

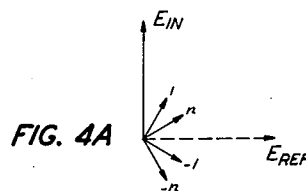
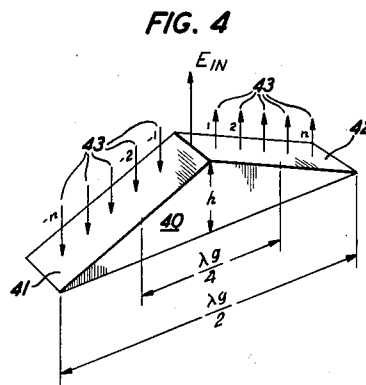
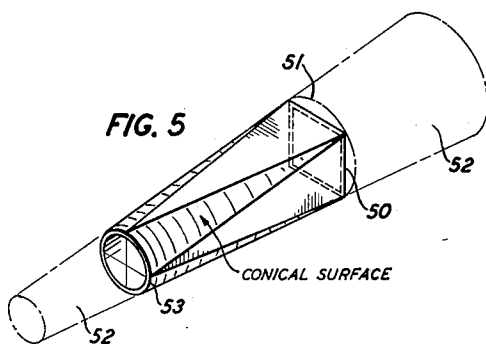
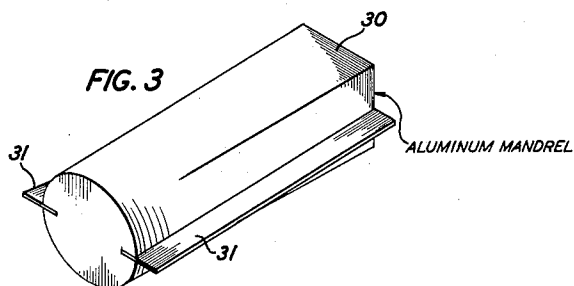
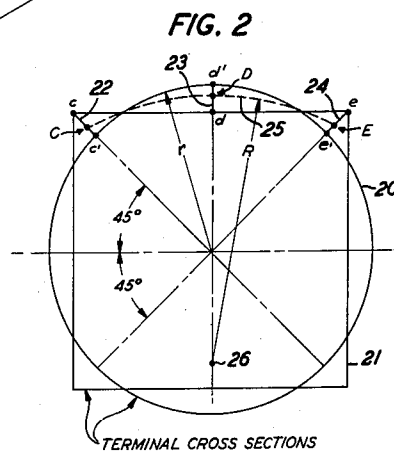
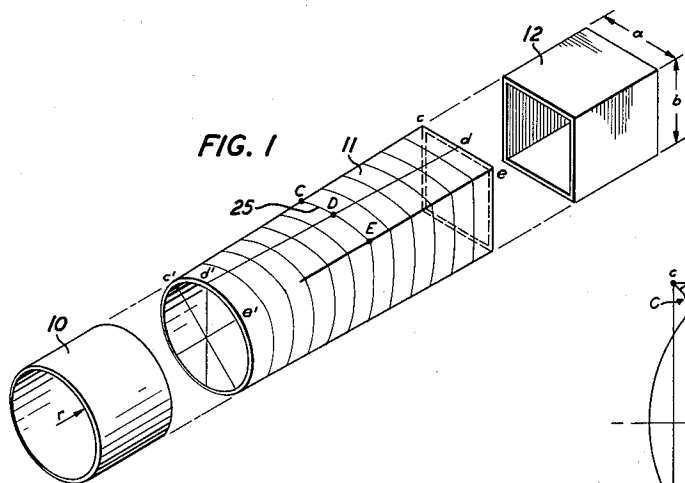
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3,040,277

WAVE GUIDE TAPER

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3,040,277 WAVE GUIDE TAPER

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This invention relates to electromagnetic wave transmission systems for use in the high, microwave, and millimeter wave frequency ranges, and more particularly to wave guide transition tapers for use in such systems.

Frequently in wave guide system practice, it becomes necessary to join successive wave guide sections which differ in physical and/or electrical properties. A substantial portion of the prior art in this area is concerned with the case of joining guides of widely differing characteristic impedances within a minimum of energy reflection. The well-known quarter wave impedance transformer, the Gaussian impedance taper, the exponential impedance taper, and the Tschebyscheff impedance taper are copiously treated in the published art. It frequently becomes desirable to join successive wave guide sections which have characteristic impedances which are similar but transverse cross-sectional shapes which are dissimilar. In much of the prior work dealing with impedance transforming transition sections, the distributed shunt susceptance associated with the particular transition involved has been assumed to be zero or, at least, negligible in view of the large impedance differential. When, however, the impedances of the sections to be joined are identical or nearly so, the distributed shunt susceptance becomes the major cause of the reflection from the transition.

It is, therefore, a major object of this invention to join successive wave guide sections having dissimilar transverse cross-sectional shapes.

It is a further object of this invention to join successive wave guide sections having similar characteristic impedances and dissimilar transverse cross-sectional shapes by means producing very low energy reflection.

It is a more specific object of the invention to join these successive guide sections by a wave guide transition section characterized by low distributed shunt susceptance.

Generally, the reflection characteristics of a wave guide transition taper may be minimized by selecting a section having a long length. However, long transitions are preferably to be avoided to conserve space.

A feature of the present invention is its over-all length, which may be of the order of three-quarters of a guide wavelength at the operating frequency.

In accordance with the principal embodiment of the invention, the guides to be joined are of circular and square transverse cross-section, respectively, and the transition section takes the form of a "smooth reference" taper. The surface contour of the taper comprises successive transverse cross-sections each of which is itself described by a set of four successive arcs struck through four determinable sets of three points each. In order to determine these points, and thus the over-all contour of the novel guide transition, the corners and centers of the rectangle sides are connected to octant points on the circle, selecting whatever impedance taper program is desired for these lines. Then, along each set of three lines (corresponding to the four sides of the rectangle locus) at locations on each line which are the same proportional part of the total length of this line, the only circular arc which will join each set of points is struck. Proceeding in this manner at successive locations from the rectangular guide to the circular guide

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results in a transition section, designated a smooth reference taper, in accordance with the invention.

A feature of the invention resides in the use of simple polyfoam tuning elements to eliminate the small shunt susceptance which remains.

The above and other objects and features of the invention will become more clearly understood by reference to the accompanying drawing in which:

FIG. 1 is a perspective view of a guide transition in accordance with the invention;

FIG. 2, given by way of explanation, is a pictorial representation helpful in visualizing the procedure leading to the transition of FIG. 1;

FIG. 3 is a perspective view of a shaped mandrel for use in a practical method of fabrication of the invention;

FIG. 4 illustrates a tuning element useful in conjunction with the invention;

FIG. 4A is a vector diagram related to the element shown in FIG. 4; and

FIG. 5 is a perspective view of an alternate transition section geometry.

Referring more particularly to the drawing, FIG. 1 illustrates a hollow conductively bounded wave guide section 10 of circular transverse cross-section of radius r joined through a smooth reference taper 11 in accordance with the invention to a hollow conductively bounded wave guide section 12 of rectangular transverse cross-section. The dimensions of guides 10 and 12 are chosen such that their characteristic impedances are equal. It should be noted at this point that any wave guide element has a property that may be called its characteristic impedance and while this quantity may be defined in several different ways, each appropriate for its own purposes, in this specification the term "characteristic impedance" shall be understood to be the ratio of the square of the R.M.S. voltage along the electric field line where the electric field is a maximum to the total power flowing when the guide is match-terminated. This impedance convention is referred to as that of power and voltage.

While the invention is applicable to any of the large variety of wave mode configurations ordinarily supported by hollow pipe guides, the specific description of the invention herein will be confined to the case of transverse electric, or TE waves by way of simplification.

The impedance of guide section 10, when air-filled is

$$Z_0 = \frac{764}{\sqrt{1 - \left[\frac{\lambda}{3.412r} \right]^2}} \text{ ohms}$$

where r is the radius and λ the wavelength of interest.

For a rectangular pipe such as guide section 12 when air-filled,

$$Z_0 = \frac{754b}{a\sqrt{1 - \left[\frac{\lambda}{2a} \right]^2}} \text{ ohms}$$

where a and b are the transverse cross-sectional dimensions of the guide.

It is readily apparent from the above equations that the characteristic impedance of a circular pipe may vary from infinity at the cut-off wavelength to 764 ohms for infinitely large pipes, whereas the characteristic impedance of the rectangular pipe may be varied from infinity at cut-off to zero. Thus the impedance of a rectangular guide may be made equal to that of a given circular guide merely by proportioning the dimensions a and b of the rectangular guide.

As disclosed in my copending application, Serial No. 724,684, filed March 28, 1958, now U.S. Patent 2,972,721, issued February 21, 1961, some wave guide system

applications require a transition between circular guides and square guides as well as between circular guides and near-square guides, both with an input polarization inclined at 45 degrees to the walls of the rectangular guide. In such a case it is necessary that the impedances seen by the vertically polarized component and the horizontally polarized component be as nearly equal as possible. For the square guide no problem is presented but for the near-square guide these impedances can never be exactly equal. However, as disclosed in the above copending application, applicant has found that the effective difference in the characteristic impedances presented to the orthogonal components of the 45-degree input polarization is zero if the impedance of the circular guide is made equal to the square root of the product of the impedances presented by the near-square guide to the two polarization components.

It becomes clear, therefore, that the transition taper to be described below has wide application to the problem of joining round and rectangular wave guides and is not limited to any single combination of guides, their characteristic impedances, wave energy polarizations, and wave modes. More particularly, when the direction of polarization of the input waves is normal to one pair of walls of the rectangular guide, it is not necessary that any equality of impedances exist between the round and rectangular guides.

Returning now to FIG. 1, the transition taper 11, or smooth reference taper, is a hollow conductively bounded wave guide element which preserves the impedance equality between guides 10 and 12 while providing a transition of transverse cross section from round to rectangular with very low attendant reflection of wave energy. The taper is characterized by smoothness of physical contour, successive cross sections being only slightly different from each other. The precise shape assumed by taper 11 may be more readily understood by reference to FIG. 2. In FIG. 2 the terminal transverse cross sections of guides 10 and 12 to be joined are symmetrically superimposed as circle locus 20 and rectangle locus 21. Since the surface contour of taper 11 may be broken down into four identical quarters, the method of synthesizing only one of these quarters will be set out, the remainder of the process being a matter of course once one side is known. In FIG. 2 the derivation of a typical cross section curvature sector for the upper portion of the smooth reference taper surface is set out. Points *c*, *d*, *e*, corresponding to the ends and center of the top of the rectangle locus 21, are connected by means of lines 22, 23, and 24, respectively, to points *c'*, *d'*, and *e'*, respectively, on the circle locus 20. Points *c'*, *d'*, and *e'* are octant points on the circle; i.e., they are each separated by an arc of circle 21 which subtends an angle of 45 degrees at the circle's center. Each of lines *c-c'*, *d-d'*, and *e-e'* is programmed; i.e., is caused to vary as a function of its length, in any desired manner. Thus, for example, from other considerations it may be desirable that each line have an exponential variation, a Gaussian variation, or some other non-linear variation. The simplest program occurs when the points are connected linearly, i.e., by a straight line, and this particular configuration has been chosen for purposes of illustration in this application, but no limitation is to be deduced therefrom. Thus, in FIG. 2 lines *c-c'*, *d-d'* and *e-e'* are straight lines. To determine any given surface contour, points C, D, and E are located on lines *c-c'*, *d-d'*, and *e-e'*, respectively, at distances from the rectangle locus on each line which bears the same proportionality to the total length of that line. Thus in FIG. 2,

$$\frac{cC}{cc'} = \frac{dD}{dd'} = \frac{eE}{ee'}$$

Through the set of three points thus determined arc 25 is struck. This arc represents the surface contour of a smooth reference taper at the transverse cross sec-

tion of which it is a part. Geometrically arc 25 may always be struck by first locating point 26 by extending the perpendicular bisectors of lines joining CD and DE until they intersect. Once point 26 is established the radius R is known. By repeating the above procedure four times at a given cross section, the complete surface contour at any given transverse cross section of a smooth reference taper may be determined. It may readily be seen from FIG. 1 that, as the rectangle locus 21 is approached along the taper section, radius R will increase and finally reach infinity at the rectangular terminal cross section. Likewise, as the circle locus is approached, R will approach *r*, the radius of the terminal cross section 20. The respective points mentioned above with reference to FIG. 2 have been set out in FIG. 1, together with arc 25 for purposes of visualization.

FIG. 3 is a perspective view of a mandrel and spacers which may be used in the fabrication of a smooth reference taper transition in accordance with the invention. The problems of fabrication are not so great as might first appear from a consideration of the procedure set out above. One method whereby the smooth reference taper may be constructed involves the use of a mandrel 30 which may be of aluminum or other suitable material and over which a smooth reference taper may be electroformed in accordance with well-known techniques.

Mandrel 30 can be rough-shaped by milling all the radii, shown typically as R in FIG. 2, for equally spaced cross sections by using a series of end mounted templates. To avoid removing material necessary for smooth surface tapering, the cutter axis may be tilted slightly toward the round wave guide axis. The excess material can then be removed, for example by filing, to join the accurate cuts smoothly. It often occurs that the relative dimensions of the terminal cross sections are such that the mandrel cannot be "pulled" from the electroformed component in the conventional manner. For example, as seen in FIG. 2, the circle locus 20 exceeds the dimensions of the rectangle locus 21 at some locations while the reverse is true at other locations. Therefore, to provide for non-destructive mandrel removal, the taper transition may be electroformed in top and bottom halves by inserting dielectric spacers 31 which may comprise polystyrene, for example, as shown in FIG. 3. After the mandrel is removed the top and bottom halves may be conductively joined by soldering metallic spacers of thickness identical to that of the dielectric spacers between the halves.

As stated hereinabove, a smooth reference taper in accordance with the present invention is characterized by a very low reflection coefficient. For some applications, however, it is desirable that the reflection coefficient be reduced even further. FIG. 4 illustrates a tuning element 40 which may be advantageously used for tuning purposes. The material of the element may be polyfoam or some other dielectric depending on the magnitude of the reflection to be canceled. In the smooth reference taper the reflection level is very low and a very low dielectric constant material is desirable. Tuning element 40 functions in some respects like a conventional metallic tuning screw. However, in at least its multimoding characteristics, the tuning wedge is superior to the tuning screw. Element 40 is physically simple, comprising an element of dielectric material in the shape of an isosceles triangle. The height *h* of element 40, which determines the reflection coefficient of the element, is determined first and the length of sloping sides 41, 42 is then chosen such that the midpoints of the sloping sides are spaced one-quarter guide wavelength at the frequency to be affected. If the midpoint of the element 40 be taken as the reference plane for an incident wave *E_{in}*, the local resistive reflections *n* to (*-n*), indicated by vectors 43 in FIG. 4 add vectorially to produce an over-all reflection which lags the input by 90 degrees as may be seen from the vector diagram of FIG. 4A. By placing the center line of element

40 ninety electrical degrees beyond the center line of a smooth reference taper section, the reflections due to the taper and the reflections due to the tuning wedge cancel. A very high quality transition section between the guides to be joined results.

For certain applications it has been found desirable to utilize four tuning triangles spaced ninety physical degrees apart around the inside surface of the transition taper. When the guide system of which the taper is a part is adapted to support a broad frequency band, the guide will inherently support many wave modes at the higher frequencies. The triangular tuning wedge causes virtually no multimoding at the higher frequencies while at the same time effectively tuning out the reflections at the lower frequencies in which range they are most severe.

FIG. 5 illustrates a transition taper which may be used as an alternate to the smooth reference taper shown in FIG. 1. In FIG. 5 the rectangular terminal cross section 50 to be joined is circumscribed by a circle 51 and the circle is connected through conical surface 52 to the circle 53 formed by the terminal aperture of the round guide to be joined. Successive planar slices of this conical surface are then taken, joining the sides of the rectangle with quadrant points on the circle. The resulting "sliced conical" taper transition is characterized by low distributed shunt susceptance and attendant reflections. The dielectric tuning element of FIG. 4 may be used with the sliced conical taper to tune out residual reflections in the same manner as it was used with the smooth reference taper.

In all cases it is understood that the above-described arrangements are illustrative of a small number of the many specific embodiments which could represent an application of the principle of the invention. Other arrangements, including transition tapers between guides of transverse cross sectional shapes other than those illustrated and characteristic impedances other than those described, could readily be devised in accordance with these principles by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In combination, a bounded wave guide section adapted to support electromagnetic wave energy, over a given band of frequencies, said section having a first ter-

minal end of a first transverse cross sectional geometry and a second terminal end of a second transverse cross sectional geometry different from said first cross sectional geometry, the surface of said section between said terminal ends conforming to eight predetermined lines between respective spaced points on each of said terminal ends, the transverse cross sectional geometry of said section being described by circular arcs through points along sets of three of said lines, said arcs having radii which vary at successive cross sections from said first terminal end to said second terminal end, said points being the same proportionate distances along each line of said sets from a given terminal end, and means for eliminating reflections due to the distributed shunt susceptance of said transition section disposed within said section intermediate the ends thereof, said means comprising at least one dielectric element having a dielectric constant different from the dielectric constant of the medium filling the remainder of said transition section, said dielectric element having a longitudinal cross section in the shape of an isosceles triangle and having a rectangular transverse cross section with midpoints of the equal sides of said triangular cross section spaced apart a distance equal to one quarter wavelength at the midfrequency of said band of frequencies.

2. The combination according to claim 1 wherein said means comprises four identical dielectric elements symmetrically disposed around the inside surface of said transition section and in the same transverse plane.

3. The combination according to claim 1 wherein the longitudinal center of said dielectric element is spaced from the transverse plane defining the center of said transition section a distance equal to one quarter wavelength at the midfrequency of said band of frequencies.

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