Dec. 10, 1940. F. H. SHEPARD, JR 2,224,199

A. C. OPERATED D. C. AMPLIFIER CIRCUITS

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Fig. 1

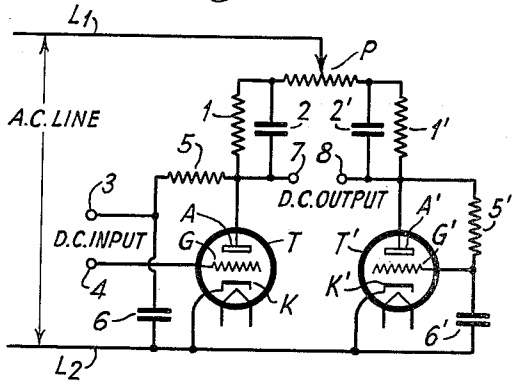


Fig. 2

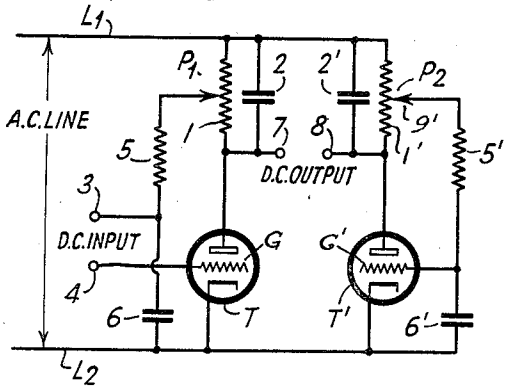


Fig. 3

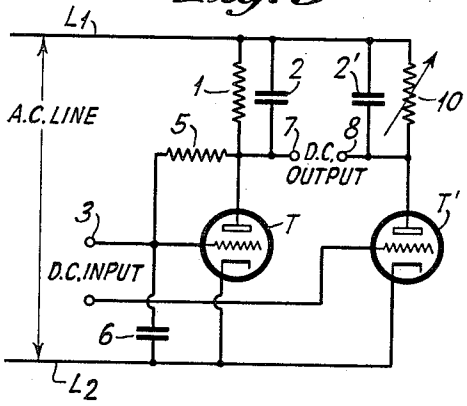


Fig. 4

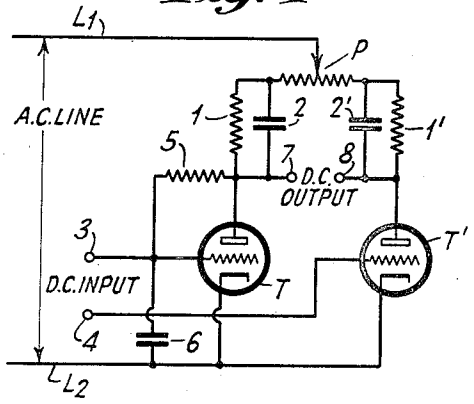


Fig. 5

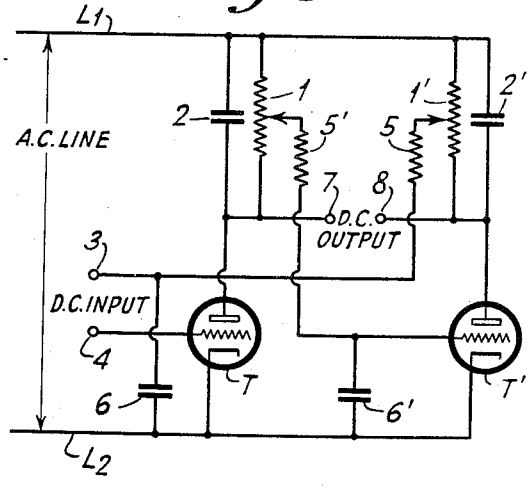
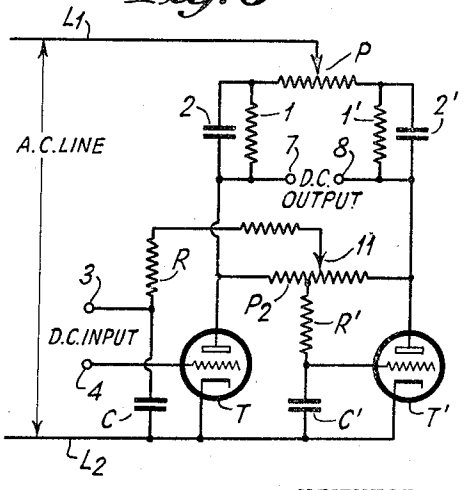


Fig. 6



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Fig. 7

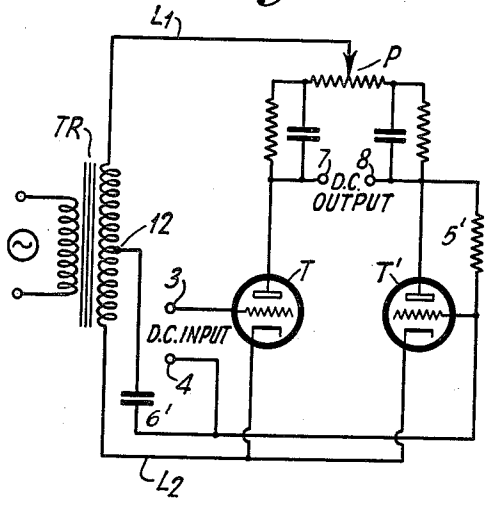


Fig. 8

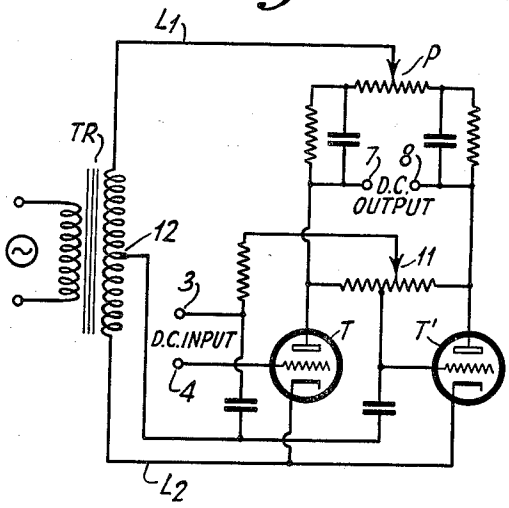


Fig. 9

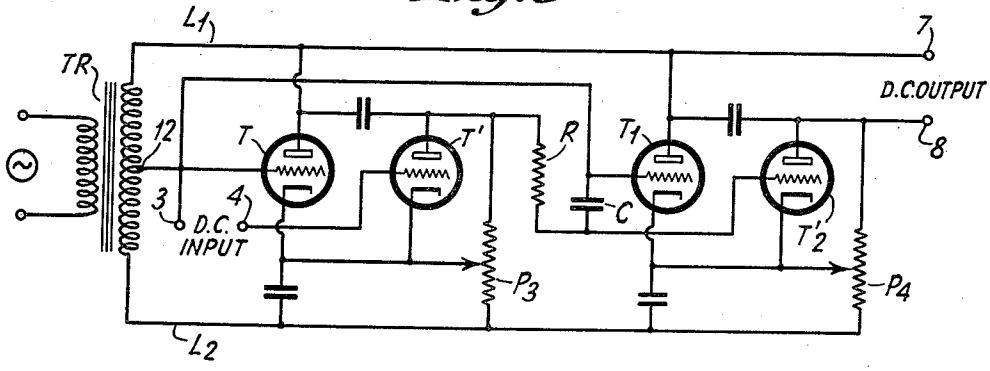


Fig. 10

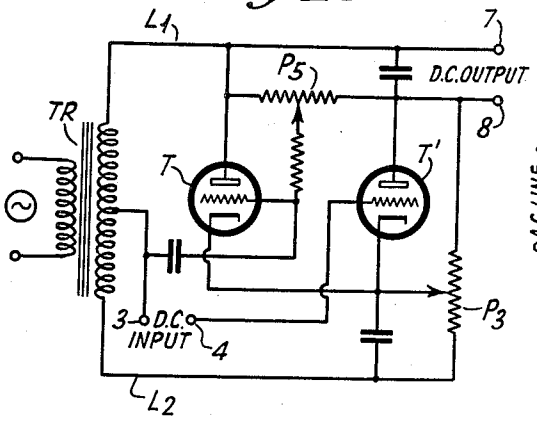
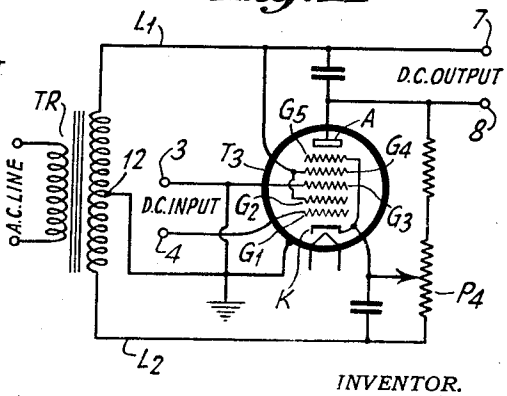


Fig. 11



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UNITED STATES PATENT OFFICE

2,224,199

ALTERNATING CURRENT OPERATED DIRECT CURRENT AMPLIFIER CIRCUITS

Francis H. Shepard, Jr., Rutherford, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application June 29, 1938, Serial No. 216,448

12 Claims. (Cl. 179—171)

The present invention relates generally to D.-C. amplifier circuits in which the energy for the operation of the amplifier is derived from a source of alternating current of the usual low frequency, and more particularly to such amplifiers of the balanced type, and is an improvement over my invention described and claimed in co-pending application Serial No. 727,968, filed May 28, 1934, and issued as Patent No. 2,137,419 on November 22, 1938. In that patent I have disclosed various types of A.-C. operated D.-C. amplifiers some of which are adjustable to provide compensation for all supply voltage variations. In order to avoid the inconvenience of a separate and rather critical compensation adjustment, such as is necessary in the circuits of the above patent, I have conceived and tested several types of self-biased, balanced, A.-C. operated D.-C. amplifiers that tend to be inherently compensated for all supply voltage variations including plate, bias and heater or filament voltage variations. The amplifier according to my present invention may be degenerative or regenerative, and any number of the circuits may be cascaded without the necessity of cascading the power supply voltages.

My invention will be better understood from the following description when considered in connection with the accompanying drawings and its scope will be pointed out in the appended claims.

In the drawings Fig. 1 shows a single stage A.-C. operated D.-C. amplifier utilizing a pair of tubes in balanced relation. Figs. 2 to 8 illustrate various modifications of the amplifier shown in Fig. 1. Fig. 9 shows a pair of coupled balanced amplifiers. Fig. 10 shows a modification of one of the balanced stages of Fig. 9, and Fig. 11 shows a balanced amplifier according to my invention utilizing a single, multi-grid tube.

Referring now specifically to Fig. 1, L1, L2 represent the line conductors of the A.-C. power supply, between which are connected in parallel relation a pair of tubes T, T' of the triode type, although it will be understood that multi-grid, multi-purpose, or other suitable tubes may be used in place thereof. The cathode K of each tube is directly connected for example to one side L2 of the A.-C. power supply and the anodes are each connected to the other side L1 of the power supply through resistor-capacity networks 1—2, 1'—2' and the potentiometer P. The input or signal potential to be measured is applied to the terminals 3, 4 which are connected respectively to anode A of tube T through the resistor 5 and to the control grid G. A condenser 6 connected between the cathode side of the line L2 and the side of the resistance 5 which is connected to input terminal 3 forms with said resistance 5 a filter network which removes the A.-C. component from the plate circuit and supplies biasing potential from the plate A to the control grid G of tube T and also opposes to a large extent the effect on the grid of the signal voltage input. A similar resistance-capacity network 5', 6' is connected as shown to provide bias for the control grid of tube T'. The output terminals 7 and 8 are connected to the respective low potential ends of the load resistors, 1, 1' of tubes T and T'. In the circuit just described the output of one tube is balanced against the output of the second, these tubes having preferably substantially similar characteristics so that changes due to variations in the supply voltage will tend to be cancelled in the common output.

In considering the operation of this single stage amplifier it should be understood that both sides of an A.-C. power supply line are at the same D.-C. potential, that is, a D.-C. voltmeter placed between the opposite sides of the A.-C. line will read zero. The current due to the electron flow from cathode K to anode A in tube T is in such direction that the IR drop in the plate load resistor 1 causes the plate to be at a negative potential with respect to the voltage of supply line L1. The plate A of the tube T will go positive with respect to the cathode each time the upper side L1 of the A.-C. line swings positive. During this time electron current flows from the cathode to the plate and, as explained above, the plate drops to a potential negative with respect to the upper side L1 of the A.-C. line. The condenser 2 in shunt to the plate load resistor 1 is of such value as to hold its charge without appreciable loss from one cycle to the next of the power supply. Since the plate is negative with respect to the line L1, it will also be negative with respect to the opposite side of the line L2 and hence after the removal of the A.-C. component of the potential by means of the filter network comprising resistor 5 and condenser 6, this potential can be applied in series with the signal input or else used as bias for the grid of tube T. It will be seen that any change in input signal voltage results in a change of grid potential which in turn changes the plate current, plate potential and hence the potential of point 3 which is one terminal of the input circuit, and hence will

react through the input circuit to tend to return the grid to its original grid to cathode potential. In other words the action will be degenerative. Tube T' operates in the same manner as tube T, and potentiometer P is adjusted to a point such that with no input signal the output terminals 7 and 8 will be at the same potential. In this condition the amplifier is said to be balanced, and subsequent application of an input signal voltage will be indicated or measured in the output across the terminals 7 and 8.

If the gain of tube T were infinite, the control grid would be returned to its initial potential. However, in practice the gain of tube T is finite hence the grid will not be restored to quite its original potential. This means that the change in the potential on the plate is not quite as great as the input signal, hence the gain of this stage is not quite unity. In the tube T' there is no input signal applied to its grid, hence the drop in resistor 1' and across condenser 2' in the plate circuit of said tube will be identical to that in tube T if the D.-C. input voltage to tube T is zero. An indicating meter connected between the output terminals 7 and 8 will read zero. A change in grid voltage of tube T changes its plate current only and hence results in a difference in the IR drops in the two plate load resistors and hence causes the output meter or indicator to read. In order to compensate for practical differences in the plate resistances of tubes T and T' there is provided the potentiometer P. If the movable contact of P is so adjusted that the output meter will read zero when the input signal is zero, variations of the A.-C. supply voltage will cause changes in the plate current, plate voltage and normal grid bias voltage of each tube to practically the same extent so that these variations will not appear in the D.-C. output.

In the circuit above described no voltage amplification is obtainable, the circuit being useful as a vacuum tube voltmeter where it is desirable to place little or no load on the measured circuit. The output of this circuit is essentially linear for D.-C. input voltages and for A.-C. input voltages in phase with the power supply.

The circuit of Fig. 2 is practically the same as that shown in Fig. 1 except that variable portions of the voltage develop across the respective load resistors 1 and 1' are applied to the respective control grids G and G', i. e., only a part of the output voltage is used for degeneration. The voltage amplification of the single stage shown in Fig. 2 is roughly proportional to the ratio of the whole of the potentiometer to the upper part, within certain practical limits set by the gain of the tube itself. The circuit is balanced by adjusting the slider 9' on the load resistance 1' for tube T'.

Figs. 3 and 4 are variations of the preceding circuits in which tube T is self-biased as in Fig. 1 and the tube T' is biased from the self-bias resistor of the tube T. The voltage gains obtainable in these circuits approach the mu of one tube. In Fig. 3 differences in the characteristics of tubes T and T' are compensated for by adjusting the plate load resistor 10 of the latter, and the bias on tube T' is obtained from the D.-C. plate potential of tube T, and because of this, changes in the potential between terminal 3 and terminal 4 result in signal being applied to the grid of tube T'. This applied voltage is such that the potential of the plate of tube T' varies in the opposite sense to the potential of the plate of tube T and hence the D.-C. output is a function of the gain of tube T'. The gain of this circuit is equivalent to the gain of one stage without degeneration. In Fig. 4 compensation of variations in the plate impedances of tubes T and T' is obtained by means of the slider on potentiometer P and the entire signal is applied to the grid of tube T' and no change in plate current of tube T will be occasioned by D.-C. input signal.

Fig. 5 shows a modification of Fig. 2 in which the tubes are cross self-biased so that the circuit becomes regenerative. Balance and regeneration are controlled by adjusting the sliders on plate resistors 1 and 1'. This method of biasing is such that a change in the plate potential of tube T causes a change of grid potential of tube T' which in turn causes a change in plate current and hence plate potential of tube T' which in turn reacts upon the grid of tube T in the same direction as the original grid change potential of tube T. It will therefore be seen that this circuit is regenerative and that if the sliders on the plate resistors are set too near the plates the circuit will become unstable, that is, it will "plop" in one direction or the other. If, however, the sliders are set at a point just above this unstable point the gain of the circuit over a portion of this characteristic can theoretically be made infinite. In Figure 5 adjustment of the slider on the plate resistors results in a change in balance of the circuit as well as a change in regeneration, and because of this it is extremely difficult to make the appropriate adjustment. The circuit shown in Fig. 6 is designed to eliminate this difficulty.

In the circuit of Fig. 6 in addition to the potentiometer P, I have provided a second potentiometer P2 connected between the anodes of tubes T and T'. The filter R'—C' is connected between the mid-point of P2 and the cathode side of the line L2, and the grid of T' is connected to a point between R' and C'. A variable tap 11 on P2 is connected through resistor R to the input terminal 3. If the circuit is properly balanced by the adjustment of slider on potentiometer P, regeneration can be adjusted by means of slider 11 on potentiometer P2 without affecting the balance of the circuit, thus greatly simplifying operation of the circuit. As the slider 11 is adjusted to the left towards the plate of tube T the gain approaches from a large value to a value of slightly less than 1 while as slider 11 is moved to the right toward the plate of tube T' the gain approaches infinity tending to make the circuit unstable. The regeneration or degeneration of this circuit may be controlled by adjusting slider 11 without disturbing the balance. Likewise the balance may be made by P without disturbing the regeneration. This circuit is easily adjustable and provides an excellent null indicator for Wheatstone bridges, etc.

In the circuit shown in Figure 7 operation is identical to that of Figure 4 with the exception that the grids are returned to an A.-C. potential intermediate the A.-C. potential of the two sides L1 and L2 of the A.-C. power supply. This introduces an A.-C. bias into the grid circuit so that the drop in the plate resistor may be increased to a value equal to the normal grid bias plus the peak value of the applied A. C. The power transformer TR shown in the figure may be utilized for this purpose, or else an autotransformer or a divider. The provision of the A.-C. bias enables the current through the plate resistors to increase and hence the normal D.-C.

bias assumes a value in excess of the peak applied voltage between points L2 and 12. This in turn enables the tubes T and T' to operate at or near the center of their operating characteristic rather than relatively near cut-off as is the case in the circuits shown in Figs. 1 to 6. It will of course be understood that this principle may be applied equally as well to the foregoing circuits.

Fig. 8 shows a circuit in which the principles involved in the circuits of Figs. 6 and 7 are combined, the former embodying regeneration, and the latter the feature of operating the tube at or near the center of its characteristic.

In Fig. 9 I have shown an improved A.-C. operated self-biased balanced bridge circuit cascaded with a second identical balanced bridge circuit. Each of said bridge circuits is essentially identical regarding operation and component parts to the circuit shown in Fig. 7. It will be noted that the A.-C. and D.-C. loads have been rearranged without changing the fundamental operation of the bridge circuit so that one side of the output can be connected to one side of the A.-C. line. In each stage the plate of one tube (T in the first stage and T_1 in the second) is held at ground D.-C. potential while the amplified D.-C. output is measured by the assumed D.-C. potential on the plate of the other tube (T' in the first stage and T'_2 in the second) of the respective stages. Both grids of each stage are normally biased at ground D.-C. potential. Hence, the output of one bridge type amplifier is capable of being used to drive the grid of a following stage providing a suitable A.-C. filter such as R—C is used to transfer the D.-C. from the plate of one stage to the grid of the next. The grids of the tubes have an A.-C. bias applied to them to enable the potential drops in the plate resistors to be great enough to allow the tubes to operate at or near the centers of their operating characteristic curves.

Electrically the only difference between Figs. 7 and 9 is that the plate load of tube T' has been placed on the other side of transformer TR. The drop across this load resistor P_3 still supplies bias for both tubes T and T'. The D.-C. load on tube T' returns to the cathode in both cases. In Fig. 7 the load resistance transformer winding is included in the return path while in Fig. 9 the return is direct. The grid of tube T receives its D.-C. bias direct from the plate of tube T in both cases. In Fig. 7 however an additional filter 5'—6' is necessary to supply the correct A.-C. bias. It will be noted that in both cases the elements of tubes T and T' receive identical A.-C. and D.-C. voltages.

The circuit shown in Fig. 10 shows how the circuit of Fig. 9 can be made regenerative. Balance adjustment is made by means of P3 independently of the regeneration, and the regeneration adjustment is made independently of balance by adjusting P5.

Any of the above described circuits will measure A. C. of the same frequency as, and in phase with the power supply voltage. Thus these circuits provide excellent balance or null indicators for Wheatstone bridges where the bridge current can be supplied from D. C. or from the same A. C. source as the amplifier.

The circuits shown in Figs. 7, 8, 9 and 10 are normally operated on the straight line portions of their characteristics, hence A. C. input voltages of frequencies other than the supply voltage produce no variations in the D. C. output voltages or currents. If the frequency of either the input or supply voltage is varied until a slow beat is obtained the output of the bridge will beat slowly, the maximum reading being a direct measure of the amplitude of the input voltage. The supply voltage amplitude will have practically no effect on the accuracy of the reading. If an oscillator is used to supply the plate or supply voltage to the bridge there is a slight tendency for the oscillator frequency to lock into step with that of the signal. This tendency is an advantage in that as soon as the oscillator frequency is brought near that of the signal the frequency of the oscillator will lock into step with that of the signal. The proper phase relations between the signal and oscillator frequencies will automatically be held for reading. This greatly facilitates any measurments to be made and it has no apparent effect on the accuracy of the readings. In other words if the above mentioned power supply voltage is from a variable frequency oscillator this device will measure only D. C. or A. C. voltages of the same frequency as the oscillator. This means that the device can be used as "wave analyzer" or an "harmonic analyzer."

In all the circuits discussed thus far I have utilized two separate and distinct tubes or sets of elements for procuring the balanced relation. In said circuits it has been assumed that changes in contact potential at the cathode of each tube will vary to substantially the same extent. However, this assumption is not strictly true, since certain changes or variations will result in contact potential. To eliminate this difficulty, I have devised the circuit shown in Fig. 11 which is electrically equivalent to and operates in much the same manner as one of the balanced stages, T and T' for example, of the amplifier circuit shown in Fig. 9. The circuit of Fig. 11 utilizes a pentagrid tube T3 which may be of the type commonly known as "6L7," although it will be understood by those skilled in the art that a simple pentode such as the "6J7" having in addition to the cathode K and the anode A the three grids G1, G2 and G3 will be entirely suitable for the purpose. In the circuit utilizing the pentagrid tube T3 the grid G1 acts as the grid of tube T' in Fig. 9 while the plate A acts as the plate of tube T' of Fig. 9. The grid G3 of the pentagrid tube acts as the signal grid of tube T shown in Fig. 9 and the grid G2 of the tube acts as the plate of the tube T in Fig. 9. The pentagrid tube shown is provided with the additional shield grid G4 connected to the grid G2 and with a suppressor grid G5 between the shield grid G4 and the plate A, although as stated above the latter two grids are not essential to to the operation of the circuit. It will be noted that in the circuit just described the cathode K serves to supply space current to both the grid G2 and the plate A of the pentagrid tube as shown or of the pentode if the grids G4 and G5 were omitted. Control is obtained by changing the ratio of currents between the grid G2 and the anode A. It will be understood that variations or changes in contact potential at the surface of the cathode affect the total cathode current but do not necessarily affect the ratio of currents between the grid G2 and the plate A. Thus, since the output is taken between said grid and plate, changes in the cathode current, when the circuit is balanced, do not cause any change in output. The circuit just described will be balanced not only for line voltage variations but also for contact potential variations.

While I have disclosed and described several systems or modifications for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organizations shown and described, but that other modifications may be made without departing from the scope of my invention as set forth in the appended claims.

What I claim is:

1. In an alternating current operated A.-C. or D.-C. voltage amplifier, a pair of electron discharge tubes each having an anode, a cathode and a grid electrode, a source of alternating current having a pair of line conductors, a load resistor and a shunt condenser connected between one of said conductors and each anode of said tubes, a direct connection between each cathode and the other line conductor, a source of input potentials connected to the grid electrode of one of said tubes, and an output circuit connected between the anodes of both said tubes.

2. In an alternating current operated A.-C. or D.-C. voltage amplifier, a pair of electron discharge tubes each having an anode, a cathode and a grid electrode, a source of alternating current having a pair of line conductors, a load resistor connected between one of said conductors and each anode of said tubes, a connection between each cathode and the other line conductor, a filter network including a resistor and a condenser connected between the anode and cathode of one of said tubes, a source of input potentials connected to the grid electrode of said last mentioned tube and a point between the filter condenser and resistor, a similar filter network connected between the anode and cathode of the other tube, and an output circuit connected between the anodes of both said tubes.

3. In an alternating current operated A.-C. or D.-C. voltage amplifier, a pair of electron discharge tubes each having an anode, a cathode and a grid electrode, a load resistor connected to each anode of said tubes, a potentiometer connected to the opposite ends of said load resistors, a source of alternating current having a pair of line conductors, one of said conductors being connected to the variable tap on said potentiometer, a connection between each cathode and the other line conductor, a source of input potentials connected to the grid electrode of one of said tubes, and an output circuit connected between the anodes of both said tubes.

4. In an alternating current operated A.-C. or or D.-C. voltage amplifier, a pair of electron discharge tubes each having an anode, a cathode and a grid electrode, a source of alternating current having a pair of line conductors, a load resistor connected between one of said conductors and each anode of said tubes, a connection between each cathode and the other line conductor, a variable connection including a resistor from the grid electrode of each tube to the respective load resistor of each tube, a condenser connected from the grid side of each of said resistors to the cathode side of the line, a source of input potentials connected to the grid electrode of one of said tubes, and an output circuit connected between the anode side of said load resistors.

5. In an alternating current operated A.-C. or D.-C. voltage amplifier, a pair of electron discharge tubes each having an anode, a cathode and a grid electrode, a source of alternating current having a pair of line conductors, a resistor-condenser network connected between each anode and one of said line conductors, a direct connection between each of the cathodes and the other line conductor, a source of signal potentials connected to the grid electrode of one of said tubes, biasing potentials for each of said grid electrodes derived from the anode resistors, and an output circuit connected between the anodes of said tubes.

6. In a system for the amplification of D.-C. voltages or A.-C. voltages in phase with the power supply, a pair of electron discharge tubes each having an anode, a cathode and a grid electrode, a power supply source of alternating current having a pair of line conductors, a resistor-condenser network connected between each anode and one of said line conductors through a potentiometer, a direct connection between each of the cathodes and the other line conductor, a source of signal potentials connected to the grid electrode of one of said tubes, biasing potentials for each of said grid electrodes derived from the anode resistors, and an output circuit connected between the anodes of said tubes.

7. In an alternating current operated direct current amplifier, a pair of electron discharge tubes each having at least an anode, a cathode and a grid electrode, a source of alternating current having a pair of line conductors, a resistor-condenser network connected between each anode and one of said line conductors, a direct connection between each of the cathodes and the other line conductor, a source of signal potentials connected to the grid electrode of one of said tubes, biasing potentials for the grid electrode of each tube being derived from the anode resistor of the other tube, and an output circuit connected between the anodes of said tubes.

8. In an alternating current operated direct current amplifier, a pair of electron discharge tubes each having at least an anode, a cathode and a grid electrode, a source of alternating current having a pair of line conductors, a resistor-condenser network connected between each anode and one of said line conductors, a direct connection between each of the cathodes and the other line conductor, a source of input potentials connected to the grid electrode of one of said tubes, a potentiometer connected between the anodes of said tubes, a variable connection from said potentiometer to the grid electrode of the tube to which the signals are applied, and an output circuit also connected between the anodes of said tubes.

9. In an alternating current operated A.-C. or D.-C. voltage amplifier, a pair of electron discharge tubes each having an anode, a cathode and a grid electrode, a source of alternating current having a pair of line conductors, a load resistor connected between one of said conductors and each anode of said tubes, a connection between each cathode and the other line conductor, a filter network including a resistor and a condenser connected between the anode and cathode of one of said tubes, a source of input potentials connected to one of the grid electrodes and a point between the filter condenser and resistor, and an output circuit connected between the anodes of both said tubes.

10. In an alternating current operated direct current amplifier, a pair of electron discharge tubes each having at least an anode, a cathode and a grid electrode, a source of alternating current having a pair of line conductors, a resistor-

condenser network connected between each anode and one of said line conductors, a direct connection between each of the cathodes and the other line conductor, a source of input potentials connected to the grid electrode of one of said tubes, a potentiometer connected between the anodes of said tubes, a variable connection from said poteniometer to the grid electrode of the tube to which signals are applied, a fixed connection from the mid-point of said potentiometer to the grid electrode of the other tube, and an output circuit connected between the anodes of said tubes.

11. In an alternating current operated direct current amplifier, a pair of electron discharge tubes each having at least an anode, a cathode and a grid electrode, a source of alternating current having a pair of line conductors, a resistor-condenser network connected between each anode and one of said line conductors, a direct connection between each of the cathodes and the other line conductor, a source of input potentials connected to the grid electrode of one of said tubes, a potentiometer connected between the anodes of said tubes, a pair of filter circuits each comprising a resistor and a series condenser connected between said potentiometer and the line conductor to which the cathodes are connected, a connection from each filter to one of the grid electrodes, and an output circuit connected between the anodes of said tubes.

12. In an alternating current operated direct current amplifier, a pair of electron discharge tubes each having at least an anode, a cathode and a grid electrode, a source of alternating current having a pair of line conductors, a resistor-condenser network connected between each anode and one of said line conductors through a potentiometer, a direct connection between each of the cathodes and the other line conductor, a source of input potentials connected to the grid electrode of one of said tubes, a second potentiometer connected between the anodes of said tubes, a variable connection from the latter potentiometer to the grid electrode of the tube to which signals are applied, a resistor and a condenser connected in series between the mid-point of the latter potentiometer and the line conductor to which the cathodes are connected, a connection from the other grid electrode to the common terminal between the series resistor and condenser, and an output circuit connected between the anodes of said tubes.

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