NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO
ATTN OF:

October 16, 1970

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General
Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned
U.S. Patents in STAR

In accordance with the procedures contained in the Code GP to Code USI memorandum on this subject, dated June 8, 1970, the attached NASA-owned U.S. patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No.	:	3,305,870
Corporate Source	:	Calif. Institute of Technology
Supplementary Corporate Source	:	Jet Propulsion Laboratory
NASA Patent Case No.	:	XNP-01057

Please note that this patent covers an invention made by an employee of a NASA contractor. Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the Specification, following the words ". . . with respect to an invention of. . . ."

GParker

Gayle Parker

Enclosure:
Copy of Patent

FACILITY FORM 602

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Feb. 21, 1967 JAMES E. WEBB 3,305,870

ADMINISTRATOR OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

DUAL MODE HORN ANTENNA

Filed Aug. 12, 1963 2 Sheets-Sheet 1

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FIG-1

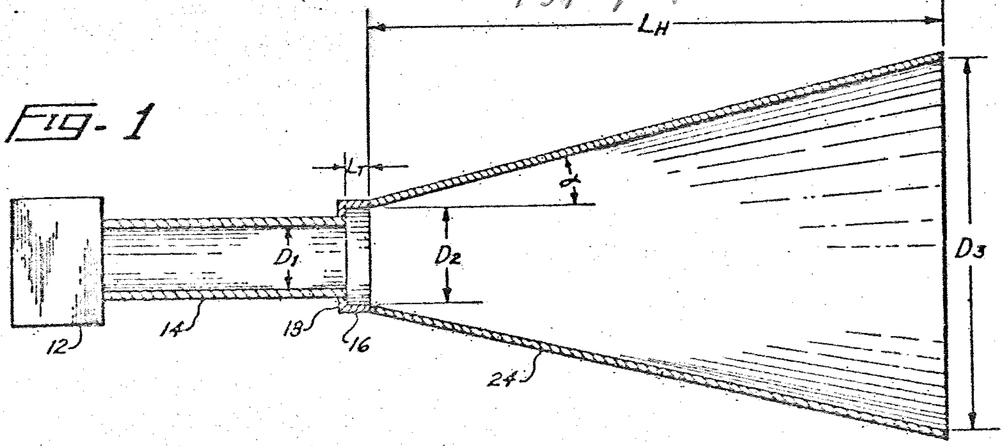


FIG-2

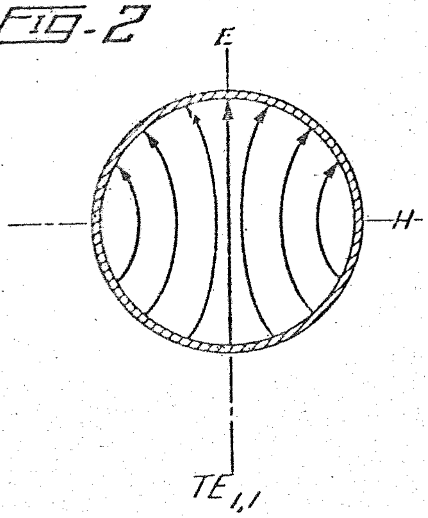
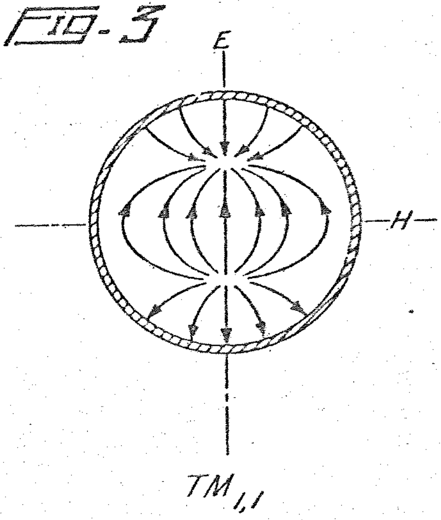


FIG-3



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ATTORNEY

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FIG. 4

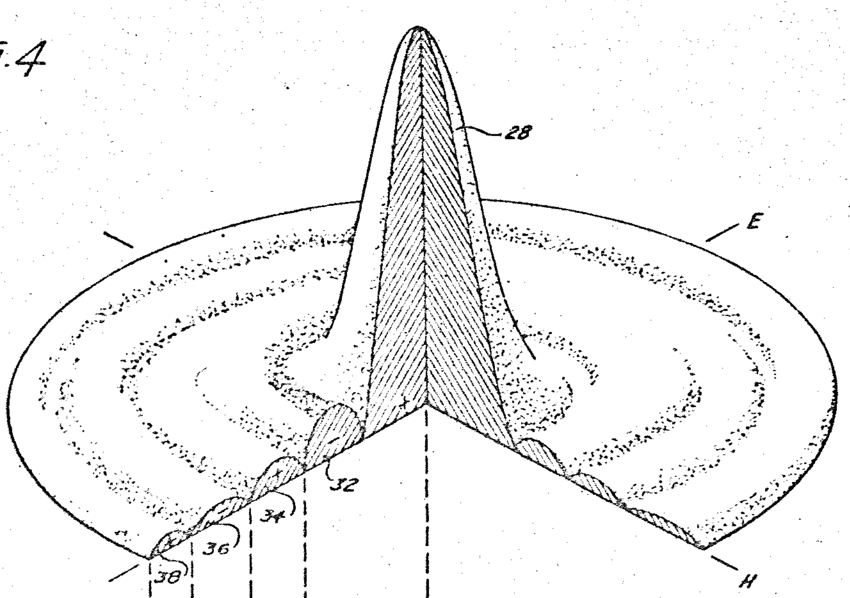
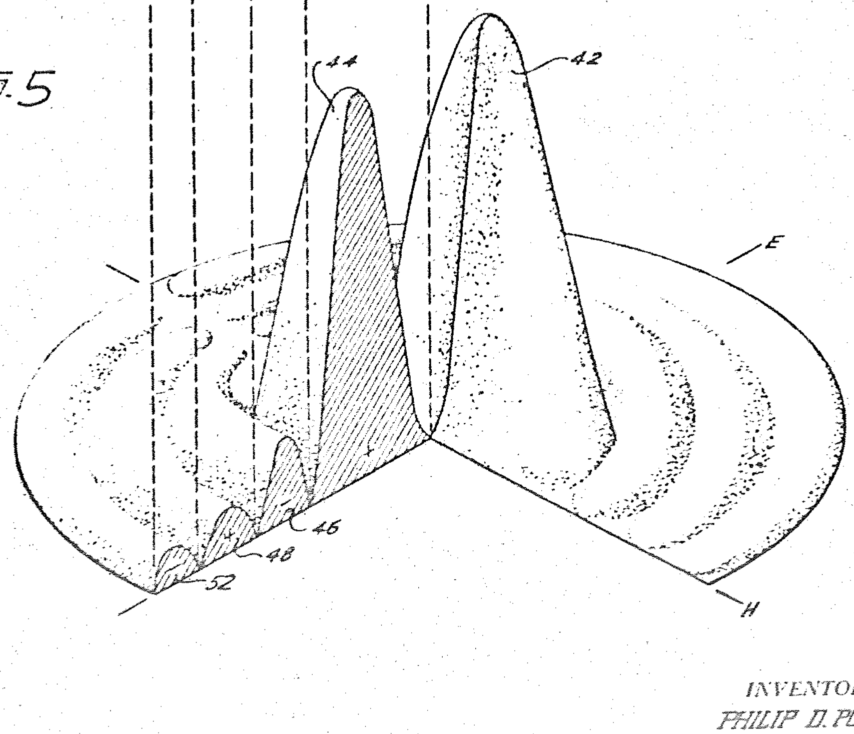


FIG. 5



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United States Patent Office

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Patented Feb. 21, 1967

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3,305,870
DUAL MODE HORN ANTENNA

James E. Webb, Administrator of the National Aeronautics and Space Administration, with respect to an invention of Philip D. Potter, Tujunga, Calif.

Filed Aug. 12, 1963, Ser. No. 301,683
6 Claims. (Cl. 343—786)

This invention relates in general to antenna systems and more particularly to apparatus for producing and radiating a beam of electromagnetic wave energy containing a plurality of modes.

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

Horn antennas have been employed for many years to radiate electromagnetic wave energy from a waveguide into free space. These types of antennas are readily adaptable for use with waveguides since they not only serve to match the impedance of the waveguide to the impedance of free space, but also to produce a directive wave pattern.

Heretofore, most horn antennas have been of rectangular cross section because of the attendant simple transition to a standard rectangular waveguide. Moreover, use of a rectangular waveguide together with a rectangular horn antenna allows the plane of polarization of the microwave energy to remain fixed.

A recent development in horn antennas which results in a radiation pattern having both equal beamwidth and low side lobes is the diagonal horn antenna. All cross sections through the diagonal horn antenna are square. For small flare angles of the horn antenna, the mode of propagation within the horn is such that the electric field vector is parallel to one of the diagonals of the antenna. The resulting radiation pattern possesses almost equal beamwidth in the E and H planes. Side lobe level for the diagonal horn antenna, however, has a theoretical limit of 31.5 decibels.

Horn antennas of conical cross section, operating in the dominant TE_{11} mode, have a beamwidth which is more nearly equal in the E and H planes than rectangular or square horns operating in their dominant modes, and these antennas are particularly desirable in applications where a variety of polarizations are needed. However, conical horn antennas have not been more widely utilized because of the high side lobe levels characteristic of their radiation patterns which have been incompatible for certain applications.

In order to overcome these attendant disadvantages in the prior art antennas, the antenna of the present invention provides a radiation pattern of equal beamwidths in the E and H plane and further characterized by having greatly suppressed side lobes. Electromagnetic wave energy in the dominant mode is transferred from a circular waveguide to a cylindrical transition section of waveguide wherein a portion of the energy is converted into energy of a higher order mode. Energy in both modes then propagates from the transition section into a conical horn antenna and hence into free space.

More specifically, according to an embodiment of the invention, a source of microwave energy in the dominant TE_{11} mode is fed into an input circular waveguide. The waveguide is abruptly connected to one end of a circular transition section of waveguide having a diameter larger than the input waveguide. As the energy in the dominant TE_{11} mode enters the transition section, due to the abrupt transition a portion of the TE_{11} mode energy is converted to the higher order TM_{11} mode. The other end of the transition section is connected to a conical horn antenna and has the same diameter as the end of the horn antenna to which it is connected. The horn antenna then flares outwardly at a fixed angle for a predetermined length. Since the two modes have different phase velocities, they travel down the transition section and horn antenna in an out of phase relationship. However, the length and diameter of the transition section, as well as the length and flare angle of the horn antenna, are so selected that the main beam of both modes will radiate into free space in phase. The resultant combination of the main beams of the two mode results in a radiation pattern having substantially equal beamwidth in the E and H planes and a very low side lobe level.

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The advantages of this invention, both as to its construction and mode of operation, will be readily appreciated as the same become better understood by reference to the following detailed description when considered in connection with the accompanying drawings in which like referenced numerals designate like parts throughout the figures and wherein:

FIG. 1 is a side view, partly in section, of a novel antenna system in accordance with this invention;

FIG. 2 is the electric field pattern of the TE_{11} mode in a circular waveguide in a plane perpendicular to the axis of the circular waveguide;

FIG. 3 is the electric field pattern of the TM_{11} mode in a circular waveguide in a plane perpendicular to the axis of the circular waveguide;

FIG. 4 is a three-dimensional radiation pattern, partially cut away, for the TE_{11} mode emanating from the horn antenna of FIG. 1; and

FIG. 5 is a three-dimensional radiation pattern, partially cut away, for the TM_{11} mode emanating from the horn antenna of FIG. 1.

Referring now to the drawings, there is shown in FIG. 1 a microwave antenna system which is used to transmit a radiation pattern employing an embodiment of the novel apparatus in accordance with this invention.

The antenna system contains a source 12 of dominant TE_{11} mode electromagnetic wave energy connected to an input end of a circular waveguide 14 having an inner diameter D_1. The other end of the waveguide 14 is connected to one end of a cylindrical transition section of waveguide 16. The section 16 has an axial length L_T and an inner diameter D_2. The section contains an end plate 18 having an aperture into which one end of waveguide 14 fits and completes an abrupt transition between the waveguide 14 and section 16. The other end of the section 16 is connected to a horn antenna 24 having a length L_H. The end of the antenna connected to the section has the same inner diameter D_2 as the section. The horn antenna is flared outwardly at an angle α towards its output end until it reaches an inner diameter D_3.

The source 12 which may be any conventional microwave generator feeds signals in the dominant TE_{11} mode into the circular waveguide 14. The electric field pattern of the TE_{11} mode in a circular waveguide is shown in FIG. 2. When the electromagnetic wave energy in the waveguide 14 reaches the end plate 18 and enters the section 16, the abrupt transition in diameter between the waveguide 14 and section 16 causes a portion of the TE_{11} mode energy to be converted into higher order TM_{11} mode energy. The electric field pattern of the TM_{11} mode in a circular waveguide is shown in FIG. 3.

Energy in the TE_{11} and TM_{11} modes are in phase in the transition section 16 at its junction with the waveguide 14. The relative phases of the TE_{11} and TM_{11} modes will vary as energy in the modes begins to travel in the transition section towards the horn antenna because each of the modes has different phase velocities in both the antenna and section. Normally the relative phases of both modes are adjusted to be in phase at the radiating end of the horn antenna 24.

The phase velocities of the TE_{11} and TM_{11} modes are a function of the diameter of the transition section 16 and the horn antenna 18. The diameter of the transition section 16 is chosen as close as possible to cut off for the TM_{11} mode because at near cut off the phase velocity of the mode varies the greatest amount with changes in diameter. Thus, by minutely changing the diameter of the transition section, the phase velocity of the TM_{11} mode may be varied over a wide range. Once the phase velocity of the TE_{11} and TM_{11} modes in the section 16 and antenna 24 have been fixed, that is, the diameter of the transition section and the size of the horn antenna connected thereto have been chosen, by merely varying the length of the transition section 16, the relative phase of each of the modes may be easily adjusted so that they radiate at the end of the horn in phase.

The amount of TE_{11} mode energy which will be converted into higher order TM_{11} mode energy is dependent upon the relative difference in diameters between the waveguide 14 (D_1) and the transition section 16 (D_2). The greater the difference between these two diameters the greater the amount of TE_{11} mode energy which will be converted into TM_{11} mode energy. As a practical matter, since it is desirable to make the diameter of the transition section as close to cut off for the TM_{11} mode as possible, the amount of TM_{11} mode energy in the transition section is increased by decreasing the diameter of the waveguide 14.

Referring now to FIGS. 4 and 5, there are depicted three dimensional representations of the radiation patterns for the TE_{11} and TM_{11} modes, respectively, which are emanating from the horn antenna 24. In FIG. 4 the main beam 28 of radiation emanating in the TE_{11} mode has its greatest amplitude in the direction in which the antenna is pointing. The first side lobe 32 of the TE_{11} mode is out of phase with the main beam 28 by 180° and is labeled with a negative sign to indicate this fact. The second side lobe 34 of the TE_{11} mode is 180° out of phase with the first side lobe 32, that is, in phase with the main beam 28. Further, adjacent side lobes 36, 38, of the TE_{11} mode are 180° out of phase with adjacent side lobes as can be seen in FIG. 4.

In FIG. 5, radiation emanating from the TM_{11} mode at the output end of the horn antenna 24 comprises a pair of main beams 42, 44, which are in phase with the main beam of radiation 28 of the TE_{11} mode and 180° out of phase with the first side lobe 32 of the TE_{11} mode. The first side lobe 46 of the TM_{11} mode is 180° out of phase with the main beams 42, 44, of the TM_{11} mode. Further, side lobes 48 and 52 of the TM_{11} mode are 180° out of phase with their adjacent side lobes.

When the electromagnetic wave energy from the TE_{11} mode is combined with the electromagnetic wave energy from the TM_{11} mode, that is, the radiation patterns of FIGS. 4 and 5 are added, the main beams 28, 42, and 44 add in phase while the side lobe 32 of the TE_{11} mode is out of phase with a portion of the main beams 42, 44 of the TM_{11} mode. Thus, the side lobe 32 of the TE_{11} mode tends to cancel a portion of the main beams 42, 44 of the TM_{11} mode. Such a cancellation of power of a portion of the main beams of the TM_{11} mode is desirable since the resultant main beam radiation pattern contains equal beamwidth in the E and H planes. Moreover, the side lobes 34, 36, and 38 will be 180° out of phase with their counterpart side lobes 46, 48, and 52 of the TM_{11} mode and will tend to cancel each other, thus reducing the strength of the side lobes in the resulting radiation pattern. While only the major side lobes of each mode have been depicted in FIGS. 4 and 5, other lobes are present in the radiation pattern, but these modes will also tend to cancel. It should be noted that the relative strength of the TE_{11} and TM_{11} modes which yields the most suppressed side lobes is also the ratio which yields equal beamwidths in the E and H planes.

As an example, it has been found that side lobes can be greatly suppressed and equal beamwidths obtained along the E and H planes for a frequency of 9600 megacycles for the following dimensions:

Diameter of waveguide 14 (D_1)	1.25 inches.
Diameter of the transition chamber 16 (D_2)	1.6 inches.
Length of transition chamber 16 (L_T)	0.25 inch.
Angular opening of the horn 24 (α)	6°
Diameter of the mouth of the horn antenna 24 (D_3)	5.4 inches.

Because the TM_{11} mode does not have any measurable amount of side lobes in the H plane, TE_{11} mode side lobes in this plane are not effectively cancelled. However, the TE_{11} mode side lobes in the H plane are usually very small and there is, therefore, no need to suppress them.

Further, although the invention has been described as producing equal beamwidths in both the E and H planes, as can be readily seen by adjusting the relative power of the TE_{11} and TM_{11} modes, the relative beamwidths in each of these planes can be easily adjusted to a predetermined value.

As is conventional, the terms "E plane" and "H plane" have been used in the specification to designate the planes parallel to the electric field vector, and at right angles to the electric field vector, respectively.

It should be understood that the foregoing disclosure relates only to preferred embodiments of the invention and that it is intended to cover all changes and modifications of the examples in the invention herein chosen for the purposes of the disclosure which do not constitute departures from the spirit and scope of the invention. What is claimed and desired to be secured by Letters Patent is:

1. Apparatus for radiating a beam of electromagnetic energy having a resultant radiation pattern whose magnitudes in both the E and H planes are substantially equal and having a low side lobe level comprising:
   - a source of electromagnetic wave enery at a predetermined frequency;
   - a circular feed waveguide of diameter D_1 and having an input end and an output end;
   - means for coupling said source of electromagnetic wave energy at said predetermined frequency in the TE_{11} mode into the input end of said feed waveguide;
   - a cylindrical transition section o fwaveguide of diameter D_2 having an input end and an output end, the input end of said transition section being abruptly connected to the output end of said feed waveguide by means of an end plate so that energy in the TE_{11} mode will be converted into TM_{11} mode energy in the transition section as the microwave energy enters the transition section from said feed waveguide, the diameter D_2 of said transition section having a cut off wavelength for modes higher than the TM_{11} mode at said predetermined frequency; and
   - a conical horn antenna having an input end and an output end, the input end of said horn antenna having the same diameter as the output end of said transition section and being connected thereto so that electromagnetic wave energy is transferred to said horn antenna and radiates into free space, the length and diameter of said transition section and the length and the flare angle of said horn antenna being so selected that energy radiating into free space in the TE_{11} and TM_{11} modes will radiate from the output end of the horn antenna with their main beams in phase.

2. Apparatus in accordance with claim 1 wherein the ratio of the diameters D_2/D_1 are selected so that a pre-

determined amount of energy in the TE_{11} mode is converted into TM_{11} mode energy.

3. Apparatus for radiating electromagnetic wave energy having a substantially equal beamwidth in the E and H planes and having a low sidelobe level comprising:
- a circular input waveguide having an input end and an output end;
- means for feeding a source of TE_{11} mode electromagnetic wave energy into the input end of said circular waveguide;
- a cylindrical transition section of waveguide having an input end and an output end and the same longitudinal axis as said input waveguide, but having a larger diameter than the input waveguide, the output end of said input waveguide being connected to the input end of said transition section by means of an end plate in a plane normal to said longitudinal axis, whereby, due to the abrupt transition between said input waveguide and said transition section, a portion of said TE_{11} mode energy will be converted into TM_{11} mode energy;
- and a conical horn antenna having an input end and an output end, said antenna input end having the same diameter as the transition section and being connected to the output end thereof, the length and diameter of said transition section and the length and the flare angle of said horn antenna being chosen so that energy in the TE_{11} and TM_{11} modes are substantially in phase at the output end of said antenna.

4. A microwave antenna system comprising in combination:
- a circular waveguide having an input end and an output end;
- means for feeding a source of electromagnetic wave energy in the TE_{11} mode into the input end of said circular waveguide;
- a cylindrical transition section of waveguide for converting a portion of said TE_{11} mode into energy in the TM_{11} mode, said section having a diameter larger than said input waveguide and having an input end and an output end, the input end of said transition section being connected to the output end of said waveguide so as to form an abrupt transition for electromagnetic wave energy travelling in said waveguide;
- a conical horn antenna having an input end of equal diameter as said transition section and connected thereto and having an output end having a diameter greater than said input end wherein electromagnetic wave energy is radiated into free space at said output end of said antenna;
- the length and the diameter of said transition section and the length and the flare angle of said horn antenna having parameters that allow the main beams of said TM_{11} and TE_{11} modes to be radiated into free space in phase.

5. Apparatus for radiating a beam of electromagnetic wave energy having a resultant radiation pattern whose magnitude in both the E plane and H plane are similar, comprising:
- a conical horn antenna having a substantially circular cross section and having an input end and an output end;
- a feed waveguide of circular diameter having an input and an output end;
- a source of electromagnetic wave energy at a predetermined frequency for introducing signals in the TE_{11} mode into the input end of said feed waveguide; and
- a cylindrical transition section of waveguide having an input end and an output end, the output end of said feed waveguide being connected to the input end of said transition section by an abrupt transition, the diameter of said transition section being large enough so that the TM_{11} mode can propagate therein at said predetermined frequency, and the output end of said transition chamber being connected to the input end of said horn antenna.

6. In combination:
- a circular waveguide having an input end and an output end;
- means for feeding electromagnetic wave energy in the TE_{11} mode into said input end of said circular waveguide;
- means connected to the output end of said waveguide for converting a portion of said TE_{11} mode energy in said circular waveguide to TM_{11} mode energy, said means comprising a transition section of waveguide having a diameter larger than said circular waveguide; and
- a conical horn antenna connected to the output end of said transition section, the length and the diameter of said transition section and the length and flare angle of said conical horn antenna being chosen so that the main beam emanating into free space from said horn antenna of both said TE_{11} and TM_{11} modes are in phase.

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