

(19)



(11)

EP 3 609 018 B1

(12)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
21.01.2026 Bulletin 2026/04

(51) International Patent Classification (IPC):
H01P 1/18 (2006.01) **H01Q 3/36** (2006.01)
H01Q 21/06 (2006.01)

(21) Application number: **19190405.1**

(52) Cooperative Patent Classification (CPC):
H01P 1/184; H01Q 3/36; H01Q 21/061

(22) Date of filing: **06.08.2019**

(54) RADIO FREQUENCY PHASE SHIFTING DEVICE AND METHOD OF OPERATION FOR THIS PHASE SHIFTING DEVICE

HOCHFREQUENZPHASENVERSCHIEBUNGSVORRICHTUNG UND BETRIEBSVERFAHREN FÜR DIESE PHASENVERSCHIEBUNGSVORRICHTUNG

DÉPHASEUR DE FRÉQUENCE RADIO ET SON PROCÉDÉ DE FONCTIONNEMENT

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(30) Priority: **06.08.2018 EP 18187483**

(43) Date of publication of application:
12.02.2020 Bulletin 2020/07

(73) Proprietor: **Beijing BOE Sensor Technology Co., Ltd.**
Beijing 100176 (CN)

(72) Inventors:
• **Gäbler, Alexander**
64287 Darmstadt (DE)
• **Karabey, Onur Hamza**
64289 Darmstadt (DE)
• **Gölden, Felix**
64380 Rossdorf (DE)

(74) Representative: **Haseltine Lake Kempner LLP**
Cheapside House
138 Cheapside
London EC2V 6BJ (GB)

(56) References cited:

- **ONUR HAMZA KARABEY ET AL: "Tunable loaded line phase shifters for microwave applications", MICROWAVE SYMPOSIUM DIGEST (MTT), 2011 IEEE MTT-S INTERNATIONAL, IEEE, 5 June 2011 (2011-06-05), pages 1 - 4, XP032006583, ISBN: 978-1-61284-754-2, DOI: 10.1109/MWSYM.2011.5972634**
- **NIKFALAZAR MOHAMMAD ET AL: "Fully printed tunable phase shifter for L/S-band phased array application", 2014 IEEE MTT-S INTERNATIONAL MICROWAVE SYMPOSIUM (IMS2014), IEEE, 1 June 2014 (2014-06-01), pages 1 - 4, XP032615297, DOI: 10.1109/MWSYM.2014.6848295**
- **MEHMOOD ARSHAD ET AL: "Dielectric resonator antenna phased array with liquid crystal based phase shifters", THE 8TH EUROPEAN CONFERENCE ON ANTENNAS AND PROPAGATION (EUCAP 2014), EUROPEAN ASSOCIATION ON ANTENNAS AND PROPAGATION, 6 April 2014 (2014-04-06), pages 2436 - 2439, XP032642783, DOI: 10.1109/EUCAP.2014.6902310**

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 3 609 018 B1

Description

Technical Field

[0001] The invention relates to a radio frequency phase shifting device with a transmission line comprising a first electrode and a second electrode that are spaced at a distance to each other, and which are suitable and used for propagation of a radio frequency electromagnetic signal along the first electrode and the second electrode with a phase difference of 180° between the respective electromagnetic signals, wherein a tunable dielectric material affects a phase shift of the electromagnetic signal that is propagated along the transmission line.

Background of the invention

[0002] Phase shifting devices can be used to modify the relative displacement between two corresponding features like peaks or zero crossings of an electromagnetic wave or signal without changing the frequency of the electromagnetic wave or signal. When two or more electromagnetic signals of the same frequency are superimposed, the result depends on the phase difference between the respective electromagnetic signals. The electromagnetic signals can be reinforced or weakened. Furthermore, by superimposing two or more electromagnetic waves that are radiated by respective antennas, the phase difference between the radiated electromagnetic waves will determine a direction of a reinforced superposition of the electromagnetic waves, resulting in a preferred direction of irradiation originating from the respective antennas.

[0003] In order to intensify the reception or emission of electromagnetic irradiation from a given direction, a phased array antenna comprises several antenna elements that are distributed next to each other. The phase difference of electromagnetic signals received or emitted by the respective antennas is predetermined in such a manner that the superposition of the respective signals is maximized for a given direction, resulting in enhanced signal sensitivity or signal emission for said direction.

[0004] There are known prior art phase shifting devices that create a pre-set phase difference between the incoming and outgoing signal. A phased array antenna that is equipped with such constant phase shifting devices can be designed to maximize the signal sensitivity or signal emission for a given single direction.

[0005] Furthermore, phase shifting devices with a tunable phase difference are known and described e.g. in EP 2 761 693 A1 or EP 2 956 986 B1. These phase shifting devices include a linear transmission line comprising a first electrode and a second electrode that are spaced at a distance to each other, wherein a tunable dielectric material is arranged between the first electrode and the second electrode. The phase difference created by a tunable phase shifting device can be tuned, i.e. it can

be operated to produce different phase differences whereby the respective phase difference can be modified and controlled by a control setting applied to the tunable dielectric material which affects the phase of the signal along the linear transmission line. A phased array antenna with several antennas that are interconnected with such tunable phase shifting devices can be operated in such a manner as to change the direction of enhanced signal sensitivity or signal emission in accordance to the requirements at a given time.

[0006] Prior art document ONUR HAMZA KARABEY ET AL: "Tunable loaded line phase shifters for microwave applications", IEEE MTT-S INTERNATIONAL MICROWAVE SYMPOSIUM, 5 June 2011, pages 1-4, discloses a tunable periodically loaded slot line phase shifter. Prior art document Mohammad Nikfalazar et al.: "Fully printed tunable phase shifter for L/S-band phased array application", IEEE MTT-S INTERNATIONAL MICROWAVE SYMPOSIUM, 1 June 2014 (2014-06-01), pages 1-4, discloses a phase shifting device with a tunable phase that is fully printed on top of a carrier substrate.

[0007] Therefore, one of the key components which are necessary to build phased array antennas with adaptive beam forming is a tunable phase shifting device, meaning a device which dynamically can adjust the phase or the delay of a radiofrequency signal. Usually, there is at least one phase shifting device for each radiating element of the array antenna. Each phase shifter device in turn is fed by a feed network. Due to the usually required large number of radiating elements, an at least equally large number of phase shifting devices must be integrated within a limited area in such a phase array antenna.

[0008] Accordingly, there is a need for a phase shifting device that allows for easy manufacturing, requires little space and provides for a large phase difference between the input signal and the output signal. Easy manufacturing is possible if techniques can be used to fabricate a large number of electrodes at high density on an area of e.g. 0.5 m² which is a typical surface area for phased array antennas operating at frequencies of e.g. 20 GHz. The necessary fabrication techniques are in principle known from Liquid Crystal Display (LCD) manufacturing but are usually not applied to building phased array antennas. In order to employ the fabrication techniques of LCD manufacturing suitable tunable phase shifter topologies have to be found which can be both electrically and also mechanically be integrated in a phased array antenna system.

[0009] Accordingly, there is a need for a phase shifting device that allows for easy manufacturing, requires little space and provides for a large phase difference between the input signal and the output signal.

Summary of the invention

[0010] The present invention relates to a radio frequency phase shifting device as set out in the appended

set of claims 1 to 16.

[0011] The phase of the electromagnetic signal that propagates along the transmission line will be affected by the parallel plate capacitor areas that are distributed along the transmission line. The electromagnetic signal is preferably a radiofrequency signal with a frequency in the range of 20 kHz to 300 GHz. The phase shifting device is adapted to transmit such a radiofrequency signal and to affect and modify the phase of this signal.

[0012] From a topological view the transmission line with non-overlapping sections and with overlapping sections is similar to a periodically loaded differential or balanced transmission line. The resulting phase shift depends inter alia on the number and the area of the parallel plate conductor areas within the overlapping sections that are implemented along the transmission line.

[0013] Preferably the tunable dielectric material is a liquid crystal material with a high dependency of the dielectric characteristics on an electric field that is applied to the liquid crystal material. Suitable liquid crystal materials as well as other tunable dielectric materials are known in the art and commercially available. The electric field that is applied to the liquid crystal material superimposes the radio frequency signal that is propagated along the transmission line, but this does not significantly interfere with the signal propagation.

[0014] A key difference between phase shifting devices known in prior art and the invention at hand is the design and embodiment of the transmission line as a differential line, i.e. as a transmission line that is suitable and can be used for signal transmission along the transmission line in a differential pair transmission mode. Thus, the arrangement and the design of the first and second electrode of the transmission line must provide for a balanced transmission line. Furthermore, the first electrode and the second electrode are electroconductively isolated from each other. The transmission line must allow for a predominant signal propagation along the transmission line in transverse electromagnetic mode (TEM-mode) with neither electric nor magnetic field in the direction of propagation, i.e. in the direction along the transmission line.

[0015] The phase shift of the electromagnetic signals that are transmitted along the first and second electrode will be affected and controlled by the dielectric characteristics of the overlapping sections, that itself are controlled by the electric field that is applied to the tunable dielectric material arranged within the overlapping sections. The combined radio frequency signal with the appropriate phase shift that has been preset by the phase shifting device can then be used for e.g. signal emission or for signal evaluation of a phased array antenna.

[0016] According to an advantageous aspect of the invention the first electrode is arranged at a distance in the first direction to the second electrode, whereby the overlapping area of the first electrode overlaps the overlapping area of the second electrode in order to provide

for one parallel plate capacitor area. Thus, no dedicated and separate capacitor electrodes are required. The first electrode and the second electrode are divided into sections that do not overlap each other and into sections that overlap each other. The tunable dielectric material is arranged between the first electrode and the second electrode. The tunable dielectric material may be arranged as a layer that is confined by glass or other material. The surface of the layer may extend over both electrodes and cover overlapping sections and non-overlapping sections of the first electrode and the second electrode. It is also possible to limit the tunable electric material to separate areas that only cover the respective capacitor electrode areas between the first electrode and the second electrode.

[0017] According to an advantageous embodiment of the invention, the first electrode is arranged at a first surface of a first substrate layer and the second electrode is arranged at a second surface of a second substrate layer, whereby the first surface of the first substrate layer faces the second surface of the second substrate layer and whereby the first surface is arranged at a distance in the first direction to the second surface. The first electrode and the second electrode can be manufactured by deposition of electroconductive material onto a corresponding nonconducting substrate layer. The two substrate layers can be spaced at a distance in the first direction to each other, thereby confining an intermediary layer of the tunable dielectric material. Such a sandwich structure can be manufactured by easily controllable and reliable methods. The space requirement is approximately one millimeter for the thickness of the sandwich structure. Manufacture of the sandwich structure is similar to fabrication of liquid crystal displays and can be integrated into the respective production methods which then include such phase shifting devices. The substrate layers can be made of glass or any other material with non-conductive or sufficiently low conductive characteristics and with sufficient surface smoothness.

[0018] According to an advantageous embodiment of the invention the first surface of the first substrate layer and the second surface of the second substrate layer confine the tunable dielectric material. Thus, no further substrate layers are required for confining the tunable dielectric material, which reduces the size and manufacturing costs for the phase shifting device.

[0019] According to an alternative aspect of the invention the first electrode and the second electrode are arranged side by side at a distance towards each other along the second direction on a same surface of a substrate layer, and a capacitor electrode is arranged at a distance in the first direction to this surface of the substrate layer with the first electrode and the second electrode in such a manner that a first capacitor electrode area of the capacitor electrode overlaps the overlapping area of the first electrode and that a second capacitor electrode area of the capacitor electrode overlaps the overlapping area of the second electrode, thus providing

for two parallel plate capacitor areas between the capacitor electrode and the respective overlapping areas within the overlapping section. The first electrode and the second electrode may be arranged next to another on the same level of the phase shifting device. In addition to the first and the second electrode at least one or a few, but preferably many capacitor electrodes are arranged at another level in the first direction with respect to the first and second electrodes. The use of separate capacitor electrodes allows for complex shapes of the parallel plate capacitor areas along the transmission line and may simplify the manufacturing of the phase shift device.

[0020] In another aspect of the invention the first electrode and the second electrode each comprise an unbranched strip-shaped transmission line segment, whereby both transmission line segments are directed along the transmission line. A strip-shaped transmission line segment usually has a uniform width. Both transmission line segments can be of linear shape, i.e. the strip-shaped transmission line segment extends along a straight line, whereby the respective transmission segments are parallel and at a distance in the second direction to each other.

[0021] The strip-shape transmission line segment can also be curved. It is also possible for the strip-shape transmission segment to comprise linear sections in combination with corners or curved sections. Furthermore, the strip-shaped transmission segment may also have a spiral shape or meandering shape. The strip-shape transmission line segment may also have a zig-zag pattern.

[0022] According to another aspect of the invention, the strip-shaped transmission segments only comprise non-overlapping sections arranged at a distance towards each other in the second direction, and each of the overlapping areas of the first electrode and/or of the second electrode is protruding in the second direction from the respective strip-shaped transmission line segment of the first electrode and/or of the second electrode. When viewed from a distance in the first direction, the combined shape of the first electrode and the second electrode can be similar to a ladder, wherein the strip-shaped transmission line segment of the first electrode and of the second electrode are similar to the first and second ladder beams, and wherein the protruding overlapping areas are similar to the rungs of the ladder. Each rung of the ladder comprises one overlapping area that protrudes in the second direction from the strip-shaped transmission line segment of the first electrode, and one overlapping area that protrudes in the second direction from the strip-shaped transmission line segment of the second electrode. Even though the two respective overlapping areas of the first and second electrode do overlap, they are spaced apart in the first direction and separated by the tunable dielectric material that is between the first electrode and the second electrode, or at least between the overlapping areas of the first electrode and the second electrode.

[0023] In yet another embodiment of the invention the respective overlapping areas of the first electrode and the second electrode provide for a rectangular or a quadratic parallel plate capacitor area. However, the overlapping areas may have any shape and contour that is advantageous for the desired phase shift or for the design of the electronic component that includes the phase shifting device.

[0024] In yet another aspect of the invention, subsequent parallel plate capacitor areas along the transmission line differ in respective distance to each other and/or in size and/or in shape. Thus, the parallel plate capacitor areas may be of identical shape and size and may be arranged in a regular pattern along the transmission line. However, it might be advantageous e.g. for signal propagation or for reduced size or manufacturing costs to arrange for parallel plate capacitor areas that have a different shape or size along the transmission line. Also, the distance in the direction of signal transmission along the transmission line between two adjacent parallel plate capacitor areas may vary according to demands related to size or cost of the phase shifting device, or in order to allow for better signal propagation or enhanced phase shifting properties of the phase shifting device.

[0025] According to another aspect of the invention, the first and second electrode can be referenced to one or more ground electrodes located at a distance in the first direction, e.g. on the outward facing surfaces of the substrate layers. However, the phase shifting device does not rely on the presence of a ground electrode. If e.g. for reasons of integrating the sandwich structure with other layers of a phased array antenna one or more ground electrodes are necessary, the size and the distance of the strip shaped transmission line segments can be easily adjusted when compared to a phase shifting device without ground electrodes.

[0026] According to an aspect of the invention, the first electrode and the second electrode are electrically connected to a bias voltage source. The bias voltage can be a constant bias voltage or a preferably low frequency voltage with a frequency of up to several kHz. The bias voltage does not interfere with the signal propagation along the transmission line of the phase shifting device. The bias voltage that is applied to the first and second electrode by the bias voltage affects the dielectric characteristics of the tunable dielectric material that is arranged between the first and the second electrode. By applying a bias voltage to the first and second electrode and thereby affecting and changing the dielectric properties of the tunable dielectric material in between the parallel plate capacitor areas, the phase difference between the input signal and the output signal of the phase shifting device can be easily and reliably controlled and modified according to the respective requirements.

[0027] According to an advantageous embodiment of the invention, the first electrode is connected to a first bias electrode which is connected to the bias voltage source, and that the second electrode is connected to a second

bias electrode which is connected to the bias voltage source. The width of the bias electrode can be small when compared to the width of the first electrode and of the second electrode. The width can be approx. 10 % or less of the width of the first or second electrode. A small width or cross-section area of the first and second bias electrodes contributes to a high impedance of the first and second bias electrode resulting in reduced leakage of the electromagnetic signal from the first and second electrode into the first or second bias electrode.

[0028] In yet another embodiment of the invention the first and second bias electrodes consists of a material with a lower electrical conductivity than the first and second electrode. The resulting higher resistance of the bias electrodes prevents the electromagnetic signal that propagates along the transmission line from leaking from the first and second electrode into the first or second bias electrode. Preferably the first and second electrode are made of or comprise a material with a high conductivity of more than $40 \cdot 10^6$ S/m like e.g. gold or copper. The first and second bias electrodes preferably has a sheet resistance of more than 20 Ohms/square and can be made of or comprise Indium Tin Oxide (ITO) or Ni-chrome (NiCr).

[0029] According to another aspect of the invention, the width of the first and second electrode in the second direction is between 100 μm and 500 μm , preferably approx. 200 μm . Furthermore, the width of the overlapping area between the first electrode and the second electrode in the second direction is between 100 μm and 500 μm , preferably approx. 200 μm . The width of the first and second electrode should be smaller than $\lambda/10$, i.e. one-tenth of the characteristic wavelength of the electromagnetic signal that propagates along the transmission line. The distance in the second direction between the first electrode and the second electrode can be less than 50 μm or even less than 25 μm . For most applications the distance is between 10 μm and 200 μm . However, it is also possible to provide for a distance of more than 200 μm . In general, it is considered advantageous for the distance to be smaller than $\lambda/10$.

[0030] The invention also relates to a method for operating the radio frequency phase shifting device as described above, whereby the method comprises steps as set out in the appended claims 11 and 12. Within the meaning of this invention the term quasi-transverse electromagnetic mode denotes a signal transmission mode that is predominantly a transverse electromagnetic mode (TEM-mode), but might also exhibit some less intense longitudinal component of the propagated signal due to the inhomogeneity at the dielectric materials that surround the first and second electrode, e.g. the substrate layers with a limited thickness and the tunable dielectric material in between the substrate layers. However, the transmission line is operated in a manner to support differential mode signal transmission, but not operated in a manner to support slot line mode or microstrip line mode of signal transmission. The space requirements for

a pair of electrodes that are suitable for differential mode transmission is significantly smaller than the space requirements for a slot line electrode arrangement. Thus, the method for operating the radio frequency phase shifting device allows for a compact and space-saving design of the phase shifting device, which promotes the use of such a phase shifting device within a phased array antenna.

[0031] According to another aspect of the invention related to the method, a phase shift of the radio device signal that is transmitted along the transmission line in a differential pair transmission mode is controlled by controlling a direct current bias voltage that is applied to the first and second electrode of the transmission line. The electric field that is used for controlling the dielectric properties of the tunable dielectric material between the first and second electrode, which results in controlling the phase shift of a radio frequency signal that propagates along the transmission line, is preset by a bias voltage that is applied to the first and second electrode itself. Thus, no additional bias voltage electrodes are required for creating the electric field that is required for dielectric tuning of the tunable dielectric material. The direct current bias voltage that is applied to the first and second electrode does not affect the signal transmission in differential mode of the radio frequency signal that is transmitted along the first and second electrode of the transmission line.

[0032] The invention also relates to a phased array antenna comprising several antenna elements as set out in the appended set of claims 13 to 16.

[0033] In order to reduce the space requirement and to facilitate the manufacturing, the phased array antenna comprises on top of each other a base layer with an entry point, a first substrate layer with a first electrode, a tunable layer that comprises the tunable dielectric material, a second substrate layer with a second electrode and an antenna layer with a radiating antenna structure. The first and second electrode can be arranged onto the respective surface of the first and second substrate layer by any suitable method, e.g. by printing or vapor deposition or by any method used within the semiconductor industry. The characteristic dimension of the phased array antenna can be some millimeters or up to some centimeters or decimeters. The dimensions are preferably adapted to the frequency of the electromagnetic signal that is received or emitted by the respective antennas. The more antennas that are incorporated into the phased array antenna, the larger the respective dimensions of the phased array antenna will be. The individual antennas are preferably arranged in a regular grid pattern of a rectangular or quadratic shape. However, it is also possible to arrange the antennas of the phased array antenna in a circular shape with several concentric circles of individual antennas.

[0034] According to an advantageous embodiment of the invention, the first substrate layer and the second substrate layer consists of a glass material, and the

tunable layer comprises a liquid crystal material with tunable dielectric properties.

Brief description of the drawings

[0035] The present invention will be more fully understood, and further features will become apparent, when reference is made to the following detailed description and the accompanying drawings. The drawings are merely representative and are not intended to limit the scope of the claims. In fact, those of ordinary skill in the art may appreciate upon reading the following specification and viewing the present drawings that various modifications and variations can be made thereto without deviating from the innovative concepts of the invention. Like parts depicted in the drawings are referred to by the same reference numerals.

Figure 1 illustrates a schematic top view of a phased array antenna that comprises 64 individual antennas arranged in a quadratic grid pattern,

Figure 2 illustrates a schematic top view of a transmission line of a single phase shifting device,

Figure 3 illustrates a sectional view of the transmission line as shown in figure 2 taken along the line III-III,

Figure 4 illustrates a sectional view of the transmission line as shown in figure 2 taken along the line IV-IV,

Figure 5 illustrates a topological representation of the transmission line as shown in figure 2,

Figure 6 illustrates a schematic top view of a transmission line of a single phase shifting device, whereby strip-shaped transmission line segments of the first and second electrode are arranged in a zig-zag pattern,

Figure 7 illustrates a schematic top view of a transmission line of a single phase shifting device, whereby the strip-shaped transmission line segments exhibit a square-wave meandering pattern,

Figure 8 illustrates a schematic top view of a transmission line of a single phase shifting device, whereby parallel plate capacitor areas along the transmission line differ in size and in shape,

Figure 9 illustrates a schematic top view of a transmission line of a single phase shifting device, whereby the first electrode 5 and the second electrode 6 are overlapped by several capacitor electrodes,

Figure 10 illustrates a sectional view of the transmis-

sion line as shown in figure 9 taken along the line X-X, and

Figure 11 illustrates a sectional view of the transmission line as shown in figure 9 taken along the line XI-XI.

Detailed description of the invention

[0036] A phased array antenna 1 that is shown in figure 1 comprises 64 individual antenna elements 2 that are arranged in a quadratic grid pattern with 8 x 8 antenna elements 2. In the center there is a single signal feed point 3 that is located on the back side of the grid pattern. An electromagnetic signal, preferably a radiofrequency signal, can be introduced into the phased array antenna 1 by the signal feed point 3 and distributed to all of the respective antenna elements 2. In the same manner an electromagnetic signal that is received by the individual antenna elements 2 of the phased array antenna 1 can be transmitted to the signal feed point 3 and extracted from the phased array antenna. All individual antenna elements 2 are connected with the signal feed point 3. The connection comprises a dedicated phase shifting device for each individual antenna element 2, however, the phase shifting devices are not shown in figure 1.

[0037] The phase shifting devices can be the electrical connection of the individual antenna elements 2 to the signal feed point 3. Preferably, for each antenna element 2 the corresponding phase shifting device is only a part or section of the electrical connection to the signal feed point 3.

[0038] Figure 2 illustrates a schematic top view of a transmission line 4 of a single phase shifting device. The transmission line 4 comprises a first electrode 5 and a second electrode 6, whereby the first electrode 5 is at a different level in a first direction 26 with respect to the second electrode 6, thus resulting in a distance in the first direction 26 between the first electrode 5 and the second electrode 6. The first direction 26 is perpendicular to the direction of the signal propagation 9, i.e. along the direction of the transmission line 9 and also perpendicular to the drawing plane of figure 2. In figure 2 the first electrode 5 is depicted on top of the second electrode 6. In order to better illustrate the distance in the first direction 26 between the first electrode 5 and the second electrode 6, the first and second electrode 5, 6 are shown slightly displaced with respect to each other within the drawing plane, i.e. along the direction of the transmission line 9 as well as along a second direction 27 that is perpendicular to the direction of the transmission line 9 as well as perpendicular to the first direction 26. Furthermore, the respective parts of the second electrode 6 that are depicted being below the corresponding parts of the first electrode 5 are shown with a dashed line. For the purpose of this description of the invention, the meaning of the first direction 26 and the second direction 27 is not limited to a single orientation but refers to an alignment along an axis

that runs along the first and second direction 26, 27 respectively. Thus, reference to a displacement or a protrusion along the first direction 26 includes a displacement or protrusion in both orientations along the respective direction 26, 27.

[0039] Each of the first and second electrode 5, 6 comprises a strip-shaped transmission line segment 7, 8 that runs along a straight line in the direction of a signal propagation direction 9. At regular intervals a rectangular overlapping area 10, 11 protrudes in the second direction 27 from the respective strip-shaped transmission line segment 7, 8 of the first electrode 5 and of the second electrode 6, whereby the rectangular overlapping areas 10, 11 are directed towards each other. Within an overlapping section 12 of the transmission line 4, one overlapping area 10 of the first electrode 5 that is perpendicular to the first direction 26 overlaps with one corresponding overlapping area 11 of the second electrode 6 that is also perpendicular to the first direction 26. The two overlapping areas 10, 11 provide for a parallel plate capacitor area 13 of quadratic shape when viewed from the top, i.e. along the first direction 26. The overlapping sections 12 of the transmission line 4 alternate with non-overlapping sections 14 that only comprises the strip-shaped transmission line segments 7, 8 that are at a distance to each other in the second direction 27 and that do not overlap like within the overlapping sections 12 of the transmission line 4.

[0040] The non-overlapping sections 14 do not change much of the phase of the electromagnetic signal that propagates along the first and second electrode 5, 6 of the transmission line 4 in the direction of the signal propagation direction 9, as only a small portion of the electromagnetic field penetrates the tunable layer. However, each of the overlapping sections 12 affects the phase of the propagating electromagnetic signal resulting in a significant phase shift of up to 2π or more from a phase shifting device that can be easily integrated into the phased array antenna 1 of figure 1.

[0041] A first bias electrode 15 is connected to the strip-shaped transmission segment 7 of the first electrode 5 and projects in the second direction 27 in the opposite orientation as the overlapping areas 10 of the first electrode 5. Similarly, a second bias electrode 16 is connected to the strip-shaped transmission segment 8 of the second electrode 6 and projects in the opposite direction of the overlapping areas 11 of the second electrode 6. The first and second bias electrodes 15, 16 are connected to a bias voltage source not shown in figure 2. The bias voltage source provides for a constant, i.e. DC voltage or for a low-frequency AC voltage that is applied to the first and second electrode 5, 6 and creates an electric field in the space between the first electrode 5 and the second electrode 6, thereby superimposing the electromagnetic field of the signal that propagates along the transmission line 4. The electric field between the overlapping areas 10, 11 of the first and second electrode 5, 6 is predominantly perpendicular to the plane of view, i.e.

perpendicular to the parallel plate capacitor areas 13 shown in figure 2 and thus along the first direction 26. Due to the material and the small width of the first and second bias electrode 15, 16, the impedance of the first and second bias electrode 15, 16 is significantly higher than the impedance of the strip-shaped transmission segments 7, 8 of the first and second electrode 5, 6 which prevents the propagating electromagnetic signal from leaking from the first and second electrode 5, 6 into the first and second bias electrode 15, 16 and away from the transmission line 4. By choosing a highly resistive bias electrode material the impedance of the bias electrodes can be further increased.

[0042] Figures 3 and 4 illustrate two sectional views of a phase shifting device 17 with a transmission line 4 as shown in figure 2. Figure 3 is a sectional view of a non-overlapping section 14 of the transmission line 4, whereas figure 4 is a sectional view of an overlapping section 12 of the transmission line 4.

[0043] The first electrode 5 is on top of a first substrate layer 18 made of glass material. The second electrode 6 is on top of a second substrate layer 19 also made of glass material. The first and second substrate layers 18, 19 are arranged at a distance to each other along the first direction 26 with the first electrode 5 facing the second electrode 6. Between the first and second substrate layer 18, 19 there is a tunable layer 20 that is filled with a liquid crystal material. The dielectric properties of the liquid crystal material can be modified by applying different bias voltages to the first and second electrode 5, 6 resulting in electric fields of different magnitude between the first and second electrode 5, 6. In the overlapping section 12 as shown in figure 3, the overlapping area 10 of the first electrode 5, the corresponding overlapping area 11 of the second electrode 6 and the liquid crystal material in between provide for a parallel plate capacitor with a capacitance that depends on the bias voltage.

[0044] The topological representation of the transmission line 4 as illustrated in figure 5 is that of a periodically loaded differential transmission line with the two electrodes 5, 6 and capacitive loads 21 of the overlapping sections 12 that alternate with the non-overlapping sections 14.

[0045] Figure 6 illustrates a schematic top view of an alternative embodiment of the transmission line 4, whereby the strip-shaped transmission line segments 7, 8 of the first and second electrode 5, 6 are arranged in a zig-zag pattern. This allows for longer non-overlapping areas 22 of the respective first and second electrodes 5, 6 between the overlapping sections 12 along the transmission line 4 when compared to a straight-line arrangement of the transmission line segments 7, 8 as shown in Figure 2.

[0046] Figure 7 illustrates a schematic top view along the first direction 26 of a transmission line 4 of a single phase shifting device, whereby the strip-shaped transmission line segments 7, 8 exhibit a square-wave meandering pattern. The first electrode is separately shown in Figure 7a, the second electrode is separately shown in

Figure 7b, and the overlapping arrangement of both first and second electrode 5, 6 is shown in Figure 7c.

[0047] Figure 8 illustrates a schematic top view of a transmission line of a single phase shifting device that is similar to the embodiment shown in Figure 2. However, the parallel plate capacitor areas 13 along the transmission line 4 differ in size and in shape. Furthermore, the distance between subsequent parallel plate capacitor areas 13 may also vary along the transmission line 4.

[0048] Figure 9 illustrates a schematic top view of a transmission line of a single phase shifting device, whereby the first electrode 5 and the second electrode 6 each consists of a straight-line strip-shaped transmission line segment 7, 8 that are directed along the direction of the transmission line 4 that equals the signal propagation direction 9. The transmission line segments 7, 8 are overlapped by several rectangular capacitor electrodes 23 that are oriented along the second direction 27 and thus perpendicular to the signal propagation direction 9. The several rectangular capacitor electrodes 23 are arranged at a distance in the first direction 26 with respect to the first and second electrode 5, 6, which are on the same level with respect to the first direction 26. A first capacitor electrode area 24 of each capacitor electrode 23 overlaps with the corresponding overlapping area 10 of the first electrode 5, and a second capacitor electrode area 25 of each capacitor electrode 23 overlaps with the corresponding overlapping area 11 of the second electrode 6. Thus, the first and second capacitor electrode areas 24, 25 and the corresponding overlapping areas 10, 11 of the first and second electrode 5, 6 provide for two separate parallel plate capacitor areas 13 within each overlapping section 12 of the transmission line 4.

[0049] Figures 10 and 11 illustrate two sectional views of a phase shifting device 17 with a transmission line 4 as shown in figure 9. Figure 10 is a sectional view of a non-overlapping section 12 of the transmission line 4, whereas figure 11 is a sectional view of an overlapping section 14 of the transmission line 4. Both first and second electrode 5, 6 are on the same level and on top of a first substrate layer 18 made of glass material. The rectangular capacitor electrodes 23 are on top of a second substrate layer 19 also made of glass material. The first and second substrate layers 18, 19 are arranged at a distance along the first direction 26 to each other, with the first and second electrode 5, 6 facing the capacitor electrodes 23. Between the first and second substrate layer 18, 19 there is a tunable layer 20 that is filled with a liquid crystal material. The dielectric properties of the liquid crystal material can be modified by applying different bias voltages to the first and second electrode 5, 6 and to the capacitor electrodes 23, resulting in electric fields of different magnitude between the first and second electrode 5, 6 and the respective overlapping areas 24, 25 of the capacitor electrodes 23. In the overlapping section 12 as shown in figure 3, the overlapping area 10 of the first electrode 5 and the corresponding overlapping area 24 of the capacitor electrode 23 as well as the

overlapping area 11 of the second electrode 6 and the corresponding overlapping area 25 of the capacitor electrode 23 in combination with the liquid crystal material in between each provide for a parallel plate capacitor area 13 with a capacitance that depends on the bias voltage. The bias electrode 16 that is connected to all capacitor electrodes 23 is a strip-shaped linear bias electrode 16 that runs parallel to the first and second electrode 5, 6, but on the same level as the capacitor electrodes 23 and provides for electrical connection of all the capacitor electrodes 23 with the bias voltage source that is not shown in the figures.

15 Claims

1. Radio frequency phase shifting device (17) with a transmission line (4) comprising a first electrode (5) and a second electrode (6), and, whereby the transmission line (4) comprises several overlapping sections (12), wherein an overlapping area (10) perpendicular to a first direction (26) of the first electrode (5) is overlapped by a capacitor electrode area (11), whereby the first direction (26) is perpendicular to a direction of a signal transmission (9) of a radio frequency electromagnetic signal along the transmission line (4), and wherein an overlapping area (11) perpendicular the first direction (26) of the second electrode (6) is overlapped by a capacitor electrode area (10) in order to provide for a parallel plate capacitor area (13) within the overlapping section (12), and whereby the transmission line (4) comprises several non-overlapping sections (14), whereby a tunable dielectric material is configured to affect a phase shift of the electromagnetic signal that is propagated along the transmission line (4), whereby the tunable dielectric material is arranged between the overlapping area (10) of the first electrode (5) and the overlapping area (11) of the second electrode (6) that is configured to affect the phase of an radio frequency electromagnetic signal that propagates along the overlapping section (12) of the transmission line (4), whereby the first electrode (5) and the second electrode (6) are spaced at a distance in the first direction (26) and in a second direction (27) to each other, whereby the second direction (27) is perpendicular to the first direction (26) and perpendicular to the direction of the signal transmission (9) along the transmission line (4), whereby the overlapping area (10) of the first electrode (5) overlaps the overlapping area (11) of the second electrode (6) in order to provide for one parallel plate capacitor area (13), and whereby the first and second electrode (5, 6) are suitable and configured for propagation of a radio frequency electromagnetic signal along the first electrode (5) and the second electrode (6) with a phase difference of 180° between the respective electromagnetic sig-

nals of the first and second electrode (5, 6), **characterized in that** the width of the first and second electrode (5, 6) is smaller than $\Lambda/10$, wherein the transmission line (4) is configured such that an electromagnetic signal with characteristic wavelength Λ propagates along the transmission line (4).

2. Radio frequency phase shifting device (17) according to claim 1, **characterized in that** the first electrode (5) is arranged at a first surface of a first substrate layer (18), **in that** the second electrode (6) is arranged at a second surface of a second substrate layer (19), whereby the first surface of the first substrate layer (18) faces the second surface of the second substrate layer (19) and whereby the first surface is arranged at a distance in the first direction (26) to the second surface.
3. Radio frequency phase shifting device (17) according to claim 2, **characterized in that** the first surface of the first substrate layer (18) and the second surface of the second substrate layer (19) confine the tunable dielectric material.
4. Radio frequency phase shifting device (17) with a transmission line (4) comprising a first electrode (5) and a second electrode (6) that are spaced at a distance in a second direction (27) to each other, whereby a first direction (26) is perpendicular to a direction of a signal transmission (9) of a radio frequency electromagnetic signal along the transmission line (4) and whereby the second direction (27) is perpendicular to the first direction (26) and perpendicular to the direction of the signal transmission (9) along the transmission line (4), wherein the first electrode (5) and the second electrode (6) each consists of a straight-line strip shaped transmission line segment directed along the direction of the signal transmission, whereby the transmission line (4) comprises several overlapping sections (12), wherein an overlapping area (10) perpendicular to the first direction (26) of the first electrode (5) is overlapped by a capacitor electrode area (24) and wherein an overlapping area (11) perpendicular the first direction (26) of the second electrode (6) is overlapped by a capacitor electrode area (25) in order to provide for a parallel plate capacitor area (13) within the overlapping section (12), and whereby the transmission line (4) comprises several non-overlapping sections (14), wherein the first electrode (5) runs at a distance to the second electrode (6) in the second direction (27), whereby a tunable dielectric material is configured to affect a phase shift of the electromagnetic signal that is propagated along the transmission line (4), whereby the tunable dielectric material is arranged between the respective capacitor electrode areas (24, 25) and the overlapping area (10) of the

first electrode (5) and the overlapping area (11) of the second electrode (6) that is configured to affect the phase of a radio frequency electromagnetic signal that propagates along the overlapping section (12) of the transmission line (4), wherein the first electrode (5) and the second electrode (6) are arranged side by side at a distance along the second direction (27) on a same surface of a first substrate layer, and the transmission line segment of the first electrode (5) and the transmission line segment of the second electrode (6) are overlapped by several rectangular capacitor electrodes (23), wherein each capacitor electrode (23) is arranged at a distance in the first direction (26) to the surface of the first substrate layer with the first electrode (5) and the second electrode (6) in such a manner that a first capacitor electrode area (24) of the capacitor electrode (23) overlaps the overlapping area (10) perpendicular to the first direction (26) of the first electrode (5) and that a second capacitor electrode area (25) of the capacitor electrode (23) overlaps the overlapping area (11) perpendicular to the first direction (26) of the second electrode (6), thus providing for two parallel plate capacitor areas (13) between the capacitor electrode (23) and the respective overlapping areas (10, 11) within the overlapping section (10) the first and second electrode (5, 6) are suitable and configured for propagation of a radio frequency electromagnetic signal along the first electrode (5) and the second electrode (6) with a phase difference of 180° between the respective electromagnetic signals of the first and second electrode (5, 6), and wherein the width of the first and second electrode (5, 6) is smaller than $\Lambda/10$, wherein the transmission line (4) is configured such that an electromagnetic signal with characteristic wavelength Λ propagates along the transmission line (4), **characterized in that** the capacitor electrodes (23) are oriented along the second direction (27) and are thus perpendicular to the direction of a signal transmission and a bias electrode (16) is connected to all capacitor electrodes (23), wherein the bias electrode (16) is a strip-shaped linear bias electrode (16) that runs parallel to the first electrode (5) and the second electrode (6) and is configured to provide for electrical connection of all the capacitor electrodes (23) with a bias voltage source.

5. Radio frequency phase shifting device (17) according to one or more of the preceding claims, wherein the first electrode (5) and the second electrode (6) each comprise an unbranched strip-shaped transmission line segment (7, 8), whereby both strip-shaped transmission line segments (7, 8) are directed along the transmission line (4).
6. Radio frequency phase shifting device (17) according to claim 5 when dependent on claim 1, **characterized in that**

terized in that the strip-shaped transmission segments (7, 8) comprise non-overlapping sections (14) arranged at a distance towards each other in the second direction (27), and that each of the overlapping areas (10, 11) of the first electrode (5) and/or of the second electrode (6) are protruding in the second direction (27) from the respective strip-shaped transmission segment (7, 8) of the first electrode (5) and/or of the second electrode (6) such that the respective overlapping areas (10, 11) of the first electrode (5) and of the second electrode (6) do overlap.

7. Radio frequency phase shifting device (17) according to one or more of the preceding claims, **characterized in that** the respective overlapping areas (10, 11) of the first electrode (5) and the second electrode (6) provide for a rectangular or a quadratic parallel plate capacitor area (13), whereby subsequent parallel plate capacitor areas (13) along the transmission line (4) differ in respective distance to each other along the direction of signal propagation (9) and/or in size and/or in shape.
8. Radio frequency phase shifting device (17) according to one or more of the preceding claims, **characterized in that** the first electrode (5) and the second electrode (6) are electrically connected to at least one bias voltage source.
9. Radio frequency phase shifting device (17) according to claim 8 when dependent on claim 1, wherein the radio frequency phase shifting device further comprises a first bias electrode and a second bias electrode, **characterized in that** the width of first and second bias electrodes (15, 16) is smaller than the width of the first and second electrode (5, 6) in the second direction (27), whereby the first electrode is connected to the first bias electrode which is connected to the bias voltage source, and that the second electrode is connected to the second bias electrode which is connected to the bias voltage source.
10. Radio frequency phase shifting device (17) according to one or more of the preceding claims, **characterized in that** the width of the first and second electrode (5, 6) in the second direction (27) is between 100 μm and 500 μm , preferably approx. 200 μm .
11. Method for operating the radio frequency phase shifting device (17) according to one or more preceding claims 1 to 10, whereby a radio frequency signal is fed at a signal entry point into the first electrode (5) and the second electrode (6) of the transmission line (4), whereby the radio frequency signal is transmitted along the transmission line (4), and whereby the radio frequency signal exits the

transmission line (4) a distance along the transmission line (4) with respect to the signal entry point, wherein the radio frequency signal is transformed into a differential mode signal with equal amplitude and opposite polarity that is transmitted along the first electrode (5) and the second electrode (6) respectively, whereby a quasi-transverse electromagnetic mode signal transmission occurs, resulting in a use of the transmission line (4) as differential pair transmission line for signal transmission of the radio frequency signal along the transmission line (4).

12. Method for operating the radio frequency phase shifting device (17) according to claim 11, whereby a phase shift of the radio device signal that is transmitted along the transmission line (4) in a differential pair transmission mode is controlled by controlling a direct current bias voltage that is applied to the first and second electrode (5, 6) of the transmission line (4).
13. Phased array antenna (1) comprising several antenna elements (2) that are arranged at a surface of an antenna substrate layer, a signal feed network from or to which a radio frequency signal is transmitted to or from the several antenna elements (2), and for each antenna element (2) a corresponding phase shifting device (17) according to one or more of the preceding claims 1 to 10, whereby a radio frequency signal is transmitted in a differential pair transmission mode along a transmission line (4) within the phase shifting device (17), and whereby the phase of each radio frequency signal that is transmitted from the single signal feed point (3) to the respective antenna element (2) or that is transmitted from the respective antenna element (2) to the single signal feed point (3) is modified in order to adjust the superposition of each radio frequency signal according to the preferred direction of radiation of the phased array antenna (1).
14. Phased array antenna (1) according to claim 13 when dependent on claim 2, **characterized in that** the phased array antenna (1) comprises on top of each other a base layer, the first substrate layer (18) with the first electrode (5), a tunable layer (20), the second substrate layer (19) with the second electrode (6) and an antenna layer with a radiating antenna structure for each of the antenna elements (2).
15. Phased array antenna (1) according to claim 13 when dependent on claim 4, **characterized in that** the phased array antenna (1) comprises on top of each other a base layer, the first substrate layer (18) with the first electrode (5) and with the second electrode (6), a tunable layer (20), the second substrate layer (19) with a capacitor electrode (23) and an antenna layer with a radiating antenna structure

for each of the antenna elements (2).

16. Phased array antenna (1) according to claim 14 or 15, **characterized in that** the first substrate layer (18) and the second substrate layer (19) consists of a glass material, and that the tunable layer (20) comprises a liquid crystal material with tunable dielectric properties.

Patentansprüche

1. Hochfrequenzphasenverschiebungsvorrichtung (17) mit einer Übertragungsleitung (4), umfassend eine erste Elektrode (5) und eine zweite Elektrode (6), und wobei die Übertragungsleitung (4) mehrere überlappende Abschnitte (12) umfasst, wobei ein Überlappungsbereich (10) senkrecht zu einer ersten Richtung (26) der ersten Elektrode (5) von einem Kondensatorelektrodenbereich (11) überlappt wird, wobei die erste Richtung (26) senkrecht zu einer Richtung einer Signalübertragung (9) eines hochfrequenten elektromagnetischen Signals entlang der Übertragungsleitung (4) ist, und wobei ein Überlappungsbereich (11) senkrecht zur ersten Richtung (26) der zweiten Elektrode (6) von einem Kondensatorelektrodenbereich (10) überlappt wird, um einen Parallelplattenkondensatorbereich (13) innerhalb des überlappenden Abschnitts bereitzustellen (12), und wobei die Übertragungsleitung (4) mehrere nicht überlappende Abschnitte (14) umfasst, wobei ein abstimmbares dielektrisches Material so konfiguriert ist, dass es eine Phasenverschiebung des elektromagnetischen Signals beeinflusst, das sich entlang der Übertragungsleitung (4) ausbreitet, wobei das abstimmbare dielektrische Material zwischen dem Überlappungsbereich (10) der ersten Elektrode (5) und dem Überlappungsbereich (11) der zweiten Elektrode (6) angeordnet ist, die so konfiguriert ist, dass sie die Phase eines hochfrequenten elektromagnetischen Signals beeinflusst, das sich entlang des überlappenden Abschnitts (12) der Übertragungsleitung (4) ausbreitet, wobei die erste Elektrode (5) und die zweite Elektrode (6) in einer Distanz in einer ersten Richtung (26) und in einer zweiten Richtung (27) zueinander beabstandet sind, wobei die zweite Richtung (27) senkrecht zur ersten Richtung (26) und senkrecht zur Richtung der Signalübertragung (9) entlang der Übertragungsleitung (4) steht, wobei der Überlappungsbereich (10) der ersten Elektrode (5) den Überlappungsbereich (11) der zweiten Elektrode (6) überlappt, um einen Parallelplattenkondensatorbereich (13) bereitzustellen, und wobei die erste und die zweite Elektrode (5, 6) für die Ausbreitung eines hochfrequenten elektromagnetischen Signals entlang der ersten Elektrode (5) und der zweiten Elektrode (6) mit einer Phasendifferenz von 180 ° zwischen den jeweiligen

elektromagnetischen Signalen der ersten und zweiten Elektrode (5, 6) geeignet und konfiguriert sind, **dadurch gekennzeichnet, dass** die Breite der ersten und zweiten Elektrode (5, 6) kleiner ist als $\lambda/10$, wobei die Übertragungsleitung (4) derart konfiguriert ist, dass sich ein elektromagnetisches Signal mit der charakteristischen Wellenlänge λ entlang der Übertragungsleitung (4) ausbreitet.

2. Hochfrequenzphasenverschiebungsvorrichtung (17) nach Anspruch 1, **dadurch gekennzeichnet, dass** die erste Elektrode (5) an einer ersten Oberfläche einer ersten Substratschicht (18) angeordnet ist, dass die zweite Elektrode (6) an einer zweiten Oberfläche einer zweiten Substratschicht (19) angeordnet ist, wobei die erste Oberfläche der ersten Substratschicht (18) der zweiten Oberfläche der zweiten Substratschicht (19) gegenüberliegt und wobei die erste Oberfläche in einer Distanz in der ersten Richtung (26) zur zweiten Oberfläche angeordnet ist.
3. Hochfrequenzphasenverschiebungsvorrichtung (17) nach Anspruch 2, **dadurch gekennzeichnet, dass** die erste Oberfläche der ersten Substratschicht (18) und die zweite Oberfläche der zweiten Substratschicht (19) das abstimmbare dielektrische Material begrenzen.
4. Hochfrequenzphasenverschiebungsvorrichtung (17) mit einer Übertragungsleitung (4), umfassend eine erste Elektrode (5) und eine zweite Elektrode (6), die in einer zweiten Richtung (27) in einer Distanz voneinander beabstandet sind, wobei eine erste Richtung (26) senkrecht zu einer Richtung einer Signalübertragung (9) eines hochfrequenten elektromagnetischen Signals entlang der Übertragungsleitung (4) steht und wobei die zweite Richtung (27) senkrecht zur ersten Richtung (26) und senkrecht zur Richtung der Signalübertragung (9) entlang der Übertragungsleitung (4) ist, wobei die erste Elektrode (5) und die zweite Elektrode (6) jeweils aus einem geradlinigen streifenförmigen Übertragungsleitungsabschnitt bestehen, der entlang der Richtung der Signalübertragung ausgerichtet ist, wobei die Übertragungsleitung (4) mehrere überlappende Abschnitte (12) umfasst, wobei ein Überlappungsbereich (10) senkrecht zur ersten Richtung (26) der ersten Elektrode (5) von einem Kondensatorelektrodenbereich (24) überlappt ist und wobei ein Überlappungsbereich (11) senkrecht zur ersten Richtung (26) der zweiten Elektrode (6) von einem Kondensatorelektrodenbereich (25) überlappt ist, um einen Parallelplattenkondensatorbereich (13) innerhalb des überlappenden Abschnitts (12) bereitzustellen, und wobei die Übertragungsleitung (4) mehrere nicht überlappende Abschnitte (14) umfasst, wobei die erste Elektrode (5) in einer Distanz zur zweiten

Elektrode (6) in der zweiten Richtung (27) verläuft, wobei ein abstimmbares dielektrisches Material so konfiguriert ist, dass es eine Phasenverschiebung des elektromagnetischen Signals beeinflusst, das sich entlang der Übertragungsleitung (4) ausbreitet, wobei das abstimmbare dielektrische Material zwischen den jeweiligen Kondensatorelektrodenbereichen (24, 25) und dem Überlappungsbereich (10) der ersten Elektrode (5) und dem Überlappungsbereich (11) der zweiten Elektrode (6) angeordnet ist, das so konfiguriert ist, dass es die Phase eines elektromagnetischen hochfrequenten Signals beeinflusst, das sich entlang des überlappenden Abschnitts (12) der Übertragungsleitung (4) ausbreitet, wobei die erste Elektrode (5) und die zweite Elektrode (6) nebeneinander in einer Distanz entlang der zweiten Richtung (27) auf einer gleichen Oberfläche einer ersten Substratschicht angeordnet sind und der Übertragungsleitungsabschnitt der ersten Elektrode (5) und der Übertragungsleitungsabschnitt der zweiten Elektrode (6) von mehreren rechteckigen Kondensatorelektroden (23) überlappt sind, wobei jede Kondensatorelektrode (23) in einer Distanz in der ersten Richtung (26) zur Oberfläche der ersten Substratschicht mit der ersten Elektrode (5) angeordnet ist und die zweite Elektrode (6) derart, dass ein erster Kondensatorelektrodenbereich (24) der Kondensatorelektrode (23) den Überlappungsbereich (10) senkrecht zur ersten Richtung (26) der ersten Elektrode (5) überlappt und dass ein zweiter Kondensatorelektrodenbereich (25) der Kondensatorelektrode (23) den Überlappungsbereich (11) senkrecht zur ersten Richtung (26) der zweiten Elektrode (6) überlappt, wodurch zwei Parallelplattenkondensatorbereiche (13) zwischen der Kondensatorelektrode (23) und den jeweiligen Überlappungsbereichen (10, 11) innerhalb des Überlappungsabschnitts (10) bereitgestellt sind, und die erste und die zweite Elektrode (5, 6) geeignet und so konfiguriert sind, dass sie ein elektromagnetisches hochfrequentes Signal entlang der ersten Elektrode (5) und der zweiten Elektrode (6) mit einer Phasendifferenz von 180° zwischen den jeweiligen elektromagnetischen Signalen der ersten und zweiten Elektrode (5, 6) ausbreiten, und wobei die Breite der ersten und zweiten Elektrode (5, 6) kleiner ist als $\lambda/10$, wobei die Übertragungsleitung (4) derart konfiguriert ist, dass sich ein elektromagnetisches Signal mit dem Merkmal Wellenlänge λ entlang der Übertragungsleitung (4) ausbreitet, **dadurch gekennzeichnet, dass** die Kondensatorelektroden (23) entlang der zweiten Richtung (27) ausgerichtet sind und somit senkrecht zur Richtung einer Signalübertragung stehen und eine Vorspannungselektrode (16) mit allen Kondensatorelektroden (23) verbunden ist, wobei die Vorspannungselektrode (16) eine streifenförmige lineare Vorspannungselektrode (16) ist, die parallel zur ersten Elekt-

rode (5) und zur zweiten Elektrode (6) verläuft und dazu konfiguriert ist, alle Kondensatorelektroden (23) mit einer Vorspannungsquelle elektrisch zu verbinden.

5. Hochfrequenzphasenverschiebungsvorrichtung (17) nach einem oder mehreren der vorhergehenden Ansprüche, wobei die erste Elektrode (5) und die zweite Elektrode (6) jeweils einen unverzweigten streifenförmigen Übertragungsleitungsabschnitt (7, 8) umfassen, wobei beide streifenförmigen Übertragungsleitungsabschnitte (7, 8) entlang der Übertragungsleitung (4) gerichtet sind.
6. Hochfrequenzphasenverschiebungsvorrichtung (17) nach Anspruch 5, abhängig von Anspruch 1, **dadurch gekennzeichnet, dass** die streifenförmigen Übertragungssegmente (7, 8) in einer Distanz in der zweiten Richtung (27) zueinander angeordnete, nicht überlappende Abschnitte (14) umfassen, und dass jeder der Überlappungsbereiche (10, 11) der ersten Elektrode (5) und/oder der zweiten Elektrode (6) in der zweiten Richtung (27) aus dem jeweiligen streifenförmigen Übertragungssegment (7, 8) der ersten Elektrode (5) und/oder der zweiten Elektrode (6) derart vorstehen, dass sich die jeweiligen Überlappungsbereiche (10, 11) der ersten Elektrode (5) und der zweiten Elektrode (6) überlappen.
7. Hochfrequenzphasenverschiebungsvorrichtung (17) nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die jeweiligen Überlappungsbereiche (10, 11) der ersten Elektrode (5) und der zweiten Elektrode (6) einen rechteckigen oder einen quadratischen Parallelplattenkondensatorbereich (13) bereitstellen, wobei sich aufeinanderfolgende Parallelplattenkondensatorbereiche (13) entlang der Übertragungsleitung (4) in der jeweiligen Distanz zueinander entlang der Signalausbreitungsrichtung (9) und/oder in der Größe und/oder im Verlauf unterscheiden.
8. Hochfrequenzphasenverschiebungsvorrichtung (17) nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die erste Elektrode (5) und die zweite Elektrode (6) elektrisch mit mindestens einer Vorspannungsquelle verbunden sind.
9. Hochfrequenzphasenverschiebungsvorrichtung (17) nach Anspruch 8, wenn abhängig von Anspruch 1, wobei die Hochfrequenzphasenverschiebungsvorrichtung ferner eine erste Vorspannungselektrode und eine zweite Vorspannungselektrode umfasst, **dadurch gekennzeichnet, dass** die Breite der ersten und zweiten Vorspannungselektroden (15, 16) kleiner ist als die Breite der ersten und zweiten Elektrode (5, 6) in der zweiten Richtung (27), wo-

durch die erste Elektrode mit der ersten Vorspannungselektrode verbunden ist, die mit der Vorspannungsquelle verbunden ist, und dass die zweite Elektrode mit der zweiten Vorspannungselektrode verbunden ist, die mit der Vorspannungsquelle verbunden ist.

10. Hochfrequenzphasenverschiebungsvorrichtung (17) nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Breite der ersten und zweiten Elektrode (5, 6) in der zweiten Richtung (27) zwischen 100 μm und 500 μm , vorzugsweise ca. 200 μm , beträgt.
11. Verfahren zum Betreiben der Hochfrequenzphasenverschiebungsvorrichtung (17) nach einem oder mehreren vorhergehenden Ansprüchen 1 bis 10, wobei ein Hochfrequenzsignal an einem Signaleintrittspunkt in die erste Elektrode (5) und die zweite Elektrode (6) der Übertragungsleitung (4) zugeführt wird, wobei das Hochfrequenzsignal entlang der Übertragungsleitung (4) übertragen wird, und wobei das Hochfrequenzsignal die Übertragungsleitung (4) in einer Distanz entlang der Übertragungsleitung (4) in Bezug auf den Signaleintrittspunkt verlässt, wobei das Hochfrequenzsignal in ein Differenzmodussignal mit gleicher Amplitude und entgegengesetzter Polarität umgewandelt wird, das entlang der ersten Elektrode (5) und der zweiten Elektrode (6) übertragen wird, wobei eine quasi-transversale elektromagnetische Modussignalübertragung stattfindet, was zu einer Verwendung der Übertragungsleitung (4) als Differenzpaar-Übertragungsleitung für die Signalübertragung des Hochfrequenzsignals entlang der Übertragungsleitung (4) führt.
12. Verfahren zum Betreiben der Hochfrequenzphasenverschiebungsvorrichtung (17) nach Anspruch 11, wobei eine Phasenverschiebung des Hochfrequenzsignals, das in einem Differenzpaar-Übertragungsmodus entlang der Übertragungsleitung (4) übertragen wird, durch Steuern einer Gleichstrom-Vorspannung gesteuert wird, die an die erste und zweite Elektrode (5, 6) der Übertragungsleitung (4) angelegt wird.
13. Phasengesteuerte Array-Antenne (1), umfassend mehrere Antennenelemente (2), die an einer Oberfläche einer Antennensubstratschicht angeordnet sind, ein Signalzuführungsnetzwerk, von dem oder zu dem ein Hochfrequenzsignal zu den oder von den mehreren Antennenelementen (2) übertragen wird, und für jedes Antennenelement (2) eine entsprechende Phasenverschiebungsvorrichtung (17) gemäß einem oder mehreren der vorhergehenden Ansprüche 1 bis 10, wobei ein Hochfrequenzsignal in einem differentiellen Paarübertragungsmodus entlang einer Übertragungsleitung (4) innerhalb der

Phasenverschiebungsvorrichtung (17) übertragen wird, und wobei die Phase jedes Hochfrequenzsignals, das von dem einzelnen Signalzuführungspunkt (3) zu dem jeweiligen Antennenelement (2) übertragen wird oder das von dem jeweiligen Antennenelement (2) zu dem einzelnen Signalzuführungspunkt (3) übertragen wird, modifiziert wird, um die Überlagerung jedes Hochfrequenzsignals gemäß der bevorzugten Abstrahlrichtung der phasengesteuerten Array-Antenne (1) einzustellen.

14. Phasengesteuerte Array-Antenne (1) nach Anspruch 13, wenn abhängig von Anspruch 2, **dadurch gekennzeichnet, dass** die phasengesteuerte Array-Antenne (1) - jeweils übereinander - eine Basischicht, die erste Substratschicht (18) mit der ersten Elektrode (5), eine abstimmbare Schicht (20), die zweite Substratschicht (19) mit der zweiten Elektrode (6) und eine Antennenschicht mit einer strahlenden Antennenstruktur für jedes der Antennenelemente (2) umfasst.
15. Phasengesteuerte Array-Antenne (1) nach Anspruch 13, wenn abhängig von Anspruch 4, **dadurch gekennzeichnet, dass** die phasengesteuerte Array-Antenne (1) - jeweils übereinander - eine Basischicht, die erste Substratschicht (18) mit der ersten Elektrode (5), und mit der zweiten Elektrode (6), eine abstimmbare Schicht (20), die zweite Substratschicht (19) mit einer Kondensatorelektrode (23) und eine Antennenschicht mit einer strahlenden Antennenstruktur für jedes der Antennenelemente (2) umfasst.
16. Phasengesteuerte Array-Antenne (1) nach Anspruch 14 oder 15, **dadurch gekennzeichnet, dass** die erste Substratschicht (18) und die zweite Substratschicht (19) aus einem Glasmaterial bestehen und dass die abstimmbare Schicht (20) ein Flüssigkristallmaterial mit abstimmbaren dielektrischen Eigenschaften umfasst.

Revendications

1. Déphaseur de fréquence radio (17) avec une ligne de transmission (4) comprenant une première électrode (5) et une seconde électrode (6), et moyennant quoi la ligne de transmission (4) comprend plusieurs sections de chevauchement (12), dans lequel une zone de chevauchement (10) perpendiculaire à une première direction (26) de la première électrode (5) est chevauchée par une zone d'électrode de condensateur (11), moyennant quoi la première direction (26) est perpendiculaire à une direction d'une transmission de signal (9) d'un signal électromagnétique radiofréquence le long de la ligne de transmission (4), et dans lequel une zone de chevauchement

- (11) perpendiculaire à la première direction (26) de la seconde électrode (6) est chevauchée par une zone d'électrode de condensateur (10) afin de fournir une zone de condensateur à plaques parallèles (13) dans la section de chevauchement (12), et moyennant quoi la ligne de transmission (4) comprend plusieurs sections non chevauchantes (14), moyennant quoi un matériau diélectrique accordable est configuré pour affecter un déphasage du signal électromagnétique qui se propage le long de la ligne de transmission (4), moyennant quoi le matériau diélectrique accordable est agencé entre la zone de chevauchement (10) de la première électrode (5) et la zone de chevauchement (11) de la seconde électrode (6) lequel est configuré pour affecter la phase d'un signal électromagnétique radiofréquence qui se propage le long de la section de chevauchement (12) de la ligne de transmission (4), moyennant quoi la première électrode (5) et la seconde électrode (6) sont espacées l'une de l'autre d'une certaine distance dans la première direction (26) et dans une seconde direction (27), moyennant quoi la seconde direction (27) est perpendiculaire à la première direction (26) et perpendiculaire à la direction de la transmission de signal (9) le long de la ligne de transmission (4), moyennant quoi la zone de chevauchement (10) de la première électrode (5) chevauche la zone de chevauchement (11) de la seconde électrode (6) afin de fournir une zone de condensateur à plaques parallèles (13), et moyennant quoi les première et seconde électrodes (5, 6) sont adaptées et configurées pour la propagation d'un signal électromagnétique radiofréquence le long de la première électrode (5) et de la seconde électrode (6) avec une différence de phase de 180° entre les signaux électromagnétiques respectifs de la première et de la seconde électrode (5, 6), **caractérisé en ce que** la largeur de la première et de la seconde électrode (5, 6) est inférieure à $\lambda/10$, dans lequel la ligne de transmission (4) est configurée de sorte qu'un signal électromagnétique ayant une longueur d'onde caractéristique λ se propage le long de la ligne de transmission (4).
2. Déphaseur de fréquence radio (17) selon la revendication 1, **caractérisé en ce que** la première électrode (5) est agencée sur une première surface d'une première couche de substrat (18), **en ce que** la seconde électrode (6) est agencée sur une seconde surface d'une seconde couche de substrat (19), moyennant quoi la première surface de la première couche de substrat (18) fait face à la seconde surface de la seconde couche de substrat (19) et moyennant quoi la première surface est agencée à une certaine distance dans la première direction (26) par rapport à la seconde surface.
3. Déphaseur de fréquence radio (17) selon la reven-

dication 2, **caractérisé en ce que** la première surface de la première couche de substrat (18) et la seconde surface de la seconde couche de substrat (19) confinent le matériau diélectrique accordable.

4. Déphaseur de fréquence radio (17) avec une ligne de transmission (4) comprenant une première électrode (5) et une seconde électrode (6) qui sont espacées l'une de l'autre d'une certaine distance dans une seconde direction (27), moyennant quoi une première direction (26) est perpendiculaire à une direction d'une transmission de signal (9) d'un signal électromagnétique radiofréquence le long de la ligne de transmission (4) et moyennant quoi la seconde direction (27) est perpendiculaire à la première direction (26) et perpendiculaire à la direction de la transmission de signal (9) le long de la ligne de transmission (4), dans lequel la première électrode (5) et la seconde électrode (6) sont chacune constituées d'un segment de ligne de transmission en forme de bande droite, dirigé le long de la direction de la transmission de signal, moyennant quoi la ligne de transmission (4) comprend plusieurs sections de chevauchement (12), dans lequel une zone de chevauchement (10) perpendiculaire à la première direction (26) de la première électrode (5) est chevauchée par une zone d'électrode de condensateur (24) et dans lequel une zone de chevauchement (11) perpendiculaire à la première direction (26) de la seconde électrode (6) est chevauchée par une zone d'électrode de condensateur (25) afin de fournir une zone de condensateur à plaques parallèles (13) dans la section de chevauchement (12), et moyennant quoi la ligne de transmission (4) comprend plusieurs sections non chevauchantes (14), dans lequel la première électrode (5) se trouve à une certaine distance par rapport à la seconde électrode (6) dans la seconde direction (27), moyennant quoi un matériau diélectrique accordable est configuré pour affecter un déphasage du signal électromagnétique qui se propage le long de la ligne de transmission (4), moyennant quoi le matériau diélectrique accordable est agencé entre les zones d'électrode de condensateur (24, 25) respectives et la zone de chevauchement (10) de la première électrode (5) et la zone de chevauchement (11) de la seconde électrode (6) lequel est configuré pour affecter la phase d'un signal électromagnétique radiofréquence qui se propage le long de la section de chevauchement (12) de la ligne de transmission (4), dans lequel la première électrode (5) et la seconde électrode (6) sont agencées côte à côte à une certaine distance le long de la seconde direction (27) sur une même surface d'une première couche de substrat, et le segment de ligne de transmission de la première électrode (5) et le segment de ligne de transmission de la seconde électrode (6) sont chevauchés par plusieurs électrodes de condensateur rectangulaires (23), dans le-

- quel chaque électrode de condensateur (23) est agencée à une certaine distance, dans la première direction (26), par rapport à la surface de la première couche de substrat avec la première électrode (5) et la seconde électrode (6) de sorte qu'une première zone d'électrode de condensateur (24) de l'électrode de condensateur (23) chevauche la zone de chevauchement (10) perpendiculaire à la première direction (26) de la première électrode (5) et qu'une seconde zone d'électrode de condensateur (25) de l'électrode de condensateur (23) chevauche la zone de chevauchement (11) perpendiculaire à la première direction (26) de la seconde électrode (6), fournissant ainsi deux zones de condensateur à plaques parallèles (13) entre l'électrode de condensateur (23) et les zones de chevauchement (10, 11) respectives dans la section de chevauchement (10), les première et seconde électrodes (5, 6) sont adaptées et configurées pour la propagation d'un signal électromagnétique radiofréquence le long de la première électrode (5) et de la seconde électrode (6) avec une différence de phase de 180° entre les signaux électromagnétiques respectifs de la première et de la seconde électrode (5, 6), et dans lequel la largeur de la première et de la seconde électrode (5, 6) est inférieure à $\lambda/10$, dans lequel la ligne de transmission (4) est configurée de sorte qu'un signal électromagnétique avec une longueur d'onde caractéristique λ se propage le long de la ligne de transmission (4), **caractérisé en ce que** les électrodes de condensateur (23) sont orientées le long de la seconde direction (27) et sont ainsi perpendiculaires à la direction d'une transmission de signal et une électrode de polarisation (16) est connectée à toutes les électrodes de condensateur (23), dans lequel l'électrode de polarisation (16) est une électrode de polarisation linéaire en forme de bande (16) qui est parallèle à la première électrode (5) et à la seconde électrode (6) et est configurée pour assurer la connexion électrique de toutes les électrodes de condensateur (23) avec une source de tension de polarisation.
5. Déphaseur de fréquence radio (17) selon une ou plusieurs des revendications précédentes, dans lequel la première électrode (5) et la seconde électrode (6) comprennent chacune un segment de ligne de transmission en forme de bande (7, 8) non ramifié, moyennant quoi les deux segments de ligne de transmission en forme de bande (7, 8) sont dirigés le long de la ligne de transmission (4).
 6. Déphaseur de fréquence radio (17) selon la revendication 5 lorsqu'elle dépend de la revendication 1, **caractérisé en ce que** les segments de transmission en forme de bande (7, 8) comprennent des sections non chevauchantes (14) agencées à une certaine distance les unes des autres dans la seconde direction (27), et **en ce que** chacune des zones de chevauchement (10, 11) de la première électrode (5) et/ou de la seconde électrode (6) fait saillie dans la seconde direction (27) du segment de transmission en forme de bande (7, 8) respectif de la première électrode (5) et/ou de la seconde électrode (6) de sorte que les zones de chevauchement (10, 11) respectives de la première électrode (5) et de la seconde électrode (6) se chevauchent.
 7. Déphaseur de fréquence radio (17) selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** les zones de chevauchement (10, 11) respectives de la première électrode (5) et de la seconde électrode (6) fournissent une zone de condensateur à plaques parallèles (13) rectangulaires ou quadratiques, moyennant quoi les zones de condensateur à plaques parallèles (13) suivant le long de la ligne de transmission (4) diffèrent par leur distance respective les unes par rapport aux autres le long de la direction de propagation de signal (9) et/ou par leur taille et/ou par leur forme.
 8. Déphaseur de fréquence radio (17) selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** la première électrode (5) et la seconde électrode (6) sont connectées électriquement à au moins une source de tension de polarisation.
 9. Déphaseur de fréquence radio (17) selon la revendication 8 lorsqu'elle dépend de la revendication 1, dans lequel le déphaseur de fréquence radio comprend également une première électrode de polarisation et une seconde électrode de polarisation, **caractérisé en ce que** la largeur des première et seconde électrodes de polarisation (15, 16) est inférieure à la largeur des première et seconde électrodes (5, 6) dans la seconde direction (27), moyennant quoi la première électrode est connectée à la première électrode de polarisation qui est connectée à la source de tension de polarisation, et la seconde électrode est connectée à la seconde électrode de polarisation qui est connectée à la source de tension de polarisation.
 10. Déphaseur de fréquence radio (17) selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** la largeur de la première et de la seconde électrode (5, 6) dans la seconde direction (27) est comprise entre $100\ \mu\text{m}$ et $500\ \mu\text{m}$, de préférence d'environ $200\ \mu\text{m}$.
 11. Procédé de fonctionnement du déphaseur de fréquence radio (17) selon une ou plusieurs des revendications précédentes 1 à 10, moyennant quoi un signal radiofréquence est introduit à un point d'entrée de signal dans la première électrode (5) et la seconde électrode (6) de la ligne de transmission (4),

- moyennant quoi le signal radiofréquence est transmis le long de la ligne de transmission (4), et moyennant quoi le signal radiofréquence sort de la ligne de transmission (4) à une certaine distance le long de la ligne de transmission (4) par rapport au point d'entrée de signal, dans lequel le signal radiofréquence est transformé en un signal de mode différentiel d'amplitude égale et de polarité opposée qui est transmis le long de la première électrode (5) et de la seconde électrode (6) respectivement, moyennant quoi une transmission de signal de mode électromagnétique quasi-transversal se produit, ce qui conduit à une utilisation de la ligne de transmission (4) comme ligne de transmission à paire différentielle pour la transmission de signal du signal radiofréquence le long de la ligne de transmission (4).
12. Procédé de fonctionnement du déphaseur de fréquence radio (17) selon la revendication 11, moyennant quoi un déphasage du signal de dispositif radio qui est transmis le long de la ligne de transmission (4) dans un mode de transmission par paire différentielle est commandé en commandant une tension de polarisation en courant continu qui est appliquée à la première et à la seconde électrode (5, 6) de la ligne de transmission (4).
13. Antenne réseau à commande de phase (1) comprenant plusieurs éléments d'antenne (2) qui sont agencés sur une surface d'une couche de substrat d'antenne, un réseau d'alimentation de signal à partir duquel ou vers lequel un signal radiofréquence est transmis vers ou depuis les plusieurs éléments d'antenne (2), et pour chaque élément d'antenne (2) un déphaseur (17) correspondant selon une ou plusieurs des revendications précédentes 1 à 10, moyennant quoi un signal radiofréquence est transmis dans un mode de transmission par paire différentielle le long d'une ligne de transmission (4) dans le déphaseur (17), et moyennant quoi la phase de chaque signal radiofréquence qui est transmis du point d'alimentation de signal unique (3) à l'élément d'antenne (2) respectif ou qui est transmis de l'élément d'antenne (2) respectif au point d'alimentation de signal unique (3) est modifiée afin d'ajuster la superposition de chaque signal radiofréquence en fonction de la direction de rayonnement préférée de l'antenne réseau à commande de phase (1).
14. Antenne réseau à commande de phase (1) selon la revendication 13 lorsqu'elle dépend de la revendication 2, **caractérisée en ce que** l'antenne réseau à commande de phase (1) comprend, superposées les unes aux autres, une couche de base, la première couche de substrat (18) avec la première électrode (5), une couche accordable (20), la seconde couche de substrat (19) avec la seconde électrode (6) et une couche d'antenne avec une structure d'antenne rayonnante pour chacun des éléments d'antenne (2).
15. Antenne réseau à commande de phase (1) selon la revendication 13 lorsqu'elle dépend de la revendication 4, **caractérisée en ce que** l'antenne réseau à commande de phase (1) comprend, superposées les unes aux autres, une couche de base, la première couche de substrat (18) avec la première électrode (5) et avec la seconde électrode (6), une couche accordable (20), la seconde couche de substrat (19) avec une électrode de condensateur (23) et une couche d'antenne avec une structure d'antenne rayonnante pour chacun des éléments d'antenne (2).
16. Antenne réseau à commande de phase (1) selon la revendication 14 ou 15, **caractérisée en ce que** la première couche de substrat (18) et la seconde couche de substrat (19) sont constituées d'un matériau en verre, et **en ce que** la couche accordable (20) comprend un matériau à cristaux liquides avec des propriétés diélectriques accordables.

FIG 1

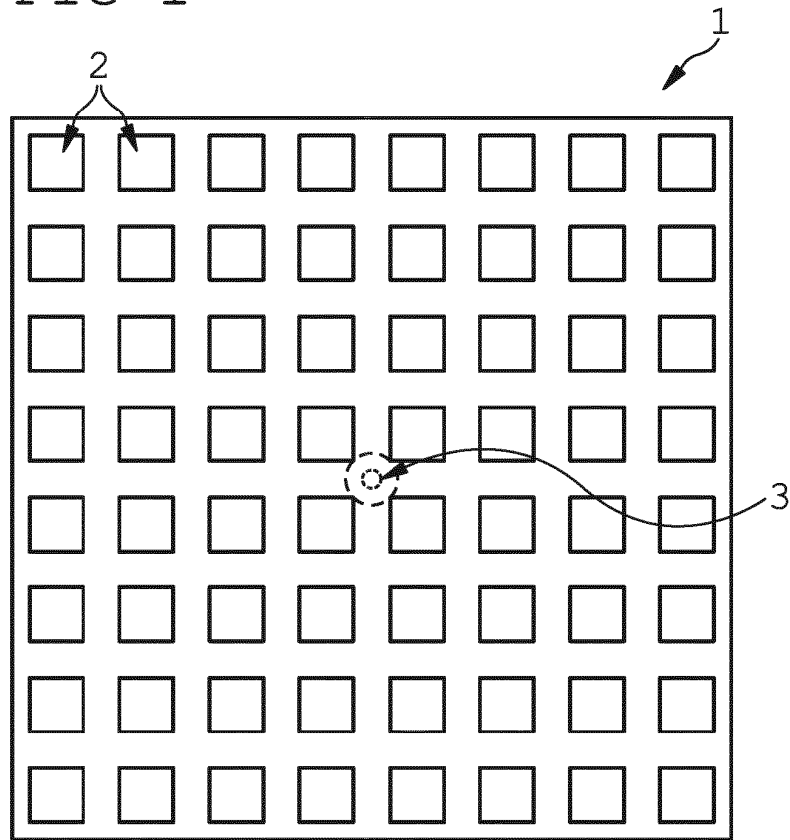


FIG 2

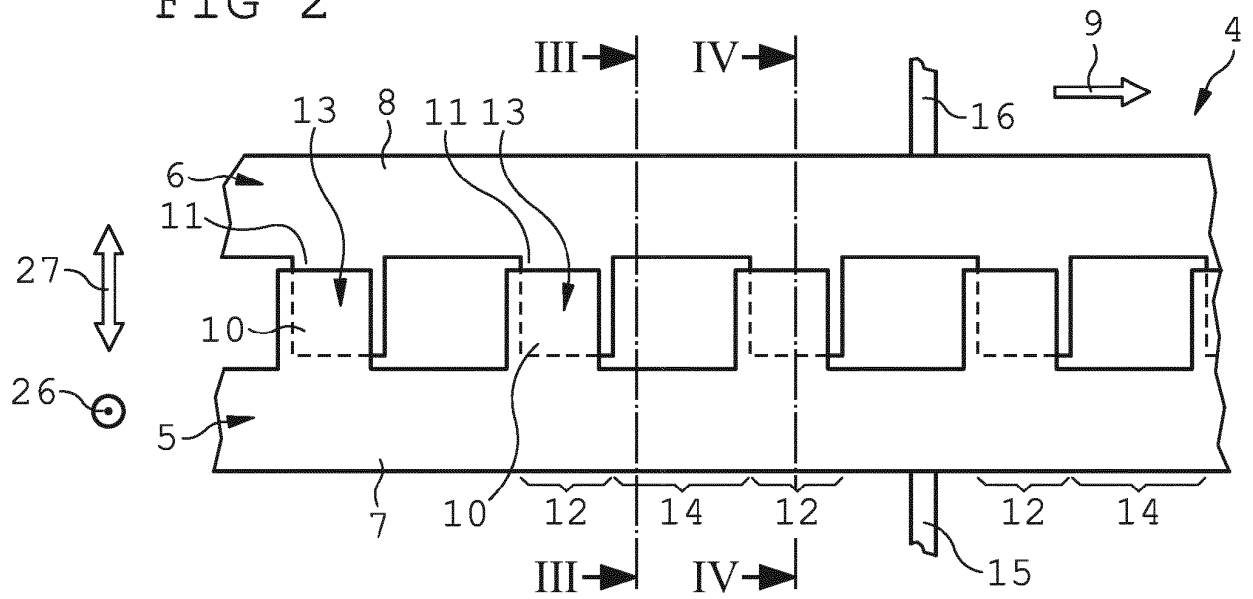


FIG 6

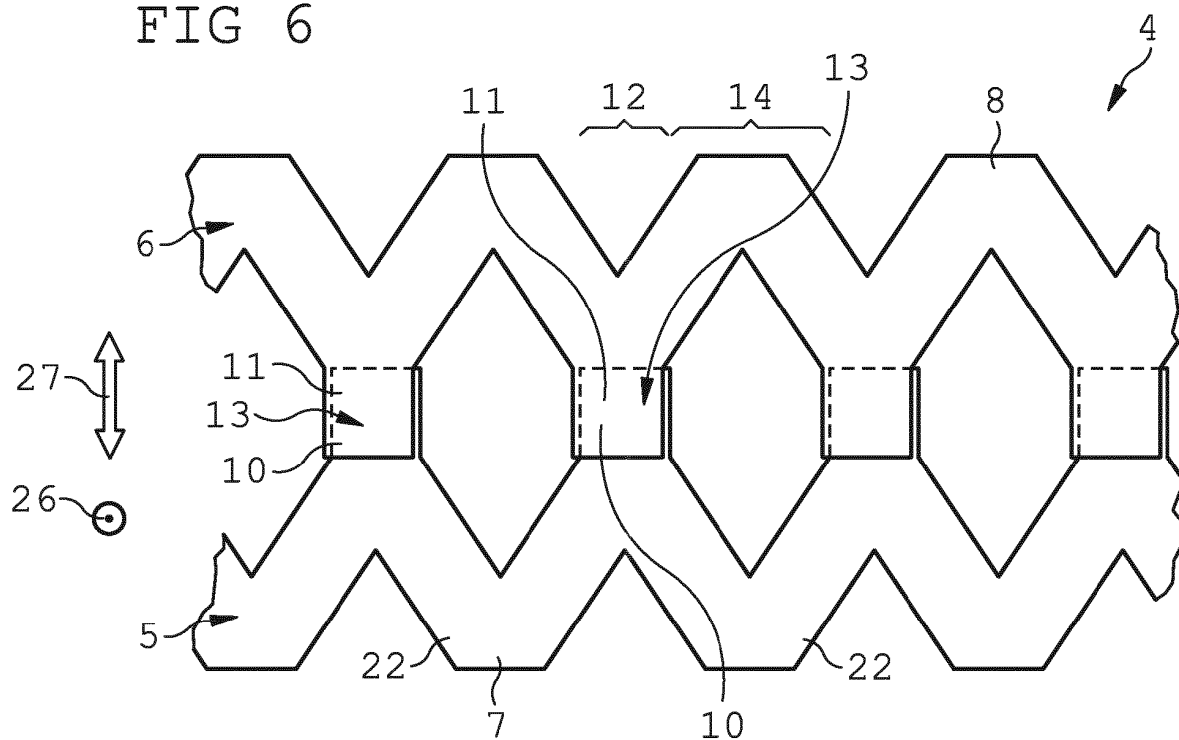
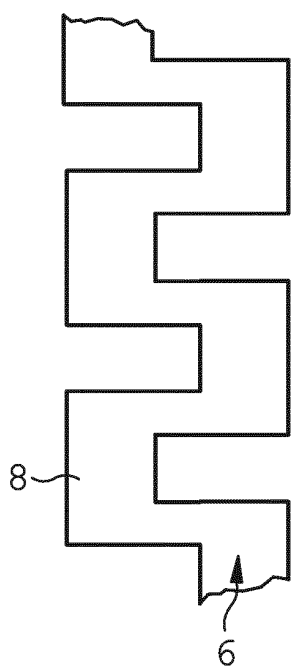
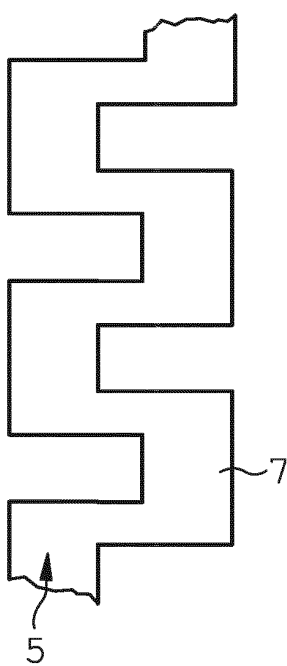


FIG 7

a)



b)



c)

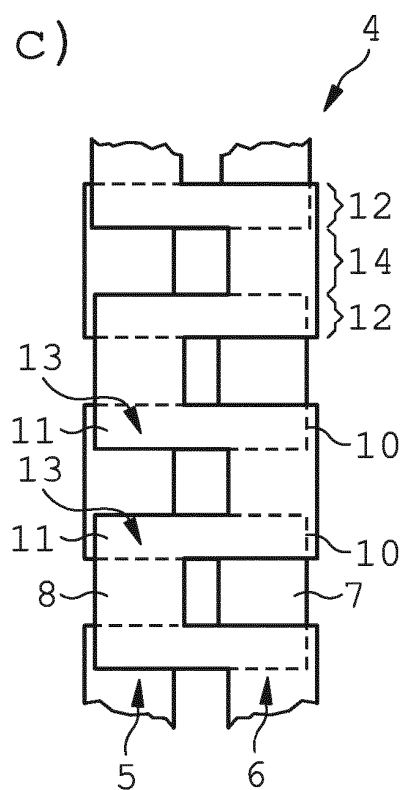


FIG 8

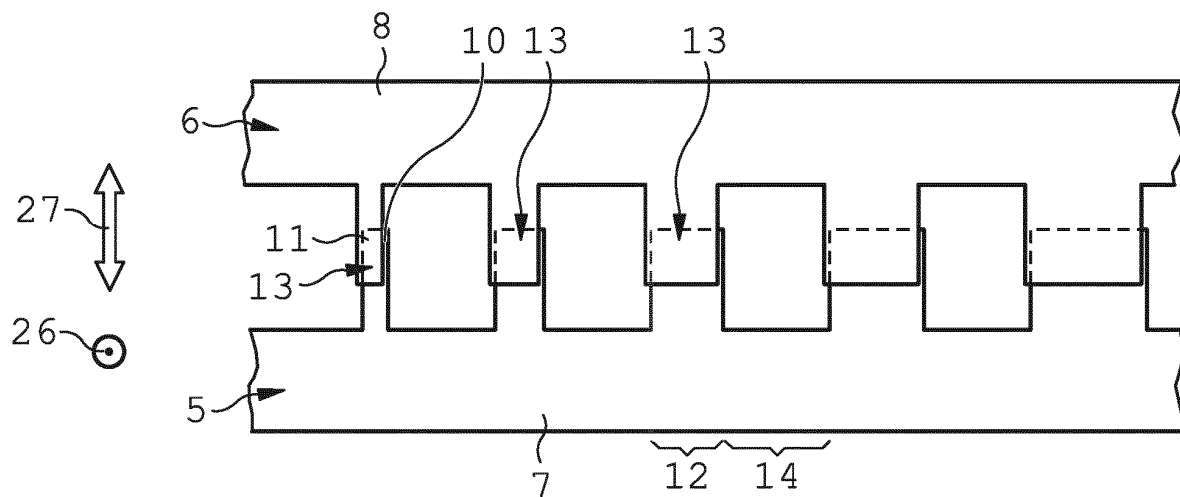


FIG 9

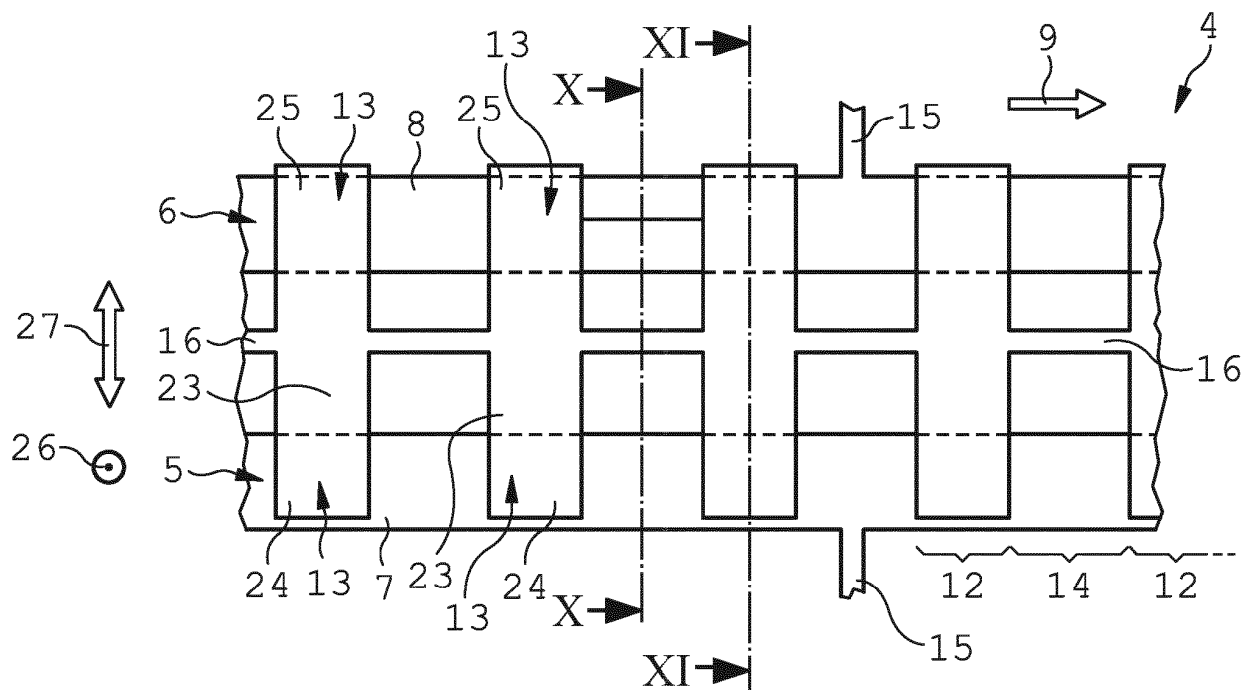


FIG 10

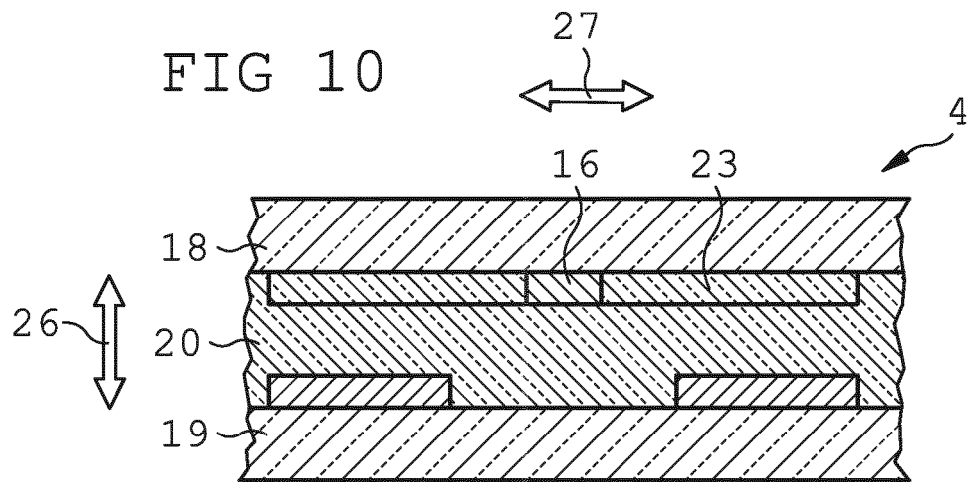
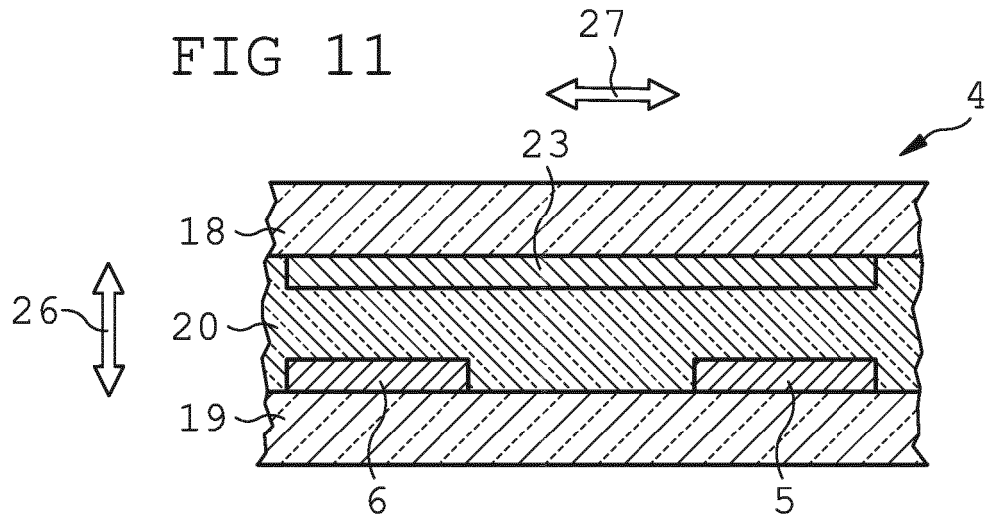


FIG 11



REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- EP 2761693 A1 [0005]
- EP 2956986 B1 [0005]

Non-patent literature cited in the description

- **ONUR HAMZA KARABEY et al.** Tunable loaded line phase shifters for microwave applications. *IEEE MTT-S INTERNATIONAL MICROWAVE SYMPOSIUM*, 05 June 2011, 1-4 [0006]
- **MOHAMMAD NIKFALAZAR et al.** Fully printed tunable phase shifter for L/S-band phased array application. *IEEE MTT-S INTERNATIONAL MICROWAVE SYMPOSIUM*, 01 June 2014, 1-4 [0006]