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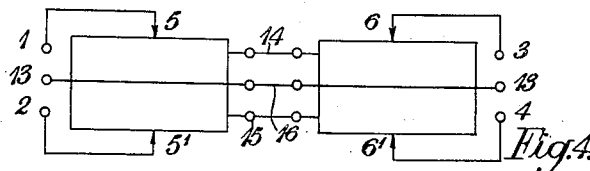
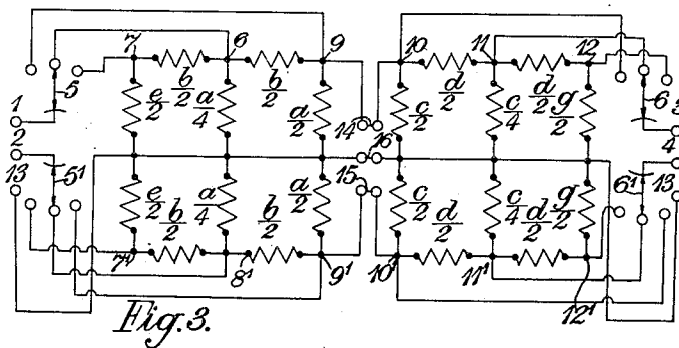
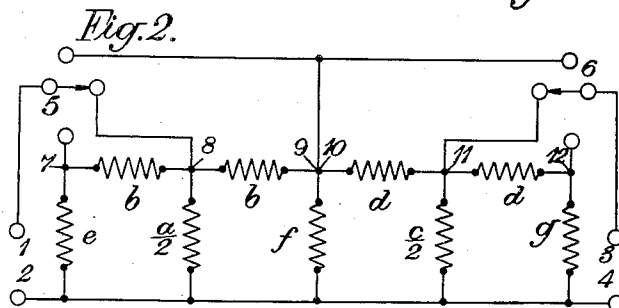
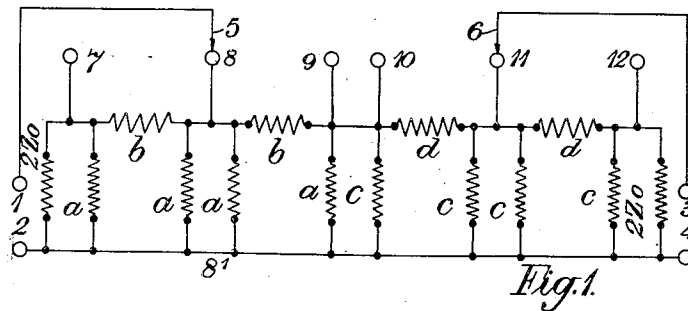
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1,975,709

ELECTRICAL TRANSMISSION DEVICE

Filed July 24, 1931

2 Sheets-Sheet 1



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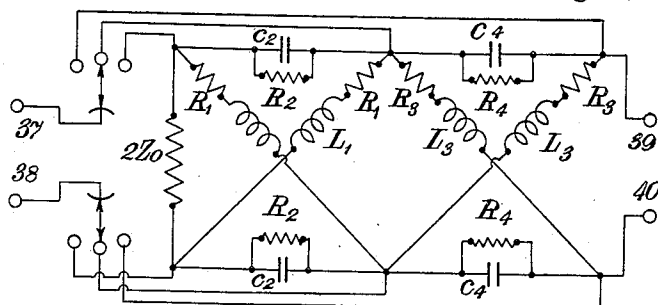
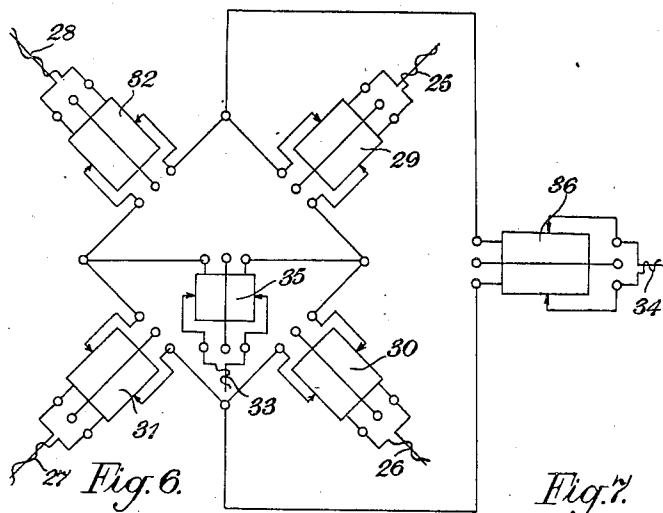
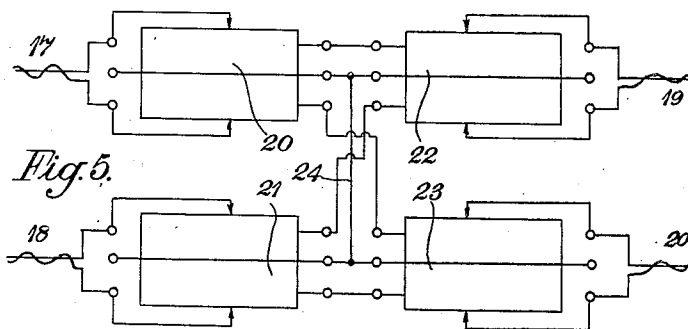
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ELECTRICAL TRANSMISSION DEVICE

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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

1,975,709

ELECTRICAL TRANSMISSION DEVICE

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Application July 24, 1931, Serial No. 553,012
In Great Britain July 30, 1930

14 Claims. (Cl. 178—44)

This invention relates to devices used for the transmission of electric currents between two or more units of electrical apparatus and the means for varying the efficiency of this transmission.

It is well known to be possible to change the efficiency of transmission by an apparatus generally referred to as an artificial line wherein an electric potential can be transferred from one piece of apparatus to another and varied in a known manner. This invention aims at producing devices of this nature, characterized by having definite impedance relationships and by using few moving contacts and resistance units in its construction.

The invention consists in an electrical transmission circuit comprising a number of symmetrical or dissymmetrical sections joined together and variable contacts adapted to alter the number of these sections included in the portion of the line between the source and the load, characterized in that substantially constant impedances are presented to the source and load and that in order to change the attenuation only one variable contact is required for an unbalanced line or two variable contacts for a balanced line.

The invention also consists in a variable line consisting of sections of symmetrical line having the same characteristic impedance terminated at one end by an impedance equal to this characteristic impedance, the other end being connected to a load (or source), connection to the source (or load) being variable and in effect capable of being bridged across the line at the junction of any two sections, so arranged that, if the load (or source) has an impedance equal to the characteristic impedance of the line, then the impedance facing the source (or load) will always be half the characteristic impedance of the line.

The invention also consists in a variable artificial line consisting of sections of dissymmetrical networks joined together so that the iterative impedance in one direction is equal to Z_1 and the iterative impedance in the other direction is equal to Z_2 , the line being properly terminated in the first direction by an impedance Z_1 at the appropriate end and by the load (or source) at the other end, connection to the source (or load) being variable and in effect capable of being bridged across the line at the junction of any two sections, so arranged that, if the load (or source) has an impedance equal to Z_2 , then the impedance facing the source (or load) will always be equal to the impedance of Z_1 and Z_2 in parallel.

Further features of the invention will be ap-

parent from the description given hereafter, which will be more readily understood by reference to the accompanying drawings, wherein

Figures 1 to 7 represent, in the usual symbols, the arrangements of various elements to form different modifications of electrical transmission lines in accordance with the invention.

The nature of the invention can best be understood by consideration of an infinitely long transmission line having a constant attenuation per unit length, across the near end of which is connected the load into which it is required to deliver electric power. For the purpose of this analogy it will be assumed that the characteristic impedance of the line is exactly equal to the impedance of the load. Across two points, one on each conductor forming the line, and equidistant from the load is connected a source of electrical energy. It will further be assumed that the impedance of this source is very high compared with the characteristic impedance of the line, and it will be apparent that the nearer to the load are the two points at which the source is tapped across the line, the greater will be the power delivered into the load, and that this power may be reduced to an infinitesimal amount by removing the tapping points to infinity.

If the line be imagined to be cut at any point along its length, the impedance as measured looking into the line in either direction along the divided line will be the characteristic impedance of the line. Hence the impedance facing the source of electrical energy will be that of two impedances (each equal to the characteristic impedance of the line) in parallel, or in effect one half of the characteristic impedance. Thus the impedance facing the source is constant no matter what is the distance between it and the load.

Similarly, if the source is of high impedance compared with the characteristic impedance of the line, the impedance facing the load will always be the characteristic impedance of the line.

Thus when the source is bridged across the near end of the line, i. e. across the load, the power delivered to the load will be one half of the power which would be delivered to the load were the line non-existent: with the source in any other position along the line, the power in the load will be the above amount attenuated by an amount which will depend upon the attenuation constant of the line and will be proportional to the length of line included between the load and the source.

In accordance with the invention lines are de-

vised on the above principle and it will be clear therefore that the invention provides a method by which it is possible to vary the attenuation introduced while maintaining the impedance relationships between the load and the source constant.

In a reciprocal manner, a source of internal impedance equal to the characteristic impedance of the line may be connected across one end of the line and a high impedance load bridged across the line at some point as described above, so that a potential attenuator in the usual sense of the word is thus produced.

It has been assumed in the foregoing that the load (or source) has an impedance equal to that of the line and that the source (or load) has a very high impedance and it will be seen that the change in attenuation between the source and load (hereinafter designated the "actual" attenuation) produced by changing the position of the tapping points by any distance along the line will be equal to the attenuation of that length of line (hereinafter designated the "nominal" attenuation). It may be shown that, for the "actual" change in attenuation to be equal to the "nominal" change in attenuation, the expression:—

$$\frac{Z_0(Z_2 - 2Z_0)}{(Z_1 + Z_0)(Z_2 + 2Z_0)}$$

must be small compared with unity where:—

$2Z_0$ =characteristic impedance of the line.

Z_1 =impedance of source (or load) tapped across the line.

Z_2 =impedance of load (or source) connected to the end of the line.

It will be observed that this condition is complied with if:—

(a) $Z_2 = 2Z_0$ i. e. the load (or source) impedance is made to match the line impedance exactly. In this case the "actual" attenuation will be equal to the "nominal" attenuation irrespective of the impedance of the source (or load).

(b) Z_1 is made very large, i. e. if the source (or load) impedance is very high, then the actual attenuation will equal the nominal attenuation, no matter what the load (or source) impedance may be.

(c) Both conditions (a) and (b) are substantially approximated to.

In carrying my invention into effect in one convenient manner the infinitely long transmission line may be replaced by an artificial line consisting of a number of sections of any of the known types. Two common types, among others, which may be employed, are the T and "π" networks (in both "balanced" and "unbalanced" forms) as described on pages 72, 73 and 74 of "Transmission Networks and Wave-Filters", T. E. Shea, published by D. van Nostrand Co., of New York, 1929. According to the invention each section is arranged to have the same required characteristic impedance and an attenuation equal to the smallest amount by which it is required to change the total attenuation in the circuit into which the complete attenuator is introduced. A number of sections is chosen such that their total attenuation is the maximum attenuation required, and these sections are joined together consecutively, the resulting line being closed at one end with an impedance equal to the characteristic impedance. The tapping points are obtained at the junction of the sections. If these latter are of the "π" formation, the adjacent shunt arms (that is to say the shunt

arm at the finish of one section and the shunt arm at the commencement of the section next to it) which are thus in parallel, may be replaced by an impedance of a value equal to the parallel impedance of the two. The final shunt impedance at the end of the line may be combined with the impedance of a value equal to the characteristic impedance mentioned above in a similar manner, and a considerable economy in the number of impedance units required to build such an attenuator can thus be obtained.

A double contact switch may be used to connect the external apparatus to any point along the line.

The invention can be modified in some circumstances by using an unbalanced artificial line, that is to say, a line in which all the series impedances are placed in one side of the circuit, the shunt impedances being bridged from the appropriate points to the other side of the circuit which is in effect a conductor of zero impedance, generally considered to be at earth potential. In this case a single moving contact only is required, making a more simple arrangement.

A further modification of this invention consists in essence, of two such attenuators as described above, either balanced or unbalanced, so connected that the one is in effect the load for the other, and vice versa. The remaining open ends of the lines will be closed by impedances equal to the characteristic impedance of the lines as in the previous case. Each line is arranged to have the same characteristic impedance but the sections in one may have greater attenuation than the sections in the other. The contact in the former will thus provide a coarse adjustment of attenuation, that on the latter providing a fine adjustment. This is analogous to a uniform transmission line extending to infinity in each direction across which are tapped a source and load each of high impedance compared with the characteristic impedance of the line. In such a case if:—

Z_1 =impedance of source or generator,

Z_2 =impedance of load,

$2Z_0$ =characteristic impedance of load,

it may be shown that for the actual attenuation to equal the nominal attenuation the expression:—

$$\frac{Z_0^2}{(Z_1 + Z_0)(Z_2 + Z_0)}$$

must be small compared with unity.

This necessitates:—

(a) Either Z_1 or Z_2 must be large compared with Z_0 , that is to say, either of the circuits bridged across the line is to be of very high impedance compared with the characteristic impedance of the latter, the other having any impedance whatever.

(b) Both Z_1 and Z_2 must be substantially larger than Z_0 .

The impedance facing both the load and source in this case will be constant and equal to one half of the characteristic impedance of the line.

A still further modification of the invention consists in the use of networks having definite impedance relationships but with known desired frequency characteristics for use as one or more of the sections in the line or lines as described above.

In order that the invention may be more easily understood description will now be given of a few forms which transmission lines in accordance with the invention may take. Referring to Fig-

ure 1 there is shown a form of line comprising a variable attenuator which is to have an impedance facing the load and the source of Z_0 Ω and is to be provided with coarse and fine controls.

5 The coarse control is to introduce x db. change and the fine control y db. change of attenuation for each step; where 1 db. stands for a current ratio of 10 to the power 0.05. For the purpose of this design it will be assumed that only two
10 steps of coarse and two steps of fine control are required, though further steps may be added if required. Figures 2 and 3 show modifications of such a line. Figure 1 shows four sections of π line terminated at each end by resistances of value
15 $2Z_0$. These sections of line are shown as symmetrical sections, that is, they have the same characteristic impedance facing both ways. The values of the resistances in the first two sections are given by the following:—

$$a = \frac{r_x + 1}{r_x - 1} \cdot 2Z_0$$

$$b = \frac{r_x^2 - 1}{2r_x} \cdot 2Z_0$$

25 where

$$r_x = 10^{\frac{x}{20}}$$

Similarly, the values for the last two sections are given by:—

$$c = \frac{r_y + 1}{r_y - 1} \cdot 2Z_0$$

$$d = \frac{r_y^2 - 1}{2r_y} \cdot 2Z_0$$

$$35 \quad r_y = 10^{\frac{y}{20}}$$

These resistances form sections of artificial line as " π " formation having an impedance both ways of $2Z_0$ and an attenuation of x or y db. These sections are assembled in succession and terminated at each end by resistances of value $2Z_0$. It would be noted that if an off position is required, this is obtained by making a " π " section of infinite
45 resistance and two shunt arms each equal in value to $2Z_0$.

It is possible to employ dissymmetrical networks for these lines. For instance, the sections of line might be made having in iterative impedance in one direction of say $2Z_1$ and in the other direction of say $2Z_2$ where

$$\frac{Z_1 Z_2}{Z_1 + Z_2} = \frac{Z_0}{2}$$

55 These lines would then be terminated at the appropriate ends by impedances $2Z_1$ and $2Z_2$ instead of $2Z_0$ as for symmetrical lines (for an explanation of the terms iterative impedance and a description of such structures, see "Transmission Circuits for Telephone Communication" by K. S. Johnson—Fourth printing, The Library Press Limited—page 127 et seq). A line using
60 dissymmetrical networks of the T type would have component impedances different from those for an equivalent symmetrical structure. A line using dissymmetrical π type sections would, if the parallel impedances of adjacent shunt arms are combined, have the same component impedances as the symmetrical structure. In general, dissymmetrical structures do not offer any particular
70 advantages for most embodiments of this attenuator, but constitute another method of achieving the same effect.

In Figure 1, 1 and 2 represent the input or output terminals, and 3 and 4 represent the out-

put or input terminals respectively. The line is shown in the unbalanced form and hence terminal 2 is connected to terminal 4 and to the lower ends of the shunt resistances. Terminal 1 is connected to a moving contact 5 which is adapted to move over points 9, 8 or 7, so introducing x db. or $2x$ db. attenuation. Similarly 3 is connected to a contact 6 which can move over points 10, 11 and 12 and so introduce y db. or $2y$ db. of attenuation.

Consider the impedance seen between terminals 1 and 2 when 5 is connected to 8 and 3 and 4 are open circuited. Imagine the network to be divided along a line between the points 8 and 8'. To the left will be a section of line properly terminated of impedance $2Z_0$. Similarly, to the right there will be three sections of line properly terminated of impedance $2Z_0$. The portions to the left and right will be in parallel as seen from terminals 1 and 2 connected to 8 and 8', and hence this impedance will be half $2Z_0$, or Z_0 the required impedance. Similarly, the impedance will be Z_0 on whichever contact 5 rests. Also the same impedance is obtained between terminals 3 and 4 when 1 and 2 are open circuited.

Figure 2 shows a rearrangement of Figure 1 whereby an economy of resistances is effected by combining resistances which are connected in parallel. The resistance values are given by

$$e = \frac{2Z_0 \cdot a}{2Z_0 + a}$$

$$f = \frac{a \cdot c}{a + c}$$

$$g = \frac{2Z_0 \cdot c}{2Z_0 + c}$$

Also in this figure it will be noted that the switches are shown diagrammatically as the more usual rotational switch. It will be observed that in this unbalanced line only one moving contact is required to alter the attenuation and only two resistances for each additional step of attenuation after the first.

Figure 3 shows a further modification of this line whereby it is made in the balanced form. The series resistances have been halved and put equally in each arm. Further, a central conductor connected to terminals 13 has been introduced, this conductor joining the centre points of the shunt resistances. This conductor need not be introduced, but it is sometimes desirable to introduce it and connect it to earth so as to prevent voltages applied simultaneously to terminals 1 and 2 arriving unattenuated at terminals 3 and 4. It will be noted that in the balanced form, either with or without the central conductor, only two moving contacts are required to alter the attenuation and only four resistances per stage of attenuation. In Figure 3, the central resistances have not been combined, but have been kept separate and terminals with connecting leads 14, 15 and 16 have been inserted. This allows each half of the line to be operated separately. Alternatively, each or either half may be operated into an impedance of $2Z_0$, or into another similar type of line. These terminals also provide a convenient point for the insertion of correction networks which are preferably of the constant impedance type having a characteristic impedance facing both ways of $2Z_0$.

Alternatively, additional artificial lines may be inserted here in order to provide attenuation adjustment in either larger or smaller steps than those provided by the two controls shown. It

must be noted that though in these figures are shown only two variable sections on each side, the actual number may be increased indefinitely, and the steps of attenuation introduced by successive movements of a switch may be different. In this connection it may be remarked that if a large number of sections say over twenty are desired to be controlled by one switch, a straight moving contact working over a long straight row of contacts might be preferable to a rotating switch.

Figure 4 shows an abbreviated way of representing in a drawing a balanced line of the double type, i. e., two sections of single type attenuators, which will be used in following figures. The terminals numbering is similar to that used in the preceding figures.

Figure 5 shows a method by means of which two incoming channels of power may be combined and fed into two outgoing channels, controls being provided which will affect either a single ingoing or a single outgoing channel without affecting the others. For example, this might be used for enabling the sound from two microphones to be mixed and led into two recording channels say one for wax recording and one for optical recording. Thus one microphone may be connected at 17 and be controlled by line 20 and the other at 18 and controlled by 21. Similarly, one recording system may be connected at 19 and controlled by 22 and the other at 20 controlled by 23. For this arrangement to operate satisfactorily, it is necessary to connect the centre points of all lines as shown at 24.

In order that the attenuation steps shall be correct at low values of attenuation it is necessary that for the recording systems the input impedances and for the microphone the output impedances be high compared with that of the lines. Figure 6 shows a more complicated coupling system where use is made of the constant impedance characteristic of these lines. By this means four sources connected at 25, 26, 27 and 28 can be controlled independently by lines 29, 30, 31 and 32 respectively and fed into receiving channels say amplifiers connected at 33 and 34 and controlled by lines 35 and 36 respectively. The impedances may be arranged so that the impedances of the sections of line controlling the microphones shall be equal to the impedance of the microphones say $2Z_0$. The impedance in the four microphone bridge arms is then equal to Z_0 . By making the impedances of the sections of lines 35 and 36 equal to Z_0 the impedance facing the amplifiers at either 33 or 34 will be constant and equal to

$$\frac{Z_0}{2},$$

independent of the setting of the lines and independent of the impedance of the other amplifier. It will be noted that for this arrangement the centre point connections are not used. It is interesting to note that for an arrangement of this type it is possible to pass speech or signals from say terminals 33 to any of lines 25 to 28 without passing power into line 34. Similarly, if the impedance of the apparatus connected at 33 and 34 is high, power will not pass from 25 to 27 nor from 26 to 28. If someone (say adjacent to a microphone controlling the performance) is provided with a telephone receiver, or "monitoring" amplifier and receivers, connected to the microphone in such a manner as to maintain the impedance connected at the points 25

to 28 substantially equal to $2Z_0$, then speech or signals introduced at 33 will be heard by him but will not pass to 34.

Many other methods of arranging these lines in combination are possible taking advantage of the impedance characteristics of these lines combined with the low number of moving contacts, and such must be understood as coming within the scope of the invention.

In order to supply several loads from one source, switches may be arranged so that more than one set of variable connections can be made to one line by paralleling the contacts of several switches.

Figure 7 shows a simple line of this type adapted for varying the frequency characteristic of a device. It consists of two constant impedance sections of lattice line and is terminated by a resistance of value $2Z_0$ at one end and intended to operate into another line of impedance $2Z_0$ or into a load of impedance $2Z_0$. By making

$$R_1 R_2 = \frac{L_1}{C_2} = R_3 R_4 = \frac{L_3}{C_4} = (2Z_0)^2$$

the impedance of the lattice sections will be $2Z_0$ and the impedance seen from terminals 37 and 38 will be equal to Z_0 when 39 and 40 are closed by a resistive impedance equal to $2Z_0$. The correctors shown are of the type which depreciate the lower frequencies and by suitably choosing the components it can be arranged that the correctors depreciate all except the high frequencies, thus in effect appreciating the high frequencies compared to the remainder. In order to compensate for the loss of volume due to inserting the correction networks, the network of Figure 7 may be connected to a resistance network of similar type, so arranged that its controlling switch is coupled mechanically to the switch controlling the frequency correction in order that when frequency correctors are inserted, resistive attenuation is removed to maintain the volume constant. Other networks may be used for producing variable phase changes or delay.

These lines may be used for other than audio frequencies, for example, they may be employed for very high frequencies, in which case the separate sections are with advantage shielded from each other. For such a line it would be advantageous to use a linearly moving switch instead of a circularly moving one, or to use plug connections adapted to fit into sockets connected to the line.

More than two degrees of control may be obtained by cascading a number of these lines, for example, a double line consisting of sections of impedance $2Z_0$ may have one pair of its moving contacts connected so as to terminate a simple line of impedance Z_0 whose moving contacts serve to terminate a simple line of impedance

$$\frac{Z_0}{2}$$

and so on.

Thus, according to the invention, it is possible, (a) To produce an attenuating device having the properties previously described consisting of a number of networks, constituting an artificial line, of any type which attenuates electric currents of all frequencies uniformly.

(b) To produce an attenuating device having the properties previously described incorporating one or more sections consisting of a network of predetermined frequency characteristics, to-

gether with sections of uniform attenuation with frequency, in order that a given frequency preference or selection may be obtained together with a uniform variation of attenuation at all frequencies, or

(c) To produce an attenuating device having the properties previously described, consisting of a number of sections connected together, all having either similar or different frequency selection characteristics, wherein the degree of frequency selection or preference obtainable may be varied at will by the operation of a moving contact switch.

The sections referred to above as having given frequency characteristics together with definite impedance relationships may conveniently be any of the known equalizer networks having a constant characteristic impedance or any of the known electric wave filter sections wherein the characteristic impedance remains sufficiently constant over the transmitting frequency band to enable such sections to operate satisfactorily in the manner described above.

The invention may further be modified in either the single or double form of line described above by arranging for one or more sources to feed the same load, or one or more sources to feed one or more loads, with definite impedance relationships, such that the relative attenuations between the various loads and source may be varied.

It should be understood that throughout this specification, and more especially in the appendant claims, the phrase "the junction of two sections" covers also the junction of a section and a terminating impedance in the line (unless the context otherwise requires) and the phrase should therefore be understood and read to include this meaning.

The invention, however, is not to be limited to the particular examples cited above which are given by way of example only to indicate the nature of the invention.

I claim:

1. An electrical transmission line comprising a plurality of sections terminated at each end, a source bridged across the line at the junction of two sections, a load bridged across the line at the junction of two sections, adjustable means whereby the bridging point of the source or load may be varied so as to vary the number of sections between source and load, so arranged that the impedance presented to the source or load when the terminals of the load or source respectively are open circuited is constant for all working positions of the adjustable means.

2. An electrical transmission line comprising a plurality of sections of symmetrical line having the same characteristic impedance, terminated at each end by an impedance equal to the characteristic impedance, a source bridged across the line at the junction of two sections, a load bridged across the line at the junction of two sections, adjustable means whereby the bridging point of the source or load may be varied so as to vary the number of sections between source and load, so arranged that the impedance presented to the source or load when the terminals of the load or source respectively are open circuited is constant for all working positions of the adjustable means.

3. An electrical transmission line comprising a plurality of sections of dissymmetrical line all having the same iterative impedances, terminated at each end by the appropriate iterative im-

pedance, a source bridged across the line at the junction of two sections, a load bridged across the line at the junction of two sections, adjustable means whereby the bridging point of the source or load may be varied so as to vary the number of sections between source and load, so arranged that the impedance presented to the source or load when the terminals of the load or source respectively are open circuited is constant for all working positions of the adjustable means.

4. An electrical transmission line comprising a plurality of sections joined together, a termination at each end of said line, a source of electrical impulses, and a load, said source and load being each connected to said sections by movable elements whereby the number of sections between the source and load may be varied, and other sections in the line not variable in number by means of said movable contacts, the sections of the line being so arranged that the impedance presented to the source or load is constant, when the terminals at the other are open circuited, for all positions of the adjustable means.

5. An electrical transmission line according to claim 4 wherein the said other sections are in permanent circuit between the source and the load.

6. An electrical transmission line according to claim 4 wherein the said other sections may be inserted, or removed from between source and load by means of switches.

7. An electrical transmission line according to claim 1 comprising an unbalanced variable artificial line having one movable contact which provides a control of propagation.

8. An electrical transmission line according to claim 1 comprising an unbalanced variable artificial line having two independent movable contacts only which provide two independent controls of propagation.

9. An electrical transmission line according to claim 1 comprising a balanced variable artificial line having a pair of mechanically interconnected contacts which provide a control of propagation.

10. An electrical transmission line according to claim 1 comprising a balanced variable artificial line having two pairs of movable contacts which provide two independent controls of propagation.

11. An electrical transmission line comprising a plurality of interconnected sections formed of portions of artificial line in π formation and terminated at each end, a source of electrical impulses bridged across the line at the junction of two sections, a load bridged across the line at the junction of two sections, means for adjusting the bridging position of the source or load so arranged that the impedance presented to the load or source when the terminals to the other are open circuited is constant for all working positions of the adjustable means.

12. An electrical transmission line according to claim 11 wherein adjacent shunt elements of consecutive π sections are combined together to form a single shunt element.

13. An electrical transmission line according to claim 11 wherein a terminating impedance and an adjacent shunt element of a π section are combined to form a single shunt element.

14. An electrical transmission line according to claim 1 wherein the elements comprising the sections are purely resistive.

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