

June 15, 1948.

W. J. FIELD

2,443,347

ELECTRONIC CONTROL CIRCUITS

Filed Nov. 19, 1942

3 Sheets-Sheet 1

Fig. 1.

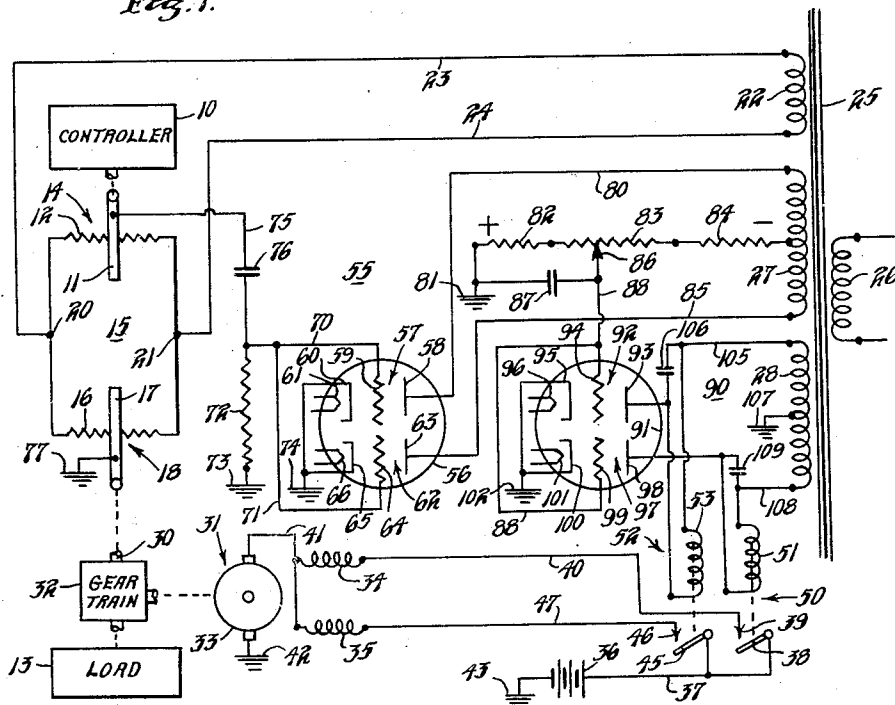


Fig. 2.

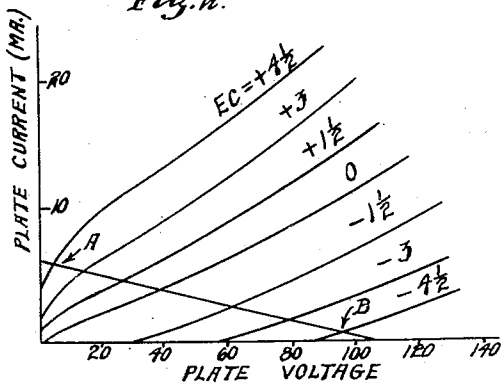
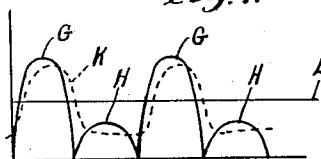


Fig. 3.



Fig. 4.



Inventor
WILLIAM J. FIELD

George H. Fisher
Attorney

June 15, 1948.

W. J. FIELD

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3 Sheets-Sheet 2

Fig. 5.

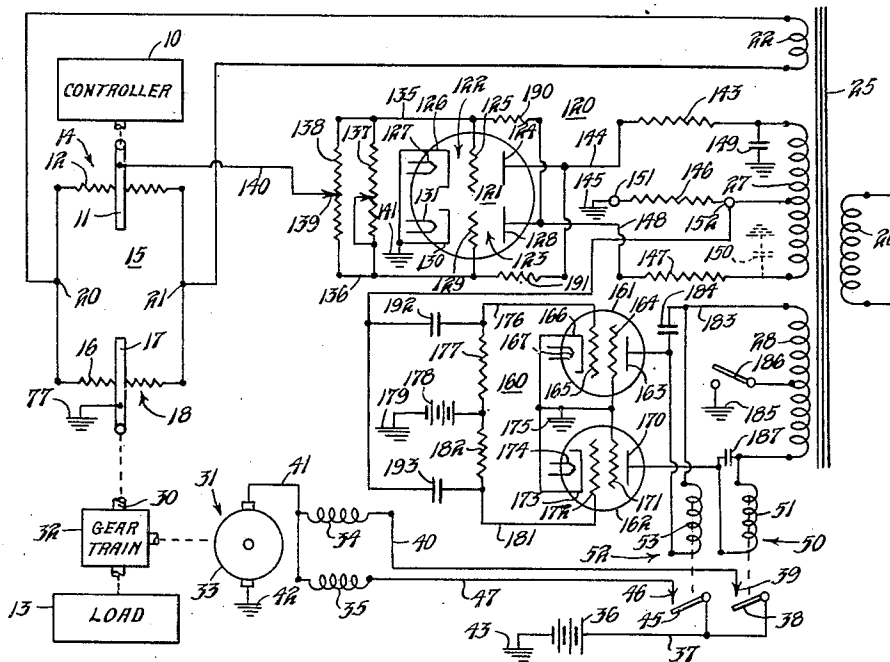
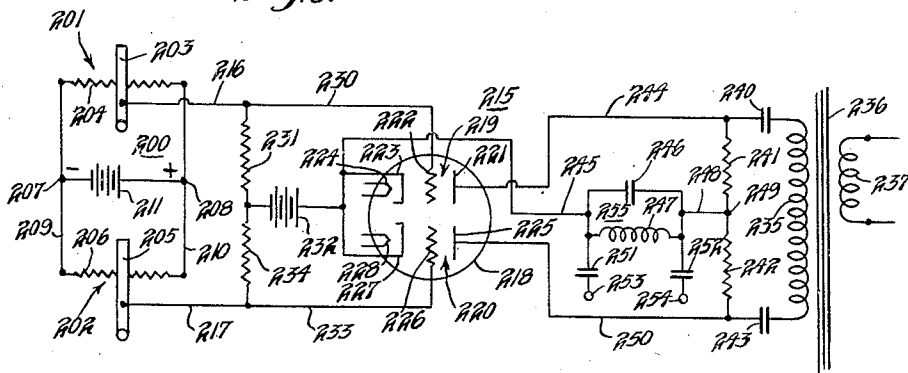


Fig. 6.



Inventor
WILLIAM J. FIELD.

By

George H. Fisher
Attorney

June 15, 1948.

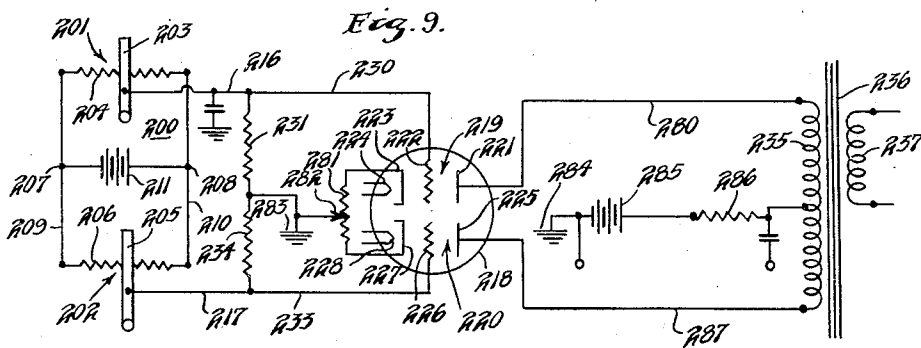
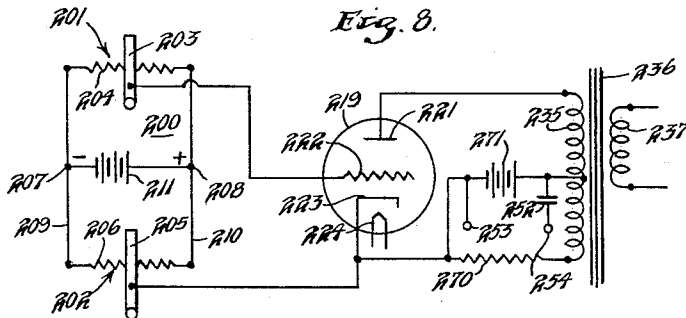
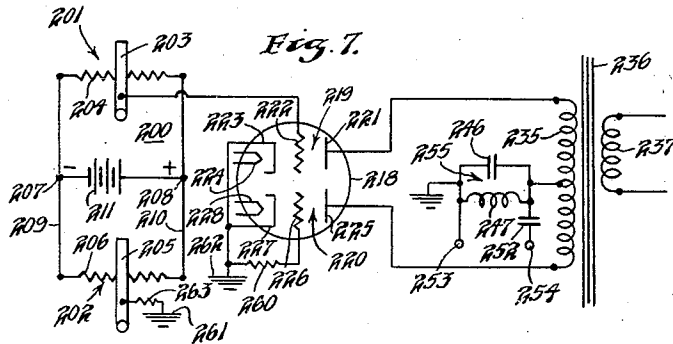
W. J. FIELD

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3 Sheets-Sheet 3



Inventor
WILLIAM J. FIELD

By

George H. Fisher
Attorney

UNITED STATES PATENT OFFICE

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ELECTRONIC CONTROL CIRCUITS

William J. Field, Minneapolis, Minn., assignor to
Minneapolis-Honeywell Regulator Company,
Minneapolis, Minn., a corporation of Delaware

Application November 19, 1942, Serial No. 466,237

16 Claims. (Cl. 250—27)

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The present invention relates to electronic amplifier circuits, and particularly to amplifier circuits adapted for use in electrical control systems.

An object of the present invention is to provide an improved amplifier circuit for use in electrical control systems.

Another object of the present invention is to provide an amplifier circuit which may be supplied with electrical energy from an alternating current supply, without the use of rectifiers or converters.

A further object of the present invention is to provide a method for determining the proper load impedance and anode-cathode voltage to be used in amplifier circuits including an electrical discharge device which is supplied with energy directly from an alternating current source.

Another object of the present invention is to provide an improved circuit for producing alternating electrical signals variable in phase in accordance with the polarity of a unidirectional signal applied to the circuit.

A further object of my invention is to provide an amplifier circuit of the type described, in which the controlling unidirectional potential is applied to the input circuit, and the output circuit is supplied with electrical energy from an alternating current source. A still further object is to provide, in the output circuit of the discharge device in said circuit, a parallel resonant circuit, and signal output terminals coupled to the terminals of said parallel resonant circuit.

A still further object of the present invention is to provide a circuit for converting unidirectional signal potentials into alternating signal potentials of a phase dependent upon the polarity of the unidirectional potential, in which means are provided to maintain the direct current impedances in a network substantially balanced, while the alternating current impedances in the network are unbalanced upon a change in the direct current signal potential.

Other objects and advantages of my invention will become apparent from a consideration of the appended specification, claims, and drawings, in which

Figure 1 is an electrical wiring diagram of an electrical control system including an amplifier, and embodying certain principles of my invention,

Figure 2 is a graphical illustration of the method of determining the proper load impedance and anode-cathode potential for use in the amplifier circuit of Figure 1,

Figures 3 and 4 are graphical illustrations of certain operating conditions of the circuit disclosed in Figure 1,

Figure 5 is an electrical wiring diagram of a modification of my invention, and

Figures 6, 7, 8, and 9 illustrate further modifi-

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cations of my invention, which are especially adapted to transform unidirectional signal potentials into alternating signal potentials.

Figures 1, 2, 3, and 4

Referring to Figure 1, there is shown a system in which a controller, generally indicated at 10, operates a slider 11 along a slide wire resistance 12. The slider 11 and the resistance 12 taken together, form a control potentiometer 14.

The controller 10 may be any device responsive to a variable condition which is indicative of the need for operation of a load device 13. For example, the controller 10 may be a temperature responsive device, such as a thermostat, and the load device 13 may be a heater or other temperature changing means.

The resistance 12 is connected in an electrical network 15, of the Wheatstone bridge type. The network 15 also includes a resistance 16. A slider 17 cooperates with resistance 16, and these two elements together form a follow-up potentiometer 18. The network 15 has a pair of input terminals 20 and 21, and the sliders 11 and 17 serve as the output terminals. The input terminals 20 and 21 are connected through conductors 23 and 24, respectively, to the terminals of a secondary winding 22 on a transformer 25. The transformer 25 also includes a primary winding 26 and secondary windings 27 and 28.

The slider 17 is fixed on a shaft 30, which is rotated by a reversible motor generally indicated at 31, acting through a gear train schematically shown at 32. A driving connection is also provided between the gear train 32 and the load device 13.

The motor 31 includes an armature 33 and field windings 34 and 35. The motor 31 is of the series type, and is so constructed that when field winding 34 is energized, the motor rotates in one direction, while when the field winding 35 is energized, the motor operates in the opposite direction.

The field winding 34 may be energized through a circuit which may be traced from the right hand terminal of a battery 36, through a conductor 37, a switch arm 38, a contact 39, a conductor 40, winding 34, a conductor 41, armature 33, and ground connections 42 and 43 to the left terminal of battery 36. The winding 35 may be energized through a similar circuit which may be traced from the right hand terminal of battery 36, through a conductor 37, switch arm 45, a contact 46, a conductor 47, field winding 35, conductor 41, armature 33, and ground connections 42 and 43 to the left terminal of battery 36. It will be readily understood by those skilled in the art, that the battery 36 may be replaced by any other suitable source of electrical energy.

The switch arm 38 is a part of a relay 50, which

also includes a winding 51 whose energization determines the position of switch arm 38. Switch arm 38 is biased to its circuit opening position, and is movable to closed position upon sufficient energization of winding 51. The switch arm 45 is part of a relay 52, and its position is controlled by the energization of a relay winding 53.

An amplifier circuit, generally indicated at 55, is provided to amplify any potentials existing between the output terminals of the bridge circuit 15. The amplifier circuit 55 includes a twin triode 56, which may be of the type commercially known as type 7N7. The twin triode 56 includes a first triode 57 having an anode 58, a control electrode 59, a cathode 60, and a heater filament 61. The twin triode 56 also includes a second triode 62 having an anode 63, a control electrode 64, a cathode 65, and a heater filament 66.

The triodes 57 and 62 have a common input circuit which may be traced from either control electrode 59 or control electrode 64, through a conductor 70 or a conductor 71 respectively, a resistance 72, and ground connections 73 and 74 to either cathode 60 or 65. The slider 11, which serves as one output terminal of bridge circuit 15 is connected through a conductor 75 and a blocking condenser 76 to the input circuit of amplifier 55. The slider 17, which serves as the other output terminal of bridge circuit 15 is connected to ground at 77.

The output circuit of triode 57 may be traced from the upper terminal of transformer secondary winding 27 through a conductor 80, anode 58, cathode 60, ground connections 74 and 81, and resistances 82, 83, and 84 to the center tap on transformer secondary winding 27. The output circuit of triode 62 may be traced from the lower terminal on secondary winding 27 through a conductor 85, anode 63, cathode 65, ground connections 74 and 81, and resistances 82, 83, and 84 to the center tap on secondary winding 27.

The resistance 83 is provided with a movable tap 86. A condenser 87 is connected between tap 86 and ground at 81. The tap 86 is connected through a conductor 88 to a discriminator circuit generally indicated at 90, which causes selective energization of the relay windings 51 and 53, depending upon the phase of an alternating potential existing between the tap 86 and ground.

The circuit 90, which functions both as a discriminator circuit and as an amplifier circuit, includes a twin triode 91, which may also be of the type commercially known as type 7N7. The twin triode 91 includes a first triode 92, having an anode 93, a control electrode 94, a cathode 95, and a heater filament 96. The twin triode 91 also includes a second triode 97, having an anode 98, a control electrode 99, a cathode 100, and a heater filament 101.

The triodes 92 and 97 have a common input circuit which may be traced from either control electrode 94 or control electrode 99 through conductor 88, tap 86, the portion of resistance 83 to the left of tap 86, resistance 82 and condenser 87 in parallel with the latter two resistances, and ground connections 81 and 102 to cathodes 95 and 100. The output circuit of triode 92 may be traced from the upper terminal of secondary winding 28 through a conductor 105, relay winding 53 and a condenser 106 in parallel therewith, anode 93, cathode 95, and ground connections 102 and 107 to the center tap on secondary winding 28. The output circuit of triode 97 may be traced from the lower terminal of secondary winding 28 through a conductor 108, relay winding 51 and a condenser

109 connected in parallel therewith, anode 98, cathode 100, and ground connections 102 and 107 to the center tap on secondary winding 28.

The heater filaments 61, 66, 96, and 101 may be energized from any suitable source of electrical energy (not shown).

The following table shows values of the various resistances and condensers in the circuit of Figure 1 which have been used in one embodiment of the invention:

Reference Numerals	Capacitance or Resistance
15	12.....5,000 ohms.
	16.....5,000 ohms.
	51, 53.....5,000 ohms.
	72.....1 megohm.
	76......05 microfarad.
	82.....3,000 ohms.
	83.....10,000 ohms.
	84.....10,000 ohms.
20	87......01 microfarad.
	106, 109.....1 microfarad.

Operation of Figures 1 to 4

Consider first the operation of the amplifier circuit 55. Since the anode to cathode potential of the triodes 57 and 62 is continuously varying, it should be apparent that this circuit is not well adapted to the use of conventional methods for determining the proper load impedance and plate voltage to be used. By the term load impedance, is meant the impedance in the output circuit of either triode externally of the triode itself. By the term "plate voltage," is meant the anode to cathode voltage of the triode when no current is flowing therethrough. By the term "plate current" is meant the current flowing through the output circuit of the triode.

Because of the continuously varying anode to cathode voltage obtained in this circuit, I find it preferable to choose the values of load resistance and plate voltage so as to obtain a maximum change in the plate resistance of the tube per unit change in the voltage applied between the control electrode and the cathode. This is in contrast to the conventional method of constructing an amplifier circuit, in which the object is to obtain the highest possible amplification factor consistent with considerations of distortionless amplification.

My method of calculating the proper load impedance and plate voltage to produce the optimum operation of the amplifier circuit 55 is illustrated in Figure 2. There is shown in Figure 2 a family of static characteristic curves for one half of a type 7N7 twin triode. As is well known in the art, each of these curves shows the variation of plate current obtained as the plate voltage is varied and the control electrode to cathode voltage (represented in Figure 2 by E_c) is maintained at a fixed value. The slope of each of these curves at any point is a measure of the plate resistance of the triode under the particular conditions obtained at that point. In other words, the slope represents the differential change in plate current divided by the differential change in plate voltage. I choose a point of substantially maximum slope, as indicated at A on the curve representing the static characteristic at the maximum expected value of control electrode potential, and a point of substantially minimum slope, as indicated at B, on the curve representing the static characteristic at the minimum expected value of control electrode potential. Through the two points so

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selected, I draw a straight line, and extend this line until it intersects the plate voltage axis. The slope of this line is then a measure of the proper load impedance to be used, and the point at which this line intersects the plate voltage axis, is a measure of the proper peak value of anode to cathode voltage to be used.

Since only one of the triodes 57 and 62 may be conductive on any given half cycle, the same load impedance may be used for both the triodes 57 and 62. This load impedance comprises the resistances 82, 83 and 84.

Figure 3 illustrates the conditions obtained when no signal is impressed on control electrodes 59 and 64. Referring to Figure 3, there are shown curves C representing the current flow taking place through the triode 57 on alternate half cycles, and curves D showing the current flow taking place through the triode 62 on the opposite half cycles. The curves C and D taken together represent the current flowing through the resistances 82, 83, and 84. Because of the smoothing effect of the condenser 87, the current flow through the resistance 82 and the portion of the resistance 83 to the left of tap 86 takes place substantially as represented by the curve E in Figure 3. The curve E may be considered as comprising two components, one a unidirectional component F of constant value, and the other an alternating component having twice the frequency of the energy supplied by winding 27.

Figure 4 shows the current and potential conditions existing in the output circuit of amplifier stage when a signal in phase with the anode-cathode voltage of triode 57 is applied to the control electrodes 59 and 64. If the signal is in phase with the anode-cathode voltage of triode 57, the control electrode 59 is thereby made more positive during the half cycles when the triode 57 may be conductive, and its conductivity is thereby increased during those half cycles. The current flow through the triode 57 under such conditions is represented in Figure 4 by the curve G. On the other hand, the signal potential is negative during the half cycles when the triode 62 may be conductive, and hence the signal potential operates to reduce the conductivity of the triode 62. The current flow through the triode 62 is represented in Figure 4 by the curve H. The current flow through the load impedance comprising the resistances 82, 83, and 84 and the condenser 87 is represented by the curves G and H taken together. The current flow through resistance 82 and the left portion of resistance 83, and hence the potential between tap 86 and ground is represented in Figure 4 by the curve K, which differs from the curves G and H by reason of the smoothing action of condenser 87. The curve K may be considered as comprising a unidirectional component L of substantially constant value, and an alternating component of the same frequency as that of the energy supplied by winding 27. It should be further apparent that the phase of the alternating component of the potential K is dependent upon the phase of the alternating signal impressed on the input circuit of amplifier 55.

It may be noted from Figure 4 that the potential K is not a pure sine wave, but that its form is considerably distorted. It has been found that the distortion obtained with this type of amplifier circuit is not sufficient to give trouble in a control system such as the one illustrated in Figure 1.

Referring now to the discriminator circuit 99

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of Figure 1, it may be seen that the output potential existing between tap 86 and ground is impressed on the input circuit of the discriminator 99. The unidirectional potential existing between tap 86 and ground is of a polarity such that, as impressed on the input circuit of the discriminator 99, it acts to bias the control electrodes 94 and 99 negatively with respect to their associated cathodes. This negative potential may be varied by adjusting the tap 86 along resistance 83. It is not necessary that this potential be great enough to maintain the triodes 92 and 97 continuously cut off, but it should be sufficient to maintain the normal output current of those triodes below the value necessary to cause effective energization of relay windings 51 and 53.

When the alternating component of the signal potential between tap 86 and ground is in phase with the anode-cathode potential of triode 92, the conductivity of that triode is increased. If the signal potential is large enough, the current flow through the triode 92 becomes sufficient to energize relay winding 53. This current flow occurs only on alternate half cycles, but is held over by means of the condenser 106 so that the relay winding is substantially continuously energized. Similarly, if the signal potential is in phase with the anode-cathode potential of triode 97, the relay winding 51 is energized.

Starting with the sliders 11 and 17 in the positions shown in the drawing, let it be assumed that the slider 11 is moved to the left along resistance 12 by the controller 10. The potential of slider 11 therefore approaches that of bridge input terminal 20, while slider 17 remains at ground potential. Therefore a signal potential exists between sliders 11 and 17 which is of the same phase as would exist if the slider 11 were connected to the upper terminal of secondary winding 22 and slider 17 were connected directly to the lower terminal. This signal potential therefore has its positive half cycle at the same time that the potential applied to the anode-cathode circuit of triode 57 and is such as to make the triode 57 more conductive. The current flow in the output circuit of the amplifier stage 55 therefore takes place as indicated in Figure 4. It will be readily understood that the potential at tap 86 increases negatively as the current flow in the output circuit of amplifier 55 increases. Therefore the alternating component of the current flow as expressed by the curve K in Fig 4 causes a potential of opposite phase to appear on the control electrodes 94 and 99 of the discriminator stage 99. Then, under the conditions of Figure 4, during the half cycles when the triode 57 is conductive, the potential applied to control electrodes 94 and 99 is highly negative, and maintains the triodes 92 and 97 non-conducting. During the following half cycle, during which the triode 97 may be conductive, the potential of the control electrodes 94 and 99 becomes more positive, and the triode 97 becomes more conductive, thereby energizing relay winding 51.

Energization of relay winding 51 causes switch arm 38 to engage contact 39, thereby completing the energizing circuit for winding 34 and armature 33 of motor 31. Completion of this circuit causes operation of motor 31 in a direction to drive slider 17 to the left along resistance 16, so as to reduce the potential difference between sliders 11 and 17 and thereby rebalance the bridge circuit 15. As this difference of potential is de-

creased, the signal applied to the amplifier 55 is decreased, and when the bridge 15 is rebalanced, the signal applied to amplifier 55 is no longer sufficient to maintain energization of relay winding 51. The energizing circuit for motor 31 is interrupted by movement of switch arm 38 away from contact 39, resulting in the stopping of motor 31 and hence in the motion of slider 17.

In a similar manner, it may be understood that if the slider 11 is moved to the right along resistance 12 a signal of the opposite phase is impressed on the input circuit of amplifier 55, and causes energization of relay winding 53. This causes completion of the energizing circuit for motor 31 which includes field winding 35, thereby causing rotation of motor 31 in the opposite direction, and movement of slider 17 to the right so as to rebalance the bridge circuit 15.

Figure 5

In Figure 5 I have shown a modification of the control system of Figure 1, in which the amplifier and discriminator circuits are somewhat different from those used in the system of Figure 1. In Figure 5, I have used the same reference numerals as in Figure 1 wherever the particular element is exactly equivalent to the corresponding element of Figure 1. These parts of the system of Figure 5 will not be described in detail.

The amplifier circuit in the system of Figure 5 is generally indicated at 120. Amplifier circuit 120 includes a twin triode 121, which may be of the type commercially known as type 7N7. The twin triode 121 includes a pair of triodes 122 and 123. The triode 122 has an anode 124, a control electrode 125, a cathode 126, and a heater filament 127. The triode 123 has an anode 128, a control electrode 129, a cathode 130, and a heater filament 131.

The control electrode 125 is connected to a conductor 135, and the control electrode 129 is connected to a conductor 136. The conductors 135 and 136 are connected through a variable resistance 137 and a fixed potentiometer resistance 138. A movable tap 139 associated with resistance 138 is connected through a conductor 140 to slider 11 of control potentiometer 14.

The input circuit of triode 122 may be traced from control electrode 125 through conductor 135, resistance 138, tap 139, conductor 140, slider 11, network 15, slider 17, and ground connections 77 and 141 to cathode 126. The input circuit of triode 123 may similarly be traced from control electrode 129 through conductor 136, resistance 138, tap 139, conductor 140, slider 11, network 15, slider 17, and ground connections 77 and 141 to cathode 130.

The output circuit of triode 122 may be traced from the upper terminal of secondary winding 27 through a resistance 143, a conductor 144, anode 124, cathode 126, ground connections 141 and 145, and a resistance 146 to the center tap on transformer secondary winding 27. The output circuit of triode 123 may similarly be traced from the lower terminal of secondary winding 27 through a resistance 147, a conductor 148, anode 128, cathode 130, ground connections 141 and 145, and resistance 146 to the center tap on winding 27. A condenser 149 is connected between the upper terminal of secondary winding 27 and ground to balance the distributed capacitance between the winding 27 and ground, which may be considered as a single lumped capacitance 150 connected be-

tween the lower terminal of winding 27 and ground.

The control electrode 125 is biased negatively with respect to its cathode 126 by a connection through a resistance 190, conductor 148, and resistance 147 to the lower terminal of secondary winding 27. The control electrode 129 is similarly biased negatively by a connection through a resistance 191, conductor 144, and resistance 143 to the upper terminal of secondary winding 27. Since each control electrode is connected through the circuit just traced to the opposite end of the secondary winding from that to which the anode associated with that control electrode is connected, it may be seen that during the half cycles when the anode is positive with respect to the cathode, the control electrode is maintained at a negative potential with respect to the cathode by this biasing connection. The magnitude of this bias is controlled by the resistance 137. It may be noted that a circuit, which is in effect a voltage divider circuit, may be traced from the upper terminal of transformer winding 27 through resistance 143, conductor 144, resistance 191, conductor 136, resistance 137 in parallel with resistance 138, conductor 135, resistance 190, conductor 148, and resistance 147 to the lower terminal of secondary winding 27. If the resistances 190 and 191 are equal and if the resistances 147 and 143 are equal, as would normally be the case, it may be seen that along this voltage divider connection just traced, the center point of the variable resistance 137 is at a potential corresponding to the potential of the midpoint of the transformer winding. By varying the resistance 137, the potentials of the control electrodes with respect to the center tap potential, and hence the potential of the control electrodes with respect to ground, may be adjusted. The resistance 137 therefore serves to adjust the biasing potential applied to the input circuit of amplifier 120, or in other words, it may be said to operate as a gain control for the amplifier.

The adjustable tap 139 is used to correct for any differences in the individual characteristics of the triodes 122 and 123. The resistance 138 also functions as a protective resistance, inasmuch as it prevents the impedance between the control electrodes and ground from becoming equal to zero, as might happen if both sliders 11 and 17 reached corresponding ends of their resistances 12 and 16. If the control electrode 125 is connected directly to the cathode with no intervening impedance, it has been found that the controlling effect of the control electrode becomes unstable and upon subsequent insertion of a positive potential into the control electrode to cathode connection, the response of the triode is unpredictable. This condition of operation of an electric discharge device is sometimes referred to as the "contact potential region" of operation. Operation of the discharge device in this region may be avoided simply by inserting an impedance, such as the resistance 138 between the control electrode and the cathode. This impedance should be permanently maintained in that connection.

The discriminator circuit of Figure 5 is shown generally at 160. The discriminator circuit 160 includes a pair of tetrodes 161 and 162, which may be gaseous electrical discharge devices of the type commercially known as type 2050. The tetrode 161 includes an anode 163, a pair of control electrodes 164 and 165, a cathode 166, and a heater filament 167. The tetrode 162 includes an anode

170, control electrodes 171 and 172, cathode 173, and a heater filament 174. The cathodes 165 and 173, and the control electrodes 164 and 171 may all be connected to ground at 175. The input circuit of tetrode 161 may be traced from control electrode 165 through a conductor 176, a resistance 177, a suitable source of biasing potential, shown as a battery 178, and ground connections 179 and 175 to cathode 166. The input circuit of tetrode 162 may be traced from control electrode 172 through a conductor 181, a resistance 182, battery 178, and ground connections 179 and 175 to cathode 173.

The output circuit of tetrode 161 may be traced from the upper terminal of secondary winding 23 through a conductor 183, relay winding 53 and a condenser 184 connected in parallel therewith, anode 163, cathode 166, ground connections 175 and 185, and a switch 186 to the center tap on secondary winding 28. The output circuit of tetrode 162 may be traced from the lower terminal of secondary winding 28 through relay winding 51 and a condenser 187 connected in parallel therewith, anode 170, cathode 173, ground connections 175 and 185, and switch 186 to the center tap on secondary winding 28.

The heater filaments 127, 131, 167, and 174, may be energized from any suitable source of electrical energy (not shown).

Since the tetrodes 161 and 162 are of the gaseous type, in which, after initiation of a discharge between the cathode and anode, the control electrode is no longer effective as long as a voltage (positive at the anode) remains between anode and cathode. However, the anode voltage in this case is alternating and consequently will extinguish the ionization if the grid circuits are properly biased. It is understood that those skilled in the art can rearrange the biasing scheme either by shifting the phase of the bias potential or by introducing a potential between cathode and shield grid. Curves of the operation with these latter biasing effects are given in published data on the 2050 tube and need not be explained here.

The switch 186 is provided so that the output circuits of the tetrodes 161 and 162 may be opened during the time the system is being started up, so that the tetrodes 161 and 162 will not be damaged by the application of potential between the anodes and cathodes before the filaments are heated.

The operation of the system of Figure 5 is entirely analogous to that of the system of Figure 1, and it is believed that further description of the operation of this system is unnecessary.

The following table shows values of the various circuit elements in the circuit of Figure 5 which have been used in one embodiment of that circuit:

Reference Numeral	Quantity
137.....	1 megohm.
138.....	1 megohm.
143.....	approximately 10,000 ohms.
146.....	50,000 ohms.
147.....	approximately 10,000 ohms.
149.....	600 to 1600 microfarads.
190.....	5 megohms.
191.....	5 megohms.
192.....	.02 microfarad.
193.....	.02 microfarad.

If no value is given above for any element, the value for the corresponding element in Figure 1 may be used.

Figure 6

There is shown in Figure 6 a circuit in which an amplifier of the type described in connection with Figure 1 is used to convert a unidirectional signal potential to an alternating signal potential. In the circuit of Figure 6, a somewhat different type of load impedance is used in the output circuit of the amplifier.

Referring to Figure 6, there is shown an electrical network 200, of the Wheatstone bridge type, which includes a control potentiometer 201 and a follow up potentiometer 202. The control potentiometer 201 includes a slider 203 and a slide-wire resistance 204. The follow up potentiometer 202 includes a slider 205 and a slidewire resistance 206. The bridge circuit 200 has input terminals 207 and 208, which are connected through the left and right terminals respectively of resistances 204 and 206 to conductors 209 and 210. The bridge circuit 200 is supplied with unidirectional electrical energy from any suitable source, which is shown, by way of example, as a battery 211.

The sliders 203 and 205, which serve as the output terminals of the network 200 are conductively coupled to an amplifier circuit generally indicated at 215 through conductors 216 and 217, respectively. Amplifier circuit 215 includes a twin triode 218, which may be of the type commonly known as type 7N7. The twin triode 218 includes two single triodes 219 and 220. The triode 219 has an anode 221, a control electrode 222, a cathode 223, and a heater filament 224. The triode 220 has an anode 225, a control electrode 226, a cathode 227, and a heater filament 228.

The input circuit of triode 219 may be traced from control electrode 222 through a conductor 230, a resistance 231, a battery 232, to cathode 223. The input circuit of triode 220 may be traced from control electrode 226 through a conductor 233, a resistance 234, and a battery 232, to cathode 227. The battery 232 serves as a source of biasing potential for the triodes 219 and 220.

The output circuits of the triodes 219 and 220 are supplied with electrical energy from the secondary winding 235 of a transformer 236 having a primary winding 237, which may be connected to any convenient source of alternating electrical energy. The secondary winding 235 supplies current to a voltage divider circuit which may be traced from the upper terminal of winding 235 through a condenser 240, a resistance 241, a resistance 242, and a condenser 243 to the lower terminal of secondary winding 235. The condensers 240 and 243 are blocking condensers, and serve to keep unidirectional electrical energy out of the transformer winding 235, where it might cause saturation of the transformer core.

The output circuit of triode 219 may be traced from the upper terminal of resistance 241 through a conductor 244, anode 221, cathode 223, a conductor 245, a parallel resonant network 255 including a condenser 246 and an inductance 247, and a conductor 248 to the common terminal 249 of resistances 241 and 242. The output circuit of triode 220 may be similarly traced from the lower terminal of resistance 242 through a conductor 250, anode 225, cathode 227, conductor 245, network 255, and conductor 248, to terminal 249. The left and right terminals of the parallel resonant network are connected through blocking condensers 251 and 252 to alternating signal output terminals 253 and 254.

The following table shows values of the various

circuit elements in Figure 6 which have been used in one embodiment of that circuit:

Table for Figure 6

Reference Numeral	Quantity
204	1000 ohms.
206	1000 ohms.
231	1 megohm.
234	1 megohm.
240	1 microfarad.
241	5000 ohms.
242	5000 ohms.
243	1 microfarad.
246	1 microfarad.
247	7 henries.
251	0.1 microfarad.
252	0.1 microfarad.

Operation of Figure 6

It is believed to be readily apparent from the circuit connections in Figure 6 that the triode 219 may be conductive during the half cycles when the upper terminal of winding 235 is positive, and that the triode 220 may be conductive during the half cycles when the lower terminal of winding 235 is positive. When the bridge circuit 200 is balanced, the current flow conditions in the output circuits of triodes 219 and 220 may be regarded as represented by the curves of Figure 3.

Under these conditions, let it be assumed that the slider 203 moves to the right along resistance 204, thereby unbalancing the bridge circuit 200, and creating a difference of potential between sliders 203 and 205 of a polarity such that slider 203 is positive with respect to slider 205, as indicated by the legend applied to the input terminals 237 and 208 of the bridge circuit 200. This potential difference between sliders 203 and 205 causes a current flow through resistances 231 and 234 in a sense such that their upper terminals are positive with respect to their lower terminals. The potential drop across resistance 231 opposes the biasing potential of the battery 232 in the input circuit of triode 219, and renders the triode more conductive. On the other hand, the potential drop across resistance 234 aids the biasing potential of battery 232 in the input circuit of triode 220, and therefore decreases the conductivity of that triode. The current flow in the common portion of the output circuits of triodes 219 and 220 now has an alternating component similar to that indicated by the curve K in Figure 4. The parallel resonant network 255 is tuned to the frequency supplied by transformer winding 235. Therefore this network presents a high impedance to the alternating component of current flow in the output circuit which is of the same frequency. A correspondingly high potential drop of that frequency is therefore developed across the terminals of the resonant network 255 by this current. This potential is transmitted through the blocking condensers 251 and 252 to the signal potential output terminals 253 and 254. The output terminals 253 and 254 may be connected to a discriminator circuit which may, for example, be one of those illustrated in Figures 1 and 5.

If the bridge circuit 200 becomes unbalanced in the opposite sense, by movement of slider 203 to the left from the position shown in the drawing, the current flow through resistances 231 and 234 is of the opposite polarity and increases the conductivity of triode 220 while decreasing the conductivity of triode 219. The alternating potential developed across the parallel resonant network is therefore of the opposite phase from

that previously obtained when the network 200 was unbalanced in the opposite direction.

Figure 7

In Figure 7 is illustrated a modification of the circuit of Figure 6. In this modification, the triode 220 has its control electrode 226 connected directly to the cathode 227 through a resistance 260, so that the triode 220 is always equally conductive. The slider 205 is connected to ground at 261 through a resistance 263, and the cathodes 223 and 227 are connected to ground at 262. The resistances 260 and 263 are provided to prevent unstable operation of the triodes, and function in a manner similar to resistance 138 of Figure 5. Any unbalance potential existing between the sliders 203 and 205 is applied between the control electrode 222 and cathode 223 of triode 219. When the bridge circuit is balanced, the output circuits of both triodes are equally conductive, since their respective control electrodes are at cathode potential. The current flow through the parallel resonant network 255 is therefore substantially unidirectional, with a small double frequency component. Since the network 255 has a very low impedance to the double frequency component, the double frequency voltage appearing across terminals 253 and 254 is very small.

If the bridge circuit becomes unbalanced, the conductivity of triode 219 is either increased or decreased from its normal value, thereby creating an alternating component in the current flowing in the output circuit. This alternating component has the same frequency as the supply, to which frequency the resonant network 255 is tuned.

When the conductivity of triode 219 is increased above its normal value, the current flow through the triode 219 represents the positive half cycle of current flow, while the current flow through triode 220 represents the negative half cycle of current flow through the network 255. On the other hand, if the conductivity of triode 219 is decreased, the current supplied by that triode to the network 255 is smaller than that supplied by the triode 220, and hence the smaller current represents the negative half cycle and the current supplied by triode 220 represents the positive half cycle. It may therefore be seen that this circuit produces an alternating signal potential at the output terminals 253 and 254 whose phase depends on the direction of unbalance of the bridge circuit.

Figure 8

In Figure 8, is shown a modification of the circuit of Figure 7, in which the triode 220 has been replaced by a constant impedance 270. The resistance 270 should preferably be designed to match the internal impedance of the triode 219. Furthermore, the parallel resonant network 255 has been replaced by a source of unidirectional potential, shown as a battery 271.

The battery 271 is provided to stabilize the unidirectional potential existing between the output terminals 253 and 254. It has been found, that upon large unbalances of a bridge circuit of the type shown at 200, or more generally speaking, upon the application of large unidirectional potentials to the input circuit of the triode 219, the unidirectional potential existing across the network 255 changes sufficiently so that the change is reflected through the blocking condenser to the discriminator circuit and may cause erratic operation of that circuit. The

provision of a battery 271, or other source of a constant unidirectional potential in the output circuit of the amplifier tends to stabilize this unidirectional potential, and prevent such erratic operations of the system.

Figure 9

In Figure 9 is shown another amplifier circuit of the same general type as those disclosed in the previous figures. In the circuit of Figure 9, additional steps have been taken to maintain the unidirectional potential condition in the output circuit of the triodes 219 and 220 stable while the alternating potential conditions vary in accordance with the unbalance of the bridge circuit 200.

Referring to Figure 9, the output circuit of triode 219 may be traced from the upper terminal of secondary winding 235 through a conductor 280, anode 221, cathode 223, a portion of a resistance 281, a tap 282, ground connections 283 and 284, a battery 285, and a resistance 286 to the center tap of secondary winding 235. The output circuit of triode 220 may similarly be traced from the lower terminal of secondary winding 235 through a conductor 287, anode 225, cathode 227, resistance 281, tap 282, ground connections 283 and 284, battery 285, and resistance 286 to the center tap on transformer winding 235.

It has been found that the provision of the resistance 286 in series with the battery 285 in the common portion of the output circuits of the triodes 219 and 220 adds to the stability of the D. C. condition in the circuit. The resistance 281 also functions to that end. Furthermore, differences between the characteristics of the two halves of the twin triode 218 may be corrected by moving the tap 282 along resistance 281.

Since the operation of the circuit of Figure 9 is very similar to the operation of the circuits previously discussed, and it is believed that further description is unnecessary.

While I have shown and described certain preferred embodiments of my invention, other modifications thereof will be readily apparent to those skilled in the art, and I therefore wish my invention to be limited only by the appended claims.

I claim as my invention:

1. Electrical amplifier circuit means, comprising in combination, at least two amplifier stages connected in cascade, the first of said stages comprising a pair of electrical discharge devices, each having an anode, a cathode, and a control electrode, an input circuit for each said device including its control electrode and cathode, an output circuit for each said device including its anode and cathode, a source of alternating electrical energy, means connecting said output circuits in phase opposition to said source, common load impedance means connected in both said output circuits, means for applying an alternating electrical signal potential to said input circuits, said first stage being effective to produce across said common load impedance means a potential having a unidirectional component and an alternating component corresponding in magnitude to said signal potential, the second of said stages comprising an input circuit and an output circuit, and means for impressing the potential across said common load impedance means on said second stage input circuit so that said unidirectional component serves as a biasing potential for said second stage.

2. Electrical control apparatus, comprising in combination, a control device, means responsive to a predetermined controlling condition for producing upon a change in said condition an electrical signal potential having an instantaneous polarity corresponding to the sense of change of said condition, amplifier circuit means and discriminator circuit means, each said circuit means including a pair of electrical discharge devices,

each discharge device having an anode, a cathode, and a control electrode, an input circuit for each discharge device including its control electrode and cathode, an output circuit for each discharge device including its anode and cathode, power supply means including a transformer having a pair of secondary windings, means connecting one of said windings to supply alternating electrical energy to the output circuits of said amplifier circuit means in phase opposition, common load impedance means connected in both the output circuits of said amplifier circuit means, the value of said load impedance means and the potential of said one transformer winding being chosen so as to provide a maximum change in the plate resistance of said amplifier discharge devices per unit change in the potentials of their control electrodes, means connecting the other of said windings to supply alternating electrical energy to the output circuits of said discriminator circuit means in phase opposition, means coupling said signal potential producing means to the input circuits of said amplifier circuit means, means coupling said load impedance means to the input circuits of said discriminator circuit means, and means connected in the output circuits of said discriminator circuit means and responsive to the difference between the currents flowing in said discriminator output circuits to control the manner of energization of said control device.

3. Electrical control apparatus, comprising in combination, a control device, means responsive to a predetermined controlling condition for producing upon a change in said condition an electrical signal potential having an instantaneous polarity corresponding to the sense of change of said condition, amplifier circuit means and discriminator circuit means, each said circuit means including a pair of electrical discharge devices, each discharge device having an anode, a cathode, and a control electrode, an input circuit for each discharge device including its control electrode and cathode, an output circuit for each discharge device including its anode and cathode, power supply means including a transformer having a pair of secondary windings, means connecting one of said windings to supply alternating electrical energy to the output circuits of said amplifier circuit means in phase opposition, load impedance means connected in the output circuits of said amplifier circuit means, means connecting the other of said windings to supply alternating electrical energy to the output circuits of said discriminator circuit means in phase opposition, means coupling said signal potential producing means to the input circuits of said amplifier circuit means, means coupling said load impedance means to the input circuits of said discriminator circuit means, and means connected in the output circuits of said discriminator circuit means and responsive to the difference between the currents flowing in said circuits to control the manner of energization of said control device.

4. Electrical amplifier circuit means, comprising

ing in combination, a pair of electrical discharge devices, each having an anode, a cathode, and a control electrode, impedance means, an input circuit for each device including its control electrode and cathode, an output circuit for each device including its anode and cathode and said impedance means, power supply means including a transformer secondary winding having terminals and a center tap, connections between each of said anodes and one of said terminals, a connection between both of said cathodes and said center tap, said power supply means and said connections serving to supply the output circuits of said devices with alternating electrical energy in phase opposition, connections between each of said control electrodes and the terminal associated with the opposite anode for biasing both of said control electrodes negatively, means for applying a signal potential to said input circuits, and electrical load means responsive to the current flow through said impedance means.

5. Electrical amplifier circuit means, comprising in combination, a pair of electrical discharge devices, each having an anode, a cathode, and a control electrode, impedance means, an input circuit for each device including its control electrode and cathode, an output circuit for each device including its anode and cathode and said impedance means, power supply means including a transformer secondary winding having terminals and a center tap, connections between each of said anodes and one of said terminals, a connection between both of said cathodes and said center tap, said power supply means and said connections serving to supply the output circuits of said devices with alternating electrical energy in phase opposition, connections between each of said control electrodes and the terminal associated with the opposite anode for biasing both of said control electrodes negatively, means for applying a signal potential to said input circuits, gain control means comprising a variable impedance connected between said control electrodes, and electrical load means responsive to the current flow through said impedance means.

6. Electrical amplifier circuit means, comprising in combination, a pair of electrical discharge devices, each having an anode, a cathode, and a control electrode, impedance means, an input circuit for each device including its control electrode and cathode, an output circuit for each device including its anode and cathode and said impedance means, power supply means including a transformer secondary winding having terminals and a center tap, connections between each of said anodes and one of said terminals, a connection between both of said cathodes and said center tap, said power supply means and said connections serving to supply the output circuits of said devices with alternating electrical energy in phase opposition, connections between each of said control electrodes and the terminal associated with the opposite anode for biasing both of said control electrodes negatively, an impedance connected between said control electrodes, a tap movable along said impedance, a source of signal potential connected between said tap and said cathodes, and electrical load means responsive to the current flow through said impedance means.

7. Electrical control apparatus, comprising in combination, a control device, means responsive to a predetermined controlling condition for producing upon a change in said condition an electrical signal potential having an instantaneous

polarity corresponding to the sense of change of said condition, amplifier circuit means including a pair of electrical discharge devices, discriminator circuit means including at least one electrical discharge device, each discharge device having an anode, a cathode, and a control electrode, an input circuit for each discharge device including its control electrode and cathode, an output circuit for each discharge device including its anode and cathode, power supply means including a transformer having a pair of secondary windings, means connecting one of said windings to supply alternating electrical energy to the output circuits of said amplifier circuit means in phase opposition, load impedance means connected in the output circuits of said amplifier circuit means, means connecting the other of said windings to supply alternating electrical energy to said discriminator circuit means, means coupling said signal potential producing means to the input circuits of said amplifier circuit means, means coupling said load impedance means to said discriminator circuit means, and means connected in said discriminator circuit means and responsive to the time phase of the current flowing in said load impedance means to control the manner of energization of said control device.

8. An electrical circuit for producing alternating electrical signals variable in phase in accordance with the polarity of unidirectional signals applied thereto, comprising in combination, transformer means having a secondary winding provided with a pair of terminals and a center tap, a pair of impedance devices, at least one of said impedance devices comprising an electrical discharge device having an anode, a cathode, and a control electrode, a connection between said anode and one of said transformer terminals, a connection between said cathode and the other of said transformer terminals including the other of said impedance devices, load impedance means, a connection between said cathode and said center tap including said load impedance means, signal output terminals coupled to said load impedance means, and means to vary the conductivity of said discharge device relative to that of the other of said impedance devices, said last named means comprising means for applying said unidirectional signals to said control electrode.

9. An electrical circuit for producing alternating electrical signals variable in phase in accordance with the polarity but not the magnitude of unidirectional signals applied thereto, comprising in combination, an electrical discharge device having an anode, a cathode, and a control electrode, a source of alternating electrical energy, a source of unidirectional electrical energy, a source of unidirectional signal voltage reversible in polarity, an input circuit for said discharge device including said control electrode and said cathode, an output circuit for said discharge device including said anode, said cathode, and said sources, means for impressing a unidirectional signal voltage from said source thereof upon said input circuit, signal output terminals, and means coupling said signal output terminals to said output circuit.

10. An electrical circuit for producing alternating electrical signals variable in phase in accordance with the polarity but not the magnitude of unidirectional signals applied thereto, comprising in combination, an electrical discharge device having an anode, a cathode, and a

control electrode, a source of alternating electrical energy, a source of unidirectional electrical energy, a source of unidirectional signal potential reversible in phase, impedance means, an input circuit for said discharge device including said control electrode and said cathode, an output circuit for said discharge device including said anode, said cathode, said sources and said impedance means in series, means for impressing a unidirectional signal voltage from said source upon said input circuit, signal output terminals, and means coupling said signal output terminals to said output circuit.

11. An electrical circuit for producing alternating electrical signals variable in phase in accordance with the polarity but not the magnitude of unidirectional signals applied thereto, comprising in combination, an electrical discharge device having an anode, a cathode, and a control electrode, a source of alternating electrical energy, a source of unidirectional electrical energy, a source of unidirectional signal voltage reversible in polarity, an input circuit for said discharge device including said control electrode and said cathode, an output circuit for said discharge device including said anode, said cathode, and said sources, impedance means common to said input and output circuits, means for impressing a unidirectional signal voltage from said source upon said input circuit, signal output terminals, and means coupling said signal output terminals to said output circuit.

12. An electrical circuit for producing alternating electrical signals variable in phase in accordance with the polarity of unidirectional signals applied thereto, comprising in combination, transformer means having a secondary winding provided with a pair of terminals and a center tap, a pair of electrical discharge devices, each said device having an anode, a cathode, and a control electrode, connections between each of said anodes and one of said transformer terminals, load impedance means, a source of unidirectional electrical energy, a connection between both of said cathodes and said center tap including said load impedance means and said source, signal output terminals coupled to said load impedance means, a source of unidirectional signal voltage reversible in polarity, and means for applying said reversible signal voltage to said control electrodes to oppositely vary the conductivity of said discharge devices.

13. Electrical amplifier circuit means, comprising in combination, a pair of electrical discharge devices, each having an anode, a cathode, and a control electrode, impedance means, an input circuit for each device including its control electrode and cathode, an output circuit for each device including its anode and cathode and said impedance means, power supply means including a transformer secondary winding having terminals and a center tap, connections between each of said anodes and one of said terminals, a connection between both of said cathodes and said center tap, said power supply means and said connections serving to supply the output circuits of said devices with alternating electrical energy in phase opposition, connections between each of said control electrodes and the terminal associated with the opposite anode for biasing both of said control electrodes negatively, means for applying a signal potential to said input circuits, an impedance connected between said control electrodes, a source of signal potential connected between an intermediate point on said impedance and said

cathodes, and electrical load means responsive to the current flow through said impedance means.

14. Electrical control apparatus, comprising in combination, a control device, means responsive to a predetermined controlling condition for producing upon a change in said condition an electrical signal potential having an instantaneous polarity corresponding to the sense of change of said condition, amplifier circuit means and discriminator circuit means, each said circuit means including a pair of electrical discharge devices, each discharge device having an anode, a cathode, and a control electrode, a substantially unbiased input circuit for each discharge device including its control electrode and cathode, an output circuit for each discharge device including its anode and cathode, power supply means including a transformer having a pair of secondary windings, means connecting one of said windings to supply alternating electrical energy to the output circuits of said amplifier circuit means in phase opposition, said output circuits having a common portion including a load impedance, means connecting the other of said windings to supply alternating electrical energy to the output circuits of said discriminator circuit means in phase opposition, means coupling said signal potential producing means to the input circuits of said amplifier circuit means, means coupling an adjustable portion of said load impedance to the input circuits of said discriminator circuit means to apply to said input circuits a biasing voltage dependent in magnitude upon the magnitude of said adjustable portion and a further voltage dependent upon the condition of said signal potential producing means, and means connected in the output circuits of said discriminator circuit means and responsive to the difference between the currents flowing in said circuits to control the manner of energization of said control device.

15. Electrical control apparatus, comprising in combination, a control device, means responsive to a predetermined controlling condition for producing upon a change in said condition an electrical signal potential having an instantaneous polarity corresponding to the sense of change of said condition, amplifier circuit means and discriminator circuit means, each said circuit means including a pair of electrical discharge devices, each discharge device having an anode, a cathode, and a control electrode, an input circuit for each discharge device including its control electrode and cathode, an output circuit for each discharge device including its anode and cathode, power supply means including a transformer having a pair of secondary windings, means connecting one of said windings to supply alternating electrical energy to the output circuits of said amplifier circuit means in phase opposition, means connecting the control electrode of each discharge device of said amplifier circuit to the terminal of said winding to which the anode of the other discharge device is connected so as to bias said control electrode negatively during the conductive half cycles of the discharge device, load impedance means connected in the output circuits of said amplifier circuit means, means connecting the other of said windings to supply alternating electrical energy to the output circuits of said discriminator circuit means in phase opposition, means coupling said signal potential producing means to the input circuits of said amplifier circuit means, means coupling said load impedance means to the input circuits of said discriminator circuit means, and means connected in the out-

put circuits of said discriminator circuit means and responsive to the difference between the currents flowing in said circuits to control the manner of energization of said control device.

16. Electrical control apparatus, comprising in combination, a control device, means responsive to a predetermined controlling condition for producing upon a change in said condition an electrical signal potential having an instantaneous polarity corresponding to the sense of change of said condition, amplifier circuit means and discriminator circuits means, each said circuit means including a pair of electrical discharge devices, each discharge device having an anode, a cathode, and a control electrode, an input circuit for each discharge device including its control electrode and cathode, an output circuit for each discharge device including its anode and cathode, power supply means including a transformer having a pair of secondary windings, means connecting one of said windings to supply alternating electrical energy to the output circuits of said amplifier circuit means in phase opposition, said output circuits having a common portion including a load impedance, means connecting the other of said windings to supply alternating electrical energy to the output circuits of said discriminator circuit means in phase opposition, means coupling said signal potential producing means to the input circuits of said amplifier circuit means, 30

a constant source of direct potential connected to said load impedance, means coupling said load impedance and said source of direct potential to the input circuits of said discriminator circuit means, and means connected in the output circuits of said discriminator circuit means and responsive to the difference between the currents flowing in said circuits to control the manner of energization of said control device.

WILLIAM J. FIELD.

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