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R. A. HEISING

2,157,336

ELECTRON DISCHARGE APPARATUS

Filed Jan. 6, 1937

FIG. 1

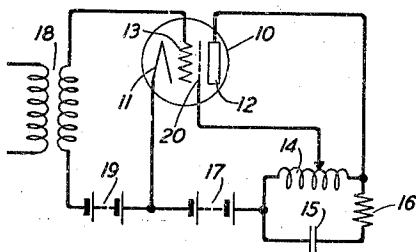


FIG. 2

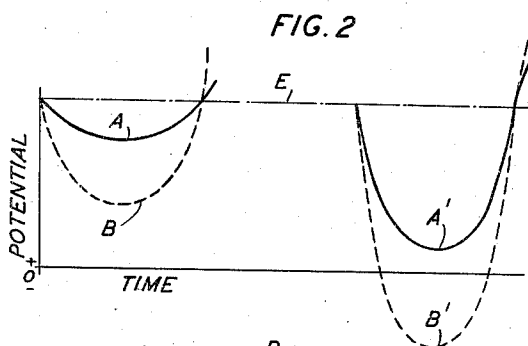


FIG. 3

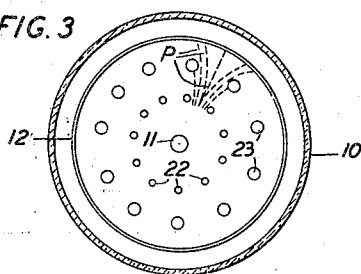


FIG. 4

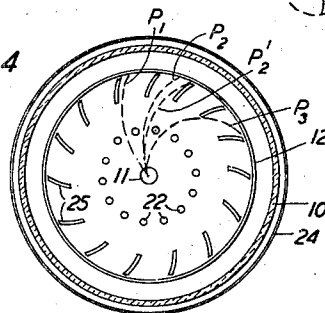


FIG. 5

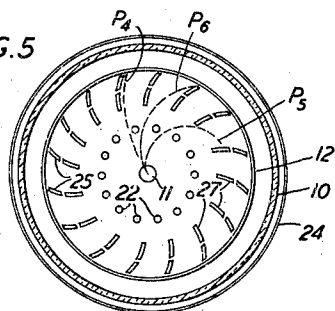


FIG. 6

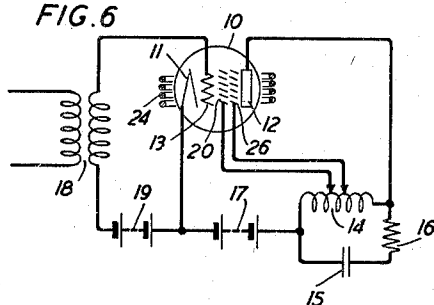
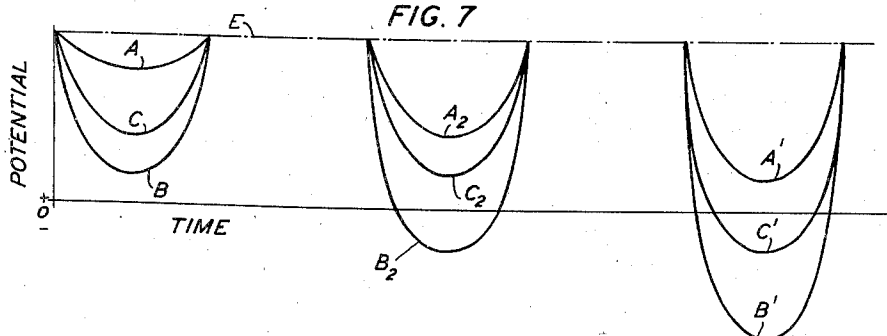


FIG. 7



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ELECTRON DISCHARGE APPARATUS

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15 Claims. (Cl. 179—171)

This invention relates to electron discharge apparatus and more particularly to electronic amplifiers of the type, generally designated as class C amplifiers, wherein the control electrode or grid is always at a negative potential with respect to all portions of the cathode and wherein the anode current is finite during the positive portions of variable potentials impressed upon the control electrode or grid and is zero during the negative portions of such impressed potentials.

As is known in the art, class C amplifiers may have a fairly high efficiency, for example of the order of 75 per cent, under certain conditions of operation. Among the more important elements contributing to the attainment of relatively high efficiencies are (1) the fact that the anode current flows throughout less than half the cycle of the alternating potential impressed upon the control electrode or grid and during that portion of the cycle of the alternating potential across the output or utilization circuit when this potential opposes the constant potential applied between the anode and the cathode, and (2) the magnitude of the impedance of the output or utilization circuit, which preferably is such that the peak value of the alternating potential across this circuit is substantially as great as the constant potential applied between the cathode and the anode.

Stating the foregoing objectively—in order that a high efficiency may be obtained for class C amplifiers, it is necessary that the electrons flowing to the anode and constituting the output current reach the anode when the instantaneous potential of the anode with respect to the cathode is markedly less than the average potential or constant applied potential, of the anode.

The variable or alternating potential appearing upon the anode is directly dependent, of course, upon the variable or alternating potential impressed upon the control electrode or grid. Although, therefore, the requisite conditions for high efficiency may obtain in amplifiers of designs known heretofore, at or near full load operation, and hence large variable grid potentials, at lower values of grid excitation and hence smaller outputs, the alternating potentials appearing upon the anode are relatively small. Consequently, the difference between the instantaneous and average anode potentials is correspondingly small and low efficiencies result.

One general object of this invention is to increase the operating efficiency of electronic amplifiers. More specifically, one object of this invention is to increase the efficiency of class C ampli-

fiers at loads corresponding to relatively small values of grid excitation so that a high efficiency is obtained throughout a wide range of input potentials impressed upon the control electrode or grid.

In one illustrative embodiment of this invention, an electronic amplifier comprises an electron discharge device having, in addition to the generally customary cathode, control electrode and anode, one or more auxiliary anodes. The several anodes are so connected to different points in the output or utilization circuit that the alternating potentials appearing thereon are substantially in phase but of different magnitudes, each of the anodes having applied thereto substantially the same constant potential with respect to the cathode. The electrodes are so constructed and arranged that during operation of the amplifier the electrons constituting the output or utilization current are selectively directed by a variable focussing action to that anode having such instantaneous potentials as to result in the highest efficiency.

In a modification, means, such as a coil encompassing the electron discharge device, may be provided for causing the electrons to traverse curved paths in flowing to the anodes, and the curvature of the paths may be altered by the changes in the potentials upon the anodes for different values of grid excitation so that the great majority of the electrons flow to and impinge upon that anode having the instantaneous potentials most satisfactory from the standpoint of efficiency.

The invention and the various features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing, in which:

Fig. 1 is a circuit diagram of an electronic amplifiers illustrative of one embodiment of this invention;

Fig. 2 is a graph illustrating the alternating potential excursions upon the anodes in the amplifier shown in Fig. 1;

Fig. 3 is a view in cross-section of an electron discharge device constructed in accordance with this invention, showing the form and relative positions of the electrodes and indicating the paths traversed by the electrons in flowing to the anodes;

Fig. 4 is a view in cross-section of electron discharge apparatus illustrative of another embodiment of this invention, including an external magnetic coil;

Fig. 5 is a cross-sectional view of a modification

of the embodiment of the invention shown in Fig. 4;

Fig. 6 is a circuit diagram of an amplifier incorporating an electron discharge device of the construction illustrated in Fig. 5; and

Fig. 7 is a graph illustrating the alternating potential excursions upon the anodes in the electron discharge device included in the circuit shown in Fig. 6.

Referring now to the drawing, the amplifier shown in Fig. 1 includes an electron discharge device comprising an enclosing vessel 10, a thermionic cathode 11, an anode 12 and a control electrode or grid 13, which may be mounted between the cathode and the anode. The cathode and anode are connected in an output or utilization circuit, which may include, for example, an inductance 14 in shunt with a condenser 15 and a series resistance 16, and a source, such as a battery 17, for applying a positive potential to the anode 12 with respect to the cathode 11. The cathode and grid or control electrode are connected in a suitable input circuit, which may include, for example, the secondary winding of an input transformer 18 and a source such as a battery 19, the source being of such character that the control electrode or grid will be maintained at a negative potential with respect to every part of the cathode.

Disposed between the anode 12 and the control electrode or grid 13 is another or auxiliary anode 20 which is connected, as shown, to a suitable point on the inductance 14.

The several electrodes may be planar in form and disposed parallel to one another or may be cylindrical in form and coaxially arranged. For example, as shown in Fig. 3, the cathode 11 may be a linear filament or it may be a cylindrical sleeve, indirectly heated and coated with a thermionic material, and the anode 12 may be a cylinder encircling the cathode and coaxial therewith. The control electrode or grid 13 may be composed of a plurality of equally spaced linear wires or rods 22 mounted parallel to each other and to the cathode and arranged in a cylindrical boundary about the cathode and coaxial therewith. Similarly, the auxiliary anode 20 may be composed of a plurality of equally and relatively widely spaced linear wires or rods 23 mounted parallel to one another and to the cathode and arranged in a cylindrical boundary coaxial with the cathode. Preferably, in order that the lines of force leaving the anode 20 will be curved in the vicinity of this anode, the wires or rods 23 of the anode 20 are mounted in radial alignment with the wires or rods 22 of the control electrode or grid 13. If a screen or shield electrode or grid is employed, preferably it should be composed of rods or wires parallel to one another and to the wires 23 and mounted in radial alignment with the latter wires.

When an alternating potential is impressed upon the input circuit through the transformer 18, alternating potentials, substantially in phase with one another and 180 degrees out of phase with the potential appearing upon the control electrode or grid, are induced upon the anodes 12 and 20. Because of the different spacing between the two anodes and the control electrode and inasmuch as the two anodes are connected to different points in the same output circuit, the alternating potentials appearing upon the two anodes are different in magnitude. For example, at relatively low values of grid excita-

tion, the alternating potentials appearing upon the anodes 20 and 12 may be of the relative magnitudes indicated by the curves A and B respectively in Fig. 2, in which figures the constant potential applied to the anodes by the source 17 is indicated by the line E.

At higher values of grid excitation, for example at values at or near the maximum intended to be employed, the alternating potentials appearing upon the anodes 20 and 12 may be of the magnitude indicated by the curves A' and B' respectively in Fig. 2. If the constants of the output or utilization circuit are properly fixed, the peak magnitude of the alternating potential upon the anode 20, as indicated by the curve A', will approach as a limit the constant component of the potential, indicated by the line E, and, for the greater portion of the half cycle during which current flows, the alternating potential upon the anode 12, as indicated by the curve B', will be greater than the constant component so that the anode 12 will be negative relative to the cathode.

When an input potential is impressed upon the control electrode or grid 13, during the positive portion of the cycle of this potential, the field in the electron discharge device attracting the electrons emanating from the cathode 11 toward the anodes 12 and 20 causes most of the electrons to travel along substantially radial paths but not directly toward the wires or rods 23 of the anode 20. At relatively low values of grid excitation, corresponding to the conditions represented by the curves A and B in Fig. 2, the paths traversed by the electrons may be approximately as indicated by the dotted lines P in Fig. 3. Some of the electrons may impinge upon the anode 20 but the greater portion of the electrons, because of their inertia and the relatively wide spacing of the rods or wires 23, in other words, electron lens focussing action, will pass between these rods or wires and flow to the anode 12. Inasmuch as the anode 12 is at relatively low instantaneous potentials with respect to the cathode, as indicated by the curve B in Fig. 2, the electrons impinging upon this anode will deliver energy at high efficiency.

At high values of grid excitation, corresponding, for example, to conditions represented by the curves A' and B' in Fig. 2, inasmuch as the anode 12 is negative throughout a large portion of the half cycle, electrons passing the anode 20 will be retarded and then will return to the anode 20 so that substantially all of the electrons will flow to the anode 20. Inasmuch as the instantaneous potentials of this anode are relatively low with respect to the cathode, as indicated by the curve A' in Fig. 2, the electrons reaching this anode will deliver energy at high efficiency.

It will be seen, therefore, that in amplifiers constructed in accordance with this invention, the electrons are subjected to automatic selective control so that throughout the range of input potentials employed, the electrons are caused to flow to the anode having the instantaneous potentials most satisfactory for the attainment of high efficiency.

As is known, the velocity of electrons flowing from the cathode to the anodes is dependent upon the potentials upon the anodes. Also, as will be apparent, the potential upon the inner or auxiliary anode 20 will exert a greater influence upon the electrons than the potential upon the outer anode 12 and, under conditions corresponding

to curve A in Fig. 2, the electrons will acquire greater velocities than under conditions corresponding to curve A'. As pointed out heretofore, in order that high efficiencies will result, under conditions corresponding to curve A, the greater portion of the electrons flow to the anode 12 and but a small portion flow to the anode 20 whereas under conditions corresponding to the curve A', substantially all of the electrons flow to the anode 20. In other words, in the attainment of high efficiencies, under conditions of operation producing relatively high electron velocities, the electrons, or at least the great majority of them, flow to the anode, the potential of which exerts the lesser accelerating effect upon the electrons, and under conditions producing relatively low electron velocities, the electrons, or at least the great majority of them, flow to the anode exerting the greater accelerating effect. At conditions producing intermediate velocities, a distribution of electrons between the two anodes will obtain, the proportion of electrons flowing to each anode being dependent upon the relative magnitudes of the instantaneous potentials appearing upon the anodes. It follows, therefore, that the selective flow or control of the electrons necessary for high efficiencies may be obtained by methods utilizing velocity discrimination.

In one illustrative embodiment of this invention utilizing this principle, shown in Fig. 4, means, such as a coil 24, encompassing the enclosed vessel 10 producing a magnetic field parallel to the axis of the electrodes and adjacent the electrodes, may be provided for causing the electrons to traverse paths of a desired configuration in flowing to the anodes 12 and 20. For example, the magnetic field may be such that with the constant potential applied by the source 17 and little energy being delivered to the output or utilization circuit, that is, for very small values of grid excitation and small loads approximating the conditions corresponding to curve A in Fig. 2, the electrons traverse curved paths approximately of the form indicated by line P₁ in Fig. 4. The auxiliary anode 20 may comprise a plurality of equally spaced, parallel strips 25 which preferably are relatively narrow and curved or warped so that substantially no electrons, traversing their average path, under the conditions of load and excitation noted, will impinge thereon.

At somewhat greater excitations and loads, the instantaneous potentials upon both the anodes 12 and 20 at the time of current flow will be less and the electrons will traverse paths such as indicated approximately by the lines P₂ and P₂'. In this case, some of the electrons will flow to the inner anode 20 and fewer than in the case described in the preceding paragraph will flow to the outer anode 12. The distribution of electrons will be such, however, depending, of course, upon the relative magnitude of the instantaneous potentials upon the anodes, that a high resultant efficiency obtains.

At and near conditions of maximum grid excitation and full load, corresponding to curves A' and B' in Fig. 2, because of the relatively small potentials attracting the electrons toward the anodes and the configuration of the strips 25, substantially all of the electrons flow to the inner anode 20 along paths such as indicated approximately by the line P₃ in Fig. 4 and, consequently, the desired high efficiency obtains.

In a modification of the embodiment shown in Fig. 4, an electron discharge device may be provided, as illustrated in Figs. 5 and 6, with a sec-

ond auxiliary anode 26 disposed between the anodes 12 and 20 and connected to an intermediate point upon the inductance 14. The anode 26 may comprise a plurality of equally spaced parallel strips 27, which may be disposed edgewise to the strips 25 and curved or warped in the same direction as the latter strips.

As shown in Fig. 7, at low values of excitation potentials the alternating potentials appearing upon the anodes 20, 12 and 26 may be of the relative magnitudes indicated by the curves A, B and C, respectively; at or near the maximum excitation potential and full load, these potentials may be of the relative magnitudes indicated by the curves A', B', and C', respectively; and at intermediate values of excitation potentials, the alternating potentials upon the anodes may be of the relative magnitudes indicated by the curves A₂, B₂, and C₂, respectively. The constants of the amplifier, such as shown in Fig. 6 preferably are such that, as indicated by the curve C' in Fig. 7, at or near full load operation, the peak value of the alternating potential appearing upon the anode 20 approximates the constant applied potential E, and the instantaneous potential upon both the anodes 12 and 26 is negative relative to the cathode throughout the major portion of the half cycle during which current flows.

At low values of grid excitation, corresponding, for example, to the anode potentials indicated by the curves A, B and C in Fig. 7, because of the magnetic field, produced by means such as the coil 24 shown in Fig. 4, and the curvature and disposition of the strips 25 and 27, the greater portion of the electrons will flow directly to the outer anode 12 along curved paths such as represented approximately by the line P₄ in Fig. 5. Inasmuch as this anode, under this condition of operation, has the largest alternating potential thereon and the smallest instantaneous potential with respect to the cathode at the time of current flow, the electrons impinging thereon will deliver energy at high efficiency. Some electrons may impinge upon the anodes 20 and 26 and will deliver energy at lower efficiencies which, however, are greater than or at least equal to those obtaining in amplifiers of constructions used heretofore.

At or near full load excitation, corresponding for example to the anode potentials indicated by the curves A', B' and C' in Fig. 7, inasmuch as both the anodes 12 and 26 are negative with respect to the cathode throughout the major portion of the half cycle during which current flows, substantially all of the electrons will impinge upon the anode 20, traversing paths such as indicated generally by the line P₅ in Fig. 5. Inasmuch as the anode 20 has thereon the potentials most satisfactory from the standpoint of efficiency, the highest efficiency for the condition of operation predicated will result.

At intermediate values of grid excitation, corresponding for example to instantaneous anode potentials as indicated by the curves A₂, B₂ and C₂ in Fig. 7, a distribution of the electrons occurs among the several anodes. Inasmuch as the potential of the outer anode 12 is negative throughout a portion of the half cycle during which current flows, as indicated by the curve B₂, and as the velocity of the electrons is relatively small in comparison to that in the case of small grid excitation, very few of the electrons will flow to this anode. Also, because of the relative instantaneous potentials upon the anodes 20 and 26, the form of the members 25 and 27 and the influence of the magnetic field,

but a comparatively small number of the electrons will flow to the inner auxiliary anode 20. The great majority of the electrons will flow to and impinge upon the anode 26, traversing paths as represented approximately by the line P₆ in Fig. 5. The anode 26, as indicated by the curve C₂ of Fig. 7, has the potentials most conducive to the attainment of high efficiency under the operating conditions predicated.

It will be apparent, therefore, that for every condition of operation, that is, for all values of grid excitation to be employed, the major portion of the electrons is discriminately directed to that anode which has thereon the most satisfactory instantaneous potentials so that a high efficiency is obtained throughout a wide range of input potentials.

Although specific embodiments of this invention have been shown and described, it will be understood, of course, that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims. For example, although the invention has been described and illustrated as applied to high frequency amplification, it may likewise be utilized for class B push-pull amplification for audio or other frequencies by using appropriate connections and types of transformers well known in the art.

What is claimed is:

1. Electron discharge apparatus comprising an electron discharge device including a cathode, a control electrode, an anode and an auxiliary anode, an input circuit coupled to said cathode and said control electrode including means for impressing variable potentials upon said control electrode, and an output circuit including means for impressing substantially equal constant potentials upon said anodes, said anodes being connected to such points in the output circuit that the varying potentials induced thereon in accordance with the varying potentials upon said control electrode are substantially in phase but of different magnitude.

2. Electron discharge apparatus in accordance with the next preceding claim wherein the impedance of the output circuit is such that for maximum variations in the potentials impressed upon said control electrode, the peak value of the corresponding varying potential induced upon one of said anodes is greater than the constant potential applied to said one anode.

3. Electron discharge apparatus in accordance with the second preceding claim wherein the impedance of the output circuit is such that for maximum variations in the potentials impressed upon said control electrode, the peak value of the corresponding potential induced upon the anode having the smaller induced potential is commensurate with the constant potential applied to said anodes.

4. An amplifier comprising an electron discharge device including a cathode, an anode, a control electrode between said cathode and said anode and an auxiliary anode between said control electrode and said first anode, means for impressing an alternating potential between said control electrode and said cathode, and an output circuit including means for applying substantially equal constant potentials to said anodes with respect to said cathode, said anodes being so constructed and connected to such points in said output circuit that the alternating potential induced upon said auxiliary anode is substantially in phase with but smaller than

the alternating potential induced upon said first anode.

5. An amplifier comprising an electron discharge device having a cathode, an anode, a control electrode between said cathode and said anode including a plurality of spaced elements, and an auxiliary electrode between said anode and said control electrode including a plurality of elements in alignment with said cathode and said first elements, an input circuit coupled to said cathode and said control electrode, and an output circuit including means for applying substantially equal constant potentials to said anode and said auxiliary electrode, said anodes being connected to spaced points in said output circuit having different instantaneous variable potentials with respect to said cathode.

6. An amplifier comprising an electron discharge device including a cathode, a control electrode and a plurality of anodes, means for impressing a variable potential between said cathode and said control electrode, means for maintaining said control electrode at a negative potential with respect to said cathode, and an output circuit coupled to said anodes and said cathode including an impedance and means for applying constant potentials of substantially equal magnitude to said anodes, said anodes being connected to said impedance at points of different varying potential with respect to said cathode, and said impedance having such value that for a certain magnitude of said variable potential the resultant potential of one of said anodes is negative with respect to said cathode and the variable potential upon another of said anodes approximates the constant potential applied thereto.

7. An amplifier comprising an electron discharge device having a cathode, a control grid including a plurality of spaced elements mounted in a cylindrical boundary coaxial with said cathode, an auxiliary electrode including a plurality of spaced elements mounted in a coaxial boundary about said control grid and coaxial therewith, each of said second elements being radially aligned with one of said first elements, and an anode encompassing said auxiliary electrode, an input circuit coupled to said cathode and said grid, and an output circuit including means for applying equal constant potentials to said anode and said auxiliary electrode, said anode and said auxiliary electrode being connected to spaced points in said output circuit so that the varying potentials induced upon said anode are of greater magnitude than those induced upon said auxiliary electrode.

8. An amplifier comprising an electron discharge device having a cathode, a control electrode, and a pair of anodes, means for impressing a potential between said cathode and said control electrode, an output circuit including means for applying substantially equal positive potentials to said anodes with respect to said cathode, said anodes being connected to spaced points in said output circuit having different varying potentials produced thereon when the potential of said first means is varied, and means for producing a magnetic field adjacent the electrodes of said device such that for small variations in the potentials of said first means, substantially all of the electrons emanating from said cathode flow to only one of said anodes.

9. An amplifier comprising an electron discharge device having a cathode, a control electrode, an anode encompassing said cathode and

an auxiliary anode between said cathode and said first anode, said auxiliary anode including a plurality of spaced arcuate strip members disposed edgewise to said cathode and said first anode, an input circuit coupled to said control electrode, an output circuit including means for applying substantially equal constant potentials to said anodes and including also impedance means connected to said anodes whereby the variable potentials induced upon said anodes in accordance with signals impressed upon said input circuit are substantially in phase but of different magnitude, and means for producing a magnetic field adjacent and substantially parallel to said cathode.

10. Electron discharge apparatus comprising an electron discharge device having a cathode, a control electrode, an anode, and a plurality of auxiliary electrodes each including a plurality of strip members, the strip members of each of said auxiliary electrodes being in alignment with said cathode and with those of the other of said auxiliary electrodes and mounted edgewise thereto, an input circuit coupled to said cathode and said control electrode, and an output circuit including means for applying substantially equal constant potentials to said anode and said auxiliary electrodes, said anode and said auxiliary electrodes being connected to such points in said output circuit that the corresponding variable potentials induced thereon in accordance with variations in potentials impressed on said input circuit are substantially in phase but of different magnitude.

11. Electron discharge apparatus in accordance with the next preceding claim comprising means for producing a magnetic field in the vicinity of the electrodes of said device such that when small variable potentials are impressed upon said input circuit, substantially all of the electrons emanating from said cathode flow directly to said anode.

12. An amplifier comprising an electron discharge device having a cathode, an anode, a control electrode and a pair of auxiliary electrodes successively disposed between said control electrode and said anode, each of said auxiliary electrodes including strip members disposed edgewise to the strip members of the other of said auxiliary electrodes and aligned therewith and with said cathode, an input circuit including means for impressing an alternating potential between said cathode and said control electrode, and an output circuit including means for applying substantially equal constant potentials to said anode and said auxiliary electrodes, said anode and said auxiliary electrodes being connected to such points in said output circuit that the alternating

potentials appearing thereon are substantially in phase but of different magnitude, and the impedance of the circuit including said anode being such that at the peak value of the potential impressed upon said control electrode the peak value of the corresponding alternating potential induced upon said anode is greater than the constant potential applied to said anode.

13. An amplifier comprising an electron discharge device including a cathode and an anode, an output circuit coupled to said cathode and said anode, means for varying the electron flow toward said anode, and means including an auxiliary electrode associated with said output circuit for substantially preventing the flow of electrons to said anode at certain degrees of electron flow and causing the electrons to flow to said auxiliary electrode at said degrees of electron flow, said anode and said auxiliary electrode being connected to such points in said output circuit that the variable potentials induced thereon are substantially in phase.

14. An amplifier comprising an electron discharge device including a cathode, an anode and a control electrode, means for impressing a varying potential between said cathode and said control electrode, an output circuit coupled to said cathode and said anode, and means including an auxiliary electrode coupled to said output circuit at such point that the variable potentials appearing thereon are substantially in phase with, but of different magnitude than the variable potentials appearing on said anode for effectively intercepting electrons flowing from said cathode to said anode when said varying potential is at approximately its maximum value.

15. An amplifier comprising an electron discharge device having a cathode, a control electrode, an anode and an auxiliary electrode, an input circuit including means for applying variable energizing potentials to said control electrode, and an output circuit coupled to said cathode and to said anode and auxiliary electrode including means for impressing substantially equal constant potentials upon said anode and said auxiliary electrode, said anode and auxiliary electrode being so constructed and so associated with said output circuit that the varying potentials induced thereon are substantially in phase and that at relatively high values of said energizing potentials substantially all of the electrons flow to said auxiliary electrode and at low values of said potentials substantially all of the electrons flow to said anode.

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