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COUPLING CIRCUITS

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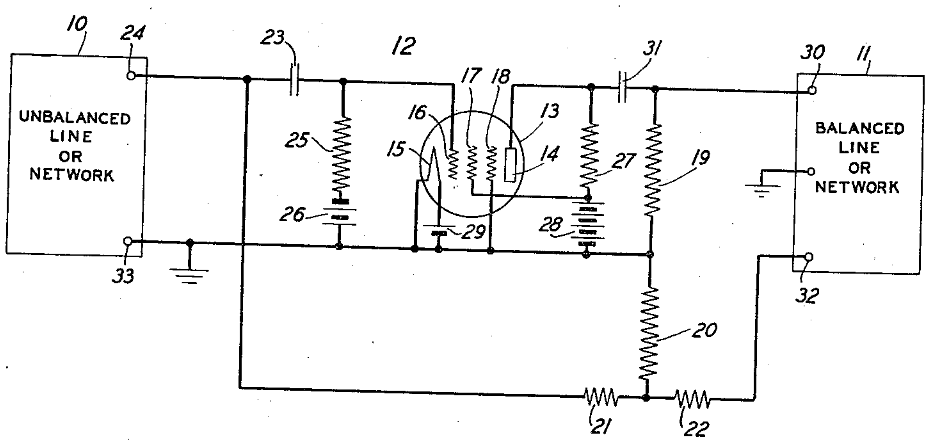


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## COUPLING CIRCUITS

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This invention relates to coupling circuits and more specifically to circuits for coupling an unbalanced line or network and a balanced line or network.

In the interconnection of a coaxial cable, one element of which is customarily connected to ground or to a point of fixed potential, and a cable pair, the elements of which are customarily balanced with respect to ground or to a point of fixed potential, coupling circuits are necessary. For the transmission of television programs, the television terminal equipment now being contemplated by a number of investigators makes use of a very wide range of frequencies extending from a few cycles to a million or more cycles. This range is beyond that which can be efficiently handled by transformers which can be built at the present time. The solution of the problem of interconnecting balanced and unbalanced circuits without the use of transformers or coils is therefore an important one.

Coupling circuits are known which interconnect a balanced and an unbalanced circuit without the use of transformer coils. In each case, however, the circuit is suitable for transmission in one direction only, that is, from the balanced circuit to the unbalanced circuit or from the unbalanced circuit to the balanced circuit, but not from one to the other as desired without rearrangement of the coupling circuit.

It is an object of this invention to provide a circuit for the interconnection of a balanced and an unbalanced circuit without the use of coils, which may be used for transmission in either direction.

In accordance with the invention, a circuit is provided for interconnecting an unbalanced circuit and a balanced circuit comprising an electron discharge device used as a phase inverter, and an impedance network. The elements comprising the network are preferably so chosen that the impedances of the circuit at high frequencies are matched in both directions. This coupling circuit is capable of transmitting an extremely wide range of frequencies, such as, for example, that used in television transmission. In general, the high frequency impedance of a transmission line is substantially a pure resistance. If a transmission line is terminated in this value of resistance, reflections are caused at low frequencies, but these reflections are ordinarily of such a nature as to render the transmission efficiency of the line more nearly uniform over the whole frequency range. The delay distortion of the over-all circuit is also reduced under these conditions. It follows that the simplification of the coupling circuit provided by the use of resistive elements will not usually entail any disadvantages in its operation.

The invention will be more readily understood from the following description taken in connection with the accompanying drawing forming a part thereof in which the single figure shows a circuit for coupling an unbalanced to a balanced circuit and vice versa, without the use of transformer coils.

Referring more particularly to the drawing, the single figure shows a box 10 representing generally an unbalanced line or network, a box 11 representing generally a balanced line or network, and a circuit 12 for interconnecting the unbalanced line 10 and the balanced line 11.

The interconnecting circuit preferably comprises an electron discharge device 13, comprising an anode 14, a cathode 15, a control grid 16, a screen grid 17, and a suppressor grid 18, which device is used as a phase inverter, and an impedance network comprising the resistance elements 19, 20, 21 and 22.

The control grid 16 of the electron discharge device 13 is connected through an appropriate coupling condenser 23 to the ungrounded terminal 24 of the unbalanced line or network 10. The cathode 15 has one terminal connected to ground, the suppressor grid 18 being also grounded. Between the control grid 16 and one terminal of the cathode 15 are connected a conventional biasing resistance 25 and a source of potential 26. Connected between the anode 14 and the cathode 15 are an anode resistance 27 and a source of anode potential 28. The source 28 or a portion thereof also serves as a means to positively bias the screen grid 17 with respect to the cathode 15. A source 29 supplies heating current to the cathode 15. The anode 14 of the electron discharge device 13 is coupled to one terminal 30 of the balanced line or network 11 by means of the coupling condenser 31. One terminal of the cathode 15 is connected to the terminal 30 (through condenser 31) by means of the resistance element 19, and this terminal of the cathode is also connected to the other terminal 32 of the network 11 by means of the resistance elements 20 and 22 in series. The terminal 24 of the unbalanced line or network 10 is connected to the terminal 32 of the balanced line or network 11 by means of resistance elements 21 and 22 in series.

Considering the transmission in the direction from the unbalanced line or network 10 to the balanced line or network 11, the phase of the line current at the terminal 32 is the same as that of the line current at the terminal 24 because no phase change occurs in the passage of current through the resistance elements 21 and 22 in series. The phase of the line current at the terminal 30 is substantially 180 degrees from that of the line current at the terminal 24 and hence of the line current at the terminal 32 because of the phase inverting action of the electron discharge device 13. The terminals 30 and 32 are balanced with respect to ground by means of the resistances 20 and 22 connected in series between the terminal 32 and ground, the resistance 20 being shunted by the series circuit comprising resistance 21 and the impedance of the unbalanced line or network 10, and the resistance 19 in parallel with the series circuit comprising the condenser 31 and the anode-cathode impedance path of the discharge device 13 shunted by the series circuit comprising the resistance 27 and the source 28. The values of the resistances 19, 20, 21, 22 and 27 are chosen with respect to that of the constants of the lines and of the electron discharge device 13 and its associated input and output circuits so that the impedances are matched in both directions of transmission between the unbalanced and balanced circuits.

Considering the transmission from the balanced line or network 11 to the unbalanced line or network 10, the line current at the terminal 30 assumes the phase of the line current at the terminal 33 inasmuch as the impedance of the circuit represented by the resistance 19 and its parallel paths is resistive. No current, of course, flows from the anode 14 to the cathode 15 when transmission is from the balanced line 11 to the unbalanced line 10. The line current at the terminal 32 is in phase with that at the terminal 24 due to the pure resistance load 21 and 22.

The values of the elements of the circuit may be determined in the following manner. The reactance of the coupling condenser 23 at the lowest frequency to be transmitted should be small compared with the resistance of element 25. The resistance of the resistor 25 is not critical, but may conveniently be made very large compared with the impedance of the unbalanced line or network 10. The reactance of the coupling condenser 23 at the lowest frequency to be transmitted is preferably small compared with the resistance 19. The impedance of the resistance element of element 27 is not critical, but may be made large compared with resistance element 19; this condition yields a smaller loss through the circuit and simplifies the determination of the values of the remaining elements. The electron discharge device 13 may be a conventional pentode vacuum tube, in which case its anode-to-cathode impedance would be large compared with that of the resistance 19. With these approximations, the impedance across the terminals of the resistance 19 with the balanced line or network 11 removed is substantially equal to the resistance of 19.

Let the high frequency impedance of the unbalanced line be represented by $R_U$, of the balanced line by $R_B$, and the resistances of elements 19, 20, 21 and 22, by $R_{19}$, $R_{20}$, $R_{21}$, and $R_{22}$, respectively. The impedance across terminals 30 and 32 when the balanced line is removed should equal $R_B$, and since this impedance must be balanced to ground, $R_{19}$ must equal

$$\frac{1}{2}R_B$$

By the same reasoning, the impedance from the right side of the T network, composed of elements 20, 21 and 22, and terminated with $R_U$, must equal

$$\frac{1}{2}R_B$$

Similarly, the impedance across terminals 24 and 33 when the unbalanced line is removed should equal $R_U$, which is the impedance from the left side of the figure of the T network terminated with

$$\frac{1}{2}R_B$$

That this latter value of termination is correct may be seen by the following reasoning: the balanced line or network 11 may be replaced by two resistances each equal to

$$\frac{1}{2}R_B$$

and connected in series; the junction between them will be at ground potential, and may therefore be connected to ground by a wire without disturbing the existing distribution of currents and voltages.

Consider the direction of transmission to be from the unbalanced to the balanced line, and let the voltage across terminals 24 and 33 be E. Then the vacuum tube may be replaced by a constant current generator of value EG where G is the mutual conductance of the vacuum tube, as described in Chapter IX of the book "The Theory of Electrical Artificial Lines and Filters" by A. C. Bartlett. This constant current generator is connected to the equal resistances $R_{19}$ and

$$\frac{1}{2}R_B$$

in parallel, and hence the voltage across

$$\frac{1}{2}R_B$$

equals

$$\frac{1}{4}EGR_B$$

The voltage E also appears across the left side of the T network and the values of $R_{20}$, $R_{21}$, and $R_{22}$ must be chosen so that the voltage

$$\frac{1}{4}EGR_B$$

appears across its termination which is of value

$$\frac{1}{2}R_B$$

The design of such a dissymmetrical T network in terms of its image transfer constant and its image impedances is given in Chapter XI of the book "Transmission Circuits for Telephonic Communication" by K. S. Johnson. Using the symbols $R_U$, $R_B$, G, $R_{20}$, $R_{21}$, and $R_{22}$, the solution is given by the equations:

$$R_{20}=\frac{\sqrt{R_UR_B}}{\sqrt{2}\sin h\theta}$$

$$R_{21}=\frac{R_U}{\tan h\theta}-R_{20}$$

$$R_{22}=\frac{R_B}{2\tan h\theta}-R_{20}$$

$$\theta=\frac{1}{2}\log_e\frac{8}{R_UR_BG^2}$$

It may happen that for certain combinations of values of $R_U$, $R_B$, and G, a non-physical solution will be obtained for certain of the elements $R_{20}$, $R_{21}$, and $R_{22}$. In this event a different vacuum tube may be chosen, or the effective mutual conductance of the tube may be reduced in any well-known manner, so that the solutions of the equations yield attainable values for the circuit elements.

When the above conditions are met, the loss occurring in the complete circuit when transmitting from the unbalanced to the balanced circuit is equal to $(8.686\theta-3)$ decibels. For transmission from the balanced to the unbalanced circuit, the loss is $(8.686\theta+3)$ decibels.

As a specific example consider the interconnection of a 75-ohm unbalanced circuit with a 600-ohm balanced circuit for a frequency range from a few cycles to about two million cycles, matching the impedances in both directions. The pentode vacuum tube used has a mutual conductance of 3000 micro-amperes per volt. The resistance 19 has a value of about 300 ohms, resistance 20 a value of 71.1 ohms, resistance 21 of 11.9 ohms and resistance 22 of 261 ohms. This circuit with these constants has a loss of approximately 10 decibels when transmitting from the 75-ohm circuit to the 600-ohm circuit, and 16 decibels in the reverse direction.

The foregoing description applies to a coupling circuit having terminating impedances which are resistive and are constant over a wide frequency range. This is not a necessary condition, for a suitable choice of impedance values for elements 20, 21 and 22, and the substitution of a similar arrangement for the single element 19, may be employed to yield terminating impedances which vary with frequency in almost any desired manner.

Other modifications may obviously be made to suit various working conditions without departing from the spirit of the invention, the scope of which is defined by the appended claims.

What is claimed is:

1. In a high frequency transmission system, a circuit substantially balanced with respect to a fixed potential, a circuit unbalanced with respect to said fixed potential, and non-inductive means coupling said circuits in energy transfer relation, said coupling means comprising an impedance network connected to the balanced circuit for transferring energy from the balanced circuit to the unbalanced circuit and a phase inverting means distinct from said impedance network connected to at least a portion of said network and to said unbalanced circuit for transferring energy in cooperation with said network from the unbalanced circuit to the balanced circuit.

2. In a high frequency transmission system, a circuit substantially balanced with respect to a fixed potential, a circuit unbalanced with respect to said fixed potential, and means coupling said circuits in energy transfer relation, said coupling means comprising an arrangement including two impedance elements connected in series, and thus having a common terminal, for connecting the terminal of said unbalanced circuit which is not at a fixed potential to one of the terminals of said balanced circuit not at said fixed potential, a phase inverting device for connecting the terminal of said unbalanced circuit which is not connected to a fixed potential to the other terminal of the balanced circuit not at said fixed potential, and a third impedance element connected between said other terminal of said balanced circuit and the common terminal of said impedances in series.

3. In a high frequency transmission system, a circuit substantially balanced with respect to a fixed potential, a circuit unbalanced with respect to said fixed potential, and means coupling said circuits in energy transfer relation, said coupling means comprising an arrangement including two resistance elements connected in series, and thus having a common terminal, for connecting the terminal of said unbalanced circuit which is not at a fixed potential to one of the terminals of said balanced circuit not at said fixed potential, a phase inverting device for connecting the terminal of said unbalanced circuit which is not connected to a fixed potential to the other terminal of the balanced circuit not at said fixed potential, and a third resistance element connected between said other terminal of said balanced circuit and the common terminal of said resistance in series.

4. In a high frequency transmission system, a circuit substantially balanced with respect to a fixed potential, a circuit unbalanced with respect to said fixed potential, and non-inductive means coupling said circuits in energy transfer relation, said coupling means comprising an electron discharge device having an anode, a cathode and a grid, means for connecting the terminal of said unbalanced circuit which is not at a fixed potential to said grid, means for connecting said terminal of said unbalanced circuit through an impedance to one terminal of said balanced circuit not at said fixed potential, means for connecting said anode to the other terminal of said balanced circuit not at said fixed potential, and means for connecting said cathode to said point of fixed potential.

5. In a high frequency transmission system, a circuit substantially balanced with respect to a fixed potential, a circuit unbalanced with respect to said fixed potential, and means coupling said circuits in energy transfer relation, said coupling means comprising an electron discharge phase inverting means and an impedance network connected between said balanced circuit, said unbalanced circuit and said phase inverting means in such a manner that energy can be transferred in both directions between said circuits.

6. In a high frequency transmission system, a circuit substantially balanced with respect to a fixed potential, a circuit unbalanced with respect to said fixed potential, and means coupling said circuits in energy transfer relation, said coupling means comprising a phase inverting means and an impedance network connected between said balanced circuit, said unbalanced circuit and said phase inverting means in such a manner that energy can be transferred in both directions between said circuits, said impedance network comprising only elements which have almost entirely resistive impedance.

7. In a high frequency transmission system, a circuit substantially balanced with respect to a fixed potential, a circuit unbalanced with respect to said fixed potential, and non-inductive means coupling said circuits in energy transfer relation, said coupling means comprising an impedance network connected to the balanced circuit for transferring energy from the balanced circuit to the unbalanced circuit and an electron discharge phase inverting means connected to at least a portion of said network and to said unbalanced circuit for transferring energy in cooperation with said network from the unbalanced circuit to the balanced circuit.

8. In a high frequency transmission system, a circuit substantially balanced with respect to a fixed potential, a circuit unbalanced with respect to said fixed potential, and means coupling said circuits in energy transfer relation, said coupling means comprising an electron discharge phase inverting means having an anode, a cathode, a control grid, a screen grid and a suppressor grid,

means for connecting said cathode and said screen grid to a point at said fixed potential, means for positively biasing said screen grid with respect to said cathode, means for connecting said anode to said cathode through an impedance and a source of fixed potential, means for connecting said anode to one of the terminals of said balanced circuit not at said fixed potential, an impedance network comprising an impedance element and a T-shaped impedance network member, means for connecting the impedance element of said impedance network between one terminal of said balanced circuit not at a fixed potential and said point of fixed potential, and means for connecting the terminals of said T-shaped network member respectively to said point of fixed potential, the other terminal of said balanced circuit not at said fixed potential, and the terminal of said unbalanced circuit not at said fixed potential.

9. A circuit for interconnecting a circuit substantially balanced with respect to a fixed potential and a circuit unbalanced with respect to said fixed potential, comprising an electron discharge device having input and output circuits, means for connecting the input circuit of said device to the terminals of said unbalanced circuit, means for connecting the output circuit of said device between one outside terminal of said balanced circuit and a point of said fixed potential, a T-shaped impedance network, and means for connecting the terminals of said network respectively to the terminal of said unbalanced circuit not at fixed potential, to the other outside terminal of said balanced circuit, and to said point of fixed potential.

10. A circuit for interconnecting a circuit substantially balanced with respect to a fixed potential and a circuit unbalanced with respect to said fixed potential, comprising an electron discharge device having input and output circuits, a T-shaped impedance network, means for connecting the input circuit of said electron discharge device to the terminals of said unbalanced circuit, an impedance element connected between one outside terminal of said balanced circuit and said point of fixed potential, means for connecting the output circuit of said electron discharge device to said impedance element, and means for connecting the terminals of said T-shaped network respectively to the other outside terminal of said balanced circuit, to the terminal of said unbalanced circuit not at said fixed potential, and to said fixed potential.

11. A circuit for interconnecting a circuit substantially balanced with respect to a fixed potential and a circuit unbalanced with respect to said fixed potential, comprising an electron discharge device having input and output circuits, a T-shaped impedance network comprising elements which have almost entirely resistive impedance, means for connecting the input circuit of said electron discharge device to the terminals of said unbalanced circuit, an impedance element connected between one outside terminal of said balanced circuit and said point of fixed potential, means for connecting the output circuit of said electron discharge device to said impedance element, and means for connecting the terminals of said T-shaped network respectively to the other outside terminal of said balanced circuit, to the terminal of said unbalanced circuit not at said fixed potential, and to said fixed potential.

12. A circuit for interconnecting a circuit substantially balanced with respect to a fixed potential and a circuit unbalanced with respect to said fixed potential, comprising an electron discharge device having input and output circuits, a T-shaped impedance network comprising elements which have almost entirely resistive impedance, means for connecting the input circuit of said electron discharge device to the terminals of said unbalanced circuit, an impedance element connected between one outside terminal of said balanced circuit and said point of fixed potential, means for connecting the output circuit of said electron discharge device to said impedance element, and means for connecting the terminals of said T-shaped network respectively to the other outside terminal of said balanced circuit, to the terminal of said unbalanced circuit not at said fixed potential, and to said fixed potential, the said impedance and the elements comprising said T-shaped impedance network being so chosen with respect to the constants of said unbalanced and balanced circuits and of said electron discharge device and its associated input and output circuits that the impedances are matched in both directions of transmission between said balanced and unbalanced circuits at high frequencies.

13. A coupling circuit for coupling a balanced line having a first, a second, and a third terminal, the potentials of the first and second terminals of which are varying but are always balanced with respect to the potential of the third terminal which is maintained at a fixed value, with a two-terminal line, the potential of a first terminal of which is maintained at said fixed potential and the potential of a second terminal of which varies with respect to said fixed potential, said coupling circuit comprising a phase inverter having input and output circuits, the terminals of said input circuit being connected respectively to the terminals of said unbalanced line and the terminals of said output circuit being connected respectively to said first and third terminals of said balanced line, an electrical connection between said second terminal of said balanced line and said second terminal of said unbalanced line, a T-impedance network having its first and second arms in series in said last-mentioned connection and the outside terminal of its third arm connected to said third terminal of said balanced line, and an impedance connected between said first and third terminals of said balanced line.

14. A coupling circuit for coupling a balanced line having a first, a second, and a third terminal, the potentials of the first and second terminals of which are varying but are always balanced with respect to the potential of the third terminal which is maintained at a fixed value, with a two-terminal line, the potential of the first terminal of which is maintained at said fixed potential, and the potential of the second terminal of which varies with respect to said fixed potential, said coupling circuit comprising a phase inverter having input and output circuits, the terminals of said input circuit being connected respectively to the terminals of said unbalanced line and the terminals of said output circuit being connected respectively to said first and third terminals of said balanced line, an electrical connection between said second terminal of said balanced line and said second terminal of said unbalanced line, a T-impedance network having its first and second arms in series in said last-mentioned electrical connection and the outside terminal of its third arm connected to said third terminal of said balanced line, and an impedance

connected between said first and third terminals of said balanced line, said phase inverter being an electronic vacuum tube repeater, the input terminals of which are coupled to said unbalanced circuit terminals through a series capacity and a shunt resistance and the output terminals of which are similarly coupled to said first terminals of said balanced line.

15. A coupling circuit for coupling a balanced line having a first, a second, and a third terminal, the potentials of the first and second terminals of which are varying but are always balanced with respect to the potential of the third terminal which is maintained at a fixed value, with a two-terminal line, the potential of the first terminal of which is maintained at said fixed potential, and the potential of the second terminal of which varies with respect to said fixed potential, said coupling circuit comprising a phase inverter having input and output circuits, the terminals of said input circuit being connected respectively to the terminals of said unbalanced line and the terminals of said output circuit being connected respectively to said first and third terminals of said balanced line, an electrical connection between said second terminal of said balanced line and said second terminal of said unbalanced line, a T-impedance network having its first and second arms in series in said last-mentioned electrical connection and the outside terminal of its third arm connected to said third terminal of said balanced line, and an impedance connected between said first and third terminals of said balanced line, all of the impedances in said coupling circuit being substantially non-reactive.

16. A coupling circuit for coupling a balanced line having a first, a second, and a third terminal, the potentials of the first and second terminals of which are varying but are always balanced with respect to the potential of the third terminal which is maintained at a fixed value, with a two-terminal line, the potential of the first terminal of which is maintained at said fixed potential and the potential of the second terminal of which varies with respect to said fixed potential, said coupling circuit comprising a phase inverter having input and output circuits, the terminals of said input circuit being connected respectively to the terminals of said unbalanced line and the terminals of said output circuit being connected respectively to said first and third terminals of said balanced line, an electrical connection between said second terminal of said balanced line and said second terminal of said unbalanced line, a T-impedance network having its first and second arms in series in said last-mentioned electrical connection and the outside terminal of its third arm connected to said third terminal of said balanced line, and an impedance connected between said first and third terminals of said balanced line, said impedances being so chosen for a suitable range of frequencies that the impedance between the first and third terminals of said balanced line with the line removed looking towards said unbalanced line is equal to one-half of the approximate line impedance between the first and second terminals of said balanced line, the impedance looking towards the unbalanced line from between the second and third terminals of the balanced line with the latter removed is also equal to one-half of the approximate line impedance between the first and second terminals of said balanced line, and the impedance between said terminals of said unbalanced line with the latter removed looking toward the balanced line is equal to the approximate line impedance of said unbalanced line looking into said unbalanced line.

17. In a high frequency transmission system, a circuit substantially balanced with respect to a fixed potential, a circuit unbalanced with respect to said fixed potential, and means coupling said circuits in energy transfer relation, said coupling means comprising an arrangement including two impedance elements connected in series, and thus having a common terminal, for connecting the terminal of said unbalanced circuit which is not at a fixed potential to one of the terminals of said balanced circuit not at said fixed potential, a phase inverting device for connecting the terminal of said unbalanced circuit which is not connected to a fixed potential to the other terminal of the balanced circuit not at said fixed potential, and a third impedance element connected between said other terminal of said balanced circuit and the common terminal of said impedances in series, said third impedance element having an intermediate terminal which is placed at said fixed potential.

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