

Dec. 13, 1938.

C. TRAVIS

2,140,339

FREQUENCY CONTROL CIRCUITS

Filed Oct. 3, 1935

2 Sheets-Sheet 1

Fig. 1

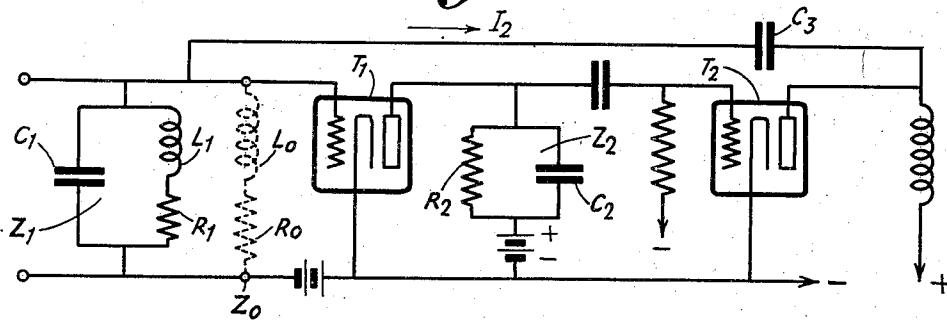


Fig. 2

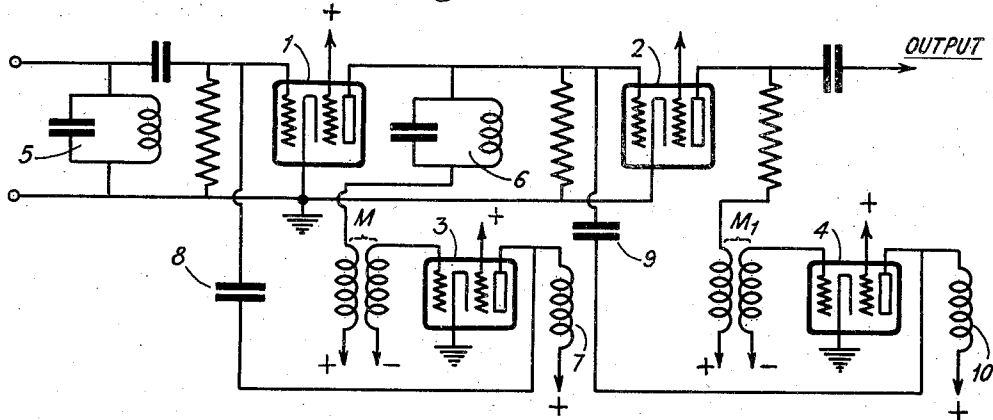
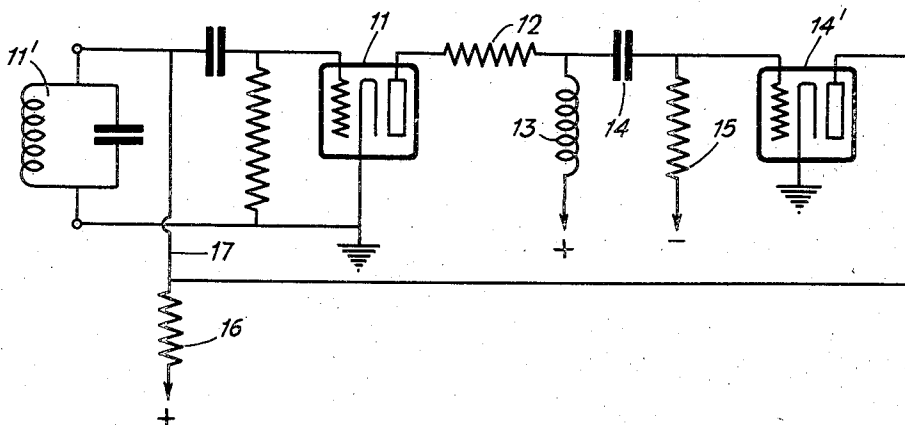


Fig. 3



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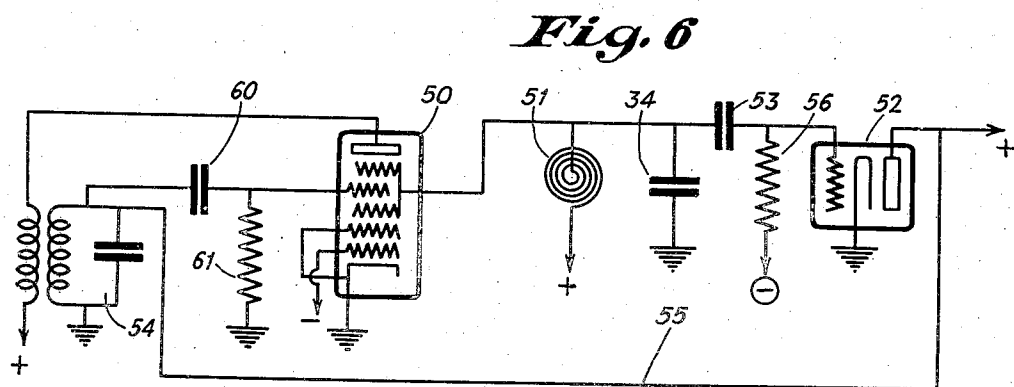
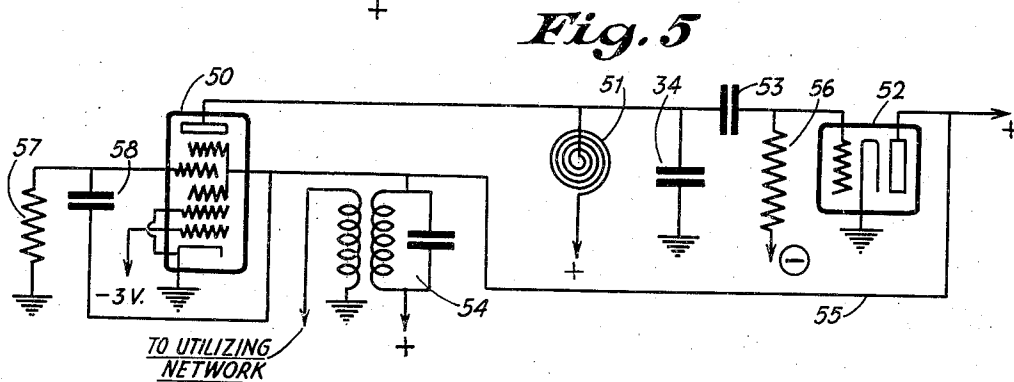
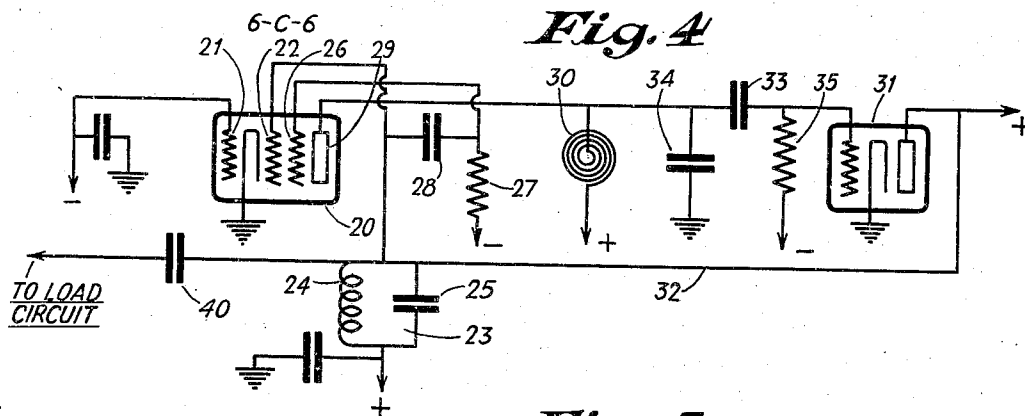
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FREQUENCY CONTROL CIRCUITS

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2 Sheets-Sheet 2



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2,140,339

FREQUENCY CONTROL CIRCUITS

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Application October 3, 1935, Serial No. 43,359

12 Claims. (Cl. 250—36)

My present invention relates to frequency control circuits, and more particularly to novel and improved arrangements for varying the resonant frequency of a tuned circuit.

5 In my co-pending application, Serial No. 19,563, filed May 3, 1935 there have been disclosed various circuits for varying the magnitude of a reactance disposed in a tuned circuit, and this has been accomplished primarily for the purpose of
10 adjusting the frequency of a local oscillator tank circuit of a superheterodyne receiver. The fundamental principle disclosed in the aforesaid application is readily adapted to other functions such as tuning over a wide range, tone control,
15 and, in general, wherever an electrically variable reactance may be utilized.

Accordingly, it may be stated that it is one of the main objects of my present invention to provide various circuit arrangements wherein high
20 frequency systems may be varied in resonant frequency over a relatively wide range by the use of electrically variable reactances, and in each case the variable reactance which accomplishes the tuning variation being a reflected one, the re-
25 flected reactance depending upon the nature of an impedance disposed in the plate circuit of a tube whose operating frequency is to be varied, and the voltage drop across which impedance is fed back to the tuned circuit whose frequency is
30 to be changed.

Another object of the invention may be said to reside in the provision of signal transmission networks whose operating frequency may be varied over a wide range of frequencies, the frequency variation being accomplished by adjustment of the operating bias of one, or more, tubes of the system.

40 Still other objects of the invention are to improve generally the tuning of high frequency signaling systems, and more especially to provide electrically variable reactances, for tuning high frequency circuits, which are reliable and efficient in operation.

45 The novel features which I believe to be characteristic of my invention are set forth in particularity in the appended claims; the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in
50 connection with the drawings, in which I have indicated diagrammatically several circuit organizations whereby my invention may be carried into effect.

55 In the drawings:

Fig. 1 is a generalized circuit employed to explain the general principles of the invention,

Fig. 2 shows one embodiment of the invention,

Fig. 3 shows another modification of the invention,

Fig. 4 illustrates a circuit employing still another embodiment of the invention,

Fig. 5 shows a modified form of the arrangement disclosed in Fig. 4,

Fig. 6 shows a further modification of the invention.

Referring now to the accompanying drawings, wherein like reference characters in the different figures designate similar circuit elements, Fig. 1 shows a generalized circuit diagram of an arrangement embodying the invention. The general principles underlying the invention will be reviewed in connection with Fig. 1, attention also being directed to the aforesaid application.

In this figure there is shown a tube T_1 having its input electrodes, grid and cathode, connected to a source of electrical waves of high frequency. A network composed of capacity C_1 , inductance L_1 and resistance R_1 is generally designated by symbol Z_1 , and represents the tuning network of the tube input circuit. The output electrodes of tube T_1 are coupled, across impedance Z_2 , to the input grid and cathode of tube T_2 . The impedance Z_2 is shown as comprising resistance R_2 and capacity C_2 in shunt. The plate of tube T_2 is connected to the grid of tube T_1 through condenser C_3 .

Let it be assumed that the plate resistances of tubes T_1 and T_2 are negligibly high (as for example when these tubes are of the screen grid type), then it can be shown that an impedance Z_0 will be reflected into the input circuit of tube T_1 . In the case of the circuit shown the reflected impedance comprises inductance L_0 and resistance R_0 . These are shown dotted to denote the reflected nature thereof. The magnitude of the impedance Z_0 depends on the load Z_2 as well as upon the mutual conductances of tubes T_1 and T_2 . Further, the sign thereof is dependent on the nature of the impedance Z_2 .

Stated generally, the impedance Z_0 is the negative reciprocal of Z_2 with respect to the square of a resistance, this being the reciprocal of the product of the mutual conductances G_1 and G_2 of tubes T_1 and T_2 . In other words:

$$Z_0 = -\frac{R^2}{Z_2}, \text{ where } R^2 = \frac{1}{G_1 G_2}$$

Z_2 may be physically a resistance; a self-inductance; a positive, or negative, mutual inductance;

a capacity; or a combination of these. It will now be seen that many possibilities exist with regard to the construction of Z_2 .

Certain of these possible Z_2 networks will now be given. While negative resistances and capacities are not directly realizable as components of Z_2 , a negative inductance is realizable by using a transformer connected in "series aiding" fashion. Employing the aforesaid relation

$$Z_0 = -\frac{R^2}{Z_2}$$

for simple networks, it can be shown that:

$$\begin{aligned} Z_2 &= R_2; \text{ then } Z_0 = -R_0 \text{ (neg. res.)} \\ Z_2 &= C_2; \text{ then } Z_0 = -L_0 \text{ (neg. ind.)} \\ Z_2 &= L_2; \text{ then } Z_0 = -C_0 \text{ (neg. cap.)} \\ Z_2 &= -M_2; \text{ then } Z_0 = C_0 \text{ (pos. cap.)} \end{aligned}$$

More complex networks follow: When Z_0 is a shunt combination of R_2 and C_2 then Z_0 is a series combination of negative R_0 and L_0 ; for Z_2 comprising L_2 and R_2 in shunt, we have negative R_0 and C_0 in series; for Z_2 comprising C_2 and L_2 in shunt, there is negative L_0 and C_0 in series. For analogous series networks at Z_2 , the Z_0 networks in each corresponding case will be shunt.

For still further complex networks we have as follows: Z_2 comprising C_2 ; L_2 ; R_2 in series, Z_0 is equal to the shunt relation of negative C_0 ; L_0 ; R_0 . Conversely, for Z_2 comprising C_2 ; L_2 ; R_2 in shunt, R_0 is the series arrangement of negative L_0 ; C_0 ; R_0 . For Z_2 comprising series L_2 and R_2 , both in shunt with C_2 , Z_0 is equal to negative L_0 in series with a shunt network of negative C_0 and R_0 .

It will now be seen that the feedback system is highly flexible in so far as tuning a network Z_1 is concerned. Z_1 can be C_1 alone; C_1 and R_1 ; L_1 R_1 ; C_1 L_1 R_1 ; and tuning can be accomplished by reflecting an appropriate combination across Z_1 in the form of Z_0 . The tuning is actually accomplished with a fixed value for Z_2 and the product G_1 G_2 is varied by means of variable bias on one, or both, tubes.

Thus, in Fig. 1 is shown a useful application of the general circuit operation analyzed above. If R_2 C_2 is made equal to

$$\frac{L_1}{R_1}$$

then L_0 R_0 will have a time constant equal to the time constant of the L_1 R_1 network

$$\left(\frac{L_1}{R_1}\right)$$

Also, the effective inductance and resistance of the Z_1 circuit are increased in the same ratio, and the tuned impedance and selectivity (measured in cycles) of the circuit are unchanged.

$$\frac{L_1}{R_1}$$

may not be constant, constancy having been assumed; and it may increase with decreasing frequency so that the circuit will have a higher impedance and greater selectivity at a lower frequency, and will finally oscillate as the frequency is sufficiently decreased. This condition may be dealt with by making as much as possible of R_1 , physically constant. Thus, a fixed resistance external to the coil may be used, or coil L_1 can be wound with resistance wire.

Suppose R_1 varies with frequency so that the effective conductance of Z_1 is different at two spaced frequencies. By a proper choice of R_2 the effective conductances of the circuit can be made equal at these spaced frequencies, which will render the selectivity the same at the latter. In be-

tween the impedance may deviate slightly from the flat relation, probably rising in the middle of the band. Except for the above frequency limitation the frequency range which is coverable would be limited only by the "decoupling" condensers necessary to separate the plates and grids of the cascaded tubes with respect to direct currents. The level would be limited by the capabilities of the device. For example, assuming an audio system with $L_1=100$ mh. and C_1 which gives a natural resonance at some high frequency, and which is lowered by the action of the tubes to a value of 60 cycles; at this frequency the out-of-phase current in L_1 due to one volt at the input is approximately 25 ma., and most of this will have to be furnished (or neutralized) by the plate current of the second tube.

In case an inductance is used for the impedance Z_2 it may be positive or negative (negative is a mutual inductance, properly poled, is used) and a negative or positive capacity respectively is reflected across the input circuit. In the first case, the resonant frequency will rise with an increase in the product G_1 G_2 , and in the second case it will fall. A resistance in series with the inductance as part of impedance Z_2 will be reflected as a negative conductance, and is equal to

$$-\frac{R_2}{R^2}$$

The presence of this negative conductance will increase the tuned impedance and selectivity of the circuit as the product G_1 G_2 increases. Hence, with a positive inductance in the impedance network Z_2 the series resistance will increase the tuned impedance (regeneration) as the frequency increases, and with a negative M for the inductive element it will increase regeneration while the frequency decreases.

Again, a resistance in shunt to the positive or negative inductance in impedance Z_2 will be reflected as a negative series resistance in the input circuit. In either case considerable control is permitted in keeping the characteristic of the tuned circuit "flat"

$$\left(\frac{L}{RC} = \text{constant}\right)$$

over the tuning band. Adaptations of this principle to control local oscillator frequency have been disclosed in my aforesaid co-pending application. For an amplifier, the connections may be similar except for the omission of the feedback coil, or the coupling impedance might be inductive; in which case the method may be employed to neutralize capacities as in an amplifier intended for a wide band of frequencies.

The frequency range of the system in Fig. 1 depends upon the variation in L_0 in relation to the value of L_1 . The following relations exist:

$$L_0 = -R^2 C_2 = -\frac{C_2}{G_1 G_2}$$

Increasing the mutual product decreases the reflected negative inductance in L_0 (in absolute value). For example, where C_2 is equal to 500×10^{-12} , and $G_1 = G_2 = 1000 \times 10^{-6}$ (max.), then $L_0 = 500$ mh. Now, if L_1 is equal to $+500$ mh., this will entirely neutralize L_0 , and give infinite inductance (zero frequency). If L_1 is 250 mh., the net circuit inductance is

$$\frac{L_1 L_0}{L_1 + L_0}$$

which equals 500 mh., or L_1 is doubled and the frequency reduced to 70.7%.

In Fig. 2 there is shown a two stage amplifier using mutual inductance M for the impedance Z_2 . It should be noted that ordinarily for purposes of oscillation or amplification, the mutual conductance of the first tube in any stage would not be controlled, and the mutual conductance of the second tube is varied by some adjustable bias means. Each of tubes 1 and 2, which are arranged in cascade, are of the screen grid type, and each of the tuning control tubes 3 and 4 are also of the screen grid type. The amplifier 1 includes between its input electrodes the tuned circuit 5, and the tuned circuit 6 is connected to the plate circuit of amplifier 1, the input electrodes of amplifier 2 being coupled across the resonant circuit 6.

The control tube 3 has its plate connected to a source of positive potential through a choke coil 7, the feedback condenser 8 being connected between the control grid of amplifier 1 and the plate side of choke 7. The input grid of control tube 3 is connected to a source of variable negative bias, and the said grid circuit is coupled to the low alternating potential side of resonant circuit 6 through mutual inductance M . The control tube 4, also, has its control grid connected to a source of variable negative bias, and mutual inductance M_1 couples the grid circuit of tube 4 to the plate circuit of amplifier 2. The feedback condenser 9 couples the control grid of amplifier 2 to the plate side of choke 10.

Variation of the negative bias of tube 3 results in tuning of the input circuit of amplifier 1. Variation of the negative bias of the control grid of tube 4 results in tuning of the input circuit of amplifier 2. It will be noted that the network 5 in Fig. 2 comprises the impedance Z_1 , whereas the negative mutual inductance M is the impedance Z_2 . There is thus reflected back across resonant circuit 5 a positive capacity. The magnitude of this capacity depends upon the negative bias of the grid of tube 3, or in other words the gain of the tube. Increasing the gain of the control tube 3 results in an increased value of reflected capacity across tuned circuit 5, and, therefore, a decrease in the frequency value of the input circuit of tube 1. The same is true of the amplifier 2 and its control circuit 4. Of course, the negative biases of the grids of tubes 3 and 4 can be simultaneously varied so that the tuning of the input circuits of amplifiers 1 and 2 may be carried out simultaneously. If the mutual comprising Z_2 is positive in sign, then a negative capacity is reflected. This decreases the total tuning capacity. Therefore, frequency increases with decreased negative bias. The frequency range of the system depends, as before, on the maximum value of the reflected capacity in reference to the capacity already physically present in Z_1 .

To provide a negative capacity, in other words to neutralize positive capacities in a wide band amplifier, the circuit in Fig. 3 should be used. Here the mutual conductances of the tubes are to be kept constant to provide a constant negative capacity. The amplifier 11 in this figure has its input electrodes connected to a source of high frequency energy, such as tuned circuit 11'. The plate of the tube is connected to a source of positive potential through a resistor 12 and a choke 13. The control tube 14' has its control grid connected to the junction of resistor 12 and choke 13 through a condenser 14, and the control grid is also connected to a source of negative bias through a resistor 15. The plate of tube 14' is

connected to a source of positive potential through resistor 16, and the high alternating potential side of the grid circuit of amplifier 11 is connected to the junction of the plate of tube 14' and resistor 16 through a lead 17.

In this circuit the following operation occurs: The impedance Z_2 is the positive inductance 13. A negative capacity is thus reflected across the input of tube 11, and the magnitude of this capacity may be adjusted by a variation in the magnitude of inductance 13, and/or of the G_m of tube 14' so that physical stray capacity in the input of tube 11 is more or less completely balanced out or neutralized. Resistance 12 is the load resistance of tube 11, and the output is taken off across this resistance 12. This network is especially adapted for a resistance coupled amplifier (as for television work) so that high frequencies can be amplified equally with the lows.

In Fig. 4 there is shown an application of the present invention wherein an oscillator circuit is tuned over a range of oscillation frequencies. The oscillator circuit comprises a tube 20 of the 6C6 type. The cathode of the tube is grounded, and the grid 21 of the tube is connected to a source of negative biasing potential, the grid 21 being bypassed to ground for high frequencies. The grid 22 is connected to a source of positive potential through a resonant network 23. The resonant network comprises coil 24, and the shunt condenser 25. The grid 26 is connected to a source of negative potential through a resistor 27, and the coupling condenser 28 connects the grid side of resistor 27 to the grid side of network 23. The plate 29 of the oscillator tube is connected to a source of positive potential through a choke 30. Oscillations are produced in the system by virtue of a negative resistance characteristic, and feedback to the circuit of grid 22 is provided through condenser 28.

The frequency of the oscillations produced depends on the constants of resonant circuit 23, and the control tube 31, with its associated circuits, is utilized for varying the frequency of the oscillator network. This is accomplished by reflecting across circuit 23 a reactance of predetermined sign, and varying the magnitude of this reflected reactance in order to vary the frequency of the oscillator network. To accomplish this the plate of tube 31 is connected to the high alternating potential side of circuit 23 through a lead 32, and the plate is also connected to a source of positive potential. The cathode of tube 31 is grounded, and the control grid thereof is connected to the plate circuit of the oscillator tube 20 through condenser 33. The plate side of condenser 33 is connected to ground through a condenser 34, and a source of variable negative bias, which source is not shown, is connected to the control grid of tube 31 through resistor 35.

The local oscillations produced in the oscillator network may be transmitted to a utilizing circuit, such as a first detector of a superheterodyne receiver, or in a transmitter to the modulating network, through condenser 40. Of course, the useful oscillations may be transmitted to the utilizing network, if desired, through a circuit magnetically coupled to the coil 24. Variation of the negative bias applied to the control grid of tube 31 varies the magnitude of the reactance reflected across circuit 23. The reflected reactance is a negative inductance, and decreases in absolute magnitude as the gain of tube 31 is increased by decreasing the negative bias. Thus, an increase in the plate current flow of tube 31 reduces the

frequency of circuit 23. The choke 30 has negligibly high impedance; the condenser 34, as in Figs. 5 and 6, is the active impedance Z_2 .

In Fig. 5, there is shown a modification of the arrangement of Fig. 4 wherein the oscillator tube is of the 6A7 type. The numeral 50 designates the oscillator tube, and the plate thereof is connected through choke 51 to a source of positive potential. The plate circuit of tube 50 is connected to the control tube 52 through condenser 53; it will be noted that the circuits associated with control tube 52 are similar to those shown in Fig. 4. Thus, the resonant circuit 54 has the high alternating potential side thereof connected by lead 55 to the plate circuit of control tube 52. The control grid of tube 52 is connected through resistor 56 to a source of variable negative potential. The useful oscillations are derived from circuit 54, and transmitted to any desired type of utilizing network. The resonant circuit 54 is connected to the grids 3 and 5 of tube 50, and these grids are operated with a positive potential.

The first grid is connected to a source of negative potential of the order of -3 volts, while the fourth grid is connected to ground through a resistor 57. The grid side of resistor 57 is connected to the high alternating potential side of circuit 54 through a condenser 58. Local oscillations are produced in the circuit including tube 50 by virtue of the well known electronic coupling phenomenon. Variation of the negative bias on the grid of tube 52 varies the magnitude of the reactance reflected across circuit 54, and, therefore, this provides a means for varying the frequency of the resonant circuit 54 over a relatively wide range.

This modification is similar to Fig. 4 in the nature of reflected reactance. In both modifications the frequency range variation depends upon the L physically present in the oscillatory circuit. If the reflected L is made small enough, it will neutralize the already present L and give a circuit with infinite total L, or zero frequency.

In Fig. 6 there is shown a variation of the arrangement shown in Fig. 5, wherein the oscillator tube 50 has its plate magnetically coupled to the resonant circuit 54, the low alternating potential side of circuit 54 being grounded. The fourth grid of the tube is connected to the high alternating potential side of circuit 54 through condenser 60, the grid side of the condenser being grounded through a resistor 61. The control tube 52 has its plate connected to the high alternating potential side of circuit 54 through lead 55, and variation of the negative bias applied to the control grid of tube 52 varies the magnitude of the reactance reflected across circuit 54. When the bias on the control grid of tube 52 is varied to increase the plate current flow of the control tube, the effect is to increase the frequency of circuit 54. The tube 52 reflects a positive inductance across circuit 54.

Instead of connecting the grid of tube 52 to the positive grids of tube 50 as shown in Fig. 6, it is possible to couple the control grid of tube 52 to the positive grids through a transformer, and in that case the impedance Z_2 will be a mutual inductance M.

While I have indicated and described several systems for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organizations shown and described, but that many modifications may be made without de-

parting from the scope of my invention, as set forth in the appended claims.

What I claim is:

1. In combination with an electron discharge tube including a resonant circuit for tuning it to a desired wave frequency, means for electrically varying the frequency of the resonant circuit, which means comprises an electron discharge tube, a reactance of a predetermined sign disposed in the output circuit of said first tube, said reactance being free of any reactive coupling to said resonant circuit, the input electrodes of said second tube being connected across said reactance, a high frequency feedback path connected between the output circuit of said second tube and said resonant circuit whereby a reactance is reflected across the resonant circuit which bears a predetermined relation to the reactance in the output circuit of said first tube, and means for varying the gain of the second tube over a range of values sufficient to vary the magnitude of the reflected reactance so as to produce a wide frequency variation of said resonant circuit.

2. In combination with a tube provided with at least a cathode, a positive cold electrode, and at least one auxiliary cold electrode in the electron stream between cathode and positive electrode, a resonant circuit connected between the cathode and one of the cold electrodes, a reactance of a predetermined sign connected to the other cold electrode, said reactance being free of any reactive coupling to said resonant circuit, means for electrically varying the frequency of the resonant circuit, said means comprising a second tube having its input electrodes connected across said reactance, a high frequency feedback path connected between the output circuit of the second tube and the resonant circuit whereby a reactance is reflected across the resonant circuit which bears a predetermined relation to the said first reactance, and means for varying the gain of the second tube over a range of values sufficient to vary the reflected reactance magnitude to produce a wide frequency variation of the resonant circuit.

3. In a system as defined in claim 2, said one cold electrode which is connected to said resonant circuit being the grid of the first tube, and the second cold electrode which is connected to said reactance being the plate.

4. In combination with a high frequency amplifier tube provided with at least a cathode, control grid and anode, a resonant input circuit connected between the cathode and control grid, an output load connected to the anode, means for tuning the input circuit over a relatively wide frequency range comprising an electron discharge tube, a reactance connected in the space current path of the amplifier tube and free of any reactive coupling to said resonant circuit, means impressing voltage developed across the reactance upon the second tube input electrodes, an alternating current path connected between the second tube output electrode and said resonant circuit, and means for controlling the value of the product of the mutual conductances of said tubes.

5. In combination with a high frequency amplifier tube provided with at least a cathode, control grid and anode, a resonant input circuit connected between the cathode and control grid, an output load connected to the anode, means for tuning the input circuit over a relatively wide frequency range comprising an electron discharge

tube, a reactance connected in the space current path of the amplifier tube and free of any reactive coupling to said resonant circuit, means impressing voltage developed across the reactance upon the second tube input electrodes, an alternating current path connected between the second tube output electrode and said resonant circuit, and means for controlling the value of the product of the mutual conductances of said tubes, said reactance being inductive, and said controlling means varying the gain of the second tube.

6. In combination with a high frequency amplifier tube provided with at least a cathode, control grid and anode, a resonant input circuit connected between the cathode and control grid, on output load connected to the anode, means for tuning the input circuit over a relatively wide frequency range comprising an electron discharge tube, a reactance connected in the space current path of the amplifier tube and free of any reactive coupling to said resonant circuit, means impressing voltage developed across the reactance upon the second tube input electrodes, an alternating current path connected between the second tube output electrode and said resonant circuit, and means for controlling the value of the product of the mutual conductances of said tubes, said reactance being capacitative.

7. In combination with a high frequency amplifier tube provided with at least a cathode, control grid and anode, a resonant input circuit connected between the cathode and control grid, an output load connected to the anode, means for tuning the input circuit over a relatively wide frequency range comprising an electron discharge tube, a reactance connected in the space current path of the amplifier tube, means impressing voltage developed across the reactance upon the second tube input electrodes, an alternating current path connected between the second tube output electrode and said resonant circuit, means for controlling the value of the product of the mutual conductances of said tubes, a second amplifier tube having its input electrodes coupled to said load, and said reactance being inductive.

8. In an oscillator circuit of the type comprising a tube provided with a cathode and at least three cold electrodes, a resonant tank circuit connected to a first of the cold electrodes, a reactive coupling between the first electrode and a second cold electrode, means for tuning said tank circuit over a wide frequency range which includes a second tube having a current connection between its output electrode and said tank circuit, a reactive element connected to the third of said cold electrodes for developing an alternating voltage from oscillation current produced by the first tube, means for impressing said alternating voltage upon the second tube input electrodes, and means for varying the gain of said second tube over a range of values sufficient to produce said wide range tuning.

9. In an oscillator circuit of the type comprising a tube provided with a cathode and at least three cold electrodes, a resonant tank circuit connected to a first of the cold electrodes, a reactive coupling between the first electrode and a second cold electrode, means for tuning said tank circuit over a wide frequency range which includes a second tube having a current connection between its output electrode and said tank circuit, a reactive element connected to the third of said cold electrodes for developing an alternating voltage from oscillation current produced by the first tube,

means for impressing said alternating voltage upon the second tube input electrodes, means for varying the gain of said second tube over a range of values sufficient to produce said wide range tuning, and said reactive element being capacitative.

10. In an oscillator circuit of the type comprising a tube provided with a cathode and at least three cold electrodes, a resonant tank circuit connected to a first of the cold electrodes, a reactive coupling between the first electrode and a second cold electrode, means for tuning said tank circuit over a wide frequency range which includes a second tube having a current connection between its output electrode and said tank circuit, a reactive element connected to the third of said cold electrodes for developing an alternating voltage from oscillation current produced by the first tube, means for impressing said alternating voltage upon the second tube input electrodes, means for varying the gain of said second tube over a range of values sufficient to produce said wide range tuning, and said three cold electrodes being arranged serially in the electron stream from said cathode.

11. In combination with a tube provided with at least a cathode, a positive cold electrode, and at least one auxiliary cold electrode in the electron stream between cathode and positive electrode, a resonant circuit connected between the cathode and one of the cold electrodes, a reactance of a predetermined sign connected to the other cold electrode, means for electrically varying the frequency of the resonant circuit, said means comprising a second tube having its input electrodes connected across said reactance, a high frequency feedback path connected between the output circuit of the second tube and the resonant circuit whereby a reactance is reflected across the resonant circuit which bears a predetermined relation to the said first reactance, and means for varying the gain of the second tube over a range of values sufficient to vary the reflected reactance magnitude to produce a wide frequency variation of the resonant circuit, a third cold electrode disposed in the electron stream of the first tube, and a high frequency coupling path between the resonant circuit and the third cold electrode whereby said first tube functions as an oscillator.

12. In combination with a tube provided with at least a cathode, a positive cold electrode, and at least one auxiliary cold electrode in the electron stream between cathode and positive electrode, a resonant circuit connected between the cathode and one of the cold electrodes, a reactance of a predetermined sign connected to the other cold electrode, means for electrically varying the frequency of the resonant circuit, said means comprising a second tube having its input electrodes connected across said reactance, a high frequency feedback path connected between the output circuit of the second tube and the resonant circuit whereby a reactance is reflected across the resonant circuit which bears a predetermined relation to the said first reactance, and means for varying the gain of the second tube over a range of values sufficient to vary the reflected reactance magnitude to produce a wide frequency variation of the resonant circuit, said first tube additionally including a plate electrode, means reactively coupling the plate electrode to said resonant circuit whereby said first tube functions as an oscillator.

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