Oct. 29, 1946. W. A. TYRRELL 2,410,114

COUPLING ARRANGEMENT FOR USE IN WAVE TRANSMISSION SYSTEMS

Original Filed Dec. 31, 1942

FIG. 1

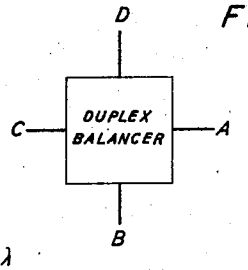


FIG. 2

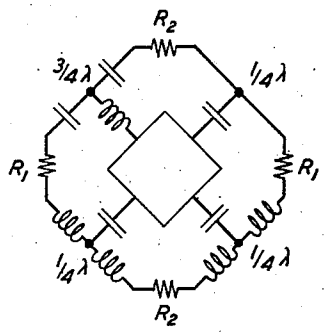


FIG. 3

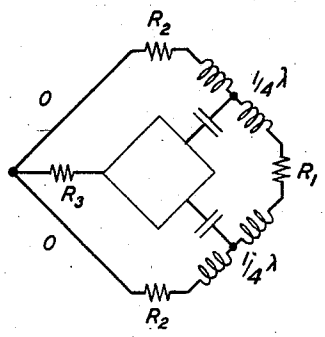


FIG. 4

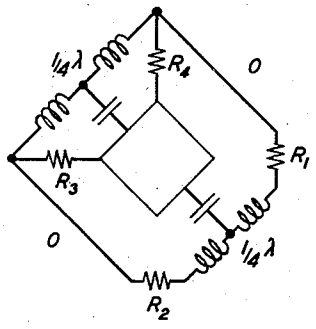


FIG. 5

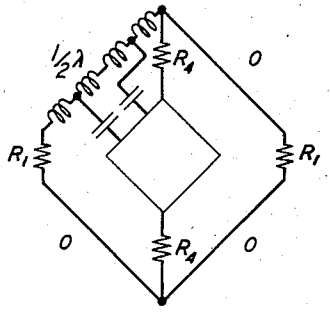


FIG. 6

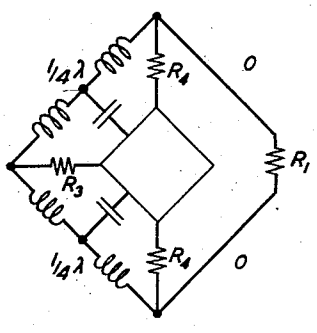
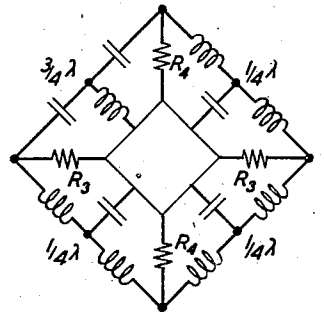


FIG. 7



FIGS. 2 TO 7 INCLUSIVE:
($R_1 = Z_0$ OR $2Z_0$, $R_2 = 2Z_0$ OR Z_0, $R_3 = Z_0$ OR $1/2\,Z_0$, $R_4 = 1/2\,Z_0$ OR Z_0
WHERE Z_0 IS THE CHARACTERISTIC IMPEDANCE OF THE TRANSMISSION LOOP)

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Patented Oct. 29, 1946 2,410,114

UNITED STATES PATENT OFFICE

2,410,114

COUPLING ARRANGEMENT FOR USE IN WAVE TRANSMISSION SYSTEMS

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Original application December 31, 1942, Serial No. 470,810. Divided and this application December 28, 1943, Serial No. 515,877

9 Claims. (Cl. 178—44)

1

This is a division of my copending patent application, Serial No. 470,810, filed December 31, 1942.

The invention relates to wave transmission systems and particularly to coupling arrangements for use in such systems.

An object of the invention is to provide efficient transmission of wave power between certain of a plurality of wave transmission lines or other transmission media in a wave transmission system while effectively preventing transmission of wave power between others of them.

Another object is to provide balance in systems involving wave motion.

A related object is to provide with simple and economical apparatus an extremely accurate balance between certain parts of a wave transmission network so as to prevent wave transmission therebetween, and a given amount of unbalance between other parts of the network to facilitate wave transmission therebetween.

A more specific object is to so couple four transmission lines or other transmission media that when power is supplied by one of them to the coupling device, two others of the lines or other transmission media will receive from the coupling device a given amount of this power, and the fourth substantially no power.

These objects are attained in accordance with the invention in the following manner. A coupling device comprising a transmission line or circuit, or equivalent circuit with lumped circuit constants, forming a closed transmission loop or ring, is used. Four individual lines or other transmission media between which wave transmission is to be respectively allowed or prevented, are connected as branches to the transmission loop at different points. The types of electrical connections of the several branches to the transmission loop are so selected, and the electrical spacings of the branches around the loop, or the equivalent line wavelengths of the lumped constant circuit portions between adjacent branches around the loop, and the characteristic impedances of the branches with respect to that of the transmission loop are respectively proportioned so that electrical balance with impedance matching for waves of given frequencies between certain of the branches and a desired amount of electrical unbalance between other branches are provided. Thus, if wave power of the given frequencies is applied through one of the branches to the transmission loop, a desired distribution of this wave power between the other branches may be obtained.

2

In one basic embodiment of the invention, electrical balance independent of frequency between each two transmission branches connected to oppositely situated portions of the transmission loop, and electrical unbalance between each two adjacently-connected branches around the loop, are attained mainly by the use of dissimilar electrical connections (one series and one parallel, respectively) for two oppositely situated branches, and similar electrical connections (both series or both parallel) for the other two oppositely situated branches.

In another basic embodiment, electrical balance at given frequencies between each two transmission branches connected to oppositely situated portions of the transmission loop and electrical unbalance at these frequencies between each transmission branch and each adjacently-connected transmission branch around the loop are attained mainly by providing between each two oppositely situated (non-adjacent) transmission branches two electrical paths around the loop differing in effective electrical length by a half wavelength.

My aforementioned parent patent application discloses various specific arrangements of the above-mentioned basic embodiments, and modifications thereof, in which the closed transmission loop used as the coupling device is formed from (1) dielectric wave guide, coaxial cable, or shielded pair cable (parallel wire line), particularly adapted for use in systems transmitting waves of high or ultra-high frequencies; or (2) from one or more coupled electrical networks of lumped circuit constants (coil-condenser arrangements) or equivalent lumped constant circuits, adapted for use in systems transmitting waves of relatively low frequency. This divisional application is specifically directed to the arrangements of the parent application in group (2) as defined above.

The various objects and features of the invention will be better understood from the following detailed description when read in conjunction with the accompanying drawing in which:

Fig. 1 shows a simple diagram used in connection with a general description of the invention; and

Figs. 2 to 7, inclusive, show schematically various forms of the coupling or balancing arrangements in accordance with the invention in which each portion of the closed transmission loop is composed of one or more symmetrical T- or π-electrical networks with lumped circuit constants, or equivalent wiring.

The scope of the principles determining the operation of the device of the invention is so general as to embrace all forms of wave motion, and limits to their applications would seem, therefore, to be set only by the dictates of practical construction. For purposes of simplification and brevity, the following detailed description will be limited to such devices in connection with alternating current transmission.

As all of the devices of the invention operate by providing wave balance and are of primary utility for use in duplex communication systems in which they render possible simultaneous two-way communication at the same frequency, for convenience in the following description each will be referred to by the general term "duplex balancer," but it is to be understood that the term where used in the specification and claims should be given a broad interpretation not limited to duplex systems.

The devices of the invention will first be described in general terms with reference to the simple diagram of Fig. 1. In that figure, the duplex balancer is represented as a box the exact nature of which is irrelevant to a general description, but it is to be understood that the contents of the box are such as to bring about the results outlined below. Emerging from the box are four "leads" identified as A, B, C and D. A lead may be composed of wave guide, coaxial cable, a shielded cable pair, a pair of wires or whatever is appropriate to the frequency of the waves being transmitted. If a wave generator is connected to lead A, and if balance has been obtained in the duplex balancer and suitable loads are connected to the other three leads, the power from the generator will be evenly divided between the loads at B and D, and no power will be developed in the load at C. Also, if the generator is connected to B, its power will be divided equally between suitable loads at A and C, and no power will flow to the load at D. In one application of such a device, a signal transmitter may be connected to lead A, a dummy load to the lead D, a signal receiver to lead C and a communication line to lead B. The receiver will be unaffected by power flowing from the transmitter through the duplex balancer to the line and to the dummy load, but the receiver will be responsive to power passing from the communication line into the duplex balancer.

A section of transmission line of any length may be represented for any particular operating frequency by a symmetrical T- or π-electrical network with lumped circuit constants, and the values of the impedances necessary for the representation are well known. In order to translate the various transmission line duplex balancers illustrated and described in the parent application into duplex balancers using circuits of lumped constants, i. e., coils, condensers and resistors, it is necessary only to know the lumped constant T- and π-section network equivalents for the half wavelength, quarter wavelength, three-quarter wavelength and one wave-length sections of transmission line used in the four portions of the closed transmission loop or ring connecting adjacent branch lines. In order to represent the dissipation of actual lines, a series resistor is usually added in each arm of the T- and π-networks. Coils and condensers, however, always possess dissipation too, so that it is most convenient for present purposes to assume that the losses in the coils and condensers are so adjusted that a given dissipative line is truly represented.

The representation of quarter and three-quarter wavelength sections of circuits with lumped constants is straight-forward; there is, to be sure, ambiguity in the signs of the reactances, but in each case this is readily resolved by an analysis of the current. The representation of half wavelength line sections is not so simple. The analytical solution based upon impedances leads to nothing but a pair of wires; analysis based upon currents, however, shows that these wires must be crossed. Nevertheless, even crossed wires cannot be used freely as a substitute for a half wavelength section. In general, crossed wires are completely inadequate to represent the behavior of a half wavelength line section with respect to frequency. Care must therefore be exercised in the representation of half wavelength line sections. It has been found that two lumped constant T- or π-network sections in series, each equivalent to a quarter or three-quarter wavelength section, will give an adequate representation in those cases where crossed wires fail. It can be shown, moreover, that the lumped constant representation of a quarter and a three-quarter wavelength section displays, for small deviations from the given frequency, the correct functional variation, differing from the transmission line expression only by numerical constants of the order of magnitude unity.

By utilizing symmetrical T- or π-electrical networks, combinations of them, or the equivalent wiring arrangements of appropriate values, in place of the corresponding lengths of wave guide in the closed transmission loop wave guide duplex balancers shown in Figs. 12 and 16 to 20 of the parent application, a large number of lumped constant duplex balancers can be derived. This number can be still further increased by applying the rule that the lumped constant representation of a half wavelength may be added to each of any two of the four loop portions connecting the four branch lines. For illustrative purposes, the circuit diagram of six of such lumped constant duplex balancers respectively derived from those of Figs. 12 and 16 to 20 of the parent application, corresponding to the arrangements of Figs. 44 to 49 of that application, are shown in Figs. 2 to 7 of this application.

In each of the duplex balancers of Figs. 2 to 7 of this application, the closed transmission loop operating as the coupling device comprises four coupled arms each including a lumped constant electrical network of the T- or π-type made up of one or more coils and condensers, equivalent to a section of transmission line of a given wavelength, or two such networks in series (Fig. 5), or a wiring representation equivalent electrically to zero or a negligible number of electrical degrees (Figs. 3 to 6). The particular wavelength of the section of transmission line represented by the network or the equivalent in each arm of the particular duplex balancers illustrated in Figs. 2 to 7 is indicated by the wavelength designation opposite that arm, the arms with wires only representing the equivalent electrically of zero or a negligible number of electrical degrees bearing the designation "0." Each of the four branch transmission lines or other branch media coupled by the transmission loop, in Figs. 2 to 7, is represented by a resistor, one of which is connected either in series or in shunt with the loop at each of the four junctions of the coupled networks. The designation R_1, R_2,

R_3 or R_4 opposite each of these resistors in Figs. 2 to 7 indicates the characteristic impedance of the branch line or other branch medium with respect to that of the closed transmission loop to provide proper impedance matching for the particular type of duplex balancer illustrated. As indicated by the table at the bottom of the drawing, $R_1=Z_0$ or $2Z_0$, $R_2=2Z_0$ or Z_0, $R_3=Z_0$ or $\frac{1}{2}Z_0$ and $R_4=\frac{1}{2}Z_0$ or Z_0, respectively, where Z_0 is the characteristic impedance of the closed transmission loop.

In the basic type of circuit shown in Figs. 2, 5 and 7 balance is achieved by providing between oppositely situated (alternate) connections of the branching lines or other branching media to the loop, two electrical paths around the loop (made up of lumped circuit constant equivalents of sections of transmission line of given wavelength), which two paths differ by a half wavelength at the design frequency. In the arrangements of Figs. 2 and 7, each of the four branching lines or other branch media is connected to the transmission loop at a different one of the four junctions of the coupled network portions by the identical type of electrical connection; all four branches in Fig. 2 being connected electrically in series with the loop, and all four branches in Fig. 7 being connected electrically in parallel with the loop. In the arrangement of Fig. 5 two oppositely situated branches are connected in series with the loop and the other two oppositely situated branches in parallel with the loop.

In this basic type of circuit, when the waves applied to the loop through one of the branches depart from the design frequency, the two electrical paths around the loop between each two oppositely situated branching connections no longer differ by exactly a half wavelength so that a perfect balance is not obtained, the amount of unbalance increasing as the difference between the operating frequency and the design frequency is increased. Thus, this basic type of circuit cannot be made to give perfect balance throughout a band of frequencies. An analysis of similar low frequency circuits indicates that for small percentage deviations from the design frequency, the extent of unbalance is given approximately by the equation

$$\frac{P_{bp}}{P_1}=C\frac{(f-f_0)^2}{(f_0)^2} \qquad (1)$$

where P_{bp} equals the power developed in the load at (what should be) the balance point, P_1 is the power developed in these loads which should receive the power, f is the operating frequency, f_0 is the design frequency and C is a constant of order of magnitude unity.

In the basic type of circuit shown in Figs. 3 and 6, two of the branching lines at oppositely situated (alternate) junctions of the coupled networks in the transmission loop are connected respectively in series and in parallel with the loop, and the other two lines are connected to the loop at the other two oppositely situated junction points by the same type of electrical connections (both series or both parallel). A load connected to either of the first two branch lines is balanced with respect to a transmitter connected to the other of these two branch lines. The proper phasing for balance results not from the use of two connecting paths of different electrical length, as in the arrangement of Figs. 2, 5 and 7, but from the dissimilarity of the two kinds of connections. In addition,

the balance depends on the equality of the two loads which are receiving the power. The degree of balance obtained at either of the first two branching points is, therefore, independent of frequency and dependent only on the extent to which the two driven loads can be made identical. The degree of balance at the other two branching points will depend upon the frequency according to the approximate mathematical expression in Equation 1. The degree of balance at some one point is often the only important criterion, and in many applications, the arrangements of Figs. 3 and 6 will effectively possess balance over a wide frequency range.

In the duplex balancer of Fig. 4, which is a modification of the basic type shown in Figs. 3 and 6, each two oppositely situated (alternate) branches are connected in series and in parallel, respectively, with the transmission loop, the balance at any point being achieved by the dissimilarity of the oppositely situated connections. In spite of this, the balance is frequency dependent. No matter to which branch the transmitter is connected, a series load and a parallel load are driven. At the design frequency, there are virtual pistons in the loop, one at the series load connection and one a quarter wavelength behind the parallel load connection. As the frequency is changed, these pistons are effectively displaced unequal distances and, accordingly, the loads no longer appear identical to the transmitter. Consequently, though two sets of waves arrive 180 degrees out of phase at the balance point, their amplitudes are not exactly equal. There is, however, a partially compensating effect which tends to give this duplex balancer a degree of balance that is more constant with frequency than in the case of the balancers of Figs. 2, 5 and 7.

The particular designated equivalent transmission line wavelengths of the lumped constant loop portions between the adjacent transmission branches, shown opposite the four loop portions in each duplex balancer of Figs. 2 to 7, are those which will result in maximum power in two oppositely situated load branches when wave power is applied to the transmission loop by a generator connected to one of the other oppositely situated transmission branches. As stated above, equivalent results will be attained if the lumped circuit constants of the loop portion are modified to effectively add a half wave length section of line to any two of the loop portions.

The discrepancies between these lengths and those of the corresponding wave guide balancers shown in Figs. 12 and 16 to 20 in the parent application are due to the use of the rules given in that application for changing the arm wavelengths to provide equivalent balance arrangements, the equivalent lengths for the arms of the balancers given in Figs. 2 to 7 of this application being chosen for illustration because the circuits are simplified by the changes. As pointed out in the parent application it may be advantageous to slightly adjust, i. e. "trim" one of the coupled impedances to compensate for slight inaccuracies (in practice) elsewhere in the system to perfect the degree of balance.

A more complete discussion of the general theory which is applicable to the low frequency lumped constant balancers of Figs. 2 to 7, as well as to the high frequency duplex balancers disclosed in the parent application, is given in that application.

Various other modifications of the devices of

the invention illustrated and described, which are within the spirit and scope of the invention, will occur to persons skilled in the art.

What is claimed is:

1. An arrangement for coupling four wave transmission media in a wave transmission system comprising a closed transmission loop consisting of four coupled loop portions with lumped circuit constants equivalent to a section of transmission line of predetermined wavelength, means for electrically connecting said wave transmission media as branches to said loop at respectively different junctions of the four loop portions, at least one of said branches being connected electrically in series with said loop, the types of electrical connection of the other branches to said loop being selected and the characteristic impedances of the four branches with respect to that of said loop and the lumped circuit constants of the four coupled loop portions being proportioned so as to substantially prevent wave transmission at certain frequencies between the transmission branch connected to each loop junction and the transmission branch connected to the oppositely situated loop junction, and to enable efficient wave transmission at said certain frequencies between the transmission branch connected to each loop junction and the two transmission branches connected to the next adjacent loop junctions around the loop.

2. A coupling arrangement for use in a wave transmission system, comprising a closed transmission loop having lumped circuit constants equivalent to a section of transmission line of predetermined wavelength, and four branch circuits electrically connected to said loop at respectively different points, at least one of said branch circuits being connected electrically in series with said loop and at least one other of said branch circuits being connected electrically in parallel therewith, the types of electrical connections of the other branch circuits to said loop being selected and the lumped circuit constants of the portions of the loop connecting the adjacent branch circuits being relatively proportioned so as to provide a high degree of electrical balance, at least for waves of certain frequencies, between each two branch circuits connected to oppositely situated points in said loop and a substantial amount of electrical unbalance between each branch circuit and each of the two next adjacent branch circuits around said loop.

3. A duplex balancer comprising a closed transmission loop having four coupled loop portions with lumped circuit constants equivalent to a section of transmission line of predetermined wavelength, and four branch circuits respectively connected to the loop at a different one of the four junctions of the coupled loop portions, electrical balance at least at certain frequencies between each two branch circuits connected at oppositely situated loop junctions and electrical unbalance at said certain frequencies between the branch circuits connected at each two adjacent junctions around the loop, being achieved mainly by the use of a parallel and a series electrical connection, respectively, with the loop for at least two of the branch circuits connected at oppositely situated loop junctions.

4. A duplex balancer comprising a closed transmission loop having four coupled loop portions with lumped circuit constants equivalent to a section of transmission line of predetermined wavelength, and four transmission branches respectively electrically connected in series with said loop at a different one of the four junctions of the coupled loop portions, electrical balance at least for waves of certain frequencies between each two transmission branches connected at oppositely situated loop junctions and electrical unbalance at said certain frequencies between each transmission branch and the transmission branches connected at the next adjacent junctions around the loop being attained mainly by selecting the lumped circuit constants of the four loop portions so as to provide two electrical paths around the loop between alternate junctions equivalent to two sections of transmission line differing in electrical length by a half wavelength.

5. The duplex balancer of claim 3, in which the electrical connections of the branch circuits to the loop at two oppositely situated junctions are of identical type, the lumped circuit constants of the loop portion between each two adjacent branch circuits having identical-type electrical connections to the loop are such as to make that portion equivalent to a quarter wavelength section of transmission, line and the loop portion between each two adjacent branch circuits having respectively a parallel and a series electrical connection to the loop, is equivalent to a negligible number of electrical degrees.

6. The duplex balancer of claim 3 in which the branch circuits at two oppositely situated loop junctions are both connected to the loop by a series electrical connection.

7. The duplex balancer of claim 3, in which the branch circuits at two oppositely situated loop junctions are both connected to the loop by a parallel electrical connection.

8. The duplex balancer of claim 3, in which two branch circuits at oppositely situated loop junctions are each connected to the loop by a series electrical connection, and to provide impedance matching the characteristic impedance of the parallel connected branch circuit is made Z_0 or $\frac{1}{2} Z_0$, that of the opposite series connected branch circuit Z_0 or $2 Z_0$ and that of each of the other two series connected branch circuits $2Z_0$ or Z_0, respectively, where Z_0 is the characteristic impedance of said closed transmission loop.

9. The duplex balancer of claim 3, in which two of the branch circuits are connected to the loop at two of the oppositely situated junctions by a parallel electrical connection, and to provide impedance matching the characteristic impedance of the series-connected branch circuit is made Z_0 or $2Z_0$, that of the oppositely situated parallel connected branch circuit Z_0 or $\frac{1}{2} Z_0$ and that of each of the two other oppositely situated parallel connected branch circuits $\frac{1}{2} Z_0$ or Z_0, respectively, where Z_0 is the characteristic impedance of said closed transmission loop.

WARREN A. TYRRELL.

Disclaimer

2,410,114.—*Warren A. Tyrrell*, Fairhaven, N. J. COUPLING ARRANGEMENT FOR USE IN WAVE TRANSMISSION SYSTEMS. Patent dated Oct. 29, 1946. Disclaimer filed Apr. 12, 1951, by the assignee, *Bell Telephone Laboratories, Incorporated.*

Hereby enters this disclaimer to the subject-matter of claims 1, 2, 3, 6, and 7 of said patent.

[*Official Gazette May 22, 1951.*]