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E. S. LEWIS ET AL

2,918,673

ANTENNA FEED SYSTEM

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Fig. 1.

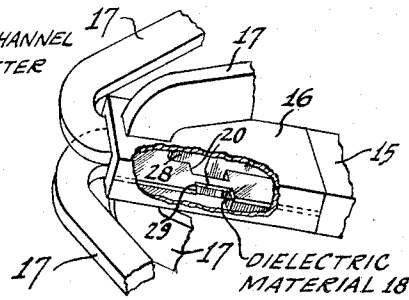
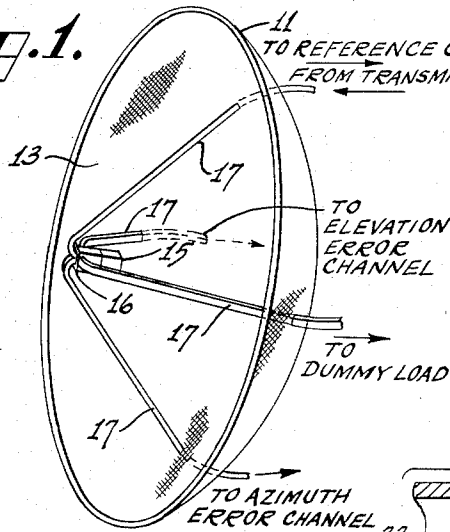


Fig. 2.

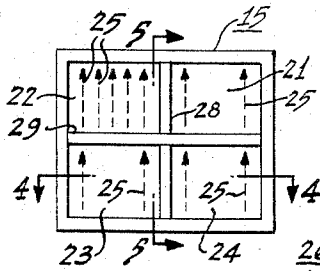


Fig. 3.

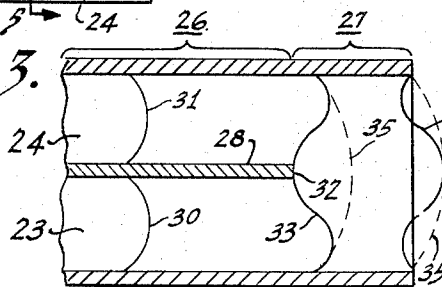


Fig. 4.

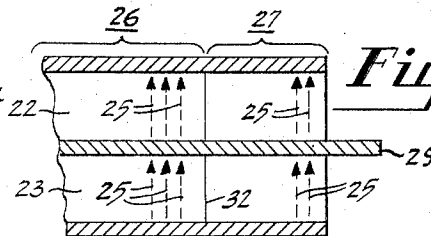


Fig. 5.

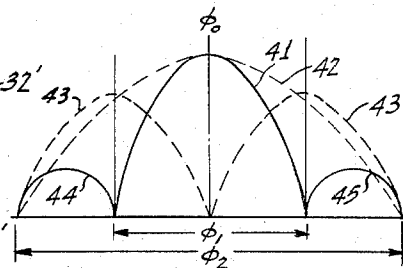


Fig. 6.

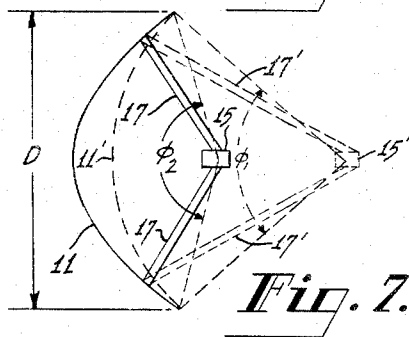


Fig. 7.

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ATTORNEYS

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2,918,673

ANTENNA FEED SYSTEM

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Application December 12, 1957, Serial No. 702,493

6 Claims. (Cl. 343—786)

This invention relates to directional antenna apparatus and more particularly to an improved horn feed for the transmission and reception of electromagnetic energy.

A common means for producing a pencil shaped beam of transmitted radio energy comprises a combination of a parabolic reflector and a plural horn feed. The same combination is frequently used to intercept or receive echoes from a target. When high gain, during transmission, and high sensitivity, during reception, are desired, a reflector having a relatively large diameter with respect to wavelength is required. For optimum performance the horn feed is located near the focal point of the paraboloid. The type of plural horn feed generally used has an emission pattern such that a relatively large ratio of focal length to diameter of the paraboloid is necessary to produce the desired gain and sensitivity. Thus, a large diameter reflector generally has its horn feed at a considerable distance from its reflecting surface. This introduces a structural problem in that such a horn feed must be rigidly supported to prevent the feed from becoming misaligned with respect to the reflector when the antenna is slewed. Beam distortion and faulty reception can result from such misalignment.

If, during reception, a horn feed is used that requires a paraboloid having a high ratio of focal length to diameter, the antenna error pattern will have undesirably high side lobes. In the past, this undesirable feature has been accepted in order to provide an antenna having optimum gain. Because of this fact, such antennas, generally speaking, will intercept target double echoes from low angle targets, one echo reflected from the target directly to the antenna, the other echo from the target being one which is re-reflected into the antenna from the ground. Since the re-reflected echo has to travel a greater distance than does the real echo, it will arrive at the antenna slightly out of phase with the real echo. As a result of this phenomenon a false error signal can be generated which is sufficiently out of phase with the proper error signal so as to cause oscillation of the tracking antenna as the target moves.

Accordingly, it is a general object of this invention to provide an improved horn feed which will produce a pencil beam substantially free from distortion.

It is another object of this invention to provide an improved plural horn feed having an emission pattern such that it can be disposed closer to the reflecting surface of a parabolic reflector than has heretofore been possible.

It is yet another object of this invention to provide an improved plural horn feed so designed that the structural problem of supporting the feed is minimized.

An additional object of this invention is to provide an improved plural horn feed so designed as to permit its use with a parabolic reflector having a focal length to diameter ratio substantially less than as heretofore been required.

It is still another object of this invention to provide a plural horn feed and parabolic antenna combination of

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an improved design wherein undesirable side lobes are minimized.

It is a further object of this invention to provide a plural horn feed and parabolic antenna combination of such improved design that antenna oscillation is minimized when tracking a moving target.

This invention accomplishes these objects by an improved plural horn feed comprising a waveguide cavity portion feeding into a modified box-type radiating horn portion. The plural horn feed is of generally rectangular cross section and includes a pair of normally disposed intersecting dividing walls extending coaxially therein and dividing the waveguide cavity portion into four substantially equal and parallel waveguide cavities. The dimensions of the waveguide cavities are substantially identical and capable of supporting the propagation of transverse electric fields of the same mode and orientation in each cavity. The one of the intersecting dividing walls which is perpendicular to the orientation of the transverse electric fields propagated in the waveguide cavities extends through the radiating horn portion of the plural horn feed. The other intersecting dividing wall, which is parallel to the orientation of the fields in the waveguide cavities is terminated at the junction where the waveguide cavity portion feeds into the radiating horn portion. Transmitting energy is fed into and received energy extracted from the waveguide cavities, by means of a waveguide coupling member to which are coupled a plurality of rectangular waveguide arms. The coupling between the waveguide arms and the coupling member and between this member and the plural horn feed is entirely conventional and is well known to those skilled in the art.

Radio energy is fed into the waveguide cavities from the coupling member in a manner such that a transverse electric field of the same mode and orientation is propagated in each of the waveguide cavities. When this energy is, in turn, fed into the radiating horn portion, transverse electric fields of different modes will be excited therein. For example, when a TE_{10} mode is propagated in phase in each of the waveguide cavity sections, a TE_{10} and a TE_{30} mode will be excited in the radiating horn portion. These modes will travel down the radiating horn portion at different speeds and, if a proper length of the radiating horn portion is selected, they can be made to reinforce one another at the center of the aperture of the radiating horn portion and will produce a cancelling effect near the edges of the aperture. This reinforcing effect of the modes excited in the radiating horn portion causes the radiation from it to appear as if it came from a single conventional horn with a width approximately half that of the plural horn feed of this invention. Thus, the radiation pattern from this plural horn feed will be considerably broader than would be the case if two or more conventional type horns were employed. The broader radiation pattern in turn, permits the plural horn feed to be used with a parabolic reflector having a considerably reduced focal length without any undesirable effect on antenna gain or sensitivity. Another result obtained with an antenna having a shortened focal length is a substantial reduction in the amplitude of side lobes and hence improved target tracking with minimum antenna oscillation. Finally the shortened focal length also simplifies the problem of properly supporting the feed at the focal point of the reflector.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

Fig. 1 is a schematic representation of a plural horn

feed illustrating its disposition relative to a parabolic reflector;

Fig. 2 is a fragmentary perspective view illustrating the coupling between the waveguide arms and the plural horn feed and having the exterior walls of the coupling member broken away to shown interior details;

Fig. 3 is an end view of a plural horn feed in accordance with this invention including a schematic representation of the transverse electric fields propagated in the feed;

Fig. 4 is a sectional view taken along a line substantially corresponding to line 4—4 in Fig. 3 and schematically illustrating the modes of the transverse electric fields propagated in the feed;

Fig. 5 is a sectional view taken along a line substantially corresponding to line 5—5 in Fig. 3 and including a schematic representation of the transverse electric fields propagated in the feed;

Fig. 6 graphically represents the emission pattern of the plural horn feed of this invention in comparison with the pattern of a feed of the prior art; and

Fig. 7 schematically presents a comparison between the plural horn feed of this invention (shown in solid outline) with a horn feed of the prior art (shown in dotted outline).

Similar reference characters are applied to similar elements throughout the drawings.

In Fig. 1 an antenna reflector 11 is shown having a parabolic reflecting surface 13 which is to be illuminated by the plural horn feed 15 of this invention. Supports 17 are provided for the plural horn feed 15. These may comprise waveguide arms which can also be used to feed energy through a waveguide coupling member 16 to the plural horn feed 15. If this is done, the supports 17 will be connected by other waveguides to the transmitting and receiving apparatus. Fig. 2 shows in greater detail the manner in which the waveguide arms 17 support and are coupled to the coupling member 16 and the plural horn feed 15. Two of the waveguide arms 17 are connected to one end of the coupling member 16 while the other two waveguide arms are connected one each to the wider sides of the coupling member 16. The coupling member 16 feeds into and is attached to the plural horn feed 15.

One method for feeding energy to a plural horn feed is described in the copending application of John R. Ford and Carl F. Crawford, Serial No. 250,726, filed October 10, 1951. Briefly, in the system as explained in the said Ford and Crawford application, energy is fed to a horn feed antenna array through a single waveguide. Adjacent to and connected to a second horn of the antenna array is a second waveguide that is coupled by a directional slot coupler to the first guide. To compensate for the 90° shift in phase occurring at the slot coupling, a 90° phase shifter is inserted in the second guide between the slot and the antenna feed. A means for obtaining the compensating phase shift comprises the insertion of dielectric material in one or both of the waveguides to provide the 90° phase shifter. When this is done the dielectric constant and transverse waveguide dimensions are selected to make the rate of change of phase shifts with respect to wave length (or frequency) equal at the operating frequency. Although the above description had reference to only two waveguides it is equally applicable with four waveguides as used herein.

Briefly, in accordance with the teaching of the above identified Ford and Crawford application, a horizontal dividing wall 29 divides the interior of the coupling member into upper and lower halves. A vertical dividing wall 28, beginning at a point beyond the coupling of the waveguide arms 17, further divides the interior of the coupling member into four waveguide cavities of substantially equal dimensions. Near the beginning end of the four waveguide cavities, coupling slots 20 connect the two upper waveguide cavities with the two lower waveguide cavities.

In order to compensate for the 90° phase shift introduced by the coupling slots 20, the two lower waveguide cavities are filled for a portion of their length with dielectric material 18. The coupling member 16 is connected to the plural horn feed 15 and the internal walls 28 and 29 are projected into the plural horn feed 15 as will be further described in connection with Figs. 3, 4 and 5. Alternatively, the coupling member 16 and the plural horn feed 15 can be constructed as a unitary structure.

In Fig. 3, looking into the radiating end of the plural horn feed 15, there are four rectangular waveguide cavities 21, 22, 23, and 24. Each waveguide cavity has dimensions capable of supporting propagation of a transverse electric field having a TE₁₀ mode. The dimensions of one cavity are substantially identical with those of each of the other cavities. The TE₁₀ modes propagated in the waveguide cavities are represented by the dotted arrows 25.

In Fig. 4 the bottom half of the plural horn feed 15 is illustrated as viewed from a line substantially corresponding to line 4—4 in Fig. 3 and it is depicted as comprising a waveguide cavity portion 26 and a radiating horn portion 27. The top half (Fig. 3) is identical to the bottom half both in structure and in function. Therefore, this description will be limited to the bottom half as shown in Fig. 4. Two of the waveguide cavities 23, 24 are shown feeding into the radiating horn portion 27. The vertical dividing wall 28 separates these two cavities but does not extend into the radiating horn portion 27.

The TE₁₀ mode propagated in the waveguide cavities 23 and 24 are schematically represented by the curve 30 in cavity 23 and the curve 31 in cavity 24 respectively. As the TE₁₀ modes 30, 31 travel in phase down the cavities 23, 24 they are supported by the dimensions of the cavities until they reach the termination 32 of the vertical dividing wall 28. At this point, since there is no wall to support propagation of the two TE₁₀ modes, they combine to produce new modes. By direct combination a TE₃₀ mode is excited in the radiating horn portion 27 because the internal width of the radiating horn portion 27 is approximately twice that of either waveguide cavity 23, 24; a new TE₁₀ mode will also be excited within the radiating horn portion 27. The TE₃₀ mode is illustrated by the curve 33 and the new TE₁₀ mode by the curve 35. Other higher odd harmonic modes will also be excited but their effect is so negligible that they may be ignored. Over 98% of the energy will exist in the TE₁₀ and TE₃₀ modes in the radiating horn portion 27.

At the beginning of the radiating horn portion 27 where the two modes TE₁₀ and TE₃₀ (curves 35 and 33 respectively) are excited, they are in phase opposition. The two modes will have different cut off wave lengths because of waveguide effect in the radiating horn portion 27. Because of this, they will travel toward the end of the radiating horn portion 27 at different velocities and their relative phases will change proportionately. By choosing a proper length for the radiating horn portion 27, the two modes can be brought into phase at the termination of the radiating horn portion 27 as illustrated by the curves 35' and 32'. The basic result obtained is to reinforce the energy radiated from the center of the radiating horn portion 27 and cancel toward the edges. This results in a radiating horn which appears electrically like one horn with perhaps one-half the width of the two waveguide cavities 23, 24. Because of this electrical effect, a radiation pattern is produced which is considerably broader than could be produced by two horns side-by-side each having the same dimensions as the waveguide cavities 23, 24.

In Fig. 5, one pair of the upper and lower waveguide cavities is illustrated as viewed from a line substantially corresponding to line 5—5 in Fig. 3. Again the plural horn feed 15 is illustrated as comprising the waveguide cavity portion 26 and the radiating horn portion 27, also the orientation of the TE₁₀ mode propagated in each waveguide cavity is again illustrated by the dotted arrows

25. The horizontal dividing wall 29 which separates the upper waveguide cavity 22 from the lower cavity 23 is extended into the radiating horn portion 27 of the feed. In order to prevent energy from the upper half of the radiating horn portion 27 from being fed back into the lower half and vice versa the horizontal dividing wall 29 is extended a short distance beyond the termination of the horn portion 27.

As a specific example of a plural horn feed constructed in accordance with this invention, reference is now made to one which was actually built and tested. A four horn feed was designed for C-band operation in the frequency range of from 5400 mc. to 5900 mc. A parabolic reflector 11 (Fig. 1) having a 12 foot diameter was specified. The feed had an overall length of approximately 18 inches and the radiating horn portion 27 a length of 3 1/4 inches. Each cavity in the waveguide cavity portion 26 of the feed was .622 inch high and 1.75 inches wide. The horizontal dividing wall 29 was extended approximately 1/2 inch beyond the termination of the radiating horn portion 27 of the feed. Construction of a four horn feed having the above dimensions made it possible to employ a parabolic reflector having a 50.4 inch focal length. In testing this feed, it was found to have a voltage standing wave ratio of less than 1.15, looking into the transmit terminal and produced a pencil beam having a half power width of less than 1.2 degrees.

In Fig. 6 the abscissa of the graph represents angles taken on either side of the axis ϕ_0 of the plural horn feed 15 (Fig. 1) and the ordinate distances represent intensity of radiation from a plural horn feed at the various angles. The solid curve 41 represents the radiation intensity pattern of a conventional plural horn feed. The dashed curve 42 represents the radiation intensity pattern for a plural horn feed constructed in accordance with this invention. The dashed curve 43 represents the intensity pattern of the portion of the energy intercepted by a parabolic reflector and focused into any plural horn feed to excite an error channel when the antenna system is accurately tracking an illuminated target. This curve is applicable to plural horn feeds of the prior art as well as to the plural horn feed of this invention.

Comparison of the radiation intensity pattern 41 of a conventional feed with the pattern 42 of the invented feed shows that the conventional feed, in order to minimize side lobes, must have its radiation restricted to an angle ϕ_1 which is much smaller than the permissible angle ϕ_2 that can be used with the invented feed. The smaller radiation angle ϕ_1 is necessary in order to prevent side lobes 44, 45 from being re-radiated by the reflector. In practice it has been found that with one type of conventional plural horn feed of the prior art the angle ϕ_1 is limited to approximately 68° while with the improved plural horn feed of this invention a larger radiation angle up to 140 degrees can be obtained.

During reception, a substantially larger portion of the energy intercepted by the reflector is focussed into the feed of this invention than is possible with the conventional feed. Because the radiation pattern of the conventional feed is restricted to the angle ϕ_1 , it has a greater spill-over loss than does the improved feed. This spill-over loss is illustrated in Fig. 6 as the area under the curve 43 which falls outside the angle ϕ_1 . Because of the improved reception made possible by the plural feed of this invention, accurate tracking of low flying targets is substantially improved and antenna oscillation during the tracking of moving targets is minimized.

In Fig. 7 the solid outline represents the configuration of a plural horn feed 15 and reflector 11 made possible by using the plural horn feed of this invention. The dotted outline represents the configuration of a plural horn feed 15' and reflector 11' of the prior art. The broader radiation angle made possible by the improved plural horn feed 15 of this invention is again represented by ϕ_2 and the smaller angle of the plural horn feed of

the prior art as ϕ_1 . In each instance we are considering that the diameter D of each reflector is the same and of a relatively large value to provide for high gain and sensitivity. Such a diameter might, for example, be 12 feet.

In order to properly re-radiate energy corresponding to the radiation angle ϕ_1 of the prior art plural horn feed, the feed must be located at or near the focal point of a paraboloid having a ratio of focal length to diameter (f/D) of about .75. By broadening radiation to an angle ϕ_2 , as is done with the plural horn feed of this invention, a paraboloid can be used which has an f/D ratio of .35. Because of this fact, it is now possible to support the feed 15 by support members 17 which are considerably shorter than the support members 17' required for the prior art plural horn feed 15'. More rigid support of the plural horn feed 15 is also provided since the support members 17 can project toward the paraboloid 11 at a far less acute angle than is necessary for the support members 17' of the prior art plural horn feed 15'. Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that with the scope of the appended claims the invention may be practiced otherwise than is specifically described.

25 What is claimed is:

1. In antenna apparatus for transmitting radio energy and including a reflector for said energy; a rectangular horn feed for said reflector comprising a waveguide cavity portion and a radiating horn portion, at least one dividing wall in said waveguide cavity portion disposed coaxially therein perpendicular to two opposite sides of said waveguide cavity portion whereby said waveguide cavity portion is divided into at least two separate waveguide cavities of substantially identical dimensions, said dimensions of said waveguide cavities being disposed so as to support propagation of transverse electric fields having the same mode and orientation in each of said waveguide cavities whereby energy of said mode fed in phase into said radiating horn portion from said waveguide cavities will excite in said radiating horn portion transverse electric fields of at least two modes one of which comprises an odd harmonic of the other, said radiating horn portion having an electrical length such that the portion of the energy of each mode near the axis of said rectangular horn feed will be radiated in phase from said radiating horn.

2. In antenna apparatus for transmitting electromagnetic energy and including a reflector for said energy, a rectangular horn feed for said reflector comprising a waveguide cavity portion and a radiating horn portion of substantially the same dimensions, a pair of normally disposed intersecting dividing walls extending coaxially within said rectangular horn feed dividing it into four substantially equal parallel waveguide cavities, one of said dividing walls extending the full length of both said waveguide cavity portion and said radiating horn portion, the other of said dividing walls extending the full length of said waveguide cavity portion only, each of said waveguide cavities having its dimensions disposed so as to support propagation of a transverse electric field having the same mode in each of said waveguide cavities and oriented within each said waveguide parallel to said one of said dividing walls whereby energy of said mode and orientation fed into said radiating horn portion from said waveguide cavity portion will excite in said radiating horn portion transverse electric fields of at least two modes, one of said two modes comprising an odd harmonic of the other, said radiating horn portion having an electrical length such that the portion of the energy of each of said two modes near said one of said dividing walls will be radiated in phase from said radiating horn portion.

3. In antenna apparatus for transmitting electromagnetic energy including a parabolic reflector, a rectangular horn feed disposed substantially at the focal point of said reflector; said plural horn feed comprising a wave-

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guide cavity portion and a radiating horn portion, at least one dividing wall in said waveguide cavity portion disposed coaxially therein perpendicular to two of the sides of said rectangular horn feed whereby said waveguide cavity portion is divided into at least two separate waveguide cavities of substantially identical dimensions, said dimensions being such that each waveguide cavity is capable of supporting a transverse electric field having a TE_{10} mode, said dimensions being disposed such that the TE_{10} mode in one of said waveguide cavities is oriented parallel with the TE_{10} mode in every other waveguide cavity, whereby when at least two TE_{10} modes are fed into said radiating horn portion from said waveguide cavities at least one new TE_{10} and one TE_{30} mode are excited in said radiating horn portion, said radiating horn portion having an electrical length such that said new TE_{10} mode and said TE_{30} mode will radiate from said radiating horn portion in phase along the axis of said rectangular horn feed.

4. In antenna apparatus for transmitting electromagnetic energy the combination of a parabolic reflector having a focal length to diameter ratio of substantially .35 and plural horn feed of rectangular cross section for said reflector disposed substantially at the focal point thereof, said plural horn feed comprising a waveguide cavity portion and a radiating horn portion, at least one dividing wall disposed coaxially within and perpendicular to two opposite sides of said waveguide cavity portion whereby said waveguide cavity portion is divided into at least two waveguide cavities of substantially identical dimensions, said dimensions having values and disposition such that each said waveguide cavity will support the propagation of a transverse electric field having a TE_{10} mode and that the TE_{10} mode propagated in one of said waveguide cavities has the same orientation as the TE_{10} mode in each other waveguide cavity, whereby energy of said TE_{10} mode fed in phase into said radiating horn portion from each of said waveguide cavities will excite in said radiating horn portion at least two transverse electric fields one of said fields having a TE_{10} mode and another having a TE_{30} mode, and said radiating horn portion having an electrical length such that said TE_{10} and TE_{30} modes are radiated in phase from said plural horn feed along the axis thereof.

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5. In antenna apparatus for transmitting electromagnetic energy the combination of a parabolic reflector having a focal length to diameter ratio of substantially .35 and a rectangular horn feed for said reflector disposed substantially at the focal point thereof, said feed comprising a waveguide cavity portion and a radiating horn portion of substantially identical dimensions, a pair of normally disposed intersecting dividing walls extending coaxially within said rectangular horn feed dividing it into four parallel waveguide cavities of substantially equal cross section, one of said dividing walls extending the full length of said waveguide cavity portion only, the other of said dividing walls extending the full length of both said waveguide cavity portion and said radiating horn portion, each of said waveguide cavities having dimensions capable of supporting propagation of a transverse electric field having a TE_{10} mode, said dimensions being disposed such that each said TE_{10} mode is oriented parallel to said one dividing wall, whereby feeding energy of said TE_{10} mode in phase from each of said waveguide cavities into said radiating horn portion will result in the excitation of at least two transverse electric fields in said radiating horn portion, one of said fields having a new TE_{10} mode and another of said fields having a TE_{30} mode, said radiating horn portion having an electrical length such that said new TE_{10} mode and said TE_{30} mode are radiated in phase from said rectangular horn feed along the axis thereof.

6. In antenna apparatus for transmitting electromagnetic energy and including a reflector for said energy, a plural horn feed for radiating energy onto said reflector comprising a plurality of means for supporting the propagation of transverse electric fields of one mode polarized in a single direction, means for combining said fields to produce a transverse electric field of said one mode and at least one other transverse electric field of an odd harmonic of said one mode and means for directing said fields onto said reflector from a point where the centers of said one mode and said odd harmonic are substantially in phase.

No references cited.