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MEANS FOR COUPLING CIRCUITS OF DIFFERENT
IMPEDANCE CHARACTERISTICS
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Fig. 1.

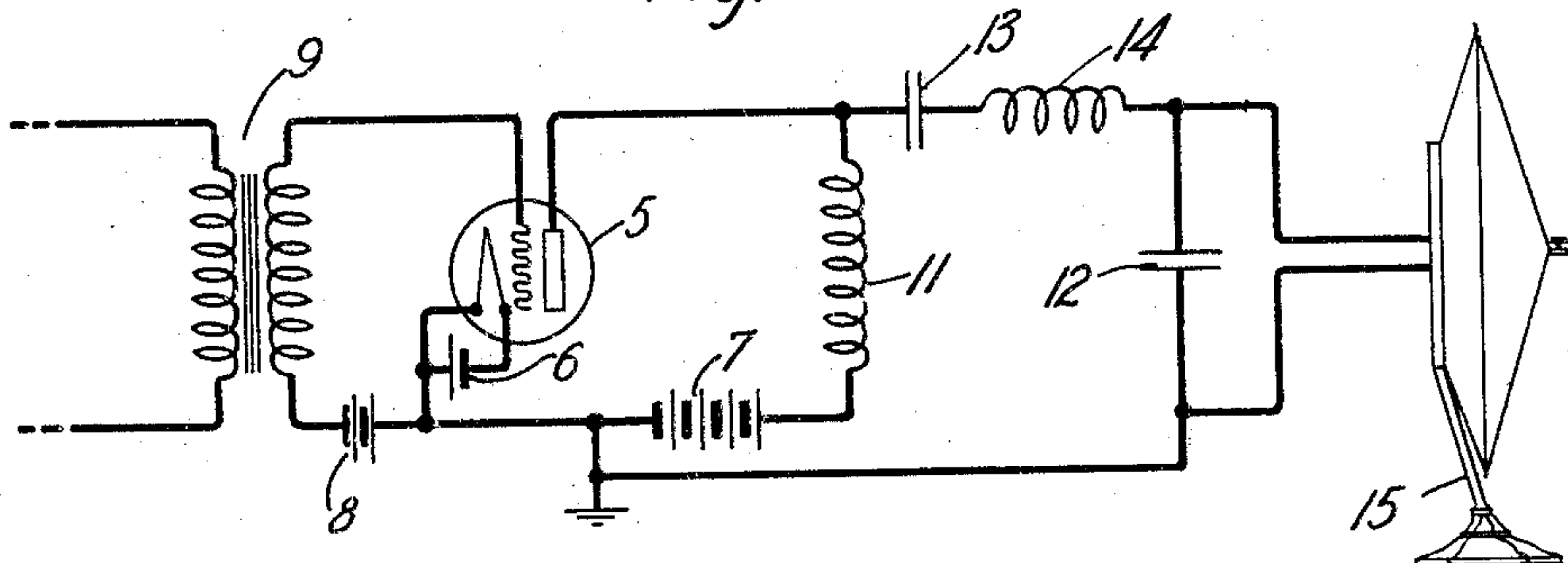
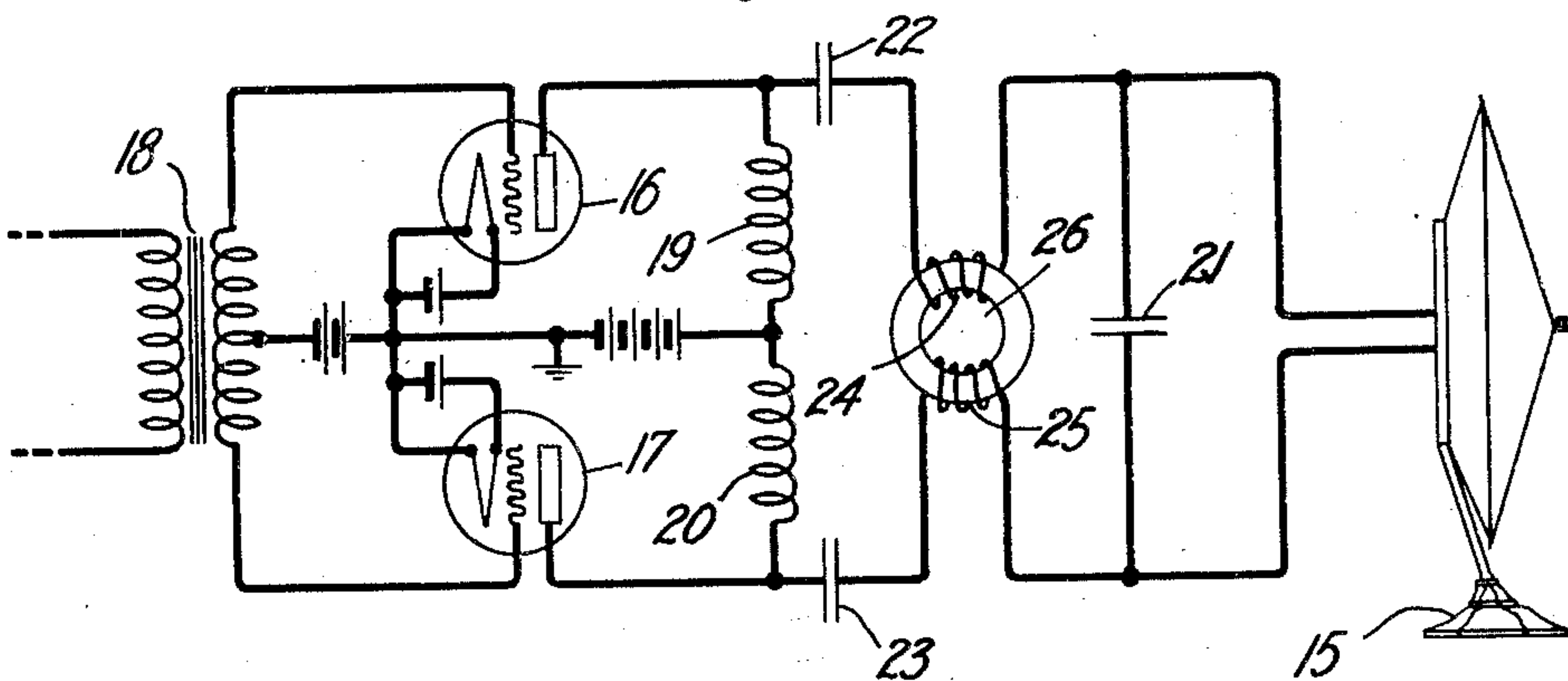


Fig. 2.



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UNITED STATES PATENT OFFICE.

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MEANS FOR COUPLING CIRCUITS OF DIFFERENT IMPEDANCE CHARACTERISTICS.

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This invention relates to electrical circuits for the transmission of multi-frequency waves and has for an object to improve the uniformity of transmission of such waves between circuits having different impedance frequency characteristics.

A more specific object of this invention is to improve the coupling between an electron discharge device and an electromagnetic receiver.

In U. S. Patent No. 1,537,101, granted to D. F. Whiting, May 12, 1925, there is described a method employing a parallel resonant circuit for coupling two circuit branches of different impedance characteristics so as to give efficient coupling for a single frequency or a narrow band of frequencies. As explained in detail in that patent, a parallel tuned circuit may have an impedance greater than the impedance of one of its arms so that waves may be transmitted substantially without reflection between a circuit branch embodied in one arm of the parallel circuit and another circuit branch having a higher impedance than the first circuit branch.

In accordance with one feature of the present invention, use is made of a plurality of such parallel resonant circuits in order to obtain uniform transmission for a wide range of frequencies.

In accordance with another feature of this invention, two circuit branches, the impedance of one of which is lower than the impedance of the other in one portion of a range of frequencies to be transmitted and higher in another portion of the range, are coupled by means of a plurality of parallel resonant circuits. One of these circuits includes in one arm the first circuit branch and is effective for transmitting frequencies in the first portion of the range and another includes the second branch and is effective in the other portion of the range.

As set forth in Patent No. 1,537,101, referred to above, the ratio, Q , of the impedance, Z , of a parallel tuned circuit to the impedance, z , of an arm thereof containing both reactance and resistance, is equal to the secant of the phase angle of the arm z , and

is greatest when the reactance of the other arm is equal to the square of the absolute value of the impedance of the first arm divided by its reactance. Thus, let us assume a parallel resonant circuit comprising a branch of reactance X_1 and negligible resistance, and another branch including a reactance X_2 and resistance R . The impedance of the first branch will be jX_1 and that of the second branch will be $R + jX_2$ which will be denoted z/A , that is, an impedance of value z having a phase angle A . If Z/b designates the impedance of the two circuits in parallel then it can be shown that:

$$Z/b = \frac{R + j \left[X_2 + \frac{1}{X_1} \left(R^2 + \frac{X_2^2}{2} \right) \right]}{\frac{R^2}{X_1^2} + \left(\frac{X_2}{X_1} + 1 \right)^2} \quad (1)$$

The absolute value of this impedance is,

$$Z = \sqrt{\frac{R^2 + X_2^2}{\frac{R^2}{X_1^2} + \left(\frac{X_2}{X_1} + 1 \right)^2}} \quad (2)$$

The ratio, Q , of Z to z is,

$$Q = \frac{Z}{z} = \frac{1}{\sqrt{\frac{R^2}{X_1^2} + \left(\frac{X_2}{X_1} + 1 \right)^2}} \quad (3)$$

If $\frac{X_2}{R}$ is called K , then

$$Q = \frac{1}{\sqrt{\frac{R^2}{X_1^2} + \left(\frac{KR}{X_1} + 1 \right)^2}} \quad (4)$$

Differentiating Equation (4) with respect to X_1 as a variable and solving for a maximum value of Q , we find Q is a maximum when

$$X_1 = -\frac{R(1 + K^2)}{K} = -\frac{R^2 + X_2^2}{X_2} = -\frac{z^2}{X_2} \quad (5)$$

Substituting the first value of X_1 given above, in Equation (4), we get

$$Q = \sqrt{1 + K^2} = \sqrt{1 + \tan^2 A} = \sec A \quad (6)$$

It will be evident that since the susceptances of the arms of the parallel circuit are

equal, when Equation (5) holds the phase angle $B=0$, hence

$$Z_{\max}/b = z \sec A/0 = \frac{z^2}{R}/O \quad (7)$$

or

$$Z_{\max} = \frac{z^2}{R} = \frac{X_2^2 + R^2}{R} \quad (8)$$

From the above, it can be seen that at a given frequency, it is possible to step up the impedance of a circuit branch containing reactance and resistance to a value equal to the secant of the phase angle of that branch by putting in parallel therewith a reactance of proper value and of opposite sign to the reactance of the circuit branch. In accordance with the present invention, by the use of a plurality of such arrangements, it is possible to obtain impedance matching over a wide range of frequencies.

This invention and particularly its application to practical arrangements can be more readily understood by reference to the following detailed description in connection with the drawings in which Fig. 1 shows one embodiment of the invention for coupling a vacuum tube amplifier to a loud speaking receiver, and Fig. 2 shows a similar arrangement in connection with a push-pull amplifier.

Referring first to Fig. 1, there is shown a vacuum tube amplifier 5 associated with which are the usual cathode heating battery 6, plate battery 7 and grid battery 8. The waves to be amplified are impressed on the input electrodes of the tube through an input transformer 9. The output electrodes of the tube are connected to a loud speaking electromagnetic receiver 15 through a coupling circuit according to this invention. This circuit consists of an inductance coil 11 connected in shunt to the output terminals of the tube 5, a condenser 12 connected in shunt to the terminals of the receiver 15 and a condenser 13 and inductance coil 14 connected in series therebetween. The coil 11, in addition to acting as a part of the coupling circuit, serves as a path for plate current from the battery 7, while the condenser 13 prevents the flow of direct current through the windings of the receiver and insulates the latter from the plate potential.

The output impedance of the tube 5 is a substantially constant resistance throughout the range of frequencies comprising speech and music, while the impedance of the re-

ceiver 15 varies from a low value of positive phase angle at 60 cycles per second to a high practically pure resistance at 6,000 cycles per second.

One method of designing the coupling circuit is as follows, assuming that uniform transmission between 60 and 6000 cycles is desired: First, condenser 13 and inductance coil 11 are designed so that, neglecting the effect of coil 14 and condenser 12, efficient transmission is obtained at 60 cycles. This is done by use of Equations (5) and (8), making $Z_{\max}$ equal to R_5 (or, if it is desired to design the circuit so as to prevent the tube from overloading prematurely at the high energy levels of the low frequency speech and music waves, $Z_{\max}$ should be equal to $2R_5$ is described and claimed in the patent application of D. F. Whiting, Serial No. 96,418, filed March 22, 1926).

In these equations

$$X_1 = \omega_{60} L_{11}$$

$$X_2 = \left(\omega_{60} L_{15/60} - \frac{1}{\omega_{60} C_{13}} \right)$$

and $R = R_{15/60}$ where $\omega_{60} = 2\pi 60$, R_5 is the plate impedance of the tube 5, L_{11} is the inductance of coil 11, C_{13} is the capacity of condenser 13, and $L_{15/60}$ and $R_{15/60}$ are respectively the inductance and resistance of the receiver 15 at 60 cycles per second.

Inductance coil 14 and condenser 12 are next designed in a similar manner to give efficient transmission at 6000 cycles. In this case $Z_{\max}$ should be made equal to $R_{15/6000}$.

$$X_1 = -\frac{1}{\omega_{6000} C_{12}}$$

$$X_2 = \omega_{6000} L_{14} + \frac{R_5^2 (\omega_{6000} L_{11})}{R_5^2 + (\omega_{6000} L_{11})^2} + \frac{1}{\omega_{6000} C_{13}}$$

and

$$R = \frac{R_5^2 (\omega_{6000} L_{11})^2}{R_5^2 + (\omega_{6000} L_{11})^2}$$

Where $\omega_{6000} = 2\pi (6000)$, $A_{15/6000}$ is the impedance of the receiver at 6000 cycles per second, C_{12} , C_{13} , L_{11} and L_{14} are, respectively, the capacities of condensers 12 and 13 and the inductances of coils 11 and 14, and R_5 is the plate impedance of the tube 5.

After this approximation, if desired, the values of elements 11 and 13 may be recomputed, taking into consideration elements 12 and 14, in which case,

$$X_2 = \frac{\omega_{60} [L_{15/60} - C_{12} (R_{15/60} + L_{15/60}^2 \omega_{60}^2)]}{R_{15/60}^2 C_{12}^2 \omega_{60}^2 + (L_{15/60} C_{12} \omega_{60}^2 - 1)^2} + L_{14} \omega_{60} - \frac{1}{C_{13} \omega_{60}}$$

and

$$R = \frac{R_{15/60}}{R_{15/60}^2 C_{12}^2 \omega_{60}^2 + (L_{15/60} C_{12} \omega_{60}^2 - 1)^2}$$

The values of elements 12 and 14 may then

be recomputed upon the basis of the revised values of elements 11 and 13.

It will generally be found that carrying the computation this far will give values as close to the exact values as the manufacture

of the elements can be controlled commercially. However, the series of approximation may be carried still further until there are no substantial changes in the values of the elements.

In the equations given above, the inductive and capacitive elements were considered as being pure reactances while in practice each may have an appreciable resistance component. It may, therefore, be found that in order to obtain the best results, it is desirable to depart somewhat from the values obtained by computation.

In the application of this invention to a particular circuit in which there was used a tube having a plate resistance of about 4,000 ohms and a receiver of the following characteristics $R_{60} = 1700\omega$, $X_{60} = 1000\omega$ and $R_{6000} = 50,000\omega$, satisfactory results were obtained when the inductance coils 11 and 14 were given the values 6 h. and 0.37 h. respectively, and the condensers 13 and 12, 1.1 mf. and 0.0018 mf. respectively.

Referring to Fig. 2, the circuit shows two tubes 16 and 17 connected in push-pull in the usual manner to receive waves to be amplified through an input transformer 18. Inductance coils 19 and 20 are connected in the plate circuits of the tubes 16 and 17, respectively. A condenser 21 is connected in shunt to the terminals of an electromagnetic loud speaking receiver 15. Condensers 22 and 23 are connected in series with the windings 24 and 25 of the balanced inductance coil 26 between the plates of the tubes 16 and 17 and the terminals of the receiver 15. The arrangement of this circuit is similar to that of the single tube of Fig. 1, the series elements being divided between two sides of the line to maintain a balanced circuit for use with the push-pull amplifier. When using a receiver, similar to that described in connection with Fig. 1, and tubes, each of which had a plate impedance of approximately 4,000 ohms, the following values for the elements were found satisfactory. Inductance coils 19 and 20 were each 6 h., the total inductance of the two windings 24 and 25 of the coil 26 was 0.75 h. Condensers 22 and 23 were 1 mf. each, and condenser 21 was 900 mmf. This arrangement gives particularly good coupling since at the mean frequency (600 cps.) the impedance of the receiver is 8,000 ohms which is the impedance of the two tubes.

Since, with this arrangement, the impedances are matched at the terminals of the receiver, if it is desired to operate more than one receiver from the amplifier, it can be done by the use of a simple two-winding or auto transformer, such as is used for coupling resistance circuits.

What is claimed is:

1. A circuit arrangement for coupling circuits of different impedance-frequency characteristics to transmit waves of a plurality of

frequencies therebetween, comprising a plurality of reactive impedance elements forming with the circuits to be coupled a plurality of parallel circuits resonant at different frequencies to be transmitted the elements being so proportioned that the impedance at the terminals of each of the circuits to be coupled is substantially equal to the impedance of the respective circuit.

2. An electrical circuit for the transmission of wave energy of a wide range of frequencies, comprising two circuit branches having different impedance characteristics, reactive elements connected in shunt and series relation between said circuits, the values of said elements being so proportioned that they form with said circuit branches a plurality of parallel circuits resonant at frequencies in the range to be transmitted, the impedance of said parallel circuits being substantially equal to the remainder of the circuit connected thereto to give uniform transmission throughout said range.

3. An electrical circuit for the transmission of wave energy of a wide range of frequencies, comprising two circuit branches of different impedance-frequency characteristics and capacity and inductance elements connected in series and shunt relation between said circuits, said elements being so arranged and having impedances of such values as to form at the terminals of each of said branches parallel circuits resonant at certain frequencies to be transmitted within said range, and having an impedance substantially equal to the impedance of the respective branch.

4. A circuit for substantially uniformly transmitting waves of a wide range of frequencies comprising one branch having an impedance which is substantially pure resistance at one frequency in said range, a second branch having an impedance which is lower than that of said first branch at said frequency and which is substantially pure resistance and higher than the impedance of said first branch at another frequency in said range, and certain impedance elements so proportioned that they form with said second branch a circuit having at said first frequency a substantially pure resistance impedance equal to the impedance of said first branch and certain other impedance elements so proportioned that they form with said first branch a circuit having at said other frequency a substantially pure resistance impedance equal to the impedance of said second branch.

5. An electrical circuit for the transmission of wave energy of a wide range of frequencies between circuits having different impedance-frequency characteristics, a plurality of inductance elements in series and in shunt with said connected circuits, and a plurality of capacity elements in series and in

shunt with said connected circuits, the values of said inductance and capacity elements being so proportioned that one of said inductance elements and one of said capacity elements resonate at a definite frequency in one portion of said range of frequencies and another of said inductance elements and another of said capacity elements resonate at another definite frequency in another portion of said range of frequencies, and said first mentioned inductance element and said last mentioned capacity element resonate at still another frequency in still another portion of said range of frequencies to give a uniform transmission characteristic throughout said range. 15

In witness whereof, I hereunto subscribe my name this 8th day of September, A. D. 1926.

DONALD F. WHITING.