



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
12.03.2008 Bulletin 2008/11

(51) Int Cl.:
H01Q 3/32 (2006.01) H01P 1/18 (2006.01)

(21) Application number: **07115572.5**

(22) Date of filing: **03.09.2007**

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

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(30) Priority: **11.09.2006 FR 0653660**

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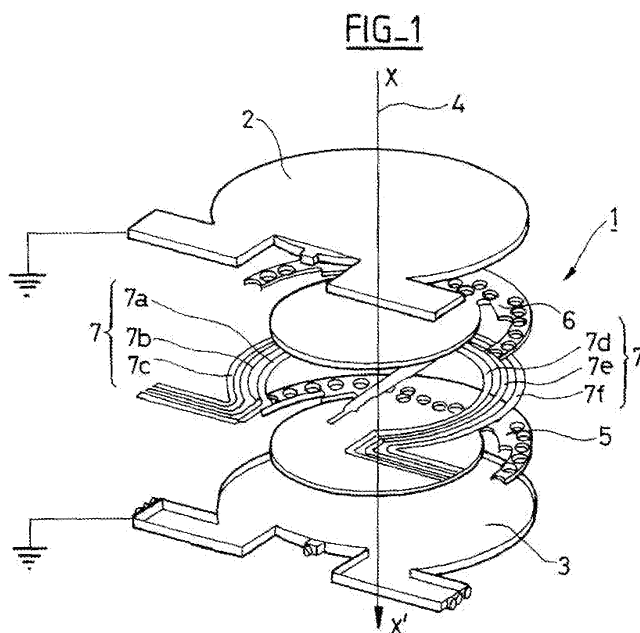
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(54) **Rotary phase-switch device**

(57) The rotary phase shift device includes an electrically conductive track (7), including a plurality of concentric segments (7a-7f) around an axis X-X', placed in a matrix (8) of low dielectric constant, at least one part (5, 6) in sliding contact with the track (7) of a material having a dielectric constant higher than that of the matrix, and adapted to be moved in rotation about the axis X-X' relative to the track (7), and at least one conductive surface (2, 3) disposed in contact with the exterior face of

the dielectric part (5, 6).

According to the invention, the track (7) includes a number Ne of input ports (31), each input port (31) being common to at least two segments (7a-7f), and a number Ns of output ports (32, 33), each of the segments (7a-7f) having an output port (32, 33), so that Ne is less than Ns. The device further comprises impedance transformation means (42) and means (43) for splitting the power between the segments (7a-7f).



Description

[0001] The present invention relates to a rotary phase shift device for applying a phase shift in particular to radiating elements, or groups of radiating elements, in particular belonging to antennas for base stations of cellular (GSM, UMTS, etc.) communication networks. The aim of this phase shifting is to depoint the direction of the main lobe of the antenna and thus to produce dynamic depointing antennas also known as "variable tilt antennas".

[0002] The invention concerns more particularly the field of microstrip type structures. Generally speaking, these are conductive surfaces formed on one of the faces of a plane dielectric substrate, to the other face of which is attached a continuous conductive sheet usually called the "ground plane". Microstrip radiating members generally take the form of a printed circuit attached to the dielectric substrate.

[0003] There are several large families of phase shift systems, according to their mode of mechanical operation.

[0004] On the one hand there are longitudinal displacement systems (described in US-5,949,303 or WO-02/35651, for example) in which a material with a high dielectric constant and low losses is used to create a relative phase shift between two radiating elements or two groups of radiating elements of an antenna. The material is inserted close to the conductive line, which can have a triplate type planar structure (stripline) or microstrip type structure. The propagation speed of the signal circulating on this conductive line is inversely proportional to the dielectric constant of the material, the thickness of the dielectric material part, and the degree to which the component is placed so as to intercept the current lines that are situated between the feed lines and ground. The major drawback of this system is that it necessitates a relatively large area to be activated, because the dielectric material part must move from one end to the other of the system in the longitudinal direction. The limits on the displacement of the part therefore limit the amplitude of the phase shift of the system.

[0005] On the other hand there are transverse displacement systems (described in EP-1 215 752, for example), in which a material with a high dielectric constant and low losses is used to create a relative phase shift between two radiating elements. The movement is transverse to the feed line of the various radiating elements. The phase shifts add together, until the last radiating element is fed. The drawback of this system is that each of the phase shifters must be moved, although they are relatively distant from each other physically.

[0006] Finally there are rotary systems (described in US-6,850,130 or JP-09-246846, for example), in which one or more metal parts provide the connection between various conductive lines. These metal parts provide an ad hoc coupling between the conductive lines, usually in the form of a contactless connection, i.e. where a capac-

itor effect between two metal parts provides RF coupling between the lines. However, the coupling between lines has the drawback that these systems are difficult to make perform well over a wide band of frequencies without necessitating compromises that impact negatively on coupling losses and thus on the overall efficiency of the phase shift system. Another drawback of these systems is that it is difficult to multiply the conductive lines that will be connected to the radiating elements.

[0007] Known phase shift systems modify the impedance of the signal propagation medium. Most authors (W.T. JOINES et al., IEEE Trans. on Microw. Theory and Techn. 19(8), 1971, 729-732; EP-1 182 724) take pains to maintain the impedance of the line equal and constant between the input and the output. To this end they increase the thickness of dielectric to vary the distance between the ground plane and the line and thereby re-establish the required impedance.

[0008] An object of the present invention is to eliminate the drawbacks of the prior art, by proposing a system for depointing a compact antenna comprising a phase shift device of simple, economic and reliable structure. It proposes in particular a rotary phase shift device offering continuous variation and low losses.

[0009] The present invention consists in a rotary phase shift device including:

- an electrically conductive track, including a plurality of concentric segments around an axis X-X', placed in a matrix of low dielectric constant,
- at least one part in sliding contact with the track of a material having a dielectric constant higher than that of the matrix, and adapted to be moved in rotation about the axis X-X' relative to the track, and
- at least one conductive surface disposed in contact with the exterior face of the dielectric part.

[0010] According to the invention, the track includes a number N_e of input ports, each input port being common to at least two segments, and a number N_s of output ports, each of the segments having an output port, so that N_e is less than N_s , and the device comprises impedance transformation means and means for splitting the power between the segments.

[0011] The rotary device of the invention achieves depointing of the antenna through the use of a low-loss material with a relatively high dielectric constant ($\epsilon_r > 1$) to create a phase shift.

[0012] This system comprises a fixed portion, including a stripline or microstrip type feed line. This line is of circular or semicircular type, and is surrounded by a material or a gas of relatively low dielectric constant ϵ_0 compared to that ϵ_r of the dielectric material; this gas can simply be air. The invention further includes one or more plates of a material of dielectric constant ϵ_r higher than that of the matrix surrounding the feed line, thereby enabling a high final phase shift to be obtained.

[0013] The use of a rotary device and concentric lines

is an easy way to obtain different phase progression speeds between the segments at the center and those on the outside. A phase progression therefore stems naturally from this particular construction. These phase progressions between the segments can be linear if the placement of the segments relative to the center of the device is chosen appropriately.

[0014] The dielectric part is advantageously in sliding contact with the segments that it covers at least partially, and is moved in rotation about the axis to modify the covering of the segments.

[0015] According to the invention, the track includes an impedance transformation first section and a current splitter second section. These sections are placed between the input and the outputs and are connected to the concentric segments. The phase shift device of the invention therefore simultaneously effects the current splitter device function.

[0016] The impedance transformation means represented by the first section are advantageously at least partly covered by a dielectric material. Such a covering contributes to improving the performance of the device. The dielectric portion preferably covers all or part of the power splitter means and impedance adaptation means referred to hereinabove.

[0017] The device includes the impedance adaptation means necessary for the branch connections to an RF send/receive device (here designated the input) and to the radiating elements (here designated the outputs). The device also provides directly, by virtue of how it is constructed, the distribution of energy appropriate and necessary to feeding the external devices (in the case of an antenna, these are the radiating elements).

[0018] In one particular embodiment of the invention, the mean dielectric constant of the dielectric component is modified by removal of material.

[0019] The present invention has the advantage of making mechanical movement of the dielectric part very easy by ensuring perfect continuity between the various feed lines of the microstrip or stripline structure radiating elements. Another advantage of the invention is that the rate of change of phase differs according to whether strip-lines or microstrips are concerned that are farther from or closer to the rotation center of the assembly. For lines placed close to the center, the phase shift is relatively slow, whereas for lines far from the center it is much faster, and this for the same angular movement. This is in contrast to longitudinal type mechanical phase shift systems in particular.

[0020] In effect, in the case of longitudinal systems, the mechanical displacement of the dielectric assembly is constant by construction, although it is necessary for the change of phase to be progressive, and preferably linear (i.e. the radiating elements at the edges of the antenna must be phase shifted much faster than those present at the center). Depending on whether the radiating elements to be fed are at the edges or at the center of the antenna, different dielectric media must be used,

i.e. media having different mean dielectric constant values. This can be achieved either by choosing a different dielectric material for each section of radiating elements to be fed or by forming voids in all or part of the dielectric material (for example by creating voids or by reducing the thickness) so that this mean value is modified.

[0021] In the context of the invention, to be sure that the phase shift between dipoles will be progressive it suffices to choose lines that are at the outside to feed the radiating elements that are placed at the edges of the antenna and the lines on the inside to feed the radiating elements that are placed at the center of the antenna. To control the speed of phase shift between the radiating elements, the distance between the tracks is chosen accordingly at the time of construction of the phase shift system. In particular, if the phase shift between the radiating elements of the antenna must be linear and progressive, an equal and constant distance between the lines will be adopted,

[0022] Of course, a change of dielectric medium can also be associated with the method so as to be able to use a supplementary construction variable. According to the invention, the dielectric material is preferably chosen from a plastic material and/or a ceramic material. In one particular embodiment, the plastic material constituting the dielectric material contains one or more polymers. The dielectric material can in particular consist of a mixture, an alloy or a stack of layers of different materials.

[0023] The invention also consists in an antenna comprising a phase shift device as described hereinabove.

[0024] Other features and advantages of the present invention will become apparent on reading the following description of one embodiment, given by way of illustrative and nonlimiting example, of course, and from the appended drawing, in which:

- figure 1 represents a diagrammatic exploded view of a first embodiment of a phase shift device according to the invention,
- figure 2 shows the device from figure 1 from which the cover has been removed,
- figure 3 shows the bottom of the device from figure 1,
- figure 4 shows the electrical circuit of the device from figure 1,
- figure 5 shows a dielectric part of the device from figure 1,
- figures 6A and 6B are views in section taken along the line A-A' of two embodiments of the dielectric part from figure 5,
- figure 7 represents a diagrammatic exploded view of a second embodiment of a phase shift device according to the invention,
- figure 8 shows the electrical circuit of the figure 7 device,
- figure 9 shows the upper dielectric part of the device from figure 6,
- figure 10 shows the lower dielectric part of the device from figure 6,

- figure 11 is a view in section taken along the line B-B' of the dielectric part from figure 9,
- figure 12 is a view in section taken along the line C-C' of the dielectric part from figure 10,
- figure 13 is a view in section taken along the line D-D' in figure 2 of the device from figure 1.

[0025] The phase shifter shown in these figures corresponds to a phase shifter designed to operate in the AMPS (Advanced Mobile Phone System) and GSM (Global System for Mobile communications) frequency bands, i.e. from 824 MHz to 960 MHz. A phase shifter according to the invention can operate in any frequency band, of course.

[0026] The invention applies to the field of microstrip type structures, i.e. structures having a conductive surface formed on one of the faces of a plane dielectric substrate, to the other face of which is attached a continuous conductive sheet called the ground plane. The microstrip radiating elements generally take the form of a printed circuit attached to the dielectric substrate. There will be described here only the more complex particular case in which the structure includes two ground planes, but it is clearly understood that everything that is described can be applied in an analogous manner to a structure including only one ground plane.

[0027] In the embodiment of the invention illustrated in figures 1 and 2, the phase shift device 1 comprises a casing made up of a cover 2 and a bottom 3 of conductive material disposed parallel to each other, connected by a central mechanical axis 4 coaxial with the direction X-X', and constituting the ground plane. The phase shifter 1 also comprises a lower portion 5 and an upper portion 6 of dielectric material placed in contact with the cover 2 and the bottom 3, respectively. The phase shifter further comprises a feed line in the form of an electrically conductive track 7 to be connected to a feed device and made up of a plurality of concentric segments 7a, 7b, 7c, 7d, 7e, 7f that are represented in the form of an array of lines. The two dielectric material parts 5, 6 are in sliding contact with the track 7. They cover the segments 7a-7f at least partially and are adapted to be moved in rotation relative to the track 7 to modify the covering of the segments,

[0028] Figure 3 represents diagrammatically the bottom 3 of the casing. The bottom 3 consists of a conductive material, at least at the surface. The cover 2 and the bottom 3 can advantageously be electrically connected, so that they are at the same potential, for example by grounding them. The bottom 3 and the cover 2 here constitute the ground planes of the phase shifter 1. The distance between them and the track 7 is fixed and does not vary during rotation. The bottom 3 and the cover 2 are here formed of a bent, cast or machined block of aluminum. The bottom 3 and the cover 2 could equally well be made from other materials, such as aluminum, copper, brass or any other metal or alloy. Here the bottom 3 has an Ω shape that covers the whole surface of the

phase shifter, but it could equally well be produced in numerous configurations other than that represented.

[0029] The bottom 3 includes at the minimum an electromagnetic signal input and two outputs each connected to a radiating element or to a group of radiating elements of the antenna. The minimum total number of input/output ports of the phase shifter 1 according to the invention is therefore 3 and only overall physical size constraints can impose a limit on the number thereof (without being limited to an even or odd number). In the present case, an input port 31 is represented in a central position, but it could equally well be placed on one of the sides of the bottom 3. The output ports 32 and 33 are carried by each end of the Ω shape. The input 31 and the outputs 32, 33 are connectors here, but they could equally well be produced in the form of direct connections to the radiating elements by means of coaxial cables or by extending the microstrip or triplate lines.

[0030] There is represented in figure 4 the electrical track 7 placed at the center of the phase shifter, which takes the form of a microstrip type line punched out from brass sheet, but it could equally well be produced in any other material having good electrical conductivity, as well as in the form of a printed circuit. The track 7 includes a plurality of segments 40 placed concentrically with the rotation axis X-X' of the phase shifter. The segments 40 are parallel to each other. During manufacture, these segments 40 are separated so as to minimize the coupling between them.

[0031] In the embodiment represented, the port 41 providing access to the track 7, common to all the segments 7a-7f, is situated at the center. The device can have a single input or several; in the latter case each input is common to at least two segments, so that the number N_e of inputs is always less than the number N_s of segments. Each of the segments has its own output, the number N_s of outputs being always equal to the number of segments. A first section 42 of the track 7, aligned with the port 41, is made up of a plurality of segments. The section 42 constitutes means enabling correct impedance transformation between the port 41 and the number N_s of connections to provide at the output ($N_s \geq 2$). The width of the segments forming the section 42 is adapted to comply with the input and output impedances required.

[0032] For example, the input impedance and the output impedance are typically of the order of 50 ohms. Nevertheless, in the context of the invention, the input impedance can be fixed at a value independent of the output impedances, and the output impedances can also be independent of each other. For example, the input impedance can be fixed at 75 ohms and the output impedances could be 35 ohms for a first output and 60 ohms for a second output.

[0033] Each segment can typically have a width of the order of 7.35 mm to 7.5 mm for a thickness of the order of 1 mm when the stripline is inscribed between two grounded dielectric components 7 mm apart.

[0034] In the present case, the distance between the

port 41 and all of the segments 40 to be fed is relatively great. This distance is exploited to enable this impedance transformation to be obtained under excellent conditions. The section 42 take the form of a Klopfenstein type progressive impedance transformation, for example. This section 42 can be produced in the form of a dielectric material or air stripline. This constitutes one of the great advantages of the invention. Known systems impose the acceptance of compromises that prejudice the width of the frequency band that can be used and the overall losses of the phase shift systems and offer few possibilities for adaptation of the input impedance of the phase shifter.

[0035] A second section 43 is used as means for splitting the power to the various segments 40. In effect, the segments 40 need not necessarily have the same amplitude of operation, although often they must allow weighting of the power available in the various outputs 32, 33. The arrangements aiming to weight these powers are usually encountered in the form of a modification of the section width of the segments 40 or in the form of voids added inside the latter.

[0036] It goes without saying that, given the reciprocity character of an antenna, a receiver element (or an antenna made up of an array of receiver elements) is capable of operating as a radiating element (or radiating antenna) without any modification of its characteristics. Consequently, the port that has just been described as an input could function as an output and the outputs could be used as a signal input.

[0037] On the bottom 3 is deposited a dielectric material part 5 represented in figure 5. A component 6 can also be deposited in the cover 2. The components 5, 6 can be produced in different ways. To facilitate the design, in the present example the components 5 and 6 are of identical shape. The components 5, 6 are typically made from a plastic material, for example polyester polypropylene (PPS RYTON®) having a dielectric constant of the order of 4 to 6. Although more costly and requiring greater accuracy, a ceramic type material could also be used as the dielectric material, having a dielectric constant ϵ_r of the order of 10 and above.

[0038] The part 5 covers only partially the surface of the bottom 3 and can be divided into three subassemblies:

- a solid central portion 51,
- two lateral wings 52 and 53 that produce an appropriate impedance transformation between the various heterogeneous media of the stripline device, and
- the peripheral portion 54 providing the phase shift function of the system.

[0039] The central portion 51 has no electrical function as such, unless it covers wholly or partly the port 41 of the track 7. In this case the dielectric can be employed to improve the performance of the progressive impedance transformation line.

[0040] In the present case, the impedance transforma-

tion is effected between the portion of the track 7 that is in contact with air and the portion of the track 7 that is enclosed between the solid portions of the two dielectric material components 5, 6. In the figure 1 embodiment, this impedance transformation function is achieved by creating voids in the dielectric material. These voids can have any required shape. For example, they have been represented here by simple voids formed in the parts 5 and 6. In figure 6A, these voids 55 pass completely through the part 5, 6; in figure 6B, the voids 56 are produced on either side of the part 5, 6 and do not communicate. The configuration of the dielectric part 5 from figure 5 thus inherently produces a gradual phase shift through the use of localized, complete or partial voids in the dielectric medium.

[0041] Calculation or simulation yields the appropriate succession of modifications to be effected in the section of the parts 5, 6 to obtain an appropriate impedance transformation between the two media using a scheme equivalent to the dielectric medium of localized elements envisaged under the succession of discrete elements: resistance R, inductances L and capacitances C. Of course, each segment of the track being able to undergo a phase shift independently, the parts 5 and 6 are not necessarily symmetrical.

[0042] Rotation about the central axis X-X' of the peripheral portion 54 of the part 5, 6, consisting of a material with a relatively high dielectric constant and low losses (of the order of less than one per thousand), produces a relative phase shift between the radiating elements (or groups of radiating elements) of the antenna. The dielectric material used is disposed in the vicinity of the conductive track in a "stripline" (stripline) configuration in the present case. The part 5, 6 is placed to intersect the current lines between the feed segments 7a, 7b and 7c and ground. The dielectric material part 5, 6 must not cause any loss of signal intensity, but has the role of retarding signal propagation. The propagation speed of the signal traveling in this conductive line is inversely proportional to the dielectric constant of the part 5, 6 and to the thickness of the part 5, 6.

[0043] The figure 13 sectional view shows the track 7 made up of the concentric segments 7a-7f. The dielectric parts 5 and 6 are disposed on either side of the segments 7a-7f and the impedance transformation means 42, and in contact with them so that they can move in rotation about the axis X-X'. The segments 7a-7f of the track 7 are surrounded by a matrix 8, here of air, in all areas in which they are not in contact with the dielectric material of the parts 5 and 6. The external faces of the dielectric parts 5 and 6 are in contact with conductive surfaces consisting of the bottom 3 and the cover 2, respectively.

[0044] In the figure 7 embodiment, the phase shift device 71 comprises a casing made up of a cover (not shown) and a bottom 72 of conductive material, an upper part 73 and a lower part 74 of dielectric material placed in contact with the cover and the bottom 72, respectively, and an electrically conductive track 75 made up of a plu-

rality of concentric segments. The two dielectric material parts 73, 74 can be moved in rotation relative to the track 75 to modify the covering of the line.

[0045] Figure 8 is a diagram that shows an example of an electrical track 81 obtained by simulation. There are shown the port 82 common to the track 81 that is situated at the center, a first section 83 of the track 81 in line with the port 82 made up of a plurality of segments, and a second section 84 used for splitting between the various segments 85a-85f each provided with an output 86.

[0046] Figures 9 and 10 respectively show two variants 91, 101 of a dielectric material part of the figure 7 embodiment. The part 91, 101 includes a central portion 92, 102, two lateral rings 92, 93 and 103, 104 that produce the impedance transformation, and a peripheral portion 95, 105 that produces the phase shift function of the system. The wings 92, 93 and 103, 104 are simplified because they are reduced here to a single reduced thickness quarter-wave section. Quarter-wave sections are used in figures 9 and 10 where the mean value of the dielectric constant is varied by modifying the thickness of the material at each stage, as represented in figures 11 and 12, for example.

[0047] The central portion 92, 102 has no electrical function as such, unless it covers all or part of the port 41 of the track 7. In figure 9, the central portion 92 is solid. However, if that choice is not adopted, voids 106 can be formed in the central portion 102 as shown in figure 10, for example.

[0048] The invention is not limited to the embodiments described but lends itself to numerous variants that will readily suggest themselves to the person skilled in the art.

Claims

1. Rotary phase shift device including:

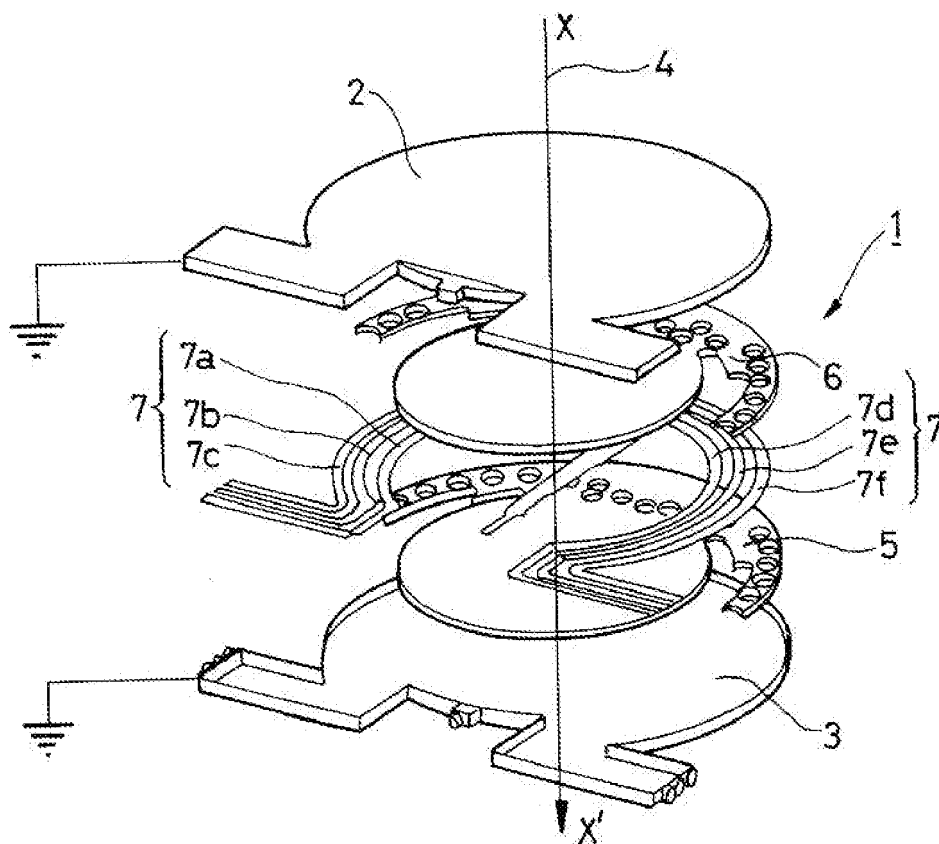
- an electrically conductive track (7), including a plurality of concentric segments (7a-7f) around an axis X-X', placed in a matrix (8) of low dielectric constant,
- at least one part (5, 6) in sliding contact with the track (7) of a material having a dielectric constant higher than that of the matrix, and adapted to be moved in rotation about the axis X-X' relative to the track (7), and
- at least one conductive surface (2, 3) disposed in contact with the exterior face of the dielectric part (5, 6),

characterized in that the track (7) includes a number M_e of input ports (31), each input port (31) being common to at least two segments (7a-7f), and a number N_s of output ports (32, 33), each of the segments (7a-7f) having an output port (32, 33), so that N_e is less than N_s , and **in that** the device com-

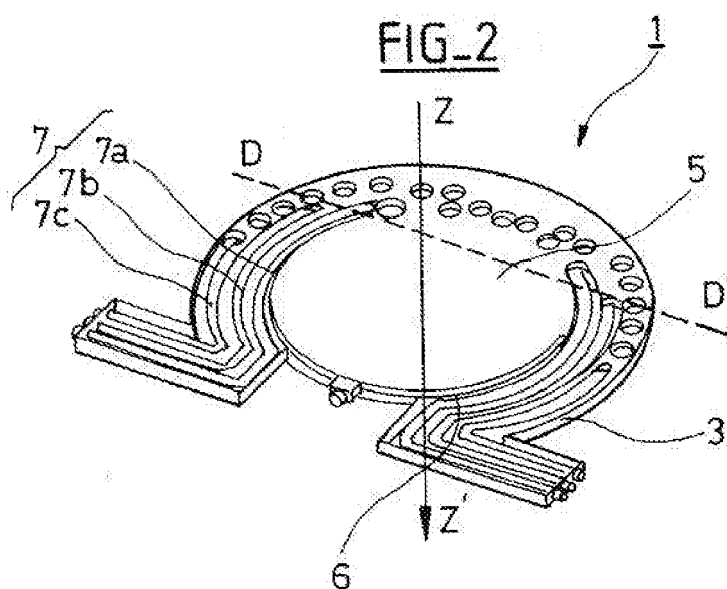
prises impedance transformation means (42) and means (43) for splitting power between the segments (7a-7f).

2. Device according to claim 1, wherein the dielectric part (5, 6) is in sliding contact with the segments (7a-7f) that it covers at least partially, and is moved in rotation about the axis X-X' to modify the covering of the segments.
3. Device according to claim 2, wherein the distance between the conductive surface (2, 3) and the track (7) is constant.
4. Device according to any one of the preceding claims, wherein the impedance transformation means (42) are at least partially covered by a dielectric material.
5. Device according to any one of the preceding claims, wherein the mean dielectric constant of the dielectric part (5, 6) is modified by removal of material.
6. Device according to any one of the preceding claims, wherein the dielectric material is chosen from a plastic material and a ceramic material.
7. Device according to claim 5, wherein the dielectric material contains one or more polymers.
8. Antenna comprising a phase shift device according to any one of the preceding claims, comprising N_e electromagnetic signal input/output ports and N_s input/output ports, each connected to at least one radiating element, where N_e is less than N_s .

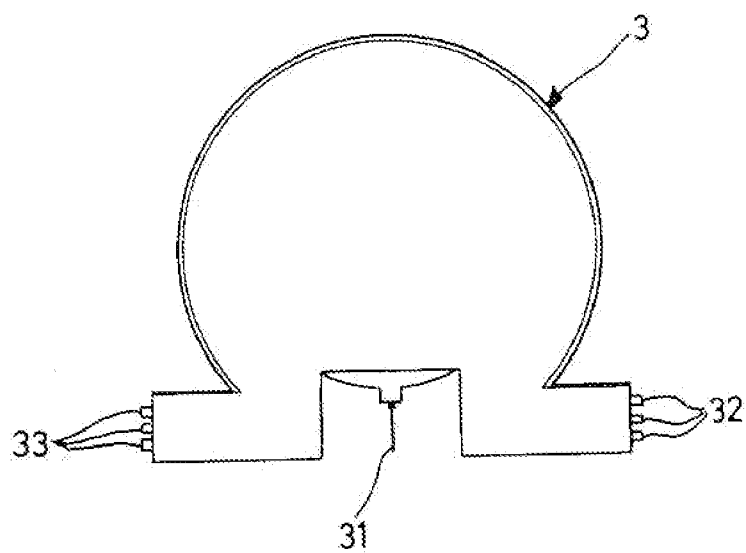
FIG_1



FIG_2



FIG_3



FIG_4

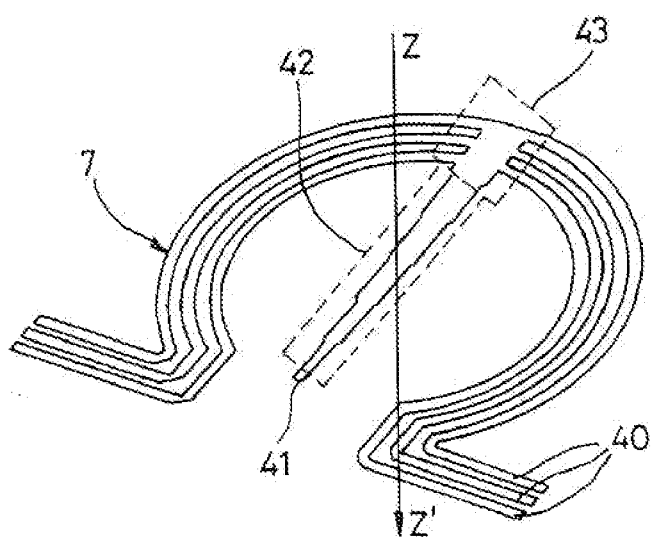


FIG. 5

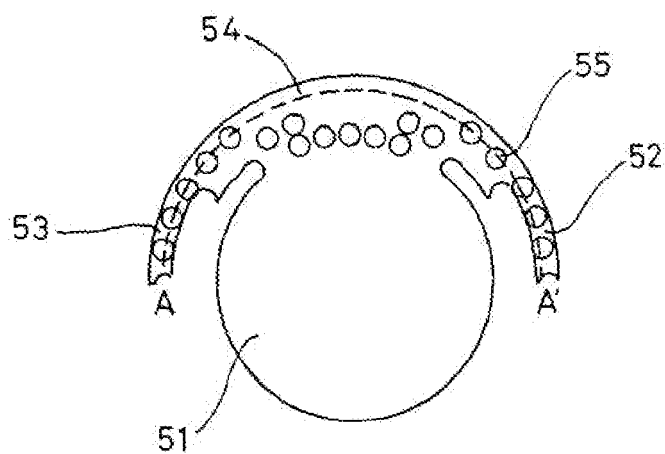


FIG. 6A

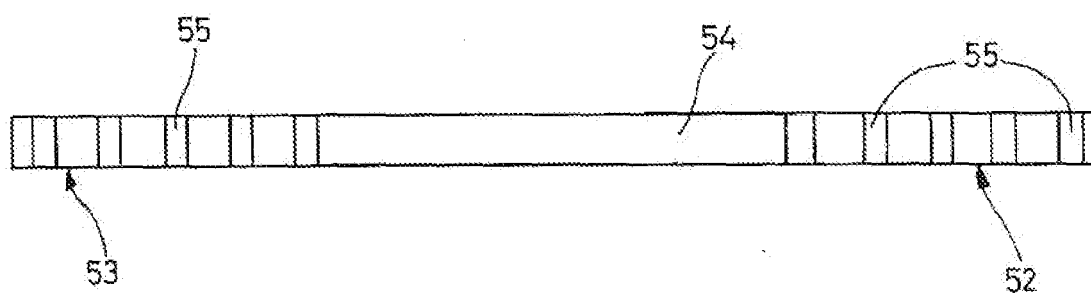
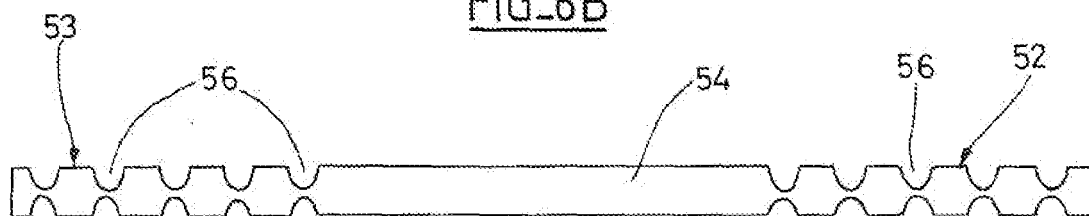
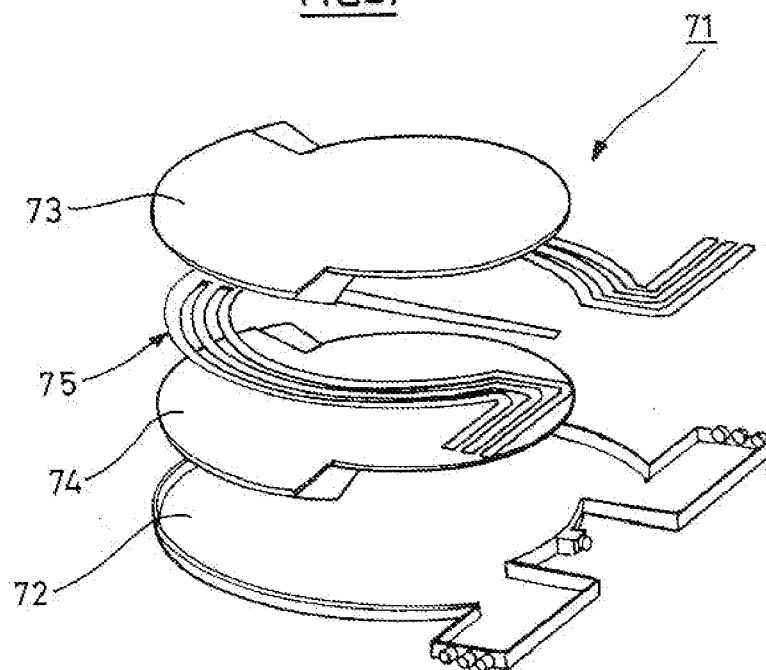


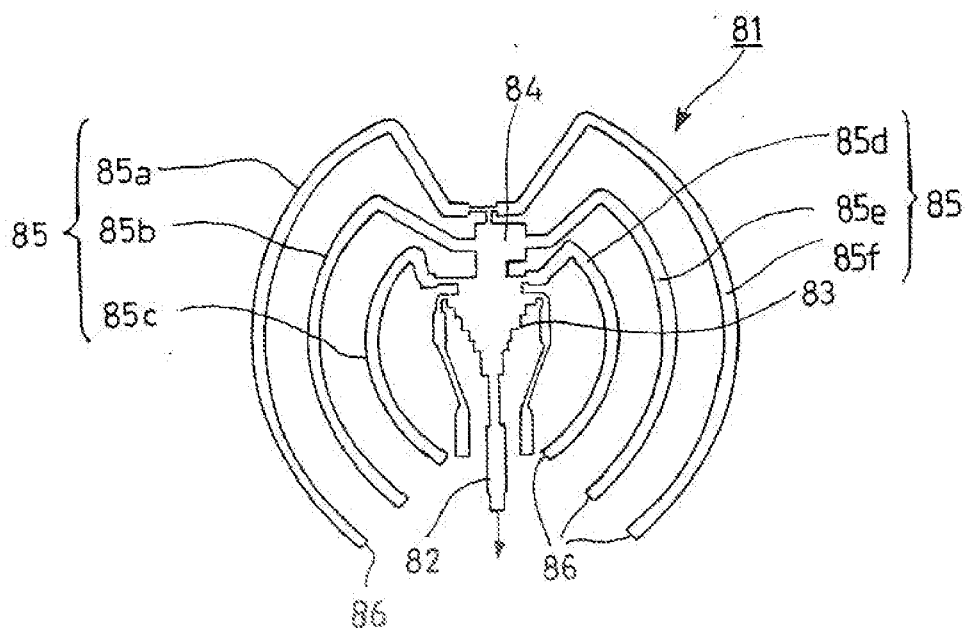
FIG. 6B



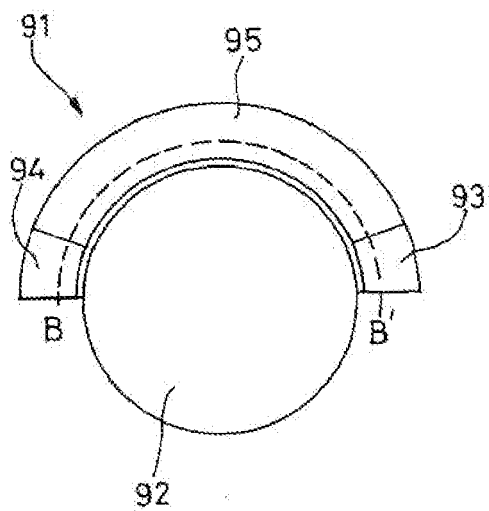
FIG_7



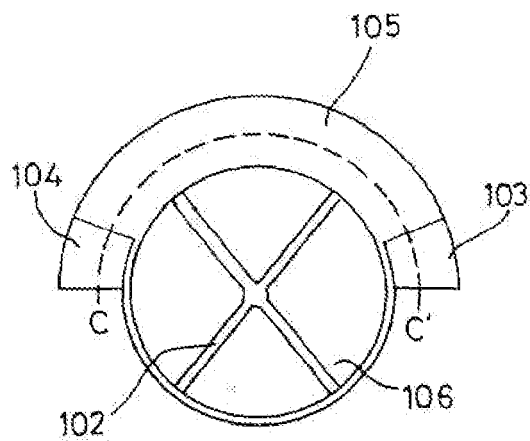
FIG_8



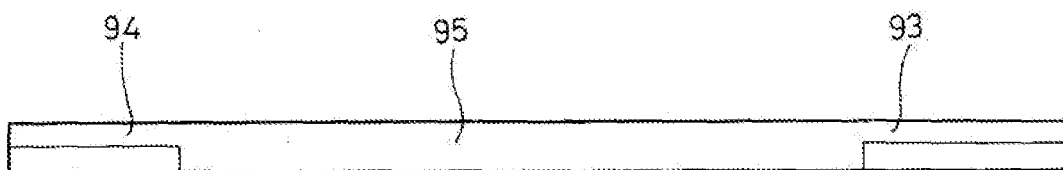
FIG_9



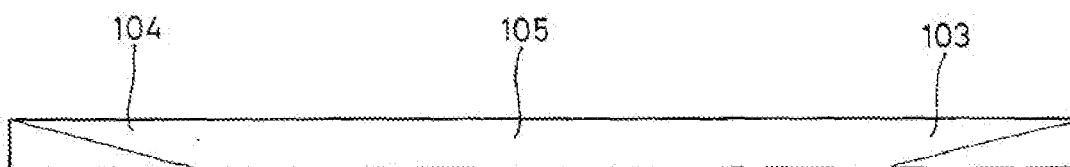
FIG_10



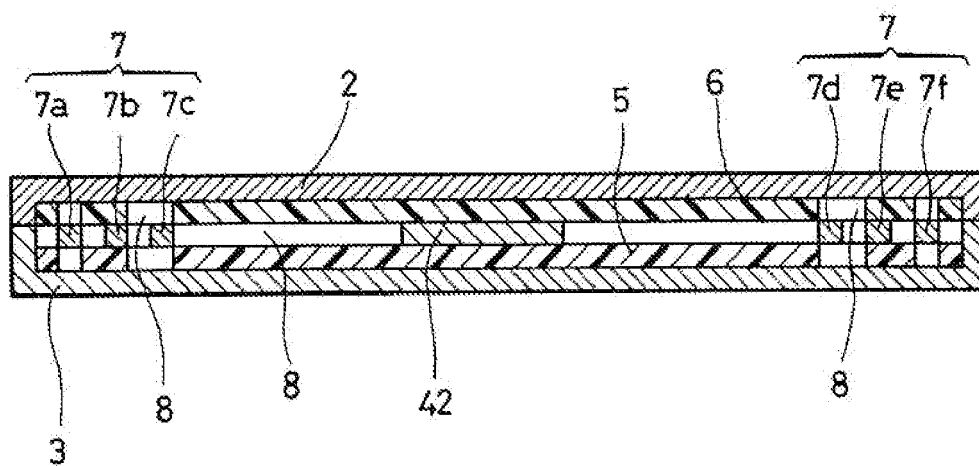
FIG_11



FIG_12



FIG_13



REFERENCES CITED IN THE DESCRIPTION

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