

Nov. 6, 1962

K. C. KELLY

3,063,049

LINEARLY POLARIZED MONOPULSE LOBBING ANTENNA HAVING
CANCELLATION OF CROSS-POLARIZATION COMPONENTS
IN THE PRINCIPAL LOBE

Filed Jan. 2, 1959

2 Sheets-Sheet 1

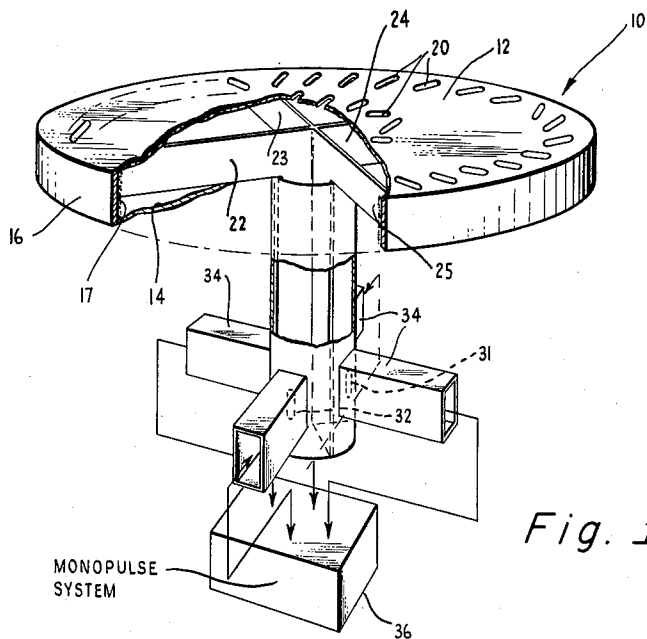


Fig. 1.

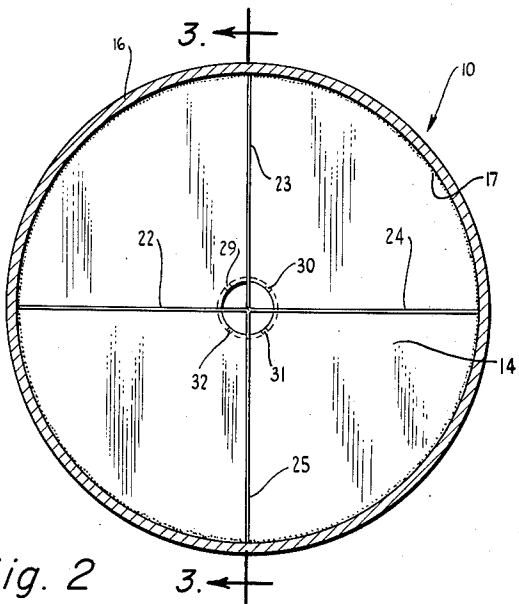


Fig. 2

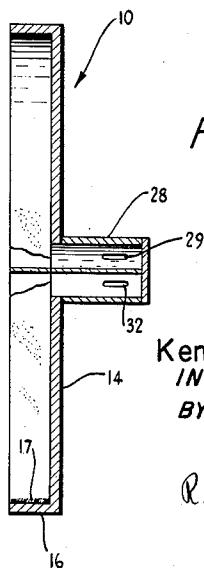


Fig. 3.

Kenneth C. Kelly,
INVENTOR.
BY.

R. A. Bogucki

ATTORNEY.

Nov. 6, 1962

K. C. KELLY

3,063,049

LINEARLY POLARIZED MONOPULSE LOBING ANTENNA HAVING
CANCELLATION OF CROSS-POLARIZATION COMPONENTS
IN THE PRINCIPAL LOBE

Filed Jan. 2, 1959

2 Sheets-Sheet 2

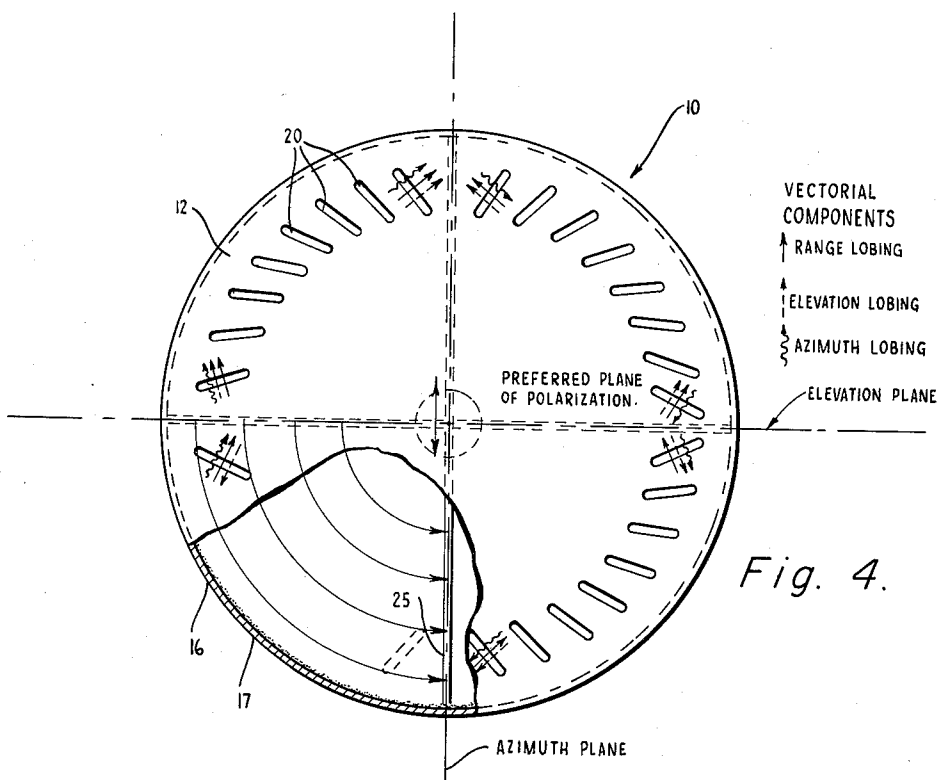


Fig. 4.

Fig. 5.

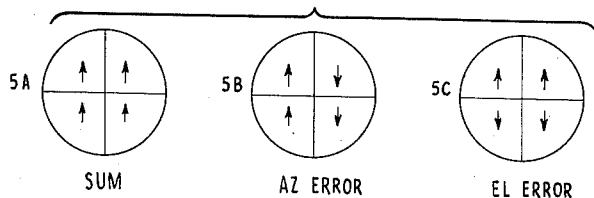
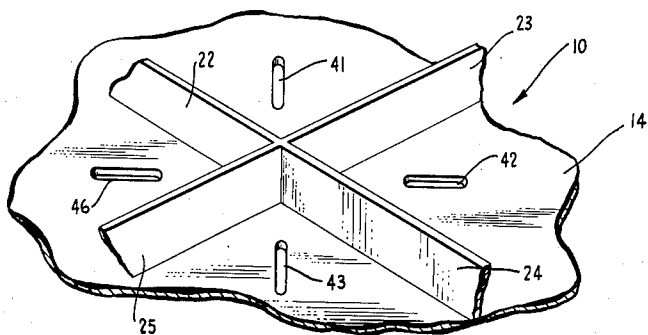


Fig. 6.



Kenneth C. Kelly,
INVENTOR.

BY.

R. A. Bogucki

ATTORNEY.

1

3,063,049

LINEARLY POLARIZED MONOPULSE LOBING ANTENNA HAVING CANCELLATION OF CROSS-POLARIZATION COMPONENTS IN THE PRINCIPAL LOBE

Kenneth C. Kelly, Gardena, Calif., assignor to Hughes Aircraft Company, Culver City, Calif., a corporation of Delaware

Filed Jan. 2, 1959, Ser. No. 784,818
11 Claims. (Cl. 343—771)

This invention relates to antennas which utilize lobing operation, and particularly to planar antennas for lobing with linearly polarized microwave energy.

A number of applications exist in which antennas are utilized to provide directional as well as distance information from wave energy upon which they operate. In contrast to conventional single horn and reflector antenna combinations, these antennas point along a given axis and derive error information as to the variation in azimuth and elevation from the given axis. To do this they may, for example, use the amplitude difference energy received at two or more different lobe positions from off-axis objects. These antennas may be referred to as lobing antennas because they utilize actual or synthesized lobing patterns to derive pointing error information.

Lobing antennas can operate with directed lobes during transmission and reception, or by utilizing a single beam transmitted along the axis and by deriving the directional information on receiving the energy. This latter type of lobing is usually referred to as monopulse or silent lobing operation.

The systems heretofore available for lobing operation have usually required a number of features which are not always practical or convenient to utilize in combination. Thus one commonly employed system utilizes a parabolic reflector, with four different source points close to the focus point of the reflector. For monopulse operation, this antenna utilizes the energy received at the four different transducer points, combining this energy in a waveguide coupler and mixing system which provides the desired error signals. Such a system requires first an extensive amount of microwave circuitry, and secondly requires a large and complicated antenna feed arrangement which causes aperture blocking. Other monopulse antennas employ rectangular waveguides coupled together with a phasing or switching system by which pointing error information can be derived. The radiating waveguide arrangements, however, tend to be heavy and difficult to manufacture.

With the systems heretofore available it has been difficult to combine the antenna system with the feed system in a simple and lightweight arrangement. The problems of providing a gimbaled support for a dish type antenna are well known. Similarly, the inconvenience and unsuitability of protruding feeds for many installations will be recognized by those familiar with the art. Particularly has it been difficult to provide an arrangement suitable for mobile applications which can at the same time be flush mounted with a streamlined surface and which has desirable radiation characteristics. It is desirable for many applications, for example, to provide linearly polarized beams of circular cross section having low side lobes. When these requirements are added to the useful constructional features mentioned above, some compromises have heretofore had to be made.

It is therefore an object of this invention to provide an improved lobing antenna which is simpler to construct and operate than the antennas heretofore available.

Another object of this invention is to provide an improved lobing antenna of small size and relatively simple construction which operates to provide a linearly polarized beam.

2

Yet another object of this invention is to provide an improved monopulse antenna which can provide pointing error information with an extremely simple wave energy feed structure.

A further object of this invention is to provide an improved form of lobing antenna, which is small in size, light in weight and which can be flush mounted with a planar surface.

These and other objects of this invention are achieved by an arrangement in accordance with the invention which utilizes an apertured radial waveguide which is divided into like angular segments. The radiating apertures are included in one planar surface of the radial waveguide and the radial waveguide is internally divided, as into quadrants, by radial conductive septa. The dimensions and mode of operation of the radial waveguide are selected such that partial modes may be established within each of the quadrants. The conductive septa permit control of the instantaneous directions of the currents induced in the surface which contains the radiating apertures. With this arrangement, the excitations of the radiating apertures in the quadrants may be individually paired and also combined by quadrants to provide sum signals or azimuth or elevation error signals which utilize linearly polarized radiation patterns.

In one form of the invention the radial waveguide may be used to establish a magnetic field mode, such as the H_{01} mode. With this arrangement the radiating apertures are arranged in concentric circles about the central axis of the radial waveguide. The apertures within each of the quadrants have like inclinations with respect to the concentric circle on which they lie. The attitudes of the radiating apertures vary between quadrants, however, so that opposed pairs of oppositely inclined apertures exist in adjacent quadrants. By controlling the direction of the current excitation in adjacent quadrants through the use of the conductive septa, the quadrants may be matched together in selected pairs to provide a single lobe along the axis, or azimuth lobing or elevation lobing. This arrangement is such that cross polarization components in the principal lobe are canceled by the matching of the opposed pairs of apertures.

The novel features of this invention, as well as the invention itself, both as to its organization and method of operation, may best be understood when considered in the light of the following description, taken in connection with the accompanying drawings, in which like reference numerals refer to like parts, and in which:

FIG. 1 is a perspective view, partially broken away, of a lobing antenna and feed system in accordance with the present invention;

FIG. 2 is a sectional plan view of the arrangement of FIG. 1;

FIG. 3 is a side sectional view of the arrangement of FIG. 1, taken along the line 3—3 in FIG. 2 and looking in the direction of the arrows;

FIG. 4 is a simplified plan view of the arrangement of FIG. 1, showing the vectorial components of radiation therein for different operation modes;

FIG. 5 is a simplified representation of the total vectorial components in the selected plane of polarization for different modes of operation, and

FIG. 6 is a fragmentary perspective view of an arrangement like that of FIG. 1, showing a different method of energy coupling.

Antennas and antenna systems in accordance with the present invention are intended to provide lobing operation. It is specifically intended that these antennas lobe along a given axis as well as providing off-axis lobes from which azimuth and elevation deviations can be derived. The lobing can be accomplished by generating pairs of lobes during the transmit operation, or by opera-

ting to provide directional information from energy. Thus when lobing on transmit, the transmitted pattern may be directed in the single lobe along the given axis, or may be divided into separate lobes on either side of an azimuthal plane or an elevation plane.

Lobing on receive is often referred to as "silent" lobing because the directional information is derived from the amplitude and phase relationships of the received energy, and because the transmitted lobe is kept uniform along the central axis. Such an arrangement provides a full amplitude transmitted signal but reveals little information to the object being tracked. Previous methods of lobing on receive have usually required, as stated above, the use of separate radiators to provide the separate signals from which phase relationships and thus error information are derived. Because of the reciprocal characteristics of antennas the fundamental nature of the antenna transducer remains the same whether the lobing is done on transmit or receive. It is intended by the present invention to provide a new family of lobing antennas which can lobe on transmit or receive to provide a pencil beam which is linearly polarized.

An arrangement in accordance with the invention, referring now to FIGS. 1, 2 and 3, utilizes principally a radial waveguide 10. A radial waveguide, as is well known in the art, employs a pair of parallel conductive plates which provide a radial distribution of energy outwardly from the center of the waveguide. For convenience, the radial waveguide 10 illustrated herein may be said to use a conductive circular top plate 12 and bottom plate 14 which are centrally disposed about and normal to the antenna axis. The terms "top" and "bottom" are of course relative, but are useful in visualizing the employment of the antenna with its top plate 12 flush with an associated vehicle surface, such as an aircraft body or wing section (not shown).

The top and bottom plates 12 and 14 respectively of the radial waveguide 10 may, in the arrangement of FIG. 1, be separated by at least one half a working wavelength at the operating frequency employed, so as to support the H_{01} mode of the radial waveguide. In this mode, electric field vectors are concentrically disposed about the given axis within the radial waveguide 10. The outer periphery of the radial waveguide 10 may terminate in a circumferential band 16, on the inner portion of which band 16 may be deposited or otherwise affixed a resistive termination layer 17. The presence of the resistive termination 17 in the outer periphery of the radial waveguide 10 results in the establishment of traveling waves within the radial waveguide 10. The device could likewise be operated with standing waves through the employment of a conductive short circuit termination at the circumferential band 16. In this case the center of the radiating slots employed should be at one quarter wavelength, or any odd multiple thereof, from the short-circuit termination. Either manner of operation results in like current distributions on the surface of the plates 12 and 14 of the radial waveguide 10.

The excitation of the plates 12 and 14 of the radial waveguide 10 with given current distributions permits the use of the radial waveguide 10 as a radiant energy transducer, or antenna. The coupling of energy between free space and a confined mode is in the present instance accomplished by the use of radiating slots 20, the arrangement and disposition of which is more fully described below. The radiating slots 20 are, however, disposed in the top plate 12 of the radial waveguide 10 in at least one annular configuration around and concentric with the antenna axis. In the arrangement of FIG. 1, two rings of slots 20 are employed, these slots 20 constituting the effective aperture of the antenna. It will be recognized that each annular arrangement of slots contributes to the total radiation pattern, and that the use of additional concentric annular dispositions of slots assists in achieving beam collimation and the reduction of side lobes.

The radial waveguide 10 is internally divided into quadrants by four conductive septa 22, 23, 24 and 25 or plates extending radially outward from the antenna axis to the outer circumferential band 16. Each of these septa 22—25 is in contact with both the top and bottom plates 12 and 14 of the radial waveguide 10. The septa 22—25 will be spoken of as individual elements, for convenience, but it is understood that they can be made as a unitary member and may consist of individual elements or pairs of elements. One pair 22 and 24 of the septa are disposed along what may be taken for reference purposes as the elevation axis of the antenna, the other pair 23 and 25 of the septa therefore being disposed along the azimuth axis. Consequently, the antenna may be considered to have an azimuthal plane and an elevation plane, which are parallel to the antenna axis and which are normal to each other.

The bottom plate 14 of the radial waveguide 10 has a central aperture about the antenna axis, the sides of the aperture registering with a circular waveguide 28 which is concentric with the given axis. The circular waveguide 28 is dimensioned to support the TE_{01} mode of a circular waveguide. The circular waveguide 28, like the radial waveguide 10, is partitioned into quadrants by portions of the septa 22—25 which extend into and along are normal to each other.

Wave energy is coupled between the circular waveguide 28 and an associated monopulse system 36 by coupling slots 29—32 in each one of the quadrants of the waveguide 28. Each of the coupling slots 29—32 has its direction of elongation parallel to the axis of the circular waveguide 28, so as to couple energy in the TE_{01} circular waveguide mode. Polarization direction sensitive transmission elements such as rectangular waveguides 34 may be employed in the coupling between the circular waveguide 28 and the monopulse system 36. The monopulse system 36 is here shown as an illustration of the type of system which may be employed to operate with the antenna. Such systems are widely known and it will be appreciated that the functions which are to be performed within the system 36 remain the same, the relationship to the antenna being confined to the provision of the wave energy to be transmitted and the utilization of the echo energy received.

The antenna of the present invention utilizes the relationship between the quadrants established by the conductive septa 22—25 and the angle of inclination and the relative attitudes of the radiating slots 20 on the radial waveguide 10. These angles of inclination and relative attitudes are best seen in the simplified representation of FIG. 4, to which reference is now made. In FIG. 4, only one annular arrangement of slots 20 is illustrated. As shown therein, the energy radiated and received by the antenna is to be linearly polarized along a preferred plane parallel to the azimuthal plane. Cross polarization components, those parallel to the elevation plane, are to be minimized. Within each of the quadrants, the radiating slots 20 (indicated in phantom in FIG. 2) have a like inclination with respect to the annular circumference or region on which they are disposed. Although the angles of inclination of all the slots 20 are the same, relative to the annular region, the attitude of the slots 20 is dependent upon the quadrant in which the slots are found. Thus each of the slots 20 within a quadrant has both a like angle and attitude, relative to the annular region in which it is located, but each group of slots 20 in a given quadrant is opposite in attitude with respect to the group of slots 20 in the adjacent quadrants. As shown, the angle of each slot 20 with respect to the circle on which it lies may be 45 degrees, although other inclinations might be used.

The disposition of these slots 20 relative to any given point on the radial waveguide 10 varies both in angle and in attitude. While it may be considered that the relative angle also determines the attitude of the slot,

it is more convenient to speak of the slots as having like angles but opposite attitudes with respect to the annular region on which they are disposed. It will be easier to visualize the slots 20 as being disposed in pairs which are oppositely disposed on the different sides of the azimuthal and elevation planes. Another way this may be stated is to say that, relative to the annulus, the slots 20 have angles of like absolute magnitude but opposite sense. The opposite attitudes of the opposed ones of each pair make possible the lobing action in the simple manner provided by the present invention.

As described above, an antenna system in accordance with this invention may lobe while transmitting or while receiving but in general is used only on receiving. It is intended to provide a pencil beam which is broadside with the antenna apertures, and which thus lies along the antenna axis. If lobing on transmission, the antenna generates individual lobes on opposite sides of elevation or azimuthal planes. The elevation and azimuthal planes, illustrated in FIG. 4, are parallel to and include the antenna axis, and normal to each other. When receiving signals, the antenna additively combines the components from all quadrants.

The converse operation applies when the antenna is operated so as to lobe on reception. The transmitted pattern in each case is a pencil beam transmitted broadside to the antenna and along the antenna axis. On reception, however, the signals from the quadrants may be combined selectively in well known fashion so as to provide signal mixing which is the equivalent of full signal operation, or azimuthal or elevation lobing.

Thus with either method of operation the monopulse system 36 operates in substantially the same fashion. For the detection of range a single lobe is directed along the antenna axis and all the components of the received signal are additively combined. The antenna may then be operated successively to generate the separate azimuth and elevation error signals, by lobing either on transmit or on receive, and by setting up first the relationships needed for transmission and then by switching these relationships before the echo is received so that the error signals are generated on reception.

Control of the antenna is accomplished, in the present system, by control of the four different inputs provided through the circular waveguide 28 which feed the radial waveguide 10. Each of the four coupling slots 29-32 is excited in a selected phase so as to couple to the TE_{01} mode of a given instantaneous direction within the circular waveguide 28. On receive, the signals are extracted in a selected phase to give sum, elevation difference and azimuth difference returns. In summary, then, the function which the monopulse system 36 performs is to set up the four modes used for feeding a desired transmitted signal, and then to switch, before an echo is received, to the desired reception modes. In typical monopulse operation, range information would appear at one terminal pair, and azimuth error and elevation error information at other terminal pairs.

The arrangement will be considered for operation in the lobing-while-transmit manner. This manner of operation permits somewhat easier visualization of the manner in which the antenna elements are excited. By reciprocity, all results described are obtainable on receive.

When it is desired to provide a single pencil beam along the antenna axis, the coupling slots 29-32 are excited in like relation through the rectangular waveguides 34 from the monopulse circuit network 36. Accordingly, the TE_{01} mode is established in the circular waveguide 28. The conductive septa 22-25 do not disturb this mode and permits clockwise or counterclockwise fields simultaneously. The portions of the septa 22-25 within the circular waveguide 28 are everywhere normal to the electric field lines of the TE_{01} mode, whose electric field lines may be considered to be circular

and concentric with the waveguide 28 axis. Instead, the electric field is uniformly terminated in each quadrant.

The significance of the septa 22-25, therefore, is that they do not disturb the establishment of the TE_{01} mode of the circular waveguide 28, but that they instead support partial modes which are quadrantally related. Between associated septa, such as septa 22 and 25, the electric field may have a selected direction of gradation which is different from the direction between other adjacent septa. Accordingly, the partial TE_{01} modes established within the circular waveguide 28 are coupled into the radial waveguide 10 and provide therein like partial H_{01} modes. When the radial waveguide 10 is viewed in plan view, the lines of electric field for the H_{01} mode may be considered as concentric circles about the antenna axis and symmetrical with the lines of the electric field in the TE_{01} mode of the circular waveguide. Accordingly, the same relationship between the electric field and the septa 22-25 applies, and partial modes also are established within the radial waveguide 10. Therefore, the top and bottom plates 12 and 14 of the radial waveguide 10 have currents induced in them which are dependent in circumferential direction upon the direction of the partial mode which is established in the quadrant being taken for reference.

The H_{01} mode in a radial waveguide provides circumferential current regions, which may be thought of as circumferential current bands in which the currents are themselves circumferential. In the traveling wave operation of the radial waveguide 10, such as is established by the use of the resistive termination 17, these bands are continually expanding to provide sinusoidal excitation of the elemental areas of the top and bottom plates 12 and 14.

The circumferential current regions on the top plate 12 of the radial waveguide 14 thus at any instant lie on circles concentric with the antenna axis. The current regions therefore also are concentric with the annular arrangement of the radiating slots 20. Each radiating slot 20 is excited in a direction normal to its direction of elongation, as is well known, and this direction of excitation determines the total vectorial component radiated from an individual slot 20. Total radiation from the antenna aperture as a whole, however, is established by summation of the individual vectorial contributions. This fact, in conjunction with the relationship of the radiating slots 20 to the partial modes which are established and the direction of currents at the slots, determines the nature of the lobing operation of the antenna.

For operation in transmitting a single lobe along the antenna axis, the vectorial radiation component of each radiating slot 20 in the top plate 12 of the radial waveguide 10 should contribute to the energy in the preferred plane of polarization. If equally excited, the slots 20 would contribute components dependent upon the extent to which the slot deviates from a line normal to the preferred plane. This result is accomplished by establishing the desired directions for the current excitations by the partial modes in the quadrants, as shown in FIG. 4. FIG. 4 shows the radial waveguide 10 in plan view, with what will be referred to as upper left, upper right, lower left and lower right quadrants. The elevation plane lies along the line between the upper and lower quadrants and the azimuthal plane divides the left and right quadrants. The antenna axis is in the center of the radial waveguide 10 and extends directly out of the paper. For lobing to provide range information, the current excitations established by quadrants correspond to the vectorial components indicated by the solid line arrows. That is, in the upper left hand and lower left hand quadrant the currents are clockwise, while in the upper right hand and lower right hand quadrants the currents are counterclockwise. Because of the direct relationship between the circular waveguide 28 modes and the radial waveguide 10 modes, these desired current di-

rections may be established simply by proper use of the desired instantaneous direction of polarization in each of the four signals from the monopulse system 36. As may be seen from FIG. 4, all of the solid line arrows have a like component (in rotational sense) in the preferred plane of polarization. This like component is established by the like inclination of the radiating slots 20 with respect to the circumference on which they lie.

A further significant feature, however, is found in the fact that the opposite attitudes of the radiating slots 10 between adjacent quadrants minimizes the cross polarization components which are present, the cross polarization becoming zero on the axis. The radiating slots 20 are grouped in opposed pairs which have cross polarization components of opposite direction. Thus, with respect to radiating slots 20 in the upper and lower right hand quadrants, one may see that each radiating slot 20 in the upper right quadrant which has a cross polarization component to the right has a paired opposed radiating slot 20 in the lower right hand quadrant, and that this slot has an opposing cross polarization component (to the left).

For ranging information (a single on-axis lobe) the vectorial contributions in the preferred plane of polarization are all in the same direction, as shown by the solid line arrows in FIG. 5A. To operate with elevation lobing, and thus to provide elevation error signals, the circumferential currents induced in the top plate 12 should have the direction needed to establish the dotted line vectorial components shown in FIG. 4. Specifically, the partial modes used establish clockwise currents in the upper left hand quadrant and in the lower right hand quadrant and establish counterclockwise currents in the upper right hand and lower left hand quadrants. The total vectorial components for each quadrant in the preferred plane of polarization are thus shown diagrammatically at 5C in FIG. 5. Again, it may be seen in FIG. 4 that the cross polarization components, between the left and right hand quadrants in this instance, effectively cancel in pairs. In the preferred plane of polarization, there is a null along the elevation plane, so that the desired two beams spaced oppositely from the elevation plane are provided.

For lobing about the azimuthal plane, the current excitations are such as to establish the wavy line arrows representing vectorial components of radiation in FIG. 4. For this type of operation, the circumferential current regions are everywhere clockwise, with the result, as shown in FIG. 5B, that there is a null along the azimuthal plane in the preferred plane of polarization. Again, comparing the upper to the lower quadrants in each half, the cross polarization components cancel by opposed pairs. Again, it is emphasized that the description of lobing on transmit is provided for purposes of visualization, and that the reciprocal nature of antennas permits like operation on receive.

The value of this arrangement in providing lobing operation will now be apparent. The antenna can be made extremely small and compact, and requires no complicated machining or structural configuration. The antenna pattern provided is broadside to the antenna surfaces, but may be precisely controlled and does not have inherent limitations as to gain or side lobe characteristics, because of the number of annular aperture arrangements which can be employed. Sum and difference error signals can be provided very simply by mere selection of the desired phases and mode of operation at the monopulse network system 36. It will be appreciated that any system which utilizes lobing operation is required to provide certain characteristics for the different signals which are to be provided. The present arrangement, however, eliminates extensive switching and mixing arrangements required by the prior art.

An alternative method of establishing the partial modes in the radial waveguide is illustrated in the fragmentary

view of FIG. 6. As shown in this figure, the bottom plate 14 of the radial waveguide 10 includes coupling slots 40—43 each of which is in a different quadrant. With the coupling slots 40—43 arranged with their directions of elongation extending radially from the antenna axis, these slots 40—43 will likewise couple to the partial H_{01} mode of the radial waveguide 10.

It will be evident to those skilled in the art that the relationship of the currents induced by the partial modes and the vectorial components provided by the radiating slots may be provided in other ways. The radial waveguide may be dimensioned to support other magnetic field modes which provide like circumferential current regions and which may be divided into partial modes through the presence of the septa. In general, it may be considered that this result may be achieved in the general case with the H_{0n} mode, wherein n is an integer of one or more.

Thus there has been described an improved antenna arrangement which provides lobing operation in a direction broadside to an antenna surface which may be flush mounted. The antenna provided is extremely simple to feed and to operate, and is compact and easily manufactured while at the same time having desirable electrical properties.

I claim:

1. An antenna comprising: a radial waveguide having radiating slots with selected attitudes and inclinations in a planar wall thereof, said radiating slots being disposed concentric with a given axis which extends through and is substantially normal to the planar walls of the radial waveguide; conductive means within the radial waveguide and dividing it into equal angular segments; and means coupled to the radial waveguide at the second planar wall for exciting in each of the angular segments a like energy mode of selected direction, such that the radiating slots in each segment have selected vectorial excitation components, there being a predetermined controllable relation between the instantaneous direction of the excitations of the radiating slots in the different segments.

2. An antenna comprising: a waveguide formed by a pair of parallel spaced plates of conductive material disposed about and normal to a central axis; a plurality of wave energy transmission devices coupled to the space between said plates adjacent said axis for feeding electromagnetic energy into said space; and means within said space for dividing said space into electrical separate quadrants for controlling currents induced therein by quadrants, a separate group of radiators for each of said quadrants, the radiators in each of said groups being coupled to the energy in its respective quadrant.

3. An antenna which operates to provide pointing error information from radiant energy transmitted along a given axis, said antenna comprising: a radial waveguide having top and bottom conductive plates and lying about and normal to the given axis, the top plate of the radial waveguide including radiation apertures lying on at least one circle concentric with the given axis, the angular disposition of said apertures separately varying along the circle in accordance with quadrants of the top plate; conductive septa extending radially outwardly from the given axis so as to divide the radial waveguide internally into the quadrants of the top plate; and wave energy feed means coupled to said radial waveguide at each of the quadrants for establishing the H_{01} mode therein, said feed means and said septa together controlling the instantaneous sense of rotation of the currents induced in the quadrants of the radial waveguide.

4. An antenna comprising: a radial waveguide formed by a pair of parallel conductive plates disposed about and normal to a central axis to form a space therebetween; a plurality of wave energy transmission devices coupled to the space formed by said radial waveguide for feeding electromagnetic energy into said space at a point dis-

posed symmetrically about said central axis; and means within said space symmetrically disposed radially outwardly from the given axis in a manner corresponding to the disposition of the wave energy transmission devices, for electrically dividing said space into a plurality of portions to thereby individually and substantially independently control the distribution of said energy in each portion of the radial waveguide, a separate group of radiators for each of said portions, the radiators in each of said groups being coupled to the energy in its respective portion.

5. An antenna comprising: a radial waveguide formed by a pair of parallel conductive plates disposed about and normal to a central axis, one of said plates being spaced from the other plate and having groups of radiation apertures disposed about the axis; means within said radial waveguide for dividing said waveguide into a separate segment for each of said groups, each of said segments being capable of maintaining a like partial mode of excitation; and means coupled to said radial waveguide for providing excitation in the individual segments of selected direction within each of the segments.

6. A monopulse antenna capable of being flush mounted with a planar surface and operating with a pattern which is broad side to the surface, said antenna comprising: a radial waveguide; a circumferential ring concentric with a central axis of the radial waveguide and terminating the radial waveguide; a circular feed waveguide concentric with the central axis of the radial waveguide and coupled thereto; four radial septa, extending radially outwardly from the central feed waveguide between the walls of the radial waveguide to the terminating ring, to divide the radial waveguide into four substantially like quadrants, the plate of the radial waveguide which is spaced apart from the feed waveguide including a plurality of slots having the centers thereof equally spaced from the central axis of the radial waveguide, the axes of the slots being inclined to the radius through the center thereof.

7. An antenna for transmitting a narrow beam along a given axis and deriving angular error information from reflected energy, said antenna comprising: a radial waveguide having radiating slots in one planar wall disposed concentric with the given axis; conductive septa within the radial waveguide and extending radially from the given axis, to divide the radial waveguide into quadrants, the angular inclinations of the radiating slots in each quadrant relative to the concentric circle on which they lie being of like degree but varying oppositely in attitude with alternate quadrants; and means coupled to each of the quadrants of the second planar wall of the radial waveguide for establishing selective coupling by quadrants of the currents excited therein.

8. An antenna for transmitting a narrow pattern along a given axis and deriving angular error information from reflected energy, said antenna comprising: a radial waveguide having radiating slots in one planar wall, the slots being disposed on a circle concentric with the given axis and disposed in groups within separate quadrants, the angular inclinations of the radiating slots in each quadrant relative to the concentric circle on which they lie being of like absolute degree but varying oppositely in sense with alternate quadrants; conductive septa within the radial waveguide and extending radially outward from the given axis, said conductive septa dividing the radial waveguide into quadrants corresponding to the separate groupings of the radiating slots; and a separate wave energy feed means coupled to said radial waveguide at each of the quadrants and at the second planar wall of the radial waveguide, for establishing the dominant magnetic mode of the radial waveguide in partial modes within each quadrant, and in selected directions for controlling the current direction in each quadrant at the radiating slots.

9. An antenna for transmitting a narrow beam along a given axis and deriving angular error information from reflected energy, said antenna comprising: a radial waveguide having a pair of spaced apart parallel planar walls, the planar walls being positioned about and normal to the given axis, said radial waveguide having a terminating band encompassing said planar walls and also including radiating slots lying on at least one circle concentric with the given axis and being dimensioned for propagation of the H_{01} mode to provide circumferential current regions in a first wall containing the radiating slots; a circular waveguide concentric with the given axis and coupled to the second wall of the radial waveguide, four conductive septa within the radial waveguide and extending radially outward from the given axis to the outer band of the radial waveguide and extending between the planar walls thereof, said septa dividing the radial waveguide and the circular waveguide into quadrants, the radiating slots being grouped within each quadrant and having angular inclinations relative to the concentric circle on which they lie of like absolute amount but of opposite sense within alternate quadrants, so that the radiating slots form pairs on opposite sides of the lines defining the quadrants, with the different ones of the pairs having equal but opposite inclinations with respect to a preferred plane of polarization; and wave energy feed means coupled to each of the quadrants of the circular waveguide for exciting therein a partial TE_{01} mode within each of the quadrants, such that a partial H_{01} mode is established in the corresponding quadrant of the radial waveguide, the partial modes establishing circumferential current regions of selected instantaneous direction within each of the quadrants so that the radiating slots are excited in given directions and the vectorial components of the excitation in the oppositely disposed pairs cancel the cross polarization components and selectively add or cancel components in the preferred plane of polarization to provide effectively controlled lobing of the antenna in accordance with the direction of excitation of the radiating slots in the separate quadrants.

10. An antenna comprising a pair of parallel sidewalls spaced to form a radial waveguide, conductive septa disposed between said sidewalls and extending radially outwardly in said waveguide to electrically divide said waveguide into sectors, each of said sectors being adapted to sustain a wave of electromagnetic energy which may have a mode and phase differing from the waves in the other of said sectors, one of said sidewalls having a separate group of slots for each of said sectors, said slots being disposed at a common radius from the center of said sidewall, all of the slots in each group being inclined to the radius through the center of the slot by a predetermined amount.

11. An antenna comprising a radial waveguide having a pair of parallel spaced sidewalls, conductive septa disposed between said sidewalls and extending radially outwardly in said waveguide and electrically dividing said waveguide into quadrants, one of said sidewalls having a ring of slots which includes a separate group of slots for each of said quadrants, said slots being angularly disposed with respect to said ring to thereby provide quadrature related pairs of slots which provide selective addition or opposition of vectorial excitation complements in a plane of polarization and which cancel in the plane normal to said first plane.

References Cited in the file of this patent

UNITED STATES PATENTS

70	2,838,754	Bickmore	June 10, 1958
	2,908,001	Kelly	Oct. 6, 1960

OTHER REFERENCES

75	Kelly: "Recent Annular Slot Array Experiments," IRE Convention Records, March 18-21, 1957, pp. 144-152.		
----	---	--	--

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,063,049

November 6, 1962

Kenneth C. Kelly

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 4, line 26, strike out "are normal to each other" and insert instead -- the circular waveguide 28 --; column 7, line 59, for "compart" read -- compact --.

Signed and sealed this 30th day of April 1963.

(SEAL)

Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents