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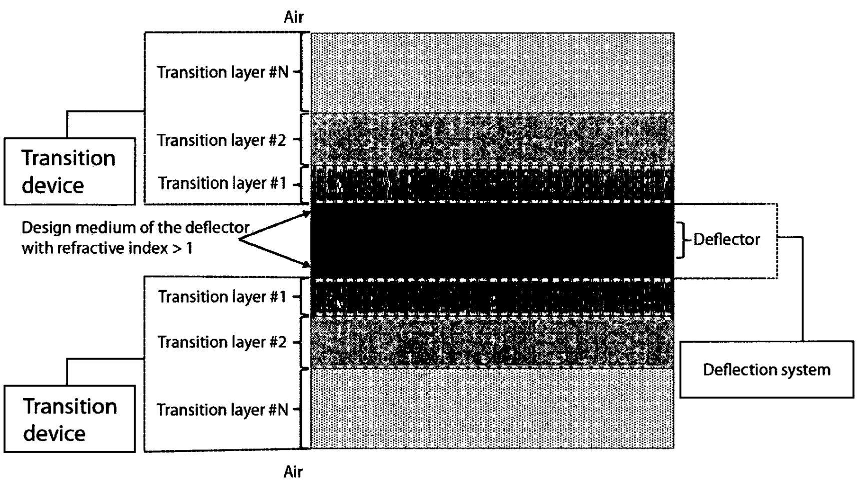
(54) **A LOW PROFILE MECHANICALLY SCANNING ANTENNA WITH REDUCED SIDELOBE AND GRATING LOBES AND LARGE SCANNING DOMAIN**

(57) This invention concerns an antenna system comprising:
- a wave launcher (10, 210);
- a deflection system configured to deflect the wave and comprising at least one planar deflector (20, 30; 210, 220), said planar deflector comprising a plurality of inclusions (300) configured to add a phase gradient to the wave incident on said deflector;
- according to the invention, said inclusions are configured to work in an environment with refractive index greater than 1 and wherein, in addition, one or more matching devices are included at the outlet from and/or inlet to the deflector.

FIG.1A



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Description

Scope of the invention

[0001] This invention belongs to the technical field of mechanical beam scanning antenna systems.

[0002] In particular, the object of this invention is to produce a new architecture for the implementation of phase gradient planar deflectors for antenna beam scanning, designed to work in an environment with refractive index • greater than one and fitted with transition devices (or equivalently called matching devices) that manage the gradual passage of radiation from a medium .with refractive index greater than one to air (refractive index one) and vice versa. This new architecture of phase gradient planar deflectors allows the secondary lobes and the grating lobes to be reduced to levels never before obtained with conventional design techniques while the main beam is scanned within a wide angular range, all with a solution that is simultaneously reliable, space-saving and structurally simple.

[0003] It is also an object of this invention to provide an antenna which comprises such an apparatus.

Overview of the prior art

[0004] The possibility of being able to move and direct an antenna beam is obviously essential whenever tracking of a target is required.

[0005] Such a target may, for example, be a moving node of a point-to-point communication system or a moving object in the context of a radar application or a satellite.

[0006] The direction of the antenna beam in general can be changed, for example, electronically, by acting on the reciprocal phase shift of the radiating elements that make up the antenna without changing its position.

[0007] Alternatively, the direction of the antenna beam can be changed mechanically by moving a part or the entire antenna system.

[0008] Further solutions may be electro-mechanical hybrid type.

[0009] Using electronic devices makes it possible to create low-profile antennas, or antennas that are thin at the cost, however, of a highly complex system and low efficiency due to losses in the structure's feeding network.

[0010] In fact, each antenna has transversal (indicated, for example, with the Cartesian coordinates X and Y) and longitudinal dimensions (indicated, for example, with the Cartesian coordinate Z). While the transverse dimensions depend on the technical requirements of the antenna (and therefore are difficult to modify once the requirements have been set), the longitudinal dimensions may vary according to the platform where the antenna is installed and according to the application. For example, if the antenna is to be installed on a car or on the roof of a train or bus, minimizing its thickness, i.e. reducing its profile, is essential even if it involves losses in terms of performance.

[0011] Conventional mechanical systems, on the other hand, reduce the antenna's complexity and losses, but at the cost of a significant structural bulk. In fact, typically, metallic parabolic reflectors or semi-reflectors are used and the beam is re-pointed by rotating the entire antenna on at least two axes of rotation. However, this solution involves considerable bulk and weight for the antenna.

[0012] Low footprint and low profile are critical aspects, for example, whenever the antenna needs to be positioned on a fast moving vehicle, such as a train or plane, or in a vehicle that has limited space for the communication system, such as a tourism coach.

[0013] An alternative solution to reflectors is based on *Risley* prisms, i.e. independently rotating dielectric wedges placed above the antenna, which add a phase gradient to the incident electromagnetic wave, so that the antenna beam that illuminates the prisms is angularly deflected according to rotation of the prisms themselves. However, this solution also involves a heavy and bulky structure.

[0014] In alternative, low profile implementations, the dielectric wedges are replaced by planar deflectors, parallel to the radiant aperture of the antenna, implemented by stacking multiple layers with many small inclusions *(pixels),* structured in a regular lattice, having dimensions and/or shapes that change or rotate gradually within a pattern that is periodic (modulation period) or almost periodic in the case in which the beam is not only deflected but also collimated.

[0015] The dimensions of the modulation period depend on the angle of deflection or phase gradient that the deflector must produce and are typically greater than the value of the wavelength of the antenna's electromagnetic signal. For this reason, in the antenna's radiation pattern, after the deflection produced by the deflection system, some undesired *grating lobes* appear which reduce the signal strength associated with the antenna's main lobe and can cause unwanted interference. The level of these *grating lobes* tends to increase compared to the level of the main lobe, the more the main lobe points in directions away from the longitudinal axis of the antenna.

[0016] In fact, by way of reminder, the radiation pattern of an antenna represents the spatial trend of the electromagnetic field generated in transmission (or received in reception) by the antenna itself. It consists of a main lobe, which represents the desired signal, and a series of side lobes and *grating lobes* which depend on the size and shape of the antenna and on the way in which the aperture field of the antenna is possibly sampled.

[0017] Presence of these secondary parasitic beams (i.e. side lobes and grating lobes) substantially limits the possible applications of these planar implementations of Risley prisms.

[0018] Furthermore, for a wide range of applications, an antenna must comply with certain regulations in order to be commercialized. The regulations (produced as recommendations by international organizations such as ETSI, FCC and ITU, for example) also require that an antenna meets certain limits in terms of maximum power output (depending on the direction of observation and the frequency band of the antenna) in order to be effectively used in commercial applications, such as satellite communications. Where these specifications are not complied with, the level of the power radiated by the antenna must be reduced to a value that allows these specifications to be respected, thus limiting the telecommunication system's performance. Beam scanning antennas, based on the planar implementation of Risley prisms, typically suffer from high levels of secondary lobes and grating lobes under certain pointing conditions, this therefore imposes limits on their performance in order to comply with the regulations.

[0019] Optimization of the geometries and materials that make up the entire structure using conventional techniques, in order to eliminate these secondary beams, is impractical due to the combination of electrically large overall dimensions of each single deflector and the large number of electrically small details of the inclusions - the number of parameters that the optimizer would have to manage would be prohibitively large and would require prohibitively long analysis times (simulations). Optimization techniques limited to the modulation period alone actually reduce the computational burden and therefore the resources and analysis times (simulations), but the optimal solutions known so far still have unsatisfactory levels of secondary lobes and grating lobes, in particular when the beam is deflected in radiant directions away from the antenna's longitudinal axis.

[0020] One known scientific publication is "A Beam-Steerable Lens Antenna for Ku-Band High-Power Microwave Applications", in IEEE Transactions on Antennas and Propagation, vol. 68, no. 11, pages 7580-7583, Nov. 2020, doi: 10.1109/TAP.2020.2979282 on behalf of Y. Sun, F. Dang, C. Yuan, J. He, Q. Zhang and X. Zhao.

[0021] This publication describes an antenna consisting of a first stationary lens on which two rotating lenses are superimposed, these in turn being superimposed on each other (see, for example, Figure 1 of the article). The two rotating lenses rotate around the vertical axis Z. Scanning of the beam is obtained by rotating the said two lenses independently of each other.

[0022] The phase gradient impressed on the beam is obtained by making inclusions in the two rotating lenses, these inclusions are positioned in the lens to form a grid in which, when moving, for example, along a column, they are progressively rotated, as shown, for example, in figure 3 of said scientific article.

[0023] A similar solution is described in a further article also in the name of the same author Zhao entitled "All-Metal Beam Steering Lens Antenna for High Power Microwave Applications", in IEEE Transactions on Antennas and Propagation, vol. 65, no. 12, pages 7340-7344, Dec. 2017, doi: 10.1109/TAP.2017.2760366.

[0024] The solutions described in these scientific articles, although functional, are not exempt from the technical problems mentioned above.

[0025] In particular, according to this solution, there are secondary lobes of rather high value present. The values present in this type of solution could even be such as not to be compatible according to the regulations envisaged for the purpose of marketing these antennas, in particular in the context of important communications such as satellite communications. Considering the current state of the art, therefore, solutions for beam scanning antennas that combine the low profile typical of an electronic scanning system with the simplicity and performance typical of mechanical scanning systems, and which, in addition, have secondary lobe and grating lobe values within limits compatible with the provisions of the regulations, do not appear to exist.

Summary of the invention

[0026] It is therefore an object of this invention to introduce a new architecture for antenna beam scanning, and relative antenna, which solves the aforementioned technical drawbacks.

[0027] In particular, it is an object of this invention to provide an apparatus which is reliable, not cumbersome and which therefore combines the advantages of electronic solutions with those of purely mechanical solutions.

[0028] A further object of this invention is to provide an apparatus in which the level of the secondary lobes and the grating lobes is minimized within limits compatible with the provisions of the regulations, in particular for important communications such as satellite communications.

[0029] These and other objects are realized with this antenna assembly, according to claim 1.

[0030] This assembly includes:

- A deflection system (20, 30; 210, 220) configured to deflect the wave produced by a wave launcher, said deflection system comprising at least one deflector having a plurality of inclusions (300) configured to add a phase gradient to the wave coming from the wave launcher whereby they orient said wave in a certain direction in elevation and azimuth.

[0031] According to the invention, said deflector is configured to operate in an environment with refractive index "n" greater than 1, for example, being immersed in a medium with refractive index greater than one.

[0032] Advantageously, therefore, the deflection system has, for at least one part thereof, refractive index greater than 1.

[0033] Advantageously, for example, the deflection system may have the classic deflector comprising the inclusions and with said deflector immersed in a medium with refractive index greater than 1, for example, coated externally with a medium with refractive index greater than 1 (Figure 1A shows the solution of the deflector between two layers with refractive index greater than 1).

[0034] In this case of a planar deflector immersed in an environment with refractive index greater than one, this implies, therefore, that the waves incident on the deflection layer come from an environment with refractive index greater than 1 and that the waves deflected by said deflection layer are still propagating in an environment with refractive index greater than 1.

[0035] The deflection system is matched to the surrounding environment by means of one or more transition or matching devices, each of said transition or matching devices composed of one or more transition layers (also called matching layers).

[0036] The matching device can be arranged, for example, at the inlet to and/or outlet from said deflection system.

[0037] Advantageously, therefore, the proposed solution provides a new architecture based on phase gradient planar deflectors designed to work in an environment with refractive index greater than one (for example, immersed in a medium with refractive index greater than one) and fitted with transition (or matching) devices that manage gradual passage of radiation from a medium with refractive index greater than 1 to air (refractive index one) and/or vice versa.

[0038] This solution, according to the above, is able to minimize the value of the secondary lobes and grating lobes to levels compatible with the standards foreseen, allowing the disturbances associated with them to be reduced with compact and functional construction solutions.

[0039] As a consequence of the above, advantageously, said inclusions scattered in said planar deflector are designed to work in an environment with refractive index n greater than 1.

[0040] Generally speaking, action is taken not so much on the shape but more on the dimensions of the inclusions to make them suitable for working in environments with refractive index greater than 1 depending on the desired phase variation. Furthermore, such inclusions are included in a dielectric material having refractive index greater than 1, equal to that of the design.

[0041] Advantageously, these matching devices are therefore configured to match the at least one planar deflector operating in an environment with refractive index greater than 1 to air (refractive index one).

[0042] For example, matching devices can be provided whose conformation and/or choice of material (for example, dielectric) is such as to allow a variation of the refractive index throughout their thickness.

[0043] According to the present solution, therefore, performances are optimized and enhanced with respect to the present solutions, by carrying out design of the metallic inclusions (pixels) arranged in a regular grid (Cartesian, hexagonal, triangular) with geometries of variable dimensions or rotated according to a periodic pattern, suitable for working in a medium with refractive index greater than 1.

[0044] Such deflector therefore allows the direction of the incident radiation to be varied, depending on the appropriate design in the medium with refractive index greater than 1 of the periodic arrangement of the elements.

[0045] In a medium with refractive index greater than one, suitably matched to air (having refractive index one) through the transition or matching devices, the radiation strikes and is transmitted with angles closer to the longitudinal axis than to air, based on the refraction phenomenon governed by Snell's law.

[0046] In carrying out design in this environment, it is therefore possible to obtain for the individual pixels a very stable transmission coefficient in amplitude (close to the value one) and in phase, depending on the wave incidence and transmission direction (in both azimuth and elevation); if the transmission coefficient of the individual pixels is stable depending on the wave incidence and transmission direction (in both azimuth and elevation), the phase gradient, produced by the deflector by distributing the pixels in a periodic pattern (modulation period), will be very stable depending on the wave incidence direction and very similar to the ideal condition required to achieve deflection in the absence of side lobes and grating lobes. All this obviously translates into a significant enhancement of performance in terms of reduction of the side lobes and in particular of the grating lobes of the deflected radiation pattern, when the direction of incident radiation is deflected in the medium with refractive index greater than 1.

[0047] One or more transition or "matching" devices are then added (for example, at the inlet and/or outlet of the deflector).

[0048] They are preferably formed by one or more matching layers which, complying with the conservation conditions of the transverse electromagnetic field phase, manage an additional deflection of the radiation from the medium with refractive index greater than one to that with refractive index one and vice versa, i.e. from angles close to the longitudinal axis to grazing angles and vice versa; if this deflection is achieved gradually, preferably by using numerous transition layers, the presence of reflected waves is considerably reduced even on relatively wide frequency bands. Consequently, the additional deflection introduced by the transition or matching layers extends the scanning range without altering performance of the side lobes and grating lobes of the deflected radiation pattern, which remain those optimized for the medium with refractive index greater than 1.

[0049] This system is therefore a beam scanning system, having a low profile, which maintains low levels of side lobes and grating lobes minimal and compatible with the provisions of the regulations while redirecting the beam in a wide angular scanning range, within a wide band of frequencies.

[0050] Each deflection system is therefore in fact a planar deflector composed of one or more layers where these inclusions are disseminated and then immersed or included in a medium with refractive index greater than one (as in figure 1A, for example).

[0051] The lens is therefore a low profile lens in a dimensional range preferably, but not exclusively, between 0.8 and 1.7 wavelengths relative to a medium with refractive index one.

[0052] This solution, therefore, is an alternative, low profile, high efficiency implementation of the classic Risley prisms for beam scanning.

[0053] For all these reasons, a low profile device, based on the Risley prism concept, which deflects the beam while maintaining the level of the side lobes and grating lobes minimal and compatible with the provisions of the regulations, is commercially interesting.

[0054] Advantageously, therefore, each deflection system further cooperates with one or more transition or matching devices configured to match each deflector to air, i.e. to a medium with refractive index 1, different from that of the design, having refractive index greater than 1; thus producing a gradual transition from the design medium to air, the transition devices greatly reduce the presence of reflected waves due to discontinuities of the various media.

[0055] The wave launcher which cooperates with the deflection system and the matching devices presented above is also part of the system object of the invention.

[0056] Obviously this invention also relates to an antenna comprising the system according to one or more of the preceding characteristics.

[0057] This invention also relates to a method of manufacturing an antenna which comprises the steps of:

- arrangement of a wave launcher (10, 210);

- arrangement of a deflection system configured to deflect the wave and comprising at least one deflector, for example, planar (20, 30; 210, 220), said deflector comprising a plurality of inclusions (300) configured to add a phase gradient to the wave coming from said wave launcher;

- and wherein the method comprises the production of the deflector designed to operate in a medium with refractive index greater than one, therefore included or immersed in the medium with refractive index greater than one, and in which, in addition, the provision of one or more matching devices configured to match said at least one planar deflector to a working environment with refractive index different from that of the design, reducing the level of reflection of the electromagnetic field as it passes through the various matching layers.

[0058] Advantageously, the inclusions disseminated in the deflector are therefore configured to work in a medium with refractive index greater than 1.

[0059] Therefore, a method is also described here for the production of planar deflectors in which a plurality of inclusions are disseminated, the design of which is carried out for a medium with refractive index greater than 1 and wherein the deflector is immersed in a medium with refractive index greater than one and includes the addition of at least one transition or matching device, preferably two transition or matching devices, for the gradual subsequent deflection of radiation from the medium with refractive index greater than one to air (refractive index one) and vice versa.

[0060] This new architecture is able to maintain levels of side lobes and grating lobes in the deflected radiation pattern that are minimal and compatible with the requirements of the regulations while the main beam is redirected in a wide angular range.

[0061] Advantageously, one possible configuration could include one or an array of wave launchers arranged side by side, preferably with an axis having a different inclination with respect to one another or with respect to the axis of the deflector system, preferably but not exclusively dedicated to increasing the deflection angle of the beams.

[0062] Advantageously, the launcher could be composed of an array of launchers operating at the same frequency or at different frequencies, preferably with the possibility of working together in said array, to increase the maximum gain of the antenna system and/or widen the operating bandwidth, or with the possibility of working separately.

[0063] Advantageously, in a possible configuration, there could, for example, be an array of launchers and a deflection system with one or more aligned deflectors, each deflector having its own modulation period for the inclusions, so that the beams produced by each launcher can be deflected in arbitrary or combined directions to produce a beam shaped depending on the deflector being illuminated.

[0064] Advantageously, in a further configuration, there could be a deflection system with one or more aligned deflectors and a plurality of launchers, rotatable or fixed, each of these providing a wave in a particular direction, so that the waves produced by the wave launchers can be further deflected in arbitrary directions or combined to produce a shaped beam.

[0065] The object of this invention is therefore:

An antenna assembly comprising:

- A deflection system (20, 30; 210, 220) configured to be able to deflect the wave coming from a wave launcher (10, 210), said deflection system comprising at least one deflector, preferably planar, comprising a plurality of inclusions (300) configured to add a phase gradient to the wave coming from said wave launcher;
- and wherein said deflector is configured to work in an environment with refractive index greater than one;
- and wherein one or more matching devices are included for managing passage of the wave from a medium with refractive index greater than one to a medium with refractive index one and/or vice versa.

[0066] For example, advantageously, said deflector is immersed in a medium with refractive index greater than one.

[0067] Advantageously, said matching devices are arranged at least at the outlet from the deflection system in such a way as to manage passage of the wave at least from said deflection system with refractive index greater than 1 to a medium with refractive index one, for example, air.

[0068] Advantageously, said medium with refractive index one is air.

[0069] This invention also relates to a method of manufacturing an antenna which comprises the steps of:

- arrangement of a wave launcher (10, 210);
- arrangement of a deflection system (20, 30; 210, 220) configured to deflect the wave, said deflection system comprising at least one deflector, preferably of the planar type, comprising a plurality of inclusions (300) configured to add a phase gradient to the wave incident on the deflector;
- and wherein the method comprises the arrangement of the deflector in such a way that it operates in an environment with refractive index greater than one and wherein, in addition, the arrangement is included of one or more matching devices arranged at the outlet from and/or at the inlet to said deflection system, said one or more matching devices being configured to manage passage of the wave from a medium with refractive index greater than one to a medium with refractive index one and/or vice versa.

[0070] Advantageously, the medium with refractive index one can be air.

[0071] Advantageously, said deflector can be arranged in the medium with refractive index greater than 1.

[0072] Even more preferably, said arrangement of the deflector in the medium having refractive index greater than one can optionally comprise at least one of the following solutions:

- the production of a multilayer printed circuit with initial and final dielectric layers with refractive index > 1;
- bonding above and below the deflector of a dielectric material with refractive index > 1;
- co-molding the deflector in a plastic material with refractive index > 1.

[0073] Also described here is a method for deflecting an electromagnetic wave from a wave launcher, the method comprising passage of the wave emitted by the wave launcher through a deflector which adds a phase gradient to the wave coming from said wave launcher and with said deflector working in an environment with refractive index greater than one and wherein is included subsequent passage of the wave through at least one matching device configured to manage at least passage of the wave from a medium with refractive index greater than one to a medium with refractive index one and/or vice versa.

[0074] Preferably the medium having refractive index one being air.

[0075] Further advantages may be derived from the remaining dependent claims.

Brief description of the drawings

[0076] Further characteristics and advantages of this device and relative method, according to the invention, will be clarified by the description that follows of some of its embodiments, provided by way of non-limiting example, with reference to the attached drawings, where:

- Figure 1A shows, according to the invention, the deflection system formed by the planar deflector and included between two layers forming the design medium having refractive index greater than one; the deflection system is then, in its turn, included between two transition devices and of which each transition device formed by one or a plurality of transition layers (one layer per face or more than one layer per face overlapped between them) through which transition of the wave occurs. In the case of Figure 1A, transition of the wave occurs from an environment with refractive index one (generally air) to the deflection system which works with refractive index greater than one; this first transition occurs through the first transition device and then a further transition occurs at the outlet of the deflection system to the outside (air) through the second transition device whereby the wave passing from a medium with refractive index greater than 1 (deflector) to the environment with refractive index one (air) through said second transition device; even if not illustrated, the solution with a single outlet transition device is preferred, whereby the wave passes from the deflection system with refractive index greater than 1 to an environment with refractive index one through a single transition device; the wave therefore crosses the medium with refractive index greater than one to intercept, at its outlet, the transition device that leads it to the external environment with refractive index one;
- Figure 1B shows a schematic diagram of this wave transition pattern;
- Figure 1 structurally shows a solution according to a first configuration in which is provided a static wave launcher 10 with a fixed beam in the longitudinal direction (broadside), in line with two rotatable beam deflectors (20, 30);
- Figure 2 schematically shows the operation of this first configuration, highlighting the deviation of the wave through the two rotations of the two deflectors; in fact, the figure shows the different angle of the beam obtained by the rotation of the first deflector 20 and of the second deflector 30;
- Figures 3 and 4 show possible examples of the geometries for the inclusions that may be used to compose a deflector; what is shown in figure 3 applies to all the configurations described;
- Figure 5 shows, again with reference to the first configuration, some examples of radiation patterns with different examples of wave launchers; in particular case a) shows a parabolic reflector with short focal length, case b) shows a modulated meta-surface antenna, case c) shows an RLSA antenna and case d) shows a pillbox antenna;
- Figure 6 shows, again with reference to the first configuration, the two deflectors (20, 30) with multiple layers of gradually rotated inclusions. The angles of rotation of the deflectors with respect to a Cartesian reference system are highlighted;
- Figure 7 shows a deflector according to the invention comprising the inclusions disseminated on its surface and gradually rotated along a dissemination direction with the phase gradient direction;
- Figure 7A is an enlarged detail of a central area constituting the deflector of Figure 7, in order to better illustrate the arrangement of the inclusions 300 (in this case of example, with shape marked +) which are arranged according to an order rotated gradually as movement occurs along the columns from 1 to N according to a pattern which, in the specific and non-limiting example, is repeated every three columns;
- Figure 7B shows a variant of a deflector according to the invention comprising the inclusions disseminated on its surface and gradually varied in their size along a direction of dissemination;
- Figures 8 and 9 show a second configuration of the invention identical to the first, except for the fact that there is only one deflector 220 rotatable in line with the wave launcher 210 which, unlike the first configuration, is also rotatable and produces a beam not in line with the deflector;
- Figures 10A to 10C illustrate examples of radiation patterns with a beam directed in some arbitrary directions and low levels of grating lobes in each scanning direction (at least 25 dB for the co-polar component and at least 28 dB for the cross-polar component, a level of performance never obtained with the techniques known up to now). At the inlet to the deflector, a plane wave is supplied;
- Figure 11 indicates the desired and undesired lobes of the co-polar and cross-polar components;
- Figure 12 shows the antenna system, based on the illustrated configurations, in which said configurations are arranged according to a polyhedral surface in order to further widen the field of view observable by said antenna system.
- Figure 13 shows the antenna system, based on the illustrated configurations, in which the launcher is constituted by a multi-beam antenna, preferably but not exclusively constituted by a pillbox antenna or by a compact reflector illuminated by several launchers each generating a beam; said system, preferably but not exclusively dedicated to radar applications, capable of rapidly scanning a wide view angle by means of several beams which can be directed in different but predictable directions according to the rotation of the deflectors. In particular, if, for example, 5 beams are generated simultaneously (this number represents only an example, the value can be arbitrary), the entire scan sector can be scanned in a time interval that can be about 5 times shorter than that which could be obtained with a single beam.
- Figure 14 shows the antenna system, in which the launcher consists of a multi-beam antenna or an array of launchers; said system preferably, but not exclusively, dedicated to solving the problem of handover between satellites in LEO orbit, capable of producing one or more beams that can be directed in different but predictable directions according to the rotation of the deflectors that follow one or more moving objects. Thanks to the possibility of being

able to activate multiple launchers, the transition between a first beam pointing direction and a second beam pointing direction (related, for example, to the positions of two users or two satellites or two targets) can be implemented more quickly, with energy saving and less wear of the mechanisms used for rotating the deflectors. Furthermore, the possibility of having and being able to activate multiple launchers means that more than one beam can be activated and multiple users/satellites/targets connected simultaneously to the antenna, even if the possible pointing directions of the beams are not entirely independent;
Figures 15 to 18 show further examples of embodiment of matching layers according to the invention while figure 19 schematically shows the deflector comprised between the matching layers. More specifically, Figure 19 shows a deflector covered by matching devices made by means of uniform dielectric layers, dielectric layers suitably perforated, matching layers made with metallic inclusions in a uniform dielectric environment, matching layers made with metallic inclusions in a non-uniform spatially dielectric environment; equivalently, the matching layers can be made by using a uniform dielectric material inside which conical or multi-section cylindrical holes are made.

Description of some preferred embodiments

[0077] This invention relates to a new architecture for the implementation of deflectors, preferably planar and therefore having a flat shape, with phase gradient for scanning the antenna beam, designed to work in an environment with refractive index greater than one.

[0078] For this purpose, in order to work in an environment with refractive index greater than one, each deflector is arranged in a medium with refractive index greater than one.

[0079] There are also one or more transition devices which manage gradual passage of radiation from a medium with refractive index greater than one to air (refractive index one) and vice versa.

[0080] The transition device is preferably arranged at least at the outlet from the deflector thereby allowing transition of the wave from a medium with refractive index greater than one to a medium with refractive index one (in this case air).

[0081] However, nothing excludes variants in which, for example, the transition device can be provided at the inlet to and/or outlet from the deflector.

[0082] A schematic is presented in figure 1A.

[0083] Figure 1A shows an assembly formed by the deflection system (described immediately below) and cooperating with one or more matching devices (or transition devices).

[0084] Figure 1A therefore shows a standard deflector having inclusions, as also clarified below. However, as shown in Figure 1A, it is immersed in a design medium with refractive index greater than one. In particular, it is coated externally, that is in correspondence with its two faces, by a medium with refractive index greater than one (for example a dielectric) so that, overall, producing a deflector device (or deflection system) which in fact has for at least one part thereof (essentially a predetermined, thick section) refractive index greater than 1. The matching devices are preferably in the form of superimposed layers and are such as to allow the gradual passage from the design medium of the deflector with refractive index greater than one to the external environment, i.e. the air, or vice versa.

[0085] Figure 1A therefore shows the entire deflection system comprised between two matching devices and of which each matching device is in the form of several matching layers. Figure 1B shows the wave pattern as it passes through air - transition layers - deflection system - transition layers - air.

[0086] This new architecture makes it possible to produce a low profile apparatus for a mechanical beam scanning antenna, comprising a primary wave launcher and one or more mechanically rotatable beam deflection systems, capable of redirecting the beam produced by the primary launcher in an arbitrary direction in azimuth and in elevation, minimizing the level of the secondary lobes and above all of the grating lobes within limits compatible with the provisions of the regulations, in particular for important communications such as satellite communications.

[0087] This invention also relates to the production of beam deflectors made of inclusions arranged in a regular grid (Cartesian, hexagonal, triangular), with variable geometries and/or rotated according to a periodic pattern.

[0088] According to the invention, the inclusions are designed to work in an environment with refractive index greater than one ($n > 1$), therefore included in the medium having refractive index greater than one.

[0089] Furthermore, the beam deflection systems are equipped with matching devices to match the deflectors to work in air, i.e. in an environment with refractive index one and therefore different from that greater than one of the design.

[0090] Basically, a new architecture is produced for the realization of phase gradient planar deflectors, in which advantageously the design of the inclusions (pixels) is carried out in a medium with refractive index greater than one, therefore included in the medium with refractive index greater than one, and transition devices formed by one or more transition layers are added for the gradual subsequent deflection of radiation from the medium with refractive index greater than one to air (refractive index one) and vice versa.

[0091] This apparatus for scanning of the antenna beam is able to maintain levels of side lobes and grating lobes that are minimal and compatible with the provisions of the regulations while the main beam is redirected within a wide angular range.

[0092] This new architecture, while the main beam is redirected within a wide angular range, is able to keep the secondary lobes and grating lobes at lower levels than any other solution known so far and compatible with the applicable regulations, particularly for important communications such as satellite communications.

[0093] The configurations that will be described immediately below in detail are two, and in particular:

In a first configuration (see, for example, Figure 1), the apparatus is composed of a wave launcher (or *primary antenna)* and by two assemblies (20, 30) each formed by a deflection system coupled with the relative one or more matching devices exactly according to the architecture presented above in figure 1A.

[0094] The primary antenna is a directional antenna, with a fixed beam in the longitudinal direction (broadside), which produces a beam of circular or linear polarization, in line with the antenna, at the inlet to the deflectors.

[0095] The beam deflectors are two planar structures, aligned along the same axis, rotatable independently and able to deflect the beam produced by the antenna in an arbitrary direction (in elevation and azimuth) when suitably rotated.

[0096] Each deflector is composed of one or more planar layers (see, for example, Figure 3 or 4), each layer comprising a plurality of small elements *(pixels* or inclusions) which add to the phase of the incident wave or incident radiation a phase gradient in a medium with refractive index greater than 1.

[0097] Each deflector is, as mentioned, designed to work in an environment with refractive index greater than 1 and therefore is immersed in a medium with refractive index greater than one.

[0098] To the layers of the deflector are added the matching layers (see, for example, Figure 1A) which manage the subsequent gradual deflection of radiation from a medium with refractive index greater than 1 to the air (refractive index one) and/or vice versa.

[0099] The direction of the outgoing beam is determined by the relative angular orientation of the two deflectors.

[0100] A second configuration (see, for example, Figures 8 and 9), is similar to the first configuration described but, in this case, the primary antenna is not fixed but can rotate around its own axis. It produces a circularly or linearly polarized beam, inclined with respect to the antenna axis, which enters a single assembly formed by the deflection system with relative matching devices (one or more than one) (and not to two assemblies such as in the first configuration) placed above the antenna and therefore made according to the new architecture presented above.

[0101] This single deflector therefore comprises one or more layers having the inclusions of the first configuration, immersed in a medium with refractive index greater than one and to which one or more matching devices are added at the outlet and/or at the inlet (as for the first configuration) and is also rotatable around its own axis, the latter aligned with the axis of the antenna.

[0102] The beam can be directed in an arbitrary direction (in elevation and azimuth) determined by the relative angular position between the primary antenna and the beam deflector.

[0103] As already mentioned, in each of the two configurations, each deflector is designed to operate in a medium with refractive index greater than 1.

[0104] For this purpose it is immersed in an environment with refractive index greater than one.

[0105] For example, from a technical point of view, the design of the deflector with refractive index greater than one can be obtained, for example, by coating the deflector at its upper and lower surfaces (above and below) with a spatially homogeneous dielectric material with refractive index > 1. The matter will also be addressed later.

[0106] Therefore, each deflector requires, above and below, matching devices composed of one or more matching layers which avoid wave reflections when the apparatus operates in the real environment with refractive index one.

[0107] This aspect will be taken up in more detail later in this description.

BRIEF STRUCTURAL DESCRIPTION OF THE FIRST CONFIGURATION:

[0108] Figure 1 structurally describes a first configuration of the invention.

[0109] As already discussed in the known art, it includes:

A wave launcher 10 of the fixed type in the longitudinal direction (broadside), therefore static.

[0110] This launcher therefore has a fixed beam in the longitudinal direction (broadside) and is aligned with a first and a second assembly (20, 30) formed, according to Figure 1A, by a deflector immersed in a medium with refractive index greater than one and having one or more transition devices. In particular, the first assembly 20 superimposed on the wave launcher is on the same axis as it, and the second assembly 30 superimposed on the first assembly 20 is still on the same axis as the wave launcher 10.

[0111] Both the assemblies (first and second deflector) are rotatable about their central axis of symmetry. They are rotatable independently of each other.

[0112] The perimeter shape of the assemblies (and therefore of the deflectors) is typically circular but can also have other shapes (for example, elliptical or square or polyhedral).

[0113] Figure 1 therefore shows the initial beam which starts from the fixed wave launcher in the longitudinal direction (broadside) and which is deflected on exiting from the second deflector.

[0114] The progression of the deflection is schematically shown in Figure 2 in which a first deflection occurs in the passage from the first deflector, through suitable rotation thereof, and a second deflection occurs in the passage through the second deflector, again following a suitable rotation thereof.

[0115] As detailed below, each deflector comprises inclusions designed to work in an environment with refractive index greater than 1 and which inclusions add, according to their arrangement, a phase gradient to the wave coming from the wave launcher, whereby they orient said wave in a certain direction in elevation and azimuth.

BRIEF STRUCTURAL DESCRIPTION OF THE SECOND CONFIGURATION:

[0116] The second configuration of the invention differs from the first, with reference to Figures 8 and 9, in that there is only one rotatable assembly 220 which is superimposed and on the same axis as the wave launcher 210, also rotatable, and in that the launcher radiates a wave not on the same axis as the deflector. The deflector and wave launcher can therefore be rotated independently of each other.

[0117] Both Figure 8 and Figure 9 show a variation in the inclination of the wave beam thanks to the two combined rotations. In particular, the rotation of the wave launcher determines a first rotation of the wave which is then deflected through passage of the wave in the deflector immersed in the medium having refractive index greater than one and fitted with a transition device. This assembly 220 further rotates and therefore determines the deflection of the beam in a direction which depends on the relative rotation of the launcher with respect to the deflector.

[0118] Also in this case, as detailed below, there are inclusions designed to work in an environment with refractive index greater than 1, which inclusions determining, based on their arrangement, a phase gradient in the wave coming from the wave launcher whereby they orient said wave in a certain direction in elevation and azimuth.

STRUCTURAL DESCRIPTION OF THE ELEMENTS COMMON TO SAID FIRST AND SECOND CONFIGURATION:

[0119] The essentially common parts for the two configurations concern the structure of the deflectors immersed in a medium with refractive index greater than one with relative inclusions.

[0120] In all the configurations of the invention described, as summarized in the next paragraph, in order to reduce the minimum elevation that can be reached by the beam without degradation and keeping the level of the secondary lobes and grating lobes at levels compatible with the provisions of the regulations, in particular for important communications such as satellite communications, the deflectors are designed to operate in an environment with refractive index greater than one ($n > 1$) and are therefore included in a medium with refractive index greater than one.

[0121] The deflectors, as schematically indicated in Figures 3 and 4, include or are composed of a plurality of inclusions 300, for example, in the form of superimposed layers, that may have various shapes.

[0122] Therefore each deflector may, for example, consist of at least two or more superimposed layers, each layer having such inclusions disseminated therein.

[0123] Theoretically, even if more difficult to achieve, even a single layer would be possible.

[0124] Examples of forms of inclusions and their arrangement are highlighted in figures 3 and 4.

[0125] They are composed, as shown in the views of figure 4, of metallic materials interposed with dielectric type materials, or of entirely metallic material.

[0126] At least a part of the deflector, or its entire surface, is therefore made up of such inclusions, which are disseminated according to an orientation that is progressively rotated in a certain direction (phase gradient direction) or with variable dimensions in a certain direction (phase gradient direction).

[0127] For example, for greater clarity, figure 7A shows an enlarged view of a direction of progression and it can be seen how, along this direction, all the inclusions present in the deflector are progressively rotated according to a pattern of rotation that is repeated with a certain frequency. Basically it is as if a grid of inclusions were created, made up of rows and columns in which the arrangement of the inclusions in the columns follows a certain order such that, for example, in the first column the inclusions have a certain arrangement, in the second column they have an arrangement rotated with respect to the previous one and so on until completing the 360° rotation so that, returning to the starting position of the first column, the sequence starts repeating.

[0128] For greater clarity, Figure 7A shows an enlarged portion of the deflector in an enlarged image showing the inclusions 300 (in this example marked with a "+"). The columns are shown and it is evident how the inclusion arrangement sequence is repeated according to a predetermined pattern every three columns. The first column therefore has an arrangement according to a certain angle of the inclusions. The second column has an arrangement rotated by a certain angle of the inclusions and the third column has a further rotated angle of said inclusions. The pattern then repeats periodically, as shown in figure 7A.

[0129] The example of figure 7A is not to be considered limiting in the sense that the inclusions can be of different shapes, as shown in figures 3 and 4 and the arrangement pattern can be different from that of figure 7A, in the sense that the rotation angles may differ from column to column so that, moreover, the pattern can be replicated, for example, every four columns or according to any number of columns.

[0130] In a further alternative variant of the invention, see, for example, Figure 7B, the progressively rotated arrangement of the inclusions, presented above, can be replaced with inclusions having variable dimensions in a certain direction (phase gradient direction) of development of the grid but maintaining the same spatial orientation.

[0131] In all the above cases, whether the inclusions made are rotated or of variable size, they are designed to work in an environment with refractive index greater than 1 and, consequently, there are transition or matching devices to make the antenna work in the real environment, i.e. with refractive index one.

[0132] It is now clear that in this invention, the deflectors redirect the beam by means of the gradual (adiabatic) rotation presented above, or variation in size, of the inclusions 300 which are small geometric elements capable of adding an appropriate and accurate phase gradient to the beam at the deflector inlet.

[0133] To this is added, unlike the prior art cited, that both deflectors, and therefore the individual inclusions, are designed to operate in an environment with refractive index greater than 1, therefore included in the medium with refractive index greater than 1, with the consequent necessary presence of "matching devices" to make the deflector adapt to operate in air (refractive index one).

[0134] Accurate setting of the phase gradient allows a beam to be produced that emerges from the deflector pointed in the desired direction maintaining the level of the side lobes and especially of the grating lobes at levels compatible with the provisions of the regulations, in particular for important communications such as satellite communications.

[0135] Therefore, in this invention, each deflector uses small inclusions of generally the same shape and size, gradually rotated in the direction of progression of the phase gradient that is added to the input beam, as already described in Figure 7, or inclusions of gradually different size such as described in figure 7B.

[0136] The length of the period of rotation or scaling of the dimensions of the inclusions determines the direction of the beam exiting from each deflector.

[0137] In particular, if a rotation or scaling period is covered by, for example, six inclusions, the beam points in a direction θ_0. If, on the other hand, for the same size of the regular grid (Cartesian, hexagonal, triangular) in which the inclusions are arranged, the period is covered by eight inclusions, then the beam exiting from the deflector is directed in a direction $\theta_1$different from θ_0.

[0138] The rotation of the deflectors with respect to each other and with respect to the launcher (configuration 1), or the rotation of the deflector and the launcher (configuration 2) are the basis of the beam scanning or re-pointing mechanism.

[0139] The fact that the single deflector deflects the incident wave depends on the rotation of the single inclusions within a periodic pattern or on the change in size of the same (depending on the configuration).

[0140] For example, in the case of rotations of the inclusions, with the same size of the regular grid (Cartesian, hexagonal, triangular) in which said inclusions are arranged, the number of rotated inclusions that make up the rotation period determines the direction in which the beam is deflected. Thus, if a period of rotation is covered by six inclusions (i.e. by counting six inclusions, the seventh will be in the same position as the first), the wave is deflected in the direction θ_2, if the period were covered by a different number of inclusions, then the wave would be deflected in the direction θ_3. The rotation of the inclusions cannot be changed once the deflector has been made. However, in the design stage, depending on requirements, one could opt to cover a rotation period with a certain number of inclusions instead of another.

[0141] Furthermore, in the case of inclusions with progressively rotated arrangement, each deflector is implemented in such a way that the co-polar component of the signal incident on one side of the deflector and the co-polar component of the signal emerging on the opposite side of the deflector have circular orthogonal polarizations.

[0142] The beam entering the deflector is produced by the launcher (10; 210) formed by a directional antenna. For example, this launcher can be a short focal parabolic reflector (to keep the profile low), or a modulated metasurface antenna or a slotted antenna (RLSA) or a pillbox antenna. The embodiment examples of wave launcher are shown in figure 5 and are valid for all configurations. All these solutions must be understood as possible alternatives for the launcher and must not be seen as a limitation.

[0143] Each deflector is formed by planar structures, generally of several layers (see for this purpose, figures 3 and 4), composed of a plurality of inclusions *(pixels)* placed inside a regular grid (Cartesian, hexagonal, triangular).

[0144] Some examples of the above inclusions are illustrated, as mentioned, in figures 3 and 4. These geometries must be understood as possible alternatives and must not be seen as a limitation.

REFRACTIVE INDEX > 1 AND MATCHING LAYERS:

[0145] As already widely anticipated above, an important element of the invention, which contributes to obtaining the desired technical effects, consists of the fact that the inclusions are designed to work with refractive index > 1 and are therefore included in the medium with index of refraction greater than 1.

[0146] In all the configurations of the invention described, the deflectors are therefore designed to operate in an environment with refractive index greater than one and therefore immersed in the medium with refractive index greater than 1 in order to reduce the minimum elevation that can be reached by the beam without degradation and keeping the level of the side lobes and above all of the grating lobes at minimal levels compatible with the provisions of the regulations, in particular for important communications such as satellite communications.

[0147] The design in a medium with refractive index greater than 1 allows pixels to be designed in an environment in which, compared to an environment with a refractive index one, the electromagnetic wave, when it enters the medium with refraction index greater than 1, is refracted (i.e. deflected) in a direction closer to the direction of the longitudinal axis of the deflectors which coincides with the normal to the surface of the interface between the two media. In fact, it is known, according to Snell's law, that a wave incident on an interface between two different media is deflected in such a way that in the medium with the higher refractive index, it tends to propagate closer to the normal at the interface. Therefore, with the same desired angle of deflection, in air, the deflector immersed in a medium with refractive index greater than one, suitably equipped with matching devices at the interface with the air, must deflect the wave by a smaller angle compared to what it should do if it was working in an environment with refractive index one. The wave will in fact be further deflected as it propagates from the medium with refractive index greater than 1 to that with refractive index one (air). The aforementioned reduction of the angle of deflection that the deflector must produce, therefore, translates into two very important aspects relating to performance enhancement listed below. 1) The phase gradient that the deflector must implement is less steep, i.e. the spatial variation of the pixels is slower, thus allowing an enhancement of performance in terms of reduction of the level of the side lobes and of the grating lobes in the deflected radiation pattern; 2) the waves incident on the deflector have angles of incidence included in a smaller range, consequently the inclusions that make up the deflector have a very stable transmission coefficient in amplitude (close to one) and in phase depending on the direction of incidence (in both azimuth and elevation); if the pixel transmission coefficient is stable depending on the direction of incidence (in both azimuth and elevation), the phase gradient created by the deflector by distributing the pixels in a periodic pattern (modulation period) will be very stable depending on the direction of incidence of the wave and very similar to the ideal condition required to achieve a deflection in the absence of side lobes and grating lobes. All this obviously translates into a significant enhancement of performance in terms of reduction of the side lobes and, in particular, of the grating lobes in the radiation pattern deflected over a greater frequency band.

[0148] Since the deflector is designed to work in an environment with refractive index greater than one and is therefore included in the medium with refractive index greater than one, it is necessary to introduce one or more "transition" or "matching" devices that gradually manage the passage of the waves to the air, i.e. to a medium with refractive index one, and different from the design index.

[0149] The inclusions are disseminated, according to what has been described above, in said medium (generally in the form of a layer or plane) and are designed (i.e. configured) to work at their best in said refractive index > 1, i.e. adding the required phase gradient.

[0150] From a technical point of view, the design of the deflector with refractive index greater than one can be obtained, for example, by coating the deflector at its upper and lower surfaces (above and below) with a spatially homogeneous dielectric material with refractive index > 1.

[0151] This could be accomplished with various technologies such as:
The production of a multilayer printed circuit (generally called PCB) with initial and final dielectric layers with refractive index > 1 or by bonding a dielectric material with refractive index > 1 above and below or even by co-molding the deflector in a plastic material with refractive index > 1.

[0152] Figure 1A therefore shows the deflection system obtained by immersing the deflector in a medium with refractive index greater than 1 according to one of the production methods indicated above.

[0153] The system, working with refractive indices > 1, requires the presence of matching devices.

[0154] The invention therefore provides for an assembly formed by a deflection system that cooperates with at least one matching device.

[0155] In particular, as also indicated in Figure 1A, each deflector must preferably include at least one or more matching devices which avoid wave reflections that would be present if the deflectors operated in the real environment with refractive index one.

[0156] The matching device could be present only at the outlet of the deflection system and therefore with such matching device superimposed on the deflection system.

[0157] The matching devices, in other configurations, could be composed of several matching layers both at the inlet and at the outlet of the deflector and, for example, such that said deflector is interposed, i.e. included or packaged, between said multiple matching layers both at the inlet and outlet of the deflector.

[0158] In this way, the wave emerging from the deflector would then be incident on the interface with the first matching layer and then cross through both the first and the second matching layer and then all the other matching layers present to finally go towards the air. Conversely, the incident wave coming from the air would follow the reverse path to reach the medium with refractive index greater than 1 and be incident on the deflector.

[0159] Above and/or below each deflector there is therefore at least one matching device composed of one or more matching layers which guarantees low insertion losses and facilitates the deflection of the beam in a grazing direction, very inclined with respect to the longitudinal axis of the system and vice versa.

[0160] These matching layers completely cover the deflector and can be implemented by means of one or more dielectric layers with different refractive index and different thickness.

[0161] In addition, each dielectric layer may or may not include metallic or dielectric inclusions, for example, having geometries of the same type as those shown in the Figures 7 which are to be considered merely by way of example and in no way limiting. Such inclusions, unlike the inclusions used for the deflector, are identical in their geometric parameters in order to obtain the most suitable refractive index of the matching layer.

[0162] The number of matching layers to be used depends on the performance required. In fact, the use of several matching layers can, for example, enable a widening of the operating frequency band and an enhancement of the performance in terms of reducing reflected waves in the transition from medium with refractive index greater than one to medium with refractive index one and vice versa. Some matching device solutions are shown in Figures 15-18 merely by way of example and in no way limiting.

[0163] For example, matching devices are shown made by means of a dielectric layer perforated with mono or multi-diameter cylindrical (figure 15 and 17) or conical (figure 16) shaped pass-through holes, matching layers made with metallic inclusions (figure 18), for example, square-shaped in a uniform dielectric environment, matching layers made with square-shaped metallic inclusions in a spatially non-uniform dielectric environment in the longitudinal direction.

[0164] Basically, the selection of material (for example, dielectric layer) and its conformation (holes and/or inclusions, etc.) determine a transition layer with refractive index value moving towards the value one.

[0165] According to the invention, therefore, by means of the gradual rotated arrangement of the inclusions or by means of a variation of their size in the deflector, each deflector adds a phase gradient to the wave striking it.

[0166] In other words, the phase of the transmission coefficient (insertion phase) of the deflector has a trend that is "sawtooth" in one direction (for example the "x" direction) and uniform in the orthogonal direction (the "y" direction). Except for the aforementioned phase change, each deflector is in any case mostly transparent to the incident radiation, to the extent that it introduces low losses in the signal passing through the deflector, i.e. ideally the transmission coefficient has unitary amplitude.

[0167] In all the configurations described, rotation of the deflector (and of the wave launcher) can be obtained through independent drive units and a controller to control the value of rotation according to the desired pointing direction.

[0168] In particular, with reference to a Cartesian system with "z" axis coinciding with the axis of rotation (see figure 6), a phase progression $\Delta\Psi = -kx \sin\delta$ (where k is the wave number in free space) tilts an input beam directed along the longitudinal axis of the antenna in the direction $\theta = \delta$, $\phi = 0$.

[0169] After rotating the deflector by an angle Φ_1 around its axis, the phase progression becomes $\Delta\Psi = -kx \sin\delta \cos\phi_1 - ky \sin\delta \sin\phi_1$: this phase progression deflects the beam in the direction $\theta = \delta$, $\phi = \phi_1$. The second deflector is placed on top and is typically (but not necessarily) identical to the first deflector, except for the angle of rotation ϕ_2 which in general is different from ϕ_1. It can be shown that the combination of the phase shifts produced by the two deflectors gives rise to a change in the pointing direction of the beam in both azimuth and elevation (Figure 1). This pointing direction is given by the equation

$$\theta = \sin^{-1}\left[2\sin\delta\cos\left(\frac{\phi_1-\phi_2}{2}\right)\right]$$

$$\phi = \begin{cases} \tan^{-1}\dfrac{\sin\phi_1+\sin\phi_2}{\cos\phi_1+\cos\phi_2} & \text{per} \quad \sin\delta\cdot(\cos\phi_1+\cos\phi_2)\geq 0 \\ \tan^{-1}\dfrac{\sin\phi_1+\sin\phi_2}{\cos\phi_1+\cos\phi_2}+180^\circ & \text{per} \quad \sin\delta\cdot(\cos\phi_1+\cos\phi_2)<0 \end{cases}$$

[0170] In an alternative configuration, one deflector can be missing and the launcher can rotate around the "z" axis in order to provide at the deflector inlet a beam inclined with respect to the axis of the launcher (Fig. 7).

Claims

1. An antenna assembly comprising:

   - A deflection system (20, 30; 210, 220) configured to be able to deflect the wave coming from a wave launcher (10, 210), said deflection system comprising at least one deflector, preferably planar, comprising a plurality of inclusions (300) configured to add a phase gradient to the wave coming from said wave launcher;

- **characterized in that** said deflector is configured to work in an environment with refractive index greater than one;
- and wherein one or more matching devices are included to manage the passage of the wave from a medium with refractive index greater than one to a medium with refractive index one, preferably air, and/or vice versa, preferably said matching devices being arranged at least at the outlet from the deflection system in such a way as to manage passage of the wave at least from said deflection system with refractive index greater than one to a medium with refractive index one, for example, air.

2. The assembly, according to claim 1, wherein said deflector is immersed in a medium having refractive index greater than one.

3. The assembly, according to claim 2, wherein the deflector is coated with a homogeneous dielectric material with refractive index greater than one, preferably the deflector being a multilayer with external dielectric layers with refractive index > 1 or wherein the two external layers of dielectric material with refractive index > 1 are bonded or wherein the deflector is co-molded in a plastic material with refractive index > 1.

4. The assembly, according to one or more of the preceding claims, wherein said matching device comprises at least one layer of dielectric material, or one layer of dielectric material perforated with through-holes of predetermined shape, for example, mono or multi-diameter cylindrical shape, or conical shape, or in the form of a dielectric layer with metallic inclusions.

5. The assembly, according to one or more of the preceding claims, wherein said one or more matching devices comprise one or a plurality of matching layers.

6. The assembly, according to one or more of previous claims, wherein at least one matching device arranged at the outlet of the deflector is included or, alternatively, at least two matching devices are included, between which said deflector is included.

7. The assembly, according to one or more of the preceding claims, wherein said inclusions (300) are arranged defining a grid, said inclusions being positioned in a progressively rotated way passing from one column to the next of the grid or passing from one row to the next of said grid in such a way that said inclusions add, depending on their arrangement, a phase gradient to the incident wave whereby they orient said wave in a certain direction in elevation and azimuth or, alternatively, said inclusions (300) being positioned in a progressively resized manner from one column to the next of the grid or passing from one row to the next of said grid in such a way that said inclusions add, depending on their size variation, a phase gradient to the incident wave whereby they orient said wave in a certain direction in elevation and azimuth.

8. The assembly, according to one or more of the preceding claims, wherein said matching devices are composed of one or more layers of dielectric material, preferably comprising a plurality of metallic or dielectric inclusions (300) and even more preferably with such dielectric inclusions implemented by means of mono or multi-diameter cylindrical or conical shapes in a homogeneous dielectric material.

9. An antenna system, comprising a wave launcher (10, 210) and at least one assembly according to one or more of the preceding claims 1 to 8.

10. The antenna system, according to claim 9, wherein a first and a second assembly are included, according to one or more of the preceding claims from 1 to 8, superimposed one on the other and superimposed on the wave launcher, preferably wherein the wave launcher is fixed while said two assemblies can be rotated independently of each other around their central axis of symmetry or alternatively only one assembly is included, according to one or more of claims 1 to 8, superimposed on the wave launcher, preferably wherein both the wave launcher and said assembly being rotatable independently of each other around one central axis of symmetry thereof.

11. The antenna system, according to claims 9 or 10, wherein the wave launcher is configured to generate one or more beams, preferably said wave launcher being made up, optionally, of at least one of the following alternatives:

- a reflector antenna;
- an RLSA antenna;
- a modulated metasurface antenna;

- a *pillbox* antenna;
- an array of printed antennas and/or dipole antennas and/or horn antennas and/or loop antennas;
- a *Fabry-Perot* cavity antenna;
- a slotted waveguide antenna.

12. The antenna system, according to one or more of the previous claims from 9 to 11, wherein one or more assemblies according to one or more of the previous claims from 1 to 8 are **characterized by** inclined axes of rotation with different angles to form an antenna conforming to a polyhedral surface, for example, of the pyramidal or truncated pyramidal type and illuminated by different launchers.

13. The antenna system, according to one or more of the previous claims from 9 to 12, wherein the wave launcher is constituted by a multi-beam antenna, preferably constituted by a pillbox antenna or compact reflector illuminated by several launchers each generating a beam, this antenna system being able to scan a wide view angle by means of several beams which can be directed according to the rotation of the deflectors.

14. A method of producing an antenna that comprises the steps of:

- arrangement of a wave launcher (10, 210);
- arrangement of a deflection system (20, 30; 210, 220) configured to deflect the wave, said deflection system comprising at least one deflector, preferably of the planar type, comprising a plurality of inclusions (300) configured to add a phase gradient to the wave incident on the deflector;
- and wherein the method comprises the arrangement of the deflector in such a way that it operates in an environment with refractive index greater than one and wherein is included, in addition, the arrangement of one or more matching devices arranged at the outlet from and/or at the inlet to said deflection system, said one or more matching devices being configured to manage passage of the wave from a medium with refractive index greater than one to a medium with refractive index one, preferably air, and/or vice versa, preferably said deflector being arranged in the medium with refractive index greater than 1, even more preferably said arrangement of the deflector in the medium with refractive index greater than one can optionally comprise at least one of the following solutions:
- the production of a multilayer printed circuit with initial and final dielectric layers with refractive index > 1;
- bonding above and below the deflector of a dielectric material with refractive index > 1;
- co-molding the deflector in a plastic material with refractive index > 1.

15. A method of deflecting an electromagnetic wave coming from a wave launcher, the method comprising passage of the wave emitted by the wave launcher through a deflector which adds a phase gradient to the wave coming from said wave launcher and with said deflector that works in an environment with refractive index greater than one and wherein is included the subsequent passage of the wave through at least one matching device configured to manage at least passage of the wave from a medium with refractive index greater than one to a medium with refractive index one and/or vice versa, preferably the medium with refractive index one being air.

FIG.1A

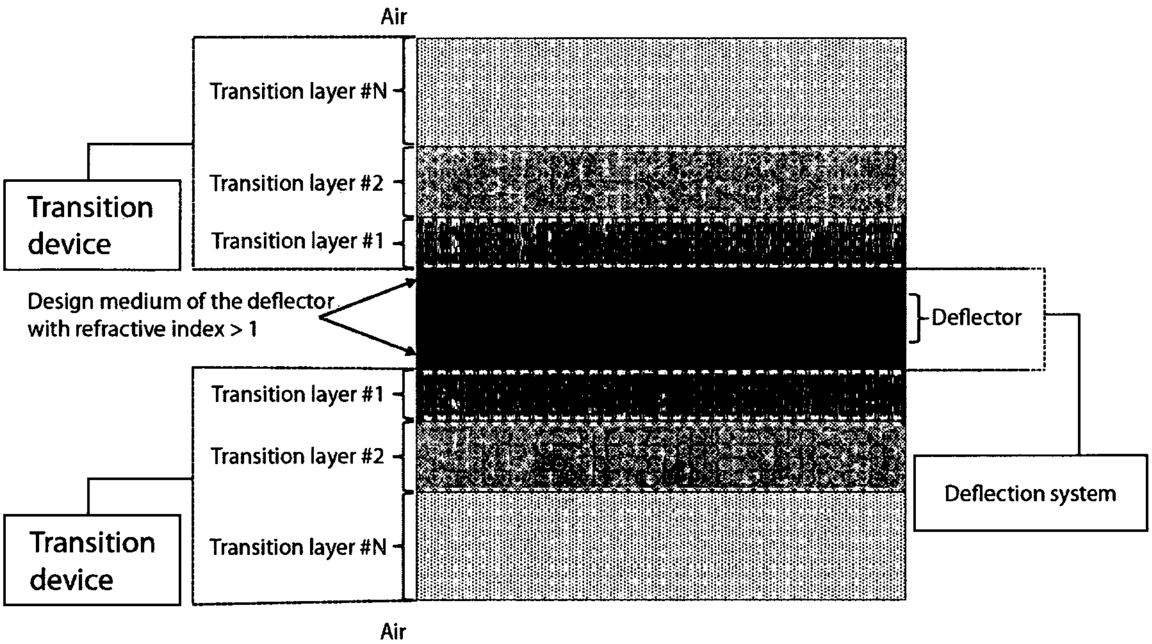

Air
Transition layer #N
Transition layer #2
Transition layer #1
Transition device
Design medium of the deflector with refractive index > 1
Deflector
Transition layer #1
Transition layer #2
Transition layer #N
Transition device
Deflection system
Air

FIG.1B

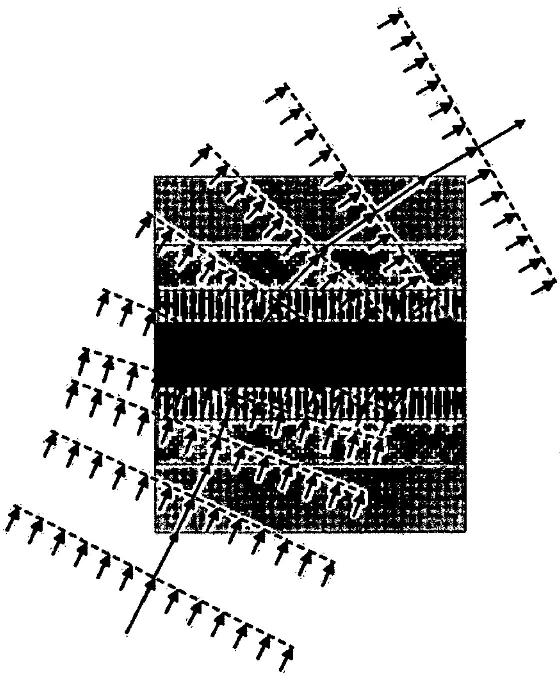


FIG.1

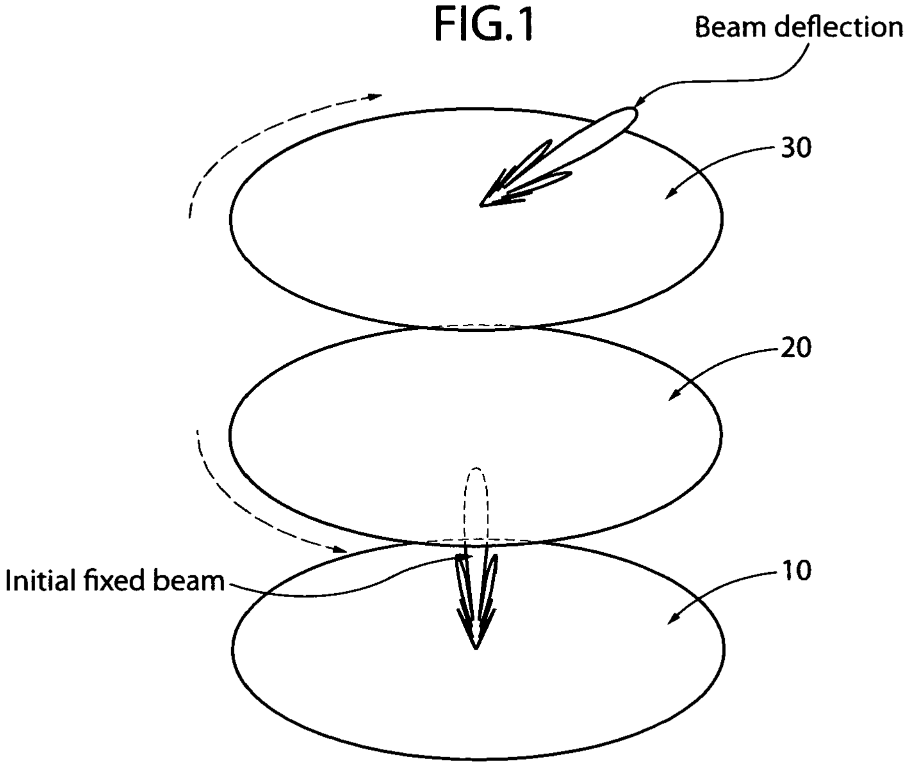


FIG.2

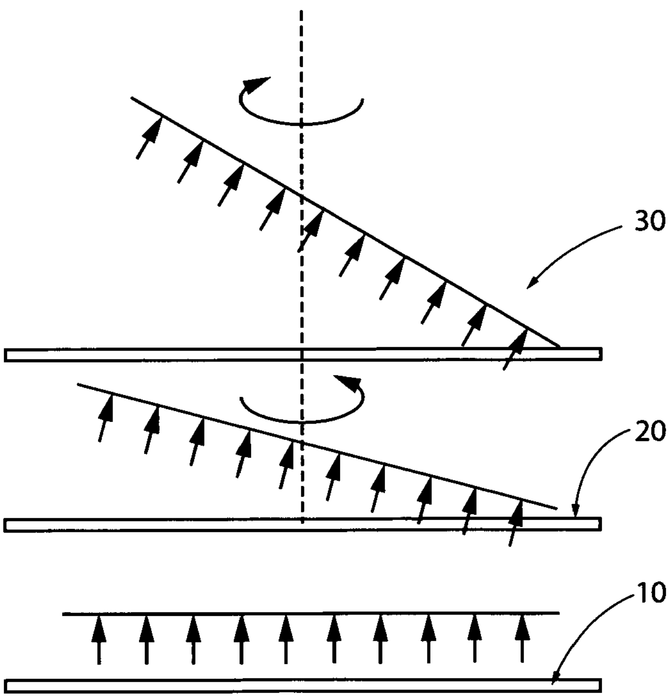


FIG.3

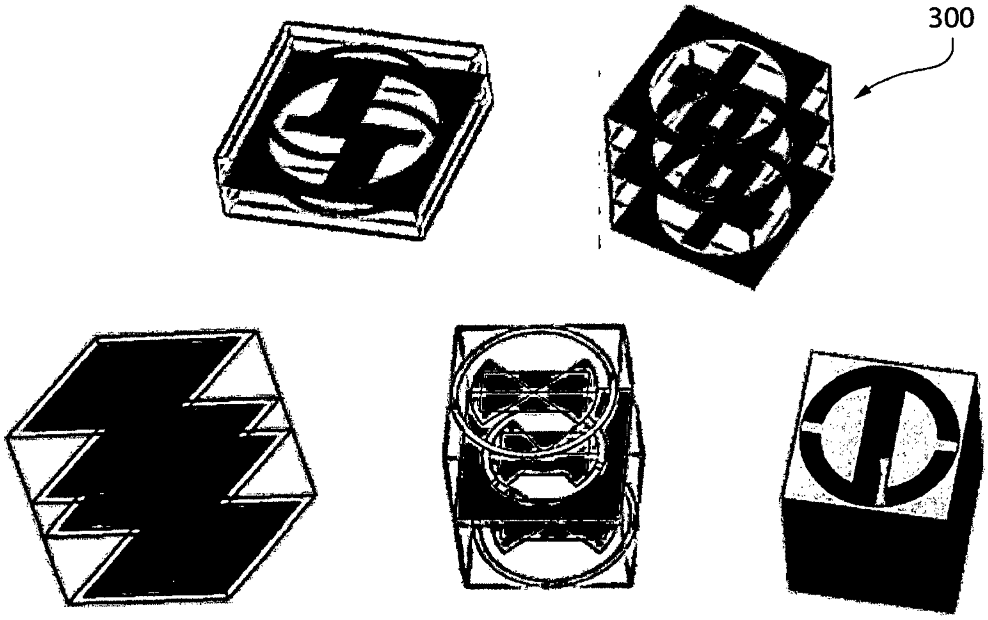


FIG.4

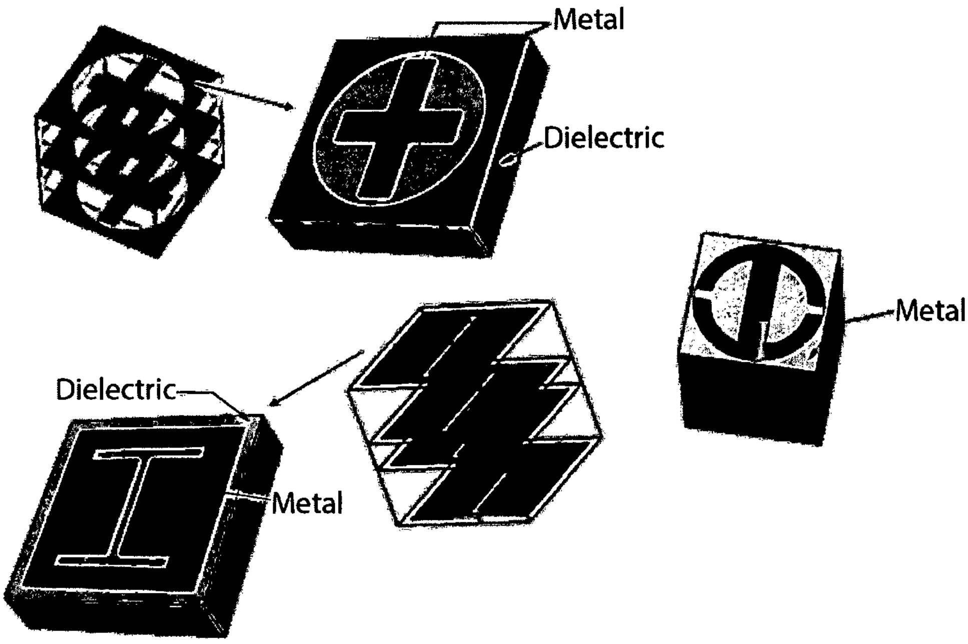
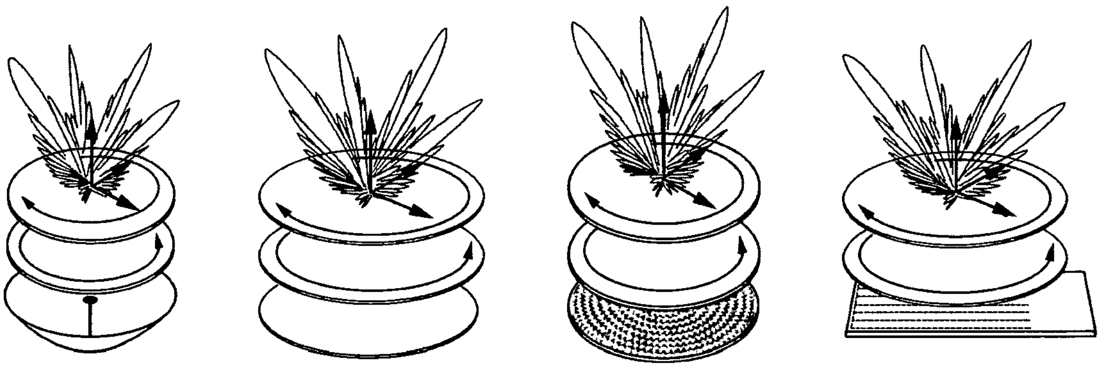


FIG.5



a) b) c) d)

FIG.6

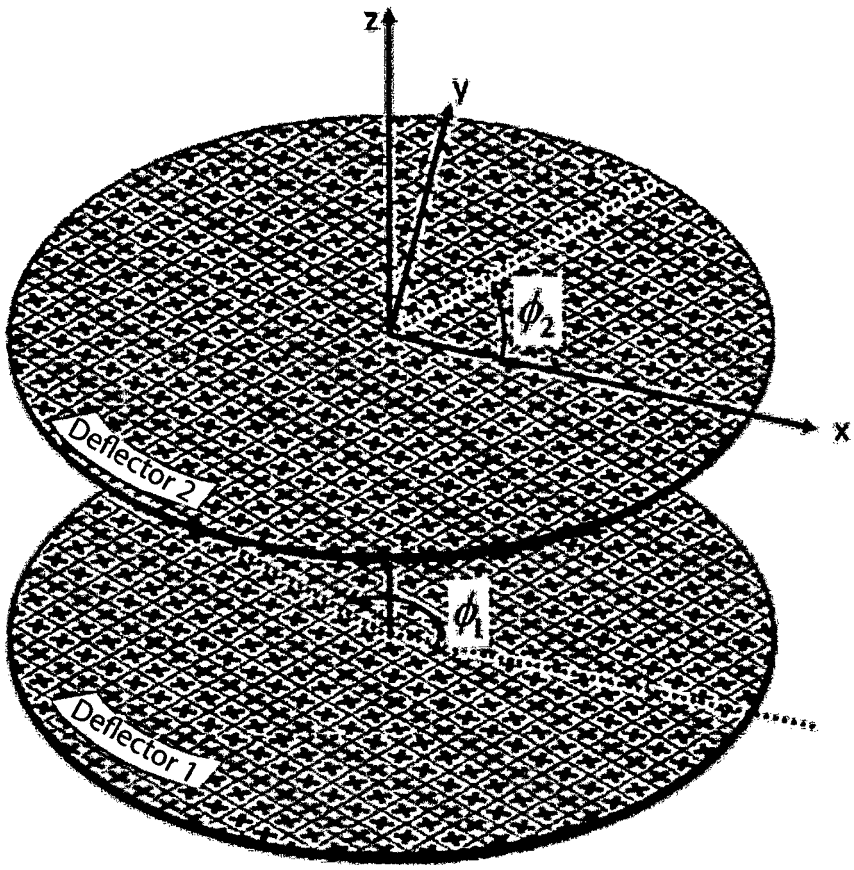


FIG.7

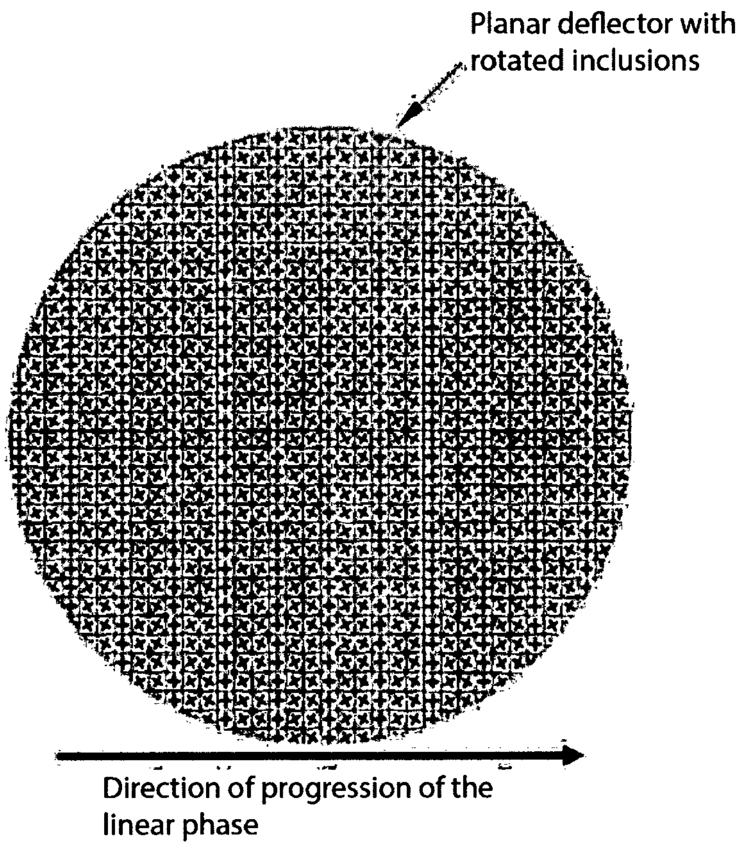

Planar deflector with rotated inclusions
Direction of progression of the linear phase

FIG.7A

Central portion of the deflector of figure 7

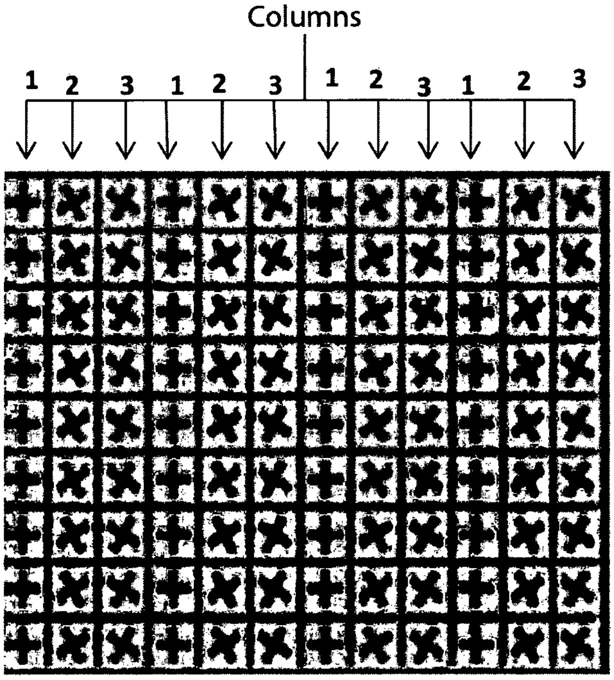


FIG.7B

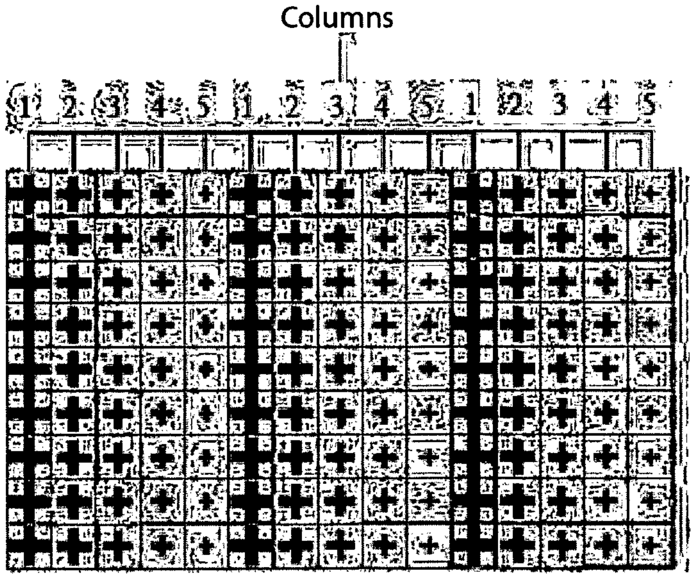


FIG.8

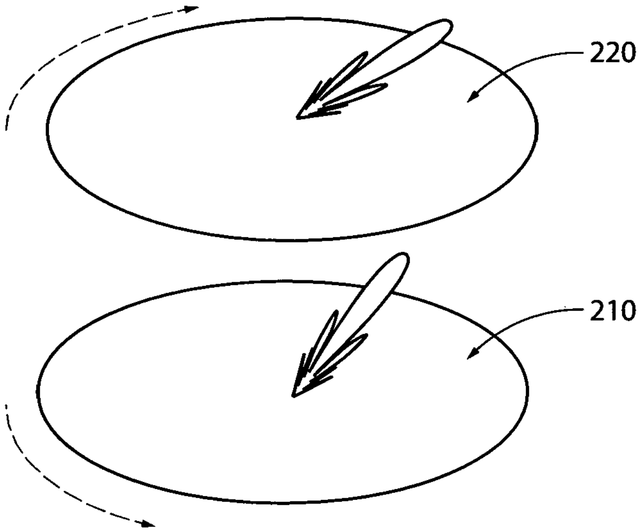

220
210

FIG.9

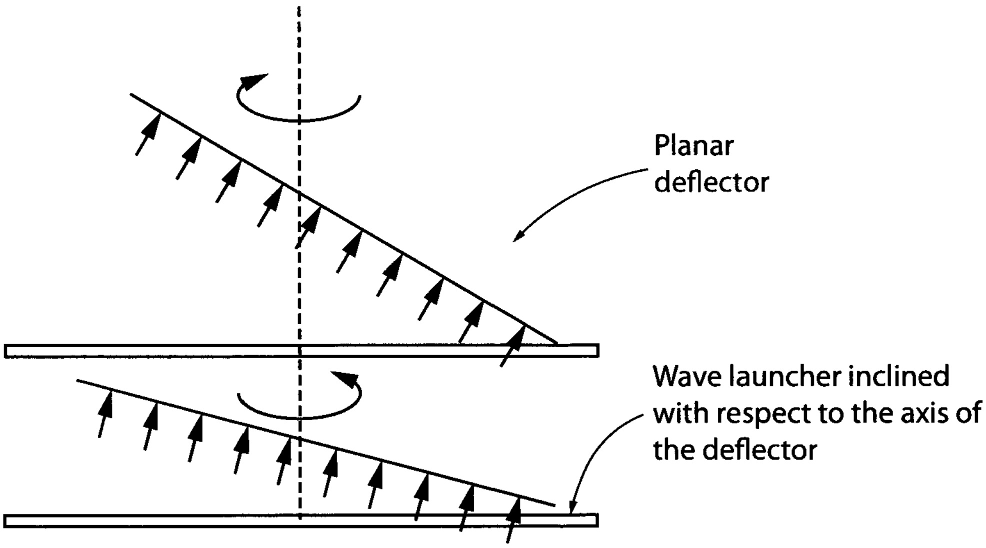

Planar deflector
Wave launcher inclined with respect to the axis of the deflector

FIG.10A

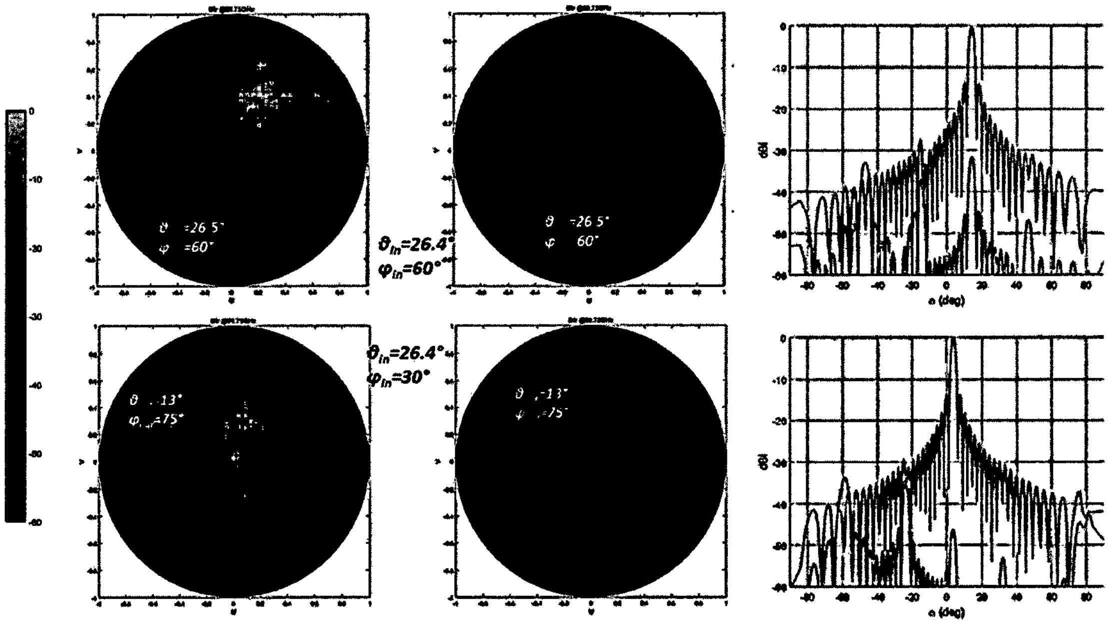


FIG.10B

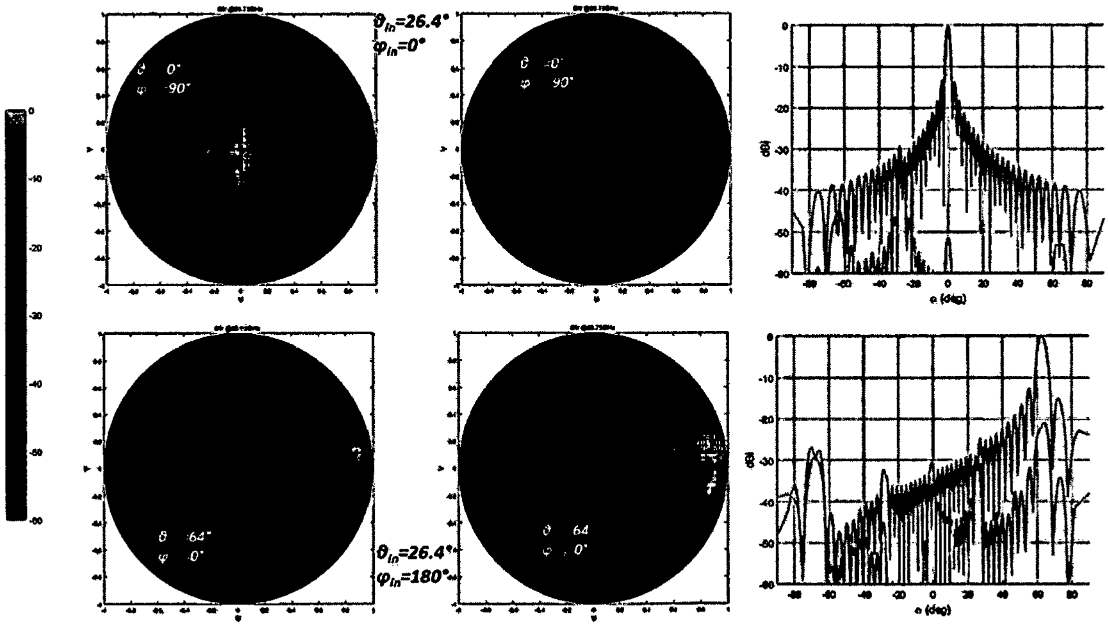
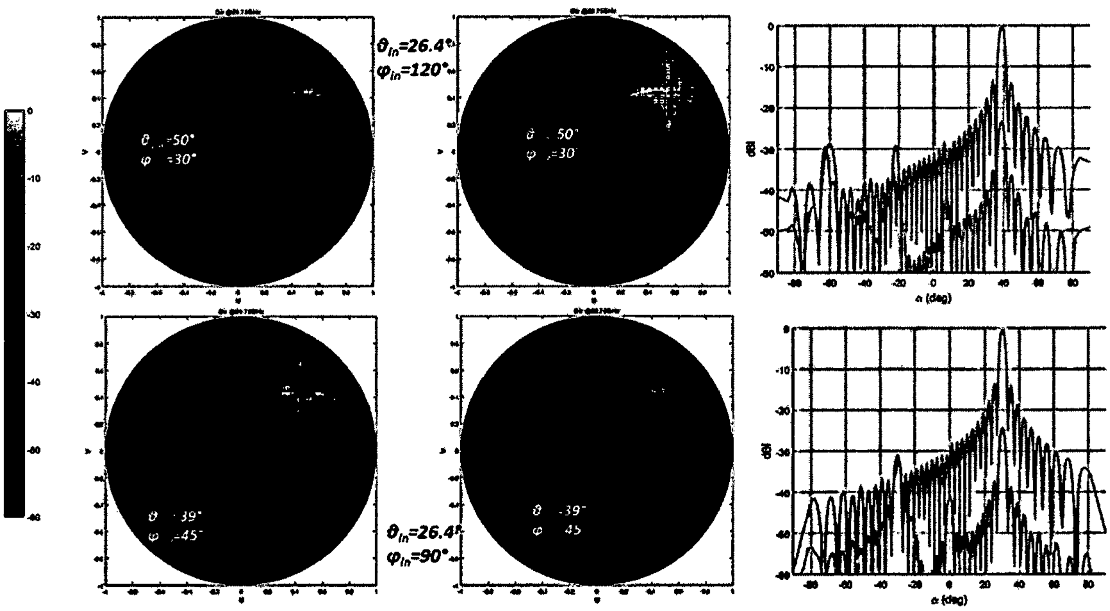


FIG.10C



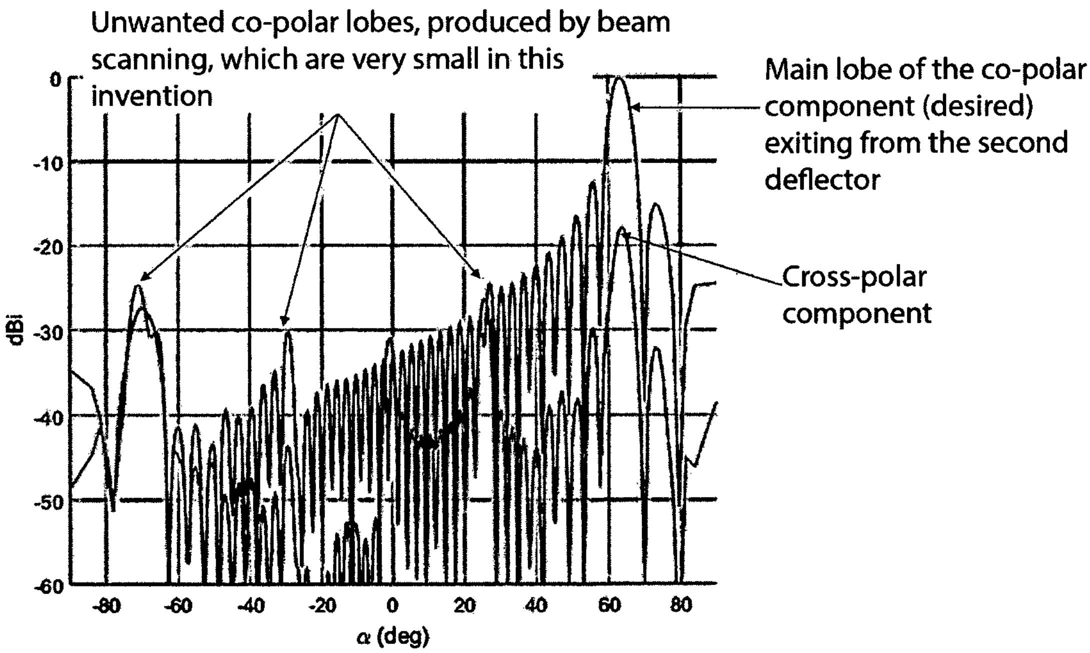


FIG.11

FIG.12

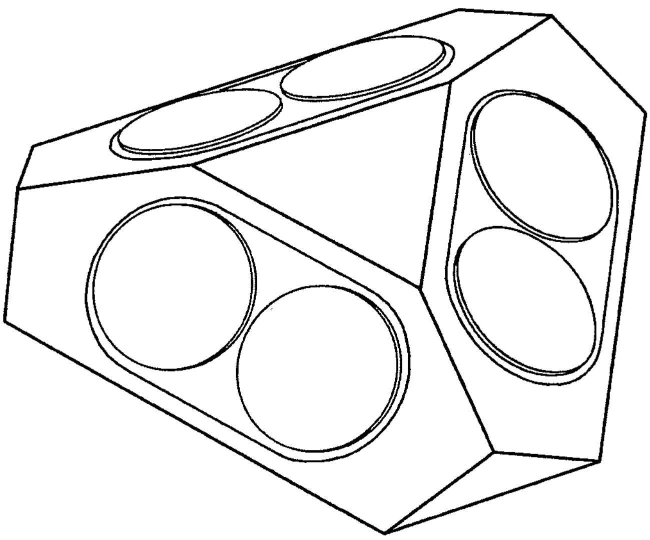


FIG.13

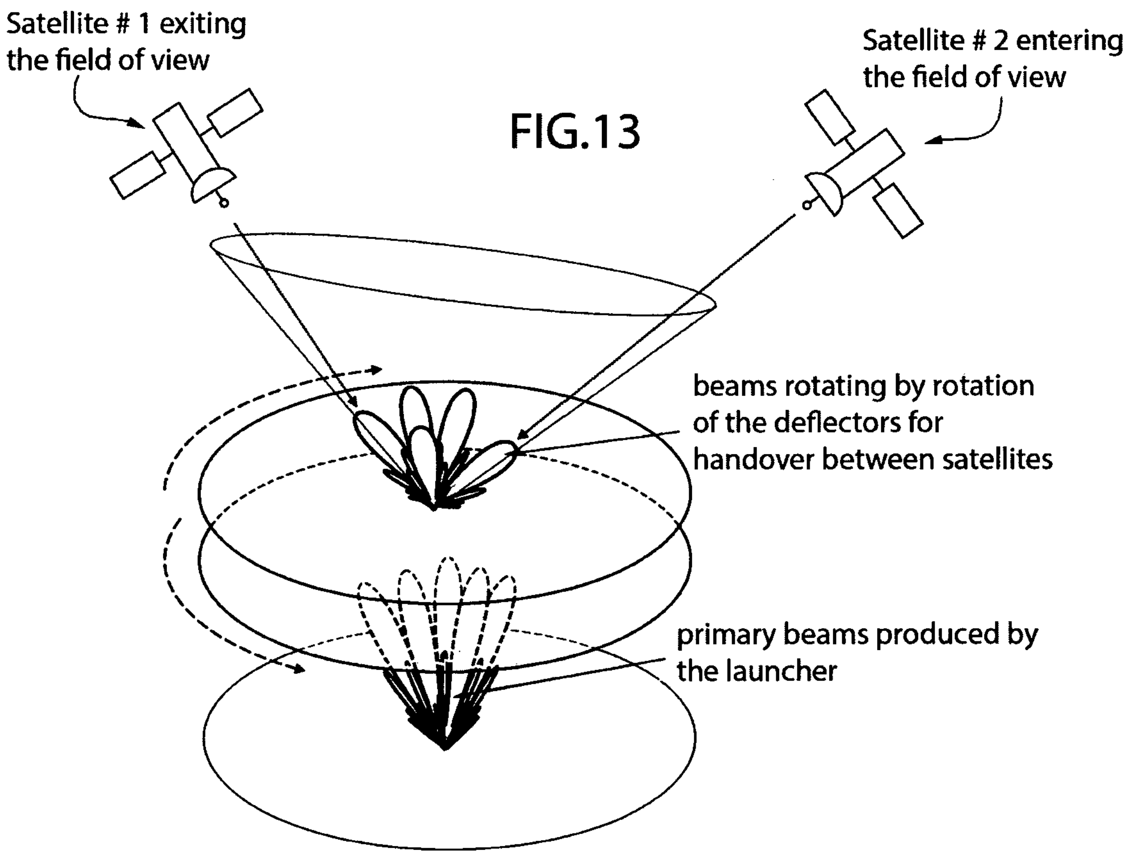

Satellite # 1 exiting
the field of view
Satellite # 2 entering
the field of view
beams rotating by rotation
of the deflectors for
handover between satellites
primary beams produced by
the launcher

FIG.14

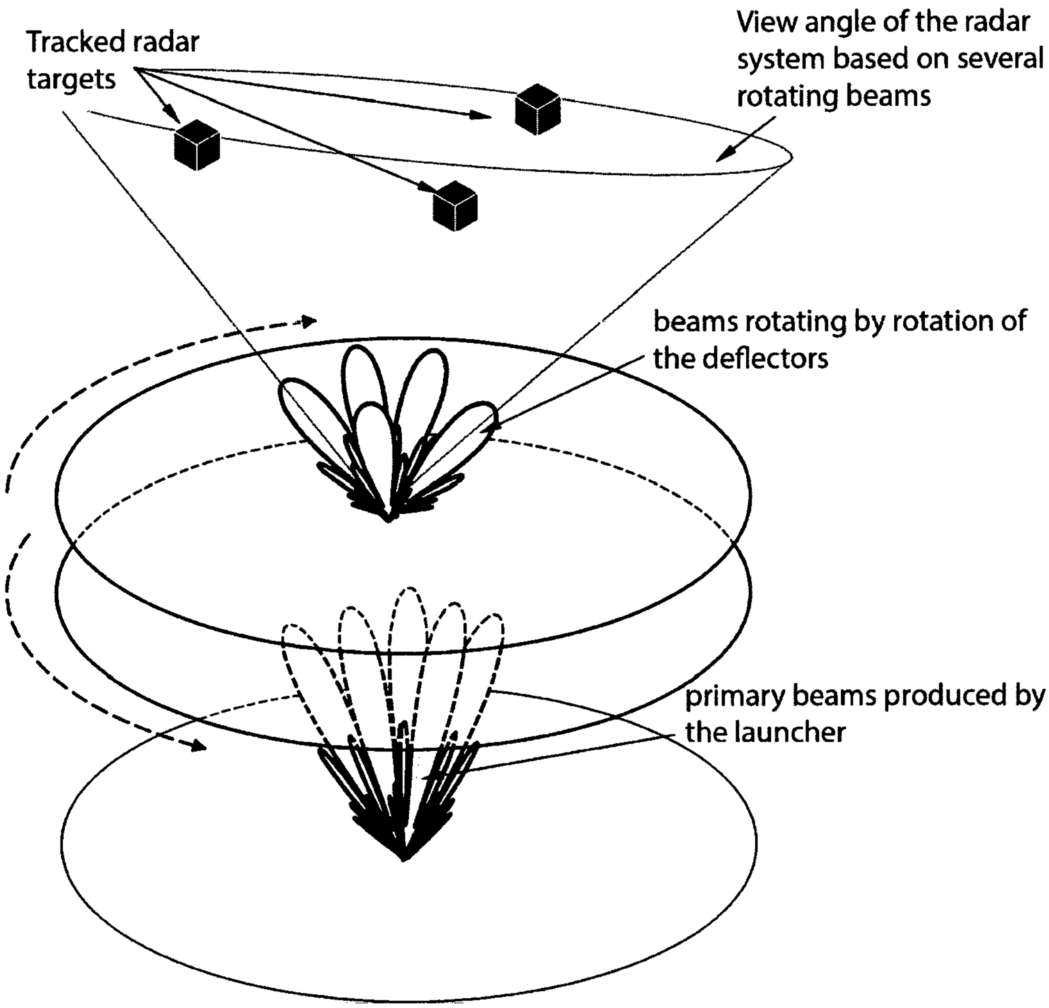

Tracked radar targets
View angle of the radar system based on several rotating beams
beams rotating by rotation of the deflectors
primary beams produced by the launcher

FIG.15

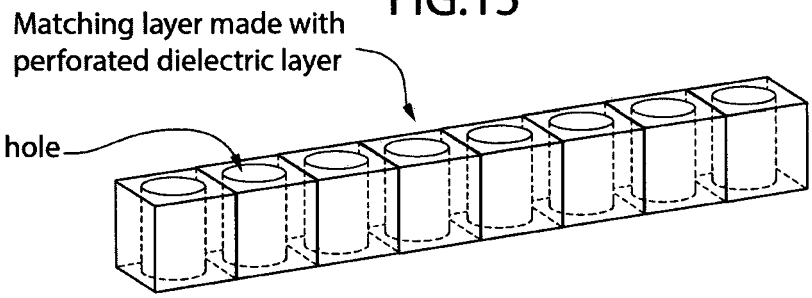

Matching layer made with perforated dielectric layer
hole

FIG.16

Matching device made with conical holes in a dielectric environment

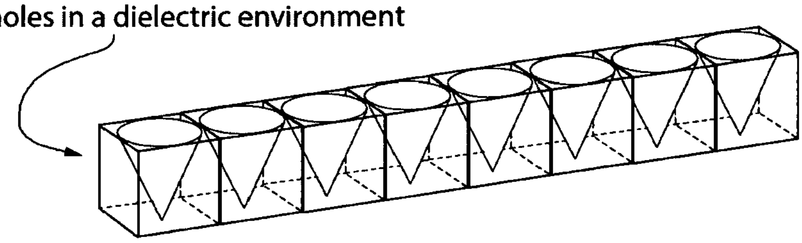


FIG.17

Matching device made with cylindrical holes with variable section in a dielectric environment

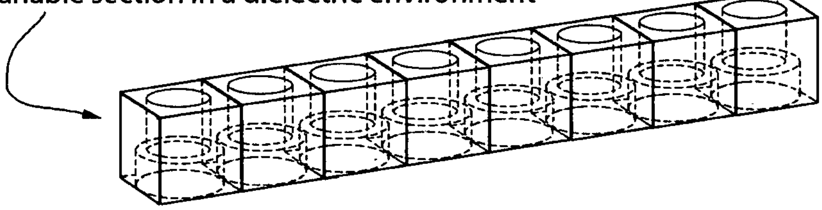


FIG.18

Matching layer made with metallic inclusions in a dielectric environment

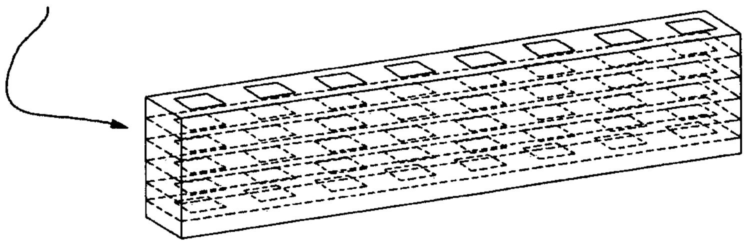
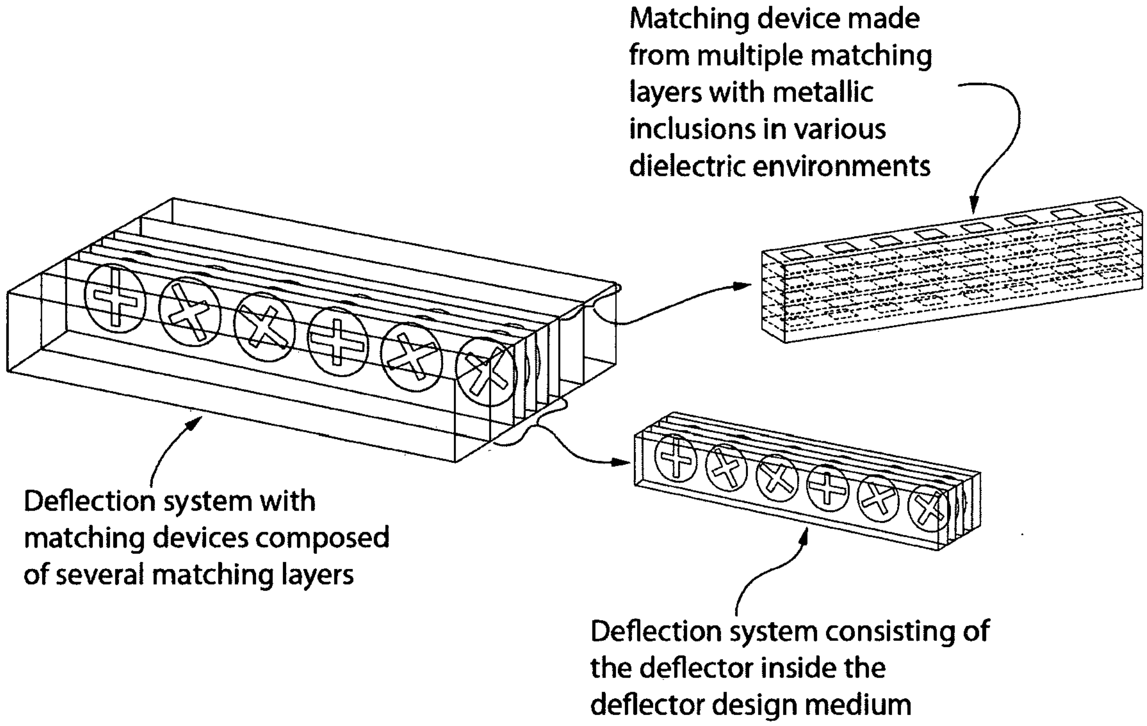


FIG.19


Matching device made from multiple matching layers with metallic inclusions in various dielectric environments
Deflection system with matching devices composed of several matching layers
Deflection system consisting of the deflector inside the deflector design medium

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EUROPEAN SEARCH REPORT

Application Number
EP 21 42 5038

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	US 2008/291101 A1 (BRAUNSTEIN MARK DAVID [US] ET AL) 27 November 2008 (2008-11-27) * figures 2, 3 * * paragraphs [0008], [0021], [0024] - [0026], [0082] *	1-15	INV. H01Q15/10 H01Q1/32 H01Q3/22 H01Q3/14
X	EP 1 976 062 A1 (ITT MFG ENTERPRISES INC [US]) 1 October 2008 (2008-10-01) * figures 1, 2 * * paragraphs [0008] - [0010], [0014], [0030], [0055] *	1-15	
X	US 2014/320361 A1 (LIU RUOPENG [CN] ET AL) 30 October 2014 (2014-10-30) * figures 3, 4 * * paragraphs [0040], [0041] - [0045] *	1-12,14, 15	
X	FR 3 043 499 A1 (THALES SA [FR]) 12 May 2017 (2017-05-12) * figures 3a, 3b * * page 10, lines 14, 15, 32 * * page 16, lines 27-31 * * page 17, lines 1-12 *	1,2, 5-12,14, 15	

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H01Q

2

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	6 January 2022	Taddei, Ruggero

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