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(54) A MICROWAVE ANTENNA, AND A METHOD OF GENERATING FIRST SIGNALS AND DETECTING SECOND SIGNALS

(57) A microwave antenna is provided comprising: a generator of first microwave signals and a detector of second microwave signals, the first microwave signals and second microwave signals being mutually orthogonal in polarisation; an aperture to the outside through which the first microwave signals are transmitted and the second microwave signals are received; a polarisation-selective plate disposed to direct the first microwave signals to the aperture and the second microwave signals to the detector; and in which at least one of the generator and the detector comprises a cluster comprising multiple microwave signal feed horns which are controllably-switchable for at least one of beam-steering and beam-forming.

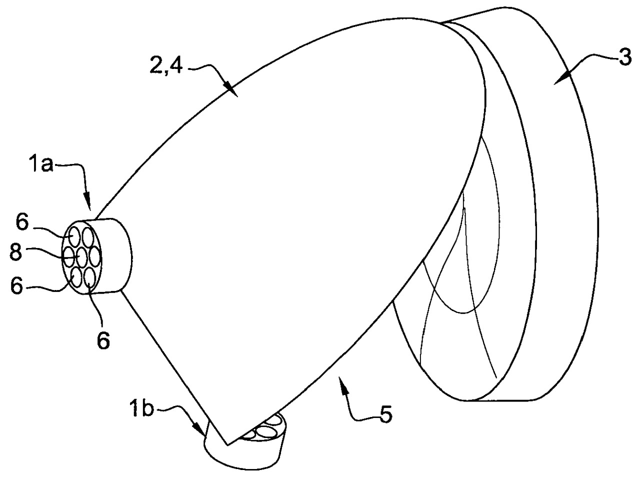

Fig. 2

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Description

Field of the Invention

[0001] The present invention relates to telecommunications, in particular to a microwave antenna, and to a method of generating first microwave signals and a detecting second microwave signals by an antenna.

Description of the Related Art

[0002] Many radio-communication systems involve transmission and reception of signals at the same time. Frequency-division duplexing (FDD) does this by transmitting and receiving at different carrier frequencies.

[0003] For example, in the unlicensed (millimetre-wave) 60-GHz frequency band, which ranges from 57 GHz to 64 GHz, the 57-60 GHz sub-band may be used for transmitting and the 61-64 GHz sub-band for receiving. This leaves the 60-61 GHz band in between as a guard band. In another example, the respective transmit and receive functionalities are provided by two different frequency bands, such as 38 and 60 GHz bands.

[0004] Some microwave antennas are known, for example frequency-division-duplex antennas involving two apertures, one for transmission and one for reception.

Summary

[0005] The reader is referred to the appended independent claims. Some preferred features are laid out in the dependent claims.

[0006] An example of the present invention is a microwave antenna comprising:

a generator of first microwave signals and a detector of second microwave signals, the first microwave signals and second microwave signals being mutually orthogonal in polarisation;

an aperture to the outside through which the first microwave signals are transmitted and the second microwave signals are received;

a polarisation- selective plate disposed to direct the first microwave signals to the aperture and the second microwave signals to the detector; and

in which at least one of the generator and the detector comprises a cluster comprising multiple microwave signal feed horns which are controllably-switchable for at least one of beam-steering and beam-forming.

[0007] Some embodiments involve transmission and reception with mutually-orthogonal linear polarisations, a common transmit-receive antenna aperture, and separating the transmit and receive antenna beams by a simple polarisation-selective plate within the antenna, so that the plate directs the transmit beam from the respective source and the receive beam to the respective detector. The polarisation-selective plate provides for aperture sharing based on polarisation diversity.

[0008] Some embodiments have frequency division duplex (FDD) functionality with a single aperture (but without a diplexer being required). For example, an antenna is provided for frequency-division-duplexing millimetre-wave communication links.

[0009] In some embodiments, each of the abovementioned generator and detector can be configured as a cluster of feeds, whereby one element produces a beam in the boresight direction and the remaining feeds in the cluster produce a selected number of transmit/receive scanned beams. For each beam, the signals from all feeds in the cluster may be combined using a beam-forming algorithm, for example to effectively counteract the swaying and flexing of the pole on which the antenna is mounted, and, at the same time, to take advantage of beam-forming's capability to increase the antenna gain.

[0010] Some embodiments involve steering scanned beams produced by feeds that are displaced relative to each other in the focal plane of the lens, thereby further enhancing the utility of the antenna. The resulting beam steering may be purely electronic, involves no moving parts. This beam steering may be achieved by simple beam-forming in the analog domain. This beam steering may be autonomous in the sense of being without a feedback loop, and is useful to counteract the swaying and flexing of the antenna mounting pole and take advantage of beam-forming's capability to increase the antenna gain. In some embodiments, the transmit and receive beams may be steered independently of each other. In some embodiments, for reduced size, the antenna makes use of multi-beam design, active beam-forming and electronically controlled beam switching.

[0011] Some embodiments include the polarisation-selective plate, the dielectric lens antenna, and beam-steering by feeds displaced in the focal plane of the lens.

[0012] Preferably the generator comprises the cluster which comprises multiple microwave signal transmitting feed horns which are controllably- switchable for at least one of transmission beam-steering and transmission beam-forming. Preferably the detector comprises a cluster comprising multiple microwave signal receiving feed horns which are controllably-switchable for at least one of reception beam-steering and reception beam-forming. Preferably beam-forming coefficients applied at the generator in transmission beam-forming are determined from those applied at the detector in the reception beam-forming.

[0013] Alternatively preferably the detector comprises the cluster which comprising multiple microwave signal receiving feed horns which are controllably-switchable for at least one of reception beam-steering and reception beam-forming.

[0014] Preferably, the first microwave signals are of a first frequency band, and the second microwave signals are of a second frequency band, the first frequency band and second frequency band being different.

[0015] Preferably, the generator provides the first microwave signals along the axis through the plate to the aperture, and the plate is positioned to allow the first microwave signals to pass along said axis. Preferably, the detector is not on said axis, and the second microwave signals are diverted by the plate at an angle to said axis so as to reach the detector. Preferably the first frequency band is higher than the second frequency band.

[0016] Alternatively, preferably the detector receives the second microwave signals along the axis through the plate and the aperture, and the plate is positioned to allow the first microwave signals to pass along said axis. Preferably the generator is not on said axis, and the first microwave signals are diverted by the plate to said axis so as to reach the aperture. Preferably the first frequency band is lower than the second frequency band.

[0017] Preferably the microwave antenna further comprises a lens of dielectric material in the aperture.

[0018] Preferably there is one or more additional polarisation-selective plates disposed for increased polarisation selection.

[0019] Examples of the present invention also relates to corresponding methods. Another example of the present invention relates to a method of generating first microwave signals and detecting second microwave signals by an antenna, in which:

the first microwave signals and second microwave signals are mutually orthogonal in polarisation;
the first microwave signals are transmitted and the second microwave signals are received through an aperture to the outside;
a polarisation- selective plate directs the first microwave signals to the aperture and directs the second microwave signals to the detector; and
in which at least one of the generator and the detector comprises a cluster of microwave signal feed horns which are controllably-switched in use for at least one of beam-steering and beam-forming.

Brief Description of the Drawings

[0020] An embodiment of the present invention will now be described by way of example and with reference to the drawings, in which:

Figure 1 is a cross sectional side view of an antenna according to a first embodiment of the invention,
Figure 2 is an oblique view of the antenna shown in Figure 1, and
Figure 3 is an illustrative back view of a portion of the polarisation-elective plate shown in Figures 1 and 2,
Figure 4 is a diagram illustrating coverage contours of either feed cluster in the azimuth elevation plane where the feed clusters are shown in Figures 1 and 2,
Figure 5 is a diagram illustrating synthesized coverage contours of either feed cluster in the azimuth-elevation plane,
Figure 6 is a diagram illustrating example hardware for beam-forming on the receive path,
Figure 7 is a longitudinal cross sectional view of an antenna according to a second embodiment of the invention,
Figure 8 is an oblique cross-sectional view of the antenna shown in Figure 7,
Figure 9 is an oblique external view of the antenna shown in Figures 7 and 8,
Figure 10 is another oblique external view of the antenna shown in Figures 7,8 and 9,
Figure 11 shows graphs of elevation-plane co-polarized far-field radiation gain patterns for the antenna shown in Figures 7 to 10 but without the microwave absorbing liner, at 60 GHz, without beam-forming; one graph is for where the signal is input via centre of the the axial feed cluster and the other graph is for where the signal is input via the centre of the side feed cluster, and
Figure 12 shows example graphs of elevation-plane co-polarized far-field radiation gain for the antenna shown in Figures 7 to 10 but without the microwave absorbing liner, at 60 GHz, with beam-forming being used (the beam-forming synthesised beams are shown at boresight and when steered to 1.4 degrees and 2.8 degrees from boresight),

Detailed Description

[0021] When considering a known system, the inventors realised that since millimetre-wave antennas for point-to-point communications are required to have a high peak gain, a radiating aperture of an appropriate area is needed to provide that peak gain. The aperture can be a reflector or lens, or be built up in the form of an array from a multitude of radiating elements.

[0022] The inventors realised that a known frequency division duplex (FDD) communication system can, in principle, use a single antenna aperture, but has the disadvantage that a diplexer is required to separate the transmit and receive (sub-) bands. This disadvantage is even more pronounced when beam-steering is required, since many more diplexers are then needed.

[0023] Accordingly, in practical known FDD communication systems, two apertures, i.e. two antennas, are provided, one on either end of the communication link, namely one antenna for transmitting and the other for receiving. If such a system is part of a repeater, which receives signals from a first direction and retransmits them in a second direction, and also receives signals from the second direction and transmits them in the first direction, a total of four antennas are needed to provide the FDD functionality. This increased number of antennas increases the complexity of the communication system and presents problems of accommodation, volume and mass where unobtrusiveness and low structural loads are required, such as on streetlight posts.

[0024] Accordingly, the inventors realised that it is desirable to have an antenna that would provide FDD capability using a single aperture, as opposed to two apertures, thereby reducing complexity, mass and volume.

[0025] The inventors realised that it is possible to provide transmit and receive beams with mutually-orthogonal polarisations, passed via a shared transmit and receive antenna aperture and separated via a polarisation-selective device within the antenna so that the transmit and receive beams are sent to their respective sources/detectors inside the antenna. In this way, FDD functionality is achieved using a single antenna aperture.

[0026] In other words, the inventors realised that an antenna with a single antenna aperture can make use of a polarisation-sensitive plate for aperture sharing by polarisation diversity. The inventors realised that a polarisation-selective plate (as used in gridded parabolic or shaped reflectors used in for example dual gridded reflector antennas) may be positioned in an antenna as a semi-transparent mirror (as used as a beam splitter in for example optical telescopes). The resulting antenna does not need a diplexer to separate the signals nor filters.

[0027] Furthermore, the inventors realised that it is possible to counteract the effects of unintended motions of the antenna, such as caused by wind-induced swaying of the streetlight post on which an antenna is mounted, by using beam-forming to steer the transmit and receive beams.

[0028] We now turn to describing specific examples in more detail.

<u>Example</u> <u>Antenna</u> <u>Structure</u>

[0029] As shown in Figure 1 and 2, the antenna ANT includes a single antenna aperture (not shown). The aperture is provided with a single dielectric lens 3. Two feed clusters 1 of microwave transmit feeds and receive feeds are provided, namely axial feed cluster 1a, which operates with vertical polarisation and side feed cluster 1b, which operates with horizontal polarisation.

[0030] In this example shown in Figures 1 and 2, the axial feed cluster 1a is a cluster of transmit feeds and the side feed cluster 1b is a cluster of receive feeds. In this example, the feeds are feed horns.

[0031] In another otherwise similar example (not shown), the side feed cluster is a cluster of transmit feeds and axial feed cluster is a cluster of receive feeds.

[0032] In this example shown in Figures 1 and 2, transmission and reception is in the same frequency band.

[0033] There is a polarisation-selective plate 2 positioned between the axial feed cluster 1a and the surface of dielectric lens 3 that is internal to the antenna ANT. In use, the plate 2 acts to intercept electromagnetic waves radiated by the axial feed cluster 1a. Specifically the plate 2 is configured and positioned to be effectively transparent to vertically polarized waves, so as to allow the electromagnetic waves radiated by the axial feed cluster 1a to pass unimpeded; and reflective to horizontally polarised waves so as to direct the received waves from the lens 3 towards the side feed cluster 1b. It can thus be considered that the plate 2 folds the optics of the horizontally polarised electromagnetic waves to the side feed cluster 1b.

[0034] As shown in Figure 1, for the purpose of explanation, the respective lens-centre and lens-rim rays are indicated. Specifically, from the axial feed cluster 1a the lens-centre ray is marked 11x and the lens-rim rays are marked as 11y and 11z. Similarly, to the side feed cluster 1b the lens-centre ray is marked 12x and the lens-rim rays are marked as 12y and 12z.

[0035] Since the polarisation-selective plate 2 is inclined by 45° with respect to the lens- centre ray 12x radiated by the side feed cluster 1b, the polarisation-selective plate 2 folds the optics of the electromagnetic rays emanating from the side feed cluster 1b by 90°.

[0036] In the antenna shown in Figures 1 and 2, the polarisation-selective plate 2 is, by way of analogy, positioned like the semitransparent mirror acting as a beam splitter in optical telescopes but functions like the gridded parabolic or shaped reflector used in dual gridded reflector antennas

[0037] Figure 3 shows the back view of a portion of the polarisation-selective plate 2. The plate 2 consists of a substantially regular parallel grid of thin electrically conducting strips 5 supported by a low-loss microwave substrate 4. Referring back to Figures 1 and 2, the strips are mounted on the substrate 4 on the side of the plate that faces towards the lens 3. (In an alternative embodiment (not shown) the strips are instead mounted on the substrate on the side of the plate that faces the axial cluster.)

[0038] In order to reflect horizontally polarized electromagnetic waves, the strips 5 are laid out horizontally, i.e. so as to be co-polarized with the electromagnetic waves.

[0039] The width of the strips and their spacing are carefully selected. The strip width is selected to be not so large as to reduce the electromagnetic transparency of the polarisation-selective plate 2 for vertically polarized (cross-polarized) electromagnetic waves in a given frequency band; and also not so narrow that the strips 5 would pose an appreciable inductance to the surface currents induced in the strips by co-polarized electromagnetic waves.

[0040] Similarly the strip spacing is selected from within a range of what would be acceptable. In contrast, on the one hand, too large a spacing would cause co-polarized electromagnetic waves to not be properly reflected. On the other hand, too small a spacing would lead to a reduced transparency for cross-polarized electromagnetic waves.

[0041] The polarisation-selective plate 2 is manufactured by conventional manufacturing techniques, in this example using known printed-circuit board technology, whereby a grid of parallel traces is etched in a suitable microwave laminate, e.g., Rogers RT/duroid 5880.

Multiple Frequency Bands

[0042] In some other otherwise similar examples (not shown), the axial feed cluster and side feed cluster operate at different frequency bands, in which case, it is generally preferred to assign the lower band to the side feed cluster.

[0043] Specifically, in some similar embodiments, namely antennas in which the axial feed cluster and the side feed cluster are required to operate in different frequency bands, for example the 60- and 38-GHz frequency bands, it is generally advantageous to assign the lower-frequency band to the side feed cluster. This way the spacing of the strips in the polarisation-selective plate is larger than the other way around, thereby posing less obstruction for cross-polarized electromagnetic waves, i.e., the waves radiated by the axial feed cluster. Accordingly, unnecessary reduction is avoided of the electromagnetic transparency of the polarisation-selective plate for the electromagnetic waves radiated by the axial feed cluster.

Lens

[0044] Returning to the Figure 1 and Figure 2 example, it will be noted that use of the polarisation-selective plate 2 is particularly well suited for the lens 3. The see-through nature of lenses eliminates aperture blockage, allowing for a compact accommodation of the polarisation-selective plate 2 and a direct connection of the feed clusters 1a, 1b to the transmitter/receiver (not shown), eliminating the need to use lossy transmission lines to connect to the transmitter/receiver. In addition, the volume of free space between the lens 3 and the feed clusters 1a, 1b that effectively serves as the signal distribution network for the lens also allows for an unproblematic accommodation of the polarisation-selective plate 2. Furthermore, the lens 3 has its two surfaces shaped by a designer so as to control both the amplitude and phase field distributions in the lens aperture (not shown). This is in contrast to a reflector, which offers only one surface to shape giving less control over the amplitude and phase field distribution in the lens aperture.

[0045] In terms of the technology choice for the lens, a dielectric lens is one option, for example lens 3 is a dielectric lens in the example shown in Figures 1 and 2. In other embodiments, another option is a waveguide lens at millimetre-wave frequencies built up from open-ended waveguides of sub-wavelength cross-sections.

[0046] The axial and side feed clusters 1a and 1b are located in the respective axial and side focal planes of the lens 3, whereby the side focal plane is that provided by the polarisation-selective plate 2.

Feed clusters

[0047] In the example shown in Figures 1 and 2, each of the feed clusters 1a, 1b consists of seven sources that are feed horns 6 of circular cross-section. The feed horns 6 are of the dual-mode type, utilizing the TE_{11} and TM_{11} field modes, for circular symmetry of the co-polarized beam and low cross-polarized radiation.

[0048] As is shown in Figure 4, the seven feed horns 6 in each focal plane are spaced so as to produce seven partially overlapping beams 7 when projected into the azimuth-elevation plane. For the reason of providing good coverage, the beam layout has a hexagonal boundary. The coverage contours shown in Figure 4 correspond to the antenna gain levels 3-4 dB below peak.

[0049] (In most communication links, a sway angle of the pole mounted antenna of larger than the antenna 3-dB beamwidth angle will lead to a loss of the communication link. Since the 3-dB beamwidths of point-to-point millimetre-wave antennas are 3° or less, the coverage area radius is chosen to be 3°, as shown in Figure 4.)

[0050] The centre feed horn 8 in each feed cluster provides the boresight beam 9, while the scanned beams are produced by the virtue of relative displacement of the feed horns 6 from the centre feed horn 8 in the focal plane of the lens.

[0051] It is a routine design task to get close to an optimal balance between the lens diameter, the lens focal length, the feed-horn spacing and the feed-horn diameter so as to achieve the coverage beam layout of Figure 4. The required beam spacing and the abovementioned cross-over contour levels, in combination with the need for optimal lens illumination, tend to require closely-packed feed clusters.

Beam-steering/ Beam-forming

[0052] The inventors realised that, in addition, each of the feed clusters is a feed cluster of transmission sources or receivers, where for example sources/receivers in a cluster together provide a transmission/reception beam in the boresight direction.

[0053] Alternatively, the sources/receivers separately provide scanned beams that can be selected between. This is done by combining the signals from selected sources/receivers under the control of a beam-steering/beam-forming controller that uses a beam-steering/beam-forming algorithm. This is useful, for example not only to counteract the movement, such as swaying of the pole on which the antenna is mounted, but also to make use of beam-forming to provide beams of increased antenna gain, namely transmission gain or reception gain.

[0054] The inventors realised that in known point-to-point millimetre-wave communication links, a major problem is the alignment of the link. The regulatory requirements are such that only high-gain antennas, with peak-gain values between 30 dBi and 40 dBi, are used on either end of the link. This means that the 3-dB beamwidths of such antennas are small (3° or less). Consequently, even a very small misalignment between the two antennas on either end of the link leads to a large loss in the link efficiency causing the link to fail. Such misalignment is commonly caused by pole on which the antenna is mounted moving. The movement may be caused by wind (typically fast swaying movements) or thermal-expansion effects (typically slow movements due to flexing). The remote ends of the communication links, where stable mounting is not always possible, are particularly vulnerable to these effects, for example at the top of a pole or mast, or on a residential rooftop.

[0055] The inventors realised that it is, therefore, desirable to equip such a communication link with an effective means for adjusting the beam direction at least at one end of the link in a way that the normally occurring changes in the antenna orientation, and hence in the beam direction, can be counteracted in real time.

[0056] The inventors realised that an antenna can be provided for FDD millimetre-wave communication links that has sufficient beam-steering capability to counteract the variations in antenna orientation in practical installations.

[0057] More specifically, the inventors realised that the use of the polarisation-sensitive plate may be seamlessly integrated with beam steering utilizing scanned beams produced by feed clusters and displaced in the focal plane of the lens. The resulting beam steering is purely electronic, i.e., involves no moving parts; the beam steering is achieved by simple beam-forming in the analog domain. This beam-forming is used to both autonomously (i.e., without a feedback loop) counteract the swaying and flexing of the pole on which the antenna is mounted, and, in addition, take advantage of beam-forming's capability to increase the antenna gain. The resulting antenna makes use of active beam-forming and electronically-controlled switching/steering among beams whilst being of small size.

[0058] In some other otherwise similar embodiments, the transmit and receive beams may be steered independently of each other.

Beam-steering

[0059] As shown in Figure 2, the feed cluster 1a consists of seven sources 6.

[0060] As shown in Figure 4, each of the feed horns 6 provides a corresponding beam 7. Beam-steering is then achieved by dynamically switching between the beams 7 in such a way that one beam at a time is operating.

Alternative beam-steering by beam-forming

[0061] In an otherwise similar embodiment, a more-advanced way to perform beam steering involves beam-forming. Namely, in each feed cluster, an analog beam-former (not shown) is employed to combine signals of all seven feeds to sequentially synthesize nineteen preset beams, whose 3-4 dB below-peak coverage contours are shown in Figure 5.

[0062] For each synthesized beam, signals from all seven feed horns are used, which yields a maximum theoretical peak-gain increase of 10•log 7 = 8.45 dB. This means that the lens may be of a smaller-diameter, as this diameter will suffice to achieve an edge-of-coverage gain value comparable to that obtained when only seven beams are used to populate the coverage area as shown in Figure 4.

[0063] In the receive operation, regularly-repeated dynamic switching among synthesized beams for one-beam-at-a-time operation can again be used, whereby the synthesized beam that provides the strongest signal is used. Since both receive and transmit antennas are mounted on the same platform - i.e., sway the same way - beam-forming coefficients in the transmit operation can be directly derived from those on receive.

[0064] Figure 6 illustrates a possible hardware implementation of beam-forming on receive, utilizing a monolithic microwave integrated circuit (MMIC). A corresponding MMIC on transmit (not shown) employs gain-controlled power amplifiers instead of low-noise amplifiers.

[0065] It will be understood that beam-forming, which is the technology enabler for the beam-steering capability of the antenna, is possible by virtue of having feed clusters, as opposed to just having a single feed.

[0066] As mentioned previously, the axial and side feed clusters each contain seven feed horns. (Note one of the feed clusters is used for transmit, the other for receive.) In order to have beam-forming, each feed cluster acts to, on receive, combine the power received by the seven feed horns and , on transmit, distribute the transmitted power among seven feed horns.

[0067] As shown in Figure 6, this distribution is accomplished by means of power dividers 16 (these are indicated in Figure 6 as the "forks" on the left-hand side showing the power-division ratios, e.g., 1:6) and attenuators 18.

[0068] In order to have beam steering, further to beam-forming, each beam feed cluster needs to also have the capability of controlling the phase of the 7 signals. This is accomplished by means of phase shifters 20.

[0069] As shown in Figure 6, there is a receiver feedback line 21 between a receiver 19 and a control unit 17. The power level of the signal received at the receiver 19 is fed to the control unit 17 which regularly switches among the nineteen sets of beam-forming phase and amplitude settings that correspond to the nineteen synthesised beams shown on Figure 5, to select the set of settings of amplitude (on attenuators 18) and phase (on phase shifters 20) that yields the strongest received signal at that time

[0070] The above description is valid for both transmit and receive. If a feed cluster is used for receive, a low-noise amplifier 22 is used right after each feed horn; on transmit, instead of low-noise amplifiers, power amplifiers are used instead.

[0071] In Figure 6, for simplicity, only three of the seven individual feed horns in the feed cluster are shown (on the right-hand side). The MMIC is located on the rear side of each feed cluster. The MMIC is miniaturized and manufactured in a single integrated assembly for use at millimetre-wave frequencies.

[0072] The MMIC shown in Figure 6 interfaces to the backs of the feed clusters 1a' and 1b' that are shown in Figure 10.

Another Example Antenna

[0073] Another example antenna ANT2 is shown in Figures 7 to 10.

[0074] The antenna was designed for the 60-GHz band. The lens 3' has the diameter of 90 mm, a focal length of 134 mm, and is made of Rexolite (which has a relative dielectric constant of 2.54 and loss tangent of 0.0001 in the 60-GHz band).

[0075] In other similar embodiments, any low-loss dielectric material with a relative dielectric constant between approximately 2 and 4 may be used in place of Rexolite.

[0076] The polarisation-selective plate 2' is made of the Rogers RT/duroid 5880 laminate. The metallic lines of the plate's conductor grid are spaced apart by 0.375 mm and measure 0.075 mm in width. Lines of these dimensions are realized by conventional etching techniques on a 0.25-oz. copper plating.

[0077] Each of the feed clusters 1a', 1b' includes seven feed horns and is produced as an integrated plastic injection-moulded unit or assembly, either metalized or metal-loaded. In addition to the axial feed cluster 1a' and side feed cluster 1b', the polarisation-selective plate 2' and the dielectric lens 3', there is an enclosure (or housing) 4' and an RF-absorbing liner 5' on the inside surface of the enclosure 4'.

[0078] In another similar embodiment (not shown), the RF-absorbing liner is not provided.

[0079] The enclosure 4' serves two main purposes: Firstly, the enclosure 4' holds the functional components of the antenna in place and, secondly, the enclosure protects the inside volume of the antenna from wind, rain etc. The enclosure 4' is made of a dielectric material, namely an extruded plastic pipe, such as of PVC (polyvinyl chloride). Such plastic pipes by their nature of not having been designed for microwave applications, tend to be lossy at microwave and millimetre-wave frequencies, which benefits the proposed antenna, since an enclosure 4' made of a lossy dielectric material reduces the lens-aperture spillover radiation from the feed clusters 1a', 1b'.

[0080] The optional RF-absorbing liner 5' is made of a conventional absorbing material suitable for absorbing millimetre-wave frequencies and may cover the inside surface of the enclosure 4' partly or fully.

[0081] In another example (not shown), the enclosure is made of an electrically conductor material, in which case, an RF-absorbing liner 5' becomes necessary in most applications.

[0082] The feasibility of the proposed antenna was verified by numerical simulations utilizing the full-wave analysis software tool known as CST Studio Suite from CST AG www.cst.com/Content/Products/CST S2/Overview.aspx

[0083] Considering the example as described with reference to Figures 7 to 10, but without the RF-absorbing liner, the computed return loss at each of the seven ports of the axial feed cluster and each of the seven ports of the side feed cluster was found to be better than 26 dB across the 60-GHz band.

[0084] The port-to-port isolation within each of the two feed clusters is better than 30 dB across the 60-GHz band. The port-to-port isolation between any one of the seven ports of the axial feed cluster and any one of the seven ports of the side feed cluster, in other words polarisation isolation, is better than 45 dB across the 60-GHz band. In some further embodiments (not shown) the polarisation isolation performance may be further improved by employing additional polarisation-selective plates (not shown), such as in front of the axial and side feed clusters.

[0085] For the example shown in Figures 7 to 10 but without the RF-absorbing liner, Figure 11 shows a plot of typical elevation-plane co-polarized far-field gain radiation pattern cross-sections when RF power is applied to the centre feed of the axial feed cluster 1a' (solid line) and the centre feed of the side feed cluster 1b' (dashed line). Note the elevation plane is that of the cross-sectional view shown in Figure 7. As can be seen, the main lobes of both pattern cross-sections are, for practical engineering purposes, effectively identical, which confirms that the polarisation-selective plate 2' works as intended, yielding balance between transparency for the vertically polarized signals radiated by the axial feed cluster 1a' and reflectivity for the horizontally polarized signals radiated by the side feed cluster 1b'.

[0086] For the example shown in Figures 7 to 10 but without the RF-absorbing liner, Figure 12 shows a plot of typical elevation-plane co-polarized far-field gain radiation pattern cross-sections when beam-forming is used to synthesize beams:

a. pointed in the antenna boresight direction (solid line graph in Figure 12),
b. Steered to 1.4 degrees (dashed line graph in Figure 12) in elevation, or
c. Steered to 2.8 degrees (dash-dotted line graph in Figure 12) in elevation.

[0087] It can be see that beam-forming is effective in steering the antenna beam, hence making feasible the coverage-contour distribution shown in Figure 5. The peak gain of the antenna is improved in all three cases.

Some possible applications

[0088] With constantly rising demand for fast-deployable and simple microwave links, self-aligning and electronically steerable millimetre-wave links as described above will be useful. This technology is not limited to backhaul or fronthaul applications, but is also applicable in Fifth Generation (5G) access systems.

Further examples

[0089] In a further embodiment (not shown) similar to that shown in Figures 7 to 10, the polarisation isolation performance may be further improved by employing additional polarisation-selective plates (not shown), such as in front of the axial and side feed clusters.

[0090] In some embodiments (not shown), the transmit and receive beams may be steered independently of each other.

[0091] The present invention may be embodied in other specific forms without departing from its essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.

[0092] A person skilled in the art would readily recognize that steps of various above-described methods can be performed by programmed computers. Some embodiments relate to program storage devices, e.g., digital data storage media, which are machine or computer readable and encode machine-executable or computer-executable programs of instructions, wherein said instructions perform some or all of the steps of said above-described methods. The program storage devices may be, e.g., digital memories, magnetic storage media such as a magnetic disks and magnetic tapes, hard drives, or optically readable digital data storage media. Some embodiments involve computers programmed to perform said steps of the above-described methods.

Claims

1. A microwave antenna comprising: a generator of first microwave signals and a detector of second microwave signals, the first microwave signals and second microwave signals being mutually orthogonal in polarisation;
an aperture to the outside through which the first microwave signals are transmitted and the second microwave signals are received;
a polarisation- selective plate disposed to direct the first microwave signals to the aperture and the second microwave signals to the detector; and
in which at least one of the generator and the detector comprises a cluster comprising multiple microwave signal feed horns which are controllably-switchable for at least one of beam-steering and beam-forming.

2. A microwave antenna according to claim 1, in which the generator comprises the cluster which comprises multiple microwave signal transmitting feed horns which are controllably- switchable for at least one of transmission beam-steering and transmission beam-forming.

3. A microwave antenna according to claim 2, in which the detector comprises a cluster comprising multiple microwave signal receiving feed horns which are controllably-switchable for at least one of reception beam-steering and reception beam-forming.

4. A microwave antenna according to claim 3, in which beam-forming coefficients applied at the generator in transmission beam-forming are determined from those applied at the detector in the reception beam-forming.

5. A microwave antenna according to claim 1, in which the detector comprises the cluster which comprising multiple microwave signal receiving feed horns which are controllably-switchable for at least one of reception beam-steering and reception beam-forming.

6. A microwave antenna according to any preceding claim, in which the first microwave signals are of a first frequency band, and the second microwave signals are of a second frequency band, the first frequency band and second frequency band being different.

7. A microwave antenna according to any preceding claim, in which the generator provides the first microwave signals along the axis through the plate to the aperture, and the plate is positioned to allow the first microwave signals to pass along said axis.

8. A microwave antenna according to claim 7, in which the detector is not on said axis, and the second microwave signals are diverted by the plate at an angle to said axis so as to reach the detector.

9. A microwave antenna according to claim 8, in which the first microwave signals are of a first frequency band, and the second microwave signals are of a second frequency band, the first frequency band and second frequency band being different, and the first frequency band is higher than the secondary frequency band.

10. A microwave antenna according to any of claims 1 to 6, in which the detector receives the second microwave signals along the axis through the plate and the aperture, and the plate is positioned to allow the first microwave signals to pass along said axis.

11. A microwave antenna according to claim 10, in which the generator is not on said axis, and the first microwave signals are diverted by the plate to said axis so as to reach the aperture.

12. A microwave antenna according to claim 11, in which the first microwave signals are of a first frequency band, and the second microwave signals are of a second frequency band, the first frequency band and second frequency band being different, and the first frequency band is lower than the second frequency band.

13. A microwave antenna according to any preceding claim, further comprising a lens of dielectric material in the aperture.

14. A microwave antenna according to any preceding claim, comprising one or more additional polarisation- selective plates disposed for increased polarisation selection.

15. A method of generating first microwave signals and detecting second microwave signals by an antenna comprising a generator and a detector, in which
the first microwave signals and second microwave signals are mutually orthogonal in polarisation,
the first microwave signals are transmitted and the second microwave signals are received through an aperture to the outside,
a polarisation- selective plate directs the first microwave signals to the aperture and directs the second microwave signals to the detector;
in which at least one of the generator and the detector comprises a cluster of microwave signal feed horns which are controllably-switched in use for at least one of beam-steering and beam-forming.

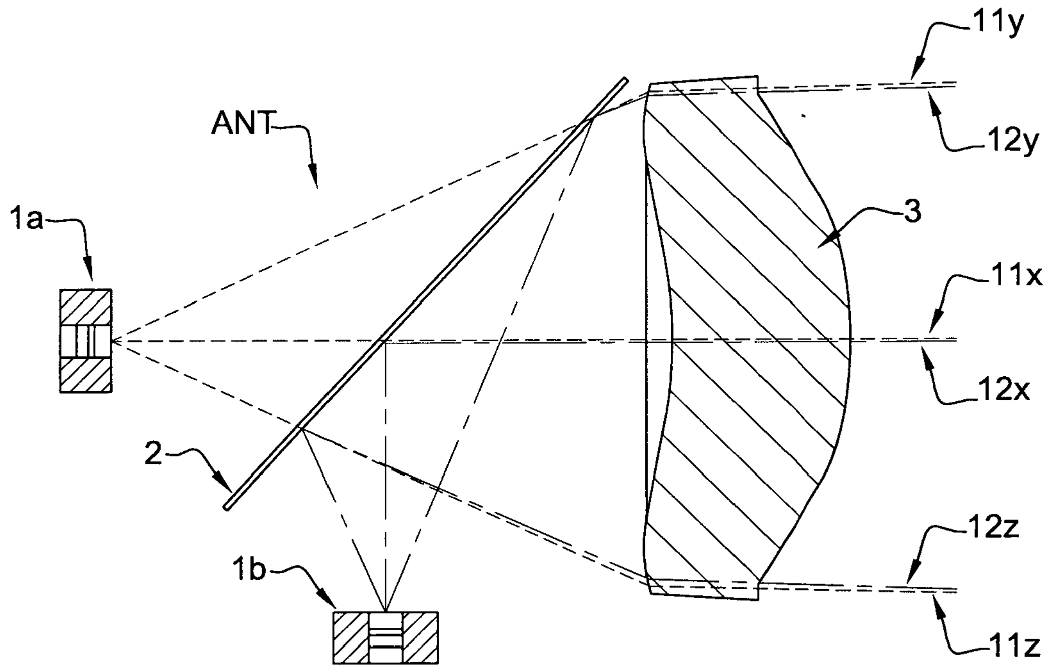

Fig. 1

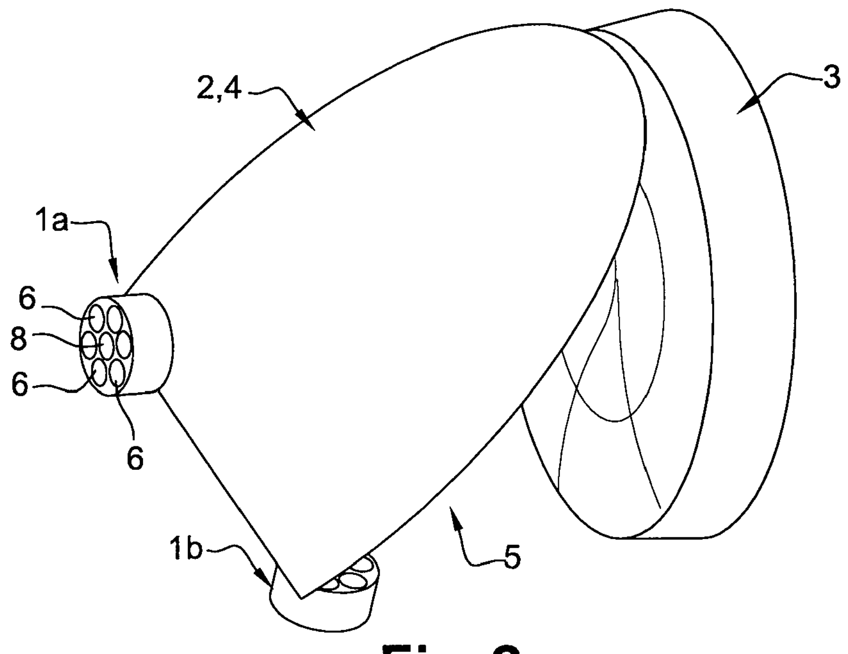

Fig. 2

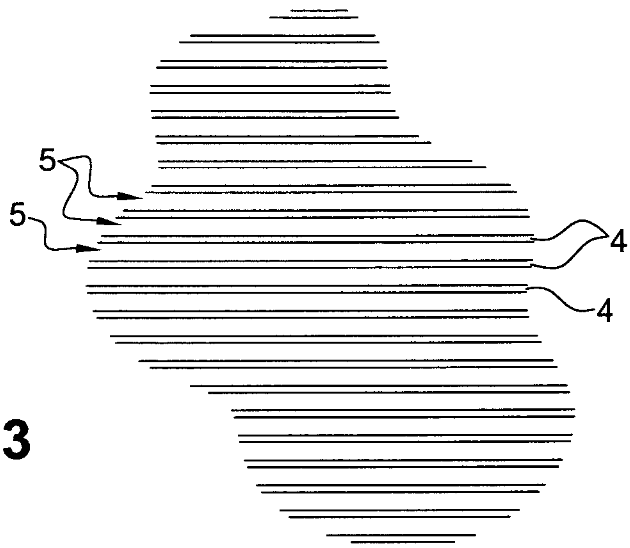

Fig. 3

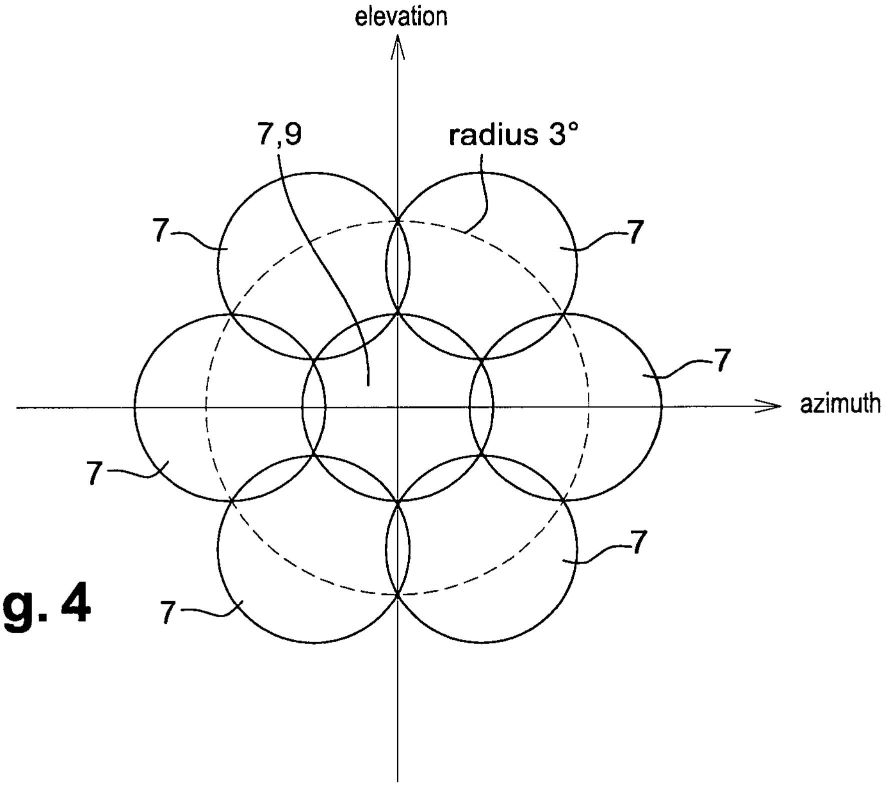

Fig. 4

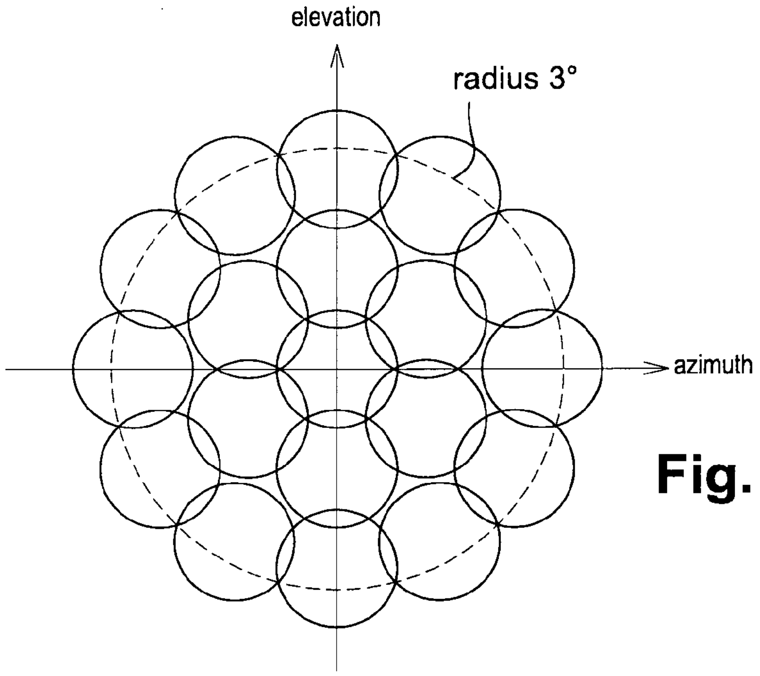
elevation
radius 3°
azimuth

Fig. 5

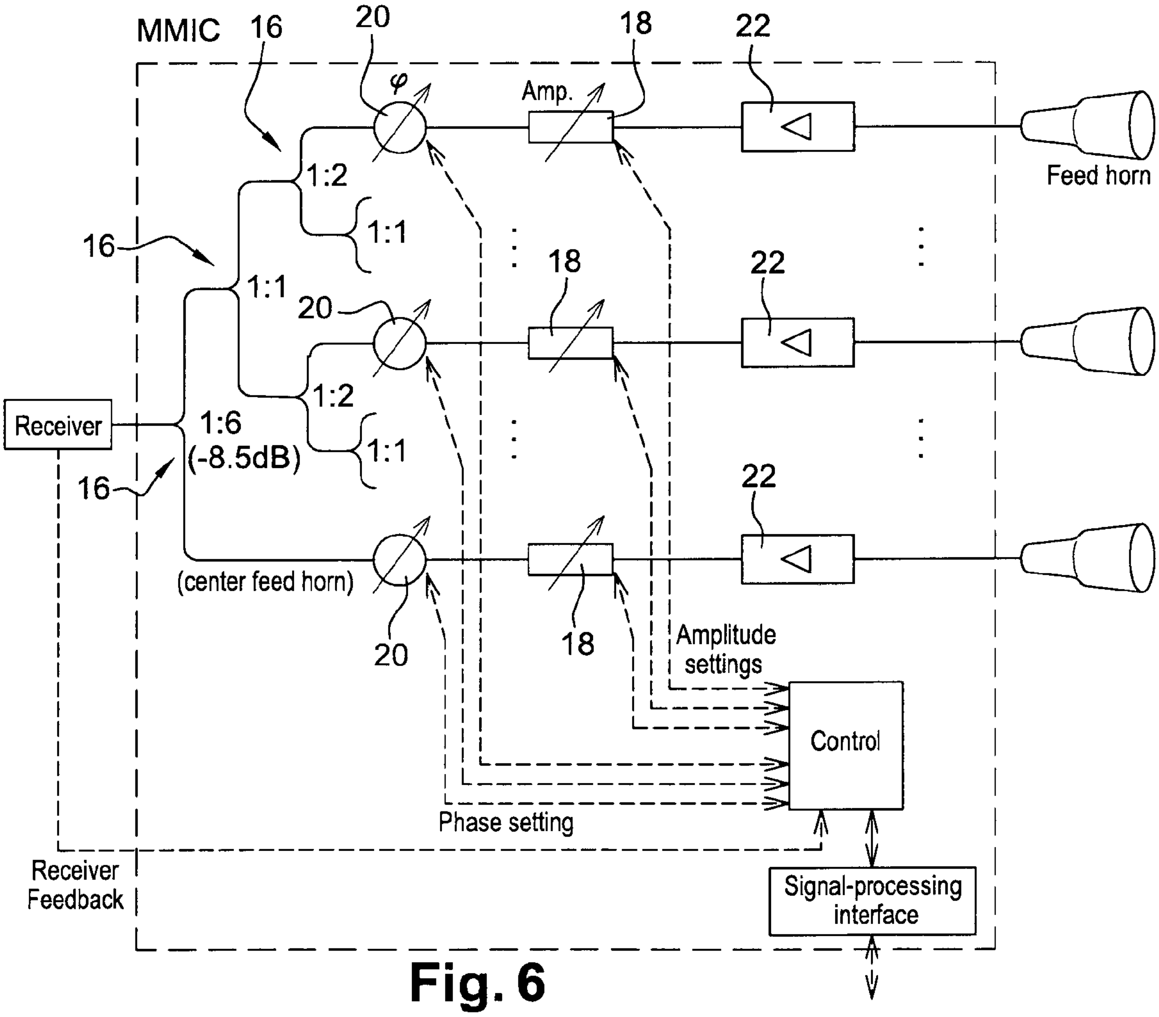
MMIC
16
20
18
22
φ
Amp.
Feed horn
1:2
1:1
16
1:1
20
1:2
1:1
Receiver
1:6
(-8.5dB)
16
(center feed horn)
Amplitude
settings
Control
Phase setting
Receiver
Feedback
Signal-processing
interface

Fig. 6

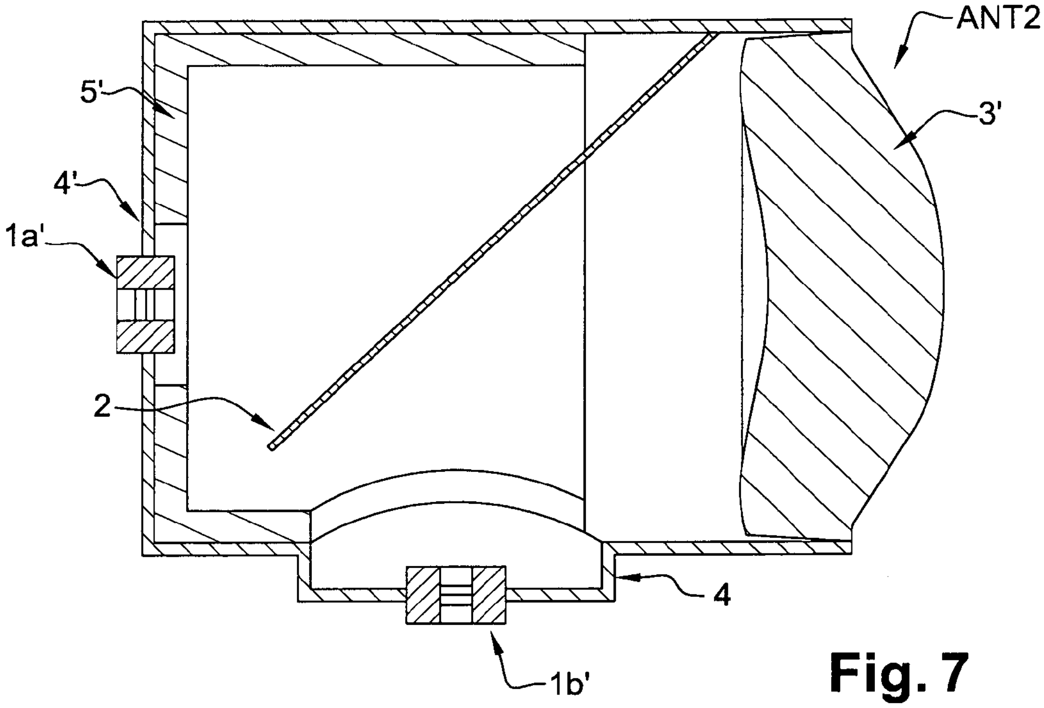

Fig. 7

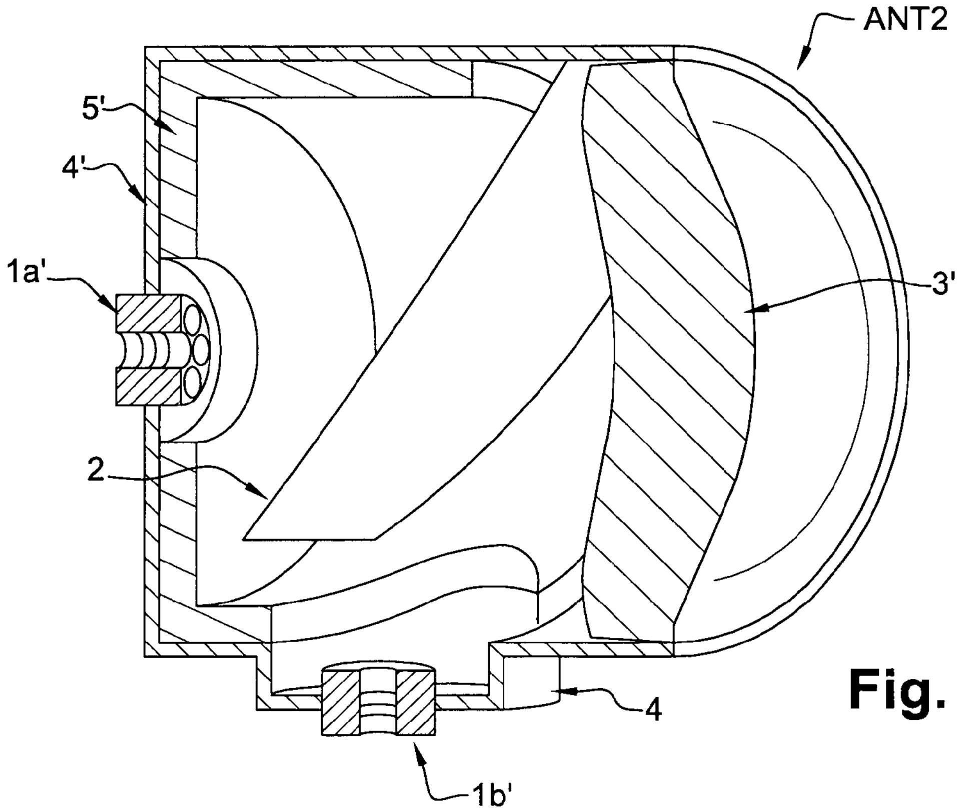

Fig. 8

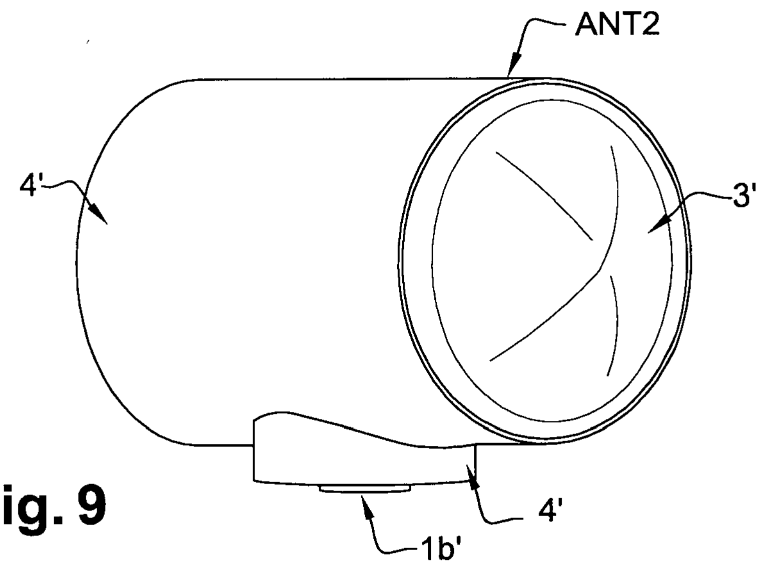

Fig. 9

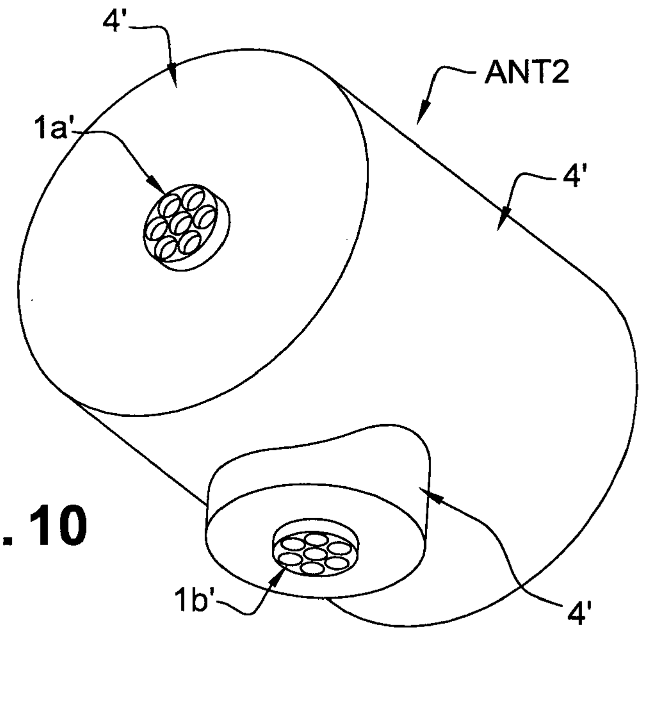

Fig. 10

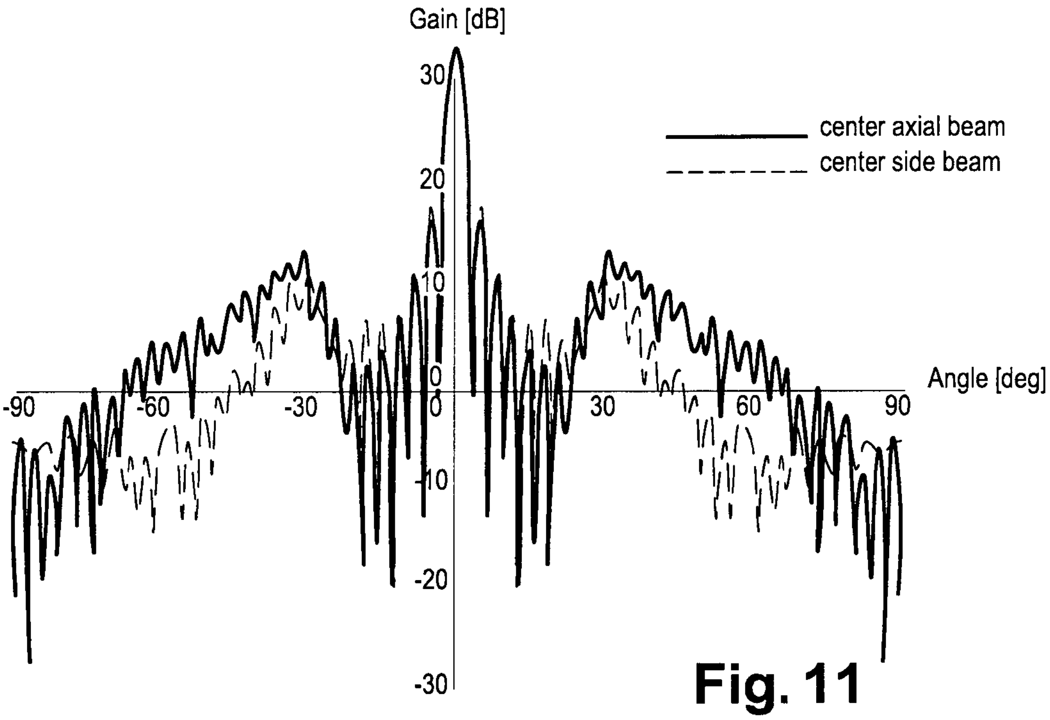
Gain [dB]
30
20
10
0
-10
-20
-30
center axial beam
center side beam
Angle [deg]
-90
-60
-30
0
30
60
90

Fig. 11

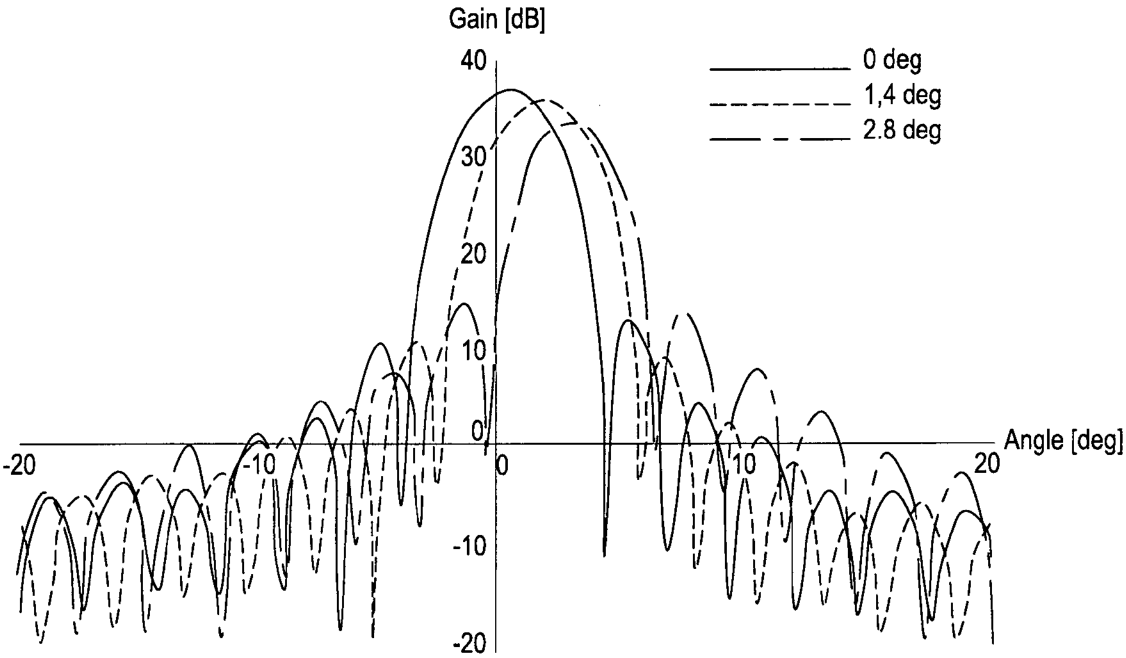
Gain [dB]
40
30
20
10
0
-10
-20
0 deg
1,4 deg
2.8 deg
Angle [deg]
-20
-10
0
10
20

Fig. 12

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EUROPEAN SEARCH REPORT

Application Number
EP 15 29 0095

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A	FR 2 538 959 A1 (THOMSON CSF [FR]) 6 July 1984 (1984-07-06) * pages 1,5,6; figure 2 * -----	1-15	
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A	WO 2009/151819 A1 (LOCKHEED CORP [US]; HSU CHIH-CHIEN [US]; RAO SUDHAKAR K [US]) 17 December 2009 (2009-12-17) * abstract; figure 12 * -----	1-15	
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			H01Q

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	9 October 2015	Ribbe, Jonas

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