Sept. 20, 1960 J. TOWNSEND 2,953,717

CATHODE HEATING APPARATUS

Filed Feb. 19, 1959 2 Sheets-Sheet 1

FIG. 1.

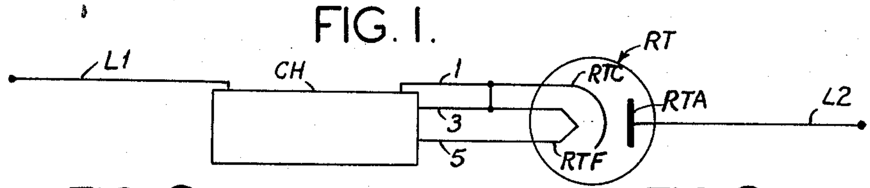


FIG. 2.

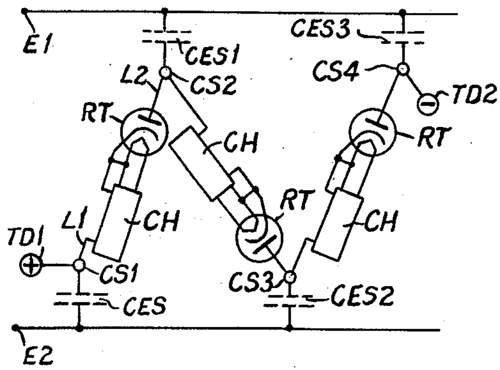


FIG. 3.

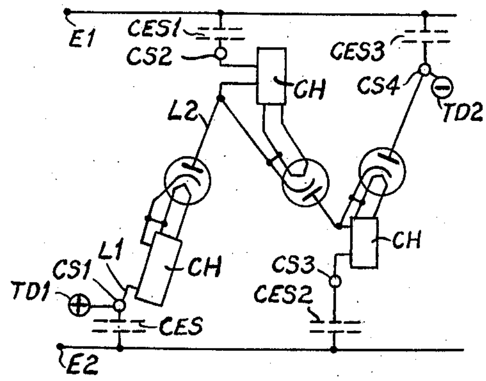


FIG. 4.

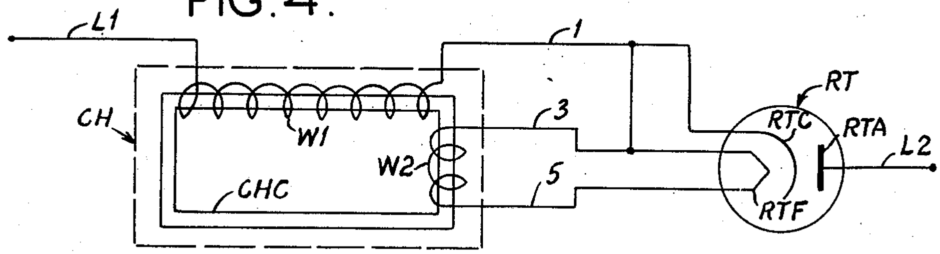
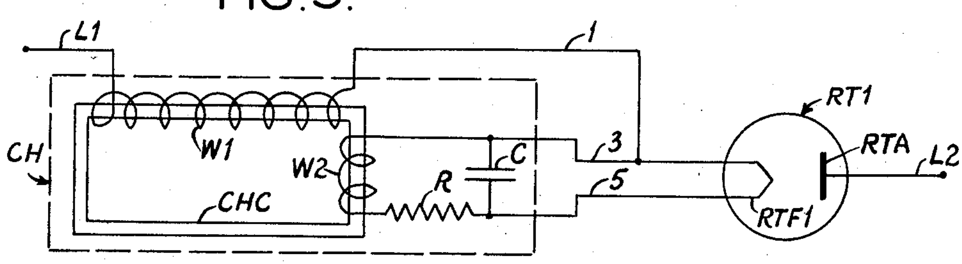


FIG. 5.



Jonathan Townsend,
Inventor.
Koenig and Pope,
Attorneys.

Sept. 20, 1960 J. TOWNSEND 2,953,717

CATHODE HEATING APPARATUS

Filed Feb. 19, 1959 2 Sheets-Sheet 2

FIG. 6.

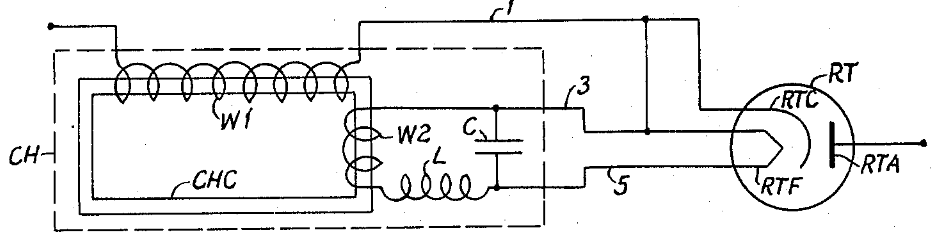


FIG. 7.

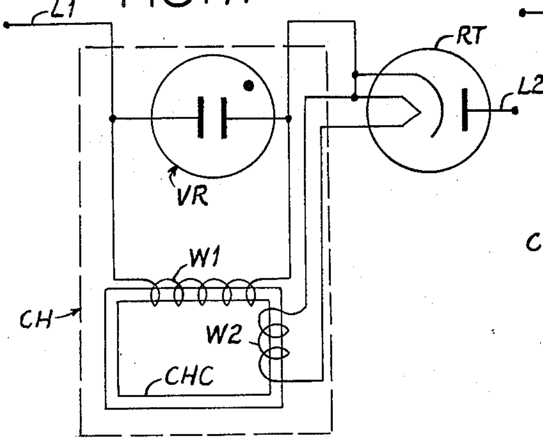


FIG. 8.

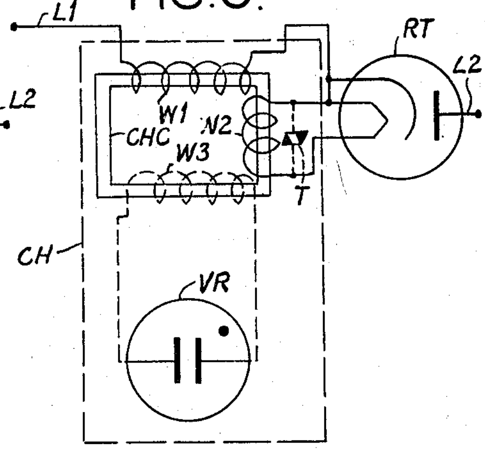


FIG. 9.

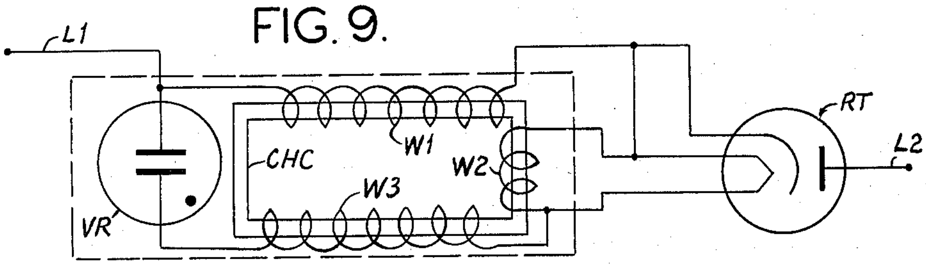
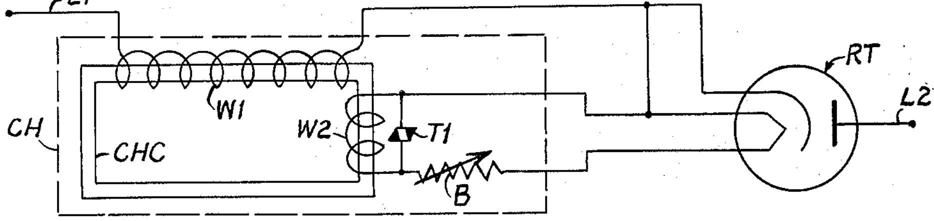


FIG. 10.



Jonathan Townsend,
Inventor.
Koenig and Pope,
Attorneys.

United States Patent Office

2,953,717

Patented Sept. 20, 1960

2,953,717

CATHODE HEATING APPARATUS

Jonathan Townsend, University City, Mo., assignor to Radiation Dynamics, Inc., New York, N.Y., a corporation of New York

Filed Feb. 19, 1959, Ser. No. 794,388

24 Claims. (Cl. 315—97)

This invention relates to a cathode heating apparatus and more particularly to voltage multiplication apparatus having means for heating the cathodes of high voltage rectifier tubes.

Among the several objects of this invention may be noted the provision of cathode heating apparatus which supplies electrical power to the cathodes of rectifier tubes without the need of auxiliary sources of power therefor; the provision of voltage multiplication apparatus in which power for heating the cathodes of the rectifier tubes thereof is made readily available directly to the cathodes and does not have to be furnished by additional devices such as auxiliary transformers; the provision of such cathode apparatus which is substantially independent of the frequency of the A.C. potentials applied to said rectifier tubes; and the provision of voltage multiplication apparatus of the class described in which the power supplied to heat the rectifier tube cathodes is substantially independent of the level of the A.C. potentials applied to the rectifier tubes. Other objects and features will be in part apparent and in part pointed out hereinafter.

The invention accordingly comprises the constructions hereinafter described, the scope of the invention being indicated in the following claims.

In the accompanying drawings, in which several of various possible embodiments of the invention are illustrated,

Fig. 1 is a schematic circuit diagram of cathode heating apparatus of the present invention interconnected with a rectifier tube;

Figs. 2 and 3 are schematic circuit diagrams of two different embodiments of voltage multiplication apparatus of the present invention; and,

Figs. 4–10 are schematic circuit diagrams of additional alternative embodiments of cathode heating apparatus of the present invention interconnected with rectifier tubes.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

The supplying of power to heat the cathodes of rectifier tubes of voltage multiplication apparatus employing cascaded rectifier tubes has presented serious problems. Because there are high A.C. and D.C. potential differences between the various tubes, it has been necessary heretofore to employ individual batteries for each rectifier tube or to use isolation transformers built to withstand these high potential differences. Neither arrangement is satisfactory inasmuch as batteries must be frequently renewed or recharged and isolation transformers of sufficient insulation and capacity to operate satisfactorily are bulky and expensive.

In accordance with the present invention voltage multiplication apparatus is provided in which no auxiliary source of power or isolation transformers are needed but power to heat the cathodes is made available right at the cathodes by novel cathode heating apparatus. The A.C. charging or displacement current flowing through the capacitance constituted by the anode-cathode circuit of each of the rectifier tubes, due to the A.C. potentials applied thereto, is utilized as the source of power for heating each of the rectifier tube cathodes. The apparatus of the present invention is substantially independent of the frequency of these applied A.C. potentials and in certain of the more preferred embodiments the power supplied to each tube cathode is also substantially independent of the level of the A.C. potentials applied to the rectifier tube anode-cathode circuit.

Referring now to Fig. 1 a cathode heating apparatus unit of the present invention is generally indicated at reference character CH. This unit is serially connected with the anode-cathode circuit of a rectifier tube RT across a source of high potential A.C. power as indicated by wires L1 and L2. This is accomplished by interconnecting three electrical leads **1**, **3** and **5** between heater unit CH and the cathode components RTC and RTF. Tube RT, which may be any of the conventonal types of tubes known to those skilled in this art (but is preferably of the high vacuum type), also includes an anode RTA, in addition to cathode RTC and filament RTF. Although tube RT is illustrated as an indirectly heated cathode type of tube, it is to be understood that directly heated cathodes are full equivalents and may be used interchangeably (see Fig. 5) in carrying out the present invention. It will be noted that cathode RTC and filament RTF are maintained at substantially the same electrical potential level by interconnecting the leads **1** and **3**.

One specific exemplary embodiment of the impedance-transforming or heating unit CH is illustrated in Fig. 4, in which CH is a transformer having a magnetic circuit constituted by a ferromagnetic core CHC with a first or primary winding W1 and a second or secondary winding W2. The core is preferably composed of ferrite but could be other ferro-magnetic material such as laminated silicon steel, etc. Upon application of an A.C. potential across L1—L2 rectifier RT will conduct when its anode RTA is positive in relation to its cathode RTC and function as a half-wave rectifier. In addition the current conducted by tube RT during the positive ½ cycles, there is a flow of A.C. displacement or charging current across the capacitance constituted by the cathode RTC and anode RTA. The amount of displacement current which flows both through RT and therefore winding W1 is a function of several parameters including that of the actual anode-cathode capacitance, the voltage level and frequency of the A.C. potential applied across L1—L2 and the impedance of any other components in the circuit including primary winding W1. The current flowing through W1 induces through transformer action an A.C. potential across winding W2 which in turn supplies A.C. power to filament RTF via wires **3** and **5** to heat cathode RTC. The turns ratio of W1 and W2 is, of course, a function of the displacement current flowing through W1 and the voltage and current requirements for energizing filament RTF. Unit CH can be manufactured quite economically and is very compact. It may be mounted directly on a base for the tube RT and needs no insulation in excess of that necessary to withstand the relatively minor potentials developed in the transformer itself.

An exemplary voltage multiplication apparatus of the present invention is shown in Fig. 2. High voltage cascade voltage-multiplying rectifier arrangements of this type are disclosed, for example, in the coassigned U.S. patent application S.N. 618,862, filed October 29, 1956, now U.S. Patent 2,875,394. The apparatus includes two metallic electrodes E1 and E2 across which is impressed an A.C. potential. Adjacent to, but spaced from, first metallic electrode E1 are several corona shields CS2, CS4. Similarly there are several corona shields CS1 and CS3 positioned adjacent to but spaced from a second metallic electrode E2. These corona shields are connected at the electrical junctions between several series circuits (each comprising one tube RT and one heater unit CH). Thus, in effect by connecting corona shields CS2 and CS4 at alternate junctions relative to CS1 and CS3, the three rectifier-heater unit circuits are shunt-connected across electrodes E1—E2 via the interelectrode capacitances inducted at CES, CES1, CES2 and CES4. These interelectrode capacitances between E1—CS2 and E1—CS4 (CES1 and CES3, respectively) and between E2—CS1 and E2—CS3 (CES and CES2, respectively) serve to capacitively couple the A.C. potential across E1—E2 to the rectifier and heater units. Although these rectifier-heater unit circuits are shunt-connected across the A.C. potential of E1—E2 through the capacitances CES, CES1, CES2 and CES4, tubes RT are electrically connected in an anode-to-cathode relationship between two high voltage D.C. terminals TD1 and TD2, thereby effectively connecting in series the rectified D.C. output potentials of each of rectifier tubes RT.

Upon application to metallic electrodes E1—E2 of an A.C. potential, for example, in the order of 50,000 to 150,000 v., and a frequency of about 20 to 200 kc., the series circuits each comprising a unit CH and a rectifier tube RT are energized. Considering the anode-to-cathode capacitances of tube RT as capacitors, a charging or displacement current is caused to flow through each of the first windings of the transformers, which induces a flow of current through the filament RTF. The cathodes of tubes RT are thereby heated and tubes RT will function as half-wave rectifiers, the rectified outputs of which are additively impressed across high voltage terminals TD1 and TD2. With twenty rectifier tubes RT, for example, connected as illustrated and an A.C. potential in the order of 100 kv. applied by E1—E2 to tubes RT, a D.C. output potential in the order of 2 megavolts will be produced. The cathode heater transformer CH is not a resonant circuit and is therefore not significantly affected by moderate shifts in the frequency of the A.C. potential across E1 and E2 and thus the A.C. power supplied by winding W2 is substantially independent of this frequency. This substantial independence of the heater power to such frequency variations is an important advantage of the present invention inasmuch as it is difficult to economically maintain the frequency of the A.C. applied across E1—E2 within a narrow range. Moreover, it is desirable to be able to vary this frequency and it would be quite disadvantageous if the filament heater power were seriously affected by such frequency shifts.

A second embodiment of voltage multiplication apparatus of the present invention is shown in Fig. 3, which is identical to the Fig. 2 embodiment except as to the interconnection of the corona shields to the junctions between the several electrical circuits comprising a rectifier tube RT and a cathode heater CH. In Fig. 2 these electrical junctions are connected directly to the corona shields whereas in Fig. 3 these junctions are connected through winding W1 of heater units CH to the corona shields. An advantage of the Fig. 3 arrangement is that the winding W1 of each cathode heater unit CH which is connected between the electrical junctions (i.e., not the terminal units such as for example the unit CH connected to CS1) will carry the displacement currents flowing through two rectifiers RT, instead of merely one as is the case in the Fig. 2 embodiment. In the Fig. 3 embodiment, therefore, the turns ratio between W1 and W2 may be reduced over that utilized in Fig. 2 for the same output potential of winding W2.

In many instances during operation of voltage multiplication apparatus of the present invention, it is desirable to vary the A.C. potential across E1—E2 without changing the potential applied by W2 to the filaments RTF. Figs. 5–9 are exemplary embodiments of cathode heating apparatus which will function to provide a substantially constant level of power to cathodes. In Fig. 5 heater unit CH includes a capacitor C and a resistor R series-connected in a loop circuit with said secondary winding W2. The core CHC is so constructed that the displacement current through winding W1 will saturate core CHC during most of the A.C. cycle. The voltage waveform of the secondary W2 is, therefore, in the shape of pulses of short time duration. As the area of these pulses is proportional to the saturation flux density, these pulse areas are independent of the displacement current carried by winding W1. Resistor R and capacitor C constitute an integrating network to produce a voltage waveform at the cathode-filament RTF1 which has an r.m.s. value proportional to the area of the secondary winding pulses. Thus the power supplied to the cathode of RTF1 is independent of the displacement current through W1. It will be noted that rectifier tube RTA of Fig. 5 is of the directly heated cathode type, i.e. one in which the cathode is constituted by a filament. Accordingly, wire **1** does not connect to an indirectly heated cathode, as in Fig. 4, but is simply connected to one side of the filament RTF1. It will be understood that this arrangement of connecting wire 1 to one side of the filament is the equivalent of connecting it to a center tap of winding W2.

The embodiment of Fig. 6 is identical to that of Fig. 5, with but two exceptions. The impedance constituted by resistor R of Fig. 5 is replaced by an inductor L in Fig. 6, and an indirectly heated type of cathode construction (comprising both a cathode RTC and a filament RTF) is used in Fig. 6.

In the Figs. 7–9 embodiments regulation of heater power is also provided. In these three embodiments a voltage regulator unit VR is utilized. This unit VR may be of the gaseous diode type (where application of a potential in excess of a predetermined value will cause gas to ionize and the regulator to conduct) or the Zener diode type, or a varistor (such as a thyrite resistor) or any equivalent thereof. The Fig. 7 voltage regulator VR is connected in shunt across winding W1. In addition to providing regulation the use of a voltage regulator VR, particularly of the thyrite or glow-tube type, across the primary winding W1 also has the advantage of supplying protection against the possibility of high voltage spark breakdown at the high voltage terminal of a cascade rectifier. As these windings constitute high impedance elements to the spark which might otherwise develop damaging high voltages thereacross, the regulating element will provide a low impedance by-pass under such conditions.

The Fig. 8 embodiment illustrates two alternative arrangements for providing regulation. Either a varistor type of voltage regulator, such as a thyrite resistor T, is connected across the secondary winding W2, or a tertiary winding W3 with any other conventional voltage regulator, such as is indicated at VR, may be employed.

In Fig. 9 tertiary winding W3 and unit VR are connected in series in an electrical circuit which in turn is connected across windings W1 and W2. In each of the Figs. 7, 8 and 9 embodiments the windings are tightly coupled by means of ferromagnetic core CHC and insure that the power supplied to the filament of the rectifier tube RT is substantially independent of the level of the A.C. potential of E1—E2, as well as the frequency thereof.

The last illustrated embodiment, Fig. 10, is similar to that of Fig. 4 except that a current sensitive resistance element B (such as a barretter) is connected in series with the winding W2 and filament RTF, and an impedance, such as a thyrite resistor T1, is shunt-connected across winding W2. Component B functions to limit the current supplied to RT and thus assure regulation of the power supplied to the cathode of RT. The use of the parallel-connected thyrite varistor T1 across secondary

W2 in combination with element B further improves the regulation.

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results attained.

As various changes could be made in the above constructions without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. Voltage multiplication apparatus comprising first and second metallic electrodes, a source of A.C. power connected to said electrodes, a plurality of first corona shields spaced from said first electrode, a plurality of second corona shields spaced from said second electrode, a plurality of rectifier tubes each having an anode and a cathode, means substantially independent of the frequency of said A.C. power source for electrically heating each of the rectifier tube cathodes comprising a transformer for each rectifier tube having a magnetic circuit including a ferromagnetic core and first and second windings thereon, and a plurality of electrical circuits each including a rectifier tube and the first winding of a transformer series-connected respectively between pairs of first and second corona shields whereby an A.C. potential is capacitively coupled from said electrodes through said corona shields to each of said electric circuits, each of said second windings being electrically connected to the cathode of a respective one of said rectifier tubes to heat it, said rectifier tubes being electrically connected in an anode-to-cathode relationship between two electrical terminals and adapted to supply a high D.C. potential thereto.

2. Voltage multiplication apparatus comprising first and second metallic electrodes, a source of A.C. power connected to said electrodes, a plurality of first corona shields spaced from said first electrode, a plurality of second corona shields spaced from said second electrode, a plurality of rectifier tubes each having an anode and a cathode, means substantially independent of the frequency of said A.C. power source for electrically heating each of the rectifier tube cathodes comprising a transformer for each rectifier tube having a magnetic circuit including a ferromagnetic core and first and second windings thereon, each of said first windings interconnecting the anode of one rectifier tube with the cathode of the next rectifier tube at electrical junctions, each of said first and second corona shields respectively connected to alternate electrical junctions whereby an A.C. potential is capacitively coupled from said electrodes through said corona shields to each of said rectifier tubes, each of said second windings being electrically connected to the cathode of a respective rectifier tube to heat it, said rectifier tubes electrically connected in an anode-to-cathode relationship between two electrical terminals and adapted to supply a high D.C. potential thereto.

3. Voltage multiplication apparatus comprising first and second metallic electrodes, a source of A.C. power connected to said electrodes, a plurality of first corona shields spaced from said first electrode, a plurality of second corona shields spaced from said second electrode, a plurality of rectifier tubes each having an anode and a cathode, said rectifier tubes being series-connected anode-to-cathode at electrical junctions between two electrical terminals and adapted to supply a high D.C. potential thereto, and means substantially independent of the frequency of said A.C. power source for electrically heating each of the rectifier tube cathodes comprising a transformer for each rectifier unit having a magnetic circuit including a ferromagnetic core and first and second windings thereon, each of said first and second corona shields respectively connected to alternate electrical junctions through the first winding of one of said transformers, whereby an A.C. potential is capacitively coupled from said electrodes through said corona shields to each of said rectifier tubes, each of said second windings being electrically connected to the cathode of a respective rectifier tube to heat it.

4. Voltage multiplication apparatus as set forth in claim 3, in which said cathodes are directly heated cathodes constituted by filaments, each of said first windings having one end thereof connected to one side of a respective one of said filaments, said second winding being electrically connected across said filament.

5. Voltage multiplication apparatus as set forth in claim 3, in which each of said cathodes is indirectly heated by a respective filament, said second winding being electrically connected across said filament.

6. Voltage multiplication apparatus as set forth in claim 3, said core being composed of ferrite.

7. Voltage multiplication apparatus as set forth in claim 3 in which said cathodes each comprise a filament and which further includes an integrating network comprising a capacitor and an impedance serially connected in a loop circuit with said second winding, said first winding having one end thereof connected to said cathode and adapted to saturate said core during substantial portions of each cycle of the A.C. potential, said filament being electrically connected across said capacitor whereby the power supplied to heat said cathode is substantially independent of the level of said A.C. potential.

8. Voltage multiplication apparatus as set forth in claim 7, in which said impedance comprises a resistor.

9. Voltage multiplication apparatus as set forth in claim 3 which further includes a voltage regulator unit shunt-connected across said first winding whereby the power supplied to heat said cathode is substantially independent of the level of said A.C. potential.

10. Voltage multiplication apparatus as set forth in claim 3 which further includes a voltage regulator unit shunt-connected across one of said windings whereby the power supplied to heat said cathode is substantially independent of the level of said A.C. potential.

11. Voltage multiplication apparatus as set forth in claim 3 in which said transformer includes a third winding, and which further includes a voltage regulator unit connected across said third winding whereby the power supplied to said cathode is substantially independent of the level of said A.C. potential.

12. Voltage multiplication apparatus as set forth in claim 3 which further includes a third winding, a voltage regulator unit, and a circuit shunt-connected across said first and second windings, said circuit constituted by said regulator unit serially connected with said third winding whereby the power supplied to heat said cathode is substantially independent of the level of said A.C. potential.

13. Voltage multiplication apparatus as set forth in claim 3 which further incldes a current-sensitive resistor element and an impedance, said current-sensitive resistor element being serially connected in a circuit with said second winding and said cathode, said impedance being shunt-connected across said second winding, whereby the power supplied to heat said cathode is substantially independent of the level of said A.C. potential.

14. In voltage multiplication apparatus including a plurality of rectifier tubes each having an anode and a cathode and each adapted to have an A.C. potential impressed thereacross, said rectifier tubes electrically connected in an anode-cathode relationship between two electrical terminals and adapted to supply a high D.C. potential thereto; means substantially independent of the frequency of said A.C. potentials for electrically heating the rectifier tube cathodes comprising a transformer for each rectifier unit having a magnetic circuit including a ferromagnetic core and first and second windings thereon, said first winding interconnecting the anode of one rectifier tube with the cathode of the next rectifier tube, said second winding electrically connected to said cath-

ode to heat it, and a voltage regulator unit shunt-connected across one of said windings whereby the power supplied to heat said cathode is substantially independent of the level of said A.C. potential.

15. In voltage multiplication apparatus as set forth in claim 14, said cathodes being directly heated cathodes constituted by filaments, each of said first winding having one end thereof connected to one side of the filament of the next rectifier tube, said second winding being electrically connected across said filament.

16. In voltage multiplication apparatus as set forth in claim 14, each of said cathodes being indirectly heated by a respective filament, said second winding being electrically connected across said filament.

17. In voltage multiplication apparatus as set forth in claim 14, said core being composed of ferrite.

18. In voltage multiplication apparatus including a plurality of rectifier tubes each having an anode and a cathode comprising a filament and each tube adapted to have an A.C. potential impressed thereacross, said rectifier tubes electrically connected in an anode-filament relationship between two electrical terminals and adapted to supply a high D.C. potential thereto; means substantially independent of the frequency of said A.C. potentials for electrically heating the rectifier tube filament comprising a transformer for each rectifier unit having a magnetic circuit including a ferromagnetic core and first and second windings thereon, and an integrating network comprising a capacitor and an impedance serially connected with said secondary winding, said first winding interconnecting the anode of one rectifier tube with one side of the filament of the next rectifier tube and adapted to saturate said core during substantial portions of each cycle of the A.C. potential, said filament being electrically connected across said capacitor whereby the power supplied to heat said cathode is substantially independent of the level of said A.C. potentials.

19. In voltage multiplication apparatus as set forth in claim 18, said impedance comprising a resistor.

20. In voltage multiplication apparatus including a plurality of rectifier tubes each having an anode and a cathode and each adapted to have an A.C. potential impressed thereacross, said rectifier tubes electrically connected in an anode-cathode relationship between two electrical terminals and adapted to supply a high D.C. potential thereto; means substantially independent of the frequency of said A.C. potentials for electrically heating the rectifier tube cathodes comprising a transformer for each rectifier unit having a magnetic circuit including a core and first and second windings thereon, said first winding interconnecting the anode of one rectifier tube with the cathode of the next rectifier tube, said second winding electrically connected to said cathode to heat it, and a voltage regulator unit shunt-connected across said first winding whereby the power supplied to heat said filament is substantially independent of the level of said A.C. potentials.

21. In voltage multiplication apparatus including a plurality of rectifier tubes each having an anode and a cathode and each adapted to have an A.C. potential impressed thereacross, said rectifier tubes electrically connected in an anode-cathode relationship between two electrical terminals and adapted to supply a high D.C. potential thereto; means substantially independent of the frequency of said A.C. potentials for electrically heating the rectifier tube cathodes comprising a transformer for each rectifier unit having a magnetic circuit including a core and first and second windings thereon, said first winding interconnecting the anode of one rectifier tube with the cathode of the next rectifier tube, said second winding electrically connected to said cathode to heat it, and a voltage regulator unit shunt-connected across said second winding whereby the power supplied to heat said filament is substantially independent of the level of said A.C. potentials.

22. In voltage multiplication apparatus including a plurality of rectifier tubes each having an anode and a cathode and each adapted to have an A.C. potential impressed thereacross, said rectifier tubes electrically connected in an anode-cathode relationship between two electrical terminals and adapted to supply a high D.C. potential thereto; means substantially independent of the frequency of said A.C. potentials for electrically heating the rectifier tube cathodes comprising a transformer for each rectifier unit having a magnetic circuit including a core, and primary, secondary and tertiary windings thereon, said first winding interconnecting the anode of one rectifier tube with the cathode of the next rectifier tube, said secondary winding electrically connected to said cathode to heat it, and a voltage regulator unit connected across said tertiary winding whereby the power supplied to heat said filament is substantially independent of the level of said A.C. potentials.

23. In voltage multiplication apparatus including a plurality of rectifier tubes each having an anode and a cathode and each adapted to have an A.C. potential impressed thereacross, said rectifier tubes electrically connected in an anode-cathode relationship between two electrical terminals and adapted to supply a high D.C. potential thereto; means substantially independent of the frequency of said A.C. potentials for electrically heating the rectifier tube cathodes comprising a transformer for each rectifier unit having a magnetic circuit including a core, and primary, secondary and tertiary windings thereon, said primary winding interconnecting the anode of one rectifier tube with the cathode of the next rectifier tube, said secondary winding electrically connected to said cathode to heat it, a voltage regulator unit, and a circuit shunt-connected across said secondary and primary windings constituted by said regulator unit serially connected with said tertiary winding whereby the power supplied to heat said filament is substantially independent of the level of said A.C. potentials.

24. In voltage multiplication apparatus including a plurality of rectifier tubes each having an anode and a filament and each adapted to have an A.C. potential impressed thereacross, said rectifier tubes electrically connected in an anode-filament relationship between two electrical terminals and adapted to supply a high D.C. potential thereto; means substantially independent of the frequency of said A.C. potentials for electrically heating the rectifier tube filament comprising a transformer for each rectifier unit having a magnetic circuit including a core and first and second windings thereon, said first winding interconnecting the anode of one rectifier tube with one side of the filament of the next rectifier tube, a current-sensitive resistor element, and an impedance, said second winding and said current-sensitive resistor element being serially connected with said filament, said impedance being shunt-connected across said second winding, whereby the power supplied to heat said filament is substantially independent of the level of said A.C. potentials.

References Cited in the file of this patent

UNITED STATES PATENTS

2,026,407	Westendorp	Dec. 31, 1935
2,072,278	Schade	Mar. 2, 1937