Aug 5, 1941. W. H. MAYNE 2,251,594

VOLUME CONTROL FOR ELECTRICAL SIGNALS

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FIG. 1.

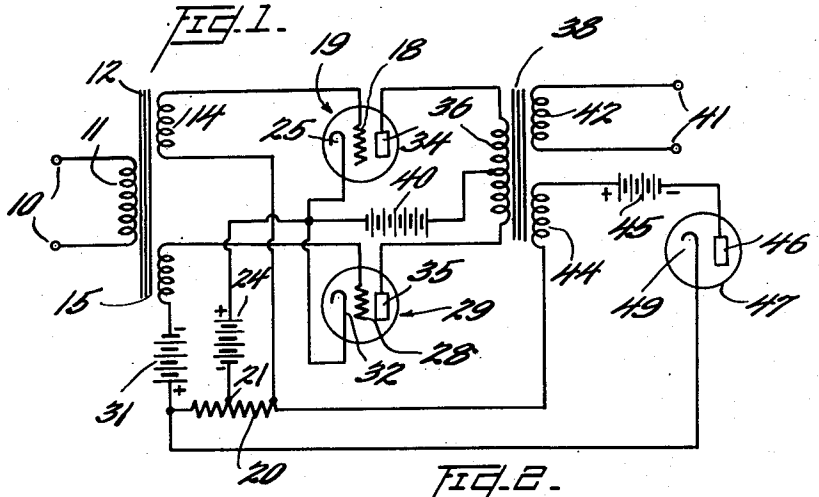


FIG. 2.

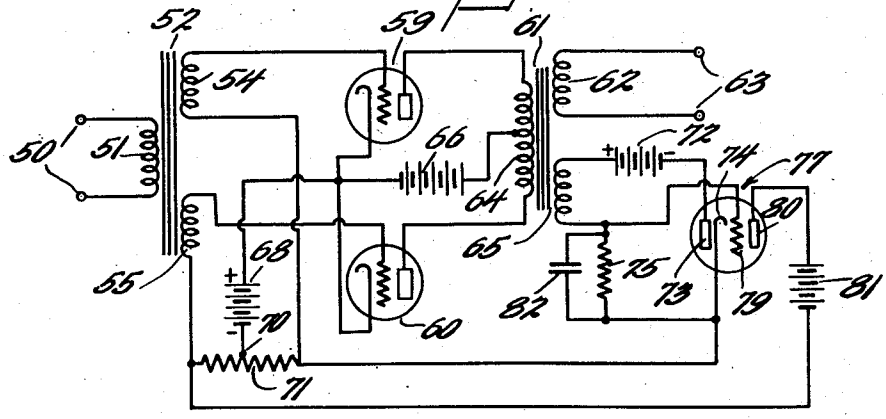


FIG. 3.

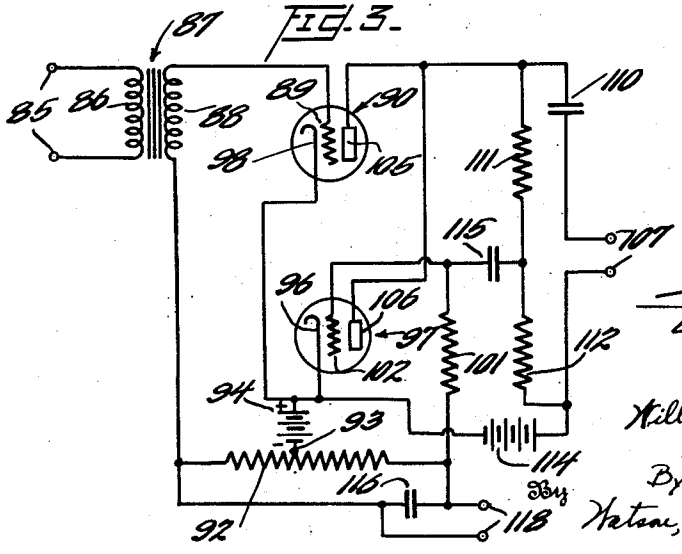
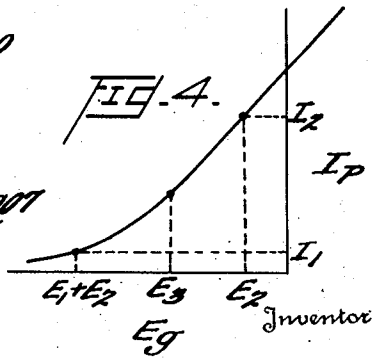


FIG. 4.



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FIG. 5.

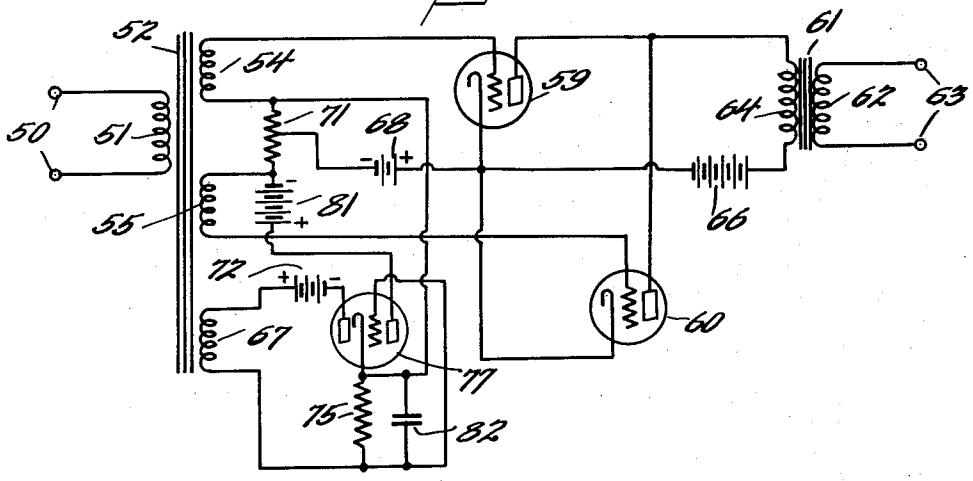
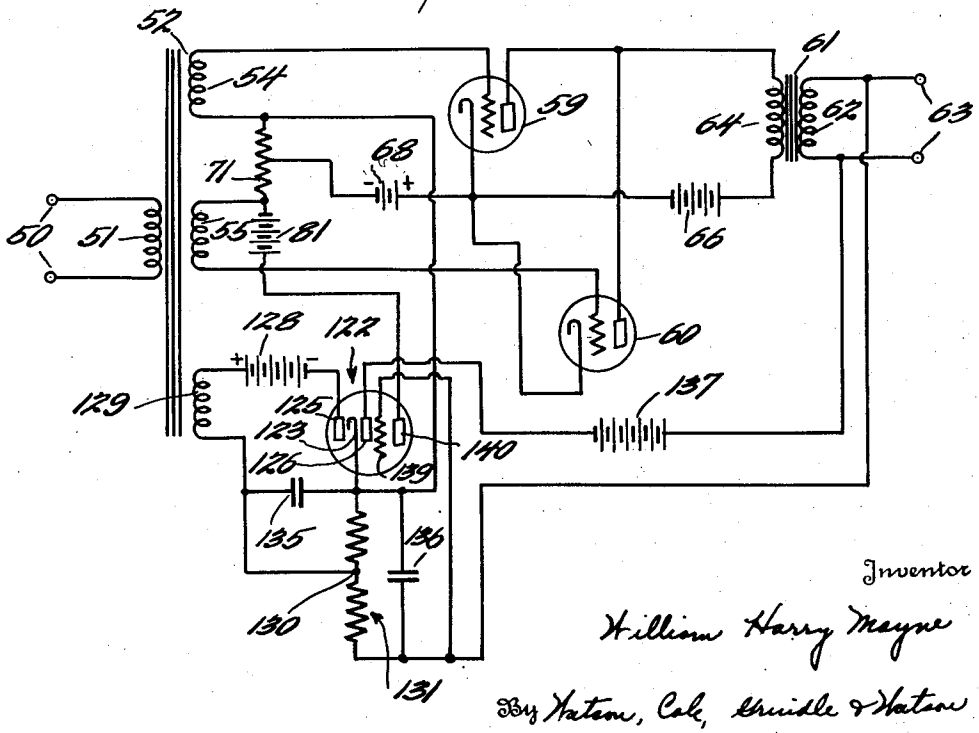


FIG. 6.



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VOLUME CONTROL FOR ELECTRICAL SIGNALS

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Application March 8, 1940, Serial No. 323,009

1 Claim. (Cl. 179—171)

This invention relates to improvements in methods of and apparatus for controlling the amplitude of wave-form signals and has for its principal object the automatic control of the gain in an amplifier in response to variation in amplitude of the signals impressed thereon.

It is common practice in various fields to regulate amplifier gain by means of a control circuit operable by and in response to the signal energy in such manner as to reduce the gain when the level of signal energy is high and to increase the gain when the level is low. Circuits for achieving this result are widely used in radio receiving systems in order to compensate in part for fading of signals from distant transmitters and in order to establish a generally uniform signal level for the reception of stations of different but comparable field strength. Circuits functioning in the reverse sense, to vary the amplifier gain inversely to the amplitude of the received signal energy are also employed to a considerable extent in the reproduction of recorded music signals, and to a lesser extent in the reception of transmitted music signals, in order to expand the volume range. Thus in the preparation of recordings of the type employing a record groove, there is a limit to the intensity of signal which can be so recorded, since signals of high amplitude tend to cause the cutting stylus to break down the walls between adjacent grooves. Again, there is a lower limit of amplitude which must be observed in such recordings, the signals of very low amplitude producing insufficient effect on the recording mechanism and the record to permit of proper reproduction. It is consequently the practice in the preparation of such recordings to control the signal either manually or automatically so as to reduce the higher amplitudes and increase the lower amplitudes, whereby the recording may register only such signal amplitudes as fall within the described limits. Similar precautions are observed in the broadcasting of music signals to establish a range of volume which can be satisfactorily dealt with by the transmitter and by the ordinary receiving equipment. Thus by amplifying the signal in inverse ratio to the strength of the signal, an approximation of the original volume range may be established in the reproduction. Such devices may be referred to as "volume expanders."

In these and other applications of gain control, it has been difficult heretofore to achieve as wide a variation of the amplification factor as is desirable. For example, a common type of gain control heretofore employed has regulated the degree of amplification by controlling the grid bias of a tube in the amplifier. It can be shown, however, that with such an arrangement it is difficult to reduce the gain to a low value without introducing distortion, since the usual thermionic valve is constructed so as to operate on the more nearly linear portion of its plate current-grid voltage curve only when the gain exceeds a predetermined minimum. Reduction of the gain to a low value results in operation of the valve on an arcuate portion of the curve, and the plate current does not vary uniformly in response to change in the applied grid voltage.

It is therefore an object of the invention to avoid these difficulties and to provide an amplifying circuit in which the gain may be varied from a maximum down to nearly zero without appreciable signal distortion.

In order to accomplish this result it is proposed to feed the signal energy through two paths, to combine the output of these paths in opposition, and to control the gain in each path in such manner that when minimum gain is required, the signal output of the two paths will substantially cancel. Preferably the arrangement is such that when minimum gain is to be effected, the valves in both paths are functioning substantially on the linear portion of the I_p—E_g curve, so that even for an extremely small or zero gain, the signals are undistorted. On the other hand, when maximum amplification is desired, the gain in one path is reduced to a minimum, whereby distortion of the signal in that path may result, but since the gain in the other path is concurrently the maximum, the combined energy output of the two paths is derived primarily from that path in which the valves are functioning on the linear portion of the I_p—E_g curve, so that distortion is not appreciable.

A further object of the invention is to provide, with a circuit of the character described affording two paths for signal energy, a grid bias control for the valves in the two paths which is responsive to and operable in accordance with the amplitude of the signal energy, so as automatically to establish the gain of the amplifier in accordance with the strength of the applied signal energy.

A further object of the invention is to provide an automatic gain control operating over a wide range without appreciable distortion and without the use of specially designed and expensive valves and other equipment.

Further objects and features of the invention

will be apparent from the following description taken in connection with the accompanying drawings, in which

Figure 1 is a wiring diagram of a circuit embodying the principles of the invention;

Figures 2 and 3 are similar diagrams illustrating modified circuit arrangements;

Figure 4 is a representation of an I_p—E_g curve of a thermionic valve such as may be employed in the practice of the invention; and

Figures 5 and 6 are wiring diagrams illustrating further modifications.

In order to facilitate an understanding of the invention, several preferred embodiments thereof are illustrated in the drawings and specific language is employed to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, the several embodiments being merely representative of specific methods of carrying out the principles of the invention. Further modifications and alterations are contemplated such as would occur to one skilled in the art to which the invention relates.

Figure 1 illustrates a control system which is operable automatically to reduce the gain on reception of signals of high amplitude and to increase the gain when signals of lower amplitude are received. Thus the signal energy, which may be amplified or otherwise treated in any desired manner before delivery to the control circuit, is fed to the input terminals 10 and thence through the primary winding 11 of a transformer 12. At this point the signal energy is divided into two paths by the use of separate secondary windings 14 and 15. One end of the winding 14 is connected to the grid 18 of a thermionic valve 19, the other end of the winding being connected to one end of a resistance 20. A center tap 21 on the resistance leads through a source of grid bias voltage 24 to the cathode 25 of the valve 19.

Similarly, one end of the secondary winding 15 is connected to the grid 28 of a thermionic valve 29. The other end of the winding 15 is connected through a source 31 of grid bias voltage to the opposite end of the resistance 20, the grid circuit for the valve 29 being completed through the center tap 21 of the resistance and the grid bias source 24 to the cathode 32 of the valve.

The outputs of the valves 19 and 29 are combined in opposition, the plates 34 and 35, respectively, of the valves being connected to opposite ends of the primary winding 36 of an output transformer 38. The main portion of the signal energy is applied to output terminals 41 by the secondary winding 42 of the transformer 38. Plate voltage for the valves is supplied from a source 40 which is connected between the cathodes of the valves and a center tap on the winding 36 of the transformer 38.

The transformer 38 includes an additional secondary winding 44 which is used to apply a portion of the output signal energy to control the gain of valves 19 and 29. Thus one end of the winding 44 is connected through a voltage source 45 to the anode 46 of a diode 47. The cathode 49 of the diode 47 is connected to one end of the resistance 20 and the opposite end of the secondary winding 44 is connected to the opposite end of this resistance.

The source of grid bias voltage 24 operates through the respective parts of the resistance 20 to supply substantially equal negative grid bias to the valves 19 and 29, but the grid 28 of valve 29 is supplied with an additional negative bias from the source 31. Thus the valve 19 will normally be operated on the linear portion of the I_p—E_g curve to deliver its normal output, whereas the strongly negative bias on the valve 29 will cause the latter to operate on the lower or arcuate portion of the curve so as to afford greatly reduced gain. Consequently, although the outputs of the valves 19 and 29 are combined in opposed phase, the output energy will be derived principally from the valve 19, which is operating on the linear portion of the curve, and distortion which might be occasioned by the excessive negative bias applied to the valve 29 will be minimized.

The anode 46 of the diode 47 is initially provided with a negative bias by the source 45, so that no current flows in the diode circuit. However, when the signal energy in the output transformer 38 exceeds a predetermined minimum, the potential developed in the winding 44 will exceed the potential established by the source 45, the anode 46 of the diode valve will become positive, and current will flow in the diode circuit. This will in turn develop potential differences across the two parts of the resistance 20, with the result that the bias voltage applied to grid 28 of valve 29 will become less negative, whereas the bias voltage applied to the grid 18 of the valve 19 will become more negative, the extent of this change in grid bias on the two valves being determined by the amplitude of output signal energy of the circuit. Thus the gain in the valve 29 will be increased and the gain in the valve 19 will be decreased, so that the output signal energy resulting from opposing the energy from these two paths will be decreased. The constants of the circuits may obviously be so selected that as the amplitude of received signal energy increases, a point is reached at which the outputs of the valves 19 and 29 are substantially equal, and the gain of the whole circuit will be reduced to an absolute minimum or to zero. Since both valves are then operating on a substantially linear portion of the I_p—E_g curve, there will still be no appreciable distortion of the signal.

It will be obvious that the relative amounts of signal energy flowing in the two paths will determine the extent of gain in each path required for proper operation. For example, if the amount of signal energy applied to the valve 29 is substantially less than that applied to the valve 19, greater gain must be effected in the valve 29 than in the valve 19 in order that the outputs of the two valves may nearly cancel at high levels of input signal energy to reduce the amplification factor of the whole system to a minimum. It is therefore intended, when reference is made herein to substantially equal gain in the two paths for the purpose of producing a minimum gain in the whole circuit, to include within the scope of the language an arrangement employing a relative gain producing the desired result when different amounts of energy are caused to flow in the two paths.

In order to employ the circuit shown in Figure 1 as a so-called volume expander, it is only necessary to delete the source 31 of grid bias voltage for the valve 29, so that valves 19 and 29 normally operate at nearly the same point on the I_p—E_g curve so that the gain of the whole system is very small. If, then, the input signal energy increases so as to cause current to flow in the circuit of the diode valve 47, the operating points of the two valves 19 and 29 will be displaced along the I_p—E_g curve to afford increased gain as hereinbefore explained. In other words, when the am-

plitude of the signal energy in the transformer 38 exceeds a certain predetermined minimum value, the gain represented by the difference in amplification of the two paths will be correspondingly increased, with appropriate increase in the volume range of the amplified signal.

The operation of the circuit will be more clearly understood from an inspection of Figure 4 of the drawings which represents a typical I_p—E_g curve of a thermionic valve such as may be used in the circuit just described. For example, if the potential applied to the grid 28 of the valve 29 by the source 31 be represented as E_1, and the potential applied to the grids of both valves 19 and 29 by the source 24 be represented as E_2, the plate current of the valve 29 may be represented at I_1 and the plate current of the valve 19 may be represented at I_2. The output of the whole circuit will be represented by the difference between these values of plate current and will be quite lage; since distortion occurs principally in the valve 29, by reason of operation on the lower portion of the curve, the distortion will be small since the output of the valve is small.

If the signal amplitude now increases to the extent necessary to cause current flow in the circuit containing the diode 47, the operating points of the two valves will be displaced toward each other on the curve, and as the signal continues to increase, these points of operation will eventually coincide at the point represented by E_3, at which point the output energy will be a minimum or zero. It will be observed that when this condition is established, the valves are both operating under favorable conditions so that distortion will be minimized.

Figure 2 illustrates a further embodiment of the invention in which the control bias for the valves is supplied in inverse relation to the amplitude of the signal energy. Thus the incoming energy is delivered to the terminals 50 and thence through the primary winding 51 of a transformer 52. Two secondary windings 54 and 55 are employed, the winding 54 delivering energy to the valve 59 and the winding 55 delivering energy to the valve 60 in precisely the manner described with reference to Figure 1. The output of valves 59 and 60 is fed in opposed relation to the primary winding 64 of a transformer 61 of which the secondary winding 62 delivers energy to the output terminals 63 while the secondary winding 65 delivers energy to a control circuit hereinafter described. Plate voltage for the valves is supplied from a source 66 connected between the valve cathodes and a center tap on the transformer primary 64. The initial grid bias voltages are supplied from a source 68 of which the positive terminal is connected to the cathodes of the valves 59 and 60 and the negative terminal is connected to the center tap 70 of a resistance 71, the ends of which are connected to the grids of the valves through the respective secondary windings 54 and 55. It will be appreciated that the circuit thus far described is identical with that shown in Figure 1 with the exception that the grid bias source 31 is omitted, the valves being adjusted to normally operate at or substantially at the same point on the I_p—E_g curve, to afford minimum gain as hereinbefore explained.

One end of the secondary control winding 65 is connected through a source of bias voltage 72 to the anode 73 of a diode-triode valve 77, the cathode 74 of which is returned through a resistance 75 to the opposite end of the winding 65. As in the previously described embodiment, no current flows in the diode circuit until the energy developed in the winding 65 exceeds a predetermined minimum, at which time the bias afforded by the source 72 will be exceeded, the anode 73 will become positive with respect to the cathode 74, and current will flow in the diode circuit, with the result that a potential difference will be established across the resistance 75. The resistance 75 is also connected to the grid 79 of the triode circuit, and the bias on the grid 79 becomes more negative as the potential across the resistance 75 increases, thus regulating the flow of current in the circuit including the cathode 74, the plate 80, the plate voltage source 81, and the resistance 71, to vary the potential difference across the latter. A by-pass condenser 82 affords a path for pulsating current in the triode circuit.

It will be appreciated that when no current flows in the diode circuit between the cathode 74 and the anode 73, as will be the case when the received signal amplitude is low, the associated triode will deliver maximum plate current. Maximum potential will then be developed across the resistance 71, and the operating points of the valves 59 and 60 will be displaced widely on the I_p—E_g curve, so as to afford maximum gain as hereinbefore described. When, however, the level of received signal energy increases, current will flow in the diode circuit, the grid 79 of the triode will be rendered more negative to reduce the potential developed across the resistance 71, and the difference in grid bias applied to the valves 59 and 60 will be correspondingly reduced, so that the points of operation of these valves will be moved toward each other on the I_p—E_g curve to reduce the gain effected thereby. Eventually, as the input signal energy continues to increase, the points of operation of the valves 59 and 60 will reach approximately the same point on the I_p—E_g curve, and the gain will be reduced to a minimum.

It will be understood that the diode and triode elements are incorporated in one unit merely for convenience; separate units, employing separate but connected cathodes, could be provided if desired.

In Figure 3 is shown an embodiment of the invention which is in some respects simpler than those previously described. Thus the energy to be amplified is supplied to the input terminals 85 and thence through the primary winding 86 of a transformer 87, one end of the secondary winding 88 being connected to the grid 89 of a valve 90, and the other end being connected to one end of a resistance 92. The center tap 93 of this resistance is connected through a source of grid bias voltage 94 to the cathode 96 of a valve 97 and the cathode 98 of the valve 90. The other end of the resistance 92 is connected through a resistance 101 to the grid 102 of valve 97.

The operating voltage for the grid 102 is derived from the combined outputs of the valves 90 and 97. Thus the plates 105 and 106 of the respective valves are connected to each other and the output is delivered to output terminals 107 by means of a resistance coupling including the condenser 110 and the resistance 111 and 112, the source 114 of plate voltage for these valves being connected between the remote end of these resistances and the valve cathodes 96 and 98. The grid 102 of valve 97 is connected through condenser 115 to the adjacent ends of resistances 111 and 112. The resistance 92 is shunted by a

condenser 116 and the opposite ends of the resistance are fed with control voltage from terminals 118 by control circuits which may be constructed as described with reference to Figures 1 and 2.

It will be seen that this circuit permits the use of resistance coupling and of an input transformer having a single winding, and is to this extent a simplification of the circuits hereinbefore described. Except that the driving voltage applied to the grid 102 of valve 97 is supplied from the subtractive outputs of valves 97 and 90, so that there must always be a residual signal to excite the grid, the operation is quite similar to that described in connection with the aforementioned figures, bias voltages on the valves being varied in accordance with variation in amplitude of the received signal so as to displace the operating points of the valves on the I_p—E_g curve and thus automatically regulate the gain.

Turning now to Figure 5, it will be observed that the arrangement of the circuit elements is generally similar to that shown in Figure 2, and to simplify the description, the same reference numerals are applied as in Figure 2 to elements functioning similarly. There is one minor difference in the circuit arrangement, the input energy being delivered to the grids of the valves 59 and 60 in opposed phase relation, and the outputs of the valves being combined by directly connecting the anodes of the valves. It will be appreciated that this alteration is more or less obvious and is an arrangement which may be employed in any of the circuits described herein. With either arrangement the outputs of the valves may be described as "opposed," this language being used in the generic sense to signify the combination in opposed phase relation of energy flowing in the two paths.

A more significant distinction between the circuits shown in Figures 2 and 5 is the derivation of control energy in Figure 5 from the input rather than the output side of the valves. Thus in Figure 5 the control energy is taken from the input transformer 52 by a secondary winding 67, in lieu of the secondary winding 65 of the form of the invention shown in Figure 2. The control circuit including the valve 77, is otherwise identical with that shown in Figure 2 and the grid bias on the valves 59 and 60 is similarly varied.

Certain advantages are secured with the modified arrangement shown in Figure 5. Thus by the use of the variation in amplitude level of the incoming signals to control the gain of the amplifier, greater controlling effect can be obtained, since this effect is independent of gain. In other words, when the control voltage is derived from the output of the valves 59 and 60, such voltage decreases as the gain decreases, and consequently as the output approaches the normal level, little or no control voltage is available. It is of course highly desirable, in the event the control voltage is derived from the incoming signal, to so adjust the constants of the circuit that the gain varies inversely as a linear function of the signal.

In the further modification illustrated in Figure 6, the general principle is the same as that involved in the operation of the circuits shown in Figures 2 and 5, but the control voltage is derived both from the incoming signal and the output of the main valves, so that the advantages of both systems are obtained. This involves alteration only of the control circuit including the control valve, and the reference numerals used in Figures 2 and 5 to designate corresponding elements of the main circuit are employed in Figure 6.

The control valve indicated at 122 is constructed to afford in effect two diodes having a single cathode 123 and anodes 125 and 126. The anode 125 is connected through a source of anode voltage 128 and a secondary winding 129 associated with the transformer 52 to the tap 130 of a resistor 131, and thence through one end of the resistor to the cathode 123, by-pass condensers 135 and 136 being associated with the resistor 131. The anode 126 is connected through a source of anode voltage 137, the secondary winding 62 of the transformer 61, and the resistor 131 to the cathode 123. The grid 139 of the valve 122 is connected to that end of the resistor 131 which is remote from the cathode, and the output anode 140, supplied with voltage from a source 81, varies the potential difference across the resistor 71 to vary the grid bias of the valves 59 and 60 as in the form of the invention shown in Figure 2.

It will be apparent from a comparison of the circuit shown in Figure 6 with those previously described that the control voltage which serves to vary the grid bias of the main valves is a function of both the input and the output signal energy, and adjustment of the gain is therefore correspondingly improved, control voltage being available from the incoming signal even though the combined energy output of the valves 59 and 60 is quite low, so that the proper gain value is promptly established.

Whether the energy delivered to the control circuit is derived from the input or the output side of the amplifying means, or from both, it is obviously appropriate to state that the control circuit is operable by and in response to variation in amplitude level of the signal energy.

It will be appreciated that the invention is especially applicable to signaling devices in which a very wide range of gain control is desirable. Such is the field of radio receivers for use in automobiles, in which the received signal varies widely in strength while the vehicle is in motion. Another important field is geophysical exploration, including seismic surveying and the like, in which it is desirable to maintain a generally uniform amplitude level in a record of seismic impulses where the amplitude of the incoming signal may vary in the ratio of 600:1 or more. It will be appreciated that the circuit described herein is applicable to amplification control of signal energy at both radio and audio frequencies, and that the circuits illustrated in the drawings can in general be introduced at any convenient point in any amplifying system for wave-form energy and may be used with or without additional amplification as desired.

Having thus described the invention, what is claimed as new and desired to be secured by Letters Patent is:

In a gain control for wave-form signal amplifiers, the combination with thermionic valve amplifying means affording two paths for signal energy, means combining the outputs of said valve means, means feeding back a portion of the combined output energy to one of said valve means, and means controlling the relative amplification effected by said valve means to cause the outputs thereof to approach or recede from a common amplitude level.

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