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ELECTRIC AMPLIFYING CIRCUITS

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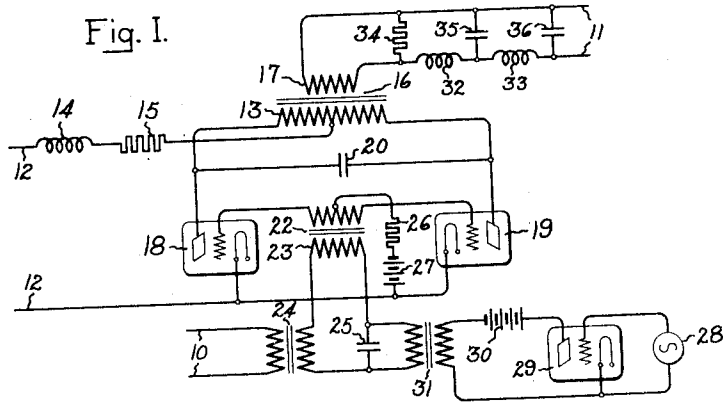


Fig. 2.

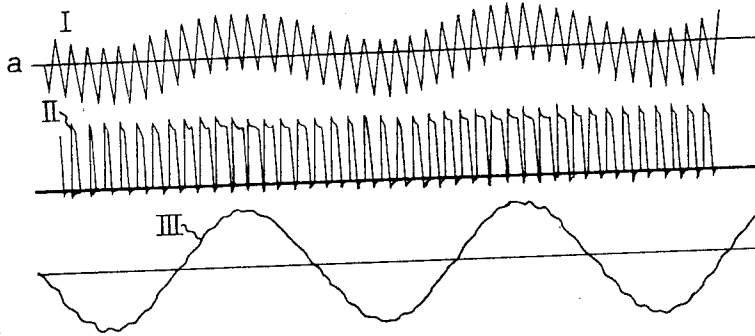


Fig. 3.

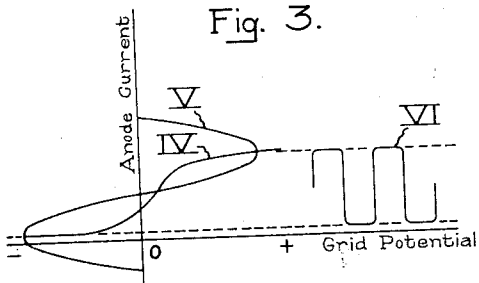
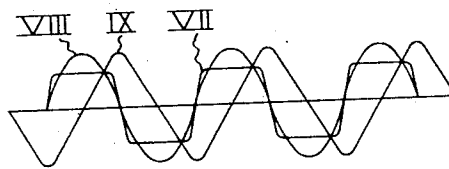


Fig. 4.



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## UNITED STATES PATENT OFFICE

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## ELECTRIC AMPLIFYING CIRCUITS

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My invention relates to electric circuits for amplifying electric signals and more particularly to electric circuits including controlled electric valves for accurately reproducing and amplifying electric signals.

Heretofore there have been proposed various arrangements for amplifying electric signals such as are common in telephony, radiotelephony, the transmission of pictures, etc., by means of grid controlled electric valves, the grids of which are energized in response to the signal to be amplified. These arrangements of the prior art are, however, adapted for use only in connection with electric valves of the pure electron discharge type in which the current in a valve is continuously controlled by the potential on its grid. Such arrangements have the inherent disadvantages of large tube losses and low power output for ordinary operating voltages.

It is an object of my invention to provide an electric circuit for amplifying electric signals which shall overcome the disadvantages of the arrangements heretofore proposed and will be efficient, and reliable and which shall be capable of delivering a large power output.

It is a further object of my invention to provide a circuit for amplifying electric signals which shall be adaptable for use either in connection with electric valves of the pure electron discharge type or with vapor electric discharge valves in which the starting of current in a valve is controlled by the potential impressed upon its control grid but in which the current in the valve may be interrupted only by reducing the anode potential below its critical value.

It is a further object of my invention to provide an improved excitation for electric valves used in electric amplifying circuits.

In accordance with my invention, I provide an electric circuit, including electric valves, for converting direct current to alternating current and I provide high frequency periodic potential of a particular wave form for exciting the grids of the valves. This high frequency grid potential is modulated by the signal to be amplified. The output of such

a circuit will have a component of the same frequency as the high frequency grid excitation and another component of the same frequency as that of the signal to be amplified. By means of a suitable filter the high frequency component is eliminated leaving only that component having the frequency of the signal to be amplified.

For a better understanding of my invention, together with other and further objects thereof, reference is had to the accompanying drawing and its scope will be pointed out in the appended claims. Fig. 1 of the drawing is a diagrammatic representation of my invention as applied to an electric power converting apparatus of the type known in the art as a parallel inverter, by means of which an electric signal may be amplified; Fig. 2 comprises reproductions of oscillograms of certain operating characteristics of the apparatus illustrated in Fig. 1, and Figs. 3 and 4 show certain characteristics of one feature of my invention by means of which I secure the desired excitation for the grids of the electric valves.

Referring more particularly to Fig. 1 of the accompanying drawing, I have illustrated an electric power converting apparatus for amplifying an electric signal impressed upon the circuit 10 and delivering the amplified output to the circuit 11. This power converting apparatus derives energy from the direct current circuit 12 and includes an inductive winding 13 provided with an electrical midpoint connected to the positive direct current terminal through a smoothing reactor 14 and a resistor 15. The inductive winding 13 may be a reactor or, as shown, the primary winding of a transformer 16, the secondary winding 17 of which is connected to the output circuit 11. Between opposite terminals of the inductive winding 13 and the negative direct current terminal 12 are connected electric valves 18 and 19. These valves may be of any of the several types well known in the art but I prefer to use vapor electric discharge valves provided with an anode, a cathode and a control grid. A capacitor 20 is connected between the circuits of the electric valves 18 and 19 for commutat-

ing the current between them. The grid circuits of the electric valves 18 and 19 include opposite halves of the secondary winding of a grid transformer 22. The primary winding 23 of the transformer 22 includes the electric signal to be amplified, which may be derived from the circuit 10 by means of a transformer 24, and a source of relatively high frequency alternating potential of substantially triangular wave form, shown as derived from the terminals of the capacitor 25. In some cases it may also be desirable to include a current limiting resistor 26 and a negative bias battery 27 in the grid circuit of the electric valves 18 and 19.

The apparatus for generating the high frequency potential of substantially triangular wave form comprises a source of high frequency alternating potential of substantially sine wave form shown as the alternating current generator 28, which may be of any of the several types well known in the art, an electric valve 29, preferably of the pure electron discharge type and provided with an anode, a cathode and a control grid, a source of direct current shown as a battery 30, a series transformer 31, and a capacitor 25. In order to filter from the output of the transformer 16 the component frequencies other than those appearing in the signal impressed upon the electric circuit 10, I have provided a filter circuit comprising reactors 32 and 33 connected in series with the circuit 11 and a resistor 34 and capacitors 35 and 36 connected across said circuit.

The above described apparatus relies for its operation upon the fact that, while it is necessary for current to flow continuously in either the electric valve 18 or 19, it is not essential that the time interval during which the current flows in these two valves should be equal. Current in the electric valves 18 and 19 corresponds to half cycles of the alternating current output of opposite polarity. by properly varying the ratio of the time during which current flows in the respective valves the average current over a complete cycle may be varied from approximately zero to maximum in either direction.

The operation of the electric power converting apparatus, which will be understood by those skilled in the art, is as follows: If a positive potential is initially impressed upon the grid of electric valve 18, current will flow from the positive direct current line 12 through the left hand portion of the inductive winding 13, and the electric valve 18 to the other direct current line 12. As the current builds up in the left hand portion of the inductive winding 13, this winding acts as an auto-transformer and a still more positive voltage is induced in the right hand portion. The full potential across the terminals of the winding 13, which is approximately twice that of the direct current circuit, is

impressed on the capacitor 20 which becomes charged to this potential. When the grid potential reverses its polarity, so that the grid of the valve 18 is made negative while that of the valve 19 is made positive, the capacitor 20 is short circuited through the electric valves 18 and 19. The potential across the capacitor 20 is opposite in direction to that tending to send the current through the electric valve 18 and many times its magnitude with the result that the current in this valve is instantly interrupted and current flows only in the valve 19. When the grid potential again reverses polarity, the current is transferred from electric valve 19 to electric valve 18 and the cycle is repeated indefinitely. The reactor 14 serves to maintain the current taken from the direct current circuit 12 substantially constant while the resistor 15 serves to limit the high frequency component of current delivered to the output circuit 11 as will be explained hereinafter.

In explaining the operation of the electric power converting apparatus as an amplifier, it will be assumed that a high frequency alternating potential of substantially triangular wave form appears at the terminals of the capacitor 25 and the operation of the apparatus for generating this alternating potential will be described hereinafter. It will also be assumed that the signal to be amplified is a 60 cycle alternating potential having an amplitude somewhat less than that of the high frequency potential. The resultant of these two potentials, which is applied to the grid circuit of the valves 18 and 19, is shown by Curve I of Fig. 2, in which the line *a* represents the cathode potential of the electric valves 18 and 19. Since the grid potentials of the valves 18 and 19 are opposite in polarity it is clear that the portions of the Curve I above the line *a* may be taken as the positive potential applied to the grid of the electric valve 18 while that portion of the Curve I below the line *a* may be taken as the positive potential applied to the electric valve 19. As the grid signal to be amplified varies from the maximum in one direction to the maximum in the other direction, it will be seen that the relative intervals during which the valves 18 and 19 are conducting vary between a maximum conducting period of the valve 18 and a minimum of the valve 19, to a maximum conducting period of the valve 19 and a minimum of the valve 18. Curve II of Fig. 2 is a reproduction of an oscillogram of the current output of one of the electric valves, for example, valve 18. The output curve of the valve 19 will be similar but displaced by 180° in time phase and having an opposite polarity with respect to the load circuit 11. The resultant output current will be an alternating current of a frequency the same as that of the high frequency grid exciting potential, but in which the positive and

negative half cycles are of unequal value. Such a wave is substantially the equivalent of a symmetrical wave plus a direct current component of a polarity dependent upon whether the positive or negative half cycle is the larger. This direct current component reverses its polarity at a frequency equal to that of the signal to be amplified and, by filtering out the high frequency component, the resultant output of the apparatus will be a periodic current of a frequency and wave form similar to that of the electric signal to be amplified. Curve III of Fig. 2 is a reproduction of an oscillogram of the amplifier output with a 60 cycle electric signal and approximately a 1000 cycle grid exciting potential. It will be obvious to those skilled in the art that the accuracy with which the electric signals may be reproduced increases with an increase in frequency of the grid exciting potential. As described above, I have provided a filter circuit comprising the series connected reactors 32 and 33 and the parallel capacitors 35 and 36 for filtering out the high frequency component of the output current. It has been found that the resistor 15 connected in series with the direct current line 12 and a relatively high resistance 34 connected across the primary winding 17 of the transformer 16 will aid in eliminating the high frequency component from the output circuit 11. However, this filter circuit is merely illustrative and any other form of filter circuit examples of which are well known in the art may be substituted in place thereof without departing from my invention.

While any arrangement for producing a high frequency alternating potential of substantially triangular wave shape may be used to supply the grid excitation of electric valves 18 and 19, I prefer to use the apparatus described above. In the operation of this apparatus the alternating current generator 28, which may be either of the dynamo-electric or the oscillation generator type, delivers a high frequency potential of substantially sine wave form to the grid circuit of the electric valve 29 which is preferably of the pure electron discharge type having a grid potential-anode current characteristic similar to that shown in Curve IV of Fig. 3. The amplitude of the alternating potential of the generator 28 is sufficient to considerably excite the valve 29 beyond saturation, that is, such as to operate the valve 29 at both extremes of the grid potential-anode current characteristic as shown by Curve V of Fig. 3. When the valve 29 is operating at either extreme of this characteristic curve it will be seen that a relatively large change in grid potential effects a very small change in anode current with the result that the anode current is of substantially rectangular wave form as illustrated by Curve VI of Fig. 3 and Curve VII of Fig.

4. Curve VIII of Fig. 4 represents the grid potential of the valve 29. The anode current of electric valve 29 is caused to flow through the capacitor 25 either by connecting it directly in series in the anode circuit or by inserting a series transformer 31 in order to step up the voltage applied to the capacitor 25. The voltage in abvolts appearing across a capacitor is represented by the equation

$$e = \frac{1}{c} i dt$$

where  $c$ =the capacity in farads;  $i$ =current in abamperes;  $t$ =time in seconds, so that, during those portions of the cycle of the anode current in which the current is constant, which would be for a complete half cycle if the anode current were exactly rectangular in wave form, the voltage across the capacitor 25 will build up at a constant rate and, when the anode current reverses its polarity, the capacitor 25 will likewise build up to an opposite polarity at a constant rate. The potential across the capacitor 25 is represented by Curve IX of Fig. 4, which, it is seen, is substantially triangular. The approximation of this curve to an exactly triangular wave is directly proportional to the approximation of the anode current to a rectangular wave which may be made very close by applying a very large grid potential to the electric valve 29.

While I have shown and described what I at present consider the preferred embodiment of my invention, it will be obvious to those skilled in the art that various changes and modifications may be made without departing from my invention and I, therefore, aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. Apparatus for amplifying an electric signal comprising a source of direct current and a load circuit, an interconnection between said source and said circuit including an inductive winding and an electric valve, means independent of the signal for periodically rendering said valve conducting, and means responsive to the signal to be amplified for determining the interval during which the valve remains conducting.

2. Apparatus for amplifying an electric signal comprising a source of direct current, a load circuit, an interconnection between said source and said circuit including an inductive winding and a pair of electric valves, means independent of the signal for periodically and alternately rendering said valves conducting, and means responsive to the signal to be amplified for determining the periods during which the valves remain conducting.

3. Apparatus for amplifying an electric

signal comprising a source of direct current, a load circuit, an interconnection between said source and said circuit including an inductive winding and a pair of electric valves, means for alternately rendering said valves conducting, and means responsive to the signal to be amplified for varying the ratio of the intervals during which said valves remain conducting.

4. Apparatus for amplifying an electric signal comprising a source of direct current, a load circuit, an interconnection between said source and said circuit including an inductive winding and a pair of electric valves, means for alternately initiating a flow of current in said valves, means responsive to the flow of current in one of said valves for interrupting the current in the other, and means responsive to the signal to be amplified for determining the time intervals between the starting of current in successive valves.

5. Apparatus for amplifying an electric signal comprising a source of direct current, a load circuit, an interconnection between said source and said circuit including an inductive winding and a pair of electric valves, means for alternately initiating a current in said valves, means responsive to the starting of current in one of said valves for interrupting the current in the other, and means responsive to the instantaneous value of the signal to be amplified for determining the difference in the time intervals between the starting of current in the successive valves.

6. Apparatus for amplifying an electric signal comprising a source of direct current, a load circuit, an interconnection between said source and said circuit including an inductive winding and a pair of electric valves, means for alternately starting a current in said valves, means responsive to the starting of current in one of said valves for interrupting the current in the other, and means for causing the difference in the time intervals between the starting of current in the successive valves to vary substantially in accordance with the instantaneous value of the signal to be amplified.

7. Apparatus for amplifying an electric signal comprising a source of direct current, a load circuit, an interconnection between said source and said circuit including an inductive winding and a pair of electric valves, each provided with a control element, means for energizing said control elements with a periodic potential of a frequency relatively high with respect to that of the signal and of an amplitude less than that of the signal, and means for modulating said high frequency potential with said signal.

8. Apparatus for amplifying an electric signal comprising a source of direct current, a load circuit, an interconnection between said source and said circuit including an inductive winding and a pair of electric valves,

each provided with a control grid, and a grid circuit for said valves including the electric signal and a source of alternating potential of substantially triangular wave form of a frequency relatively high with respect to that of the signal, and of an amplitude less than that of the signal.

9. Apparatus for amplifying an electric signal comprising a source of direct current, a load circuit, an interconnection between said source and said circuit comprising an inductive winding, the electrical midpoint of which is connected to one direct current terminal, a pair of electric valves, provided with control grids connected between opposite terminals of said inductive winding and the other direct current terminal, and a capacitor connected between the circuits of said valves for commutating the current between them, a grid transformer, grid circuits for each of said valves including opposite halves of the secondary winding of said transformer, an energizing circuit for the primary winding of said transformer including said electric signal and a source of alternating potential of substantially triangular wave form, of a frequency relatively high with respect to that of said signal and of lesser amplitude, and means connected in said output circuit for filtering substantially all frequencies except those of the signal.

10. The method of operating an electric valve, provided with a control element, for amplifying an electric signal, which comprises generating a periodic potential of substantially triangular wave form and of a relatively high frequency with respect to that of the signal and of a lesser amplitude, combining the signal with the high frequency potential, and applying the resultant to the control element of the electric valve.

11. The method of amplifying an electric signal which comprises generating a periodic potential of substantially triangular wave form and of a relatively high frequency with respect to that of the signal and of a lesser amplitude, combining the signal with the high frequency potential, controlling the average value of a periodic current in accordance with the difference in the time intervals of successive positive and negative half cycles of said combined potential wave with respect to a fixed potential, and filtering from said periodic current substantially all frequencies except those included in the signal to be amplified.

12. The method of amplifying an electric signal which comprises generating a periodic potential of substantially triangular wave form and of a relatively high frequency with respect to that of the signal and of a lesser amplitude, combining the signal with the high frequency potential, controlling the flow of current from a direct current source by means of said combined potential to produce

a periodic current of substantially rectangular wave form and constant amplitude and having an average value varying in accordance with the difference in the time intervals of successive positive and negative half cycles of said combined potential wave with respect to a fixed potential, and filtering from said periodic current substantially all frequencies except those included in the signal to be amplified.

In witness whereof, I have hereunto set my hand this 25th day of September, 1930.

BURNICE D. BEDFORD.