

## SYSTEM FOR DEFLECTING AND POINTING A MICROWAVE BEAM

The field of the invention is that of systems for deflecting and pointing a microwave beam.

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The invention is applicable to the processing of a microwave, corresponding to frequencies comprised between 300 MHz and 300 GHz, beam of wavelength typically between 1 mm and 1 m. Such frequencies are in particular used in the fields:

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- of satellite telecommunications from mobile platforms,
  - of reconfigurable data links for high-throughput communications, and
  - of low-cost millimeter- or centimeter-wave radars.

Many systems need to be able to control the direction in which a beam is emitted or received. This property is referred to as pointing control.

15 Among these systems, mention may for example be made of on-board radars, missile seekers, sense-and-avoid systems, communication systems, jammers and radar systems for periscopes.

To be pointed, an antenna must be configured to emit and receive a wave in a given spatial direction. For example, at the present time, in the telecommunications field, it is increasingly necessary to be able to redirect an antenna, following an update to the coverage of a region. It is important to be able to produce smart and remotely controllable antennas, i.e. antennas that are "smart" because they are able to be oriented to cover different spatial zones, and "remotely controllable" because they are able to be steered

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25 remotely from a center of operations.

For tracking, the antenna must be configured to follow a target such as a satellite or airplane.

Furthermore, it is increasingly sought to obtain orientable-beam antennas that are compact, small in bulk and weight, easy to use, easy to integrate into a platform, and of low cost.

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Various known techniques allow an orientable-beam antenna to be produced, but they have certain drawbacks.

Cassegrain-type parabolic antennas are handicapped by shadowing effects due to the position of the source (more specifically the

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secondary reflector) in front of the reflector. Also, to preserve a good efficiency, a high diameter-to-wavelength ratio is required. At low frequencies, this antenna can thus not be integrated into a small volume.

In addition, conventional mechanical solutions for orienting the antennae use a fragile 2-axis gimbal mechanism. This pointing system requires a substantial amount of mechanical freedom as the volume occupied by the antenna varies depending on its orientation. Moreover, to avoid placing active RF emitters on moving parts, the emission and reception signals must pass through rotary microwave joints that decrease performance and may be expensive and bulky when high power levels (several tens of watts) are required.

This type of antenna is furthermore held back by its travel range, which is generally limited to  $60^\circ$ .

To do away with moving parts, one known solution consists in using an active electronically scanned antenna, which allows recourse to mechanical pointing control to be avoided: its profile remains flat whatever the direction of orientation, this being a major advantage when the antenna is to be placed in a shroud. The orientation is controlled electrically. However, this type of antenna has drawbacks in terms of price, of power consumption, of complexity, of temperature management vis-à-vis heating, of power maintenance and also of accessible angular domain, which remains limited to less than  $60^\circ$ .

One way of producing an RF deflecting system is to use two diffractive components that are able to rotate about the same axis, in combination with a lens and an RF source. Such a system is described in patent FR 3 002 697. These diffractive components and the lens each comprise a plurality of periodic subwavelength microstructures MS formed in a dielectric material, in a Risley-scanner configuration; these microstructures are arranged so as to form an artificial material presenting a periodic variation in effective refractive index, this arrangement allowing the diffractive function to be performed. As shown in figure 15 of patent FR 3 002 697, the structure of the diffractive component C1 may be manufactured on one face of the component, the structure of the lens L being produced on its other face. The beam emitted by the source S is pointed via independent rotations (symbolized by the arrows) of the dual lens-grating diffractive component

L+C1 and of the diffractive component C2 about an axis  $\Omega$ , as illustrated in figure 1; the components L+C1 and C2 are placed in a plane normal to the axis of rotation  $\Omega$  and the axis of symmetry of the beam emitted by the source S, and which passes through the center thereof, coincides with this axis  $\Omega$ . The advantage of such a deflecting system is that it is compact, may employ a fixed power supply S, has mechanical orientation capacities and is still highly efficient. For example, for an application at 30 GHz (Ka band) using a dielectric material of refractive index of 1.5 (dielectric constant of 2.25), the thickness of the diffractive component is about 30 mm. The total thickness of the deflecting system is therefore about 100 mm. For a source located in the object focal plane of the lens L, i.e. at about 200 mm therefrom, the total thickness of the agile antenna is about 300 mm. However, this thickness may nevertheless be too large for certain applications in which the antenna is integrated into a mobile platform.

Furthermore, it is difficult to dynamically, and in particular rapidly, point to certain zones, in particular zones located around and in the direction of the axis of rotation  $\Omega$  of the components. Specifically, in the same way as pointing systems employing gimbals controlled in azimuth and in elevation, in this direction the pointing system of the antenna has a keyhole, i.e. a particular zone that requires the prisms to be rotated at very high (or even infinite) speeds when a tracked object passes in proximity to the axis of rotation  $\Omega$ .

Therefore, there currently remains a need for a orientable-beam deflecting system that satisfactorily meets all of the aforementioned requirement at once, in particular the requirements in terms of weight and bulk, which must be low, of travel range, of ease of use and of integration into a platform, and of low cost.

The deflecting system according to the invention employs two deflecting devices, at least one of which includes a diffractive dielectric component that is structured at a scale smaller than the wavelength. Combined with a simple rotation-based mechanism, this approach allows, at lower cost, angular travel ranges of as large as  $120^\circ$  to be obtained with one (or more than one) microwave frequency source(s), i.e. a solid-angle

coverage of  $3\pi$  sr, i.e. three times what is possible with an electronically scanned antenna, without a servo-control keyhole and without moving active microwave parts.

5           More precisely, one subject of the invention is a system for steerably deflecting an microwave beam having a wavelength comprised between 1 mm and 1 m, which includes:

- a forming device configured to collimate said beam in emission mode or to focus said beam in reception mode,
- 10       - a first device for deflecting an incident microwave beam comprising a first diffractive dielectric component comprising subwavelength microstructures arranged so as to form an artificial material presenting a periodic variation in effective refractive index, called the first diffractive dielectric component, this first diffractive dielectric
- 15       component being associated with a first mechanism for rotating about a first steerable axis.

It is mainly characterized in that it comprises, upstream of the first deflecting device in emission mode or downstream of the first deflecting device in reception mode:

- 20       - a second deflecting device configured to deflect an incident microwave beam toward the first deflecting device in emission mode, or issued from the first deflecting device in reception mode, this second deflecting device being associated with a second mechanism for rotating about a second steerable axis,

25           in that the angle made by the first and second axes of rotation is larger than  $0^\circ$  and smaller than or equal to  $90^\circ$ , and in that the first rotating mechanism is securely fastened to the second rotating mechanism so that a rotation of the second rotating mechanism about its steerable axis leads to a rotation of the first rotating mechanism about the same axis.

30           According to one feature of the invention, the first deflecting device comprises another diffractive dielectric component comprising subwavelength microstructures, said component being placed parallel to the first diffractive dielectric component (and being called the third diffractive dielectric component), this third diffractive dielectric component being

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associated with a third mechanism for rotating about the first steerable axis, which is independent of the first rotating mechanism but securely fastened to the second rotating mechanism.

5 The second deflecting device may include a second diffractive dielectric component comprising subwavelength microstructures (called the second diffractive dielectric component) and the device for forming the beam emitted by the emitting means or received by the receiving means may include a lens. It optionally includes a fourth diffractive dielectric component comprising subwavelength microstructures (called the fourth diffractive  
10 dielectric component), said component being placed parallel to the first diffractive dielectric component.

Each diffractive dielectric component may typically be a prism or a grating.

15 The lens of the device for forming the beam and the second diffractive dielectric component are advantageously combined to form a non-resonant two-faced holographic component comprising subwavelength microstructures formed on a single face in a non-periodic arrangement determined by a calculation of the interference on said face between an incident beam and a predetermined exit beam; the holographic component is  
20 associated with the second rotating mechanism.

The microstructures of the holographic component may be formed on a predetermined 3D surface. Alternatively, they are formed in a predetermined volume that abuts against said face of the holographic component, and arranged in a nonperiodic three-dimensional arrangement.

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According to another feature of the invention, the device for forming the beam and the second deflecting device are combined to form a Cassegrain-type system of mirrors.

30 Preferably, the second deflecting device is configured to deflect the beam onto the first deflecting device with a normal incidence.

The first deflecting device deflects the beam with a first deflection angle with respect to the first axis and the second deflecting device deflects  
35 the beam with a second deflection angle with respect to the second axis. The

first deflecting angle is advantageously larger than or equal to the second deflecting angle.

Another subject of the invention is an orientable-beam antenna  
5 that includes means for emitting/receiving a microwave beam having a wavelength comprised between 1 mm and 1 m and a system for deflecting the beam such as described.

The emitting/receiving means, the shaping device and the second  
10 deflecting device may be combined to form an assembly able to form an incident beam on the first deflecting device in emission mode or to receive a beam issued from the first deflecting device in reception mode; this assembly is associated with the second rotating mechanism. This assembly is for example an antenna array.

15 Other features and advantages of the invention will become apparent on reading the following detailed description, which is given by way of nonlimiting example and with reference to the appended drawings, in which:

figure 1 schematically shows an orientatable antenna according to  
20 the prior art,

figures 2a and 2b schematically show, seen in cross section, an orientatable antenna equipped with a first exemplary embodiment of a deflecting system according to the invention, comprising two prisms and a lens for shaping the beam emitted by the source (figure 2a), comprising one  
25 prism and a holographic component combining the second prism and the shaping lens (figure 2b),

figure 3 schematically shows, seen in cross section, an orientatable antenna equipped with a second example embodiment of a deflecting system according to the invention, comprising three prisms,

30 figure 4 schematically shows, seen in cross section, an orientatable antenna equipped with a third example embodiment of a deflecting system according to the invention, comprising four prisms,

figure 5a schematically shows, seen from above, a first example implementation of subwavelength microstructures of a holographic  
35 component, these microstructures having a constant cross section over their

height and being arranged in a square Cartesian grid that is shown in detail at a larger scale in figure 5b, and in perspective in figure 5c,

figure 6a schematically shows, seen from above, another example implementation of subwavelength microstructures of a holographic component, these microstructures being arranged in a grid defined by iso-  
5 phase lines and phase-gradient lines, which grid is detailed at larger scale in figure 6b,

figures 7a and 7b schematically show, seen in cross section, an orientatable antenna equipped with a fourth example embodiment of a  
10 deflecting system according to the invention, the second deflecting device of which includes a two-mirror Cassegrain-type configuration, with a concave primary mirror (figure 7a) and a reflect-array primary mirror (figure 7b),

figures 8a and 8b schematically show, seen in cross section, an orientatable antenna including a patch antenna array (figure 8a) and a blazed  
15 antenna array (figure 8b).

In all the figures, elements that are the same have been referenced with the same references.

In the rest of the description, the expressions "in front" and "behind" are used with reference to the orientation of the described figures.  
20 Likewise, the "upstream-downstream" direction is that of the beam; in the figures, the direction of the beam indicated by arrows is that of the emission mode. In so far as the device may be positioned with other orientations, the directional terminology is given by way of illustration and is nonlimiting.

Insofar as the deflecting system according to the invention is  
25 intended to be used in collaboration with a source able to emit (and/or with a receiver able to receive) a microwave beam, a source is shown in the figures in order to illustrate the deflections of the beam. The description is given with respect to an antenna in emission mode; however, of course the invention applies to the reception mode. Dielectric prisms are used by way of example  
30 of diffractive dielectric components; however, dielectric gratings could equally well be employed. The expression "diffractive component" is of course used with the same meaning as indicated in the introduction with reference to patent FR 3 002 697, i.e. a component comprising subwavelength microstructures arranged so as to form an artificial material presenting a

periodic variation in effective refractive index in order thus to perform the diffractive function.

An example deflecting system according to the invention will now be described with reference to figure 2a.

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The system for deflecting a microwave beam having a wavelength comprised between 1 mm and 1 m and intended to be associated with emitting(-receiving) means S, includes:

- 10 - A device for shaping the incident beam (or forming device) configured to collimate in emission mode (the wave front emitted by the source, which is almost spherical in the case of a point source S, is formed into a plane wave), or to focus in reception mode.
- 15 - A first device for deflecting the microwave beam, which comprises a first dielectric prism C1 comprising subwavelength microstructures. This prism C1 is associated with a first mechanism R1 for rotating (rotation indicated by the arrow) about a first axis  $\Omega 1$  normal to the plane of the prism C1. This first deflecting device is thus configured to deflect the incident beam by a first set nonzero angle  $\theta 1$  with respect to the axis of rotation  $\Omega 1$ . The rotation of C1 about the axis  $\Omega 1$ , which is ensured by the first steerable rotating mechanism R1, allows the beam to describe a circle about  $\Omega 1$ . By design, this angle  $\theta 1$  may be set to between 0 and  $60^\circ$ .
- 20 - Between the emitting-receiving means and the first deflecting device, a second deflecting device associated with a second mechanism R2 for rotating about a second steerable axis  $\Omega 2$  (rotation indicated by the arrow). It is configured to, in emission mode, deflect toward the first deflecting device by a set nonzero angle  $\theta 2$  with respect to the axis of rotation  $\Omega 2$ , the incident microwave beam issued from the source, and to, in reception mode, deflect toward the forming device by a set nonzero angle  $\theta 2$  with respect to the axis of rotation  $\Omega 2$ , the incident microwave beam issued from the first deflecting device. The angle ( $\Omega 1, \Omega 2$ ) made by the first and second axes of rotation is larger than  $0^\circ$  and smaller than or equal to  $90^\circ$ :  $0^\circ < (\Omega 1, \Omega 2) \leq 90^\circ$ ; in other words, the prism C1 of the first deflecting device is inclined with respect to
- 35  $\Omega 2$ .

- The first rotating mechanism R1 is mounted on the second rotating mechanism R2. Thus, the first rotating mechanism R1 is securely fastened to the second rotating mechanism R2: the rotation of the second deflecting device about the axis  $\Omega_2$  causes the first deflecting device to rotate about  $\Omega_2$ . However, the rotation of the first deflecting device about the axis  $\Omega_1$  is independent of the rotation about the axis  $\Omega_2$ : it does not cause the second deflecting device to rotate.

In order to ensure a complete angular coverage, it is then necessary for the prism C1 and the second deflecting device to deflect the beam with  $\theta_1 \geq \theta_2$ . The rotation of C1 about the axis  $\Omega_1$ , which is ensured by the first rotating mechanism R1, allows the beam to describe a circle about  $\Omega_1$ , which, combined with a rotation of the second deflecting device about the roll axis  $\Omega_2$ , which is ensured by the second rotating mechanism R2, allows the beam to be placed in a cone of solid angle of a value of  $2\pi(1-\cos(2\theta_1))$ .

The second deflecting device may itself include one or more dielectric prisms comprising subwavelength microstructures, as shown in figures 2a, 2b, 3 and 4.

According to a first embodiment described with reference to figure 2a, the second deflecting device includes a single dielectric prism C2 comprising subwavelength microstructures, which prism is called the second prism, and likewise the first deflecting device includes only a single prism C1. This allows the compactness of the antenna to be improved.

This second prism allows the beam to be pre-deflected upstream of the first deflecting device in emission mode, by a set nonzero angle  $\theta_2$  with respect to the axis  $\Omega_2$  normal to the plane of the prism C2. The angle between the axes  $\Omega_1$  and  $\Omega_2$  may also be equal to  $\theta_2$  as shown in the figures; in this case, the beam deflected by this second prism C2 advantageously has a normal incidence on the prism C1 in emission mode. By design, this angle  $\theta_2$  may be set to between 0 and 60°. Combined with the first prism C1, this allows a maximum deflection  $\theta_1 + \theta_2$  of 120° to be achieved. In order for the angular coverage to be complete (i.e. to include the

direction of  $\Omega_2$ ), it is necessary for the angle  $\theta_1$  to be larger than or equal to the angle  $\theta_2$ . The addition of a roll mechanism for rotating about the axis  $\Omega_2$  leads to a pointing domain of solid angle  $3\pi$  sr.

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According to a second embodiment described with reference to figure 3, the second deflecting device includes a single prism, called the second prism C2, and the first deflecting device includes, in addition to the first prism C1, another prism called the third prism C3.

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This dielectric prism C3 comprising subwavelength microstructures is placed parallel to the first prism C1 (it is therefore normal to the axis  $\Omega_1$ ) and on said prism; it is able to deflect the incident beam by a set nonzero angle  $\theta_3$  with respect to the axis  $\Omega_1$ . By design, this angle  $\theta_3$  may be set to between 0 and  $60^\circ$ . It is associated with a third mechanism R3 for rotating about the steerable axis  $\Omega_1$  (rotation indicated by the arrow), which is independent of the first rotating mechanism R1 associated with C1. Like the first rotating mechanism R1, this third rotating mechanism R3 is mounted on the second rotating mechanism R2. Thus, the first and third rotating mechanisms R1 and R3 are securely fastened to the second rotating mechanism R2. This first deflecting device, which comprises two structured dielectric prisms C1 and C3 that are able to rotate independently about the axis  $\Omega_1$ , allows the beam to be dynamically off-pointed in a solid-angle cone with a variable deflection angle  $\theta_{13} = \theta_3 + \theta_1$  (with respect to  $\Omega_1$ ) able to reach an angle of  $\theta_{13\max}$ . Depending on the configuration of C1 and C3, by design,  $\theta_{13\max}$  may reach  $60^\circ$  to  $70^\circ$ , depending on the sought performance level. The directions of rotation of the first and third rotating mechanisms R1, R3 may optionally be opposite; counter-rotary prisms C1 and C3 then being spoken of.

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The combination of these two deflecting devices allows a maximum deflection  $\theta_{13\max} + \theta_2$  of  $120^\circ$  to be achieved. In order for the angular coverage to be complete, it is necessary for the angle  $\theta_{13\max}$  to be larger than or equal to the angle  $\theta_2$ . Combined with the roll mechanism for rotating about the axis  $\Omega_2$ , a pointing domain of solid angle  $3\pi$  sr is obtained.

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The rotating mechanisms R1, R2 and R3 are controllable for example manually or preferably by a motor controlled by a servo-mechanism.

According to a third embodiment described with reference to figure 4, the second deflecting device includes, in addition to the prism C2, a second prism comprising subwavelength microstructures, which is called the fourth prism C4. This fourth prism C4 is placed parallel to the prism C1 of the first deflecting device and just in front (= upstream) in emission mode as shown in the figure, and is therefore normal to the axis  $\Omega 1$ ; therefore, it is inclined with respect to the prism C2 by an angle made by the axes  $\Omega 1$  and  $\Omega 2$ . It is configured to deflect the incident beam (issued from the prism C2 and therefore already deflected by an angle  $\theta 2$ ) by a set nonzero angle  $\theta 4$ . This prism is associated with the mechanism R2 of the second deflecting device, for rotating about the axis  $\Omega 2$ . By design, this angle  $\theta 4$  may be set to between 0 and  $60^\circ$ . The deflection angle of the second deflecting device is then equal to  $\theta 2 + \theta 4$  with respect to the axis  $\Omega 2$ . In the figure, the angle made by the axes  $\Omega 1$  and  $\Omega 2$  is also equal to  $\theta 2 + \theta 4$ : thus the beam issued from C4 has a normal incidence on C1.

In all these embodiments, the device for forming the beam issued from the source includes a lens, at the focal point of which are placed the emitting means S. This lens allows the almost spherical wave front emitted by a point source S to be shaped. The shaping lens L may be fixed and independent of the second prism C2 and its rotating mechanism as shown in figures 2a, 3 and 4. In this case, the assembly made up of the source S and the shaping lens L is fixed with respect to the rotations about  $\Omega 1$  and  $\Omega 2$  and allows an easy interconnection with the microwave emission and/or reception circuits.

This shaping lens L may be:

- a diffractive bulk dielectric lens with a hyperbolic profile, or
- a microstructured dielectric lens such as described in patents FR 2 980 648 or FR 3 002 697, and may be diffractive or refractive.

According to one variant that is applicable to the embodiments described above, the lens L for shaping the beam emitted by the emitting

means S (or toward the receiving means) is combined with the second prism C2 into a holographic component CH, in order to obtain a single component that performs the dual function of shaping and deviating the beam emitted by the source S, as illustrated in figure 2b. In this case, the sub-wavelength microstructures are produced on a single face of the component CH in a non-periodic arrangement determined by a calculation of the interference, on said face, between the beam emitted by the source incident on this face and the desired exit beam (of this component CH), in the present case a plane wave deflected with an angle  $\theta_2$ . It will be recalled that microstructures are qualified subwavelength when the cells (or divisions) in which they are arranged meet the following condition:

$$(\text{Distance between the centers of adjacent cells}) < \lambda/n$$

where  $\lambda$  is the target wavelength chosen in the wavelength range corresponding to microwave frequencies, i.e. a wavelength typically comprised between 1 mm and 1 m, and  $n$  is the refractive index of the dielectric material in which the microstructures are formed.

In the case where this holographic component is planar faced (2-D surface) as shown in figure 2b, it is a question of a calculation of the interference on this planar face between the incident beam emitted by the source and the exit beam that, in the case of an orientable-beam antenna, is a plane wave with an exit angle (in emission mode) corresponding to the angle of orientation of the beam. The height and size of each microstructure MS of CH (which may also be seen in figure 5c) are determined experimentally or calculated so as to make the phase delay modulo  $2\pi$  introduced locally by each microstructure correspond to the conjugate of the phase of the hologram at the same point.

The subwavelength implementation of the microstructures MS is achieved using a geometric grid M generally of Cartesian basis, i.e. of rectangular or even square basis, as shown in figures 5a, 5b and 5c. A hexagonal or even circular grid may also be envisioned. Within this grid, the base of a microstructure may of course not occupy more than one division (or cell) of the grid, but may occupy this division (or cell) only partially. Certain divisions may be empty, others entirely occupied by the base of the microstructure and in yet others, lastly, the base of the microstructure only

partially occupies the corresponding division, depending on the chosen implementation.

This implementation, which is simple to produce, leads however to a phase error due to the resolution of the sampling, and therefore to a decrease in the aperture efficiency of the antenna. To solve this problem, the grid basis is defined in a suitable coordinate system in order to adjust the phase as best as possible. A subwavelength geometric structure is produced from a grid  $M$  that coincides with iso-phase lines in one direction and with phase-gradient lines in directions that are respectively perpendicular to the iso-phase lines, as illustrated in figures 6a and 6b.

In order to improve orientation performance for small elevation angles (large angle  $\theta$ ), the microstructures of the holographic component may be formed on a nonplanar surface, i.e. on a predetermined 3-D surface, such as a surface of axial symmetry like a cone, sphere or any arbitrary 3-D surface.

The microstructures are all formed in a dielectric material with shapes that are determined beforehand, and either protrude in the form of pillars, or are recessed in the form of holes. A combination of holes and pillars is also possible. The microstructures may be of any shape and preferably have axes of symmetry. They have a cross section that is square, hexagonal or circular, or a combination of various geometries, or a cross section that is defined by iso-phase lines and phase-gradient lines. Their cross section over their height may be constant, or variable as in the case of a pyramid structure, a conic structure, etc. The height of the microstructures  $MS$  is generally identical (as illustrated in figure 5c), but not necessarily. They may be perpendicular to the surface of the component or inclined, for example to  $30^\circ$ . It is also possible to have an inclination that is variable over a given component. The inclination is determined experimentally, typically depending on the direction of inflection or of incidence of the beam.

According to one generalization of the preceding embodiment, and again to perform the function of collimating or focusing (in the emission or reception mode) and of deflecting the beam, the holographic component  $CH$  includes superpositions of layers of subwavelength microstructures  $MS$  formed in the volume of said component and positioned in a nonperiodic

three-dimensional arrangement determined by a calculation of the interference, in said volume, between the incident beam emitted by the source into this volume and the desired exit beam. This volume of course abuts against the face of the component CH on which the microstructures are formed; this volume is in particular bounded by this face. The calculation of the voluminal interference may be carried out experimentally by successive adjustments or by calculation, for example by converting the CH volume into a stack of K 2-D or 3-D surfaces that are parallel to one another (with K an integer typically comprised between 2 and 100) on each of which surfaces an areal interference pattern is calculated. The stack of layers of microstructures is for example obtained by making correspond, to each calculational point of the volume, a microstructure of height decreased by a factor K, and the cross section of which allows a local phase delay corresponding to the conjugate of the phase of the hologram at the same point, but decreased by a factor K, to be generated.

Another way of obtaining the distribution of 3-D microstructures consists, on the basis of the calculation of the interference, obtained on the face of the component CH, between the incident beam emitted by the source and the exit beam, in projecting the cross section of each of the microstructures into the volume of the component along the curves resulting from the intersection between the iso-phase planes of the voluminal hologram and the planes containing the phase gradients.

In other words, this calculation of interference in said volume may be carried out

- discretely for various values of  $z$  (dimension of the stack); it is a question in certain respects of a reiteration, for a plurality of implementational surfaces considered at various values of  $z$ , of the 2-D interference calculation described above for a single implementational surface. The height and cross section of the microstructures is then to be determined on each of these surfaces as indicated above, or
- continuously over  $z$ , the height and cross section of the microstructures then being determined by the calculation itself.

This component CH is accommodated in the second deflecting device and is therefore rotated about the axis  $\Omega_2$  by the second rotating mechanism. This holographic component CH allows weight to be decreased and performance to be improved.

5           An example configuration with a holographic component CH is shown in figure 2b: a single prism C1, which deflects the beam by a set angle  $\theta_1$  with respect to its axis of rotation  $\Omega_1$ , is used in the aperture of the antenna. As already indicated, in order to ensure a complete angular coverage, it is then necessary for the prism C1 and the holographic  
10       component CH to deflect the beam with  $\theta_1 \geq \theta_2$ . The rotation of C1 about the axis  $\Omega_1$ , which is ensured by the first rotating mechanism, allows the beam to describe a circle about  $\Omega_1$ , which, combined with a rotation of the assembly made up of C1 and CH about the roll axis  $\Omega_2$ , which is ensured by the second rotating mechanism, allows the beam to be placed in a cone of solid  
15       angle of a value of  $2\pi(1-\cos(2\theta_1))$ .

It is also possible to add to the preceding configurations a mechanism for translating the emitting(/receiving) means S along the vertical axis (parallel to the axis  $\Omega_2$ ) in order to control the aperture of the emitted  
20       and received beam.

To assist the two deflecting devices, and/or to compensate for the variation in the deflection of C2 when the frequency of the wave emitted by the source S is modified, it is also possible to add to the preceding configurations a mechanism for translating the emitting(/receiving) means S  
25       in the plane normal to the axis  $\Omega_2$ . This is particularly useful for generating small deflection angles and it avoids making a complete turn in roll (= a complete turn of the second rotating mechanism) in particular about keyholes such as those in the direction of  $\Omega_2$  for example. This thus allows the beam (its position and aperture) to be easily and completely controlled.

30           In the preceding examples, the second deflecting device included one or more prisms, but it may not include any prisms. This alternative to the embodiments described above, which allows space to be saved, is based on a combination of the device for shaping the beam emitted by the source and  
35       of the second deflecting device, employing reflector-antenna-type

configurations; this combination remains associated with the second mechanism R2 for rotating about the axis  $\Omega 2$ . The beam emitted by the source is for example deflected and distributed to the first deflecting device by:

- 5       - an off-axis Cassegrain-type configuration with a parabolic primary mirror M1 and a concave secondary mirror M2, as may be seen in figure 7a,
- A Cassegrain-type configuration in which the mirror M1 is a reflect-array mirror, as may be seen in figure 7b.

10       In these two reflector-based variants, the concave secondary mirror M2 may be replaced by any other type of reflector in order to produce a Gregorian configuration, an ADE (axially displaced ellipse) configuration or a "dielguide" configuration (also known as the splashplate configuration).

Another subject of the invention is an orientatable antenna  
15 comprising a deflecting system such as described, and point microwave emitting(/receiving) means S placed at the focal point of the shaping device as shown in the figures described above.

In all the described configurations, the source S may be monopulse and optionally connected to a 'magic T' allowing direct extraction  
20 of monopulse signals (sum and differences along the two axes of the horn). These signals allow the angular offset between the target and the pointing angle of the sum beam to be determined, which angle is determined by adding coders to the three axes of rotation of the device. This therefore allows the angular offset of a target in the main radiation lobe of the radiation  
25 pattern of the source to be measured.

Variants of all these orientatable antenna embodiments may also be produced by combining a non-point source (or more generally non-point emitting-receiving means), its shaping device, and the second deflecting  
30 device in order to form an assembly configured to emit a plane wave to the first deflecting device in emission mode or to receive a plane wave issued from the first deflecting device in reception mode. This assembly is for example itself an antenna array A (e.g. a patch antenna array as illustrated in figure 8a, a slot antenna array, a Vivaldi antenna array, etc.) without phase  
35 shifters or with fixed phase shifters. Specifically, this antenna array does not

have to be equipped with phase shifters since the off-pointing of angle  $\theta_2 + \theta_{13}$  is achieved by the deflecting system. In contrast, it may have a plurality of channels in order to carry out advanced radar processing operations. The antenna array may be placed perpendicular to the axis  $\Omega_2$  as shown in figures 8a and 8b, but not necessarily. It may also be placed directly against the prism C1. Whatever its configuration, this antenna array A is associated with the second mechanism R2 for rotating about the axis  $\Omega_2$ .

It is possible for the antenna array A to be blazed as shown in figure 8b. The blaze angle  $\theta_2$  makes it possible not to lose patch efficiency in the fixed pointing direction of the antenna.

This assembly, configured to emit a plane wave deflected toward the first deflecting device in emission mode (or to receive a plane wave deflected by the first deflecting device in reception mode), may also be a reflector antenna or a high-gain horn, *inter alia*.

The alternatives described with reference to figures 7a, 7b, 8a and 8b are also applicable with a first deflecting device including only a single prism C1.

In these embodiments, each prism (C1 and optionally C3) of the first deflecting device is associated with a mechanism for rotating about  $\Omega_1$  (R1 and optionally R3), whereas a single mechanism for rotating about  $\Omega_2$  (R2) is associated with the second deflecting device that includes one or more prisms (C2 or CH and optionally C4), or that has a Cassegrain-type configuration, or that is an antenna array. Furthermore:  $0^\circ < (\Omega_1, \Omega_2) \leq 90^\circ$ .

The source and optionally the shaping device or even also the first deflecting device is/are advantageously housed in a shroud. This shroud is either covered on the exterior, or lined in the interior, with an absorber allowing the waves emitted by the source S but not intercepted by the lens L, as well as the parasitic reflections in the device, to be absorbed. This contributes to improving the radiation pattern of the antenna and to decrease its radar cross section. This absorber may be made of a dielectric and/or magnetic material (or of a composite) structured at a subwavelength scale in order to decrease the level of the reflections at the air/absorber interfaces.

This structuring may be carried out in two ways:

- Either using a layer including subwavelength microstructures so that the height and thickness of the structure are locally such that the structure has an equivalent effective index (such as disclosed in patent FR 2 980 648) allowing an antireflection layer that is locally suitable for the incidence and for the frequency of the incident wave to be produced.
  - Or using three-dimensional structuring, for example of the pyramidal type (see the article by de W. H. Southwell "Pyramid-array surface-relief structures producing antireflection index matching on optical surfaces", J. Opt. Soc. A., Vol 8, No 3, March 1991), at the interface, the subwavelength microstructures for example being oriented depending on the incidence of the beam. This orientation is not indispensable, it is possible to keep an orientation normal to the surface of the shroud.
- The size of the microstructures therefore differs depending on the operating wavelength of the device. These structured surfaces may be produced by machining, by additive manufacturing or by chemical etching.

The advantages of the invention are as follows:

- ❖ The mechanisms required for this type of deflecting system are more reliable than rod-based mechanisms (annular motors). The rotated weight is small because of the use of plastic dielectric materials, allowing additive manufacturing techniques to be used, and ensuring a weight that is acceptable for a light and rapid mechanism. The dimensions of the actuators and the servo-control of the rotating mechanisms do not depend on the weight distribution in the emitter portion, thereby facilitating modularity.
- ❖ The angular domain accessible by the system in emission/reception is  $3\pi$  sr (max deflection  $120^\circ$ ) versus less than  $\pi$  sr (max deflection  $60^\circ$ ) for other systems.
- ❖ The use of dielectric prisms ensures bandwidth and makes this system accessible to the highest frequencies.
- ❖ The use of a central emitter allows cost to be decreased through use of a centralized power emitter (e.g. travelling wave tube - TWT) for high frequencies; there is no need to use rotary joints to pass the microwave signal.

❖ Control of the position of the source with respect to the lens along the perpendicular axis allows the aperture of the beam to be controlled.

## CLAIMS

- 5 1. A system for steerably deflecting an incident microwave beam having a wavelength comprised between 1 mm and 1 m, which includes:
- a forming device configured to collimate said beam in emission mode or to focus said beam in reception mode,
  - 10 - a first device for deflecting an incident microwave beam comprising a first diffractive dielectric component (C1) comprising subwavelength microstructures arranged so as to form an artificial material presenting a periodic variation in effective refractive index, called the first diffractive dielectric component, this first diffractive dielectric component being associated with a first mechanism (R1) for rotating
  - 15 about a first steerable axis ( $\Omega_1$ ), characterized in that it comprises, upstream of the first deflecting device in emission mode or downstream of the first deflecting device in reception mode:
  - a second deflecting device configured to deflect an incident
  - 20 microwave beam toward the first deflecting device in emission mode, or issued from the first deflecting device in reception mode, this second deflecting device being associated with a second mechanism (R2) for rotating about a second steerable axis ( $\Omega_2$ ),
  - in that the angle ( $\Omega_1$ ,  $\Omega_2$ ) made by the first and second axes of rotation is larger than  $0^\circ$  and smaller than or equal to  $90^\circ$ , and in that
  - 25 the first rotating mechanism (R1) is securely fastened to the second rotating mechanism (R2) so that a rotation of the second rotating mechanism about its steerable axis ( $\Omega_2$ ) leads to a rotation of the first rotating mechanism about the same axis.
  - 30
- 35 2. The steerable deflecting system as claimed in the preceding claim, characterized in that the first deflecting device comprises another diffractive dielectric component (C3) comprising subwavelength microstructures, said component being placed parallel to the first diffractive dielectric component (C1) and being called the third diffractive dielectric component, this third diffractive dielectric

component being associated with a third mechanism (R3) for rotating about the first steerable axis ( $\Omega_1$ ), which is independent of the first rotating mechanism (R1) and securely fastened to the second rotating mechanism (R2).

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3. The steerable deflecting system as claimed in one of the preceding claims, characterized in that the second deflecting device includes a diffractive dielectric component (C2) comprising subwavelength microstructures, said component being called the second diffractive dielectric component, and in that the device for forming the beam emitted by the emitting means or received by the receiving means includes a lens (L).
- 10 4. The steerable deflecting system as claimed in the preceding claim, characterized in that the second deflecting device includes another diffractive dielectric component (C4) comprising subwavelength microstructures, said component being placed parallel to the first prism (C1) and being called the fourth diffractive dielectric component.
- 15 5. The steerable deflecting system as claimed in either of claims 3 and 4, characterized in that the lens (L) of the device for forming the beam is a microstructured dielectric diffractive lens.
- 20 6. The steerable deflecting system as claimed in either of claims 3 and 4, characterized in that the lens (L) of the device for forming the beam is a microstructured dielectric refractive lens.
- 25 7. The steerable deflecting system as claimed in either of claims 3 and 4, characterized in that the lens (L) of the device for forming the beam is a bulk dielectric refractive lens.
- 30 8. The steerable deflecting system as claimed in either of claims 3 and 4, characterized in that the lens (L) of the device for forming the beam and the second diffractive dielectric component (C2) are combined to form a non-resonant two-faced holographic component (CH) comprising subwavelength microstructures formed on a single face in a non-periodic arrangement determined by a calculation of the
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interference on said face between an incident beam and a predetermined exit beam, and in that the holographic component (CH) is associated with the second rotating mechanism (R2).

- 5        9. The steerable deflecting system as claimed in the preceding claim, characterized in that the microstructures (MS) of the holographic component (CH) are formed on a predetermined 3D surface.
- 10       10. The steerable deflecting system as claimed in claim 9, characterized in that the microstructures of the holographic component (CH) are formed in a predetermined volume that abuts against said face of the holographic component, and arranged in a nonperiodic three-dimensional arrangement.
- 15       11. The steerable deflecting system as claimed in either of claims 1 and 2, characterized in that the device for forming the beam and the second deflecting device are combined to form a Cassegrain-type system of mirrors.
- 20       12. The steerable deflecting system as claimed in one of the preceding claims, characterized in that each diffractive dielectric component is a prism or a grating.
- 25       13. The steerable deflecting system as claimed in one of the preceding claims, characterized in that the second deflecting device is configured to deflect the beam onto the first deflecting device with a normal incidence.
- 30       14. The steerable deflecting system as claimed in one of the preceding claims, characterized in that the first deflecting device deflects the beam with a first deflection angle ( $\theta_1$ ,  $\theta_{13}$ ) with respect to the first axis ( $\Omega_1$ ) and the second deflecting device deflects the beam with a second deflection angle ( $\theta_2$ ,  $\theta_2+\theta_4$ ) with respect to the second axis ( $\Omega_2$ ), and in that the first deflecting angle is larger than or equal to the
 

35       second deflecting angle.

- 5 15. An orientable-beam antenna that includes means for emitting/receiving a microwave beam having a wavelength comprised between 1 mm and 1 m and a system for deflecting the beam as claimed in one of the preceding claims.
16. The orientable-beam antenna as claimed in the preceding claim, characterized in that the emitting means (S) are configured to be monopulse.
- 10 17. The orientable-beam antenna as claimed in either of claims 15 and 16, characterized in that it includes a mechanism for translating the emitting/receiving means along the second axis ( $\Omega_2$ ) and/or in a plane normal to the second axis ( $\Omega_2$ ).
- 15 18. An orientable-beam antenna that includes means for emitting/receiving a microwave beam having a wavelength comprised between 1 mm and 1 m and a system for deflecting the beam as claimed in either of claims 1 and 2, characterized in that the emitting/receiving means, the forming device and the second
- 20 deflecting device are combined to form an assembly able to form an incident beam on the first deflecting device in emission mode or to receive a beam issued from the first deflecting device in reception mode and in that this assembly is associated with the second rotating mechanism (R2).
- 25 19. The orientable-beam antenna as claimed in the preceding claim, characterized in that this assembly is an antenna array (A).
- 30 20. The orientable-beam antenna as claimed in the preceding claim, characterized in that the antenna array is blazed.