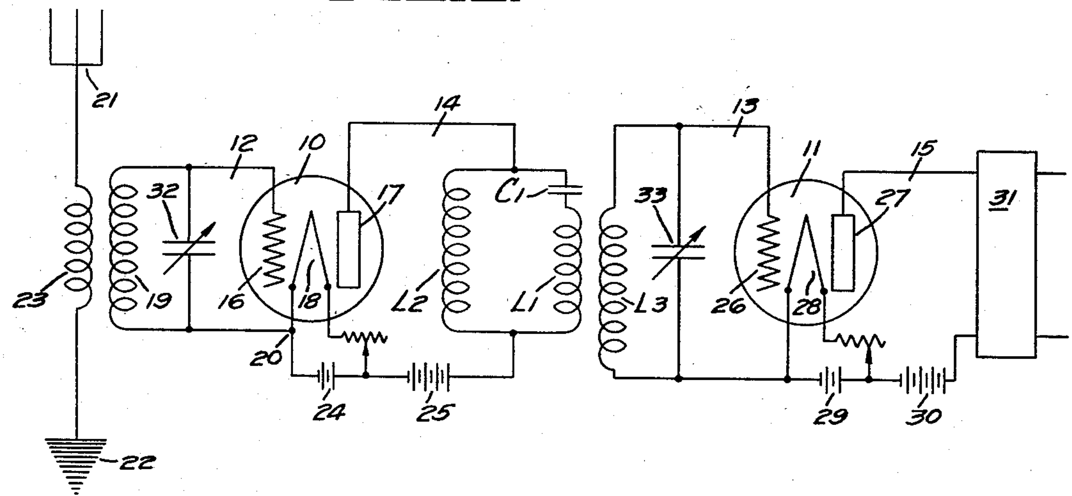
Aug. 10, 1937. F. A. KOLSTER 2,089,271

ELECTRICAL COUPLING SYSTEM

Original Filed Aug. 26, 1925

FIG. 1.



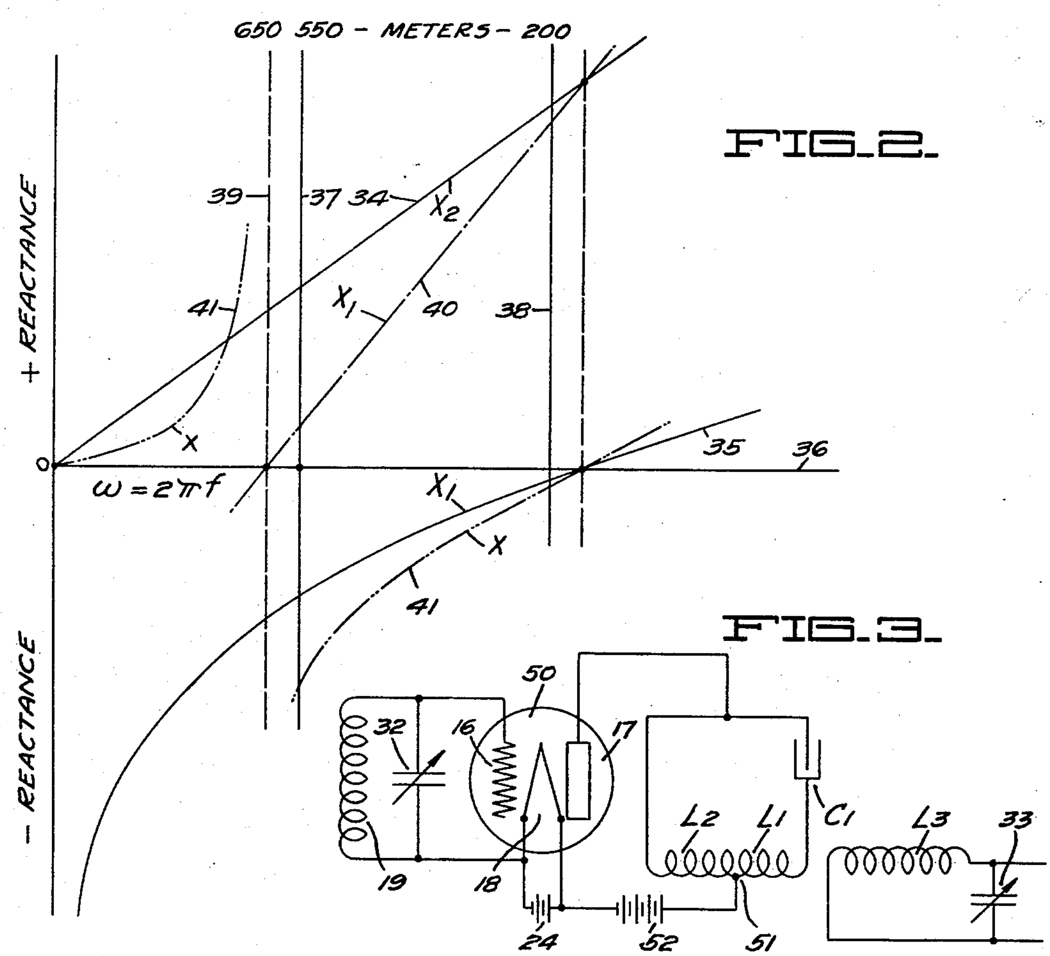


FIG. 2.

FIG. 3.

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ELECTRICAL COUPLING SYSTEM

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13 Claims. (Cl. 179—171)

This invention relates to systems in which two electrical circuits are coupled together for transferring electrical energy from the one circuit to the other. Such systems are commonly used in coupling together the various high frequency circuits of radio receiving sets employing vacuum tube amplifiers.

It is an object of this invention to devise a system for coupling together two circuits so that the proportion of energy transferred from one circuit to the other will be a function of the frequency of the current, that is, as the frequency of the current increases the proportion of the energy transferred will decrease. It is proposed to apply such a system to selectively tuned radio frequency circuits.

More specifically it is an object of this invention to devise a coupling system in which the one circuit is provided with two branch parallel impedances one of which has a negative reactance value for all of the frequencies within the frequency range with which the system is adapted to be used, the total impedance of the two branches together having always a negative value of reactance within the said frequency range.

It is a further object of this invention to devise a novel system for coupling a circuit to the output of a vacuum tube by means of a reactance in the output circuit of the tube having a value of reactance which is always negative thruout the frequency range with which the system is to be used and which reactance is shunted with a second reactance which in parallel with the first reactance will have a natural wave length below the minimum wave length of the frequency range.

It is a further object of this invention to devise a coupling system for coupling together the output of the vacuum tube amplifier with another circuit in such a manner that there will always be a substantially constant amplification ratio for the system and in which the proportion of the current transferred will always be relatively high.

Further objects of the invention will appear from the following description in which I have set forth the preferred embodiment of my invention.

Referring to the figures of the drawing:

Figure 1 shows the coupling system of this invention applied to a vacuum tube circuit comprising two radio frequency amplifiers.

Figure 2 is a curve illustrating the reactance values of the coupling impedances.

Figure 3 is a modification of the system shown in Fig. 1.

In the past it has been common to couple together two electrical circuits by means of a coupling device comprising a primary and secondary inductance inductively coupled together and connected in the respective circuits. When this system is used in radio frequency circuits it is the practice to employ a primary coil which is comparatively small so that its natural wave length will be below that of the wave length range with which the system is adapted to be used. In this way local oscillations in the first circuit are prevented. However, this coupling device has several inherent disadvantages; the primary coil being relatively small, it cannot transfer a very large proportion of the current from the one circuit to the other and the system therefore has a very low efficiency. Also, since the reactance value of an inductance is directly proportional to the frequency of the current, the system will transfer a larger proportion of energy at high frequencies than at low frequencies. In the device of this invention these disadvantages have been overcome and an efficient coupling device has been produced which will not set up local oscillations in the first circuit and which will compensate for the increased reactance of the coupling inductance at the higher frequencies.

In the system of this invention there is preferably employed a primary and secondary inductance, but the primary inductance need not have a natural wave length period below that of the frequency range with which the system is to be used. It is proposed to operate the primary inductance in series with a capacity and to shunt both the capacity and the primary inductance with the second inductance. The values of the two inductances and the capacity are so selected that the reactance of the primary inductance together with the series capacity is always negative for a given frequency range. However, the value of the shunt inductance is such that the natural period of the capacity together with the two series inductances is always greater than the given wave length range of the system. Also, the combined reactive impedance of the system decreases negatively as a function of the frequency of the current.

In the drawing, the system has been shown as applied to the coupling of two radio frequency vacuum tube amplifiers, altho it is to be understood that the system is not limited to such use. Thus there has been shown two vacuum tube amplifiers 10 and 11 having input circuits 12 and 13 respectively and output circuits 14 and 15 respectively. The amplifier 10 is preferably of the standard three element type and accordingly comprises a grid or control element 16, an anode or plate 17, and an electron-emission element or filament 18. The input circuit 12 for the vacuum tube 10 preferably includes an inductance 19, one end of which is connected to the grid 16 and the other end of which is connected to the terminal 20 of the filament 18. The input circuit 12 is coupled to a suitable source of signal energy such as an antenna 21 connected to the ground 22 thru a primary inductance 23 which is inductively coupled to the inductance 19. An A-battery 24 is provided to energize the filament 18 in the usual manner. A B-battery 25 is also provided to energize the output circuit 14 and has its negative terminal connected to the positive terminal of the battery 24. The positive terminal of the B-battery 25 is connected to the coupling device presently described.

The vacuum tube 11 also comprises a grid 26, an anode or plate 27, and a filament 28. The input circuit 13 of the tube 11 preferably includes an inductance L_3, one end of which is connected to the negative terminal of the A-battery 29. Means are also provided for selectively tuning the entire system over a given frequency range. For this purpose there are preferably provided two variable condensers 32 and 33 which are shunted across the inductances 19 and L_3 respectively. The A-battery 29 supplies energy to the filament 28 as in the case of the tube 11. The output circuit 15 includes the B-battery 30 having its negative terminal connected to the positive terminal of the A-battery 29 and its positive terminal connected to some suitable energy absorption device 31 which has been shown diagrammatically.

In the output circuit 14 there is provided a novel means for coupling together this output circuit to the input circuit 13 of the tube 11. This coupling device preferably comprises two branch parallel impedances, one of which is coupled to the input circuit 13. These branch impedances preferably comprise an inductance L_1 in series with a capacity C_1, and an inductance L_2 connected in parallel to L_1C_1. The inductance L_1 is preferably inductively coupled to the inductance L_3 of the input circuit 13. The reactance values of the inductances L_1 and L_2 and the capacity C_1 are preferably selected so as to produce the curves illustrated in Fig. 2.

Referring to Fig. 2, the abscissae represent ω or two π times the frequency of the current, while the ordinants represent values of reactances. The curve 34 represents a reactance curve of the inductance L_2, while the curve 35 represents the reactance values of the inductance L_1 with the series capacity C_1. The branch L_2 is theoretically a pure inductance so that its curve 34 will be a straight line according to the following well known equation—

$$X_2=\omega L_2 \qquad (1)$$

Where:

X_2 is the reactance of branch L_2.

ω is equal to 2π times the frequency.

L_2 is the absolute inductance of this branch.

From this expression it is seen that the reactance X_2 varies as a linear function of ω. The curve representing the combined reactance of L_1C_1 is plotted from the expression

$$X_1=L_1\omega-\frac{1}{C_1\omega} \qquad (2)$$

Where:

L_1 is the absolute inductance of this branch.

C_1 is the absolute capacitance of the series condenser.

For certain values of L_1C_1 there will be a value of ω at which the reactance X_1 will be zero. This corresponds to a condition of resonance in the branch L_1C_1 and is represented by the intersection of the curve 35 with the horizontal zero reactance line 36 in accordance with the equation given below:

$$L_1\omega=\frac{1}{C_1\omega} \qquad (3)$$

As ω decreases from the point of intersection of the line 36 and the curve 35 the reactance X_1 will of course increase negatively and approach infinity. The values of L_1C_1 and L_2 are so selected that the lines 37 and 38 may represent the limit of the wave length range with which the system is adapted to be used. In the common broadcast receiver, this wave length range will be from approximately 200 meters to 550 meters. It should be noted that line 38 intersects the line 35 to the left of the intersection point between the line 35 and the line 36 and that therefore the branch L_1C_1 does not become resonant within this wave length range. The line 37 is also so located that it intersects the curve 34 at a greater distance from the line 36 than the distance from the line 36 to the intersection of the line 37 with the curve 35. Thus at the value of ω represented by the position of the line 37 the total reactance of L_1C_1 and L_2 in series will be positive. The line 39 represents that value of ω at which the combined reactance of L_1C_1 and L_2 equal zero and therefore the point at which the impedance circuit is resonant. In the particular instance this line 39 corresponds to approximately 650 meters on the wave length scale. The condition of resonance is shown by the following equation:

$$\omega(L_2+L_1)=\frac{1}{C_1\omega} \qquad (4)$$

Thus it will be seen that the values of L_1C_1 and L_2 have been so selected that within the range of frequencies intended to be covered by the system the reactance X_1 of the branch L_1C_1 will always be negative and will decrease as the frequency of the current increases and that the reactance of branch L_2 is always positive and increases as the frequency of the current increases.

The total series reactance of the two branches L_1C_1 and L_2 is represented by the curve 40 and is plotted in accordance with the following equation:

$$X=\omega L_2+\left(\omega L_1-\frac{1}{\omega C_1}\right) \qquad (5)$$

Where:

X is the total reactance of the two branches L_1C_1 and L_2 in series.

It will be seen from this equation that X will be resonant when the conditions of Equation 4 are met, that is where line 39 intersects line 36, and will have the same value as branch L_2 at that value of ω where branch L_1C_1 is resonant. Thus the total reactance of branches L_1C_1 and L_2 in series will always be positive and will increase as a function of the frequency within the frequency range.

The total reactance of the output circuit 14, that is, of the branches L_1C_1 and L_2 in parallel, is shown by the curves 41 of Fig. 2 and are plotted from the following equation:

$$X=\frac{1}{\dfrac{1}{\omega L_2}+\dfrac{1}{\left(\omega L_1-\dfrac{1}{\omega C_1}\right)}} \qquad (6)$$

Where:

X is the total output reactance of circuit 14.

From the above equation, it follows that curve 41 will approach infinity on both sides of the line 39, and that within the frequency range represented by lines 37 and 38, will always be negative and will decrease negatively as the frequency increases.

In operation, there is an actual flow of local current between branches L_1C_1 and L_2 because of the negative value of the reactance of branch L_1C_1. The more negative this branch becomes relative to the reactance of L_2, the more local current will flow. Thus as the frequency decreases within the frequency range, the current in the inductance L_1 will increase and effect a greater transfer of energy to the inductance L_3, and the proportion of energy transferred from the circuit 14 to the circuit 13 will vary inversely as a function of the frequency. The output circuit 14 will not oscillate locally because the natural wave length period of branches L_1C_1 and L_2 in parallel is always below that of the wave length range covered by the system. Furthermore the impedance circuit will not oscillate within itself because the natural period of L_1C_1 and L_2 in series is always greater than the longest wave length of the frequency range. The value of inductance L_1 may therefore be sufficiently large to effect efficient transfer of energy to the inductance L_3 without causing local oscillations.

In Fig. 3 there is shown a modification of the system described above and in this modification the inductances L_1 and L_2 are combined in a single coil 51 which is placed in inductive relation to the inductance L_3. The capacity or condenser C_1 is placed in series with the one terminal of the inductance 51, while the other terminal of this inductance is connected to the anode of the vacuum tube 50 in the same manner as previously described. The B-battery 52 is connected to an intermediate tap on the inductance 51 in order to divide this inductance into the two portions L_1 and L_2. Otherwise this modification is the same as that shown in Figure 1 and the operation is identical except that in this case both portions L_1 and L_2 are inductively coupled with the inductance L_3.

I claim:

1. In a radio amplifier stage including a vacuum tube having a filament, a grid and a plate, an electric coupling system which comprises a main resonant circuit including a fixed secondary coil and an adjustable condenser adapted to tune the coupling system over a range in frequency, a fixed coil electromagnetically coupled to said secondary coil, a circuit including said fixed coil and a fixed capacity effectively in parallel, said fixed capacity being external to said main resonant circuit, a primary coil electromagnetically coupled to said secondary coil, and a path through said coupling system between said plate and said filament including in series said fixed capacity and said primary coil, whereby in the operation of the amplifier stage there is developed in said resonant circuit a resonant voltage whose ratio to the voltage between the plate and the filament automatically rises when said adjustable condenser is adjusted for higher frequencies.

2. In a radio amplifier stage including a vacuum tube having a filament, a grid and a plate, an electric coupling system which comprises a main resonant circuit including a fixed secondary coil and an adjustable condenser adapted to tune the coupling system over a range in frequency, a fixed coil electromagnetically coupled to said secondary coil, a circuit including said fixed coil and a fixed capacity effectively in parallel, and having a resonant frequency lower than the lowest frequency within said range, said fixed capacity being external to said main resonant circuit, a primary coil electromagnetically coupled to said secondary coil, and a path through said coupling system between said plate and said filament including in series said fixed capacity and said primary coil, whereby in the operation of the amplifier stage there is developed in said resonant circuit a resonant voltage whose ratio to the voltage between the plate and the filament automatically rises when said adjustable condenser is adjusted for higher frequencies.

3. In a radio amplifier stage including a vacuum tube having a filament, a grid and a plate, an electric coupling system which comprises a main resonant circuit including a fixed secondary coil and an adjustable condenser adapted to tune the coupling system over a range in frequency, a fixed coil electromagnetically coupled to said secondary coil, a circuit including said fixed coil and a fixed capacity effectively in parallel, said fixed capacity æbeing external to said main resonant circuit, a primary coil electromagnetically coupled to said secondary coil, and a path through said coupling system between said plate and said filament including in series said fixed capacity and said primary coil, said primary coil having such polarity relative to said fixed coil that the terminal of the primary coil connected to one side of said fixed capacity is of opposite open-circuit polarity to the terminal of the fixed coil connected to the other side of the fixed capacity, whereby in the operation of the amplifier stage there is developed in said resonant circuit a resonant voltage whose ratio to the voltage between the plate and the filament automatically rises when said adjustable condenser is adjusted for higher frequencies.

4. In a radio amplifier stage including a vacuum tube having a filament, a grid and a plate, an electric coupling system which comprises a main resonant circuit including a fixed secondary coil and an adjustable condenser adapted to tune the coupling system over a range in frequency, a fixed coil electromagnetically coupled to said secondary coil, a circuit including said fixed coil and a fixed capacity effectively in parallel and having a resonant frequency lower than the lowest frequency within said range, said fixed capacity being external to said main resonant circuit, a primary coil electromagnetically coupled to said secondary coil, and a path through said coupling system between said plate and said filament including in series said fixed capacity and said primary coil, said primary coil having such polarity relative to said fixed coil that the voltages across said primary coil and said fixed capacity are additive, whereby in the operation of the amplifier stage there is developed in said resonant circuit a resonant voltage whose ratio to the voltage between the plate and the filament automatically rises when said adjustable condenser is adjusted for higher frequencies.

5. In a radio amplifier stage including a vacuum tube having a filament, a grid and a plate, an electric coupling system which comprises a main resonant circuit including as elements a coil and a condenser, at least one of which is adjustable to tune the coupling system over a range in frequency, a second circuit coupled to said resonant circuit including a fixed self-inductance effectively in parallel with fixed capacity external to said main resonant circuit, said second circuit being resonant at a frequency lower, but not greatly lower, than the lowest frequency within said range, said fixed self-inductance being electromagnetically coupled to said resonant circuit, a circuit element having a substantially fixed voltage ratio relative to said main resonant circuit, and a path through said coupling system between said plate and said filament

including in series said circuit element and at least a portion of said fixed capacity, whereby in the operation of the amplifier stage there is developed in said main resonant circuit a resonant voltage whose ratio to the voltage between the plate and the filament automatically rises when said adjustable elements is adjusted for higher frequencies.

6. In a radio amplifier stage including a vacuum tube having a filament, a grid and a plate, an electric coupling system which comprises a main resonant circuit including a fixed secondary coil and an adjustable condenser adapted to tune the coupling system over a range in frequency, a fixed coil electromagnetically coupled to said secondary coil, a circuit including said fixed coil and a fixed capacity effectively in parallel, a primary coil electromagnetically coupled to said secondary coil, and a path through said coupling system between said plate and said filament including in series said fixed capacity and said primary coil.

7. In a radio amplifier stage including a vacuum tube having a filament, a grid and a plate, an electric coupling system which comprises a main resonant circuit including as elements a secondary coil and a condenser, at least one of which is adjustable to tune the coupling system over a range in frequency, a fixed coil electromagnetically coupled to said secondary coil, a circuit including said fixed coil and a fixed capacity effectively in parallel, a primary coil electromagnetically coupled to said secondary coil, and a path through said coupling system between said plate and said filament including in series said fixed capacity and said primary coil.

8. In a radio amplifier stage including a vacuum tube having a filament, a grid and a plate, an electric coupling system which comprises a main resonant circuit including as elements a secondary coil and a condenser, at least one of which is adjustable to tune the coupling system over a range in frequency, a second circuit coupled to said resonant circuit including a fixed self-inductance electromagnetically coupled to said secondary coil and effectively in parallel with fixed capacity, said second circuit being resonant at a frequency lower than the lowest frequency within said range, a primary coil electromagnetically coupled to said secondary coil, and a path through said coupling system between said plate and said filament including in series said primary coil and at least a portion of said fixed capacity.

9. In a radio amplifier stage including a vacuum tube having a filament, a grid and a plate, an electric coupling system which comprises a main resonant circuit including as elements a coil and a condenser, at least one of which is adjustable to tune the coupling system over a range in frequency, a second circuit coupled to said resonant circuit including a fixed self-inductance effectively in parallel with fixed capacity external to said main resonant circuit, and being resonant at a frequency lower, but not greatly lower, than the lowest frequency within said range, said fixed self-inductance being electromagnetically coupled to said resonant circuit, a circuit element having a substantially fixed voltage ratio relative to said main resonant circuit, and a path through said coupling system between said plate and said filament including in series said circuit element and at least a portion of said fixed capacity, whereby in the operation of the amplifier stage there is developed in said main resonant circuit a resonant voltage whose ratio to, the voltage between the plate and the filament automatically rises when said adjustable elements is adjusted for higher frequencies.

10. In a radio amplifier stage including a vacuum tube having a filament, a grid and a plate, an electric coupling system which comprises a main resonant circuit including as elements a secondary coil and a condenser, at least one of which is adjustable to tune the coupling system over a range in frequency, a second circuit coupled to said resonant circuit including a fixed self-inductance electromagnetically coupled to said secondary coil and effectively in parallel with fixed capacity, and being resonant at a frequency lower than the lowest frequency within said range, a primary coil electromagnetically coupled to said secondary coil, and a path through said coupling system between said plate and said filament including in series said primary coil and at least a portion of said fixed capacity.

11. In a radio frequency amplifier, a thermionic device having an output circuit comprising a plurality of inductors, a thermionic device having a tunable input circuit coupled to said inductors, and means in effective shunt to one of said inductors to constitute therewith a circuit tuned to a frequency lower than any frequency to which said input circuit is intended to be tunable.

12. In a radio frequency amplifier, a thermionic device having an output circuit comprising a plurality of inductors, a thermionic device having a tunable input circuit coupled to said inductors, and means in effective shunt to one of said inductors to constitute therewith a circuit tuned to a frequency lower than any frequency to which said input circuit is intended to be tunable, and the impedances of said inductors and said means being so related that for all frequencies to which said input circuit is intended to be tunable said output circuit is negatively reactive.

13. In a radio frequency amplifier, a thermionic device having an output circuit comprising a plurality of inductors, a thermionic device having a tunable input circuit coupled to said inductors, and means in circuit with one of said inductors to constitute therewith a path coupled to said input circuit and tuned to a frequency lower than any frequency to which said input circuit is intended to be tunable, and the impedances of said inductors and said means being so related that for all frequencies to which said input circuit is intended to be tunable said output circuit is negatively reactive.

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