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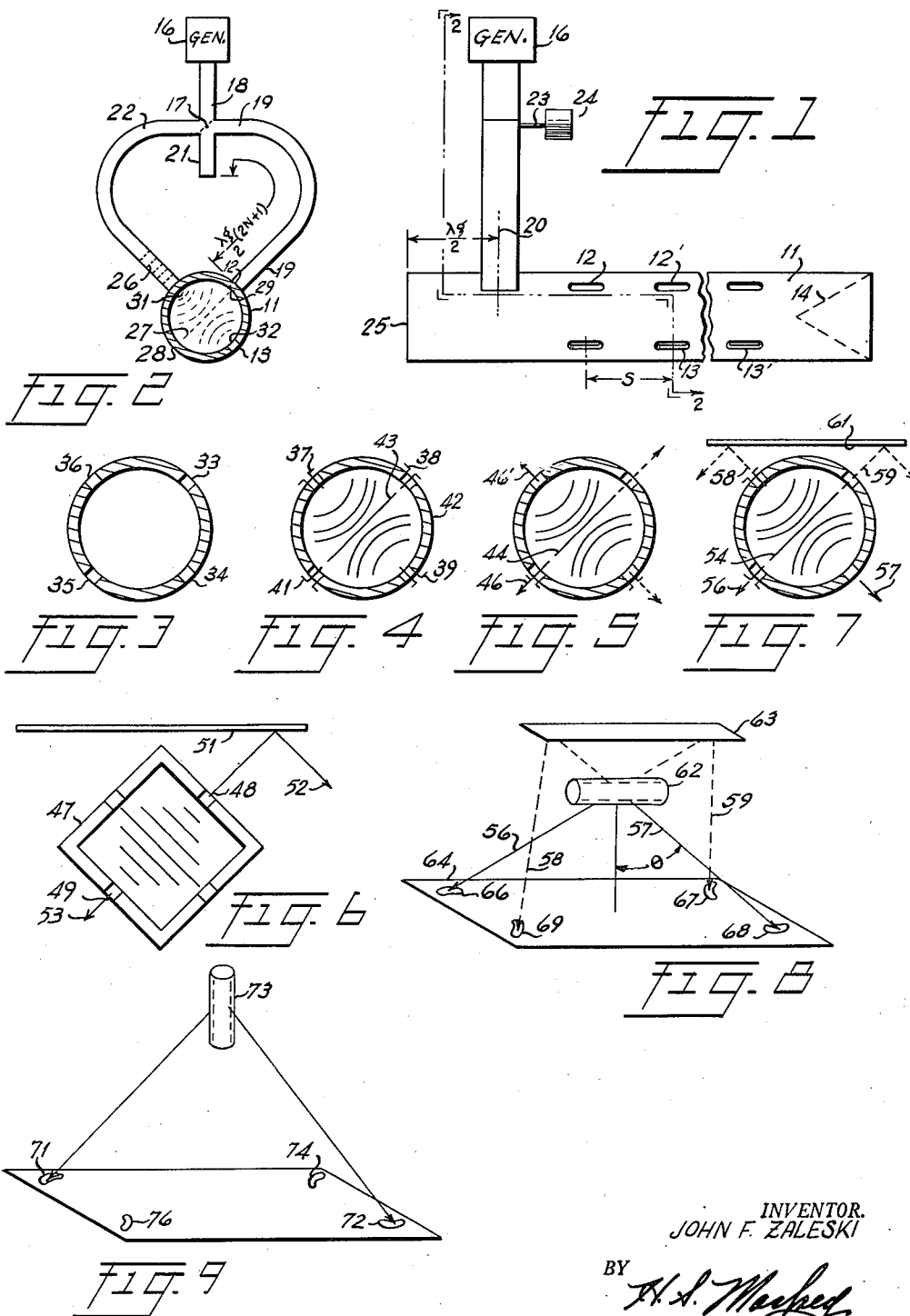
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MICROWAVE LOBE SHIFTING ANTENNA

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2 Sheets-Sheet 1



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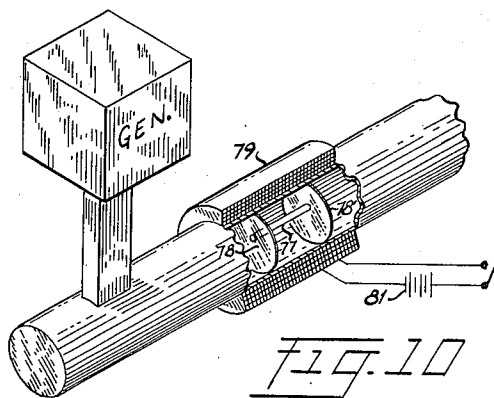
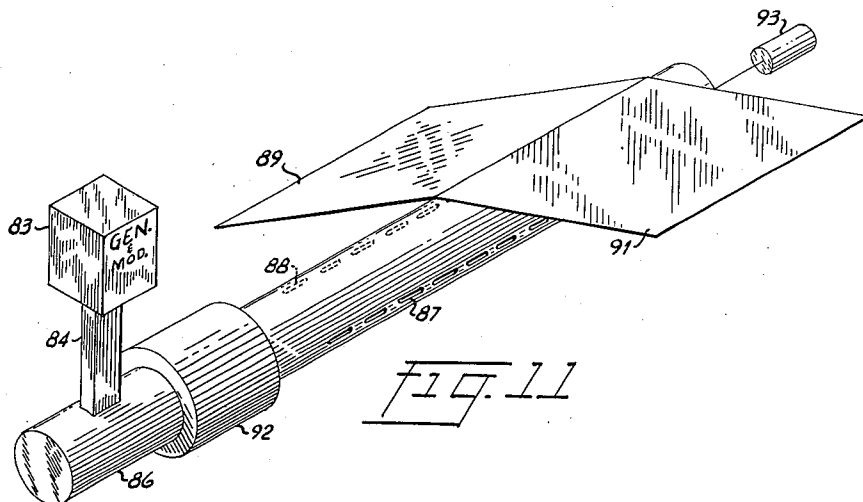
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MICROWAVE LOBE SHIFTING ANTENNA

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7 Claims. (Cl. 343-768)

This invention relates to linear array microwave antenna assemblies of the lobe-shifting type and particularly to such structures wherein a plurality of arrays are mounted on a single energy-conducting member.

In various microwave circuits in which relatively narrow beams of electromagnetic energy are either transmitted from or received by an antenna system, it is frequently desirable to alter periodically the direction of transmission or reception of such beam or lobe. Such arrangements are generally termed lobe switching or shifting systems and it is to such an arrangement that the present invention is directed.

However, whereas in previous arrangements of this nature it has been necessary to duplicate the energy conducting and directing members for each beam or lobe direction required, the present invention contemplates the use of a single energy carrying element on which are mounted the desired number of beam directing arrays, the individual arrays being selectively energized and de-energized in accordance with the desired angular direction of reception and/or transmission.

Likewise in the instant invention the single array carrying member may be provided with such number of separate arrays so disposed as respects each other that the beam or lobe direction may be alternated between two angular directions or two beams directed in different directions may be shifted to be directed in two other directions.

A purpose of the invention therefore is to provide a compact structure permitting lobe switching of energy in a desired illuminating pattern, the term illuminating being here used to include transmission to and/or reception from an object which either reflects or produces electromagnetic energy.

In general the purpose of the invention is accomplished by providing a single wave guide structure with a plurality of linear arrays which are angularly disposed with respect to each other. The wave guide structure is energized in a mode of noncircular symmetry and relative rotation between the field in the guide and the guide is provided so that, depending on the orientation of the field and the arrays carried by the guide, some are energized while others are not.

A further understanding of this invention may be secured from the detailed description and associated drawings, in which:

Figures 1 and 2 illustrate an embodiment of this invention employing a circular wave guide with slot antenna elements and an electromechanical polarity changing device.

Figures 3, 4, 5, 6, and 7 illustrate various combinations of a wave guide, linear arrays and reflectors.

Figures 8 and 9 depict ways of employment of the invention in producing radiation patterns.

Figures 10 and 11 illustrate lobe switching arrangements in which the microwave energy polarization is rotated by magnetic and mechanical means, respectively.

Referring now to Fig. 1, a round hollow microwave guide 11, having preferably a circular cross section, but which may be elliptical, is provided with two linear an-

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tenna arrays situated 90° apart on the circumference of the guide. The two arrays are similar and are composed of short longitudinal slots such as, for instance, slots 12, 12' in the upper array and 13, 13' in the lower array.

This constitutes the leaky pipe type of antenna assembly with current-excited slots. When microwave energy is applied at the left end of the assembly the slots may be successively excited. What energy remains is absorbed at the right end of the assembly by a cone 14 made of lossy resistance material. The microwave energy is generated in a generator 16, Figs. 1 and 2, and is applied through a switch 17 to the guide at two alternative positions in its periphery in order to excite either array without excitation of the other. This switch is disclosed in Patent No. 2,690,539, issued September 28, 1954, and may be here briefly described as follows.

The generated microwave energy is applied from generator 16 in the TE_{1,0} mode through a rectangular guide 18 to a four-branched series guide junction composed of the branch 18 and branches 19, 21, and 22 meeting at right angles. At the center of the junction a metal rod 17 having a length approximately equal to one-half of the microwave length emitted by generator 16 is pivoted on an axis 23 so that it nearly spans the diagonal dimension of the guide junction. A rotary solenoid or electric motor 24 with 90° stops is provided to rotate the rod 17 into either the position shown or into the position 90° therefrom. This action connects the branches 18 and 22, or 18 and 19, respectively. The branch 21 is short-circuited and has a matching length of the amount necessary to match the impedance discontinuity presented during switching.

The branches 19 and 22 are connected to points 90° apart on the guide 11, the distance from the blanked end of stub 21 to the guide by way of either branch 19 or 22 being the same and equal to an odd multiple of one-half wave length. The distance from the input guide axes 20, Fig. 1, to the short-circuited end 25 of guide 11 is also any integral multiple of one-half wavelength in the guide.

In the switch position shown the TE_{1,0} field in the guide 22, having an electric component indicated at 26, generates a TE_{1,1} field in the round guide with its electric plane oriented as indicated at 27. Such a field has voltage maxima at the diametrically opposite points 28 and 29 of the interior surface of the guide, and has current maxima at the points 31 and 32. With the field as described, therefore, the slot array 13-13' will be energized and will consequently radiate, while the array 12-12' will not be energized, since the electric vector components of the TE_{1,1} mode combine in phase-opposition at the radiating elements of array 12-12' when guide 22 is used as the input. When the switch 17 is moved to its other position the field energy is all applied to the round guide through branch 19; consequently the field set up within the guide has a polarization at 90° from that shown in Fig. 2 and the slots 12-12' are energized, while slots 13-13' are not.

The input branch that is not being used does not interfere with the operation of the assembly because the components of the electric field associated with the TE_{1,1} mode existing in the round guide combine in phase-opposition at the input branch not being used.

A microwave linear array emits radiation in the form of a partial principal cone or cones of more or less concentrated radiation, and the intersection of a plane containing the array axis with this cone is often called a lobe of radiation, with the lobe angle θ defined as the angle which the lobe makes with the array transverse plane. If now the slot spacing S, Fig. 1, be made different in the two arrays, the lobe angle θ will be different

for the two arrays. Operation of the switch 17 will then shift the lobe angle in switching excitation from one array to the other. Thus this arrangement provides a means for rapid lobe shifting.

The round guide may be provided with three or four arrays, spaced at 90°, instead of only the two described, as shown in Fig. 3 at 33, 34 and 35 for a three-array assembly and at 33, 34, 35 and 36 for a four-array assembly.

Higher modes can be excited in round guide of sufficiently large size, some of these modes satisfying the requirement of this invention that regions of current loops and nodes, or regions of voltage nodes and loops, must alternate around the circumference of the guide, and a guide operating in such modes can be provided with linear arrays spaced for operation as described. The simplest higher mode in round guide of this sort is TE_{2,1}, which has eight such alternating peripheral current maxima and minima. However, operation at higher modes is not important and in any case the method and means of such higher mode operation are amply obvious from the discussion relative to the operation in the TE_{1,1} mode.

Operation of square guide in the TE_{1,0} and TE_{0,1} modes is well understood, and it is obvious that since these modes are analogous to the TE_{1,1} mode in round guide, square guide can be substituted for round guide in the descriptions associated with Figs. 1 and 2, without any change in operation. Square guide in fact offers the advantage of eliminating any slight rotation of the field which may fortuitously occur as it progresses down an array assembly using non-uniform round guide. Such square guide is depicted in Fig. 6.

Radiators other than short longitudinal current-operated slots can be employed, such as, for example, a continuous longitudinal current-operated slot, transverse voltage-operated slots and dipole radiators. Of the latter, one form is the well-known slotted dipole. It and other voltage-operated radiators must, of course, be positioned for operation in the electric potential plane of the guide. For example, in Fig. 4 the four slotted dipole radiator arrays are spaced at 90° intervals at 37, 38, 39 and 41 in the round guide 42 which is so excited in the TE_{1,1} mode that the plane of its maximum field potential is as indicated at 43, passing through the arrays 38 and 41. These arrays are then fully excited while the arrays 37 and 39 are unexcited. When the field is rotated 90° so that electric maxima occur at arrays 37 and 39, these arrays are excited while arrays 38 and 41 are unexcited.

Several types of radiator arrays can be combined in a single assembly as, for example, as illustrated in Fig. 5. In this figure two slotted dipole voltage-operated arrays are used with two current-operated slot arrays. With the instantaneous directions of maximum electric field potential as indicated by the line 44, the directions of radiation are as indicated by the solid arrows 46—46'. Upon rotation or shift of the field by 90° the excitation is removed from these arrays and shifted to the other pair of arrays, and the emitted radiations are indicated by the dashed arrows.

The described arrays can be assembled, excited, and used in a large variety of ways, and reflecting metal surfaces can be employed with them to redirect the emitted lobes or to change their direction slightly. For example, the square guide 47, Fig. 6, is operated in the TE_{1,0} mode so that the current-operated slot radiator arrays 48 and 49 are excited. If the assembly be placed horizontally and a metal sheet 51 be positioned above it, the radiation of the array 48 will be deflected from a +45° upward direction to a 45° downward direction at 52, while the direct radiation at 53 of array 49 is at -45°.

A combination of slots and slotted dipoles in Fig. 7 produces a similar effect in another way, the field direction shown at 54 producing lobes 56 and 57 at +45° and -45° downward. When the field is rotated 90° the lobes 58 and 59, shown as dashed lines, are reflected from the horizontal metal plane reflector 61 to take similar +45°

and -45° downward directions. If the element spacing is different in array 56 from that in 58, and in 57 from that in 59, the change from emissions at 56 and 57 to emissions at 58 and 59 will effectively change the emitted lobe angles.

This change of emitted lobe angles is illustrated in Fig. 8, in which the four-array assembly and reflector of Fig. 7 are indicated at 62 and 63 respectively. They are positioned above and parallel to the earth plane indicated at 64, intersections of portions of the radiation cones or lobes with the earth being indicated by illuminated areas 66, 67, 68 and 69. When the two lower arrays are excited the radiating lobes 56 and 57 are produced, and when excitation is shifted to the two upper arrays the lobes 58 and 59 are radiated. Thus by use of the described switch the earth is alternately illuminated first at 66 and 68, then at 67 and 69.

The lobe angle θ is dependent upon the distance S between successive radiating elements of a microwave linear array, and upon the microwave length λ applied together with the wavelength in guide λ_g , the relation being

$$\sin \theta = \frac{\lambda}{\lambda_g} - \frac{M\lambda}{S}$$

in which M is any integer including zero. From this relation it also is seen that the radiation of principal lobes from a linear array may be confined to a single lobe or may be radiated in two or more lobes simultaneously. Although in the example given, each linear array emits a single lobe only, other uses of this invention may require the emission of more than one lobe by one or more arrays of the assembly, and as the equation shows this is possible and the invention may be so applied.

A four-array assembly may be used without the aid of a reflector to produce the pattern of Fig. 9, which is similar to that of Fig. 8 except that the lobes are more restricted as to possible angles and the earth illumination is in segments of a circle instead of in sections of hyperbolas. Although the pattern of Fig. 8 has advantages, the array assembly of Fig. 9 is lighter and simpler and therefore advantageous for airborne use. The illuminated spots 71 and 72 of Fig. 9 are simultaneously formed by two arrays on opposite sides of the array assembly 73. Upon switching the energy to the two remaining arrays the other spots 74 and 76 are illuminated instead. Sharper delineation of the spots may be secured by interposing radial reflectors between the linear arrays.

Other methods of switching than that shown in Figs. 1 and 2 may be employed. One successful method of rotating the microwave field in a round guide to transfer excitation from one array to another employs a poly-iron or mixed ferrite rod 77 within the guide and an electromagnet outside of the guide as illustrated in Fig. 10. The rod is held in position coaxial with the guide by two polystyrene discs 78 and 78' which, however, can alternatively be made of tetrafluorethylene resin or of any other low loss material transparent to microwave field energy. The guide is surrounded by a solenoid 79 energized by a battery 81. When the rod is magnetized by closing switch 82, the plane of polarization of microwave energy passing through the guide is rotated. This means of polarization is more fully described in Patent No. 2,644,930, issued July 7, 1953, and application Serial No. 308,575, filed September 9, 1952.

Lobe switching may also be effected simply by physically rotating a horizontal leaky pipe antenna assembly, the several arrays carried by it being constructed to produce different lobe angles. For example, the earth pattern of Fig. 8 may be produced by use of a two-array assembly with reflectors, or by use of a four-array assembly without reflectors. The former is illustrated in Fig. 11, in which a microwave generator 83 generates short pulses of microwave energy at suitable intervals. This energy is applied through guide 84 to one end of a round guide 86, propagating in the TE_{1,1} mode in which two

rows of apertures 87 and 88 are cut to form two linear current-operated antenna arrays, spaced circumferentially 180° apart. Two plane reflectors 89 and 91 are arranged to redirect radiated energy downward at the desired angle. The round guide 86 is broken at 92 by a rotary joint so that the part to the right can be rotated by a motor and intermittent mechanism 93. The speed of rotation is one revolution per second, with stationary time periods at the two positions in which the arrays are horizontal. The two arrays have different radiator spacings with the result that their lobe angles are different, resulting in the type of ground plane pattern indicated in Fig. 8. Obvious variations include employing continuous microwave energy with continuous antenna rotary motion, and continuous motion with intermittent microwave energization. It is also obvious that a 4-array assembly can be employed with omission of the reflectors.

What is claimed is:

1. A microwave lobe-shifting antenna assembly comprising, a microwave guide having a circular cross section, means for exciting said microwave guide by microwave energy to form a microwave field therein having the dominant $TE_{1,1}$ mode having successive electric current maxima and minima spaced apart circumferentially by 90°, a plurality of microwave longitudinal slot radiator linear arrays in said guide circumferentially spaced at angles of 90° between adjacent arrays, the positions of said arrays coinciding with positions of said electric current maxima and minima, whereby said arrays coinciding in position with said current maxima are positioned for excitation and radiation and said arrays coinciding in position with said electric current minima are unexcited, a non-reflective termination on one end of said microwave guide distant from said means for exciting said microwave guide, and means for rotating said microwave field and said microwave guide relative to each other by an angle of 90°.

2. A microwave lobe-shifting antenna assembly comprising, a microwave guide having a circular cross section, means for exciting said microwave guide by microwave energy to form a microwave field therein having the dominant $TE_{1,1}$ mode having successive electric current maxima and minima spaced apart circumferentially by 90°, a plurality of microwave longitudinal slot radiator linear arrays in said guide circumferentially spaced at angles of 90° between adjacent arrays, the positions of said arrays coinciding with positions of said electric current maxima and minima, whereby said arrays coinciding in position with said current maxima are positioned for excitation and radiation and said arrays coinciding in position with said current minima are not excited, a non-reflective termination on an end of said microwave guide distant from said means for exciting said microwave guide, a magnetizable mass having the property when magnetized of electromagnetic field polarization positioned in said guide between said exciting means and said linear arrays, and means for magnetizing said magnetizable mass.

3. A microwave lobe-shifting antenna assembly comprising, a microwave guide having a circular cross section, means for exciting said microwave guide by microwave energy to form a microwave field therein having the dominant $TE_{1,1}$ mode having successive electric circumferential current maxima and minima spaced apart by 90°, a plurality of microwave longitudinal slot radiator linear arrays in said guide circumferentially spaced at 90°, the positions of said arrays coinciding with positions of said electric current maxima and minima, whereby said arrays coinciding in position with said current maxima are positioned for excitation and radiation and said arrays coinciding in position with said current minima may not be excited, a non-reflective termination on an end of said microwave guide distant from said means for exciting said microwave guide, means for shifting said microwave field within the circular guide including means for dividing ap-

plied microwave energy into two guide branches, apertures terminating said two guide branches at positions on said circular guide circumferentially separated by 90° for introducing microwave energy to the circular guide and means for alternately inhibiting the transmission of microwave energy through respective ones of said branches while establishing energy transmission through the remaining branch.

4. A microwave lobe-shifting antenna assembly comprising, an elongated waveguide section, means for exciting said waveguide section in a field mode producing alternate electric potential maxima and minima at equal peripheral intervals, a plurality of microwave linear antenna arrays extending along the length of said waveguide section and spaced peripherally from each other by an integral multiple of said equal peripheral intervals, at least one of said arrays being comprised of a series of radiators coupled to said waveguide section for excitation thereby only at a selected orientation of the field mode in said waveguide section, at least one other of said arrays being comprised of a series of radiators coupled to said waveguide section for excitation thereby only at a field mode orientation in said waveguide section which departs from said selected orientation by said peripheral interval, and means for producing relative rotation between said field mode and said arrays.

5. A microwave lobe-shifting antenna assembly in accordance with claim 4 including at least one conductive reflective surface positioned externally of said waveguide section and adjacent to at least one of said plurality of microwave linear arrays for changing the direction of the energy radiated outward therefrom.

6. A microwave lobe-shifting antenna assembly comprising, an elongated round waveguide section, a plurality of linear antenna arrays carried thereby, said arrays being positioned in straight lines parallel to the longitudinal axis of said waveguide section, adjacent arrays being circumferentially displaced with respect to each other by an integral multiple of 90° angles, means for exciting said round waveguide section at a transverse plane therein by microwave energy in the $TE_{1,1}$ mode, at least one of said arrays being comprised of a series of radiators coupled to said waveguide section for excitation thereby only at a selected orientation of the $TE_{1,1}$ mode in said waveguide section, at least one other of said arrays being comprised of a series of radiators coupled to said waveguide section for excitation thereby only at an orientation of the $TE_{1,1}$ mode in said waveguide section which departs from said selected orientation by 90°, and means for rotating said $TE_{1,1}$ mode relative to said arrays by 90°.

7. A microwave lobe-shifting antenna assembly comprising, an elongated round waveguide section, four linear antenna arrays carried thereby, said arrays extending along the length of said waveguide section and circumferentially spaced thereabout by angular separations of 90°, means for exciting said round waveguide section by microwave energy in the $TE_{1,1}$ mode, one pair of said arrays being comprised of respective series of radiators coupled to said waveguide section for excitation thereby only at a selected orientation of the $TE_{1,1}$ mode in said waveguide section, the other pair of said arrays being comprised of respective series of radiators coupled to said waveguide section for excitation thereby only at an orientation of the $TE_{1,1}$ mode in said waveguide section which departs from said selected orientation by 90°, and means rotating said $TE_{1,1}$ mode relative to said arrays by 90°.

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