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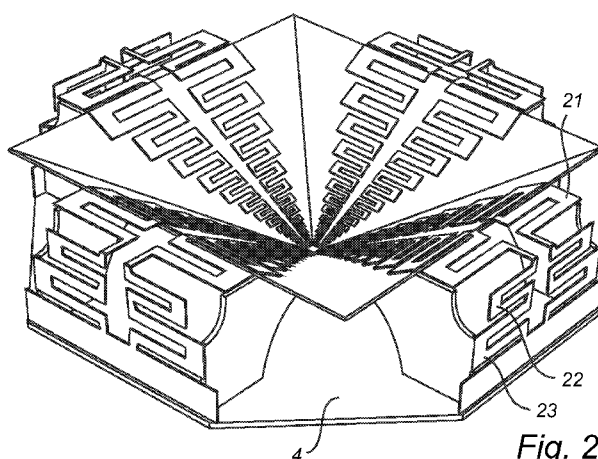
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- (54) **Title:** IMPROVED BROADBAND MULTI-DIPOLE ANTENNA WITH FREQUENCY-INDEPENDENT RADIATION CHARACTERISTICS



**Fig. 2**

(57) **Abstract:** An improved eleven antenna is disclosed, comprising a conducting body acting as a ground plane; and at least one pair of log-periodic dipole arrays arranged above the ground plane, the dipoles of said pair of log-periodic arrays of dipoles forming dipole pairs of parallel and oppositely located dipoles of the same dimensions and arranged in such a way that the geometrical centres of each of said dipole pairs and their images in the ground plane are coinciding, wherein each dipole is a folded dipole comprising two or more parallel or nearly parallel conducting strips that are connected at one or more points or over an extended part of the conducting strips. Further, a plurality of the folded dipoles, within each of said log-periodic dipole array, being closer to said geometrical centre are extending in a first plane, and wherein the remaining at least one folded dipole being located most far away from said geometrical centre is arranged to extend in at least one additional plane, said additional plane(s) forming an angle relative to said first plane. Hereby, a more compact antenna is achieved.



IMPROVED BROADBAND MULTI-DIPOLE ANTENNA WITH FREQUENCY-  
INDEPENDENT RADIATION CHARACTERISTICS

Field of the invention

The present invention relates to a broadband multi-dipole antenna, and in particular an antenna that has low input reflection coefficient, low cross polarization, rotationally symmetric beam and constant beam width and phase centre location over  
5 octave bandwidth or more, or over multiple frequency bands together covering octave bandwidth or more.

Background

Reflector antennas find a lot of applications such as in e.g. radio-link point-to-point and point-to-multipoint systems, radars and radio telescopes. Modern reflector  
10 antennas are often fed by different types of corrugated horn antennas. They have the advantage compared to other feed antennas that they can provide a rotationally symmetric radiation pattern with low cross polarization over a large frequency band. It is also possible with appropriate choice of dimensions to obtain a beam width that does not vary with frequency. Still, the bandwidth is normally limited to about an  
15 octave. Corrugated horns are also expensive to manufacture, in particular at low frequency where their physical size and weight become large.

Reflector antennas are mass-produced for some markets, in particular when they are small and up to about a meter in diameter, such as e.g. for application to satellite TV reception or for radio communication links between base stations in a  
20 mobile communication network. Even within radio astronomy there are proposals for radio telescopes that consist of several cost-effective mass-produced antennas, such as the Allen telescope array (ATA) and the square kilometer array (SKA). ATA is already being realized in terms of mass-produced large reflector antennas, and there exist similar proposals for SKA. The requirement for bandwidth is incredible in both  
25 ATA and SKA, covering several octaves. In some proposed future mobile and wireless communication systems there are also requirements for antennas with large bandwidth. Such systems are often referred to as ultra wide band (UWB) systems and the broadband antenna technology as UWB antennas. As a result of the above there is a need for new types of broadband antennas, in particular antennas that can be used to  
30 feed reflectors in an efficient way.

There is also other commercial interests in both broadband and multiband antenna technologies, e.g. for satellite communication (satcom). The ground terminal

of a satcom system is very often a reflector antenna, and it is a desire to combine several satcom frequency bands in one antenna, e.g. two or more of the so-called L-, S-, C-, X, Ku- and Ka-bands. In order to do this, broadband or multiband feeds are of interest.

5           For satcom applications it is also of interest to use an antenna that can provide information about the position of the satellite relative to the pointing direction of the antenna, in such a way that the antenna can be moved to point exactly at the satellite. This is referred to as tracking, and such antennas have tracking capabilities. One way to obtain such pointing information is by using a feed with several ports that can be  
10 combined to provide so-called tracking (or difference) patterns in both horizontal and vertical planes in addition to the common (and in this connection so-called “sum”) pattern over which the communication signals are transferred. The levels and phases of the signals received via the two tracking patterns, relative to the amplitude and phase of the signal received via the sum pattern, gives information about the position  
15 of the satellite relative to the pointing direction of the antenna. Therefore, there is also a need for multiport reflector feeds for tracking purposes.

Multiport antennas are also needed in future proposed communication systems for use in environments with fading, i.e. having large signal level variations between the transmit antenna port and the receive antenna port due to interference between  
20 many reflected and scattered propagation paths from the transmitting to the receiving side. The signal level in the interference minima will be so low that it causes reception problems. These problems can be reduced by setting up more channels between the transmitting and receiving sides, by using antennas with many ports, i.e. multiport antennas. Such communication systems designed for an optimum spatial  
25 distribution of the information between the different channels are commonly referred to as MIMO systems (multiple input multiple output). Multiport antennas for such systems should have uncoupled ports (to give uncorrelated channels) and high radiation efficiency, whereas there ideally in a rich and isotropic multipath environment is no requirement to the antenna gain and directivity. However, it may  
30 be desirable with an extra directive beam, because there may in reality often be a line-of-sight component present in the environment. Therefore, there is a need for adaptive or reconfigurable multiport antennas that has efficient uncoupled ports, and in addition can provide an additional directive beam. Such antennas can with advantage be wideband to cover more communication systems, and compact to make them  
35 cheap on the market. Consequently, antennas designed as multiport feeds with tracking capability for satcom could also be used as multiport antennas for MIMO systems with an extra directive beam.

There have recently been developed broadband feeds for reflectors that are much more broadband, lighter and cheaper to manufacture than corrugated horns. They have been obtained by locating four log-periodic antennas together in a pyramidal geometry, see Greg Engargiola "Non-planar log-periodic antenna feed for integration with a cryogenic microwave amplifier", Proceedings of IEEE Antennas and Propagation Society international symposium, page 140-143 ,2002. The beam width is constant and the reflection coefficient at the input port is low over several octaves bandwidth. However, for log-periodic antennas of this kind the phase centre moves with frequency. This causes problems with reduced directivity due to defocusing at most frequencies. Also, these antennas have a rather complex mechanical solution.

From WO 05/015685 and WO 05/015686 by the inventor of the present invention, it is known how to alleviate the above-mentioned drawbacks of previously known antennas. In particular, the antenna of WO 05/015685 and WO 05/015686 is a relatively small and simple antenna, with at least one, and preferably all, of the following properties: constant beam width and directivity, low cross polarization as well as crosspolar sidelobes, low input reflection coefficient and constant phase centre location over a very large frequency band of several octaves. Typical numerical values are between 8 and 12 dBi directivity, lower than - 12 dB crosspolar sidelobes, and lower than -8 dB reflection coefficient at the antenna port. At the same time the antenna is preferably cheap to manufacture and has light weight. The same inventor also discloses improvements in relation to this antenna type in EP 2 120 293.

The antenna of WO 05/015685 and WO 05/015686 is now in the scientific literature known as the "eleven antenna", see e.g. R. Olsson, P.-S. Kildal, S. Weinreb, "The Eleven antenna: a compact low-profile decade bandwidth dual polarized feed for reflector antennas", IEEE Transactions on Antennas and Propagation, vol. 54, no. 2, pt. 1, pp. 368-375, Feb. 2006, and J. Yang, M. Pantaleev, P.-S. Kildal, Y. Karadikar, L. Helldner, B. Klein, N. Wadefalk, C. Beaudoin, "Cryogenic 2-13 GHz Eleven feed for reflector antennas in future wideband radio telescopes", IEEE Transactions on Antennas and Propagation, Vol. 59, No. 6, pp. 1918-1934, June 2011. The reason for the "eleven antenna" name is that the basic linearly polarized radiating element is a set of two parallel dipoles spaced half wavelength apart, i.e. in eleven configuration. To achieve large bandwidth such parallel dipoles are scaled log-periodically and connected together. For dual or circular polarization an orthogonal set of log-periodically scaled dipoles is located orthogonal to the first, with its geometrical centre coinciding with that of the first set of dipoles.

However, it is difficult to use the antennas of WO 05/015685 and WO 05/015686 over large frequency ranges due to problems with mechanical tolerances when small and large mechanical parts are combined, and in particular it is difficult to design it for use at high frequencies above typically 10 GHz with good performance due to the small dimensions in the centre of it and the associated mechanical support required. Also, it is desirable to reduce the size of the eleven antenna in order to make it smaller.

The eleven antennas in WO 05/015685 and WO 05/015686 have four two-wire lines feeding them from the centre, two for each polarization.

As discussed above, the eleven antenna has proven very effective and useful for a number of various applications. However, there is still a need for improvements in relation to dimension and performance of the antenna.

#### Summary of the invention

Therefore, it is the object of the present invention to provide further improvements in relation to the above-discussed type of antenna, i.e. the so-called eleven antenna. In particular it is an object of the present invention to provide improvements in relation to the dimensions and performance of the eleven antenna.

This object is achieved with the antenna as defined in the enclosed claims.

As will be understood from the following description, the present invention comprises several aspects which are used in the same specific context, and all being related to obtain the same purpose, viz. to obtain improved performance and reduced size. These parts can be used one by one, but preferably in combinations, and most preferably all at the same time.

The antenna of the present invention can be used to feed a single, dual or multi-reflector antenna in a very efficient way. However, the application is not limited to this. It can be used whenever a small, lightweight broadband antenna is needed, and in particular when there is a requirement that the beam width, directivity, polarisation or phase centre or any combination of these measures should not vary with frequency. In addition, the antenna of the invention can be designed with multiple ports, which makes it possible in addition to the directive beam to achieve either tracking beams for satcom terminals or multiple uncoupled and efficient beams for use in MIMO systems.

The basic component, from which the desired radiation characteristics of the antenna is constructed, is a pair of parallel dipoles, preferably located 0.5 wavelengths apart and about 0.15 wavelengths over a ground plane. This is known to

give a rotationally symmetric directive radiation pattern according to e.g. the book Radiotelescopes by Christiansen and Högbom, Cambridge University Press, 1985. Such a dipole pair is also known to have its phase centre in the ground plane, herein referred to as their geometrical ground-plane center in the sense that it is the  
5 geometrical center of the two dipoles and their images in the ground plane. However, the bandwidth is limited to the 10-20 percent bandwidth of a single dipole.

The broadband behaviour is obtained by locating several such dipole pairs of different sizes in such a way that their geometrical ground-plane centres coincide according to the invention in WO 05/015685 and WO 05/015686. This means that the  
10 dipole pair operating at the lowest frequency is located outermost, and that the smaller higher frequency dipole pairs are located inside the outermost with the highest frequency pair in the innermost position. In addition there may be a set of similar, but orthogonally oriented, dipole pairs with the same geometrical ground-plane centre to provide dual linear or circular polarization. All these characteristics  
15 can be combined with the present invention.

According to a first aspect of the invention, there is provided an antenna for transmitting and/or receiving electromagnetic waves, comprising:

a conducting body acting as a ground plane; and

at least one pair of log-periodic arrays of dipoles arranged above the ground  
20 plane, the dipoles of said pair of log-periodic arrays of dipoles forming dipole pairs of parallel and oppositely located dipoles of the same dimensions and arranged in such a way that the geometrical centres of each of said dipole pairs and their images in the ground plane are coinciding, wherein each dipole is a folded dipole comprising two or more parallel or nearly parallel conducting strips that are connected at one or more  
25 points or over an extended part of the conducting strips;

wherein a plurality of the folded dipoles, within each of said log-periodic dipole array, being closer to said geometrical centres are extending in a first plane, and wherein the remaining at least one folded dipole being located most far away from said geometrical centre is arranged to extend in at least one additional plane,  
30 said additional plane(s) forming an angle relative to said first plane.

The log-periodic dipole arrays form two or more petals in the antenna, and in a preferred embodiment four petals. Each petal comprises a cascaded log-periodic array of dipoles. The length, widths and heights over the ground plane for the folded dipoles are preferably scaled in relation to the wavelength intended for each dipole in  
35 a log-periodic manner.

Dipoles always have a gap, referred to as a port, across which the exciting voltage is provided. Folded dipole normally has port in only one of the parallel strips.

Each or at least almost each of the log-periodic folded dipoles of the present invention has ports in the centre of both the parallel strips. The folded dipoles within each petal are connected together by combining the two closer ports of two neighbouring dipoles with a two-wire line (two parallel strips) in such a way that all dipoles are connected in cascade. Thereby, each log-periodic dipole array forms two opposing serpentine-shaped metal strip lines.

The eleven antenna may typically be used for a frequency band up to 13 GHz. The lower frequency limit can be chosen freely and determines the overall size of the antenna. The lower frequency limit is around 2 GHz for VLBI 2010 application and 1.2 GHz for square kilometre array. In previous known antennas of eleven antenna type, there are included larger dipoles working at frequencies below the lower end of the operative frequency band. These outer dipoles do not radiate (or receive), and are only required as a termination of the radiating (or receiving) part of the log-periodic array, in order for the radiating (or receiving) dipoles to perform adequately. Thus, the function of these outer dipoles is to create a termination of the log-periodic array in order to have the same radiation performance at the low end of the operating band as at the rest of the band, and in particular a good input reflection coefficient over the operating band. Thus, the outer dipoles, in the following also referred to as termination dipoles, are non-radiating, and it is thus possible to re-arrange them to achieve a more compact geometry while maintaining the same performance for the array.

Thus, it is hereby rendered possible to arrange the outer termination dipoles in another plane, e.g. in a bent or curved shape, and hereby it is possible to significantly reduce in particular the height but also the width of the whole eleven antenna.

It has been found that by this re-arrangement of the outer termination dipoles, the height of the antenna can be reduced to about 50% of a comparable previous type eleven antenna having the same operative frequency band, and the width be reduced to about 85%. As a consequence, the overall volume is reduced to about 40% of the volume of the previous type eleven antenna.

A reduction in size is of great importance. For example in antenna systems requiring low or extremely low system noise temperature, the eleven antenna needs often be placed in a cryogenic chamber (cryostat) to be cooled to cryogenic temperatures being typically 20 to 30 K. For such applications, and also many other types of applications, it is of great importance that the overall dimensions of the feed antenna are as compact as possible.

The term strip is used in the description below. This term must not be taken literary, as it can also mean a conducting tube or wire of any cross-sectional shape as described in the patent claims.

Preferably, the dipoles are arranged at certain heights over the ground plane, the height being the same for the dipoles within each dipole pair.

The antenna further preferably comprises a feeding system connected to the smallest dipole of each log-periodic dipole array, that is the highest frequency dipoles located closest to the geometrical centre of the antenna in the ground plane.

Even though arrangement of only one termination dipole within each petal will reduce dimensions of the antenna, it is preferred that there is provided at least two termination dipole pairs, and preferably three termination dipole pairs in order to get good enough performance at the lowest frequency of operation. If several termination dipoles are used, it is further preferred that the termination dipoles comprise one termination dipole extending in a first additional plane, and at least two termination dipole pairs extending in a second additional plane preferably extending downwards towards the ground plane and being connected to the ground plane.

It is further preferred that the first plane and the at least one additional plane form an acute angle as seen from the ground plane. This results in the termination dipoles being folded down towards the ground plane, which reduces the height of the antenna. It is further preferred that at least two additional planes are provided, said at least two additional planes forming an acute angle towards each other as seen from the ground plane, which results in a further down-folding of the outer rim of the antenna.

All dipoles of said log-periodic dipole arrays may be oriented in one direction in order to transmit or receive waves of one linear polarization. Such a realization of the antenna will typically have only two petals, i.e. only one pair of log-periodic dipole arrays. However, preferably approximately half the dipole pairs of said log-periodic dipole arrays are oriented in one direction and the rest in an orthogonal direction, in order to transmit or receive waves of dual linear polarization or circular polarization. Such a realization of the antenna will typically have four petals, i.e. two pairs of log-periodic dipole arrays.

Preferably, all the dipoles of each of said log-periodic dipole array that are radiating and extending in a first plane are printed as metal strips on a flat substrate like a printed circuit board. However, it is also possible that these dipoles are realized partly as a printed circuit board and partly being solid strips cut from a thicker stiff metal plate, the latter being almost self-supporting requiring only a few dielectric supporting pins or walls to the ground plane. There is metal contact between the inner



thin metal strips on the circuit board and the outer thick metal strips. It is also possible that the at least one termination dipole extending in at least one additional plane is realized as strips on at least one additional flat printed circuit board or being cut out as thick strips from at least one flat metal plate.

5           According to a second aspect of the invention, there is provided an antenna for transmitting and/or receiving electromagnetic waves, comprising:

          a conducting body acting as a ground plane; and

          at least one pair of log-periodic arrays of dipoles arranged above the ground plane, the dipoles of said pair of log-periodic arrays of dipoles forming dipole pairs of  
10       parallel and oppositely located dipoles of the same dimensions and arranged in such a way that the geometrical centres of each of said dipole pairs and their images in the ground plane are coinciding, wherein each dipole is a folded dipole comprising two or more parallel or nearly parallel conducting strips that are connected at one or more points or over an extended part of the conducting strips;

15           wherein the two or more conducting strips of said dipoles are extending in a convexly curved manner in relation to the geometrical ground-plane centres.

          This aspect of the invention may be used in combination with the above-discussed first aspect of the invention, or separately.

          Previously known ultra-wideband (UWB) or decade bandwidth antennas, e.g.  
20       used for feeds in reflector antennas, are non-rotationally symmetrical. This also applies to the standard eleven antenna. Therefore, one important measure of the performance of these wideband feeds is the so-called BOR<sub>1</sub> efficiency, which characterizes how rotationally symmetric the radiation field function is. It has been found by the present inventors that the BOR<sub>1</sub> efficiency of the eleven antenna can be  
25       greatly improved by arranging the conducting strips of the dipoles non-linearly, so that they are convexly curved in relation to the geometrical centres.

          In particular it has been found advantageous to arrange the curved dipoles of a log-periodic array on a flat plane, e.g. on flat printed circuit boards (PCB). This enables the antenna to be formed and produced in a similar fashion as the standard  
30       eleven antenna, with two or four petals, but still obtain a significantly improved symmetry and BOR<sub>1</sub> efficiency, see P.-S. Kildal, Z. Sipus, "Classification of Rotationally Symmetric Antennas as Types BOR<sub>0</sub> and BOR<sub>1</sub>", IEEE Antennas and Propagation Magazine, Volume 37, Issue 6, p. 114, Dec. 1995. Simulations show that the new, circularly curved antenna has a BOR<sub>1</sub> efficiency of -0.25 dB over a  
35       frequency band of 2-5 GHz, which is a 0.3 dB improvement compared to a standard eleven antenna, and similar improvements are expected at higher frequencies.

The plurality of dipoles being closest to said geometric centre in said log-periodic dipole arrays are preferably extending in a common plane. Hereby, the curved dipoles may be formed in a curved shape, but still be arranged on a plane, and e.g. on a PCB. Preferably, the two or more conducting lines of said dipoles are  
5 forming essentially circular segments.

It is further preferred that the conducting lines of corresponding dipoles in the petals essentially forms a circle when projected onto the ground plane, i.e. when seen from above the antenna.

According to still another aspect of the present invention, there is provided an  
10 antenna for transmitting and/or receiving electromagnetic waves, comprising:

a conducting body acting as a ground plane;

at least one pair of log-periodic arrays of dipoles arranged above the ground plane, the dipoles of said pair of log-periodic arrays of dipoles forming dipole pairs of parallel and oppositely located dipoles of the same dimensions and arranged in such a  
15 way that the geometrical centres of each of said dipole pairs and their images in the ground plane are coinciding, wherein each dipole is a so-called folded dipole comprising two or more parallel or nearly parallel conducting strips that are connected at one or more points or over an extended part of the conducting strips; and

a feeding system comprising at least one printed circuit board having metal  
20 strips arranged on both sides, wherein the conducting ground plane comprises at least one opening arranged in the vicinity of the geometric centre, and wherein the at least one printed circuit board is arranged to extend through said opening.

This aspect of the invention may be used in combination with the above-discussed first and/or second aspect of the invention, or separately.

25 Due to the small physical size at the high frequencies used for the eleven antenna, and also the need to use such antennas e.g. in cryogenic environments, designing of manufacturable and cost-effective feeding networks has previously been a real challenge. However, by means of this new development, different feeding solutions, useable for different configurations of the eleven antenna, obtainable in a relatively simple and cost-effective way, has been rendered possible. By the use of a  
30 feeding system comprising PCBs extending into an opening in the ground plane, manufacturing tolerances can be minimized, to guarantee the performance of the antenna, and in addition production and assembling costs are greatly reduced. Simulations and measurements show that the new feeding solution provides better  
35 performance than previously used solutions.

According to one embodiment, the at least one printed circuit board extend in a direction being essentially perpendicular to the ground plane.

The metal strips on both sides of the at least one printed circuit board extending through said opening are preferably connected, and preferably by soldering, to the two feed points of each log-periodic array petal. Thereby, the two-wire strip line feeding the log-periodic dipoles within one petal is connected to a two-wire strip line formed by one strip on one side and another strip on another side of one of the printed circuit boards extending through the opening in the ground plane. According to one embodiment, one of the metal strips of this two-wire strip line has an increasing width in the direction away from the opening in the ground plane, thereby forming a gradual transition to wide ground plane in such a way that the companion strip on the other side of the substrate become a single microstrip line with a metal ground plane. Hereby, a balun is formed in an integrated manner, i.e. a transition from a balanced two-wire line to an unbalanced microstrip line, and this balun is relatively easy and cost-effective to produce and mount, one for each dipole petal.

It is further preferred that feeding system further comprises at least one wideband power combiner integrated in a printed circuit board. The printed circuit boards of the baluns of opposite located petals, and the printed circuit boards of the additional power combiner could be combined on a common printed circuit board.

For all the different aspects of the present invention, it is preferred that the dipoles are made by conducting strips on a dielectric substrate.

It is further preferred that the dimensions of each dipole pair in said log-periodic dipole arrays are essentially as follows: dipole length approximately 0.5 wavelengths, dipole height over ground between 0.05 and 0.50 wavelengths, and dipole spacing approximately 0.5 wavelengths, where the wavelengths is for that frequency of which the given dipole pair is the dominating contributor to the radiation pattern.

Still further, the radiation patterns of the antenna preferably have an almost constant beam width over a very wide frequency band, said frequency band preferably comprising several octaves.

As already discussed, the antenna may be used to illuminate a single or dual reflector antenna system.

In the above descriptions the ground plane is explained as if it is a planar ground. However, the ground plane can also have other shapes. It can have a pyramidal shape, so that the surface on top of the conducting support structure becomes more flat. It can also be provided with grooves or a periodic pattern in order to improve the performance as a ground plane. The invention makes use of a dipole pairs as the basic building component. This does not mean that two such dipoles are

connected together mechanically to one unit, e.g. by locating them on the same thin dielectric substrate, in such a way that if one is removed the other is removed as well. On the contrary, the dipole pair is only a basic electromagnetic building component when we construct the radiation pattern from electric current sources, i.e., we need  
5 two equal dipoles that radiate at the same frequency and are spaced about 0.5 wavelengths apart to get the desired rotationally symmetric radiation pattern. Actually, the dipoles on one side of the geometrical centre are mechanically connected by their feed lines, so that removing one of the dipoles of a pair will mean that we at the same time remove one of the dipoles of all the pairs, i.e. one complete  
10 petal. The connected dipoles may also be located on the same supporting material, such as a dielectric substrate. However, even if we normally may do so this is not at all necessary. The dipoles to be used together with the invention are not limited to such realization. Also, the log-periodic dipole arrays within each petal can be realized partly as strips on a substrate to form a printed circuit board and partly as thicker  
15 strips cut from a metal plate and in conducting contact with the largest metal strip dipoles on the substrate part.

The dipoles and feed lines can be realized as thin strips on a substrate, thick strips cut from a metal plate, tubes, or wires. They can also be located on both sides of one or more thin dielectric layers, e.g. the dipoles on one side and the feed lines on  
20 the other side, or part of the dipoles and feed lines on one side and the rest on the other side.

The presently discussed antenna is a broadband multi-dipole antenna, that has several advantages compared to other types of antenna, such as low input reflection coefficient, low cross polarization, low crosspolar sidelobes, rotationally symmetric  
25 beam and almost constant directivity, beam width and phase centre location over several octaves bandwidth. Further, the dipoles are fed from one or a few centrally located two-wire feed points or ports.

The antenna is very well suited for feeding single, dual or multi-reflector antennas.

30 The centrally located feed area may contain T-type power combiners and a balun or a 180 deg hybrid thereby providing a transition from a coaxial line to the two opposite directed two-wire lines feeding opposite located log-periodic dipole arrays of the same linear polarization. The balun may be active, meaning that it is combined with a receiver or transmitter circuit. In the case of a dual polarized antenna there  
35 need to be similar combination network also for the two logarithmic dipole arrays of the orthogonal linear polarization. The power combination network can also be located on printed circuit boards behind the ground plane as described in J. Yang, M.

Pantaleev, P.-S. Kildal, Y. Karadikar, L. Helldner, B. Klein, N. Wadefalk, C. Beaudoin, "Cryogenic 2-13 GHz Eleven feed for reflector antennas in future wideband radio telescopes", IEEE Transactions on Antennas and Propagation, Vol. 59, No. 6, pp. 1918-1934, June 2011..

5 For scientific applications the low noise receivers will in many cases be cooled to provide as low receiver noise temperature as possible. It can also be advantageous to cool the whole feed. This is possible with the antenna as discussed above, because of its small size.

The antenna can also be used as a multiport antenna as explained previously.  
10 Each petal has a two-wire feed line, and each of these wires can be fed from a separate port as described in J. Yang, M. Pantaleev, P.-S. Kildal, Y. Karadikar, L. Helldner, B. Klein, N. Wadefalk, C. Beaudoin, "Cryogenic 2-13 GHz Eleven feed for reflector antennas in future wideband radio telescopes", IEEE Transactions on Antennas and Propagation, Vol. 59, No. 6, pp. 1918-1934, June 2011. This gives 4  
15 ports per polarization, i.e. a 2x4 port antenna. Thereby difference patterns in two orthogonal planes per polarization can be realized.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

The different feed lines must be correctly excited in such a way that the  
20 radiating currents on the two dipoles of the same dipole pair are excited with the same phase and amplitude.

### Drawings

For exemplifying purposes, the invention will be described in closer detail in  
25 the following with reference to embodiments thereof illustrated in the attached drawings, wherein:

Figure 1 shows a log-periodic dipole array, which is useable in embodiments of the present invention.

Figure 2 shows a perspective view of an antenna having termination dipoles  
30 arranged in different planes, according to an embodiment of the present invention.

Figures 3 and 4 show cross-sectional views of two different embodiments of antennas having termination dipoles arranged in different planes, according to embodiment of the present invention.

Figures 5 and 6 show a perspective view and a top view of an antenna having  
35 curved dipoles, according to another embodiment of the present invention.

Figures 7 and 8 show a perspective view of PCB feeding systems according to embodiments of the present invention.

Figures 9-11 show schematic feeding systems according to embodiments of the present invention.

Detailed description of the figures

5           The invention will now be described in more detail with reference to preferred embodiments. However, it should be understood that different features in the specific embodiments are, unless otherwise stated, exchangeable between the embodiments. Further, all embodiments relate to locating the radiating dipole parts of a multi-dipole antenna in such a way that the radiation pattern gets rotational symmetry with low  
10           cross polarization and a frequency independent beam width over a large bandwidth.

          The dipole pair is the basic component of the invention. The dipole pair is arranged at a predetermined separation distance above a ground plane.

          Fig 1 shows a standard configuration of a log-periodic array of dipoles of a standard eleven antenna, which is also useable for embodiments of the present  
15           invention. At least two such log-periodic dipole arrays are used to form the antenna, thereby forming oppositely located dipoles of the same dimensions and arranged in such a way that the geometrical centres of said dipole pairs and their images in the ground plane are at least approximately coinciding.

          Preferably, the dipoles 1 has a feed gap 2 in the center so that two dipole arms  
20           3 are formed, as shown in Figure 1.

          Further, each dipole comprises two or more conducting lines 1a, 1b that are connected at one or more points or over an extended part of the conducting lines. Such dipoles are commonly known as folded dipoles. A folded dipole can be fed by a two-wire line connected to the feed gap 2 between the right and left arms of dipole  
25           1a. In the invention, there is also a gap in the second wire 1b of each dipole as shown in figure 1, at which a new two-wire line 7 is connected and continuing to the feed gap of the next neighbouring dipole. Thereby, two opposing serpentine lines running from the two-wire line feed point 6 are created, exciting all dipoles by a propagating wave.

30           Two or four log-periodic dipole arrays of the type shown in Figure 1 are located by means of a support structure over a ground plane 4 (not shown in Fig. 1, but seen e.g. in Fig. 2).

          Several dipole pairs 1 are provided, to realize broadband linearly or dually polarized radiation. The feeding of the dipoles can be done in many different ways, as  
35           will be described later. The main point is that they have to be fed in such a way that the currents on the dipoles of each dipole pair have the same direction, amplitude and phase.

The dipoles 1 of the invention are preferably located above the ground plane and in such a way that the height increases log-periodically in a direction away from the geometrical center of the dipole pairs. The ground plane is preferably flat and plane, whereas in some applications it may be desirable and possible to make it  
5 slightly conical, pyramidal, doubly curved or any other shape deviating from a plane.

An antenna according to the invention can also be used for dual linear or circular polarization. Then, regardless of the configuration, there exists for each dipole pair an orthogonal dipole pair having the same dimensions. The feeding of the dipoles are preferably the same within each quadrant (petal) of the geometry.

10 The antenna may comprise four log-periodic dipole arrays, or petals, but may also comprise only one pair of log-periodic dipole arrays. The innermost log-periodic dipoles of each array are preferably arranged on one planar dielectric substrate, a petal, The two or four plates are preferably arranged in a slanted disposition relative to each other, so that the functional antenna elements of the antenna plates are in pairs  
15 facing each other. An antenna having four petals is a dual polarisation antenna.

The antenna preferably comprises two or four antenna plates facing each other. However, the invention is not limited to such realizations. In particular, there may be one plane antenna plate containing all the log-periodic dipole arrays rather than two or four plates.

20 The dipoles within each log-periodic array are of different dimensions. In the example illustrated in Fig. 1 there are dipoles of 13 different dimensions. However, this number is arbitrarily chosen, as the antenna can consist of any number of dipole pairs of different dimensions, smaller, larger or much larger than this. Also, the log-periodically increasing spacing between neighbouring dipoles is arbitrarily chosen. It  
25 can be smaller or larger dependent on the results of the optimization of the design.

The drawings in the figures show multi-dipole antennas where the dimensions of the different dipole pairs vary approximately log-periodically. This means that the dimensions of all dipole pairs are scaled relative to the dimensions of the closer inner pair of each of them by the same constant factor. This is done in order to provide an  
30 environment for each dipole pair that looks the same independent of whether it has large dimensions for operation at some of the lowest frequencies or small dimensions for operation at some of the highest frequencies.

In a dipole array as illustrated in Fig. 1, the inner, smaller dipoles will be radiating, whereas the outer largest dipoles may be non-radiating, as discussed in the  
35 foregoing.

Fig. 2 illustrates an embodiment in which a more compact antenna is provided by arranging the outer, non-radiating dipoles, here referred to as terminating dipoles,

in planes different than the plane in which the radiating dipoles of the log-periodic array occur. Here, a plurality of dipoles being closest to said geometrical centre in the ground plane are extending in a first plane, and preferably in the above-discussed slanted disposition. These dipoles are all radiating. Further, there is provided at least one termination dipole being more distant from the geometrical centre which extend in at least one additional plane, wherein the additional plane(s) forms an angle relative to the first plane. In the illustrated example, three terminating dipoles 21-23 are provided, but it is also feasible to use one or two terminating dipoles arranged in this way, or more than three.

10       The first terminating dipole 21 is preferably arranged in a plane essentially parallel to the ground plane, whereas the other terminating dipoles 22, 23 are preferably arranged in planes directed towards the ground plane. According to one configuration, the two outermost terminating dipoles 22 and 23 may be arranged in a common plane, and this plane may form a right angle to the plane of the first  
15       terminating dipole. Such a configuration is illustrated in Figs. 2 and 3. It is also feasible to arrange the outermost dipoles 22, 23, in order to obtain a more curved shape of the antenna. Such a configuration is illustrated in Fig. 4.

      The terminating dipoles are preferably dimensioned to obtain an adequate termination of the log-period dipole array. Such termination may be achieved in  
20       various ways, and the terminating dipoles need not be dimensioned in accordance with the log-periodic design of the radiating part of the dipole array. For example, one or several of the terminating dipoles, such as the second terminating dipole 22, may be smaller than the first terminating dipole 21, and may also be smaller than the outermost dipole of the log-period dipole array.

25       The dipoles of the log-period dipole array are preferably arranged on flat printed circuit boards, or on a combination of a flat printed circuit board and as a thick metal strip without substrate that could be cut from a metal plate. The termination dipoles may also be arranged on flat printed circuit board, or may be provided in alternative ways.

30       In the above-discussed embodiments, the dipoles are of a straight configuration. However, as discussed in the foregoing, the dipoles may also be curved, in order e.g. to improve the BOR<sub>1</sub> efficiency. An embodiment having such curved dipoles is illustrated in Figs. 5 and 6.

      Here, the dipoles 1' are essentially arranged as in the previous embodiments,  
35       and with the same function. However, here the two or more conducting lines of the dipoles 1' are extending non-linearly, so that they are convexly curved in relation to



the geometrical centres. Preferably, dipoles are still extending in a common plane, and are preferably are still arranged on flat supporting plates.

The dipoles preferably form circular segments, and most preferably the dipoles of the different petals, form a circle when seen from above the antenna. This is illustrated in the top view of Fig. 6.

The feeding system preferably comprises at least one printed circuit board having metal strips arranged thereon. Further, the conducting ground plane preferably comprises at least one opening arranged in the vicinity of the geometric centre, wherein the at least one printed circuit board is arranged to extend through this opening. Preferably, the substrate supporting each log-periodic dipole arrays is provided with slot openings to receive the extension of the corresponding PCB of the feeding system. Such embodiments will now be discussed with reference to Figs. 7-11.

Fig. 7 schematically illustrates an embodiment where PCBs 81 of the feeding system are arranged through an opening 80 in the ground plane. There are conducting strips 82 arranged on opposite sides of the PCBs, in such a way that two strips together form a two-wire line. Each of these are connected, preferably by soldering, to the strips of the two-wire lines 6 of the log-periodic array.

Preferably, four such PCBs are provided, or two PCBs arranged to intersect each other. Such an embodiment is illustrated in Fig. 8. Here, the PCBs extend below the ground plane and essentially perpendicular to the ground plane. Further, the PCBs are preferably arranged in a housing 90.

In the illustrative example, four two-wire strip lines on PCB boards passes the ground plane through the corresponding opening(s) in the ground plane, and are soldered to the corresponding two-wire strip lines 6 leading to the log-periodic arrays. The dimensions of the strip lines at the junction are preferably matched so that a smooth impedance-matched transition occurs.

The two-wire strip lines on the PCBs are preferably gradually separated and one of the strips of each two-wire strip line is gradually increasing in width so as to make it a ground plane for the strip on the other side of the substrate. Thereby, a transformation from a two-wire line to a single microstrip line is achieved, i.e. a balun.

Three alternative configurations for the feed system suitable for the PCB realization discussed above will now be discussed. The components are preferably realized as integrated components on the PCB(s).

In a first embodiment, as shown in Fig. 9, the configuration is intended to feed four log-periodic dipole arrays with two different polarizations. There are received

voltage waves present at the two wire ports 97 of each log-periodic dipole array. The two wires of each of these two-wire lines, also called differential or balanced lines, are then separated into two separate single-ended lines such as microstrip or coaxial lines 96, and low noise receivers (LNAs) 95 are located on each of these single-ended lines. Then, there are needed 4 LNAs per polarization, but they are standard LNAs normally with 50 ohms input impedance. The 4 outputs of the LNAs will then be combined with wideband 180 deg hybrids 94 and a two-way power combiner 93 to one port per polarization. The two 180 deg hybrids and the power combiner can be exchanged with two power combiners and one 180 deg hybrid, respectively.

10 In a different configuration, as illustrated in Fig. 10, the received voltage waves on the 4 two-wire differential ports 97 are transformed to 4 single-ended lines by means of a wideband active balun 98. This is a so-called differential LNA, which is not so easily available as single-ended LNAs. After the differential LNAs the voltages are combined using one single wideband power combiner 93 per polarization.

15 In still another configuration, as illustrated in Fig. 11, the received voltage waves on the 4 two-wire differential ports 97 are transformed to 4 single-ended lines by means of a wideband passive balun 99, and these 4 single-ended lines are combined to two ports, one for each polarization by means of wideband power combiners 93. Each passive balun may be realized as transitions from two-wire strip lines to microstrip lines by increasing the width of one of the strips to become the ground plane of the other strip.

20 The above-discussed embodiments of antennas according to the invention have many features in common. For example, all, or at least most, of said embodiments encompass the following features:

- The antennas comprise dipoles arranged in pairs.
- The antenna dipoles are arranged on one side of a ground plane, and in such a way that the main lobe of the output radiation pattern is directed in a direction perpendicular to said ground plane.
- The lengths of the receiving dipoles (antenna elements) increase along the feed line away from a centrally located feed point. The length of succeeding dipoles preferably differ in length from the dipole positioned immediately before in a log-periodic fashion.

- The spacings between the dipoles increases along the feed line away from the centrally located feed point as well.
- 5       - The two (linearly polarized version) or four (dual polarized version) parts of the antenna are fed by separate feed lines that are connected to the ports of a feeding system preferably located at least partly behind the ground plane.
- 10       - The antenna elements/dipoles are essentially formed as straight conducting wires or strips.
- 15       - The antenna elements are formed on supporting dielectric substrates, such as PCBs, and preferably by means of etching techniques, as is per se known in the art.
- 20       - The antennas could be used for a wide range of different operating frequencies, and is particularly useful for the frequency range 1-15 GHz.

Specific embodiments of the invention have now been described. However, several alternatives are possible, as would be apparent for someone skilled in the art.

20   For example, different arrangement designs of the dipoles are possible, different combination of antenna planes are possible, various feeding arrangements are feasible, etc. Such and other obvious modifications must be considered to be within the scope of the present invention, as it is defined by the appended claims. It should be noted that the above-mentioned embodiments illustrate rather than limit the

25   invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims.

## CLAIMS

1. An antenna for transmitting and/or receiving electromagnetic waves, comprising:
  - 5 a conducting body acting as a ground plane; and
  - at least one pair of log-periodic dipole arrays arranged above the ground plane, the dipoles of said pair of log-periodic arrays of dipoles forming dipole pairs of parallel and oppositely located dipoles of the same dimensions and arranged in such a way that the geometrical centres of each of said dipole pairs and their images in the
  - 10 ground plane are coinciding, wherein each dipole is a folded dipole comprising two or more parallel or nearly parallel conducting strips that are connected at one or more points or over an extended part of the conducting strips;
  - wherein a plurality of the folded dipoles, within each of said log-periodic dipole array, being closer to said geometrical centre are extending in a first plane, and
  - 15 wherein the remaining at least one folded dipole being located most far away from said geometrical centre is arranged to extend in at least one additional plane, said additional plane(s) forming an angle relative to said first plane.
2. The antenna of claim 1, wherein the dipoles are arranged at certain heights over the ground plane, the height being the same for the dipoles within each
- 20 dipole pair.
3. The antenna of claim 1 or 2, further comprising a feeding system connected to the smallest dipole of each log-periodic dipole array, i.e. the highest frequency dipoles located closest to said geometrical centre of the antenna in the ground plane.
- 25 4. The antenna of any one of the preceding claims, wherein there is provided at least two termination dipole pairs, and preferably three termination dipole pairs.
5. The antenna of any one of the preceding claims, wherein the termination dipoles comprise one termination dipole extending in a first additional plane, and at least one more termination dipole extending in a second additional plane.
- 30 6. The antenna of any one of the preceding claims, wherein the first plane and the at least one additional plane form an acute angle as seen from the ground plane.

7. The antenna of any one of the preceding claims, wherein at least two additional planes are provided, said at least two additional planes forming an acute angle towards each other as seen from the ground plane.

8. The antenna of any one of the preceding claims, wherein the antenna  
5 comprises at least two pairs of log-periodic dipole arrays, the dipole arrays forming petals extending symmetrically from a common centre.

9. The antenna of any one of the preceding claims, wherein all the dipoles of each of said log-periodic dipole arrays and extending in a first plane are printed as metal strips on a flat substrate like a printed circuit board, but there is no ground  
10 plane on the substrate.

10. The antenna of claim 9, wherein the at least one termination dipole extending in at least one additional plane is arranged on at least one additional flat printed circuit board.

11. The antenna according to any one of the preceding claims, wherein each  
15 dipole comprises two opposite arms with a feed gap between them, and each dipole arm comprises two conducting strips that are connected at the outer end, and where the inner ends of these two strips are connected with the inner end of the closer strip of the neighbouring inner or outer dipole arm, respectively, using strips, so that one array of dipoles is formed by two opposing serpentine-shaped strips.

12. The antenna according to any one of the preceding claims, wherein the  
20 two or more conducting strips of said arms of said dipoles of said log-periodic array of dipoles are extending non-linearly, so that they are convexly curved in relation to the said geometrical centres.

13. The antenna of claim 12, wherein the two or more conducting strips of  
25 said dipoles are forming circular segments.

14. The antenna of any one of the preceding claims, further comprising a feeding system comprising at least one printed circuit board having metal strips arranged on both sides, wherein the conducting ground plane comprises at least one opening arranged in the vicinity of the geometric centre, and wherein the at least one  
30 printed circuit board is arranged to extend through said opening.

15. An antenna for transmitting and/or receiving electromagnetic waves, comprising:

a conducting body acting as a ground plane; and

at least one pair of log-periodic arrays of dipoles arranged above the ground plane, the dipoles of said pair of log-periodic arrays of dipoles forming dipole pairs of parallel and oppositely located dipoles of the same dimensions and arranged in such a way that the geometrical centres of each of said dipole pairs and their images in the ground plane are coinciding, wherein each dipole is a folded dipole comprising two or more parallel or nearly parallel conducting strips that are connected at one or more points or over an extended part of the conducting strips;

wherein the two or more conducting strips of said dipoles are extending in a convexly curved manner in relation to said geometrical centre in the ground plane.

16. The antenna of claim 15, wherein a plurality of dipoles being closest to said geometrical centre of said log-periodic dipole arrays are extending in a common plane.

17. The antenna of claim 15 or 16, wherein the two or more conducting strips of said dipoles are forming circular segments.

18. The antenna of any one of the claims 15-17, wherein the antenna comprises at least two pairs of log-periodic dipole arrays, the dipole arrays forming petals extending symmetrically from a common centre.

19. The antenna of claim 18, wherein the conducting lines of corresponding dipoles in said petals essentially forms a circle when projected onto the ground plane, i.e. when seen from above the antenna.

20. The antenna of any one of the claims 15-19, wherein the dipoles of each log-periodic dipole array are arranged on at least one flat printed circuit board.

21. The antenna of any one of the claims 15-20, further comprising a feeding system comprising at least one printed circuit board having metal strips arranged on both sides, wherein the conducting ground plane comprises at least one opening arranged in the vicinity of said geometrical centre, and wherein the at least one printed circuit board is arranged to extend through said opening with a minor part of it.

22. An antenna for transmitting and/or receiving electromagnetic waves, comprising:

a conducting body acting as a ground plane;

at least one pair of log-periodic arrays of dipoles arranged above the ground plane, the dipoles of said pair of log-periodic arrays of dipoles forming dipole pairs of parallel and oppositely located dipoles of the same dimensions and arranged in such a way that the geometrical centres of each of said dipole pairs and their images in the ground plane are coinciding, wherein each dipole is a folded dipole comprising two or more parallel or nearly parallel conducting strips that are connected at one or more points or over an extended part of the conducting strips; and

5 a feeding system comprising at least one printed circuit board having metal strips arranged on both sides of the substrate, wherein said conducting ground plane comprises at least one opening arranged in the vicinity of said geometrical centre, and  
10 wherein the at least one printed circuit board is arranged to extend through said opening.

23. The antenna of claim 22, wherein the at least one printed circuit board extend in a direction being essentially perpendicular to the ground plane.

15 24. The antenna of claim 22 or 23, wherein metal strips on both sides of the at least one printed circuit board extending through said opening are connected, preferably by soldering, to the two feed points of each log-periodic array petal.

25. The antenna of any one of the claims 22-24, wherein at least one metal strip has an increasing width in the direction away from the opening in the ground plane, thereby forming a gradual transition from a two-wire line realized by two narrow strips on either side of the substrate to a single microstrip line with a metal ground plane.  
20

26. The antenna of any one of the claims 22-25, wherein the feeding system further comprises at least one wideband power combiner integrated in a printed circuit board, and preferably the same printed circuit board extending into the ground plane, or combined with two such boards extending into the ground plane to one board.  
25

27. The antenna according to any one of the preceding claims, wherein all dipole pairs of said log-periodic dipole arrays are oriented in one direction in order to transmit or receive waves of one linear polarization.  
30

28. The antenna according to any one of the preceding claims, wherein approximately half the dipole pairs of said log-periodic dipole arrays are oriented in

one direction and the rest in an orthogonal direction, in order to transmit or receive waves of dual linear polarization or circular polarization.

29. The antenna according to any one of the preceding claims, wherein the dipoles are made by conducting strips, wires or tubes.

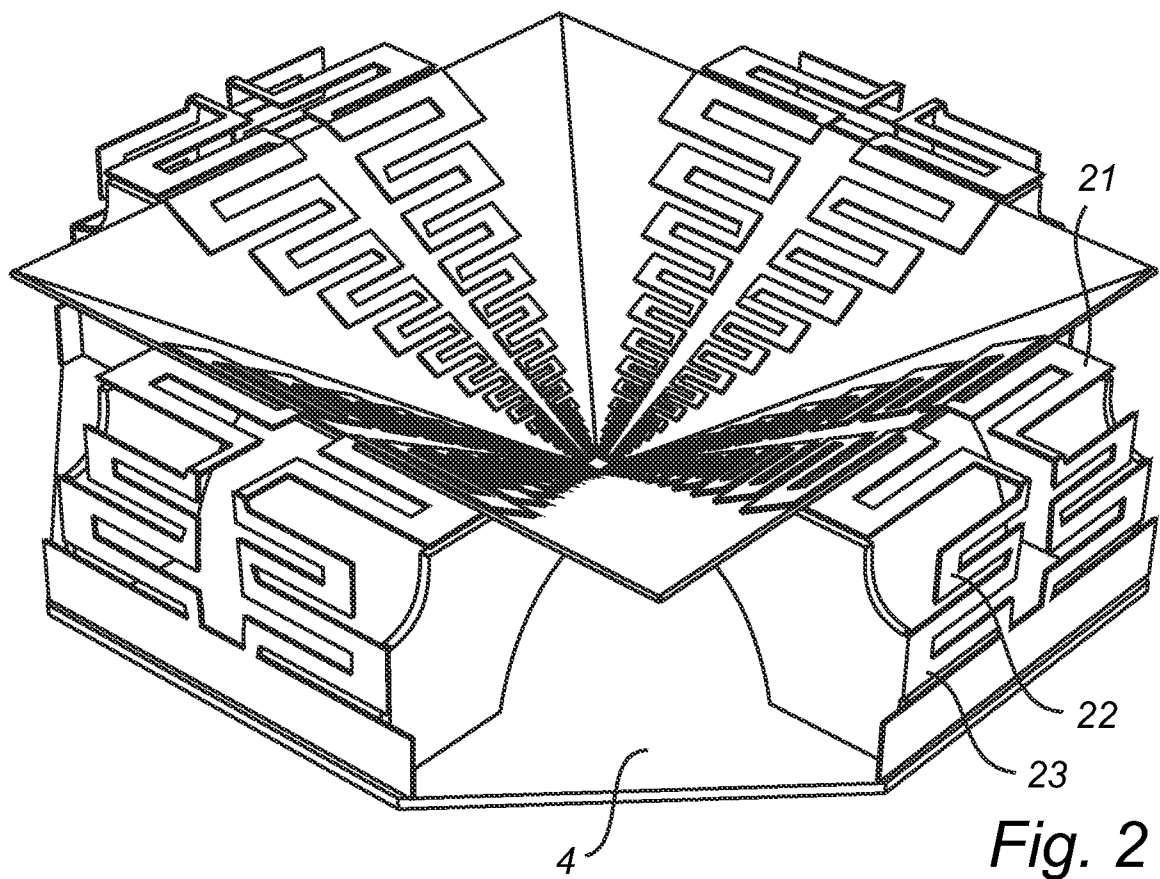
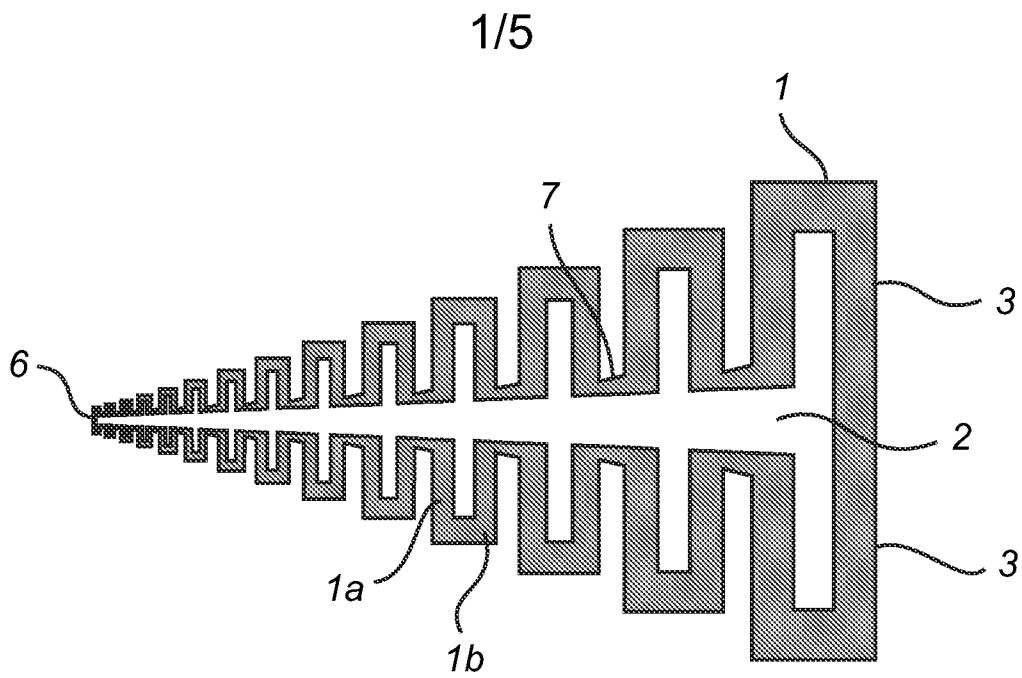
5           30. The antenna according to any one of the preceding claims, wherein the dipoles are made by conducting strips on a dielectric substrate.

31. The antenna according to any one of the preceding claims, wherein the dimensions of each dipole pair in said log-periodic dipole arrays are essentially as follows: dipole length approximately 0.5 wavelengths, dipole height over ground  
10   between 0.05 and 0.25 wavelengths, and dipole spacing approximately 0.5 wavelengths, where the wavelengths is for that frequency at which the given dipole pair is the dominating contributor to the radiation pattern.

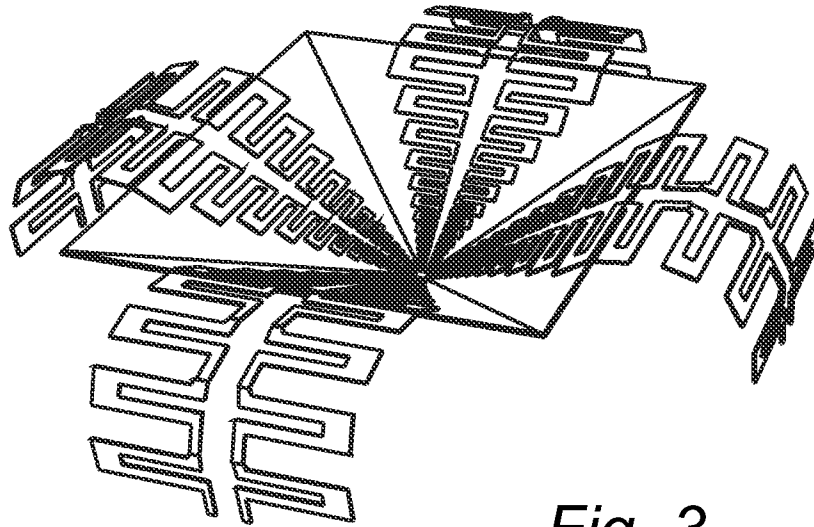
32. The antenna according to any one of the preceding claims, wherein the radiation patterns have an almost constant beam width over a very wide frequency  
15   band, said frequency band preferably comprising several octaves.

33. The antenna according to any one of the preceding claims, wherein the antenna is used to illuminate a single or dual reflector antenna system.

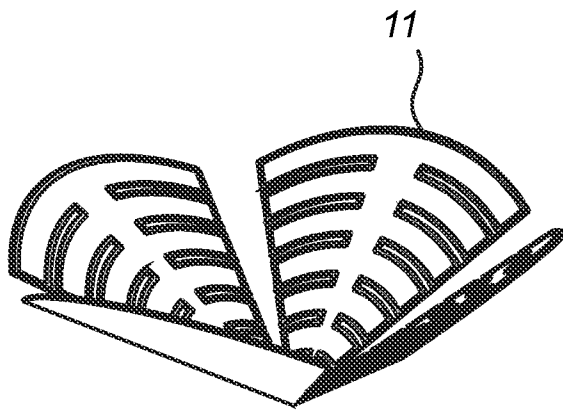




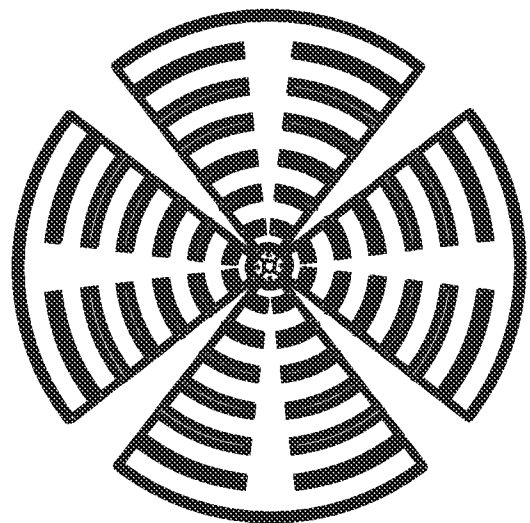
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*Fig. 3*



*Fig. 5*



*Fig. 6*

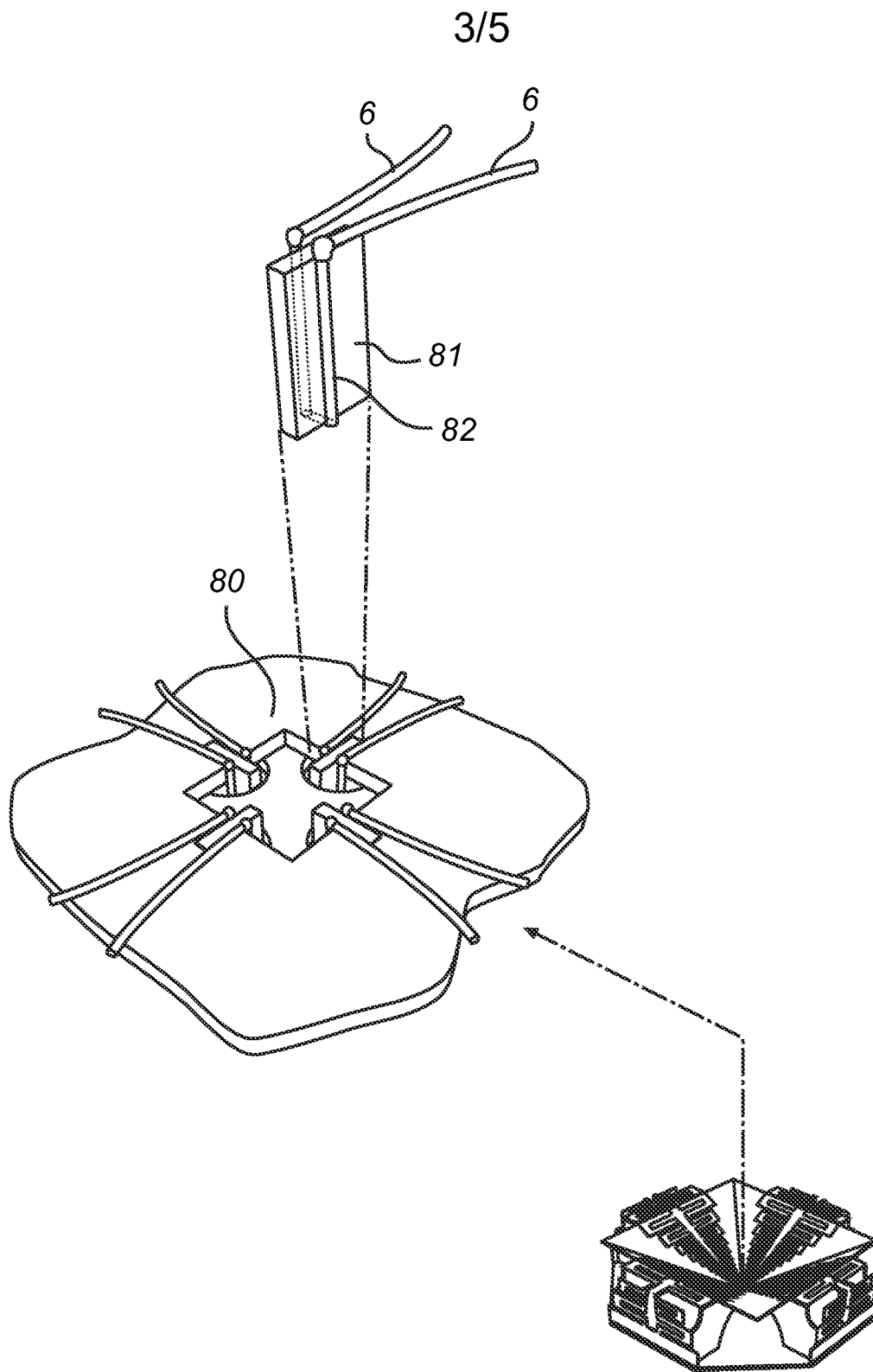
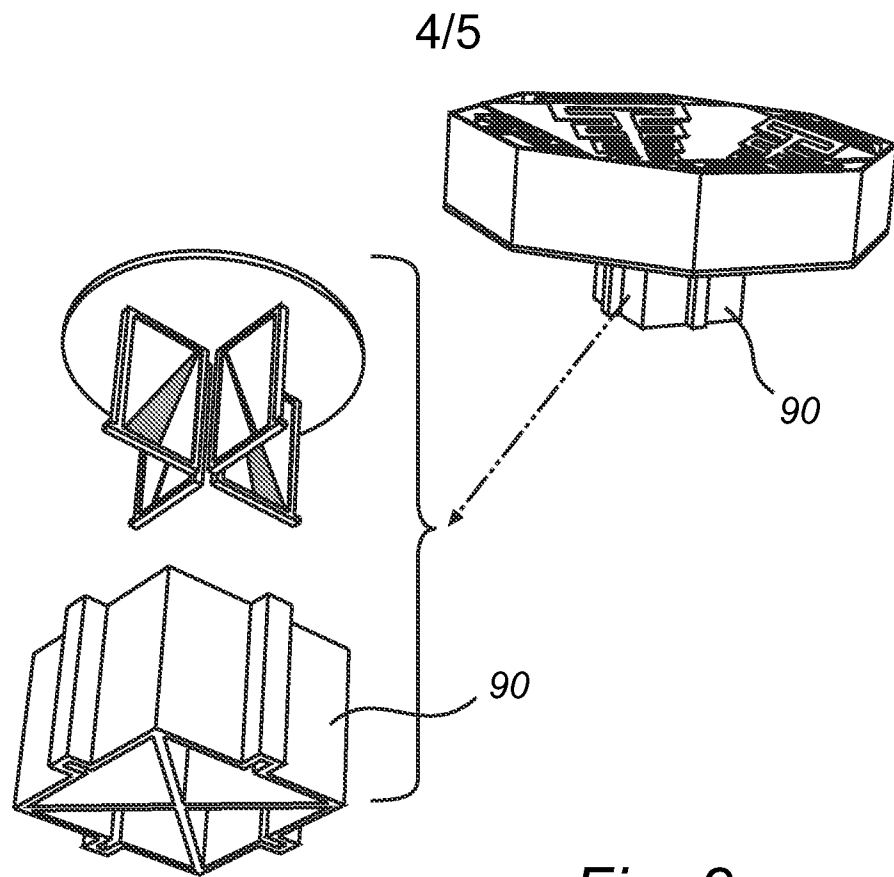
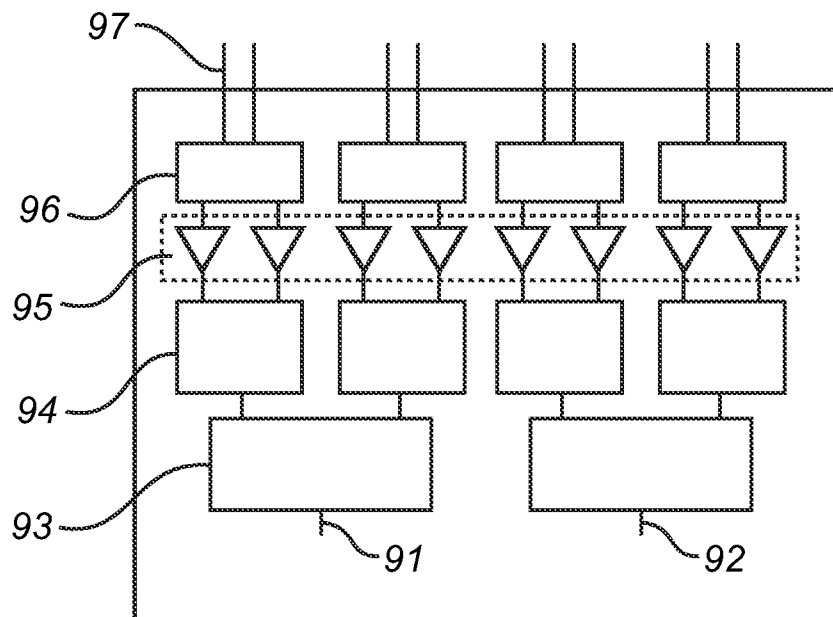


Fig. 7

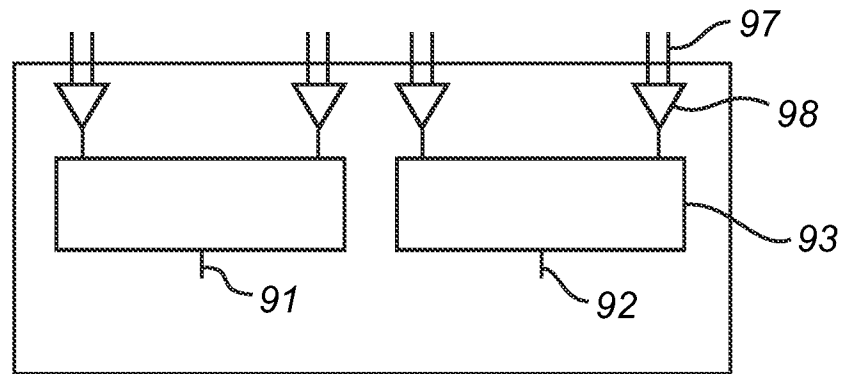


*Fig. 8*

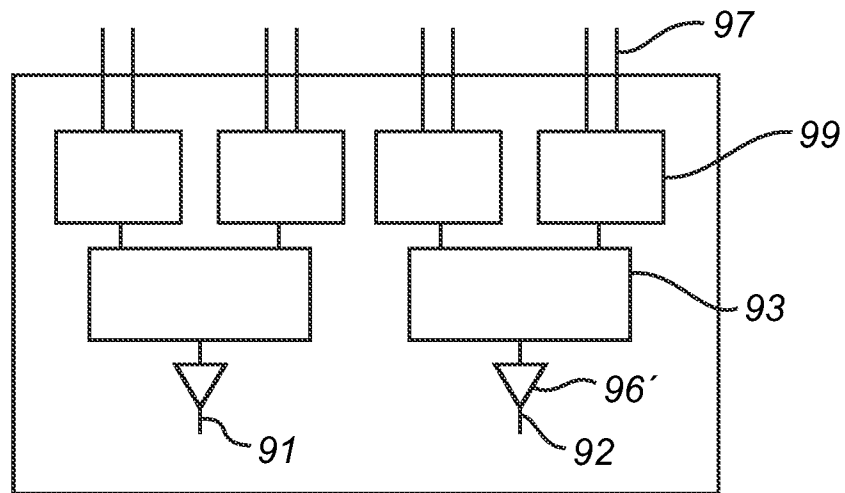


*Fig. 9*

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*Fig. 10*



*Fig. 11*