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DUAL-MODE CONICAL HORN ANTENNA

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FIG. 1

(PRIOR ART)

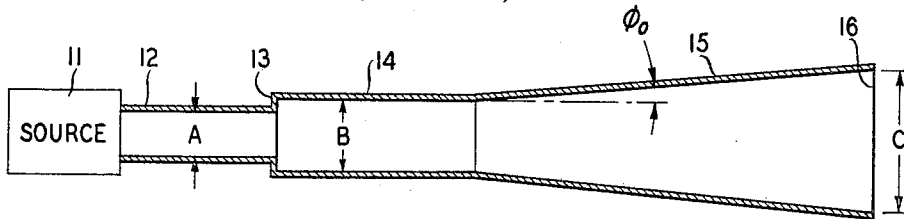


FIG. 2

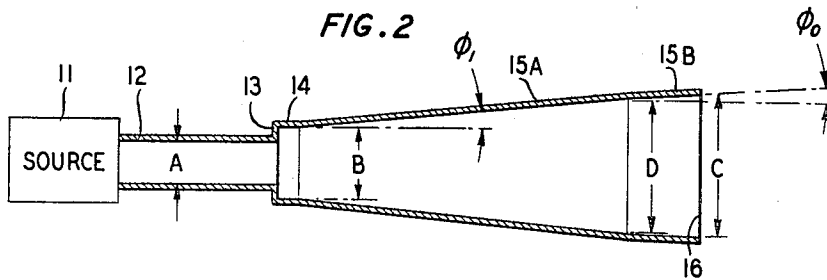
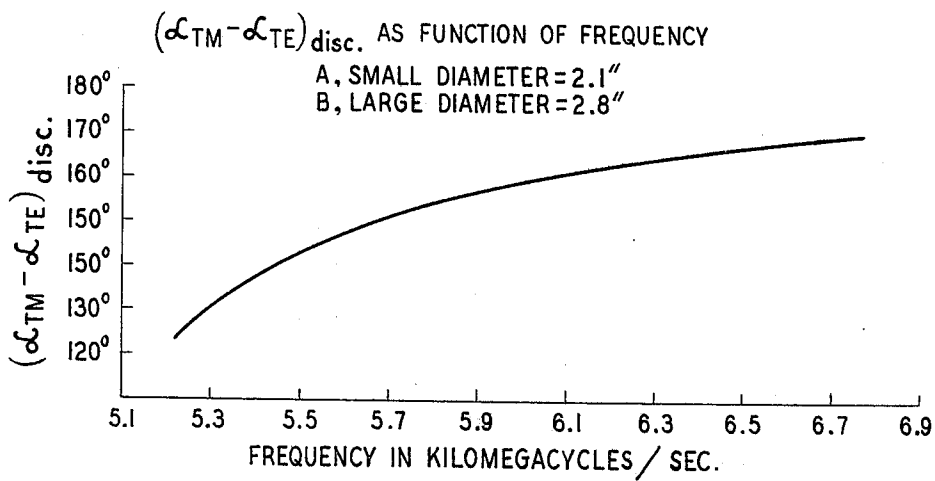


FIG. 3



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DUAL-MODE CONICAL HORN ANTENNA

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5 Claims

ABSTRACT OF THE DISCLOSURE

A horn antenna wherein the horn member is excited by more than one electromagnetic mode signal. The use of a predetermined configuration for the horn member mitigates the effect of aperture phase dispersion.

BACKGROUND OF THE INVENTION

Field of the invention

This invention pertains to antennas and, more particularly, to dual-mode conical horn antennas.

Description of the prior art

The dual-mode conical horn antenna, for example of the type described in an article by P. D. Potter, entitled "A New Horn Antenna with Suppressed Sidelobes and Equal Beamwidths," in the June 1963 issue of the *Micro-wave Journal*, page 71, has proven to be a very useful primary feed element for low noise antennas, particularly those of the Cassegrain type. Its applicability to other general uses is now recognized as one of its more important features. By exciting the antenna horn aperture with an appropriate combination of spherical TE_{11} (dominant) and TM_{11} modes it is possible to produce a horn radiation pattern with approximately equal E-plane and H-plane beam widths, and sidelobe levels substantially lower than those for conventionally excited (TE_{11} only) horns with the same aperture dimensions. This improvement, obtained at a modest expenditure of gain, is achieved by equalizing the E-plane and H-plane illumination taper, thereby reducing the E-plane edge current and the corresponding sidelobe levels.

Generally, the most important phenomenon affecting dual-mode horn performance, over a band of frequencies, is "aperture phase dispersion," a term used to describe the difference in relative phase between the TE_{11} and TM_{11} modes at the horn opening. For optimum performance it is required that the radial components of the electric field for the two modes be 180 degrees out of phase at the edge, i.e., at the boundary walls of the antenna.

Potter, in the above-mentioned article, teaches that mode conversion from the TE_{11} mode to the TM_{11} mode may be effected by a simple step transition between guide sections of a first and second predetermined diameter. The length of the guide section of said second predetermined diameter, identified by Potter as the phasing section, is selected to account for the relative phase lengths of the horn for the two propagating modes in the horn. Since overall antenna specifications usually determine the antenna aperture diameter, cone angle, and diameter of the phasing section, the length of the horn section is therefore determined, and, thus, so is the relative phase shift between the two propagating modes. Correction of this differential phase shift at the horn aperture by varying the length of the phasing section, as per Potter, quite often results in a deterioration of overall antenna performance, rather than an improvement in performance. As the length of the phasing section is increased, its inherent phase dispersion with changes in operating fre-

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quency also increases, causing a degradation of the circular symmetry of the antenna radiation pattern, a decrease in overall antenna gain and an increase in unwanted sidelobe levels.

SUMMARY OF THE INVENTION

It is, therefore, an object of this invention to mitigate the effects of aperture phase dispersion in order to optimize the performance of dual-mode conical horn antennas.

It is another object of this invention to mitigate the effect of aperture phase dispersion without resorting to lengthy and highly dispersive phasing sections.

In accordance with this invention, the effect of aperture phase dispersion is mitigated by the use of a horn antenna of a predetermined configuration. More particularly, a dual-mode conical horn is utilized which is characterized by a double flare. One section of the horn, i.e., the frustum of a cone, has a predetermined half angle to give the correct aperture dimensions, and another section, i.e., a second frustum of a cone, has a half angle selected to yield the correct relative phase. Thus, the dispersive phasing section, relied upon in the prior art, is relegated to a vernier or trimming function, required only to compensate for small errors in design and construction. The necessity for a lengthy and highly dispersive phasing section is therefore eliminated with a corresponding improvement in antenna performance.

These and further features and objects of this invention, its nature and various advantages may be more readily apprehended and understood upon consideration of the attached drawings and of the following detailed description of the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an illustrative diagram of a prior art dual-mode conical horn antenna;

FIG. 2 is an illustrative diagram of a dual-mode conical horn antenna which embodies the principles of this invention; and

FIG. 3 is a graphical presentation of the differential phase shift of a particular waveguide configuration.

DESCRIPTION OF EMBODIMENTS OF THE INVENTION

In order to appreciate the invention more fully, FIG. 1 is included to represent a typical prior art dual-mode conical horn antenna.

Source 11, of FIG. 1, excites in hollow waveguide section 12, of circular cross section, energy which propagates in the TE_{11} (dominant) wave mode. The diameter A of section 12 is selected, in a manner well known to those skilled in the art, so that the guide is "cut off" for modes other than the TE_{11} . The step discontinuity 13, which forms a conductive boundary between guide section 12 and hollow waveguide section 14, also of circular cross section, converts a portion of the incident TE_{11} energy to the TM_{11} wave mode. Mode conversion via the use of a discontinuity is discussed in detail in an article by J. Shefer and me in the *Bell System Technical Journal*, vol. 44, at page 1321, entitled "Mode Conversion in Circular Waveguides." The combined TE_{11} - TM_{11} wave mode mixture propagates in horn section 15, e.g., a hollow frustum of a cone, and is radiated into the atmosphere at aperture 16.

As discussed above, the principal difficulties in the design of dual-mode horn antennas are in properly phasing the two modes, TE_{11} and TM_{11} , and maintaining the correct relative phase over the frequency range of interest. Generally, design specifications comprise the horn aperture diameter, indicated as C in FIG. 1, the half angle flare θ_0 , of the conical horn, and the relative power in the

two propagating modes, the specifications being determined on the basis of overall antenna requirements. Usually, there is a certain degree of freedom in selecting the diameter B of guide section 14; it should be made sufficiently large so that the TM₁₁ mode is well above cut-off, but not so large that the required input waveguide 12, itself, becomes overmoded. A detailed discussion of antenna requirements and their relationship to antenna dimensions may be found in the article entitled "The Open Cassegrain Antenna: Part I, Electromagnetic Design and Analysis," authored by J. S. Cook, E. M. Elam and H. Zucker, appearing in vol. 44 of the Bell System Technical Journal, at page 1255.

The most important phenomenon affecting dual-mode performance is aperture phase dispersion, a term used to describe the difference in relative phase between the TE₁₁ and TM₁₁ modes at the horn aperture 16. Proper phasing of these two modes at the horn aperture is therefore the dominant problem in constructing an efficient dual-mode conical horn antenna. Unfortunately, once the aperture diameter C, cone angle θ_0 and guide diameter B are specified, the length of the horn section 15 is also determined and so, therefore, is the relative phase shift between the two modes. Quite often, the error in relative phase between the two modes at the aperture is so large that it becomes necessary to use a long and therefore highly dispersive phasing section 14. For example, in a particular horn antenna it was found that in order to substantially decrease the relative phase shift between the two modes, a phasing section 14 of length L was required which had phase dispersion by itself, over a ten percent frequency band, equal to approximately 25 degrees. Coupled with the intrinsic phase dispersion of the horn 15, which may, by itself, be of the same order of magnitude, the total aperture phase dispersion would be approximately 50 degrees. The effect of such a large phase dispersion, especially in a reflector feed system, is to decrease the circular symmetry of the radiation pattern and also to cause a decrease in the antenna gain with a concomitant increase in unwanted sidelobe levels.

This deleterious effect of prior art antennas may be eliminated in accordance with the principles of this invention by using a horn antenna of the type illustrated in FIG. 2. The antenna of FIG. 2 is characterized by a horn with a double flare, one section 15b, to yield the correct aperture dimensions (diameter and angle) and another section 15a, whose angle is selected to yield the correct relative phase at the aperture 16. The phasing section 14, is thus relegated to a trimming function used only to compensate for small errors in design and construction.

More particularly, analogous to the operation of the antenna of FIG. 1, source 11 of FIG. 2, excites in waveguide section 12 a propagating wave in the TE₁₁ mode. The step discontinuity 13, which forms a conductive boundary between guide sections 12 and 14, converts a portion of the incident propagating energy into the TM₁₁ mode. The combined wave modes, TE₁₁ and TM₁₁, propagate in horn sections 15a and 15b and are radiated into the atmosphere at aperture 16.

The horn of the antenna, as illustrated in FIG. 2, comprises two frustrums, 15a and 15b, each having a predetermined half angle θ_1 and θ_0 , respectively. As discussed above, general antenna requirements determine the magnitude of the horn aperture diameter C, the angle θ_0 of section 15b, and the relative diameters A and B of guide sections 12 and 14. In order to substantially reduce the effect of phase aperture distortion, section 15a of the horn, in accordance with the principles of this invention, is constructed to have a different half angle θ_1 than that of section 15b. Generally, the value of the half angle θ_1 is determined to be such that the relative phase between the TE₁₁ and TM₁₁ modes at the horn aperture is equal to an odd multiple of π radians. This relative phase can be calculated from the relationship

$$(\alpha_{TM}-\alpha_{TE})_{aperture} = (\alpha_{TM}-\alpha_{TE})_{disc.} + (\alpha_{TM}-\alpha_{TE})_{\theta_1} + (\alpha_{TM}-\alpha_{TE})_{\theta_0} = (2n+1)\pi \quad (1)$$

where n =integer, and $(\alpha_{TM}-\alpha_{TE})$ in each case denotes the relative phase shift between the two modes in the respectively identified sections. Thus, $(\alpha_{TM}-\alpha_{TE})_{aperture}$ denotes the relative phase at the horn aperture, $(\alpha_{TM}-\alpha_{TE})_{disc.}$ denotes the relative phase at the discontinuity between diameters A and B, $(\alpha_{TM}-\alpha_{TE})_{\theta_1}$ denotes the differential phase shift in the frustrum of half angle θ_1 , and $(\alpha_{TM}-\alpha_{TE})_{\theta_0}$ denotes the differential phase shift in the frustrum of half angle θ_0 . The quantity $(\alpha_{TM}-\alpha_{TE})_{disc.}$ is calculated by solving the electromagnetic boundary value problem of the given discontinuity impinged upon by electromagnetic energy in the form of a TE₁₁ mode. For example, FIG. 3 shows

$$(\alpha_{TM}-\alpha_{TE})_{disc.}$$

as a function of frequency for A=2.1 inches and B=2.8 inches.

The quantities $(\alpha_{TM}-\alpha_{TE})_{\theta_1}$ and $(\alpha_{TM}-\alpha_{TE})_{\theta_0}$ can be expressed, respectively, in terms of θ_1 or θ_0 and the diameters B, C and D, from the well-known formulas describing the propagation of electromagnetic waves in conical waveguides. See, for example, F. Borgnis and C. H. Papas, "Electromagnetic Waveguides and Resonators," Encyclopedia of Physics, vol. XVI, Springer, Berlin, 1958, page 356.

In a specific application, a horn antenna for use at X-band frequencies was constructed in accordance with the principles of this invention having the following dimensions:

$A=7.2/k$, $B=9.6/k$, $C=18.8/k$, $D=16.8/k$, $\theta_0=5.5^\circ$ and $\theta_1=6.7^\circ$, where k is equal to 2π divided by the signal wavelength at the center frequency of the operating band. The antenna was provided with a variable trimming section 14, whose length could be adjusted in order to optimize the performance of the antenna. Phasing of the two propagating modes was achieved by monitoring the longitudinal wall currents and varying the length of section 14 until a minimum was observed. This condition occurs when the electric fields of the two modes perpendicular to the walls of the horn are the required 180 degrees out of phase. The length L of section 14 for this condition was approximately $.26\lambda$, where λ is the signal wavelength at the center frequency of operating band, corresponding to approximately one-tenth the length required if prior art techniques had been utilized. Thus, proper phasing of the two modes is accomplished without resorting to long phasing sections which are highly dispersive and degrade overall antenna performance.

It is to be understood that the embodiments shown and described are illustrative of the principles of this invention only, and that further modifications of this invention may be implemented by those skilled in the art without departing from the scope and spirit of the invention. For example, though the principles of this invention are particularly applicable to feed horn antennas, they are also applicable to any other situation where horn antennas are used. In addition, diverse configurations may be implemented using mode signals other than the TE₁₁ and TM₁₁.

I claim:

1. A dual-mode conical horn antenna comprising:
 - a first circular hollow waveguide section having a first predetermined diameter,
 - a second circular hollow waveguide section having a second predetermined diameter conductively coupled to said first waveguide section,
 - a third truncated conical hollow waveguide section having a first predetermined half angle for reducing the phase differential between mode signals propagating in said third waveguide section conductively coupled to said second waveguide section, and
 - a fourth truncated conical hollow waveguide section having a second predetermined half angle conductively coupled to said third waveguide section.

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2. An improved dual-mode conical horn antenna, wherein mode conversion is accomplished by a discontinuity between first and second hollow waveguide sections, having a horn member comprising:

- a third hollow waveguide section comprising a frustrum of a cone having a first predetermined half angle for diminishing the aperture phase dispersion of propagating mode signals, and
- a fourth hollow waveguide section comprising a frustrum of a cone having a second predetermined half angle,

wherein said third and fourth waveguide sections are conductively united and have a common axis of propagation.

3. A dual-mode conical horn antenna comprising:

- a first circular hollow conductively bounded waveguide section of first predetermined diameter having input and output means, said input means responsive to applied electromagnetic signals,
- a second circular hollow conductively bounded waveguide section of second predetermined diameter having input and output means,

conductive means uniting said first waveguide section output means and said second waveguide section input means for converting a proportional part of incident electromagnetic energy into a different order mode signal,

- a third hollow conductively bounded waveguide section comprising a frustrum of a cone having a first predetermined half angle coupled to said second waveguide section output means for reducing the phase differential between propagating mode signals, and

- a fourth hollow conductively bounded waveguide section comprising a frustrum of a cone having a second predetermined half angle coupled to said third waveguide section.

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4. An improved dual-mode conical horn antenna comprising:

mode conversion means responsive to a first electromagnetic mode signal for converting a predetermined percentage of said mode signal into a second mode signal,

a horn member,

a first section of said horn member, responsive to said first and second mode signals, comprising a frustrum of a cone having a first predetermined angle for diminishing the aperture phase dispersion between said two mode signals, and a second section of said horn member comprising a frustrum of a cone having a second predetermined angle for radiating said signals at the aperture thereof.

5. An antenna having a horn member responsive to more than one microwave mode signal wherein said horn member comprises:

a first hollow conductive frustrum of a cone having a first preselected half angle for reducing the phase differential of said mode signals, and

a second hollow conductive frustrum of a cone having a second preselected half angle for radiating said mode signals.

References Cited

UNITED STATES PATENTS

3,373,431 3/1968 Webb ----- 343—786

FOREIGN PATENTS

963,705 5/1957 Germany.

H. K. SAALBACH, Primary Examiner

35 T. VEZEAU, Assistant Examiner