

March 4, 1947.

W. L. BARROW

2,416,790

TRANSMISSION LINE BRIDGE CIRCUIT

Filed Jan. 28, 1941

4 Sheets-Sheet 1

Fig. 1.

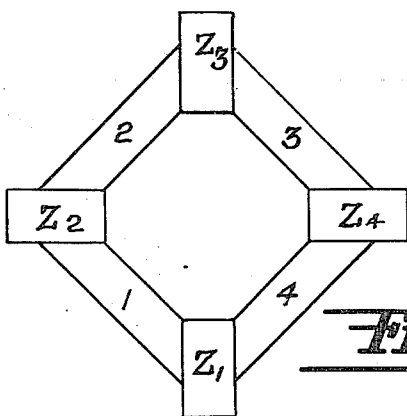


Fig. 2.

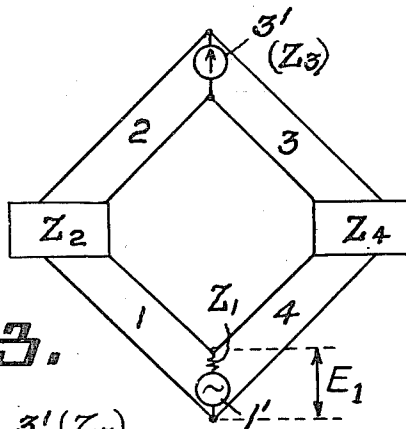


Fig. 3.

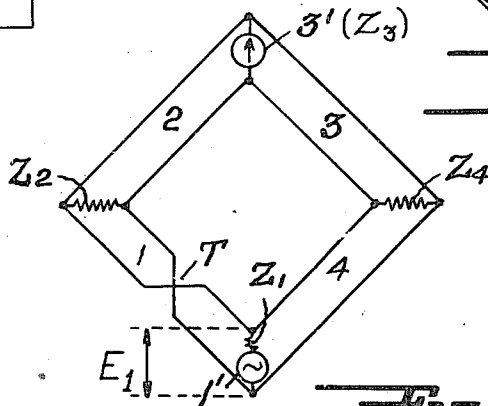


Fig. 4.

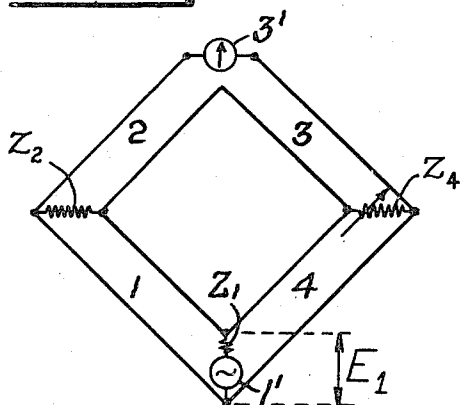
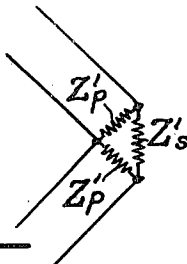
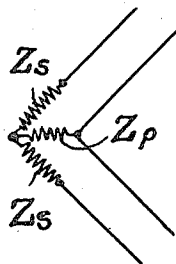
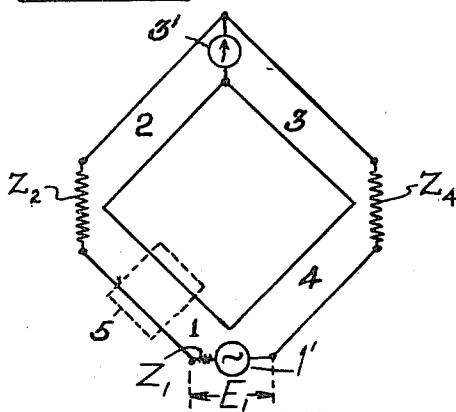


Fig. 5.



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Fig. 6.

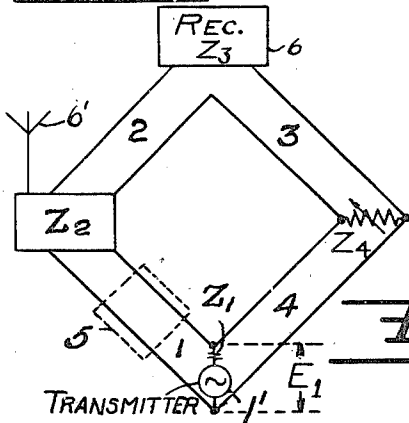


Fig. 7.

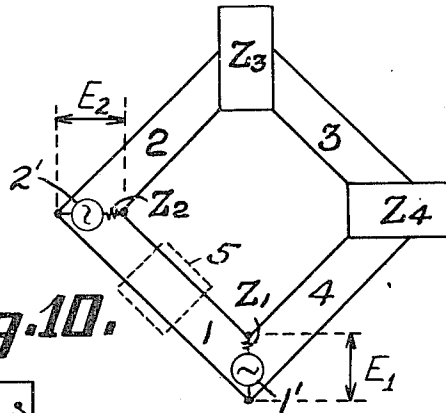


Fig. 10.

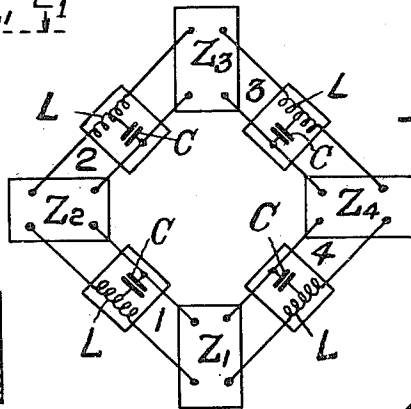


Fig. 11.

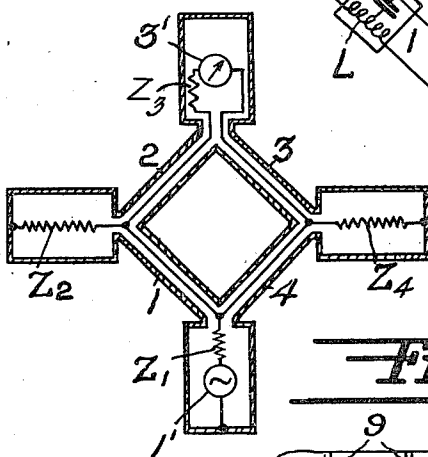


Fig. 13.

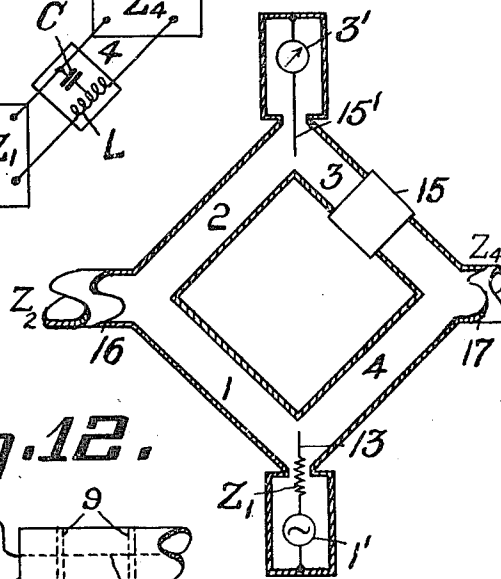
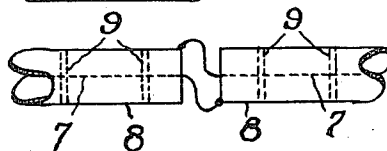


Fig. 12.



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Fig. 14.

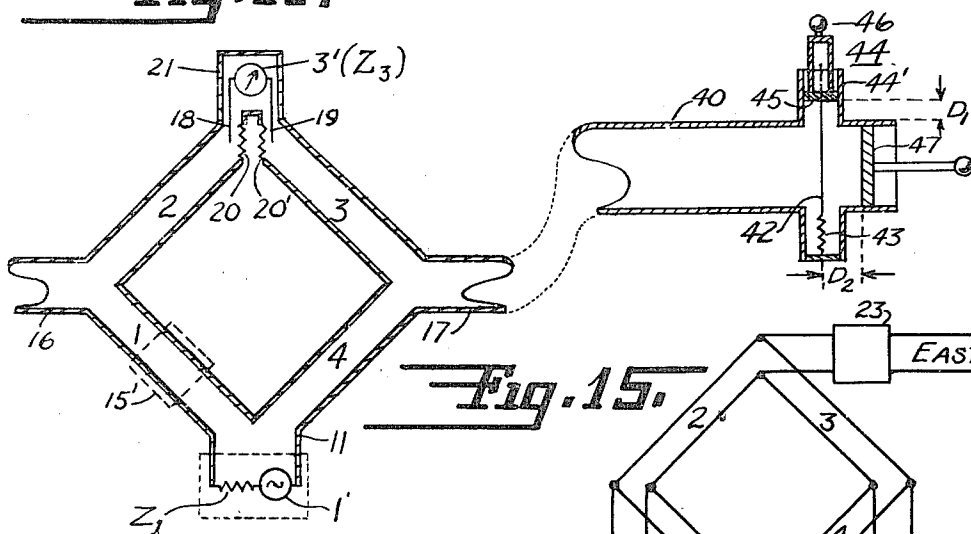


Fig. 15.

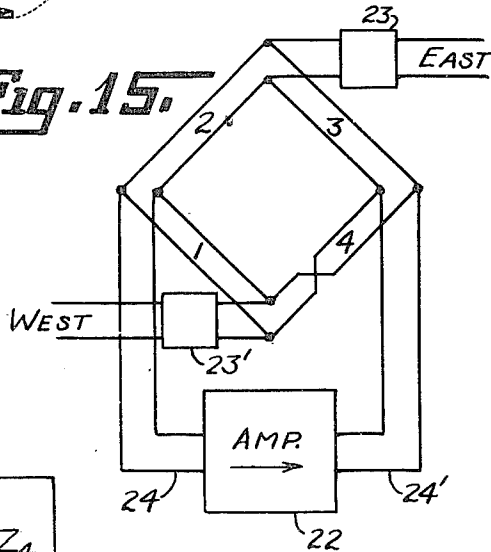


Fig. 17.

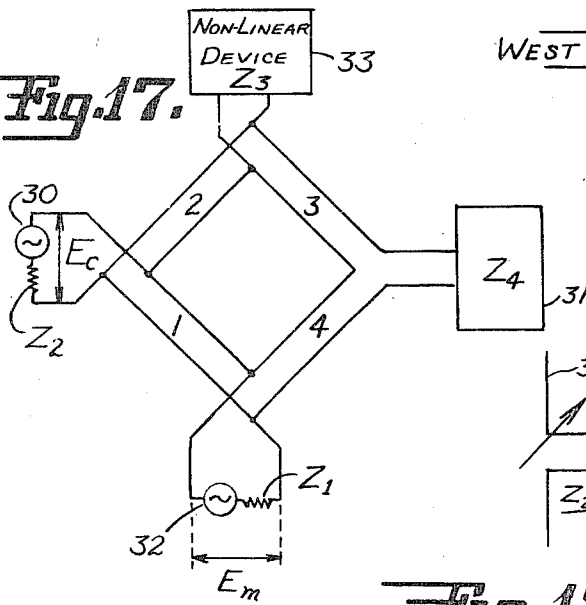
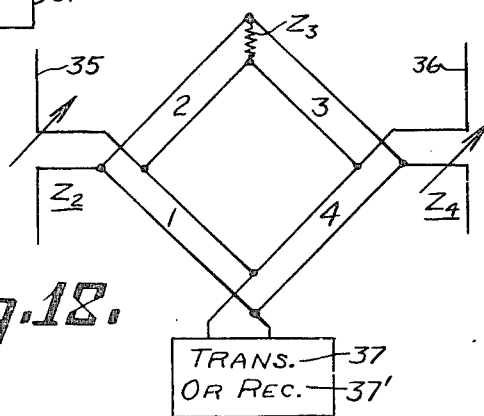


Fig. 18.



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Fig. 16.

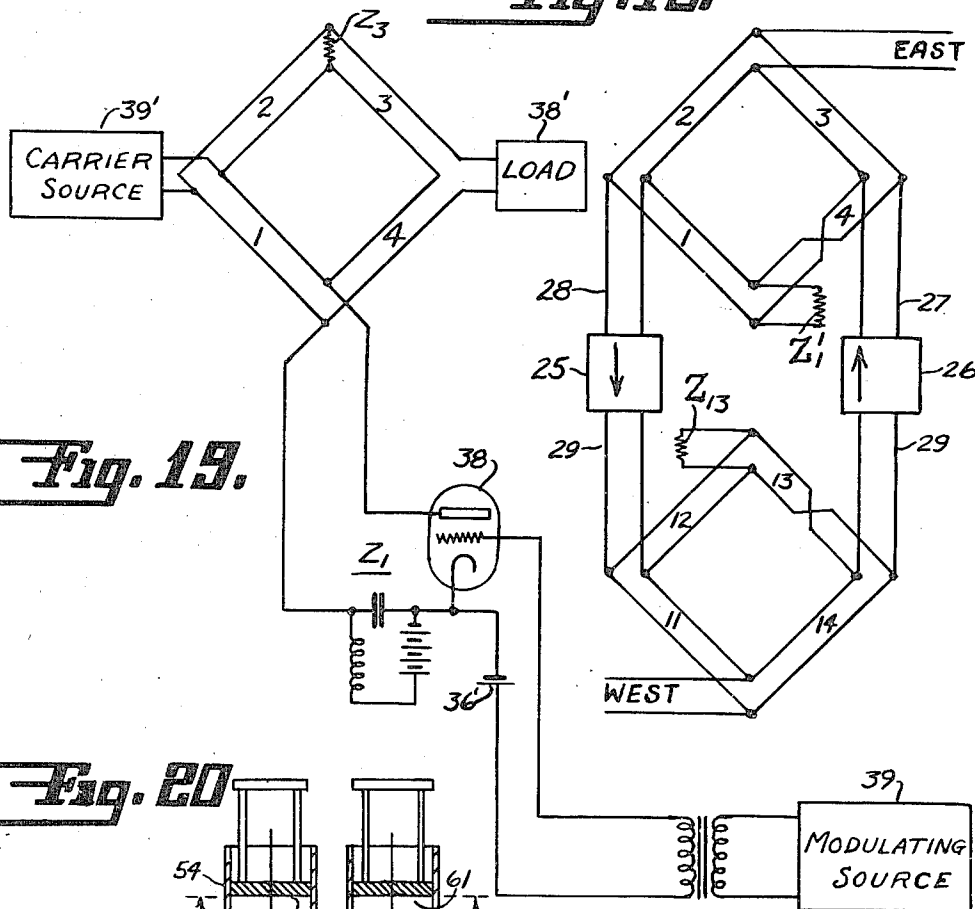
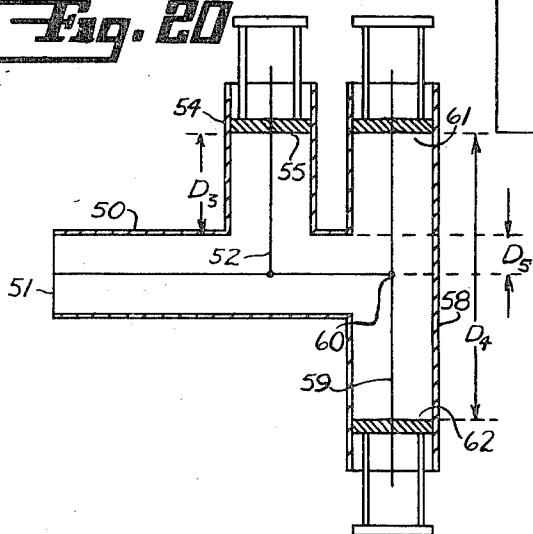


Fig. 19.

Fig. 20.



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UNITED STATES PATENT OFFICE

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TRANSMISSION LINE BRIDGE CIRCUIT

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Application January 28, 1941, Serial No. 376,253

30 Claims. (Cl. 178-44)

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This invention relates to ultra high frequency bridge circuits and refers, more particularly, to bridge circuits in which transmission lines are essential elements. The difficulties encountered in extending the use of conventional bridge circuits to ultra high frequencies are well known and are very great. Bridges have been constructed that function at frequencies as high as ten megacycles per second or even somewhat higher but little work has been done at very high frequencies such as those of the order of 100 megacycles per second and above, due to complications and uncertainties which arise and which increase rapidly with increasing frequency. For example, as applied to the measurement of impedance, the use of bridge circuits at ultra high frequencies is adversely affected by the impedance and calibration of the indicating instrument, by the effect of leads to auxiliary equipment and similar factors which vary with frequency, so that the useful frequency range of a given piece of equipment is usually very limited. In addition, conventional circuits do not provide true equivalents of bridge circuits at high frequencies in many applications where it is desirable to take advantage of the characteristics of a bridge connection.

My improved circuit making use of transmission lines as bridge elements among other advantages provides the complete equivalent of a bridge, while in the form adapted for making impedance measurements, the impedance of the indicating instrument and its calibration do not enter into the precision of the measurement.

The term transmission line as used herein in its narrower sense refers to any means for guiding electromagnetic waves which provides a restricted path having distributed electrical constants but it also has a wider meaning which includes, in addition, lumped impedance artificial transmission lines having propagation characteristics similar to those of actual transmission lines. While the length of transmission lines having distributed constants is a bar to their use in most low frequency apparatus, at high frequencies they become relatively short, which makes their use practical in a wide variety of applications. For example, at 300 megacycles per second a quarter wave length line is approximately only 10 inches in length.

One object of the present invention is to provide a bridge circuit adapted to operate over a wide range of frequencies and particularly at ultra high frequencies.

Another object is to provide a bridge circuit

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which makes use of the properties of transmission lines.

Another object is to provide a device suitable for operation at ultra high frequencies having the same general characteristics as conjugate circuit devices commonly used at low frequencies, such as hybrid coils.

Another object is to provide arrangements for interconnecting a plurality of circuits with one or more other circuits that inhibit interaction among the said plurality of circuits.

Another object is to provide a bridge circuit adapted for making impedance measurements at ultra high frequencies.

Another object is to provide a bridge circuit of the character described employing metal pipe wave guides and adapted for interconnection in systems of metal pipe wave-guide construction.

A still further object is to provide a transmission line bridge circuit which does not require line transpositions and is therefore particularly adapted to utilize coaxial cable and wave-guide lines.

Other objects and advantages of this invention will become apparent as the description proceeds.

In the drawings:

Fig. 1 is a generalized circuit diagram illustrating the connection of four transmission lines in a bridge arrangement with four lumped impedances at bridge points.

Fig. 2 is a schematic diagram of a transmission line bridge circuit having a connected high frequency source and an indicator.

Fig. 3 is a diagram of a circuit having shunt-connected impedances at a pair of opposite bridge points and a transposition in one of the lines.

Fig. 4 illustrates a circuit having a shunt-connected source and series connected indicator.

Fig. 5 illustrates a circuit having a series-connected source and series-connected intermediate impedances.

Figs. 6 and 7 are diagrams for demonstrating the independence of elements at opposite bridge points of a balanced bridge.

Figs. 8 and 9 illustrate various forms of connected impedances at bridge points.

Fig. 10 illustrates the use of artificial lines in a bridge circuit in place of lines having distributed constants.

Fig. 11 is a diagram of a bridge circuit using one form of coaxial line construction.

Fig. 12 illustrates a transposition in a coaxial line.

Fig. 13 illustrates the use of one form of

hollow-pipe line construction in a bridge circuit.

Fig. 14 illustrates a hollow-pipe line bridge having a series of connected indicator and shows a construction for an adjustable termination for a hollow-pipe transmission line.

Figs. 15 and 16 illustrate the application of transmission line bridge circuits to high frequency two-way repeaters.

Fig. 17 is a circuit diagram of a carrier suppression modulator employing a transmission line bridge.

Fig. 18 illustrates the independent connection of two antennae to one piece of apparatus through a transmission line bridge.

Fig. 19 is a circuit for a modified form of bridge circuit modulator.

Fig. 20 shows a construction for an adjustable termination for a coaxial line.

In Fig. 1 there is shown the basic diagram of a generalized bridge circuit composed of four transmission lines 1, 2, 3, 4 arranged in tandem to form a closed loop with a lumped impedance connected between each pair of adjacent lines. These bridge point impedance, Z_1 , Z_2 , Z_3 and Z_4 may take any form of single elements or combination of elements and may be the impedances of apparatus units, for example, generators or meters.

In Fig. 2 there is shown one modification in which a high frequency E. M. F. E_1 is supplied to the circuit in series with an impedance Z_1 , which may be the internal impedance of a generator or source 1', and an indicator 3' having an impedance Z_3 is connected at the opposite bridge point. Ignoring for the moment the two impedances Z_2 and Z_4 , it may be considered that the four transmission lines 1, 2, 3 and 4 form a pair of separate transmission paths 1, 2 and 4, 3 between high-frequency source 1' and indicator 3'. If the source impresses the voltage E_1 across lines 1 and 4, electromagnetic waves will travel along both paths and impress two alternating voltages across the impedance Z_3 of the indicator. Assuming that the lines have similar transmission characteristics and lengths, the two alternating voltages impressed by the two respective waves across Z_3 will have the same amplitude and phase while the currents flowing in the lines 2, 3 and arriving at the terminals of indicator 3' by the two paths 1, 2 and 4, 3 will have the same magnitude but opposite phase, resulting in a voltage anti-node and a current node at this point. If some means is included in one of the two paths for shifting the phase of the transmitted wave 180°, as, for example, the transposition T shown in line 1 of Fig. 3, the respective voltages at Z_3 resulting from transmission of waves from the source 1 over the two paths will be of opposite phase, while the currents in lines 2, 3, will be of the same phase, resulting in a voltage node and a current anti-node at this point. The net voltage impressed across the indicator will therefore be zero and the circuit is balanced in the sense that an ordinary bridge network is balanced since a voltage applied to one pair of terminals is incapable of producing any voltage across a second or conjugate pair of terminals. In referring to this condition, one bridge point of a transmission line bridge will be said to be balanced against another point.

The insertion of equal impedances Z_2 and Z_4 , respectively, at corresponding points in the two paths 1, 2 and 4, 3 of Fig. 2 changes the magnitude of the voltages and currents at Z_3 but not their relative phase or the equality of the magni-

tudes of these quantities. If the lines have dissimilar propagation characteristics, Z_2 and Z_4 may be made unequal to compensate for such differences. It is not necessary that the length of path 2, 3 be equal to that of path 1, 4 so long as the equality of voltages and currents is maintained at the position of indicator 3'.

In order to use the circuit for making impedance measurements by a null method when one of the lines is transposed, the indicator 3' is connected across the two terminal lines using a shunt connection, as represented in Fig. 3. Then zero or null indication on indicator 3' shows that an impedance to be measured, for example, Z_2 , is equal to a standard impedance, for example Z_4 . On the other hand, when all lines are untransposed, a series indicator connection is employed, as in Fig. 4. Since a current node exists at the position of indicator 3' when equal transmission paths 1, 2 and 4, 3 are provided, indicator 3' will read zero when Z_2 equals Z_4 , providing a method of measuring Z_2 when Z_4 is known or calibrated.

If instead of being used for null indication, indicator 3' is intended to indicate the magnitude of the voltage or current anti-nodes existing at the terminals of the two transmission paths 1, 2 and 4, 3, the type of connection employed will depend upon the quantity to be indicated. Thus, as in Fig. 2 where there is no transposition or other phase-shifting means, to indicate voltage across the line indicator 3' is shunt connected. On the other hand, where one path contains a transposition such as T in Fig. 3, or other phase shifting means set for 180° phase shift, such as the device 5 in Fig. 5, to indicate voltage between adjacent lines a series connection is used, such a series connection being shown in Fig. 4. It will be apparent that if power utilizing devices are used in place of indicators, they will also be connected with due regard to the voltage and current nodes or anti-nodes existing at the point of connection. The source or generator 1' supplying an E. M. F. to the circuit may similarly be shunt-connected as shown in Figs. 2-4 and 6 or series-connected as shown in Fig. 5. The latter connection is of advantage in certain types of line construction since connection is made to one conductor only of a line or pair of adjacent lines.

The impedances Z_2 and Z_4 , shown as simple shunt elements in Figs. 3 and 4 and simple series elements in Fig. 5, may take a variety of forms including known forms of networks. Different types of networks are illustrated in Figs. 8 and 9 as T-connected and π -connected combinations of impedance elements. Networks having series impedance in both sides of the line may, of course, be used.

Fig. 8 shows a T connection having shunt element Z_p and symmetrical series elements Z_s while Fig. 9 shows a π connection having series elements Z_s' and symmetrical shunt elements Z_p' . Each type of connection has advantages in specific circuits. It is to be understood that any impedance element may itself be a complex impedance made up of resistive and reactive components. Furthermore, it is to be understood that the showing of impedances is symbolic only, the actual construction varying with the type of transmission line construction adapted as will be later illustrated and described.

If all circuit elements are linear and bilateral, the generator and the indicator (or any receiver taking the place of the indicator) are interchangeable. Either may be connected in circuit in series between terminal portions of two adja-

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cent transmission lines or as a common shunt element to both.

For measurement purposes, one impedance, for example Z_2 , may represent an unknown to be balanced against a standard Z_4 at the opposite bridge point. The circuits of Figs. 3 and 5 are examples of arrangements adapted for making impedance measurements by balancing against a standard. The arrangement of Fig. 5 is shown as including a series-connected source I' , the series connection at this point having the advantages previously pointed out. The dotted rectangle 5 represents a phase shifting device which may be selectively connected in the circuit depending on the type of indicator connection used. Indicator $3'$ furnishes zero indication when the impedances Z_2 and Z_4 are equal, it being understood that in this case the two transmission line paths 1, 2 and 4, 3 connecting I' and $3'$ also have the same transmission characteristics. The impedance of neither source nor indicator affects this relationship. Of particular importance is the fact that the meter may have a low impedance and that it requires no calibration either for linearity or voltage. Furthermore, the balance may be made at any frequency provided only that the lines are long enough to function as transmission lines at that frequency.

The circuit of Fig. 5 illustrates an arrangement having series-connected elements at three bridge points, these elements being the impedances Z_2 and Z_4 and the impedance Z_1 of the source.

The operation of the circuit of Fig. 5 may best be explained by first considering this circuit with indicator $3'$ and source I' interchanged. Thus modified, the circuit is similar to Fig. 4, but with series impedances Z_2 , Z_4 instead of shunt impedances as in Fig. 4. This modified circuit thus operates the same as Fig. 4, described above.

By the well-known Reciprocity Theorem (see Terman's "Radio Engineers' Handbook," 1943, page 198) in any linear network the interchanging of a source and a load does not affect the current flowing through (or the voltage across) the load. Hence, by replacing source I' and indicator $3'$ in their original positions shown in Fig. 5, operation is unchanged, and the circuit may be used as a bridge, as described above.

From another viewpoint, source I' is connected across the series circuit of (a) the open end of line 1 and (b) the open end of line 4. Lines 1 and 4 are, of course, four-terminal networks with distributed inductance and capacitance. Hence line 1 and line 4, being identical, each receive half the voltage of source I' , so that the usual waves are sent down these lines 1 and 4, to cause operation of the indicator $3'$ in the manner discussed above.

In an arrangement, such as shown in Fig. 2, for example, the source and the receiver are so connected that power supplied by the source may be utilized by a receiver connected at the opposite bridge point while, at the same time, power is also supplied to impedances Z_2 and Z_4 at the conjugate bridge points.

In Fig. 6, generator I' , which may be the output stage of a radio transmitter as before, supplies an E. M. F. E_1 through its internal impedance Z_1 to lines 1 and 4. Z_2 in this case is the impedance of an antenna $6'$ which simultaneously transmits and receives energy while Z_4 is an adjustable balancing impedance therefor. If Z_3 is the impedance of a radio receiver at the bridge point opposite the transmitter which should be insensitive to generator or transmitter I' , and if Z_4 is adjusted to balance Z_2 , a network is obtained in which power from the transmitter is delivered to antenna

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$6'$ while received power is delivered to receiver 6.

So far, a source of E. M. F. at only one bridge point has been described. Other circuits to be described herein involve the connection of sources of E. M. F. at a plurality of bridge points. For example, an E. M. F. may be applied in series with any other impedances besides Z_1 , as shown in Fig. 7, where a generator or source $2'$ applies an E. M. F. E_2 in series with impedance Z_2 , which may be its internal impedance. If impedances Z_1 and Z_3 are equal, power will be delivered from $2'$ to Z_1 and Z_3 and excluded from Z_4 . If, further, the impedances Z_2 and Z_4 are equal, power will be delivered from I' to Z_2 and Z_4 and excluded from Z_3 . This arrangement will be referred to as a double balance. A voltage derived from a parallel or shunt connection of a generator to the circuit may of course be impressed across any of the impedances in a doubly balanced circuit instead of a series-impressed E. M. F.

It is possible to extend balancing arrangements of the described character so that power generated at any of the bridge points may be supplied to the two adjacent bridge points and excluded from the opposite bridge point.

In a doubly balanced system, if one of the balances is destroyed another type of interconnection of two sources is provided. For example, let the balance of Z_4 against Z_2 be destroyed so that an E. M. F. impressed on the network by I' in series with Z_1 will cause currents to flow in Z_2 , Z_3 , and Z_4 , but the balance of Z_1 against Z_3 be preserved so that an E. M. F. impressed on the network by $2'$ in series with Z_2 will cause currents in Z_1 and Z_3 but not in Z_4 . Under such conditions, power from the source I' may be supplied to three elements connected to the bridge, while power from source $2'$ is fed to only two elements and is excluded from the remaining or diametrically opposite element.

As has been pointed out, my invention includes circuits in which there are substituted for transmission lines having distributed constants, simulated lines composed of lumped impedances and a bridge circuit comprising such artificial lines is shown in Fig. 10. In general, to simulate actual lines artificial lines will have series resistance and inductance and shunt capacity and conductance, although the relative importance of these several factors varies with the frequency range for which the apparatus is designed and one or more of them may be omitted in some applications. In the circuit of Fig. 10 series inductance L and shunt capacity C only are shown.

Where reversal of phase of the electromagnetic wave in one of the transmission lines is desired, the means for accomplishing this phase shift may take a variety of forms. The simplest form is a transposition of the two conductors of a two-conductor line as shown in Fig. 3. A network which produces a phase shift of 180° may also be used and this may take the form of a transmission line having a length equivalent to an odd integral number of half wave-lengths, or the network may be composed of lumped impedances, preferably non-attenuating. The shifting of phase by the introduction of a length of transmission line is particularly suited to hollow-pipe wave-guide construction.

In some cases the impressed E. M. F. instead of being supplied by an actual generator may be due to a disturbance induced in one of the lines either externally or by internal variations of the line or terminating impedances, and it may be desired to prevent any effect of this disturbance

from reaching the opposite bridge point while that point is receiving power from adjacent bridge points. The described balanced bridge provides a means for accomplishing this result.

The construction of the transmission lines forming the four sections of the described bridge circuits may take a wide variety of forms, the following being cited as examples and not by way of limitation:

Two conductors unshielded.
Two conductors shielded.
One conductor shielded (coaxial line).
Hollow-pipe "wave-guide."
Dielectric-wire "wave-guide."

For description of the last two types of transmission lines, reference may be had to U. S. Patents Nos. 2,129,711 and 2,129,712 issued to G. C. Southworth, wherein "wave-guides" are defined. The coaxial type of line and the wave guide type of line are examples of what may be called self-shielding or enclosed field transmission lines, since the electrostatic and electromagnetic fields are confined within the outer boundary of the line and have no reaction with external fields.

Fig. 11 illustrates the application of coaxial construction to one type of the bridge circuit. As is well known such lines consist of a central conductor and an outer shield. The series connection of voltage indicator 3' (or a power receiving impedance which may take the place of said indicator) at the bridge point opposite the source, as in Fig. 4, eliminates the necessity of transpositions or phase shifting devices in one of the lines. A schematic showing of a transposition in a coaxial line, which illustrates the disadvantages of such arrangements, is found in Fig. 12. The transmission line consists of central conductor 7 and cylindrical metallic envelope or shield 8 coaxial therewith, the two conducting members being spaced at intervals by insulating washers 9. In order to connect the central conductor on one side of the transposition to the shield on the opposite side and the shield on the first side to the central conductor on the other side to effect a transposition, a break in the otherwise continuous outer envelope is necessary which results in leaving a certain portion of the line unshielded and therefore subject to radiation losses. A further disadvantage of a transposition in a coaxial line is that currents may leave the internal shielded portion of the line at the place of transposition and travel along the outside of the shield, resulting in a substantial loss of the shielding effect of the outer conductor of the line. The basic series connection of Fig. 11, however, obviates this difficulty completely and provides a bridge which may be substantially perfectly shielded from interference by or to external systems.

Figs. 13 and 14 illustrate modifications of the bridge employing hollow pipe construction. In these figures the pipes are assumed to be seen in section and it is to be understood that the two sectioned lines connecting adjacent bridge points represent diametrically opposite portions of a single cylindrical conductor and not two paths as in the preceding figures. This means of realizing the bridge of the present invention affords unusual adaptability to micro waves, i. e., waves whose lengths are, say, a few centimeters or less. At these extremely short wavelengths, ordinary lines, including even the coaxial form, have high losses because of the imperfections in the insulators separating the two or more conductors of

the line, and the construction of coaxial lines is difficult because their size becomes quite small. The hollow pipe modification, however, circumvents these difficulties and provides an efficient bridge even at the highest frequencies used in radio. Furthermore, the operation of a hollow-pipe bridge of this type with waves of the hollow pipe type affords opportunities for a unique mode of operation. For example, the phase velocity of the waves may be made appreciably greater than the velocity of light in a medium having the same constants as those of the medium inside of the pipe, permitting unexpected design features, such as a physical lengthening of the paths 1, 2, 3, 4 for an effect equivalent to that of a coaxial line of shorter length, where this is desirable.

In the arrangement of Fig. 13, one terminal of indicator 3' is connected to an extension of the cylindrical conductor or pipe forming the outer conducting boundary of the electromagnetic waves, while the opposite terminal is connected to a terminal rod or electrode 15' positioned to receive energy from the wave existing at the center of the pipe. This arrangement is equivalent to the shunt connection of the indicator shown, for example, in Fig. 2. Source 1' is connected similarly in shunt fashion.

A phase shifting device which may be a line an odd number of half wavelengths long is shown at 15. The balancing impedances Z_2 and Z_4 intermediate the source and indicator in this construction take the form of pipe extensions 16 and 17, respectively, which may be terminated in any suitable manner. Appropriate terminations for hollow wave guides may be designed to give any desired impedance characteristic. Fig. 14 illustrates one form of adjustable termination, herein below described. It will be understood that the pipes 16 and 17 may extend appreciable distances before reaching the point of termination. It will also be understood that the invention is not limited to the use of non-radiating purely absorptive or reflecting impedances Z_2 and Z_4 as, analogous to the arrangements of Figs. 6 and 19, one or both of the impedances Z_2 or Z_4 may be arranged for radiation or include radiating means when it is desired to radiate part of the energy delivered to a bridge point by the source 1'. If the end of a wave guide is left open either with or without a flare, radiation will take place into the space beyond the mouth of the guide as explained in my articles in the Proceedings of the Institute of Radio Engineers, vol. 24, pages 1298, 1326, October (1936) and vol. 26, page 1498, December (1938). When energy is radiated at a bridge point adjacent the source, an indicator at the point opposite the source may not be required. In this case indicator 3' may be replaced by a balancing impedance.

Fig. 14 shows a hollow pipe line bridge of the type of Fig. 4 with one form of series connection for indicator 3'. The indicator 3' in this case is connected to a pair of electrodes 18 and 19 positioned to receive energy from the waves arriving over the two lines 2 and 3, respectively. Indicator 3' is preferably enclosed in a shielded compartment 21. Each pipe 2 and 3 may be terminated in its characteristic impedance, this being represented symbolically only by impedances 20 and 20'. The actual terminations employed are to be understood as being of a type suitable for connection to hollow-pipe lines.

An adjustable termination for a transmission line bridge constructed in hollow pipe form according to the invention is also shown in Fig. 14.

In this figure, a section of pipe 40 is adapted to be connected at one end to either or both pipe 16 or 17 of the bridge, being illustrated as coupled to pipe 17. This same pipe section 40 may also be used with the bridge of Fig. 13, being then coupled to pipe 16 or 17 (or both) thereof. The termination includes a conducting rod 42 extending transversely to the pipe axis having a resistance 43 at one end connected between said end and the wall of the pipe while at its other end the rod forms a part of a coaxial conductor 44. This coaxial conductor comprises the central conductor 42 and an outer conductor or shield 44'. An adjustable short-circuiting plunger 45, which is shown as adjustable by means of the rods and handle 46 determines the effective length. This coaxial line portion of the terminal device provides a series reactance for the rod 42. A second plunger 47 tightly closes the end of the pipe 40 opposite to end 41. The adjustable length of hollow pipe between the rod 42 and the plunger 47 provides an adjustable shunt reactance for the transverse rod 42. For a given value of the resistance or impedance 43 the lengths D_1 and D_2 may be so adjusted to provide an impedance match for the pipe connected to 40. Other adjustments of the lengths, D_1 and D_2 and other values of the impedance 43 provide impedances of other desired values. Such terminal means are particularly adapted for the operation of the bridge in hollow-pipe form with waves of the type referred to in the aforementioned Patent No. 2,129,712, as a symmetric magnetic or H₁ wave. Other terminal arrangements for this wave may be employed, and still other terminal arrangements adapted for operation with other types of waves are considered to be within the scope of the present invention.

Similar adjustable terminations for the transmission line bridge in coaxial form may be employed. One such construction is shown as Fig. 20. In this figure a section of coaxial line 50 is shown adapted to be joined at end 51 to a coaxial bridge. For example, the device of Fig. 20 may be connected at its end 51 to the bridge of Fig. 11 at the junction between lines 3 and 4 to provide the impedance Z_3 of this figure. The adjustable coaxial impedance of Fig. 20 comprises an adjustable shunt reactance in the form of a coaxial line having outer conductor 54 and inner conductor 52 connected across the line 50. This section of line is provided with an adjustable short-circuiting plunger 55 so that its length D_3 may be varied. By this means, a reactance of either positive or negative character and of any desired magnitude may be connected across the line. A further element of this adjustable impedance comprises a line having an outer conductor 58 and an inner conductor 59. This latter section is connected to the line 50 at 60 and this junction may be made adjustable by providing sliding connections between the two lines. Two adjustable plungers 61 and 62 provide any desired distance D_4 between their respective faces. Of particular importance in its application to balancing a bridge is a length

$$D_4 = \frac{n\lambda}{2}$$

where n is a positive integer, preferably 1, and λ is the wavelength. For this length, the line section between the plungers 61 and 62 provides a resonant electrical system and this resonant system is connected to the transmission line at a distance D_5 from one plunger. The magnitude

of the resistive impedance connected across the line 50 at the point 60 may be varied between wide limits by appropriate adjustment of the length D_5 . By relatively varying the shunt reactance element 54 and the substantially resistive element 58 any value of complex impedance may be made to appear at the terminal 51.

An important application of the principle of excluding power from an opposite bridge point while supplying power to bridge points adjacent the source is a two-way repeater in a high frequency communication circuit in which a wave travelling in either direction along the line may be amplified and retransmitted in the same direction, or both directions, by means of an amplifier so connected as to prevent singing or oscillation. A repeater of the so-called "21" type, that is, a two-way repeater having a single amplifier element 22 is shown in Fig. 15 where the east line and west line are connected to and form the impedances at two opposite bridge points of a transmission line bridge with amplifier 22 connected across the conjugate bridge points.

Impedance adjusting networks 23 and 23' are preferably included in the east and west lines, respectively, to facilitate balancing the bridge. In such a circuit a wave traveling from east to west arrives at the junction of lines 2 and 3 and divides between these two paths. Due to the passage of the wave over the path including lines 2 and 1 an E. M. F. is generated at the junction of 2 and 1, which, when applied to the input 24 of amplifier 22, causes a greatly amplified voltage from the output 24' of this amplifier to be applied at the junction of 3 and 4 from which point the amplified wave reaches the west line over two paths, i. e., bridge lines 4 and lines 3, 2, and 1. Another portion is transmitted back to the east line over the bridge.

As is known, if the line impedances connected at the junctions 1, 4 and 2, 3 are adjusted to equality, none of the output of the amplifier is transmitted to the input at the opposite bridge point and therefore "singing" or amplifier oscillation cannot occur. Similar considerations apply to the amplification of a wave arriving over the west line.

While the east and west lines of Fig. 15 are shown as shunt connected to the bridge, so far as balancing is concerned the characteristic impedances of these lines act merely as terminating impedances for the bridge and a series connection as shown for example in Figs. 4 and 5 may be employed.

Fig. 16 represents a repeater of the so-called "22" type, that is, a two-way repeater having two separate amplifying elements 25 and 26, each serving to amplify transmission in one direction only as indicated by the arrows. In this case the east line, for example, is balanced at the opposite point of one transmission line bridge having arms 1, 2, 3, 4 to which it is connected, by an impedance Z_1' equal to the characteristic impedance of the east line. An E. M. F. is applied by a wave arriving over the east line at the bridge point between lines 2 and 3, and through these lines to the output 27 of amplifier 26 and the input 28 of amplifier 25, respectively. Due to the directional characteristics of the amplifiers only the voltage applied to the input 28 of amplifier 25 is effective in producing an amplified voltage at the output 29, this output being applied to the bridge circuit having lines 11, 12, 13, 14, shown in the lower portion of the diagram, across the junction of lines 11 and 12, and thence across

the balancing impedance Z_{13} , and reaches the west line over the bridge transmission lines 11, 12, 13, 14.

Similarly, a wave arriving by the west line arrives at the junction between lines 11 and 14 of the lower transmission line bridge comprising lines 11, 12, 13, and 14. The west line is balanced by impedance Z_{13} at the opposite bridge point. The incoming wave is prevented from passing to the upper bridge through amplifier 25 because of the unilateral characteristic of this amplifier, but is amplified by amplifier 26 and reaches the east line by way of lines 3, and 4, 1, 2 of the upper bridge. It will be apparent that energy cannot be transferred around the conducting loop formed by the two amplifiers and bridges since the input of one amplifier is applied at the opposite bridge point of a balanced bridge from that point at which the output of the other amplifier is applied. The amplifiers therefore cannot "sing" around the loop.

Fig. 17 illustrates the application of a high frequency transmission line bridge circuit to a modulator in which the carrier frequency is suppressed. In this application a carrier source 30 supplies an E. M. F. E_c through the impedance Z_2 to the junction joint between lines 1 and 2 of the bridge. The load 31 having an impedance Z_4 in this case is shown for illustration connected in series between lines 3 and 4 at their junction and, since no transpositions are employed, no power due to the carrier source will appear in Z_4 as long as the impedances Z_1 of source 32 and the effective internal impedance Z_3 of device 31 at carrier frequency are balanced. If now at one of the conjugate bridge points a modulating source 32 is connected to supply an E. M. F. E_m to impedance Z_1 and thus also to the non-linear device 33 connected across the bridge at the opposite bridge point, the impedance of the carrier source Z_2 and the load impedance Z_4 not having values to fulfill the condition for balance, device 33 will receive power from both the carrier and modulating sources. Due to the non-linear characteristics of this device modulation occurs and the side bands resulting from modulation supply power to the load impedance Z_4 , the carrier being excluded.

Fig. 18 illustrates another important application of a high frequency bridge circuit in providing a connection between two radio antennae, either for transmitting or receiving, such that there is no interaction of one antenna on the other. By this means, individual tuning, phasing, or other adjustments of either antenna, as indicated by the two arrows, may be carried on without affecting the other antenna.

In Fig. 18, antenna 35 is shown as connected in the place of impedance Z_2 of the basic bridge circuit while antenna 36 is shown as connected in the position of impedance Z_4 . These designations are retained for the impedances of the respective antennae. A device 37, 37' which may be either a transmitter or receiver depending on whether 35 and 36 transmit or receive energy is shown connected in the position of Z_1 while impedance Z_3 balances the impedance of the said transmitter or receiver. It will be apparent that E. M. F.'s originating in either antenna will have no effect on the other antenna when the bridge is balanced but when the antennae are receiving energy will supply power to receiver 37, while on the other hand, if the antennae are transmitting energy they will be independently supplied by transmitter 37'.

Fig. 19 shows another form of modulating circuit employing a transmission line bridge. In this circuit impedance Z_1 of the basic circuit is the output impedance of an electron discharge device 38 which, by the inclusion of a suitable biasing E. M. F. in the input circuit as from battery 36', may be varied under the control of an E. M. F. supplied by modulating source 39. If for a particular value of output impedance a balance against Z_3 is obtained no energy from carrier source 39' is supplied to load 38'. As the output impedance of 38 is caused to vary from this value by the input voltage supplied from modulating source 39, the carrier energy supplied to load 38' varies proportionally, that is modulation takes place.

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. A circuit network comprising a pair of transmission line paths, a common A. C. source connected to adjacent terminals of said two paths for initiating the transmission of electromagnetic waves thereover, the wave length of the source being comparable with the lengths of the transmission line paths, a receiver connected to said two paths at terminals remote from said source for actuation by the resultant energy received from said two waves, and a pair of impedance means, one of said impedance means being connected in each of said paths intermediate the terminals thereof, one of the two elements referred to as a receiver and as a source being series-connected and the other being shunt-connected to the transmission paths.
2. A circuit network comprising a pair of transmission paths, each comprising a pair of transmission lines designed for transmission of waves comparable in length with the length of the lines, said lines being connected in tandem as a continuous loop, thereby forming a bridge circuit with junctions between lines at the four bridge points thereof, an alternating-current source and an alternating-current energy-receiving device, one of said latter two elements being serially connected to adjacent lines at one of said bridge points and the other being shunt-connected to adjacent lines, at a different bridge point.
3. A circuit network comprising a pair of transmission paths, each comprising a pair of transmission lines designed for transmission of waves comparable in length with the length of the lines, said lines being connected in tandem as a continuous loop, thereby forming a bridge circuit with junctions between lines as the four bridge points thereof, an alternating-current source and an alternating-current energy-receiving device, said latter two elements being connected to adjacent lines at different bridge points thereof, one of said latter two elements being serially connected to adjacent lines.
4. A circuit network as claimed in claim 1, having means in one of said paths for adjusting the relative phase of the two waves at the receiver.
5. A circuit network as claimed in claim 1, in which at least one of said pair of impedance means has independently adjustable series and shunt elements.
6. A circuit network comprising four transmis-

sion lines designed for transmission of waves comparable in wavelength with the length of the lines and four impedance means, said transmission lines being connected in tandem as a continuous loop with one of said impedance means connected at the junction of each pair of adjacent lines, thereby forming a bridge circuit with said impedance means at the four bridge points thereof, at least one of said impedance means being serially connected between adjacent lines, an A. C. source connected to impress a potential upon one of said impedance means for initiating the transmission of electromagnetic waves in opposite directions along a pair of adjacent lines and the lines respectively succeeding them, and means for utilizing the potential jointly induced by said two waves across the impedance means at the bridge point opposite said source.

7. A circuit network as claimed in claim 6, in which at least one of said impedance means has independently adjustable series and shunt elements.

8. A circuit network as claimed in claim 6, in which said potential-utilizing means is connected to said series-connected impedance means.

9. A circuit network as claimed in claim 6, in which at least one of said impedance means is symmetrical relative to the two adjacent lines for similarly terminating said lines.

10. A bridge type network comprising four transmission lines connected as the arms of the bridge, and defining four bridge points as the junctions between adjacent arms, an input circuit connected to two adjacent arms of said bridge and adapted to be connected to a high frequency A. C. source for initiating the transmission of electromagnetic waves over said two adjacent arms, an output circuit serially connected between the other two adjacent lines, and at least one adjustable impedance element connected to said bridge at a respective bridge point for balancing said bridge.

11. A high frequency bridge network, comprising four transmission lines connected as bridge arms and four impedance elements, one of said impedance elements being connected between each pair of adjacent lines at bridge points of said network, said transmission lines comprising a central conductor and an outer cylindrical conductor co-axial therewith and separated therefrom by a dielectric, at least one of said impedance elements being connected from said central conductor to said cylindrical conductor and the remaining elements being serially connected between the central conductors of adjacent transmission lines.

12. A bridge network as claimed in claim 11, in which at least one of said four impedance elements is adjustable both as to resistance and reactive components.

13. A bridge network as claimed in claim 11, having a source of A. C. connected to impress an E. M. F. upon one of said impedance elements and connected means for utilizing the energy supplied thereby to another bridge point.

14. A high frequency bridge network having four transmission lines connected as bridge arms and four impedance elements, one of said impedance elements being connected between each pair of adjacent lines at bridge points of said network, said transmission lines being constructed to serve as "wave guides" for electromagnetic waves of a type transmitted through said guides only when the frequency of said waves exceeds a critical frequency, said critical frequency being

dependent on the transverse dimensions of said guides, and one of said impedance elements being series-connected.

15. A network as claimed in claim 14, in which at least one of said transmission lines is coupled to an impedance adjustable as to its resistance and reactance components.

16. A network as claimed in claim 14, in which at least one of said impedance elements is constructed to serve as a "wave guide."

17. A bridge type network comprising four transmission lines connected as the arms thereof and four impedance elements, one of said elements being connected to said lines at each of the four bridge points of said network, one of said elements being series-connected, said transmission lines each having an outer conducting boundary for the waves transmitted thereover, said four conducting boundaries being connected to form an unbroken shield preventing interchange of energy between said network and means external thereto.

18. A bridge type network comprising four transmission lines connected as the arms thereof and four impedance elements, one of said elements being connected to said lines at each of the four bridge points of said network, said transmission lines being constructed as hollow-pipe "wave guides."

19. A transmission line bridge of the character described comprising four hollow-pipe "wave guide" transmission lines and four connected impedance elements, at least one of said impedance elements being of a conventional type having two accessible terminals, and means for connecting said terminals to suitable portions of said bridge for causing said impedance element to be effectively connected to adjacent lines at a bridge point thereof.

20. A transmission line bridge of the character described comprising four hollow-pipe "wave guide" transmission lines and four impedance elements connected at bridge points, said transmission lines being so constructed and arranged that for a selected operating frequency the phase velocity of the waves transmitted thereover is greater than the velocity of light.

21. A circuit network, comprising a pair of transmission paths each comprising a pair of enclosed-field-type transmission lines, said lines being connected in tandem as a continuous loop, thereby forming a bridge circuit with four bridge points at the junctions between adjoining pairs of said lines, an input circuit, and an output circuit, said latter two circuits being connected to adjacent lines at different bridge points thereof, one of latter two circuits being serially connected to adjacent lines and said lines having a common shielding outer boundary with said output circuit.

22. A high frequency bridge network comprising a pair of similar coaxial transmission lines each having an inner conductor and an outer conductor, said inner conductors and said outer conductors being connected together at one end, a source connected between said connected inner conductors and said connected outer conductors at said end, a pair of similar impedance elements each connected between an inner conductor and a corresponding outer conductor at similar positions intermediate the ends of said two lines, and an indicator connected in series between the other ends of said inner conductors.

23. A high frequency network comprising four sections of coaxial line each having an inner conductor and a concentric outer conductor and

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connected in tandem to form a closed loop providing four junction points, three impedance elements each connected at a respective junction point between the inner conductors and the outer conductors of the lines adjacent thereto, and a fourth impedance element connected in series with the inner conductors at the fourth of said junction points.

24. High frequency apparatus comprising a pair of wave guide paths, an input connection coupled to both said paths, an output connection coupled to both said paths, one of said connections being series-connected to said two wave guide paths and the other connection being shunt-connected to said two paths.

25. Apparatus as in claim 24, wherein said input and output connections are coupled respectively to spaced points of said paths.

26. Apparatus as in claim 24 further comprising a pair of circuit elements coupled symmetrically to said wave guide paths, whereby the impedance values of said elements determine the transfer of energy from said input connection to said output connection.

27. Apparatus as in claim 24 comprising a pair of circuit elements coupled to said paths at points spaced from said input and output connections.

28. Apparatus as in claim 24 further comprising a high frequency source coupled to a first one of said connections and a high frequency utilization device coupled to the remaining one of said connections.

29. High frequency apparatus comprising a pair of enclosed-field transmission line means, an input connection coupled to both said transmission line means and adapted to be connected to a

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source of high frequency energy for exciting both said transmission line means, an output connection coupled to both said transmission line means and adapted to be connected to a utilization device for said energy, one of said connections being series-connected to said two transmission line means and the other connection being shunt-connected to said two transmission line means.

30. Apparatus as in claim 25, further including a pair of circuits also coupled to said two transmission line means, said circuits determining by their impedance values the transfer of energy from said input connection to said output connection.

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