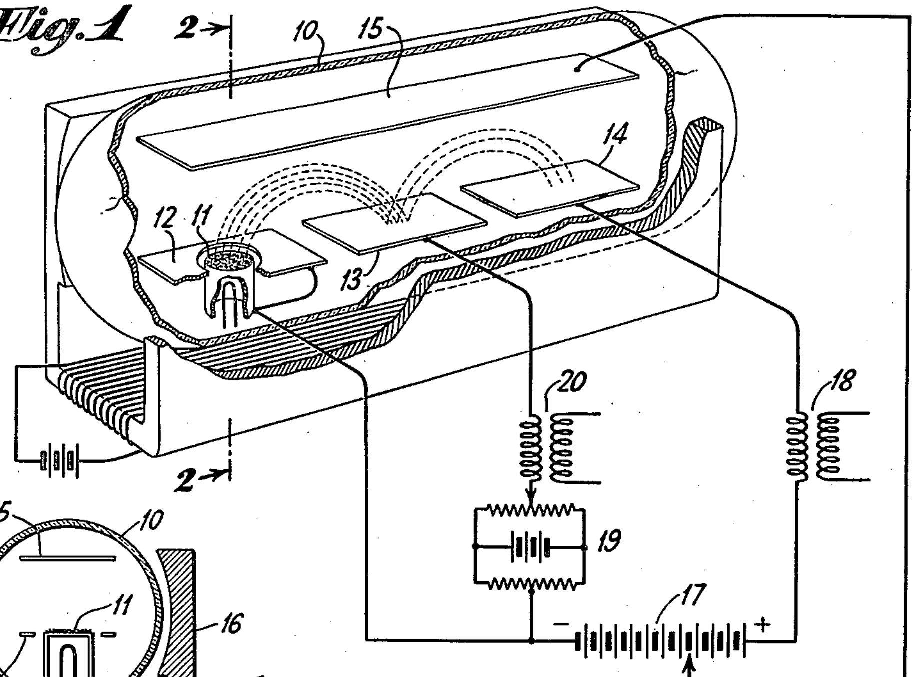
Oct. 10, 1939. H. NELSON 2,175,697

ELECTRON DISCHARGE AMPLIFIER

Filed Feb. 26, 1937 2 Sheets-Sheet 1

Fig. 1



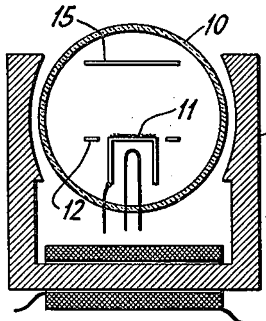


Fig. 2

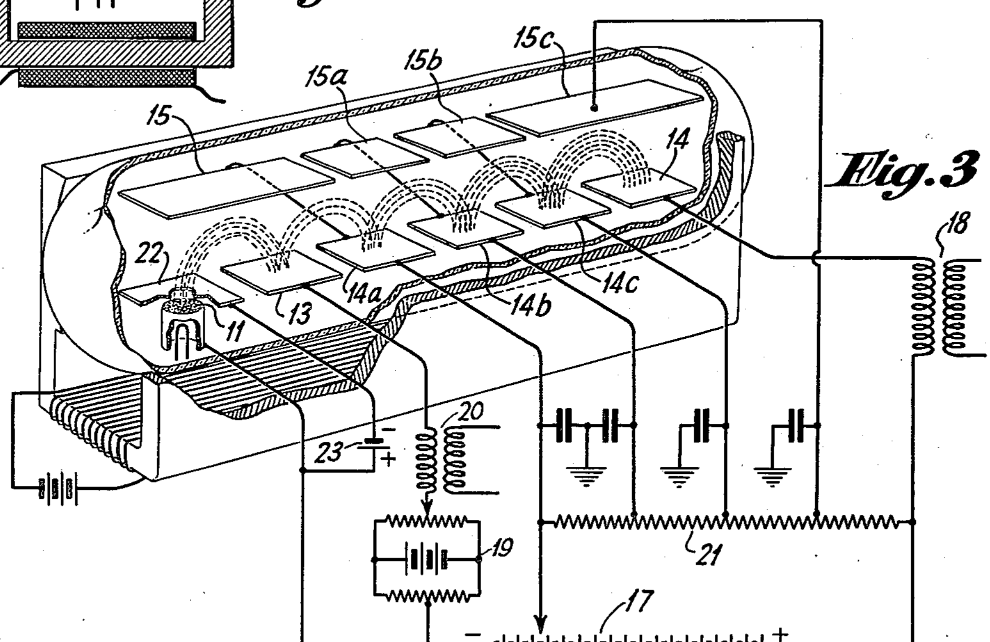


Fig. 3

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Fig. 4

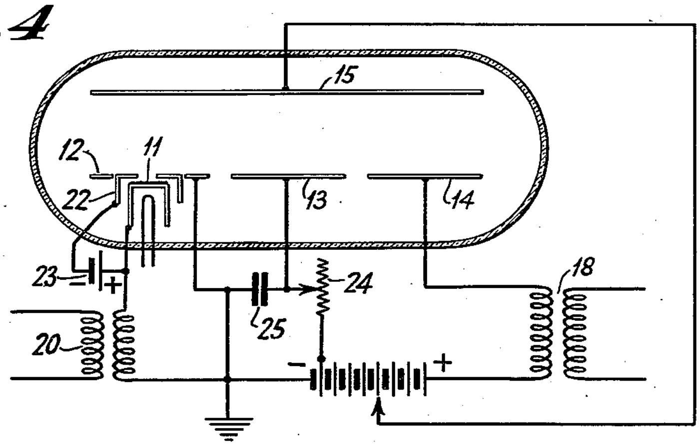
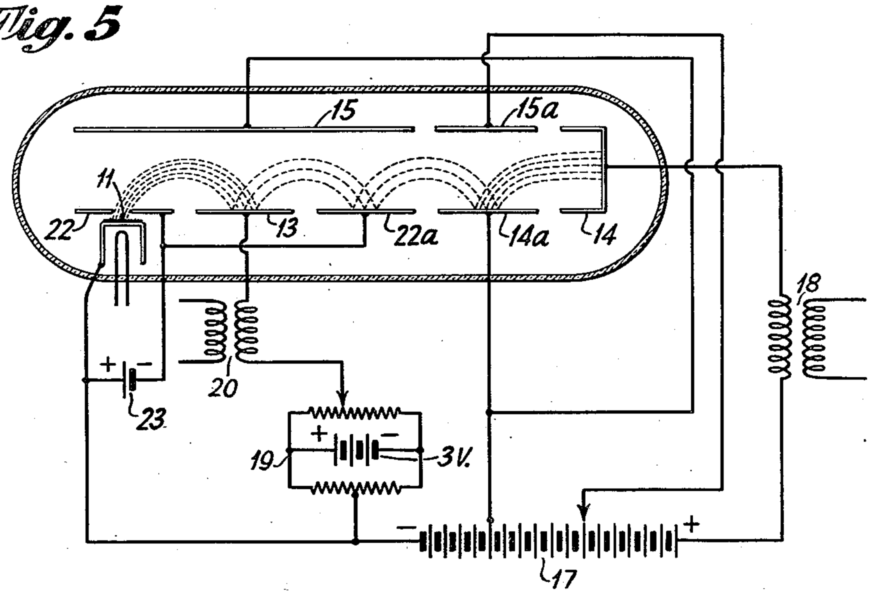


Fig. 5



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ELECTRON DISCHARGE AMPLIFIER

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Application February 26, 1937, Serial No. 127,828

5 Claims. (Cl. 179—171)

My invention relates to electron discharge devices in which the discharge is modified in certain respects, and more particularly to thermionic amplifiers which have high transconductance and in which a control input is multiplied by a relatively large factor.

For various reasons it is desirable in thermionic amplifiers that the ratio of transconductance to anode or plate current be high, one reason being that this high ratio decreases the noise to signal ratio of the amplifier. In the conventional thermionic amplifier where the discharge from a thermionic cathode is controlled by a grid electrode of the usual open structure, this high ratio cannot be obtained merely by decreasing the anode current, as the transconductance varies with the plate current and becomes low when the output current is small, so that the practical limit for this ratio is about a transconductance of 2000 micromhos per milliampere of plate current, although it can be shown that under ideal conditions a much higher ratio is possible.

Electron multipliers of the secondary electron emission type in which a discharge from an electron source is directed in succession to a series of emitters which have a secondary electron emission ratio greater than unity, may be made to multiply or amplify a primary electron discharge many thousand fold. A conventional thermionic amplifier with a control grid may be used as the source of the modulated discharge in an electron multiplier, but the transconductance and the anode current are multiplied by the same factor, so that the ratio between transconductance and anode current does not change. Such a device in effect magnifies the conventional thermionic amplifier without changing its characteristics, and for this reason, among others, the results obtained are practically no better, except in magnitude, than those obtainable with the conventional thermionic amplifier.

An object of my invention is to provide a method and means by which an electron discharge may at will be modified to produce a discharge in which the velocity of the electrons is much more nearly uniform in the region of a control element than in devices heretofore used.

Another object of my invention is to provide an electron discharge device in which the ratio of transconductance to anode current is much greater than in the conventional thermionic amplifiers, while the anode current is within permissible limits.

Still another object of my invention is to provide a device in which the transconductance increases as the anode current decreases, and the transconductance is high even when the anode current is exceedingly small.

A further object is to provide an improved electron multiplier which has a thermionic cathode and which is more useful and of higher transconductance than electron multipliers with conventional grid control.

In accordance with my invention I select from the electrons emitted by a thermionic cathode and transmit to an anode only those electrons emitted from the cathode with an initial velocity less than a predetermined limiting velocity. In a desirable form of device a continuous surface element positioned between a thermionic cathode and an anode has impressed upon it an effective negative potential with reference to the cathode which is within the voltage range of the cathode emission, and the electron discharge from the cathode is directed, preferably by electrostatic and electromagnetic fields, along an unobstructed curved path so chosen that immediately adjacent the continuous surface of that element there is a region which is a substantial facsimile in electron voltage or velocity of the region of electron emission at the cathode surface and from which only those electrons having a velocity exceeding the retarding voltage between that element and the cathode will be able to move to the element and thus be abstracted or removed from the electron stream. The electrons with velocities below the limit are unable to reach the element, and being constrained to follow a path away from the element to an anode or to another collecting electrode by which they are collected, constitute the output current, which is the original electron stream from the cathode less the electrons which were emitted from the cathode with a velocity exceeding a preselected limit and abstracted from the stream by the element. If the element is biased with reference to the cathode to a voltage within the range of velocities of the greater part of the cathode emission slight variations in potential of the element produce such comparatively great changes in ratio between the electrons reaching the element and those failing to reach it that the transconductance is very high.

My invention, of which other objects and advantages will be apparent from the following description, will best be understood in connection with the acompanying drawings in which Figure 1 is a perspective view partly broken away and showing one form of three electrode devices constructed in accordance with my invention; Figure 2 is a cross-section along the line 2—2 of the device shown in Figure 1; Figure 3 is a view similar to Figure 1 of my invention embodied in an electron multiplier of several stages; Figure 4 is a form of device in which the input signal causes a voltage swing on the cathode; and Figure 5 shows diagrammatically a modified form of a device of the kind shown in Figure 1.

The particular form of device shown in Figure 1 as one illustrative embodiment of my invention is a triode comprising a highly evacuated envelope 10, preferably somewhat elongated, and enclosing the various electrodes of the device. Near one end of the envelope is a source of electrons, such as an indirectly heated cathode 11 with a flat oxide coated surface, preferably in the form of a disc, which is surrounded by a flat field plate 12 substantially flush with the flat surface of the cathode. Adjacent the cathode 11 is a continuous surface sheet electrode or control element 13 substantially in the plane of the cathode surface, and near the other end of the envelope is a flat anode or output electrode 14 in substantially the same plane as the element 13 and the field plate 12. An accelerating electrode 15 extends lengthwise of the envelope parallel to and equidistant from the field plate 12 and the electrodes 13 and 14. A magnetic field substantially uniform throughout the length of the tube and with its lines of force extending transversely of the envelope and parallel to the accelerating electrode and to the other electrodes 13 and 14 is produced by means such as an electromagnet 16 with elongated pole pieces arranged, as best shown in Figure 2, to extend along opposite sides of the envelope. The electron stream from the cathode 11 is concentrated into a beam by the field plate 12 which is connected to be at the same potential as the cathode. The beam is accelerated from the cathode toward the accelerating electrode 15 and is, as a result of the combined effects of the electrostatic field of the accelerating electrode 15 and of the transverse magnetic field produced by the magnet 16, constrained to follow a curved or cycloidal path to the vicinity of the control element 13, and from there a similar path to the anode 14.

The potentials necessary for the operation of the device are supplied by a source of potential such as a battery 17 having its negative terminal connected to the cathode 11, its positive terminal connected through a load circuit 18 to the anode 14, and some point of positive potential connected to the accelerating electrode 15. The element or control electrode 13 is maintained at a fixed bias with reference to the cathode by a variable potentiometer 19. The significant potential of the element 13 with reference to the cathode is the effective negative potential, which may differ from the measured bias potential by the amount of the contact potential. Usually this effective negative potential is a small fraction, for exmple, a few tenths, of a volt, and is well within the range of the voltage of the cathode emission. For modulation the potential on the element 13 may be varied by an input circuit 20.

In operation, the accelerating electrode 15 and anode 14 are maintained at positive potentials and the control element 13 is biased to a potential which is effectively somewhat negative with respect to the cathode. Under the influence of the crossed electrostatic and magnetic fields in the tube the electron stream emitted from the cathode will follow a curved and substantially cycloidal path to the vicinity of the element 13, and to the anode 14. If the electrostatic field in the space between the field plate 12, the control element 13, and the accelerating electrode 15 is uniform, the electrons emitted by the cathode are accelerated so they move toward the electrode 15, and decelerated as they move against the field of the electrode 15 and toward the control element 13. The potentials are so chosen that in the vicinity of the control element the velocity of the electron stream is substantially zero. As a result, the electrons in the region immediately adjacent the control element have substantially the same velocity as they had when they left the surface of the cathode, consequently, in this region there is in effect a facsimile of the electron emission at the cathode. Those electrons in this region which have sufficient energy to overcome the slightly negative field of the element 13 will reach the element and be collected by it, while the remaining electrons which are unable to overcome the field and reach the element are rejected and will be directed away from the element 13 along an arcuate or cycloidal path to the anode 14 and be collected by it.

The electrons are emitted by the cathode with a Maxwellian distribution of velocities. Assuming that the electrons arrive at the region adjacent the element 13 with the same distribution of velocities, and neglecting the effect of secondary emission and the reflection of electrons from the electrodes 13 and 14, it can be shown that as the fraction of the cathode current which is collected by the element 13 increases and the fraction collected by the anode 14 decreases, the ratio of transconductance to plate current increases, approaching infinity as the anode current approaches zero. Loss of electrons from the anode by secondary emission may be substantially prevented by proper design and the choice of the positive potential on the anode. Reflection of the electrons from the element 13 presents a more serious problem, but it has been found that the electron current loss from the element 13 by reflection may be made a small fraction of the electron current collected by the element 13, and ratios of transconductance to plate current have been obtained which are far higher than are obtainable in triodes of conventional design.

When the ratio of transconductance to plate current is high, the electron current to the control element 13 in the triode shown in Figure 1 may be as large or larger than the plate current to the anode 14. In accordance with my invention, the triode may be combined with an electron multiplier to increase the plate current to a practical value without a corresponding increase in current to the control element. One form of device for this purpose is illustrated in Figure 3, in which a row of three intermediate positive electrodes or anodes 14*a*, 14*b*, and 14*c*, constructed to have a secondary electron emissivity greater than unity, extends from the control element 13 to the output anode 14. Positive potentials, which increase successively from the intermediate electrode 14*a* to the anode 14, are supplied through conventional connections such as a resistor 21 connected to the battery 17. In this form of device the accelerating electrode 15 has supplementary sections 15*a*, 15*b*, and 15*c* in the plane of the accelerating electrode and connected to have successively greater positive potentials. A simple expedient is, as shown in Figure 3, to connect each section of the accelerating electrode to the next following intermediate anode or emitter, so that the accelerating electrode 15 is at the potential of the emitter 14*a*, the section 15*a* is at the potential of the emitter 14b, and so on. With this arrangement, the electron stream impinging upon the secondary emitter 14a produces a stream of secondary electrons which is directed along a trochoidal path to the emitters 14b, 14c, and to the anode 14. In this way the output current of the tube may be multiplied many fold and raised to a practical value, while the cathode current collected by the control element 13 is unchanged and is a very small fraction of the total output of the tube from the anode 14.

In this particular form of device I prefer to form the discharge from the cathode into a beam by a field plate 22 with a central aperture, and which, instead of being flush with the surface of the cathode, is positioned slightly above the cathode with the aperture in the field plate in registry with the emitting surface of the cathode. The field plate 22 is preferably maintained about one and a half volts negative with reference to the cathode by some means such as a battery 23. It is usually sufficient to maintain a difference of potential of about 100 volts between the emitters 14a, 14b, 14c, and the anode 14.

Figure 4 shows diagrammatically a modification of the device in which the input impedance is increased to a practical value by applying the input signal to the cathode 11 instead of to the control element 13. In this particular form of the device the zero potential field plate 12 is annular, surrounds the apertured beam forming field plate 22, and is connected through a condenser 25 to the control element 13, and may be connected directly to ground. The input signal is impressed by the input circuit 20 between the field plate 12 and the cathode. The element 13 is maintained at the desired potential with reference to the cathode by a variable resistor 24 and is grounded for high frequency through the condenser 25.

In operation, the resistor 24 is set to produce a potential which causes a suitable fraction of the electron current leaving the cathode to be collected by the element 13, while the remainder, constituting the plate current, is collected at the anode 14. In determining the sign and absolute value of this potential on the element 13 consideration must be given to the so called contact potential which in operation of such a device appears between the cathode and the cold element 13, and as a result the element 13 at a static potential which is slightly positive with reference to the cathode may, during operation of the tube, be effectively at a slight negative potential. As the potential of the cathode with reference to the field plate 12 varies with the signal input, the electron current collected by the element 13 also varies and with it the electron current to the anode 14. The change in current leaving the cathode voltage is small and may be made a very small fraction of the change in plate current to the anode, so that a tube of this type may be made which has a high transconductance and a comparatively high input impedance.

Figure 5 shows diagrammatically a modification in which the electrostatic field in the vicinity of the element 13 is made more uniform and is protected from distortion due to the presence in the vicinity of the element 13 of a positive electrode such as an emitter plate or an anode, by interposing between the element 13 and the first positive electrode to which the discharge flows an auxiliary field plate 22a, which is connected inside the tube to the field plate 22 and is therefore also maintained about one and a half volts negative with reference to the cathode. In this form of device the electron beam from the cathode flows along a path which is substantially trochoidal, first to the element 13, where the electrons which exceed a predetermined velocity move to the element 13 and are abstracted from the electron stream, after which the rejected electrons then move along a similar arcuate path to the vicinity of the auxiliary field plate 22a which is sufficiently negative to prevent the collection of any electrons by it. The discharge, substantially unchanged, then moves along another similar arcuate or cycloidal path to the emitter 14a upon which the discharge impinges with sufficient velocity to produce a copious flow of secondary electrons which are directed to and collected by the anode 14.

I have obtained goods results with the form of device shown in Figure 5 in which the electrodes of sheet nichrome about 30 millimeters wide, were so set that the center to center spacing of the cathode and the electrodes 13, 22a, and 14a was about 16 millimeters, and the distance between the accelerating electrode 15 and the control element 13 about 8 millimeters. I have found that good results are obtained with a cathode 11, about 120 mils in diameter, with a field plate 22 spaced about 15 mils from the cathode and having an aperture about 50 mils in diameter in registry with the cathode. With this arrangement good results were obtained with the accelerating electrode 15 about 100 volts positive with reference to the cathode, and the emitter plate 14a about 150 volts positive. In such a device a three volt battery is sufficient for the potentiometer.

With a device of this kind in which the magnetic field was adjusted to give maximum output current at the anode 14, there was obtained a maximum transconductance of about 10,000 micromhos, and a ratio of transconductance to plate current roughly ten times as great as is obtained in a conventional triode.

I claim:

1. The method of modifying an electron discharge from an electron emitting cathode which consists in controlling said discharge to produce in a region remote from said cathode an electron velocity facsimile of the electronic emission at the surface of said cathode, collecting and abstracting from said region substantially all electrons having velocities greater than a preselected velocity within the velocity range of the cathode emission, rejecting from said region to a point more remote from said cathode substantially all remaining electrons having a lesser velocity, and collecting said remaining electrons at said remote point.

2. The method of modifying an electron discharge from an electron emitting cathode which consists in directing the electron discharge from said cathode to an element having an imperforate surface as a beam having the same axial and velocity relation to said element as to the cathode and forming in a region adjacent said element an electron facsimile of the electron velocity emission at the cathode, maintaining the element at a negative potential with reference to the cathode within the range of voltage of initial emission of electrons from the cathode, collecting from said region only those electrons of sufficient velocity to move to said element, and directing the electrons rejected by said element along a path away from said element and from said cathode.

3. In an electron discharge modifier the com-

bination with an electron discharge device comprising an anode, a continuous surface element spaced from said anode, a source of electrons for delivering in a region beside and in the plane of said element a stream of electrons in a direction transverse to the plane of said element and means for producing fields to direct said stream to said element along a curved path normal to said element at its intersection with said element and thence away from said element from said cathode to said anode, of means for maintaining said element at an effective potential of a few tenths of a volt negative with reference to said source.

4. In an electron discharge modifier the combination of an electron discharge device comprising an anode, a continuous surface element spaced from said anode, a source of electrons beside and in the plane of said element and means comprising an accelerating electrode in front of said element and of said source and a magnet producing a magnetic field parallel to the surface of said element and transverse to the field of said accelerating electrode for causing the discharge from said cathode to move toward said element against the field of said accelerating electrode and along a path normal to the surface of said element and to arrive at said element with substantially zero velocity, of means for varying the potential of said element with reference to said source over a range of voltage within a fraction of a volt.

5. In an electron discharge modifier, the combination with an electron discharge device comprising an electron emitter for producing a beam of electrons, an accelerating electrode in front of said emitter, a continuous surface element beside said emitter, an anode beyond and exposed to the said element, means for maintaining on said accelerating electrode a potential positive with reference to said emitter for accelerating the electron stream from said emitter, and a magnet for producing a magnetic field transverse to the field of said accelerating electrode and parallel to the plane of said emitter and element to direct said electron stream toward said element and against the field of said accelerating electrode to decelerate said stream to substantially zero velocity at said element, of means for maintaining said element at a negative potential with reference to said emitter which effectively differs from the potential of said emitter by a voltage no greater than the voltage corresponding to the maximum velocity of emission of electrons emitted by said emitter.

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