

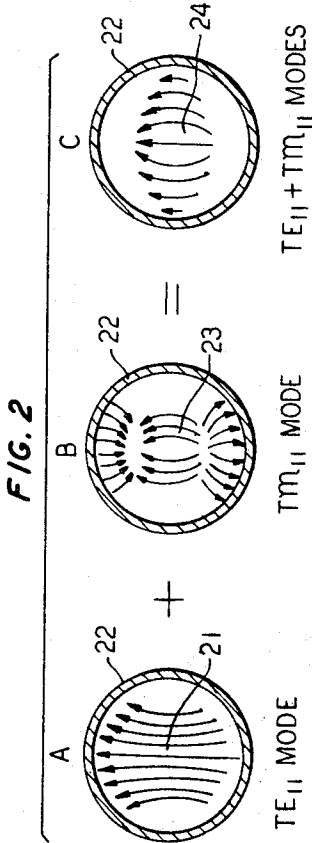
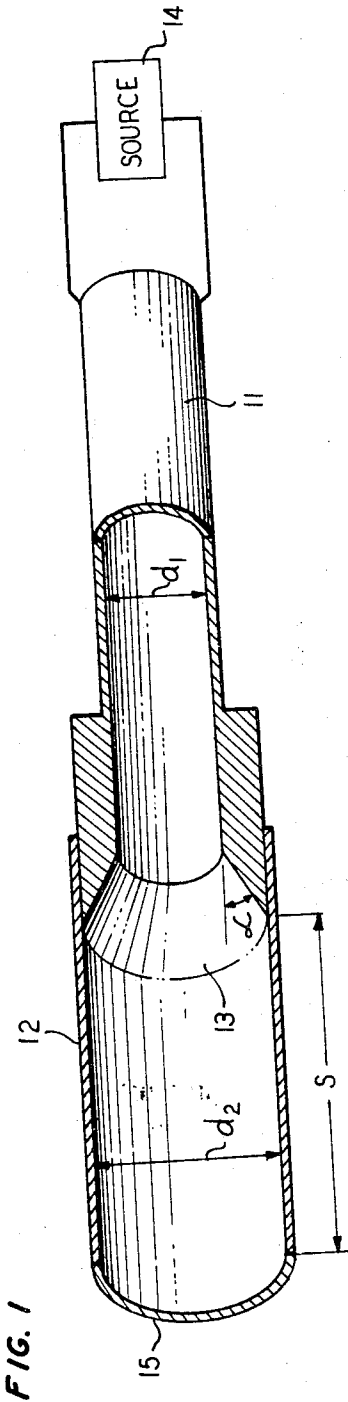
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R. H. TURRIN
DUAL MODE ANTENNA

3,413,641

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3 Sheets-Sheet 1



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FIG. 3A

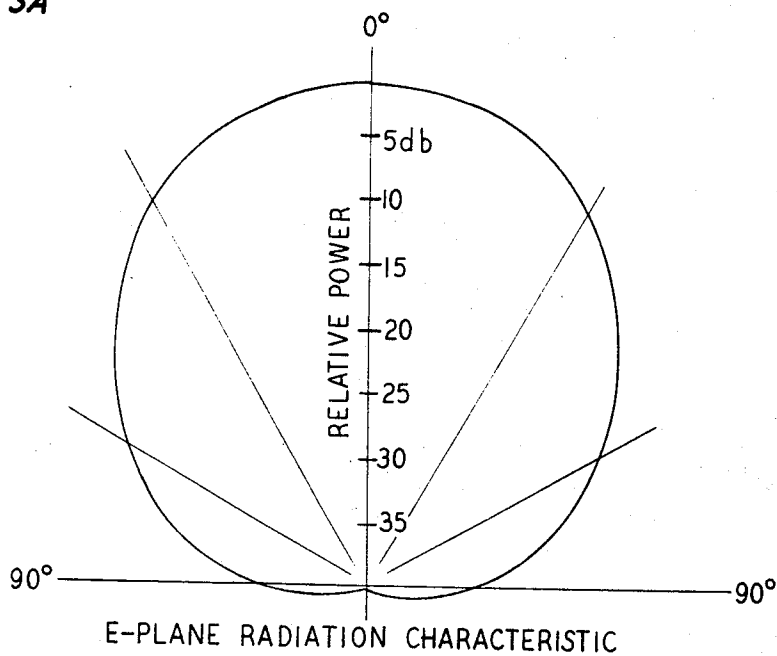
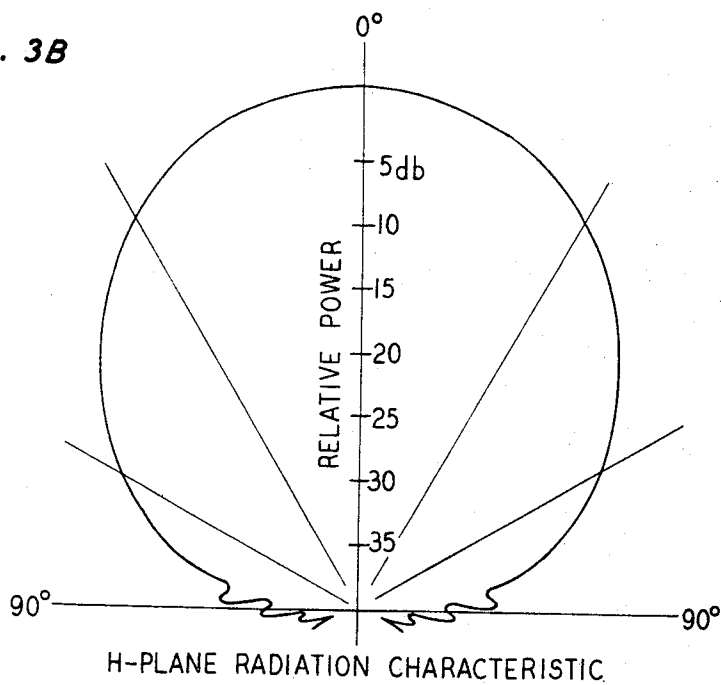


FIG. 3B



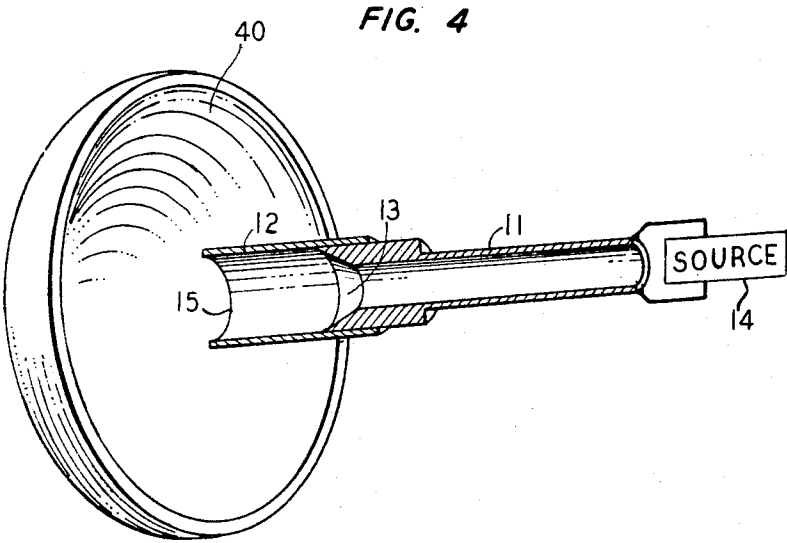
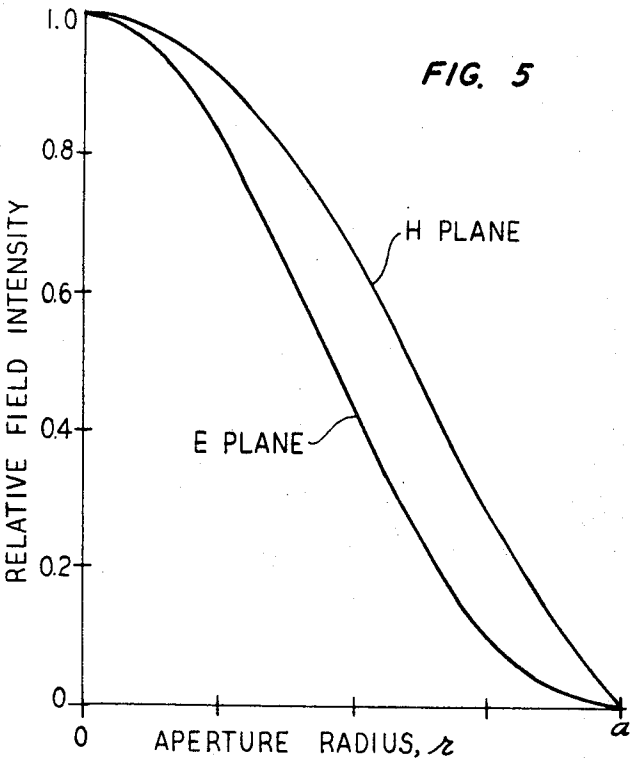
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3,413,641

DUAL MODE ANTENNA

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Filed May 5, 1966, Ser. No. 547,992

3 Claims. (Cl. 343-781)

This invention relates to small aperture antennas and, more particularly, to dual mode microwave antennas having low sidelobe radiation characteristics.

In the past, considerable emphasis has been placed on horn antennas of rectangular cross section both as horn antennas per se and as feeds for reflector type antennas. More recently, attention has been given to antennas of circular transverse cross section.

A major characteristic of microwave antennas, and one by which their performance is most often evaluated, is the shape and direction of the atmospheric volumes illuminated by the emitted energy; that is, their radiation patterns.

In most typical situations, it is desirable that the antenna have a radiation pattern in which nearly all the emitted energy is confined to a single solid angle, or lobe. However, the typical radiation pattern comprises a major lobe and a plurality of minor side or rear lobes which are undesirable since minor lobe power reduces the intensity of the main lobe and therefore lessens the distance over which a signal can be successfully transmitted. In addition, such minor lobes broaden the radiation pattern and are of considerable concern with regard to radio frequency interference.

An object of the present invention is, therefore, to suppress minor lobe radiation in small aperture antennas.

In general, an aperture antenna excited in a mode which produces electric field components normal to the conductive boundary wall at the aperture must have associated therewith longitudinal electric currents flowing across the surface of the boundary. These currents, designated edge currents, act as radiating elements in addition to the aperture field distribution and are the primary cause of rear and sidelobe radiation in small aperture horn type antennas. In the past, attempts have been made to suppress these edge currents with traps or chokes formed at the aperture edge. Such arrangements are only partially effective due to frequency sensitivity and difficulty of construction.

A more specific object of the invention is therefore to reduce longitudinal edge currents at the mouth of a small aperture antenna.

In accordance with the invention, energy in the dominant mode is selectively converted to higher order mode energy with amplitude and phase at the aperture which produces longitudinal current cancellation.

In accordance with a preferred embodiment of the invention, dominant mode TE_{11} energy propagating toward the aperture in a feedline section of circular guide is partially converted to TM_{11} mode energy upon incidence on a conically flared waveguide section of selected flare angle and length. Beyond the flare, the two modes propagate in an aperture section of circular guide with different phase velocities. By adjusting the propagation distance in the aperture section to effect a 180 degree phase differential between the normal field components of the respective modes at the aperture boundary, longitudinal current cancellation can be effected and thus suppression of sidelobe radiation.

The above and other objects of the invention, together with its various features and advantages, will become more apparent from a consideration of the accompanying drawing and of the detailed description thereof which follows.

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In the drawing:

FIG. 1 is a perspective view, partially broken away, of an embodiment of the present invention;

FIG. 2 is a series of three cross sectional views of a circular waveguide showing electric field lines in the indicated wave modes;

FIGS. 3A and 3B are measured graphical plots of relative radiation intensity in the principal E and H planes of the far field for the embodiment of FIG. 1;

FIG. 4 is a perspective view, partially broken away, of the antenna of FIG. 1 used as the feed in a parabolic reflector-type antenna; and

FIG. 5 is a graphical plot illustrating the electric field distribution in the principal planes of the aperture.

Referring now to the drawing in greater detail, FIG. 1 illustrates a preferred embodiment of the present invention in which a hollow conductively bounded waveguide feedline section 11 of diameter d_1 is slidably mounted within hollow conductively bounded waveguide aperture section 12 of diameter d_2 . The end portion 13 of section 11 lies coaxially within section 12 and forms a conical taper of angle α , providing a transition for energy propagation between the two guide sections. In accordance with the invention, mode conversion occurs within tapered end portion 13. Energy radiates from the open end, or aperture 15, of guide 12.

When used as a transmitting antenna or as a primary feed for a reflector-type antenna, electromagnetic wave energy in the dominant TE_{11} wave mode from a source or transmitting device 14, shown in block form, is fed into the end of guide 11 which is opposite flare 13. Diameter d_1 is selected in accordance with well known principles to support only the dominant TE_{11} wave mode. The energy from source 14 can be applied to section 11 through a coaxial-to-waveguide transducer, through a waveguide transformer section, or through another length of waveguide of circular cross section.

Before proceeding to a consideration of the mode of operation of this invention, it may be helpful to consider the electromagnetic field distributions in an open-ended circular guide supporting dominant mode TE_{11} wave energy. As a specific example, consider that guide section 12 in FIG. 1 supports TE_{11} wave mode energy propagating from right to left. The transverse electric field pattern associated with such a mode configuration is shown as diagram A of FIG. 2. In diagram A, arrows 21 within guide 22 indicate electric field lines at maximum intensity extending substantially vertically and "terminating" at the conductive guide surface. Of course one-half period later in time, the arrows point 180 degrees opposite, or downward. As is well known, when electric field lines terminate on a conductive wall normal thereto, electric currents are induced in the wall. In the model, the TE_{11} mode therefore generates currents in the conductive wall, and these currents have longitudinal components. Within the guide section itself no undesirable effects are produced by the presence of such currents. However, at the open end, or aperture, of guide section 12, each longitudinal current segment acts as a small energy radiator, the cumulative effect of which is to produce radiated energy in lobes other than the main lobe. Such lobes, known typically as rear or sidelobes, are undesirable.

As suggested by P. D. Potter in an article beginning at page 71 of the June 1963 issue of The Microwave Journal entitled "A New Horn Antenna with Suppressed Sidelobes and Equal Beamwidths," antenna performance can be improved by introducing energy in the TM_{11} wave mode into the guide section containing TE_{11} mode energy and terminating in the radiating aperture. In the Potter structure, however, the mode converter is a simple step transition from dominant mode to multimode waveguide. Such a converter is frequency sensitive and is rela-

tively difficult to adjust. According to the present invention, control over the mode conversion process is afforded by using a conical flare converter 13 in which the flare angle α controls the amount of conversion, and the distance S between the end of the flare converter 13 and the aperture 14 controls the relative phases of the TE₁₁ and TM₁₁ energy at the aperture.

As stated hereinbefore, the disclosed arrangement utilizes the TE₁₁+TM₁₁ mode combination to eliminate the normal electric field components at the aperture wall. FIG. 2 illustrates the combinational process in three diagrams lettered A, B, and C. Diagram A is a cross sectional view of the TE₁₁ wave mode in circular waveguide 22 as discussed hereinbefore. Since guide 22 is not dominant mode guide, higher order mode configurations are permitted to propagate therein. Thus, diagram B of FIG. 2 is a cross sectional view of the same guide 22 supporting wave energy in the TM₁₁ wave mode. Arrows 23 represent the electric field lines of such mode. If the field pattern of diagrams A and B are combined in guide 22, the resulting field pattern, indicated by arrows 24, is as shown in diagram C, in which the wall normals of the electric fields of the superposed TE₁₁ and TM₁₁ wave modes cancel in the regions at the guide wall but reinforce in the central guide region. The degree of cancellation and reinforcement depends on the relative magnitudes and phases of the fields of the two superimposed modes. Since the radial or normal component of field at the boundary or guide wall has exactly the same circumferential dependence for both the TE₁₁ and TM₁₁ modes, cancellation of the aperture field at the wall is complete around the entire periphery. FIG. 5 shows the electric field distribution in the principal planes of FIG. 2C.

At this point, it should be stated that the concept of mixed mode pairs can be extended to the synthesis of various aperture field distributions. To accomplish this, the mode pairs selected must be ordered such that their radial field distributions at the mode circumference correspond in order that the combined fields at the boundary wall cancel. Each mode pair can be defined as

$$TE_{am} + TM_{an},$$

where subscripts m , n , and a are dictated by the field distribution requirements. Subscript a , which must be the same for each mode of the chosen mode pair, determines the even or odd property of the mode. Since the mode pair must have zero aperture wall field by definition, any desired number of mode pairs may be combined at the aperture, with their relative phase and amplitude chosen to produce a particular aperture field distribution.

Returning now to the embodiment of FIG. 1, the conversion of TE₁₁ to TM₁₁ wave energy is accomplished in conical flare 13. As will be discussed in greater detail hereinbelow, the flare angle α and the length S between flare and aperture determine the magnitude and phase of the TM₁₁ wave energy and, consequently, the shape and directivity of the radiation pattern of the embodiment. Since for a given operating frequency, the cutoff diameter for TM₁₁ wave energy is greater than that for TE₁₁ wave energy, it is simple to proportion guides 11 and 12 such that guide 11 supports only TE₁₁ wave energy and guide 12 supports both TE₁₁ and TM₁₁ wave energy simultaneously.

A clearer understanding of the aperture distribution for the dual mode embodiment of FIG. 1 can be gained from reference to FIG. 5 in which the normalized electric field intensity at the guide aperture is shown for the orthogonal E and H principal planes of reference. The resultant radiation lobe symmetry is considerably better than typical single TE₁₁ mode radiation patterns, and the performance of the dual mode antennas is therefore superior to that of prior art single mode arrangements. This improvement in lobe characteristics outweighs the factor of an accompanying decrease in aperture efficiency, a factor

of minor importance in small aperture type antennas or antenna feeds.

Experimental models of the embodiment of FIG. 1 have been constructed and operated. These devices were designed for operation at a center design frequency of 11.2 kilomegacycles per second. In these embodiments inside diameter d_1 was 0.750 inch and inside diameter d_2 was 1.375 inches. A taper from d_1 to d_2 in which $\alpha = 30^\circ$ was employed as the mode converter. The distance S was 1.44 inches. The basic considerations when selecting the specific parameters are that:

(1) Feed section 11 propagate only the dominant TE₁₁ mode;

(2) Mode converter 13 have a flare angle α which converts the TE₁₁ incoming mode energy into the required amplitude of TH₁₁ mode energy;

(3) Aperture section 12 propagate the TM₁₁ mode as its highest order mode; and

(4) The aperture section be of a length S to produce a 180 degree phase difference between the field components of the two modes at aperture 15.

Since the nature of wave propagation is periodic, it is clear that S will have discrete periodic values. In practical designs it is desirable to use the shortest length which does not introduce field distortion due to evanescent modes. In the circular geometry of the disclosed embodiment, odd order modes, defined as TE_{om} or TM_{nm} where n is an even integer above unity, are not excited. Thus the TM₁₂ mode is the next higher order mode of concern. In the design set out hereinbefore, the TM₁₂ attenuation is 70 db per inch, and its presence can therefore be ignored. Higher order modes are even more severely attenuated; thus the shortest periodic length of S can be used.

The described mode conversion section 13 is a one parameter adjustment converter, the adjustable parameter being the flare angle, shown and described as 30 degrees. Partial conversion of the TE₁₁ wave mode to the TM₁₁ mode occurs as a result of field distortion or fringing in going from smaller diameter guide to larger diameter guide, and the amplitude of conversion is proportional to the size of the flare angle. Since this angle is subject to control, the amount of energy conversion is likewise controllable.

Far field radiation patterns were measured for the embodiment of FIG. 1 and are shown in FIGS. 3A and 3B. The mode phasing is adjusted to produce minimum sidelobes in the E plane. The smallest periodic length S at frequency 11.2 kilomegacycles, 1.44 inches, was found to produce essentially identical sidelobe characteristics as higher periodic lengths of S. Measurements in normal polarization planes indicate that the radiation pattern is highly circularly symmetric. Voltage standing wave ratio measured at the design frequency is 1.07:1, and it increases to 1.4:1 at 4 percent bandwidth. The desirable low sidelobe radiation characteristic of FIGS. 3A and 3B is degraded as the frequency bandwidth increases around the design frequency. The bandwidth limits of the device are controlled by dispersion between the two modes.

The dual mode small aperture antenna of FIG. 1 can also be used as the primary feed for large aperture antennas of the reflecting or refracting type. In FIG. 4 reflecting paraboloid 40 of a type well known in the art to act as a focuser is fed by guide 12 which forms the aperture section of the dual mode antenna of FIG. 1. Corresponding numerals have been carried over from FIG. 1 to designate corresponding structural elements.

The operation of the embodiment of FIG. 4 is substantially identical to other paraboloidal or "dish" reflectors well known in the art except that the antenna feed allows the reflector to be illuminated by a composite mode made up of TE₁₁ and TM₁₁ energy superposed in amplitude and phase at aperture 15 to produce a highly symmetrical, substantially single, radiation lobe.

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Certain related aspects of dual mode antenna arrangements are disclosed and claimed in the copending application of J. S. Cook, Ser. No. 547,993, filed May 5, 1966, and assigned to the assignee of this application.

In all cases it is understood that the above-described arrangements are merely illustrative of the application of the principles of the invention. Numerous and varied other arrangements can be devised by those skilled in the art in accordance with these principles without departing from the spirit and scope of the invention.

What is claimed is:

1. An aperture type antenna comprising
 - a first hollow conductively bounded waveguide section of circular cross section of diameter d_1 having an input end and an output end,
 - a second hollow conductively bounded waveguide section of circular cross section of diameter d_2 coaxially disposed in part with respect to said first section and having an input end and an aperture end,
- said output end of said first section including mode conversion means comprising a smooth conical taper of angle α and diameter between d_1 and d_2 ,

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and means for exciting said input end of said first section in the TE_{11} wave mode, said taper angle α and the distance from the end of said taper of diameter d_2 to said aperture end being such as to produce cancellation of the electromagnetic field components normal to the guidewall at said aperture end.

2. The antenna according to claim 1 in which said diameter d_1 effectively cuts off said first section for all modes except TE_{11} , and said diameter d_2 effectively cuts off said second section for all modes of order higher than TM_{11} .

3. The antenna according to claim 1 including additional means for focusing the wave energy radiated from said aperture end.

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