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(71) Applicant: NEC CORPORATION
33-1, Shiba 5-chome, Minato-ku
Tokyo 108(JP)

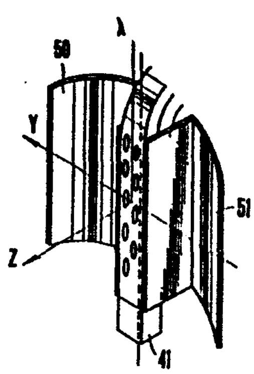
(72) Inventor: Kusano, Mitsuhiro
c/o NEC Corporation 33-1, Shiba 5-chome
Minato-ku Tokyo(JP)

(72) Inventor: Seki, Hajime
c/o NEC Corporation 33-1, Shiba 5-chome
Minato-ku Tokyo(JP)

(74) Representative: Vossius Vossius Tauchner Heunemann Rauh
Siebertstrasse 4 P.O. Box 86 07 67
D-8000 München 86(DE)

(54) Shaped beam antenna.

(57) A shaped beam antenna comprises an array antenna having a planar surface on which a plurality of radiating elements are arranged, and a main reflector disposed behind with respect to the radiating direction of the array antenna. The main reflector comprises a plurality of partial cylindrical or planar reflector segments. Where Cartesian coordinates is assumed having an origin in the center of the planar surface of the array antenna, an X-axis extending in a vertical center axis of the array antenna, a Z-axis extending in a direction perpendicular to the planar surface through the origin, and a Y-axis, extending in a direction perpendicular to the X- and Z-axes through the origin, the shaped beam antenna is characterized in that the longitudinal axis of each reflector segments is in parallel with the X-axis, the main reflector is symmetrical with respect to the X-Z plane and formed convex in a negative direction of the Z-axis, and each radiating element is disposed so that its excitation amplitude is symmetrical with respect to the Y-Z plane and its excitation phase is antisymmetrical with respect to the Y-Z plane, whereby a radiation beam formed by the main reflector is symmetrical with respect to the Z-axis on the Y-Z plane and is asymmetrical with respect to the Z-axis on said X-Z plane. Thus, with this antenna, a good beam shaping performance and an excellent cross polarization discrimination can be obtained.



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VOSSIUS · VOSSIUS · TAUCHNER
HEUNEMANN · RAUH
PATENTANWÄLTE
SIEBERTSTR. 4, 8000 MÜNCHEN 80
TEL. (089) 47 40 75

0174579

Our Ref: U 018 EP
Case: 8536-A
NEC Corporation
Tokyo,Japan

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Shaped Beam Antenna

Background of the Invention

The present invention relates to a reflector type array antenna utilized in radio communication, and more particularly to a shaped beam antenna in which a radiation beam extends in a sector shape in a plane but in another shape in a plane perpendicular thereto. The present invention is utilized in radio communication between a single master station and a plurality of slave stations.

In an ordinary radio communication, communication is effected between specified radio stations, i.e., on the basis of point-to-point system. Accordingly, there is generally used an antenna having high gain and low sidelobe characteristic. On the contrary, in the case where communication is effected between a single master station and a plurality of slave stations locally distributed in an area, i.e., on the basis of point-to-multipoint system, an antenna provided in the master station is required to have a so-called shaped beam which presents effective irradiation converage over the area where slave stations are locally distributed.

An example of such a shaped beam antenna has been previously proposed in US Patent Application Serial No. 664,712 assigned to the same assigner as the present invention. This earlier application is now briefly described, although it will be referred to later in greater detail. The shaped beam antenna shown in this earlier patent application comprises a main reflector and a primary radiator for irradiating a radio wave on the main reflector wherein the main reflector has a central section comprising a plurality of torus reflector segments and side end sections each comprising a plurality of parabolic reflector segments. Reflector surfaces thus segmented are grouped to allow either grouped reflector surface to be symmetrical or assymetrical, respectively, with respect to a horizontal plane. With this arrangement of the segmented reflector surfaces, the maximum radiation direction of the beam reflected from one portion located near the reflector axis of the main reflector lies in the horizontal plane, while the maximum radiation direction of the beam reflected from the other portion located spaced from the reflector axis of the main reflector lies in planes other than the horizontal plane. Thus, this shaped beam antenna can improve cross polarization characteristic. However, the drawbacks with this earlier application are as follows: First is that the cross polarization characteristic is greately degraded at portions except for the reflector axis plane to narrow an angular range where a good cross polarization characteristic is obtained, resulting in a small elevational difference allowable in design. Second is that the primary radiator is provided in a radio wave propagating path to allow the radio wave to be blocked, thus making it difficult to form a desired beam pattern. Third is that the fabrication of the reflector having torus and parabolic reflector surfaces is complicated, resulting in high cost of the shaped beam antenna.

Summary of the Invention

With the above in view, an object of the present invention is to provide a shaped beam antenna of a new structure having desirable beam shaping and cross polarization characteristics.

Another object of the present invention is to provide a shaped beam antenna which does not require a particular jig in fabrication, and has a reduced number of fabrication steps and a reduced cost thereof.

A further object of the present invention is to provide a shaped beam antenna of a novel structure having good beam shaping performance and capability of reducing unnecessary radiation.

According to the present invention, there is provided a shaped beam antenna comprising: an array antenna having a planar surface on which a plurality of radiating elements are arranged; and a main reflector having a plurality of vertically extending reflector segments and disposed behind with respect to a radiation direction of each radiating element of the array antenna, wherein Cartesian coordinates are assumed having an origin in the center of the planar surface of the array antenna, an X-axis extending in a vertical center axis of the array antenna, a Z-axis extending in a direction perpendicular to the planar surface through the origin, and a Y-axis extending in a direction perpendicular to the X- and Z-axes through the origin, the improvement wherein the longitudinal axis of each reflector segment is in parallel with the X-axis, the main reflector is symmetrical with respect to the X-Z plane and is formed convex in a negative direction of the Z-axis, and each of the radiating elements of the array antenna is disposed so that its excitation amplitude is symmetrical with respect to the Y-Z plane and its excitation phase is antisymmetrical with respect to the Y-Z plane, whereby a radiation beam formed by the main reflector is symmetrical with respect to Z-axis on the Y-Z plane and is asymmetrical with respect to Z-axis on the X-Z plane.

The main reflector may comprise a plurality of partial cylindrical reflector segments. The partial cylindrical reflector segment may be configured as a parabolic reflector. The parabolic reflector may have a focal line vertically extending in parallel with the X-axis, the array antenna having a central point at which the Y-Z plane and the focal line intersect with each other. The central point may be a phase central point of radiation wave of the radiating element. The central point may be the origin.

The main reflector may have a reflector surface formed by a plurality of vertically extending planar reflector segments. The main reflector may be configured as a modified corner reflector.

The main reflector may further comprise conductive members at the longitudinally opposite ends. The conductive members may be arranged in parallel with the Y-axis. The reflector may further comprises a radio wave absorber along at least a part of the reflector surface thereof. A blind having metallic grids may be provided on the surface of the radio wave absorber, the metallic grids being arranged in parallel with a polarized wave radiation of the array antenna, the spacing of the metallic grids being more than one-half of a wavelength of a frequency used.

The array antenna may be comprised of a rectangular waveguide having a plurality of slots serving as the radiating elements. The array antenna may comprise a dielectric base, metal strips serving as the radiating elements and serving as power feed lines, respectively, provided on the dielectric base, a metal conductor provided on the back side of the dielectric base, and connector means fixed to the metal conductor for connecting the metal strip serving as power feed line to the metal conductor. The array antenna may be configured with a dipole array or a crossed dipole array.

Brief Description of the Drawings

The features and advantages of a shaped beam antenna according to the present invention will become more apparent from the following description taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a plan view illustrating an arrangement of a master station and a plurality of slave stations locally distributed within a radio communication area;

Fig. 2 is a side view of Fig. 1 wherein a pencil radiation beam is used;

Fig. 3 is a side view of Fig. 1 wherein a shaped radiation beam is used;

Fig. 4 is a plan view illustrating an example of two radio communication areas closely adjacent to each other;

Fig. 5 is a front view illustrating a conventional shaped beam antenna;

Fig. 6 is a horizontal cross-section of the antenna shown in Fig. 5;

Fig. 7 is a vertical longitudinal section of the antenna shown in Fig. 5;

Fig. 8 shows the radiation characteristics in a vertical plane of the antenna shown in Fig. 5;

Fig. 9 is an explanatory view for the cross polarization characteristic of the antenna shown in Fig. 5;

Fig. 10 is a perspective view illustrating a first embodiment of an antenna according to the present invention;

Fig. 11 is a front view of the antenna shown in Fig. 10;

Fig. 12 is an enlarged fragmentary perspective view of an array antenna employed in the antenna shown in Fig. 10;

Fig. 13 is a perspective view illustrating another form of an array antenna employed in the present invention;

Fig. 14 shows a radiation characteristic in a vertical plane in connection with the antenna shown in Fgi. 10;

Fig. 15 is a horizontal cross-section of the antenna shown in Fig. 10;

Fig. 16 shows a radiation characteristic in a horizontal plane in connection with the antenna shown in Fig. 10;

Fig. 17 is a plan view, partly exploded, illustrating another form of the antenna shown in Fig. 10;

Fig. 18 is a perspective view illustrating a second embodiment of an antenna according to the present invention;

Fig. 19 is a front view of the antenna shown in Fig. 18;

Fig 20 is a horizontal cross-section of the antenna shown in Fig. 18;

Fig. 21 shows a radiation characteristic in a horizontal plane in connection with the antenna shown in

Fig. 18;

Fig. 22 is a plan view, partly exploded, illustrating another form of the antenna shown in Fig. 18;

Fig. 23 is a perspective view illustrating a third embodiment of an antenna according to the present invention;

Fig. 24 is a plan view of the antenna shown in Fig. 23;

Fig. 25 shows a radiation characteristic in a horizontal plane in connection with the antenna shown in Fig. 23;

Fig. 26 is a perspective view illustrating another form of the antenna shown in Fig. 23;

Fig. 27 is a radiation characteristic in a horizontal plane in connection with the antenna shown in Fig. 26;

Fig. 28 is a side view illustrating another form of a wave absorber with a metal blind employed in the antenna shown in Fig. 26;

Fig. 29 is a front view illustrating the wave absorber with the metal blind shown in Fig. 28; and

Fig. 30 shows radiation characteristic in a horizontal plane in connection with the antenna provided with the wave absorber with the metal blind shown in Figs. 29 and 30.

Detailed Description of the Present Invention

Prior to describing preferred embodiments according to the present invention, the effect based on beam shaping will be initially referred to with reference to Figs. 1 to 4, and then an example of the prior art will be described with reference to Figs. 5 to 9.

Fig. 1 is a plan view illustrating an arrangement of a master station and a plurality of slave station locally distributed within a radio communication area for effecting a radio communication of a so-called point-to-multipoint system. Figs. 2 and 3 are side views of Fig. 1. In the arrangement shown in Fig. 1 wherein the master station is labelled A and the slave stations are labelled B, C, D and E, it is desirable that a beam 1 radiated from the master station A extends in the horizontal plane in the form of a sector as shown in dotted lines to cover the entire slave stations B, C, D and E. On the other hand, in the vertical plane, when the difference in altitude between the respective slave stations and the difference in distance between the master station and the respective slave stations are taken into account, the shape of a radiation beam 3 as shown in Fig. 3 is more advantageous than an oridnary pencil beam as shown in Fig. 2. In case where two communication areas of the master and slave stations are closely adjacent as shown in Fig. 4, orthogonally polarized radiation waves are used so that shaped beams 1 and 1' do not interfere with each other. The degree of the orthogonality of the polarized radiation waves, i.e., the quality of cross polarization discrimination between the two communication areas governs the quality of the communication circuit.

In the prior art, for a method of forming such a shaped beam, there has been proposed a shaped beam antenna as shown in US Patent Application Serial No. 664,712 mentioned previously. This conventional antenna will be described with reference to Figs. 5 to 9 wherein Fig. 5 is a front view, Fig. 6 a cross-sectional view in a horizontal plane, Fig. 7 a longitudinal sectional view in a vertical plane, Fig. 8 an explanatory view of the radiation characteristics in a vertical plane, and Fig. 9 an explanatory view of the cross polarization characteristic. A shaped beam antenna shown in the earlier patent application comprises a feed horn 20 serving as a primary radiator and a main reflector 30 having a central section including torus reflector segments 34, 37 and 38 and horizontal side sections including parabolic reflector segments 35-1, 35-2, 36-1, 36-2, 39-1 and 39-2. These segments are grouped into first and second portions of the main reflector 30. The first reflector portion of the main reflector 30 includes reflector segments 34, 35-1 and 35-2 which are symmetrical with respect ot the horizontal (Y - Z) plane and the vertical (X - Z) plane, while the second reflector portion includes reflector segments 37, 36-1 and 36-2 and 38, 39-1 and 39-2 which are asymmetrical with respect to the horizontal (Y - Z) plane.

The radiation characteristic in the horizontal plane of the shaped beam antenna will be described with reference to Fig. 6. The torus reflector segment 34 within the first portion is formed by rotating the sectioned curve in the vertical (X - Z) plane shown in Fig. 7 about the vertical axis (X-axis) by an angle θ_o, while the parabolic reflector segments 35-1 and 35-2 have their axes P 35-1 and P 35-2 as the centers and a focal point F.

A spherical wave radiated by the primary radiator 20 is reflected by the torus reflector segment 34 in the horizontal plane to travel along paths as indicated by broken lines 4 and 5, to become concentrical radiation wavefront with the origin being the center. On the other hand, radio waves reflected by the parabolic reflector segments 35-1 and 35-2 travel along paths as indicated by broken lines 6 and 7, and they are converted into plane waves propagating in the direction of the axes P 35-1 and P 35-2. Accordingly, the radiation characteristic in the horizontal plane of a shaped beam obtained by synthesizing the above-mentioned wavefronts is substantially uniform within an angular range of $\pm\theta_o$ with respect to the reflector axis and steeply attenuates in a range where the absolute value of the angle is above θ_o, thus making it possible to synthesize a so-called sector shaped beam.

Then, the radiation characteristic in the vertical plane will be described with reference to Figs. 8

and 9. The sectioned curve of the first reflector segment 34 shown in Fig. 7 is of a parabola having a focal point at the point F and a center axis at the reflector axis, the sectioned curve being symmetrical with respect to the reflector axis. On the other hand, sectioned curves of the second reflector segments 37 and 38 are of parabolas having focal points at the point F and center axes P37 and P38, respectively. Accordingly, the spherical wave radiated by the feed horn and reflected by the torus reflector surface 34 is radiated at a wavefront propagating in the direction of the reflector axis, i.e., in a horizontal direction through paths 8-1 and 8-2. The radio wave reflected by the reflector surfaces 37 and 38 are radiated as wavefronts propagating in the directions of axes P37 and P38 through paths 9 and 10. The radiation characteristic in the vertical plane is determined by the synthesis of the above-mentioned wavefronts. As will be seen from a radiation beam characteristic 12 shown at solid line in Fig. 8, a synthesized or resultant beam becomes asymmetrical with respect to the horizontal plane. Dotted line radiation beam characteristics 13 and 14 respectively correspond to the main polarization characteristic and the cross polarization discrimination characteristic of the radio wave radiated from the segment 34 of the first reflector portion, while a dotted line radiation beam characteristic 15 represents the main polarization component of the radio waves radiated by the second segments 37 and 38 of the reflector second portion. The cross polarization discrimination characteristic such as the dotted line beam characterisitc 14 is excellent because the torus reflector segment 34 is symmetrical with respect to the reflector axis and hence, the cross polarization wave components generated by this reflected segment cancel with each other on the reflector axis.

The cross polarization wave components produced by torus reflector segments 37 and 38 which are asymmetrical with respect to the reflector axis do not have any adverse effect upon the reflector axis because the maximum radiation directions of respective main polarization components produced by the asymmetrical segments 37 and 38 deviate from the reflector axis. As a consequence, the overall cross polarization discrimination becomes excellent along the reflector axis as indicated by a solid line radiation beam characteristic 16.

As can be noted from the description regarding Fig. 6, the characteristic in the vertical plane is substantially uniform within an angular range of $\pm \theta_0$ so that in the horizontal plane including the reflector axis, an excellent cross polarization discrimination can be obtained.

However, with the above-described conventional shaped beam antenna, as indicated by the solid line 16 in Fig. 8, the cross polarization characteristic is steeply degraded when deviating from the reflector axis, i.e., horinzontal plane, and a desirable cross polarization characteristic can be obtained only in an area extremely close to the horizontal plane. This provides the following problem in connection with the communication channel. Namely, when effecting selection of the stations A and C and stations A and A' in Fig. 4, it is impossible to allow the difference in altitude to be large. Accordingly, when actual geometry or the height difference between buildings etc. is taken into account, there is a possibility that selection of a station is impossible. To solve this, it is required to additionally provide a special tower. Namely, when an angular range within which a desirable cross polarization characteristic can be obtained is $\pm\beta_o$, an allowed difference D in altitude in the communication system design is expressed as follows:

$$D = (\text{horizontal distance between respective stations}) \times \tan\beta_o \quad \ldots\ldots (1)$$

From this equation, it is understood that the magnitude of the angle β_o directly affects the configuration of the communication system.

The maximum factor which determines the magnitude of the angle β_o is the magnitude of the cross polarization components. Fig. 9 shows an explanatory view for cross polarization components produced in the reflector surface. In this figure, for simplicity of explanation, only a part of the first reflector portion of the reflector surface shown in Fig. 5 is illustrated. Dotted lines 17 and 18 indicate current flows induced in the reflector surface by a radiation wave coming from the feed horn 20.

As well known, when a magnetic field vector of an incident wave and a normal vector are denoted by $\mathbb{H}$ and $\mathbb{n}$, an induced current vector $\mathbb{J}$ in the reflector surface is expressed by

$$\mathbb{J} = \mathbb{n} \times \mathbb{H} \qquad \ldots\ldots (2).$$

In this instance, since the magnetic field vector $\mathbb{H}$ is a spherical wave and the configuration of the reflector surface is as stated above in regard to the normal vector $\mathbb{n}$, they have three components in the Cartesian coordinate system, respectively. Accordingly, the induced current vector $\mathbb{J}$ also have three components. With reference to a front view shown in Fig. 9, this is illustrated as the main polarization components M_1 to M_4 and the cross polarization components C_1 to C_4. Namely, a current component itself induced in the reflector surface inherently includes cross polarization components. The quantities of the main polarization and the cross polarization of the radiation characteristic are proportional to the magnitude of the induced current.

As previously stated, the reflector segment 34 is symmetrical with respect to the horizontal and vertical planes. Accordingly, for instance, as far as the horizontal plane is concerned, the components C_1 and

C_2 have directions opposite to each other and have the same distance from the horizontal plane. The relationship between the components C_3 and C_4 is the same as that between the components C_1 and C_2. Accordingly, the equation (1) holds in the horizontal plane. However, in connection with a deviated plane from the horizontal plane, the equation (1) does not hold because the distance between the component C_1 and the deviated plane is different from the distance between the component C_2 and the deviated plane, with the result that cross polarization components remain uncancelled. As a consequence, the characteristic is degraded except for the horizontal plane as indicated by dotted lines 14 in Fig. 8.

In practice, with the conventional antenna configured as shown in Figs. 5 to 7, in a communication channel which requires a cross polarization characteristic of, for example, more than 20 dB, the angle β_o can be about 0.5° at the most, providing the serious difficulty in realizing an actual communication channel.

Further, as seen from the configuration of the conventional antenna, the feed horn 20 exists within a path of radiation wave, with the result that the radiation wave is partially blocked. This makes it difficult to obtain a synthesized beam having desired shapes in both the horizontal and vertical planes. As seen from the description relevant to Figs. 6 and 7, the beam is shaped by synthesizing reflected waves from respective reflector segments. Accordingly, the above-mentioned blocking prevents a necessary synthesis, resulting in a degraded shaping of the beam. This is a serious problem particularly in a vertical plane where the beam is required to be shaped down to a relatively low level.

Furthermore, from a technical point of view, it is difficult to shape the three dimensional reflector surface configured as indicated in Figs. 5 to 7. To do this, an expensive jig is generally required. In addition, the number of steps of shaping is increased, with the result that the total cost required for the antenna becomes high.

Preferred Embodiments

Referring to Figs. 10 and 11, there is shown a first embodiment of a shaped beam antenna according to the present invention. In this embodiment, an antenna structure comprises an array antenna 40 as a primary radiator constituted with a waveguide slot antenna, and a main reflector having a plurality of (two in this example) vertically extending reflector surface segments 50 and 51. Specifically, each segment takes the form of a part of cylinder, providing a partial cylindrical refelctor segment. The main reflector is provided at the middle portion thereof with a fastening member 42 serving as a transducer.

The array antenna 40 has a rectangular plane on which a plurality of radiating elements are arranged. The array antenna 40 is provided at one end with a terminator 41. In this embodiment, the Cartesian coordinate system is applied to the array antenna as follows: The center of the aperture where slots are provided is an origin. The X axis is set along the longitudinal direction. The Z axis is set in a direction which is perpendicular to the aperture and away from the main reflector. The Y axis is set in a direction perpendicular to the X and Z axes. The reflector segments 50 and 51 have longitudinal axes, with respect to which sectioned curves of the respective reflector segments are identical in planes perpendicular to the longitudinal axes. The longitudinal axes are in parallel with the X axis, respectively. The entire reflector is symmetrical with respect to the X-Z plane.

Fig. 12 shows an enlarged fragmentary view of the array antenna which has, in a so-called magnetic field surface of a waveguide, a plurality of elliptical slots which are parallel with each other in a direction of the waveguide axis, i.e., in the longitudinal direction. Radio wave propagating within the waveguide is radiated from the individual slots.

Excitations at individual slots occur due to a current flowing in the direction of Y-axis along the inner wall of the waveguide. An adjustment of its amplitude is made mainly by the dimension L in the direction of X-axis between slots shown in Fig. 12. Further, an adjustment of a relative excitation phase is made mainly by the dimension S between the slot and the X-axis shown in Fig. 12.

For instance, in Fig. 10, assuming that the Y-Z and X-Z planes denote horizontal and vertical planes, respectively, reference is made to a case where an asymmetrical beam as shown by solid curve 60 in Fig. 14 is synthesized in the vertical plane about the Z-axis which is representative of an angle of 0°. In this instance, excitation amplitudes of the individual slots are symmetrical with respect to the Y-Z plane, whereas the excitation phases thereof are antisymmetrical with respect thereto. The term "antisymmetrical" means that the absolute value of the phase is the same and its sign is inverted.

In the example shown in Fig. 14, when the total number of the slots is 21 and the slot locataed in the central portion has an excitation amplitude of 1 and an excitation phase of 0°, excitation amplitudes and phases from the first to the tenth slots on the upper side are shown in Table.

Table showing relative amplitude and relative phase of the slots

Slot number from the central portion	Relative amplitude	Relative phase (degree)
1	0.885	17.8
2	0.691	13.5
3	0.563	11.6
4	0.412	6.11
5	0.352	2.09
6	0.257	-3.78
7	0.176	0.40
8	0.113	-2.97
9	0.053	-7.09
10	0.015	-50.91

The excitation amplitudes and excitation phases from the first to the tenth slots on the lower side exhibit the same numerical values as those in Table with the exception that only the sign of each phase is inverted. The above-mentioned numerical example is given only for the purpose of realizing a shaped beam with an array antenna, and therefore other excitations may be possible. As seen from the above discussion, in the case where a beam as indicated by the solid line 60 in Fig. 14 is obtained based on synthesis, the excitation amplitude is symmetrical with respect to the Y-Z plane and the excitation phase is antisymmetrical with respect thereto.

Fig. 13 is a perspective view illustrating another form of the array antenna employed in the present invention. The array antenna in this example is configured as a printed array antenna and comprises a dielectric base 44, metal strips 43, 46 and 47 on the base 44, and a metal conductor 45 provided on the back side of the base 44. Each metal strip 43 is square shaped and serves as a radiation element. On the other hand, the metal strips 46 and 47 serve as power feed lines for feeding two orthogonally polarized waves to each radiation element 43. More particularly, the metal strip 46 is a power feed line for feeding a polarized wave having electric field component directed in X-axis direction, and the metal strip 47 is a power feed line for feeding a polarized wave having electric field component directed in Y-axis direction. These strips 46 and 47 have their input/out terminals connected to connectors 48 and 49 fixed to the metal conductor 45. These connectors 48 and 49 are electrically coupled to the power feed lines in a manner that their coaxial external conductors and central conductors are connected to the metal conductor 45 and to the metal strips 46 and 47, respectively.

With the array antenna shown in Fig. 13, the excitation amplitude and excitation phase of the polarized wave fed to each radiation element can be controlled by adjusting the width and the line length of the metal strips 46 and 47.

The beam shaping by the above-mentioned antennas differs from the beam shaping by the reflector surface which has been previously described with reference to Fig. 5. In accordance with the beam shaping of the invention, when an element having a good cross polarization discrimination is used as each radiating element, any cross polarization component is not included in a wave source in principle, enabling a desirable beam formation. Accordingly, even if an attempt is not made to cancel cross polarization components included in a wave source by making use of symmetry of the main reflector as described with reference to Figs. 8 and 9, the employment of the novel antennas of the above-mentioned embodiments according to the present invention makes it possible to provide a good cross polarization characteristic.

It is to be noted that the present invention can be implemented using a radiation element, e.g., a dipole array, or a crossed dipole array etc. instead of the above-mentioned array antennas shown in Figs. 12 and 13.

Fig. 15 shows an example of sectioned curves in the embodiment shown in Fig. 10 and Fig. 16 shows a radiation characteristic in a horizontal plane. In the example shown in Fig. 15, the reflector segments 50 and 51 are configured as parabolic ones having longitudinal focal lines coincident with a straight line 53 (See Fig. 10). In Fig. 15, a point at which the Y-Z plane and the focal line intersect with each other is represented by symbol Q. Accordingly, the sectioned curves shown in Fig. 15 are all of parabolas. The center axes of these parabolas and

Z-axis do not overlap with each other as indicated by symbols P50 and P51, and are symmetrical with respect to Z-axis. In most cases, the point Q is in correspondence with the origin and, actually, phase center point of radiation waves from the slots of the waveguide. Accordingly, on the basis of the geometrical property of the parabolic segment, radio waves radiated from the waveguide slots and reflected by the partial cylindrical reflector segments 50 and 51 are radiated as radio waves propagating in the directions of the center axes of parabolas through paths 72 and 73, and 74 and 75, respectively. The overall radiation characteristic is determined as a wave obtained by synthesizing the above-mentioned radio waves with radiation waves on paths 70 and 71 directly radiated from the waveguide slots.

On the Y-Z plane, the direct radiation waves from the slots of the waveguide form concentric wavefronts from the point Q and the maximum radiation direction thereof is along Z-axis. In general, the radiation wave from a small wave source, such as, for example, the slot or the radiating element shown in Fig. 13 represents a radiation characteristic having a broad beam width in the same plane. On the other hand, radiation waves from the partial cylindrical reflector segments 50 and 51 form wavefronts aligned with the parabola center axis directions, respectively, thus providing each radiation characteristic having a beam width narrowed in the parabola center axis direction.

Taking into account the above-mentioned discussion and the symmetry of the beam shaped antenna with respect to Y-Z plane, a radiation pattern 61 extending in a sector shape is obtained as the radiation characteristic in Y-Z plane, providing a shaped beam symmetrical with respect to Z-axis of zero-degree angle in Fig. 16.

The above discussion has been directed to the beam shaping of the main polarization components. Then, cross polarization characteristic will be described. As previously described in connection with the conventional cross polarization discrimination, each current induced in the partial cylindrical reflector segments is determined by the above-mentioned equation (2). When the equation (2) is developed in terms of X, Y and Z components, respective components J_X, J_Y and J_Z are expressed as follows:

$$J_X = n_Y H_Z - n_Z H_Y$$
$$J_Y = n_Z H_X - n_X H_Z$$
$$J_Z = n_X H_Y - n_Y H_X \quad \ldots\ldots (3)$$

where n_X, n_Y and n_Z denote X, Y and Z components of the normal vector $\mathbb{n}$, respectively.

Further, the magnetic field $\mathbb{H}$ and the electric field vector $\mathbb{E}$ are orthogonal with each other. Accordingly, when the main polarized wave, which is a so-called vertically polarized wave, i.e., which is a radiation wave of which electric field vector is directed along X-axis, is radiated from the array antenna, it can be said that the electric field vector incident to the partial cylindrical reflector surface is substantially expressed by only H_Y component. This is due to the fact that the radiation wave from the array antenna essentially exhibits a good cross polarization charactristic inherent therein as understood from the description in connection with Fig. 14.

On the other hand, the normal vector n on the partial cylindrical reflector surface is characterized in that n_X component is zero as apparent from the configuration. Accordingly, components of a current induced in this instance are expressed as follows:

$$J_X = n_Y H_Z - n_Z H_Y$$
$$J_Y = n_Z H_X \doteqdot 0$$
$$J_Z = n_Y H_X \doteqdot 0 \qquad \ldots\ldots (4)$$

As seen from the equation (4), it can be said that a current induced at each reflector segment is substantially expressed by only the component in X-axis direction of the main polarized wave. When this result is compared to the conventional current distribution shown in Fig. 9, it is apparent that the improvement in cross polarization characteristic is expected. A comparison of the shaped beam antenna of the invention with the conventional shaped beam antenna is carried out on a calculation basis. Namely, the shaped beam antenna shown in Figs. 5 to 7 exhibits a cross polarization characteristic above 20 dB which can only cover the range where an elevational angle is in the vicinity of ±0.5°. In contrast, with the shaped beam antenna according to the present invention, it has been confirmed that the range of an elevational angle nearly equal to ±5° can be covered. Further, it is appreciated from the description in connection with the derivation of the equation (4) that the present invention can also provide a good cross polarization characteristic where the main polarized wave is a so-called horinzontally polarized wave, i.e., where the electric field vector is directed along Y-axis.

In the above-described embodiment, parabolic segments are used for shaping a beam in a horizontal plane. However, the present invention can be practiced by utilizing a method to control a power beam in each angular direction by making use of geometrical optics to form sectioned curves shown in Fig. 15 as a continuous curve.

Further, in the example shown in Fig. 15, two partial cylindrical reflector segments are used, but the number of the reflector segments is not limited. For instance, four or six reflector segments are arranged symmetrically with respect to X-Z plane, thus making it possible to increase the degree of freedom in shaping the beam.

With the beam shaped antenna according to the present invention, there is no possibility that the main reflector blocks radiation wave from the array antenna. Accordingly, the present invention is advantageous in that the shaping of the beam is not degraded as compared to the conventional antenna. Particularly, this is advantageous when a beam is shaped in X-Z plane for the reason stated below. Namely, as seen from the comparison of Fig. 14 with Fig. 16, it is necessary for the case shown in Fig. 14 to shape the beam down to a considerably weak level as compared to the case shown in Fig. 16. Accordingly, the beam shaping performance is greatly influenced even by the small influence like a blocking.

The antenna of the present invention has such a structure that the partial cylindrical reflector surface is formed concave with respect to the maximum radiation direction, i.e., in a positive direction of Z-axis of the array antenna. This structure does not cause blocking phenomenon. The shaped beam antenna of the present invention is further characterized in that the maximum angle of the radiation wave from each reflector segments falls within an angle of ±90° with respect to Z-axis.

Referring to Fig. 17, there is shown another form of the antenna with the partial cylindrical reflector segments according to the invention. This modified embodiment is characterized in that two conductive side plates 54 are provided in parallel with Y-axis at the upper and lower edges of the reflector segments of the embodiment shown in Fig. 10. This conductive side plate

54 functions, from an electrical point of view, to physically shield unnecessary radiation wave toward the horizontal direction to thereby provide a good radiation characteristic in the range of a wide angle, and from a structural point of view, to increase mechanical strength of the reflector segments in a plane parallel to X-Z plane.

A second preferred embodiment of a shaped beam antenna according to the present invention will be described with reference to Figs. 18 to 22, wherein parts identical to those in the first embodiment are designated by the same or like reference numerals, and therefore their explanation will be omitted.

The shaped beam antenna of the second embodiment is characterized in that the main reflector comprises a plurality of (four in this example) vertically extending planar reflector segments. Namely, as best seen from Figs. 18 and 19, the main reflector comprises four reflector flat plates 150 and 151, and 152 and 153 as planar reflector segments. The reflector plates 150 to 153 have, in parallel with the X-axis, longitudinal axes, with respect to which sectioned lines of the respective plates are identical in planes perpendicular to the longitudinal axes. The entire reflector plate is symmetrical with respect to the X-Z plane.

Fig. 20 shows a cross-section cut along the Y-Z plane in the embodiment shown in Fig. 18 and Fig. 21 shows a radiation characteristic in the horizontal plane. In the example shown in Fig. 18, the reflector plates 150, 151, 152 and 153 individually serve as plane reflectors of which wave source is the array antenna 40, but on the whole they serve as a modified corner reflector. As well known, the corner reflector is used for converging a beam width of a radiation wave from a wave source producing a radiation wave having a wide beam width to form a radiation beam having high directivity like a dipole antenna. The beam shape formed in such a case is adjusted by the spacing between the main reflector and the wave source or an opening angle formed between adjacent two reflector plates.

The present invention is implemented by the application of this principle. Radiation wave radiated from the array antenna 40 is divided into a first group of radiation waves which are directly radiated via paths indicated by broken lines 171 and 172 and a second group of radiation waves which are radiated from the wave source and reflected by the reflector plates as indicated by broken lines 172 to 175. The overall radiation caracteristic is determined as a resultant wave of these radiation waves.

Namely, an adjustment of each vertical distance of the reflector plates 150, 151, 152 and 153 with respect to the origin and an inclined angle with respect to the Z-axis is made, thus making it possible to shape the beam into various forms in the Y-Z plane, i.e., in the horizontal plane.

The antenna structure of the embodiment shown in Fig. 20 provides a radiation characteristic which is symmetrical with respect to Z-axis wherein a radiation beam extends in a sector shape as indicated by a solid line 161 in Fig. 21 in Y-Z plane for the reasons below: First is that the maximum radiation direction is directed in Z-axis, i.e., in an angle of 0° in Fig. 21 along which an energy level radiated from the array antenna is the maximum. Second is that radiation wave from a small wave source such as a slot or metal strip 43 in Fig. 13 has a broad radiation characteristic in the Y-Z plane. Third is that reflected waves from the reflector plates 150 and 151 and those from the reflector plates 152 and 153 concentrate substantially in the same direction. Fourth is that the antenna has a configuration symmetrical with respect to X-Z plane.

Referring to Fig. 22, there is shown another form of the second embodiment according to the invention. This modified embodiment is characterized in that two conductive side plates 154 are provided in parallel with Y-axis at the upper and lower edges of the main reflector of the embodiment shown in Fig. 18. This modified embodiment can provide the same advantages obtained with the embodiment shown in Fig. 17.

Finally, a third embodiment of the invention implemented for further improving the second embodiment will be described.

When an attempt is made to improve a beam shaping performance in a horizontal plane, it is difficult to enlarge the size of each reflector segment, resulting in the following drawbacks. First is that there occurs unnecessary radiation toward the outside of a radiation zone. Second is that even if the radiation area is defined by a range within ±45° in the horizontal plane as indicated by solid line 161 in Fig. 21, a radiation pattern having a maximum relative power level in the vicinity of an angle of 0° and a reduced relative power level in the vicinity of an angle of ±45° is obtained. Third is that even if a relative power level is raised in the vicinity of an angle of ±45° in order to eliminate the second drawback, a large level variation of the radiation pattern occurs. The reason why unnecessary radiation is increased because of small-sized reflector segment is that it is impossible to enlarge the size of the reflector segment with respect to a wavelength in the frequency used, with the result that the strength of diffracted wave etc. becomes large at the end edge of the reflector segment labelled 300 in Fig. 20. On the other hand, the reason why the employment of the large-sized reflector segment allows the level variation within a radiation zone to be large is that the phase of a reflected wave from the reflector varies relative to the phase of a wave directly reflected by the array antenna, and such a variation is proportional to the size of the reflector.

The third embodiment made with the above in view will be described with reference to Figs. 23 to 30 wherein parts identical to those in the second embodiment are designated by the same reference numerals, and therefore their explanation will be omitted.

Fig. 23 is a perspective view illustrating the third embodiment of the invention and Fig. 24 shows a plan view of Fig. 23. In this embodiment, the main reflector comprises a first reflector segments 255 disposed on the opposite side surfaces of the array antenna 40 and second reflector segments 256 disposed so as to surround the array antenna 40 and the first reflector segments 255 wherein each second reflector segment 256 is provided on the inside thereof with a radio wave absorber 257 (which will be simply referred to as "wave absorber" hereinafter).

The reflector segments 255 and 256 have, in parallel with X-axis, longitudinal axes with respect to which sectioned lines of the respective reflector segments are identical in planes perpendicular to the longitudinal axes. The entire reflector is symmetrical with respect to X-Z plane. The present invention aims at improvement in beam shaping performance in a horizontal plane of the above-mentioned antenna. For this reason, the configuration and function are the same as the antenna shown in Fig. 18.

Radiation characteristic in a horizontal surface in the antenna of the present invention taking Y-Z plane as a horizontal plane will be described with reference to Fig. 24. As well known, the radiation characteristic in the horizontal plane from each slot of the array antenna 40 is half-isotropic, which is uniform within an angle of ±90° with respect to Z-axis in Y-Z plane. In order to converge a radiation energy amount within a necessary angular range, e.g., ±45° without, to much extent, changing uniformity in Y-Z plane which is the feature of the radiation characteristic from the slot itself, first is to use the first reflector segment 256 having a wavelength which is at the most several times the wavelength of the frequency used to form a beam pattern as indicated by broken lines 265 in Fig. 25. The reason why the size of the first reflector segment is set at a small value is to ensure that the difference between the phase of a reflected wave from the reflector segment 256 and the phase of a radio wave directly radiated from the slot is not large. However, this makes it difficult to reduce the level of a radiation toward the outside of the necessary angular range as indicated broken lines 265. Namely, there is complementary relationship between level variation width Δ G and the level of the radiation toward the outside of the necessary angular range. For this reason, an attention is first drawn only to the beam shaping within the necessary angular range to determine the form and the size of the first reflector segment 256.

Then, in order to reduce the level of unnecessary radiation toward the outside of the necessary angular range, the second reflector segment 256 to which the wave absorber 256 is added is used. Namely, with reference to Fig. 25, for the purpose of allowing the beam to have a pattern indicated by solid line 266 instead of the pattern indicated by broken lines 265 so that an unnescessary radiation level can be reduced, the wave absorber is provided in a path through which a direct wave from the slot toward unncessary angular direction and a diffracted wave at the end edge of the first reflector segment 255 propagates. Further, the wave absorber 257 and the second reflector segment 256 are provided to reduce radiation in a negative direction of Z-axis. The shaped beam antenna thus configured can reduce an unnecessary radiation level without degrading beam shaping performance within an necessary angular range. In addition, when a radome of dielectric material is provided in a positive direction of Z-axis in the front of the antenna, the employment of the wave absorber 257 advantageously ensures absorption of the reflected wave from the radome, easiness of impedance matching and mitigation of degradation in beam shaping performance.

Fig. 26 is a perspective view illustrating another form of the third embodiment. The first reflector segment 255A is utilized as so-called image plate to adjust a distance Δl between the first reflector segment

255A and the slot array antenna 40, thus shaping a beam within a necessary angular range as indicated by broken lines 265A in Fig. 27. Further, the second reflector segments 256 and the wave absorbers 257 connected to the end edge of the first reflector segment 255A or integrally formed therewith are provided to reduce the level of a radiation outside the necessary angular range as indicated by the solid line 266A.

Figs. 28 and 29 are side and front views illustrating another form of the wave absorber employed in the present invention wherein a metallic blind 59 is additionally provided on the surface of the wave absorber 257 in parallel with the radiation electric field vector E. The metallic blind 259 is generally added to the surface of the wave absorber 257 through a dielectric base 258. In Fig. 29, the setting is made such that the spacing T between metallic grids of the blind 259 is above one-half of the wavelength of a frequency used. By this setting, a part of the incident radio wave is reflected by the metallic blind 259 while the remainder is absorbed by the wave absorber 257. In contrast, with the conventional antenna, the spacing between metallic grids generally used as a reflector is the order of one-tenth of the wave length of a frequency used. Such a wave absorber with metallic blind in this embodiment is employed for utilizing even part of energy of radiation toward outside of an unnecessary angular direction to improve the overall beam shaping performance without simply absorbing the entire energy thereof like the examples shown in Figs. 23 and 26. By the employment of the wave absorber with metallic blind, the beam pattern within a necessary angular range as indicated by broken lines 265B is changed to a beam pattern indicated by solid line 266B. Thus, the resultant beam pattern 266B has a somewhat increased number of undulations as shown, but becomes advantageous in reducing the level of a radiation toward the outside of the necessary angular range. Namely, as discussed with reference to Fig. 21, the enlargement of the size of the reflector leads to an increase in level variation under the influence of the relative phase variation between a direct wave from the array antenna and a reflected wave from the reflector. However, the employment of the wave absorber with metallic blind allows the amplitude of the reflected wave to be small, thus enabling level variation to be limited to a small value regardless of the relative phase difference. This can be readily understood from the following discussion: For instance, when the direct wave and the reflected wave have the same amplitude and anti-phase relationship, the resultant wave has an amplitude of zero. In contrast, in case where the direct wave has an amplitude ten times larger than that of the reflected wave, even if they have anti-phase relationship, the resultant wave has an amplitude which is the order of 0.9 in terms of power ratio. Thus, this modification of the third embodiment can effectively reduce the level variation within a necessary angle of a beam pattern as indicated by broken lines 162 in Fig. 21.

The present invention has been described on the assumption that the subject antenna of the invention is a transmitting antenna by using the term "radiation". However, since propagating direction of radio wave utilized in an antenna is reversible, the present invention is applicable not only to transmitting antennas but also to receiving antennas.

As described above, the present invention can realize an antenna having a good beam shaping performance and an excellent cross polarization discrimination. In addition, since the reflection surface is partially cylindrical or planar, the fabrication cost is lower than that of the complicated specular surface used in the prior art. The present invention is particularly advantageous when applied to an antenna for a master station in a radio communication area where point-to-multipoint sytem is adopted.

Claims

1. A snaped beam antenna comprising:

an array antenna having a planar surface on which a plurality of radiating elements are arranged; and

a main reflector having a plurality of vertically extending reflector segments and disposed behind with respect to a radiating direction of each radiating element of said array antenna, wherein Cartesian coordinates are assumed having an origin in the center of said planar surface of said array antenna, an X-axis extending in a vertical center axis of said array antenna, a Z-axis extending in a direction perpendicular to said planar surface through said origin, and a Y-axis extending in a direction perpendicular to said X- and Z-axes through said origin,

the improvement wherein the longitudinal axis of each reflector segment is in parallel with said X-axis, said main reflector is symmetrical with respect to the X-Z plane and formed convex in a negative direction of said Z-axis, and each of said radiating elements of said array antenna is disposed so that its excitation amplitude is symmetrical with respect to the Y-Z plane and its excitation phase is antisymmetrical with respect to said Y-Z plane, whereby a radiation beam formed by said main reflector is symmetrical with respect to said Z-axis on said Y-Z plane and is asymmetrical with respect to said

Z-axis on said X-Z plane.

2. A shaped beam antenna as set forth in claim 1, wherein said main reflector comprises a plurality of partial cylindrical reflector segments.

3. A shaped beam antenna as set forth in claim 2, wherein said partial cylindrical reflector segment is configured as a parabolic reflector.

4. A shaped beam antenna as set forth in claim 3, wherein each parabolic segment has a focal line vertically extending in parallel with said X-axis, said array antenna having a central point at which said Y-Z plane and said focal line intersect with each other.

5. A shaped beam antenna as set forth in claim 4, wherein said central point is a phase central point of radiation wave from said radiating element.

6. A shaped beam antenna as set forth in claim 4, wherein said central point is said origin.

7. A shaped beam antenna as set forth in any of claims 1 to 6, wherein said main reflector comprises a plurality of vertically extending planar reflector segments.

8. A shaped beam antenna as set forth in claim 7, wherein said main reflector is configured as a modified corner reflector.

9. A shaped beam antenna as set forth in any of claims 1 to 8 wherein said main reflector further comprises conductive members at the longitudinally opposite ends, said conductive members being arranged in parallel with said Y-axis.

10. A shaped beam antenna as set forth in any of claims 1 to 9, wherein said reflector further comprises a radio wave absorber along at least a part of the reflector surface thereof.

11. A shaped beam antenna as set forth in claim 10, wherein a metallic blind having grids is provided on the surface of said radio wave absorber, said grids being arranged in parallel with a polarized radiation from said array antenna, the spacing between said grids being more than one-half of a wavelength of a frequency used.

12. A shaped beam antenna as set forth in any of claims 1 to 11, wherein said array antenna is comprised of a rectangular waveguide having a plurality of slots serving as the radiating elements.

13. A snaped beam antenna as set forth in any of claims 1 to 12, wherein said array antenna comprises a dielectric base, metal strips respectively serving as the radiating elements and power feed lines, provided on said dielectric base, a metal conductor provided on the back side of said dielectric base, and connector means fixed to said metal conductor for connecting said metal strip serving as power feed line to said metal conductor.

14. A snaped beam antenna as set forth in any of claims 1 to 13, wherein said array antenna is configured as a dipole array or a crossed dipole array antenna.

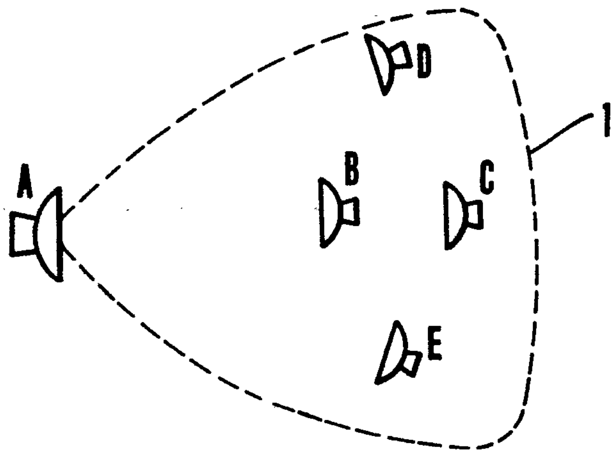


FIG.1

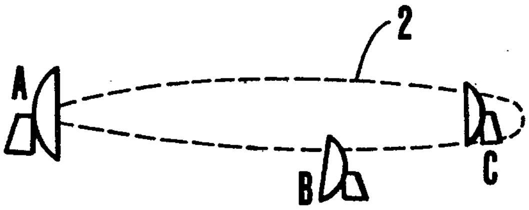


FIG.2

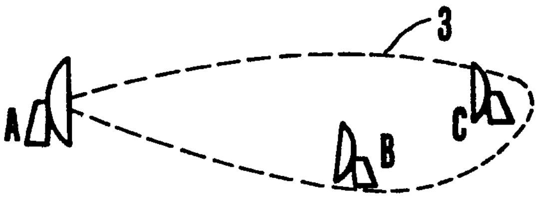


FIG.3

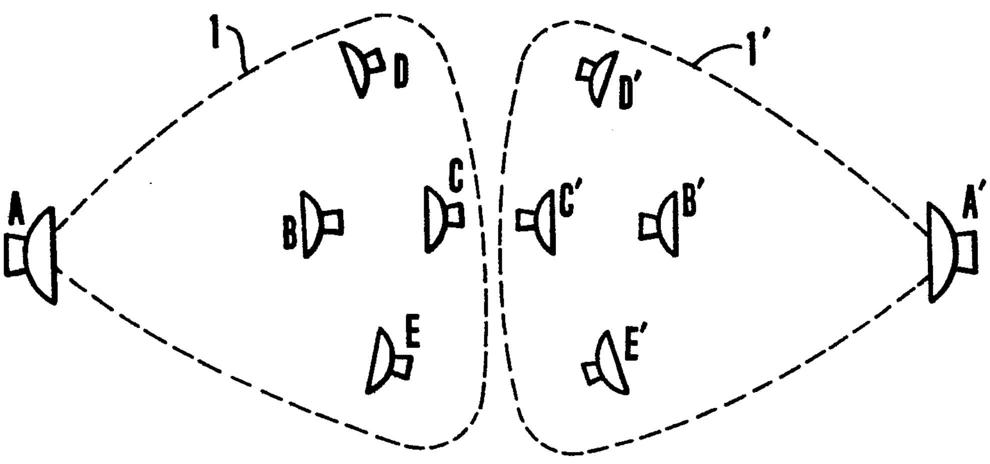


FIG.4

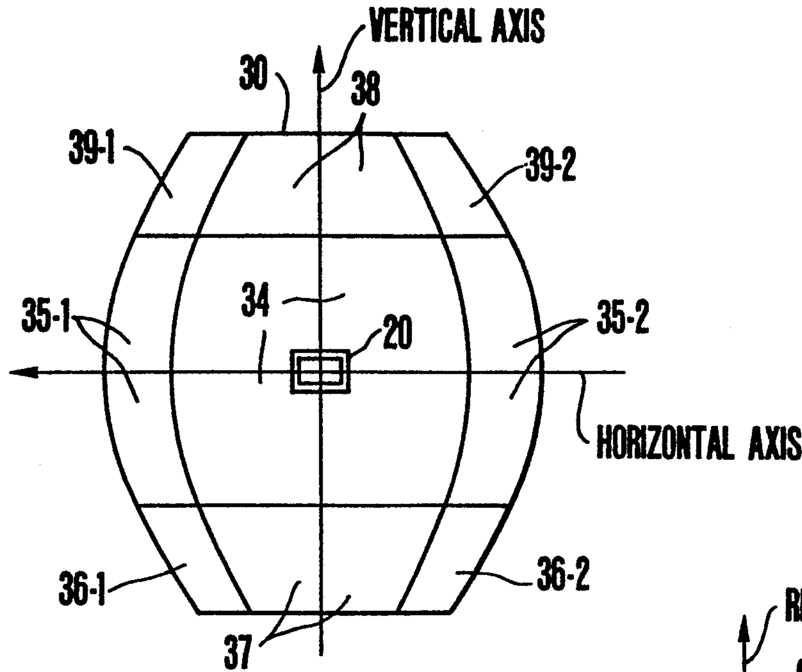


FIG.5
PRIOR ART

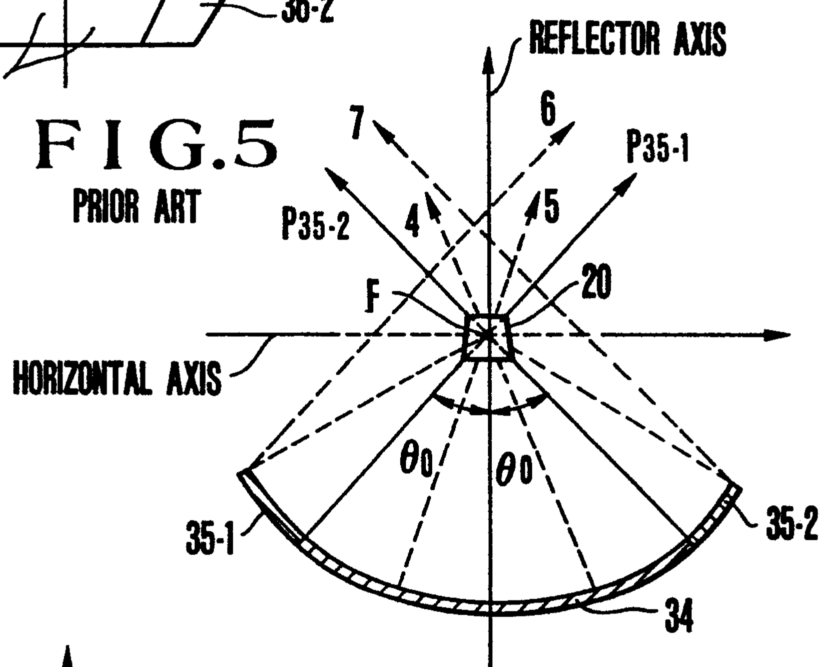


FIG.6
PRIOR ART

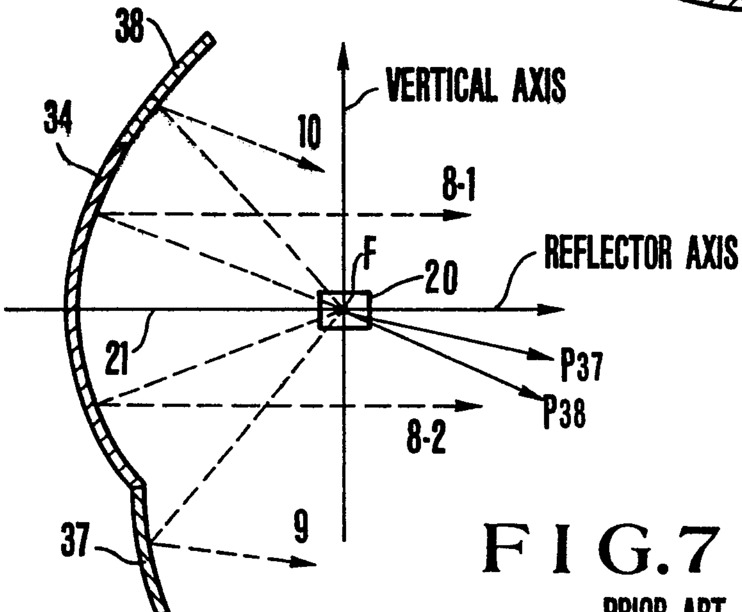


FIG.7
PRIOR ART

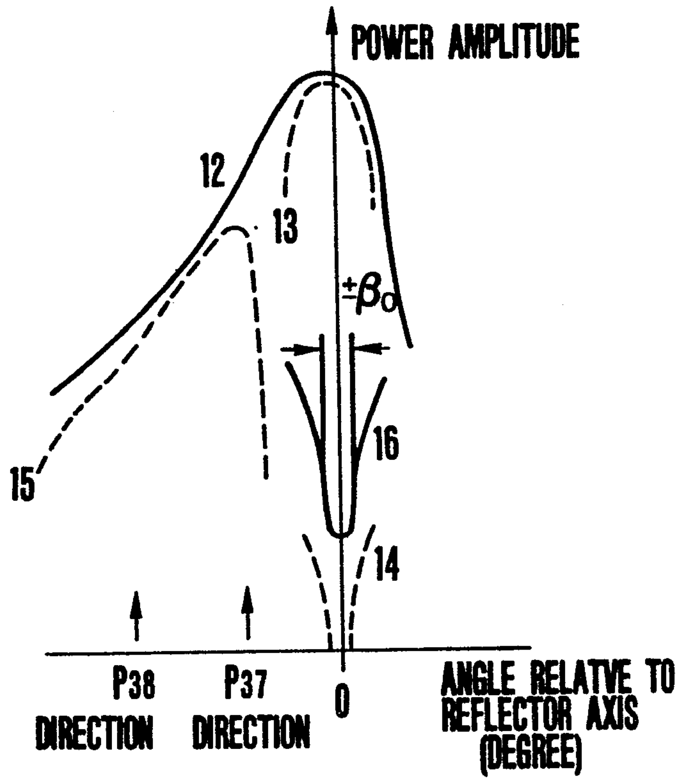


FIG.8
PRIOR ART

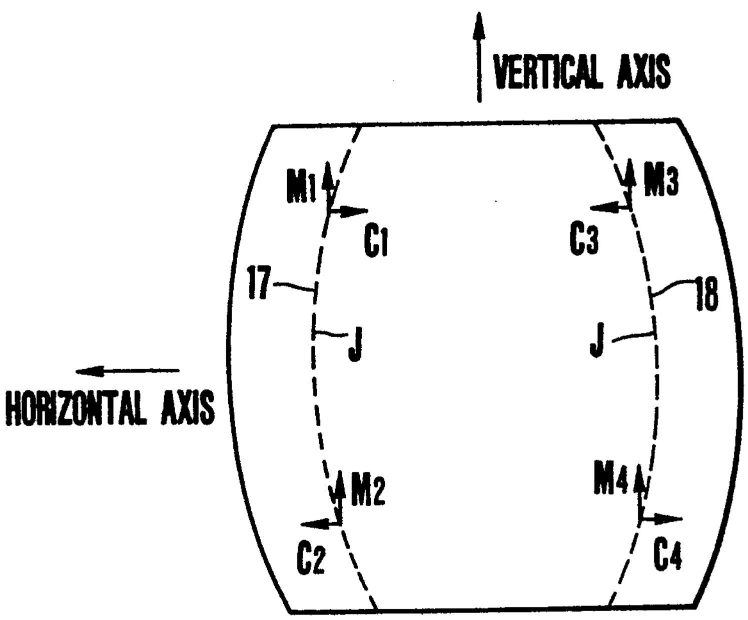
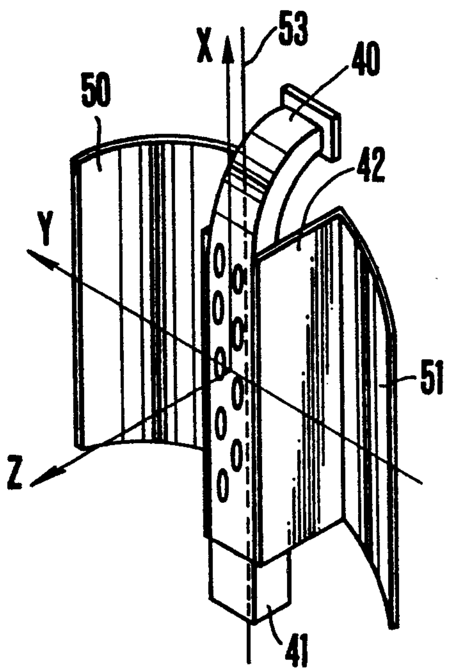
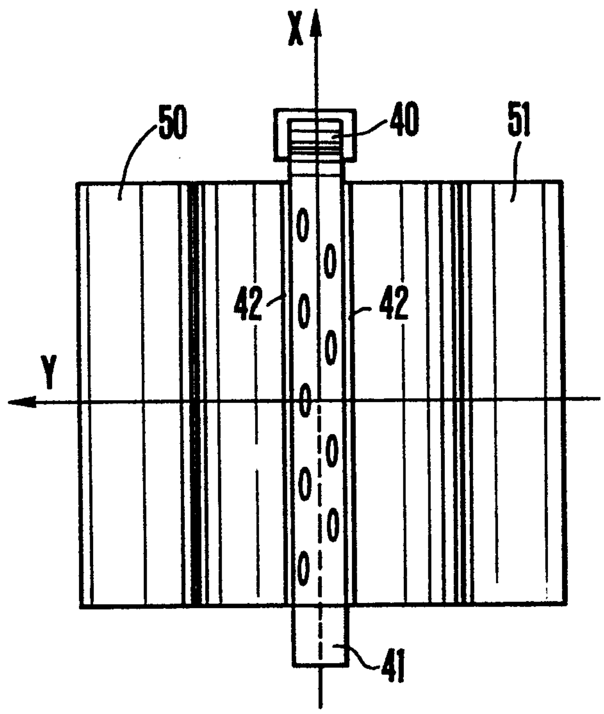


FIG.9
PRIOR ART



F I G.10



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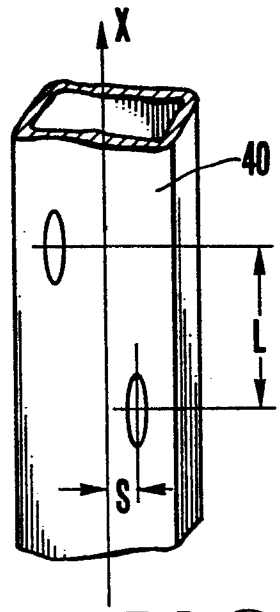

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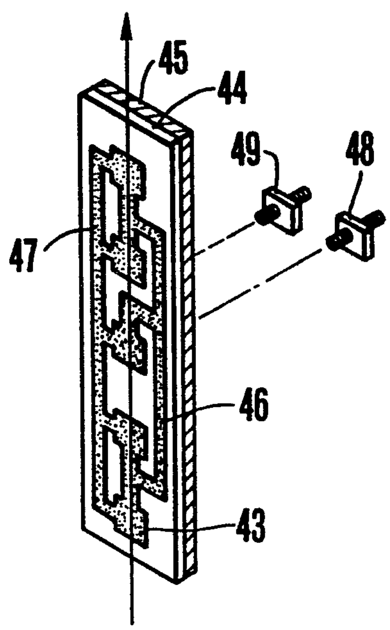

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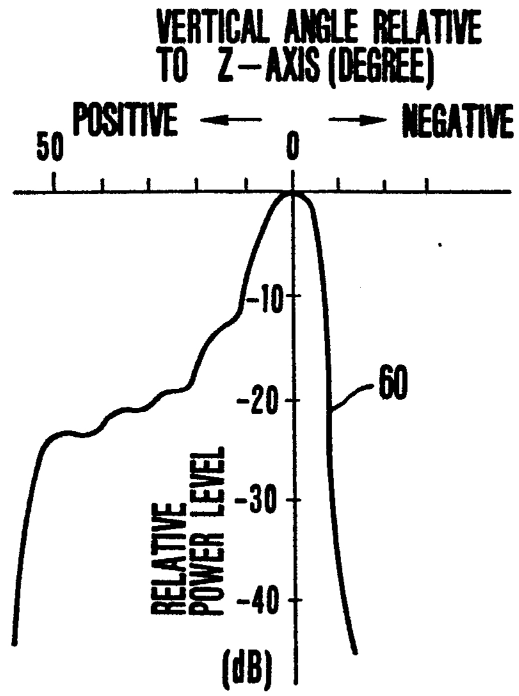

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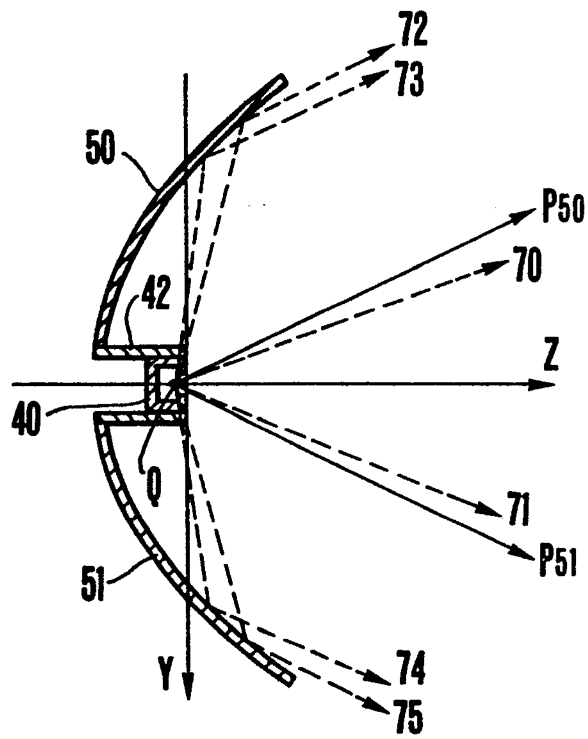

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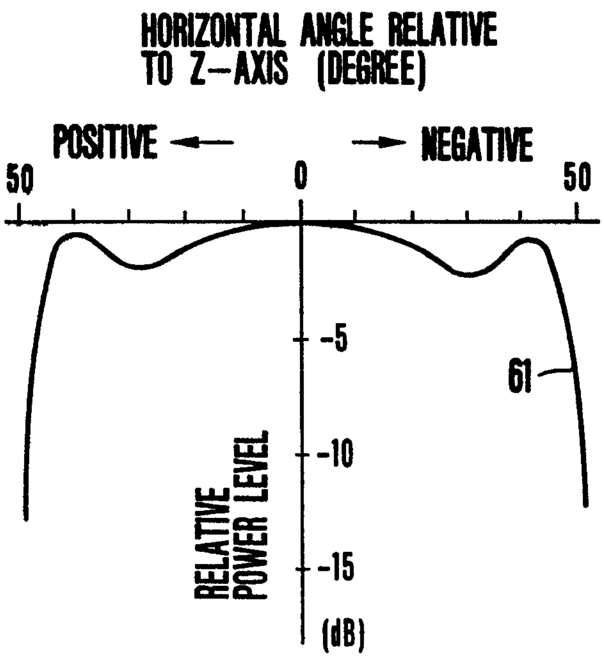

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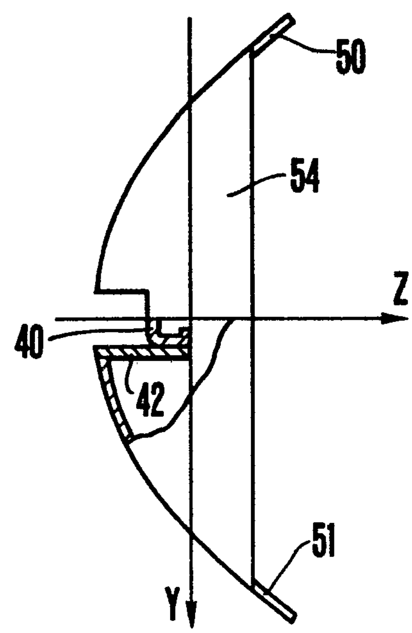

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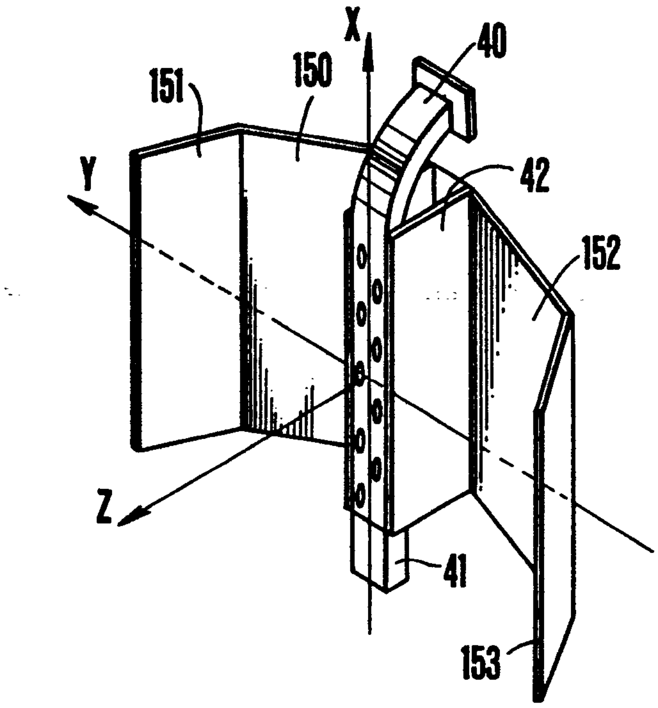

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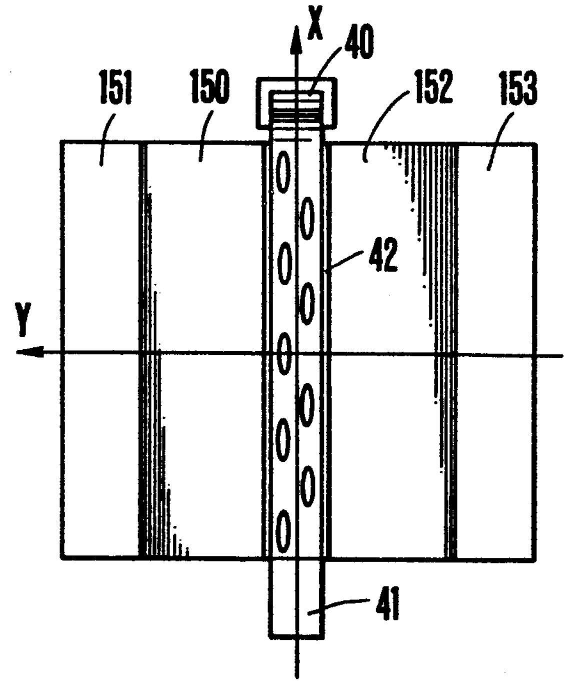

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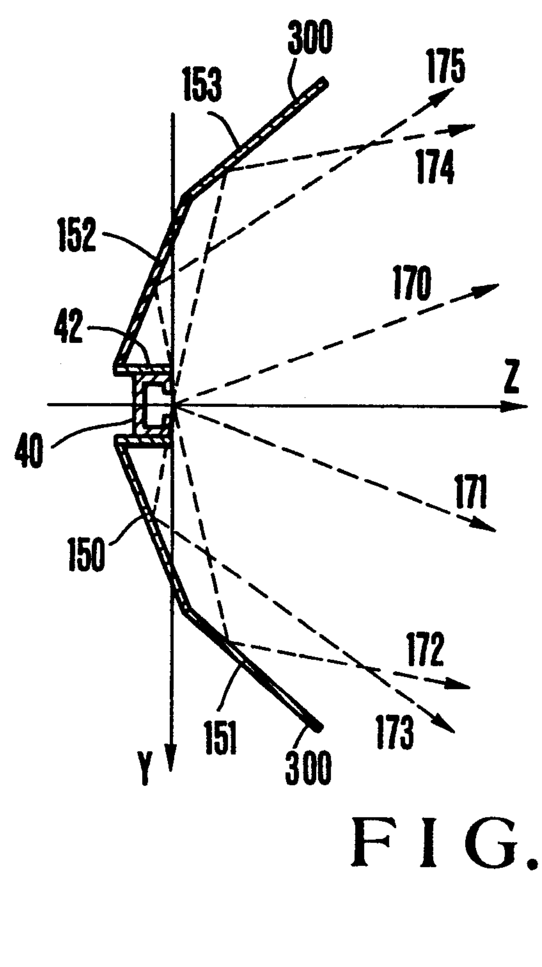


F I G.20

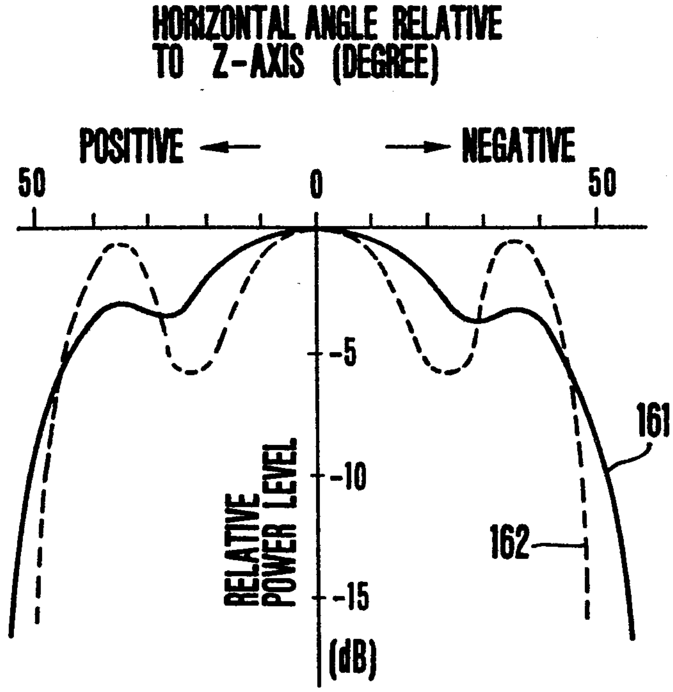

HORIZONTAL ANGLE RELATIVE
TO Z-AXIS (DEGREE)
POSITIVE
NEGATIVE
50
0
50
-5
-10
-15
(dB)
RELATIVE
POWER LEVEL
161
162

FIG.21

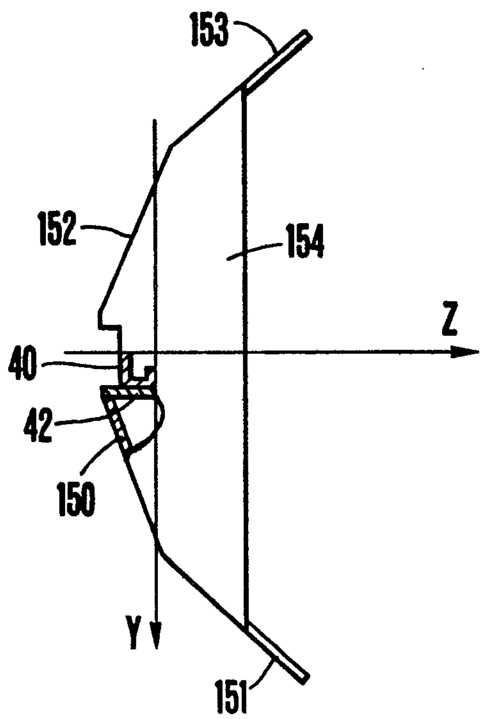
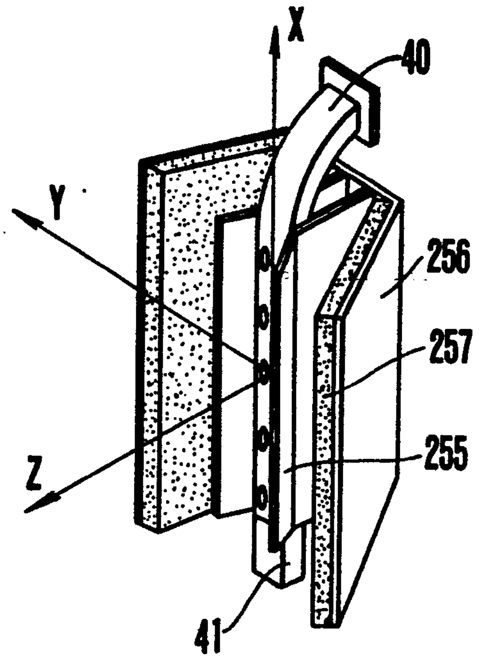
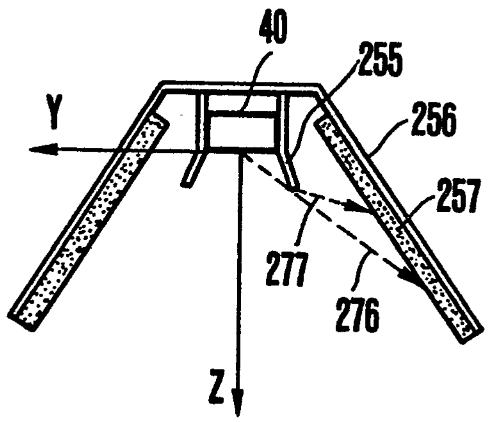

153
152
154
Z
40
42
150
Y
151

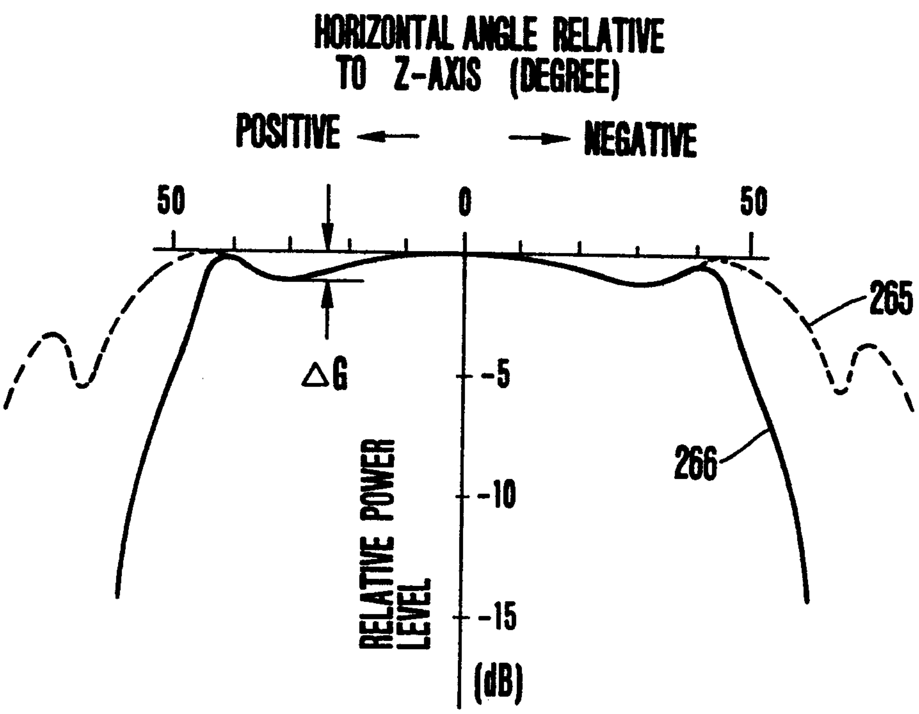
FIG.22



F I G.23



F I G.24



F I G.25

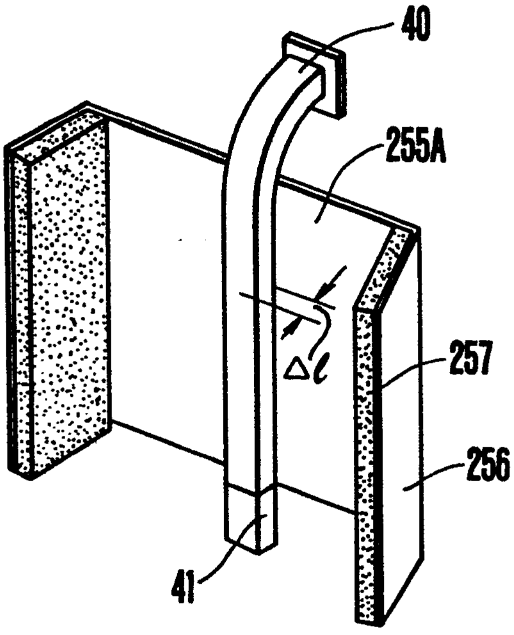

40
255A
Δℓ
257
256
41

FIG.26

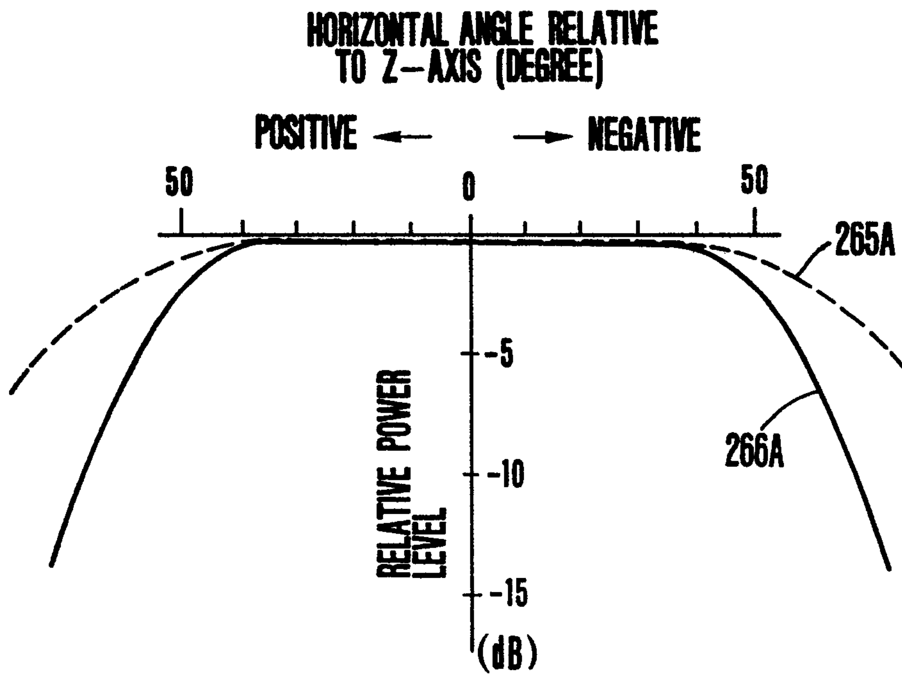
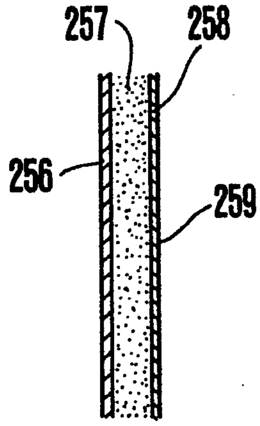
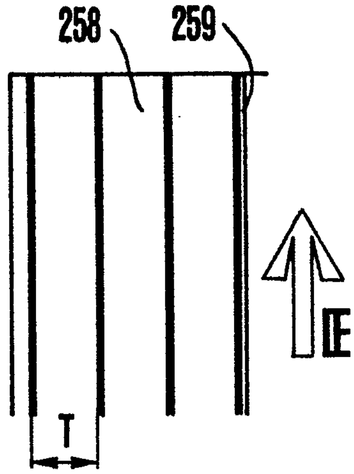

HORIZONTAL ANGLE RELATIVE
TO Z-AXIS (DEGREE)
POSITIVE
NEGATIVE
50
0
50
265A
-5
-10
-15
(dB)
RELATIVE POWER
LEVEL
266A

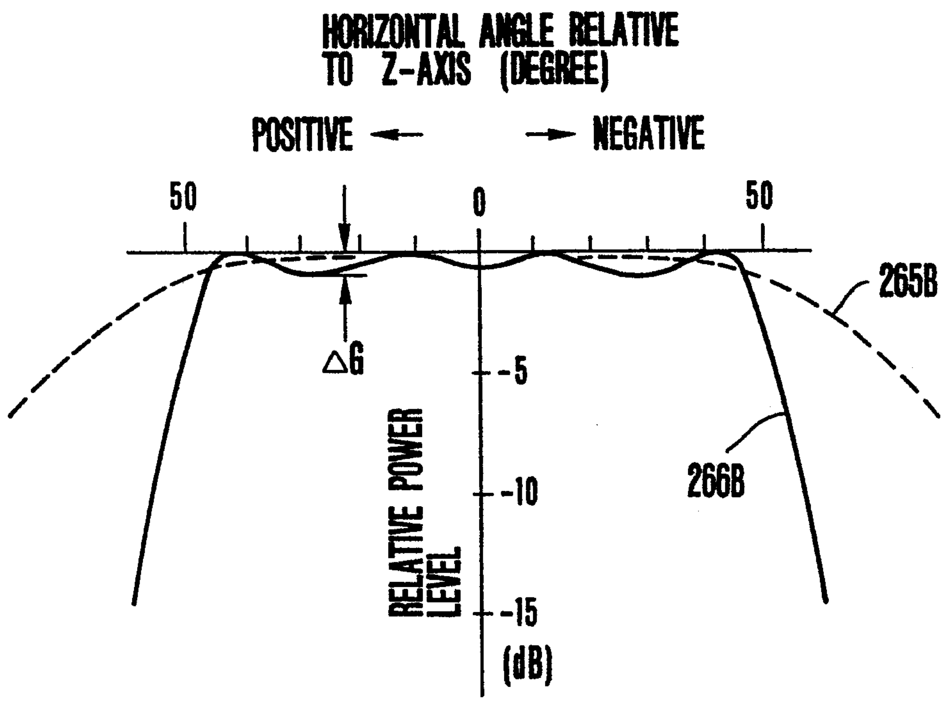
FIG.27



F I G.28



F I G.29



F I G.30