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(57) An antenna element comprising a first conductive radiating surface mounted at a predefined distance from a surface plane of a ground plate, a second conductive radiating surface mounted at substantially the same predefined distance from the surface plane of the ground plate as the first conductive element, the second conductive radiating surface separated from the first conductive radiating surface by a gap of a predefined width, and at least one conductive interconnect coupling the two conductive radiating surfaces and configured to introduce substantially no additional phase shift at the fun-

damental resonant frequency of the overall antenna element comprising the conductive radiating surfaces and the gap in a signal traveling from one conductive radiating surface to the other conductive radiating surface via the conductive interconnect, and a phase shift of substantially 180° at the first harmonic frequency of the overall antenna element comprising the conductive radiating surfaces and the gap for a signal traveling from one conductive radiating surface to the other conductive radiating surface.

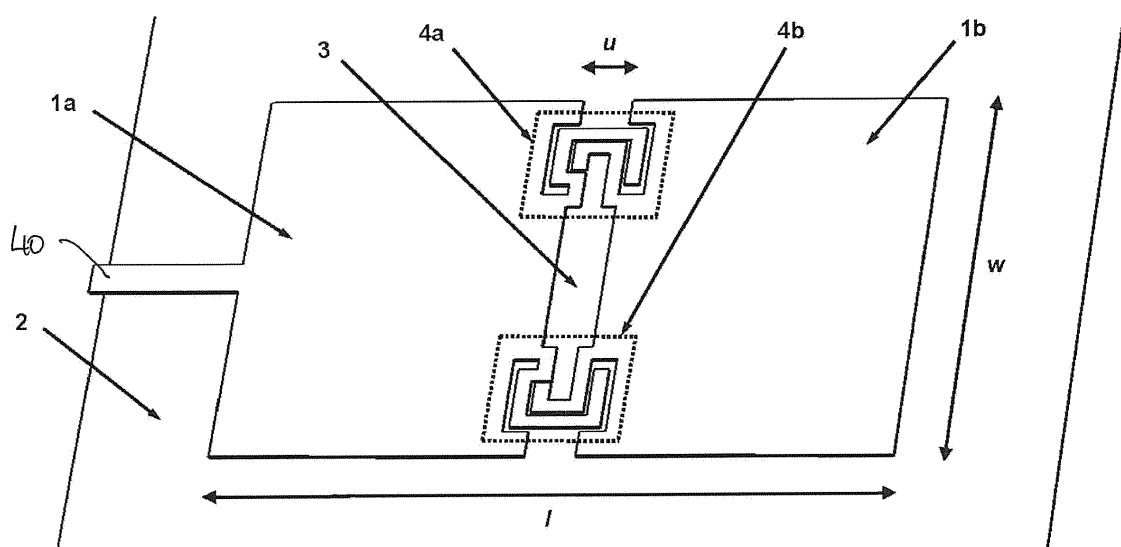


Figure 4

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Description

TECHNICAL FIELD

5 **[0001]** Aspects relate, in general, to an antenna element, an interconnect, a method and an antenna array.

BACKGROUND

10 **[0002]** Antennas for mobile cellular communications, as used in base-station nodes and user equipment for example, are typically based on resonant radiating elements that resonate at a fundamental frequency and integer multiples thereof (harmonics).

[0003] A radiating element consisting of a single resonant radiator radiates at harmonic frequencies with very different radiation properties compared to those at the fundamental frequency. The fact that the radiation patterns are different means that in most practical applications an antenna composed of single-radiator radiating elements cannot be utilized for a simultaneous operation at two frequency bands whose center-frequency ratio is approximately 2:1, such as the 1,800 and 900 MHz mobile cellular communication bands, or 3:1, such as the 2,400 and 800 MHz bands for example.

15 **[0004]** Different radiation patterns of resonant radiators at the fundamental frequency, f_1 , and the first harmonic frequency, $f_2 = 2f_1$, can be circumvented by composing the radiating element of two radiators, with one radiator resonating at the first frequency, f_1 , and the other resonating at the second frequency, f_2 . In such an arrangement, both radiators operate at their respective fundamental frequencies, meaning the ratio of the resonant lengths of the two radiators is approximately 2:1.

[0005] In practical realizations, such dual-radiator radiating elements employ either parasitic radiators or branch structures. In the former, the radiating element is composed of two radiators, whereby one radiator (typically the long one, radiating at f_1) is fed, i.e., directly excited with radio-frequency (RF) power, and the other (parasitic) radiator (typically the short one, radiating at f_2) is excited by proximity-coupling of electromagnetic energy from the fed radiator. In the latter, the long and the short radiators are connected by an electrically-conductive branch that feeds RF power to both radiators. Both approaches are successful in obtaining dual-band performance, but they share the common drawback that in either of the two operating frequency bands only one of the two radiators constituting the dual-band radiating element makes a substantial contribution to the radiating element's operation. That is, neither of the approaches yields an efficient design. Furthermore, care must be taken to alleviate undesired interactions between the short and the long radiators.

SUMMARY

35 **[0006]** According to an example, there is provided an antenna element comprising a first conductive radiating surface mounted at a predefined distance from a surface plane of a ground plate, a second conductive radiating surface mounted at substantially the same predefined distance from the surface plane of the ground plate as the first conductive element, the second conductive radiating surface separated from the first conductive radiating surface by a gap of a predefined width, and at least one conductive interconnect coupling the two conductive radiating surfaces and configured to introduce substantially no additional phase shift at the fundamental resonant frequency of the overall antenna element comprising the conductive radiating surfaces and the gap in a signal traveling from one conductive radiating surface to the other conductive radiating surface via the conductive interconnect, and a phase shift of substantially 180° at the first harmonic frequency of the overall antenna element comprising the conductive radiating surfaces and the gap for a signal traveling from one conductive radiating surface to the other conductive radiating surface. The conductive interconnect can comprise a first arm connected to the first conductive radiating surface, and a second arm connected to the second conductive radiating surface, the first and second arms configured in a predefined geometrical arrangement to form the interconnect so as to electromagnetically couple the first and second elements. The first and second arms can be arranged in spaced geometrical arrangement from one another such that the arms are not in contact with one another. The interconnect coupling can be mounted between the radiating surfaces and the surface plane of a ground plate. The first and second conductive radiating elements can be substantially identical in shape and size. A third conductive radiating surface separated from the first and second conductive radiating surfaces and including at least one conductive interconnect to couple the third conductive radiating surface to the first or second conductive radiating surfaces can be provided. An interconnect to couple conductive radiating surfaces can be located in substantially the same plane as the conductive radiating surfaces. Respective conductive radiating surfaces can include multiple interconnects to couple the conductive radiating surfaces at more than one point.

55 **[0007]** According to an example, there is provided an interconnect for coupling a pair of conductive radiating surfaces, the interconnect configured in a predefined geometrical arrangement so that the interconnect introduces substantially no additional phase shift in signals traveling through the interconnect in a frequency band centred about a predetermined

frequency, and an additional phase shift of around 180° in signals traveling through the interconnect in a frequency band centred about the first or the second harmonic of the predetermined frequency. A conductive radiating surface can extend across a portion of the interconnect. The interconnect can comprise at least a first arm for a first conductive radiating surface of the pair, and a second arm for a second conductive radiating surface of the pair, the first and second arms configured in a predefined geometrical arrangement to form the interconnect so as to electromagnetically couple the first and second elements.

[0008] According to an example, there is provided a method, in an antenna arrangement including N conductive radiating surfaces coupled using at least N-1 interconnects, for transmitting and receiving signals in selected two of N frequency bands separated by a fundamental frequency, the method comprising configuring an interconnect between respective ones of two radiating surfaces so that each radiating surface resonates at the predetermined fundamental frequency and the Nth multiple of the predetermined fundamental frequency by arranging multiple arms of the interconnect, respective ones of which are conductively connected to respective ones of the two radiating surfaces, in a predefined geometrical arrangement, whereby to electromagnetically couple the two radiating elements. The frequency bands of operation are extended by configuring the at least N-1 interconnects to provide the required phase shifts to the applied RF signal at the interconnects.

[0009] According to an example, there is provided an antenna array comprising multiple antenna elements as described herein, respective ones of the antenna arrangements configured in a planar array. Respective ones of the antenna elements can be individually addressable to beamform an output signal of the array.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Embodiments will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of a conventional patch antenna;

Figure 2 is a frequency-dependence plot of the magnitude of the input reflection coefficient ($|S_{11}|$) of the antenna in figure 1;

Figure 3 is a plot of co-polarized far-field gain radiation pattern of the antenna in figure 1;

Figure 4 is a schematic isometric representation of an antenna element according to an example;

Figure 5 is a schematic representation of the equivalent circuit of an LC cell above the ground plane, 2, of an antenna element according to an example;

Figure 6 is a graph of the variation of (5) as a function of C_X/C_C ;

Figure 7 is a schematic representation of the frequency dependence of the magnitude of the input reflection coefficient ($|S_{11}|$) of the antenna of figure 4;

Figure 8 is a plot of the corresponding co-polarized E-plane far-field gain radiation patterns of the antenna in figure 4;

Figures 9-11 are schematic representations of an antenna element according to an example, shown from various perspectives;

Figure 12 is the frequency-dependence plot of the magnitude of the input reflection coefficient ($|S_{11}|$) of the antenna of figures 9-11 according to an example;

Figure 13 is a plot the co-polarized E-plane far-field gain radiation patterns of the antenna of figures 9-11 according to an example;

Figure 14 is a plot the corresponding co-polarized H-plane far-field gain radiation patterns of the antenna of figures 9-11 according to an example; and

Figure 15 is a schematic representation of a radiating antenna element according to an example.

DESCRIPTION

[0011] Example embodiments are described below in sufficient detail to enable those of ordinary skill in the art to embody and implement the systems and processes herein described. It is important to understand that embodiments can be provided in many alternate forms and should not be construed as limited to the examples set forth herein.

[0012] Accordingly, while embodiments can be modified in various ways and take on various alternative forms, specific embodiments thereof are shown in the drawings and described in detail below as examples. There is no intent to limit to the particular forms disclosed. On the contrary, all modifications, equivalents, and alternatives falling within the scope of the appended claims should be included. Elements of the example embodiments are consistently denoted by the same reference numerals throughout the drawings and detailed description where appropriate.

[0013] The terminology used herein to describe embodiments is not intended to limit the scope. The articles "a," "an," and "the" are singular in that they have a single referent, however the use of the singular form in the present document should not preclude the presence of more than one referent. In other words, elements referred to in the singular can number one or more, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises," "comprising," "includes," and/or "including," when used herein, specify the presence of stated features, items, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, items, steps, operations, elements, components, and/or groups thereof.

[0014] Unless otherwise defined, all terms (including technical and scientific terms) used herein are to be interpreted as is customary in the art. It will be further understood that terms in common usage should also be interpreted as is customary in the relevant art and not in an idealized or overly formal sense unless expressly so defined herein.

[0015] Figure 1 is a schematic representation of a conventional patch antenna. A patch 1 is positioned above a ground plane 2. The antenna of figure 1 displays a first resonance at the frequency of 1 GHz and the first harmonic at 1.97 GHz. Figure 2 is a frequency-dependence plot of the magnitude of the input reflection coefficient ($|S_{11}|$) of the antenna in figure 1.

[0016] At the fundamental frequency, the electrical length travelled by the electric current distribution, J , on the surface of the radiating element is about one half of the guided wavelength along the current's resonant path. At the first harmonic, the electrical length travelled by the electric current is a full guided wavelength long. Since the phase of the surface current in the second half of the guided wavelength is of the opposite sign to the phase of the surface current in the first half of the guided wavelength, the far-field radiation pattern of the antenna of figure 1 displays a sharp minimum, theoretically a null, broadside.

[0017] This is shown in figure 3 which is a plot of co-polarized far-field gain radiation pattern of the antenna in figure 1, in which the solid line represents the E-plane cut at 1 GHz and the dashed line is the E-plane cut at 1.97 GHz. That is, the co-polarized E-plane far-field gain radiation pattern of the antenna in figure 1 at 1.97 GHz (dashed line) is shown in comparison with that at 1 GHz (solid line).

[0018] As noted, the fact that the radiation patterns are different (figure 3) means that in most practical applications an antenna composed of single-radiator radiating elements cannot be utilized for a simultaneous operation at two frequency bands whose center-frequency ratio is approximately 2:1, such as the 1,800 and 900 MHz mobile cellular communication bands, or 3:1, such as the 2,400 and 800 MHz bands.

[0019] According to an example, an antenna element comprises first and second conductive radiating surfaces mounted at a predefined distance from a surface plane of a ground plate. The surfaces can be patch type antennas (or surfaces composed from one patch antenna), such as that described with reference to figure 1 for example. However, other antenna types - e.g., wire antennas - may be used. That is, a patch antenna is used merely as a specific example. In principle, the concept can be extended to a number of other resonant antenna technologies.

[0020] Figure 4 is a schematic isometric representation of an antenna element according to an example. In the example of figure 4, a patch antenna has a length, l , and is formed from two sections 1a, 1b forming respective conductive radiating surfaces that are separated by a gap 3 of width u which is void of metallization. The sections are positioned above a ground plane 2, and a feed 40 for receiving an input signal for the element is provided on one of the sections 1a (although may equally be provided on section 1b for example). In an example, the sections 1a and 1b are substantially equal in size. The portions are connected or otherwise coupled together using at least one suitable filter or interconnect. More specifically, in the example of figure 4, two interconnects 4a and 4b, are depicted and outlined by dotted lines, although only one such interconnect forming a filter for the element may be used.

[0021] The antenna element of figure 4 has the same overall length l and width w as the conventional patch of figure 1; consequently the overall patch antenna of figure 4 resonates at the same fundamental frequency (1 GHz) as the antenna shown in figure 1. At the same time, subdividing the patch into two equal-size parts, 1a and 1b, along the resonant path of the electric current on the patch surface makes it possible to view the patch as a linear array of two series-fed patches, whereby the fundamental frequency of the array is that of the patch segments 1a, 1b. Further, if the gap width, u , is kept small relative to the overall patch length, l , the fundamental frequency of the patch segments will be about twice the fundamental frequency of the overall patch, i.e., about 2 GHz.

[0022] Interconnects, 4a, 4b, are composed of conductive elements operable to couple the two conductive radiating

surfaces 1a, 1b and are configured to introduce substantially no additional phase shift at the fundamental resonant frequency of the overall patch of length l is a signal traveling from one conductive radiating surface 1a to the other conductive radiating surface 1b via the conductive interconnect 4a, 4b. At the same time, a phase shift of substantially 180° is introduced at the first harmonic frequency of the overall patch of length l for a signal traveling from one conductive radiating surface to the other conductive radiating surface via the conductive interconnect 4a, 4b.

[0023] In an example, an interconnect 4a, 4b is composed of a pair of arms, respective ones of which are connected to respective surfaces 1a, 1b. The geometry of an interconnect, that is, the geometrical configuration of the arms of an interconnect, is selected to couple the surfaces 1a, 1b whereby to enable operation of the conductive radiating surfaces in resonance simultaneously at two frequencies.

[0024] In an example, the equivalent circuit of one possible implementation of each of the interconnects, 4a and 4b, is the series combination of an inductance and a capacitance. An interconnect 4a, 4b can therefore be referred to as an LC (inductor-capacitor) cells.

[0025] Figure 5 is a schematic representation of the equivalent circuit of an LC cell above the ground plane, 2, of an antenna element according to an example. The circuit consists of a series reactance, composed of L_C and C_C , and a shunt reactance, C_X . The series combination of L_C and C_C represents the LC cell itself, while C_X stands for the parasitic capacitance between the LC cell and the ground plane of the antenna element. The ratio of the voltages at the output and input ports of the LC cell, V_2/V_1 , is:

$$\frac{V_2}{V_1} = \frac{1}{1 - \omega^2 L_C C_X + C_X / C_C} \quad (1)$$

[0026] The LC cell is designed to resonate at the fundamental frequency, f_1 , of the overall patch, i.e., the patch of length l . As a result, the values of f_1 , L_C and C_C are related as:

$$\omega_1 = 2\pi f_1 = \frac{1}{\sqrt{L_C C_C}} \quad (2)$$

[0027] That is, at frequency f_1 , (1) becomes:

$$\left. \frac{V_2}{V_1} \right|_{\omega=\omega_1} = 1 \quad (3)$$

[0028] At the first harmonic of f_1 , i.e., $f_2 = 2f_1$, (1) becomes:

$$\left. \frac{V_2}{V_1} \right|_{\omega=\omega_2} = \frac{1}{1 - \omega_2^2 L_C C_X + C_X / C_C} = \frac{1}{1 - 4\omega_1^2 L_C C_X + C_X / C_C} \quad (4)$$

[0029] Substituting (2) to (4) provides:

$$\left. \frac{V_2}{V_1} \right|_{\omega=\omega_2} = \frac{1}{1 - 3 C_X / C_C} \quad (5)$$

[0030] Figure 6 is a graph of the variation of (5) as a function of C_X/C_C . According to an example, when $C_X/C_C = 2/3$, the ratio $V_2/V_1 = -1$, meaning the function of the LC cell at the frequency f_2 is to change the phase of the input voltage by 180° . As a result, while at frequency f_1 the patch antenna of figure 4 behaves like the patch antenna of figure 1 (due to (3)), at frequency f_2 - i.e., the first harmonic of the overall patch of length l - the electrical length of the current on the surface of the patch is a full guided wavelength long, just like in the case of the conventional patch of figure 1. However, since the phase of the surface current in the second half of the guided wavelength - i.e., the surface current on the patch

segment 1b - has the same sign as the phase of the surface current on patch segment 1a, the far-field radiation pattern of the antenna of figure 4 no longer has a sharp minimum at broadside. In other words, at frequency f_2 , the patch antenna of figure 4 can be viewed as a linear array of two series-fed patches whereby each element of the array - patch segments 1a and 1b - is fed with the same voltage phase for broadside radiation. This behavior is achieved without the conventional half-wavelength-long section of transmission line between the patch segments 1a, 1b.

[0031] The interconnects between patch segments 1a and 1b of figure 4 are one example of interconnects in which a 180° phase shift is introduced by the LC cell at the first harmonic.

[0032] Figure 7 is a plot of the frequency dependence of the magnitude of the input reflection coefficient ($|S_{11}|$) of the antenna of figure 4. The resonance at 1.11 GHz is that at the fundamental frequency (compared with 1 GHz of the conventional patch antenna having the same overall dimensions as shown in figure 2), and the resonance at 2.12 GHz is that at the first harmonic (compared with 1.97 GHz of the conventional antenna having the same overall dimensions as shown in figure 2).

[0033] Figure 8 is a plot of the corresponding co-polarized E-plane far-field gain radiation patterns of the antenna in figure 4. As shown in figure 8, the pattern at 2.12 GHz (dashed line) is very similar in shape to the pattern at 1.11 GHz (solid line); likewise the peak-gain values at the two frequencies are quite similar, namely 8.73 dBi at 1.11 GHz and 9.75 dBi at 2.12 GHz. The similarities of radiation-pattern shapes and peak-gain values make the antenna useful for engineering applications in dual-band wireless communication systems.

[0034] By extension, the concept can be applied to higher harmonics. For example, at the second harmonic of f_1 , i.e., $f_3 = 3f_1$, (I) becomes:

$$\left. \frac{V_2}{V_1} \right|_{\omega=\omega_3} = \frac{1}{1 - \omega_3^2 L_C C_X + C_X/C_C} = \frac{1}{1 - 9\omega_1^2 L_C C_X + C_X/C_C} \quad (6)$$

[0035] Substituting (2) to (6) provides:

$$\left. \frac{V_2}{V_1} \right|_{\omega=\omega_3} = \frac{1}{1 - 8 C_X/C_C} \quad (7)$$

[0036] Thus, according to an example, frequency-selective interconnects can be introduced into conventional resonant radiating elements in order to obtain a radiation pattern at the first, or higher, harmonic frequency that is fully comparable to the radiation pattern at the fundamental frequency, thereby yielding a dual-band antenna with useful radiation properties at two frequency bands whose center-frequency ratio is approximately 2:1, 3:1, and so on. In an example, practical designs can be obtained within a range of frequency ratios, e.g., anywhere between 1.8:1 and 2.2:1 for example.

[0037] Alternatively, the above can be viewed as maintaining the functionality of a radiating element at the fundamental frequency and, at the first (or higher) harmonic frequency, introducing the functionality of a series-fed linear array without the typical half-wavelength-long sections of transmission line employed in such series-fed arrays. The configuration of figure 4 can be viewed as an antenna element with integral frequency-selective components for enhanced radiation properties.

[0038] The RF performance of an antenna element according to an example and as depicted in figure 4 is depicted in figures 7 and 8. More particularly, the overall length, l , of the element in figure 4, resulting in the RF performance as shown in figures 7 and 8, is 135 mm, and the width, w , is 93.8 mm. The gap width, u , is 10 mm, and the LC cell measures 18.6 mm along the patch length and 20 mm along the patch width. A dielectric is provided between the patch and the ground plane, 2, which in the case of figure 4 is air; the thickness of the dielectric is 10 mm. An RF signal can be fed to the antenna by conventional means of feeding patch antennas, such as the depicted microstrip line 40 or a coaxial probe (not shown) from the ground plane 2.

[0039] Another exemplary radiating element according to the principles of the present invention is shown in figures 9-11. Comparing this embodiment to the one shown in figure 4, stubs 9a, 9a' and 9b, 9b' are added to the respective LC cells 4a, 4b (figure 11). The stubs increase the input-impedance bandwidth of the radiating element in the frequency band around the fundamental resonance, as will be described in more detail below. In order for the stubs 9a, 9a' and 9b, 9b' to fit into the arrangement, the LC cells 4a, 4b can be relocated from the plane of the patch segments 1a, 1b onto a plane between the patch segments 1a, 1b, and above the ground plane 2. The electrical connections of the LC cells 4a, 4b to the patch segments 1a, 1b are provided by means of the respective pairs of pins, 8a, 8a' and 8b, 8b'.

[0040] In practical realizations, the radiating element can be built as a stack-up of two microwave substrates 6, 7 (figure 10), whereby the patch segments 1a, 1b and the feeding microstrip line 5 are etched on the top surface of the upper substrate 7, the ground plane 2 is patterned on the bottom surface of the lower substrate 6, while the LC cells 4a, 4b with their stubs 9a, 9a', 9b, 9b' are etched on the bottom surface of the upper substrate 7. The pins 8a, 8a', 8b, 8b' can be manufactured as metal-plated via holes in the upper substrate 7 (figure 10).

[0041] Figure 12 is the frequency-dependence plot of the magnitude of the input reflection coefficient ($|S_{11}|$) of the antenna of figures 9-11 according to an example. The fundamental frequency of the antenna is around 1.08 GHz and two resonances can be observed there: one at 1.06 GHz, which is due to the LC cells themselves, while the resonance at 1.11 GHz results from the electromagnetic coupling of the stubs 9a, 9a' and 9b, 9b' to the respective LC cells 4a and 4b. Increasing the input-impedance bandwidth around the fundamental frequency, by the introduction of the second resonance, is the purpose of the stubs 9a, 9a' and 9b, 9b'. The shapes and the lengths of the stubs 9a, 9a' and 9b, 9b' are utilized to tune the stub-induced resonance in frequency and maintain the co-polarized beam integrity at the frequency of the stub-induced resonance. The first harmonic frequency of the antenna is around 2.09 GHz; one resonance can be seen there.

[0042] Figure 13 depicts the co-polarized E-plane far-field gain radiation patterns of the antenna of figures 9-11 according to an example. The typical pattern in the frequency band around the fundamental frequency is plotted with a solid line, and the typical pattern in the frequency band of the first harmonic is plotted with a dashed line.

[0043] Figure 14 depicts the corresponding co-polarized H-plane far-field gain radiation patterns of the antenna of figures 9-11 according to an example. As with the case of the antenna in figure 4, the E- and H-plane radiation patterns around the fundamental frequency (solid lines in figures 13 and 14) are similar in shape to the corresponding patterns around the first harmonic (dashed lines in figures 13 and 14). Moreover, the peak-gain values in the two frequencies bands are quite similar, namely 8.51 dBi around the fundamental frequency and 8.70 dBi around the first harmonic. Overall, good co-polarized beam integrity and good polarization purity are observed throughout the two frequency bands. The abovementioned radiation properties make the antenna suitable for dual-band wireless communication systems with center-frequency ratio of approximately 2:1.

[0044] In providing the RF performance plots as described herein, ohmic losses are included and copper (Cu) has been considered for all metallic parts.

[0045] Figure 15 is a schematic representation of a radiating antenna element according to an example. The element of figure 15 includes three conductive radiating surfaces to provide a frequency ratio of approximately 3:1.

[0046] Similarly to the element of figure 4 and figures 9-11, the element of figure 15 is in the form of a patch antenna of length, l . It is formed from three sections 15a, 15b and 15c forming respective conductive radiating surfaces that are separated by gaps 17 of width v which are void of metallization.

[0047] The sections are positioned above a ground plane 2, and a feed 40 for receiving an input signal for the element is provided on one of the sections 15a (although may equally be provided on section 15c for example). In the example of figure 15 the sections 15a-c are substantially equal in size. The portions are connected or otherwise coupled together using at least one suitable filter or interconnect between respective ones of the sections. More specifically, in the example of figure 15, two interconnects 19a, 19b are provided between sections 15a and 15b, and two interconnects 21a, 21b are provided between sections 15b and 15c. One interconnect may be provided between respective ones of the sections rather than two as depicted. That is, generally, for N conductive radiating surfaces, at least $N-1$ interconnects can be provided to couple the surfaces.

[0048] The antenna element of figure 15 has the same overall length l and width w as the patch of figure 1 and as the element of figure 4 and figures 9-11; consequently the overall patch antenna of figure 15 has the same fundamental frequency (1 GHz) as the antenna shown in figure 1. At the same time, subdividing the patch into three equal-size parts, 15a-c, along the resonant path of the electric current on the patch surface makes it possible to view the patch as a linear array of three series-fed patches, namely the patch segments 15a-c. If the gap width, v , is kept small relative to the overall patch length, l , the fundamental resonant frequency of the patch segments will be close to the second harmonic of the overall patch, i.e., about three times the fundamental frequency of the overall patch, namely about 3 GHz.

[0049] Interconnects, 19a-b, 21a-b, are composed of conductive elements operable to couple the conductive radiating surfaces of the element of figure 15 and are configured to introduce substantially no additional phase shift at the fundamental resonant frequency of the overall patch of length l in a signal traveling from one conductive radiating surface 15a to the other conductive radiating surface 15c through the second surface 15b via the conductive interconnects and a phase shift of substantially 180° at the second harmonic of that frequency, i.e., at the fundamental resonant frequency of the patch segments 15a-c.

Claims

1. An antenna element comprising:

a first conductive radiating surface mounted at a predefined distance from a surface plane of a ground plate;
 a second conductive radiating surface mounted at substantially the same predefined distance from the surface
 plane of the ground plate as the first conductive element, the second conductive radiating surface separated
 from the first conductive radiating surface by a gap of a predefined width; and

at least one conductive interconnect coupling the two conductive radiating surfaces and configured to introduce
 substantially no additional phase shift at the fundamental resonant frequency of the overall antenna element
 comprising the conductive radiating surfaces and the gap in a signal traveling from one conductive radiating
 surface to the other conductive radiating surface via the conductive interconnect, and a phase shift of substantially
 180° at the first harmonic frequency of the overall antenna element comprising the conductive radiating surfaces
 and the gap for a signal traveling from one conductive radiating surface to the other conductive radiating surface.

2. An antenna element as claimed in claim 1, wherein the conductive interconnect comprises a first arm connected to
 the first conductive radiating surface, and a second arm connected to the second conductive radiating surface, the
 first and second arms configured in a predefined geometrical arrangement to form the interconnect so as to elec-
 tromagnetically couple the first and second elements.

3. An antenna element as claimed in claim 2, wherein the first and second arms are arranged in spaced geometrical
 arrangement from one another such that the arms are not in contact with one another.

4. An antenna element as claimed in any preceding claim, wherein the interconnect coupling is mounted between the
 radiating surfaces and the surface plane of a ground plate.

5. An antenna element as claimed in any preceding claim, wherein the first and second conductive radiating elements
 are substantially identical in shape and size.

6. An antenna element as claimed in any preceding claim, further including a third conductive radiating surface sep-
 arated from the first and second conductive radiating surfaces and including at least one conductive interconnect
 to couple the third conductive radiating surface to the first or second conductive radiating surfaces.

7. An antenna element as claimed in any preceding claim, wherein an interconnect to couple conductive radiating
 surfaces is located in substantially the same plane as the conductive radiating surfaces.

8. An antenna element as claimed in any preceding claim, wherein respective conductive radiating surfaces include
 multiple interconnects to couple the conductive radiating surfaces at more than one point.

9. An interconnect for coupling a pair of conductive radiating surfaces, the interconnect configured in a predefined
 geometrical arrangement so that the interconnect introduces substantially no additional phase shift in signals traveling
 through the interconnect in a frequency band centred about a predetermined frequency, and an additional phase
 shift of around 180° in signals traveling through the interconnect in a frequency band centred about the first or the
 second harmonic of the predetermined frequency.

10. An interconnect as claimed in claim 9, wherein a conductive radiating surface extends across a portion of the
 interconnect.

11. An interconnect as claimed in claim 9 or 10, wherein the interconnect comprises at least a first arm for a first
 conductive radiating surface of the pair, and a second arm for a second conductive radiating surface of the pair, the
 first and second arms configured in a predefined geometrical arrangement to form the interconnect so as to elec-
 tromagnetically couple the first and second elements.

12. A method, in an antenna arrangement including N conductive radiating surfaces coupled using at least N-1 inter-
 connects, for transmitting and receiving signals in selected two of N frequency bands separated by a fundamental
 frequency, the method comprising:

configuring an interconnect between respective ones of two radiating surfaces so that each radiating surface
 resonates at the predetermined fundamental frequency and the Nth multiple of the predetermined fundamental
 frequency by arranging multiple arms of the interconnect, respective ones of which are conductively connected
 to respective ones of the two radiating surfaces, in a predefined geometrical arrangement, whereby to electro-
 magnetically couple the two radiating elements.

13. A method as claimed in claim 12, further including extending the frequency bands of operation by configuring the at least N-1 interconnects to provide the required phase shifts to the applied RF signal at the interconnects.
- 5 14. An antenna array comprising multiple antenna elements as claimed in any of claims 1 to 8, respective ones of the antenna arrangements configured in a planar array.
15. An antenna array as claimed in claim 14, wherein respective ones of the antenna elements are individually address-
able to beamform an output signal of the array.

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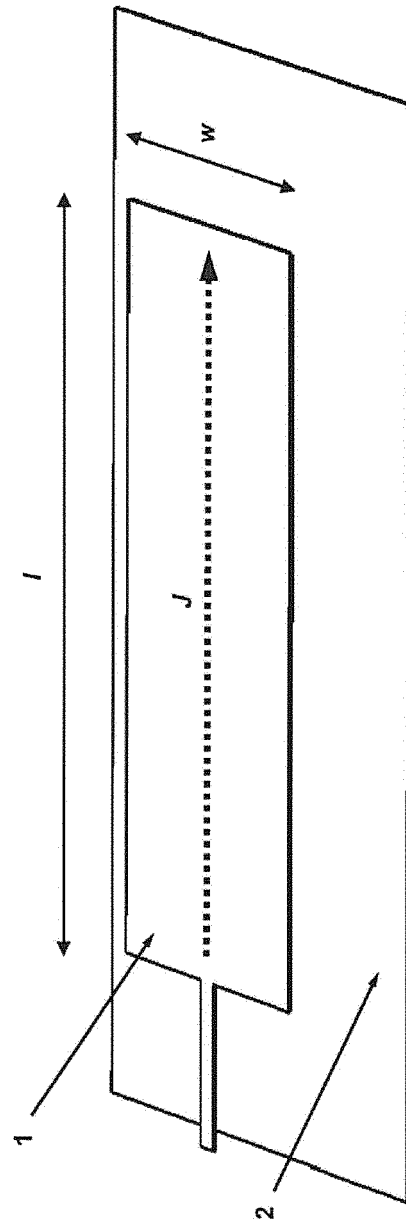


Figure 1

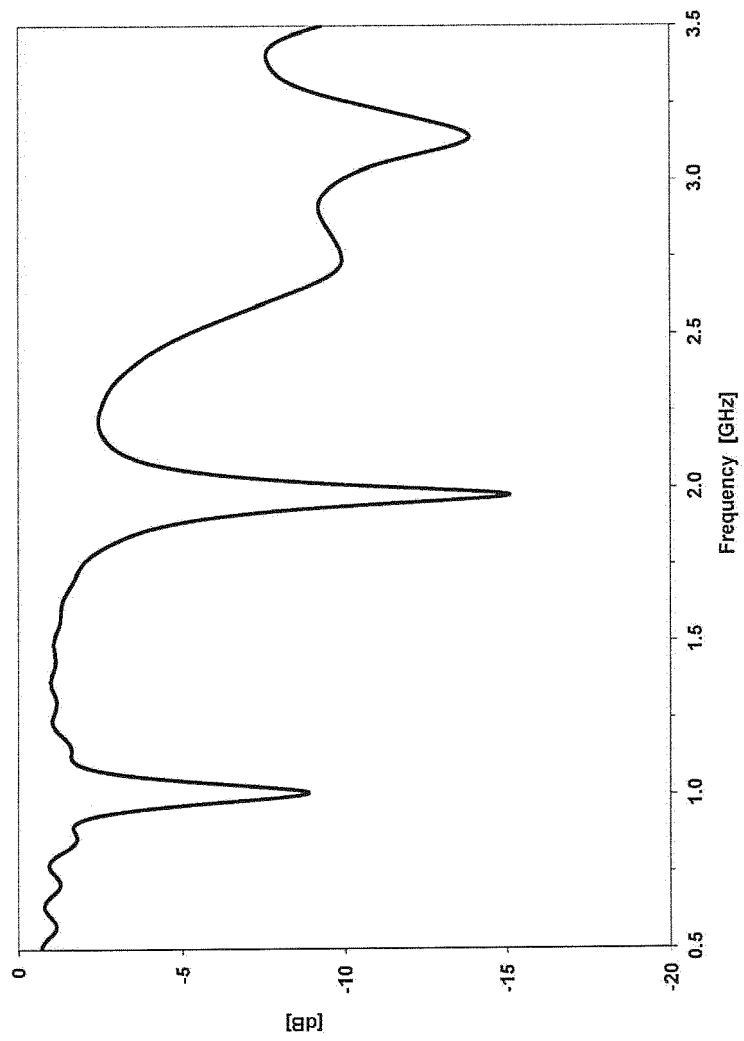


Figure 2

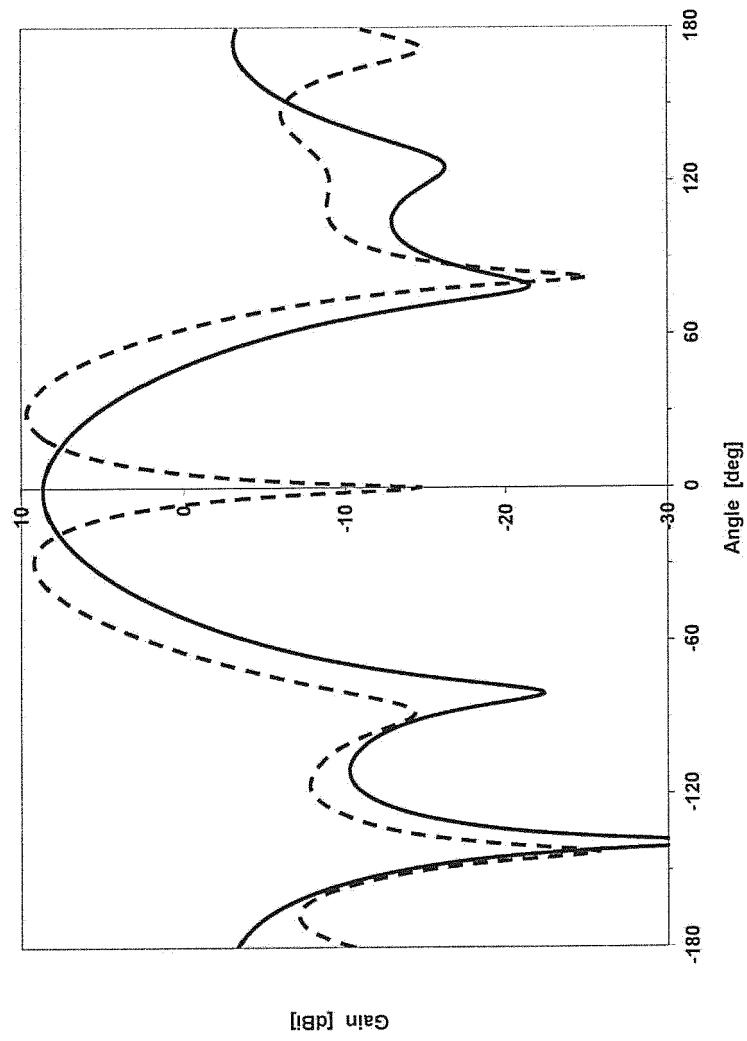


Figure 3

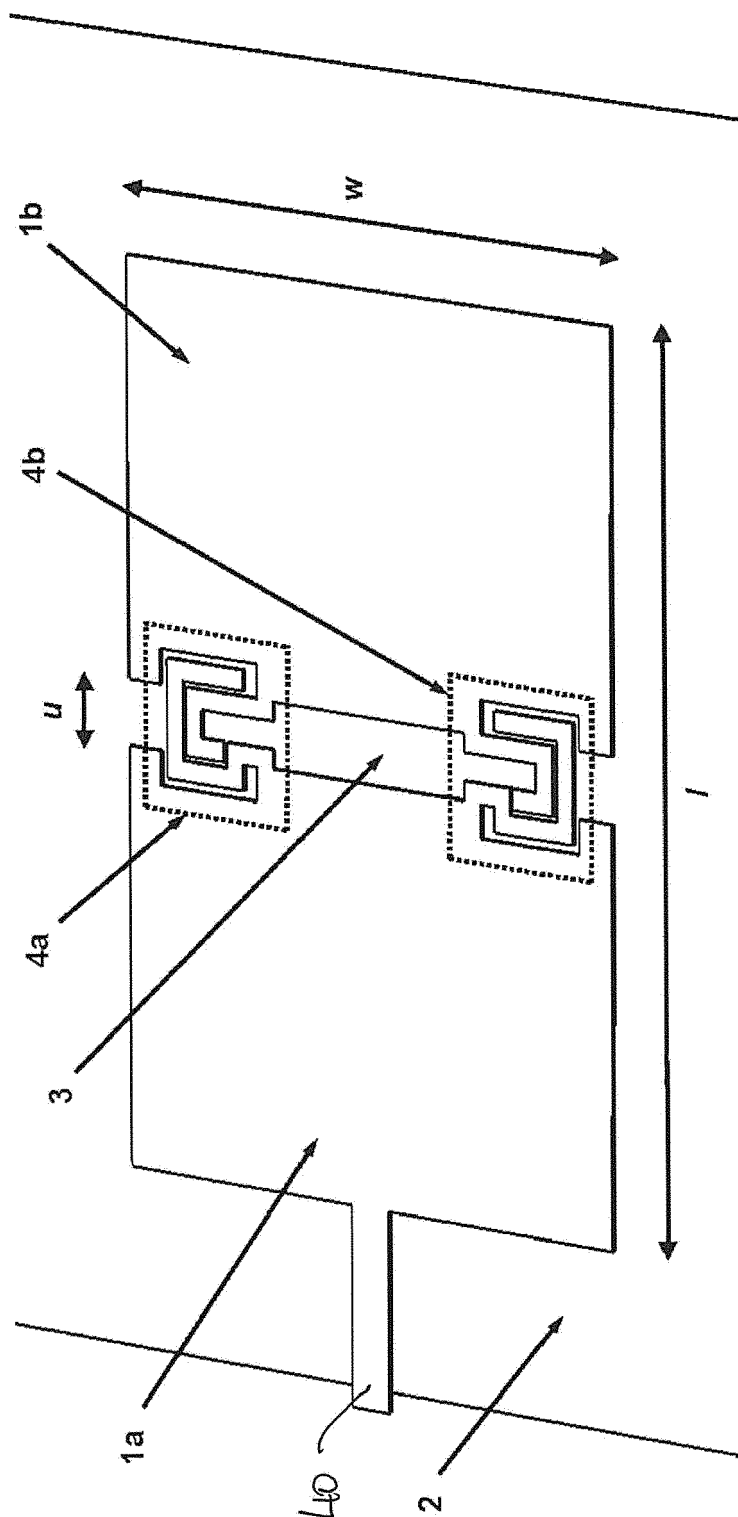


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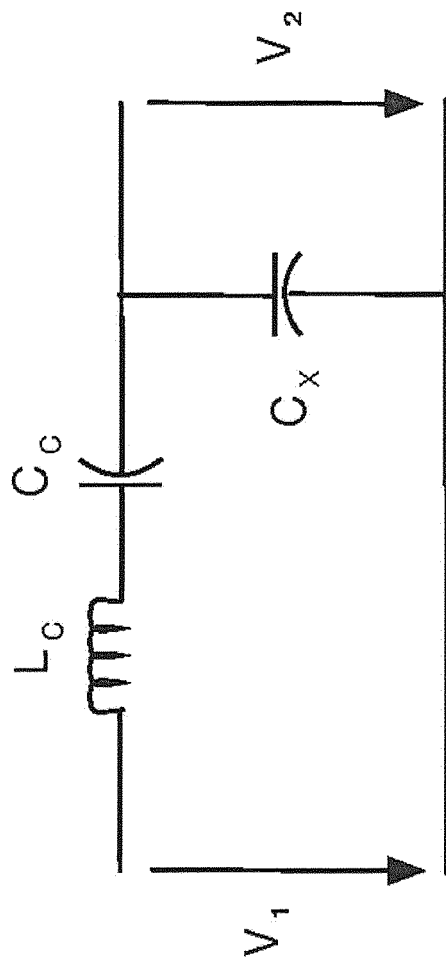


Figure 5

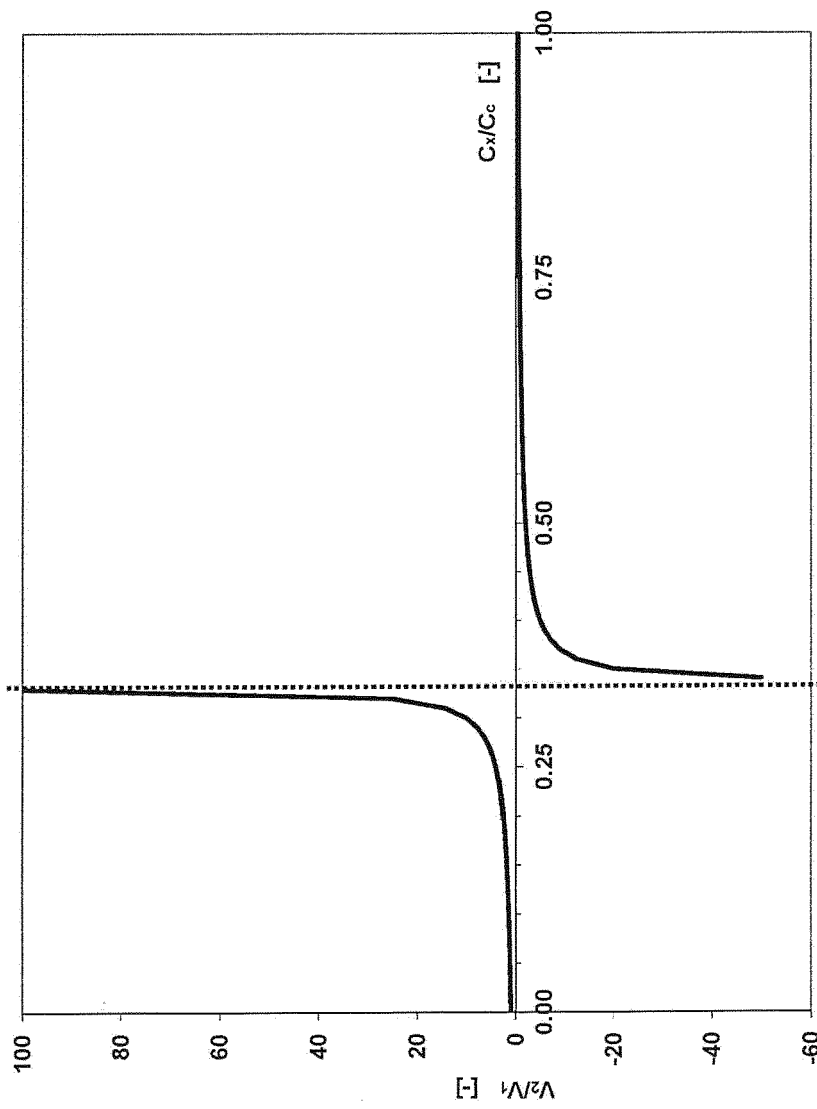


Figure 6

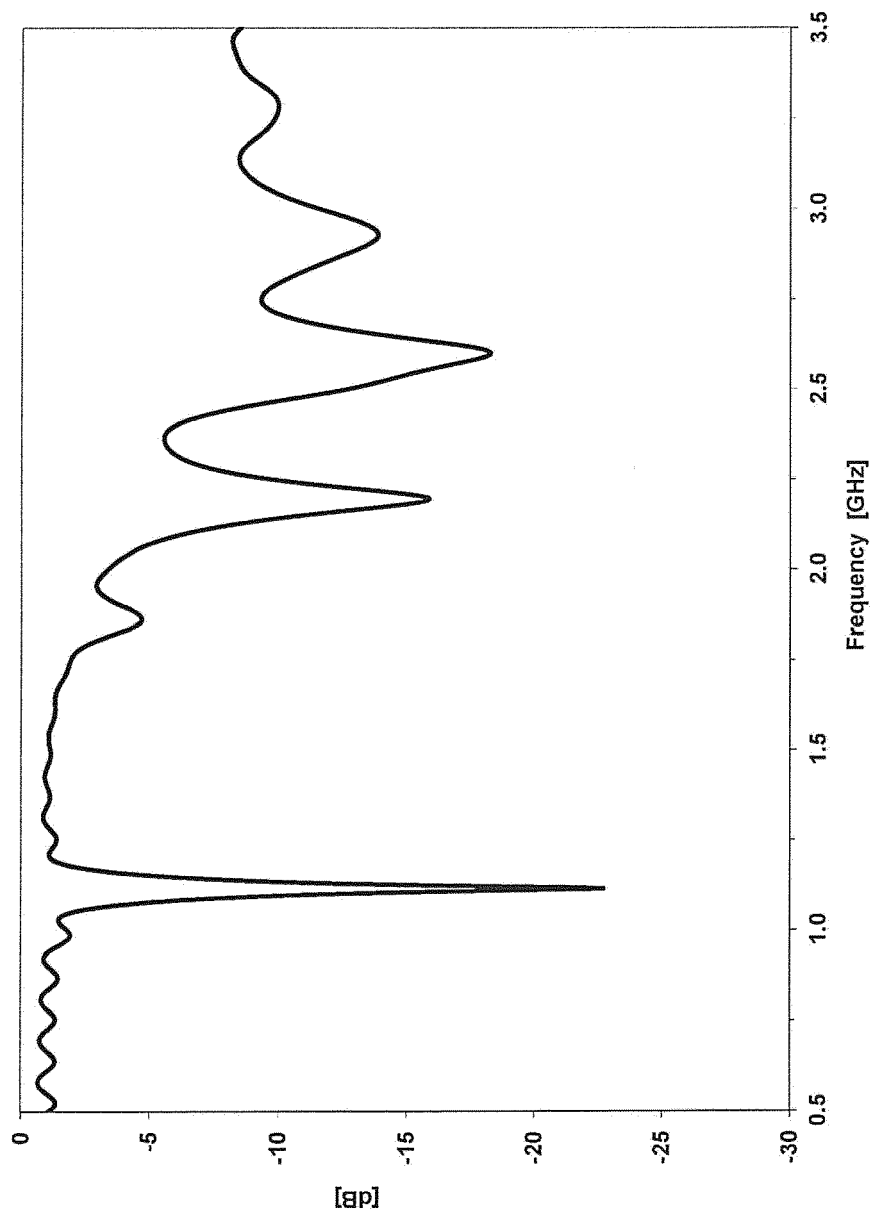


Figure 7

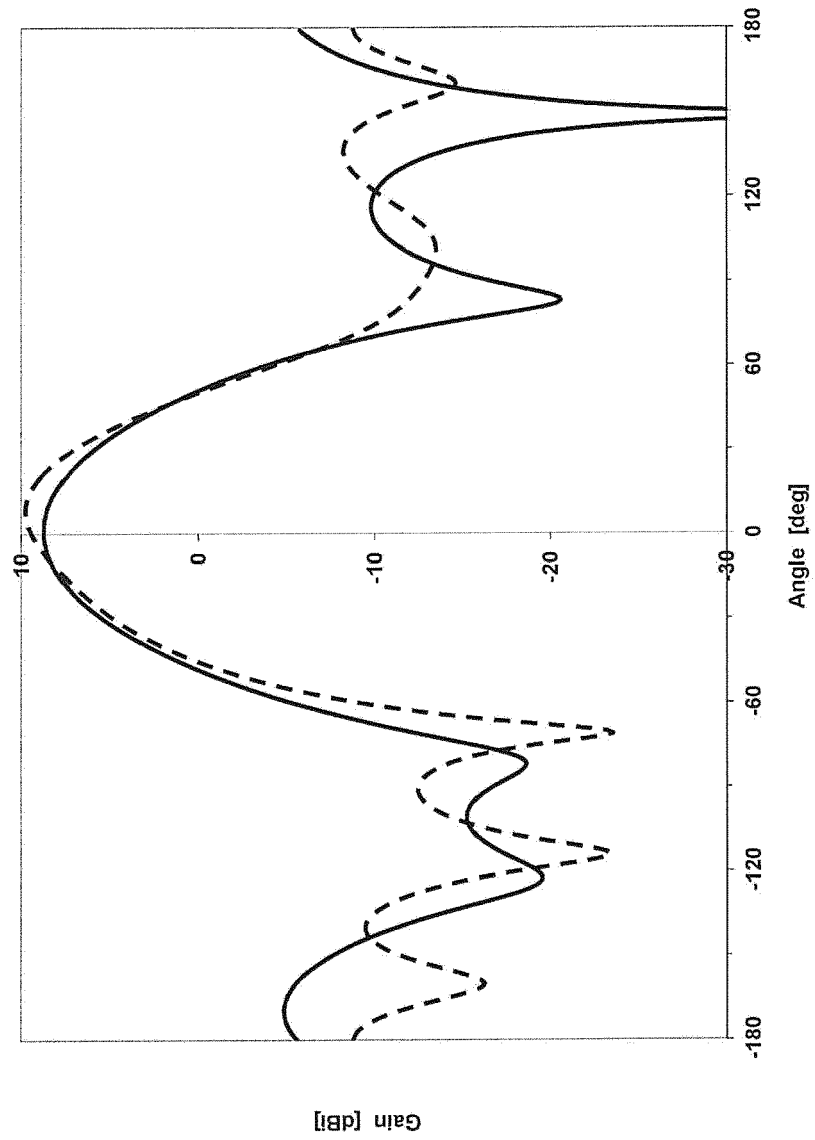


Figure 8

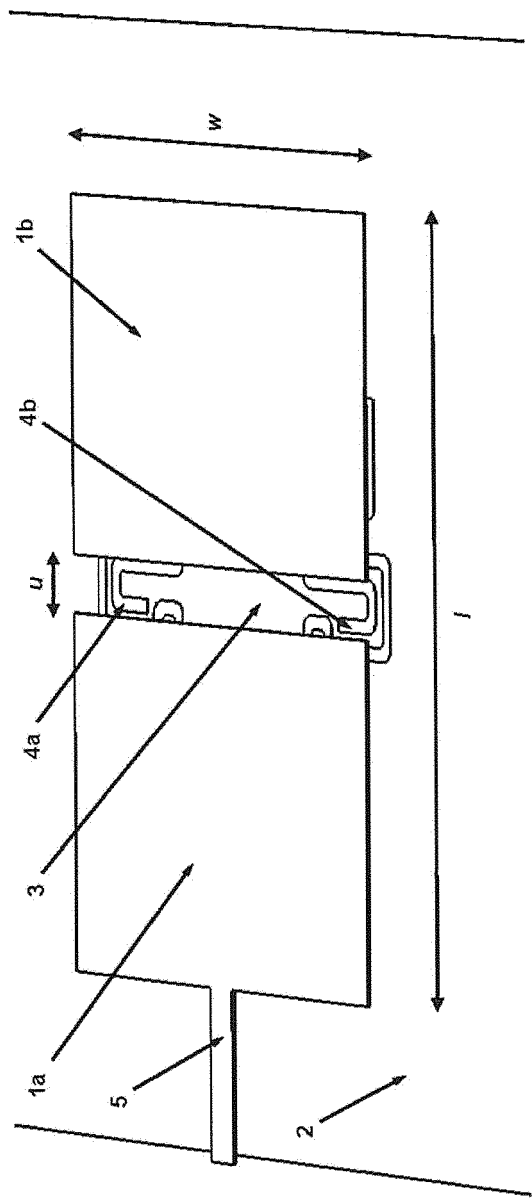


Figure 9

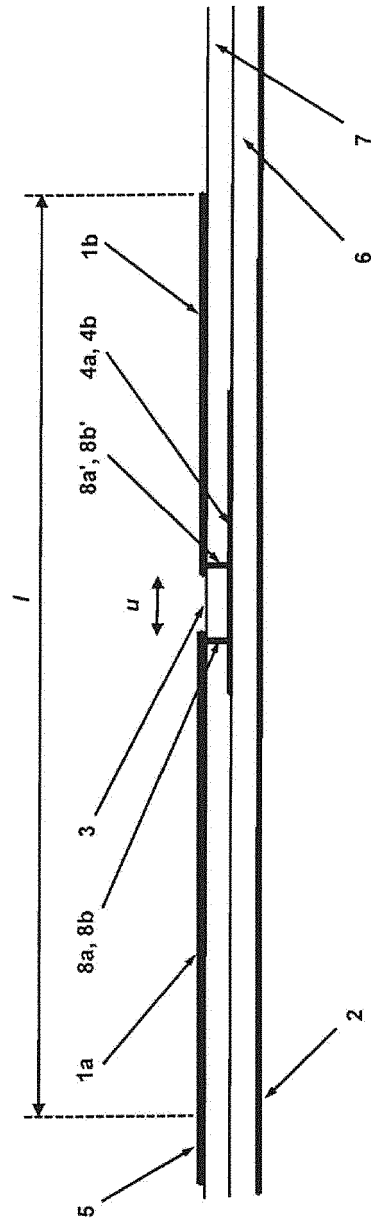


Figure 10

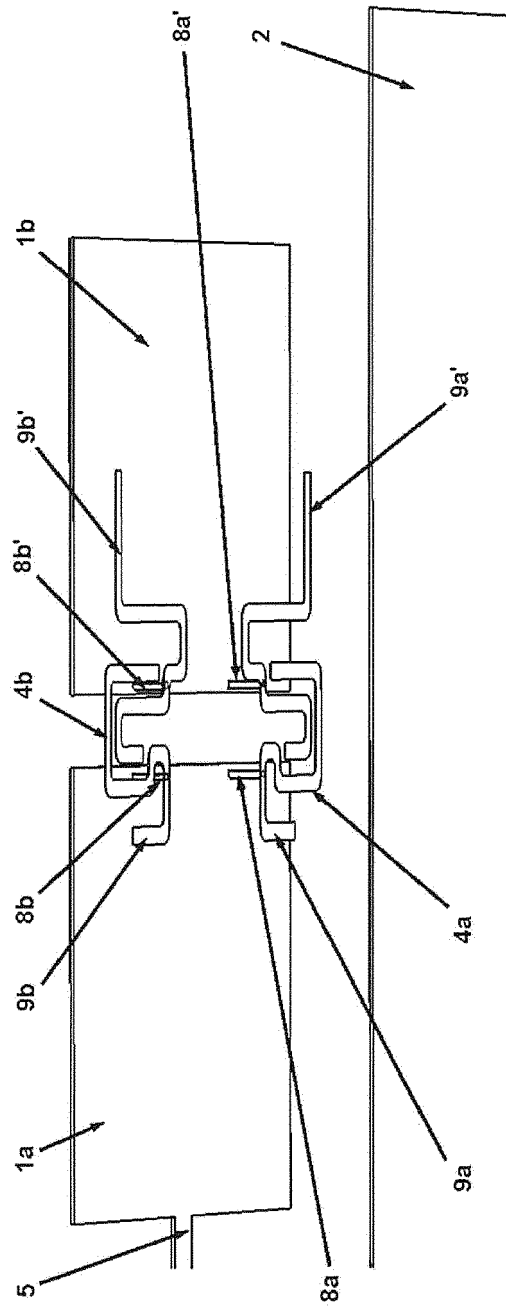


Figure 11

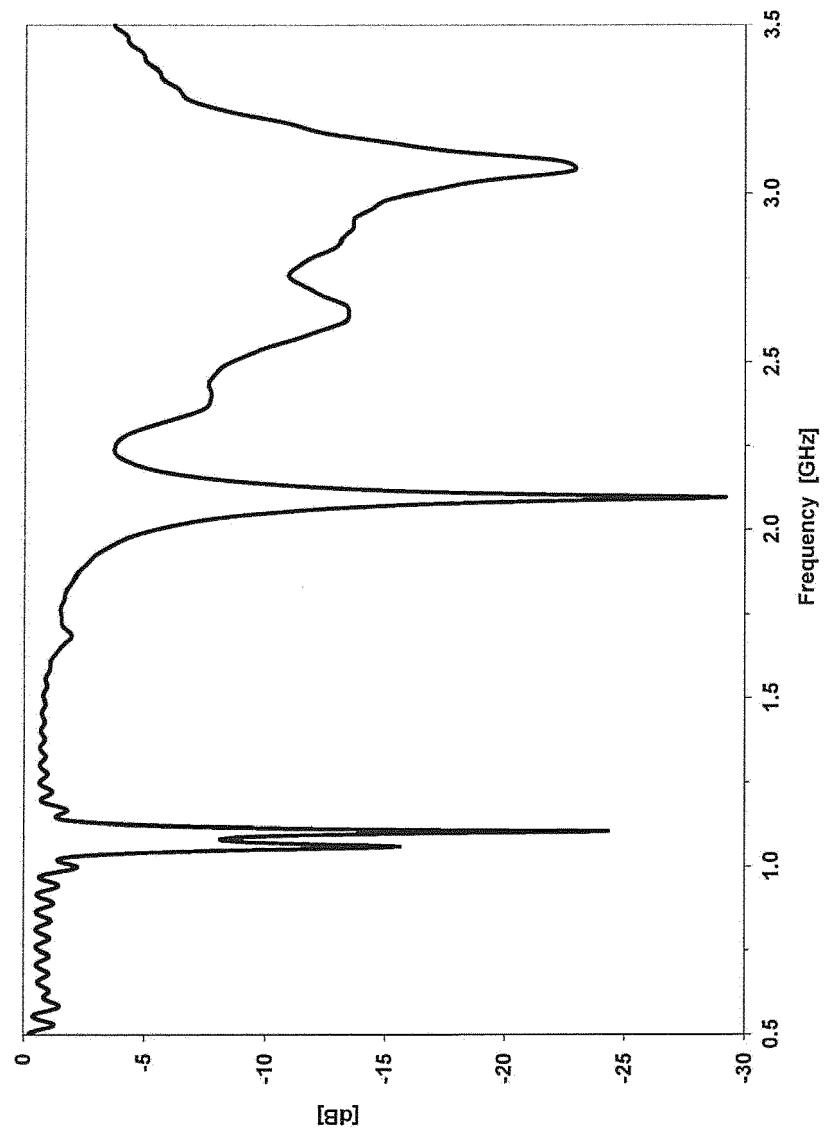


Figure 12

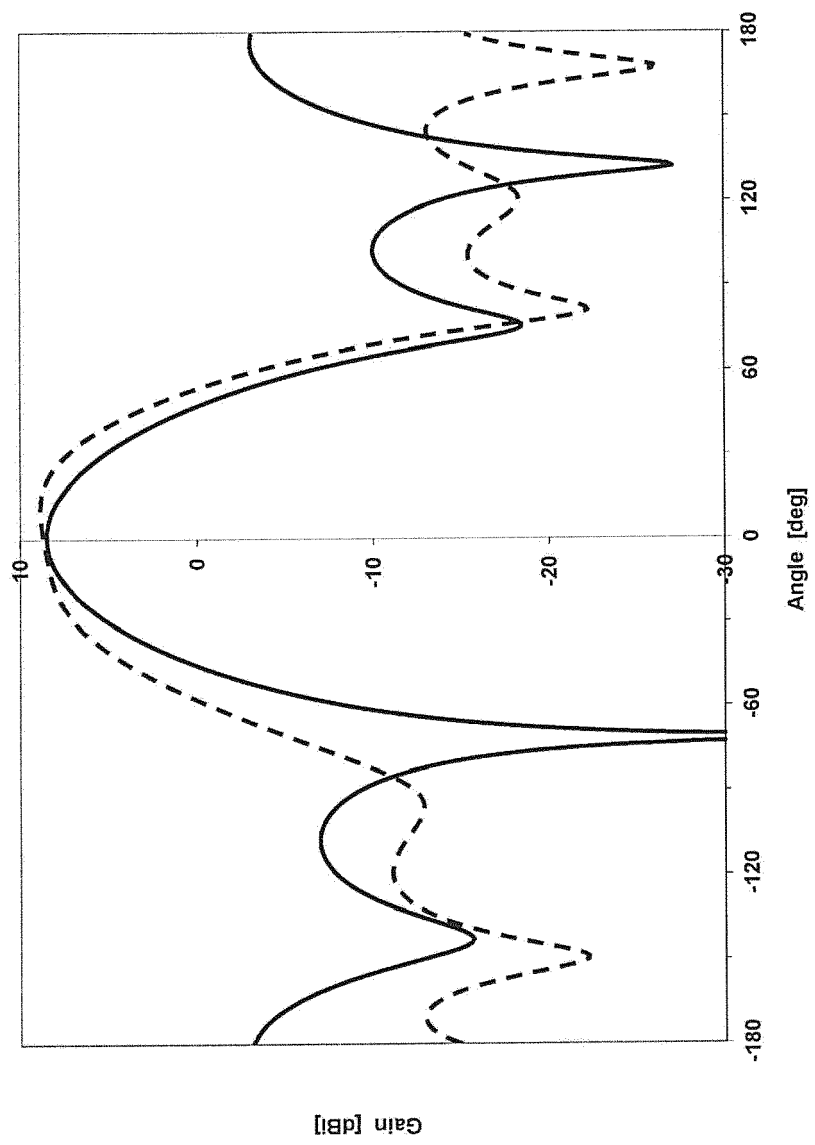


Figure 13

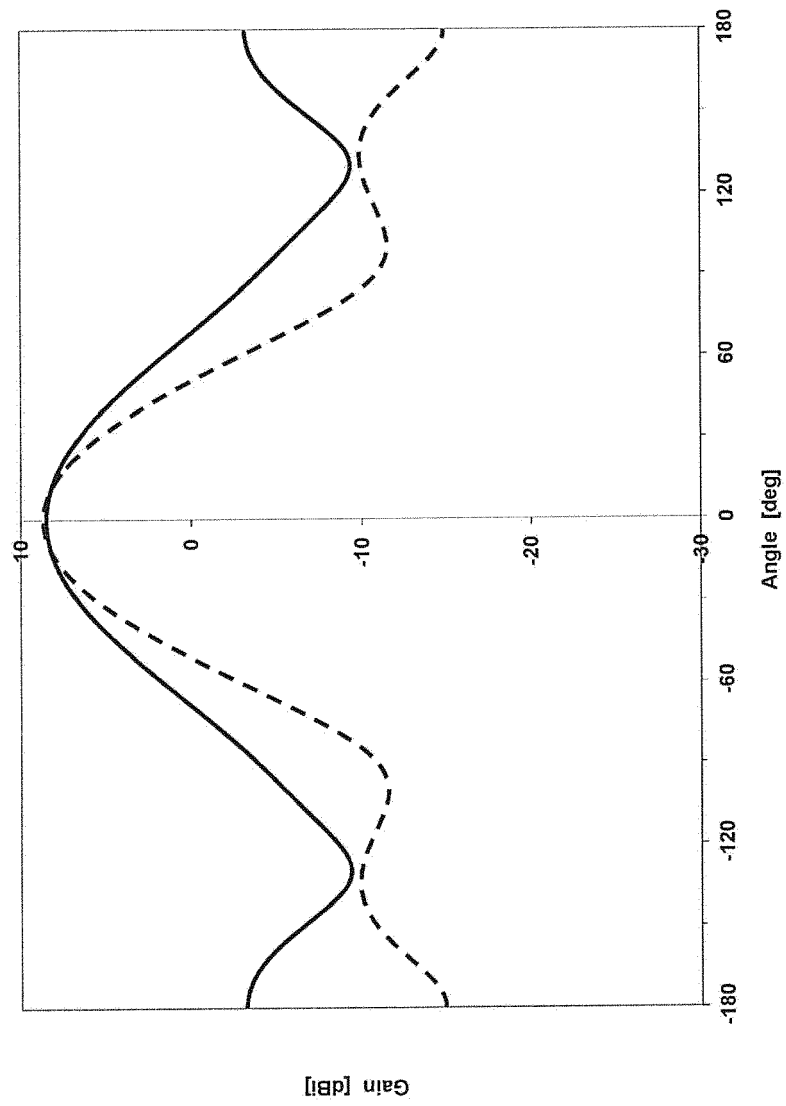


Figure 14

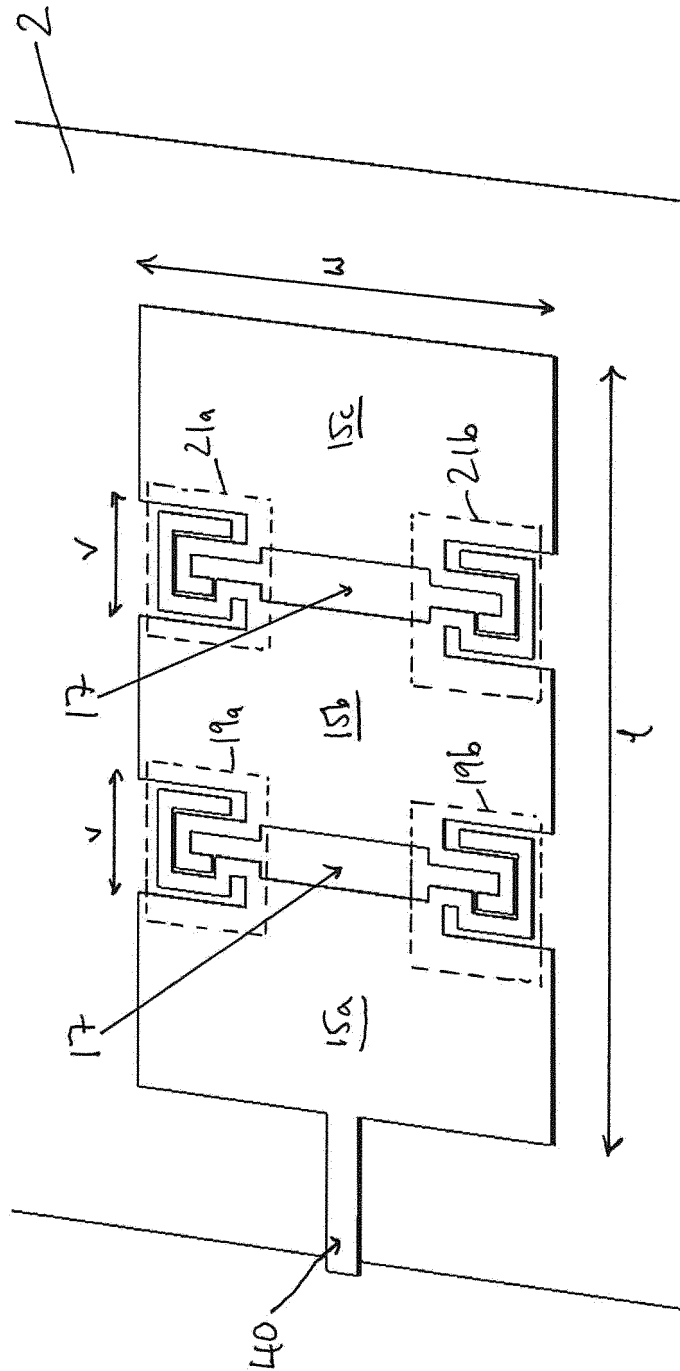


Figure 15



EUROPEAN SEARCH REPORT

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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 3 August 2015	Examiner Sípál, Vít
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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