

BEAM-STEERING DEVICE USING DISPLACEMENT OF EFFECTIVE DIELECTRIC ROLLERS

The invention relates to the area of directional antennas, and relates in particular to a device allowing for the steering of an electromagnetic beam emitted by an active or passive antenna, and the associated steering method.

The term "steering", when associated with an antenna, describes the fact of orienting the electromagnetic beam emitted by this antenna in a precise direction.

Hereinbelow, the term "elevation angle" denotes the angle between the horizontal plane and the straight line going from an antenna to a targeted point above the horizon. This angle is counted as positive when the targeted point is above the horizontal plane indicated, negative otherwise. The term "azimuth angle" denotes the horizontal angle between a straight line going from the antenna to the targeted point and a straight line leaving the antenna in a reference direction.

Another expression used is "form factor" of an antenna, defined as being the ratio between its length and its width. Thus, a round antenna will have a form factor of one, whereas an elongate antenna will have a high form factor.

Modifying the direction of aiming of an antenna is of interest in many areas. Examples that can be cited are the field of radars, in order to scan a geographic area or track a moving target, but also that of satellite antennas, where a receiver will seek to direct the beam from its antenna to a moving satellite, or, conversely, the applications in which a mobile carrier will seek to position its antenna towards a fixed point, like a geostationary satellite. Modifying the direction of aiming of antennas is also of interest in a context of territorial coverage, when the addition or the removal of an antenna necessitates a repositioning of all the other elements of the network.

There are many techniques that make it possible to orient the beam from an antenna. Among these, the most conventional is to mount the antenna on axes in order to direct it mechanically.

Such a device does however present a certain number of drawbacks. Indeed, in order to displace the beam from an antenna both in azimuth and in elevation, it is necessary to have recourse to two mechanical axes. Such a device generally takes the form of a revolving plate allowing the orientation in azimuth, and a device mounted on the revolving plate rotating the antenna about an axis to ensure the orientation in elevation. In so doing, there is a so-called "singular" point at the zenith: when the antenna reaches the zenith of its trajectory and it has to be displaced in a direction at right angles to the elevation axis, the positioner has to perform a rapid rotation of 90° on the azimuth axis. This rotation results in a break in reception, and can cause rapid wear of the device. This problem is solved through the use of a three-axis device, which does not exhibit any singular point, but for which the mechanics become complex and prove costly. These positioners are more bulky, in particular when the antenna has a large form factor and the beam from the antenna has to scan the plane formed by the beam in its initial position and the great axis of the antenna. They also require the use of rotating joints, which are costly and subject to wear, and exhibit a significant inertia which necessitates the use of powerful motors and limits the speed of displacement of the assembly.

There are also techniques for orienting the beam from an antenna said to use electronic steering, which offer the advantage of being accurate and fast. The electronic steering principle consists in applying a phase shift exhibiting a gradient over all of the wave front to modify the direction of the beam emitted.

These are for example the so-called "active" antennas, composed of radiating elements generally spaced apart by a distance less than or equal to $\lambda/2$, λ being the wavelength of the signal. Each of the radiating elements is linked to a phase shifter, the electromagnetic beam being directed by driving the phase of each of the radiating elements. However, the constraints on the dimension and the spacing of the radiating elements, their number, and the need to link each of these elements to a drivable phase shifter mean that such devices very soon become complex and therefore costly. Furthermore, the phase shifters may struggle to support high emission powers.

The orienting of the electromagnetic beam can also be done by steering, by modifying the direction of the beam after its emission. An electronic beam steering device is described in the patent US 4,480,254 by Spencer et al. This device consists in passing the emitted electromagnetic beam through pairs of lenses whose permittivity, and therefore phase delay, can be controlled. The electrical beam can then be steered in the desired direction. Such a device is, for its part, also costly and complex to implement, the lenses being composed of precious metals, and each of the lenses having to be powered independently. The patent US 5,557,286 A dispenses with the precious metals through the use of ferrites. However, the device is also complex to implement and can be limited in its range of operation in terms of frequency and/or temperature through the use of magnetically controlled dielectrics.

Also known are electromagnetic beam steering devices using mechanical translation of a lens. Such a device is described in the IEEE article: E. Lima et al, "Circular Polarization Wide-Angle Beam Steering at Ka-Band by In-Plane Translation of a Plate Lens Antenna", IEEE Transactions on antennas and propagation, Vol. 63, 12 December 2015. Its defect is that it is applied to a cylindrical or spherical wave front (curvature of the wave front non-zero on at least one axis), but not to a flat wave front. Furthermore, it is necessary to ensure a significant separation between the feed and the lens, which effects the bulk of the antenna system. Finally, a displacement of the lens leads to a variation of the phase shift applied at the centre of the beam transmitted, which can result in errors upon the reception of the signal if it is too rapid, and a deformation of the radiating pattern that can be detrimental with respect to the emission masks and standards to be observed.

Finally, steering devices are known like those described in the patent applications US 2010/0039338 A1, WO 2014/128015 A1 or US 2007/0285327 A1, for which two dielectric lenses of variable thicknesses arranged in the form of discs are positioned above the emitting antenna, their centres aligned with the centre of the beam. The steering is done by mechanical rotation of the lenses on the axis of propagation of the incident beam. The rotation of one of the discs in relation to the other makes it possible to control the elevation of the beam whereas the rotation of both discs makes it possible to control the azimuth. The fact that the discs pivot

about an axis centred on the beam makes it possible to keep the phase shift applied at the centre of the beam unchanged. This device does however exhibit a bulk defect since the wave front emitted is not of rounded form. Since the diameter of the discs is linked to the dimension of the great axis of the antenna, the discs are then overdimensioned, in particular when the form factor of the antenna becomes great.

This bulk problem makes the device incompatible with certain uses subject to size constraints, as is the case for example for satellite antennas embedded on aircraft. In effect, the antenna device is then subject to significant dimensioning constraints, in particular with regard to the height of the radome, in order to minimize its impact on the general aerodynamics of the aeroplane. Because of this, the satellite antennas used may not be parabolic antennas, but several patch antennas arranged in line and forming a very elongate antenna, to maximize the antenna surface. The use of two dielectric lenses of round form is not then suitable for this type of antennas because of the excessive bulk.

Because of this, the steering devices for such satellite antennas generally consist of a mechanical steering mechanism associated with an electronic steering mechanism, such as, for example, a revolving plate ensuring scanning azimuth coupled to an electronic steering axis allowing a scan in elevation. This device makes it possible to not implement a mechanical axis of rotation on the small axis of the antenna, such a rotation requiring a significant volume, and to ensure a quasi-instantaneous displacement of the beam, but does exhibit a singular point at the zenith. Another device commonly used implements two mechanical steering axes (in elevation and azimuth) associated with an electronic steering axis at right angles to the elevation axis, making it possible to avoid the presence of a singular point at the zenith. However, such devices combining mechanical and electronic are very costly.

Therefore, the object of the invention is to propose a mechanical device that allows for the steering of an electromagnetic beam on one or two axes which is inexpensive, compatible with any type of emission antenna, and which has a reduced bulk. The invention is all the more advantageous as it makes it possible to steer the beam from the antenna by making it scan a

plane defined by the initial position of the beam and the great axis of the antenna, by increasing the bulk of the total device by a quantity which does not depend on this dimension, which is of particular benefit since the antenna has a high form factor.

5 To this end, the invention describes a device for steering an electromagnetic beam comprising at least two superposed dielectric lenses. In the steering device according to the invention, the dielectric lenses are of variable effective thicknesses, and at least one of the dielectric lenses being mobile in at least one direction substantially orthogonal to a plane in which
10 the electromagnetic beam is steered.

Each of the dielectric lenses comprises a reference point, the effective thickness of the dielectric lenses varying as a function of the product between the distance in relation to this reference point in a first direction and the distance in relation to this reference point in a second direction at right angles
15 to the first direction.

The dielectric lenses can be described as comprising four dials defined from a reference point, the opposing dials in relation to the reference point forming a pair of dials, the effective thickness of each of the dielectric lenses increasing as a function of the distance in relation to said point of intersection
20 in one of the pairs of dials and decreasing as a function of the distance in relation to said point of intersection in the other pair of dials.

Advantageously, the increases and reductions of the effective thickness of the dielectric lenses are done periodically, the period being linked to a wavelength of the electromagnetic beam.

25 According to one embodiment of a steering device according to the invention, the variation of the effective thickness of the dielectric lenses comprises a variation of the local thickness.

According to another embodiment of a steering device according to the invention, the variation of the effective thickness of the dielectric lenses
30 comprises a variation of a refraction index.

According to one embodiment, the dielectric lenses of the steering device according to the invention each have a reference point. The device then has a position in which the reference points of the dielectric lenses are

superposed at the centre of an antenna element emitting said electromagnetic beam, and in which the sum of the effective thicknesses of the dielectric lenses is constant over all the surface passed through by said electromagnetic beam.

5 According to one embodiment, the dielectric lenses of the steering device according to the invention each have a reference point. The device then has a position in which the reference points of the two dielectric lenses are superposed at the centre of an antenna element emitting said electromagnetic beam, and in which the effective thickness of the two
10 dielectric lenses varies inversely to one another.

 According to one embodiment, the steering device according to the invention comprises two dielectric lenses, the two dielectric lenses being mobile and being displaced in opposite directions.

 According to one embodiment, the dielectric lenses are planar.
15 According to another embodiment, they are wholly or partly rollers.

 According to one embodiment of the steering device according to the invention, the mobility on an axis of the dielectric lens or lenses is assured by a translation of the dielectric lens or lenses. According to another embodiment, the mobility on an axis of the dielectric lens or lenses is assured
20 by a rotation of the dielectric lens or lenses about an axis collinear to an axis of the antenna.

 Advantageously, the steering device according to an embodiment of the invention further comprises a first correcting lens configured to modify the form of a wave front, said first lens being positioned on one side of the
25 dielectric lenses, and a second correcting lens configured to modify the form of a wave front inversely to the first lens, and positioned on the other side of the dielectric lenses.

 According to one embodiment of the invention, the steering device further comprises a mechanical aiming axis for the electromagnetic beam.

30 The invention also describes an antenna comprising at least one steering device as presented previously.

 Finally, the invention relates to a method for steering an electromagnetic beam emitted by an antenna element. The method

comprises at least one first step of superpositioning of the antenna element by at least two dielectric lenses of variable effective thickness, and a second step of displacement of at least one of the dielectric lenses in at least one direction substantially orthogonal to a plane in which the electromagnetic beam is steered.

The invention will be better understood and other features and advantages will become more apparent on reading the following description, given in a nonlimiting manner, and from the attached figures in which:

- 10 • Figures 1a and 1b respectively represent a steering device according to an embodiment of the invention in which the configuration of the dielectric lenses does not cause steering of the electromagnetic beam, and a flat view of the dielectric lenses that make up this device;
- 15 • Figure 2 is a three-dimensional representation of a dielectric lens used to implement the invention according to the embodiment described in Figures 1a and 1b;
- 20 • Figures 3a and 3b respectively represent a steering device according to the embodiment described in Figures 1a and 1b, in which the configuration of the dielectric lenses drives the steering of the electromagnetic beam, and a flat view of the dielectric lenses that make up this device;
- 25 • Figure 4 represents a flat view of the dielectric lenses of a steering device according to another embodiment of the invention, in which only one of the dielectric lenses is mobile;
- 30 • Figure 5 represents a steering device according to another embodiment of the invention, in which the dielectric lenses are implemented in the form of rollers;
- Figures 6a and 6b represent a cross-sectional view of a steering device according to another embodiment of the invention in which the dielectric lenses are implemented in the form of truncated rollers;

- Figures 7a and 7b illustrate a steering device according to another embodiment of the invention, in which lenses whose object is to modify the form of the wave front are shown;
- Figures 8a and 8b represent two embodiments of an antenna comprising a steering device according to an embodiment of the invention;
- Figure 9 is a state diagram of a method for steering an electromagnetic beam according to an embodiment of the invention.

In the figures which are presented hereinbelow, the antenna, also referred to as antenna element, is represented in the form of an antenna having a rectangular form factor. The latter is positioned in an orthonormal reference frame (xOy), the large side of the antenna on the x axis, the centre O of the reference frame being positioned at the centre of the antenna element.

The antenna is represented in a rectangular form, because this form factor poses particular bulk problems when associated with a steering device according to the prior art. The invention is nevertheless not limited to rectangular antennas, and applies identically, whatever the form factor of the antenna, which includes the case of round, spherical and conical antennas, as well as the case of antenna elements composed of a plurality of radiating elements.

Figure 1a represents a device for steering an electromagnetic beam according to an embodiment of the invention, in which the configuration of the device does not cause steering of the beam. The antenna element A_1 emits, along the z axis, a beam F_{inc} which passes through the steering device. The resulting beam F_e is oriented identically to the initial beam F_{inc} .

The device also comprises two superposed dielectric lenses D_{11} and D_{12} , whose effective thickness varies proportionally to the product of their coordinates in relation to their respective centres C_{11} and C_{12} on the x axis and on the y axis. These dielectric lenses are prisms whose faces are not necessarily planar, that can be obtained by diffractive structures, by structuring the dielectric to a scale less than the wavelength of the electromagnetic beam. The grey level of the dielectric lenses represented is

a function of their effective thickness, the thickness increasing when the level darkens and vice versa.

The phase shift applied to an electromagnetic wave passing through a lens is a function of the local thickness of the lens passed through, and of its refractive index: it is equal to $\frac{2\pi}{\lambda}ne$, with λ the wavelength of the signal (in metres), e the local thickness of the dielectric passed through (in metres) and n the refractive index of the dielectric (in the absence of lens, in vacuum $n=1$, in air $n\sim 1$). Replacing air with a dielectric of index n for a same thickness e passed through induces a phase delay $\frac{2\pi}{\lambda}(n-1)e$. Effective thickness of a dielectric lens should be understood to be the thickness corresponding to a given phase shift for a given and constant refractive index. The object of the variation of the effective thickness of the dielectric lenses is to more or less delay a wave front as a function of the geographic area of dielectric passed through, so as to create controlled phase offsets on the wave front emitted, and therefore orient the beam.

This variation of effective thickness can be obtained by varying the local thickness of the dielectric, that is to say its height on the z axis, in a dielectric whose density, or refractive index, is constant.

Another means for varying the effective thickness is to vary its density, that is to say the refractive index of the substrate. In this way, an electromagnetic wave passing through the dielectric will be more or less delayed depending on its position, which makes it possible to orient the beam as a whole. The patent application EP 2573872 A1 or the international patent application WO 01/697419 A2 present such a dielectric in which the effective thickness is modified by the variation of an effective refractive index of the substrate, obtained by changing the density of material locally used (for example by changing the density of dielectric micropillars per unit of surface area, the pillars not being perceived by the wave as such because they are small compared to the wavelength, but the average local density of material influencing the phase). Such a dielectric can advantageously be used to implement the steering device according to the invention, its local thickness, that is to say its height on the z axis, then being able to be constant over all of the lens.

It is also possible to envisage combining variation of the refraction index and variation of the local thickness.

In Figure 1a, the centres of the dielectric lenses are situated at their intersection with a straight line orthogonal to the plane of the antenna element A_1 and which passes through its centre O . In the figure, this straight line corresponds to the axis z . The dielectric lenses are of dimensions greater than the dimensions of the antenna element A_1 according to at least one dimension at right angles to the desired steering direction. Parts of the dielectric lenses facing the antenna element, which are passed through by the electromagnetic beam, are indicated in the figure under the references R_{11} and R_{12} .

The effective thickness of the dielectric lenses follows a very precise law: it varies as a function of the product of the distance in relation to the centres C_{11} and C_{12} in one direction and the direction at right angles, i.e. as a function of the product of x by y . In this way, the phase ϕ of an electromagnetic wave passing through the dielectric in normal incidence varies as a function of its coordinates (x, y) . The effective thickness should be considered modulo 2π of the phase offset resulting from the passage through the dielectric. Thus, the dielectric can have an effective thickness which does not increase (or is not reduced) linearly over all of its surface, but according to a periodically reproduced scheme.

For one of the dielectric lenses, when x and y are of the same sign, the effective dielectric thickness increases with the distance in relation to centre. When x and y are of different signs, this effective thickness decreases. The effective thickness of the second dielectric lens varies in a way complementing that of the first, that is to say that when x and y are of the same sign, it decreases with the distance in relation to the centre, and it increases when x and y are of different signs.

Another way of representing the structure of each of the dielectric lenses is to divide them into four dials. These four dials are for example defined by the axes x and y . They are grouped together in pairs of opposing dials, that is to say dials having only the point of intersection of the dials as common point. For one of the dielectric lenses, the effective thickness increases as a function of the product of the distances according to the axes

x and y in one of the two pairs of dials, and decreases as a function of this same product in the other. When the centres of the lenses are superposed at the centre of the antenna, the effective thickness of the second dielectric lens varies inversely to that of the first lens: the pair of dials in which the effective
 5 thickness increases is facing that of the first lens in which the effective thickness decreases, and vice versa.

Through the structure of each of the dielectric lenses, the electromagnetic beam emitted by the antenna element A_1 is deflected a first time by the first dielectric lens, then a second time by the second dielectric
 10 lens. Since the two dielectric lenses mirror one another, this deflection is done first in one direction then in the opposite direction, the two deflections then cancelling one another. This property is due to the fact that the total effective thickness passed through by an incident wave, the sum of the effective thicknesses of the two dielectric lenses, is constant over all of the
 15 surface passed through by the beam. Thus, the phase shift applied to the electromagnetic beam is identical at all points, and the direction of aiming of the incident beam emitted by the antenna element is not modified.

Figure 1b is a flat view of the dielectric lenses that make up a steering device according to the embodiment of the invention represented in
 20 Figure 1a. The first dielectric D_{11} can be broken down into four dials delimited by the axes x and y: Q_{11} , Q_{12} , Q_{13} and Q_{14} . In the pair of opposing dials Q_{11} and Q_{13} , the effective thickness of the dielectric increases with the product of the distances in relation to the centre C_{11} , whereas in the pair of opposing dials Q_{12} and Q_{14} , the latter decreases in the same way. In the second
 25 dielectric D_{12} , the effective thickness increases with the product of the distances in the opposing dials Q_{22} and Q_{24} , which are facing the dials Q_{12} and Q_{14} in which the effective thickness decreases. Similarly, the effective thickness decreases in the dials Q_{21} and Q_{23} , facing the dials Q_{11} and Q_{13} in which it increases.

30 E1 represents the total effective thickness of dielectric passed through by an incident beam emitted when the two dielectric lenses D_{11} and D_{12} have their centres C_{11} and C_{12} superposed at the centre of the antenna element, which represents the so-called "initial" position of the device. The structures of the two dielectric lenses are complementary, when the latter are in their

initial position, the effective thickness passed through is constant both on the x axis x and on the y axis y . An incident beam F_{inc} passing through the two dielectrics will not therefore be steered.

More specifically, since the thickness of the dielectrics varies mirroring
 5 one another, the total effective thickness e_{total} passed through by a wave in normal incidence at the point (x, y) can be expressed as being:

$$\begin{aligned} e_{total}(x, y) &= e_{D11}(x, y) + e_{D12}(x, y) \\ &= A + \Delta e_{D11}(x, y) + A - \Delta e_{D12}(x, y) \\ &= 2A + \alpha * x * y - \alpha * x * y = 2A \end{aligned}$$

at any point (x, y) , with A the thickness of dielectric at the reference points C_{11} and C_{12} , e the effective thickness of dielectric, Δe the variation of this effective thickness in relation to A , and α the coefficient of variation of the
 10 effective thickness of the dielectrics, that is to say the coefficient of proportionality between the product of the distances at the centres on x and on y and the thickness of the dielectric, $\alpha * x * y$ having to be considered to be within modulo 2π of the phase shift introduced. It is found that the effective thicknesses of dielectrics are compensated at all points, the
 15 effective thickness having the value $2A$ and not varying as a function of the coordinates (x, y) of the position passed through by the electromagnetic wave. There is therefore no beam deflection introduced by the device. It should be noted that the effective thickness A of dielectric has been considered to be equal in the two lenses, but that the result is identical by
 20 taking different dielectric thicknesses. The only constraint lies on the coefficient α , which must be identical in both dielectrics.

Figure 2a is a three-dimensional representation of a dielectric lens D used to implement the invention according to the embodiment described previously. Its local thickness varies in two dimensions as a function of the
 25 product of the coordinates in relation to its centre, measured according to each of the dimensions.

Figure 2b is also a three-dimensional representation of a dielectric lens D used to implement the invention according to the embodiment described previously. Its local thickness varies periodically, such that the phase shift
 30 applied to an electromagnetic wave passing through it is that targeted, modulo 2π . The repetition period of the pattern is therefore a function of the

coefficient α and of the wavelength of the electromagnetic beam. The effective thickness of the dielectric lenses therefore increases (or decreases) progressively as a function of the product $x \cdot y$, until the associated phase variation has scanned all of the range $[0; 2\pi]$, then abruptly reassumes its initial value before increasing again (or decreasing again). In this way, the local thickness of the lens is maintained within a range of values, even when the latter is of large size. This periodic variation of the thickness of the lens, corresponding to a phase shift modulo 2π of the wave passing through it, is described for example in the patent application US 2010/0039338 A1 for one dimension. It must be adapted to the wavelength of the electromagnetic beam, and extended to two dimensions in order to implement the invention. The periodic variation of the effective thickness of the dielectric can also correspond to a periodic variation of the refractive index of the lens.

Figure 3a illustrates the implementation of the steering of the electromagnetic beam in the embodiment of the invention presented in Figures 1a and 1b. In order to perform the steering of the beam F_{inc} emitted by the antenna element A_1 , it is sufficient to displace the dielectric lenses in opposite directions in translation along an axis at right angles to the desired steering axis. Thus, steering the beam F_{inc} emitted in a given direction along the great axis x of the antenna, that is to say in the plane xOz , requires the displacement of both the dielectrics in translation in opposite directions along the y axis.

The effective thickness of the areas R_{11} and R_{12} of dielectric facing the antenna element A_1 , that is to say passed through by the incident beam F_{inc} , exhibits a phase gradient along the x axis, which causes the steering of the beam F_e having passed through the two dielectric lenses.

Figure 3b is an exploded view of the two dielectric lenses D_{11} and D_{12} , in which are represented the areas R_{11} and R_{12} facing the antenna element, as well as the total effective thickness E_3 of dielectric passed through by the emitted beam F_{inc} , which is the sum of the effective thicknesses of the two dielectric lenses D_{11} and D_{12} .

In this example, the thicknesses of the dielectric lenses are no longer compensated. The total effective thickness then exhibits a gradient on the x axis, but remains constant on the y axis. The electromagnetic wave passing

through this total effective thickness will therefore be phase shifted on the x axis only, that is to say in the plane xOz. In the example, the phase shift will be higher on the negative x values than on the positive x values, thereby causing a steering of the beam emitted toward the negative x values.

- 5 To illustrate this steering, the total effective thickness e_{total} passed through by a wave in normal incidence at the point (x, y) when each of the dielectric lenses is displaced by one position, can then be expressed as being:

$$\begin{aligned}
 e_{total}(x, y) &= e_{D11}(x, y) + e_{D12}(x, y) \\
 &= A + \Delta e_{D11}(x, y + 1) + A - \Delta e_{D12}(x, y - 1) \\
 &= 2A + \alpha * x * y - \alpha * x * y \\
 &= 2A + 2\alpha x
 \end{aligned}$$

- 10 The variation of the effective thickness is therefore a function of the position on x only. Since it is constant on y, the electromagnetic beam does not steer on the y axis, that is to say in the plane yOz. It should be noted in particular that the phase shift applied at the centre of the beam, that is to say at the point O, does not vary in relation to that applied when the device is in
15 its initial position, as illustrated in Figures 1a and 1b. This property is advantageous, a variation of the phase shift applied at the centre of the beam emitted generating an advance or a delay on the signal which can generate errors in the reception of the signal.

- In an identical manner, a steering on the y axis can be performed by
20 varying the position of the dielectric lenses on the x axis. Generally, the steering of the electric beam is done therefore on an axis at right angles to the axis of displacement of the dielectric lenses, this displacement being assured mechanically by translation. The steering speed and the precision thereof depend on the coefficient α chosen, α being the coefficient of
25 proportionality between the product of the distances in relation to the centre and the thickness of the lenses. By choosing α to be small, the precision in terms of steering angle will be great but the size of the dielectric lenses required to obtain a given phase shift will be great and the steering speed less high, whereas, conversely, by choosing α to be great, the dielectric
30 lenses required to obtain a given phase shift are of small size, the steering speed significant, but the precision lesser. A trade-off must therefore be made as a function of the requirements of precision, speed and bulk. In order

for the thickness of the dielectric lenses not to reach excessive dimensions on the edges when the antenna element is of large size, the dielectric lenses can be obtained by locally decreasing the thickness by one or more wavelengths to revert to a thickness overall of between a minimum value and
 5 a maximum value that are close to one another allowing the phase shift generated by the passage through the lens to scan the range $[0; 2\pi]$. This variation of the effective thickness in levels makes it possible to obtain the desired phase shifts without the local thickness or the refractive index of the lenses reaching excessively restrictive values.

10 The embodiment of the invention presented previously can be broken down into multiple variants by the person skilled in the art:

- the translation of the dielectric lenses is not necessarily limited to one dimension, but can be performed in two dimensions, which causes a deflection of the incident electromagnetic beam in the
 15 two orthogonal dimensions;
- the number of dielectric lenses used can be greater than two;
- the reference points, from which the effective thicknesses of the dielectric lenses vary and which make it possible to define the initial position in which the beam is not steered, are, in the
 20 examples, the centres C_{11} and C_{12} of the dielectric lenses, but these reference points can be chosen elsewhere than at the centre;
- the dielectric lenses are not necessarily square or rectangular, and can be of any form and not necessarily identical so long as
 25 they come to be facing the antenna element over all of their translation area;
- the displacement can be limited to a single lens.

Figure 4 represents a flat view of the dielectric lenses of a steering device according to another embodiment of the invention, in which only one
 30 of the dielectric lenses (D_{12}) is translated, whereas the other (D_{11}) remains immobile.

The result is the same as that presented when the two dielectric lenses are displaced, that is to say, to return to the preceding notations:

$$\begin{aligned}
e_{total}(x, y) &= e_{D11}(x, y) + e_{D12}(x, y - 1) \\
&= A + \Delta e_{D11}(x, y) + A - \Delta e_{D12}(x, y - 1) \\
&= 2A + \alpha * x * y - \alpha * x * (y - 1) \\
&= 2A - \alpha x
\end{aligned}$$

By displacing just one of the dielectric lenses on the y axis, the equivalent surface E_4 passed through by the beam exhibits a gradient on the x axis only, which causes it to be steered on this axis (in the plane xOz). The equivalent surface passed through does not exhibit a gradient on the y axis, the beam is not steered on this axis (in the plane yOz). The phase shift applied at the centre of the beam is always identical. The difference with respect to the steering obtained by the displacement of both the dielectric lenses, with coefficient α constant, stems from the fact that the steering speed is divided by two but the precision is two times greater. To avoid being subject to these drawbacks, it is possible to double the value of the coefficient α of variation of the thickness of the dielectric lenses. However, such a modification can have consequences on the network lobes of the pattern of the steered beam, and on the width of the passband.

This embodiment is nevertheless advantageous because it opens the door to many modes of implementation, such as for example:

- gluing the dielectric layer closest to the antenna element directly thereon, and ensuring the mobility of the layer furthest away, or
- gluing the dielectric layer furthest away onto a radome, and ensuring the mobility of the closest layer, or incorporating the dielectric lens in the radome.

Figure 5 represents another embodiment of a steering device according to another embodiment of the invention.

In this embodiment, the dielectric lenses D_{51} and D_{52} are no longer planar, but are in the form of rollers positioned around the antenna element A_5 . The rollers form two nested cylinders. The displacement of the rollers is then no longer assured by translation of the dielectric lenses, but by rotation. The dielectric lenses are in rotation about an axis that is normal or quasi-normal to the direction of propagation of the incident beam, and it is this rotation which causes the deflection of the electromagnetic beam. The axis of rotation of the dielectric lens rollers will advantageously be able to be chosen

to be collinear with the greatest dimension of the radiating surface. So as to avoid the undesirable deflections close to the edges of the antenna, it is preferable for the thickness of the dielectric lenses to remain small in relation to the diameter of the rollers.

5 The operation of this device is equivalent to that presented for planar dielectric lenses. When the two dielectric rollers are in initial position, the total effective thickness passed through by a beam arriving according to a normal incidence is the same at all points, the direction of aiming of the beam is not therefore modified. By turning one or more rollers about their axis, the
10 displacement of the parts of dielectric lenses facing the antenna element can be likened to a translation on the y axis. The total effective thickness of dielectric passed through by the electromagnetic beam then varies, and exhibits a gradient on the x axis causing a steering of the beam on this axis (in the plane xOz).

15 Likewise, a translational displacement of the dielectric lenses in the form of rollers D_{51} and D_{52} makes it possible to steer the electromagnetic beam in the plane yOz .

20 Compared to the use of planar dielectric lenses, the use of dielectric lenses arranged in rollers makes it possible to further reduce the bulk of the device. Furthermore, it is easier to rotate two rollers on one and the same axis than to displace two planes in translation.

25 According to another embodiment, the rollers are truncated on a plane parallel to the axis of the cylinder. The device then takes the form of two portions of rollers superposed on an antenna element, even further reducing the bulk of the device. The base of the cylinders defined by the rollers before truncation does not necessarily take the form of a disc: by choosing cylinders whose base is elliptical and by truncating these cylinders, the radius of curvature of the truncated rollers can be adjusted, so that it is greater or lesser in the area facing the electromagnetic beam.

30 Figures 6a and 6b represent a cross-sectional view of such a device implemented from two truncated rollers. In Figure 6a, the dielectric lenses D_{61} and D_{62} , arranged in the form of truncated rollers, are in their initial position: their thicknesses are compensated at all points.

The incident beam F_{inc} emitted by the antenna element A_6 passes through the two dielectric lenses, and the resulting beam F_e is not deflected.

In Figure 6b, the dielectric lenses D_{61} and D_{62} are rotated relative to one another about their axis, collinear to x , and in opposite directions. In the part
 5 of the dielectrics facing the electromagnetic beam emitted, this rotation causes a displacement of the dielectric lenses facing the electromagnetic beam comparable to a translation on the y axis. The resulting beam F_e passing through the dielectrics therefore undergoes a gradient on the x axis, and is deflected on this axis (therefore in the plane xOz).

10 The embodiments of the invention in which the dielectric lenses take the form of rollers or truncated rollers are particularly suitable when their radius is great in relation to the antenna element, the part of the dielectrics facing this antenna element then being able to be likened to a plane, and the displacement of the dielectrics then being able to be seen as a translation in
 15 this plane.

They are also suited, whatever their radius, to the cases where the wave front emitted by the antenna element is cylindrical, as is the case for example for a row of patch antennas, or a row of slits for which all the element are in phase. In this case, the radius of curvature of the rollers does
 20 not affect the thicknesses of dielectric passed through. This is not the case when the wave front is flat, as for example when the antenna element is a parabolic antenna or a patch antenna array distributed in two dimensions in which all the elements are in phase, and the radius of curvature of the dielectric rollers is not great in relation to the antenna element.

25 Figure 7a illustrates such a case in point, in which the incident wave front F_{inc} emitted by the antenna A_7 is planar, whereas the two dielectric lenses D_{71} and D_{72} have identical local thicknesses. The incident wave front F_{inc} can be broken down into a superpositioning of independent electromagnetic waves which intersect the dielectric lenses at different
 30 positions. Because of the radius of curvature of the rollers, the thickness of dielectric passed through varies. In the example, the thickness τ_1 of dielectric passed through by a wave situated at the top of the wave front will be greater than the thickness τ_2 of dielectric passed through by a wave situated at the middle of the front, and which arrives on the dielectric with a normal

incidence. Over all of the wave front, the thickness of dielectric passed through will therefore be maximal at the ends, and minimal in the middle. The total effective thickness then exhibits an undesired gradient which will cause an unwanted and uncontrolled local steering of the beam F_e having passed
 5 through the two dielectric lenses, and potentially generate a loss of gain, the degradation of the appearance of the radiating pattern, and then aiming error.

To fight against this phenomenon, one embodiment of the invention, represented in Figure 7b, consists in adding a divergent correcting lens L_{71} between the antenna element and the first dielectric lens D_{71} . The object of
 10 this correcting lens is to transform the planar incident wave front into a cylindrical wave front, and therefore to compensate the radius of curvature of the dielectric lenses D_{71} and D_{72} . In this way, the thickness of dielectric passed through is identical at all points. The invention also proposes adding a convergent correcting lens L_{72} after the second dielectric lens D_{72} , so as to
 15 transform the cylindrical wave front into a planar wave front F_e .

In this way, it is possible to apply the invention to an antenna element emitting a planar wave front while limiting the radius of curvature of the dielectric rollers.

The reverse mechanism of adding correcting lenses can also be
 20 envisaged conversely, for the case where the antenna element emits a cylindrical wave front, and where the dielectric lenses are planar in translation.

The device for steering an electromagnetic beam according to the invention can be used in conjunction with any type of antenna, whether it is
 25 active or passive, whether it emits a planar, cylindrical or spherical wave front.

It relies on the use of at least two superposed dielectric lenses whose effective thickness varies in two dimensions, and having a structure mirroring one another. The use of two lenses or more makes it possible to control the
 30 steering of the antenna, so that it is done on one or more very precise axes. By using a single dielectric lens, the aiming would not have been able to be contained on one axis, and the device would have been difficult to associate with another mechanical steering means.

In the device according to the invention, the displacement of the dielectric lenses is done at right angles, or at quasi-right angles when the lenses are arranged in the form of rollers, to the plane scanned by the beam, and not in this plane. That makes it possible in particular for the device to
 5 propose a mechanical steering device for the beam whose inertia is low and which retains a finite size. In the case of an elongate antenna, an additional elongation of the device requires that elongation of the rollers or of the dielectric plane is only by the same quantity in the same direction. The other dimensions of bulk of the device do not vary, which is not the case when
 10 using the techniques known from the prior art in which the dielectric lenses take the form of discs. Furthermore, the device makes it possible to retain a phase shift applied at the centre of the beam that is constant in the displacement of the lenses.

The invention relates also to an antenna comprising a steering device
 15 as described previously. Figures 8a, 8b and 8c describe three embodiments of such an antenna, but other embodiments can easily be developed by a person skilled in the art.

In the embodiment described in Figure 8a, the antenna element A_8 is driven in rotation about the axis x by a mechanical means M . This rotation
 20 makes it possible to steer the beam in the plane yOz .

The antenna also comprises two rollers D_{81} and D_{82} of dielectric lenses rotating about the axis x' , collinear to the axis x . These rollers have structures such as those described previously, their effective thickness varying mirroring one another both in length (on the x axis) and in width (along their
 25 circumference). The displacement of one or both lenses makes it possible to adjust the total effective thickness passed through by the beam emitted by the antenna A_8 , and thus to adjust the steering of the beam in the plane xOz .

The antenna as described therefore exhibits a reduced bulk. In effect, the use of a mechanical axis to steer the beam on the x axis would have
 30 exhibited a significant bulk not exhibited by the two nested dielectric rollers according to the invention. The antenna associates a mechanical axis with a steering device as described by the invention to offer the antenna a possibility of steering in two dimensions. The device cannot scan the yOz axis beyond an angle linked to the coefficient α of the dielectric lenses, but

does not exhibit singular points in the surface scanned. It should be noted that, for cost reasons, steering of the beam in the plane yOz is here performed using a mechanical beam steering, but it could be obtained in equivalent fashion by electronic steering.

5 In another embodiment, described in Figure 8b, the two superposed dielectric lenses D_{83} and D_{84} are positioned above the antenna element A_8 and take the form of portions of rollers. The assembly is positioned on a revolving plate P , the rotation of the plate being assured mechanically.

10 The rotation of one or both dielectric lenses according to the invention makes it possible to steer the elevation of the electromagnetic beam emitted, while the rotation of the plate P makes it possible to control the azimuth thereof.

15 The antenna devices described above are proposed by way of illustration, the person skilled in the art being able to easily define novel antenna devices from the teachings given previously. The embodiments do not limit the scope of the invention, which is defined by the claims.

In another embodiment, described in Figure 8b, the antenna element A_8 the two superposed dielectric lenses D_{85} and D_{86} are arranged rotationally about a mast M on the axis z .

20 This embodiment requires the use only of a single revolving joint. In idle position, the antenna aims its electromagnetic beam in the horizontal plane. The synchronous rotation of the antenna element and of the dielectric rollers makes it possible to vary the aiming azimuth 801 of the antenna, whereas the rotation of one of the rollers, or of both rollers in opposite directions, makes it
25 possible to vary the aiming elevation 802 of the antenna.

Such a device can advantageously be implemented on a mast or on a vehicle.

The steering device according to the invention therefore fits particularly well in an aiming device also comprising one or more mechanical positioners.
30 The steering according to the invention does not necessarily require the use of materials sensitive to wear, such as, for example, the revolving joints necessary to ensure a mechanical rotation about an axis. The fact that the translation of the dielectric planes or the rotation of the dielectric rollers is

done in a direction at right angles to the incident beam makes it possible to limit their bulk. The choice of the coefficient α of variation of the effective thickness of the dielectrics makes it possible to adjust the switching speed of the antenna, as well as the bulk of the device and its precision.

5 The invention also relates to a method for steering an electromagnetic beam, for which a state diagram is represented in Figure 9. Said method comprises:

- 10 • A step 901 of superpositioning of an antenna element by at least two dielectric lenses, the lenses having an effective thickness varying as described previously. The superpositioning is done in such a way that the beam emitted by the antenna element is directed along the z axis, and the lenses are arranged in the plane xOy.

 A step 902 of displacement of at least one of the lenses, in at least one
15 direction substantially at right angles to the desired steering axis of the electromagnetic beam. A steering of the beam in the plane xOz is therefore obtained by a translation of the dielectric lenses on the y axis. When the lenses are arranged in the form of rollers or portions of rollers, this translation on the y axis is implemented by rotation of the dielectric lenses about an axis
20 collinear to the axis x.

CLAIMS

1. Device for steering an electromagnetic beam (F_{inc}) comprising at least two superposed dielectric lenses (D_{11} , D_{12}), said device being characterized
 5 in that the dielectric lenses are of variable effective thicknesses, and in that at least one of the dielectric lenses is mobile in at least one direction (y) substantially orthogonal to a plane (xOz) in which the electromagnetic beam is steered.
- 10 2. Steering device according to Claim 1, in which each of the dielectric lenses comprises a reference point (C_{11} , C_{12}), the effective thickness of the dielectric lenses varying as a function of the product between the distance in relation to this reference point in a first direction (x) and the distance in relation to this reference point in a second direction (y) at right angles to the
 15 first direction.
3. Steering device according to one of the preceding claims, in which each of the dielectric lenses comprises four dials (Q_{11} , Q_{12} , Q_{13} , Q_{14}) defined from a reference point, the opposing dials in relation to said reference point
 20 forming a pair of dials, the effective thickness of each of the dielectric lenses increasing as a function of the distance in relation to said point of intersection in one of the pairs of dials (Q_{11} , Q_{13}) and decreasing as a function of the distance in relation to said point of intersection in the other pair of dials (Q_{12} , Q_{14}).
 25
4. Steering device according to one of the preceding claims, in which said increases and reductions of the effective thickness of the dielectric lenses are done periodically, the period being linked to a wavelength of the electromagnetic beam.

5. Steering device according to one of Claims 1 to 4, in which the variation of the effective thickness of the dielectric lenses comprises a variation of a local thickness.
6. Steering device according to one of Claims 1 to 4, in which the
5 variation of the effective thickness of the dielectric lenses comprises a variation of a refraction index.
7. Steering device according to one of the preceding claims, in which the dielectric lenses each have a reference point (C_{11} , C_{12}), the device having a
10 position in which the reference points of the dielectric lenses are superposed at the centre (O) of an antenna element (A_1) emitting said electromagnetic beam (F_{inc}), and in which the sum of the effective thicknesses of the dielectric lenses is constant over all of the surface (R_{11} , R_{12}) passed through by said electromagnetic beam.
- 15
8. Steering device according to one of the preceding claims, comprising two dielectric lenses each having a reference point (C_{11} , C_{12}), the device having a position in which the reference points of the two dielectric lenses are superposed at the centre (O) of an antenna element (A_1) emitting said
20 electromagnetic beam (F_{inc}), and in which the effective thickness of the two dielectric lenses varies inversely to one another.
9. Steering device according to one of the preceding claims, comprising two dielectric lenses, in which the two dielectric lenses are mobile and are
25 displaced in opposite directions.
10. Steering device according to one of the preceding claims, in which the dielectric lenses are planar (D_{11} , D_{12}).
- 30 11. Steering device according to one of the preceding claims, in which the dielectric lenses are wholly or partly rollers (D_{51} , D_{52}).

12. Steering device according to one of the preceding claims, in which the mobility along an axis of the dielectric lens or lenses is assured by a translation of the dielectric lens or lenses.

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13. Steering device according to one of the preceding claims, in which the mobility along an axis of the dielectric lens or lenses is assured by a rotation of the dielectric lens or lenses about an axis (x') collinear to an axis (x) of the antenna.

10

14. Steering device according to one of the preceding claims, further comprising a first correcting lens (L_{71}) configured to modify the form of a wave front, said first lens being positioned on one side of the dielectric lenses, and a second correcting lens (L_{72}) configured to modify the form of a wave front inversely to the first lens, and positioned on the other side of the dielectric lenses.

15

15. Steering device according to one of the preceding claims, said device further comprising a mechanical aiming axis (M) for the electromagnetic beam (F_{inc}).

20

16. Antenna, characterized in that it comprises at least one steering device according to one of the preceding claims.

25 17. Method for steering an electromagnetic beam (F_{inc}) emitted by an antenna element (A_1), characterized in that it comprises:

- a first step (901) of superpositioning of the antenna element by at least two dielectric lenses (D_{11} , D_{12}) of variable effective thickness, and
- a second step (902) of displacement of at least one of the dielectric lenses in at least one direction (y) substantially orthogonal to a plane (xOz) in which the electromagnetic beam is steered.

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