Oct. 31, 1950 H. C. HEY 2,527,817

VARIABLE IMPEDANCE WAVE GUIDE MATCHING TRANSFORMER

Filed Oct. 10, 1945 2 Sheets-Sheet 1

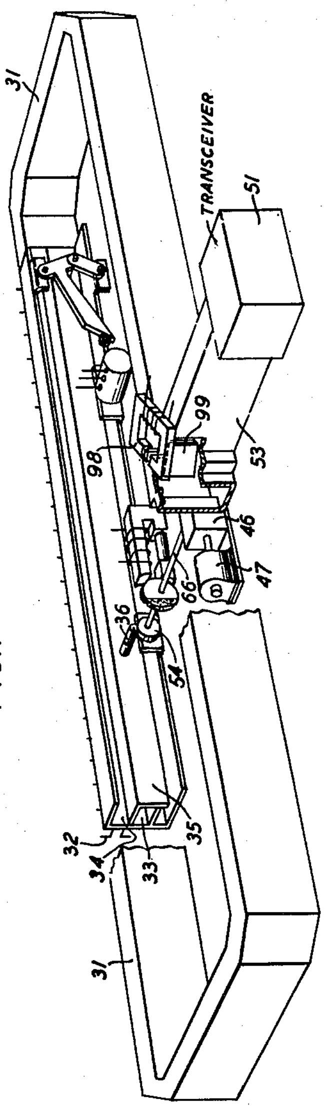

FIG. 1

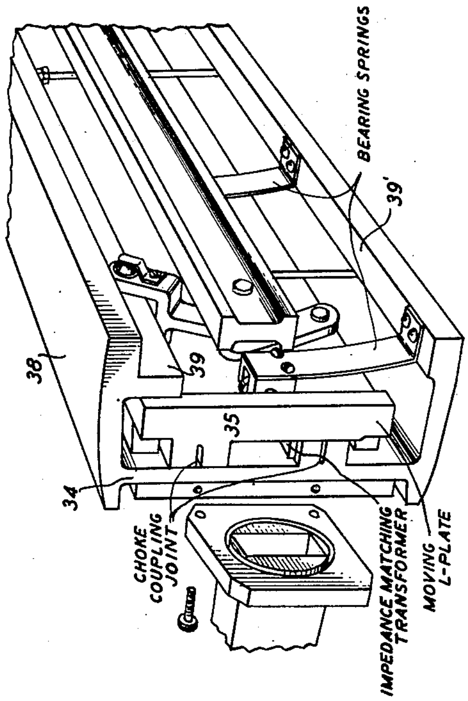

FIG. 3

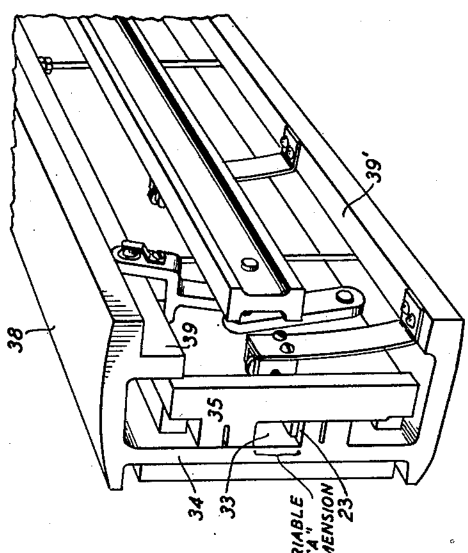

FIG. 2

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FIG. 4

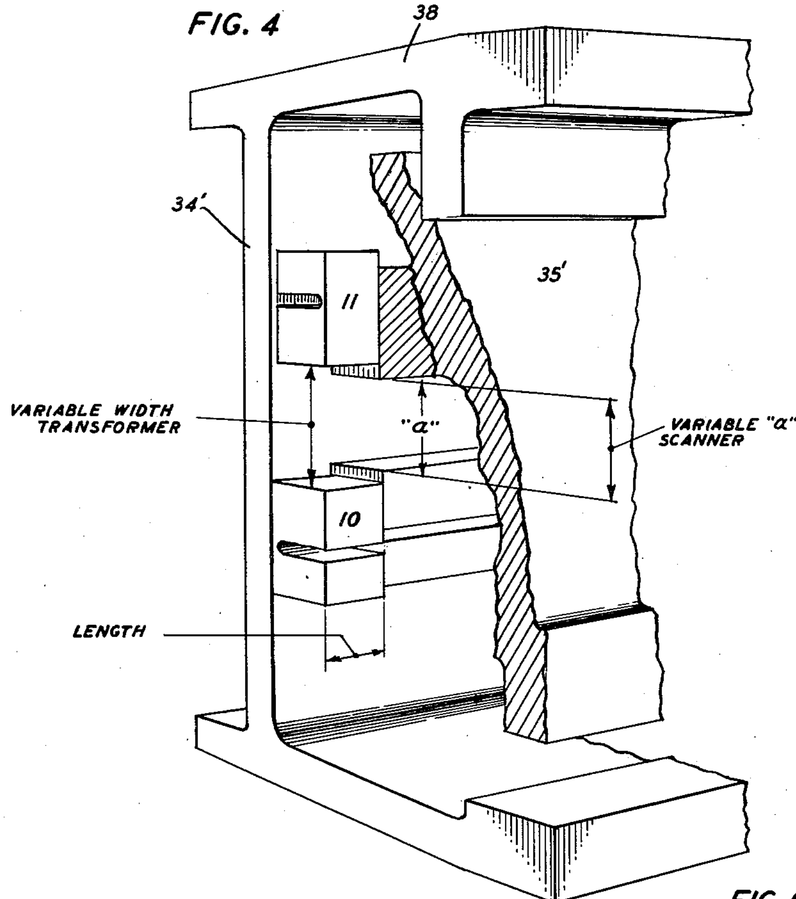


FIG. 5

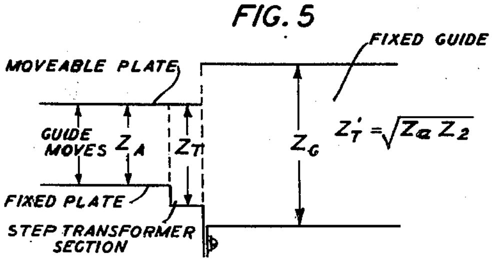


FIG. 6A

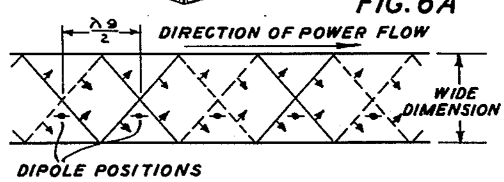


FIG. 6B

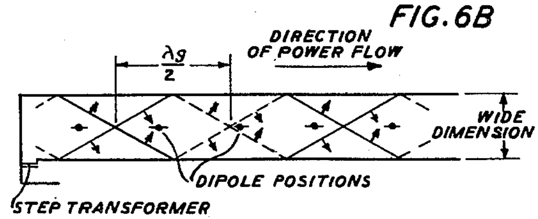
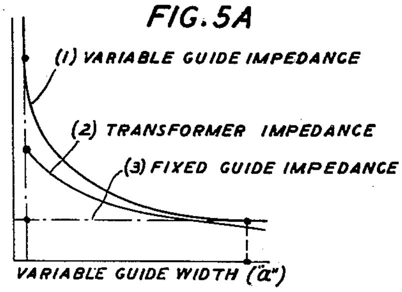


FIG. 5A



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VARIABLE IMPEDANCE WAVE GUIDE MATCHING TRANSFORMER

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Application October 10, 1945, Serial No. 621,580

5 Claims. (Cl. 178—44)

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This invention relates to impedance transformers for smoothly matching the impedance of wave guides to each other.

A principal object of the invention is to provide a variable impedance transformer for matching the impedance of a wave guide of fixed cross-section to a wave guide having a varying cross-sectional dimension.

Another object of the invention is to provide a variable impedance transformer for matching a wave guide of fixed cross-section to a wave guide formed of movable parts, which produce a cross-section having a variable dimension.

A feature of the invention is a cut-out step formation in a rectangular wave guide of variable cross-section, for matching it to a guide of fixed rectangular cross-section.

Referring to the figures of the drawing:

Fig. 1 shows an antenna system and wave guide feeds, with which the variable impedance matching transformer may be used;

Fig. 2 shows a view of the variable wave guide, contracted, with the impedance transformer;

Fig. 3 shows a corresponding view of the variable wave guide expanded;

Fig. 4 shows an alternative form of the variable impedance transformer;

Fig. 5 is a schematic and explanatory view of the wave guides and the impedance matching transformer; and

Figs. 6A and 6B show the wave fronts in the variable guide as the wide dimension varies.

Wave guide impedance matching transformers for connecting wave guides of different cross-sections have been disclosed heretofore, e. g., in the United States Patent to G. C. Southworth No. 2,106,769, issued February 1, 1938.

Certain antenna systems are characterized by a wave guide feed having a variable dimension in its cross-section for producing electrical scanning by phase velocity variation. One of the problems encountered in the successful operation of such a system is to provide a simple means for connecting a wave guide of fixed cross-sectional dimensions to the variable guide. A principal objective in the solution of this problem is to avoid mechanical complexity, additional moving parts, etc.

In practice, this expedient was found to be impractical and a simpler and more efficient coupling had to be devised.

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Heretofore, a coupling characterized by a fixed taper feed, and a mechanical device which always kept the taper centered with the "*a*" dimension, has been used.

In accordance with the invention, a variable impedance matching transformer between a rectangular guide of fixed cross-section and a similar guide having a variable ("*a*") dimension in its cross-section, has been achieved by the simple expedient of cutting a "step" in the latter.

This does away with the "center in feed" and with all extra mechanical and moving parts required in the "center in feed" and at the same time provides a better impedance match over the band of the variable ("*a*") scanner.

In one embodiment of the invention, the step is cut into a fixed channel portion of the variable guide, the depth of the step being determined by

$$Z_T=\sqrt{Z_1Z_2} \qquad (1)$$

where

Z_1=impedance of the variable guide at minimum guide cross-section,

Z_T=impedance of the transformer at minimum guide cross-section,

Z_2=impedance of the fixed guide,

and its longitudinal extent l being determined by

$$l=\frac{\lambda_T}{4}=\sqrt{\frac{\lambda_{min}\lambda_{max}}{4}} \qquad (2)$$

where λ_{max} and λ_{min} are the wavelengths corresponding respectively to the minimum and maximum cross-section of the variable guide.

The selection of Z_1 at minimum guide cross-section in Formula 1 above, is advantageous in view of the consideration that maximum loss of power and maximum mismatch between the guides occur at the particular variable ("*a*") dimension corresponding thereto.

In a rectangular wave guide, the characteristic impedance Z with reference to wave of dominant type is given by

$$Z=\frac{465b}{\sqrt{1-\left(\frac{\lambda}{2a}\right)^2}}$$

where

a=wide dimension (variable)

b=narrow dimension (fixed)

In one practical application of the invention, the impedance matching transformer and the associated matched wave guides have been used in a radar antenna, utilizing a linear array of 250 spaced dipoles for radiating a very narrow beam of radiation, which scans electrically a sector 30 degrees wide.

As is well known, the radiation pattern of a single horizontal dipole remote from the ground may be represented by a solid of revolution formed by a circle tangent to the dipole and rotated about the dipole axis. As the number of dipoles in a linear array is increased, the pattern becomes narrow and the circle of revolution degenerates into a long narrow loop of revolution. Thus, the sharpness of the directional pattern may be increased with increasing length of the array. When the array comprises 250 half-wave dipoles fed in phase with one another, a very narrow beam of radiation may be produced confined to a direction perpendicular to the length of the antenna array. The radiated energy may be thought of as following radial paths on a plane surface normal to the antenna. Actually, the beam width is approximately 0.4 degree.

Since mechanical means for scanning are impracticable in this case, the beam may be deflected to scan electrically by shifting the phase of the currents in the respective dipoles, and this may be accomplished by varying the wide dimension of movable wave guide feed into which the pick-up probes of the dipoles project.

Mechanical construction of variable wave guide and impedance transformer

Referring specifically to Fig. 1, an electrical scanning system for radars, used preferably on airplanes, and more fully disclosed in the United States applications of C. N. Nebel, Serial No. 607,054 filed July 25, 1945, now Patent No. 2,518,564, issued August 15, 1950, and of A. K. Schenck, Serial No. 607,055 filed July 25, 1945, is shown.

In Fig. 1, a main wave-guide **53** serves to connect a fixed frequency transceiver **51** and the variable wave-guide feed **33** for energizing the antenna array of dipoles **32**. The array and feed is similar to the velocity variation type disclosed in U. S. application Serial No. 496,325 of C. B. H. Feldman, filed July 27, 1943. Dipoles **32** in the array are uniformly distributed along the length of the variable wave-guide **33**, with their probes extending into the interior thereof.

The variable wave-guide **33** comprises a hollow pipe of rectangular cross-section formed of L-shaped plates **34**, **35** abutting each other to form a cross-section, having its "*a*" dimension or wide dimension variable. The energy from the transceiver **51** is fed into the variable guide **33** at each end thereof by means of a U-shaped elbow pipe section **31**, of fixed rectangular cross-section.

The direction of flow of energy into either end of the wave-guide **33** is regulated by means of the radio frequency switch **98** which comprises an aluminum vane **99** attached to a core which is positioned in the field of an electromagnet, as disclosed in the aforementioned Nebel application.

The portion of the wave-guide **33**, to which is attached the dipole array, is of variable ("*a*") vertical dimension, the movable L-shaped plate member **35** being positioned to ride on plate **34** by means of the knob **36** on the eccentric cam **54**. The cam **54** is rigidly fixed to the drive shaft **66**, which is attached to the drive motor **47** through the gear reduction box **46**, as disclosed in said Nebel application.

The lower inner edge of the fixed guide **31** is fastened to the stationary inner edge of the movable guide **33**. The upper edge of the fixed guide comes between the maximum and minimum extensions of the variable guide.

A change in the "*a*" or wide dimension of a rectangular wave guide is accompanied by a corresponding change in the wavelength λ_g propagated therein. This can best be explained by considering the resultant wave in the rectangular guide as formed from the superposition of plane electromagnetic waves traveling at an angle to each other and successively reflected from the side walls thereof.

The $TE_{0,1}$ mode in a rectangular guide may be considered as the resultant arising from the superposition of two plane waves moving in cross-directions at an angle depending upon the frequency of the waves and the size of the guide. Usually, the plane electric field components traveling at an angle across the wide or "*a*" dimension of the guides are considered. This is illustrated in Figs. 6A and 6B where the wave-fronts of the plane waves are shown traveling in zig-zag formation through the guide. The separation of the resultant crests and troughs, determines the wavelength in the guide. As the guide is made smaller in its wide dimension, these crests and troughs become more widely spaced and hence the wavelength is increased.

As the wavelength in the guide changes, the antenna probes which are in a fixed position appear at different instantaneous phase positions in the passing cycles of the waves traveling through the guide. Therefore, as the wide dimension becomes smaller the fixed probes become closer together as measured in wavelengths. This results in a uniform change in phase of the currents in the dipoles from one end of the array to the other. The points at which the electric field intensities reinforce each other in space is consequently altered so that instead of the elements of radiation forming a sheet perpendicular to the array, the elements now all make an angle θ with the perpendicular. When the currents are traveling from right to left, the beam is deflected to the right and conversely, thereby producing scanning electrically.

Since there is a limit to which the wide dimension of the guide may be varied and still propagate the $TE_{0,1}$ wave, there is a limit to the amount of electrical scanning possible. The limit of motion has been restricted to a 1.20-inch maximum and 0.665-inch minimum (inner dimension) which develops approximately a 90-degree lead in respective dipole currents in the direction of energy flow. A resultant beam deflection of 30 degrees is obtained for a single cycle of motion of the variable guide.

However, by feeding power into the antenna wave guide from the other end, the currents can be made to lead from the opposite end so that a scan angle of 30 degrees on the opposite side of 0 degree (straight ahead) is obtained. This gives a total scan angle of 60 degrees in the forward direction.

In Figs. 2 and 3, the variable wave guide **33** which feeds the dipoles of the antenna array forms part of an aluminum channel **38** provided with two flanges **39**, **39'**. The inner surface of the channel comprises an L-shaped plate **34** with a raised portion located about one-third of the distance from the bottom and extending the full length as shown in Fig. 2. A movable L-shaped aluminum plate **35** with a similar raised parallel section located two-thirds of the distance from the bottom is placed along the inner side of the channel.

The parallel raised sections thereby form two opposite relatively movable outer walls of a variable rectangular wave guide **33**. The L-shaped plates **34**, **35** which together constitute the variable guide are held together by means of springs and rollers at equally spaced points therealong.

Fig. 3, which is identical in structural details to Fig. 2, shows the variable wave guide **33** with the rectangular cross-section expanded due to the increase in the "*a*" dimension.

The rate of the vertical motion of L-shaped plate **35** is such that a uniform rate of scan of the radiation beam is attained.

In order to obtain approximately equal power of pick-up from the successive dipoles, the first one, which is exposed to the maximum power, should be inserted a lesser amount than succeeding ones. Preferably, the succeeding dipoles should be inserted to greater depths at approximately an exponential rate. However, to permit a similar distribution of energy pick-up from both ends, a compromise may be effected, wherein the increase of penetration progresses from each end to a maximum at the middle.

A variable, impedance matching transformer **23** is formed in the movable guide **33** at the transition points from the fixed to the movable wave guide. The transformer comprises a "step" cut into the L-shaped plate **34** on the movable guide **33**, as shown in Figs. 2 and 3, and schematically in Figs. 5 and 6B, the depth and longitudinal dimension thereof being determined by Equations 1 and 2, supra. The step sets up an impedance transformer section Z_T between Z_2 of the fixed guide and Z_a of the variable guide.

In the operation of the transformer, as illustrated in Fig. 5,

$$Z'_T=\sqrt{Z_aZ_2} \qquad (4)$$

where Z'_T and Z_a represent the impedances of the transformer section and variable guide, respectively, both varying as plate **35** is moved along plate **34**.

The improvement in performance resulting from the variable transformer section is shown in Fig. 5A. Curve **2** shows the transformer impedance as a function of the "*a*" dimension of the variable guide. As the "*a*" dimension varies, the transformer provides a better match between the impedance of the variable guide, illustrated by steep curve (**1**) and the constant impedance value, curve (**3**), characteristic of the fixed guide. In general, the interposition of the impedance transformer section serves to limit the standing wave ratio to 1.25 or less.

The transformer action represents a compromise match over the variable "*a*" region. Its interposition between the fixed and variable wave guide in a practical radar embodiment, contributed to reliable performance and successful operation of the aforementioned scanning system.

The choke coupling joint shown in Fig. 3 prevents leakage of energy between the relatively movable plates **34**, **35**.

An alternative form of variable impedance transformer is illustrated in Fig. 4. A pair of blocks **10**, **11** constitute a variable width, impedance transformer—the spacing therebetween being variable by moving plate **35'** on which block **11** is fastened, along the base **34'** of channel **38**. Block **10** is fixed to the base. The length of the blocks and their relative spacing apart is determined from Equations 2 and 1, supra.

In one physical embodiment of the form shown in Fig. 4, the transformer was designed on the following numerical basis:

Z_1=Impedance of variable guide at minimum guide width, a=.670''.

Z_2=Impedance of fixed feed guide, a=1.125''.

Z_T=Impedance of transformer at minimum guide width=$\sqrt{Z_1Z_2}$

and the transformer a_T dimension is calculated and determined from Z_T. Similarly, the length of the transformer $\lambda T/4$ is made equal to the geometric mean between the transformer wavelength at minimum and maximum transformer widths. For the linear dipole antenna array these transformer constants were determined to be:

a_T=.770'' when "a" dimension=.670''

$\lambda T/4$=.440''.

Whereas the transformer has been disclosed as applied to a linear array of dipoles, it should be understood that the antenna may be of any suitable type known to the microwave art, such as disclosed, for example, in the aforementioned Feldman application or equivalents thereof.

What is claimed is:

1. In combination, a wave guide of fixed cross-section having a characteristic impedance, a wave guide of continually variable cross-section having a continually variable characteristic impedance, said variable wave guide having an end contiguous an end of said fixed guide with a portion of the end faces thereof in sliding contact, means for matching said wave guides comprising a step cut in said contiguous end of said variable guide, said step having a variable impedance at all times intermediate said impedance of the fixed guide and said variable impedance of the variable guide.

2. In combination, a wave guide of fixed cross-section, a wave guide of continually variable cross-section comprising separable parts coextensive in length, and an impedance transformer for matching said guides comprising a third wave guide connected between said fixed guide and said variable guide, said third guide abutting said fixed guide and adapted to vary uniformly in cross-section with said variable guide, the impedance of said impedance transformer at minimum guide cross-section being the mean of said variable guide impedance at minimum guide cross-section and the impedance of said fixed guide.

3. In a high frequency electrical wave transmission system comprising a rectangular wave guide of fixed cross-section having "*a*" and "*b*" cross-sectional dimensions and a rectangular wave guide of continually variable cross-section having "*a*" and "*b*" cross-sectional dimensions, dimension "*a*" being variable, means for coupling and matching said guides comprising a wave guide section connected between said fixed and said variable guides as an integral extension of said variable wave guide, said section having an "*a*" dimension varying concurrently with said "*a*" dimension of said variable guide by virtue of said integral connection and remaining at all times intermediate said last-named dimension and said fixed "*a*" dimension.

4. In combination, a wave guide of fixed rectangular cross-section, a wave guide of continually variable rectangular cross-section having a

variable dimension in the wide direction thereof, and means for coupling said guides comprising a rectangular wave guide section connected as an integral extension of said variable wave guide, the end of said wave guide section opposite said variable guide and adjacent said fixed guide having a portion of the end face thereof in sliding contact with the end face of said fixed guide, said guide section having a variable cross-section with the wide dimension thereof being intermediate the wide dimensions of said fixed guide and said variable guide, the wide dimension thereof being variable concurrently with said wide dimension of said variable wave guide, said guide section proportioned to have a length substantially equal to one fourth of the mean wavelength of the waves in said section at a predetermined operating frequency.

5. The structure of claim 4 wherein the wide dimension of said guide section is proportioned to give said guide section a characteristic impedance at its minimum cross-section equal the square root of the product of the impedance of the variable guide at minimum guide cross-section and the impedance of said fixed guide, and wherein the length of said guide section is equal the square root of one quarter of the product of the wavelengths in the variable guide at minimum cross-section and at maximum cross-section.

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