

Sept. 7, 1965

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3,205,498

DUAL MODE RADAR BEACON ANTENNA

Filed Nov. 30, 1960

2 Sheets-Sheet 1

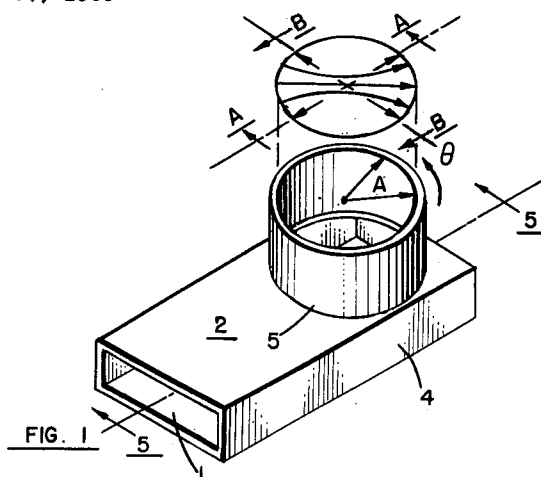


FIG. 1

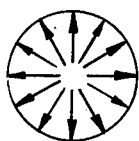


FIG. 2a

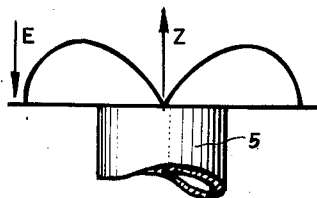


FIG. 2b

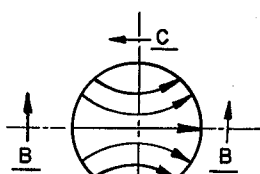


FIG. 3a

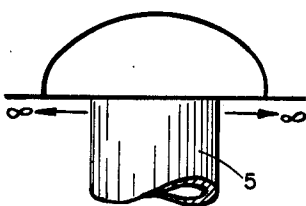


FIG. 3b

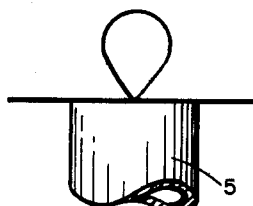


FIG. 3c

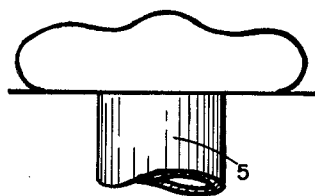


FIG. 4a

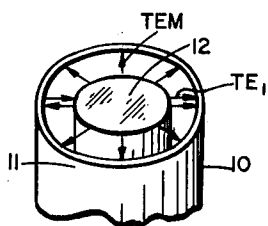


FIG. 6

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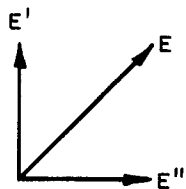


FIG. 4C

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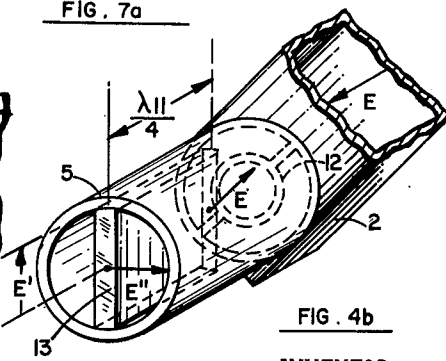
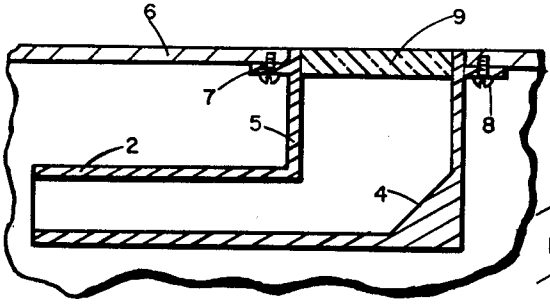
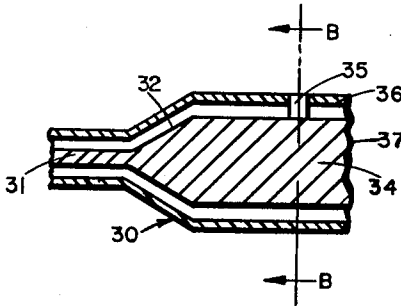
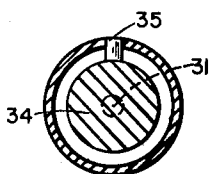
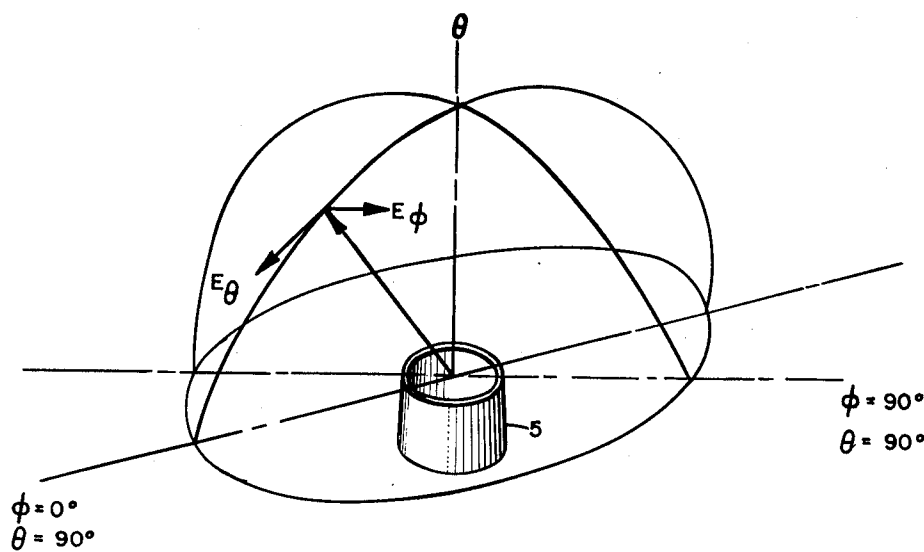
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3,205,498
DUAL MODE RADAR BEACON ANTENNA
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Filed Nov. 30, 1960, Ser. No. 72,821
5 Claims. (Cl. 343—705)

This invention relates to an airborne antenna structure and particularly to an antenna radiating linearly polarized waves in a substantially hemispherical pattern.

This application is a continuation in part of my application Serial Number 831,843 for a Dual Mode Radar Beacon Antenna filed August 5, 1959, now abandoned.

The invention provides a flush-mounted antenna for airborne use capable of establishing a substantially hemispherical radiation pattern especially suited to use with a beacon. In the past, such radiation pattern coverage has been obtainable only by the simultaneous use of two or more separate antennas, each of which provides a part of the desired pattern. Such installations suffer from the added weight and complexity of operation imposed by multiple elements and the feed means associated therewith.

A radio beacon of the type herein described may be used in identifying and tracking the separate planes which make up a squadron. Each of the planes may be assigned an individual code designation, and by the use of an antenna with a hemispherical radiation pattern may be located and tracked, regardless of its direction in azimuth from a monitoring or control station. The invention may be extended in usefulness by directing one antenna downwardly from the under side of a plane and another upwardly from the top side of the fuselage. In this way contact may be maintained regardless of the attitude of the tracked plane. It will be obvious that the tracked plane may return an indication of its whereabouts at its own volition or as an automatic response to a coded inquiry signal, and both techniques are well-known to those skilled in the art.

The antenna of the present invention provides the desired radiation field by utilizing two modes of propagation in a cylindrical waveguide connected by a suitable matching impedance to one of the broad sides of a rectangular guide. This permits substantial reductions in weight and system complexity, since it is only necessary for the transmitter to feed into the rectangular guide.

It will be appreciated that the design of antennas for modern aircraft travelling at supersonic speeds presents problems that differ by an order of magnitude from those encountered with aircraft travelling at subsonic speeds. Any antenna projecting from the surface of the aircraft will introduce problems of wind resistance or air drag of a very serious nature, and an ideal antenna would be one which presented no obstruction to the flow of air over the airframe or wing surface. This invention permits the antenna to be mounted inside the fuselage, and to communicate with the outside atmosphere by means of a window impervious to the passage of air but completely transparent so far as the passage of electromagnetic radiation is concerned. It has been my discovery that by combining a first symmetrical radially polarized mode and a second TE_{11} mode in a coaxial line or in a section of circular or cylindrical waveguide, the outer or terminal end of which may then be mounted flush with the surface of the fuselage, such that the ratio of the peak field amplitude of the first mode to that of the second mode is substantially 10 db, it is possible to produce a single antenna structure having a substantially hemispherical radiation pattern, yet free from the necessity for multiple antenna elements and feeds.

The terms "circular waveguide" and "cylindrical wave-

guide" may be used interchangeably. While these sections are physically cylindrical, the fields therein are treated as they exist in a plane perpendicular to the cylindrical axis. The intersection of the plane and the cylinder, of course, defines a circle.

The objects of the invention thus include providing an improved antenna arrangement for airborne beacon equipment.

Another object is to provide a hemispherical radiation pattern for airborne beacon use.

A still further object is to provide for a hemispherical radiation pattern with a flush mounted antenna wholly contained within the fuselage of an aircraft vehicle.

Yet another object is to reduce the complexity and weight of antenna systems for producing a substantially hemispherical radiation pattern with a minimal antenna structure.

A further object is to reduce the weight and complexity of antenna systems where it is desired to obtain linearly polarized radiation in hemispherical patterns extending both upwardly and downwardly from an airborne fuselage.

These and other objects of this invention will become apparent from the following specifications when taken with the accompanying drawings, in which:

FIG. 1 is a perspective view of a preferred embodiment of the waveguide structure of the invention;

FIG. 2a illustrates the radial electric field which may be obtained by using the circular or cylindrical waveguide portion of FIG. 1, acting alone;

FIG. 2b is a side elevational view of such a cylindrical waveguide, together with the electric field pattern produced thereby when acting in the TM_{01} mode;

FIG. 3a is a representation of the electric field produced in the cylindrical guide portion of the antenna shown in FIG. 1 when operating alone in the TE_{11} mode;

FIG. 3b illustrates the radiation field produced by the electric field in the antenna of FIG. 3a when operating in the TE_{11} mode, taken in the plane indicated by lines B—B of that figure;

FIG. 3c is a view corresponding to FIG. 3b but taken as indicated by lines C—C of FIG. 3a;

FIG. 4a shows the electric field pattern obtained with the antenna of FIG. 1 when operating with both the TM_{01} and the TE_{11} modes present;

FIG. 4b shows a quarter wave plate used to split the TE_{11} mode into two parts, as shown in FIG. 4c vectorially;

FIG. 4c shows vectorially the component into which the TE_{11} mode is split by the quarter wave plate shown in FIG. 4b;

FIG. 5 shows in sectional schematic form the details of a section used to match the impedance of the cylindrical waveguide section to that of the rectangular waveguide section;

FIG. 6 shows an alternative embodiment utilizing a coaxial line as the radiating element;

FIG. 7a shows another preferred embodiment, utilizing coaxial elements, in the side sectional view;

FIG. 7b shows a sectional view, taken as indicated by line B—B of FIG. 7a of the embodiment there illustrated; and

FIG. 8 is a schematic showing of the angular relations at the radiating end of the antenna.

Referring now to the drawings for a more detailed understanding of the invention, the improved antenna structure is shown in perspective in FIG. 1 separated from adjacent structure, and as it relates to the fuselage of an airborne vehicle in which it may be installed in the sectional showing of FIG. 5.

The operation will be described in terms of an antenna for transmitting purposes, but it will be recognized that the receiving function may be obtained from the principle

of reciprocity. Energy is fed from a transmitter, not shown, into the input, or open, end 1 of a rectangular waveguide 2 and then is propagated through a transition section 4 into a circular or cylindrical waveguide section 5. The TE₁₀ mode is the lowest order mode of the rectangular wave guide shown, and is used to excite the desired modes in the cylindrical section. Otherwise the use of higher order modes in the rectangular section would excite other and undesired modes in the circular section. The cylindrical section 5 is disposed at right angles to the longitudinal axis of the rectangular guide section 2, and adjacent the end of that section opposite open end 1. The transition section 4 for matching the impedances of the two guide sections may be conventional. One satisfactory form is that shown by FIG. 6.55, page 367, of "Microwave Transmission Circuits" by Ragan, published in 1948 by McGraw-Hill as Volume 9 of the Radiation Laboratory Series. While the effect of such transition section is to provide an impedance match or maximum power transfer from the rectangular section (as a power source) to the cylindrical section (as a load impedance) such transition section effects a change in mode of the energy transferred from the TE₁₀ mode to the TM₀₁ mode. Further, such transition section effects a discontinuity in the cylindrical section to the extent that the TE₁₁ mode is thereby excited. The relative magnitude of the TE₁₁ mode field peak to the TM₀₁ field peak increases as the discontinuity effect presented by the transition section increases. Therefore, one means for controlling the several mode magnitudes so as to obtain the critical ratio of substantially 10 db is the varying of the TM₀₁ purity of the transition section. Such mode purity is defined on page 99 of Microwave Transmission Circuits (Volume 9 of Radiation Laboratory Series, McGraw-Hill (1948)) as the extent to which the transition from rectangular waveguide section operating in the lowest or TE₁₀ mode to a round waveguide operating in the second or TM₀₁ mode occurs without excitation of the lowest or TE₁₁ mode. For example, in order to increase the relative magnitude of the TE₁₁ mode one would increase the discontinuity afforded by the transition section. Limitations on the feasibility of such a means is its reliance on empirical procedures in manufacture of such means, and the difficulty in achieving a close tolerance on the critical mode magnitude ratio.

There are present in the cylindrical waveguide waves whose radial components of electric field may be represented by the equation for the TE₁₁ mode:

$$E_r = E_h \sin \phi e^{i\left(\omega t - \frac{2\pi X}{\lambda_{11}}\right)} \quad (1)$$

and for the TM₀₁ mode, which may be represented by:

$$E_r = E_e e^{i\left(\omega t - \frac{2\pi X}{\lambda_{01}}\right)} \quad (2)$$

where:

E_h = the amplitude of the TE₁₁ mode wave
 E_e = the amplitude of the TM₀₁ mode wave
 X = the distance along the axis of the cylindrical guide
 ϕ & θ = the standard IRE field angles, as shown in FIG. 8
 λ_{11} = the guide wavelength of the TE₁₁ mode wave
 λ_{01} = the guide wavelength of the TM₀₁ mode

Assuming matched conditions for both modes, the total radial electric field is given by

$$E_r = E_e e^{i\left(\omega t - \frac{2\pi X}{\lambda_{01}}\right)} + E_h \sin \phi e^{i\left(\omega t - \frac{2\pi X}{\lambda_{11}} + \alpha\right)} \quad (3)$$

where α is the phase difference between the modes when $X=0$ and $t=0$.

Dividing the righthand side of Equation 3 by

$$e^{i\left(\omega t - \frac{2\pi X}{\lambda_{01}}\right)}$$

and introducing as a new factor

$$\frac{1}{\lambda'} = \frac{1}{\lambda_{11}} - \frac{1}{\lambda_{01}}$$

5 Equation 3 may be reduced to the form

$$E_r = E_e' + E_h' \sin \phi e^{i\left(\omega t - \frac{2\pi X}{\lambda'} + \alpha\right)} \quad (4)$$

The equations set forth above indicate that the TM₀₁ mode has no dependence on ϕ and hence will give rise to a radiation pattern similar to that of a monopole over a ground plane, namely a semi-toroid. The dependence of the TE₁₁ mode on ϕ causes a radiation pattern which varies as a function of ϕ .

15 The radiation patterns generated by these modes in the planes A—A and B—B of FIG. 1 are shown in the several parts of FIGS. 2 and 3, and the angular relations are shown in FIG. 8. FIG. 2b shows section A—A, which is typical of all sections rotated about the Z axis for the TM₀₁ mode alone. The pattern is shown in FIGS. 3b and 3c for the TE₁₁ mode alone: FIG. 3b showing the pattern as taken along axis B—B of FIG. 3a; and FIG. 3c showing that taken along axis C—C. When both modes TM₀₁ and TE₁₁ are present, the radiation pattern will be the vector sum of these individual patterns. The combined result, if the modes are present in the proper relative amplitudes of E_h and E_e , is that shown in FIG. 4a. The proper relative amplitude of E_e to E_h is the ratio 10 db. In connection with those transition sections which provide both TM₀₁ and TE₁₁ modes having somewhat like amplitudes, this ratio is readily obtained by the use of a mode filter 12 (in FIG. 4b) which passes the TM₀₁ mode substantially unattenuated and which serves to attenuate the TE₁₁ mode to the desired amplitude ratio. Such a device may be conventional and is well understood in the art. For instance, such device may be of the type more particularly described on pages 391–393 of Microwave Transmission Circuits (Volume 9, Radiation Laboratory Series, McGraw-Hill (1948)).

40 The waveguide structure of FIG. 1 may be mounted in the fuselage 6 of the ship, as shown in FIG. 5, with the axis of the cylindrical portion vertical to the horizontal for level flight, in order to radiate the pattern of FIG. 4a omni-directionally upward. The guide is secured by means such as a flange 7 to the fuselage by means of suitable fasteners, such as bolts 8. The cylindrical section 5 is sealed to prevent passage of air between the inside and outside of the aircraft by means such as a window 9, impervious to air but transmitting electromagnetic radiations freely. Polyethylene is a suitable material for such a window, but any equivalent may be substituted.

Because the radiation pattern produced by this antenna is a function of the radial electric field in a cylindrical guide, it will be apparent that the construction is not limited to a hollow waveguide as described, but may also take any form capable of producing the desired radial electric field. For example, the combination of the TEM and TE₁₁ modes in a coaxial line will produce such a field and, hence, the desired radiation pattern. This has been illustrated in FIG. 6 in schematic form, with arrows indicating the direction of the radial field for the TEM mode and the field for the TE₁₁ mode, corresponding to the showing in FIG. 3a.

Another coaxial line embodiment is shown in FIG. 7a in side sectional view, with a transverse section taken along a line B—B of that figure illustrated in FIG. 7b.

Here a coaxial line 30 having a center conductor 31, and of proper size to support the TEM mode only, is joined by a tapered transition section 32 to a section 34 of diameter sufficient to support both TEM and TE₁₁ modes. The section 34 is surrounded by a correspondingly increased diameter outer conductor portion 36. The second mode, TE₁₁, is excited by introducing a cylindrical metal plug or screw element 35 into the space between the inner section 34 and the outer conductor 36. The shorting effect

of the plug upon the field in that area creates the discontinuity which excites the TE_{11} mode. The ratio or relative magnitude of the TE_{11} mode peak vector thus propagated to that of the TEM mode peak vector increases as the diameter of the plug is made to increase, thence, the desired 10 db ratio of TEM mode field strength peak, E_e , to TE_{11} mode field strength peak, E_h , may be obtained by adjusting such dimension until such ratio is obtained. The axial distance of the plug 35 from the tapered section 32 is selected to aid the impedance matching function of section 32. The outer end 37 is shown as broken away, but it is understood that it may be terminated by a window such as that shown at 9 in FIG. 5, or the window omitted, depending on whether or not a solid dielectric is used in the line between the inner and outer conductors, as explained in connection with the figure.

Assuming an upright orientation of the configuration of FIG. 1, the field pattern in the ground plane ($\theta=90$ degrees), will not be entirely circular (not radially uniform for all values of ϕ or azimuth), due to the difference in field strength between the TE_{11} mode plane of symmetry and the transverse plane normal to the plane of symmetry, as shown in FIGS. 3b and 3c. Further, such patterns would be slightly skewed relative to the waveguide axis in the azimuth direction of the TE_{11} mode plane of symmetry due to the TE_{11} mode polarization. However, the skewed effect is slight due to the low amplitude ratio of the TE_{11} mode to the TM_{01} mode.

Both these effects (1) failure of uniform field strength in azimuth, and (2) skew or radiation pattern axis inclination, can be offset or avoided by resolving the TE_{11} mode vector into two mutually orthogonal vectors of somewhat similar amplitudes, and if further refinement is desired, by imparting an angular velocity to the TE mode about the waveguide axis of RF magnitudes. This refinement to the embodiment of FIG. 1 is depicted in FIG. 4b, in which a dielectric quarter wave length plate 13, having a width equal to the diameter of the waveguide section is contained within the cylindrical section 5 at the aperture end thereof and oriented radially about the waveguide axis of the cylindrical section as to form an angle of substantially 45 degrees with the waveguide axis of the rectangular waveguide section. This orientation thus provides a 45 degree angle between the quarter wave plate and the incident plane of symmetry of the incident TE_{11} mode wave travelling from the transition section. The TE_{11} mode vector is thus split into two quadrature components having differing phase velocities, one component parallel to the plate and having a greater phase velocity than that of the other component which is perpendicular to the plane of the plate. The effect of the differing phase velocities is (1) a separation of the TE_{11} mode components in time and space at the end of the plate as shown vectorially in FIG. 4c and (2) a rotational velocity of the resultant vector about the cylindrical waveguide axis at the aperture. The quarterwave plate 13 has no effect upon the TM_{01} mode. The resultant of the combined TM_{01} mode and rotating vector of the resolved TE_{11} mode is a radiation pattern similar to that in FIG. 4a for all sections containing the Z axis or waveguide axis. For the coaxial section embodiment shown in FIGS. 7a and 7b, a refinement in structure analogous to the quarter wavelength plate would be the addition of a second plug (not shown) oriented radially at 90 degrees to the first plug 35.

A specific embodiment of this antenna which has been utilized for testing autonavigating equipment had the following equations and constants applicable: in the cylindrical waveguide, assuming that the radius a was equal to 3.80 centimeters, then the cut-off wavelength, λ_c , for each mode may be determined as follows:

$$\lambda_c = \frac{2\pi a}{U_{m,n}}$$

where $U'_{m,n}$ =n'th root of the Bessel function $J'_m(U)$ =0

Then for the TE_{11} mode $\lambda_c=12.95$ centimeter for $U'_{11}=1.841$

$$\lambda_c = \frac{2\pi a}{U_{m,n}}$$

where $U_{m,n}$ =n'th root of $J_m(U)=0$

For the TM_{01} mode:

$$\lambda_c=9.92 \text{ centimeters where } U_{01}=2.405$$

The cut-off wave length so computed for each mode may be shown to be long enough as to indicate that the cylindrical section selected will support the two modes sought to be employed, in accordance with formulas well known to those versed in the art.

Thus, by a combination of a first symmetrically radially polarized field and a second TE_{11} mode field in the cylindrical waveguide, the relative magnitude of the first field to the second field being the ratio of 10 db, the energy introduced into the waveguide can be made to radiate from the free end thereof in a substantially hemispherical pattern. In neither of the embodiments shown is the length of the output waveguide section critical.

When applied to an airborne device such as the monitoring or control plane, a pair of such antennas, one mounted to radiate hemispherically upward and one mounted to radiate hemispherically downward, provide substantially complete omni-directional covering for radar beacon use.

Although the invention has been described and illustrated in detail, it is to be clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of this invention being limited only by the terms of the appended claims.

I claim:

1. In an antenna system the combination of a rectangular waveguide section; a cylindrical waveguide section for supporting a TM_{01} mode and communicating with a broad side of said rectangular guide section; impedance matching means disposed between said rectangular and said cylindrical sections and presenting a discontinuity for exciting a TE_{11} mode, the relative magnitude of the TM_{01} mode to the TE_{11} mode being 10 db; a quarter wave plate disposed in said cylindrical section symmetrically about the longitudinal axis of said cylindrical section at an angle of 45 degrees with the waveguide axis of said rectangular waveguide section; and means for mounting said system in an outer wall of a fuselage, said means being transparent to electromagnetic radiation and adapted to close the end of said cylindrical section opposite to that communicating with said rectangular section.

2. In an antenna system for use in an airborne radar beacon device, the combination of a rectangular waveguide section; a cylindrical waveguide section capable of supporting both a TM_{01} mode and TE_{11} mode and of diameter substantially similar to the width of a broad side of said rectangular guide section, and communicating therewith; said cylindrical section having its axis of revolution disposed substantially normal to the longitudinal axis of said rectangular section; a transition disposed between said rectangular and said cylindrical waveguide sections, and arranged to match the impedance of said cylindrical section to that of said rectangular section and to excite a TE_{11} mode; mode filter means for maintaining the relative magnitude of the TM_{01} mode to the TE_{11} mode in the ratio 10 db; a quarter wave plate disposed in said cylindrical section symmetrically about the longitudinal axis of said cylindrical section at an angle of 45 degrees to said longitudinal axis of said rectangular section; and means for closing the end of said cylindrical guide section opposite that associated with said rectangular section to the passage of air while permitting unobstructed passage therethrough of electromagnetic waves.

3. In an antenna system for use in an airborne device, the combination of a rectangular waveguide section; a

cylindrical waveguide section communicating with a broad side of said rectangular section; transition means disposed for matching the impedance of said sections associated therewith; means for setting up electric fields in said cylindrical guide in the TE_{11} mode; means for simultaneously therewith setting up electric fields in said cylindrical guide in the TM_{01} mode; the relative magnitude of the TM_{01} mode peak vector to that of the TE_{11} mode being the ratio 10 db; means for splitting the fields in the TE_{11} mode into two quadrature components of substantially equal amplitudes in said cylindrical guide; and means transparent to electromagnetic radiation for closing off the end of said cylindrical section opposite said rectangular section from the exterior of said airborne device, whereby the resultant radiation pattern is substantially hemispherical about the axis of revolution of the cylindrical waveguide section.

4. In an antenna system the combination of
 - a rectangular waveguide section;
 - a cylindrical waveguide section capable of supporting both a TM_{01} and a TE_{11} mode, communicating with a broad side of said rectangular guide section;
 - means for producing said TM_{01} and said TE_{11} modes;
 - means for causing the relative magnitude of the TM_{01} mode to the TE_{11} mode to be 10 db; and
 - means for producing a rotational phase of said T_{11} mode relative to the TM_{01} mode.
5. In an antenna system the combination of
 - a rectangular waveguide section;
 - a cylindrical waveguide section, capable of supporting both a TM_{01} and a TE_{11} mode, and communicating

with a broad side of said rectangular waveguide section;

impedance-matching means disposed between said rectangular and said cylindrical sections;

means for producing said TM_{01} and said TE_{11} modes;

means for causing the relative magnitude of the TM_{01} mode to the TE_{11} mode to be 10 db; and

means, comprising a quarter wave plate disposed in said cylindrical waveguide section at an angle of 45 degrees with the waveguide axis of said rectangular waveguide section, for producing a differential phase velocity of said TE_{11} mode relative to said TM_{01} mode.

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GEORGE N. WESTBY, ELI LIEBERMAN, *Examiners*.