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ANTENNA

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This invention relates to radio transmission and more particularly to directive antennas.

The principal object of the invention is to improve the radiation pattern of a directive microwave antenna of the type comprising an array of horns. Other objects are to simplify the construction and reduce the cost of such antennas.

One type of directive antenna for radiating into space or intercepting microwaves comprises a linear array of tapered electromagnetic horns connected to a hollow-pipe wave guide with a longitudinal spacing approximately equal to an integral number of wavelengths within the guide at the operating frequency. The minimum spacing of the horns is thus one wavelength within the guide. However, since a wavelength is shorter in free space than in the guide, the spacing of the horns at their mouths will be greater than a wavelength in free space.

In an array of the type described, undesired secondary radiation lobes appear on each side of the main lobe. I have found, however, that these undesired lobes may be greatly reduced or substantially eliminated by decreasing the spacing of the horns at their mouths, preferably to less than a wavelength in free space. But it is apparent that the horns cannot be spaced closer, because they would no longer be fed with in-phase energy.

In accordance with the present invention this difficulty is overcome by subdividing each horn into a plurality of similar horns by means of one or more partitions in its magnetic plane. If only one partition is used, it is centrally positioned in the horn and extends inwardly from the plane of the horn mouth. In the preferred embodiment the partition at first gradually increases in thickness from its outer end, at such a rate as to divide the original horn into two horns whose longitudinal axes are parallel, and then gradually decreases in thickness to a line in the magnetic plane, to minimize reflections. In order to provide a distribution of energy among the original horns which will give the greatest directivity, the feed guide is preferably tapered in the electric plane. This desired energy distribution may be maintained between the two horns formed by each partition by locating the inner end of the partition somewhat to one side of the center line of the original horn. To provide the best over-all impedance characteristic for the divided horn, the flaring portion and the tapering portion of the partition each preferably have an axial length approximately equal to an integral number of half wavelengths in free space at the operating frequency.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawings, of which

Fig. 1 is a perspective view of a portion of an antenna array embodying the invention; and

Fig. 2 is a sectional side elevation of the antenna structure shown in Fig. 1.

The figures show an end portion only of an antenna array, constituting one embodiment of the invention, comprising a hollow-pipe wave guide 3 to which are connected

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a plurality of tapered electromagnetic horns 4, 5, and 6 arranged in line, with their mouths in the same plane 8. The horns may be made of any suitable conducting material. The complete antenna array may, for example, be a balanced structure of the general type shown in Fig. 13 of United States Patent No. 2,405,242, granted to G. C. Southworth on August 6, 1946.

As indicated by the double-pointed arrow 9, the electromagnetic waves of the operating frequency f are either supplied to or withdrawn from the guide 3 at the left end. In the description which follows it will be assumed that the antenna is operating as a radiator. The guide 3 is rectangular in cross section and the electric field of the energy therein is perpendicular to its wider sides, as indicated by the arrow E1 in Fig. 2. In the horns 4, 5, and 6 the electric field has the direction indicated by the arrow E2. In order to improve the directivity of the array, the guide 3 is preferably tapered in the electric plane so that the horns receive less and less energy as their distance from the source increases. Therefore, as shown, the E-plane dimension is shorter at the right end than at the left end of the guide 3.

The horns 4, 5, and 6 are connected to the guide 3 through the apertures 10, 11, and 12, respectively, which extend transversely across one of the wider sides thereof and have a uniform longitudinal spacing A approximately equal to an integral number of wavelengths λ_g within the guide 3 at the frequency f . Each of the horns 4, 5, and 6 is provided at its throat with a scoop 14 which extends across the guide 3 in the magnetic plane thereof and serves to divert the proper amount of energy into the associated horn. It is to be noted that, with this tapered construction of the guide 3, the scoops 14 are all identical, thus simplifying the construction. The scoops 14 are held in place by means of the pins 15 which pass through holes in the narrower sides of the guide 3 and fit into holes 16 in the scoop.

The horns 4, 5, and 6 are secured to the guide 3 by means of the bars 17 which extend transversely across the top of the guide and are fastened thereto by the screws 19. The horn is secured at its throat to the side of the bar 17 as, for example, by soldering, pinning or otherwise. Adjacent horns are separated at their mouths by the spacers 20 and the assembly is held together by means of two rods 21 which pass through holes near the ends of the spacers 20 and are secured by the pins 22. The horn array may be fastened to an appropriate supporting structure, not shown, by means of brackets such as 24 attached to the end spacer 20 by a screw 25.

A horizontal horn array of the type thus far described may be designed to radiate a horizontally polarized beam which is quite sharply directive. As a typical example, a balanced array of 18 horns has been built in which the major lobe is 2.75 degrees wide in azimuth angle, at 3 decibels below the peak intensity, when the operating frequency f is 8815 megacycles per second. There were also present, however, two undesired minor lobes, each $3\frac{1}{2}$ degrees in width, located at 41 degrees on either side of the axis of the array. Investigation showed that this extraneous wide-angle radiation was caused largely by the fact that the spacing B of the horns at their mouths was too great. The spacing B, although equal to λ_g , is equal to approximately 1.5λ , where λ is a wavelength in free space. It was found that the undesired wide-angle lobes could be substantially eliminated if the spacing B could be decreased to λ or less. However, the horns 4, 5, and 6 cannot be spaced closer because the spacing A of the apertures 10, 11, and 12 already has its minimum permissible value of λ_g . If A and B are further reduced, the horns will not be fed with in-phase energy from the guide 3.

In accordance with the present invention this difficulty

is overcome by inserting into each horn a partition 26 in the magnetic plane, thus in effect doubling the number of horns in the array and thereby reducing their spacing to $B/2$, which is only 0.75λ . These partitions may be made of metal, or of other suitable material covered or coated with metal or metal foil, preferably of good conductivity, and soldered or otherwise secured in place. For best results the partitions must be of special shape, determined largely by the shape of the original horn. It is necessary that the two horns, such as 5' and 5'' into which the horn 5 is divided, shall have their longitudinal axes parallel to each other as well as to the longitudinal axis of the original horn. To accomplish this, the partition 26 is centrally positioned in the horn 5 and extends inwardly from the plane 8 for a distance C throughout which it gradually increases in thickness at such a rate as to divide the horn 5 into two identical horns 5' and 5'' whose longitudinal axes are parallel. Stated another way, the surfaces of the partition 26 are gradually flared inwardly at the same (but oppositely inclined) angle as that of the corresponding wall of the original horn 5. Similar partitions 26 are also inserted in the same manner into the horn 4 to form the horns 4', 4'', and into the horn 6. In order that all of the identical horns thus formed shall have a uniform spacing $B/2$ between their longitudinal axes, the width D of the partition 26 at the top is made equal to the width G of the spacer 20. To minimize reflections, the partition 26 is tapered throughout its lower portion H substantially to a line, or knife edge, 30 in the magnetic plane. In order to improve the overall impedance characteristic of the horn assembly, the axial length of each of the portions C and H of the partition 26 is made approximately equal to an integral number of half wavelengths in free space at the frequency f. In order to preserve the desired amplitude taper at the throat of the horns, such as 4', 4'', the inner end 30 of the partition 26 may be displaced somewhat from the center of the original horn 4, in the direction away from the source of energy. Thus, in the horn 4 the distance J from the end 30 to the left wall is greater than the distance K to the right wall.

When the partitions 26 were added to the 18-horn array mentioned above, the two unwanted wide-angle radiation lobes were substantially eliminated without materially affecting the major central lobe.

As a further extension of the invention, each of the original horns may be divided into four or more substantially identical horns. As shown in Fig. 2, the horn 6 may first be divided into two identical horns by the partition 26. Then, a partition 31, similar to the partitions 26, may be centrally positioned in the magnetic plane of each of these two horns to form four substantially identical horns 33, 34, 35, and 36 having parallel axes. In like manner the horns 4', 4'', 5', and 5'' may be subdivided by additional partitions 31, not shown. With this baffle arrangement the spacing A between the apertures 10, 11, 12 can be made equal to $2\lambda_g$ and still the spacing L of the horns 33, 34, 35, 36 will be only 0.75λ , which is sufficiently close in many cases.

What is claimed is:

1. A radio antenna comprising a hollow-pipe wave guide having in one side thereof a plurality of apertures with a longitudinal spacing approximately equal to an integral number of wave-lengths within said guide at the operating frequency, a corresponding number of tapered electromagnetic horns of rectangular cross section connected at their throats to said guide respectively at said apertures, each of said horns including a longitudinal partition extending into said horn, the outer end of said partition lying in the plane of the mouth of said horn and dividing said horn into two equal rectangles and said partition at first increasing in thickness from the outer end thereof at such a rate as to divide the original horn into two substantially identical rectangular horns whose longitudinal axes are substantially parallel and then gradually decreasing in thickness substantially to a line.

2. An antenna in accordance with claim 1 in which the thickness of said partition at its outer end is substantially equal to the distance at the mouth between the inner surface of the wall of one of said original horns and the inner surface of the wall of an adjacent original horn.

3. An antenna in accordance with claim 2 in which said partition increases in thickness from the outer end thereof for an axial distance equal to an integral number of half wavelengths in free space at said operating frequency.

4. An antenna in accordance with claim 3 in which said partition decreases in thickness from its widest point for an axial distance equal to an integral number of half wavelengths in free space at said operating frequency.

5. An antenna in accordance with claim 4 in which the inner end of said partition is nearer to one wall of the original horn than to the opposite wall thereof.

6. An antenna in accordance with claim 1 in which said partition increases in thickness from the outer end thereof for an axial distance equal to an integral number of half wavelengths in free space at said operating frequency.

7. An antenna in accordance with claim 6 in which said partition decreases in thickness from its widest point for an axial distance equal to an integral number of half wavelengths in free space at said operating frequency.

8. An antenna in accordance with claim 1 in which said partition decreases in thickness from its widest point for an axial distance equal to an integral number of half wavelengths in free space at said operating frequency.

9. An antenna in accordance with claim 1 in which all of said identical horns have substantially uniform spacing between their longitudinal axes.

10. An antenna in accordance with claim 1 in which said guide is rectangular in cross section with unequal cross-sectional dimensions, and said apertures are in one of the wider sides of said guide.

11. An antenna in accordance with claim 1 in which said horns are of the same length.

12. An antenna in accordance with claim 1 in which the mouths of said horns are adjacently arrayed in line in the same plane.

13. A radio antenna comprising a rectangular hollow-pipe wave guide with unequal cross-sectional dimensions having in a wider side thereof a plurality of apertures with a longitudinal spacing approximately equal to an integral number of wavelengths within said guide at the operating frequency, a corresponding number of tapered rectangular electromagnetic horns each having a rectangular throat with unequal cross-sectional dimensions and a rectangular mouth, each of said horns being connected at its throat to said guide at one of said apertures with the larger cross-sectional dimension of said throat parallel to the larger cross-sectional dimension of said guide, each of said horns including a longitudinal partition with major faces parallel to the larger cross-sectional dimension of the throat of the horn, the outer end of said partition dividing the mouth of the horn into two equal rectangles, said partition at first increasing in thickness for an axial distance C from the outer end thereof at such a rate as to divide the original horn into two substantially identical horns whose longitudinal axes are substantially parallel and then gradually decreasing in thickness for an axial distance H.

14. An antenna in accordance with claim 13 in which said original horns are of equal length.

15. An antenna in accordance with claim 13 in which the inner end of said partition is substantially a line.

16. An antenna in accordance with claim 13 in which said distance C is equal to an integral number of half wavelengths in free space at said operating frequency.

17. An antenna in accordance with claim 13 in which said distance H is equal to an integral number of half wavelengths in free space at said operating frequency.

18. An antenna in accordance with claim 13 in which

the thickness of said partition at its outer end is equal to the distance at the mouth between the inner surface of the wall of one of said original horns and the inner surface of the wall of an adjacent original horn.

19. A radio antenna comprising a plurality of similar tapered rectangular electromagnetic horns having rectangular mouths adjacently arrayed in line in the same plane and having a common longitudinal center plane, means for feeding into each of said horns electromagnetic waves of the same phase to establish therein electric fields in a direction parallel to said common center plane, each of said horns including a longitudinal partition with major faces perpendicular to said common center plane, the outer end of said partition dividing the mouth of the horn into two equal rectangles, and said partition at first increasing in thickness from the outer end thereof at such a rate as to divide the original horn into two substantially identical horns whose longitudinal axes are substantially parallel and then gradually decreasing in thickness.

20. A tapered electromagnetic horn of rectangular cross section having unequal cross-sectional dimensions at the throat and a longitudinal partition within said horn, said partition having its major faces parallel with the larger cross-sectional dimension of said throat, the outer end of said partition dividing the mouth of said horn into two equal rectangles, said partition at first increasing in thickness from the outer end thereof at such a rate as to divide said horn into two substantially identical horns whose longitudinal axes are substantially parallel and then gradually decreasing in thickness, and the inner end of said partition being nearer to one wall of the original horn than to the opposite wall thereof.

21. A horn in accordance with claim 20 in which said partition decreases in thickness substantially to a line.

22. A tapered electromagnetic horn of rectangular cross section and a longitudinal partition within said horn, the outer end of said partition dividing the mouth of said horn into two equal rectangles, said partition increasing in thickness from the outer end thereof at such a rate as to divide said horn into two substantially identical horns whose longitudinal axes are substantially parallel and then gradually decreasing in thickness, and the inner end of said partition being nearer to one wall of the original horn than to the opposite wall thereof.

23. A radio antenna comprising a hollow-pipe wave guide having in one side thereof a plurality of apertures with a longitudinal spacing approximately equal to an integral number of wavelengths within said guide at the operating frequency, a corresponding number of tapered electromagnetic horns of rectangular cross section connected at their throats to said guide respectively at said apertures, each of said horns including a longitudinal partition extending into said horn, the outer end of said partition lying in the plane of the mouth of said horn and dividing said mouth into two equal rectangles, said partition at first increasing in thickness from the outer end thereof at such a rate as to divide the original horn into two substantially identical rectangular horns whose longitudinal axes are substantially parallel and then gradually decreasing in thickness substantially to a line, the thickness of said partition at its outer end being substantially equal to the distance at the mouth between the

inner surface of the wall of one of said original horns and the inner surface of the wall of an adjacent original horn, and the inner end of said partition being nearer to one wall of the original horn than to the opposite wall thereof.

24. A radio antenna comprising a hollow-pipe wave guide having in one side thereof a plurality of apertures with a longitudinal spacing approximately equal to an integral number of wavelengths within said guide at the operating frequency, a corresponding number of tapered electromagnetic horns of rectangular cross section connected at their throats to said guide respectively at said apertures, each of said horns including a longitudinal partition extending into said horn, the outer end of said partition lying in the plane of the mouth of said horn and dividing said mouth into two equal rectangles, said partition at first increasing in thickness from the outer end thereof at such a rate as to divide the original horn into two substantially identical rectangular horns whose longitudinal axes are substantially parallel and then gradually decreasing in thickness substantially to a line, and the inner end of said partition being nearer to one wall of the original horn than to the opposite wall thereof.

25. A radio antenna comprising a hollow-pipe wave guide having in one side thereof a plurality of apertures with a longitudinal spacing approximately equal to an integral number of wavelengths within said guide at the operating frequency, a corresponding number of tapered electromagnetic horns of rectangular cross section connected at their throats to said guide respectively at said apertures, each of said horns including a longitudinal partition extending into said horn, the outer end of said partition lying in the plane of the mouth of said horn and dividing said mouth into two equal rectangles, said partition at first increasing in thickness from the outer end thereof at such a rate as to divide the original horn into two substantially identical rectangular horns whose longitudinal axes are substantially parallel and then gradually decreasing in thickness substantially to a line, and said guide being rectangular in cross section with unequal cross-sectional dimensions and tapering in the smaller cross-sectional dimension.

26. An antenna in accordance with claim 25 in which the inner end of said partition is nearer to one wall of the original horn than to the opposite wall thereof.

27. An antenna in accordance with claim 13 in which the inner end of said partition is nearer to one wall of the original horn than to the opposite wall thereof.

28. An antenna in accordance with claim 19 in which the inner end of said partition is nearer to one wall of the original horn than to the opposite wall thereof.

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