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J. M. MILLER

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METHOD OF AND APPARATUS FOR THE CONTROL OF ELECTRICAL CURRENTS

Filed July 24, 1923

Fig. 1

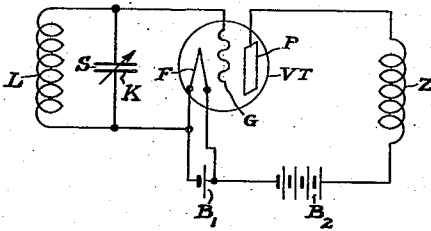


Fig. 2

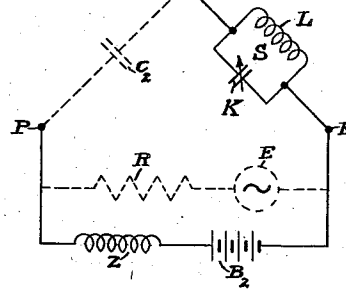


Fig. 3

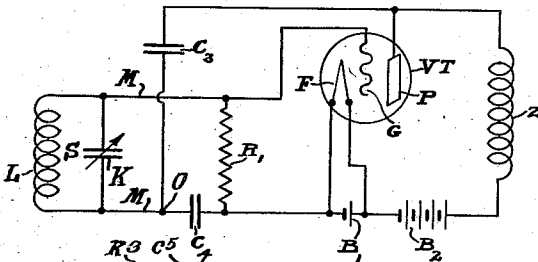


Fig. 4

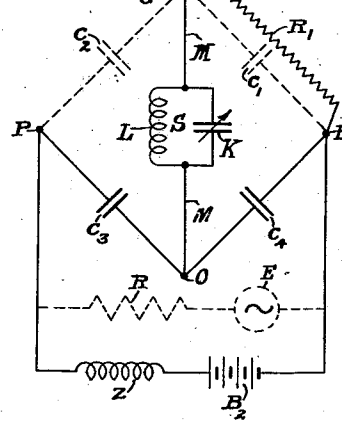


Fig. 7

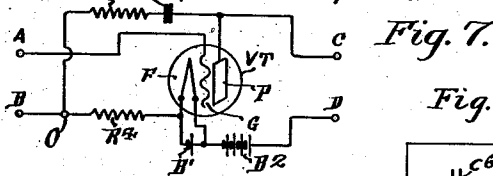


Fig. 5

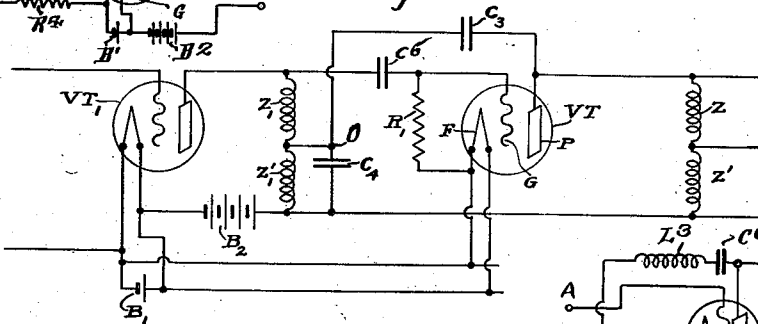


Fig. 6

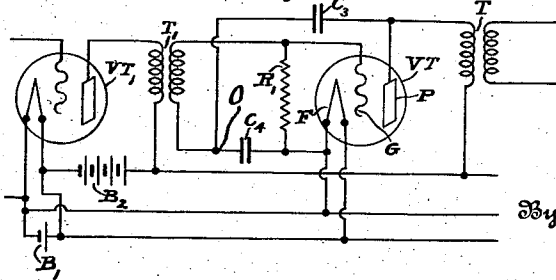
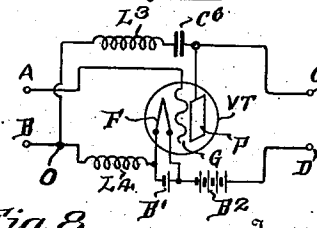


Fig. 8



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METHOD OF AND APPARATUS FOR THE CONTROL OF ELECTRICAL CURRENTS

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While my invention relates broadly to the control of electrical currents, it has as a particular object control of high frequency electrical currents such as those encountered
5 in radio signaling and wired radio.

A particular object is the control or elimination of reaction of output circuits on input circuits of relay and amplifying devices, such as the controlling of the reactions of the
10 plate circuit on the grid circuit of 3-electrode vacuum tubes.

A further object is the stabilization of amplifying devices and circuits to prevent self-oscillation, or to control the extent of
15 self-oscillation or regeneration.

A still further object is an improvement in the selectivity of amplifying circuits.

My invention will be best understood by reference to the figures of the accompanying
20 drawing which illustrate and explain it with particular reference to radio frequency amplifier circuits used with 3-electrode vacuum tube amplifying devices.

Figures 1, 2 and 4 are explanatory illustrations, and Figures 3, 5, 6, 7 and 8 are illustrations of several ways in which my invention
25 may be used.

Figure 1 shows the usual circuit connections of the first vacuum tube of a radio
30 frequency amplifier. The circuits S, comprising inductance L and variable condenser K, may be the secondary tunable circuit of a radio receiver which is customarily connected between the grid G and filament F of
35 the vacuum tube VT. Batteries B₁ and B₂ are the usual filament and plate batteries encountered in such devices. The impedance Z in the plate circuit of the tube represents a coil or transformer which serves as
40 the coupling unit with the succeeding tube of the amplifier. The amplifier is normally operated over a band of frequencies about that frequency for which the impedance Z, including such capacities as are contributed
45 by the leads, tubes and so forth, is resonant. At resonance, the impedance Z behaves as a pure resistance for alternating currents, for frequencies lower than the resonant frequency the impedance Z has an inductive
50 component and for frequencies higher than

the resonant frequency it has a capacitive component. By reason of the capacity between the plate P and grid G of the vacuum tube, there is a reaction between the plate circuit of the tube and the input circuit S and
55 the nature of this reaction depends upon the character of the load impedance Z. This effect has been treated mathematically and experimentally by me in a paper entitled "Dependence of the input impedance of a
60 three-electrode vacuum tube upon the load in the plate circuit", published as Scientific Paper No. 351 of the Bureau of Standards, and also treated mathematically by H. W. Nichols in the Physical Review, vol. 13, p.
65 405, 1919. The results of these investigations are also given in the book by H. J. Van Der Bijl entitled "The thermionic vacuum tube" on page 205 and following. These show
70 that when the load impedance Z is a pure resistance, or has a capacitive component, the reaction of the plate circuit upon the input circuit S is such as to take power from the input circuit thus increasing its effective resistance and also to increase the apparent
75 capacity in the input circuit. When the load impedance Z has an inductive component the reaction is such as to tend to feed power from the plate circuit of the tube into the input circuit, thus reducing the apparent
80 resistance of the input circuit while there is still the same tendency to increase the apparent capacity in said input circuit. Either of these effects can be detrimental to the operation of the amplifier. An increase in
85 the apparent resistance of the circuit S will lead to broadness of tuning and loss of signal strength. On the other hand, if the power fed back from the plate circuit to the circuit S exceeds a certain amount, the tube will
90 self generate oscillations and the usefulness of the amplifier will usually cease. This latter effect is generally met with in amplifiers and heretofore oscillations have been prevented by so-called stabilizers which in
95 general are means of causing losses to occur in the circuit S to counterbalance the power fed into the circuit from the plate circuit. The present invention discloses means by
100 which reactions can be controlled or elimi-

nated. Figure 2 is an explanatory diagrammatic sketch corresponding to Figure 1, the dots marked F, G and P representing the vacuum tube elements. The circuit S and impedance Z correspond to Figure 1. The capacity C_2 drawn in dotted lines from P to G represents the capacity between the grid and plate electrodes of the tube. It has been shown that the reaction in the plate circuit of a vacuum tube can be simulated by the assumption of a resistance R and alternating electromotive force in series inside the tube between the plate and filament as shown by R and E in dotted lines in Figure 2. It is evident that the alternating potential E will produce an alternating potential difference between plate P and filament F, the phase and amplitude of this potential depending upon impedance Z. As a result of the capacity between plate P and grid G there will be an alternating electromotive force applied to the circuit S. It is this electromotive force which represents the reaction of the plate circuit on the input circuit. As stated before when the load Z is capacitive or resistive, the reaction is such as to increase the effective resistance of the circuit S, when this load is inductive, the reaction can be such as to decrease the effective resistance and can lead to the self generation of oscillations, circuit S usually being of low resistance and therefore readily oscillatory.

Figure 3 shows diagrammatically one form of my invention which permits the elimination or control of these reactions. In this diagram the circuit of Figure 1 is changed by the addition of the capacities C_3 and C_4 connected in series from the plate P to the filament F, the circuit S being connected from the grid G to a branch point which is the common junction of these two capacities. Since this new mode of connection would insulate the grid for continuous currents, the leak resistance R_1 is connected from grid G to filament F. Normally R_1 will be a high resistance. Figure 4 is an explanatory representation of the circuit of Figure 3, drawn in a manner similar to explanatory Figure 2. The capacity C_1 between the grid electrode and filament electrode, including that of leads, terminals, and other parts, is shown in dotted lines. The circuit of Figure 4 is similar to an alternating current Wheatstone bridge for comparing the capacity of condensers. Neglecting the resistance R_1 , the bridge can be balanced by giving capacities C_3 and C_4 the proper values. In such a case there would be no electromotive force impressed upon the circuit S due to the reactive electromotive force E. The balance of the bridge being independent of the frequency, this would hold for all frequencies. Thus the circuit S would not be affected by the load in the plate circuit of the tube;—its resistance would neither be increased when the load is resistive or ca-

pacitive nor decreased when the load is inductive. On the other hand, the bridge can be thrown out of balance say by variation of the capacities C_3 and C_4 either in such a way as to reduce the resistance of the circuit S when the load is capacitive or to reduce it when the load is inductive. In order to prevent a radio frequency amplifier from oscillating it is, of course, not necessary to obtain a perfect balance but merely to reduce the reaction from the plate circuit by the requisite amount. It is normally not necessary to take into account the resistance R_1 or dielectric losses in balancing the bridge, though by putting the proper resistance in parallel or in series with the condensers C_3 and C_4 a perfect balance could be obtained for precision work. The above assumes that R is of the order of a megohm as usually used with receiving tubes; in the case of power tubes, however, R might be of the order of several thousand ohms and then it would usually be desirable to obtain a more perfect balance as by shunting C_4 with the proper resistance.

The received signal which is impressed upon the circuit S must impress a voltage between the grid and filament of the tube. If, in Figure 4, the capacity C_4 is equal to C_1 , only one half of the voltage across the tuning condenser of the circuit S will be impressed upon the tube input, therefore it is desirable to make C_4 greater than C_1 .

The same principle can be applied to control or eliminate the reaction between succeeding tubes in an amplifier as has been described for the first tube. In general the most difficulty with the self-generation of oscillations is met with in the first tube, but reactions between succeeding tubes can lead to reduced amplification or it may be desired to introduce reactions which lead to an enhanced amplification. In Figure 5 is shown one circuit in which the invention is applied between the stages of a multistage amplifier which utilizes reactance or resistance coils as coupling units. The impedance Z_1 represents the coupling unit between vacuum tubes VT_1 and VT_2 . The impedance Z'_1 is a choke coil which has a natural frequency below the frequency range of the amplifier so that it behaves as a capacity reactance throughout that range. By the natural frequency of choke coil Z'_1 is meant the frequency at which the coil inductance with its natural capacity is a resonant circuit or behaves as a power resistance. The capacity of this choke plus the capacity C_4 acts in place of C_4 in the previous figures. The capacity C_3 has the same significance as in the previous figures. C_3 is the customary grid coupling condenser and R_1 the usual grid leak resistance. To control regeneration C_3 and C_4 can be made variable. The terminal of C_4 which is connected to the positive plate

battery B_2 bus can be connected in lieu to either the positive or negative filament battery bus.

The circuit in the case of a transformer type amplifier is somewhat simpler and is shown in Figure 6. Here T_1 and T represent coupling transformers and the capacities C_3 and C_4 and resistance R_1 correspond with the previous figures, as well as do other reference letters.

The same principle is applicable to the case where a vacuum tube is employed as a coupling between the primary and secondary circuits of a receiver. Stability of such a circuit can readily be obtained and reaction of the secondary upon the primary eliminated or controlled as desired.

It is apparent that partial or complete balance of the bridge of Figure 4 can also be obtained by other means which however seem less desirable. In place of the capacities C_3 and C_4 , either resistances or inductances can be employed, a by-pass condenser being employed to prevent a short circuit of the plate battery.

In Figure 7 there is shown a circuit employing resistances. The points A and B represent the terminals to which the input circuit is connected, while the points C and D are the terminals to which apparatus in the output circuit may be connected. The resistances R_3 and R_4 replace the capacities C_3 and C_4 of the previous figures, while the capacity C_6 serves as a by-pass for the oscillations but prevents a short circuit of the plate battery B_2 . Similarly, Figure 8 shows a circuit when inductances are employed, L_3 and L_4 being substituted in place of C_3 and C_4 respectively. In these last two cases the resistance R_1 will, in general, be unnecessary since the grid will usually be connected to the filament through the circuit connected to points A and B.

It is characteristic of one of the aspects of my invention as hereinbefore described that by means of the condensers, as C_3 , C_4 , resistances R_3 , R_4 , or inductances L_3 , L_4 , connected in series with each other between the cathode or filament F and a point at which exists a varying potential, in phase with the disturbing potential, and specifically, between the filament or cathode F and the anode P or other suitable point in the anode circuit, there is defined a point, as O, at which the potential is different from that of cathode F and varies in phase with the disturbing potential; between the point O and the grid G there is zero difference of potential as regards reaction produced by the disturbing potential; and between the point O and the grid is impressed the input energy by or through the input element. The input element, as circuit S or equivalent, has its one terminal connected to the point O and its other to the grid, whereby in effect the reactions produced by

the disturbing potential produce substantially zero difference of potential between the terminals of the input element.

In accordance with another aspect of my invention, I utilize a true Wheatstone bridge in no arm of which is included any part of the input element, as of the circuit S or equivalent, and in whose conjugate conductor M is connected the input element, as the circuit S or equivalent, which, and the entire conjugate conductor M, are at the same potential with reference to the cathode F and whose potential caused by the disturbing potential rises and falls throughout in phase with the disturbing potential.

It is further characteristic of my invention that the capacity between grid and filament, together with the associated capacity in parallel therewith imparted by connections, leads, etc., is in one arm of the bridge; and more particularly, there may be included in the same arm with the capacity C_1 a resistance, as the grid leak resistance R_1 ; and similarly, there may be utilized in either or both of the arms including the capacities C_3 and C_4 series or parallel resistances.

Commonly in the prior art the input terminals to a vacuum tube have been the grid and filament terminals thereof, whereas in accordance with my invention the input terminals are those of the grid and the aforesaid point, such as O, and with respect to these terminals in accordance with my invention, the amplifying apparatus operates uni-laterally, in the sense that reaction is reduced or entirely prevented as between the source of disturbing potential and the input element connected to these input terminals.

For brevity in the appended claims, the term "input element" includes a circuit, as S, or any equivalent means, per se, commonly heretofore used in the art for transferring to or impressing upon the grid or input circuit the energy or electro-motive-force to be amplified or, in general, to affect the impedance of the anode circuit.

Having described my invention I claim:

1. Radio receiving apparatus comprising cascaded thermionic tubes, impedance in the anode circuit of one of said tubes, a connection from intermediate point of said impedance to the anode circuit of the following tube, an impedance in said connection, and connections from the input electrodes of said second tube to said first impedance on opposite sides of said intermediate point.
2. Radio receiving apparatus comprising cascaded thermionic tubes, impedance in the anode circuit of one of said tubes, a connection from an intermediate point of said impedance to the anode circuit of the following tube, capacity in shunt to the portion of said impedance common to the anode circuits of said tubes, and impedance in said connection, and connections from the input elec-

trodes of said second tube to said first impedance on opposite sides of said intermediate point.

3. Radio receiving apparatus comprising cascaded thermionic tubes, impedance in the anode circuit of one of said tubes, a connection from an intermediate point of said impedance to the anode circuit of the following tube, a condenser in said connection, and connections from the input electrodes of said second tube to said impedance on opposite sides of said point, said condenser and capacities between said input electrodes and between the grid and anode of said second tube forming three capacitive arms of a Wheatstone bridge, including the input and output circuits of said second tube in conjugate conductors thereof.

4. Radio receiving apparatus comprising cascaded thermionic tubes, a coupling impedance and a capacitive impedance in series in the anode circuit of one of said tubes, a condenser connected between the anode circuit of the following tube and a point between said impedances, and connections from the input electrodes of said tube to said coupling impedance, said condenser, said capacitive impedance, and capacities between said input electrodes and between the grid and anode of said second tube forming the four capacitive arms of a Wheatstone bridge whose conjugate conductors include said coupling impedance and the output circuit of said second tube.

5. In an amplifier, the combination with a thermionic tube having an input circuit, an inductance having a natural frequency lower than the frequency range of said amplifier connected between a point in said input circuit and the cathode of said tube, a condenser connected between said point and the anode circuit of said tube, and an input element connected between said point and the grid of said tube.

6. An amplifier comprising cascaded thermionic tubes, a coupling inductance and an inductance having a natural frequency lower than the frequency range of said amplifier traversed in succession by anode current of one of said tubes, a condenser connected between the anode circuit of the following tube and a point between said inductances, and connections from the input electrodes of said second tube to said coupling inductance.

7. In an amplifier, the combination with a thermionic tube having an input circuit, an inductance having a natural frequency lower than the frequency range of said amplifier connected between a point in said input circuit and the cathode of said tube, a condenser connected between said point and the anode circuit of said tube, and an input element connected between said point and the grid of said tube, said inductance, said condenser, and capacities between the input electrodes of

said tube and between the grid and plate thereof comprising the four capacitive arms of a Wheatstone bridge whose conjugate conductors include said input element and the output circuit of said tube.

8. An amplifier utilizing a thermionic tube, and a plurality of capacitive impedances forming an alternating current Wheatstone bridge whose conjugate conductors comprise respectively the input and output circuits of said amplifier, characterized by the fact that at least one of said impedances is an inductance having a natural period below the frequency range of said amplifier to afford a direct current path between the cathode and another electrode of said tube.

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