

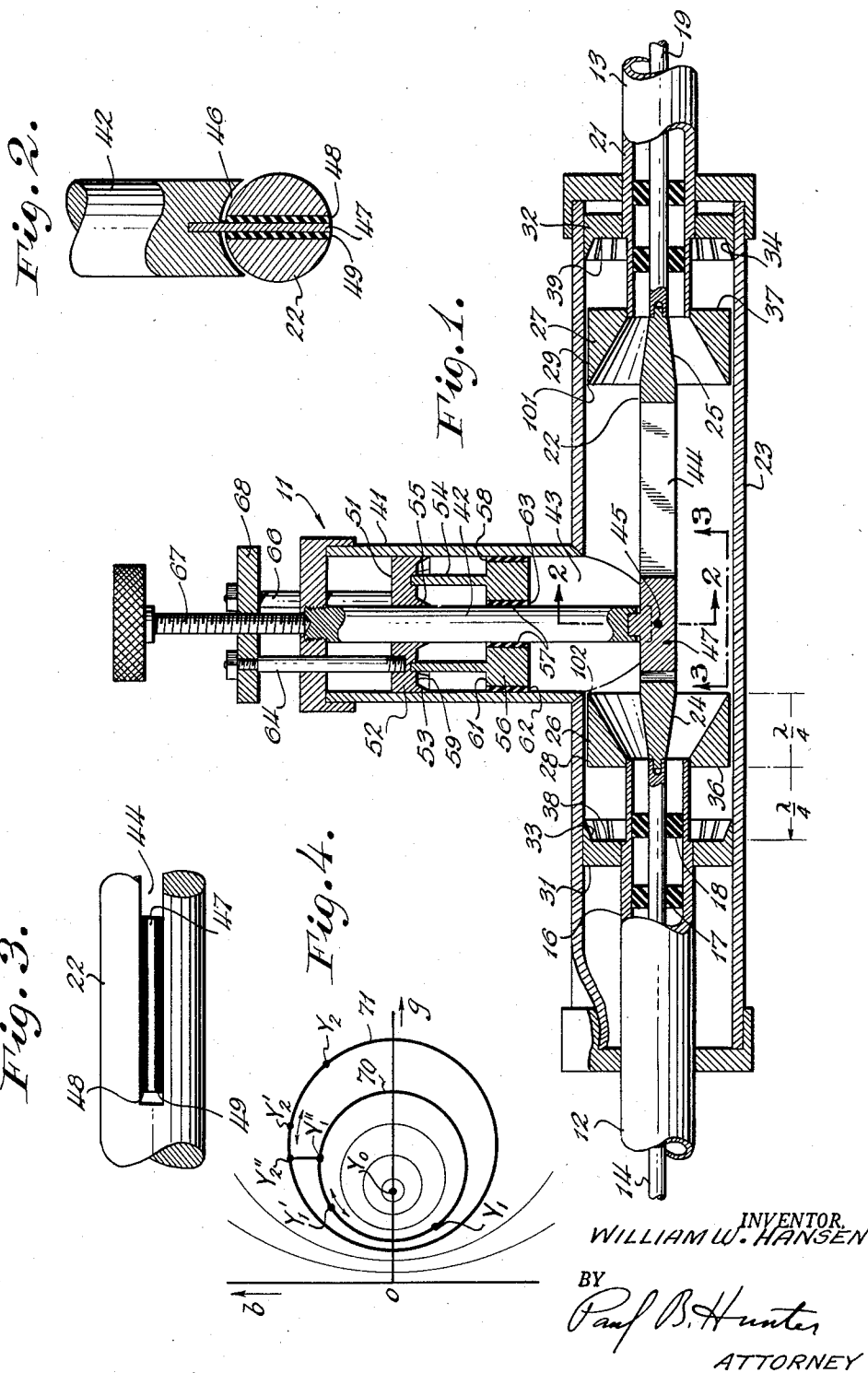
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IMPEDANCE TRANSFORMER FOR CONCENTRIC LINES

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IMPEDANCE TRANSFORMER FOR
CONCENTRIC LINES

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The present invention relates to the art including impedance matching and transforming devices especially adapted for use in systems utilizing high frequency electromagnetic energy. The present application is a division of application Serial No. 448,992 filed June 29, 1942, now Patent No. 2,438,912, issued April 6, 1948.

In transferring energy from one high frequency device to the other, it is well known that the impedances thereof must be properly matched in order to avoid the production of standing waves with attendant increase in losses and decrease in the energy transmitting capacity of the system. In addition, for greatest efficiency it is known that the impedance of a load device must be properly transformed to match that of its source.

The present invention is directed toward the provision of improved impedance matching and transforming devices which are adapted to efficiently couple and match any two arbitrary impedances, and to transform any arbitrary impedance into any other arbitrary impedance, with a minimum of adjustment and a maximum facility and efficiency.

According to the present invention, such impedance transformers are provided of the concentric line type having fixed physical length whereby they may readily be manufactured and permanently and rigidly connected into a system. Concentric line impedance transformers have been disclosed in Hansen and Woodyard Patent No. 2,406,372 granted August 27, 1946. In such devices, it is known that by the provision of only a single adjustment, a very restricted range of transformation is obtained. By providing three adjustments, any desired transformation may be obtained, but the practical difficulties of making three simultaneous inter-dependent adjustments renders such devices of limited utility. When using two adjustments, the range of possible transformations is increased greatly over that with one adjustment, but it is only in special cases that all transformations may be obtained. Such transformers are described in the present case.

Also, special provision is made for the elimination of losses by the use of special spacing of the insulating spacers required to maintain proper relationship between the concentric conductors of the device, and by the use of special contact-resistance-reducing means useful wherever sliding contact is required.

Accordingly, it is an object of the present invention to provide improved impedance matching

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transformers for matching any two arbitrary impedances.

It is another object of the present invention to provide improved impedance matching transformers of fixed effective length suitable for rigid connection in a system.

It is still another object of the present invention to provide improved impedance transformers having a minimum number of adjustments and a maximum range of transformations.

It is a further object of the present invention to provide improved impedance matching transformers including high efficiency joints therein for reducing the effects of sliding contact.

It is a still further object of the present invention to provide improved sliding joints for concentric transmission line devices.

It is another object of the present invention to provide improved means for adjustably connecting one concentric transmission line in shunt with a second.

Further objects and advantages of the present invention will become apparent from the following specification and drawings, in which,

Fig. 1 shows a longitudinal cross-sectional view partly in elevation of one form of the present invention;

Fig. 2 shows an enlarged cross-section of a detail of the device of Fig. 1 taken along lines 2-2 thereof;

Fig. 3 shows an enlarged elevational view of a detail of the device of Fig. 1 taken along lines 3-3 thereof; and

Fig. 4 shows an admittance bipolar coordinate diagram useful in explaining the theory of operation of the device of Figs. 1-3.

Referring to Figs. 1 to 3, there is shown one form of impedance transformer adapted to efficiently couple and match two arbitrary impedances or to transform an arbitrary impedance into any other impedance. Impedance transformer 11 of Fig. 1 comprises a pair of stationary concentric line end sections 12 and 13 which are adapted to be coupled fixedly to the impedances to be matched by means of suitable concentric line couplings (not shown) which may be of any desired type. Sections 12 and 13 may be of any convenient length. Transmission line 12 comprises an inner conductor 14 and an outer conductor 15 held in proper relation by suitable insulating discs 17 and 18. Insulating discs 17, 18 may be provided at suitable points along the length of line 12 as required by considerations of mechanical support. Preferably, however, these insulating spacers are placed in

pairs having their centers spaced apart by a distance electrically equivalent to a quarter wavelength or 90 electrical degrees of the operating frequency. By so doing, the effect of these insulating spacers, due to the discontinuity they present in the dielectric medium within line 12, is greatly minimized, and standing waves caused thereby are substantially eliminated.

Thus, considering for example an electromagnetic wave travelling from left to right down conductor 12, such a wave would meet a dielectric discontinuity at the spacer 17 and a portion of this wave will be reflected thereby. Another portion of the wave will be transmitted further to the right and will be reflected by spacer 18. These two reflected waves will be superposed in the portion of the line 12 to the left of spacer 17. Since spacers 17 and 18 have been placed a distance apart equivalent to a quarter wavelength, the wave reflected by spacer 18 will be a half-wavelength or 180° out of phase with respect to the wave reflected by spacer 17, and these two waves will tend to neutralize and cancel one another. In this way, the electrical effects of such insulating spacers, which are necessarily present because of the mechanical considerations of the device, are minimized and substantially eliminated.

The impedance transformer 11 of Fig. 1 is adapted to provide an adjustable short-circuited stub transmission line in shunt with the concentric lines 12 and 13, the point of connection of this shunt line section with the concentric lines 12, 13 being made adjustable longitudinally of lines 12, 13. For this purpose, inner conductor 14 of line 12 and inner conductor 19 of line 13 are joined by a conductor 22 which together with a slidable tubular shell 23 form a central concentric transmission line section joining lines 12 and 13 in cascade.

Conductor 22 is made of larger diameter than inner conductors 14 and 19, and is joined to them at each end by respective tapered portions 24 and 25. The diameters of inner conductor 22 and outer conductor 23 are so chosen that the characteristic impedance of the transmission line 22, 23 will be equal to that of lines 12, 13. In order to join lines 12 and 13 smoothly and without reflections or mismatch to line 22, 23, respective internally tapered portions 26, 27 are attached to outer conductors 16 and 21 of lines 12 and 13. The internal tapers of portions 26 and 27 are so selected and are so placed relative to tapered portions 24, 25 of inner conductor 22, that the ratio of inner conductors 14, 24, 22, 25, 19 to the respective outer conductors 16, 26, 23, 27, 21 remains uniform and constant for the entire length of the impedance transformer 11, thereby assuring a uniform characteristic impedance and substantially no reflections or mismatch which might provide undesirable standing waves and consequent reduced efficiency and other attendant disadvantages.

The internally tapered portions 26, 27 are provided with cylindrical outer surfaces 28, 29 having diameter just slightly smaller than the internal diameter of tubular shell 23 whereby portions 26 and 27 do not contact shell 23, and shell 23 may be easily slid along the device. To provide electrical contact between shell 23 and outer conductors 16, 26 and 27, 21 to complete the main line section of the device, connecting discs 31 and 32 are provided fastened to outer conductors 16 and 21 and provided at their peripheries with spring fingers 33 and 34 extending peripherally

therearound and adapted to form good electrical contact with shell 23.

In this manner, shell 23 may be axially displaced along lines 12, 13 without in any way changing the electrical properties of the cascaded lines 14, 16; 24, 25; 22, 23; 25, 27; and 19, 21. In order to provide efficient electrical contact between shell 23 and the stationary outer conductors of these lines it is most desirable that very low resistance appear at the innermost ends of the internally tapered portions 26, 27 which are the points at which the electric currents flowing along the outer conductor of the device would cross from outer conductor 21 or 16 to shell 23. For this purpose, the axial length of the cylindrical outer surface of each of the tapered sections 26 and 27 is made to be electrically exactly a quarter wavelength of the operating frequency, and their outer diameters are selected to be as nearly equal to the inner diameter of shell 23 as possible without obtaining direct mechanical contact. In this way, sections 26 and 27 form quarter wavelength low impedance concentric transmission line sections with outer conductor 23. Furthermore, the spacing between the outermost edges such as 36, 37 of portions 26, 27 from the innermost surfaces 28, 29 of contacting discs 31, 32 is also made to be electrically equivalent to a quarter wavelength of the operating frequency whereby a second quarter wave section of concentric transmission line is formed by shell 23 serving as outer conductor, and conductors 16 and 21 of lines 12, 13 serving as inner conductors. In order to make the characteristic impedance of the latter sections as large as possible, the outer diameter of conductors 16 and 21 is reduced by thinning the wall thickness thereof, whereby the impedances of these sections is increased without affecting that of lines 12 and 13.

It will be seen that the quarter wave line 16, 23 is short-circuited at the left by disc 31, this short-circuit being produced by the low radial resistance of disc 31 in series with the contact resistance between fingers 33 and outer conductor 23. This fairly low impedance will be transformed by the high impedance line 16, 23 to a high impedance at point 36 having the value

$$\frac{Z^2}{R}$$

where Z is the characteristic impedance of line 16, 23 and R is the short-circuiting resistance. It will be noted that this value will be extremely high due to the low value of resistance R and to the high value of the characteristic impedance Z.

By the action of the low impedance quarter wave line section 26, 23 this high impedance is transformed to a low impedance having the value

$$R \cdot \left(\frac{Z'^2}{Z^2} \right)$$

at the innermost end of tapered section 26 where Z' is the characteristic impedance of line 26, 23. Since Z' is much smaller than Z, it will be clear that the effective gap resistance at the innermost point of tapered portion 26 will be much lower than the contact resistance between fingers 33 and sleeve 23, and in this manner a highly efficient and extremely low resistance sliding joint between outer conductor 16 and 23 is provided. If desired, further alternately high and low impedance quarter-wave sections formed similarly to 16, 23 and 26, 23 may be inserted here to further decrease the ultimate gap resistance.

As described above, line section 16, 23 forms a

quarter-wave section short-circuited at the left by disc 31 and fingers 33. As is well-known, such a line section has a current antinode or loop at the shorting point, resulting in relatively high current intensity. This high current flowing through the contact resistance of fingers 33 would produce high losses. To minimize these losses, fingers 33 are made of substantial length relative to a quarter wavelength of the operating frequency whereby the actual sliding contact occurs at a point of lower current intensity, thus reducing losses and heating.

It will be clear that the same type of joint is provided between outer conductor 21 and sleeve 23.

In order to adjustably insert a shunt section of concentric transmission line, shell 23 is connected perpendicularly to an outer conductor 41 which cooperates with inner conductor 42 to provide a concentric transmission line section 43. To connect this section 43 in shunt with section 22, 23 it is necessary to connect inner conductor 42 to inner conductor 22. However, as described above, it is also desired to adjust the point of connection of line section 43 with respect to line 22, 23.

For this purpose, conductor 22 is formed with a longitudinally extending slot 44 shown more clearly in Figs. 2 and 3. The end of conductor 42 is provided with an internally circularly rounded portion 46 for cooperation with conductor 22 to provide an extremely small gap between conductors 22 and 42. Suitably fixed to inner conductor 42, as by soldering, etc., is a flat metallic plate 47 extending axially of conductor 42 and within the slot 44 of conductor 22. In this manner, conductors 22 and 42 may be connected in high frequency fashion through the large capacitance formed by the small arcuate gap between conductors 22 and 42 and by the small gap between plate 47 and conductor 22. In order to increase and maintain this capacitance substantially constant, a pair of dielectric plates 48, 49 are preferably fixed to either side of plate 47 to maintain its spacing constant relative to slot 44.

In order to provide as large a capacitance and as small an impedance as possible, it is desirable to have plate 47 of substantial extent along the axis of conductor 22. However, any length in either direction from the center exceeding a quarter wavelength would be superfluous and inefficient, since the effective capacitance becomes a maximum for a quarter wavelength of conductor. Accordingly, the length of plate 47 along the axis of conductor 22 is preferably made substantially equal to a half wavelength, although it may be less if desired. In this manner, the line section 43 may be axially adjusted in position along the line section 22, 23, an efficient connection being provided by the means just described.

Preferably the length of slot 44 in conductor 22 is made of such length that at least a half-wavelength of adjustment of the tapping point of connection between sections 43 and 22, 23 may be provided.

In order to suitably adjust the length of line section 43, a slidable plunger 51 is provided having a shorting disc 52 provided with spring fingers 53, 55, and thereby serves to interconnect the inner conductor 42 and outer conductor 41 through a fairly low resistance. In order to still further reduce this contact resistance, impedance transforming means are provided similar to that described with respect to the sliding joint between conductors 16, 21 and sleeve 23.

For this purpose, a cylindrical shell 54 is suitably fastened to shorting disc 52, and concentrically thereof. At the opposite end, shell 54 is connected to an annular disc 56 which is spaced only slightly from inner conductor 42 and outer conductor 41 by suitable thin rings of dielectric material, such as 57 and 58. The length of cylindrical shell 54 as measured between the inner face 59 of plunger 52 and the outer face 61 of annular disc 56 is selected to be electrically equivalent to a quarter wavelength of the operating frequency. The axial thickness of disc 56 is also chosen to be electrically equivalent to a quarter wavelength. Since dielectric material is provided between disc 56 and both inner conductor 42 and outer conductor 51, the physical length required for conductor 56 will be substantially less than a quarter wavelength in free space.

In this manner, shell 54 and outer conductor 41 form a high impedance quarter-wave line section short-circuited at the outer end by the contact resistance between fingers 53 and outer conductor 41. This line section is in cascade with the low impedance quarter-wave section 56, 41, whereby the contact resistance between disc 52 and conductor 41 is transformed to point 62 as a much lower resistance in the manner already described above.

At the same time, shell 54 and inner conductor 42 form a high impedance quarter-wave line which together with the low impedance quarter-wave line formed by ring 56 and inner conductor 42 also serves to transform the contact resistance between fingers 55 and inner conductor 42 to a much lower resistance at point 63. In this way, extremely low effective contact resistances are produced at points 62, 63, whereby the lower face of annular disc 56 provides an effective short-circuiting plug or piston for line section 43.

As noted above, it is desirable that the characteristic impedances of the two cascaded quarter-wave line sections forming the contact resistance transformer have as high a ratio as possible in order to provide the lowest transformed contact resistance. For line 54, 41 this would necessitate the smallest possible outer diameter of shell 54. However, for line 54, 42 this would necessitate the largest innermost diameter of shell 54. Since these two conditions are mutually exclusive, and since the net contact resistance provided by annular disc 56 is the sum of the resistances reflected at points 62, 63, which is to be minimized, shell 56 is made to be as thin as possible and its diameters are so chosen that the characteristic impedances of line sections 42, 54 and 54, 41 are substantially equal. This requires that the average diameter of shell 54 be substantially the geometric mean between the diameters of inner conductor 42 and outer conductor 41. In this manner a minimum effective contact resistance is obtained.

In order to suitably adjust the position of shorting plunger 56 along line section 43, several thrust rods are provided, of which two, namely, 64 and 66, appear in the section taken. These rods are fastened to disc 52 and are movable axially of line 43 by means of a suitable screw 67 threaded into member 68, to which rods 64, 66, etc., are also fastened. In this manner, both the length of the line section 43 and its point of connection in shunt with the concentric line formed along the major axis of the device may be suitably adjusted, and by so doing the arbitrary impedance connected at the end of one

of lines 12 and 13 may be properly and efficiently transformed to any other impedance at the end of the other line 13 or 12. It will be clear that any other suitable adjusting means may be used.

The operation of the device of Fig. 1 may be explained by reference to Fig. 4 which shows an admittance diagram having coordinate axes representing conductance g and susceptance b , as shown. Point Y_0 on this diagram represents the characteristic admittance of lines 22, 23; 14, 16 and 19, 21 which are all equal, as discussed above.

If an arbitrary admittance represented by point Y_1 is connected to an adjustable length transmission line having characteristic admittance Y_0 , it may be shown that the admittance Y_1' , looking through the line toward Y_1 , may be represented by the equation

$$Y_1' = \frac{Y_0 \sinh \mu + j Y_0 \sin (\phi + \pi 4x)}{\cosh \mu - \cos (\phi + 4\pi x)}$$

where μ and ϕ are quantities defined by

$$\coth \mu = \frac{G_1^2 + B_1^2 + Y_0^2}{2Y_0 G_1}$$

and

$$\cot \phi = \frac{G_1^2 + B_1^2 - Y_0^2}{2Y_0 B_1}$$

Here x is the length of line in wavelengths, G_1 is the conductance of Y_1 and B_1 is the susceptance of Y_1 . Graphically, the locus of resultant admittance Y_1' as x varies as given by the circle defined by setting μ equal to zero, which may be termed a bipolar coordinate circle having Y_0 as pole. Such a circle is shown at 70 in Fig. 4. For each added half-wavelength of line, one complete traverse of circle 70 is made by Y_1' .

Accordingly, if an admittance Y_1 is connected to one end, say the left end, of the transformer of Fig. 1, the resultant admittance Y_1' looking left from the tap point 45 will vary clockwise from Y_1 along circle 70 as the tap is moved from left to right.

If it is desired to produce a transformed admittance Y_2 at the right end of transformer 11, then the admittance Y_2' at point 45 looking to the right, which is required to produce Y_2 at the end of the line, will lie somewhere on the bipolar coordinate circle 71 passing through Y_2 displaced counter-clockwise from Y_2 , depending on the position of point 45. As tap 45 moves rightward, Y_2' also moves clockwise about Y_0 . Since one of these circles 70 is completely within the other circle 71, it will be clear that for some particular setting of the junction 45, Y_1' and Y_2' will be one directly above the other; that is, they will differ only by pure susceptance. Such a position is shown by Y_1'' and Y_2'' in Fig. 4.

When such a position is found, the admittance Y_2'' and therefore the desired transformed admittance Y_2 at the right end may be produced by adjusting the position of plunger 51 to add or subtract the required amount of susceptance to admittance Y_1'' . In this manner any arbitrary admittance Y_1 at one end of transformer 11 may be transformed into any other arbitrary admittance Y_2 at the other end.

Since in practice the condition of matching or proper transformation is most usually tested by observing the standing wave ratio or power output, it will be clear that these two adjustments, namely that of the position of the junction point 45 and of the position of plunger 52, 75

must be adjusted by trial and error to produce the desired result. Usually this will be done by setting one of these values to an optimum position, which generally will not be the desired condition, and then resetting the other to improve upon this optimum condition. Thus by alternately resetting each of the two adjustable portions of the device, the proper transforming condition can be obtained after only a few manipulations.

Throughout this description, wherever the electrical lengths of a quarter of half-wave-length are used, it is to be understood that an odd multiple or an even multiple, respectively, of a quarter-wavelength may be used equally as well.

Wherever the term "electrical length" is used in the present specification, it is to be understood as meaning a physical length of such value as to give the same electrical effect as a physical length equal to the electrical length would yield in free space. All wavelengths are referred to waves in free space.

All distances referred to in terms of wavelength are intended to be electrical lengths as defined above.

As many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. An impedance transformer for transforming an arbitrary impedance into any other desired impedance, comprising a pair of concentric line end sections, a conductor joining the inner conductors of said sections, an axial slot formed along said joining conductor, an outer conductor cooperating with said slotted conductor to form a concentric transmission line therewith, means for slidably adjusting said first outer conductor along the outer conductors of said sections, a further outer conductor fixed perpendicularly to said first outer conductor, an inner conductor fixed concentrically within said further outer conductor, means slidably connecting said last inner conductor to said slotted conductor in high frequency fashion, comprising a flat extension of said last inner conductor slidably engaging within said slot, and means adjustably short-circuiting said last outer and inner conductors, whereby any one impedance connected to one of said end sections may be transformed to any other impedance at the end of the other of said end sections by adjustment of the connection of said inner and slotted conductors and by adjustment of said short-circuiting means.

2. An impedance transformer for transforming an arbitrary impedance value into any other desired impedance value, comprising a first section of concentric transmission line, a pair of concentric line end sections, means connecting the outer conductors of said end sections and said line section comprising a pair of contacting discs each radially extending from the outer conductor of each of said concentric line end sections to the outer conductor of said first transmission line section, said contacting discs having axially extending fingers at the periphery thereof to prevent the escape of energy endwise of said first line section, a second section of a concentric transmission line located perpendicularly to said

first line section, and having a center conductor, one end of said center conductor being capacitively coupled with the center conductor of said first line section and a radially extending contacting diaphragm located between said second center conductor and the outer conductor of said second line section and having spring fingers attached thereto, whereby an efficient transmission of energy is provided.

3. An impedance transformer for transforming an arbitrary impedance value into any other desired impedance value, comprising a pair of concentric line end sections, a conductor joining the inner conductors of said end sections and having an axial slot formed along said joining conductor, a first outer conductor cooperating with said slotted conductor to form a concentric transmission line section therewith, means for slidably adjusting said first outer conductor along the outer conductors of said end sections, a pair of axially-adjustable contacting discs each extending radially from the outer conductors of said end sections to the first outer conductor and having axially extending spring fingers thereon, a second outer conductor fixed perpendicularly to said first outer conductor, an inner conductor fixed concentrically within said second outer conductor, means slidably connecting said inner conductor to said slotted conductor in high frequency fashion and consisting of a flat extension of said inner conductor slidably engaged within said slot, and a further axially-adjustable contacting disc extending between said inner conductor and said second outer conductor and having axially extending fingers thereon, whereby any one impedance value connected to one of said end sections may be transformed to any other impedance value at the end of the other of said end sections by adjustment of the connection of said second inner and slotted conductors and by adjustment of said contacting discs and said further contacting discs.

4. An impedance transformer comprising a pair of concentric line sections, a conductor joining the inner conductors of said sections, an axial slot in said joining conductor, an outer conductor

surrounding said joining conductor concentrically, means for slidably adjusting said outer conductor along the outer conductors of said sections, a further outer conductor fixed to and extending transversely from said first mentioned outer conductor, an inner conductor concentric within said further outer conductor, and an extension on said inner conductor slidably engaging within said slot in said slotted conductor.

5. An impedance transformer comprising a pair of concentric line sections, a conductor joining the inner conductors of said sections, an axial slot in said joining conductor, an outer conductor surrounding said joining conductor concentrically, means for slidably adjusting said outer conductor along the outer conductors of said sections, a further outer conductor fixed to and extending transversely from said first mentioned outer conductor, an inner conductor concentric within said further outer conductor, a flat extension on said inner conductor slidably engaging within said slot in said slotted conductor, and means for adjusting the effective electrical length of said inner conductor within said transversely extending outer conductor.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,929,878	Clavier	Oct. 10, 1933
2,213,054	Schussler	Aug. 27, 1940
2,226,479	Pupp	Dec. 24, 1940
2,267,539	Thorne	Dec. 23, 1941
2,342,254	Dallenbach	Feb. 22, 1944
2,373,233	Dow et al.	Apr. 10, 1945
2,401,205	Usselman	May 28, 1946
2,438,912	Hansen et al.	Apr. 6, 1948

FOREIGN PATENTS

Number	Country	Date
508,297	Great Britain	June 28, 1939