June 6, 1944. R. D. NEWCOMB 2,350,803

AUTOMATIC VOLUME CONTROL

Filed June 18, 1941

Fig. 1.

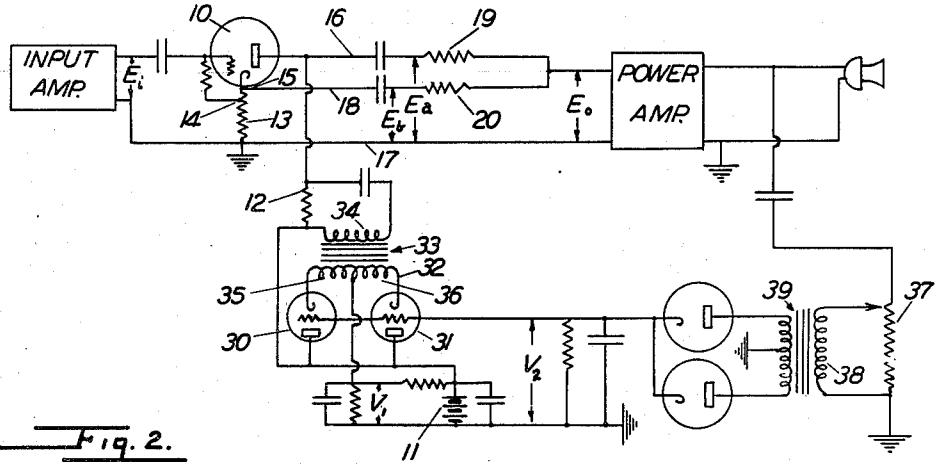


Fig. 2.

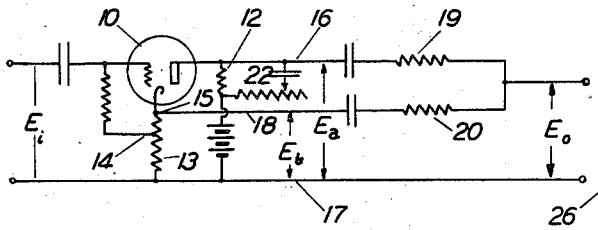


Fig. 3.

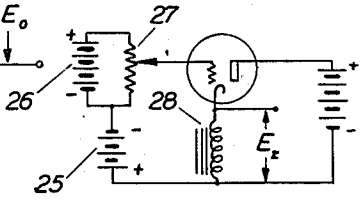
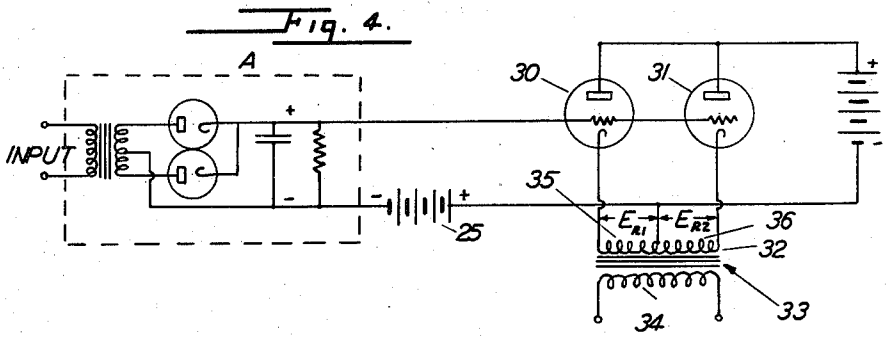


Fig. 4.



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AUTOMATIC VOLUME CONTROL

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13 Claims. (Cl. 179—171)

My invention relates generally to circuits used for controlling the amplitude of the output wave of certain alternating current systems, and more particularly to such circuits used to control the volume output of radio, public address, and similar circuits.

In public address systems, provision must be made for controlling the amount of amplification of the speaker's voice, and while it is possible to do this by manual controls, such a method is far from satisfactory since it requires the special services of an operator and also because of the time delay always associated with human control. Circuits have been developed to provide an automatic control for such systems so that regardless of the volume of the speaker's voice or his distance from the microphone, the output of the loudspeakers will remain substantially constant. However, such circuits have generally had a restricted range of control or have introduced extraneous noises into the system, and some have had a delayed action which can produce very undesirable results.

It is therefore a major object of my invention to provide an automatic volume control circuit which is substantially instantaneous in operation, has a wide range of control, and which does not cause distortion or introduce extraneous noise into the system.

It is a further object of my invention to provide such a system which may be used to provide a substantially constant volume output, in which case it is known as a volume contractor; or with a few simple changes, may be used to increase the range of volume changes, in which case it is known as a volume expander.

These and other objects of my invention will become apparent from the following description of a preferred form thereof and from the drawing illustrating that form, in which

Fig. 1 is a schematic wiring diagram of the complete circuit,

Fig. 2 is a schematic diagram of an elementary portion of the circuit of Fig. 1,

Fig. 3 is a schematic diagram of a control circuit which may be used to provide a variable impedance, and

Fig. 4 is a schematic diagram of the circuit of Fig. 3 adapted to use with the circuit of Fig. 2 to provide the circuit of Fig. 1.

Referring now to the drawing and particularly to Fig. 2 thereof, a signal voltage E_1 is applied to the input of a vacuum tube 10 having a load resistance in both the plate and cathode circuit. The usual plate voltage supply 11 is connected between the plate resistance 12 and the cathode resistance 13, and the values of these two resistances are chosen so that the voltage drop across the plate resistance 12 is much greater than that across the cathode resistance 13. A tap 14 is preferably provided in the cathode resistance 13 so that the grid of the tube 10 may be supplied with a negative bias, but it is apparent that other methods of biasing may be used if preferred. If the output voltage E_a of the tube 10 taken across plate lead 16 and lead 17 is now compared to the voltage E_b taken across the cathode resistor 13 (across leads 17 and 18), E_a will be found to be much larger than E_b, and as is well known in the art, the two voltages will be 180° out of phase, considering only the A. C. components of these two voltages. If E_a and E_b are passed through suitable resistors 19 and 20, respectively, and then combined, the resulting output voltage E_o will be equal to E_a—E_b, which, because of the great difference between the two will be nearly equal to E_a alone.

If the value of the plate resistance 12 is decreased, the voltage E_a will be decreased and the output voltage E_o will likewise be decreased; and if, instead of varying the resistance 12, a variable resistor 22 is connected in shunt with it, the same results will be secured. While it might seem that under these conditions the presence of E_b is mere surplusage, it has been found impractical to secure a resistor having the necessary range, and hence E_b is necessary to provide a complete cancelling of voltage E_a, should such an extreme range be desirable. It will thus be seen that the circuit of Fig. 2 provides a volume control having a great range of control, but one which nevertheless must be manually controlled.

To make the control automatic, it is necessary to provide an impedance which may be substituted for the variable resistor 22 and which will almost instantaneously reduce in value as the input voltage is increased, and will do this without sending serious D. C. impulses through the system. A circuit having an impedance which is almost instantaneously reduced as a voltage is increased, is shown in Fig. 3, which, assuming proper voltages are applied, will have a reflected impedance when looking into E_2 of R_p/μ where R_p is the internal plate resistance of the tube and μ is the amplification factor. If the grid bias voltage is increased to cutoff, the internal resistance R_p approaches infinity and hence the reflected impedance at E_2 across inductance 28 likewise approaches infinity. As the grid bias voltage is decreased, the reflected im-

pedance is proportionately decreased until a minimum is reached. In the circuit shown, the grid bias voltage is supplied by the battery 25, and a second battery 26, shunted by a potentiometer 27, is connected so that it may oppose to a greater or lesser degree the voltage of the battery 25. If the reflected impedance at E_2 were now used in place of the resistance 22 of the circuit shown in Fig. 2, volume control could be accomplished by varying the setting of the potentiometer 27, which would still require manual operation, but with the difference that here a voltage is being varied instead of merely varying a resistance. As a result, it is possible to use a rectified signal current in place of the battery 26 and potentometer 27.

However, before this may be done, other problems must be solved and to do this the circuit of Fig. 4 was developed. Since the rectified current will contain signal components which would be harmful if allowed to re-enter the circuit of Fig. 2, this rectified current must be filtered. The various inductances and capacitances used in filters, however, produce a time delay in the circuit in proportion to their size, and hence units as small as possible should be used. One method of keeping these members small is to use a full-wave rectifier for the input, and hence in Fig. 4 I have shown a full-wave rectifier A which has filter members of a minimum size, thus providing substantially instantaneous response. The polarity of the output, as indicated, opposes that of the grid bias voltage supply 25, and the rectifier A thus corresponds to the battery 26 and potentiometer 27 of the circuit of Fig. 3.

Instead of using the single tube of Fig. 3, however, I prefer to use a pair of tubes 30 and 31 which have their outputs connected to the opposite ends of a center-tapped winding 32 of a transformer 33, the center-tap furnishing the necessary common connection for the two tubes. The other winding 34 of the transformer 33 will thus reflect the impedance R_p/μ of the tubes 30 and 31, and in addition, because of the characteristics of this arrangement, the changing impedance will be reflected as if it were purely a resistance change. To analyze this, it should be noted that as the grid bias of the tubes 30 and 31 is changed, equal current changes occur in their output connections, and these outputs, designated as E_{R1} and E_{R2} respectively, are connected to the two halves 35 and 36 of the winding 32 of the transformer 33 as shown, so that they oppose each other. By using such a system, the change in current flowing through the half 35 of the winding 32 will cause an opposing voltage to be induced both in that half of the winding and the half 36. At the same time, a similar current change is taking place in the half 36 of the winding 32, and a similar voltage is being induced in the half 35 of the winding 32. These two induced voltages oppose each other and substantially cancel themselves, and this permits the use of much smaller filter capacitors which in turn greatly shortens the time delay of the circuit.

In addition to permitting the use of much smaller filter capacitors, the circuit of Fig. 4 has another very important feature. When the grid bias of the tube in Fig. 3 is changed, the plate current, which flows through the inductance 28, will likewise change, and as a result a signal or voltage change will appear across the inductance. If this voltage change is permitted to reach the amplifier, objectionable sounds will occur, and if the change in impedance is fast enough, it may even result in "blocking" of the amplifier. By using the circuit of Fig. 4, however, the output of tube 30 induces a current in one direction in the winding 34 of transformer 33, and the output of tube 31 induces an equal current but in the opposite direction in the same winding. These two currents cancel each other, and as a result the changing internal resistance of the tubes 30 and 31 may appear as a purely resistance change at the winding 34 without any direct current change therein, and the latter may be used in place of the resistance 22 of Fig. 2. It will be apparent that if desired, the transformer 33 may be an autotransformer instead of two winding transformer shown. However, in general I prefer to use the two winding transformer.

In the diagrams shown, it will be noted that the cathodes of the tubes 30 and 31 are connected to the outer terminals of the transformer winding 32, while the plates are connected together and to the center tap thereof. I have found that by using this method, I am able to obtain a much greater range of impedance. The improvement in range resulting from placing the transformer in the cathode circuit instead of in the plate circuit is a function of the amplification factor of the tube. This generally represents an improvement of ten or twenty times the usual range.

When this is done, the circuit of Fig. 1 results. Here the input voltage E_i is furnished by the input amplifier and the output E_o is amplified by a power amplifier and then goes to a loudspeaker. The input voltage is delivered to the tube 10, corresponding to the similarly numbered tube of Fig. 2, and the out-of-phase voltages E_a and E_b are produced and combined to form E_o as previously described. However, instead of the resistance 22 being used to shunt the resistance 12, between the plate supply battery 11 and the lead 16, the winding 34 of the transformer 33 is used for this purpose, and thus as the reflected resistance from the transformer is reduced, the effective value of the total resistance between the battery 11 and the lead 16 is reduced. The reflected resistance from the transformer 33 is controlled by rectifying a portion of the output power amplifier and using this rectified current to control the grids of tubes 30 and 31 as previously described. A potentiometer 37 is preferably connected across the primary 38 of a transformer 39 feeding the rectifier, with the variable connection and one fixed connection connected to the transformer, and the supply leads connected to the fixed connections, and in this manner the volume of the output may be fixed.

In operation, the movable connection of the potentiometer 37 is placed next to the fixed connection of the primary of the transformer 39 so that no current is induced in the transformer and hence the rectified output thereof, V_2, is zero. The voltage V_1, which is applied to the grids of the tubes 30 and 31, is then adjusted so that no plate current flows through these tubes. This means that these tubes are biased substantially to cutoff, as is the condition when the battery 25 is connected directly to the grid of the tube in Fig. 3, and the reflected impedance appearing at the winding 34 of the transformer 33 is thus nearly infinity. If the movable connection of the potentiometer 37 is now moved away from the fixed connection, current will flow in transformer 39, be rectified, and will appear as voltage V_2 opposing the bias voltage V_1 supplied by the battery 11. As a result,

the voltage applied to the grids of the tubes 30 and 31 is reduced and plate current may flow through them. The reflected impedance appearing at the winding 34 is thus reduced, corresponding to a reduction of the resistance 22 of Fig. 2, and as seen from a study of Fig. 2, this reduces the voltage E_a and hence E_o. Thus by setting the movable arm of the potentiometer 37 at a point which will give the desired volume, the various elements of the circuit will cooperate to maintain the volume at this level, regardless of the changes in volume (voltage) of the input, within the range of the circuit.

It will at once be apparent that with minor changes the circuit may be used as a volume expander instead of a volume contractor, a volume expander being used where it is desired to restore a compressed range of volume to its original range, or to produce an exaggerated effect. The change may be produced in several ways, the principle involved in all of them being that as the output volume is increased, the reflected impedance at the winding 34 of the transformer 33 is likewise increased, resulting in a further increase in volume of the output.

While I have shown and described the circuit as using batteries for a source of power, it will be apparent that any other suitable source may be used, and likewise while the tubes have been indicated as two and three element tubes, tubes having other numbers of elements may be used with appropriate modifications in the circuit which will be apparent to those skilled in the art. Similarly, condensers have been indicated at various points in the circuit to prevent the passage of direct current, and while I prefer to use the condensers as indicated, the circuit will work, though generally not so well, if they are changed or omitted. While I have shown and described a preferred form of my invention fully capable of achieving the objects and advantages set forth, it will be apparent that modifications may be made which do not depart from the fundamental principles of my invention, and I do not wish to be limited to the particular form shown, except as indicated in the following claims.

I claim as my invention:

1. A volume control circuit which includes: an electron tube having at least three elements; a source of plate voltage; a resistance connected in series with said source of plate voltage and the plate of said tube; a second resistance connected in series with said source of plate voltage and the cathode of said tube, said second resistance being relatively small compared to said first resistance; a third resistance having one of its terminals connected to the plate of said tube; a fourth resistance having one of its terminals connected to the cathode of said tube, and its other terminal connected to the other connection of said third resistor; and means for varying the value of said first resistor whereby the output through said third resistor may be changed, the output through said fourth resistor cancelling a portion of the output through said third resistor.

2. A volume control circuit which includes: an electron tube containing at least a grid, a plate, and a cathode; a pair of input leads, one of said leads being connected to said grid and the other of said leads going to and becoming an output lead; a relatively high resistance connected to said plate; a source of plate potential connected in series with said resistance and the second of said input leads; a relatively low resistance connected in series with said second input lead and said cathode; a third resistance connected in series with said plate and a second output lead; a fourth resistance connected in series with said cathode and said second output lead, the output through said fourth resistance being substantially 180° out of phase with the output through said third resistance and cancelling a portion of the latter; and means for varying said first resistance whereby the output through said third resistance, and hence the output of said output leads, may be varied.

3. A volume control circuit which includes: an electron tube having at least three elements; a source of plate voltage; a resistance connected in series with said source of plate voltage and the plate of said tube; a second resistance connected in series with said source of plate voltage, said second resistance being relatively small compared to said first resistance; a third resistance having one of its terminals connected to the plate of said tube; a fourth resistance having one of its terminals connected to the cathode of said tube and its other terminal connected to the other connection of said third resistor; means operated by the current in the circuit being controlled, to change the grid bias of an electron tube; means to convert said change in grid bias to a reflected impedance change; and means connecting said reflected impedance in shunt with said first resistor whereby the voltage of the output passing through said third resistor is automatically changed to vary the resultant output of said circuit.

4. A volume control circuit which includes: an electron tube containing at least a grid, a plate, and a cathode; a pair of input leads, one of said leads being connected to said grid and the other of said leads going to and becoming an output lead; a relatively large resistance connected to said plate; a source of plate potential connected in series with said resistance and the second of said input leads; a relatively small resistance connected in series with said second input lead and said cathode; a third resistance connected in series with said plate and a second output lead; a fourth resistance connected in series with said cathode and said second output lead, the output through said fourth resistance being substantially 180° out of phase with the output through said third resistance and cancelling a portion of said latter output; means operated by the current in the circuit being controlled, to change the grid bias of an electron tube; means to convert said change in grid bias to a reflected impedance change; and means connecting said reflected impedance in shunt with said first resistor whereby the voltage of the output passing through said third resistor is automatically changed to vary the resultant output of said circuit.

5. A volume control circuit which includes: a pair of input leads; a pair of output leads; an electron tube having at least a cathode, a plate, and a grid, said grid being connected to one of said input leads; a relatively large resistance connected to said plate; a source of plate potential connected in series with said resistance and the other of said input leads; a relatively small resistance connecting said cathode to the second of said input leads; a third resistance connected in series with said plate and one of said output leads; a fourth resistance connected in series with said cathode and said output lead, said second input lead being connected to the other of said

output leads; a rectifier connected to said output leads whereby a portion of said output is rectified; a pair of electron tubes; means for supplying a voltage to the grids of said tubes which acting alone will bias said tubes to cutoff," the output of said rectifier being connected in series with said voltage but so as to oppose the action of said voltage whereby said tubes are caused to operate with a bias below that sufficient to produce cutoff; a transformer having a center-tapped winding, said tubes being connected to said center-tapped winding so that their outputs oppose each other in said winding; and means for connecting the other winding of said transformer in shunt with said relatively large resistance whereby the reflected impedance appearing at said winding acts to reduce the total resistance across said relatively large resistance, thereby reducing the output in said output leads.

6. A volume control circuit which includes: a pair of input leads; a pair of output leads; an electron tube having at least a cathode, a plate, and a grid, said grid being connected to one of said input leads; a relatively large resistance connected to said plate; a source of plate potential connected in series with said resistance and the other of said input leads; a relatively small resistance connecting said cathode to the second of said input leads; a third resistance connected in series with said plate and one of said output leads; a fourth resistance connected in series with said cathode and said output lead, said second input lead being connected to the other of said output leads; a rectifier connected to said input leads whereby a portion of said input is rectified; a pair of electron tubes; means for supplying a voltage to the grids of said tubes, the output of said rectifier being connected in series with said voltage and so as to aid it whereby said tubes are caused to operate with a bias below cutoff but varying with the output of said rectifier; a transformer having a center-tapped winding, said tubes being connected to said center-tapped winding so that their outputs oppose each other in said winding; and means for connecting the other winding of said transformer in shunt with said relatively large resistance whereby the reflected impedance appearing at said winding acts to reduce the total resistance across said relatively large resistance, thereby reducing the output in said output leads.

7. A volume control circuit which includes: an electron tube containing at least a grid, a plate, and a cathode; a pair of input leads, one of said leads being connected to said grid and the other of said leads going to and becoming an output lead; a relatively high resistance connected to said plate; a source of plate potential connected in series with said resistance and the second of said input leads; a relatively low resistance connected in series with said second input lead and said cathode; a third resistance connected in series with said plate and a second output lead; means connecting said cathode to said second output lead, the output through said means being substantially 180° out of phase with the output through said third resistance and cancelling a portion of the latter; and means for varying said first resistance whereby the output through said third resistance, and hence the output of said output leads, may be varied.

8. A volume control circuit which includes: an electron tube containing at least a grid, a plate, and a cathode; a pair of input leads, one of said leads being connected to said grid and the other of said leads going to and becoming an output lead; a relatively high resistance connected to said plate; a source of plate potential connected in series with said resistance and the second of said input leads; a relatively low resistance connected in series with said second input lead and said cathode; means connecting said plate to the second of said output leads; a third resistance connected in series with said cathode and said second output lead, the output through said third resistance being substantially 180° out of phase with the output through said means and cancelling a portion of the latter; and means for varying said first resistance whereby the output through said first means, and hence the output of said output leads, may be varied.

9. A volume control circuit, which includes: means connected to the source of energy to be controlled, said means being adapted to produce two alternating voltages substantially 180 degrees out of phase with each other as measured from a point common to both voltages, one of said voltages being normally greater than the other, but both having substantially the same wave form as the energy from said source; a resistance connected in series with said normally greater voltage and an output lead; a second resistance connected in series with said normally smaller voltage and said output lead; and a variable resistance connected between said normally greater voltage lead and said common lead whereby said normally greater voltage may be decreased relative to said normally smaller voltage, the latter voltage cancelling a portion of said normally greater voltage and providing a resultant output voltage determined by the difference between said normally greater voltage and said normally smaller voltage.

10. A circuit adapted to convert an alternating current voltage variation to a variation in reflected impedance, which includes: a rectifier adapted to convert said varying alternating current voltage to a varying direct current voltage; a pair of electron tubes; means for supplying a substantially constant potential to the grids of said tubes; means for connecting said rectified voltage to said substantially constant potential whereby the grids of said tubes are provided with a bias determined by said varying alternating current voltage; and a transformer having a center-tapped winding, the plates of said tubes being connected together and to the center-tap of said transformer, and the individual cathodes of said tubes being separately connected to the end terminals thereof so that the outputs of said tubes produce opposing magnetic effects in said center-tapped winding, a reflected impedance appearing across the other winding of said transformer and having a value controlled by said varying alternating current voltage.

11. A circuit adapted to convert an alternating current voltage variation to a variation in reflected impedance, which includes: a full-wave rectifier connected to said varying alternating current voltage and having a minimum of components which will delay the speed of response of said rectifier; a pair of electron tubes; means for supplying a substantially constant potential to the grids of said tubes; means for superimposing said rectified voltage on said substantially constant grid potential, whereby the bias of said electron tubes is determined by the envelope of said varying alternating current voltage without regard for the frequency of the voltage; and a transformer having a center-tapped winding, the

plates of said tubes being connected together and to the center-tap of said transformer, and the individual cathodes of said tubes being separately connected to the end terminals thereof so that the outputs of said tubes produce opposing magnetic effects in said center-tapped winding, a reflected impedance appearing across the other winding of said transformer and having a value controlled by said varying alternating current voltage.

12. A circuit adapted to convert an alternating current voltage variation to a variation in reflected impedance, which includes: a full-wave rectifier; a nonresonant filter circuit which introduces a minimum of time delay in the speed of response of said filtered voltage to said alternating current voltage; a pair of electron tubes; means for supplying a substantially constant voltage to the grids of said tubes; means for connecting said filtered voltage to said substantially constant voltage whereby the grid bias of said tubes is determined by the envelope of said alternating current voltage without regard to the frequency thereof; a source of plate potential, the positive terminal of which is connected to the plates of said tubes; and a center-tapped transformer, the center tap of which is connected to the negative terminal of said source of plate potential and the outer terminals of said transformer are separately connected to the cathodes of said tubes, thereby causing a reflected variable impedance whose value is dependent only upon the envelope of said alternating current voltage, to appear across the output terminals of said transformer, a minimum of time delay having been introduced between the variation of said voltage and the variation of said impedance.

13. A circuit adapted to convert an alternating current voltage variation to a variation in reflected impedance, which includes: a full-wave rectifier combined with a minimum of filter elements adapted to convert said varying alternating current voltage to a varying direct current voltage whose magnitude at all times corresponds to the envelope of said alternating current voltage; a pair of electron tubes; means for supplying a substantially constant potential to the grids of said tubes; means for connecting said rectified voltage to said substantially constant potential whereby the bias of said tubes is determined by the envelope of said alternating current voltage without regard to the frequency thereof; a source of plate potential; and a transformer having a center-tapped winding, the plates of said tubes being connected together and to the positive terminal of said source of plate potential, the negative terminal of said source of plate potential being connected to the center tap of said transformer, and the individual cathodes of said tubes being separately connected to the end terminals thereof, so that a reflected impedance appears across the output terminals of said transformer, said impedance having a value determined by the envelope of said alternating current voltage and not by the frequency or wave form thereof.

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