

Dec. 24, 1957

G. V. DALE ET AL

2,817,837

MICROWAVE HORN AND PARABOLOIDAL REFLECTOR ANTENNA SYSTEM

Filed June 16, 1953

3 Sheets-Sheet 1

FIG. 1

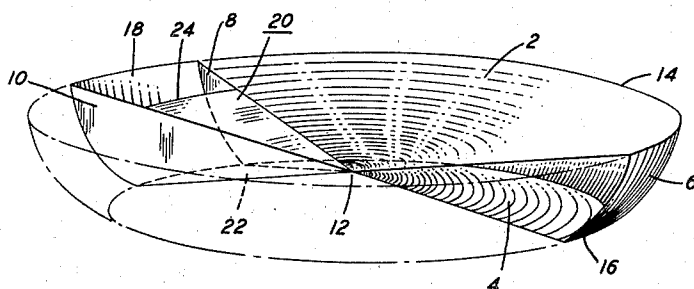
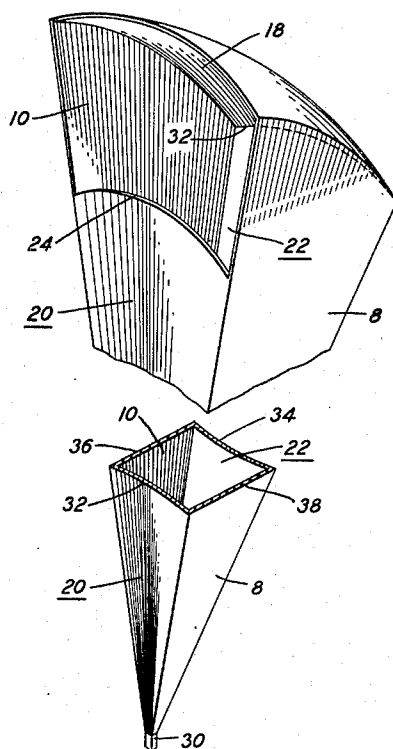


FIG. 2



INVENTORS: G.V. DALE
H.T. FRIIS

BY *H. O. Wright*
ATTORNEY

Dec. 24, 1957

G. V. DALE ET AL

2,817,837

MICROWAVE HORN AND PARABOLOIDAL REFLECTOR ANTENNA SYSTEM

Filed June 16, 1953

3 Sheets-Sheet 3

FIG. 4

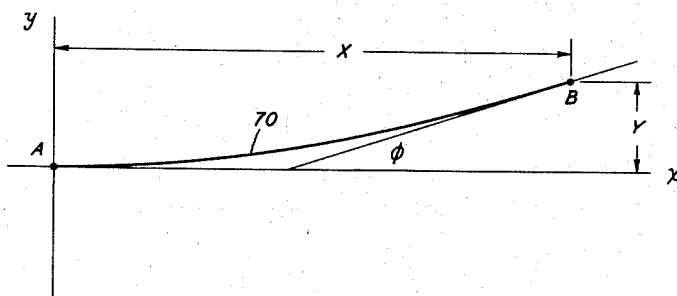
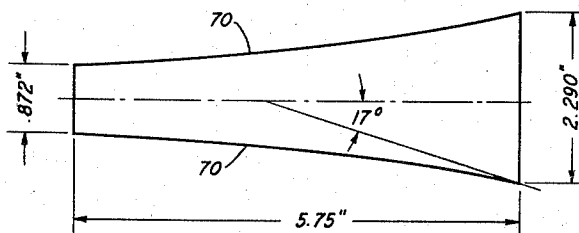


FIG. 5



INVENTORS: G. V. DALE
H. T. FRIIS

BY

H. O. Wright
ATTORNEY

1

2,817,837

MICROWAVE HORN AND PARABOLOIDAL REFLECTOR ANTENNA SYSTEM

George V. Dale, Oakhurst, and Harald T. Friis, Rumson, N. J., assignors to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application June 16, 1953, Serial No. 361,958

5 Claims. (Cl. 343—775)

This invention relates to a mechanically and electrically improved form of horn-reflector type antenna which will have substantially uniform and highly efficient electrical transmission characteristics at substantially any frequency and throughout substantially any range of operating ambient temperatures. For example, devices of the invention have proven very efficient for the transmission of audio frequency sound waves as well as for electromagnetic waves of all frequencies up to and including the very highest "microwave" frequencies which can, in the present state of the art, be generated by those most highly skilled in the ultra-high microwave frequency art. Indeed, when further advances toward higher frequencies of microwaves are achieved, the antennas of the invention, it is confidently believed, will be found very efficient for their transmission.

The most important use at present contemplated for the antennas of this invention is for the transmission and reception of broad bands of high and ultra-high frequency, microwave, electromagnetic waves. For this use the "sectoral biconical" horn and the paraboloidal reflector comprising an antenna of the invention are preferably fabricated from rigid material having highly conductive inner surfaces. Suitable materials, for example, are sheet copper or sheet aluminum or plywood coated with aluminum foil or painted with highly conductive paint. External ridges or braces can, of course, be added to the horn and reflector members to provide additional strength and rigidity, if desired. For use with acoustic or sound waves, antennas of the invention may be fabricated of any material the surfaces of which are efficient reflectors of sound wave energy, i. e., metallic materials having smooth surfaces, hard woods having smooth surfaces, ceramics, or the like.

The antennas of the invention are an improvement over the antennas disclosed and claimed in United States Patent 2,416,675, granted March 4, 1947, to A. C. Beck and applicant H. T. Friis, jointly. The antennas of the patent employ a horn flaring in two orthogonally related cross-sectional dimensions, the horn having four plane sides with paraboloidally shaped reflector at the mouth end of the horn to direct the energy emitted by the horn in a concentrated plane-wavefront beam at an angle (usually in the order of 90 degrees) with respect to the longitudinal axis of the horn member.

While the antennas disclosed in the patent are highly satisfactory in most respects, they are difficult to construct, principally because intersection or junction lines between the plane front and rear sides and the paraboloidal reflector are irregular curves and the upper end of the rear side, particularly, must be very carefully shaped, point by point, to insure a proper junction with the reflector. Some difficulties have also been encountered in situations where broad frequency band transmission has been desired or where large ambient temperature variations have been encountered. The reality of the difficulties mentioned will be more readily appreciated when the size of typical antenna assemblies of the invention is considered. By way of example in a typical antenna of the invention, the over-all length of the antenna is substantially 25 feet and the

2

paraboloidal reflector is substantially 10 feet long and 10 feet in width. Such large surfaces as are required for the four sides of the horn and for the paraboloidal reflector are, as a practical matter, therefore, more conveniently provided by dividing each large member of the structure longitudinally into a plurality of segments. A typical number of such segments for each of the sides and for the reflector of an antenna assembly of the invention of 25 feet over-all length is, by way of example, eight. The simplification of the shape of these large members is accordingly a most important consideration from the standpoints of manufacture, assembly, and maintenance of true conformance to the accurate surface contours required. The assemblies of the invention have been found to be substantially free from difficulty involving deformation or distortion of the paraboloidally shaped reflecting surface and, in general, maintain well the desired coincidence of the focal point of the paraboloidally shaped reflecting surface with the common apex point of the conically shaped front and rear sides of the horn.

The above-mentioned sources of difficulties are substantially eliminated in structures of the present invention by modifying the shape of the horn so that the latter becomes a section of a "biconical" radiator of a type based on principles disclosed and claimed in United States Patent 2,235,506, granted March 18, 1941, to S. A. Schelkunoff, assignor to applicants' assignee. As explained in detail in said patent, a "biconical" structure, comprising a pair of like oppositely-disposed cones having a common apex point, has the characteristics of a true transmission line of definite uniform impedance. The realization of a very broad frequency band, close impedance match at the smaller end, or throat aperture, of a horn structure of the present invention is, therefore, much more readily accomplished than with prior art structures of comparable size.

The preferred proportions of the horn are such that the cross-sectional area of the horn throughout its length is substantially square.

The modified horn structure of the present invention, having outwardly-concave, conically-shaped, "front" and "rear" surfaces, the common apex point of which is coincident with the focal point of the paraboloidally shaped reflector surface, has circular lines of intersection between the front and rear horn surfaces and the paraboloidal surface. The major portions of the structure are, therefore, readily cut to the exact appropriate shapes and can be fitted together mechanically with a high degree of accuracy. Furthermore, they tend to mutually support each other, thus substantially reducing any tendency toward distortion.

Where, as is normally the case, the horn and reflector are both fabricated from the same material, expansion or contraction resulting from changes in ambient temperature will not result in the development of excessive stresses particularly along the junction line between the rear surface of the horn and the reflector, of the over-all structures of the present invention. The surface of the reflector will, therefore, have substantially no tendency to become distorted.

All parts of the new structure can be manufactured and assembled without the necessity of individually shaping each of numerous parts and/or the use of specially shaped templates, since all junction lines are simple, smooth, readily constructed geometrical curves. Furthermore, the front and rear sides of the horn, obviously, can conveniently be fabricated of several identical sections, and where the angle between the longitudinal axis of the horn and the direction of propagation of the energy reflected by the paraboloidally shaped reflector is 90 degrees, the front and rear sides can both be made of sec-

3

tions of identical size. By virtue of the seemingly small modification in the horn shape, therefore, a structure which lends itself extremely well to "mass production, assembly-line" processes is attained. In view of the tremendous growth of microwave transmission facilities the above considerations are, obviously, of very substantial importance. The contribution of the invention to the art is, therefore, manifestly, of a very real and significant character.

The novel type of horn employed in the antennas of the invention can aptly be described as a "sectoral biconical horn" and will be referred to as such throughout the present application and in the appended claims.

A principal object of the invention is, therefore, to provide a mechanically and electrically improved horn-reflector type of antenna.

A further object is to provide a horn-reflector type antenna having improved impedance versus frequency characteristics over broad ranges of frequency.

A still further object is to provide a horn-reflector type antenna which is more readily manufactured and which will have substantially no tendency to become distorted by temperature changes.

Other and further objects of the invention will become apparent during the course of the following detailed description of illustrative structures embodying the principles of the invention, and from the appended claims.

The principles of the invention will be more readily understood from the following detailed description of particular illustrative embodiments of the invention and from the accompanying drawings, in which:

Fig. 1 illustrates the geometrical development of a combined sectoral biconical horn and a paraboloidally shaped reflector to form the horn-reflector type antenna of the invention;

Fig. 2 shows a perspective view of a specific design of antenna of the invention with a section intermediate the ends of the horn removed to show the cross-section of the horn;

Fig. 3 represents in diagrammatic form an extremely wide band, very high frequency, microwave repeater station employing two antennas of the invention;

Fig. 4 illustrates diagrammatically the development of an exponential taper design for a wide band wave-guide transformer section suitable for connecting a standard rectangular wave guide to the throat end of a horn-reflector antenna of the invention;

Fig. 5 is a side view of a wave-guide transformer employing the taper designed as illustrated in Fig. 4; and

Fig. 6 illustrates the development of a parabolic taper design for a wide band wave-guide transformer section suitable for connecting a standard rectangular wave guide to the throat end of a horn-reflector antenna of the invention.

In more detail in Fig. 1, two like, oppositely-disposed, conical members 2 and 4 having a common apex point 12 and equal apex angles are joined at their rims or outer edges 14 and 16 by a paraboloidally shaped bowl-like member 6, the focal point of which is coincident with the common apex point 12 of the two conical members 2 and 4. A sector of the over-all structure, comprising portions of cones 2, 4 and of paraboloidal section 6 is partitioned off by the radially-disposed, vertical, flat members 8 and 10, said members enclosing between them an angle (to be referred to throughout this application as "the lateral apex angle" of the conical sides 20, 22) shown in Fig. 1 as being substantially equal to the angle between the two cones 2, 4. (This latter angle will be referred to throughout this application as the "lateral apex angle" of the plane sides 8, 10).

A sectoral biconical horn suitable for use in the horn-reflector antenna of the invention is, in Fig. 1, then geometrically defined by a back, outwardly-concave, conically shaped side 22; a front, outwardly-concave, con-

4

ically shaped side 20 and two flat or plane, radially-disposed, vertical identical side members 8 and 10.

With the symmetrical arrangement illustrated in Fig. 1, the front side 20 of the horn will be identical to the back side 22 and the outer edge 24 of the front side 20, will fall short of the rim 14 of cone 2 to leave an appropriate mouth aperture for the over-all horn-reflector antenna formed by capping the sectoral biconical horn 8, 10, 20, 22 by the section 18 of the paraboloidally shaped member 6, included between the flat sides 8, 10 of the horn and removing a small portion of the structure near the common apex point 12 so that it has a throat end aperture of suitable size for connection through a wave-guide transformer to a standard wave guide (a detailed description of two specific suitable forms of wave-guide transformers for this purpose will be given hereinafter).

Energy introduced at the throat end of the horn will, obviously, be directed to impinge upon the reflector 18 by which it will be reflected to pass through the mouth aperture at an angle of 90 degrees with the longitudinal axis of the horn member. As explained in the above-mentioned patent to Beck and applicant Friis, the reflected energy emerging from the mouth aperture of the antenna will have a plane or flat wavefront and the horn-reflector antenna of the present invention will have a sharply directive or narrow radiation beam. By the maxim of reciprocity, its receiving characteristics will be similarly sharply directive.

In Fig. 2, a larger-scale, perspective view, omitting the geometrical matrices, of a sectoral biconical horn and paraboloidal reflector antenna of the invention is shown, with a portion intermediate its throat and mouth apertures removed to show clearly the cross-sectional form of the horn. Like portions of the structures of Figs. 1 and 2 are given like designation numbers. In a typical structure of the invention, by way of example, the overall length of the assembly will be substantially 25 feet and the paraboloidal reflector will be substantially 10 feet by 10 feet.

As described in connection with Fig. 1, the sectoral biconical horn comprises a back 22, a front 20 and two sides 8 and 10. The front and back sides 20, 22 can, in a symmetrical structure, be identical, outwardly-concave, conically shaped, members, having a common apex point. The apex point in Fig. 2 will be located on the longitudinal axis of the horn intermediate the ends of wave-guide transformer 30 at the throat end of the horn (the position of the apex point will become apparent during the course of the detailed description of two suitable forms for transformer 30, given hereinafter). The side members 8 and 10 of the sectoral biconical horn are plane or flat and serve, as shown, to join the corresponding edges of the front and back sides 20, 22. In the horn-reflector antenna of the invention, side members 8, 10 are preferably, but not necessarily, extended upwardly beyond the upper ends of the front and back sides 20, 22, to join the lateral edges, respectively, of the paraboloidally shaped reflector 18. The extended portions of side members 8, 10, just described, serve solely as shielding members preventing the leakage of transmitted energy, or the reception of energy from undesired directions, with the possible consequent impairment of the directive characteristics of the over-all antenna for either transmission or reception, respectively. The focal point of the paraboloidal reflector 18 is, as stated in connection with Fig. 1, coincident with the common apex point of the conically shaped front and back surfaces 20, 22.

A right cross-section of the horn member is represented by the edges 32, 34, 36, 38; edges 32, 34 showing the outwardly-concave shape of the front and rear conically shaped sides of the horn and edges 36, 38 showing the plane or flat character of the sides 8, 10. As shown, the choice of the lateral apex angles of the four sides of the particular antenna illustrated is preferably such

5

that the cross-sectional shape of the horn is substantially square throughout the length of the horn structure. The upper edges 24, 32 of the front and rear sides, respectively, are circular as is the lateral curvature of the paraboloidal reflector 18, edge 32 thus fitting snugly to reflector 18 and tending to maintain the reflector shape undistorted.

When all members of the horn-reflector structure are made of the same material such as sheet aluminum, for example, there will be substantially no tendency for stresses to develop along the junction line 32 between the back 22 of the horn and the reflector 18 with even the most extreme changes in temperature which are likely to be encountered in service. In view of the large size of the four sides of the horn and of the paraboloidal reflector, it is more practicable to make each of these parts of a number of segments, eight segments each having been found suitable for the typical 25 foot over-all length of structure of the invention mentioned above.

In Fig. 3, there is shown diagrammatically, by way of illustrating a preferred use of antennas of the invention, an extremely wide frequency band microwave repeater, comprising two sectoral biconical horns 50, 52 and associated paraboloidal reflectors 54, 56, the throat apertures of the horns being connected to the input and output, respectively, of a traveling wave tube amplifier 60. The latter can be, for example, of the type shown in Fig. 2.1 at page 7 of the book entitled "Traveling Wave Tubes" by J. R. Pierce published by D. Van Nostrand Co., Inc., New York City, 1950.

The two horns 50, 52 are placed back to back, and in order to be able to bring their throat apertures sufficiently close together to connect to the input and output, respectively, of the same traveling wave tube amplifier, their respective longitudinal axes 51, 53 are tilted slightly from the vertical, as illustrated. This, of course, necessitates increasing the angles of the paraboloidal reflectors 54, 56 by corresponding amounts with respect to horizontal so that an incoming horizontal wave 57 will be reflected along the longitudinal axis 51 of horn 50 to the input of traveling wave tube 60. After amplification in tube 60, the amplified wave proceeds in the direction of the longitudinal axis 53 of horn 52 and is reflected by reflector 56 in a horizontal direction toward a subsequent station of a radio relay transmission system. The antennas 50, 52 and the amplifier 60 can all be made to transmit a very broad band of microwave frequencies, a band width in the order of 1000 megacycles or more, for example, being entirely feasible in the present state of the art, particularly with improved wave-guide transformers, such as those described hereinunder in connection with Figs. 5 and 6, interconnecting the horn throat apertures and the input and output of the tube 60, respectively. Except for the increase in the angle of the paraboloidal reflector, the over-all horn-reflector antennas of Fig. 3 can be as described in detail for the antennas of Figs. 1 and 2, hereinabove.

In Figs. 4 and 5, the development of an exponentially tapered wave-guide transformer section is illustrated, which transformer section will provide a smooth broad band impedance match between the throat end of the horn of an antenna of the invention and a wave guide of rectangular cross-section having internal dimensions of .872 inch by 1.872 inches (nominally having outside dimensions of 1 inch by 2 inches).

In Fig. 4 the development of an exponential taper in accordance with the equation

$$y = Kx^n \quad (1)$$

for one of the sides 70 of the wave-guide transformer is illustrated. The length of the transformer section of wave guide is designated X which is the horizontal distance between the end points A and B, as shown. At point A the slope of the curve should be zero to register in alignment with the side of the wave guide. At point

6

B the slope of the curve should be Φ to match the angle of the side of the horn (Φ is 17 degrees for the specific case to be computed, i. e., in Fig. 2 this would correspond to a lateral apex angle of 34 degrees for the sides).

From the Equation 1 above,

$$\frac{dy}{dx} = nKx^{n-1} \quad (2)$$

When $x=X$, $y=Y$, then

$$Y = KX^n, \text{ and } \frac{Y}{X} = KX^{n-1} \quad (3)$$

When

$$x=X, \frac{dy}{dx} = \tan \Phi = nKX^{n-1}$$

and

$$\frac{\tan \Phi}{n} = KX^{n-1} = \frac{Y}{X} \quad (4)$$

whence

$$n = \tan \Phi \frac{X}{Y} \quad (5)$$

For the dimensions $X=5.75$ inches, $Y=.709$ inch, $\Phi=17$ degrees and $\tan \Phi=.306$

$$n = \frac{.306(5.75)}{.709} = 2.48 \quad (6)$$

and from the above relation $Y=KX^n$,

$.709=K(5.75)^{2.48}$ whence $K=.00926$ and the equation for the curve 70 with the parameters given above is

$$y = .00926x^{2.48}$$

In Fig. 5 a side view of a wave-guide transformer having the exponentially tapered sides 70, tapering from a separation of .872 inch to a separation of 2.290 inch inside dimensions, as developed in connection with the diagram of Fig. 4 is shown. The horn is, for the instant example, therefore, cut at a point where its sides are 2.290 inches apart (inside dimension). The broader sides of the waveguide transformer are exponentially tapered from a separation of 1.872 inches to a separation of 2.290 inches following the same procedure as for the narrow sides as described in detail above.

In Fig. 6 the development of a parabolically tapered wave-guide transformer for interconnecting the throat aperture of an antenna of the invention with a wave guide having inside cross-sectional dimensions .872 inch by .372 inch (nominally having outside dimensions of 1 inch by one-half inch) is shown.

In this case, the length of the transforming section, that is, the horizontal distance, between end points A and C is chosen as 8 inches and the horn angle to be matched is again 17 degrees. Lines 82 and 86 are extensions of the inner edges (upper and lower, respectively) of the narrow dimensioned sides of the above-mentioned wave guide to which the wave-guide transformer is to match the throat aperture of the horn. The other sides are similarly designed to register with the horn as described above for the transformer of Fig. 5.

In accordance with a well known method of constructing a parabolic curve between points A and C, tangents to the points A and C, namely, lines 80 and 82, respectively, are first drawn. Line 80 between A and B, and line 82 between B and C are each then divided into the same number of equal parts numbered 1, 2, 3, 4 and 5 and 1', 2', 3', 4' and 5', respectively, as shown. Like numbers are then joined giving lines 1-1'; 2-2'; 3-3'; et cetera. These last-mentioned lines are all tangents of the desired parabolic curve 84. Curve 88 is constructed in the identical manner. Curves 84 and 88 are then the upper and lower contour lines of the sides of a wave-guide transformer providing a wide band smooth impedance match between the throat aperture of the sectoral biconical horn and the nominally 1 inch by one-half inch

7

rectangular wave guide described above. The identical method can obviously be employed to determine the parabolic curvature required for the upper and lower sides of the wave-guide transformer.

Either of the wave-guide transformers of Figs. 5 and 6 is adapted to connect the horn to wave guides which normally are employed to transmit waves of a particular linear polarization, i. e., of a linear polarization parallel to the shorter sides of the wave guide. The horn-reflector antenna of the invention, on the other hand, can efficiently transmit a linearly polarized wave having its polarization parallel to the plane side walls of the horn or perpendicular to said walls. Either of the above-described transformers and its associated feed-wave guide can, therefore, be rotated 90 degrees with respect to the horn to transmit an orthogonally related polarization of the wave through the horn. Alternatively, a round feed guide connected to the horn through a transformer section which first tapers to a square cross-section and then exponentially or parabolically tapers to make a smooth junction with the horn, as for the transformers of Figs. 5 or 6, can be employed for the simultaneous transmission of two independent waves having orthogonally related polarizations, through the horn-reflector antenna of the invention. In all cases, the length of the wave-guide transformer employed is preferably at least two wavelengths of the lowest frequency to be employed.

Numerous and varied other structures within the spirit and scope of the principles of the present invention can obviously be readily devised by those skilled in the art and no attempt to comprehensively illustrate such variations is here undertaken. By way of example, electromagnetic waves can be guided and/or reflected by grids or meshes of conductive elements, the spacing between successive ones of the elements in a direction parallel to the direction of polarization of the waves being less than a half wavelength of the shortest wavelength being used. Therefore, radio antennas of the invention could be constructed of appropriately shaped wire-grid or wire-mesh members and would have less "wind-resistance" where antennas of the invention are to be mounted on exposed towers or natural prominences. Many other forms of structures embodying the principles of the present invention will also readily occur to those skilled in the art.

What is claimed is:

1. An electromagnetic wave, horn-reflector type micro-

8

wave antenna, comprising a sectoral biconical horn, having a longitudinal dimension several times greater than its maximum transverse dimension, and a paraboloidal reflector adjacent to the mouth aperture of said horn, said horn including front and rear conical sections having a common apex point and a pair of plane sides, both conical sections being outwardly concave, their corresponding edges being joined by said plane sides, respectively, said paraboloidal section having a focal point coincident with said common apex point and being disposed with respect to said horn to reflect energy emitted from said horn at an angle in the order of ninety degrees with respect to the longitudinal axis of said horn.

2. The antenna of claim 1, in which the lateral apex angle of each of the conically shaped sides of the sectoral biconical horn is substantially the same as for the corresponding angle of the plane sides.

3. The antenna of claim 2, in which the rear conical side of the horn and the two plane sides of the horn are extended to meet the said paraboloidal reflector.

4. The antenna of claim 3 and a smoothly tapered wave-guide transformer connected to the throat aperture of the sectoral biconical horn and adapted to connect said horn with a standard wave guide of rectangular cross-section, whereby a substantially uniform impedance input to said horn over a wide band of microwave frequencies is achieved.

5. The antenna of claim 1, in which the rear conical side of the horn and the two plane sides of the horn are extended to meet the said paraboloidal reflector.

References Cited in the file of this patent

UNITED STATES PATENTS

2,416,675 Beck Mar. 4, 1947
2,477,694 Gutton Aug. 2, 1949

FOREIGN PATENTS

600,101 Great Britain Mar. 31, 1948

OTHER REFERENCES

"Biconical Electromagnetic Horns," by Barrow, Chu and Jansen, Proceedings of the I. R. E., vol. 27, No. 12, December 1949, pages 769-779.