Jan. 15, 1929. 1,699,110

A. V. LOUGHREN

ALTERNATING CURRENT AMPLIFIER

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Fig. 1.

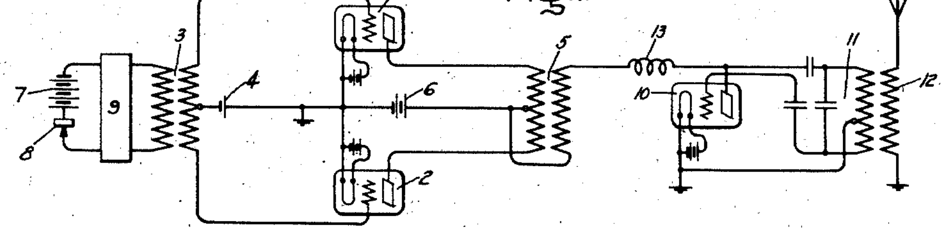

Fig. 2.

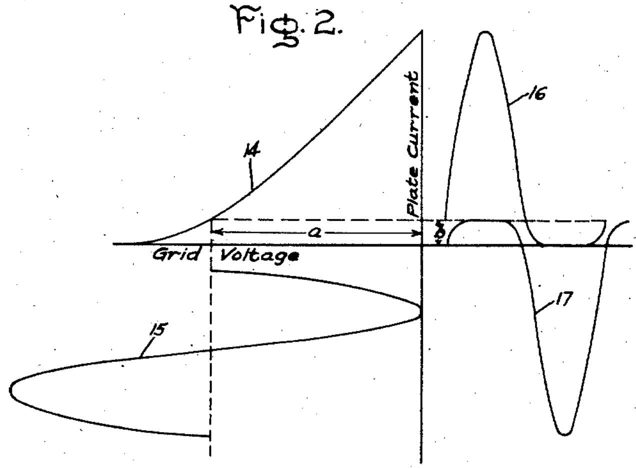

Fig. 3.

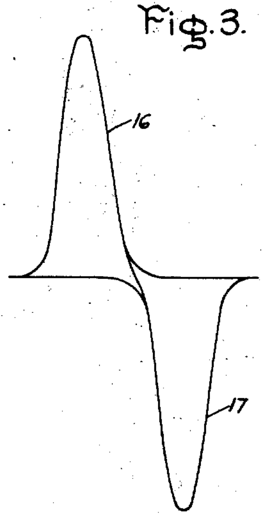

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Fig. 4.

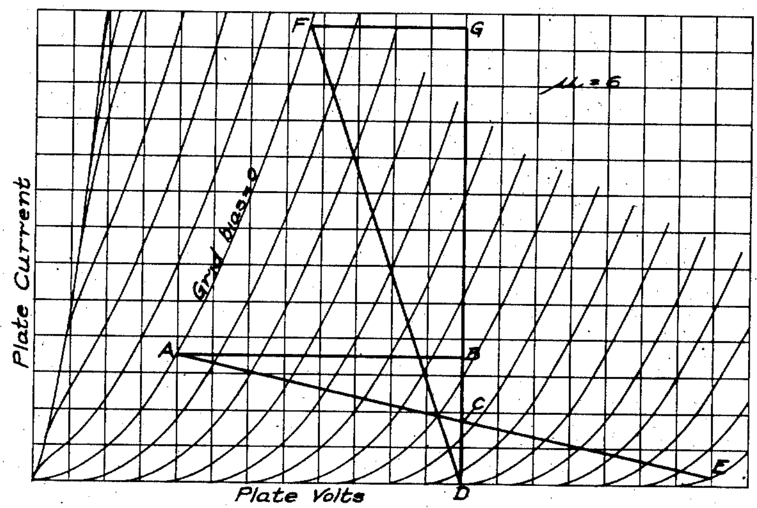
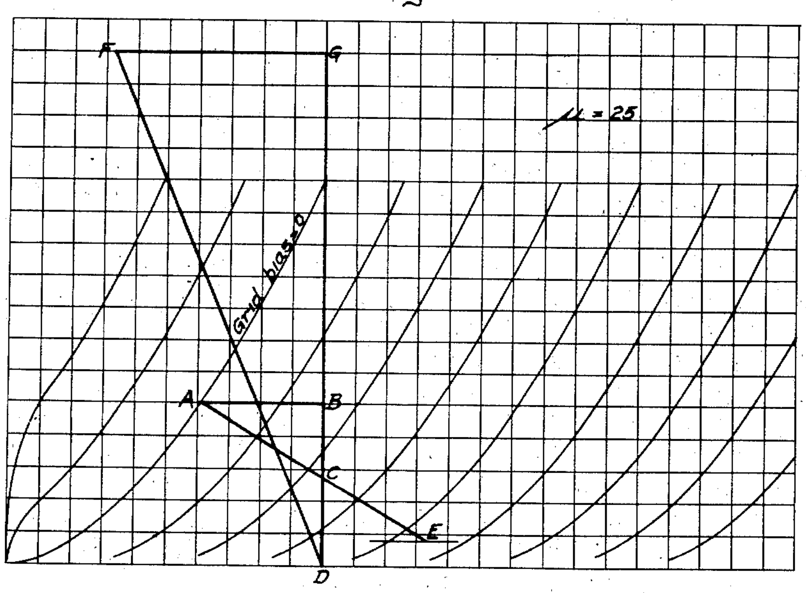


Fig. 5.



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Patented Jan. 15, 1929. 1,699,110

UNITED STATES PATENT OFFICE.

ARTHUR V. LOUGHREN, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ALTERNATING-CURRENT AMPLIFIER.

Application filed October 4, 1927. Serial No. 223,961.

My invention relates to means for amplifying alternating currents and more particularly to amplification circuits customarily known as of the "push pull" type. It has for its purpose to provide means whereby circuits of this type employing electron discharge devices of a certain rated capacity may be caused to produce in their output circuits far greater amounts of alternating current power than has heretofore been practicable.

Heretofore in the operation of circuits of this type it has been customary to adjust the anode current and voltage of the electron discharge devices at a value such that their product was equal to the rated anode dissipation of the tube. This is particularly true where the device is employed for the purpose of producing large amounts of alternating current power in its output circuit and in other applications the normal no load anode current value lies at the center of the straight portion of the characteristic curve of the tube. Since the maximum value of the alternating current component of the anode current can never exceed the no load anode current it can readily be shown that the maximum value of alternating current output can never exceed one half of the rated anode dissipation and in practical cases is generally below three tenths of this value. This practical value results from the fact that as the anode current approaches zero it no longer reproduces the impressed wave and distortion results. To eliminate this it is customary to operate the tubes with a negative grid bias such that during the negative half of the impressed alternating current wave the plate current does not fall below the lower limit of the straight portion of the anode current-voltage curve. This rated no load anode dissipation and the incident grid bias so limited the device that notwithstanding that an alternating current input having perfect regulation was available still the alternating current output power could never exceed the value mentioned.

I have found that by reducing the grid voltage to a value such that substantially no current flows in the anode circuit during no load conditions I am able not only to reduce the no load losses substantially to zero, but also to increase the distortionless alternating current power output to, in many cases, several times the rated anode dissipation.

The novel features which I believe to be characteristic of my invention will be set forth in the appended claims. My invention itself, however, both as to its organization and method of operation may best be understood by reference to the following description taken in connection with the accompanying drawings, in which Fig. 1 represents a circuit with which my invention may be employed and which is shown as a modulator. Figs. 2, 3, 4 and 5 represent curves indicative of the operation of my invention.

With reference to Fig. 1, 1 and 2 represent a pair of electron discharge devices the grids of which are connected to opposite extremities of the secondary winding of an input transformer 3, an intermediate point of which is connected through the grid biasing battery 4 to the cathodes of both devices. The anodes of these devices are likewise connected to opposite points on the primary winding of the output transformer 5 an intermediate point of which is connected to the positive side of the potential source 6. The negative side of this source is connected to the cathodes of both devices. For the purpose of impressing upon the grids of these devices an alternating electromotive force which is to be amplified I have shown the primary winding of the transformer 3 connected to a source of potential 7 and a microphone 8 through the intermediary of suitable additional amplifying means 9. 10 represents an electron discharge device which is employed as an oscillation generator and which is provided with the usual oscillatory circuit 11 which is adapted to supply high frequency currents to the load circuit 12 which is represented in the form of an antenna. Anode potential is supplied to the device 10 through a circuit including ground, source of potential 6, secondary winding of the transformer 5, radio frequency choke coil 13, space between the anode and cathode of the device 10 and ground. As thus arranged alternating currents produced by the source 8 are amplified by the devices 1 and 2 and caused to modulate the currents produced by the oscillation generator 10.

In practicing my invention I adjust the potential source 4 in such a way that the grids are maintained sufficiently negative with respect to the cathodes to substantially preclude the flow of anode current from these devices, or at least, to preclude the generation of third harmonics in a manner later to be set forth. The operation of the device, with the grid bias thus adjusted, may best be understood by reference to Fig. 2 where I have plotted at 14 a portion of the grid voltage anode current characteristic of the device. It will be seen that with the grid biased negatively to a value equal to *a* the anode current will be very small, this value being represented by *b*. If an alternating current wave having the form shown at 15 and an amplitude equal to *a* be impressed upon the grid of one of these devices the anode current will take the form shown at 16 reaching a very high value during the positive half cycle and zero during the substantial portion of the negative half cycle. Since the anode current curve of the opposite electron discharge device is 180° displaced in phase with respect to that of the first device this may be represented by the curve 17. It will be seen that while each of these curves 16 and 17 represents a badly distorted wave that the sum of the two as combined in the secondary winding of the output transformer represents an undistorted sine wave. Thus the positive half cycles of the input wave are amplified by one of the electron discharge devices and the negative half cycles are amplified by the other electron discharge device, these waves being combined to produce an undistorted sine wave in the secondary winding of the output transformer. For this reason I prefer to term my system a "push-push" amplifier as distinct from the well-known "push-pull" amplifier of the prior art.

While in Fig. 2 I have shown the characteristics of the device with a no load plate current equal to a small value flowing in the output circuits of each device it will, of course, be understood that in many cases an undistorted output may be had even though no plate current flows under no load conditions. In Fig. 3 I have shown the form of anode current curve which frequently results when the grid is so adjusted that no anode current flows under no load conditions. It will be seen that the curves 16 and 17, which correspond to the similarly numbered curves of Fig. 2 do not add up to produce a sine wave form near the point of intersection with the zero axis. I have found that this form of distortion of the output wave is represented by a pronounced third harmonic and other odd harmonics in the secondary winding of the output transformer and that this may be completely eliminated by permitting a small amount of no load current to flow. However, this no load anode current value, due to the additive effects of the two distorted waves, represents a value considerably below the straight portion of the anode current grid voltage characteristic curve, and a no load anode loss which is negligible.

Further advantages of my device are apparent from a consideration of Figs. 4 and 5. In each of these figures I have plotted the anode voltage anode current characteristics of a standard fifty watt tube of commercial construction with different bias voltages upon the grid. In Fig. 4 the tube employed was one having a ratio

$$\mu = \frac{\Delta E_p}{\Delta E_g}\Big]_{I_p = K} = 6$$

where ΔE_p = an increment of plate voltage change corresponding to an increment, ΔE_g, of grid voltage change, the plate current I_p remaining constant. In Fig. 5 the tube employed was one having this ratio equal to about 25.

Referring to Fig. 4 the area of triangle ABC is indicative of the power output of a single tube connected in the usual push pull circuit and operating with a no load anode current equal to CD. Due to the rated anode dissipation of the tube this value cannot be increased. During maximum alternating current in the output circuit the grid must swing between values represented by the curves which include points A and E corresponding respectively to zero grid volts and a minimum value determined by the curvature of the anode current anode voltage characteristic which will not give more than permissible distortion. The amplitude of the alternating current in the plate circuit will then be equal to BC, that of the anode voltage will be equal to AB and the load resistance will be represented by the slope of the line AC. The triangle FGD represents the output power from a pair of the same tubes operated with the grids biased to cut off in accordance with my invention and with practically the same internal heating of the tubes. It will be seen that the alternating current power output per tube is equal to about double that of the former case.

In accordance with the general principle that a maximum energy transfer from a current source may be had when the internal impedance of the source equals the external impedance, the maximum efficiency of a vacuum tube is attained when the external anode circuit resistance is equal to the internal anode resistance. Graphically this means that the lines FD and AC should be of the same slope as the anode voltage-current characteristic but opposite in sign. It will be seen that this is approximately attained in the case of the line FD, indicative of the operation of my invention, whereas a similar result is impracticable when the usual grid bias is employed.

I have found that a similar advantage

may be attained by my invention when tubes having a high μ are employed but that it is not so pronounced except as the grid of the tube is driven positive during a portion of one half cycle of the wave. This result is illustrated by the triangles FGD and ABC of Fig. 5 which correspond to the similarly lettered triangles of Fig. 4, the triangle of Fig. 5 being indicative of the operation of a tube having a ratio $\mu=25$. Of course, when the grids of the tubes are driven positive it is essential to a distortionless output that the voltage of the input to the tube should not vary appreciably with the flow of grid current. In the case shown in Fig. 5 the tube, the operation of which the triangles FGD and ABC are indicative, operated with very approximately the same internal heating whereas the alternating current output represented by the triangle FGD is far greater than that represented by triangle ABC. Likewise it will be noted that in the former case the tube may be operated into a proper external impedance for maximum efficiency since the slope of the line FD is practically equal to that of the anode current voltage characteristics.

Since the advantages resulting from the practice of my invention vary greatly with different types of tubes and since Figs. 2 to 5 are only indicative of the operation of particular types it will of course be understood, that these figures are presented only as a general indication of the results which may be had. For example in the case of tubes of low rated capacity and of low μ I have found that the resulting advantage is attained largely by virtue of the fact that the grids may be driven positive. I have found the same true with high μ tubes of large capacity. This, however, is a distinct advantage since when using the usual grid bias it is generally impracticable to drive the grids positive to any considerable degree due to distortion which results at the lower portion of the anode current grid voltage curve, such as at the points E in Figs. 4 and 5. I also find that greater advantages resulting from my invention may be expected when practiced in connection with tubes of large capacity.

While I have shown and described a single embodiment of my invention it will, of course, be understood that I do not wish to be limited thereto, since modifications may be made in the circuit arrangement and in the instrumentalities employed without departing from the spirit and scope of my invention as set forth in the appended claims.

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

1. In combination, a pair of three element electron discharge devices, means connecting said discharge devices in push pull relation including means for impressing alternating potentials upon the grids of both devices for amplification thereby and a source of potential for biasing the grids of said devices during said amplification to a negative value sufficiently great substantially to preclude the flow of no load anode current and such that current flows in each device through substantially the entire period of alternate half cycles of the alternating current wave when alternating potential is impressed upon the grids.

2. In combination, a pair of electron discharge devices, means connecting said discharge devices in push pull relation including an input circuit and an output circuit, means for impressing an alternating potential upon said input circuit for reproduction by said devices in said output circuit, a source of direct current potential connected to bias negatively the grids of said devices during said reproduction the value of said biasing potential being determined by the substantial absence of direct current in the anode circuits of said devices when no alternating potential is impressed upon the grids, said connecting means including a non-resonant output circuit and means for supplying energy from each device to said circuit thereby to combine the output currents from said devices in said non-resonant circuit to reproduce the impressed alternating current wave.

3. In combination, a pair of electron discharge devices, means connecting said discharge devices in push pull relation including means for impressing an alternating potential upon the control elements thereof, means for impressing a negative direct current potential on each of said control elements of value such that the flow of current from each of said devices during a substantial portion of alternate half cycles of the impressed alternating current wave is precluded and such that each device reproduces the other half cycle of the impressed wave with substantially true wave form, and means included in said connecting means for combining the current flowing from said devices during the last mentioned portion of the alternating current cycle to reproduce the impressed alternating current wave.

4. In combination, a pair of electron discharge devices, means connecting said devices in push pull relation including an input circuit, means for impressing an alternating current potential upon said input circuit for amplification by said devices and a source of potential connected to bias the grids of said devices during said amplification sufficiently to reduce the anode current to a value lying in the lower curved portion of the anode current grid voltage characteristic, said connecting means being adapted to

combine the output from said devices to produce an alternating current wave.

5. In combination, a pair of electron discharge devices, means connecting said devices in push pull relation including an input circuit and an output circuit, means for impressing an alternating current potential upon said input circuit for reproduction by said devices in said output circuit and a source of potential connected to bias the grids of said devices during said reproduction sufficiently to reduce the anode current to a value lying in the lower curved portion of the anode current grid voltage characteristic, said value being determined by the absence of odd harmonics of the impressed wave in the output circuit, said connecting means being adapted to combine the output from said devices to reproduce the impressed alternating current wave.

6. In combination, a pair of space discharge devices having control electrodes, means connecting said devices in push pull relation including means for impressing upon the control electrodes thereof alternating current potential for amplification thereby, means for impressing a steady biasing potential upon said grids during said amplification of a value such as to cause a small change in anode current from each of said devices during one half cycle of the alternating current wave and comparatively greater change in anode current during the opposite half cycle, said connecting means being adapted to combine the output from both of said devices to produce an alternating current wave.

7. In combination, a pair of space discharge devices having control electrodes, means connecting said devices in push pull relation including means for impressing upon the control electrodes thereof alternating current potential for reproduction thereby, means for impressing a steady biasing potential upon said grids during said reproduction of a value such as to cause one of said devices to repeat one half cycle of the alternating current wave and the other of said devices to repeat the opposite half cycle of said wave and to produce comparatively small change in plate current in each device during alternate half cycles, said connecting means being adapted to combine the currents from both of said devices to reproduce the impressed wave.

In witness whereof, I have hereto set my hand this 3d day of October, 1927.

ARTHUR V. LOUGHREN.