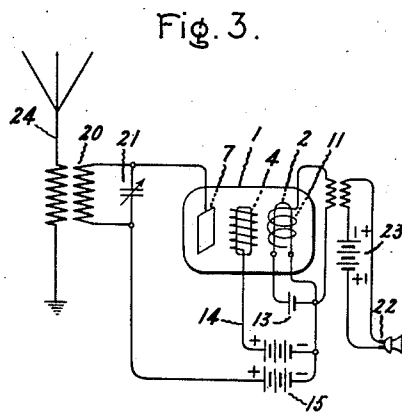
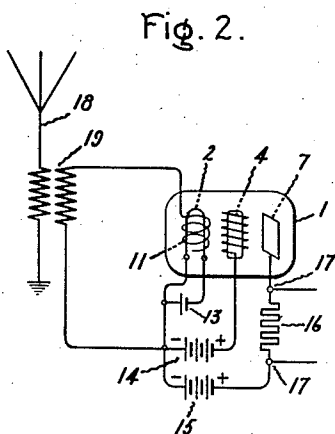
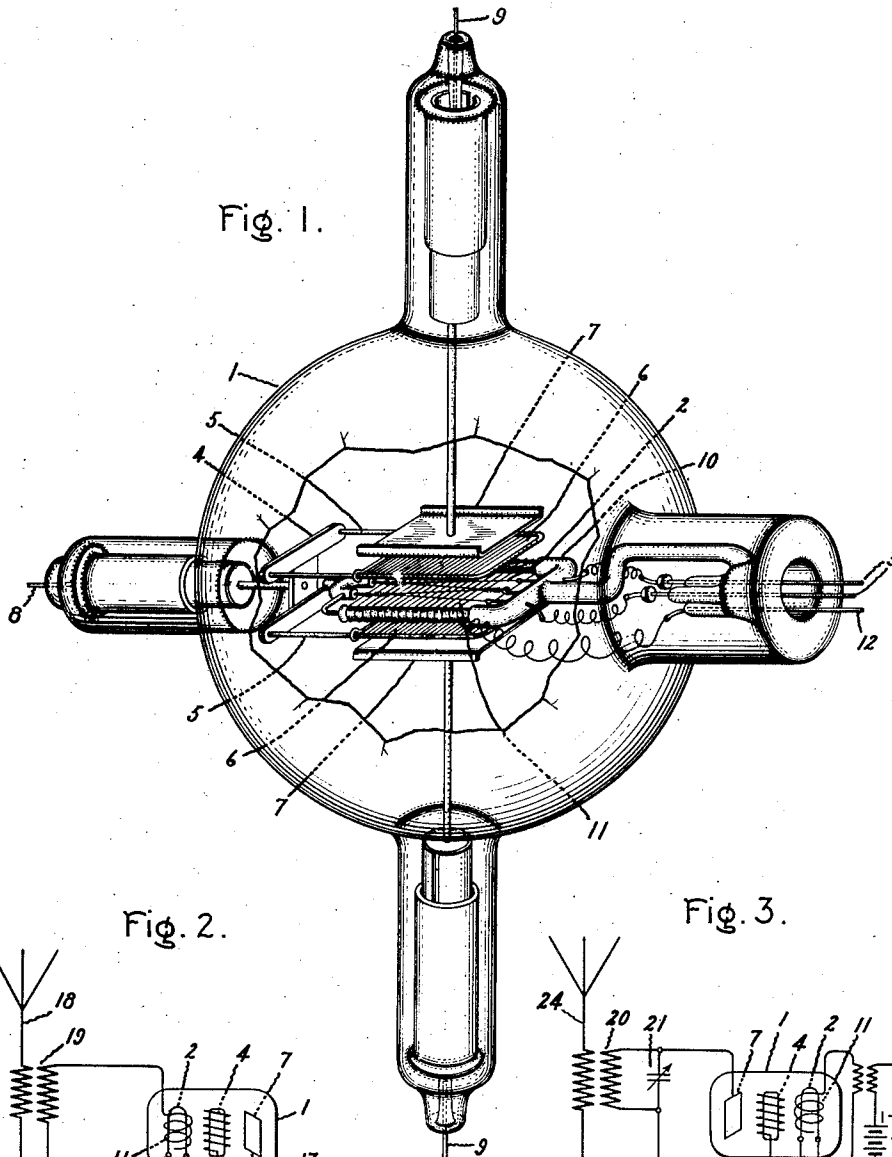


A. W. HULL.
ELECTRON DISCHARGE APPARATUS.
APPLICATION FILED JUNE 5, 1916.

1,385,873.

Patented July 26, 1921.

2 SHEETS—SHEET 1.



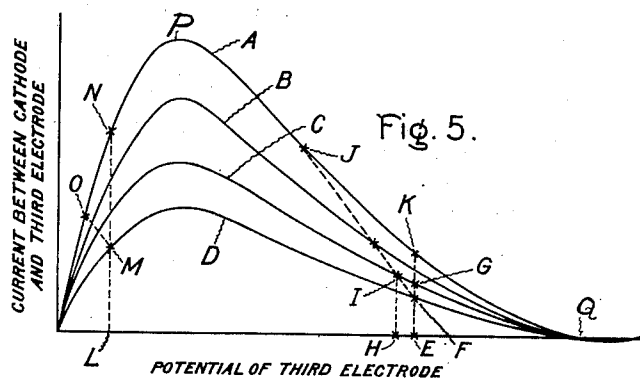
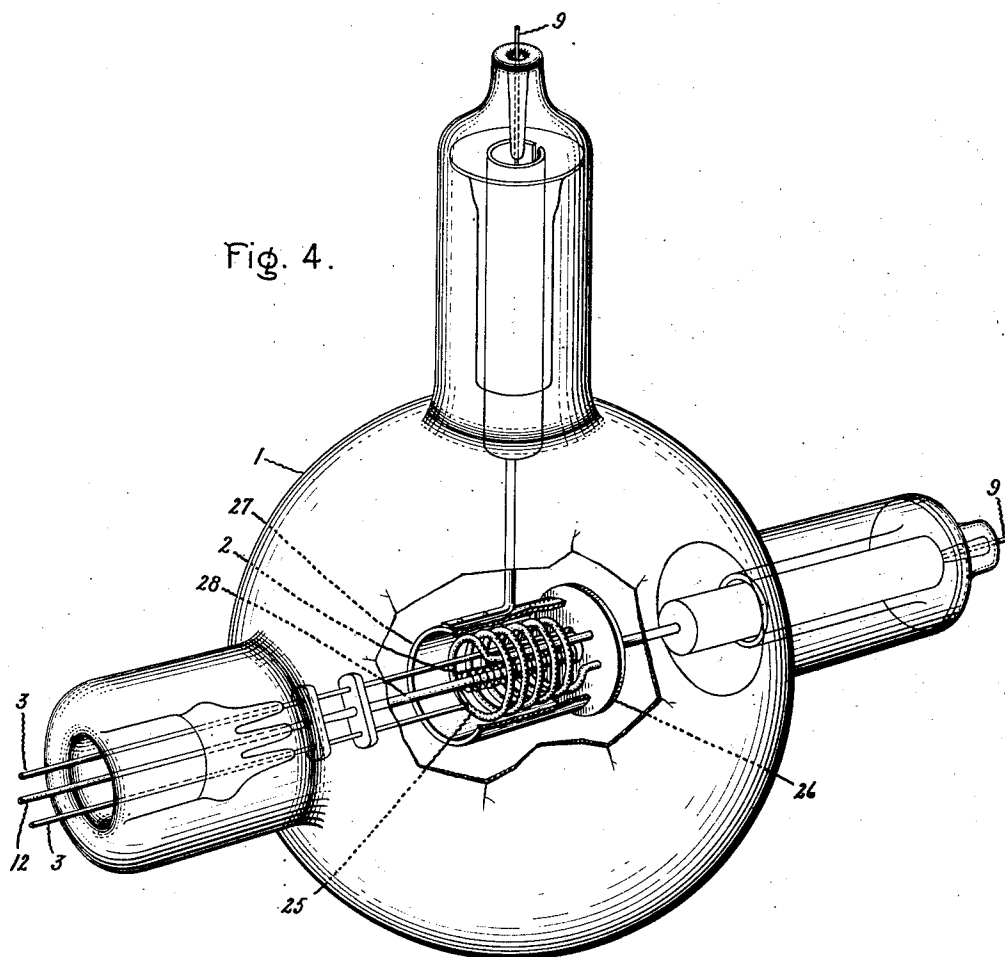
Inventor:
Albert W. Hull,
by *Alfred S. Davis*
His Attorney.

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UNITED STATES PATENT OFFICE.

ALBERT W. HULL, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-DISCHARGE APPARATUS.

1,385,873.

Specification of Letters Patent. Patented July 26, 1921.

Application filed June 5, 1916. Serial No. 101,729.

To all whom it may concern:

Be it known that I, ALBERT W. HULL, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Electron-Discharge Apparatus, of which the following is a specification.

My present invention relates to electron discharge apparatus and more particularly to apparatus of this type, so designed and operated that it has a negative resistance characteristic.

In a prior application, Serial No. 47,938, filed August 30, 1915, I have described and claimed an electron discharge device in which a negative resistance characteristic is obtained by producing, from an incandescent cathode, an emission of primary electrons, and from a coöperating electrode, an emission of secondary electrons of such a magnitude that the current between the two electrodes in an external circuit varies inversely as the potential between the electrodes. In this case the current between the electrodes is varied by varying the potential between the electrodes. If the potential between the electrodes remains constant the current may also be varied by varying the temperature of the cathode and thereby varying the number of primary electrons produced, since a variation in the number of primary electrons which reach the third electrode will cause a corresponding variation in the number of secondary electrons emitted. In this case the value of the negative resistance will be varied, thereby causing a variation in the current.

The object of my present invention is to provide a convenient means for controlling or varying the value of the negative resistance in such a device and thereby controlling the flow of current between the cathode and coöperating electrode, which will be independent of the two variables above mentioned.

In carrying my invention into effect I provide a charge controlling member in proximity to the cathode and by varying the potential between this member and the cathode, vary the effective emission of primary electrons; that is, vary the number of primary electrons which will reach the co-

operating electrode. When this is done the number of secondary electrons produced and the negative resistance of the device are also varied and the current in an external circuit between the cathode and the coöperating electrode is varied accordingly.

My invention both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following description taken in connection with the accompanying drawing in which Figure 1 shows one form of my device; Fig. 2 shows circuit connections which may be employed when it is used as an amplifier of wireless signals; Fig. 3 illustrates diagrammatically a wireless telephone transmitting system in which one of my devices is utilized for producing high frequency oscillations which vary in amplitude in accordance with variations in sound waves; Fig. 4 shows a modified form of my device, and Fig. 5 shows a set of characteristic curves of one of my devices.

As indicated in Fig. 1 an evacuated receptacle 1 is provided with a cathode 2 which is preferably a filament of tungsten connected to the leading-in conductors 3 by means of which current may be supplied for heating it to incandescence to cause it to emit primary electrons. An anode 4 is provided consisting of two metal frames 5 on each side of the cathode and wires 6 wound upon these frames. Other forms of anode may equally well be used, the essential requirement being that openings be provided in the anode through which electrons may pass in order to reach the third electrodes 7. Anode 4 is connected to leading-in conductor 8 and the third electrodes 7 are connected to leading-in conductors 9. While in the construction shown these electrodes are entirely separate they may be connected together externally and operated as a single electrode. The framework 10 which serves to support the cathode also supports a discharge controlling member 11 consisting of a wire wound back and forth upon the framework in such a manner that it surrounds the cathode. This discharge controlling member is connected to leading-in conductor 12. The receptacle 1 is preferably exhausted to such a degree that with any

operating voltage which may be employed the flow of current between the electrodes is not accompanied by any visible manifestation of gas ionization such, for example, as blue glow.

In the operation of a device such as the one I have described a definite positive potential is applied to the anode 4, the cathode being considered as at zero or earth potential. If the cathode is heated to incandescence there will be a flow of electrons from cathode to anode. If the third electrode 7 is at the same potential as the cathode no electrons will be received thereby. If, however, a small positive potential is applied to the third electrode a portion of the electrons will pass through the anode and reach the third electrode. The velocity with which these electrons will strike the third electrode will depend upon the potential between it and the cathode. If this potential is increased the velocity will increase until the electrons striking the third electrode are able by their impact to liberate secondary electrons. These secondary electrons leaving the third electrode will be attracted to the more positive anode. As the potential is increased a point will be reached at which the number of secondary electrons leaving the third electrode increases faster than the number of primary electrons received and the current which will flow in the external circuit between the cathode and third electrode will begin to decrease. A point will finally be reached at which the number of secondary electrons leaving the third electrode is just equal to the number of primary electrons which strike it. That is, each electron that strikes liberates on an average one secondary electron. No current will then flow in an external circuit between the cathode and the third electrode. If the potential of the third electrode is further increased the number of secondary electrons given off becomes greater than the number of primary electrons received and as a result the current in the external circuit will reverse in direction, the third electrode supplying current to the anode instead of receiving current. Thus it will be apparent that the device has a working range through which it has a negative resistance characteristic; that is, over which the current in the external circuit between cathode and third electrode varies inversely as the potential between the electrodes.

If, with any given potential upon the discharge controlling member, a constant potential is applied to the external circuit between cathode and third electrode and other conditions are constant there will be a constant flow of current in the external circuit. If, however, a variable potential is applied to the discharge controlling member 11 the number of electrons which leave the cathode and reach the third electrode will be varied

accordingly and the current in the external circuit will be varied. That is, if the member 11 is made more positive the flow of electrons to the third electrode will increase and if member 11 is made more negative the flow of electrons will decrease. If the potential of the third electrode is adjusted so that the device has a negative resistance characteristic a small change in the potential of member 11 will be capable of producing a large change in the current between cathode and third electrode. When operated in this way my device has an advantage over devices such as the "audion" and "pliotron" which have positive resistance operating characteristics.

This advantage will be understood by reference to the set of curves shown in Fig. 5 in which curves A, B, C and D show the relation between current in an external circuit between cathode and the third electrode and the potential of the third electrode for different potentials upon the discharge controlling member. The beginnings of these curves where the current is increasing are similar in form to the current characteristics of previous electron discharge devices when operated in the customary manner. Those parts of the curves where the current decreases show the negative resistance characteristic of devices constructed and operated in accordance with my invention. Suppose now for example the device, of which the curves given are characteristic, has applied to its third electrode a potential corresponding to point E. Then if the discharge controlling member has a potential corresponding to curve D, current F will flow in the external circuit between cathode and third electrode. If now the potential of the discharge controlling member be changed to that corresponding to curve C the current will tend to increase to a value corresponding to point G on curve C. On account of the increased resistance drop in the external circuit, however, the potential of the third electrode will decrease to some new value as H and the current will rise to a value I considerably greater than the value corresponding to point G. When the potential of the discharge controlling member is changed to the value corresponding to curve A it may be found that the current has risen to a value J which is much greater than the value K which it would have reached if the potential of the third electrode had remained constant. If on the other hand the device were to be operated with a potential L on the third electrode where it has a positive resistance characteristic the effect will be entirely different. When the potential of the discharge controlling member changes from the value corresponding to curve D to that corresponding to curve A, the current instead of increasing from value M to value

N may only increase to a value O because of the decrease in potential of the third electrode with increase in current.

In Fig. 2 I have shown diagrammatically circuit connections which may be employed when my device is utilized as an amplifier of wireless signals. As here indicated a battery 13 is employed for heating the cathode 2 to incandescence, a battery 14 furnishes a constant positive potential for anode 4 and a third battery 15 supplies a positive potential to the third electrode 7 of such a value that the device will operate upon that portion of its current curve over which it has a negative resistance. For example, in case curve A of Fig. 5 represents the operating characteristic the device should be so adjusted that it will operate between the points P and Q of the curve. The external circuit connecting the cathode and third electrode includes a resistance 16. The signals which are to be amplified are received upon the antenna 18 and impressed upon the charge controlling member 11 by means of the inductive coupling 19. The potential variations thus produced upon the charge controlling member 11 will produce corresponding fluctuations in the current through the resistance 16, and since the drop through the resistance is proportional to the current there will be potential variations between the terminals 17 of this resistance corresponding to those impressed upon the member 11 but of much greater amplitude. These amplified potential variations may be utilized for the operation of another amplifier or suitable detecting apparatus. For the selective reception of signals the antenna or the circuit which includes member 11 may be tuned according to any of the usual well known methods.

I have found that if suitable values of capacity and inductance are provided in the circuit between cathode and third electrode, a device constructed and operated in accordance with my invention will serve as a generator of continuous high frequency oscillations. Such an arrangement is indicated in Fig. 3, in which case an inductance 20 and variable capacity 21 are included in the external circuit between cathode and third electrode. The frequency of the oscillations may be conveniently varied by varying the capacity 21. The amplitude of the oscillations may be varied by varying the potential of member 11. In the present case I have indicated a method of adapting my device for use as a wireless telephone transmitter, the potential of member 11 being varied in accordance with variations in sound waves in the transmitter 22 which is supplied with current by battery 23. The transmitting system is completed by coupling inductance 20 to the antenna 24.

In Fig. 4 I have shown one of my devices

which operates in the same manner as the one shown in Fig. 1, but in which the construction is varied somewhat. In this case the cathode 2 instead of being supported upon a framework is made in the form of a spiral, self-supporting coiled filament. The anode consists of a heavy coil of wire 25 surrounding the cathode and supported upon the plate 26 which is connected to leading in conductor 9. The third electrode consists of a metal cylinder 27 surrounding the cathode and anode. The discharge controlling member consists of a rod 28 located within the coiled filament. The effect of potential variations of this member upon the current between cathode and third electrode is similar to that which occurs when the charge controlling member surrounds the cathode, only with the internal charge controlling member it will usually be found desirable to have a negative potential impressed thereon at all times. Under these conditions very little current will be taken by the control member. This feature is of special advantage when the device is used as an amplifier, as, for example in the arrangement shown in Fig. 2 as it permits of the use of a high ratio of potential transformation in the coupling 19.

While I have described only two modifications of my device and have illustrated but two organizations in which it may be employed, it will be apparent that many modifications of the specific structure of the device, as well as its application, may be made without departing from the 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. The combination in an apparatus of the class described of an evacuated receptacle containing an electron emitting cathode, an anode, a third electrode and a discharge controlling member, means for producing an emission of secondary electrons from the third electrode sufficient in value to produce a negative resistance characteristic between cathode and third electrode, and means for applying a variable potential to the discharge controlling member to vary the number of secondary electrons emitted from the third electrode.

2. The combination in an apparatus of the class described of an evacuated receptacle containing a cathode adapted to be heated to incandescence, an anode, a third electrode and a discharge controlling member, said anode and third electrode being so constructed and related to each other that electrons may pass through openings in the anode and reach the third electrode, means for impressing a constant positive potential upon the anode, means for impressing a smaller positive potential upon the third electrode, and means for impressing a vari-

able potential upon the discharge controlling member.

3. The combination in a negative resistance device of means for producing an emission of primary electrons from a cathode to a cooperating electrode, an external circuit between said cathode and cooperating electrode, means for producing an emission of secondary electrons from said cooperating electrodes and a discharge controlling member for varying the effective emission of primary electrons to vary the emission of secondary electrons and thereby vary the current in said external circuit between the cathode and cooperating electrode.

4. The combination in an apparatus of the class described of an evacuated receptacle containing an electron-emitting cathode, an anode, a third electrode and a discharge controlling member, of means for supplying a definite positive potential to said anode, means for supplying a lower positive potential to the third electrode of such a value that the third electrode will emit a sufficient number of secondary electrons to produce a negative resistance characteristic between cathode and third electrode, and means for applying a variable potential to the discharge controlling member to vary the number of secondary electrons emitted from the third electrode.

5. The combination in an apparatus of the class described of an evacuated receptacle containing an electron emitting cathode, an anode, a third electrode external to said cathode and anode, and a discharge controlling member, means for applying a definite positive potential to the anode, means for applying a smaller positive potential to the third electrode, and means for applying a variable potential to the discharge controlling member.

6. The combination in an apparatus of the type described of an electron discharge device so constructed and organized that it has a negative resistance characteristic between an electron emitting cathode and a cooperating electrode, a discharge controlling member in proximity to the cathode adapted to vary the discharge between cathode and cooperating electrode and means for applying a variable potential to said discharge controlling member.

7. The combination in an apparatus of the class described of an evacuated receptacle containing an electron emitting cathode, an anode and a third electrode, means for producing an emission of secondary electrons from said third electrode and a discharge controlling member adjacent the cathode for varying the effective secondary electron emission from said third electrode.

8. The combination in an apparatus of the class described of an evacuated receptacle containing an electron-emitting cathode, an

anode and a third electrode, means for impressing a constant positive potential upon the anode, means for producing an emission of secondary electrons from the third electrode, and a discharge controlling member adjacent the cathode for varying the effective secondary electron emission from said third electrode.

9. The combination in an apparatus of the class described of an evacuated receptacle containing an electron emitting cathode, an anode and a third electrode, means for impressing a constant positive potential upon said anode, means for impressing a lower positive potential upon the third electrode of such a value as to produce an emission of secondary electrons from said electrode, a discharge controlling member adjacent the cathode and means for impressing a variable potential thereon to vary the effective secondary electron emission from the third electrode.

10. The combination of an electron discharge device comprising a cathode, an anode, a third electrode and a discharge controlling member inclosed in an evacuated envelop, means for impressing a definite positive potential upon the anode, means for impressing a lower positive potential upon the third electrode, means for impressing a variable potential upon the discharge controlling member, the electrodes being so proportioned and related to each other and the potentials being so chosen that the current in an external circuit between cathode and third electrode varies inversely as the potential applied to the third electrode over a given working range and varies with variations in the potential on the discharge controlling member, increasing as that potential becomes more positive and decreasing as it becomes more negative.

11. The combination in an apparatus of the class described of a highly evacuated envelop having therein a discharge controlling member, a filamentary cathode surrounding said member, an anode having openings therein surrounding said cathode and a third electrode surrounding said anode.

12. The combination in an apparatus of the class described of a highly evacuated envelop having therein a discharge controlling member, a cathode in the form of a coiled filament surrounding said member, an anode having openings therein surrounding said cathode, a third electrode surrounding said anode, means for impressing a definite positive potential upon said anode, means for impressing a smaller positive potential upon the third electrode and means for impressing a variable potential upon the charge controlling member.

13. The combination in an apparatus of the type described of an evacuated envelop having therein a discharge controlling mem-

ber, a filamentary cathode, an anode and a third electrode, said anode being located between said third electrode and said cathode, and said cathode being located between said anode and said discharge controlling member.

14. Means for amplifying electric currents comprising an evacuated receptacle containing a cathode adapted to be heated to incandescence, an anode, a third electrode and a discharge controlling member located adjacent said cathode, a circuit comprising the cathode and discharge controlling member, means for producing a flow of primary electrons from said cathode to said third electrode, and for producing an emission of secondary electrons from said third electrode to the anode and means for causing the currents to be amplified to flow in the circuit comprising the cathode and the discharge controlling member.

15. Means for amplifying potential variations comprising an evacuated receptacle containing a cathode adapted to be heated to incandescence, an anode, a third electrode and a discharge controlling member located adjacent the cathode, means for impressing a constant positive potential upon the anode, a circuit connection between cathode and third electrode which includes means for impressing a smaller positive potential upon the third electrode, means for impressing the potential variations which are to be amplified upon the discharge controlling member, and means included in the circuit connection between cathode and third electrode for utilizing the current variations in that circuit.

16. Means for amplifying potential variations comprising a negative resistance device having an electron emitting cathode, an anode, a third electrode and a discharge controlling member inclosed in a highly evacuated envelop and having sources of potential connected in external circuits between cathode and anode and between cathode and third electrode of such values that the device has a working range over which the current flow in the external circuit between cathode and third electrode varies inversely as the potential applied thereto, and means for impressing the potential variations which are to be amplified upon the discharge controlling member.

17. The method of operating an electron discharge device which comprises a filamentary cathode adapted to be heated to incandescence independently of the operating current, a cooperating electrode and a discharge controlling member inclosed in an evacuated receptacle and which is so constructed and organized that it has a negative resistance characteristic between the cathode and cooperating electrode, which consists in varying the negative resistance of the device

by applying a variable potential to the discharge controlling member.

18. The method of operating an electron discharge device which consists in producing an emission of primary electrons from a cathode to a cooperating electrode, producing an emission of secondary electrons from said cooperating electrode, and applying a variable potential to a discharge controlling member in proximity to the cathode and thereby varying the number of secondary electrons effectively emitted.

19. The method of operating an electron discharge device comprising an electron emitting cathode, an anode, a third electrode and a discharge controlling member which consists in producing an emission of secondary electrons from the third electrode sufficient to give the device a negative resistance characteristic between cathode and third electrode and applying a variable potential to the discharge controlling member to vary the number of secondary electrons emitted from the third electrode.

20. The method of operating an electron discharge device comprising an electron emitting cathode, an anode, a third electrode and a discharge controlling member which consists in supplying a uniform positive potential to said anode, supplying a lower positive potential to the third electrode of such a value that the third electrode will emit a sufficient number of secondary electrons to give the device a negative resistance characteristic between cathode and third electrode and applying a variable potential to the discharge controlling member to vary the number of secondary electrons emitted from the third electrode.

21. The method of varying the value of the negative resistance of a device comprising an electron emitting cathode, an anode, a third electrode, and means for causing an emission of secondary electrons from the third electrode, which consists in varying the number of primary electrons which may reach said third electrode with any given potential applied thereto and thereby varying the number of secondary electrons which will be effectively emitted therefrom.

22. The method of varying the value of the negative resistance of a device comprising an electron emitting cathode, an anode, a third electrode, a discharge controlling member and means for causing an emission of secondary electrons from the third electrode, which consists in applying a variable potential to said discharge controlling member and thereby varying both the number of primary electrons which may reach said third electrode with any given potential applied thereto and the number of secondary electrons which will be effectively emitted therefrom.

23. The method of controlling the value

of the negative resistance of a device comprising an electron emitting cathode, an anode, a third electrode, and means for causing an emission of secondary electrons from the third electrode, which consists in controlling the number of primary electrons which may reach the third electrode with any given potential applied thereto and thereby controlling the number of secondary electrons which will be effectively emitted therefrom.

24. The method of operating an electron discharge device comprising an electron emitting cathode, an anode, a third electrode external to said cathode and anode, and a discharge controlling member which consists in applying a definite positive potential to the anode, applying a smaller positive potential to the third electrode, applying a variable potential to the discharge controlling member and utilizing the resultant variable current between cathode and third electrode to give an indication of the variable potential applied to the discharge controlling member.

25. The method of amplifying a variable electric current which consists in producing an emission of primary electrons from a cathode to a cooperating electrode both of which are inclosed in a highly evacuated receptacle, producing an emission of secondary electrons from the cooperating electrode sufficient to give the device a negative resistance characteristic between cathode and cooperating electrode, causing the electric current to be amplified to flow in a circuit comprising the cathode and a discharge controlling member adjacent the cathode and thereby causing a current of greater magnitude but having corresponding variations to flow in a circuit comprising the cathode and cooperating electrode.

26. The method of operating an electron discharge device comprising an electron emitting cathode, an anode, a third electrode, and a discharge controlling member, which consists in producing an emission of secondary electrons from the third electrode sufficient to give the device a negative resistance characteristic between cathode and third electrode, producing high frequency oscillations by means of said device, and varying the amplitude of the oscillations thus produced by applying a variable potential to the discharge controlling member.

27. The method of operating an electron discharge device comprising an electron emitting cathode, an anode, a third electrode, and a discharge controlling member, which consists in producing an emission of secondary electrons from the third electrode sufficient to give the device a negative resistance characteristic between cathode and third electrode, producing high frequency oscillations by means of said device, and va-

rying the negative resistance of said device by applying to the discharge controlling member a potential which varies periodically at an audible frequency.

28. The method of transmitting signals in a system comprising a transmitting circuit and an electron discharge device comprising an electron emitting cathode, an anode, a third electrode, and a discharge controlling member, which consists in producing an emission of secondary electrons from the third electrode sufficient to give the device a negative resistance characteristic between cathode and third electrode, producing high frequency oscillations by means of said device, varying the amplitude of the oscillations thus produced by applying a signaling potential to the discharge controlling member, and supplying to the transmitting circuit the oscillations of varying amplitude.

29. The method of transmitting signals in a system comprising a transmitting circuit and an electron discharge device comprising an electron emitting cathode, an anode, a third electrode, and a discharge controlling member, which consists in producing an emission of secondary electrons from the third electrode sufficient to give the device a negative resistance characteristic between cathode and third electrode, producing high frequency oscillations by means of said device, varying the negative resistance of said device by applying to the discharge controlling member a potential which varies periodically at an audible frequency, and supplying to the transmitting circuit the oscillations produced.

30. The combination in an apparatus of the type described, of means for producing alternating currents comprising an evacuated receptacle containing an electron emitting cathode, an anode, a third electrode and a discharge controlling member, means including an external circuit between cathode and third electrode for producing an emission of secondary electrons from the third electrode sufficient in value to produce a negative resistance characteristic between cathode and third electrode, said external circuit between cathode and third electrode comprising an inductance and a capacity and means for varying the negative resistance of said device comprising a source of variable potential and means for applying a variable potential from said source to the discharge controlling member.

31. The combination in an apparatus of the type described, of means for producing high frequency alternating currents comprising an evacuated receptacle containing an electron emitting cathode, an anode, a third electrode and a discharge controlling member, means including an external circuit between cathode and third electrode for producing an emission of secondary elec-

trons from the third electrode sufficient in value to produce a negative resistance characteristic between cathode and third electrode, said external circuit between cathode and third electrode, comprising an inductance and a capacity and means for applying to the discharge controlling member a potential which varies periodically at an audible frequency.

- 10 32. The combination in a signaling system of a transmitting circuit, means for producing high frequency currents comprising an evacuated receptacle containing an electron emitting cathode, an anode, a third electrode and a discharge-controlling member, means including an external circuit between cathode and third electrode for producing an emission of secondary electrons from the third electrode sufficient in value
15 to produce a negative resistance characteristic between cathode and third electrode, said external circuit between cathode and third electrode comprising an inductance and a capacity and means for supplying to

the discharge controlling member a potential which varies in accordance with variations in sound waves, and means for supplying the high frequency currents produced in said external circuit to said transmitting circuit.

33. The combination in an apparatus of the class described of a highly evacuated receptacle having therein an electron emitting cathode, an anode, a third electrode and a discharge controlling member, means including external circuits between cathode and anode and between cathode and third electrode for producing a negative resistance characteristic between cathode and third electrode, and means for applying to the discharge controlling member a variable potential and thereby varying the current in the external circuit between cathode and third electrode.

In witness whereof I have hereunto set my hand this 2nd day of June, 1916.

ALBERT W. HULL.