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(54) Dual-polarisation reflectarray antenna with improved cros-polarization properties

(57) Dual-linear polarisation reflectarray antenna with improved cross-polarization properties. The reflectarray antenna consists of a planar array of phasing cells illuminated by a feed, that produces a collimated or shaped beam in dual-linear polarisation, where the phasing cells are made of varying-sized conductive patches with a rotation angle that has been adjusted to minimise the cross-polarisation. In a first implementation, the patches in which the angle of incidence is larger than a prefixed threshold are rotated so that the propagation direction of the incident field is contained on a symmetry plane of the patches. In a second implementation, the rotation angle of the patches in each cell is optimized to minimize the cross-polarisation in a prefixed frequency band. The invention can be applied to dual-polarization antennas in Telecommunication satellites

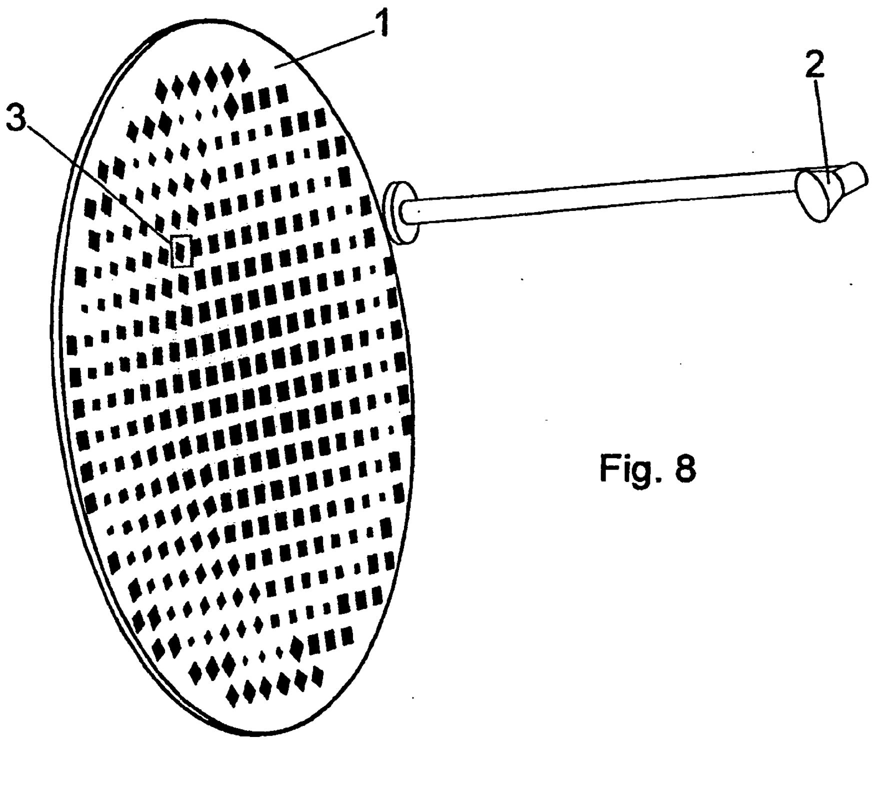

Fig. 8

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Description

Field of the Invention

[0001] This invention is framed in the telecommunication, radar and space technology sectors. More particularly, the invention is related to planar or curved reflector antennas called "reflectarrays" working in dual-polarisation, in which the phasing elements are arranged in order to minimise the cross-polarisation components generated by the antenna.

Prior state of art

[0002] A reflectarray antenna [D. G. Berry, R. G. Malech W. A. Kennedy, 'The Reflectarray Antenna IEEE Trans. on Antennas and Propagat., Vol. AP-11, 1963, pp.646-651] consists of a planar array of radiating elements with a certain adjustment in the phase of the reflected field to produce a collimated electromagnetic beam when it is illuminated by a primary feed (figure 1). Printed reflectarrays use metallic patches printed on a grounded substrate to produce the required phase adjustment. One practical implementation of the phase adjustment in rectangular patches consists of connecting transmission line segments of different lengths to the printed elements [R. E. Munson, H. A. Haddad, J. W. Hanlen, 'Microstrip Reflectarray for Satellite Communications and RCS Enhancement or Reduction ', patent US4684952, August 1987]. In this technique, the phase delay of the reflected wave is proportional to the length of the stubs. However, the stubs produce some ohmic losses and spurious radiation when bent that increase the cross-polarisation of the antenna. Other concepts have been developed for printed reflectarrays, such as the adjustment of resonant length in crossed dipoles [D.G. Gonzalez, G.E. Pollon, J.F. Walker, "Microwave phasing structures for electromagnetically emulating reflective surfaces and focusing elements of selected geometry", Patent US 4905014, Feb. 1990] or rectangular patches [D. M. Pozar and T. A. Metzler, "Analysis of a reflectarray antenna using microstrip patches of variable size," Electr. Lett. Vol. 29, No. 8, pp.657-658, April 1993], aperture-coupled patches with stubs [A.W. Robinson, M.E. Bialkowski, and H.J. Song, "An X-band passive reflect-array using dual-feed aperture-coupled patch antennas", Asia Pacific Microwave Conference, pp. 906-909, December 1999], apertures of different length on the ground plane [M.R. Chaharmir, J. Shaker, M. Cuhaci, A. Sebak, "Reflectarray with variable slots on ground plane", IEE Proc.-Microw. Antennas Propag., Vol. 150, No. 6, pp. 436-439. December 2003]. In principle, these implementations are valid for any type of polarization including dual-linear or circular polarization, by appropriately adjusting the phase-shift of the two orthogonal components of the reflected electric field.

[0003] The operating principle of the reflectarrays using variable-sized printed elements is based on the fact that the phase of the reflected wave varies with the resonant length of the elements. A printed patch is a resonant antenna, so that its length should be approximately half a wavelength in the dielectric. If the patch length is modified in the array, the phase of the reflected wave changes. The phase control by varying the resonant dimensions produces lower ohmic losses and lower cross-polarization levels than the stubs of different lengths attached to the radiating patches. However, the maximum range of phase variation that can be achieved is in the order of 330°, and the phase variation versus the length is strongly non-linear because of the narrow band behaviour of printed patches, which limits the working bandwidth in reflectarray antennas. The main limitation to reflectarray performance is the narrow bandwidth, generally lower than 5% and even less for large reflectarrays. Bandwidth limitation is an inherent characteristic of reflectarrays, although much effort has been made in recent years in order to improve the bandwidth.

[0004] The bandwidth limitation in varying-sized patches has been overcome by using two or three stacked layers of patch arrays [J. A. Encinar, "Printed circuit technology multi-layer planar reflector and method for the design thereof", European Patent EP 1 120 856 A1, June 1999] (figure2). For example, a two-layer reflectarray can be designed to produce a collimated beam in the frequency band 11.45-12.75 GHz (figures 4 and 5). Further improvements in bandwidth have been achieved by applying optimisation techniques to adjust the patch dimensions in each layer in order to obtain the required phase distribution in a predefined frequency band [J. A. Encinar and J. A. Zornoza, "Broadband design of three-layer printed reflectarrays," IEEE Trans. Antennas Propagat., vol. 51, no. 7, pp.1661-1664, Julio 2003].

[0005] Different types of reflectarray elements have been proposed in recent years to improve the element bandwidth in printed reflectarrays. Several geometries of printed ridged-shaped patches with varying dimensions have been analyzed in [M. Bozzi, S. Germani, L. Perregrini, "Performance comparison of different element shapes used in printed reflectarrays", Antennas and Wireless Propagation Letters, Volume 2, Issue 1, 2003 pp. 219 - 222], and the phase-shift performances have been compared with those relevant to more traditional elements (rectangles, dipoles, and rectangles with tuning stubs). The ridge-type patches have a slightly better performance in phase-shift than a single layer of rectangular patches, but the irregular shape increase the cross-polarization. Double-layer structures have been also analyzed showing better performance with respect to single-layer configurations. Stacked metallic rings have been proposed as a reflectarray element in [N. Misran, R. Cahill, V. Fusco, "Reflection phase response of microstrip stacked ring elements", Electronics Letters, Volume 38, Issue 8, pp. 356 - 357, April 2002]. As in rectangular stacked patches, the phase of the reflected field is controlled by varying the size of the printed rings. Bandwidth is improved for the stacked ring configuration, but the results are not superior to those achievable when using stacked rectangular patches. Another solution to improve the bandwidth using multi-resonant dipoles in a single layer has been proposed in [J.A. Encinar, A. Pedreira, "Flat reflector antenna in printed technology with improved bandwidth and separate polarizations", Spanish patent P200401382] where the reflectarray incorporates several parallel printed dipoles in the same phasing cell and in the same layer, in order to achieve a similar bandwidth improvement as in the case of stacked patches, but with a single layer of printed patches, producing a simplification in the manufacturing process and a reduction in manufacturing costs. The dimensions of the parallel dipoles are optimised to improve the bandwidth in a similar manner as done in the staked patches. In that patent, a reflectarray for dual polarization has been also proposed, which includes other arrangement of parallel dipoles printed on the opposite side of substrate (bottom side in Figure 3) placed perpendicular to those on the top side and located at a certain distance from the conductive ground plane. The phase-shift is adjusted independently for each polarisation by varying the length of the printed dipoles on each side, resulting in a low level of coupling between polarizations, although, the residual cross-polarisation may not be compliant with the stringent cross-polarisation requirements in space antennas for Telecommunications.

[0006] An important application of reflectarrays is their use as dual polarisation reflectors for frequency reuse. In a communications satellite, independent signals are transmitted and received in orthogonal polarisations using the same frequency bands. Although the two orthogonal polarisations can be circular, clockwise and anti clockwise, the most common case is to use two linear polarisations, designated as vertical and horizontal. The frequency reuse requires a very high isolation between polarisations. A reflectarray antenna acting as a dual polarisation reflector for frequency reuse has been patented [J. R. Profera, E. Charles, "Reflectarray Antenna for Communication Satellite Frequency Re-use Applications", patent US5543809, August 1996], which is made up of crossed-dipole arrays, being the length of the orthogonal dipoles adjusted independently to produce the required phase-shift for each polarisation. The dipoles for each polarisation can also be separated. This type of reflectarray exhibits severe bandwidth limitations in both embodiments, because they are based on a single layer of varying-sized dipoles, not being suitable for most commercial applications. In addition, the residual cross-polarisation may not be compliant with the stringent requirements in space antennas for Telecommunications.

[0007] In order to reduce the coupling between orthogonal polarizations in reflectarrays with crossed dipoles, a configuration with two stacked layers of orthogonal dipoles separated by a grid of conductive wires or strips has been proposed in [k. C. Clancy, m. e. Cooley, D. Bressler, "Apparatus and method for reducing polarization cross-coupling in cross dipole reflectarrays", patent US2001/0050653 A1, March 2000]. In that invention is also included an embodiment, in which the orthogonal dipoles for the two polarizations are located on the same layer. In this case, each dipole is made of several parallel wires close to each other, which act as single wider dipole, but reducing the coupling with the orthogonal polarisation. In this configuration, the phase curves as a function of the length are similar as those obtained for a single dipole, and consequently the bandwidth is insufficient for most commercial applications. The cross-polarisation is drastically reduced in this invention, but as in the case of the previous invention, the technique and the embodiments are based on reflectarray elements made of varying-sized dipoles for each polarisation, which exhibits severe limitations in bandwidth.

[0008] Reflectarray antennas based on elements with variable rotation angles [J. Huang, "A Ka-Band Microstrip Reflectarray with Elements Having Variable Rotation Angles", IEEE Trans. Antennas Propagat., Vol. 46, No. 5, pp. 650-656, May 1998] have been proposed to produce a focused beam in circular polarisation. In this concept, all the reflectarray elements are identical and the rotation angle is used to adjust the phase-shift of the reflected wave when a circularly polarized field is incident; however the rotation angle does not have a direct influence on the cross-polarisation. This technique is only valid for circular polarisation and cannot be applied for linear or dual-linear polarisation. In addition, this concept is limited to a really narrow frequency band.

[0009] Reflectarray antennas have been used to generate contoured beams by using one layer of varying-sized patches [D. M. Pozar, S. D. Targonski, and R. Pokuls, "A shaped-beam microstrip patch reflectarray," IEEE Trans. Antennas Propagat., vol. 47, no. 7, pp. 1167-1173, July 1999], or several layers of stacked patches to improve the bandwidth [J. A. Encinar and J. A. Zornoza, "Three-layer printed reflectarrays for contoured beam space applications," IEEE Trans. Antennas Propagat., vol. 52, no. 5, pp. 1138-1148, May 2004]. The beam shaping to create a coverage over certain geographic zones can be obtained by a suitable design of the dimensions of the printed patches in a multi-layer configuration for Direct Broadcast Satellite (DBS) antennas working in dual linear polarisation [J. A. Encinar et al. "Dual-Polarization Dual-Coverage Reflectarray for Space Applications", IEEE Trans. on Antennas and Propag., Vol. 54, No. 10, Pp. 2828-2837, Oct. 2006]. The required bandwidth for DBS applications, around a ten percent bandwidth, can be achieved by properly optimising the patch dimensions in a three-layer configuration of varying-sized patches. Although the levels of cross-polarisation are low enough in pencil beam antennas (in the order of 30 dB below the maximum), when the DBS antenna is designed to provide a wider coverage, the level of co-polar radiation is reduced to provide the same coverage level in the whole prescribed Geographical area, but the level of cross-polarization produced by the patches is not proportionally reduced. In that case, the level of cross-polarization might not be acceptable for Telecommunications antennas in space applications, where independent channels are transmitted in each linear polarization (vertical and horizontal) and a high isolation between orthogonal polarisations is required, typically 30dB.

[0010] As mentioned in this section, the reflectarray antennas proposed in the prior state of the art have several drawbacks and limitations. On one side, the most severe limitation in reflectarray antennas is associated to their operation in a narrow frequency band, which has been alleviated by several techniques, including stacked patches, multiple resonant cells (dipoles and rings) and optimization techniques. On the other side, the cross-polarisation must be reduced as much as possible for dual-polarisation reflectarrays, particularly for contoured beam antennas in Space applications, where a high isolation between polarisations is required. Several concepts have been proposed in the last decades in order to reduce the coupling between polarisations. However, in all the configurations presented until now, the reflectarray elements are constituted by narrow band printed dipoles, and the concepts proposed to reduce the cross-polarisation are not compatible with other broad-band reflectarray elements as staked patches or multiple resonant cells. As a consequence, the proposed reflectarray antennas exhibit a narrow band characteristic peculiar of conventional single-layer reflectarrays, not being suitable for most commercial applications.

Description of the invention

[0011] The invention relates to a dual-linear polarization reflectarray antenna with improved cross-polarization properties according to claim 1, and to a method for obtaining said antenna according to claim 11. Preferred embodiments of the antenna and of the method are defined in the dependent claims.

[0012] The dual-linear polarization reflectarray antenna comprises a reflectarray and a primary feed configured to illuminate an array of phasing cells of the reflectarray, each phasing cell comprising at least one dielectric layer and a conductive plane, each dielectric layer having at least one conductive element printed on its surface, the size of each conductive element of each phasing cell being determined to produce a previously defined radiation beam. The key aspect of the present invention is that each conductive element of each phasing cell is disposed in a previously calculated orientation with respect to the phasing cell so as to reduce the cross-polarization effect, wherein said orientation is dependent upon the particular phasing cell considered.

[0013] In the proposed antenna a reflectarray coordinate system (X_R, Y_R, Z_R) can be considered, with axis Z_R perpendicular to the reflectarray. It can also be considered in each phasing cell ***i*** a local coordinate system (X_{Ri}, Y_{Ri}, Z_{Ri}) centred in the cell and parallel to the reflectarray coordinate system (X_R, Y_R, Z_R).

[0014] In a first preferred embodiment, the at least one conductive element of each dielectric layer of each phasing cell ***i*** comprises a conductive patch which symmetry axes (X_{Pi}, Y_{Pi}) form a previously calculated angle α_i with respect to the corresponding axes (X_{Ri}, Y_{Ri}) of the local coordinate system (X_{Ri}, Y_{Ri}, Z_{Ri}), said angle α_i being dependent upon the particular phasing cell ***i*** considered.

[0015] The conductive patches of the reflectarray can have any of the following shapes: rectangular-shaped, square-shaped, cross-shaped, elliptical-shaped, polygonal-shaped.

[0016] For each phasing cell ***i*** the angle α_i can be selected such that the propagation direction of the incident field coming from the feed to said phasing cell *i* is contained in a symmetry plane of the conductive patch of each dielectric layer of the phasing cell *i*.

[0017] In a second preferred embodiment the at least one conductive element of each dielectric layer of each phasing cell *i* comprises a first set of parallel conductive dipoles printed on a side of the dielectric layer and a second set of parallel conductive dipoles printed on the opposite side of the dielectric layer, the phasing cell *i* comprising at least one further dielectric layer to separate the at least one dielectric layer from the conductive plane. The first set of parallel conductive dipoles are oriented such that its associated axis Y_{Di}, parallel to said first set of dipoles, forms a previously calculated angle α_{yi} with respect to the corresponding axis (Y_{Ri}) of the local coordinate system (X_{Ri}, Y_{Ri}, Z_{Ri}), and the second set of parallel conductive dipoles is oriented such that its associated axis (X_{Di}), parallel to said second set of dipoles, forms a previously calculated angle α_{xi} with respect to the corresponding axis (X_{Ri}) of the local coordinate system (X_{Ri}, Y_{Ri}, Z_{Ri}), said angles α_{yi} and α_{xi} being dependent upon the particular phasing cell *i* considered.

[0018] In a third preferred embodiment, each phasing cell *i* comprises at least one pair of dielectric layers with a first set of parallel conductive dipoles printed on a side of one dielectric layer and a second set of parallel conductive dipoles printed on the other dielectric layer. The first set of parallel conductive dipoles is oriented such that its associated axis Y_{Di}, parallel to said first set of dipoles, forms a previously calculated angle α_{yi} with respect to the corresponding axis (Y_{Ri}) of the local coordinate system (X_{Ri}, Y_{Ri}, Z_{Ri}), and the second set of parallel conductive dipoles is oriented such that its associated axis X_{Di}, parallel to said second set of dipoles, forms a previously calculated angle α_{xi} with respect to the corresponding axis (X_{Ri}) of the local coordinate system (X_{Ri}, Y_{Ri}, Z_{Ri}), said angles α_{yi} and α_{xi} being dependent upon the particular phasing cell *i* considered.

[0019] In both the second and third embodiments, the angle α_{yi} can be selected, for each phasing cell, such that the axis Y_{Di} defining the direction of the first set of conductive dipoles is contained in the plane of incidence of the field coming from the feed to the said phasing cell i, and the angle α_{xi} can be selected such that the axis X_{Di} defining the direction of the second set of conductive dipoles is perpendicular to the plane of incidence of the field coming from the feed to the said phasing cell i.

[0020] In any of the first, second or third embodiment, the dimensions of each conductive element of each phasing cell *i* can be selected such that there is a phase-shift of 180 degrees between the two components of the reflected electric field parallel to the axes associated to the conductive elements (X_{Pi}, $_{YPi}$; X_{Di}, Y_{Di}), being the orientation of each conductive element of each phasing cell *i* such that the total cross-polarization produced by both geometrical projections and coupling in the phasing cell is minimised in a prefixed frequency band and for the two linear polarizations.

[0021] The phasing cells can be arranged, in all cases, in any of the following dispositions: a rectangular lattice, a square lattice, a triangular lattice, an hexagonal lattice, non-periodic array, sparse arrangement.

[0022] The orientation of each conductive element of those phasing cells where the angle of incidence θ_i of the field coming from the feed with respect to the axis Z_R is lower than a predetermined threshold angle θ_t can be selected such that the axes associated to the corresponding conductive element (X_{Pi}, Y_{Pi}; X_{Di}, Y_{Di}) are parallel to the corresponding axes (X_R, Y_R) of the reflectarray coordinate system (X_R, Y_R, Z_R).

[0023] In accordance with another aspect of the invention, a method for obtaining a dual-linear polarization reflectarray antenna with improved cross-polarization properties is provided. The method comprises:

- providing a reflectarray and a primary feed configured to illuminate an array of phasing cells of the reflectarray, each phasing cell comprising at least one dielectric layer and a conductive plane, each dielectric layer having at least one conductive element printed on its surface, the size of each conductive element of each phasing cell being determined to produce a previously defined beam;
- calculating, for each conductive element of each phasing cell, an orientation with respect to the phasing cell so as to reduce the cross-polarization effect, said orientation being dependent upon the particular phasing cell considered;
- disposing each conductive element of each phasing cell in the previously calculated orientation.

[0024] In a preferred embodiment, the orientation of each conductive element of each phasing cell can be calculated such that the propagation direction of the incident field coming from the feed to the said phasing cell *i* is contained in a symmetry plane of said conductive element.

[0025] In another preferred embodiment, the step of calculating the orientation of each conductive element comprises minimising, by using an optimisation routine, the total cross-polarization produced by both geometrical projections and coupling in the phasing cell, in a prefixed frequency band and for the two linear polarizations.

[0026] In yet another preferred embodiment, the step of calculating the orientation of each conductive element comprises:

- calculating the dimensions of each conductive element of each phasing cell such that there is a phase-shift of 180 degrees between the two components of the reflected electric field parallel to the axes associated to the conductive elements (X_{Pi}, Y_{Pi}; X_{Di}, Y_{Di});
- minimising, by using an optimisation routine, the total cross-polarization produced by both geometrical projections and coupling in the phasing cell, in a prefixed frequency band and for the two linear polarizations.

[0027] The method can further comprise:

- defining an threshold angle θ_t, such that the cross-polarisation produced by those phasing cells where the angle of the incidence with respect to Z_R axis is lower than the threshold angle θ_t, is lower than a prefixed level for the two orthogonal polarisations;
- disposing each conductive element of those phasing cells where the angle of incidence (θ_i) of the field coming from the feed with respect to the axis Z_R is lower than said threshold angle θ_t such that the axes associated to the corresponding conductive element (X_{Pi}, Y_{Pi}; X_{Di}, Y_{Di}) are parallel to the corresponding axes (X_R, Y_R) of the reflectarray coordinate system (X_R, Y_R, Z_R).

Explanation of the drawings

[0028] A series of drawings which aid in better understanding the invention and which are expressly related with at least one embodiment of said invention, presented as a non-limiting example thereof, are very briefly described below.

Figure 1. Perspective of a reflectarray illuminated by a feed, according to the prior art.

Figure 2. Lateral and front views of a reflectarray cell comprising two stacked conductive patches, according to the prior art.

Figure 3 represents a perspective of a reflectarray cell comprising conductive dipoles, according to the prior art.

Figure 4 shows a mask with varying-sized patches, according to the prior art.

Figure 5 shows the co-polar and cross-polar radiation patterns in a plane tilted by 20 degrees with respect to the coordinate plane Y_RZ_R, for a reflectarray with two layers of varying-sized patches, where the first layer is shown in Fig. 4, for the linear polarization with the electric field contained on the X_RZ_R plane.

Figure. 6 represents, according to a first embodiment of the present invention, a lateral and top view of a reflectarray cell with two stacked conductive patches printed on dielectric layers with an angle of rotation α_i respect the rectangular lattice.

Figure 7A shows, according to a second embodiment, a perspective of a reflectarray cell comprising three parallel conductive dipoles printed on the top side of a dielectric layer rotated an angle α_{yi} with respect the Y_{Ri} axis and three conductive dipoles printed on the bottom side of the dielectric layer and rotated an angle α_{xi} with respect to the axis X_{Ri}.

Figure 7B shows, according to a second embodiment, a perspective of a reflectarray cell comprising three parallel conductive dipoles printed on the top side of a dielectric layer rotated an angle α_{yi} with respect the Y_{Ri} axis and three conductive dipoles printed on the top side of a second dielectric layer and rotated an angle α_{xi} with respect to the axis X_{Ri}.

Figure 8 represents a perspective of a reflectarray antenna made of an array of varying-sized patches illuminated by a feed, in which the printed patches are rotated in each phasing cell in order to reduce the cross-polarisation.

Figure 9 shows, according to an embodiment of the present invention, an example of a mask to scale with rotated varying-sized patches .

Figure 10 shows the co-polar and cross-polar radiation patterns in the plane tilted by 20 degrees with respect to the coordinate plane Y_RZ_R, for a reflectarray with two layers of varying-sized patches, where the first layer is shown in Fig. 9.

Figure 11 depicts a sketch showing that the electric field E_{ref} reflected by a reflectarray element is rotated by 2β degrees with respect to the incident electric field E_{inc}, when the reflectarray cell is designed to produce a phase difference of 180 degrees between the two components of the reflected field parallel to the sides of the rectangular patches.

Description of a Preferred Embodiment of the Invention

[0029] In this invention, a reflectarray antenna comprising a plurality of broad-band phasing elements made of one or several layers of varying-sized conductive patches or dipoles printed on a dielectric substrate over a conductive ground plane is proposed, in which the printed patches are individually rotated in order to reduce the cross-polarisation.

[0030] Figure 1 shows a perspective of a reflectarray (1) illuminated by a feed (2). In each element (3) of the reflectarray, an adjustment is introduced in the phase of the reflected field so that the divergent field coming from the feed (2) is reflected as a collimated or a shaped beam in a given direction (4).

[0031] In the prior state of the art, it has been demonstrated that reflectarray antennas can be designed to be compliant with most of the requirements for communications satellites, being the most critical ones the bandwidth and the low cross-polarisation levels required for dual-polarisation antennas. Although reflectarrays produce low cross-polarization, this might not be sufficient to remain compliant with the specifications of Telecommunication missions in dual linear polarization. In a reflectarray antenna made of several layers of arrays with varying-sized patches and designed to produce a given contoured beam in a specified frequency band (typically around 10%), the cross-polarization is produced by two different phenomena: the first one is the generation of the orthogonal component of the field on the reflectarray surface produced by the field projections when illuminated by a linear-polarised feed, and the second one is the coupling of polarisations produced at the conductive patches. Both cross-polarisation components are zero when the incident signal is on one of the principal planes (φ_i=0° or φ_i=90°, in the spherical coordinate system shown in figure 1 for the phasing cell i) and increase for other angles of incidence (θ_i, φ_i), especially for large values of the angle θ_i (Figure 1). The second factor is the most significant in a reflectarray and increases when the patches are near the resonance. In a reflectarray antenna the angle of incidence at each element varies with the element position on the array, and so the level of cross polarisation produced by both phenomena, coupling and field projections. As a consequence, the cross polarisation levels are only significant in those areas of the reflectarray where the angles of incidence (θ_i, φ_i) are far away from the principal planes and predominantly for large values of θ_i, therefore the reduction of the cross-polarisation is particularly necessary in those zones.

[0032] Figure 2 shows a lateral and front views of a reflectarray cell of dimensions p_x by p_y with two stacked conductive patches, where the phase of the reflected field is adjusted by varying the patch dimensions. The reflectarray element consists of a first rectangular conductive patch (5) of dimensions a_1xb_1, a dielectric layer (6) of thickness t_1, a second rectangular conductive patch (7) of dimensions a_2xb_2, a second dielectric layer (8) of thickness t_2, and a conductive plane (9).

[0033] Figure 3 depicts a perspective of a reflectarray cell comprising three parallel conductive dipoles (10, 11 and 12) printed on the top side of a dielectric layer (13) and three conductive dipoles (14, 15 and 16) perpendicular to the first ones, printed on the bottom side of the dielectric layer (13), separated from a conductive plane (17) by another dielectric layer (18), where the phase of the reflected field for each linear polarization is controlled independently by varying the lengths of the dipoles printed on each side of the top dielectric layer (13).

[0034] It is important to observe that once a reflectarray comprising a plurality of broad-band phasing elements, which are made of one or several layers of varying-sized conductive patches (Fig. 2) or dipoles (Fig. 3) printed on dielectric layers above a conductive plane, has been designed to generate or to receive the same beam in the two orthogonal polarisations, a small rotation of the patches will practically no alter the co-polar radiation patterns, but it will modify significantly the cross-polar patterns. Then, the patches on the reflectarray can be individually rotated at each cell to minimise the cross-polarisation produced at each reflectarray cell. For the analysis of the reflectarray, the local periodicity approach can be used, i.e. each phasing element *i* is assumed located in a periodic planar array with all the elements rotated by the same angle α_i (specified in Fig. 6) with respect to the reflectarray coordinate system ($X_R Y_R$). The co- and cross-polar components of the reflected field are computed independently at each cell assuming local periodicity and from them, the co- and cross-polar radiation patterns of the reflectarray antenna are computed.

[0035] A first principal object of this invention is a reflectarray antenna formed by a planar array of phasing cells arranged in a rectangular lattice, where each cell is made of one or several layers of varying-sized patches or dipoles printed on dielectric layers placed above a conductive plane, which are designed by adjusting their dimensions to produce the phase-shift in the reflected field required to collimate or to shape the beam in dual-linear polarisation (vertical and horizontal) in a given frequency band, when illuminated by a feed (2) located at a focal point (in transmit mode); or to receive radio-frequency signals from a given direction in dual-linear polarisation and in the same frequency band, by concentrating them at the focal point where the feed is located; where the patches are individually rotated at each cell with respect to the rectangular lattice in order to minimise the cross-polarisation produced at each reflectarray cell.

[0036] The phasing cells in the reflectarray antenna can be arranged not only in a rectangular lattice, but also in different types of lattices, such as square, triangular, hexagonal or following a different type of pattern, including non regular arrangements of the elements. Triangular lattices can be used to achieve a more dense distribution of the elements in the array, or to interleave reflectarray elements for different frequency or different polarisation. On the other side, non-regular lattices, such as sparse or non-periodic arrays can be used to reduce the total number of elements in the reflectarray, which is particularly important when the phasing elements include switches or other control devices.

[0037] In a first embodiment, depicted in figure 6, each element of the reflectarray consists of several stacked layers of conductive patches (5,7) separated by dielectric sheets (6,8) with an angle of rotation α_i respect the rectangular lattice, all of them placed above a conductive ground plane (9), considering in each layer squared or rectangular patches, or conductive patches with other geometric shapes that allow independent adjustment in two dimensions to control the phase of the reflected field for the two orthogonal polarisations of the incident field, such as cross-shaped metallisations, where the phase for each polarisation is controlled with the length of each arm of the crosses. The symmetry axes of the stacked patches in the element *i* are rotated α_i degrees with respect to the local coordinate axes $X_{Ri} Y_{Ri}$ which are parallel to the reflectarray coordinate axes $X_R Y_R$.

[0038] The conductive patches can be printed on a thin dielectric layer, which are bonded to the dielectric separators (6,8) by a bonding film, so that the number of dielectric layers between the conductive ground plane (9) and the conductive patches (7), or between stacked conductive patches (5,7), can be increased for structural concerns or for technological reasons in the manufacturing process. The use of several layers with printed patches (two, three or even more) allows phase curves as a function of the patch size to be less sensitive to frequency variations, which produces an increase in bandwidth. Additionally, the dimensions of the stacked patches can be optimised to provide the required beam shaping in the whole working band and the angles of rotation will be adjusted to minimise the cross-polarisation, in order be compliant with the stringent requirements in bandwidth and cross-polarisation.

[0039] In a second embodiment, depicted in Figure 7.A, each reflectarray cell comprises several parallel conductive dipoles of different length in the same plane, typically two or three dipoles (10,11,12), printed on the same side of a first dielectric layer (13) forming an angle α_{yi} with respect to the local coordinate axis Y_{Ri} in the ***i*** reflectarray cell for phase control in one polarisation, and a set of two or three conductive dipoles (14, 15, 16) printed on the opposite side of the dielectric layer (13) forming an angle α_{xi} with respect to the local coordinate axis X_{Ri} in the ***i*** reflectarray cell for the phase control in the orthogonal polarisation, where the lengths of the dipoles in each cell are adjusted to produce the required collimated or shaped beam in dual-linear polarisation in a given frequency band, and the angles of rotation are adjusted on each cell to minimise the cross-polarisation, being the angle of rotation identical for all the parallel dipoles in the same cell. The dipoles are separated from a conductive plane (17) by another dielectric layer (18), and the phase of the reflected field for each linear polarization is controlled independently by varying the dimensions of the dipoles printed on each side of the first dielectric layer (13).

[0040] Another embodiment of the present invention is to use reflectarray cells with two or more stacked layers of parallel dipoles to adjust the phase in one polarisation (vertical) and two or more stacked layers of parallel dipoles in the orthogonal polarisation (horizontal), including several dielectric layers between the conductive ground plane and the conductive dipoles, or between adjacent layers with parallel dipoles, where the dipoles for each polarisation are rotated to minimise the cross-polarisation. This configuration with several stacked layers of parallel dipoles for each polarisation allows designing reflectarray antennas for dual or multiple frequency operation, where the phase is adjusted at several frequency bands by varying the dimensions of the parallel dipoles in the different stacked layers. This configuration can also be used for the design of an antenna in the frequency bands assigned for transmission and reception, or to achieve a larger bandwidth.

[0041] In order to minimise the cross-polarisation produced in reflectarray antennas, a systematic procedure is proposed to adjust the angle of rotation in each reflectarray cell. To illustrate the technique, a circular reflectarray made of 20 rows and 20 columns has been designed in the frequency band 11.45GHz-12.75GHz to produce a collimated beam on the plane X_R-Y_R at 20 degrees from Z_R axis when illuminated by a horn antenna located at coordinates x_f = -120, y_f = 0, z_f = 300 in mm that provides a 9dB taper illumination from the reflectarray centre to the edges. The periodic cell (15mmx15mm) and the relative size of the staked patches (a_1=0.7a_2, b_1=0.7 b_2) have been chosen to achieve a broadband reflectarray element using two layers of varying-sized patches. The resulting array layout for the first layer of varying-sized patches is depictured in figure 4.

[0042] Figure 5 shows the co-polar (in continuous line) and cross-polar (in broken line) radiation patterns in a plane tilted by 20 degrees with respect to the coordinate plane Y_RZ_R (for the reflectarray previously described) for the linear polarization with the electric field contained on the X_RZ_R plane. Since the cross-polarisation is increased for larger angles of incidence, the first step is to identify the reflectarray elements in which the angle of incidence (θ_i in Fig. 1) is higher than a prefixed threshold angle θ_t, in order to introduce the appropriate rotation in those elements. Then, the rotation angle for the patches in the reflectarray elements illuminated under an angle of incidence (θ_i in Fig. 1) higher than the prefixed threshold angle θ_t, is defined so that the propagation direction of the incident field coming from the feed is contained on a symmetry plane of the rectangular patches, i.e. the plane of incidence must be parallel to two sides of the patches and perpendicular to the other two. The threshold angle θ_t is defined to rotate those elements that mostly contribute to the cross-polarisation.

[0043] Figure 8 represents a perspective of a reflectarray (1) made of varying-sized patches illuminated by a feed (2), in which the printed patches are rotated in each phasing cell (3) in order to reduce the cross-polarisation.

[0044] Figure 9 shows, according to an embodiment of the present invention, a scaled mask with varying-sized patches (5) for the first layer of a reflectarray designed to produce a collimated beam in the direction address θ_0=20°, φ_0=0° in the frequency band 11.45GHz-12.75GHz when the phase centre of the feed-horn is placed at coordinates x_f = -120, y_f = 0, z_f = 300 (in mm) with respect to the reflectarray centre, after rotating the patches so that the propagation direction of the incident field coming from the feed is contained on a symmetry plane of the rectangular patches for those elements where the angle of incidence is higher than 28 degrees. Thus, in the case represented in figure 9, a 28-degree threshold has been chosen; and in this case, the maximum of cross-polarisation is reduced in 4.8 dB for the polarisation with the electric field on the X_RZ_R plane when the cross-polarisation introduced by the rotated patches is eliminated. The reduction in cross-polarisation is observed when comparing the radiation patterns shown in figure 10 (which shows the co-polar and cross-polar radiation patterns in the plane tilted by 20 degrees with respect to the coordinate plane Y_RZ_R, for a reflectarray with two layers of varying-sized patches, where the first layer is shown in Fig. 9, for the linear polarization with the electric field contained on the X_RZ_R plane, when the cross-polarisation produced by the patch coupling is eliminated in those elements where the angle of incidence is higher than 28 degrees) with those in figure 5. The angle of rotation of the axes associated to the patches (X_{Pi}, Y_{Pi}) or dipoles (X_{Di}, Y_{Di}) is defined locally at each element denoted as i, as the angle φ_i that forms the incidence plane (of the incident field coming from the feed to the element *i*) with the coordinate plane X_RZ_R, shown in figure 1. By this patch orientation, the cross-polarization component produced by the patches is virtually eliminated, because the incidence on each element is on one of the symmetry planes of the rectangular patches or dipoles. As a result, the overall cross-polarization of the antenna is reduced.

[0045] In accordance with a further aspect of the present invention it is provided a method based on the rotation of patches for improving the cross-polarisation properties in a reflectarray antenna comprising a plurality of elements made of one or more layers of varying-sized conductive rectangular patches or dipoles, that has been designed by adjusting the dimensions of the conductive patches by a technique known in previous state of the art in order to generate or receive a collimated or a shaped beam in a prefixed frequency band for dual linear polarisation, being the method defined by the following steps: first, the cross polarisation produced on the reflectarray elements is computed; second, a threshold θ_t is defined for the angle of incidence so that those elements where the angle of the incidence with respect to Z_R axis is lower than the threshold produce a cross-polarisation lower than a certain level for the two orthogonal polarisations said vertical and horizontal; and third, for those elements where the angle of incidence is higher than the prefixed threshold angle θ_t, the rotation angle α_i of the printed conductive patches is defined so that the propagation direction of the incident field coming from the feed is contained on a symmetry plane of the rectangular patches or dipoles, i.e. the incidence plane is parallel to two sides of the patches and perpendicular to the other two.

[0046] In the previous method, the cross-polarisation generated by polarisation coupling in the printed patches or dipoles is virtually eliminated in those elements where the angle of incidence is larger than the prefixed threshold angle θ_t, however there is still another component of the cross-polarisation in the radiated field that is produced by the geometrical projections of the field incident from the feed. Another object of the present invention is a method for improving the cross-polarisation properties in a reflectarray antenna wherein the rotation angle of the patches or dipoles in each cell is obtained by an optimisation routine to minimize in a prefixed frequency band the total cross-polarization, produced by geometrical projections and patch coupling, for the two linear polarisations (vertical and horizontal), in such a way that the cross-polarisation introduced by the patch coupling should partially compensate the component produced by the geometrical projections. Since the component of cross-polarisation produced by the geometry projections is more significant in one polarisation (the one with electric field in Y_R direction), the rotation must be optimised to minimise, in the defined frequency band, the overall cross-polarisation for the two linear polarisations.

[0047] Another method to improve the cross-polarisation of the reflectarray is based on the fact that the cross-polarisation radiation, including both contributions from patch coupling and field projections, represents an undesired rotation of the radiated electric field by an angle y, and this effect can be reduced by a small rotation of the electric-field vector reflected on the reflectarray, by applying the technique schematically depicted in Figure 11 and explained hereafter. Let's assume that a local plane wave is impinging on a phasing cell made of one or several layers of rectangular patches, where the incident electric field forms an angle β with respect to the local coordinate system associated to the rectangular patches $X_{Pi}Y_{Pi}$, then the incident electric field can be broken-down into two components parallel to the patch sides; if the reflectarray cells are designed so that the phase of the reflected field in one of the components (Y_{Pi}) is increased by 180 degrees with respect to the phase of the reflected electric field in the other component (X_{Pi}), which means a change of sign in this field component, the resulting reflected electric field will be rotated by an angle equal to 2β with respect the incident field. Each patch can be rotated so that the reflected electric field is parallel to one of the axes of the reflectarray coordinate system X_RY_R, in order to cancel the total cross-polarisation. Note that the same angle will be rotated for the field of the two polarisations (vertical and horizontal). The use of this technique is proposed in the present invention to rotate the reflected field at each reflectarray cell in order to minimise the cross-polarisation in both linear polarisations. Since the rotation angles required to completely cancel the cross-polarisation in general will not be the same for the two linear polarisations, the rotation angle will be determined by using an optimisation routine in order to minimise simultaneously the cross-polarisation in both linear polarisations for the required frequency band.

[0048] Another object of the present invention is a method for improving the cross-polarisation of a reflectarray made of one or several layers of varying-sized patches or dipoles designed to produce or to receive a focused or a contoured beam in a prefixed frequency band for both orthogonal lineal polarisations (vertical and horizontal), where the dimensions of patches in the reflectarray elements have been optimised to produced a phase-shift of 180 degrees between the two orthogonal components of the reflected electric field parallel to the patch sides in order to produce a rotation of the reflected electric field (Fig. 11), and where the rotation angle of the patches in each cell is optimised to minimise the total cross-polarisation for both linear polarisations (vertical and horizontal) in a prefixed frequency band. In this method, the cross-polarization produced by the patches will partially compensate the cross-polarization produced by the projection of the field radiated by the feed.

[0049] Concerning the complexity and the cost of the reflectarray antenna, it is important to say that the manufacturing process of the reflectarray antenna is not modified by the rotation of the patches. The patch arrays are manufactured by conventional photo-etching techniques and the different layers of conductive patches, ground plane and dielectric layers can be bonded by well known curing processes used for sandwich manufacturing using composite materials and honeycomb cores. These processes are not affected by the patch orientations.

[0050] The rotation of the patches permits reducing the cross-polarization level. This feature is extremely important in several applications as for instance, for satellite dual-polarization Telecommunication antennas, which have to respect stringent requirements. Because of the larger bandwidth of the multilayer configuration, and taking advantage of the low level of cross polarisation of the proposed reflectarray, another object of this invention consists of its application for antennas in Telecom satellites, where the dimensions and rotation of the patches are optimised to radiate, receive or radiate and receive a collimated or a contoured beam providing the same coverage in dual linear polarisation (vertical and horizontal).

[0051] One advantage of the present invention is that because its improved bandwidth and cross-polarisation properties, it can be used in space antennas as alternative to conventional shaped reflectors. A shaped reflector such as those used in satellites for direct broadcast television, consists of a reflector with deformities on its surface, so that the radiation pattern illuminates a certain geographical area. The design and construction of shaped reflectors is carried out specifically for each coverage, requiring moulds, which are very expensive to manufacture and cannot be reused for other antennas. The proposed reflectarray antenna and its design process for cross-polarisation improvement can be used to design Telecom satellite antennas with the same electrical performances as those provided by shaped reflectors, providing a significant reduction in the production costs and time because of the elimination of the custom moulds.

[0052] The steps for carrying out the design and construction of a printed reflectarray with rotated patches for improving the cross-polarisation performances of the antenna are described below.

[0053] First, the technology and the materials to be used in the realisation of the reflectarray antenna are chosen. In the example that is described, 3-mm thick Quartz honeycomb has been chosen for the dielectric separators (6,8) between the layers with printed conductive patches, which has a relative dielectric constant of 1.06 and a loss tangent of 10^{-3}. The arrays of rectangular metallic patches are generated by photo-etching from a 50-micron thick Kapton (trademark for a poly(4,4'-oxydiphenylene-pyromellitimide material) film with an 18 micron copper cladding. The Kapton has a relative dielectric constant of 3.5 and a loss tangent of $3x10^{-3}$. The conductive patches printed on the Kapton layers are bonded to the honeycomb using a 76-micron thick quartz-fibre fabric pre-impregnated with resin, with relative dielectric constant of 3.2 and a loss tangent of 4x 10^{-3}. The last honeycomb layer is bonded to the conductive ground plane by another quartz-fibre layer. The periodic cell is shown in figure 5 for the case of two layers of rectangular patches, where the thin layers of Kapton and quartz have not been shown.

[0054] Second, a reflectarray antenna is designed to produce or receive a collimated or a shaped beam with the same beam shaping in the two orthogonal polarisations, said vertical and horizontal. In the present example a circular reflectarray made of 20 rows and 20 columns is designed in the frequency band 11.45GHz-12.75GHz to produce a collimated beam on the plane $X_R Z_R$ at 20 degrees from Z_R axis when illuminated by a feed-horn with its phase centre placed at coordinates $\mathbf{x_f}$ = -120, $\mathbf{y_f}$ = 0, $_{\mathbf{zf}}$ = 300 (in mm) respect to the reflectarray centre. The feed-horn produces an illumination on the reflectarray edges 9dB below the illumination level at the reflectarray centre. The periodic cell has been defined as 15mmx15mm and the relative size of the staked patches has been fixed as $a_1=0.7a_2$ and $b_1=0.7b_2$ to achieve a broadband reflectarray element. Once the antenna configuration is defined, the phase distribution of the reflected field required to produce the defined collimated beam for both linear polarisations is obtained. In order to implement the rotation of the reflected field when the patches are individually rotated with respect to the direction of electric incident field, the required phase distribution on the reflectarray in one polarisation is increased 180 degrees with respect the phase of the other polarisation.

[0055] The patch dimensions are adjusted to obtain the previous phase distributions for each linear polarisation, said vertical and horizontal. To determine the dimensions of each patch, a zero finding routine that calls iteratively an analysis routine is used. For the analysis of the reflectarray, the phase of the reflected field is computed for each polarisation in every cell assuming local periodicity, i.e. analysing each element with its dimensions in a periodic environment. The routine calls the analysis program and adjusts the dimensions of each element until the required phase is obtained for each polarisation. Note that the phase in one polarisation is increased 180 degrees with respect to the other one. For the analysis of the multilayer periodic structure, a full wave method is used such as the well-known Moments Method in spectral domain, and the phase of the reflected field is computed for the two polarisations of the incident field. This procedure gives the patch dimensions $\mathbf{a}_1$, $\mathbf{b}_1$, $\mathbf{a}_2$ and $\mathbf{b}_2$ in each element of the reflectarray.

[0056] Third, once the reflectarray has been designed for the two linear polarisations, a rotation of the patches is introduced to minimise the cross-polarisation. As a result of the 180 degree phase difference in the two components of the reflected field parallel to the patch sides, when the incident electric field forms an angle β with respect to the local coordinate system associated to the rectangular patches, the resulting reflected electric field will be rotated by an angle equal to 2β with respect the incident field in each reflectarray element for both linear polarisations (vertical and horizontal). This technique is used to produce a rotation of the reflected electric field at each reflectarray cell in order to minimise the cross-polarisation in both linear polarisations. Since the required rotation angles in general will not be the same to completely cancel the cross-polarisation for both linear polarisations, and because the required angle of rotation will vary with the frequency, the rotation angle at each reflectarray element is determined by using an optimisation routine. The optimisation routine can be based on a gradient technique that provides the rotation angle at each element that minimises an error function, which accounts for the levels of cross-polarisation at the element for both linear polarisations and at several frequencies in the defined frequency band. When the optimisation process is completed in all the reflectarray elements where the angle of incidence is higher than the prefixed threshold, the rotation angles are obtained for all reflectarray elements.

[0057] Fourth, once the patch dimensions and the rotation angles are defined for all the reflectarray elements, the reflectarray is manufactured. The photo-etching masks for each reflectarray layer are generated from the file with the dimensions of the patches and the angles of rotation for each element obtained in the design stage. For the manufacturing of the reflectarray, the traditional photo-etching techniques used in the production of printed circuits can be used and the different layers are bonded by using conventional curing processes.

[0058] This invention can be applied to reflector antennas in satellite communications, with significant advantages compared to conventional parabolic or shaped reflectors, or other reflectarray antennas available in the prior state of the art. Compared to previous reflectarray antennas, the present invention allows to fulfil the stringent requirements in bandwidth and cross-polarisation for dual-polarisation antennas in Direct Broadcast and Telecommunications Satellites, keeping the advantages of a flat panel and the simplicity of manufacturing. Because of the planar characteristic, it can be built in several pieces to be folded and later deployed, being of great use in applications in which large reflectors are required. Owing to the fact that it is a planar reflector with the possibility of redirecting the beam, the reflector surface can be fitted to existing structures, such as structural planes in communication satellites. It can be used as a dual polarisation reflector with an isolation level between polarisations better than those obtained with conventional reflectors.

[0059] The present invention can be built using space qualified materials and a technology already developed in space applications for the manufacture of dichroic subreflectors. Therefore, this type of reflectarray with rotated patches is very suitable for a significant range of applications in the space industry as an alternative to the different types of onboard shaped reflectors in satellites, such as carbon fibre reflectors, dual-gridded reflectors or metallic mesh reflectors.

Claims

1. A dual-linear polarization reflectarray antenna with improved cross-polarization properties, comprising a reflectarray (1) and a primary feed (2) configured to illuminate an array of phasing cells (3) of the reflectarray (1), each phasing cell (3) comprising at least one dielectric layer (6,8;13;19,20) and a conductive plane (9,17), each dielectric layer (6,8;13;19,20) having at least one conductive element (5,7;10,11,12;14,15,16) printed on its surface, the size of each conductive element of each phasing cell (3) being determined to produce a previously defined radiation beam, **characterized in that** each conductive element of each phasing cell (3) is disposed in a previously calculated orientation with respect to the phasing cell (3) so as to reduce the cross-polarization effect, said orientation being dependent upon the particular phasing cell (3) considered.

2. A dual-linear polarization reflectarray antenna according to claim 1, in which a reflectarray coordinate system (X_R,Y_R,Z_R) is considered, being axis Z_R perpendicular to the reflectarray (1), being also considered in each phasing cell *i* (3) a local coordinate system (X_{Ri},Y_{Ri},Z_{Ri}) centred in the cell and parallel to the reflectarray coordinate system (X_R,Y_R,Z_R), wherein the at least one conductive element of each dielectric layer (6,8) of each phasing cell *i* (3) comprises a conductive patch (5,7) which symmetry axes (Xpi,Ypi) form a previously calculated angle a_i with respect to the corresponding axes (X_{Ri},Y_{Ri}) of the local coordinate system (X_{Ri},Y_{Ri},Z_{Ri}), said angle a_i being dependent upon the particular phasing cell (3) considered.

3. A dual-linear polarization reflectarray antenna according to claim 2, wherein the conductive patches (5,7) of the reflectarray (1) have any of the following shapes: rectangular-shaped, square-shaped, cross-shaped, elliptical-shaped, polygonal-shaped.

4. A dual-linear polarization reflectarray antenna according to any of claims 2-3, wherein for each phasing cell *i* (3) the angle a_i is selected such that the propagation direction of the incident field coming from the feed (2) to said phasing cell *i* (3) is contained in a symmetry plane of the conductive patch (5,7) of each dielectric layer (6,8) of the phasing cell *i* (3).

5. A dual-linear polarization reflectarray antenna according to claim 1, in which a reflectarray coordinate system (X_R,Y_R,Z_R) is considered, being axis Z_R perpendicular to the reflectarray (1), being also considered in each phasing cell *i* (3) a local coordinate system (X_{Ri},Y_{Ri},Z_{Ri}) centred in the cell and parallel to the reflectarray coordinate system (X_R,Y_R,Z_R), wherein the at least one conductive element of each dielectric layer (13) of each phasing cell *i* (3) comprises a first set of parallel conductive dipoles (10,11,12) printed on a side of the dielectric layer (13) and a second set of parallel conductive dipoles (14,15,16) printed on the opposite side of the dielectric layer (13), the phasing cell *i* (3) comprising at least one further dielectric layer (18) to separate the at least one dielectric layer (13) from the conductive plane (17), and wherein the first set of parallel conductive dipoles (10,11,12) is oriented such that its associated axis Y_{Di}, parallel to said first set of dipoles (10,11,12), forms a previously calculated angle ay_i with respect to the corresponding axis (Y_{Ri}) of the local coordinate system (X_{Ri},Y_{Ri},Z_{Ri}), and the second set of parallel conductive dipoles (14,15,16) is oriented such that its associated axis (X_{Di}), parallel to said second set of dipoles (14,15,16), forms a previously calculated angle α_{xi} with respect to the corresponding axis (X_{Ri}) of the local coordinate system (X_{Ri},Y_{Ri},Z_{Ri}), said angles α_{yi} and a_{xi} being dependent upon the particular phasing cell (3) considered.

6. A dual-linear polarization reflectarray antenna according to claim 1, in which a reflectarray coordinate system (X_R,Y_R,Z_R) is considered, being axis Z_R perpendicular to the reflectarray (1), being also considered in each phasing cell *i* (3) a local coordinate system ($X_{Ri,}$$Y_{Ri,}$$Z_{Ri}$) centred in the cell and parallel to the reflectarray coordinate system (X_R,Y_R,Z_R), wherein each phasing cell *i* (3) comprises at least one pair of dielectric layers (19,20) with a first set of parallel conductive dipoles (10,11,12) printed on a side of one dielectric layer (19) and a second set of parallel conductive dipoles (14,15,16) printed on the other dielectric layer (20), and wherein the first set of parallel conductive dipoles (10,11,12) is oriented such that its associated axis Y_{Di}, parallel to said first set of dipoles (10,11,12), forms a previously calculated angle α_{yi} with respect to the corresponding axis (Y_{Ri}) of the local coordinate system ($X_{Ri,}$$Y_{Ri,}$$Z_{Ri}$), and the second set of parallel conductive dipoles (14,15,16) is oriented such that its associated axis

(X_{Di}), parallel to said second set of dipoles (14,15,16), forms a previously calculated angle α_{xi} with respect to the corresponding axis (X_{Ri}) of the local coordinate system ($X_{Ri,}Y_{Ri,}Z_{Ri}$), said angles α_{yi} and α_{xi} being dependent upon the particular phasing cell (3) considered.

7. A dual-linear polarization reflectarray antenna according to any of claims 5-6, wherein for each phasing cell *i* (3) the angle a_{yi} is selected such that the axis Y_{Di} defining the direction of the first set of conductive dipoles (10, 11, 12) is contained in the plane of incidence of the field coming from the feed (2) to the said phasing cell *i* (3), and the angle α_{xi} is selected such that the axis X_{Di} defining the direction of the second set of conductive dipoles (14,15,16) is perpendicular to the plane of incidence of the field coming from the feed (2) to the said phasing cell *i* (3).

8. A dual-linear polarization reflectarray antenna according to any of claims 2-3,5-6, wherein the dimensions of each conductive element of each phasing cell *i* (3) are selected such that there is a phase-shift of 180 degrees between the two components of the reflected electric field parallel to the axes associated to the conductive elements (X_{Pi},Y_{Pi};X_{Di},Y_{Di}) and wherein the orientation of each conductive element of each phasing cell *i* (3) is such that the total cross-polarization produced by both geometrical projections and coupling in the phasing cell is minimised in a prefixed frequency band and for the two linear polarizations.

9. A dual-linear polarization reflectarray antenna according to any of preceding claims, wherein the phasing cells (3) are arranged in any of the following dispositions: a rectangular lattice, a square lattice, a triangular lattice, an hexagonal lattice, non-periodic array, sparse arrangement.

10. A dual-linear polarization reflectarray antenna according to any of preceding claims, in which a reflectarray coordinate system (X_R,Y_R,Z_R) is considered, being axis Z_R perpendicular to the reflectarray (1), being also considered in each phasing cell *i* (3) a local coordinate system (X_{Ri},Y_{Ri},Z_{Ri}) centred in the cell and parallel to the reflectarray coordinate system (X_R,Y_R,Z_R), wherein the orientation of each conductive element of those phasing cells (3) where the angle of incidence (θ_i) of the field coming from the feed (2) with respect to the axis Z_R is lower than a predetermined threshold angle θ_t is selected such that the axes associated to the corresponding conductive element (X_{pi},Y_{pi};X_{Di},Y_{Di}) are parallel to the corresponding axes (X_R,Y_R) of the reflectarray coordinate system (X_R,Y_R,Z_R).

11. Method for obtaining a dual-linear polarization reflectarray antenna with improved cross-polarization properties, the method comprising:

providing a reflectarray (1) and a primary feed (2) configured to illuminate an array of phasing cells (3) of the reflectarray (1), each phasing cell (3) comprising at least one dielectric layer (6,8; 13;19,20) and a conductive plane (9,17), each dielectric layer (6,8;13;19,20) having at least one conductive element (5,7;10,11,12,14, 15,16) printed on its surface, the size of each conductive element of each phasing cell (3) being determined to produce a previously defined beam; **characterized in that** the method further comprises:

calculating, for each conductive element of each phasing cell (3), an orientation with respect to the phasing cell (3) so as to reduce the cross-polarization effect, said orientation being dependent upon the particular phasing cell (3) considered;
disposing each conductive element of each phasing cell (3) in the previously calculated orientation.

12. Method according to claim 11, wherein the orientation of each conductive element of each phasing cell (3) is calculated such that the propagation direction of the incident field coming from the feed (2) to the said phasing cell *i* (3) is contained in a symmetry plane of said conductive element.

13. Method according to claim 11, wherein the step of calculating the orientation of each conductive element comprises minimising, by using an optimisation routine, the total cross-polarization produced by both geometrical projections and coupling in the phasing cell, in a prefixed frequency band and for the two linear polarizations.

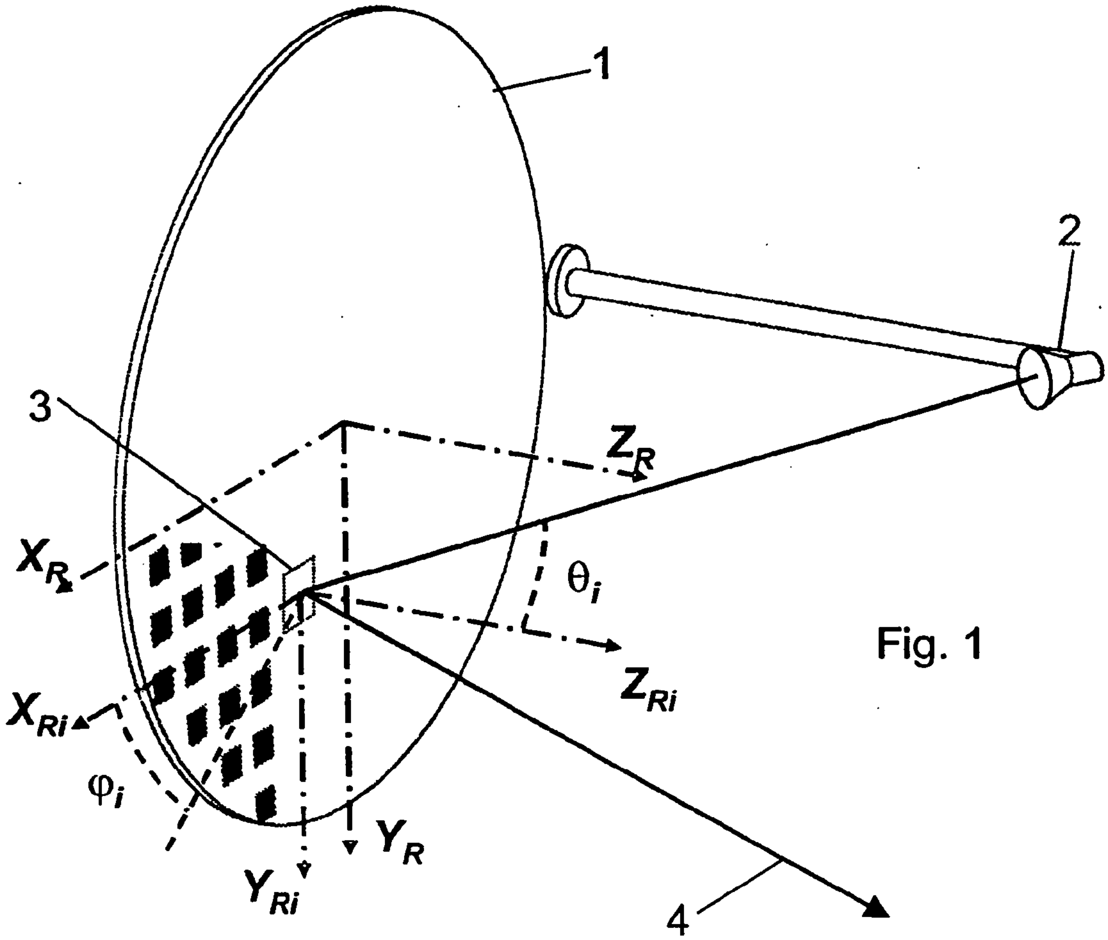
14. Method according to claim 11, a reflectarray coordinate system (X_R,Y_R,Z_R) being considered, with axis Z_R perpendicular to the reflectarray (1); being also considered in each phasing cell *i* (3) a local coordinate system ($X_{Ri,}Y_{Ri,}Z_{Ri}$) centred in the cell and parallel to the reflectarray coordinate system (X_R,Y_R, Z_R); wherein the step of calculating the orientation of each conductive element comprises:

calculating the dimensions of each conductive element of each phasing cell (3) such that there is a phase-shift of 180 degrees between the two components of the reflected electric field parallel to the axes associated to the conductive elements (X_{Pi},Y_{Pi};X_{Di},Y_{Di});
minimising, by using an optimisation routine, the total cross-polarization produced by both geo-

metrical projections and coupling in the phasing cell, in a prefixed frequency band and for the two linear polarizations.

15. Method according to any of claims 11-14, in which a reflectarray coordinate system (X_R,Y_R,Z_R) is considered, being axis Z_R perpendicular to the reflectarray (1), being also considered in each phasing cell *i* (3) a local coordinate system (X_{Ri},Y_{Ri},Z_{Ri}) centred in the cell and parallel to the reflectarray coordinate system (X_R,Y_R,Z_R), **characterised by** further comprising:

defining a threshold angle θ_t, such that the cross-polarisation produced by those phasing cells (3) where the angle of the incidence with respect to Z_R axis is lower than the threshold angle θ_t, is lower than a prefixed level for the two orthogonal polarisations;
disposing each conductive element in those phasing cells (3) where the angle of incidence (θ_i) of the field coming from the feed (2) with respect to the axis Z_R is lower than said angle threshold θ_t such that the axes associated to the corresponding conductive element (X_{Pi},Y_{Pi};X_{Di},Y_{Di}) are parallel to the corresponding axes (X_R,Y_R) of the reflectarray coordinate system (X_R,Y_R,Z_R).


1
2
3
Z_R
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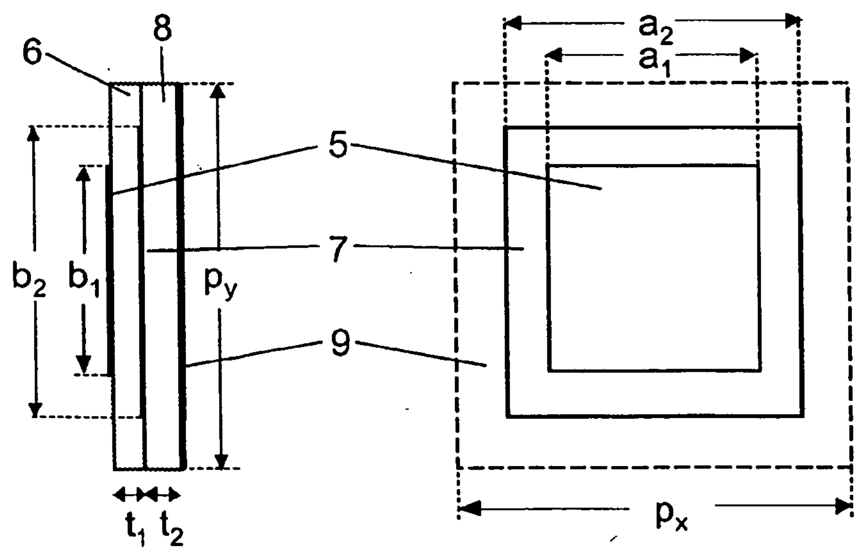
4

Fig. 1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6
5
7
9
b_2
b_1
p_y
t_1
t_2
p_x

Fig. 2

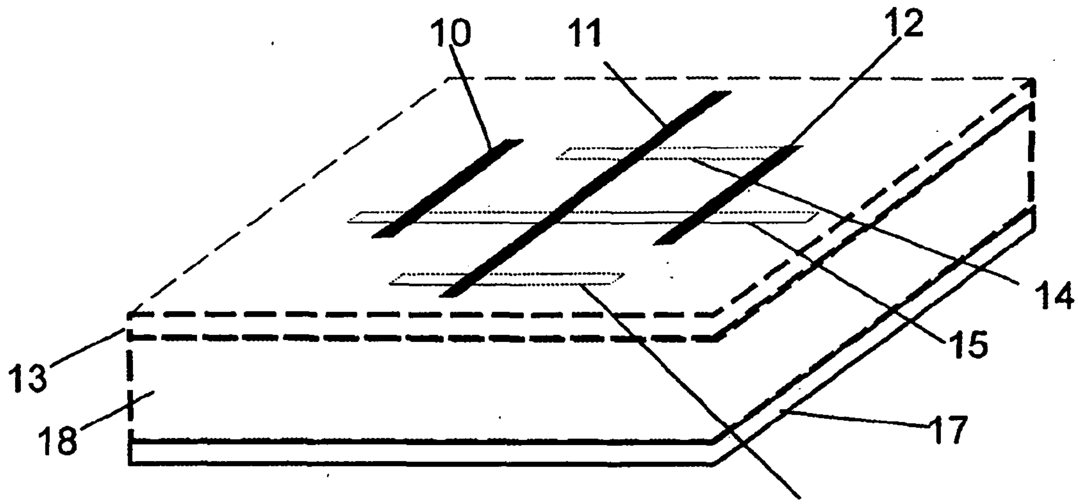
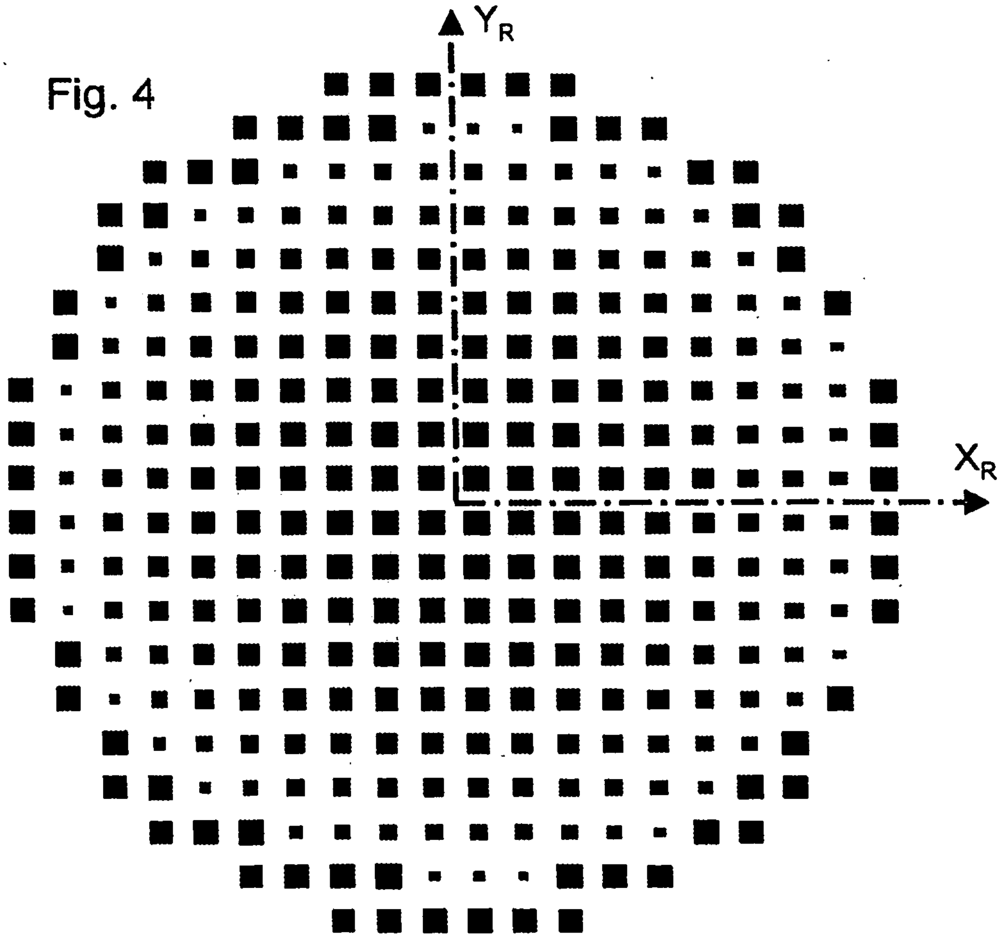


Fig. 3

Fig. 4



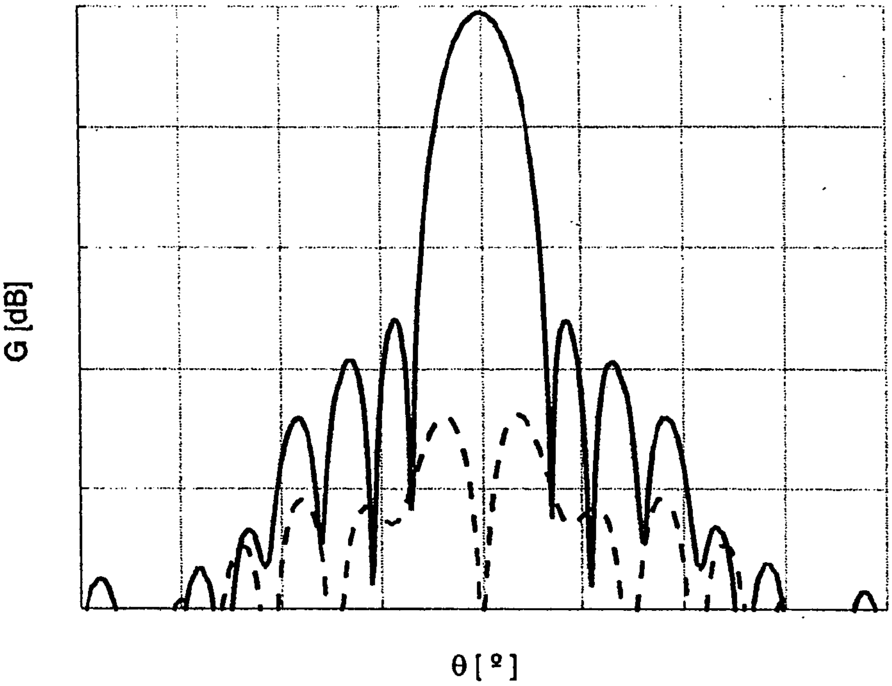


Fig. 5

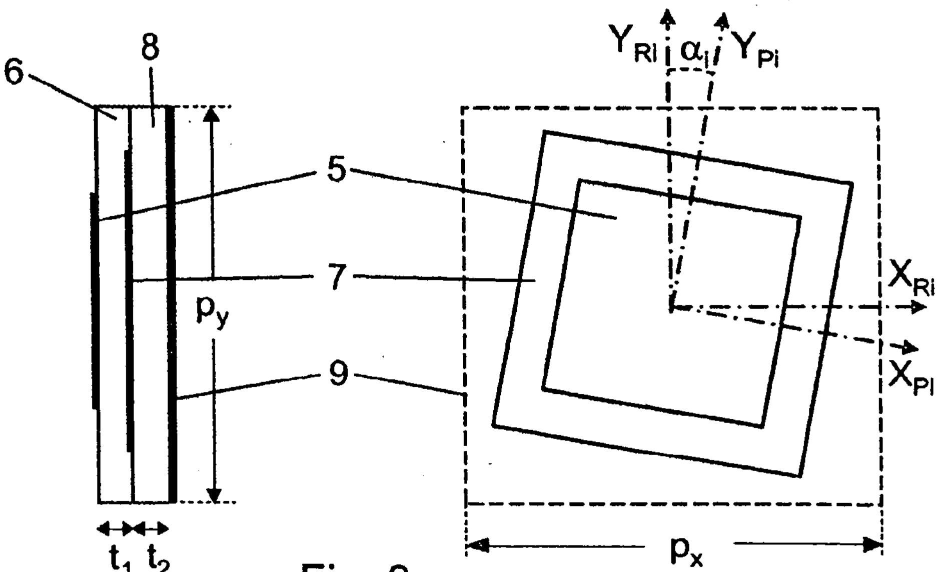
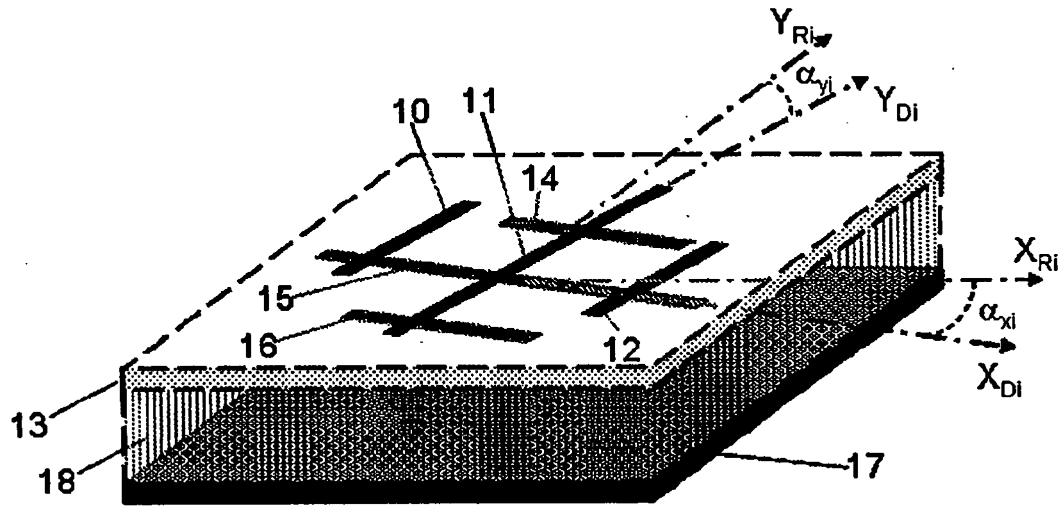
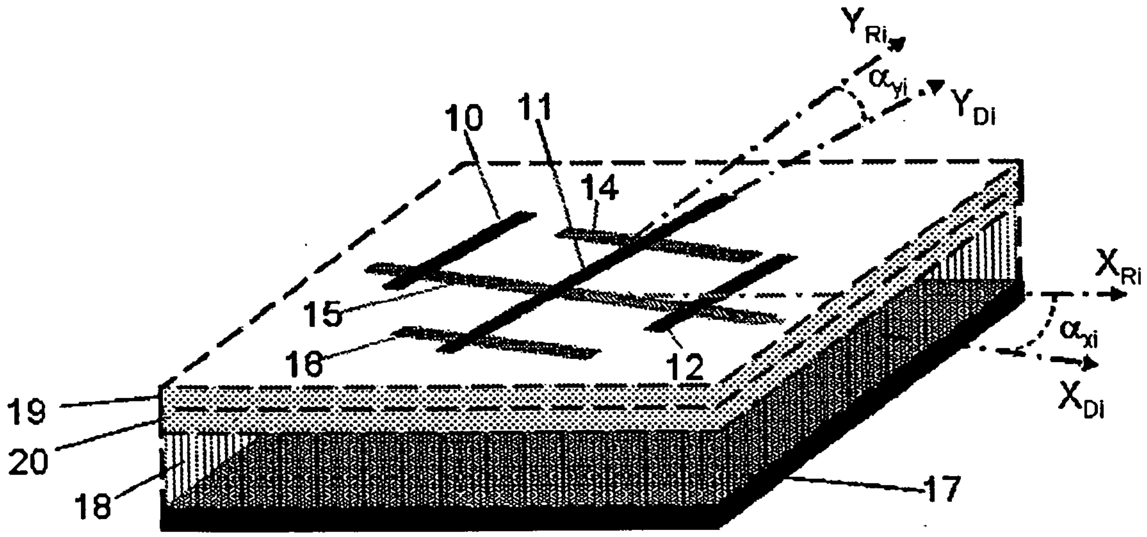


Fig. 6



Y_{Ri}
α_{yi}
Y_{Di}
10
11
14
X_{Ri}
15
α_{xi}
16
12
X_{Di}
13
18
17

Fig. 7A



Y_{Ri}
α_{yi}
Y_{Di}
10
11
14
X_{Ri}
15
α_{xi}
16
12
X_{Di}
19
20
18
17

Fig. 7B

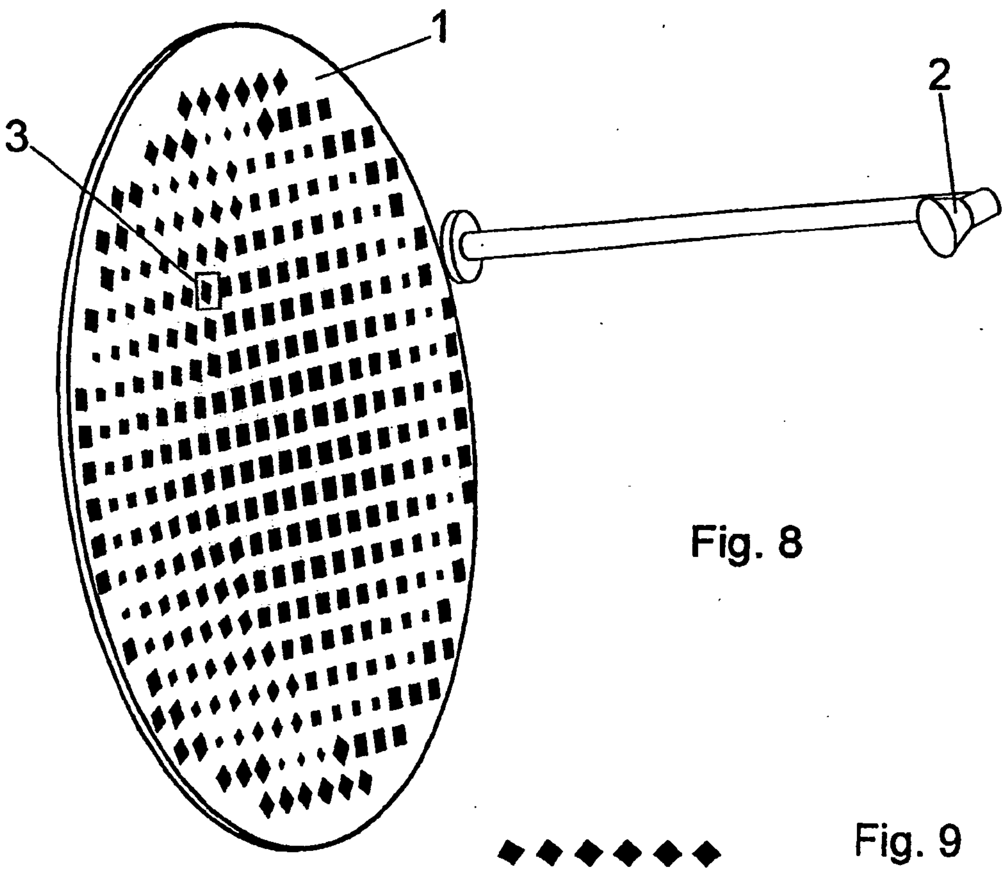


Fig. 8

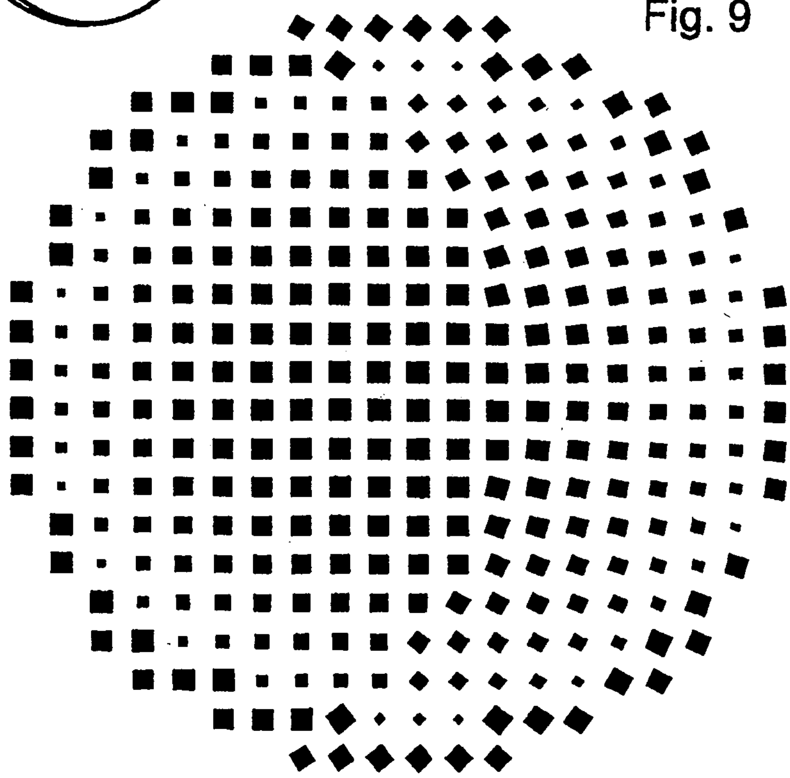


Fig. 9

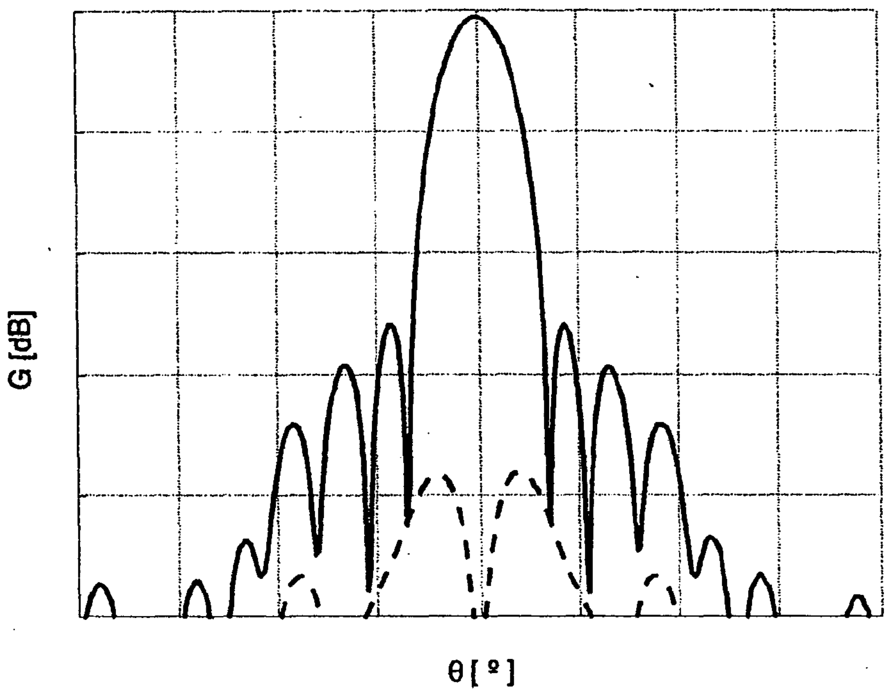


Fig. 10

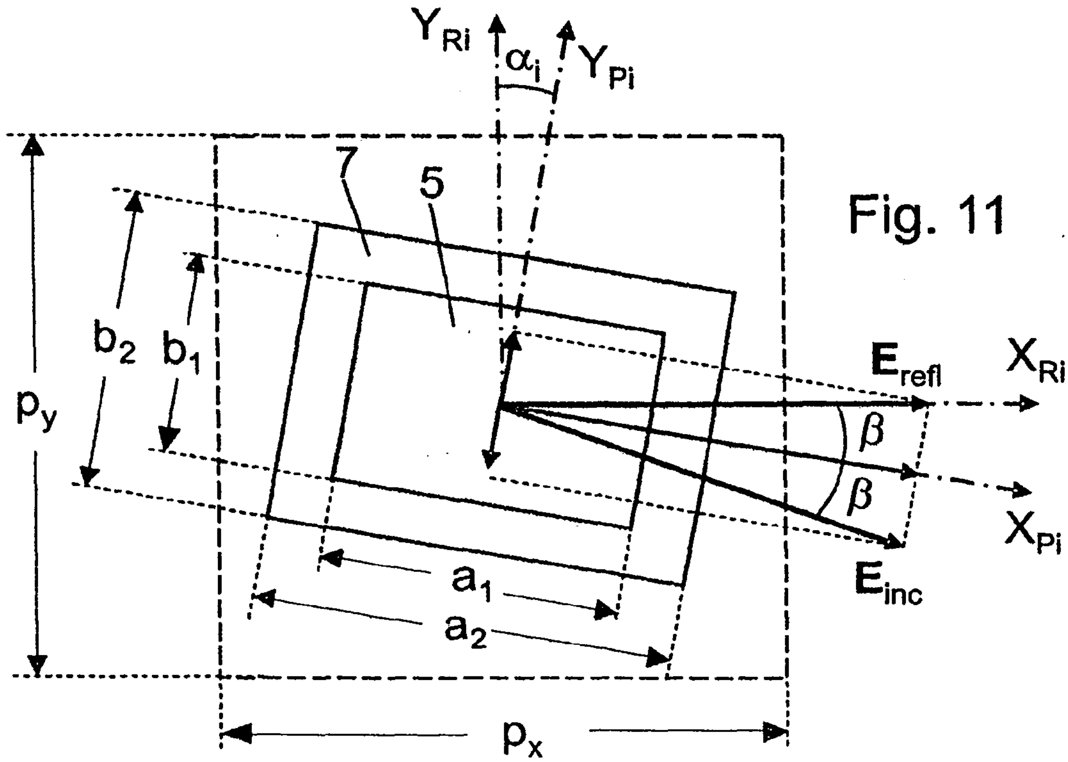


Fig. 11

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EUROPEAN SEARCH REPORT

Application Number
EP 10 29 0640

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X A	WO 2007/051487 A1 (CENTRE NAT RECH SCIENT [FR]; ELECTRONIC NAVIGATION RES INST [JP]; MIGL) 10 May 2007 (2007-05-10) * page 11, lines 27-34; figure 1 *	1,2,9,11 3-8,10, 12-15	INV. H01Q3/46 H01Q1/28 ADD. H01Q1/38
A	JOHN HUANG ET AL: "A Ka-Band Microstrip Reflectarray with Elements Having Variable Rotation Angles", IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 46, no. 5, 1 May 1998 (1998-05-01), XP011003230, ISSN: 0018-926X * abstract; figure 1 *	1-15	
A	US 6 081 234 A (HUANG JOHN [US] ET AL) 27 June 2000 (2000-06-27) * figure 1b *	1-15	
A	WO 03/003507 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; PHILIPS CORP INTELLECTUAL PTY [DE]) 9 January 2003 (2003-01-09) * figure 2 *	1-15	TECHNICAL FIELDS SEARCHED (IPC) H01Q
A	US 2006/092087 A1 (LANGE MARK J [US]) 4 May 2006 (2006-05-04) * figure 1j *	1-15	

1

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	28 April 2011	Marot-Lassauzaie, J

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28-04-2011

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2007051487 A1	10-05-2007	EP 1943699 A1	16-07-2008
		WO 2007052112 A1	10-05-2007
		JP 2009515397 T	09-04-2009
		US 2009153391 A1	18-06-2009
US 6081234 A	27-06-2000	NONE	
WO 03003507 A1	09-01-2003	CN 1520625 A	11-08-2004
		DE 10131283 A1	09-01-2003
		EP 1405368 A1	07-04-2004
		JP 2004531176 T	07-10-2004
		TW 535328 B	01-06-2003
		US 2004164908 A1	26-08-2004
US 2006092087 A1	04-05-2006	WO 2006050369 A2	11-05-2006

EPO FORM P0459

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 4684952 A **[0002]**
- US 4905014 A **[0002]**
- EP 1120856 A1 **[0004]**
- ES P200401382 **[0005]**
- US 5543809 A **[0006]**
- US 20010050653 A1 **[0007]**

Non-patent literature cited in the description

- **D. G. BERRY ; R. G. MALECH ; W. A. KENNEDY.** *The Reflectarray Antenna IEEE Trans. on Antennas and Propagat.,* 1963, vol. AP-11, 646-651 **[0002]**
- **D. M. POZAR ; T. A. METZLER.** Analysis of a reflectarray antenna using microstrip patches of variable size. *Electr. Lett.,* April 1993, vol. 29 (8), 657-658 **[0002]**
- **A.W. ROBINSON ; M.E. BIALKOWSKI ; H.J. SONG.** An X-band passive reflect-array using dual-feed aperture-coupled patch antennas. *Asia Pacific Microwave Conference,* December 1999, 906-909 **[0002]**
- **M.R. CHAHARMIR ; J. SHAKER ; M. CUHACI ; A. SEBAK.** Reflectarray with variable slots on ground plane. *IEE Proc.-Microw. Antennas Propag.,* December 2003, vol. 150 (6), 436-439 **[0002]**
- **J. A. ENCINAR ; J. A. ZORNOZA.** Broadband design of three-layer printed reflectarrays. *IEEE Trans. Antennas Propagat.,* July 2003, vol. 51 (7), 1661-1664 **[0004]**
- **M. BOZZI ; S. GERMANI ; L. PERREGRINI.** Performance comparison of different element shapes used in printed reflectarrays. *Antennas and Wireless Propagation Letters,* 2003, vol. 2 (1), 219-222 **[0005]**
- **N. MISRAN ; R. CAHILL ; V. FUSCO.** Reflection phase response of microstrip stacked ring elements. *Electronics Letters,* April 2002, vol. 38 (8), 356-357 **[0005]**
- **J. HUANG.** A Ka-Band Microstrip Reflectarray with Elements Having Variable Rotation Angles. *IEEE Trans. Antennas Propagat.,* May 1998, vol. 46 (5), 650-656 **[0008]**
- **D. M. POZAR ; S. D. TARGONSKI ; R. POKULS.** A shaped-beam microstrip patch reflectarray. *IEEE Trans. Antennas Propagat.,* July 1999, vol. 47 (7), 1167-1173 **[0009]**
- **J. A. ENCINAR ; J. A. ZORNOZA.** Three-layer printed reflectarrays for contoured beam space applications. *IEEE Trans. Antennas Propagat.,* May 2004, vol. 52 (5), 1138-1148 **[0009]**
- **J. A. ENCINAR et al.** Dual-Polarization Dual-Coverage Reflectarray for Space Applications. *IEEE Trans. on Antennas and Propag.,* October 2006, vol. 54 (10), 2828-2837 **[0009]**