Jan. 14, 1936. R. P. BALLOU 2,027,510

ELECTRON TUBE APPARATUS

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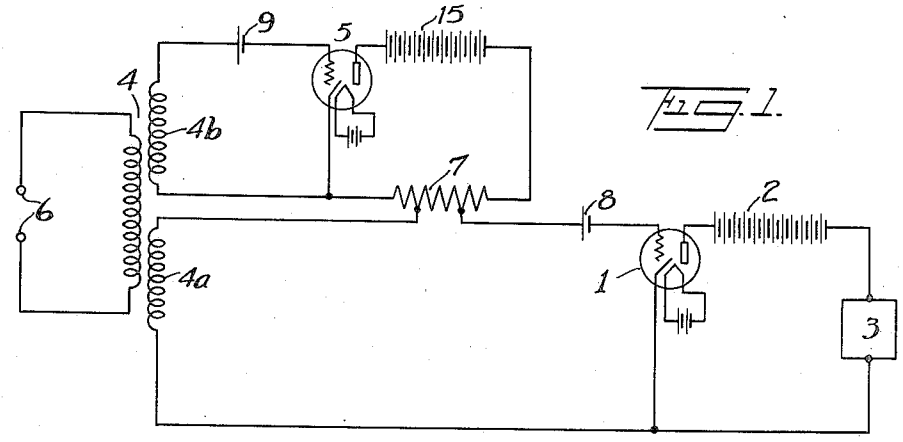


FIG. 1.

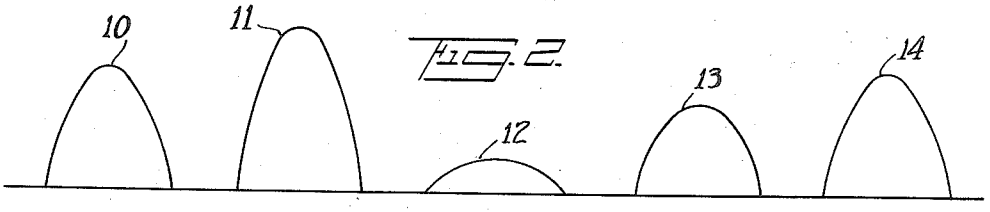


FIG. 2.

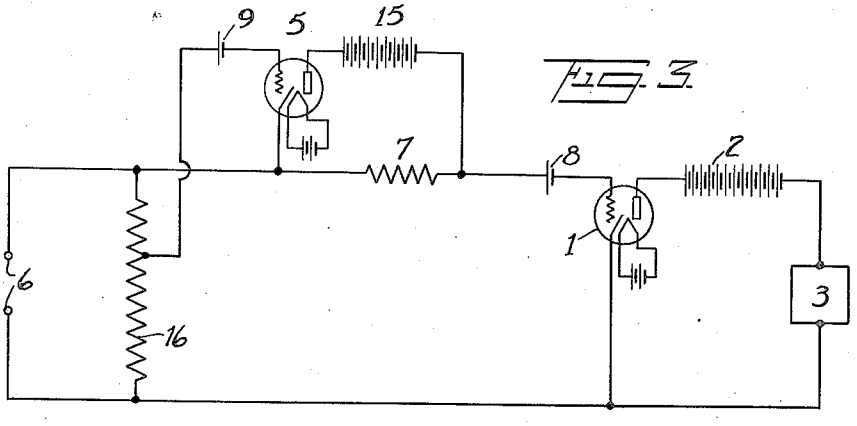


FIG. 3.

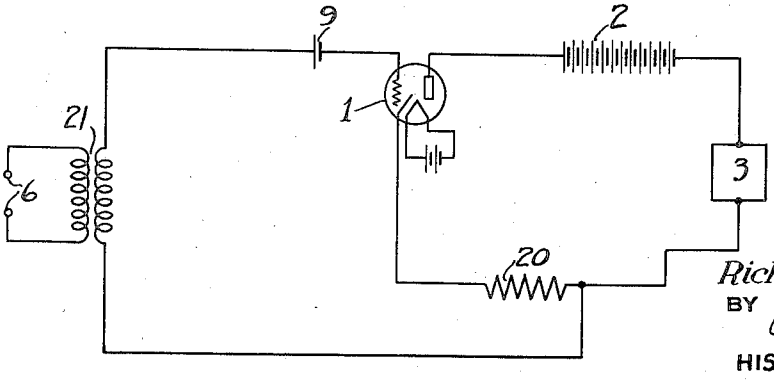


FIG. 4.

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FIG. 5.

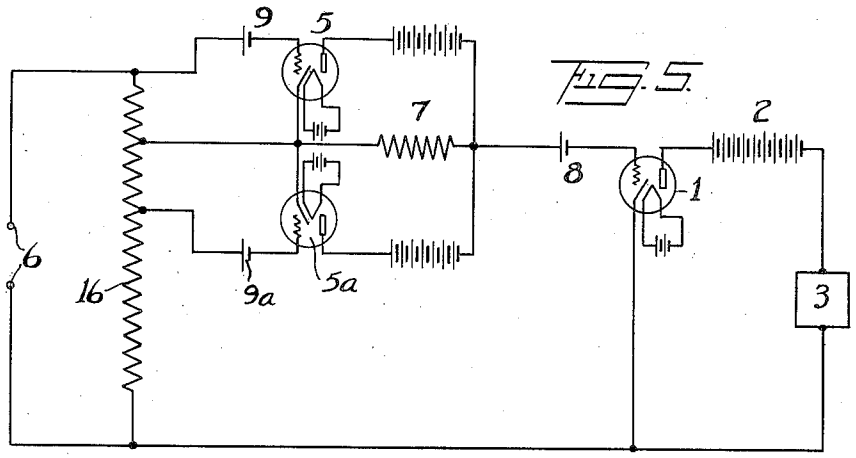
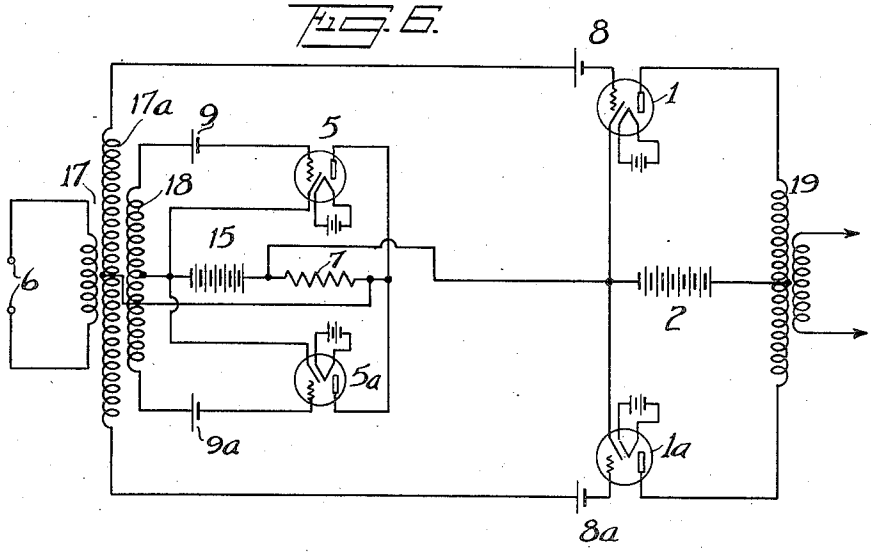


FIG. 6.



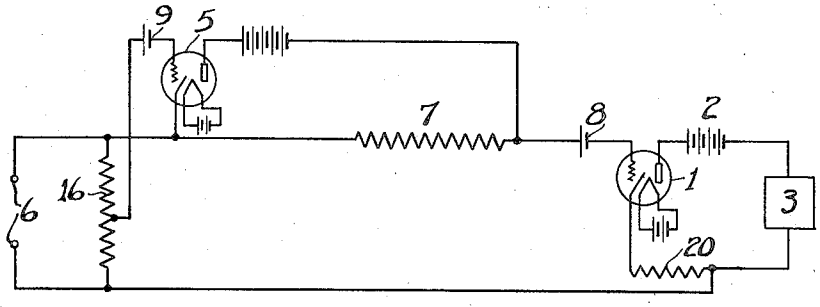


FIG. 7.

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Fig. 8.

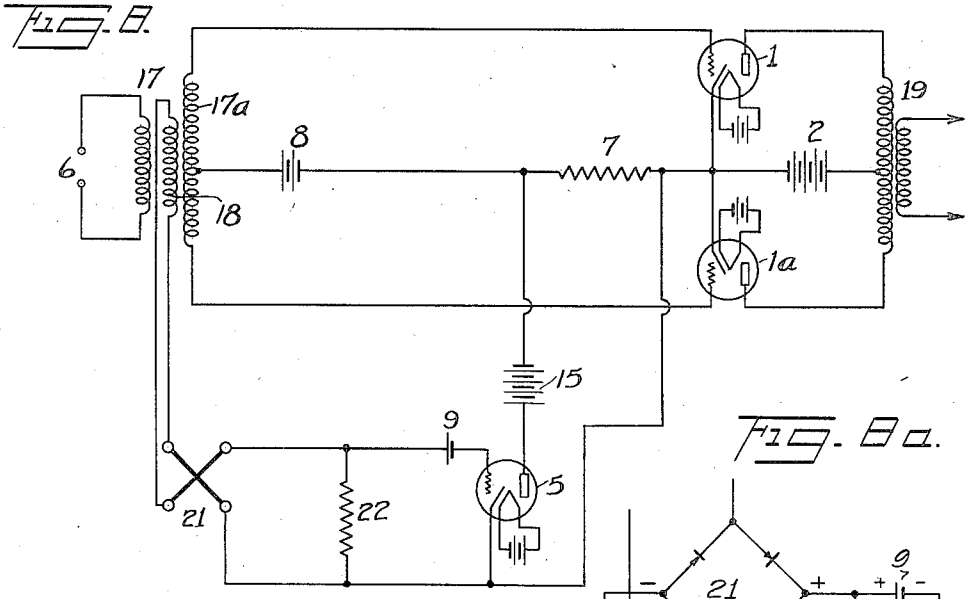
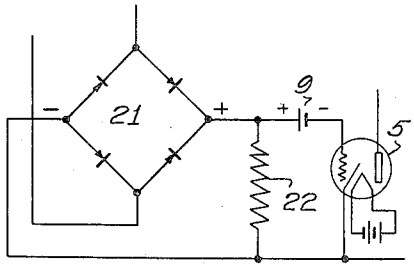
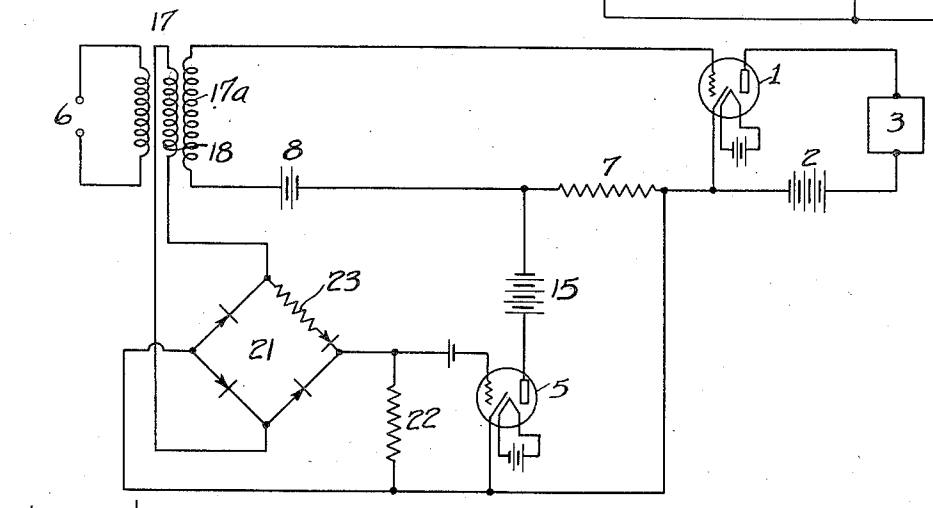


Fig. 8a.





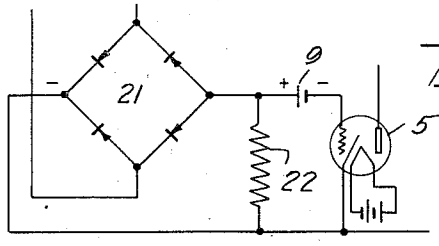


Fig. 9.

Fig. 8b

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ELECTRON TUBE APPARATUS

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Application February 26, 1932, Serial No. 595,319

12 Claims. (Cl. 179—171)

My present invention relates to a method of controlling the mutual characteristic of an electron tube circuit, and to means for carrying out the new method. More particularly, the invention comprises a method for straightening out the curved mutual characteristic of a vacuum tube, thus gaining an increase in the over-all efficiency and output of a vacuum tube amplifier by permitting operation without distortion over a wider range of the tube's mutual characteristic than hitherto found possible with a particular type of circuit.

The mutual characteristic of a vacuum tube having three or more elements is a curve representing the relation between applied grid voltage and output plate current. It is said to be static if the plate voltage is kept constant, or dynamic if, as in usual operating conditions, the battery voltage remains constant and the plate voltage decreases with increasing positive grid excitation. Such curves are ordinarily substantially linear over a relatively short portion of their length, corresponding to a relatively small range of applied grid voltage. The dynamic curves are generally linear over a relatively greater range than the static curves. While various operating conditions may imply the dynamic condition the method of compensation hereinafter disclosed is equally applicable to either condition. When used as an audio amplifier, the operation of the tube has had to be limited to this relatively small range of applied grid voltage to prevent distortion of the applied grid voltage, introduced into the output by the curvature of the mutual characteristic. One object of the present invention is thus to provide a method of, and means for, increasing the available range of operation of an audio amplifier in a class A circuit. Another object is to improve the operation of a push-pull class B amplifier by providing a more definite cut-off point on the lower end of the mutual characteristic.

Broadly the method comprises the compensation of one or both ends of the mutual characteristic of a tube by the addition of a voltage in the grid circuit which voltage is a continuous function of the excitation voltage and which is so superimposed thereupon as to leave the midpoint of the characteristic unchanged while applying gradually increasing compensation toward one or both of the extremities thereof; the superimposed negative voltage acting to decrease the positive potential and to increase the negative potential applied to the grid by the excitation voltage in such a manner as to increase the range of the linear portion of the mutual characteristic. Preferably the compensating negative voltage for the grid of the tube whose mutual characteristic is to be compensated varies with the plate current of a second tube to the grid of which the excitation voltage is also applied, for, in this manner, the distortion of the applied grid voltage may be made just sufficient to counteract the distortion introduced by the tube, with the result that the output plate current is substantially proportional to the excitation voltage over a wide range. The method may be applied to either or both ends of the mutual characteristic as desired and, should such a result be desired, could be so applied as to increase, rather than eliminate, the curvature of the mutual characteristic.

For a better understanding of the invention reference may be had to the accompanying drawings of which: Fig. 1 is a simple circuit illustrating the preferred method of correcting the curvature of the upper end only of the mutual characteristic. Fig. 2 is a diagram of various voltage and current wave forms explanatory of the operation of Fig. 1. Fig. 3 is a circuit of the type of Fig. 1 but arranged for correcting the lower end of the mutual characteristic. Fig. 4 is a circuit illustrating an alternative method of correcting the curvature of the upper end of the mutual characteristic, basically different. Fig. 5 is a circuit combining features of the circuits of Figs. 1 and 3 to straighten out both ends of the mutual characteristic. Fig. 6 is a circuit arranged to compensate both ends of the characteristics of two tubes of a push-pull stage of audio amplification. Fig. 7 is a circuit combining features of Figs. 3 and 4 for compensating both ends of the characteristic of a single audio amplifier. Fig. 8 is a circuit illustrating the use of a full wave rectifier and a single compensating tube to improve the operation of a push-pull amplifier. This circuit is equivalent to that of Fig. 6 in performance. Fig. 8*a* is a fragmentary view of Fig. 8 showing the connections of the rectifier for a class A amplifier. Fig. 8*b* is a fragmentary view of Fig. 8 showing the connections of the rectifier for a class B amplifier. Fig. 9 is a circuit similar to that of Fig. 8 but including means for applying greater compensation to one end of the mutual characteristic than to the other end. As shown, this circuit is equivalent to that of Fig. 5 in performance.

In Fig. 1, the amplifier 1 whose characteristic is to be compensated is shown with its plate connected through a suitable source of potential 2

with a load device 3. Device 3 may be coupling to a succeeding amplifier or may represent a loud speaker or some other load. An input transformer 4 having a secondary 4a for supplying the excitation voltage to the grid of tube 1 and a secondary 4b for supplying excitation voltage to the grid of a compensating tube 5 has its primary connected across the input terminals 6 of the circuit. A resistor 7 in the plate circuit of tube 5 is so connected in the grid circuit of tube 1 as to cause the potential difference thereacross due to current flowing in the plate circuit of tube 5 to increase the negative bias of the grid of tube 1; fixed negative bias for tube 1 being provided by a battery 8 and for tube 5 by a battery 9.

With the above described circuit if a voltage wave of the form illustrated at 10 (Fig. 2) is impressed upon the transformer 4, the mutual characteristic of tube 5 will distort this wave into the form illustrated at 11 which results in a voltage drop across resistor 7 illustrated at 12. The potential difference across resistor 7 being opposite to that across secondary 4a, the wave impressed upon the grid of tube 1 will take the form illustrated at 13; being the difference between the wave forms 10 and 12. Tube 1 will distort this impressed voltage in the same way that tube 5 distorted the original voltage wave, with the result that the output current wave will have the form illustrated at 14, which is similar to the impressed wave 10. In Fig. 2 no amplification is illustrated for simplicity and the transformer is assumed to be distortionless. Only the positive half cycle of the various waves has been illustrated in Fig. 2 as it is only during this portion of the cycle that the characteristic of tube 1 will be compensated. Thus the circuit of Fig. 1 increases the range of operation of the audio amplifier 1 by superimposing upon the excitation voltage the negative voltage due to the potential difference across resistor 7 which is a continuous function of the excitation voltage and thus in effect, extending the upper extremity of the linear portion of the mutual characteristic. The circuit thus makes possible the operation of the tube with grid voltages of greater amplitude with corresponding increase in efficiency and power output.

If, for any reason, it is desired to increase the curvature of the upper end of the mutual characteristics only a slight change in the circuit of Fig. 1 would be required for this purpose. This change involves only the reversal of the connection to resistor 7; that is, the battery 8 would be connected to the end of resistor 7 connected to the cathode of tube 5 and the upper end of secondary 4a would be connected to the end of resistor 7 connected through the plate battery 15 with the plate of tube 5. This might be desirable in case the mutual characteristic of the circuit were linear—usually a sign of approaching saturation.

If the lower end rather than the upper end of the characteristic of tube 1 is to be compensated the circuit of Fig. 3 may be employed. Fig. 3 differs from Fig. 1 only in the substitution for the transformer 4 of resistance coupling to the input terminal 6 by a resistor 16, and in the connections of the compensating tube 5 which, in Fig. 3, is arranged for the application of positive potential to the biasing battery 9 of tube 5 during the half cycle when negative potential is applied to the biasing battery 8 of tube 1; for this purpose the grid of tube 5 is connected through battery 9 with a tap along resistor 16 and the cathode of tube 5 is connected to the end of resistor 16 to which the grid of tube 1 is connected through battery 8 and resistor 7. With this arrangement when the end of resistor 16 connected to the cathode of tube 1 is positive with respect to the other end thereof, current will flow through the plate circuit of tube 5 and cause the potential difference across resistor 7 to increase the negative potential applied to the grid of tube 1, thus compensating the lower end of the characteristic by the addition of a variable negative voltage to the excitation voltage during the negative half cycle thereof. In audio amplification this circuit of Fig. 3 is of particular value.

Obviously either transformer or resistance coupling to the input terminal 6 could be employed with the circuits of Figs. 1 and 3 as desired.

In Fig. 4 is illustrated an arrangement for compensating the upper end of the mutual characteristic of tube 1 which does not require the provision of the compensating tube 5. In Fig. 4 a compensating resistor 20 is inserted in the plate circuit of tube 1 and the potential difference across this resistor due to current flowing therethrough is superimposed upon the excitation voltage of the tube to add a negative voltage thereto during the positive half cycle of the excitation voltage, which negative voltage continuously increases as the excitation voltage approaches its peak. For this purpose one end of the secondary of the input transformer 21 is connected to the cathode of tube 1 through resistor 20; the other end thereof being connected to the control grid of the tube. The grid biasing battery 9 may be included in the grid connection as shown, or, if desired, grid bias may be provided by shunting a portion of resistor 20 with a large capacity condenser. With the circuit above described compensation is effected not only in the input circuit but, to a certain extent, in the plate circuit as well. The distortion of the excitation voltage by the potential difference across resistor 20 will not be such as to give a complete linear relationship between the excitation voltage and the plate current but will substantially increase the efficient operating range of the tube and decrease the distortion introduced thereby. The circuit is simpler than that of either Fig. 1 or Fig. 3 in not requiring the provision of a compensating tube but is not as satisfactory if absolutely constant plate voltage is required and, as mentioned heretofore, cannot give as complete compensation as is given when a compensating tube is employed. In this case the plate circuit must be resistive, rather than highly inductive, so that there is actually a change in plate current throughout each cyclic change in grid voltage.

In Fig. 5 a circuit of the type of Figs. 1 and 3 but arranged for compensating both ends of the characteristic of tube 1 is indicated. In this circuit two compensating tubes 5 and 5a are used. The grid of tube 5 is connected through the biasing battery 9 with one end of the resistor 16 connected across the input terminals 6. The grid of tube 5a is connected through the grid biasing battery 9a with a tap along resistance 16. The cathodes of tubes 5 and 5a are connected to a second tap on resistance 16 between the grid connections thereto and the grid of tube 1 is connected through grid biasing battery 8 and resistor 7 with the last mentioned tap on

resistor 16. Resistor 7 is common to the plate circuits of both tube 5 and tube 5a. With this arrangement during the half cycle, when the end of resistor 16 connected to the grid of tube 5 is positive with respect to the other end of resistor 16, the current through the plate circuit of tube 5 causes a potential drop across resistor 7 in a direction to decrease the positive grid potential applied between battery 8 and the cathode of tube 1, which is connected, of course, to the other end of resistor 16. The upper end of the characteristic of tube 1 is thus compensated by tube 5. During the other half cycle of the input wave, the potential applied to the grid of tube 5a will cause a potential drop across resistor 7 in a direction to increase the negative potential applied to the grid of tube 1 and thus compensate the lower end of the characteristic of this tube. The resistor 16 could, of course, be replaced by an input transformer, if desired.

In Fig. 6 double end compensation of two tubes of a push-pull stage of amplification is illustrated. In Fig. 6 two tubes 1 and 1a whose characteristics are to be straightened are arranged with their control grids connected through the respective biasing batteries 8 and 8a to opposite ends of the secondary 17a of an input transformer 17 to the mid-point of which the cathodes of tubes 1 and 1a are connected through resistor 7. The compensating tubes 5 and 5a are connected across an additional secondary winding 18 of transformer 17; their control grids being connected through the biasing batteries 9 and 9a respectively with opposite ends of the winding 18 and their cathodes connected to the mid-point thereof. The plate battery 15 serves in common for tubes 5 and 5a, its positive terminal being connected through resistor 7 with the plates of these tubes, and its negative terminal being connected with the cathodes of the tubes. Similarly the plate battery 2 serves in common for the plate circuits to tubes 1 and 1a. An output transformer for the push-pull amplifying stage comprising the tubes 1 and 1a is indicated at 19.

With the arrangement of Fig. 6 during the half cycle when the upper end of the secondary of transformer 17 is positive with respect to the lower end, tube 5 operates to decrease the positive potential applied to tube 1 and to increase the negative potential applied to tube 1a. During the other half cycle tube 5a operates to decrease the positive potential applied to tube 1a and to increase the negative potential applied to tube 1. Thus the circuit operates to compensate both ends of the characteristics of both tubes 1 and 1a.

Very satisfactory double end compensation can be obtained with the simple circuit of Fig. 7 which combines features of the circuit of Figs. 3 and 4.

In Fig. 7 the lower end of the characteristic of tube 1 is compensated by the tube 5 in the same manner as explained in connection with Fig. 3; the grid of tube 5 being connected to a tap along the resistance coupling 16 and the cathode of tube 5 being connected to the same end of resistor 16 as is the grid of tube 1 through resistor 7. As in Fig. 4, resistor 20 is included in the plate circuit of tube 1 to apply a degree of compensation to the upper end of the characteristic; the cathode of tube 1 being connected to the other end of resistor 16 through this resistor 20. The potential difference across resistor 20 due to flow of current in the output circuit is in a direction to reduce the positive grid excitation voltage and also, of course, to cut down the effective plate potential with increasing plate current thus introducing some compensation into both grid and plate circuits.

In Fig. 8 is illustrated a circuit in which a single compensating tube in cooperation with a four-element full wave rectifier (which may be of the metal oxide type) compensates both ends of the mutual characteristic of two tubes of a push-pull amplifier. The two tubes 1 and 1a whose characteristics are to be compensated have their grids connected to opposite ends of the secondary 17a of input transformer 17, their cathodes connected together and to the mid-point of secondary 17a through the compensating resistor 7 and their plates connected to opposite ends of the primary of the output transformer 19, all as in Fig. 6. Fixed grid bias for both tubes 1 and 1a is provided by battery 8 in the common portion of their grid circuits. The third winding 18 of transformer 17, instead of being connected to the grids of two compensating tubes as in Fig. 6, is connected across the alternating current terminals of a full wave rectifier indicated diagrammatically at 21. A resistor 22 is connected across the direct current terminals of rectifier 21. The grid of the single compensating tube 5 is connected, through grid biasing battery 9, with one end of resistor 22, and the cathode of this tube is connected to the other end of this resistor. The cathode of tube 5 is connected to the cathodes of tubes 1 and 1a and one end of resistor 7, and the plate of tube 5 is connected, through the plate battery 15 to the other, or grid end of this resistor.

The specific connections of resistor 22 to the rectifier 21 and the particular value selected for battery 9 depend upon the type of amplifier circuit with which the compensating circuit is to be employed. When used with a class A amplifier, as compensation is desired whenever the instantaneous excitation voltage departs from zero in either direction, the grid end of resistor 22 is connected to the positive direct current terminal of the rectifier as shown in Fig. 8a, and battery 9 is so chosen as to insure substantially no current through resistor 7 when the potential difference across resistor 22 is zero. Thus, departure from zero excitation voltage in either direction causes a flow of current through resistor 7 in a direction to add an increasingly negative voltage to the grids of both tubes 1 and 1a in the same manner as described in connection with Fig. 6.

When used with a class B amplifier, however, the grid end of resistor 22 is connected to the negative direct current terminal of rectifier 21 as shown in Fig. 8b, and battery 9 is so chosen that maximum current flows through resistor 7 when the instantaneous excitation voltage is zero, as in this class of circuit the nearer to cut off that tubes 1 and 1a can be biased without distortion the better, and the connection and adjustment above indicated permit of a greater negative biasing of tubes 1 and 1a by the introduction of an additional negative bias during approximately zero instantaneous voltage which is gradually removed as the excitation voltage increases positively for either tube.

The compensating circuit of Fig. 8 may be used, of course, for double end compensation of one instead of two tubes if desired and when so used may be readily modified, as shown in Fig. 9, to give a greater degree of compensation on

one end of the mutual characteristic than on the other. To effect this difference in compensation a resistor 23 may be inserted in one arm of the rectifier 21 to vary the potential difference across resistor 22, and consequently the plate current of tube 5, with opposite halves of the excitation voltage wave. With the connections illustrated in Fig. 9 when the excitation voltage across tube 1 is positive no current flows through resistor 23, but when the excitation voltage applied to tube 1 is negative current flows through resistor 23 and consequently the voltage across resistor 22 is relatively less during the negative half cycle of the impressed voltage. Except when a resistance 23 is used in one arm of the rectifier circuit the resistance 22, although it may be used, is theoretically unnecessary.

It will be understood that the circuit of Fig. 9 is but one possible arrangement for obtaining unequal compensation in the two ends of a mutual characteristic. In Fig. 5, for example, this same result could be obtained by insertion of a resistance in one or the other of the plate circuits of tubes 5 and 5a, and in Fig. 7 the same general result may be obtained by proper choice of values for resistors 7 and 20.

As will be readily appreciated, a two-element instead of a four-element rectifier could be used in the circuit of either Fig. 8 or Fig. 9; the two elements being connected across the winding 18 and having their output sides connected through resistor 22 with the mid-point of winding 18, if equal compensation at both ends of the mutual characteristic is desired, or with winding 18 at a point suitably removed from the mid-point or with a resistance in one of the A. C. leads if unequal compensation of the two ends of the characteristic is desired.

The combination of a full wave rectifier and a single compensating tube is thus capable of performing all of the functions of two compensating tubes in straightening both ends of the mutual characteristics of one or two tubes of a class A amplifier and, in addition, is capable of improving the operation of class B amplifiers by providing a more definite cut-off point on the lower end of the mutual characteristic.

Various circuits have now been described, with particular reference to their utility in so distorting the grid excitation voltage of an audio frequency amplifier as to increase the range of operation and the efficiency and output of the tube by, in effect, increasing the linear portion of the mutual characteristic thereof. The method and circuits disclosed may be used for compensating the mutual characteristic of any multiple element tube, whether of the type illustrated or of any other type as, for example, one having a screen grid. As heretofore indicated in connection with Figs. 8 and 9, the new method and the new circuits described may be used in connection with other than audio amplifiers. Furthermore, a circuit such as that shown in Fig. 1 for example could be used to deliver a frequency just twice that of the input voltage. For this purpose (considering one half cycle) the grid bias for the compensating tube is so chosen as to permit appreciable current to flow in the plate circuit thereof during only half of each (half) cycle and the value of the resistance 7 is so chosen that the potential difference thereacross when maximum current flows in the plate circuit of the compensating tube is exactly equal to the positive grid excitation voltage for tube 1. Under these conditions, with proper phase relation, the potential drop across the resistance 7 neutralizes the excitation voltage for tube 1 at its peak and thus causes tube 1 to respond as if excited by a frequency twice that impressed upon the input transformer. Also, as mentioned heretofore, any one of the circuits could be used if desired to increase, rather than decrease, the distortion by merely reversing connections to the compensating resistance. The new circuits or others adapted for the practice of the method may be advantageously employed in any one, several or all stages of a multi-stage fundamental circuit. As compared with methods heretofore employed for decreasing distortion in electron tubes the present method is superior in that it does not depend on uncertain and widely varying grid characteristics of the tubes and in that it can be used in a circuit in which the grids draw no current. In all the circuits except Figs. 6, 8 and 9 the compensation is shown introduced directly in the grid lead, the conventional way. If, however, the compensation be introduced in the cathode lead (and it makes no difference, since it is a part of the grid circuit) a common source of filament supply can be used for both the fundamental and compensating tubes. This is the case in Fig. 6; however to use Fig. 6 with a common filament battery it would be necessary to move the plate battery 15 from the location indicated, inserting it between the two connections on the extreme right of resistance 7. All filaments in the circuit would then be at the same potential.

The following is claimed:

1. The method of distorting the wave form of the voltage applied to the grid of a vacuum tube which comprises rectifying a voltage varying with that to be distorted, exciting a compensating tube with the instantaneous rectified voltage and utilizing variations in the current delivered by the compensating tube to vary the voltage applied to the grid of the first mentioned tube, the rectified voltage being impressed as a positive voltage to the compensating tube and the compensating tube being so biased as to yield substantially no current when the instantaneous excitation voltage is zero.

2. The method of distorting the wave form of the voltage applied to the grid of a vacuum tube which comprises rectifying a voltage varying with that to be distorted, exciting a compensating tube with the instantaneous rectified voltage and utilizing variations in the current delivered by the compensating tube to vary the voltage applied to the grid of the first mentioned tube, the rectified voltage being impressed as a negative voltage to the compensating tube and the compensating tube being so biased as to yield maximum current when the excitation voltage is zero.

3. The method of distorting the wave form of the voltage applied to the grid of a vacuum tube which comprises rectifying a voltage varying with that to be distorted, exciting a compensating tube with the instantaneous rectified voltage and utilizing variations in the current delivered by the compensating tube to vary the voltage applied to the grid of the first mentioned tube, the rectification of the voltage varying with that to be distorted being so effected as to impress a relatively lower voltage upon the compensating tube during one half cycle of the voltage wave than during the other half cycle to effect unequal distortion of the voltage ap-

plied to the first-mentioned tube during opposite half cycles of the excitation voltage.

4. An electric circuit including in combination an amplifier tube, a full wave rectifier, a compensating tube connected in the output circuit of the rectifier, a source of excitation voltage for said amplifier and said rectifier, a resistor in the output circuit of said compensating tube and so connected in the input circuit of the amplifier tube as to superpose an increasing negative voltage upon the excitation voltage for the amplifier tube as the output current of said compensating tube increases.

5. An electric circuit according to claim 4 wherein the grid of said compensating tube is connected to the positive direct current terminal of said rectifier and such grid biasing means are provided for said compensating tube as to cause substantially no current to flow through said resistor when the instantaneous excitation voltage is zero whereby double end compensation of the mutual characteristic of said amplifier tube is obtained.

6. An electric circuit according to claim 4 wherein the grid of said compensating tube is connected to the negative direct current terminal of said rectifier and such grid biasing means are provided for said compensating tube as to cause maximum current to flow through said resistor when the instantaneous excitation voltage is zero.

7. An electric circuit comprising in combination a source of excitation voltage a pair of amplifiers connected in push-pull arrangement for excitation by said source, a resistor common to the input circuits of said amplifiers, a rectifier connected to said source, a compensating tube having its control grid connected to one direct current terminal of said rectifier and its cathode connected to the other direct current terminal of said rectifier, said resistor being so connected in the output circuit of said compensating tube as to superpose an increasing negative voltage upon the excitation voltage for said amplifiers as the output current of said compensating tube increases.

8. An electric circuit according to claim 7 wherein the control grid of said compensating tube is connected to the positive direct current terminal of said rectifier whereby minimum current flows in the plate current of said compensating tube when the instantaneous value of the excitation voltage is zero and both ends of the mutual characteristics of both amplifier tubes are compensated.

9. An electric circuit according to claim 7 wherein the control grid of said compensating tube is connected to the negative direct current terminal of said rectifier whereby maximum current flows in the output circuit of said compensating tube when the instantaneous value of the excitation voltage is zero permitting adjustment of the bias of said pair of amplifiers closer to the cut-off values.

10. An electric circuit for compensating both ends of the mutual characteristic of an amplifier tube comprising in combination a source of alternating excitation voltage for said amplifier tube, a resistor in the input circuit of the tube, means for causing a unidirectional current varying with the magnitude of the excitation voltage to flow through said resistor when the instantaneous excitation voltage of said source departs from zero in either direction, said last mentioned means including at least one compensating tube having said resistor in the output circuit thereof and including a second resistor adapted to vary the relation between the current through said first mentioned resistor and the magnitude of the instantaneous excitation voltage with opposite half cycles of the excitation voltage, the direction of current through said first mentioned resistor being such as to cause the potential difference thereacross to operate as a superposed negative voltage to the excitation voltage in said tube.

11. A circuit according to claim 10 wherein said means for causing current to flow through said first mentioned resistor include a full wave metal oxide rectifier connected between said source and said compensating tube to impress upon said compensating tube a varying direct voltage when the excitation voltage departs from zero said rectifier being arranged to impress upon said compensating tube a relatively greater voltage during one half cycle of the excitation voltage than during the other half cycle thereof.

12. An electric circuit according to claim 10 wherein said means for causing current to flow through said first mentioned resistor include a four-element full wave rectifier across the alternating current terminals of which a voltage varying with the excitation voltage is impressed and across the direct current terminals of which the input terminals of said compensating tube are connected, said second resistor being included in series with one element of said rectifier whereby the voltage impressed across said compensating tube depends upon the phase as well as the magnitude of the excitation voltage.

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