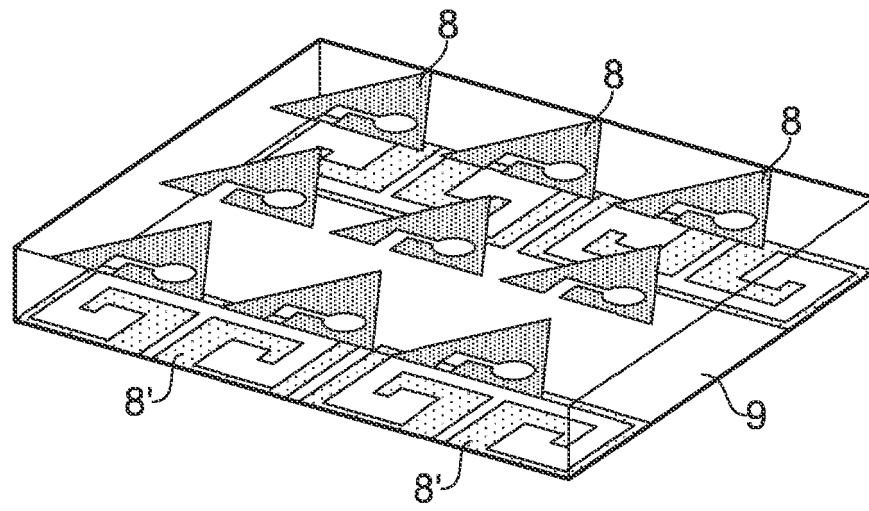


FIG. 12

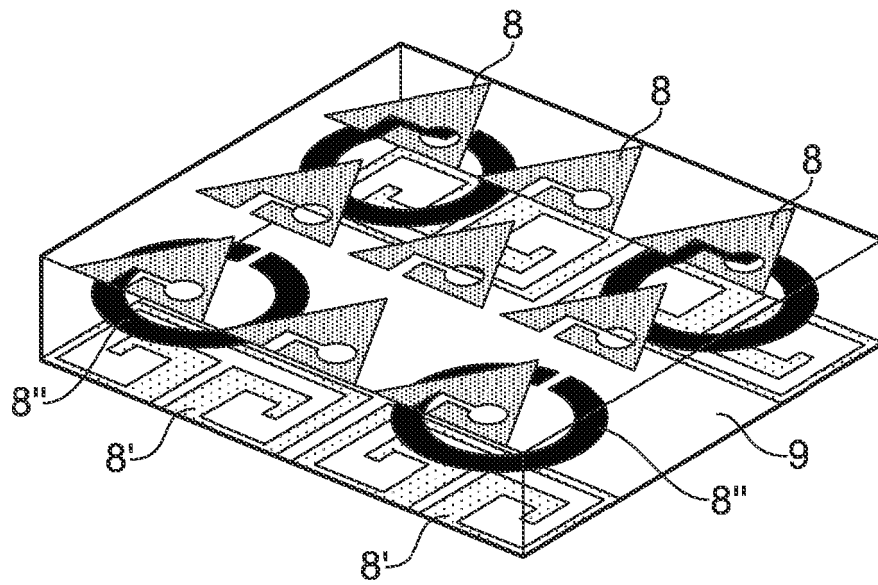


FIG. 13

REFERENCES CITED IN THE DESCRIPTION

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