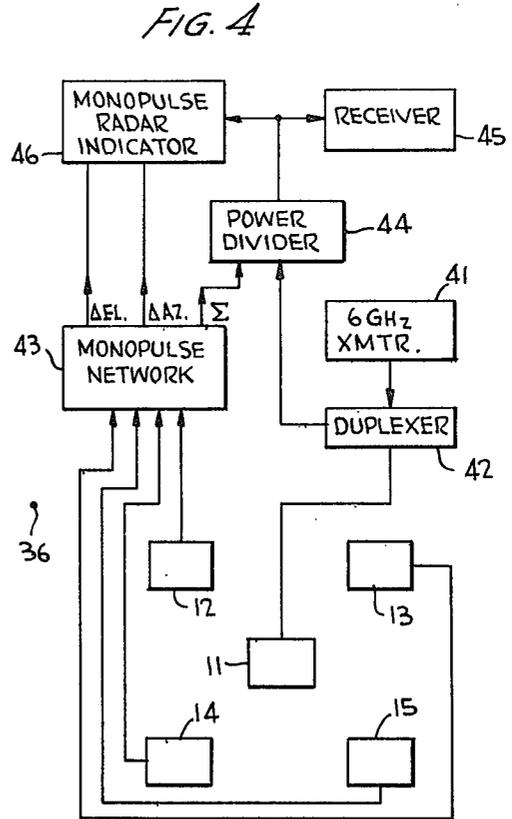
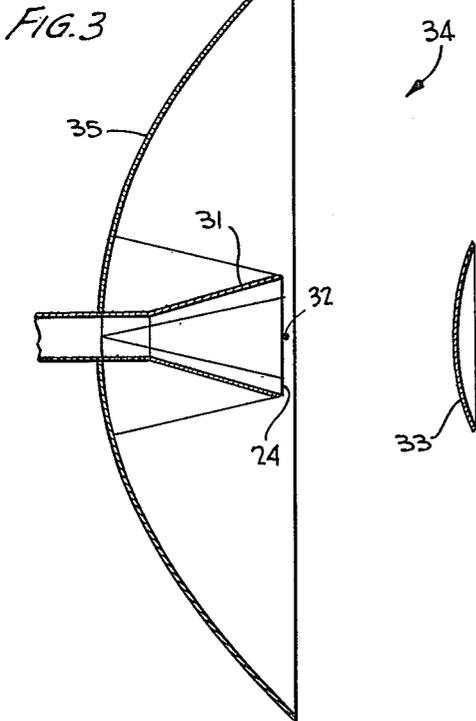
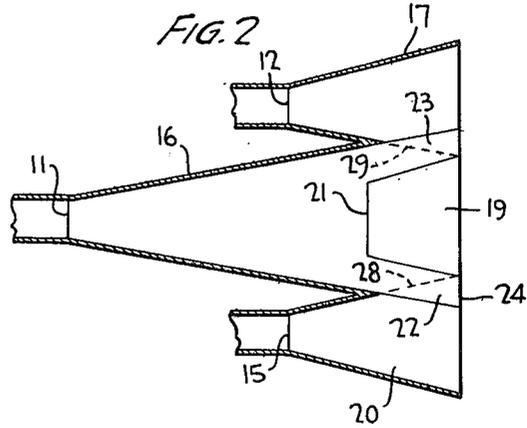
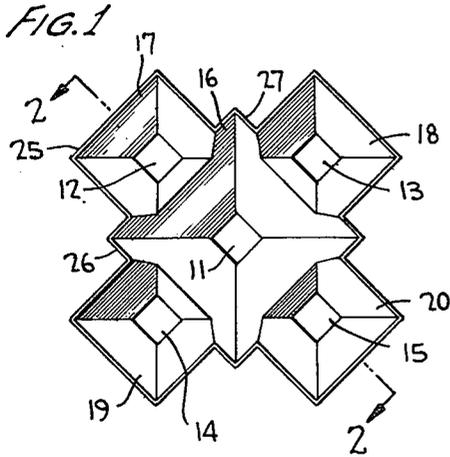


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HORN FEED HAVING OVERLAPPING APERTURES
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HORN FEED HAVING OVERLAPPING APERTURES

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8 Claims

ABSTRACT OF THE DISCLOSURE

A feed for exciting a Cassegrain reflector system includes a center horn and four peripheral horns, symmetrically located about the center horn. Walls of the peripheral and center horns intersect at a plane intermediate wave guide terminations exciting the horns and a common aperture plane of the feed, coincident with outer walls of the peripheral horns. The central horn is responsive to a transmitter generating a first frequency, while the entire array is responsive to a second frequency, transmitted from an external source and lower than the first frequency. The source position is determined utilizing monopulse techniques in response to the outputs of the peripheral horns.

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 U.S.C. 2457).

The present invention relates generally to antenna horn feeds and, more particularly, to a horn feed including a central horn and a plurality of peripheral horns having apertures overlapping with the central feed due to intersections between the walls of the feeds in a plane behind the feed aperture plane.

Five-horn feed arrays for exciting antenna reflector systems are developed and extensively utilized for monopulse tracking and other applications. Generally, five-horn feeds include a central feed and a plurality of peripheral feeds. For the monopulse tracking application, the central horn has generally been excited at a first frequency by a local transmitter, while both the central and peripheral feeds have been excited at a second frequency, lower than the first frequency, by radiation transmitted back to the antenna site from a transponder on an object being tracked which may be a space vehicle. Generally, the two frequencies at which the horn array is excited are relatively widely spaced, a typical example being a 3:2 frequency ratio in the microwave spectrum.

Typical prior art five-horn configurations with dual frequency excitation have seen limited use because of relatively low efficiencies in coupling energy to the reflector system at both frequencies. Typical prior art five-horn feeds produce diverse radiation beam characteristics at the two frequencies, precluding the derivation of equal radiation beam widths and amplitudes for the transmit and receive frequencies. Because the feed radiation patterns have different beam widths at the two frequencies efficient illumination of reflectors comprising the antenna reflector system cannot be derived for both excitation frequencies. If the reflector is illuminated throughout its area at the lower frequency, only a portion of the reflector is illuminated at the higher frequency. In contrast, if the higher frequency excitation illuminates the entire reflector, a portion of the low frequency excitation spills over past the reflector. Thereby, unequal beam widths at the two frequencies produce inefficient operation of the feed and reflector system. If a compromise between the two situations which produce the most efficient illumina-

tion at one of the extreme frequencies is employed there is inefficiency at both frequencies; the entire reflector area is not employed at one frequency and substantial spillover occurs at the other frequency. In addition to problems related to antenna efficiency a target tracking system operates most effectively if the transmit and receive patterns have substantially the same beam widths.

The prior art horn feed array configurations which have produced these deleterious results have taken three basic forms. In one of the feed arrays, each of the horns is of the square type and all have apertures of equal area. In a second square-horn configuration, the peripheral horns are smaller in aperture size than the center horn, while in still a third configuration, the central horn is of the square type, while the peripheral horns are of a pyramidal shape. In all three of these horn arrays, each horn has a separate and distinct aperture, resulting from intersections between walls of the peripheral horns with walls of the central horn at a plane coincident with the outer plane of the peripheral horns, the array aperture plane.

To provide radiation patterns having equal beam widths at two widely spaced frequency bands, it is necessary to provide a feed having an aperture with the same effective wave length at the two different bands. It is also desired to maintain the phase distribution across the aperture substantially constant for both frequencies. These two factors enable excitation of radiation patterns having substantially the same beam width for the diverse frequency bands. With the prior art feeds of the type specified, it has been found virtually impossible to equalize the feed aperture in terms of wave length and maintain constant phase at both frequencies. Hence, with the prior art techniques, it has generally been difficult to derive radiation patterns having substantially identical beam widths at diverse frequencies.

In accordance with the present invention, the ability to derive radiation patterns having substantially identical beam widths at relatively widely spaced frequencies is attained by providing a central square horn and a plurality of peripheral square horns, arranged so that the apertures of the peripheral and central horns overlap. Aperture overlap between the central and peripheral horns is attained by intersecting adjacent walls thereof at a plane intermediate an aperture plane of the array, defined by edges of the outer walls of the peripheral horns, and wave guide terminations exciting the horns. To enable the beam widths at the two frequencies to be substantially the same, the ratio of the aperture area of one of the peripheral horns to the aperture area of the central horn equals the square of the ratio of the frequency bands exciting the feed array, whereby

$$\frac{A_P}{A_C} = \left(\frac{F_{LO}}{F_{HI}} \right)^2$$

where:

A_P =aperture area in the aperture plane of one peripheral horn;

A_C =aperture area in the aperture area of the central horn;

F_{LO} =low frequency exciting the central and peripheral horns; and

F_{HI} =high frequency exciting only the peripheral horns.

A particular application of the feed of the present invention relates to monopulse tracking wherein in-phase responses from the central and peripheral feeds at the receive frequency are combined to derive a sum pattern, that has the same beam width as the central horn beam width at the transmit frequency. To equalize the gain of the central and peripheral horns for the sum pattern at the receive frequency, the receive frequency response

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of the central feed is combined with the sum of the responses from all four of the peripheral feeds with a 3:1 ratio.

It is, accordingly, an object of the present invention to provide a new and improved horn feed array.

Another object of the invention is to provide a new and improved horn feed array particularly adapted for deriving radiation patterns having substantially equal beam widths at diverse frequencies.

A further object of the invention is to provide a new and improved antenna feed array for illuminating a reflector efficiently to derive secondary radiation patterns having substantially equal beam widths at diverse frequencies.

An additional object of the invention is to provide a new and improved feed system particularly adapted for monopulse tracking.

Still a further object of the invention is to provide a horn feed array including a central horn and a plurality of peripheral horns arranged to excite a reflector system efficiently at a pair of relatively widely spaced frequency bands.

Yet an additional object of the invention is to provide a horn feed array including a central horn and a plurality of peripheral horns arranged to derive radiation excitation patterns having substantially the same beam widths at a pair of relatively widely spaced frequency bands.

Still another object of the present invention is to provide a feed having a central horn and a plurality of peripheral horns, wherein apertures between the central and peripheral horns overlap.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a front view of a horn array in accordance with a preferred embodiment of the present invention, particularly illustrating the aperture configuration;

FIGURE 2 is a side sectional view taken through the lines 2—2 of FIGURE 1;

FIGURE 3 is a schematic view of a Cassegrain antenna system of the type with which the feed of the present invention is particularly designed to function; and

FIGURE 4 is a circuit diagram of a preferred network with which the feed of the present invention is adapted to operate.

Reference is now made to FIGURES 1 and 2 of the drawings wherein central wave guide termination 11 and peripheral coplanar wave guide terminations 12-15 are illustrated in elevation view. Each of wave guide terminations 11-15 is square and has essentially the same area. Each of peripheral terminations 12-15 is symmetrically located about central termination 11, with one of the peripheral terminations being located in each of the four quadrants about the central termination. The E plane axes of terminations 11-15 are parallel to each other and each of the several terminations is positioned so that the diagonals between opposite corners of the wave guides are horizontally and vertically disposed. The center of each of peripheral terminations 12-15 is equidistant from the center of central termination 11 due to the symmetrical relationship between the peripheral and central terminations.

Extending from and excited by wave guide terminations 11-15 are respectively square horns 16-20 that comprise an antenna feed array. The apertures of peripheral horns 17-20 overlap with the aperture of central horn 16 in aperture plane 24, coincident with the outer edges of peripheral horns 17-20. The overlapping relationship between the apertures of central horn 16 and peripheral horns 17-20 is achieved by arranging the walls of the central and peripheral horns so that the central horn walls intersect the inner walls of the peripheral horns in plane 21 intermediate aperture plane 24 and the wave guide terminations. Where the inner walls of horns 17-20 in-

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intersect the walls of central horn 16, the walls of both horns terminate. Those portions of the walls of horn 16 which do not intersect the inner walls of horns 17-20 extend to aperture plane 24. The overlapping areas between the apertures of central horn 16 and peripheral horns 17 and 19 are illustrated in FIGURE 2 by the bases of triangles 22 and 23, one side of each of which is shown by dashed lines 28 and 29.

In operation, only central horn 16 is excited in response to energy transmitted from the array at a second frequency band, while all of horns 16-20 are excited in response to energy received by the array in a first frequency band. Typically, there is a relatively wide separation between the transmit and receive frequencies, exemplary values thereof being 6 GHz., and 4 GHz., respectively. To enable efficient operation of a reflector system excited by the feed array, the transmit frequency from central horn 16 is always higher than the receive frequency exciting each of the horns 16-20. To enable excitation of horn 16 at both frequency bands, the central horn has a relatively long length and small taper angle compared to the length and taper angle of peripheral horns 17-20, which are excited at only one frequency band.

In one particular embodiment of the invention actually constructed and adapted for transmission of 6 gigahertz energy from central horn 16 and reception of a 4 gigahertz energy by the entire horn array, the taper angles of the sides of peripheral horns 17-20 were 14° from the walls of the wave guide terminations, while the taper angle of the walls of central horn 16 was 9°. The length of horn 16 was approximately 20 inches, while the length of each of horns 17-20 was on the order of 7.5 inches. The length of one side of horn 16 in aperture plane 24, e.g. between edges 26 and 27 (FIG. 1), was 8.76 inches, while the length of one peripheral edge of each of peripheral horns 17-20, for example along edge 25, was 5.84 inches. It has been found that this particular configuration provides a beam width of approximately 23.8° for 6 GHz. excitation of central horn 16 and the same beam width for 4 GHz. in-phase excitation of each of the horns 16-20 comprising the array.

As is known, the beam width, BW, of a radiation pattern derived from a conventional horn feed is:

$$BW = K\lambda/L \quad (1)$$

where:

K=a constant dependent upon the feed configuration,
 λ =the feed excitation wavelength, and
 L=the length of the horn aperture in the plane containing the pattern beam width of interest.

For the values of frequency and horn dimensions specified supra, it would appear that the beam widths for the 4 and 6 gigahertz excitations would differ. It has been found, however, that the value of K in Equation 1 is different for the two excitation modes so that substantially the same beam width is derived at both frequencies. In one mode, energy excites aperture plane 24 between the outer edges of horn 16, while in the other mode energy excites plane 24 through the complex coupling between overlapping areas of horns 16-20. In particular, for the 6 GHz. excitation, only central horn 16 plays a predominant role in coupling energy from a wave guide termination to free space. In contrast, for the 4 GHz. excitation, each of the wave guides 11-14 couples energy into free space, with coupling being by way of a complex mechanism involving interaction between the peripheral horns 17-20 and central horn 16 in the volume between planes 21 and 24.

For the five horn configuration of FIGURES 1 and 2, it has been found that the relative couplings for the two modes are such that equal beam widths at transmit and receive frequencies F_1 and F_2 , respectively, are derived if the separation between axes coincident with the centers of terminations 11 and 12-15 equals the aperture length

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of one of peripheral horns 17-20 along a peripheral edge, such as edge 25, and the ratio of the aperture lengths of central horn 16 to one of the peripheral horns equals F_1/F_2 . Under such circumstances, the ratio of the aperture areas of horn 16 to any of horns 17-20 equals

$$\left(\frac{F_1}{F_2}\right)^2$$

These relationships are confirmed by the data specified for the exemplary horn described.

While the coefficient K in Equation 1 is different for the two excitation modes and frequencies, it has been found that the phase center for both excitation modes is approximately in aperture plane 24. The phase center at both frequencies is within one inch of aperture plane 24, for both E and H plane patterns. Because the phase centers are located approximately in aperture plane 24, it is possible to utilize the horn array of the present invention in combination with a high gain reflector system to derive high gain, narrow beam width radiation patterns suitable for tracking purposes.

To this end, feed 31 (FIGURE 3), of the type illustrated by FIGURES 1 and 2, is mounted so that the center of the array in aperture plane 24 is mounted at one foci 32 of hyperboloid subreflector 33 of Cassegrain reflector system 34 including paraboloid reflector 35. Array 31 is mounted so that aperture plane 24 is intermediate the apices of reflectors 33 and 35. In one particular embodiment of the invention, aperture plane 24 was located one-eighth of the distance between the apex of paraboloid reflector 35 and the other focus 36 of hyperboloid reflector 33. In this embodiment, the separation of the apex of reflector 33 from focus 36 was one-eighth of the distance between focus 36 and the apex of paraboloid 35.

Because the radiation pattern beam widths for the 4 gHz. and 6 gHz. excitations of feed 31 are equal, subreflector 33 and main reflector 35 are illuminated equally by them. The separation between subreflector 33 and aperture plane 24 of feed 31 is such that energy spillover past the subreflector from feed 31 is minimized to provide efficient energy interchange between the primary radiation feed source 31 and the Cassegrain reflector system at both the 4 and 6 gHz. excitations. It has been found that even greater efficiencies, without material modification of the radiation patterns, can be derived by providing a splash ring on hyperboloid subreflector 33.

The feed of the present invention is particularly adapted for use in conjunction with monopulse tracking systems. For such applications, 6 gHz. transmitter 41, FIGURE 4, is coupled through duplexer 42 to a wave guide ending in central wave guide termination 11, which feeds central horn 16. The 6 gHz. energy excites Cassegrain reflector system 34 and is received on a body being tracked, such as a spacecraft. The tracked body includes a transponder for converting the 6 gHz. signal into a coded 4 gHz. signal that is transmitted back to the Cassegrain reflector system 34, FIGURE 3. The 4 gHz. energy excites the horns 16-20 comprising array 31. The 4 gHz. energy is coupled by horns 16-20 to wave guide terminations 11-15. R.F. energy in wave guide terminations 12-15 is coupled to a monopulse error sensing network 43 which derives R.F. signals, Δ_{EL} and Δ_{AZ} , indicative of the tracked object angles relative to the antenna boresight axis in the elevation and azimuth planes, in a manner well known to those skilled in the art. In addition, monopulse network 43 includes circuitry for deriving a 4 gHz. signal, Σ , having an amplitude substantially equal to the sum of the energy exciting peripheral horns 17-20 and wave guide terminations 12-15.

Wave guide termination 11 responds to the 4 gHz. excitation from the tracked object transponder and couples it through duplexer 42 to power divider 44, also responsive to the output of network 43 equal to the sum of the R.F. energies coupled to wave guide terminations 12-15. Power divider 44 is operated in the inverse mode, whereby

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the energies coupled to the inputs thereof are added together to form an R.F. output. Power divider 44 is constructed so that 75% of its output results from the contribution of center horn 16, while the remaining 25% of its output is due to the combined contributions of peripheral horns 17-20. It has been found that the 3:1 ratio between the relative amplitudes of horn 16 to horns 17-20 equalizes the responses of the in-phase excitation of the peripheral horns 17-20 to the response of central horn 16. This is the expected result because the combined aperture area of peripheral horns 17-20 is greater than the aperture area of central horn 16.

The sum of the energies derived from peripheral horns 17-20 and central horn 16, derived at the output of power divider 44, is fed in parallel to a communications receiver 45 and a monopulse radar indicator 46, also responsive to the azimuth and elevation error indicating output signals of monopulse network 43. Indicator 46 and receiver 45 are tuned to slightly different frequencies in the 4 gHz. band, so that tracking and communication links can be established between the tracked vehicle and a receiver including the feed of the present invention.

While there has been described and illustrated one specific embodiment of the invention, it will be clear that variations in the details of the embodiment specifically illustrated and described may be made. For example, cylindrical wave guides and conical horns can be substituted for the square wave guides and horns shown. It is important, however, to maintain diagonal symmetry to the wave guide terminations and horns, as exists with elements having square and circular cross sections, to provide efficient reflector system illumination for the E and H planes.

What is claimed is:

1. An antenna feed system adapted to provide radiation patterns having similar characteristics for a pair of relatively widely spaced frequency bands comprising a central wave guide termination and a plurality of coplanar peripheral wave guide terminations, said peripheral terminations being equispaced from and symmetrically located about said central termination, a separate horn for each of said terminations, whereby there are provided peripheral horns and a central horn, said horns having coplanar apertures, each of said peripheral horns having outer wall means extending to the plane including said apertures and inner wall means intersecting wall means of the central horn in a plane intermediate the plane including said apertures and the plane of the peripheral terminations, said inner wall means and the wall means of the central horn terminating at the intersection points between them.

2. The feed system of claim 1 wherein each of said terminations and horns is diagonally symmetrical.

3. The feed system of claim 2 wherein the cross section of each of said terminations is substantially square.

4. The system of claim 2 wherein four peripheral terminations are provided.

5. The system of claim 4 wherein the ratio of the square of the frequencies of said bands substantially equals the ratio of the aperture area of one of the peripheral horns to the aperture area of the central horn.

6. The system of claim 5 wherein axes coincident with the centers of each of said peripheral terminations are spaced from the center of the central termination by an amount equal to the aperture length of one of the peripheral horns.

7. The system of claim 1 including a network for exciting only said central termination with transmitter energy at the upper frequency band and means for exciting at the lower frequency band the central and peripheral terminations with a sum radiation pattern and a pair of the peripheral terminations in the same plane on opposite sides of the central termination with a difference radiation pattern.

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8. The system of claim 7 wherein said exciting means includes power divider means for deriving the sum radiation pattern, said power divider exciting said central and peripheral terminations with a power ratio commensurate with the ratio of the sum of the aperture areas of the peripheral horns to the area of the central horn so that the amplitude of the sum pattern of the peripheral horns at the lower frequency equals the amplitude of the pattern of the central horn at the lower frequency.

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