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SERVO CONTROL AMPLIFIER

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2 Sheets-Sheet 1

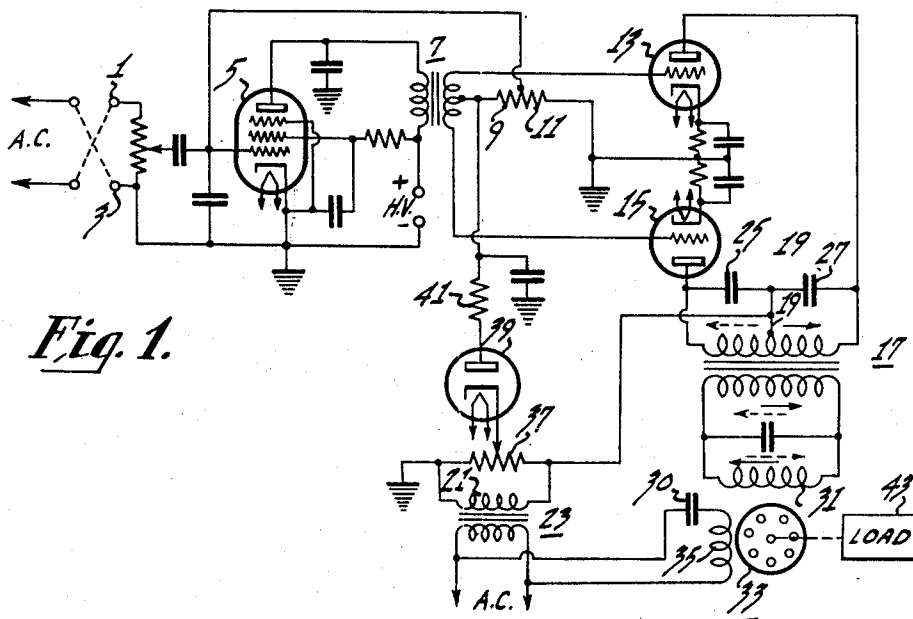


Fig. 1.

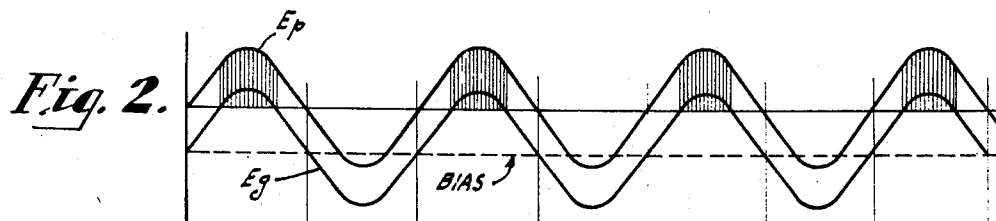


Fig. 2.

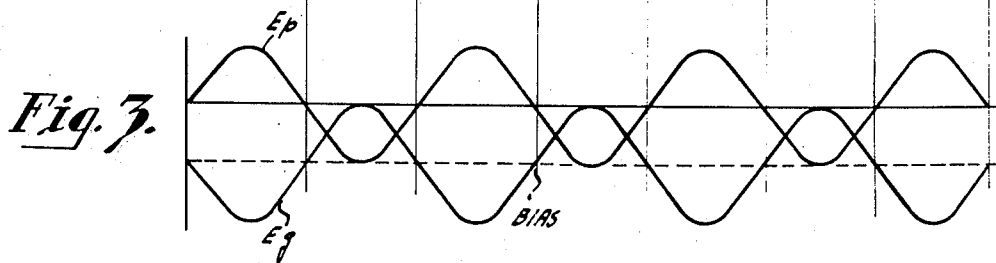


Fig. 3.

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2 Sheets-Sheet 2

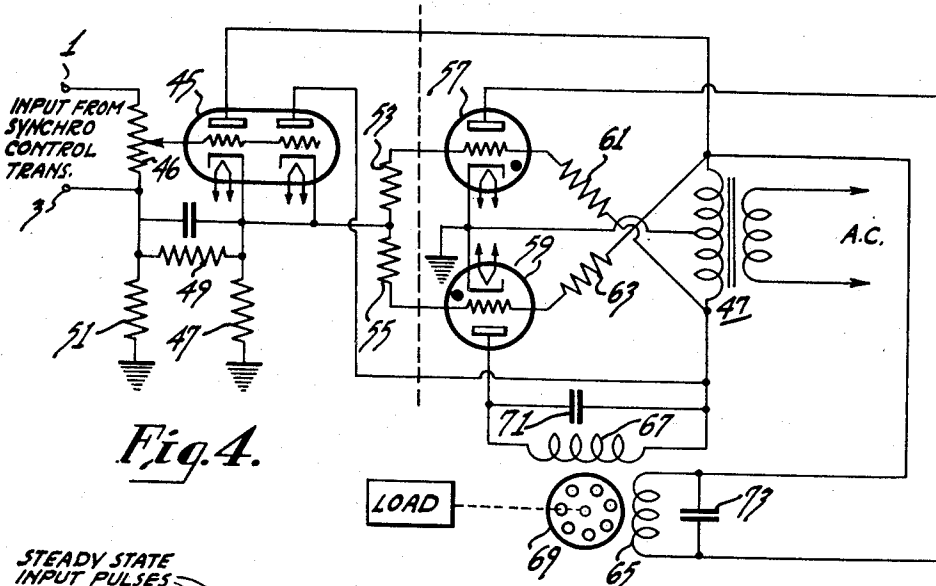


Fig. 4.

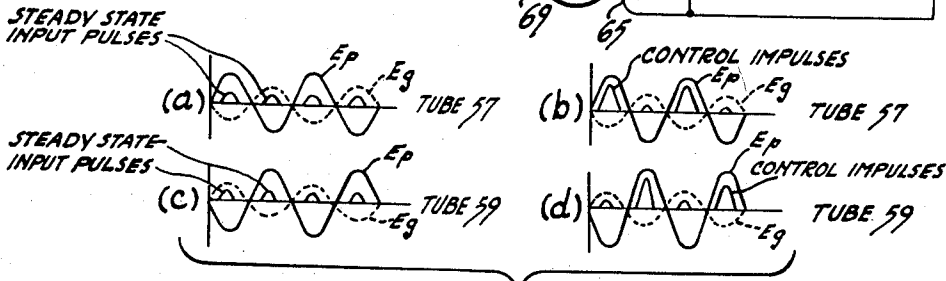


Fig. 5.

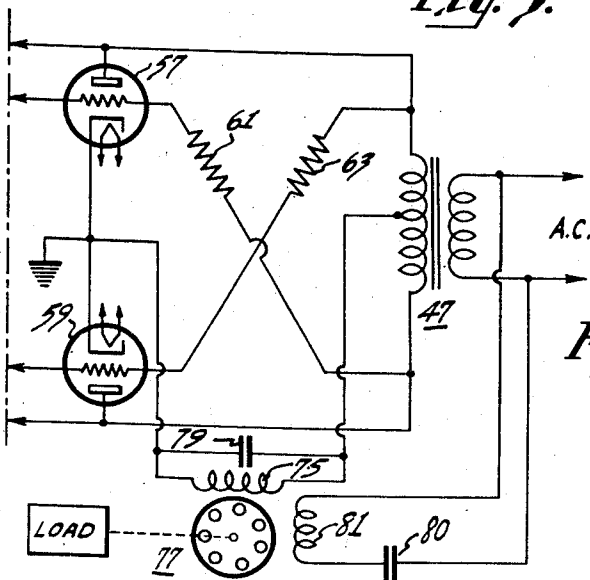


Fig. 6.

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SERVO CONTROL AMPLIFIER

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The subject invention relates to servo control amplifiers of the type used in servo mechanisms and which are capable of selectively producing output potentials of different polarity under the influence of a control voltage.

Servo mechanisms have commonly been used for the purpose of controlling the angular position of an antenna array, for example, from a remote point through electrical means. Such systems employ a self-balancing arrangement by means of which the instantaneous position of the antenna is electrically compared to that of a manual control device to produce a differential or "error" voltage which sets into motion a sequence of events which automatically corrects the difference in the relative position of the control device and the antenna. The "error" voltage is generally of small amplitude and power capacity and is insufficient to operate directly the reversible driving motor connected to the antenna. Consequently, it is necessary to provide a servo control amplifier capable of producing sufficient power in its output circuit to drive the motor in one direction or the other in accordance with the error voltage produced by the system. It is the primary purpose of this invention to provide an improved servo control amplifier of this type, capable of producing an output current whose phase reverses in accordance with the control signal and is of sufficient amplitude to operate a reversible motor designed to rotate the large mass of an antenna array or to rotate by remote control other similar devices.

A further object of this invention is to provide an improved servo control amplifier in which alternating voltages may be applied directly to the amplifier tubes.

A still further object of this invention is to provide a servo control amplifier adapted for utilization with thermionic tubes as well as Thyratrons.

A still further object of this invention is to provide a control amplifier which is readily adjustable so that an output current of the desired amplitude may be obtained.

The above objects, as well as other objects which will be seen from a further study of this invention, are achieved by applying alternating currents of like phase to the plate electrodes of two output tubes while at the same time applying a biasing potential plus alternating voltages of opposite phase to the respective grid electrodes of the output tubes, one of the input voltages which are applied to the grid electrodes being reversible through 180° in accordance with the

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desired direction of movement of the load or antenna. Conversely, the voltages of like phase may be applied to the grid electrodes, and the out of phase voltages to the plates.

This invention will be better understood from the following description when considered in connection with the accompanying drawings. Its scope is indicated by the appended claims.

Referring to the drawings,

Figure 1 is a circuit diagram of a servo control amplifier in accordance with this invention, Figures 2 and 3 are voltage curves illustrating the operation of the device shown in Fig. 1.

Figure 4 is a circuit diagram of a modification of this invention,

Figure 5 is a series of voltage curves illustrating the operation of the modification shown in Fig. 4, and

Figure 6 is a circuit diagram of an alternate means of deriving output from the device shown in Fig. 4.

Referring now to Fig. 1, the circuit connections for an embodiment of this invention will be described. A pair of input terminals 1, 3 are coupled respectively to ground and the input electrode of a thermionic tube 5. The output electrode of tube 5 is connected to a source of positive potential, not shown, through the primary of a coupling transformer 7. The secondary of this transformer is center tapped, the center tap being connected to ground through resistors 9, 11. The outer ends of the secondary are connected, respectively, to the input electrodes of a pair of control tubes 13, 15. The cathode electrodes of the latter tubes are connected to ground through by-passed biasing resistors in the customary manner. The output electrodes of tubes 13 and 15 are connected, respectively, to the ends of the primary winding of an output transformer 17, the center point 19 of which is connected to one side of the high voltage secondary 21 of a power transformer 23, the other side being grounded. Condensers 25 and 27 are connected across the two halves of the primary of transformer 17 and tune the circuits to resonance at the operating frequency of 60 cycles per second. The secondary of transformer 17 is also tuned by a capacitor 29 and is connected to one field coil 31 of an induction motor 33. The other field coil 35 of the induction motor is connected to a source of 60 cycle current through the 90° phase shifting condenser 30 as shown. A potentiometer 37 is connected across the high voltage secondary of transformer 23 and its contact arm is connected to the cathode of a diode rectifier tube 39, the

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anode electrode of which is connected through a resistor 41 to the center point of the secondary of transformer 7 to produce a D.-C. bias voltage across resistors 9, 11. This bias is applied to tubes 5, 13 and 15 as shown.

The operation of the servo control amplifier illustrated in Fig. 1 will be better understood by making reference at the same time to the curves illustrated in Figs. 2 and 3. The device requires for its operation an alternating input voltage whose phase is changed 180° to determine the desired direction of rotation of the output motor 33 which drives the load 43 in the desired direction. The reversible nature of this input voltage is indicated in Fig. 1 by showing a reversing switch connected to the input, but it must be understood that when connected in a normal servo system the alternating "error" voltage produced by the system will inherently have this phase reversing feature. For the control amplifier to serve its intended purpose it is only necessary to show that when an alternating voltage of a given phase is applied to the input terminals 1, 3, motor 33 will rotate in a given direction and when the input voltage is of the opposite phase the motor 33 will rotate in the opposite direction.

Transformer 23 applies to the anode electrodes of the output tubes 13 and 15, through the respective portions of the secondary of transformer 17, voltages which are in phase as indicated by the respective curves E_p in Figs. 2 and 3. An adjustable negative grid bias is applied to the grid electrodes 13 and 15 by the action of the diode rectifier 39. This voltage is indicated by the dotted "bias" line shown in Figs. 2 and 3. The input voltage is applied in phase opposition by transformer 7 to the grid electrodes of the amplifier tubes 13 and 15 as indicated by the curves E_g in Figs. 2 and 3 respectively. It will be observed that the grid and plate voltages of the tube 13, for example, are therefore in phase and the tube will become conductive whenever the applied grid voltage is of sufficient amplitude to bring the effective grid voltage to the value necessary to operate the particular tube being used. The periods during which tube 13 becomes conductive, on the assumption that conductivity occurs at zero grid bias, are indicated by the shaded areas in Fig. 2. This output current passes through one half the primary of transformer 17 in the direction indicated by the solid arrow and induces in the secondary a like current which flows through the motor field winding 31 in the direction also indicated by the solid arrow. Tube 15 remains non-conductive, however, since at all times the grid voltage is negative when the plate voltage is positive and vice versa, as shown in Fig. 3. The purpose of the tuning capacitors 27 and 29 is to smooth out the current impulses and to produce in the field winding 31 a substantially sine wave current.

Motor 33 is a standard two-winding induction motor which rotates in one direction when the respective field windings are energized by currents of a given relative phase, and which rotates in the opposite direction when the phase of the current energizing either of the windings is reversed. Since winding 35 is connected to a constant source of 60 cycle current, the direction of rotation will be determined by the relative instantaneous current flow in winding 31. The 90° phase relation for one phase of the motor is obtained by the condenser 30 in series with motor winding 35.

If the phase of the applied input voltage is reversed 180°, as is the case when the error volt-

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age reverses, it will be understood that tube 13 becomes non-conductive and tube 15 now becomes conductive. As a result, no current will flow in the output circuit of tube 13, but a current will flow through half the primary of transformer 17 in the direction indicated by the dotted arrow which will induce in the secondary winding a corresponding current also flowing in the direction shown by the dotted arrow which energizes the field winding 31 with a current of opposite phase to that in the case previously discussed. As a result the direction of rotation of the motor 33 will be opposite to that previously produced.

By readjusting the bias voltage produced by rectifier 39 a different mode of operation is available which has certain advantages. In the absence of input voltage, potentiometer 37 is adjusted to reduce the negative grid bias to such a value that both tubes 13 and 15 become conductive during the half cycle the applied plate voltage is positive. The resultant rapidly reversing current tends to lock the motor, preventing its rotation. A braking effect is therefore produced which is useful in quickly stopping the system when the balance point has been reached. The applied input voltage shuts off one tube or the other, and thus, when an error voltage is received, the system works as described above.

An alternative embodiment of this invention is illustrated in Fig. 4 to which reference is now made. Input voltages from the servo system are applied to input terminals 1 and 3 as before. A double triode vacuum tube 45 of the 6N7 type is used for the input amplifier and rectifier combined, thus obviating the need of the additional rectifier tube 39 employed in the embodiment previously described. Input is applied to both grid electrodes in parallel, the output electrodes being connected to the outer terminals of the secondary of a high voltage transformer 47, the primary of which is connected to a standard source of 60 cycle current. The cathode electrodes of tube 45 are connected together and to ground through a biasing resistor 47. Two additional resistors 49 and 51 are also connected in series between the cathodes of tube 45 and ground. Their mid-point is connected to input terminal 3 to provide bias for tube 45 through the input potentiometer 46. The cathodes are also connected through coupling resistors 53, 55 to the grid electrodes of a pair of Thyratrons 57 and 59. These grid electrodes are also cross-connected to the outer terminals of transformer 47 through coupling resistors 61, 63 respectively. The anode electrodes of the Thyatron tubes are connected, respectively, to the high potential terminals of the secondary of transformer 47 through field windings 65 and 67 of an induction motor 69. The field windings are preferably tuned to resonance by capacitors 71 and 73 respectively.

The operation of the servo control amplifier illustrated in Fig. 4 will be understood in connection with the voltage curves shown in Fig. 5. The zero motor speed voltages applied to the Thyratrons 57 and 59 are illustrated in Figs. 5 (a) and (c), respectively. It will be seen that the plate voltages are in phase opposition and that the grid voltages which result from the potentials applied through resistors 61 and 63, not considering the effect of tube 45, indicated by curves E_g , are in phase opposition to the plate potentials applied to the respective tubes. Resistor 47 preferably has a low value as compared to resistors 55 and 63, or 53 and 61, and it has little or no effect on the value of the grid volt-

ages applied to the Thyatron tubes, not considering the action of tube 45. The latter tube, however, rectifies both halves of the A. C. voltage applied to the plate electrodes and a positive pulse is produced during each half wave due to the rectifying action of the tube. These pulses are superimposed on the Thyatron grids and are as shown in Figs. 5 (a) and (c) and are indicated as "steady state input pulses." It will be observed that so long as the amplitude of these pulses does not exceed the grid bias E_g , the grid bias will remain negative and no current will flow in the output.

The application of an alternating voltage to the input terminals, however, causes an additional input voltage to be applied which will increase the effective Thyatron grid voltage during one half of each cycle, and decrease the effective grid voltage during the other half of each cycle as shown in Fig. 5 (b) corresponding to the operation of tube 57 for a given phase of applied input voltage. It will be observed that the added positive impulse in the first half cycle will cause the grid of tube 57 to become positive at the same time its plate is positive, and current will flow during this period. At the same time, however, tube 59 will remain non-conductive since, as shown in Fig. 5 (c) during the first half-cycle its plate is negative and during the second half-cycle the control impulse of decreased amplitude is insufficient to overcome the applied steady state grid biasing voltage E_g . As a result, for the assumed phase of input voltage current will flow through field winding 65 of motor 69, but field winding 67 will not be activated. If the phase of the input voltage is reversed, the conditions will likewise be reversed and the voltage applied to tube 59 will be as indicated in Fig. 5 (d). The tube will become conductive during the second half cycle of the applied plate voltage and current will flow through winding 67 of motor 69, whereas winding 65 will not be activated. Motor 69 in this case is a Telechron type motor having two separate field windings, and direction of rotation is determined in accordance with which of the two windings is energized. Consequently when the amplifier is energized by a control voltage of a given phase, the motor will rotate in one direction, and when the amplifier is energized by a control voltage of an opposite phase, the motor will rotate in the opposite direction.

An alternative utilization of the circuit illustrated in Fig. 4 is shown in Fig. 6, to which reference is now made. The circuit to the left of the dotted vertical line in Figs. 4 and 6 is as shown in Fig. 4. If it is desired to employ a standard type induction motor similar to that described in connection with Fig. 1 above, the circuit may be modified as shown. It should be kept in mind that the type motor to be employed in this case requires both fields to be energized, and the direction of rotation is determined by the relative phase of the currents in the two fields. This is accomplished by connecting the plate electrodes of the Thyatron tubes 57 and 59 directly to the high potential terminals of transformer 47, while the grid electrodes are biased through a cross-connection to opposite ends of the secondary through resistors 61 and 63 as before. The field winding 75 of induction motor 77 is connected between the center tap of the high potential secondary and the cathodes of the Thyatron tubes and may be tuned by a capacitor 79 as before. The second field winding

81 is energized directly from the 60 cycle current by suitable connections across the primary of transformer 47 through a 90° phase shifting condenser 80.

Referring again to Figs. 5 (b) and 5 (d), it will be observed that when tube 57 is conductive, the current flows in the output circuit in a given direction during the first half of the alternating cycle and that when current flows in tube 59 the period of conductivity is initiated in the second half cycle, and current flows in the output circuit in the same direction during the second half of the alternating cycle. When considered in relation to the current flowing in field winding 81, it will therefore be observed that the instantaneous direction of current in field winding 75 will go through a phase reversal depending upon which of the Thyatron tubes is conductive. As pointed out above, this in turn depends upon the phase of the applied alternating voltage. Consequently, for an applied voltage of a given phase, the motor 77 will rotate in one direction and for an applied voltage of the opposite phase, the motor 77 will rotate in the opposite direction.

The method of operation in which the output tubes are both conducting in the absence of an error voltage, as described above with reference to the embodiment illustrated in Fig. 1, may also be employed in the embodiments illustrated in Figs. 4 and 6. By suitably adjusting the fixed grid bias the tubes become operative during the zero error signal period, producing a desirable braking effect which quickly stops the motor.

I have thus described an improved servo control amplifier, together with several modifications thereof, in which a small control voltage produced, for example, in a servo system, is employed to control thermionic or Thyatron tubes so as to control the direction of rotation of a motor which, in accordance with the usual custom, is employed to rotate a device in such a direction as to return the servo system to a balanced condition. The control amplifiers are A. C. operated and do not require special transformers or other equipment in their operation.

I claim as my invention:

1. In a device of the character described, the combination which includes a pair of discharge devices having a cathode, anode and grid electrodes, a first source of alternating current potentials connected between the anode and cathode electrodes of said devices, a second source of alternating current potentials connected between the grid and cathode electrodes of said devices, said connections being such that in one of said devices the cathode-grid voltage is in phase with the cathode-plate voltage and in the other of said devices the corresponding voltages are in phase opposition whereby one or the other of said devices may become conductive depending on the phase of the potential applied by said second source, output means in circuit with said anode electrodes and responding in a first mode to current flowing in one of said devices and in a second mode to current flowing in the other of said devices, a rectifier connected to said first source of potentials for developing a rectified voltage, and means for applying said rectified voltage between said grid and cathode electrodes of both of said pair of devices.

2. In a device of the character described, the combination which includes a pair of discharge devices having cathode, anode and grid electrodes,

a first source of alternating potentials connected between the anode and cathode electrodes of said devices, input terminals adapted to receive an alternating current control voltage of reversible phase, an amplifier having a pair of grid electrodes and a pair of anode electrodes, said grid electrodes being coupled to said input terminals, means coupling said first source of alternating potentials to said amplifier anode electrodes in opposite phase, means for applying the same rectified alternating and amplified control voltages developed by said amplifier between the cathode and grid electrodes of both said devices, whereby one or the other of said devices becomes conductive as a function of the phase of the voltage applied to said input terminals, and output means in circuit with said devices operable in a first direction when one of said devices is conductive and in an opposite direction when the other of said devices is conductive.

3. In a device of the character described, the combination which includes a pair of discharge devices having cathode, anode and grid electrodes, a first source of alternating potentials connected between the anode and cathode electrodes of said devices and between the grid and cathode electrodes of said devices in phase opposition thereto, input terminals adapted to receive an alternating current control voltage of reversible phase, an amplifier having a pair of grid electrodes and a pair of anode electrodes, said grid electrodes being coupled to said input terminals, means coupling said first source of alternating potentials to said amplifier anode electrodes in opposite phase, means for applying the same rectified alternating and amplified control voltages developed by said amplifier between the cathode and grid electrodes of both said devices, whereby one or the other of said devices becomes conductive as a function of the phase of the voltage applied to said input terminals, and output means in circuit with said devices operable in a first direction when one of said devices is conductive and in an opposite direction when the other of said devices is conductive.

4. A device of the character described in claim 3 in which, in the absence of an input control voltage, the peak amplitude of the rectified alter-

nating voltage applied between the cathode and grid electrodes of said devices is less than the peak value of the voltage applied to said grid electrodes from said first source, whereby both of said devices remain non-conductive until an input control voltage is applied.

5. A system including a pair of discharge tubes each including at least an anode, a cathode, and a control grid; an alternating current supply source for said tubes, a motor coupled to said anodes so that the flow of anode current through one of said tubes energizes said motor for rotation in one direction, and the flow of anode current through the other of said tubes energizes said motor for rotation in the other direction; a source of alternating control voltage synchronous with said supply current, means applying said control voltage to both of said control grids in such manner that the instantaneous polarity of said control voltage at one of said control grids is the same as that at the corresponding anode, and the instantaneous polarity of said control voltage at the other of said control grids is opposite to that at the corresponding anode; and means for applying alternating bias voltage to the control grids of said tubes in phase opposition to the respective anode voltages of said tubes, and further means applying a positive direct current bias to the control grids of both said tubes, said direct current bias having such a value that both said tubes are conductive when said control voltage is zero.

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