

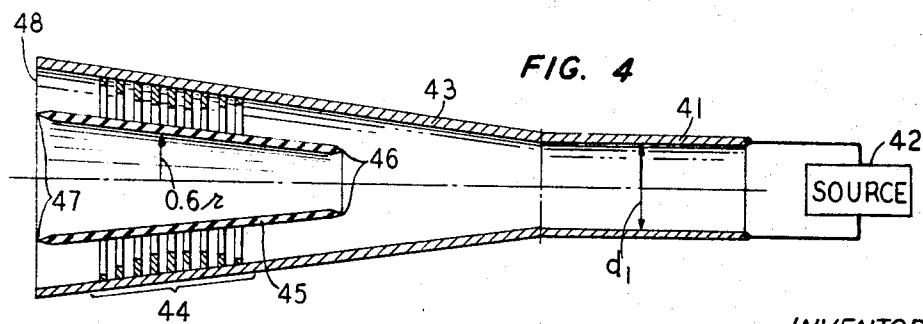
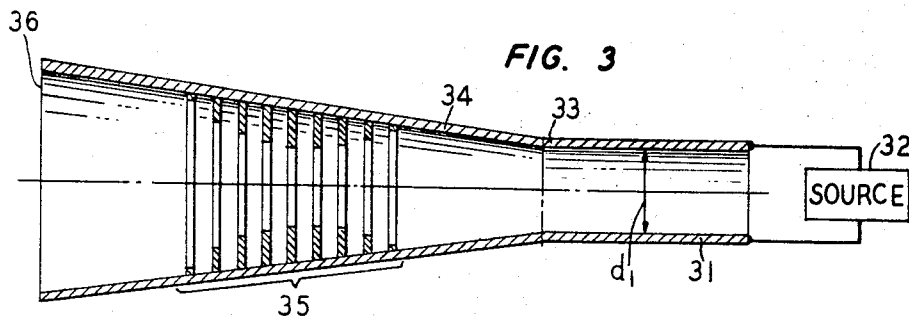
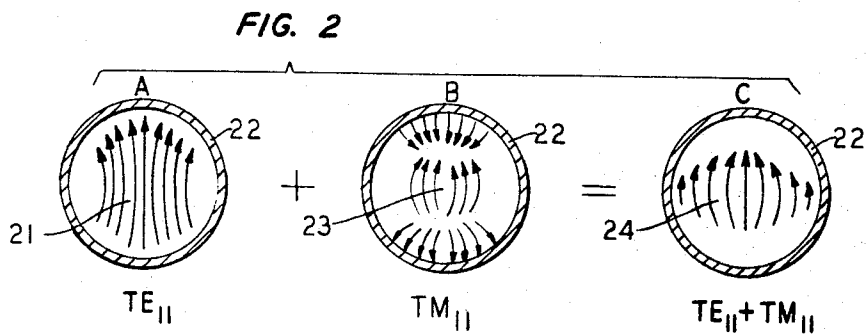
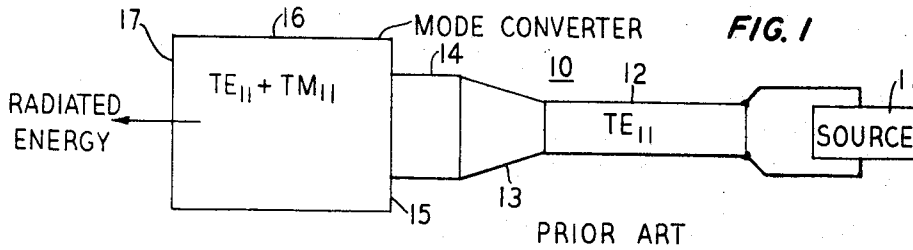
Nov. 26, 1968

J. S. COOK
DUAL MODE ANTENNA

3,413,642

Filed May 5, 1966

2 Sheets-Sheet 1



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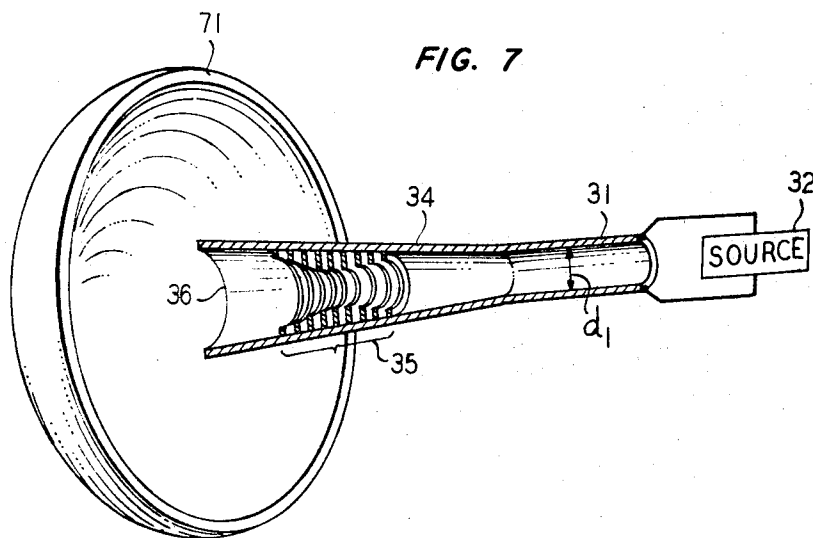
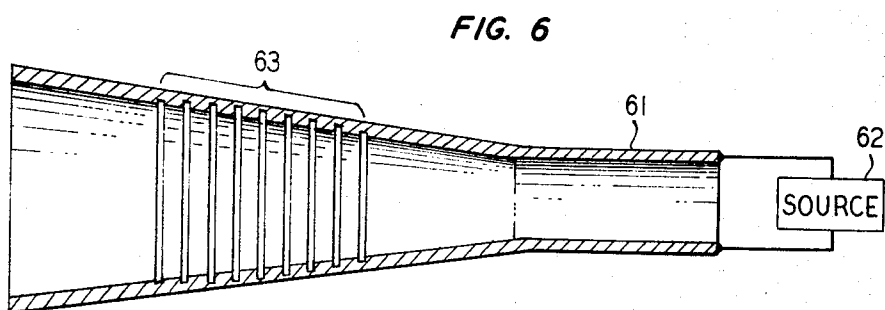
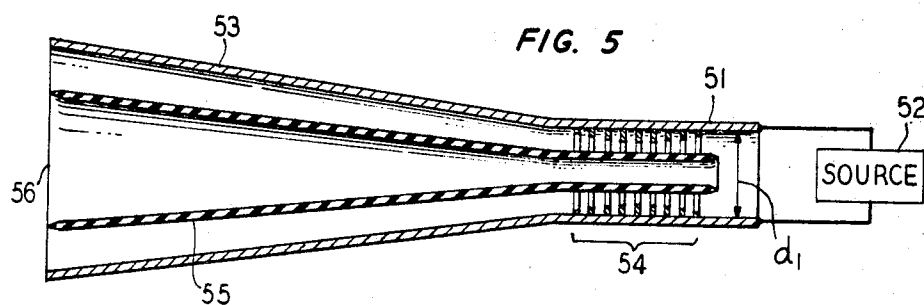
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DUAL MODE ANTENNA

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8 Claims. (Cl. 343-781)

This invention relates to 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.

One 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 in addition to the major lobe, a plurality of minor side or rear lobes which are often undesirable. Such minor lobes broaden the radiation pattern and can cause increased ratio 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 horn type antennas. In the past, attempts have been made to suppress these edge currents in 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 an amplitude and phase at the aperture which produces longitudinal current cancellation.

In an article entitled "A New Horn Antenna with Suppressed Sidelobes and Equal Beamwidths," which begins at page 71 of the June 1963 issue of The Microwave Journal, P. D. Potter suggests that energy propagating in the TE_{11} mode be converted in part to the TM_{11} mode to improve antenna performance. Mode conversion occurs, in that embodiment at a simple step transition between guide sections of different diameters. Such a mode conversion process is significantly frequency dependent due to the nature of the converter and to the differential phase velocity of the two modes between the mode conversion point and the radiating aperture. In addition, a certain amount of dominant mode wave energy is reflected from the converter.

Another object of the invention is therefore to reduce the frequency dependence of the priorly known dual mode antenna employing the TE_{11} - TM_{11} wave mode pair.

In accordance with the present invention, mode conversion is effected in a distributed series of small discontinuities on the inside surface of the aperture section of a small aperture antenna. Phase differentials and domi-

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nant mode reflection are reduced by disposing a thin dielectric annulus coextensively with the conversion discontinuities in a region of higher relative field intensity for the higher order one of the two propagating modes.

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.

In the drawing:

FIG. 1 is a plan view of one prior art structure;

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

FIG. 3 is a longitudinal section of an antenna in accordance with the invention;

FIG. 4 is a longitudinal section of a further embodiment of the invention;

FIGS. 5 and 6 are longitudinal sections of alternative geometries in accordance with the invention; and

FIG. 7 is a perspective view, partially broken away, of the antenna of FIG. 3 used as the feed in a parabolic reflector-type antenna.

Referring now to the drawing in greater detail, FIG. 1 illustrates a prior art antenna 10 in which energy in the TE_{11} wave mode from source 11 is incident on guide section 12 of circular cross section. Section 12 is selected to have a constant diameter which causes the section to be cut off for modes other than TE_{11} . The energy, after traversing section 13 of gradually increasing diameter passes through a mode suppressing section 14 of constant diameter and is converted in part to the TM_{11} wave mode at step transition mode converter 15. Beyond the converter 15 the TE_{11} - TM_{11} wave mode mixture propagates to the left in section 16 and is radiated at aperture 17. For a selected frequency, the phase and amplitude of the radiated energy can be controlled by the antenna dimensions. Since, however, the mode converter is a single step transition, impedance match can be sustained only over a narrow frequency band of operation. Outside this band, undesirable dominant mode energy reflection is experienced, and the amplitude and phase of the converted energy depart from the desired values.

Before proceeding to a consideration of the specific embodiments of the invention and to an explanation of their modes of operation, 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 16 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 22, 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 end, or aperture 17, of guide section 16 of FIG. 1, each longitudinal current segment acts as a small energy radiator, the cumulative effect which is to produce radiated energy in lobes other than the main lobe, which is excited by the aperture distribution alone. Such lobes, known typically as sidelobes, are undesirable since they can reduce antenna directivity as well as antenna power in the main lobe.

According to the present invention, sidelobe radiation is decreased over a substantial frequency band by the introduction of TM_{11} wave mode energy in a distributed mode converter and phase changer. The mode converter can comprise either a plurality of irises along a conductive guide or a plurality of grooves in the wall thereof. A thin dielectric annulus, if disposed coextensively with the irises or grooves, improves the impedance match over the frequency band.

FIG. 2 illustrates the combinational process in three diagrams lettered A, B, and C. Diagram A is a cross-sectional view of the TE_{11} wave mode in circular waveguide 22 as discussed hereinbefore. Since guide 22 is multimode, it can support higher order mode configurations. Thus, diagram B of FIG. 2 is a cross-sectional view of the same guide 22 supporting wave energy in the TM_{11} wave mode. Arrows 23 represent the electric field lines of such mode. If the field patterns of diagrams A and B are combined in a 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 TE_{11} and TM_{11} wave mode are seen to cancel in the regions near the guide wall and to reinforce in the central guide region. The degree of cancellation and reinforcement depends on the relative magnitudes of the fields in the two superposed modes.

Although the above description is in terms of the transverse electric fields within a circular waveguide, it is equally applicable to the transverse magnetic fields. That is, the transverse magnetic fields in the TE_{11} and TM_{11} wave mode also cancel in the regions near the guide wall and reinforce in the central guide portion. Thus the resultant transverse electromagnetic field distribution in the aperture is more nearly circularly symmetric, leading to an improved main radiation lobe. Compared, therefore, to an aperture antenna using a single TE_{11} mode distribution, the radiation characteristics of the dual mode configuration will be nearly circularly symmetric as well as virtually free of rear or side lobes. These advantages far outweigh the factor of an accompanying decrease in aperture efficiency, a factor of minor importance in small aperture type antennas or antenna feeds.

Returning now to the drawing, FIG. 3 illustrates a first embodiment of the present invention in which a hollow conductively bounded waveguide feedline section 31 of diameter d_1 , is excited in the TE_{11} wave mode by source 32, shown in block form. Diameter d_1 , is chosen in accordance with well-known principles to support only the dominant TE_{11} wave modes. The energy from source 32 can be applied to section 31 through a coaxial-to-waveguide transducer, through a waveguide transformer section, or through another length of waveguide of circular cross section. Section 31 merges at juncture 33 into slightly flared aperture section 34, which contains mode conversion means 35. The conversion means comprises a plurality of circular irises spaced apart along the axis 36 of guide section 34 a distance of the order of one-quarter wavelength. Each iris, acting as a small discontinuity in the guide, causes a portion of the energy incident in the TE_{11} wave mode to convert to the TM_{11} mode. It is thus necessary to ensure that the guide diameter at the discontinuities be large enough to permit propagation of the higher order TM_{11} mode. The individual irises comprise either metallic or dielectric material have a typical thickness small compared to a wavelength, and have aperture dimensions which decrease smoothly from a maximum at the first and last irises to a minimum at the center of the converter. This aperture taper, similar to the tapering of the coupling holes in a multiple hole directional coupler, minimizes energy reflection from the converter. Furthermore, the distributed nature of the discontinuities broadens the frequency band over which the relative amplitudes of the TE_{11} and TM_{11} wave modes can be maintained at the desired level to ensure longitudinal current cancellation at the radiation aperture 36.

FIG. 4 is an illustration of a further embodiment of the invention in which an additional bandwidth broadening structure is included. In dual mode antenna devices, an important consideration is the phase relationship between the TE_{11} and TM_{11} mode wave energy at the radiation aperture. The single step mode converters of the prior art are subject to phase mismatch at the radiating aperture for frequencies departing from the center frequency because the two modes of interest propagate beyond the converter with different phase velocities. This is also true, to a lesser degree, of the embodiment of FIG. 3. In FIG. 4, the feed line section 41, again of diameter d_1 , is fed from source 42, shown in block form, and the energy propagates to the left along flared guide section 43. Mode converter section 44 comprises a plurality of circular irises similar to those described with reference to FIG. 3 and, in addition, a hollow dielectric cone section 45, of local radius $0.6r$ where r is the local radius of section 43 at the point of interest. Cone 45 typically comprises a material having a dielectric constant of the order of 2, but the dielectric constant may be more or less with similar results by adjusting the annular thickness of the cone. The local radius is selected in order that the dielectric be disposed at a location for which the electric field intensity of the TM_{11} wave mode is considerably greater than that of the TE_{11} wave mode, thereby affecting the former mode to a greater extent than the latter. The specific result of the presence of the dielectric cone is to decrease the phase velocity of the TM_{11} wave mode relative to that of the TE_{11} wave mode and thereby to synchronize them over a broader frequency band of operation. The ends 46, 47 of cone 45 can be tapered in annular thickness to reduce energy reflection. Additionally, since a phase shift of 90° takes place in the converter, in which the TM_{11} wave lags the TE_{11} wave, the tapered dielectric at the radiating aperture 48 establishes the proper radiating phase relationship.

In some applications, the taper of the horn can be very shallow or, in antenna feed combination, the guide can be of uniform diameter. In such applications, the embodiment of FIG. 5 can be useful. In FIG. 5, source 52 excites the TE_{11} wave mode in circular guide section 51 having a diameter d_1 which is large enough to support the TM_{11} wave mode. The radiating portion 53 is flared to the desired degree, with distributed discontinuity mode conversion means 54 disposed within the guide section 51 of constant diameter. Dielectric annulus 55 extends from the source side of converter 54, through the converter and to the radiating aperture 56. The dimensions, physical constants, and mode of operation are similar to those of FIG. 4.

An alternative to the iris discontinuity arrangements of FIGS. 3 through 5 is depicted in FIG. 6, in which a microwave horn antenna 61 is excited in the TE_{11} wave mode by source 62, and partial mode conversion to TM_{11} is accomplished by circular groove discontinuities 63 which are milled in the wall of the flared portion of horn 61. The groove depth varies from shallow at the ends to maximum depth at the center, typical values being small compared to a wavelength. The dielectric annulus phase synchronizer, not illustrated in FIG. 6, is equally appropriate in the groove discontinuity embodiments as in the iris discontinuity embodiments of FIGS. 4 and 5. The groove discontinuity can also be used in a nontapered horn embodiment if desired.

The embodiments of the preceding FIGS. 3, 4, 5 and 6 can also be used as the primary feed for large aperture antennas of the reflecting or refracting type. In FIG. 7 reflecting paraboloid 71 of a type well known in the art is fed by feed guide 34 which can comprise the dual mode antenna of FIG. 3, for example. Corresponding numerals have been carried over from FIG. 3 to designate corresponding structural elements.

The operation of the embodiment of FIG. 7 is substantially identical to other paraboloidal or "dish" reflectors well known in the art except that the means for

feeding the antenna allows the reflector to be illuminated by a composite mode made up of TE_{11} and TM_{11} energy superposed in amplitude and phase at aperture 36 to produce a highly symmetrical, substantially single radiation lobe. The feed can, of course, comprise any of the structures of FIGS. 4, 5, and 6 as well.

Certain related aspects of dual mode antenna arrangements are disclosed and claimed in the copending application of R. H. Turrin, Ser. No. 547,992, 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. A dual mode antenna comprising a hollow conductively bounded guiding structure having an input portion and an output portion with a central axis of propagation, said structure being adapted to support the TE_{11} and TM_{11} wave modes simultaneously along at least said output portion, mode conversion means comprising a plurality of closely spaced discontinuities disposed within said structure, and means for applying energy in the TE_{11} wave mode to said input portion, said discontinuities causing conversion of a portion of said energy to the TM_{11} wave mode.

2. The antenna according to claim 1 in which said conversion means comprises a series of closely spaced circular irises.

3. The antenna according to claim 2 in which said input portion is of a constant diameter supportive of the TE_{11}

wave mode only, and said mode conversion means is disposed within said output portion.

4. The antenna according to claim 2 in which said input portion is of a diameter supportive of the TE_{11} and TM_{11} wave modes simultaneously and said mode conversion means is disposed within said input portion.

5. The antenna according to claim 3 including a hollow dielectric cylinder extending within said mode conversion means and continuing to the output aperture of said antenna, said cylinder being symmetrically disposed with respect to said axis, and at a constant distance from the inside surface of said bounding structure.

6. The antenna according to claim 4 including a hollow dielectric cylinder extending within said mode conversion means and continuing to the output aperture of said antenna, said cylinder being symmetrically disposed with respect to said axis, and at a constant distance from the inside surface of said bounding structure.

7. The antenna according to claim 1 in which said conversion means comprises a series of closely spaced grooves in the inside surface of said bounding structure.

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

References Cited

UNITED STATES PATENTS

3,216,018	11/1965	Kay	343—786
3,305,870	2/1967	Webb	343—786
3,324,423	6/1967	Webb	343—786

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