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3,337,821

TRANSMISSION LINE TUNING ARRANGEMENT

Filed Dec. 26, 1963

3 Sheets-Sheet 1

FIG. 1A

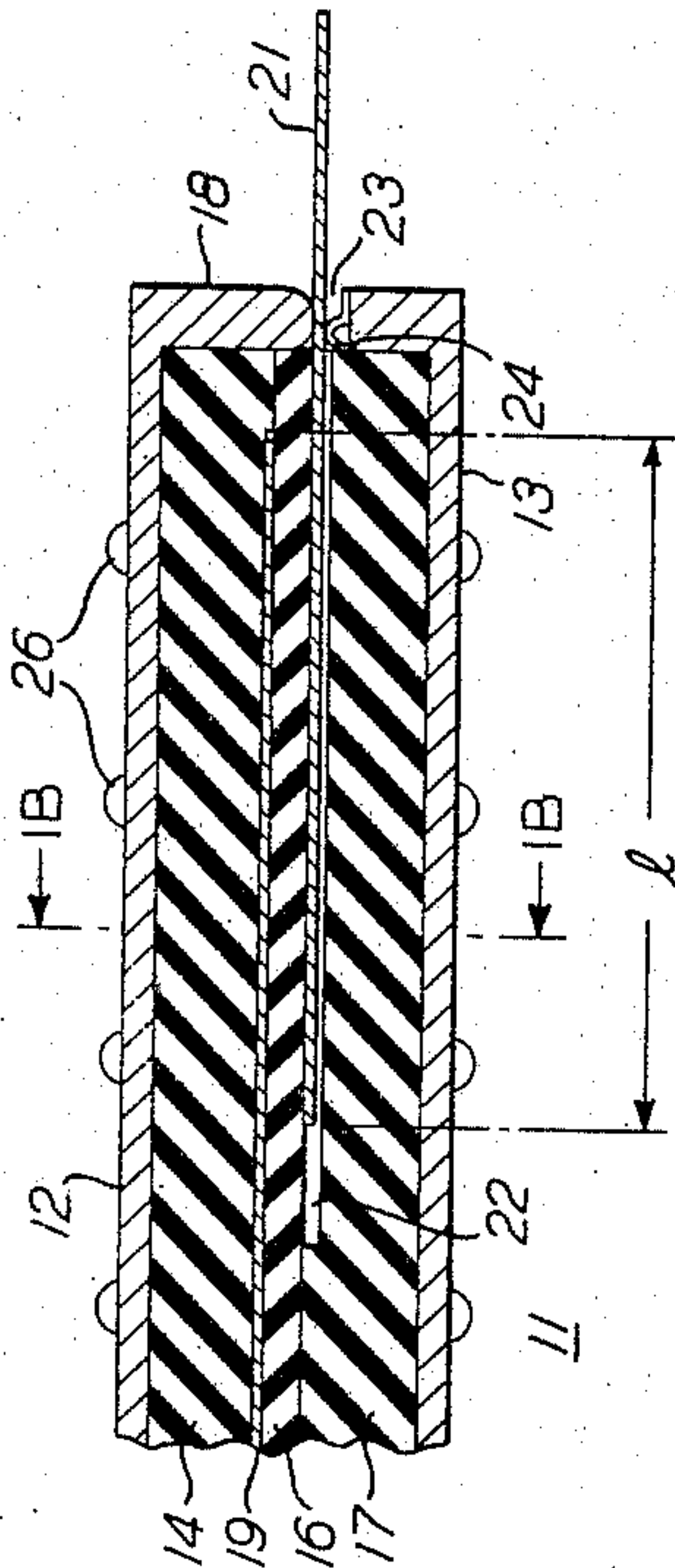


FIG. 1B

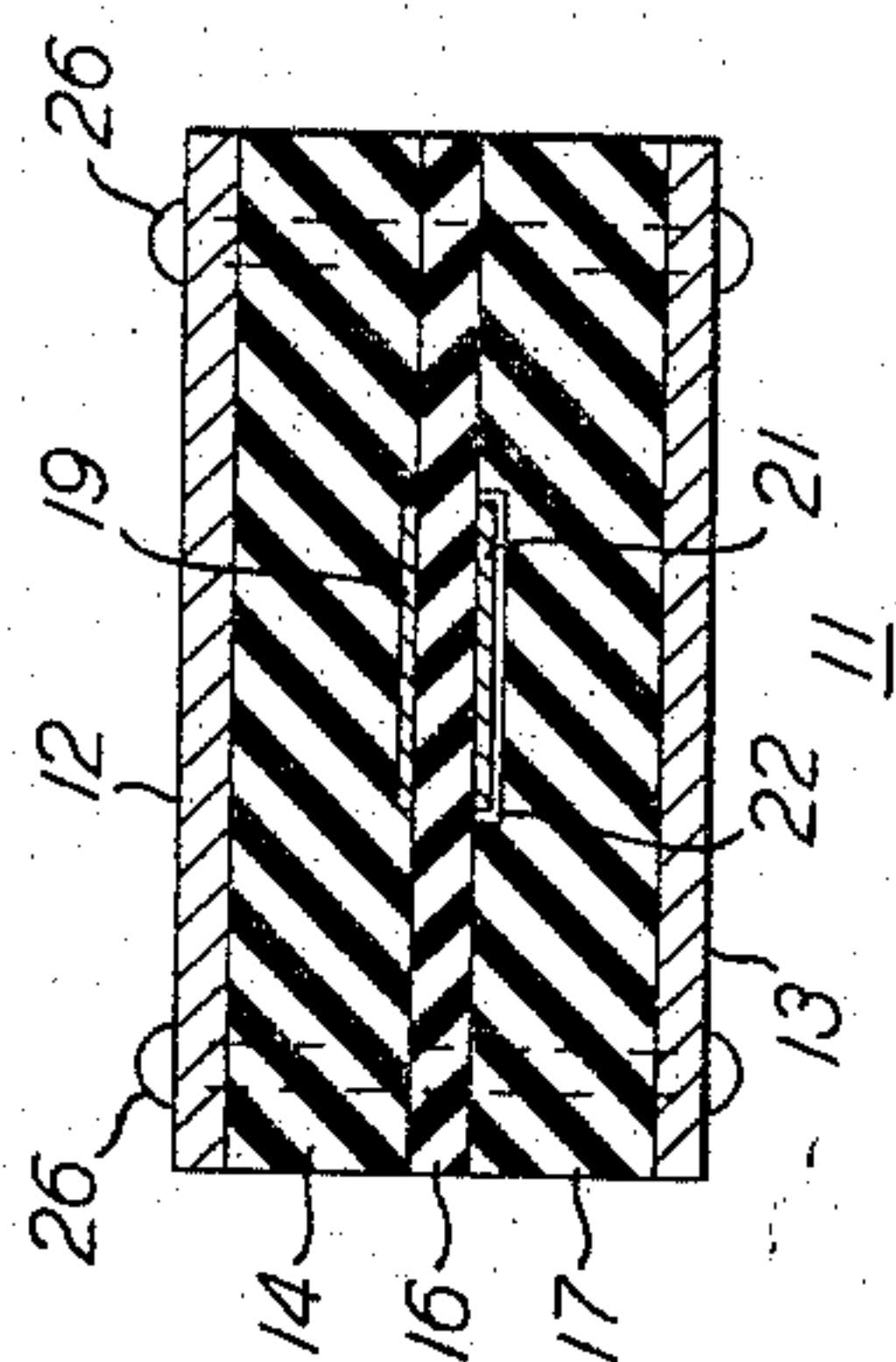


FIG. 2

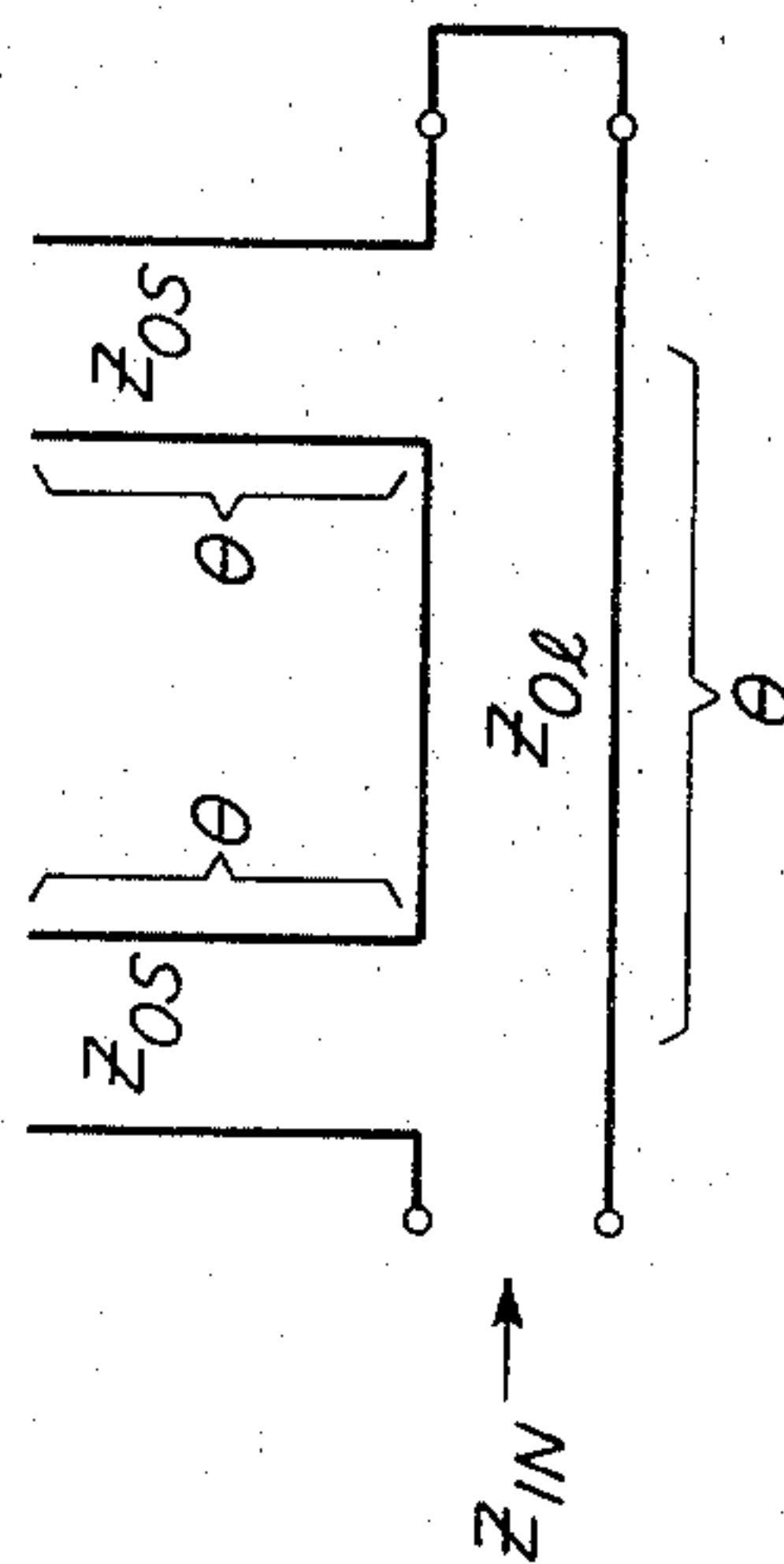
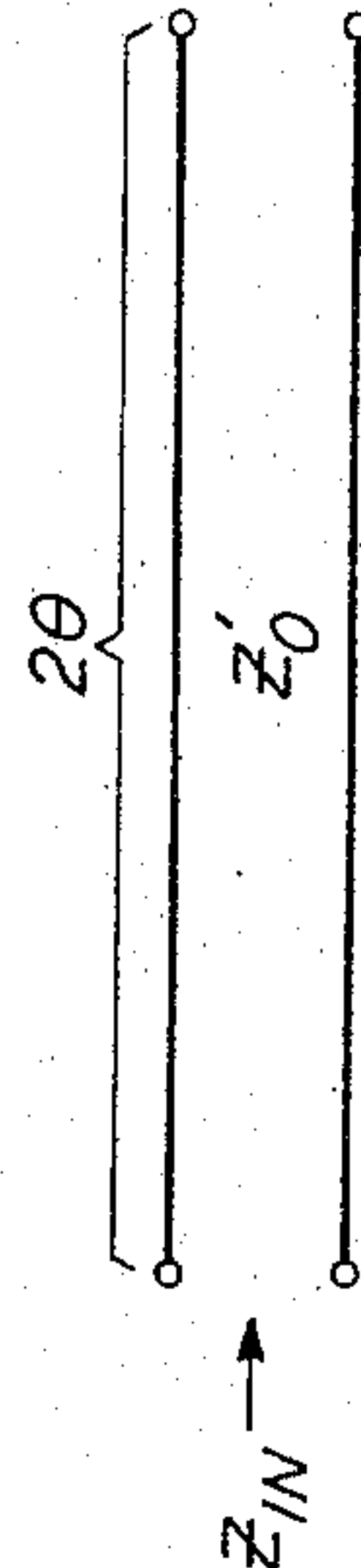


FIG. 3



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FIG. 5A

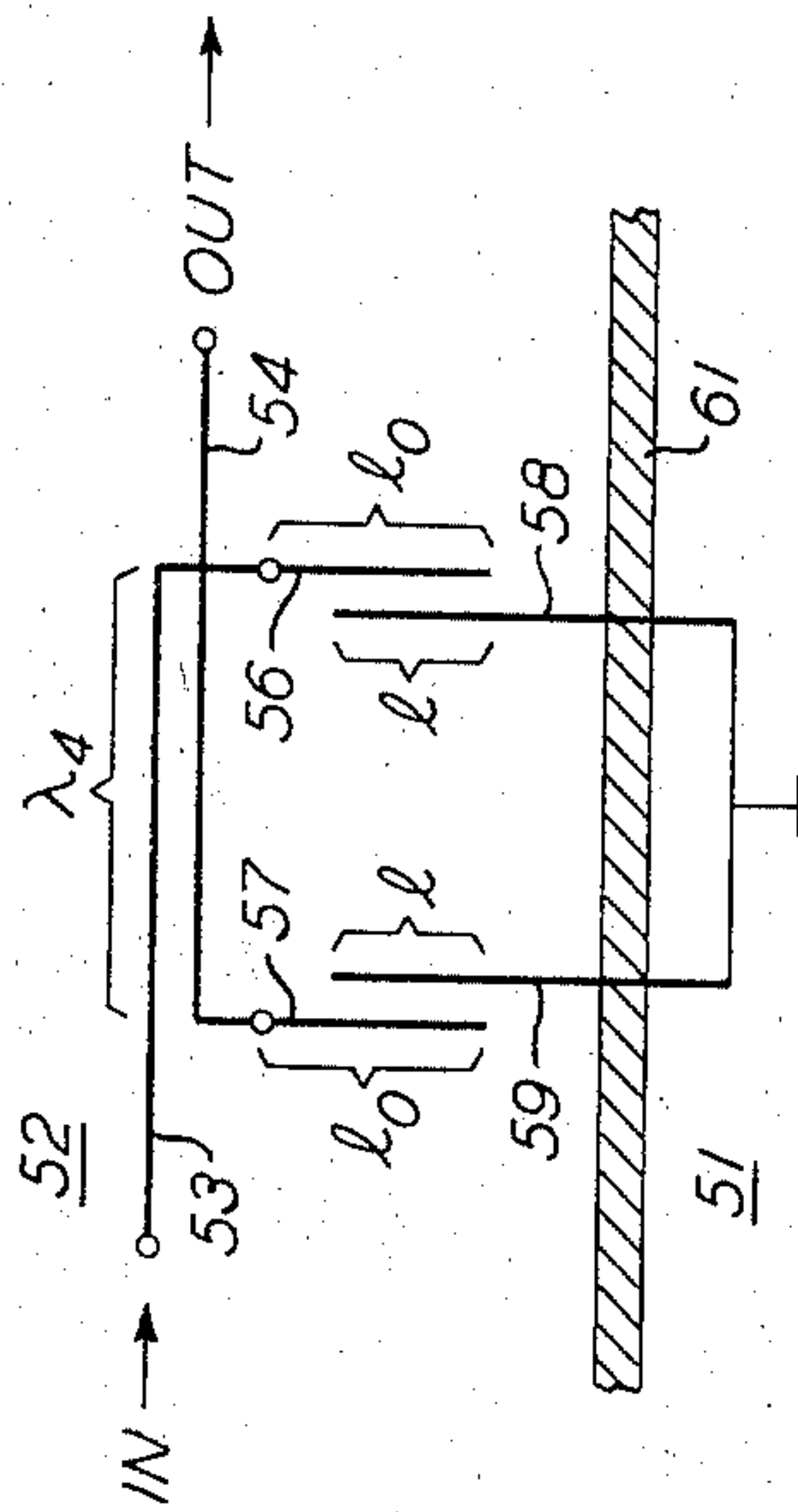


FIG. 5B

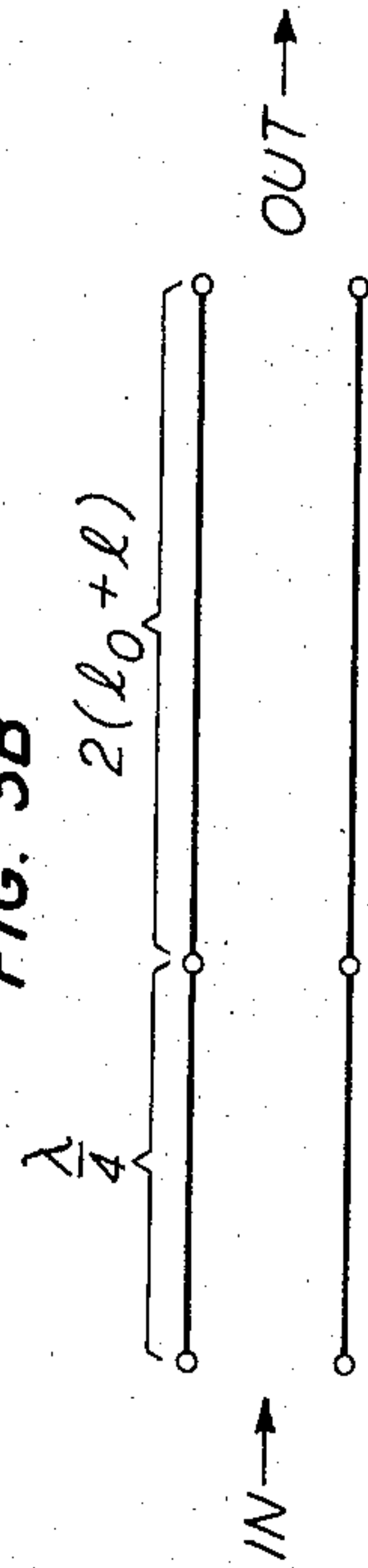


FIG. 6B

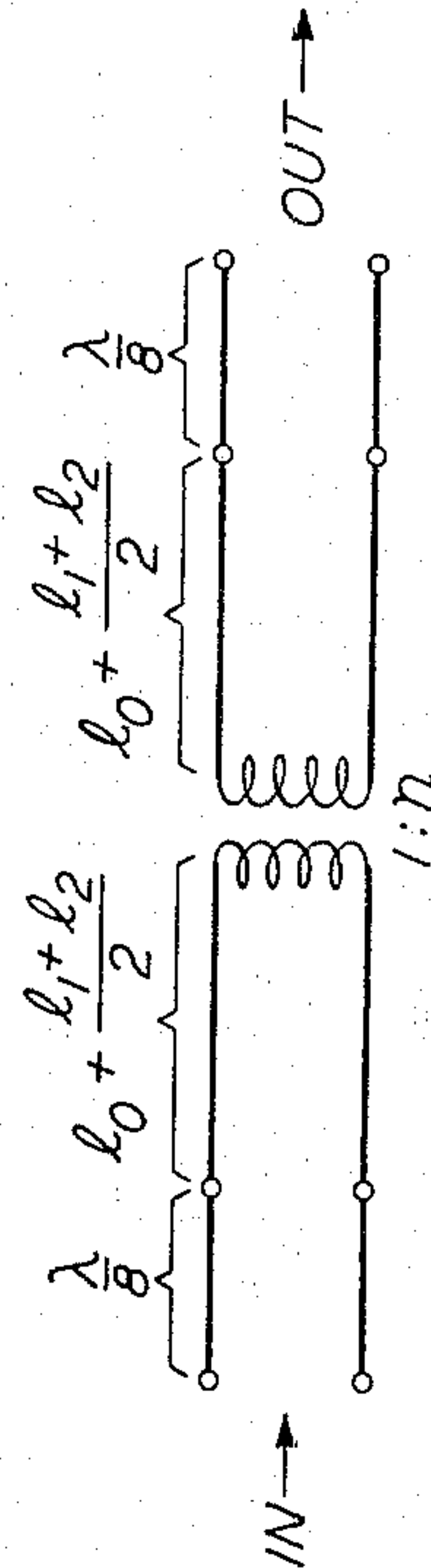


FIG. 4

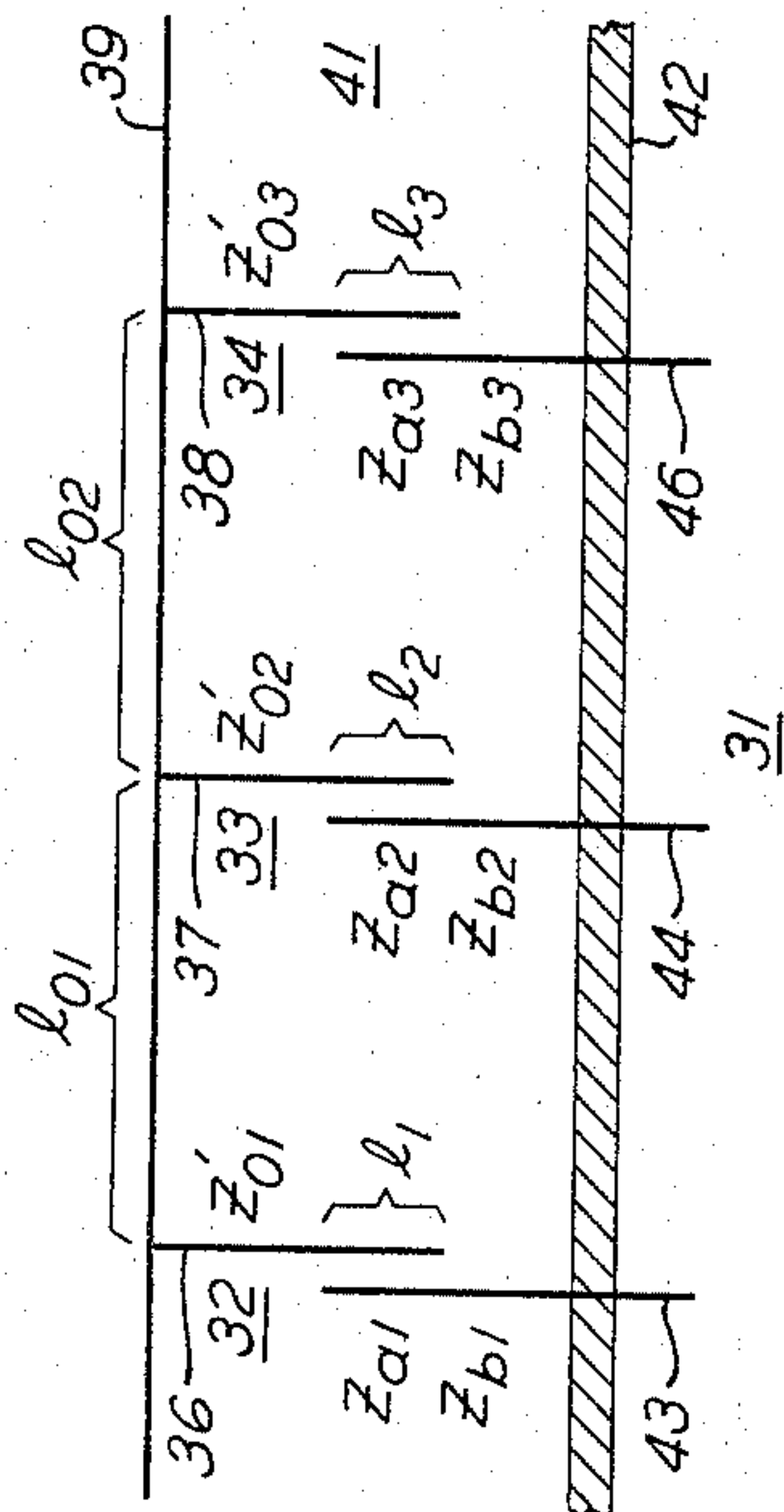
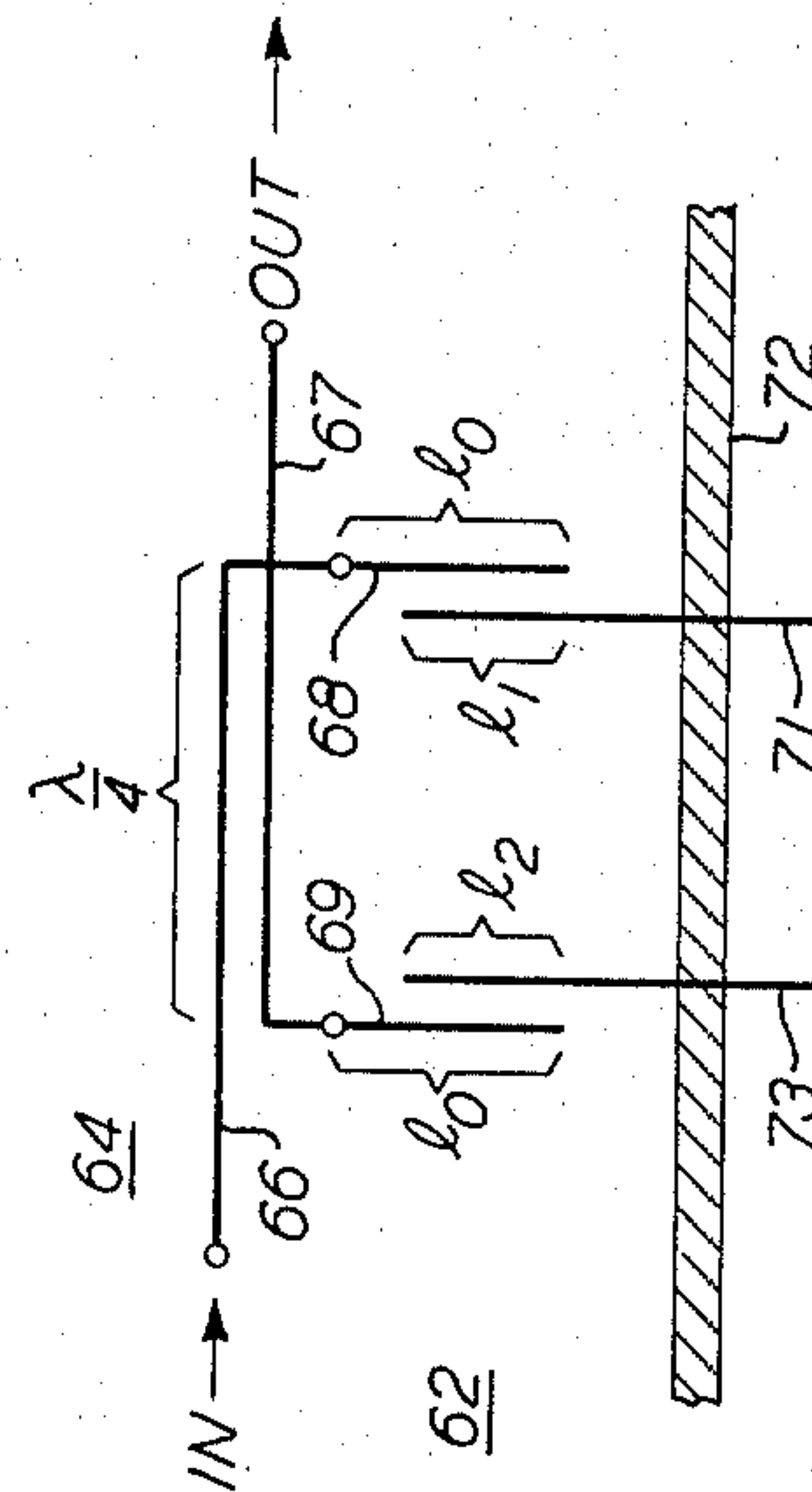


FIG. 6A



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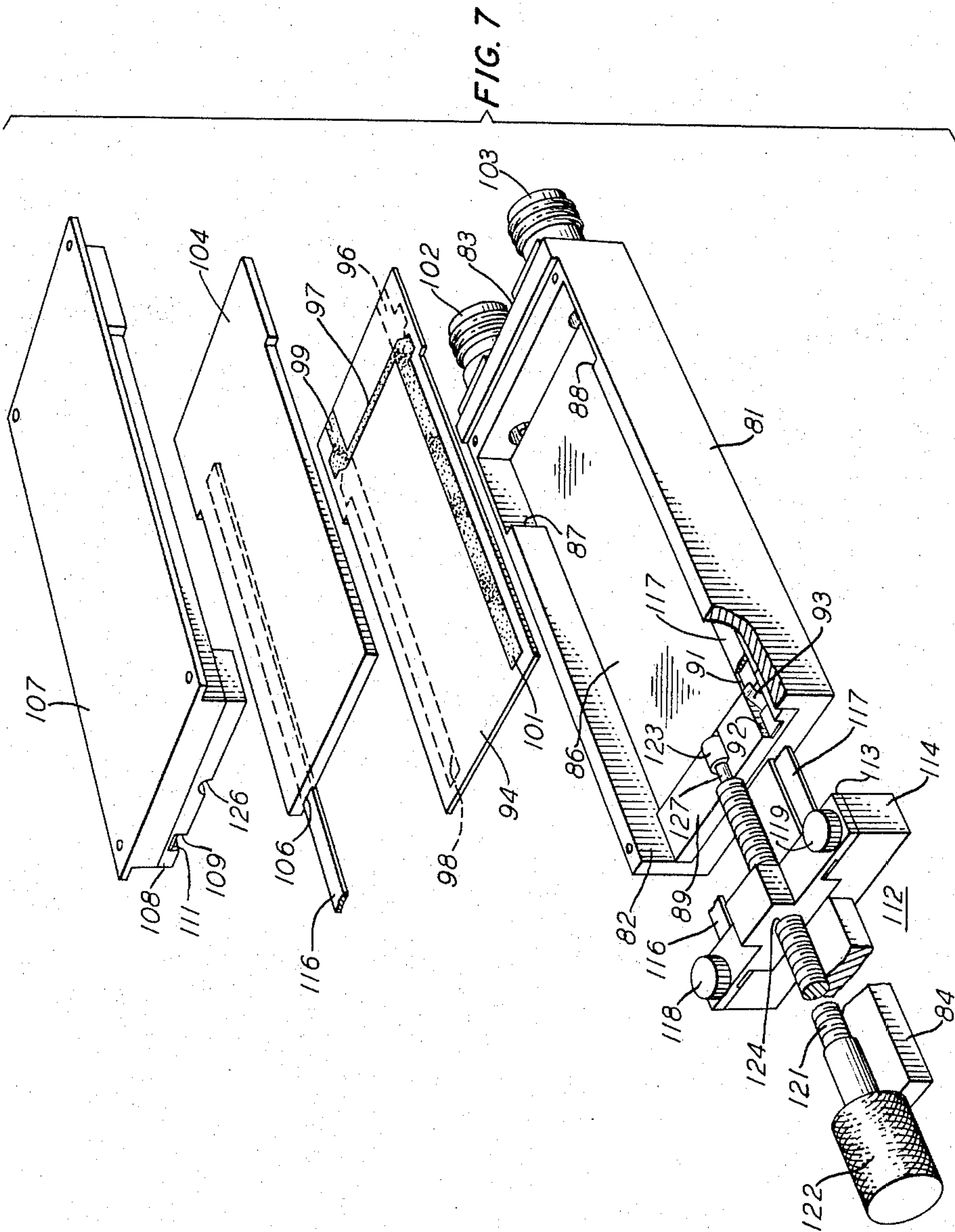
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TRANSMISSION LINE TUNING ARRANGEMENT

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3,337,821

TRANSMISSION LINE TUNING ARRANGEMENT
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5 Claims. (Cl. 333-73)

This invention relates to electrical transmission lines, and, more particularly, to high frequency transmission lines and tuning arrangements therefor.

At the present time, the two most common types of microwave transmission lines which are used in communication systems are the coaxial cable and the waveguide. Both of these types of transmission lines suffer from certain drawbacks. In the case of coaxial cables, they are quite difficult to manufacture, and, although they can be used over extended distances, the cost of manufacture increases for increased distance. Waveguides, on the other hand, do not lend themselves to use over extended distances, and, because of the close tolerances required, are even more difficult and expensive to manufacture than the coaxial cable. However, the waveguide is useful at much higher frequencies than is the coaxial cable.

As an alternative to both the coaxial cable and the waveguide, a third type of transmission line which combines the good feature of both the cable and the waveguide is becoming more and more useful, especially in communications. This line, known as the "strip line" is manufactured through the use of printed circuit techniques. In general, the strip line consists of a pair of spaced planar outer conducting members, commonly referred to as ground planes, and an inner conducting member spaced between the two ground planes and held in place by dielectric material which fills the space between the two ground planes. Such a transmission line is relatively easy to manufacture and is capable of transmitting extremely high frequencies, in addition to which it has a broad frequency bandwidth characteristic.

In waveguide and coaxial cable microwave circuits, tuning is most frequently accomplished by varying the length of the transmission line elements. Examples of such tuners are T-stub tuners having adjustable short circuited stubs, E-H tuners having adjustable short circuits on the E and H arms of a hybrid, and line stretchers in which a constant impedance line of varying length is obtained by means of sliding metallic contacts. Previous attempts to construct the counterparts of such tuning arrangements for strip transmission line arrangements have not, because of the unusual nature of the strip line, been entirely successful. Because of the small space available in a strip line, precise machining of the parts in adjustable shorts has heretofore been necessary. In addition, firm contact between the sliding and fixed parts of the tuner is usually required. This means that free motion of the sliding part is difficult to obtain because of friction with the dielectric. This requirement of firm contact also produces wear on the center conductor after prolonged use since the center conductor is usually made of soft copper. When using extended sections of overlapping center conductors, as in the case of line stretchers, instability of the dielectric material often causes erratic shifts in the contact points or areas between the center conductors which, in turn, produce erratic or unstable transmission characteristics.

The objects of the present invention are to produce variable tuning in strip transmission lines with structures that eliminate conductor wear, are freely movable, are stable in their transmission or electrical characteristics and do not require precise machining of parts.

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These and other objects of the present invention are achieved in a first illustrative embodiment thereof which comprises a stub-tuning section which functions in the manner of an adjustable short-circuited stub or line stretcher. The tuning section comprises a stationary section of strip line having a fixed center conductor, and a movable center conductor contained in a groove in the dielectric material and spaced from the fixed center conductor and electromagnetically coupled thereto. The movable conductor is electrically shorted to the ground planes of the line and is slidable within its groove longitudinally with respect to the fixed conductor. As will be explained more fully hereinafter, when certain conditions are satisfied, the tuner is substantially frequency independent and stable in its electrical characteristics. As a consequence, it functions as a tuner for a strip-line transmission system over the frequency range of the system.

In a second illustrative embodiment of the invention, a plurality of individually variable tuning stubs of the type just described are connected to a strip transmission line to produce a variable Q filter. Such filters, as is well known, are useful in controlling the bandpass characteristics of a transmission line. As will be more apparent hereinafter, proper choice of the spacing of the stubs and the effective impedance thereof produces any desired bandpass characteristic over a wide range.

In another illustrative embodiment of the invention, a directional coupler having an adjustable stub tuner in each arm thereof functions as a line stretcher. The stubs are ganged together and movable to vary the length of the region over which they are coupled to the stationary line thereby effecting a variation in the electrical length of the line.

In still another embodiment of the invention, a directional coupler having a tuning stub in each arm thereof functions as an impedance transformer. Each of the stub tuners is movable independently and, as will be explained more fully hereinafter, the effective turns ratio of the transformer is governed by the difference in effective electrical length between the two stub tuners.

It is a feature of the present invention that a stub-tuning section for a strip line is substantially completely frequency independent, and there is no physical contact between the movable inner conductor of the stub and the fixed inner conductor which is connected to the inner conductor of the strip line.

It is another feature of the present invention that a basic strip line tuning stub configuration can be used to provide a plurality of functions, such as line stretching, impedance transforming, and bandpass filtering.

These and other features of the present invention will be more readily apparent from the following detailed description, taken in conjunction with the accompanying drawings, in which:

FIG. 1A is a sectional view of one embodiment of the invention;

FIG. 1B is a cross-sectional view of the arrangement of FIG. 1A;

FIG. 2 is a schematic view of the equivalent circuit of FIG. 1A;

FIG. 3 is another schematic of the equivalent circuit of FIG. 1A;

FIG. 4 is a schematic of a bandpass filter utilizing the present invention;

FIG. 5A is a schematic of a line stretcher utilizing the present invention;

FIG. 5B is a schematic of the equivalent circuit of the arrangement of FIG. 5A;

FIG. 6A is a schematic of an impedance transformer utilizing the present invention;

FIG. 6B is a schematic of the equivalent circuit of the arrangement of FIG. 6A, and

FIG. 7 is an exploded view of a physical embodiment of the arrangement of FIG. 5A.

Turning now to FIGS. 1A and 1B, there is depicted a stub-tuning arrangement 11 embodying the principles of the present invention. FIG. 1A is a side-sectional view of the arrangement and FIG. 1B is a cross-sectional view. Tuner 11 comprises first and second ground plane numbers 12 and 13 of conducting material which are spaced apart by layers 14, 16, 17 of suitable dielectric material and are connected at one end by a conducting plate 18. The other end of tuner 11 is connected to a strip-transmission line which, for simplicity, has not been shown. A thin planar center conductor 19 of suitable conducting material is located between members 12 and 13 and spaced therefrom as shown. Conductor 19 is connected at one end to the strip-transmission line, not shown, and the other end is unconnected. A movable conducting member 21 is also situated in the space between members 12 and 13 and is spaced therefrom and from conducting member 19. Dielectric layer 17 has a groove 22 in which member 21 is located. Groove 22 not only serves to locate member 21 laterally and vertically (in conjunction with layer 16), but also substantially eliminates any friction between member 21 and the dielectric when member 21 is moved back and forth.

Plate 18 has an aperture 23 therein to permit translational movement of member 21. A conductive spring element 24 bears against one surface of member 21, holding it in conductive contact with plate 18 at all times while permitting movement of member 21. A plurality of rivets 26 serve to hold the entire assembly together and also serve as conductive connections between plates 12 and 13.

For an understanding of the operation of tuner 11 of FIGS. 1A and 1B, reference is made to FIGS. 2 and 3.

From an article entitled "Design of Wide-Band (and Narrow-Band) Band-Pass Microwave Filters on the Insertional Loss Basis" by G. Matthaei, I.R.E. Transactions of the Professional Group on Microwave Theory and Techniques, November 1960, pp. 580-593, it can be shown that the equivalent circuit of the arrangement of FIGS. 1A and 1B is as shown in FIG. 2, where $\theta = 2\pi l/\lambda_e$, l being the actual length of the tuning section, that is, the region over which members 19 and 21 are electromagnetically coupled together, and λ_e being the wavelength in the dielectric. The circuit of FIG. 2 is the substantial equivalent of the circuit of FIGS. 1A and 1B provided conductor 21 is quite thin and of the same width as conductor 19.

It is desired to adjust the parameters of the circuit of FIGS. 1A and 1B so that its equivalent circuit is as depicted in FIG. 3, in which case arrangement 11 functions as a tuning stub having an adjustable electrical length. From conventional transmission line theory, as set forth in "Transmission Lines and Networks" by W. C. Johnson, 1st. Ed., 1950, McGraw-Hill, for example, we can derive from Eq. 4.42 (page 105) of that text, substituting $\tan$ for $\tanh$, the input impedance, Z_{in} of the circuit of FIG. 2, which is

$$Z_{in} = \frac{-j[Z_{0s}(2Z_{01} + Z_{0s}) - Z_{01}^2 \tan^2 \theta]}{\tan \theta (Z_{01} + Z_{0s})} \quad (1)$$

and that of the circuit of FIG. 3 by

$$Z_{in} = -jZ_0' \cot 2\theta \quad (2)$$

where Z_{0s} is the impedance of each shunt arm of the circuit of FIG. 2 and Z_{01} the impedance of its series arm, and Z_0' is the equivalent impedance of the circuit of FIG. 3. Equating the two input impedances and using the identity

$$\cot 2\theta = \frac{1 - \tan^2 \theta}{2 \tan \theta} \quad (3)$$

we obtain the following relationships

$$Z_{0s} = (\sqrt{2} - 1)Z_{01} \quad (4)$$

$$Z_0' = \sqrt{2}Z_{01} \quad (5)$$

which are, as can be seen, independent of frequency. Thus where Equations (4) and (5) are satisfied, the circuit of FIG. 2 is the equivalent of the circuit of FIG. 3 independent of frequency.

If, now, we define a first impedance Z_a as the impedance between ground and the conductors 19 and 21 when these conductors are connected together throughout the coupling length l , and a second impedance Z_b as the impedance between conductors 19 and 21 in the presence of ground, then the following relationships exist

$$Z_{0s} = Z_b/2 \quad (6)$$

$$Z_{01} = Z_a - Z_b/4 \quad (7)$$

Substituting (6) and (7) into (4) and (5), we obtain

$$Z_b = \frac{4(\sqrt{2} - 1)}{\sqrt{2} + 1} Z_a \quad (8)$$

and

$$Z_0' = \frac{2\sqrt{2}}{\sqrt{2} + 1} Z_a \quad (9)$$

The impedance Z_a is primarily a function of the width of the conductors 19 and 21, and the spacing between the ground planes 12 and 13. It is also, to a slight extent, a function of the spacing between conductors 19 and 21. Impedance Z_b , on the other hand, is primarily a function of the width of the conductors 19 and 21 and the spacing between them, and also, to a slight extent, of the spacing between members 12 and 13. It is possible, therefore, to vary these two impedances by varying the aforementioned parameters. As a typical example, if it is desired that $Z_0' = 50\Omega$, then we select the parameters to make $Z_a = 42.7\Omega$ and $Z_b = 29.3\Omega$. The net result is that, effectively, conductor 19 is lengthened by a length l (the length of the coupling region) and in conjunction with members 12 and 13, has a characteristic impedance Z_0' . It is readily apparent that the length is readily variable through translational movement of conductor 21, hence the arrangement 11 of FIGS. 1A and 1B is a variable tuner that is independent of frequency over its tuning range.

The adjustable stub tuner 11 of FIGS. 1A and 1B is adaptable to a large number and variety of uses. In FIG. 4, there is shown schematically an arrangement 31 of a multiplicity of stub tuners 32, 33, 34 which functions as variable Q or bandpass filter. Each of the stub tuners 32, 33, 34 comprises a fixed length of transmission lines 36, 37, 38, respectively, attached to the center conductor 39 of a transmission line 41 and spaced at intervals l_{01} , l_{02} . The transmission line 41 further includes a ground plane 42. In addition, stub tuners 32, 33, 34 have movable members 43, 44, 46, respectively, which pass through ground plane 42 and are in electrical contact therewith. Members 43, 44 and 46 electromagnetically coupled to lines 36, 37, 38 over variable coupling lengths l_1 , l_2 , and l_3 , respectively. The various impedances Z_{01}' , Z_{02}' , Z_{03}' are chosen in accordance with well-known prior art techniques, such as the aforementioned Matthaei article, to give the desired filter characteristics. These impedances are achieved by individual adjustment of the coupling lengths l_1 , l_2 , l_3 , as taught in the foregoing. In addition, where a maximum flat variable Q filter is desired, l_{01} , l_{02} , l_{03} are made equal to one-quarter wavelength at the centerband frequency.

In FIG. 5A, there is disclosed a line stretcher or delay line 51 utilizing the principles of the present invention which produces line stretching or delay independent of frequency. Stretcher 51 comprises a 3db directional coupler 52 leaving an input arm 53 and an output arm 54

which are coupled together over a quarter wavelength at the centerband frequency. A fixed transmission line 56 of length l_0 is connected to arm 53 and a fixed line 57 of length l_0 is connected to arm 54, as shown. A pair of movable arms 58, 59 are electromagnetically coupled to lines 56 and 57, respectively, and conductively connected together so that they move in unison. Arms 58 and 59 pass through a ground plane member 61 and are in conductive contact therewith.

In operation, electromagnetic energy on arm 53 is divided equally between arms 53 and 54 in the 3db coupler and passes into lines 56 and 57. Arms 58 and 59 are coupled to lines 56 and 57, respectively, over a coupling line l which varies with the movement of arms 58 and 59. As explained in connection with FIGS. 1A and 1B, this arrangement has the effect of increasing the lengths of lines 56 and 57, each by a length l . Energy is then reflected by through lines 56 and 57 into coupler 52 where it is combined into arm 54. In FIG. 5B, there is depicted the equivalent electrical circuit of the line stretcher 51, of FIG. 5A, arrived at in the manner discussed in connection with FIGS. 2 and 3, with, of course, the length l as a variable. From FIG. 5B it can be seen that the arrangement produces a variable line length or delay for the electromagnetic energy.

In FIG. 6A, there is shown an impedance transformer arrangement 62 utilizing the principles of the present invention as set forth in the foregoing. Transformer 62 comprises a 3db directional coupler 64 having an input arm 66 and an output arm 67 coupled together over a quarter wavelength at the center frequency of interest. A fixed conductor 68 of length l_0 is connected to arm 66 and a fixed conductor 69 of length l_0 is connected to arm 67, as shown. A movable arm 71 which passes through a ground plane 72 and is in electrical contact therewith is electromagnetically coupled to conductor 68 over a coupling length l_1 . A second movable arm 73 which also passes through ground plane 72 and is in electrical contact therewith is electromagnetically coupled to conductor 69 over a coupling length l_2 . Arms 71 and 73 are movable independently of each other, hence, the length l_1 and l_2 can be varied independently.

In FIG. 6B, there is shown the equivalent circuit for the transformer 62 of FIG. 6A, where $1:n$ is the turns ratio of the transformer, and n is given by the expression

$$n^2 = \frac{1 + \sin \beta(l_1 - l_2)}{1 - \sin \beta(l_1 - l_2)} \quad (10)$$

and β is the propagation constant in the dielectric. It can be seen from Equation 10 that where l_1 and l_2 are equal, the turns ratio is unity and transformer 62 becomes the line stretcher of FIG. 5A.

In FIG. 7, there is shown an exploded view of an actual physical embodiment of the line stretcher of FIGS. 5A and 5B. The line stretcher of FIG. 7 comprises a casing 81 of conducting material having an open end 82 and a closed end 83. Integral with casing 81 and extending longitudinally from the open end 83 is a slide bar 84, the purpose of which will be discussed subsequently.

A first layer or plate 86 of suitable dielectric material is mounted within container 81 and held in place by means of steps 87 and 88 in the walls of container 81, mating with shoulders on the dielectric plate 86. Plate 86 is also held in place by a metallic member 89 which extends across the open end 82 of container 81. The upper surface of plate 86 has a longitudinally extending groove 91 therein, the purpose of which will be explained more fully hereinafter. Member 89 has a slot 92 milled therein which is aligned with groove 91 and has a spring 93 of conducting material mounted therein.

Resting on plate 86 is a thin dielectric plate 94 on which is printed, on the underside, one arm 96 of a directional coupler 97 and one stationary arm 98 of the line stretcher.

Arms 96 and 98 are thin flat strips of conducting material printed on the plate 94 by well-known printed circuit techniques. On the upper side of plate 94 are printed arm 99 of coupler 97 and arm 101 of the line stretcher. Arms 96 and 99 form the two arms of 3db directional coupler 97. Input and output contacts to these arms are made by a pair of coaxial couplers 102 and 103 which extend through wall 83 of container 81.

On top of plate 94 is a dielectric plate 104 of substantially the same configuration as plate 86 and having a longitudinally extending slot 106 cut therein. Slots 91 and 106 are aligned with arms 101 and 98, respectively, both vertically and horizontally. Atop plate 104 rests a plate 107 of conducting material which is bolted or fastened to container 81 by suitable means, not shown. Across one end of plate 107 is a metallic member 108 having a slot 109 milled therein which is aligned with groove 106 and in which is mounted a spring 111 of conducting material. As thus far described, the plates 86, 94, and 104 are pressed firmly together by container 81 and plate 107, and held in place by steps 87 and 88 and members 89 and 108.

Slidably mounted on slide bar 84 is a member 112 having an upper member 113 and a lower member 114 of conducting material, such as, for example, copper. A pair of thin flat conducting members 116 and 117 are mounted between members 113 and 114 and held firmly in place through pressure exerted by knurled head screws 118 and 119. This arrangement permits adjustment of the effective lengths of conductors 116 and 117 while insuring that they will not slip during tuning. Conductor 116 is positioned so that it rides in groove 106 of plate 104 and conductor 117 is positioned to ride in groove 91 of plate 86. Springs 93 and 111 exert pressure against conductors 117 and 116, respectively, to insure good electrical contact and to inhibit vertical movement of the conductors. A tuning screw 121 having a knurled knob 122 at one end and an enlarged cylindrical bearing 123 at the other end passes through a threaded hole 124 in member 112. Bearing 123 rides in a stepped cylindrical aperture formed by milled grooves 126 and 127 in members 108 and 89, respectively. As a consequence, screw 121 is free to move rotationally, but is prevented from moving translationally.

In operation, conductors 116 and 117 are mounted in member 112 so as to be of equal length, in the case of the line stretcher, and their position, and hence the length over which they are coupled to conductors 98 and 101 is adjusted by turning of knob 122. The electrical characteristics have been explained in conjunction with FIGS. 5A and 5B. In the actual physical embodiment of FIG. 7, the thickness of plate 94 was 0.0275 inch, the total thickness of plates 86, 94, and 104 was 0.270 inch, the width of conductors 98, 101, 116 and 117 was 0.220 inch and the thickness of conductors 116 and 117 was 0.020 inch thick. The dielectric constant was approximately 2.32. The length of arms 98 and 101 was approximately 3.5 inches. For $0 \leq l \leq 1.5$ in., the circuit of FIG. 5B corrects over a range from 1000 mc. to 1500 mc., to within approximately 1.5 electrical degrees. For $1.5 \text{ in.} \leq l \leq 3 \text{ in.}$, there was some deviation from linearity with a maximum of approximately 20 electrical degrees. This deviation from linearity resulted from the fact that Z_a and Z_b did not equal their optimum values ($Z_a \approx 42.1\Omega$ instead of 42.7Ω and $Z_b \approx 25\Omega$ instead of 29.3Ω). Proper care in choosing Z_a and Z_b and somewhat thinner conductors 116 and 117 would substantially eliminate the deviation from linearity.

From the foregoing, it can readily be seen that the objects of the invention have been achieved, i.e., a frequency independent, stable, wear-free tuner free from precise machining tolerances. Various modifications of the tuner of the present invention may occur to workers in the art without departure from the spirit and scope of the invention.

What is claimed is:

1. A tuning device for use in microwave transmission circuits comprising first and second spaced ground planes, the space between said planes being filled with dielectric material, a first flat conducting member held in fixed spaced relation to said ground planes by said dielectric material, a second flat conducting member extending parallel to said first member and insulated therefrom, said second member being spaced from said ground planes and electromagnetically coupled to said first member and conductively connected to at least one of said ground planes, such that the equivalent impedance of the device is given by

$$Z_0' = \sqrt{2}Z_{01}$$

where Z_{01} is the series impedance and the shunt impedance is given by

$$Z_{0s} = (\sqrt{2} - 1)Z_{01}$$

means for moving said second member longitudinally with respect to said first member for varying the distance over which said members are electromagnetically coupled, and means for introducing microwave energy into said device.

2. A tuning device as claimed in claim 1, wherein the equivalent impedance of the device is given by

$$Z_0' = \frac{2\sqrt{2}}{\sqrt{2} + 1}Z_a$$

wherein Z_a is the impedance between ground and said first and second conducting members when said members are shorted together along their lengths.

3. A tuning device for use in microwave transmission circuits comprising first and second spaced ground planes, the space between said planes being filled with dielectric material, first and second flat conducting member held in fixed spaced relationship to each other and to said ground planes by said dielectric material, said conductor forming the input and output arms of a directional coupler, a third flat conducting member connected to one of said arms and a fourth flat conducting member connected to the other of said arms, said third and fourth members being held in fixed space relationship to said ground planes by said dielectric, a first movable flat conducting member extending parallel to said third member

and insulated therefrom, said first movable member being supported in a groove in said dielectric and spaced from said ground planes and being electromagnetically coupled to said third member, a second movable flat conducting member extending parallel to said fourth member and insulated therefrom, said second movable member being supported in a groove in said dielectric and spaced from said ground planes and being electromagnetically coupled to said fourth member, means conductively connecting said first and second movable members together including means for adjusting the effective length of each of said movable members, means for varying the length over which said movable members are coupled to said third and fourth members, and input and output means connected to the arms of said directional coupler.

4. A tuning device as claimed in claim 3 wherein the movable members have the same effective length and are coupled to said third and fourth members over the same distance.

5. A tuning device as claimed in claim 3 for operation as an impedance transformer having a turn ratio given by the expression

$$n^2 = \frac{1 + \sin \beta(l_1 + l_2)}{1 - \sin \beta(l_1 + l_2)}$$

where β is the propagation constant of the microwave energy in the dielectric, l_1 is the distance over which the first movable member is coupled to said third member and l_2 is the distance over which the second movable conductor is coupled to said fourth member.

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