CURRENT OR VOLTAGE REGULATOR

Filed Nov. 28, 1936 2 Sheets-Sheet 1

Fig. 1.

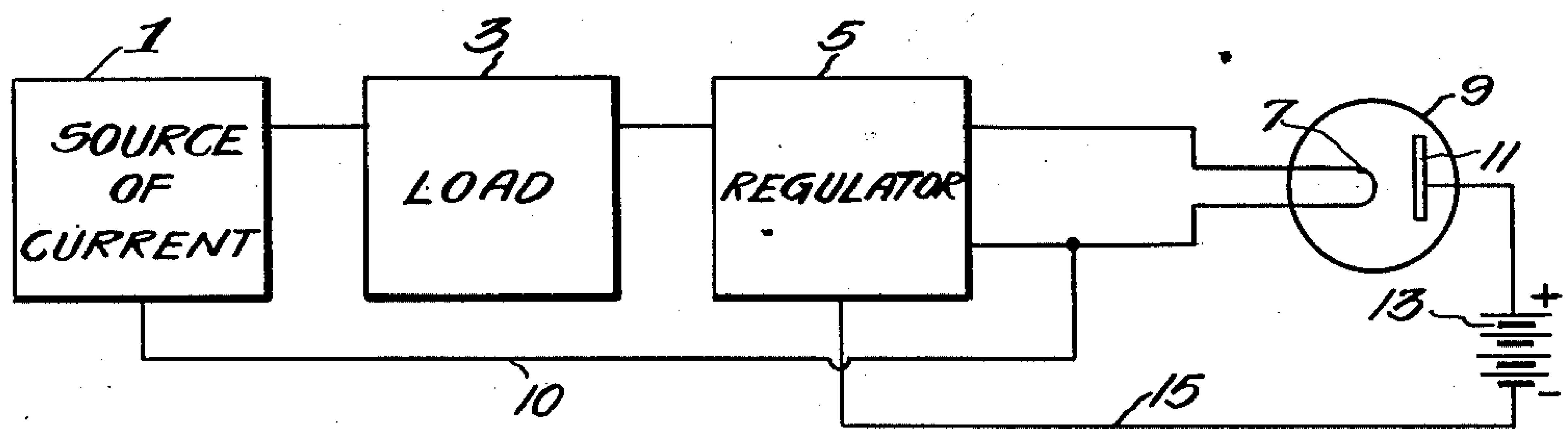


Fig. 2.

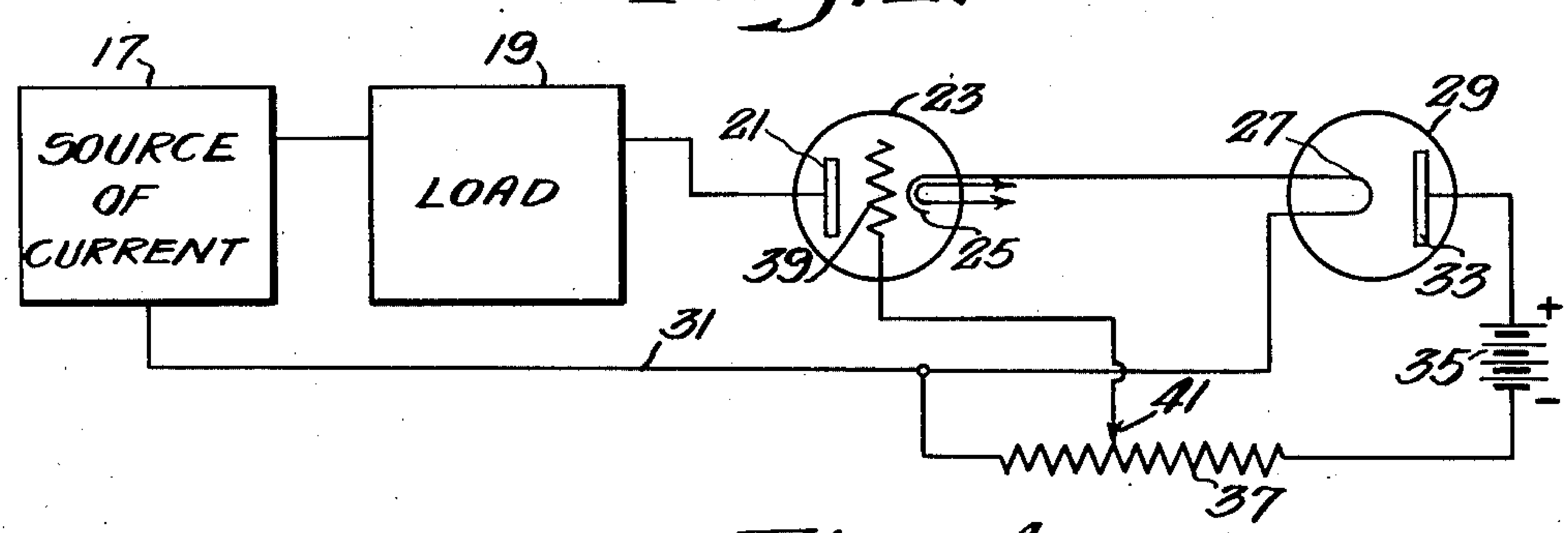
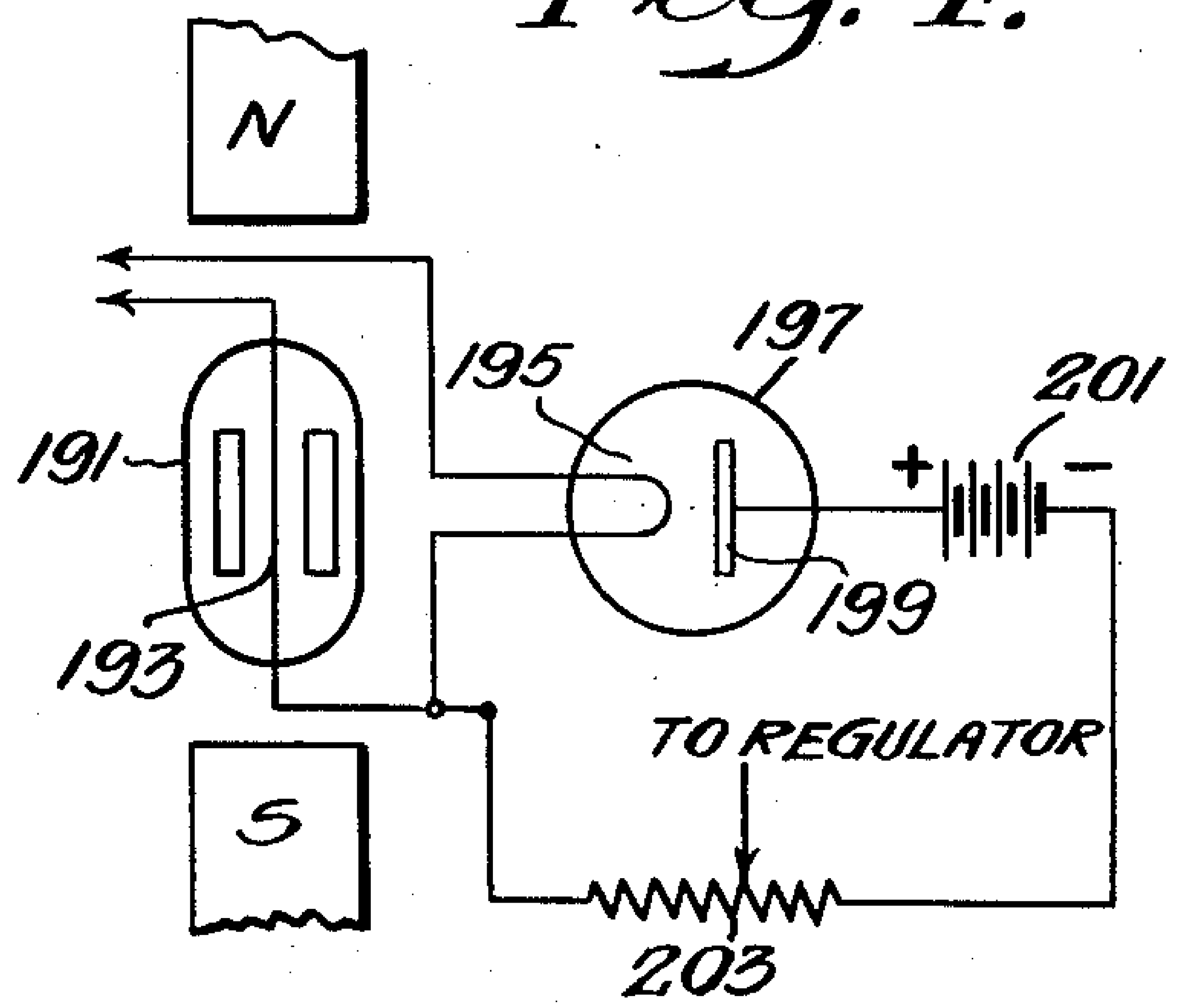


Fig. 4.



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Feb. 28, 1939. I. WOLFF 2,149,080

CURRENT OR VOLTAGE REGULATOR

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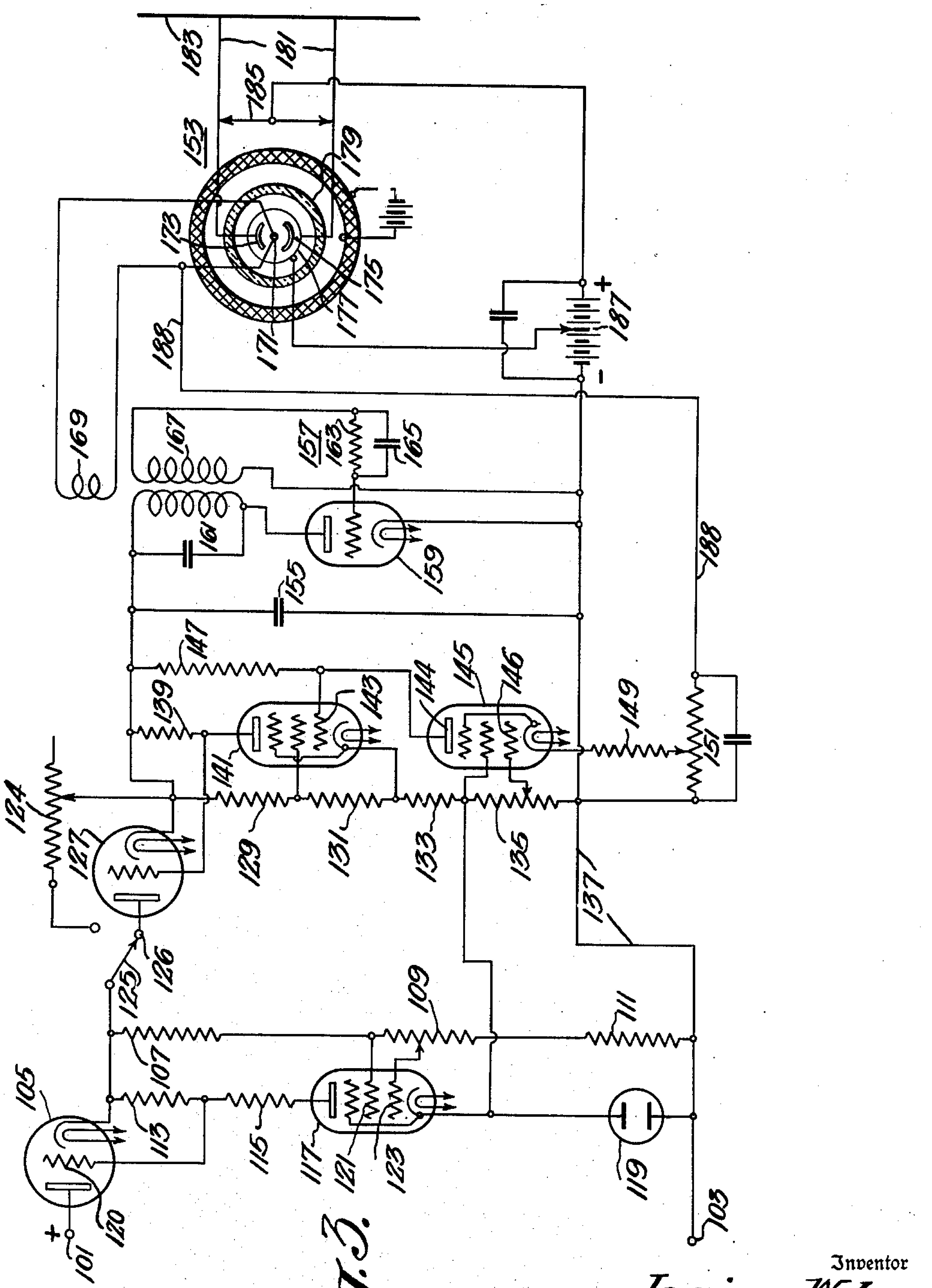

Fig. 3.

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UNITED STATES PATENT OFFICE

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CURRENT OR VOLTAGE REGULATOR

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11 Claims. (Cl. 250—27)

My invention relates to the regulation of current or voltage in a load circuit as a function of thermionic emission and, more particularly, to means for maintaining constant current or constant voltage by deriving a regulating voltage which depends upon electronic emission in a vacuum tube.

I am aware of the use of numerous types of current or voltage regulators which employ vacuum tubes as amplifiers for the regulating means. In general, such devices depend upon current or potential differences in the load circuit. I propose to greatly increase the sensitivity of a regulator by regulating the current as a function of thermionic emission. The substantial increase in regulation which I obtain is due to the fact that the proportional change of emission currents is about twenty to sixty times as great as the current change in the cathode which produces the emission, depending upon the type of cathode and cathode temperature. It should be understood that my invention may be applied to regulation of current in a resistive load, an electron emissive load, the regulation of magnetizing current, and the like.

It is well known to those skilled in the art that ultra high frequency tubes have operating characteristics which may be very erratic. One of the principal sources of variability is the filament emission of a microwave oscillator. One reason for such variation is due not only to variations in filament current but to filament bombardment. It has been proposed that suitable means be employed to maintain constant filament current. I have found that constant filament current is not a complete solution of the problem.

I propose, as a principal object of my invention, means for maintaining constant current in a load circuit by means of a regulating voltage derived from a thermionic emission current which is dependent upon the flow of current through the load circuit.

Another object of my invention is to maintain a constant voltage across a load circuit by means of a regulating voltage derived from a thermionic emission current which is dependent upon the current flowing through the load circuit.

Another object of my invention is to provide means for maintaining constant emission from the cathode in a thermionic tube.

Another object is to provide means for controlling the emission in one tube by means of regulating currents which are derived from the emission currents in an auxiliary tube.

Another object is to provide means for regulating a high frequency oscillatory current, which is used to heat the cathode of an ultra high frequency thermionic tube, by a controlling potential derived from the emission currents of the ultra high frequency tube.

A still further object is to provide means for maintaining a constant emission in a thermionic tube by energizing the cathode of the tube from a source of regulated high frequency oscillatory current.

An additional object is to provide means for protecting the catode of a thermionic tube in the event that failure develops in the regulation of the cathode heating control means.

My invention may be best understood by referring to the accompanying drawings, in which—

Fig. 1 is a schematic circuit diagram of one embodiment of my invention,

Fig. 2 is a modification of the circuit diagram of Fig. 1, in which a thermionic tube is used as a regulator,

Fig. 3 is a circuit diagram of an embodiment of my invention which includes direct current amplifiers and a converter which is regulated to maintain constant emission in an ultra high frequency tube, and

Fig. 4 is a modification which may be applied to the circuit of Fig. 3 and which employs an auxiliary tube.

Referring to Fig. 1, a source of current 1 is connected to a load circuit 3, which is in turn serially connected to a regulator 5. The regulator 5 is connected to the cathode 7 of a vacuum tube 9. The cathode 7 is connected by a lead 10 to the source of current 1. The vacuum tube 9 includes an anode 11, which is connected to the positive terminal of the anode battery 13. The return to the cathode 7 from the negative terminal of the anode battery is made by means of a lead 15 through the regulator 5.

The operation of Fig. 1 is as follows: The vacuum tube 9 is adjusted to operate below the point of emission saturation, i. e., on the sloping portion of the characteristic cathode current-anode current curve. If the source of current varies, the current flowing through the cathode 7 will likewise vary. The currents emitted from the cathode will have a proportional change about twenty or more times as great as the cathode current variation producing the change. This change in emissive current is applied to the regulator to thereby increase or decrease the impedance of the regulator which regulates the current flow in the load circuit. If the load is of the resistive type and maintains a constant resistance, then the current through resistance may be maintained constant, and hence the voltage drop across the resistance will be constant. In this manner, the circuit of Fig. 1 may be used to regulate either the current or the voltage.

In Fig. 2, a simple form of regulator is substituted for the schematic illustration in Fig. 1. Referring to Fig. 2, a source of current 17 is connected to a load circuit 19, which in turn is connected to the anode 21 of a thermionic tube 23. The cathode 25 of this tube is connected to the cathode 27 of a vacuum tube 29. The cathode circuit is completed by a lead 31, which returns to the current source. The vacuum tube 29 has an anode 33 which is connected to the positive terminal of the anode battery 35. The negative terminal of the anode battery is connected to a resistor 37 which terminates in the lead 31. A control grid 39, which is included within the thermionic tube 23, is connected to a slider 41, which is adjustably connected to the resistor 37.

The operation of the circuit of Fig. 2 is essentially as follows: When the cathode of the thermionic tube 23 is suitably heated, currents will flow from the source of current 17 through the lead 31, through the cathode 27 of the vacuum tube 29, from the cathode 25 to the anode of the regulator tube 23, through the load circuit and back to the source 17. Since the vacuum tube 29 is adjusted, as previously described, to operate on the sloping portion of the emission curve, any variation in current through the cathode 27 will change the emission currents and thereby vary the current flowing through the resistor 37. The variation in current through the resistor 37 will cause potential changes which are impressed on the grid 39. These potential changes will vary the impedance of the regulator tube 23 to thereby neutralize or compensate for the changes in current.

More specifically, if the current increases, the potential of the gird 39 will become more negative and thereby increase the impedance of the regulator tube, which in turn decreases the current flow. Conversely, if the current through the cathode 27 decreases, the emission currents decrease and the voltage drop applied to the grid 39 becomes less negative or more positive. A more positive potential applied to the grid 39 tends to decrease the impedance of the regulator tube and thereby increase the flow of current and compensate for the diminishing current.

Referring to Fig. 3, a source of electric current is represented by the terminals 101, 103. The upper or positive terminal 101 is connected to the anode of a thermionic tube 105. The cathode of this tube is connected, through serially arranged resistors 107, 109, 111, to the negative terminal 103. The three resistors 107, 109, 111 are shunted by a serial array, comprising, in the order named, two resistors 113, 115, the anode-cathode path of a thermionic tube 117, which is a direct current amplifier, and a gaseous discharge tube 119. The grid 120 of the first mentioned thermionic tube 105 is connected to a point between the two resistors 113, 115. The screen grid 121 of the direct current amplifier tube 117 is connected to the junction of resistors 107, 109. The control grid 123 of tube 117 is adjustably connected to resistor 109.

Briefly, the operation of the above described circuit is to maintain a constant voltage across the three resistors 107, 109, 111, to prevent excessive voltages from being applied to the cathode of the ultra high frequency tube which is to be regulated. If the voltage across the resistors 107, 109, 111 rises, the potential of control grid 120 becomes more negative or less positive, thereby increasing the impedance of the tube 105. The tube 105, being serially arranged with respect to the source 101, 103 and the resistors 107, 109, 111, will, when its anode-cathode impedance increases, decrease the voltage drop across the resistors 107, 109, 111. Likewise, when the voltage across these resistors drops, the grid 120 becomes more positive and thereby decreases the anode-cathode impedance of tube 105 and increases the voltage across the resistors 107, 109, 111. Thus the voltage is regulated.

The three resistors 107, 109, 111 may be considered as the source of a constant voltage. This source is connected as follows: The upper terminal of resistor 107 is connected through a switch 125 and contact 126 to the anode of a thermionic tube 127. The cathode of this tube 127 is connected to four serially connected resistors 129, 131, 133, 135, which terminate in the lead 137 connected to resistor 111 and terminal 103. Two, 129, 131, of the four resistors are shunted by a serially connected array comprising resistor 139 and the anode-cathode path of a direct current amplifier tube 141. The screen grid of the amplifier tube 141 is connected to the junction of resistors 129, 131. The control grid 143 of the first direct current amplifier tube 141 is connected to the anode 144 of a second direct current amplifier which is connected as follows: Anode 144 of tube 145 is connected, through resistor 147, to the upper terminal of resistor 129. The cathode of tube 145 is connected through a resistor 149 to a slider on a resistor 151, which is connected to the lower terminal of resistor 135 and to the cathode of the magnetron 153. The screen grid of tube 145 is connected to the junction of resistors 133, 135. The control grid of tube 145 is adjustably connected to the fourth resistor 135. The four resistors 129, 131, 133, 135 are shunted by a capacitor 155.

An oscillator 157 is connected as follows: A thermionic tube 159 is arranged with its cathode connected to the lead 137. The anode is connected through a resonant circuit 161 to the upper, or positive, terminal of resistor 129. The grid is connected through a grid-leak resistor 163 and grid capacitor 165 to an inductor 167, which is mutually coupled to the resonant circuit 161. This oscillator generates a current preferably of superaudible frequency; e. g., 20 kilocycles per second. This high frequency current is induced in the tertiary winding 169 which is coupled to the resonant circuit 161.

The tertiary winding 169 is connected to the cathode 171 of the magnetron 153. The magnetron 153. The magnetron circuit includes split anodes 173, 175, end plates 177, and the cathode 171, which are mounted within an evacuated envelope 179. The anodes 173, 175 are connected to a transmission line 181, which terminates in an antenna 183. The mid-point of a bridging member 185, which is adjustably mounted on the transmission line, is connected to the positive terminal of a B voltage source 187. The end plates 177 are also connected to the B voltage source. The cathode return is made by the lead 188, which connects the cathode 171 to the resistor 151, which is in turn connected to the negative terminal of the B voltage source 187.

Neglecting for the moment the characteristics of the constant voltage source, the theory of operation of the circuit may be explained as follows: The magnetron cathode 171 is heated by high frequency currents from the oscillator 157. The emission from the magnetron cathode 171 to the anodes 173, 175 and end plates 177, establishes an anode current which flows through the resistor 151 and back to the cathode through lead 188. While the emission currents are steady, no change in voltage is established across the resistor 151 through which the magnetron emission current flows and no regulation is obtained.

If, however, the emission current decreases, less current flows through the resistor 151, and the cathode of tube 145 becomes more negative with respect to its control grid 146. With a more positive control control grid (i. e., more negative cathode), more current will flow in this tube 145, and therefore its anode 144 will be less positive. Since the control grid of tube 141 is connected to the anode 144 of tube 145, the control grid 143 will likewise be less positive. A less positive control grid 143 will decrease the current in the anode circuit of tube 141, and therefore the anode will become more positive. The control grid of tube 127, being connected to the anode of tube 141, will become more positive, and therefore will decrease the impedance of tube 127.

The decrease in impedance of tube 127 will decrease the voltage drop in this tube, and therefore raise the potential of the anode of the oscillator tube 159. This increase in potential will increase the high frequency oscillatory output currents of the oscillator 157, whereby the high frequency oscillatory current in the cathode 171 will be increased to increase its emission. Thus, a decrease in emission is compensated or neutralized by increasing the cathode emission. In a reverse manner, an increase in the magnetron emission current will be neutralized by a decrease in the high frequency oscillator 157 output.

Thus, the emission from the cathode of the magnetron 153 is maintained substantially constant by increasing or decreasing the cathode current, not to maintain constant cathode current, but constant cathode emission. This method of control is much more sensitive than attempting to maintain a constant cathode heating current. I have determined that control by emission regulation is not only about twenty or more times more sensitive than control of the heating current, but also that the latter method does not provide means for compensating for cathode bombardment, which is very important in ultra high frequency oscillators of either positive grid or magnetron type.

In some instances, I have found that the cathode emission is too low to provide a suitable type of control. In such cases, an auxiliary emitter may be arranged with its cathode heater serially connected to the heater of the tube to be controlled. This arrangement is indicated in Fig. 4, in which the circuit has been limited to the essential parts. The magnetron 191 has a cathode 193, which is serially connected to the cathode 195 of an auxiliary diode 197. The serially connected cathodes are connected to the tertiary winding of the high frequency oscillator illustrated in Fig. 3. The anode 199 of the auxiliary tube 197 is connected to the positive terminal of a B battery 201. The negative terminal of the B battery is connected through a resistor 203 to the junction of the cathodes 193, 195. The resistor 203 corresponds to the resistor 151 of Fig. 3. The description of the remaining connections is similar to that of Fig. 3, and will, therefore, not be repeated.

In the present circuit, Fig. 4, the emission in tube 191 is not sufficient to provide suitable regulation. The emission in the auxiliary tube is determined by the characteristics of the tube 197 and the anode battery 201 voltage. The emission of the auxiliary tube is regulated to maintain constant emission currents, and since the cathode of the main tube 191 and the auxiliary tube 197 are in series, the emission of the former, 191, will be regulated by the latter, 197. In the present application, the effects of the cathode bombardment in the main tube 191 will not be controlled, but fortunately, with low emission cathode bombardment may generally be neglected. The cathode emission of the main tube is much more closely regulated by the control of emission in the auxiliary tube than it would be if the regulator were of the ordinary constant cathode current type.

While the foregoing description has been limited to magnetron tubes, it should be understood that the invention may be applied to positive grid oscillators, ultra high frequency tubes, or any thermionic tube. Likewise, while a constant voltage source is shown, such source is by way of illustration. Its function is to limit the maximum voltage on the oscillator 153 to prevent burn-out of the cathode 171, if the emissive regulation should fail. In some instances it may be desirable to omit the emission control during adjustment. This may be effected by connecting switch 125 to the adjustable resistor 124. The frequency of the high frequency oscillator 157 is described as above audible frequencies, but it is not my intention to thereby limit the frequency to any particular value.

The direct current amplifiers of Fig. 3 may be applied to amplify the regulating voltage of the systems described by Figs. 1 and 2. Likewise, the current source of Figs. 1 and 2 may be applied to a converter or generator as shown in Fig. 3. In a similar manner, the constant voltage source of Figs. 1 and 2 may be substituted for the constant voltage regulator which is applied to the source 101 of Fig. 3. Numerous other modifications within the scope of my invention will occur to those skilled in the art.

I claim as my invention:

1. In an apparatus of the character described, a source of current, a load circuit, a variable impedance device, means for emitting thermionic currents, means for serially connecting said source, load circuit, variable impedance device and emitting means, means for deriving a regulating potential from said thermionic currents, and means for applying said regulating potential to said variable impedance device whereby its impedance is varied to regulate the current flowing in said load circuit.

2. In an apparatus for regulating current, a source of current, a load network, a three-element vacuum tube including grid, cathode and anode electrodes, a two-element vacuum tube including cathode and anode electrodes, means for passing currents from said source through said load network, the cathode-anode path of said three-element tube, and the cathode of said two-element tube, means including a resistor for passing thermionic currents from the cathode to the anode of said two-element tube whereby a regulating potential is developed across at least a portion of said resistor, and means for impressing said regulating potential on the grid electrode of

said three-element tube whereby the impedance of said three-element tube is varied to thereby regulate the flow of current through said load network.

3. The method of controlling cathode emission currents which comprises generating an oscillatory current, applying said oscillatory current to heat said cathode to an emissive temperature, deriving a regulating voltage from said emission, applying said regulating voltage to control the said applied oscillatory heating currents and thereby control the emission from said cathode.

4. The method of controlling cathode emission by means of an auxiliary emissive source which comprises generating an oscillatory current, applying said oscillatory current to said cathode and said auxiliary emissive source to heat the same to emissive temperatures, deriving a regulating voltage from said auxiliary emission, applying said regulating voltage to control the oscillatory heating currents applied to said cathode and auxiliary emissive source.

5. The method of controlling cathode emission which comprises generating an oscillatory current from a source of current including a variable impedance, heating said cathode by said oscillatory current whereby emissive currents are established, deriving a controlling voltage from said emissive currents, applying said controlling voltage to said variable impedance, regulating the value of said variable impedance by said applied controlling voltage whereby the voltage derived from said source and the amplitude of said oscillatory currents are varied to neutralize any changes in said emissive currents.

6. The method described in claim 5 plus the additional step of regulating the voltage of the source prior to its application to said variable impedance.

7. The method described in claim 5 plus the additional step of amplifying said controlling voltage before applying said controlling voltage to said variable impedance.

8. In a device of the character described, the combination of a source of current, a variable impedance, means for converting the currents from said source into oscillatory currents, means for serially connecting said source, said variable impedance and said current converting means, a vacuum tube including cathode and anode electrodes, means for applying said oscillatory currents to said cathode whereby said cathode is heated to emit electrons, means for deriving a controlling potential from said emitted electrons, and means for applying said controlling potential to said variable impedance whereby the amplitude of said oscillatory currents is regulated.

9. In a device of the character described, the combination of a source of current, a variable impedance, means for converting said source currents into oscillatory currents, means for serially connecting said source, said variable impedance and said current converting means, a vacuum tube including cathode and anode electrodes, means for applying said oscillatory currents to said cathode whereby emission currents are established between said electrodes, means for deriving a controlling potential from said emission currents, means for amplifying said controlling potential, and means for applying said amplified potential to vary said impedance whereby the potential of the currents from said source is varied and the amplitude of the converted currents regulated to maintain substantially constant emission currents.

10. In a device of the character of claim 8, separate means for maintaining the potential of said source substantially constant to thereby limit the potential applied to said current converting means independently of said controlling potential.

11. In a device of the character of claim 9, a second vacuum tube including at least a cathode electrode, and means for regulating emission currents from the cathode of said second tube as a function of the emission currents in said first vacuum tube.

IRVING WOLFF.