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MOTOR CONTROL CIRCUIT

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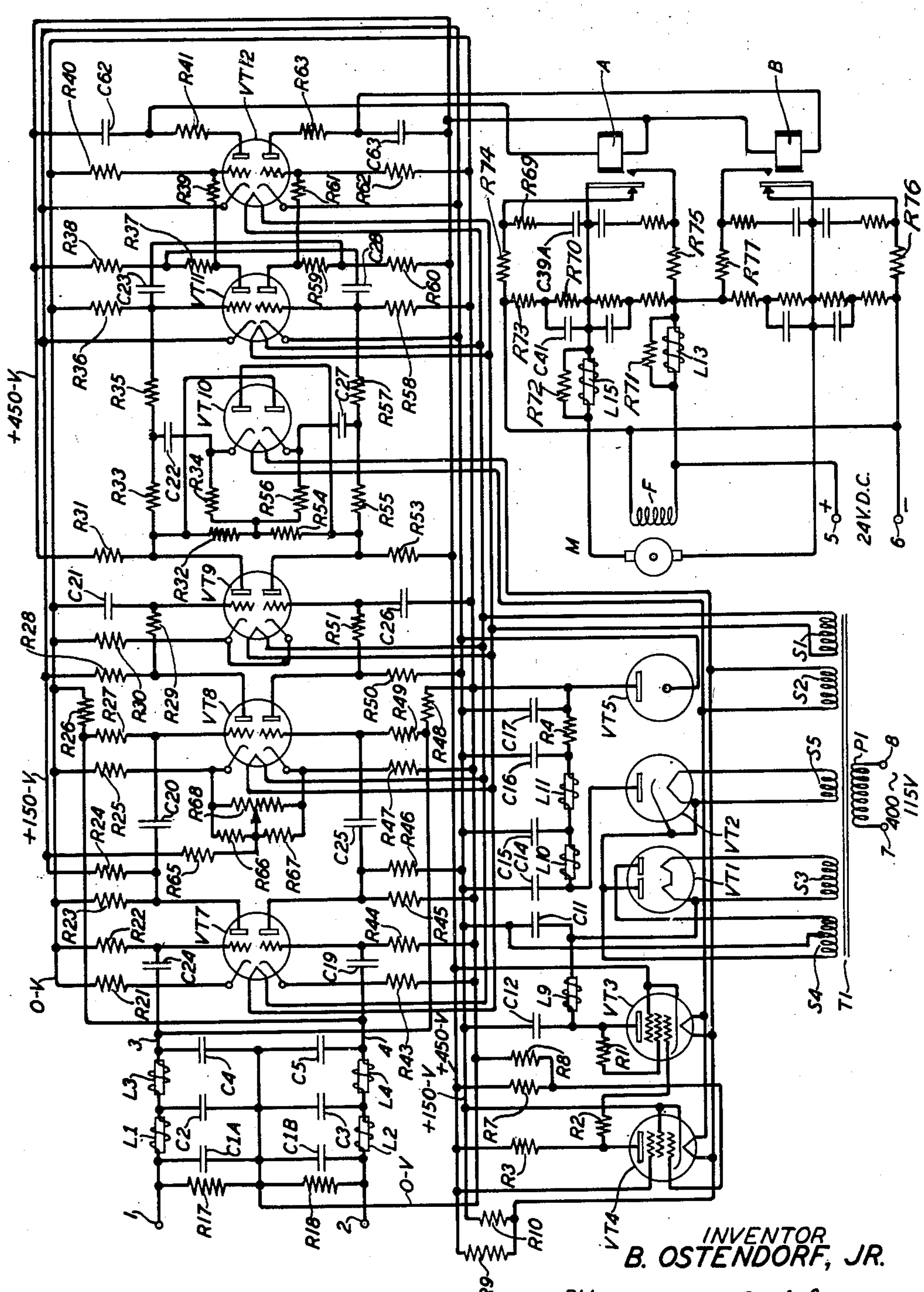

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MOTOR CONTROL CIRCUIT

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This invention relates to an amplifier and more particularly to a balanced amplifier responsive to a control signal for controlling the operation of a servomotor.

It is an object of the invention to provide a servo-amplifier in which the tendency of the servomotor to hunt upon sudden changes in the control signal is materially reduced.

A further object of the invention is to provide means in a servo-amplifier for slowing down the effect upon the servomotor of sudden large voltage changes which would tend to cause the motor to accelerate too rapidly with a consequent shock to apparatus driven thereby, but which means does not respond to sudden voltage changes which would tend to cause the motor to decelerate rapidly.

The servo-amplifier in accordance with the present invention comprises an input filter section, a direct current amplifier section, an equalizer section, a clutch section, a multivibrator section, a buffer section and a relay section.

One feature of the invention by which the objects thereof are attained comprises two triode equalizer tubes which may, for convenience, be a twin tube. The input filter connects through series resistors to the first direct current amplifier stage. The two equalizer tubes are resistance-condenser coupled and are cross-connected across the aforementioned series resistors. This connection is such that any changes in the direct current voltage going from the filter to the direct current amplifier stage is aided by the condenser coupled equalizer stage. The equalizer tubes respond only to voltage changes and accordingly have no effect on the servo-amplifier if there is no change in the amplitude of the direct current component of the control signal. Any sudden change in the direct current component actuates the equalizer tubes in a manner which steps up the rate of acceleration or deceleration and thus acts as a brake to prevent the servomotor from hunting.

Another feature of the invention comprises two diode tubes having their plates connected respectively to the output plates of the last stage of the amplifier section and having their cathodes reversely connected through condensers to the same amplifier outputs. Preferably these tubes are two units of a twin diode tube. The clutch tubes slow down the effect of sudden large voltage changes which would tend to rotate the motor but do not affect voltage changes which would result in stopping the rotation of the motor. A sudden large signal voltage may be presented to the servo-amplifier when the amplifier is switched into service after a period of idleness or if a control wheel in the transmitter to which the servo-amplifier is switched is jerked rather than moved at a uniform rate of speed. The twin diode clutch tube temporarily short-

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circuits any incoming signal voltage output from the preceding amplifier stage. This condition lasts only during the brief period while the condenser is charging. Thus the tube tends to moderate extremely large signal voltages by presenting them somewhat more gradually to the multivibrator tube. Due to the polarity relations of the circuit only one unit of the clutch tube conducts at any instant.

A further feature of the invention is the provision of a twin triode multivibrator tube which receives the outputs from the amplifier. It has symmetrical feedback circuits for each of its two sections. Under balanced operating conditions during which both grid bias voltages are equal, the multivibrator oscillates to produce approximately balanced square waves at its plate terminals, the waves alternating at a frequency of about 40 cycles per second with approximately equal open and closed periods, the output from one plate is the negative component of the output of the other plate. However, if the variable direct current signal voltages impressed on the two grid terminals become unequal, then the periods of the square wave will also become unequal. The square wave outputs from the two plates of the multivibrator tube are employed to drive two relays which in turn apply driving impulses to the armature circuit of the servomotor.

Other features of the invention will become apparent upon reference to the following detailed description when read in connection with the single sheet of drawing.

The servo-amplifier is responsive to a non-grounded control signal or error voltage, consisting of rectified half sine waves, connected between terminals 1 and 2. The error voltages are positive or negative only with respect to each other. A positive voltage on terminal 1 with respect to terminal 2 can exist or conversely a positive voltage on terminal 2 with respect to terminal 1 can occur; the input resistors R17 and R18 provide a neutral or center tap voltage which is connected to circuit zero or neutral. The polarity of the input voltage determines whether the motor M will rotate in a clockwise or counterclockwise direction and the amplitude of the voltage determines the relative speed at which the motor will run.

The pulsating voltage applied between the terminals 1 and 2 is filtered by the low-pass lattice type filter comprising the series connected choke coils L1 and L2, L3 and L4 and bridged condensers C1 to C5, inclusive. The impedance of the filter matches the load impedance of 39,000 ohms (resistors R26 and R48) connected to the grid terminals of the twin triode amplifier tube VT3.

The double resistor-double capacitor bridge consisting of resistors R17 and R18 and condensers C1A and C1B balances out any spurious alternating or direct current voltages leaking to the terminals 1 and 2 or induced thereon. This is necessary because of the high gain amplification following. The condenser bridge is a low impedance shunt for extraneous high frequency voltages. The center tap of the bridge connects to the isolated 0—V reference bus bar of the amplifier. This establishes an arbitrary reference for the signal voltages which are applied across the terminals 1 and 2. Thus with respect to other apparatus components of the amplifier, one half of the effective signal voltage is positive or negative on one terminal as compared with the opposite polarity on the other terminal of the pair.

The double condenser bridge comprising condensers C4 and C5 with its center tap also connected to the 0—V reference bus bar of the amplifier, balances out any extraneous longitudinal voltage which may be present at the signal terminals 1 and 2.

The twin triode equalizer tube VT7 has its control electrodes connected to the output signal conductors 3 and 4 of the filter section of the amplifier through the condensers C24 and C19, respectively, and through the resistors R22 and R44 with the 0—V reference bus bar. Tube VT7 also has its cathodes connected through the resistances R21 and R43 to the 0—V reference bus bar. Plate potentials for the tube VT7 are supplied through the voltage dividers comprising resistors R23 and R24, of 27,000 and 120,000 ohms respectively, for the plate of the upper unit and resistors R45 and R46, of 27,000 and 120,000 ohms respectively, for the plate of the lower unit. One end of each of these voltage dividers is connected to the 0—V bus bar and the other end of each divider is connected to the +150—V bus bar. Any 400-cycle alternating current hum which is superimposed on the output of tube VT7 is thus reduced in signal strength as regards the control grid of the succeeding amplifier tube VT8 in the ratio of 27,000 ohms to 147,000 ohms. This reduction in alternating current hum is accomplished without sacrificing gain in the equalizer tube VT7. The plates of tube VT7 are connected with the grids of the succeeding amplifier tube VT8 through the condensers C20 and C25.

The relative importance of the equalizer tube can be better understood if it is realized that the servo-amplifier could be operated with the tube removed from the socket. However, the tube adds very desirable operating features previously mentioned, namely that of increasing the effect of signal voltage changes. This is of particular importance in connection with a signal voltage change resulting from stopping or changing the direction of the control element of an associated transmitter. A quick effective braking of the control circuit helps to prevent the motor and the follow-up apparatus which may be driven by the motor from overrunning or overshooting.

The necessity for servo accuracy requires the use of a high gain amplifier which, of course, tends to offer the basic condition for producing electro-mechanical oscillations. In the event of a tendency to oscillate, the equalizer tube VT7 enables the mechanism to more rapidly recognize a change in the rate of motion. This tends to prevent it from overshooting through zero, then reversing its direction and coasting back past zero and continuing to do this thus setting up a "hunt" or oscillation.

Tube VT7 provides a class A amplifier having a rising gain versus frequency characteristic. The voltage gain is zero at zero cycles, about 2 at 5 cycles and rises to 10 at frequencies higher than 20 cycles. Accordingly there is no circuit function performed by the tube if the transmitter is operated at a slow or at a very gradually accelerated rate.

It will be assumed that a positive control signal changing in a positive direction exists on terminal 1 with respect to terminal 2. A positive direct current bias is placed on the control grid of the lower unit of tube VT8 whereas a negative voltage is impressed on the control grid of the lower unit of tube VT7. The output of the lower unit of tube VT7 is therefore in a positive direction. This positive voltage is connected to the control grid of the lower unit of tube VT8 to reenforce the signal voltage rather than to oppose it. It can readily be shown that a similar correspondence in polarity exists between the signal voltage and the output voltage of the upper unit of tube VT7 and that the voltages join to bias the grid of the upper unit of amplifier tube VT8.

It can be stated therefore that a change in signal voltage produces a change in direct current component which places the equalizer tube VT7 in operation to magnify the signal voltage change connected to the succeeding amplifier stage.

The dual triode amplifier tubes VT8 and VT9 provide a two-stage high gain class A direct-current amplifier. Tube VT8 has an amplication factor of about 70 to 1 and employs a high plate load resistance comprising resistors R28 and R50. A condenser-resistance filter is provided in the input leads of tube VT9 to reduce further any residual 400-cycle alternating current hum which may have passed the amplifier tube VT8. These filters comprise the resistor-condenser combinations R29—C21 and R51—C26.

The cathode resistor network associated with the tube VT8 produces a bias of about 1.5 volts and includes a screwdriver-adjustable potentiometer R68 to permit the balancing of the tube operation by offsetting resistance variations of the apparatus. The resistance network includes the potentiometer R68 connected between the cathodes of the two units of tube VT8 connected in parallel with the series-connected equal resistances R66 and R67, the junction point between which is connected to the slider of potentiometer R68 and through resistance R65 to the +150—V bus bar, and resistors R25 and R49 which connect the cathodes of the tube to the 0—V bus bar.

The cathode resistor R30 which is common to the two cathodes of the twin triode amplifier tube VT9 provides stabilized bias for such tube. Tube VT9 is directly coupled to the output of tube VT8 through the coupling resistors R29 and R51 and is connected in push-pull circuit to reduce longitudinal voltages arising from the variations in the preceding stages.

As in the case of the equalizer tube VT7, the servo-ampiifier would operate even if the clutch tube V10 were removed from its socket. However, the tube slows down the effect of those sudden large voltage changes which tend to cause the motor to rotate but does not effect changes which result in stopping the rotation of the motor. A sudden large signal voltage may be presented to the servo-amplifier when the servo-amplifier is switched into connection with the control transmitter after a period of idleness or if a handwheel of the transmitter is jerked rather than moved at a uniform rate of speed. The clutch tube, a twin diode, temporarily short-circuits any incoming positive signal voltage. This condition lasts only during the brief period while either condenser C22 or condenser C27 is charging. Thus the tube tends to moderate extremely large signal voltages by presenting them somewhat more gradually to the multivibrator tube but it introduces no delay in braking the circuit.

Amplifier tube VT9 is directly coupled to the multivibrator tube VT11. The coupling between the upper units of these tubes comprises the voltage divider including resistors R31, R33, R35 and R36 connected in series between the +450—V bus bar and the 0—V bus bar, the plate of the upper unit of tube VT9 being connected to the junction point between resistors R31 and R33 and the grid of tube VT11 being connected to the junction point between resistors R35 and R36. The coupling between the lower units of these tubes comprises the voltage divider including resistors R53, R55, R57 and R58 connected in series between the +450—V bus bar and the 0—V bus bar, the plate of the lower unit of tube VT9 being connected to the junction point between resistors R53 and R55 and the grid of tube VT11 being connected to the junction point between resistors R57 and R58.

The twin diode clutch tube VT10 shunts only those voltage outputs of the amplifier tube VT9 which change in a positive direction. Due to the polarity relations of the circuit only one unit of tube VT10 conducts at any instant. To accomplish this the plates of amplifier tube VT9 are interconnected through the two resistors R32 and R54, the junction point between which resistors is connected through other resistors R34 and R56 with the cathodes of tube VT10. The cathode of the upper unit of tube VT10 is also connected through the condenser C22 to the junction point between resistors R33 and R35 and the cathode of the lower unit of tube VT10 is connected through condenser C27 to the junction point between resistors R55 and R57. The plate of the upper unit of tube VT10 is connected to the plate of the lower unit of tube VT9 and the plate of the lower unit of tube VT10 is connected to the plate of the upper unit VT9. The shunted positive voltage produced in one unit of the tube VT10 is superimposed on one grid of the multivibrator tube VT11 but in a direction opposite to that of the normal signal output from the amplifier tube VT9 and accordingly decreases the net difference otherwise existing between the two grids of the multivibrator tube VT11.

Assuming that a signal voltage at a particular instant is changing in a positive direction on the terminal 1, while it is changing correspondingly in a negative direction on terminal 2, then the polarity relations of the voltage conditions in the servo-amplifier circuit are as shown in the following table:

Direction of voltage changes

Tube	Grids		Plates		Notes
	Upper	Lower	Upper	Lower	
VT7	+	−	−	+	
VT8	−	+	+	−	Signal voltages on grids are reenforced by output of the tube VT7.
VT9	+	−	−	+	
VT10	lower cathode is + upper cathode is 0				
VT11	−(S)	+(S)	+(S)	−(S)	(S) resulting from signal voltage.
	+(R)		−(R)		(R) resulting from rectifier action of tube VT10.

It may be noted from the above table that the output voltages on the plates of the multivibrator tube VT11 will differ in peak values by amounts which are less than would result from the effect of signal voltages alone due to the action of the clutch tube VT10. In other words the unbalance of the circuit is temporarily lessened. The shunting action of tube VT10 in temporarily reducing this voltage difference is effective in slowing down only sudden changes in voltage which would cause the motor to speed up. From its rectifying nature the tube has no effect on voltage changes in a negative direction which occur when braking the circuit for stopping the motor.

The dual multivibrator tube VT11 has symmetrical feedback circuits for each of its two units. Under balanced operating conditions during which both grid bias voltages are equal, the multivibrator oscillates to produce approximately balanced square waves at its plate terminals, the waves alternating at a frequency of about 40 cycles per second with approximately equal "open" and "closed" periods. The output from one plate is the inverted counterpart of the output from the other plate. This relationship results from the symmetrical circuit conditions wherein the frequency of oscillation and the relation of the periods are established by the constants of the two resistor-condenser feedback circuits. One of these circuits includes the resistor R37 connected in series with condenser C28 between the plate of the upper unit of the tube and the grid of the lower unit. The other of these circuits includes the resistor R59 connected in series with condenser C23 between the plate and the lower unit of the tube and the grid of the upper unit. As before stated, the grids of the tube are also connected through resistors to the plates of the amplifier tube VT9.

The cathodes of the tube VT11 are connected to the +150—V bus bar and plate potential from the +450—V bus bar is supplied to the plate of the upper unit through serially connected resistances R37 and R38 and to the plate of the lower unit through serially connected resistances R59 and R60.

If the signal voltages impressed on the two grids of tube VT11 should become unequal, then the periods of the square waves would become unequal. The time at which one unit of the multivibrator tube cuts off or again conducts then depends not only upon the resistor-condenser time constant of the circuit but also on the level of potential toward which the circuit tends to charge. For example, with a given resistor-condenser circuit and a fixed starting voltage, it will take a longer time for the circuit to charge to a potential resulting in tube conduction if the charging cycle approaches a lower rather than a higher voltage on the grid.

It is to be understood that the various components of the servo-amplifier are balanced under operating conditions only when the servomotor operated apparatus and the transmitter are oriented in exactly the same direction since then no error or signal voltage is impressed across the terminals 1 and 2. At all other times unbalanced voltages occur, the polarities and magnitudes of which vary depending upon the direction and amount that the transmitter and motor-operated apparatus are out of phase. If unbalanced voltages are eventually connected to the grids of the two units of multivibrator tube VT11, the unbalanced voltages cause one unit to take a longer time to cut in than the other, thus producing unbalanced square waves as an output. The progression of the unbalanced period of the waves in a positive or negative direction depends upon the direction in which the motor driven apparatus departs from the transmitter and the relative duration of the periods are approximately proportional to the magnitude of the out of phase relationship (error).

The multivibrator tube VT11 is coupled with the dual triode buffer tube VT12 which functions as a power amplifier. The plate of the upper unit of tube VT11 is coupled with the grid of the upper unit of tube VT12 through resistor R39 which is included in the voltage divider extending from the +450—V bus bar through the serially connected resistors R38, R37, R39 and R40 to the 0—V bus bar. The plate of the lower unit of tube VT11 is coupled with the grid of the lower unit of tube VT12 through resistor R61 which is included in the voltage divider extending from the +450—V bus bar through the serially connected resistors R60, R59, R61 and R62 to the 0—V bus bar.

The two outputs of the buffer tube VT12 operate two control relays which jointly cause the motor M to rotate in a clockwise or a counterclockwise direction and at varying speeds. The plate of the upper unit of tube VT12 is connected through resistor R41 and through the winding of relay A to the +450—V bus bar and the plate of the lower unit of the tube VT12 is connected through resistor R63 and through the winding of relay B to the +450—V bus bar. Condenser C62 provides a shunt across the winding of relay A to absorb the inductive disturbances arising from the operation and the release of the relay and condenser C63 performs a similar function in connection with relay B. An important function of the buffer tube is to separate the relay electrically from the multivibrator circuit so that inductive disturbances arising from the operation of the relays will not produce adverse effects in the multivibrator operation.

The relays A and B are preferably of the mercury contact type, such as is disclosed in the application of E. T. Burton, Serial No. 545,985, filed July 21, 1944, now Patent No. 2,459,306 patented January 18, 1944, but relays of other types could be used, provided they are fast in operation, sensitive and are capable of handling a considerable power load over their contacts. Each of these relays comprises an envelope of glass or other suitable material, through the bottom of which an armature terminal is sealed and through the top of which two other terminals are sealed. Secured to the inner end of one of the upper terminals is a front contact of magnetic material and secured to the inner end of the other upper terminal is a back contact of non-magnetic material. Secured to the lower terminal by a reed is an armature of magnetic material biased against the back contact and attractable toward the front contact. A pool of mercury is placed in the bottom of the envelope from which mercury is conducted to the contacts by wick action. Surrounding the envelope is an operating coil or winding which when energized sets up a flow of magnetic flux through the armature and front contact to cause the movement of the armature towards the front contact.

The motor M has its field F connected across the terminals 5 and 6 to which a source of 24-volt direct current is connected. The armature circuit of the motor is connected between the swing contacts of the relays through the choke

coil L15, paralleled by resistance R72, to limit the alternating components of the current in the motor armature and to serve to smooth the operation of the motor. The choke coil L13, paralleled by resistor R71, is included in the connection from terminal 5 of the direct current source to the front contacts of the relays to minimize contact deterioration during the brief periods when a contact transfer occurs in either relay and all the contacts are in engagement. A network of resistors and condensers is provided for protecting the contacts of the relays. For example the swing and back contact of relay A are bridged by the series combination of resistor R69 and condenser C39A and also by a bridge consisting of resistor R73 in series with a parallel combination involving resistor R70 and condenser C41. These bridges are separated by an inductive resistor R74. Similar networks are provided for protecting the swing and front contact of relay A, the swing and back contact of relay B and the swing and front contact of relay B.

The association of the two control relays A and B with the multivibrator and buffer tube previously described, provides an arrangement whereby one relay is operated while the other is released. The relays operate in this manner at a rate of about 40 cycles per second. If the servo-amplifier is in a balanced condition, that is, no signal voltage is applied across the terminals 1 and 2, symmetrical square waves are produced at the outputs of the buffer tube VT12 and the relays A and B alternately operate and release in response to the essentially square waves but in an opposite order.

Accordingly with relay A operated and relay B released, current will flow from terminal 5 of the power source, through the resistor R71 in parallel with choke coil L13, through resistor R75, over the front contact of relay A, through resistor R72 in parallel with choke coil L15, through the armature circuit of motor M, over the back contact of relay B and through resistor R76 to the terminal 6 of the power source. When relay B is operated and relay A is released, current will flow from terminal 5 of the power source, through resistor R71 in parallel with choke coil L13, through resistor R77, over the front contact of relay B, through the armature circuit of motor M, through the resistor R72 in parallel with choke coil L15, over the back contact of relay A and through resistor R74 to the terminal 6 of the power source. These impulses of power are equal and are transmitted alternately in opposite directions through the armature circuit of the motor and accordingly the net direct current voltage connected across the armature circuit of the motor is zero and the motor remains at rest. However, the armature will vibrate sufficiently to overcome the static friction of the motor enabling the motor to rotate smoothly at very low rates of speed.

If unbalanced voltage conditions exist, resulting for example in relay A remaining in its front contact closure position for a longer time in any given interval than it remains in its back contact closure position and at the same time, relay B remains in its back contact closure position for a longer time than it remains in its front contact closure position, the impulse of power transmitted through the armature circuit of the motor M, when relay A is operated and relay B is released, will be lengthened and the impulse of power transmitted in the opposite direction through the armature circuit of the motor when relay

A is released and relay B is operated will be shortened and the net voltage across the armature circuit of the motor will cause the motor to turn in one direction of rotation. This net effective voltage will, of course, govern the speed of rotation. A higher net voltage results if the closed period for operating one of the relays greatly exceeds in duration the open period during which the relay is released.

Power for operating the tubes of the servo-amplifier is provided through the equipment shown in the lower left portion of the drawing. This power is derived from a source of 400-cycle 115-volt alternating current connected across terminals 7 and 8 which are connected to the terminals of the primary winding P1 of power transformer T1. Heater supply current is applied to the filaments of tubes VT7, VT8, VT9, VT11 and VT12 from the secondary winding S1 of transformer T1 and heater supply current is applied through the filament of tube VT10 from the secondary winding S2 of transformer T1.

For supplying +300 volts between the +450—V and +150—V bus bars, the full wave rectifier tube VT1 is provided, the filament of which is heated by current from the secondary winding S3 of the transformer T1. The secondary winding S4 of transformer T1 supplies 400-cycle, 400-volt alternating current to the plates of tubes VT1, the mid-point terminal of the winding S4 being connected to the +150—V bus bar.

The rectified output of tube VT1 is smoothed by a filter consisting of the series choke coil L9 and the bridged condensers C11 and C12 and is regulated at a potential of about +300 volts with respect to the +150—V bus bar connected to the center tap of the secondary winding S4 of the transformer T1. This regulation is accomplished by vacuum tubes VT3 and VT4. The pentode tube VT3 serves as a variable impedance connected in series between the output of tube VT1 and the +450—V bus bar. The value of the impedance in series with the output depends upon the plate-cathode current of tube VT3 which in turn is changed by the potential connected to the control grid of the same tube. The control grid is influenced by the voltage drop across resistor R2, a drop which is caused by the plate-cathode current of the amplifier pentode tube VT4.

The plate-cathode current of tube VT4 changes depending on variations in the potential connected to the control grid of this tube. A varying grid potential is obtained from a point on a voltage divider bridge comprising resistors R7 and R8 connected between the +450—V and the 0—V bus bars.

If the voltage on the bus bar designated +450—V should tend to rise, a proportion of the voltage difference between this point of 0 volts is impressed on the control grid of tube VT4 and results in an increased plate-cathode current and accordingly an increased voltage drop across the resistor R2. This increased voltage drop lowers the potential on the control grid of the regulator tube VT3 thereby reducing its plate output. The reduction in plate output is, of course, accomplished by an increase in the impedance between the plate and cathode of tube VT3, thus tending to lower the voltage on the +450—V bus bar. All of these actions to bring the output into regulation occur almost instantaneously.

In a similar manner a tendency of the voltage between the bus bars +450—V and 0—V to decrease, causes a decrease of the potential applied to the control grid of tube VT4 which results in a decrease in the plate-cathode current and accordingly a decreased voltage drop through resistor R2. This decreased voltage drop increases the potential on the control grid of the regulator tube VT3 thereby increasing its plate output. The increase in plate output is accomplished by a decrease in the impedance between the plate and cathode of tube VT3, thus tending to raise the voltage on the +450—V bus bar. As stated previously, all of these actions take place almost instantaneously.

The junction of the two resistors R9 and R10 bridged in series between the +450—V and +150—V bus bars is connected to the filaments of tubes VT3, VT4 and VT10 to keep the potential of these tubes within the heater cathode requirement. Anti-sing resistors for parasitic suppression include the screen grid resistor R1 and the grid resistor R2 associated with tube VT3.

For supplying 150 volts between the +150—V and 0—V bus bars, a half wave rectifier tube VT2 is provided. A 400-volt, 400-cycle alternating current input to the tube is obtained from the left half of the secondary winding S4 of transformer T1 and the filament is heated from the secondary winding S5 of the transformer. The direct current output from the plate of tube VT2 is smoothed by a double section filter comprising the series choke coils L10 and L11 and the bridged condensers C14, C15, C16 and C17. The rectified voltage output is reduced by the series resistor R4 and the output potential is fixed at 150 volts by the shunt regulator gas tube VT5.

What is claimed is:

1. An amplifying system comprising two power amplifier tubes, signal voltage amplifier tubes arranged in push-pull relationship for applying an amplified signal potential to the control grids of said power amplifier tubes, two condensers, a rectifier tube in the charging circuit of each of said condensers responsive to a sudden increase of said amplified signal potential in a positive direction for applying a potential to the control grid of one of said power amplifier tubes in opposition to said amplified signal potential but unresponsive to a sudden decrease of said amplified signal potential, a signal input circuit for applying equal signal potentials of opposite polarity upon the inputs of said signal voltage amplifier tubes, two condensers chargeable in response to changes in the signal input potentials, and equalizer tubes responsive to the charging of said latter condensers for applying amplified derivatives of said input potentials to the inputs of said voltage amplifier tubes to increase the effects of said signal potentials upon said voltage amplifier tubes.

2. In a servo-amplifier system, a multivibrator comprising two tubes with substantially identical condenser resistance feedback circuits whereby with balanced grid potentials applied to the grids of said tubes oppositely poled square waves are generated in the plate circuits of said tubes having substantially equal closed and open periods, power amplifier tubes upon the inputs of which said output waves are impressed, relays in the output circuits of said power amplifier tubes operable in alternation in response to said amplified output waves, a source of power, a servo-motor operable in response to impulses transmitted thereto from said source by the alternate opera-

tion of said relays, a signal input circuit, and means responsive to the application of a signal potential to said signal input circuit to render the grid potentials of said multivibrator tubes unequal whereby the closed periods of one of said output waves become lengthened and the closed periods of the other of said output waves become shortened to increase the net voltage of the impulses transmitted by said relays to said motor whereby said motor is caused to run in a direction determined by the polarity of the net voltage and at a speed determined by the magnitude of the net voltage.

BERNARD OSTENDORF, JR.

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