Dec. 8, 1936. N. M. RUST 2,063,125

MODULATION SYSTEM

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Fig. 1

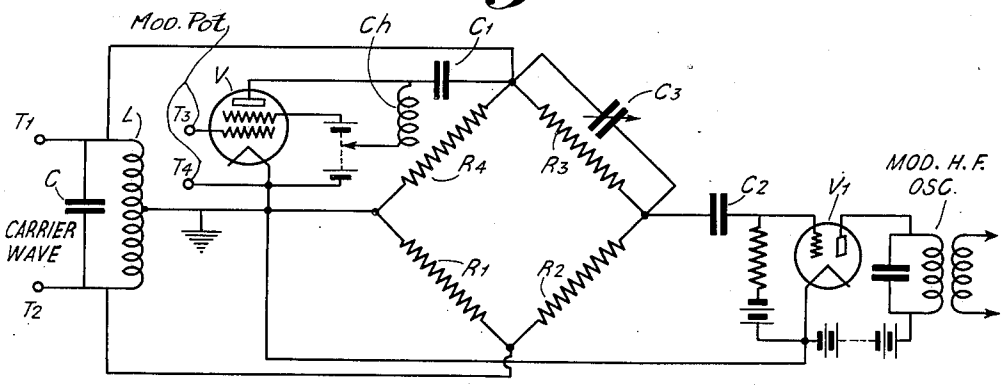


Fig. 2

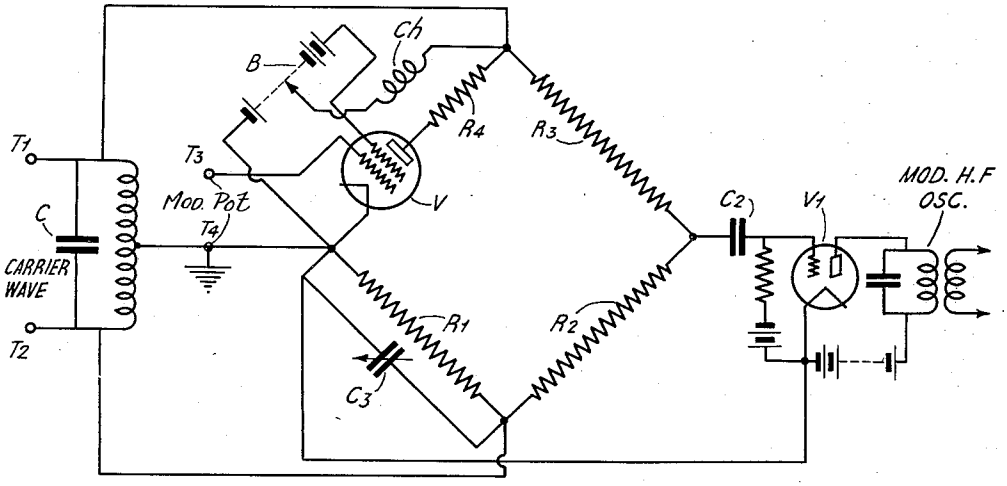


Fig. 3d

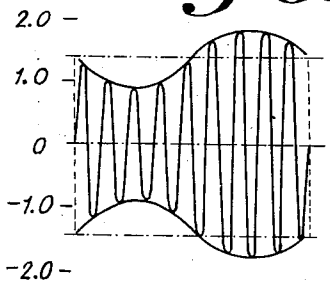
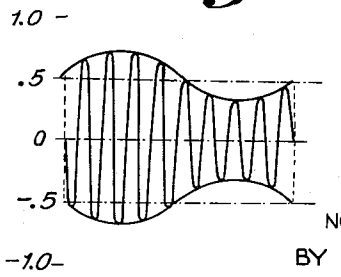


Fig. 4d



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MODULATION SYSTEM

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Fig. 3a

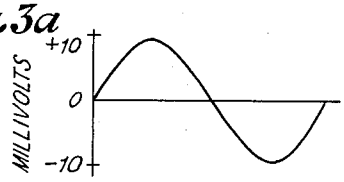


Fig. 4a

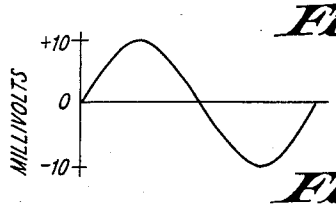


Fig. 3b

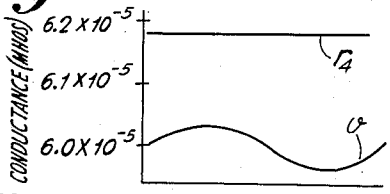


Fig. 4b

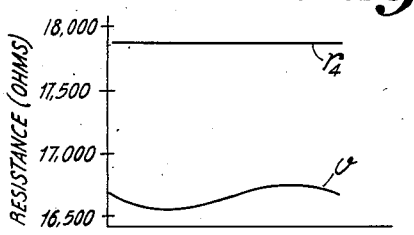


Fig. 3c

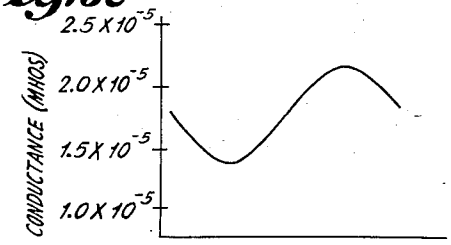


Fig. 4c

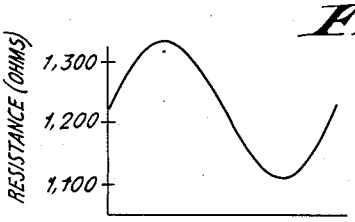


Fig. 5

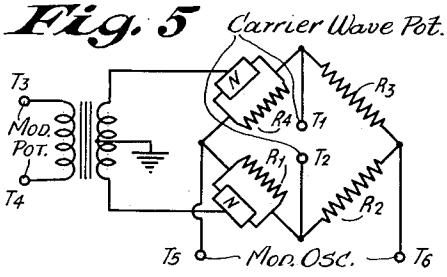


Fig. 6

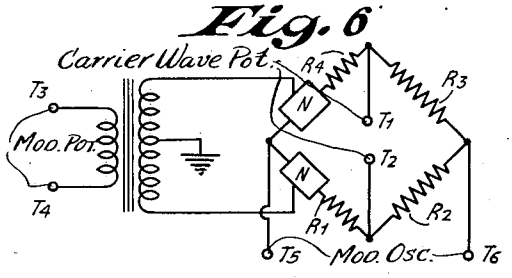


Fig. 8

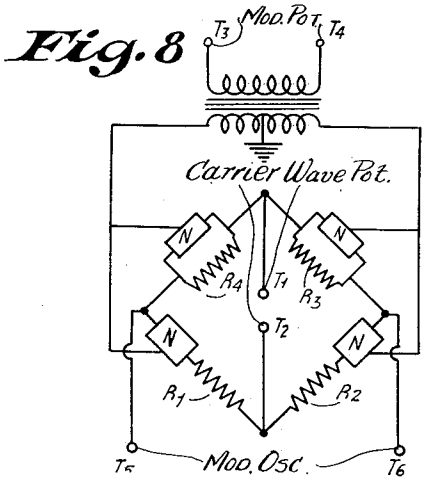
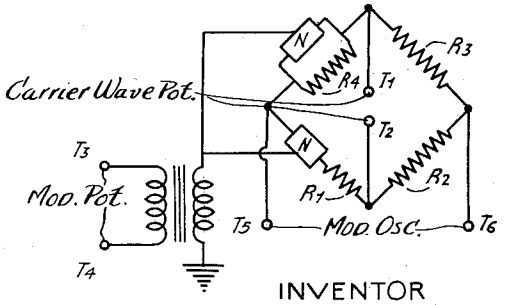


Fig. 7



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UNITED STATES PATENT OFFICE

2,063,125

MODULATION SYSTEM

Noël Meyer Rust, Chelmsford, England, assignor to Radio Corporation of America, a corporation of Delaware

Application February 20, 1934, Serial No. 712,102
In Great Britain February 23, 1933

20 Claims. (Cl. 179—171)

This invention relates to modulation systems suitable for use for wireless signalling and similar purposes.

According to this invention modulated electrical oscillations are obtained by means including a Wheatstone bridge, a negative resistance valve or valves included in or in effect forming part of one or more of the arms of said bridge, means for applying modulating potentials to control electrodes of said negative resistance valve or valves, means for applying high frequency potentials to be modulated to the opposite ends of one diagonal of the bridge, and means for taking off modulated high frequency potentials from the ends of the other diagonal of the bridge.

The bridge is preferably operated in a nearly balanced condition and the arm or arms containing a negative resistance valve may be constituted by a resistance in parallel or in series with the negative resistance valve.

The invention is illustrated in the accompanying drawings which show various circuit arrangements in accordance with the said invention.

In the drawings through which like reference characters take like parts insofar as possible, Figure 1 illustrates a carrier wave modulation circuit arranged in accordance with the present invention. In this circuit the carrier wave to be modulated is applied to the diagonals of a bridge having resistive arms as shown. The modulating potentials are applied by means of a thermionic valve to the resistance in one arm of the bridge, while the modulated carrier wave may be derived from the other diagonal of the bridge.

Figures 2 to 7, inclusive, show modifications of the arrangement of Figure 1. These modifications consist in the application of the modulating potentials to an arm or two arms of the bridge circuit in different manners.

Figures 3*a* to 3*d*, inclusive, and 4*a* to 4*d*, inclusive, are curves or graphs which serve to illustrate the operation of applicant's invention.

Referring to Figure 1 oscillations from any convenient source are applied to terminals T_1 T_2 connected to the opposite ends of a tuned oscillatory circuit LC whose centre point is earthed. The oscillatory circuit LC is connected in one diagonal of a Wheatstone bridge three arms of which are constituted by resistances R_1 R_2 and R_3 and the fourth arm of which is constituted by a resistance R_4 and the anode cathode space of a screen grid valve V in parallel with said resistance a blocking condenser C_1 being connected between the anode of the valve V and one end of resistance R_4 as shown. Operating potentials are applied to the screen grid and anode of the valve V by means of a battery B whereby said valve is caused to operate as a dynatron. A choke C*h* having a high impedance at the operating frequency is connected in the anode voltage supply lead. Modulating potentials are applied to terminals T_3 T_4 connected respectively to the control grid and cathode of the valve V. Modulated oscillatory energy appearing across the second diagonal of the bridge is applied by means of a coupling condenser C_2 to the input circuit of an amplifying valve V_1. A variable condenser C_3 is connected across the resistance R_3 and is adjusted to compensate for stray capacities due to the valve V.

A modification of the above described arrangement is shown in Figure 2 of the accompanying drawings in which the valve V in place of being in parallel with the resistance R_4 is connected in series therewith. In other respects the circuit is generally similar to that shown in Figure 1 the condenser C_3 however being connected in the present case across the resistance R_1.

In the arrangement shown in Figure 1 the resistances R_1 R_2 and R_3 are made equal and the value of resistance R_4 is made less than that of the other resistances. The effective resistance of the arm of the bridge constituted by the negative resistance of the valve V and the resistance R_4 in parallel is made such that at peak values of modulating potentials corresponding to "trough" modulation and applied to the control electrode of valve V the bridge is nearly balanced. The values of the resistances R_1 R_2 and R_3 in the bridge circuit in Figure 2 are also made equal but in this case the resistance R_4 is made greater than the value of the other resistances the effective value of the resistance of the arm of the bridge containing resistance R_4 being reduced by the negative resistance of valve V. In this case also the bridge is nearly balanced in the presence of peak values of modulating potentials corresponding to "trough" modulation.

Perfect balance of the bridge under conditions of peak values of modulating potential would, of course, correspond to 100% modulation.

It will be appreciated that with these arrangements alterations of the control grid potential applied to the screen grid valve will produce changes of negative resistance therein and since the bridge is operated in approximately balanced condition these changes of negative re-

sistance will change the degree of out-of-balance of the bridge and thereby produce variations in the high frequency output from said bridge these variations, of course, constituting the modulation.

The advantages of arrangements in accordance with this invention are (1) that it is possible to produce substantially linear changes of negative resistance for changes in the applied modulating potentials (2) that great sensitivity is obtained and (3) that by arranging the static resistance in the case of a series connected negative resistance valve (or the positive conductance, in the case of a parallel connected negative conductance valve) in the arm of the bridge containing the negative resistance (or negative conductance) valve to be nearly equal and opposite to the negative resistance (or negative conductance) of said valve under working conditions, the out-of-balance between the negative and positive resistances (or conductances) of this arm being in turn nearly equal to the resistances (or conductances) of the remaining arms, a very sensitive control condition is obtained and changes of negative resistance can be made to produce relatively large percentage changes of net bridge arm resistances.

It should be noted that the terms "negative resistance" and "negative conductance" in the present specification are employed as a convenient means of expressing the effective result obtained by connecting a source of energy e. g. a dynatron respectively in series or in parallel with a positive (real) resistance or conductance and that these quantities have, of course, no real existance apart from the effect produced upon the circuit.

In the case of a parallel connected valve, it is convenient to deal with conductances, since these can be added directly and the valve can be said to have a negative conductance of x mhos when the effect of connecting the valve in circuit is to reduce the effective conductance of the resistance with which it is connected in parallel and to which it supplies energy by x mhos. In other words the valve is said to have a negative conductance of x mhos when the effect of connecting it in circuit is to reduce the value of the ratio of the total current flowing in the circuit constituted by the valve and resistance in parallel to the voltage across said circuit by a value x. Similarly in the case of a series connected valve the valve may be said to have a negative resistance of y ohms when the effect of connecting said valve in series with a real resistance is to reduce the overall resistance value by y ohms, i. e. when the ratio of voltage across the circuit constituted by the valve and resistance in series to the current flowing in said circuit is reduced by a value y.

The sensitivity of control obtainable with arrangements in accordance with the present invention will best be appreciated by consideration of the following numerical example of circuit constants for use in arrangements in accordance with Figures 1 and 2.

In the following examples it is assumed that a screen grid valve is used which, with the normal applied voltages for negative resistance operation gives a negative conductance of 6.0×10^{-5} mhos corresponding to a negative resistance of 16,666 ohms and which exhibits a change of 0.666% for a change of 10 milli-volts in control grid potential.

Considering first the circuit arrangement shown in Figure 1, if the resistances R_1 R_2 and R_3 be made equal to 100,000 ohms then for conditions of "trough" modulation (for 100% modulation "trough" modulation corresponds to zero carrier) the effective resistance of the bridge arm containing the resistance R_4 would have to be 100,000 ohms, and the percentage change of effective resistance of the bridge arm for a grid swing of ±10 milli-volts on the control grid of the valve V would be ±4%. A resistance value of 14,200 ohms would have to be chosen to reproduce this condition.

If it were practical to make R_1 R_2 R_3 and the net resistance of the arm containing R_4 at "trough" modulation setting each equal to 1,000,000 ohms, the net change in the resistance of the arm containing R_4 would be increased to ±28%. The resistance R_4 would be 16,300 ohms to secure this condition. Apart from the difficulty in balancing stray capacities for this high impedance condition it will be seen that the resistance of R_4 (16,300 ohms) becomes much nearer to that of the valve V (16,666 ohms). Conditions of operation would therefore become very critical and any accidental change bringing the valve negative resistance below the resistance of R_4 would tend to cause spurious oscillation.

The relationship existing between the conductances in the bridge arm containing R_4 suitable for approximately 50% modulation with a grid swing of ±10 millivolts (R_1 R_2 and R_3 each being 100,000 ohms) and the modulating potential applied to the grid of valve V over a single cycle of grid potential is shown graphically in Figures 3*a*, 3*b* and 3*c*. Figure 3*a* shows the variation of grid potential over a single cycle between peak values of ±10 millivolts; curve *v* of Figure 3*b* shows to the same time base the corresponding variations of negative conductance of the valve V; the curve r_4 of Figure 3*b* represents the (constant) positive conductance of R_4; and the curve of Figure 3*c* shows the net (positive) conductance of the bridge arm constituted by the resistance R_4 and the valve V in parallel. The accompanying Figure 3*d* shows the corresponding modulated output from the bridge.

Considering now the series arrangement shown in Figure 2 if R_1 R_2 and R_3 were each made equal to 1,000 ohms R_4 being given a value of 17,790 ohms so that at "trough" modulation the difference between positive and negative resistance would just balance the bridge it is found that a change of 10% in the net resistance of the bridge arm containing R_4 is produced for a 10 millivolt change under 100% modulation conditions. However if lower values of resistance be chosen for the bridge arms while a higher percentage net change of bridge balance could be obtained this would be at the expense of stability. Moreover the impedance values would not be convenient for applying the bridge output directly to the grid of an amplifying valve and some form of step up transformer would be necessary between the output bridge terminals and the valve grid circuit.

Figures 4*a*, 4*b*, 4*c* and 4*d* show curves which correspond to the curves of Figures 3*a*, 3*b*, 3*c* and 3*d* but which are worked out for the arrangement shown in Figure 2 for a modulation of approximately 50% with a grid swing of ±10 millivolts on the control grid of the valve V, R_1, R_2 and R_3 each being made 1,000 ohms.

The arrangements so far considered are concerned with the provision of a negative resistance valve in association with one arm only of the bridge circuit, but the invention is not limited to such an arrangement and various modifications

in which two or more negative resistance valves are employed are illustrated schematically in the accompanying Figures 5, 6, 7 and 8.

In these Figures T_1 T_2 represent the unmodulated high frequency input terminals, T_3 T_4 the modulation input terminals, and T_5 T_6 the modulated high frequency output terminals. In each case the negative resistance devices consisting of a screen grid valve together with means for applying the necessary potentials to obtain dynatron operation are represented merely by rectangles N. In Figure 5 a negative resistance device N is connected across each of resistances R_4 and R_1 and modulating potentials are applied to the devices N in push pull. In Figure 6 a negative resistance device N is connected in series with each of resistances R_4 and R_1 and again modulating potentials are applied to the devices N in push pull. In Figure 7 a negative resistance device N is connected in parallel with resistance R_4 and in series with resistance R_1 modulating potentials being applied in parallel to these devices. In Figure 8 a negative resistance device N is connected in series with each of resistances R_1 and R_2 and in parallel with each of resistances R_3 and R_4 modulating potentials being applied in parallel to the devices associated with resistances R_1 and R_4 and also in parallel to the devices associated with R_2 and R_3 and to these two pairs of devices in push-pull.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:

1. In a modulation system, a Wheatstone bridge circuit having four arms, an electron discharge valve having electrodes including an anode, a control grid, and a cathode, a circuit connecting the anode to cathode impedance of said valve to one arm of said bridge circuit whereby said impedance forms part of said one arm of said bridge circuit, means for applying operating potentials to the electrodes of said valve whereby it is caused to have a negative resistance characteristic, means for applying modulating potentials to the control grid of said valve of negative resistance characteristic, means for applying high frequency potentials to be modulated to one diagonal of the bridge and means for taking off modulated high frequency potentials from the other diagonal of the bridge.

2. A modulation system comprising a Wheatstone bridge three arms of which consist of substantially equal resistances and a fourth arm of which includes the impedance between the anode and cathode of a thermionic valve in effective parallel with a fourth resistance of lower value than that of each of said equal resistances, means for applying operating potentials to the electrodes of said valve whereby it is caused to have a negative resistance characteristic, means for applying modulating potentials between the control grid and cathode of said valve, means for applying high frequency potentials to be modulated to one diagonal of said bridge and means for deriving modulated high frequency potentials from the other diagonal of said bridge.

3. A modulation system comprising a Wheatstone bridge three arms of which consist of substantially equal resistances and the fourth arm of which includes the impedance between the anode and cathode of a thermionic valve in series with a fourth resistance of greater value than that of each of said equal resistances, means for applying operating potentials to the electrodes of said valve whereby it is caused to have a negative resistance characteristic, means for applying modulating potentials between the control grid and cathode of said valve, means for applying high frequency potentials to be modulated to one diagonal of said bridge and means for deriving modulated high frequency potentials from the other diagonal of said bridge.

4. A modulation system as claimed in claim 1 in which the bridge is nearly balanced under conditions corresponding to "trough" modulation.

5. A modulation system as recited in claim 1 in which the valve employed is a screen grid valve operated over the downwardly sloping portion of its characteristic.

6. A system as claimed in claim 2, in which a variable condenser is connected across one of the bridge arms adjacent the arm containing the negative resistance valve for balancing stray capacities due to said valve.

7. A system as recited in claim 1 in which said means for applying operating potentials to the electrodes of said tube includes an anode potential source and in which a high frequency choke is connected between the anode of said valve and said source of anode potential.

8. A system in accordance with claim 2, in which the anode of the valve is connected to one end of the resistance in parallel therewith by means of a blocking condenser.

9. A system as recited in claim 2 in which the modulated bridge output is fed directly to the grid circuit of a thermionic amplifier substantially as described.

10. In a modulation system, a Wheatstone bridge circuit having four arms, two adjacent arms of which are constituted by resistances and the two remaining arms of which each include the anode to cathode impedance of an electron discharge valve, the electrodes of which are energized to produce a negative resistance effect, in effective parallel with an additional resistance, a source of carrier wave oscillations connected with one diagonal of said bridge circuit, a load circuit connected with the other diagonal of said bridge circuit, and means for applying modulating potentials to the control grids of said valves in phase opposition.

11. A modulation system as recited in claim 2 in which, the bridge is nearly balanced under conditions corresponding to "trough" modulation.

12. A modulation system as recited in claim 3 in which, the bridge is nearly balanced under conditions corresponding to "trough" modulation.

13. A modulation system as recited in claim 2 in which, the valve employed is a screen grid valve operating over the downwardly sloping portion of its characteristic curve.

14. A modulation system as recited in claim 3 in which, the valve employed is a screen grid valve operating over the downwardly sloping portion of its characteristic curve.

15. A modulation system as recited in claim 3 in which, a variable condenser is connected across one of the bridge arms adjacent the arm containing the anode-cathode space of said valve for balancing stray capacities caused by said valve.

16. A system as recited in claim 2 in which, a high frequency choke coil is connected between the valve anode and the source of anode potential.

17. A system as recited in claim 3 in which, a high frequency choke coil is connected between the valve anode and the source of anode potential.

18. A system as recited in claim 2 in which, a high frequency choke coil is connected between

the valve anode and the source of anode potential and in which a blocking condenser is interposed between the anode of the valve and one end of the resistance in parallel therewith.

19. A system as recited in claim 3 in which, the modulated bridge output is fed directly to the grid electrode of a thermionic amplifier.

20. In a modulation system, a bridge circuit comprising pairs of opposed arms each of which comprises an impedance, a thermionic valve having an anode, a cathode, a control electrode and an auxiliary electrode, circuits for applying positive potentials to the anode and auxiliary electrode relative to the cathode, the potential applied to the auxiliary electrode being greater than the potential applied to the anode whereby said tube has a negative resistance characteristic, a circuit connecting the anode to cathode impedance of said valve to the impedance in one of said arms, means for applying modulating potentials to the control electrode of said valve, means for applying carrier frequency waves to a pair of opposed points on said bridge circuit and a utilization circuit connected to another pair of opposed points on said bridge circuit.

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