United States Patent

[11] **3,573,838**

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[45] Patented **Apr. 6, 1971**
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Culver City, Calif.

[54] **BROADBAND MULTIMODE HORN ANTENNA**
11 Claims, 14 Drawing Figs.

[52] **U.S. Cl.** **343/783,** 343/786
[51] **Int. Cl.** **H01q 13/00**
[50] **Field of Search** 343/772, 776, 777, 778, 779, 786, 783

[56] **References Cited**

UNITED STATES PATENTS

3,205,498	9/1965	Child	343/705
3,268,902	8/1966	Turrin	343/786
3,413,642	11/1968	Cook	343/786

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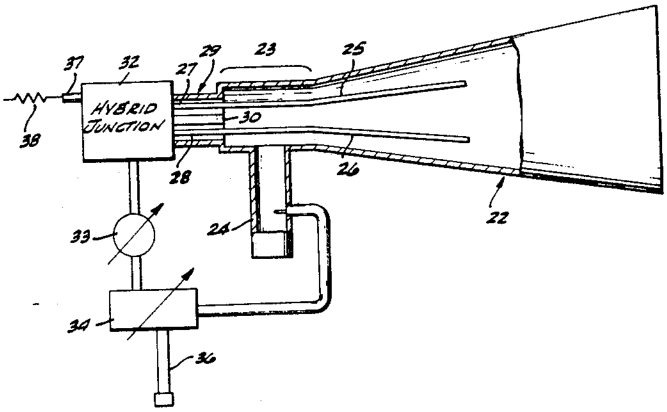
ABSTRACT: The apparatus of the present invention provides a horn antenna capable of generating a pattern with rotational symmetry and polarization purity over a broadband of frequencies with comparatively low side lobes. In achieving this operation, a first mode which propagates as a "slow wave" is launched through a first portion of the horn and is converted to a second mode which propagates as a "fast wave" through the remaining portion. At the aperture of the horn, the resulting wave combines with a "medium wave" which normally propagates along the entire length of the horn, to achieve the desired aperture distribution. Since the slow wave and the fast wave compensate each other for frequency changes, the overall desired aperture distribution can be sustained over a broad range of frequencies.



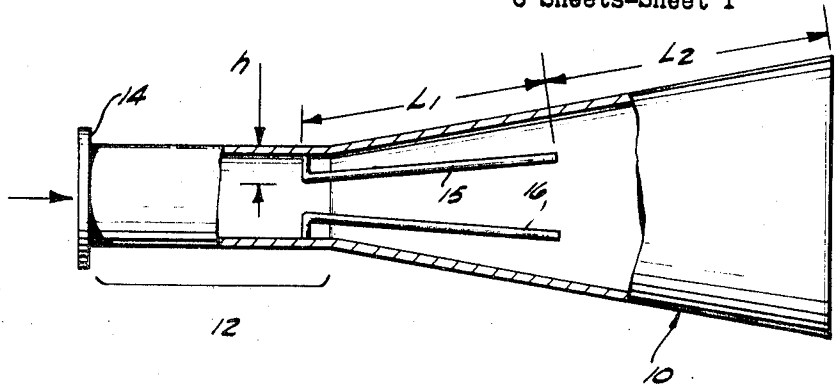


FIG. 1.

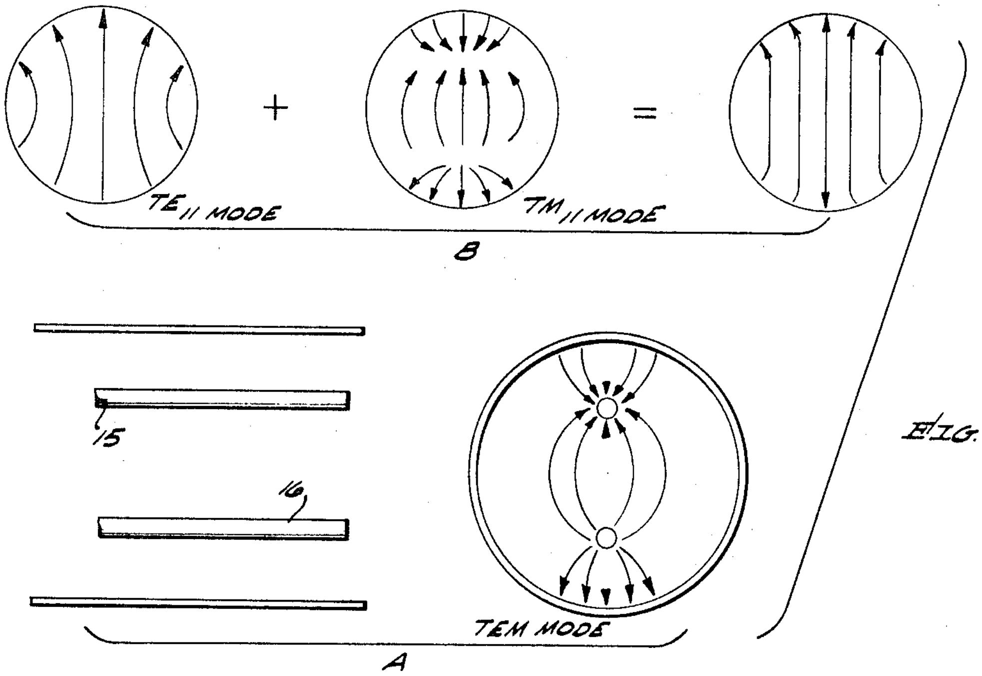


FIG. 2.

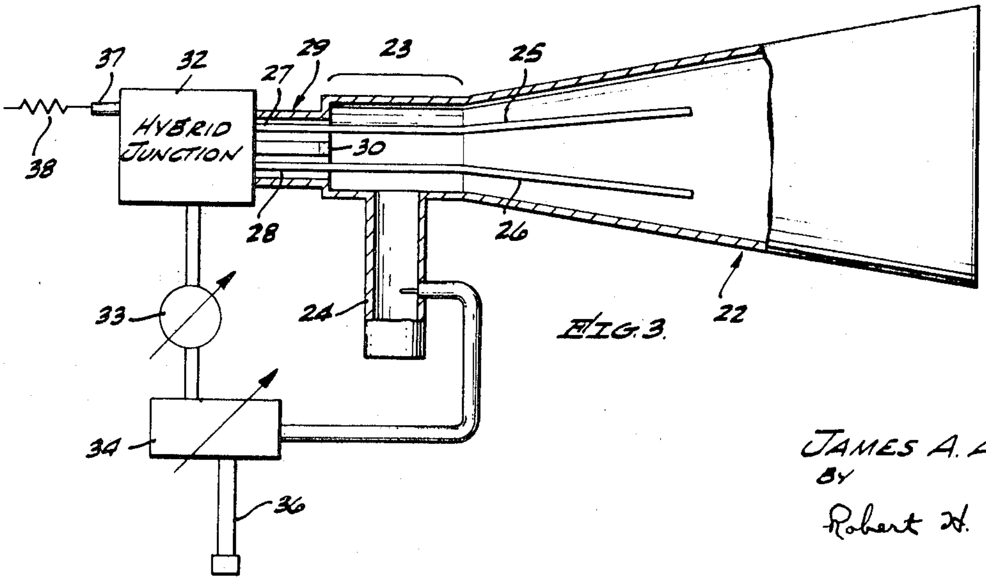


FIG. 3.

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ATTORNEY

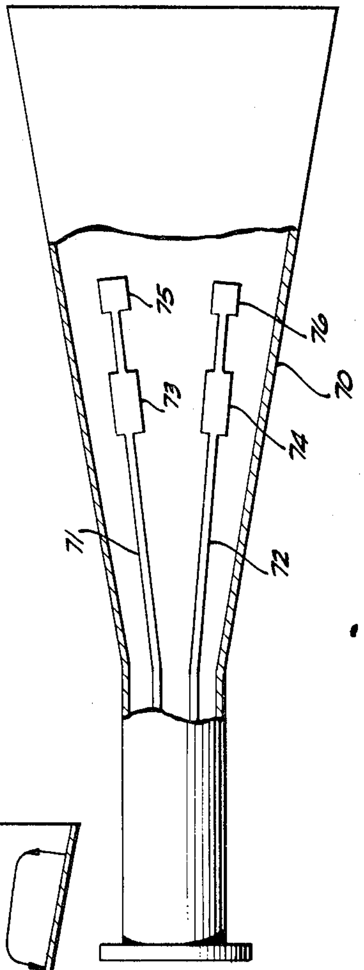


FIG. 6.

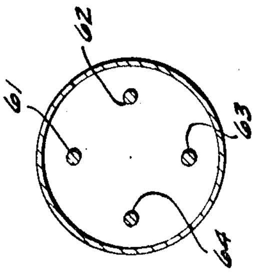


FIG. 5B.

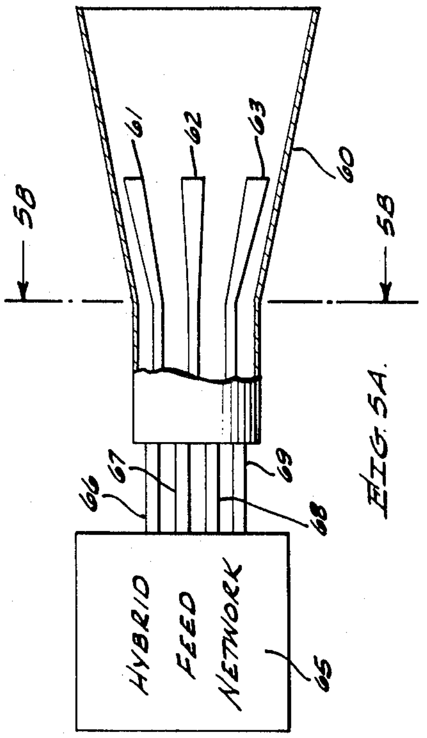


FIG. 5A.

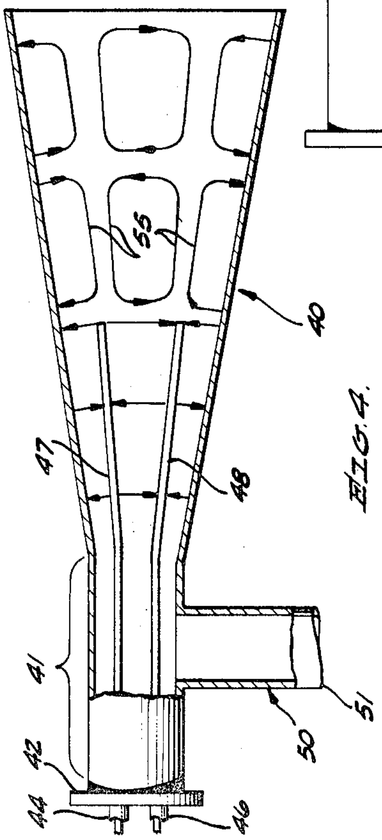


FIG. 4.

FIG. 7A.

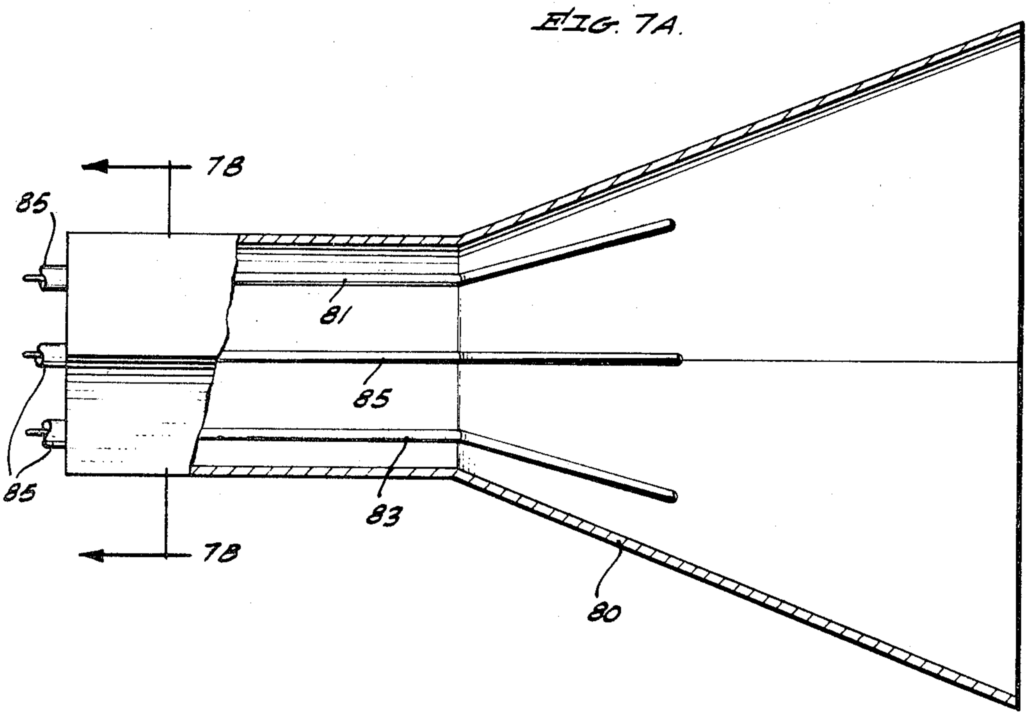
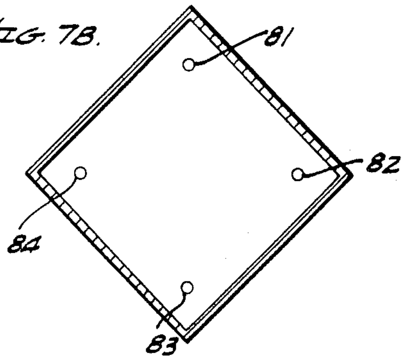


FIG. 7B.



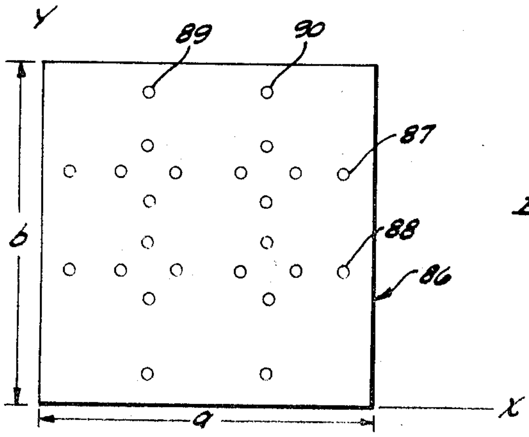
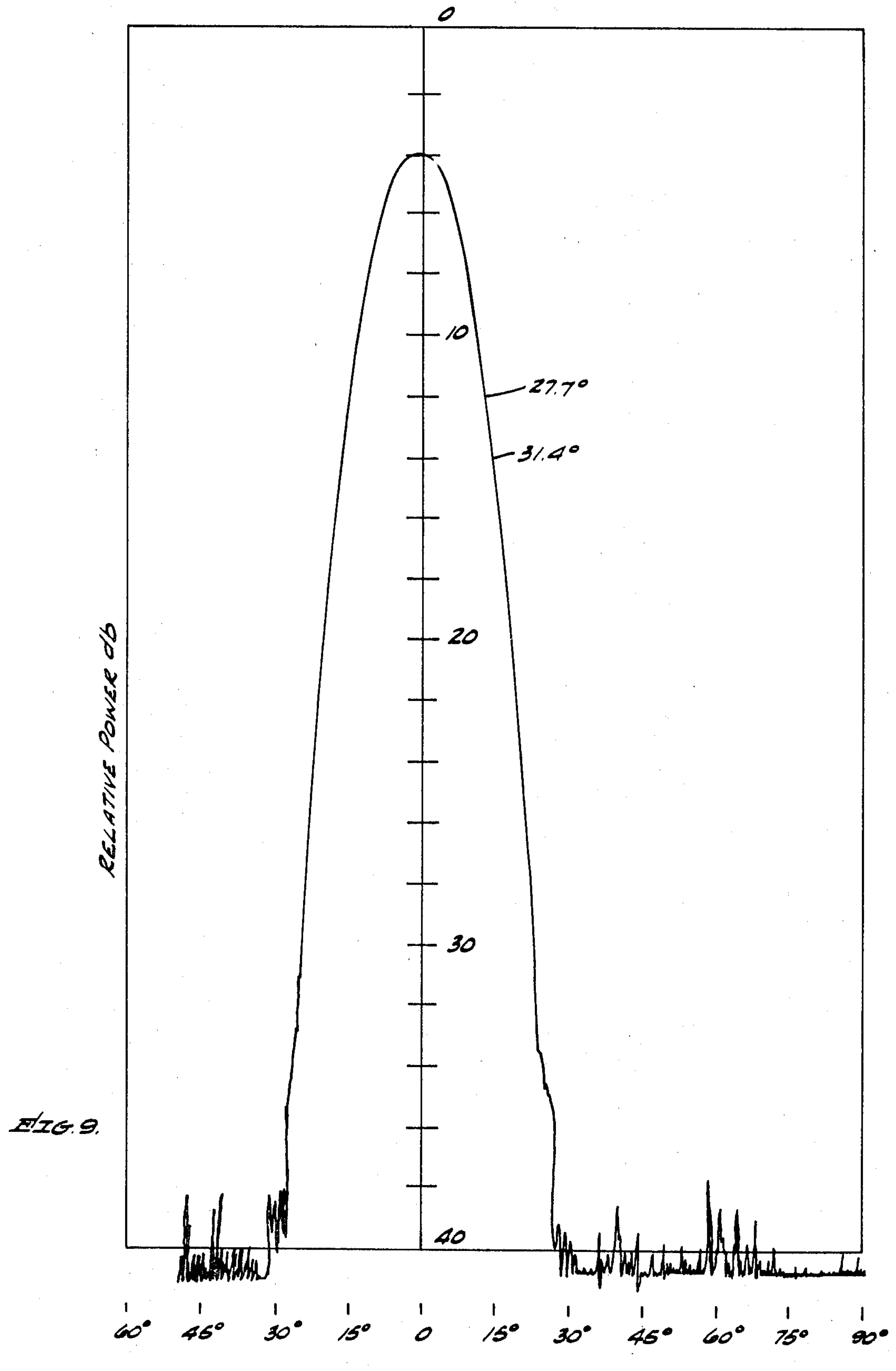


FIG. 8.


0
10
20
30
40
27.7°
31.4°
RELATIVE POWER db
60°
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90°

FIG. 9.

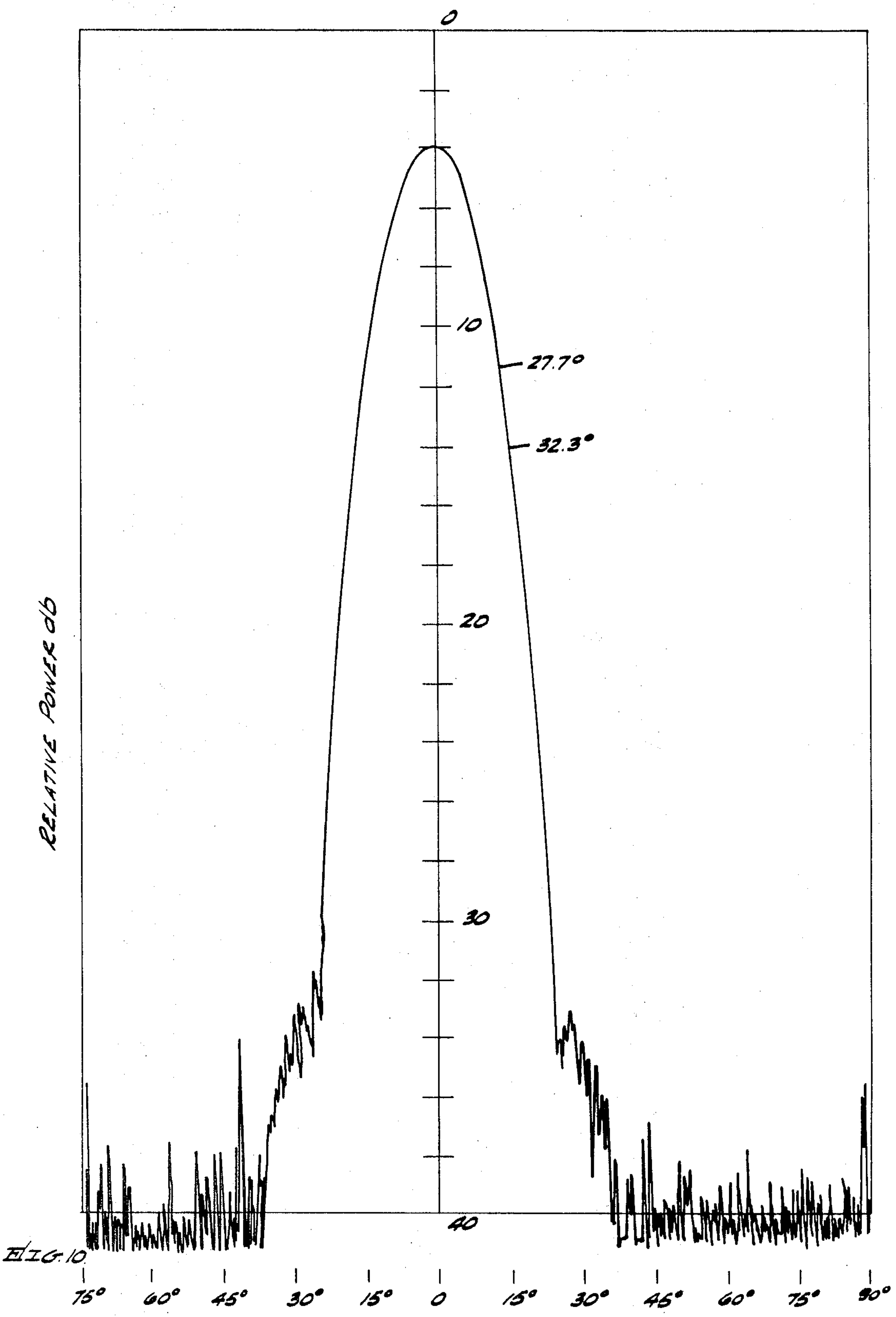
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FIG. 10

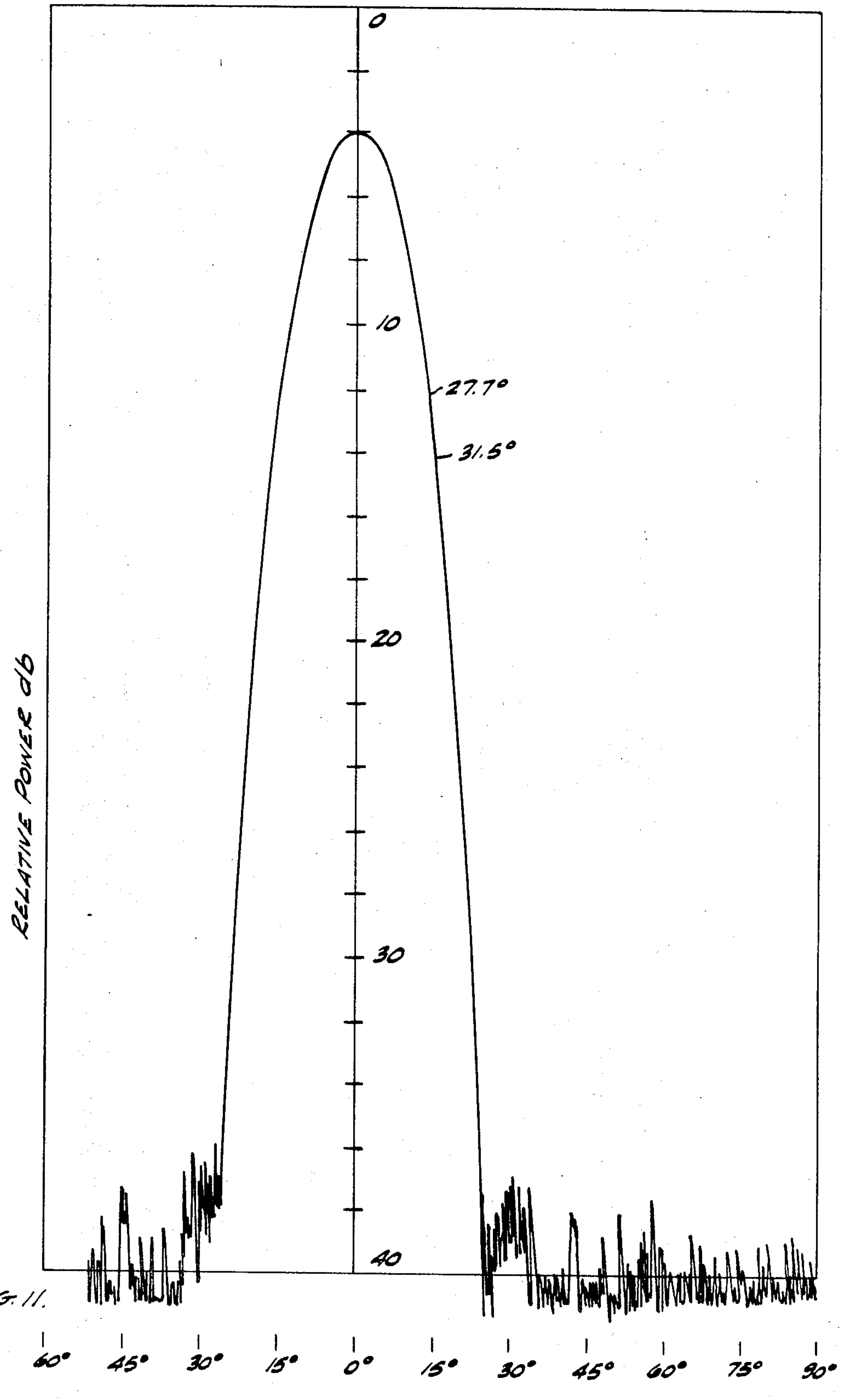
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FIG. 11.

BROADBAND MULTIMODE HORN ANTENNA

BACKGROUND OF THE INVENTION

Contemporary single conical or pyramidal horns which combine higher order modes with a dominant mode can give a variety of radiation patterns. Good control of the radiation pattern can be achieved by controlling the relative amplitudes and phases of the various modes at the horn aperture. High efficiency feed horns for cassegrain antennas utilize this technique. The principal disadvantage to contemporary multimode horns is that the bandwidth is extremely narrow. The reason for this narrow bandwidth is that the higher order modes are generated prior to or in the region of the throat of the horn and since various modes have different velocities of propagation through this region, the relative phases at the horn aperture will vary rapidly with frequency. The longer the horn, the greater is this frequency sensitivity.

One present method of generating higher order modes is the use of a step discontinuity followed by a phasing section to adjust the relative phases of the modes. The relative amplitudes are determined by the height of the step discontinuity and the length of the phasing section is adjusted to give the proper relative phase at the horn aperture. Since the higher order modes have phase velocities that vary much more rapidly with frequency change than the dominant mode, particularly in the phasing section and in the throat region of the horn, the radiation pattern will also change rapidly with changes in frequency. That is, such horns are narrow band devices. Other methods of generating higher order modes are series stub mode generators, and pins or corrugations for mode generation. These methods are narrow band for the same reason as above.

SUMMARY OF THE INVENTION

In accordance with the present invention, a plurality of spaced longitudinal conductive rods are disposed in the throat section of a conical horn which as a cross-sectional shape that can be circular, rectangular, triangular, etc. These conductive rods may be parasitically excited or driven externally from the horn to allow remote control of the relative phase and amplitude of the modes to achieve a desired field distribution pattern across the aperture of the horn. In instances where the longitudinal conductive rods are driven externally, hybrid junctions may be used to control the amplitude and phase. Also, for efficient launching of the higher order modes from the TEM lines, the impedance match in the transition from TEM to horn modes must be good. The impedance match can be enhanced by adjustment of the parameters of conductor position in the horn, conductor size and shape, any or all of which can vary along the lines.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a conical multimode horn of circular cross section having parasitically energized longitudinal rods;

FIGS. **2A** and **2B** illustrate field distribution in the horn of FIG. **1**;

FIG. **3** shows a circular multimode horn with externally controlled mode amplitudes and phases;

FIG. **4** shows a circular multimode horn illustrating at TM_{11} mode field configuration launched from TEM line;

FIGS. **5A** and **5B** show a circular multimode horn adapted for multimode generation with multiconductor TEM lines excited by a hybrid network;

FIG. **6** shows a conical multimode horn having longitudinal rods with impedance matching;

FIGS. **7A** and **7B** show a rectangular horn with four longitudinal rods for mode launching;

FIG. **8** shows a cross section of the throat portion of a rectangular horn having a plurality of longitudinal rods for mode launching;

FIG. **9** shows an E-plane aperture distribution from a TEM launched multimode conical horn;

FIG. **10** shows an H-plane aperture distribution from a TEM launched multimode conical horn; and

FIG. **11** shows a diagonal-plane aperture distribution from a TEM launched multimode conical horn.

DESCRIPTION

Referring now to FIG. **1** of the drawings, there is shown an embodiment of the present invention including a conical horn **10** having a throat section **12** which is terminated with a flange **14**. Longitudinal conductive rods **15, 16** are attached diametrically opposite each other to the inner surface and at the right extremity of the throat section **12**, as viewed in the drawing, by means of right angle extensions of length h. Thus, the rods **15, 16** commence substantially at the termination of the throat section **12** a distance, h, from the surface and extend for a distance, L_1, towards the aperture of the conical horn **10**. Although not critical, the rods may extend along lines emanating from the vertex of conical horn **10** and intersecting points a distance, h, from opposite sides of the throat section **12** at the junction with the conical horn **10**.

In the operation of the multimode circular conical horn of FIG. **1**, a dominant TE_{11} mode is initially launched through the throat section **12**. The incident TE_{11} mode excites the TEM mode on the two conductor lines formed by longitudinal rods **15, 16** at the commencement thereof. The magnitude of the TEM mode is controlled by the "antenna height," h, i.e., the support portions of the rods **15, 16**. Since only a portion of the TE_{11} mode is converted to the TEM mode, both the TE_{11} and TEM modes exist in the region L_1 of the conical horn **10**. The configuration of the TEM mode in the region L_1 in relation to the rods **15, 16** is illustrated in FIG. **2A**. At the right extremity of the rods **15, 16**, as viewed in the drawing, a TM_{11} mode is launched by the TEM mode. Thus, the TE_{11} and TM_{11} modes exist in the region L_2 of the conical horn **10**. Since the longitudinal rods **15, 16** terminated at the end of region L_1, the TEM mode cannot exist in the region L_2. The TE_{11} and TM_{11} modes combine at the aperture of the horn **10** as illustrated in FIG. **2B** to generate a field intensity pattern having very low side lobes. E, H and diagonal plane patterns generated by a TEM launched TM_{11} mode are illustrated in FIGS. **9, 10** and **11**. The side lobes in all these patterns are of the order of 30 db. down from the peak, the patterns are essentially identical in shape showing rotational symmetry and finally, the cross polarization as measured in the diagonal plane where it is greatest is seen to be entirely negligible which illustrates the desireable property of polarization purity.

The relative phase of the TE_{11} and TM_{11} modes at the aperture of the horn **10** are retained over a broad frequency range. The reason for this is because the phase of the TM_{11} mode at the horn aperture depends on the "relatively slow" phase velocity of the TEM mode over the distance L_1 and the "relatively fast" phase velocity of the TM_{11} mode over the distance L_2 and the phase of the TE_{11} mode at the horn aperture is a function of the "medium" velocity of the TE_{11} mode only over the distance L_1+L_2; that is, the composite average phase velocity of a slow wave and a fast wave can be made essentially equal to the average phase velocity of a medium velocity wave over a broad frequency range thus assuring the relative phase between the TE_{11} and TM_{11} waves at the horn aperture to be essentially constant over a broad frequency range (eg., over the entire frequency band of normal operation of a waveguide). Stated mathematically:

$$\underbrace{\beta_{\mathrm{TEM}}\, L_1 + \int_{L_1}^{L_2} \beta_{\mathrm{TM}_{11}}\, dl}_{\text{phase of } \mathrm{TM}_{11} \text{ mode}} = \underbrace{\int_{0}^{L_2} \beta_{\mathrm{TE}_{11}}\, dl}_{\text{phase of } \mathrm{TE}_{11} \text{ mode}} \qquad (1)$$

where

$$\beta_{\mathrm{TEM}} = \frac{2\pi}{\lambda_{\mathrm{TEM}}} \qquad (2)$$

$$\beta_{TM_{11}}=\frac{2\pi}{\lambda_{TM_{11}}} \quad (3)$$

$$\beta_{TE_{11}}=\frac{2\pi}{\lambda_{TE_{11}}} \quad (4)$$

β_{TEM} = wavelength of TEM mode

$\lambda_{TM_{11}}$ = wavelength of TM_{11} mode

$\lambda_{TE_{11}}$ = wavelength of TE_{11} mode

and phase velocity, v_p, of the modes are

$$\frac{2\pi \text{ frequency}}{\beta}$$

In the equation (1) above, the terms to the left of the equal sign represent the phase of the TM_{11} wave at the aperture of the horn **10** while the term to the right of the equal sign represents the phase of the TE_{11} wave at the aperture.

Changes in the frequency of the TEM and TM_{11} modes are self-compensating, i.e., as one increases the other decreases relative to the TE_{11} mode, whereby equation (1) can remain valid for a broad range of frequencies. In general, the slow TEM wave over the distance L, plus the fast TM_{11} wave over the distance L_2 can equal the medium speed TE_{11} wave over the distance L_1+84 L_2 and this equality is essentially maintained over a broad frequency range.

Another embodiment of the multimode horn of the present invention adapted to allow external control of the amplitude and phase of the modes is shown in FIG. **3**. Referring to FIG. **3**, there is shown, in partial section, a conical horn **22** including a throat section **23** with an arm **24**. Longitudinal conductive rods **25**, **26** extend from the center conductors **27**, **28**, respectively, of coaxial lines **29**, **30** through throat section **23** after which they fan out along the inner surface of conical horn **22**. The end of throat section **23** of horn **22** is terminated by a conductive disc **30** which serves as a termination for the outer conductors of the coaxial lines **29**, **30**. Coaxial lines **29**, **30** are connected to the opposite polarity outputs of a hybrid junction **32** which, in turn, is connected through a variable phase shifter **33** to one output of a variable power divider **34**. A remaining output from the variable power divider **34** is coupled to the arm **24** of horn **22** in manner to launch a TE_{11} wave therein. An input **36** to the variable power divider **34** serves as an input to the multimode horn **22**. Lastly, a remaining output **37** from the hybrid junction **32** is terminated by means of an impedance **38**, or may be used as an odd mode generator for an error (difference) channel for monopulse operation.

In operation, a microwave signal is applied to the input line **36** which divides it between the arm **24** and the hybrid junction **32**. The hybrid junction **32** applies opposite polarity signals through the coaxial lines **29**, **30** to the longitudinal rods **25**, **26** to launch a TEM wave therealong. As in the case of the device of FIG. **1**, the TEM wave launches at TM_{11} wave through the conical horn **22** commencing with the terminal of rods **25**, **26**. Concurrently, a TE_{11} wave is launched in arm **24** in which is directed through the horn **22** in the same manner as the distance L_1+L_2 in the horn **10** of FIG. **1**. The relative amplitude and phase of the TE_{11} and TM_{11} waves at the aperture may be controlled to achieve a desired pattern by the variable power divider **34** and the variable phase shifter **33**.

Referring to FIG. **4**, there is shown a multimode horn in accordance with the invention illustrating the electric field configuration for a TM_{11} mode. In particular, the apparatus of FIG. **4** illustrates a conical horn **40** in partial section with a throat section **41** terminated by a conductive disc **42**. Conductive disc **42** supports coaxial inputs **44**, **46**, the center conductors of which connect to longitudinal rods **47**, **48**. Longitudinal rods extend longitudinally through the throat section **41** and then fan out slightly in the conical section of the horn **10**. In addition, a cylindrical waveguide arm **50** terminated by a disc **51** is connected to the throat section **4**. In operation, the

coaxial inputs **44**, **46** are fed with signals of opposite phase and of a frequency sufficiently high to enable the conical section of the horn **10** to support the TM_{11} mode of propagation. Under these circumstances, a TEM mode propagates along the longitudinal rods **47**, **48** and launches at TM_{11} mode at the terminations thereof. The electric field configurations of the TM_{11} mode is illustrated by the lines **55**.

Referring to FIGS. **5A** and **5B** there is shown a multimode horn in accordance with the invention with more than two TEM mode launching rods. In particular, FIGS. **5A** and **5B** show a conical horn **60** with longitudinal TEM mode launching rods **61**, **62**, **63**, **64**. The rods **61**—**64** are tapered and spacing flared such that the characteristic impedance for the TEM mode is constant (i.e. the ratio of rod diameter and spacing to horn diameter are constant to give geometrical similarity at any cross section). In particular, FIGS. **5A** and **5B** show a conical horn **60** with longitudinal TEM mode launching rods **61**, **62**, **63**, **64** shown in cross section in FIG. **5B**. The longitudinal rods **61**, **62**, **63**, **64** are driven by means of a hybrid feed network **65** through coaxial lines **66**, **67**, **68**, **69**. In operation, the hybrid feed network **65** excites the multiconductor TEM lines **61**—**64** with signals of the proper amplitudes and phases which, in turn, launch the higher order modes in the horn **60**. The relative phase of the signals applied to the multiconductor TEM lines **61**—**64** proceeding in a clockwise direction as viewed in FIG. **5B** is $2\pi m/n$ where m32 ±0, 1, 2, 3... and n is the number of lines. Thus, for m=1 in the present case, the relative phase between adjacent lines is 90°. This phase difference is employed for exciting a TEM mode which, in turn, launches dual orthogonal (right and left circularly polarized) modes in the horn **60**.

For efficient launching of the higher order modes from the TEM lines or longitudinal rods, the impedance match in the transition from TEM to horn modes must be good. Referring to FIG. **6**, there is shown a conical horn **70** including longitudinal rods **71**, **72**. Conductive ferrules **73**, **74** are disposed near the end of the rods **71**, **72**, respectively, and ferrules **75**, **76** at the extremities thereof. The ferrules **73**, **74** are of the order of twice the length of the ferrules **75**, **76** and are spaced of the order of one length away therefrom. In addition, the diameter of ferrules **73**, **74**, **75**, **76** is of the order of two to three times the diameter of the rods **71**, **72**. The same configuration could, of course, be achieved by undercutting a heavier rod. The principal consideration to achieve impedance matching is to generate reflections to cancel out reflections developed at the transition between the rods **71**, **72** and free space within the horn **70**.

Longitudinal rods can, of course, be used with horns of other shapes such as horns with rectangular or triangular cross section. Referring to FIGS. **7A** and **7B** there is shown a rectangular horn **80** with longitudinal rods **81**, **82**, **83**, **84**. Connections to the rods **81**—**84** are made through coaxial connectors **85**. A more complex pattern of longitudinal rods in a rectangular horn **86** is shown in cross section in FIG. **8**, wherein there are two horizontal rows **87**, **88** and two vertical rows **89**, **90**, as viewed in the drawing, of six rods each. The height of the horn **86** is b, the width a, the vertical distance from the lower side, as viewed in the drawing, y, and the horizontal distance from the left side, as viewed in the drawings, x. In general, the rows **87**—**90** of rods can be driven in a manner to achieve any desired pattern as might be determined by a finite Fourier series. Higher are modes and launched, however, by driving the discrete rods in accordance with corresponding points of the desired field intensity pattern within the rectangular horn **86**. In this latter case, excitation of rods in rows **87**, **88** is in accordance with discrete sampling of $\cos(n\pi x/a)$ where x denotes position of rod in x direction. Similarly, excitation of rods in rows **89**, **90** is in accordance with discrete sampling of $\cos(m\pi y/b)$ where y denotes position or rod in y direction. In the foregoing situation, m and n are integers which denote the particular mode to be launched. The rods **81**—**84** in the horn **80** of FIGS. **7A** and **7B** are excited in accordance with the manner described in connection with FIG. **8**.

I claim:

1. A broadband multimode horn antenna comprising a conductive horn having a conical configuration, means for launching and propagating a first electromagnetic wave in the TE_{11} mode of predetermined velocity through first and second successive portions of the length of said conductive horn, means for launching and propagating a second electromagnetic wave in the TEM mode having a velocity slower than said predetermined velocity through said first portion of the length of said conductive horn, and means for converting said second wave into a third electromagnetic wave in the TM_{11} mode having a velocity faster than said predetermined velocity through said second portion of the length of said conductive horn whereby said first and third waves combine to provide a predetermined field intensity pattern at the aperture of said horn over a broad range of frequencies.

2. A broadband multimode horn antenna comprising a conductive horn having an aperture at one extremity thereof; a plurality of longitudinal conductive spaced rods disposed along a first portion of the length of said horn spaced from said aperture; means coupled to said horn for launching a wave of predetermined velocity therethrough; and means coupled to said spaced rods for launching a TEM wave therealong of a velocity less than said predetermined velocity whereby said TEM wave converts to a wave of a velocity faster than said predetermined velocity at the termination of said first portion and propagates through a second portion of the length of said horn extending from said first portion to said aperture to combine with said wave of predetermined velocity to provide a predetermined field intensity pattern.

3. The broadband multimode horn as defined in claim **2** wherein said conductive horn has a conical configuration with a constant diameter throat section, and said plurality of longitudinal conductive spaced rods constitutes first and second rods disposed opposite each other along said first portion of the length of said horn.

4. The broadband multimode horn antenna as defined in claim **2** wherein the ratio of the cross-sectional dimensions of the diameter of said rods and the relative spacing thereof to the dimensions of said horn at said cross section are constant thereby to provide a constant impedance to said TEM wave.

5. The broadband multimode horn as defined in claim **2** wherein said conductive horn has a conical configuration with a constant diameter throat section, and said plurality of longitudinal conductive spaced rods constitutes first, second, third and fourth rods disposed at quadrature points along said first portion of the length of said horn.

6. The broadband multimode horn as defined in claim **2** wherein the respective end portions of said plurality of spaced longitudinal conductive rods nearest said aperture each include no less than one step discontinuity therealong thereby to provide impedance matching between said rods and said second portion of the length of said horn.

7. A broadband multimode horn antenna comprising a conical horn having a cylindrical throat section at the narrow extremity thereof and an aperture at the remaining extremity; first and second longitudinal rods disposed along a portion of the length of said conical horn adjacent said throat section on opposite sides of the centerline thereof, said longitudinal rods being supported by right-angle extensions thereof at the extremities nearest said throat section to the inner surface of said conical horn; and means for launching a TE_{11} wave through said throat section thereby to generate a multimode field intensity pattern at said aperture.

8. A broadband multimode horn antenna system comprising a conical horn having a cylindrical throat section at the narrow extremity thereof and an aperture at the remaining extremity; first and second longitudinal rods disposed through said throat section and along a portion of the length of said conical horn adjacent thereto on opposite sides of the centerline thereof; means responsive to a signal to be radiated from said horn for dividing the power and controlling the relative phase thereof along first and second paths, said first path being coupled to said throat section for exciting a TE_{11} wave therethrough; and means including a hybrid junction having an input connected to second path and outputs connected to said first and second rods for launching said signal as a TEM wave therealong thereby to generate a controllable field intensity pattern representative of said signal at said aperture.

9. A broadband multimode horn antenna system comprising a conical horn having a cylindrical throat section at the narrow extremity thereof and an aperture at the remaining extremity; a plurality, n, of longitudinal conductive rods disposed through said throat section and along a portion of the length of said conical horn adjacent thereto at equal intervals about the centerline thereof; and a hybrid feed network responsive to a signal to be radiated from said aperture and connected to said n longitudinal conductive rods for exciting said rods with said signal with a phase difference between successive rods equal to $\cos(2\pi m/n)$ where m is an integer.

10. A broadband multimode horn antenna comprising a rectangular horn having a rectangular throat section at the narrow extremity thereof and a rectangular aperture at the remaining extremity; a plurality of conductive rods disposed longitudinally through said throat section and along a portion of the length of said rectangular horn adjacent thereto; and means connected to said rods for generating a predetermined multimode field intensity pattern at said rectangular aperture.

11. The broadband multimode horn antenna as defined in claim **10** wherein said rectangular throat section has a width a and a height b and wherein x is a variable denoting the respective positions of a portion of said rods along said width from a first reference side of said throat section and y is a variable denoting the respective positions of the remainder of said rods along said height from a second reference side of said throat section orthogonal to said first reference side and wherein said last-named means constitutes discrete sampling of $\cos(n\pi m/a$ along said width for said portion of said rods and constitutes discrete sampling of $\cos(m\pi y/b)$ along said heights for said remainder of said rods wherein m and n are integers that determine the modes of propagation.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,573,838 Dated April 6, 1971

Inventor(s) James S. Ajioka

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 6, "βTEM = wavelength of TEM mode" should be --λTEM = wavelength of TEM mode--

Column 6, line 53, "cos(nπm/a" should be --cos(nπx/a)--

Signed and sealed this 8th day of May 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patent