(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 691 801 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
10.01.1996 Bulletin 1996/02

(51) Int Cl.6: **H05G 1/06**, H05G 1/20, H05G 1/32

(21) Application number: **95304735.4**

(22) Date of filing: **06.07.1995**

(84) Designated Contracting States:
DE FR GB

(30) Priority: **08.07.1994 JP 157664/94**

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(54) X-ray source

(57) A micro-focused X-ray source includes an X-ray tube (10) and a target voltage generating circuit (112). The target voltage generating circuit (112) has a double invertor structure configured by a step down invertor (410) and a push-pull invertor (420) which generates little heat and thus no cooling fan needs to be provided. The circuit includes Cockcroft-Walton circuitry (20a) in which diodes and capacitors making up this circuitry are fixedly mounted on insulation boards (20b) so that the positions of the diodes and capacitors will not shift during their moulding into an insulation block.

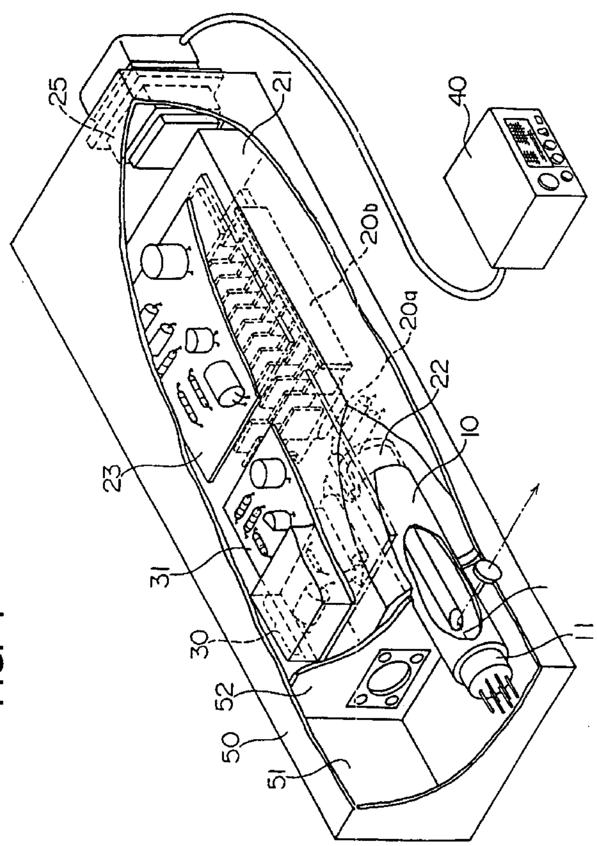

FIG. 1

CORRIGENDUM *issued on 14.02.96*

EP 0 691 801 A1

Printed by Jouve (FR), 18, rue Saint-Denis, 75001 PARIS

Description

The present invention relates to an X-ray source, and more particularly to a high-voltage generating circuitry for generating a high-voltage to be applied to a target of the X-ray source.

U.S. Patent No. 5,077,771, U.S. Patent No. 4,646,338, and U.S. Patent No. 4,694,480 describe portable X-ray sources constructed from an X-ray tube and a molded high-voltage source and its control circuitry.

When voltage is applied to an X-ray tube, either the cathode is connected to ground, or the target is connected to ground, or the focus voltage is varied. However, none of the above-described patents sufficiently describes voltage control of the X-ray tube in generating microfocused X-rays.

Voltage is controlled in the high-voltage generation circuitry using pulse width modulation (PWM) or pulse voltage control. However, the PWM method controls the effective voltage by changing the pulse width of control pulses. Therefore, the high voltage generated at the secondary coil of the high-voltage transformer does not follow changes in pulse width very well, resulting in great fluctuations in strength of the X-rays. With the pulse voltage control method, a switching transistor controls current supplied to the primary coil of the high-voltage generating transformer, resulting in great deal of power loss by heat generation. A cooling fan must therefore be provided to cool the circuitry. The vibration produced by the cooling fan prevents maintenance of a microfocus of the X-rays.

A Cockcroft-Walton multiplier array is often used as the source of high voltage for portable X-ray sources. The capacitor and diode array of the Cockcroft-Walton multiplier array are often embedded in an insulating block molded by pouring a silicon or epoxy resin over the capacitors and diodes. The positions of the capacitors and diodes can be shifted when this insulating material is poured over these components. When these components are shifted out of alignment, this can result in a variable and unstable supply of high voltage.

To solve the above-described problems, an X-ray source according to the invention includes an X-ray tube and a target voltage generating circuit. The X-ray tube has a cathode and a target. The target voltage generating circuit applies a positive voltage to the target so that a high voltage is developed between the cathode and the target. Electron beams are generated from the cathode and the target generates X-rays in response to the electron beam bombardment. The target voltage generating circuit includes a first voltage generating circuit generating a first voltage in response to an instruction voltage indicative of a voltage to be applied to the target, and a second voltage generating circuit connected to the first voltage generating circuit. The second voltage generating circuit generates an output voltage to be applied to the target. A voltage divider is provided which is connected to the second voltage generating circuit. The voltage divider divides the output voltage from the second voltage generating circuit to produce a detection voltage indicative of a voltage generated by the second voltage generating circuit. The first voltage generating circuit includes a switching element that is rendered ON until the detection voltage has reached the instruction voltage and that is alternately rendered ON and OFF after the detection voltage has reached the instruction voltage.

The first voltage generating circuit further includes a capacitive element that is charged by a current flowing through the switching element when the switching element is ON, an error amplifier having a first input terminal applied with the instruction voltage, a second input terminal applied with the detection voltage, and an output terminal, and a comparator having a first input terminal connected to the output terminal of the error amplifier, and a second input terminal supplied with the voltage developed across the capacitive element. The first voltage generating circuit further includes an inductive element. The capacitive element is charged according to a time constant determined by the capacitance of the capacitive element and the inductance of the inductive element.

The second voltage generating circuit is configured by Cockcroft-Walton multiplier array which is composed by a plurality of rectifying elements and a plurality of capacitive elements. A pair of insulation plates mount the rectifying elements and the capacitive elements which are connected by wiring formed on each of the pair of insulation plates. The Cockcroft-Walton multiplier array and the pair of insulation plates are embedded in a mold block made from an insulating material.

According to the invention, there is virtually no power loss from the first voltage generating circuit, so that substantially no heat is generated. Therefore, the target voltage generating circuit can be cooled naturally without provision of a cooling fan.

The rectification elements and capacitive elements of a Cockcroft-walton circuitry are wired and connected on an insulation plate. Because these elements are fixed in place by the insulation plates, the elements will not shift in position during molding. Variation in high-voltage output sometimes caused by positional shifting of such elements will not be produced. As such, the second voltage generating circuit outputs a stable high voltage.

A preferred embodiment will now be described with reference to the accompanying drawings, in which:-

FIG. 1 is a perspective view showing an X-ray source according to an embodiment of the present invention;

FIGS. 2(a) and 2(b) are cross-sectional views of the X-ray source according to the embodiment of the present invention;

FIG. 3 is a cross-sectional view showing construction of a microfocus X-ray tube of the present X-ray source;

FIG. 4 is a perspective view showing external appearance of a mold block of the present X-ray source;

FIG. 5(a) is a perspective view showing diodes and capacitors making up a Cockcroft-Walton multiplier array of the present X-ray source and support plates;

FIG. 5(b) is an overhead view of the Cockcroft-Walton multiplier array and support plates of FIG. 5(a);

Fig 5(c) is a side view showing wiring connecting the Cockcroft-Walton multiplier array of FIG. 5(a) to the support plates;

FIG. 6 is a block diagram showing components of the present X-ray source;

FIG. 7 is a block diagram showing detailed configuration of an operation block portion shown schematically in FIG. 6;

FIG. 8 is a graphical representation of the relationship between input voltage and output voltage of the target high-voltage generating circuit;

FIG. 9 is a circuit diagram showing examples of specific components of a target voltage circuit serving as the target high-voltage generating circuit;

FIG. 10 is a timing chart for an explanation of principles underlying operation of the target voltage circuit of FIG. 9;

FIG. 11 shows a conventional target voltage circuit of an X-ray source;

FIG. 12(a) is a graphical representation showing power loss of the target voltage circuit of FIG. 11;

FIG. 12(b) is a graphical representation showing power loss of the target voltage circuit of the present X-ray source;

FIG. 13(a) is a graphical representation of output strength of a conventional X-ray source provided with a PWM type high-voltage generation circuit; and

FIG. 13(b) is a graphical representation of output strength of the present X-ray source;

FIG. 1 shows a perspective view of the X-ray source of the present embodiment. FIGS. 2(a) is a cross-sectional view of the X-ray source cut along the line A-A' shown in FIG. 2(b) which is a vertical cross-sectional view of the X-ray source of the present embodiment. The X-ray source of the present embodiment includes a microfocus X-ray tube 10 for emitting X-rays; a Cockcroft-Walton multiplier array for applying a high voltage to the microfocus X-ray tube 10; control circuits 23 and 31 for applying a high voltage to the microfocus X-ray tube 10; and an external controller unit 40 for controlling this circuitry. The Cockcroft-Walton multiplier array includes a pair of support plates 20b made from an insulating material for supporting the array. The Cockcroft-Walton multiplier array and the support plates 20b are integratedly embedded in a mold block 21. An insulating oil reservoir cavity 21a is provided at the front side of the mold block 21. A target high-voltage supply terminal 22 is connected to the microfocus X-ray tube 10 through the oil reservoir cavity 21a.

The control circuit 23 and a Cockcroft-Walton circuit 30 are mounted on the upper surface of the mold block 21. The control circuit 23 includes a step down invertor circuit and a push-pull invertor circuit for driving the Cockcroft-Walton multiplier array . The Cockcroft-Walton circuit 30 supplies high voltage to the cathode electrode of the microfocus X-ray tube 10. A connector 25 for connecting a cable of the controller unit 40 to the circuitry of the X-ray source is provided at the rear side of the housing 50.

FIG. 3 is a cross-sectional view showing construction of the microfocus X-ray tube 10. The microfocus X-ray tube 10 includes an assembly of a metal outer envelope 12 and a glass outer envelope 13. A ceramic stem 11 is engaged with one end of the metal outer envelope 12. An X-ray emission window 14 made from beryllium is formed to the side surface of the metal outer envelope 12.

An electron gun 15 is positioned interiorly of the metal outer envelope 12. A target mounting base 16 made from a material with high thermal conductivity, such as non-oxidized pure copper, is positioned interiorly of the glass outer envelope 13. The electron gun 15 includes a heater electrode 15a, a cathode 15b, a grid electrode 15c, and a focus electrode 15d. A tungsten target 16a is brazed to the tip of the target mounting base 16 using silver.

When the cathode 15b is heated up to a prescribed temperature by the heater electrode 15a, electrons are emitted from the surface of the cathode 15b. The emitted electrons are accelerated by the grid electrode 15c and focused by the focus electrode 15d so as to be in bombardment with the tungsten target 16a, resulting in the generation of X-rays and heat. The generated X-rays are emitted outwardly from the X-ray emission window 14. The generated heat is conducted out of the X-ray source through the target mounting base 16.

The tungsten target 16a is positioned at a 25° slant to a plane perpendicular to the orbit of the electrons fired at the tungsten target 16a. This slant increases the number of generated X-rays that reach the X-ray emission window 14 and that are emitted outside the microfocus X-ray tube 10 through the X-ray emission window 14.

FIG. 4 is a perspective view showing external appearance of the mold block 21. The Cockcroft-Walton multiplier array and the support plates 20b are embedded in the mold block 21. The Cockcroft-Walton multiplier array is a circuit often used as a power source for producing high-voltage of about 70 kV. There is a particular need to mold the Cockcroft-Walton multiplier array in a mold block 21 made from an insulating material in order to reduce influence of the ambient environment on positions where voltage is increased to a high voltage. Conventionally, the positioning of the plurality of diodes and capacitors that make up the Cockcroft-Walton multiplier array shift during molding and hardening of the block. High voltage outputted from a Cockcroft-Walton circuit with position shifts is often unstable so that supplying a stable high voltage has proven difficult.

In the present embodiment, as shown in FIGS. 5(a) through 5(c), the plurality of diodes and capacitors making up the Cockcroft-Walton multiplier array are soldered to the support plates 20b and also the diodes and capacitors are connected together by wiring 20_{b1} formed on the support plate 20b. This stable structure prevents the diodes and capacitors from shifting position when the insulation material is poured over the components of the Cockcroft-Walton multiplier array during molding processes of the mold block 21. Therefore, Cockcroft-Walton multiplier array of the present embodiment can supply a stable high voltage output.

Japanese Laid-Open Patent Publication (Kokai) No. SHO-63-186,566 describes a conventional Cockcroft-Walton circuit support plate in which are formed eyelets for fixing the diodes and capacitors. However, this conventional Cockcroft-Walton circuit has insufficient voltage-proof to be used at voltages of between 70 kV and 100 kV. Additionally, the exposed wiring protruding upward from the plates is a source of potential electrical discharges. In contrast, according to the present embodiment, because holes are formed in the print board 20b of Cockcroft-Walton multiplier array in a predetermined pattern and are mutually connected by the wirings formed on the board 20b, the amount that wiring protrudes upward from the support plate 20b is reduced to a minimum and the voltage-proof characteristic of the Cockcroft-Walton multiplier array is greatly improved.

FIG. 6 is a block diagram showing components provided in association with the X-ray source of the present embodiment. The block diagram includes an operation block portion 100 for operating the microfocus X-ray tube 10 and a control block portion 200 for controlling the operation block portion 100.

The operation block portion 100 includes a target control 110 for controlling target voltage of the X-ray tube 10; an overcurrent detector 120 for detecting excessive current of the tungsten target 16a; and a grid control 130 for controlling the grid voltage of the X-ray tube 10. The operation block portion 100 further includes a cathode control 140 for controlling the cathode voltage of the X-ray tube 10 and a heater control 150 for controlling the heater of the X-ray tube 10.

The control block portion 200 includes a voltage setting D/A converter 210 for applying target voltage setting voltage to both the target control 110 and the cathode control 140; a current setting D/A converter 220 for applying target current setting voltage to the grid control 130; and an interlock detector 230 for detecting an interlock. The control block portion 200 further includes an aging portion 240 for warming up the control block portion 200; a key switch 250 for stopping generation of X-rays; and a power source control 260 for controlling change of power source voltage. The control block portion 200 also includes a ROM 270 for storing control programs; a RAM 280; a voltage control 290 for setting voltage; a current control 300 for setting current; and a mode switch 310 for setting an X-ray mode. The control block portion 200 further includes a mode indicator 320 for indicating X-ray mode, target overcurrent, target voltage, and target current; an overcurrent display 330; a target voltage display meter 340; a target current display meter 350; and a CPU 360 controlling each component.

FIG. 7 is a block diagram showing detailed configuration of the operation block portion 100. The target control 110 includes a target voltage control 111 controlling target voltage according to the target voltage setting voltage applied thereto from the voltage setting D/A converter 210; and a target high-voltage generator 112 generating a desired target high-voltage according to a signal from the target voltage control 111. The target overcurrent detector 120 includes an overcurrent detector 121 for detecting overcurrent of the target current generated at the target high-voltage generator 112; and an overvoltage detector 122 detecting overvoltage of the target voltage generated at the target high-voltage generator 112.

The grid control 130 includes a target current detector 131 for detecting the target current; a target current comparator 132 for comparing the target current detected by the target current detector 131 with the setting voltage signal outputted from the current setting D/A converter 220; and a cut-off voltage control setting portion 133. The grid control portion 130 further includes a grit voltage control 134 for controlling grid voltage based on the results of comparisons made at the target current comparator 132; and a grid voltage generator 135 for generating a desired grid voltage according to signals received from the grid voltage control 134.

The cathode control 140 includes a cathode voltage control 141 for controlling cathode voltage according to target voltage setting voltage received from the voltage setting D/A converter 210; and a cathode voltage generator 142 for generating a desired cathode voltage according to signals received from the cathode voltage control 141. The heater control 150 includes a heater voltage control 151 for controlling the heater voltage; and a heater voltage generator 152 for generating a desired heater voltage according to signals received from the heater voltage control 151.

In a microfocus X-ray tube 10, the X-ray beam diameter is maintained at a small value even when the target voltage is changed. To precisely control the intensity level of the X-ray beam, the target high-voltage generator 112 must generate voltage that changes linearly from low voltage to high voltage. U. S. Patent Nos. 4,694,480 and 4,646,338 describe a conventional target high-voltage generation unit that uses pulse width modulation (PWM) to control the voltage. The voltage generated in the conventional target high-voltage generation unit fluctuates, especially at low voltage range, and linearly changing the voltage level cannot be achieved.

The target high-voltage generator 112 of the present embodiment uses a double invertor arrangement to control target voltage. That is, a step down type invertor is provided for the low-voltage range and a push-pull invertor is provided for the high-voltage range. With such an arrangement, a variable voltage that changes linearly from low voltage to high voltage can be obtained. FIG. 8 is a graphical representation of the relationship between input voltage and output voltage according to results of measurements of the X-ray source of the present embodiment using a coil of paraffin impregnated 3:600 shunt winding and twenty-stage Cockcroft-Walton voltage multiplier. It can be seen from this graph that the relationship between the input voltage and the output voltage changes linearly between an output voltage of about 10 kV to about 100 kV.

FIG. 9 is a circuit diagram showing a detailed circuit configuration of the target high-voltage generator 112. The target high-voltage generator 112 of the present embodiment includes a step-down invertor circuit 410 for the low-voltage range and a push-pull invertor circuit 420 for the high-voltage range. A stably changing voltage can be obtained over a broad range from low to high voltage using these two types of different invertor circuits 410 and 420.

Next, an explanation of principles underlying operation of the target high-voltage generator 112 will be provided while referring to the circuit diagram of FIG. 9 and the waveform diagram of FIG. 10. First, a target voltage setting voltage (Vi) is applied to the step-down invertor circuit 410, whereupon a setting voltage signal passes through a buffer $IC_{1\text{-}a}$ and is applied to a comparator $IC_{1\text{-}c}$ through an error amplifier $IC_{1\text{-}b}$. The error amplifier $IC_{1\text{-}b}$ is also applied with the output from an operational amplifier $IC_{5\text{-}a}$. Initially a 0 V voltage is developed at the secondary coil of the transformer 430. A detection voltage representative of the voltage developed at the secondary coil of the transformer 430 is obtained from the operational amplifier $IC_{5\text{-}a}$ through a voltage divider 440 connected between the output of the Cockcroft-Walton multiplier array and ground. The detection voltage is also initially a 0 V voltage. The error amplifier $IC_{1\text{-}b}$ is saturated to a +24 V, and this saturation voltage is applied to the comparator $IC_{1\text{-}c}$. The initial voltage of the capacitor C_1 is also a 0 V voltage. The comparator $IC_{1\text{-}c}$ is saturated to a +24 V voltage as represented by level (c) in FIG. 10. As represented by levels (d) and (e) in FIG. 10, this results in the transistors Q_1, Q_2, and Q_3 being rendered ON, whereupon the capacitor C_1 is charged through a coil L_1. The transistor Q_1 repeats switching actions and thus allows the capacitor C_1 to be continuously charged until the voltage across the capacitor C_1 has reached the target voltage setting voltage Vi. The coil L_1 is connected between the transistor Q_1 and the capacitor C_1 for determining a time constant of charging current that flows in the capacitor C_1. As represented in level (d) of FIG. 10, when the voltage V_2 across the capacitor C_1 exceeds the target voltage setting voltage V_1, the output from the comparator $C_{1\text{-}c}$ is zeroed so that the transistors Q_1, Q_2, and Q_3 are rendered OFF. As such, the voltage V_2 substantially equal to the target voltage setting voltage V_1 is stably obtained.

The voltage at the primary coil of the transformer 430 is subjected to ON-OFF switchings by virtue of the transistors Q_6 and Q_7 according to oscillation frequency of the oscillator IC_4. The oscillator IC_4 is rendered ON and begins to oscillate when the comparators $IC_{2\text{-}a}$, $IC_{2\text{-}b}$, and $IC_{2\text{-}c}$ are applied with an ON voltage from the target voltage ON/OFF terminal.

The voltage developed at the secondary coil of the transformer 430 increases to a voltage according to the turns ratio and is further increased to a high voltage by the Cockcroft-Walton multiplier array . The increased output voltage is voltage-divided by the divider 440. The divided voltage passes through the operation amplifier $IC_{5\text{-}a}$ and is applied to the error amplifier $IC_{1\text{-}b}$ as the detection voltage. This operation is represented by level (g) in FIG. 10. The error amplifier $IC_{1\text{-}b}$ compares the detection voltage and the target voltage setting voltage Vi and drives the comparator $IC_{1\text{-}c}$ until the detection voltage and the target voltage setting voltage Vi are in coincidence with each other.

In this way, the high-voltage output is controllable by operating the double invertor including the step down invertor circuit 410 and the push-pull invertor circuit 420. The characteristic of the circuitry at the primary coil side of the transformer 430, that is, of the step down invertor circuit 410 and the push-pull invertor circuit 420, is that the ON and OFF operation of the transistors Q_1, Q_2, and Q_3, as driven by the comparator $IC_{1\text{-}c}$, controls the charge current of the capacitor C_1. For this reason, drive is accomplished using only a minimal amount of power and with a circuit configuration that loses very little power.

FIG. 11 shows a target voltage circuit 500 of an X-ray source conceived by the present inventors (not prior art). The target voltage circuit 500 differs from the target high-voltage generator 112 in that the ON and OFF condition of a transistor Q_5, which corresponds to the transistor Q_1 of the present embodiment, is controlled by output from an error amplifier IC_{6-1}, which corresponds to the error amplifier $IC_{1\text{-}b}$ of the present embodiment, and also in that no capacitor, that is, capacitor C_2 of the present embodiment, is provided for charging by the output current from the transistor Q_5. Not only is the current flowing from the transistor Q_5 lost power, but also a source of heat because the lost power is converted into heat. The transistors Q_1 and Q_2 provided to the invertor circuit are less efficient and produce more heat than the switching transistors Q_6 and Q_7 for controlling voltage by switching transistors for controlling the current. For this reason, a cooling fan must be provided for cooling the circuitry or else operation will become unstable.

FIG. 12(a) is a graphical representation showing power loss in the target voltage circuit 500 with respect to the input power thereto. FIG. 12(b) is a graphical representation showing power loss of the target high-voltage generator 112 of the present embodiment with respect to the input power thereto. It can be seen from these graphs that less power loss is present in the target high-voltage generator 112 throughout the high-voltage output range from 10 to 70 kV. Measurements for these graphs were taken with both the target voltage circuits 400 and 500 provided with a Cockcroft-Walton multiplier array having the same configuration.

FIG. 13(a) is a graphical representation of output intensity of a conventional X-ray source provided with a PWM type high-voltage generation circuit. FIG. 13(b) is a graphical representation of output intensity of the X-ray source according to the present embodiment. It can be seen by comparing these graphs that the X-ray source of the present embodiment outputs X-rays with more stable intensity than the conventional X-ray source. In measurements for both of these graphs, both of the X-ray sources had a 40 kV target voltage applied to the target. Target current was 10 μA.

While the invention has been described in detail with reference to a specific embodiment thereof, it would be apparent to those skilled in the art that various changes and modifications may be made therein without departing from the spirit of the invention, the scope of which is defined by the attached claims. For example, the microfocus X-ray tube 10 could be an end window type instead of the side window type shown in FIG. 3.

In the X-ray source according to the present invention, the first voltage generation portion provided with a target voltage generation circuit operates according to ON and OFF switching of switching elements so that input voltage increases up to a predetermined set voltage. The switching operations of the switching elements are controlled by a signal voltage from a second voltage generation portion. For this reason, there is virtually no power loss from the first voltage generation portion. Also, very little heat is generated from this circuitry so that natural cooling without the aid of a cooling fan is sufficient. Because no cooling fan needs to be provided, problems caused by the vibration of a cooling fan, such as, inability to maintain the focus of the X-rays, will not occur.

Also the Cockcroft-Walton circuitry of the second voltage generation portion has a configuration wherein rectification elements (diodes) and capacitive elements (capacitors) are wired and connected on an insulation board. Therefore, all the elements are fixed in place by the insulation board so that the positions of the elements will not shift during molding to the insulation block. For this reason, no variability in high-voltage output, which can result from rectification elements and capacitive elements shifting in position, will not be generated so that a stable high-voltage output can be obtained from the second voltage generation portion.

Claims

1. An X-ray source comprising:

   an X-ray tube (10) having a cathode (15) and a target (16); and

   a target voltage generating circuit (112) for generating a target voltage applied to said target (16), said target voltage generating circuit (112) comprising:

   a first voltage generating circuit (410) generating a first voltage in response to an instruction voltage indicative of a voltage to be applied to said target (16), said first voltage generating circuit (410) including a switching element (Q1); and,

   a second voltage generating circuit (420, 21) connected to said first voltage generating circuit (410), said second voltage generating circuit (420, 21) generating an output voltage to be applied to said target (16);

   characterised by a voltage divider (440) connected to said second voltage generating circuit (420, 21), the voltage divider (440) dividing the output voltage from said second voltage generating circuit (420, 21) to produce a detection voltage indicative of a voltage generated by said second voltage generating circuit (420, 21);

   and in that said switching element (Q1) is rendered ON until the detection voltage has reached the instruction voltage and said switching element (Q1) is alternately rendered ON and OFF after the detection voltage has reached the instruction voltage.

2. An X-ray source as claimed in claim 1, wherein said first voltage generating circuit (410) further includes a capacitive element (C1) having a capacitance, said capacitive element (C1) being charged by a current flowing through said switching element (Q1) when said switching element (Q1) is ON, said second voltage generating circuit (420, 21) generating the output voltage based on the voltage across said capacitive element (C1).

3. An X-ray source comprising:

   an X-ray tube (10) having a cathode (15) and a target (16); and

   a target voltage generating circuit (112) applying a positive voltage to said target (16) so that a high voltage is developed between said cathode

(15) and said target (16), wherein X-rays are generated from said target (16) resulting from bombardment of electron beams generated from said cathode (15), said target voltage generating circuit (112) comprising:

a step down invertor (410) generating a first voltage in response to an instruction voltage indicative of a voltage to be applied to said target (16), said step down invertor (410) including a switching element (Q1);

a push-pull invertor (420) generating a second voltage in response to said first voltage, the second voltage being higher than the first voltage;

a transformer (430) having a primary winding connected to said second voltage generation circuit, and a secondary winding;

a high voltage generating circuit (20a) connected to said secondary winding of said transformer (430) and producing an output voltage for applying to said target (16); and,

a voltage divider (440) connected to said high voltage generating circuit, said voltage divider dividing the output voltage from said high voltage generating circuit (20a) to produce a detection voltage indicative of a voltage generated by said high voltage generating circuit (20a);

wherein said switching element (Q1) is alternately rendered ON and OFF after the detection voltage has reached the instruction voltage so that the first voltage is lowered to a first pre-determined level after reaching a second pre-determined level to thus substantially maintain the first voltage at a constant level corresponding to the instruction voltage, a current being allowed to flow through said switching element (Q1) when said switching element (Q1) is rendered ON.

4. An X-ray source as claimed in claim 3, wherein the step down invertor (410) further includes a capacitive element (C1) having a capacitance, said capacitive element (C1) being charged by the current flowing through said switching element (Q1), said switching element being held ON until a voltage developed across said capacitive element (Q1) reaches the detection voltage, the voltage across said capacitive element (Q1) being applied to said push-pull invertor (420) as the first voltage.

5. An X-ray source as claimed in claim 2 or 4, wherein said first voltage generating circuit (410) or said step down invertor (410) further includes an inductive element (L1) having an inductance, and wherein said capacitive element (C1) is charged according to a time constant determined by the capacitance of said capacitive element (C1) and the inductance of said inductive element (L1).

6. An X-ray source as claimed in claim 2, 4 or 5, wherein said first voltage generating circuit (410) or said step down invertor (410) further includes an error amplifier ($1C_{1\text{-}b}$) having a first input terminal applied with the instruction voltage, a second input terminal applied with the detection voltage, and an output terminal, and a comparator ($1C_{1\text{-}c}$) having a first input terminal connected to the output terminal of said error amplifier ($1C_{1\text{-}b}$), and a second input terminal supplied with the voltage developed across said capacitive element (C1).

7. An X-ray source as claimed in any preceding claims, wherein said second voltage generating circuit (420) or said high voltage generating circuit (21) comprises a Cockcroft-Walton multiplier array (20a) having a plurality of rectifying elements and a plurality of capacitive elements, and a pair of insulation plates (20b) for mounting said plurality of rectifying elements and said plurality of capacitive elements, said plurality of rectifying elements and said plurality of capacitive elements being connected by wiring (20b) formed on each of said pair of insulation plates (20b).

8. An X-ray source as claimed in claim 7, wherein said Cockcroft-Walton multiplier array (20a) and said pair of insulation plates (20b) are embedded in a moulded block made from an insulating material.

FIG. 1

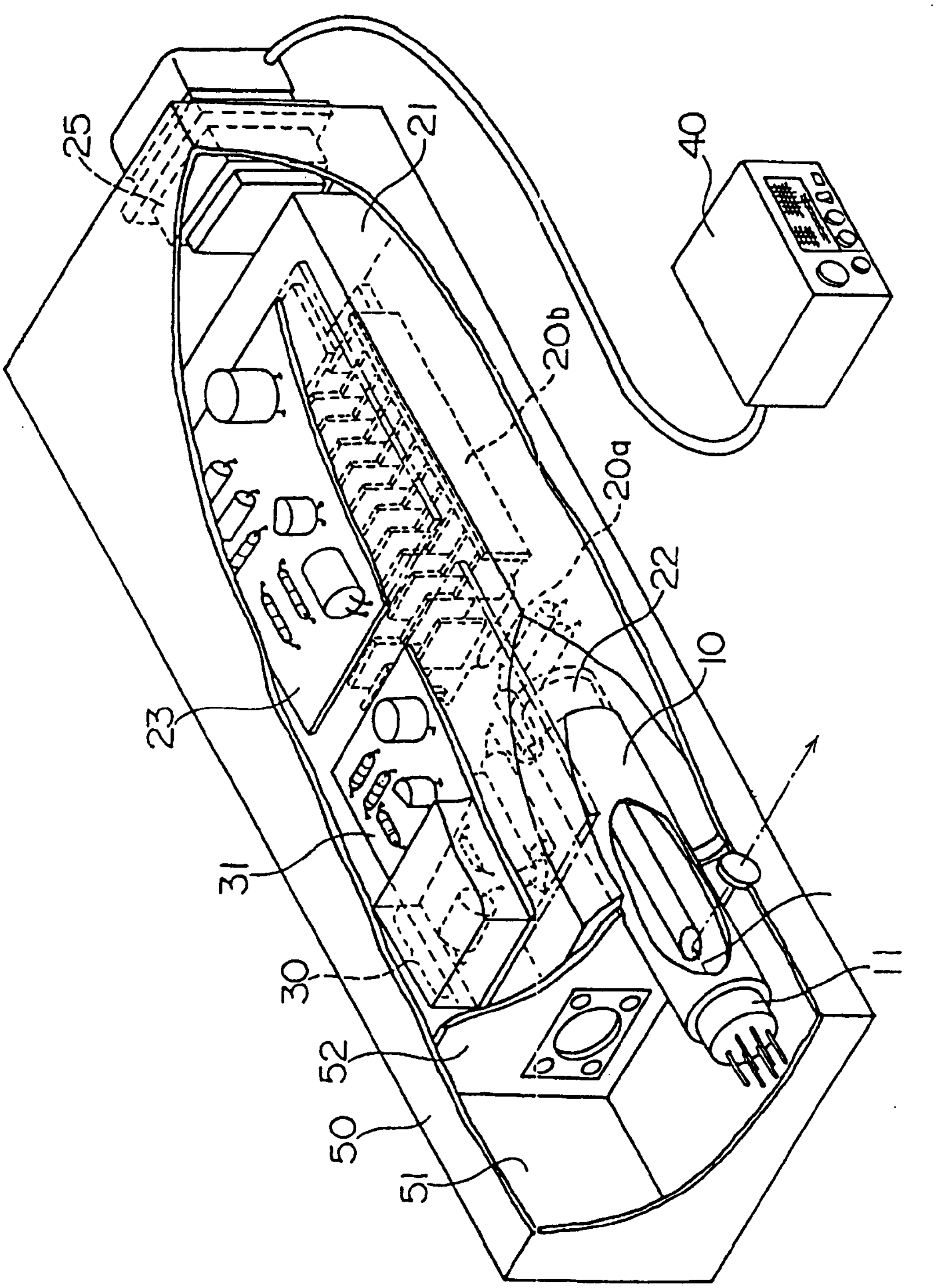

FIG. 2 (a)

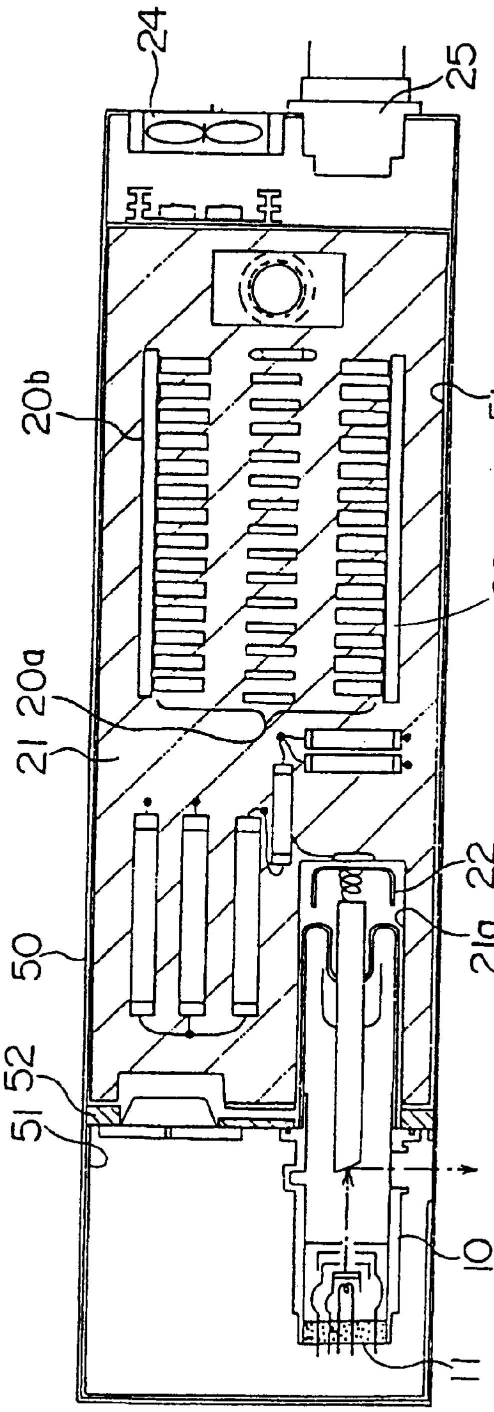
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FIG. 2 (b)

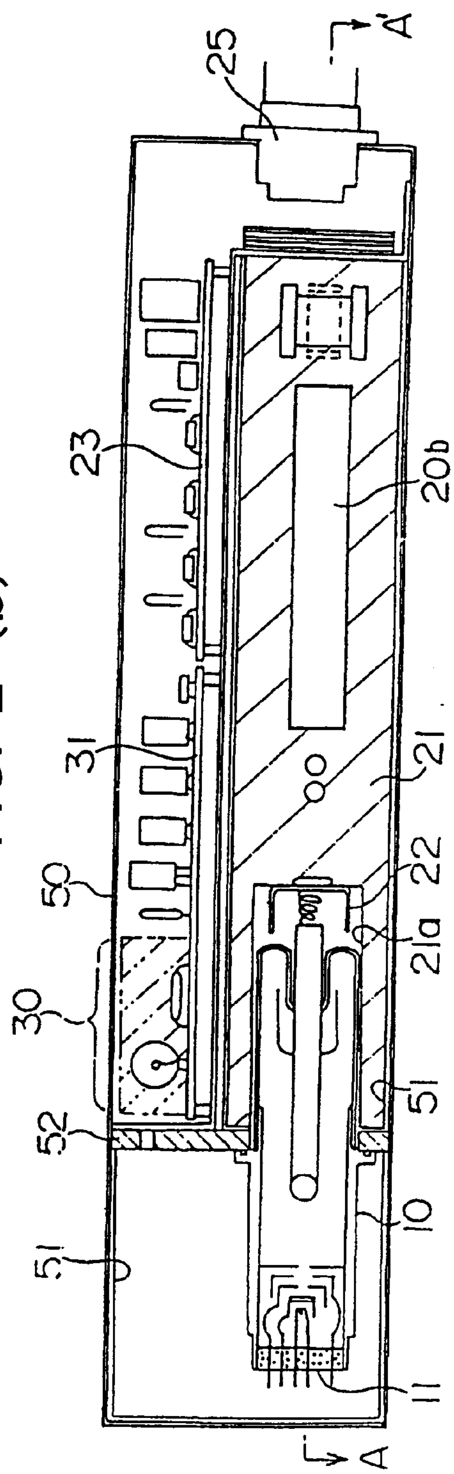
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FIG. 3

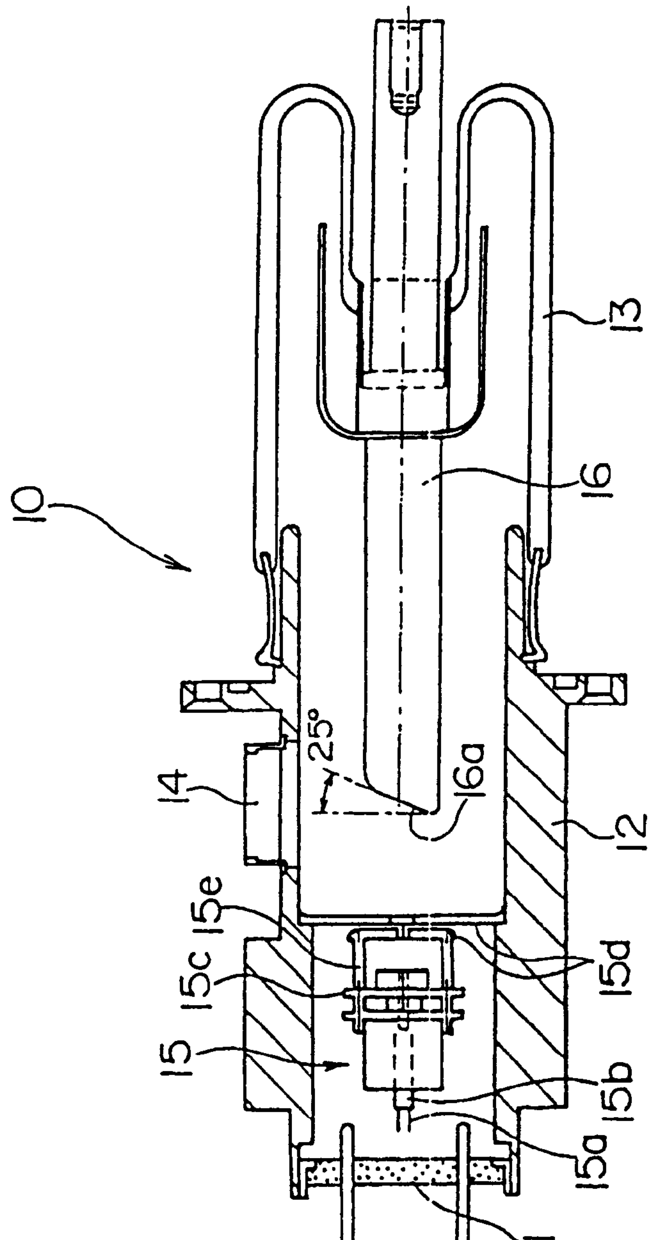


FIG. 4

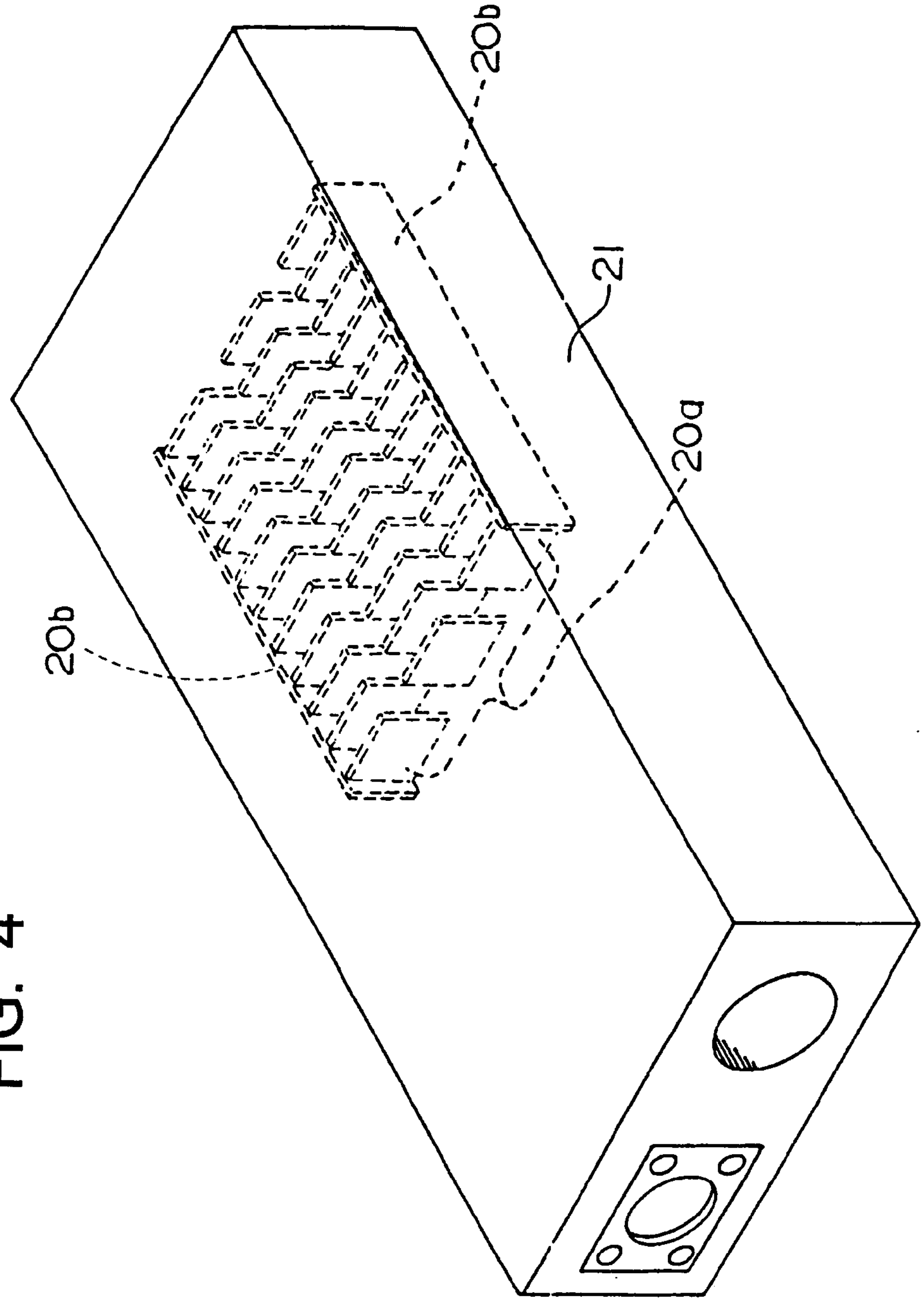


FIG. 5 (a)

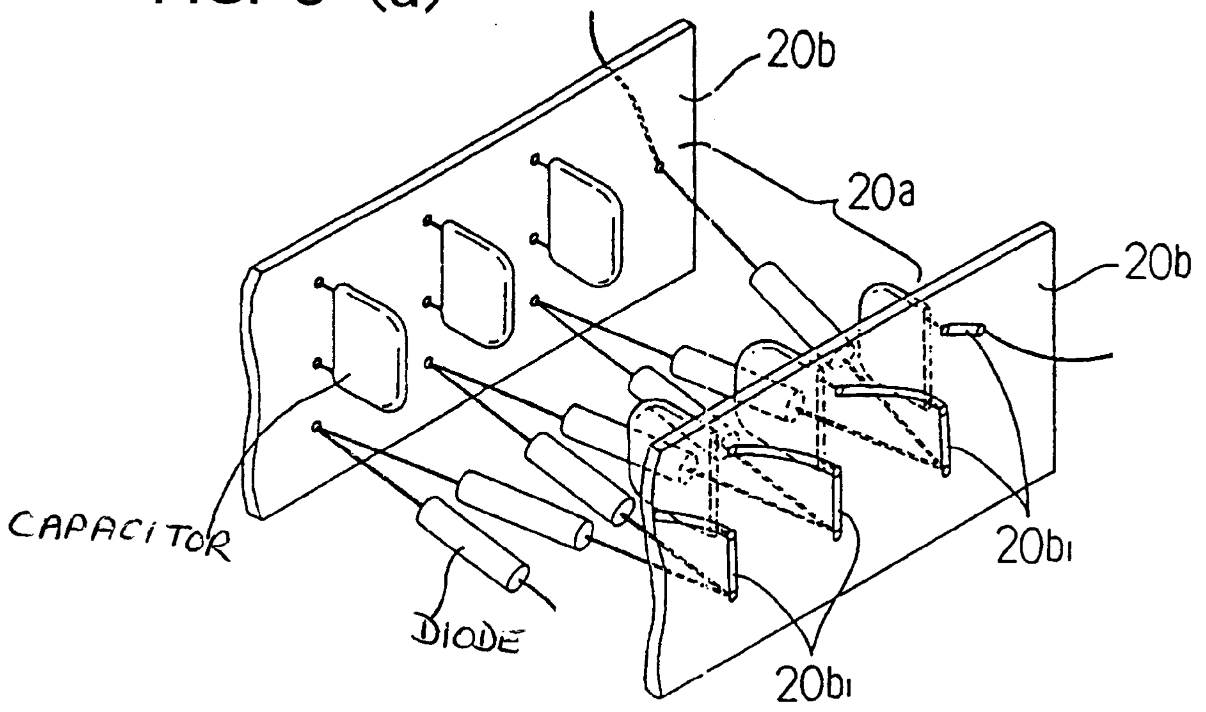


FIG. 5 (b)

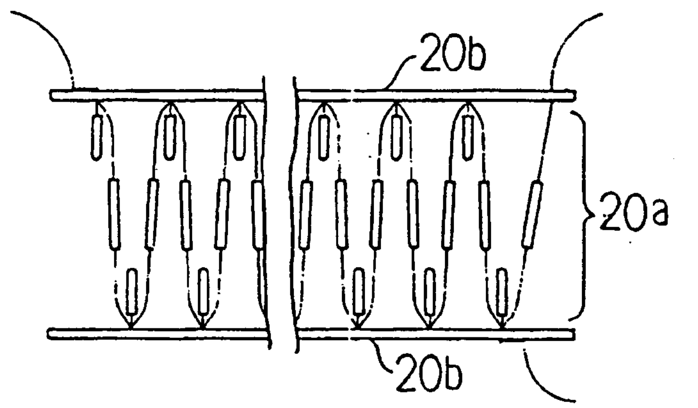


FIG. 5 (c)

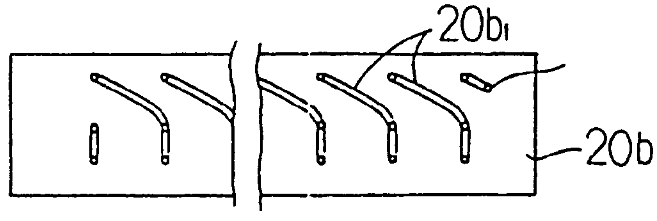


FIG. 6

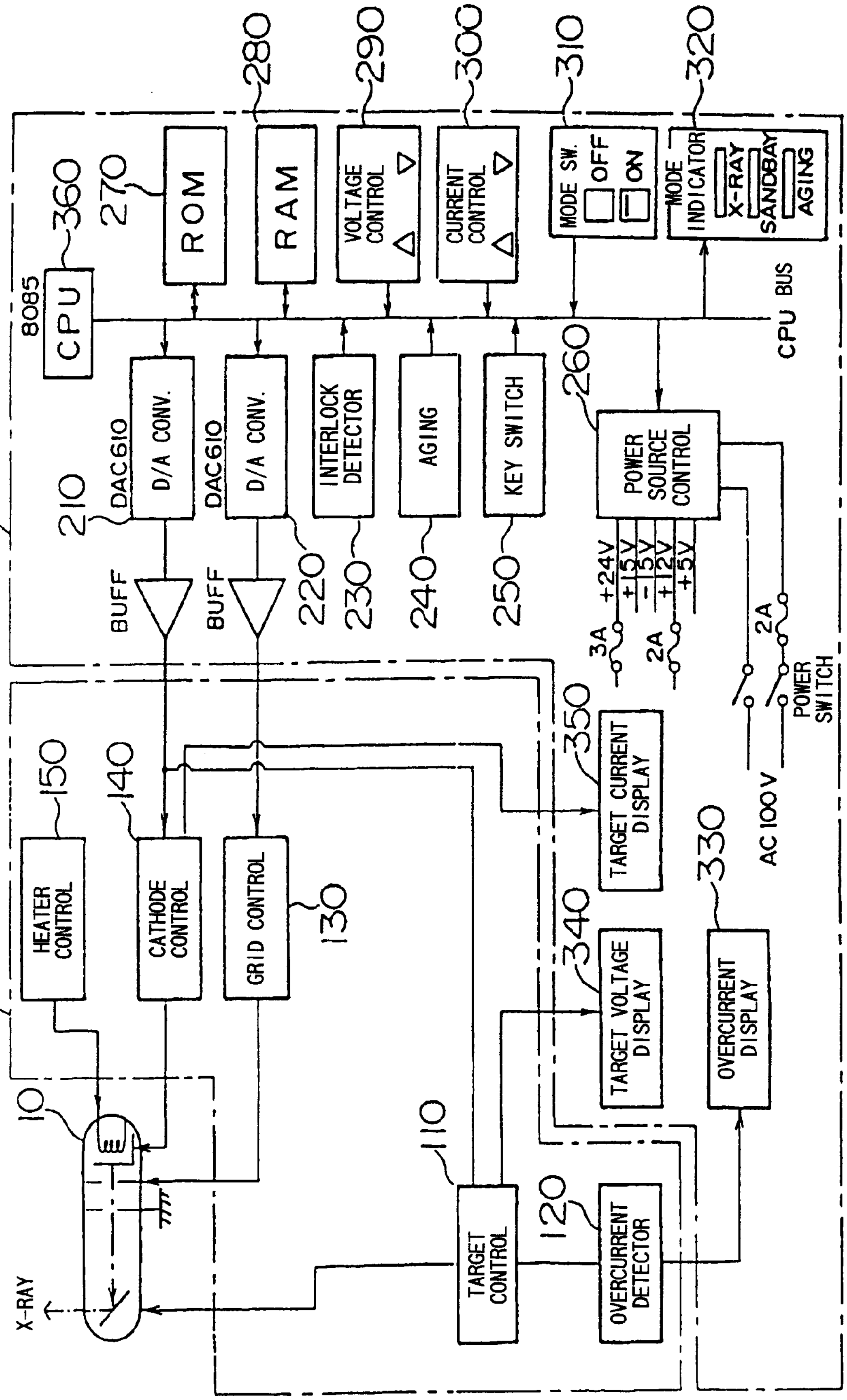

200
360
CPU
8085
270
ROM
280
RAM
290
VOLTAGE CONTROL
300
CURRENT CONTROL
310
MODE SW.
OFF
ON
320
MODE INDICATOR
X-RAY
SANDBAY
AGING
CPU BUS
210
DAC610
D/A CONV.
220
DAC610
D/A CONV.
230
INTERLOCK DETECTOR
240
AGING
250
KEY SWITCH
260
POWER SOURCE CONTROL
+24V
+15V
−15V
+12V
+5V
3A
2A
2A
POWER SWITCH
AC100V
BUFF
BUFF
100
150
HEATER CONTROL
140
CATHODE CONTROL
130
GRID CONTROL
350
TARGET CURRENT DISPLAY
340
TARGET VOLTAGE DISPLAY
330
OVERCURRENT DISPLAY
10
X-RAY
110
TARGET CONTROL
120
OVERCURRENT DETECTOR

FIG. 7

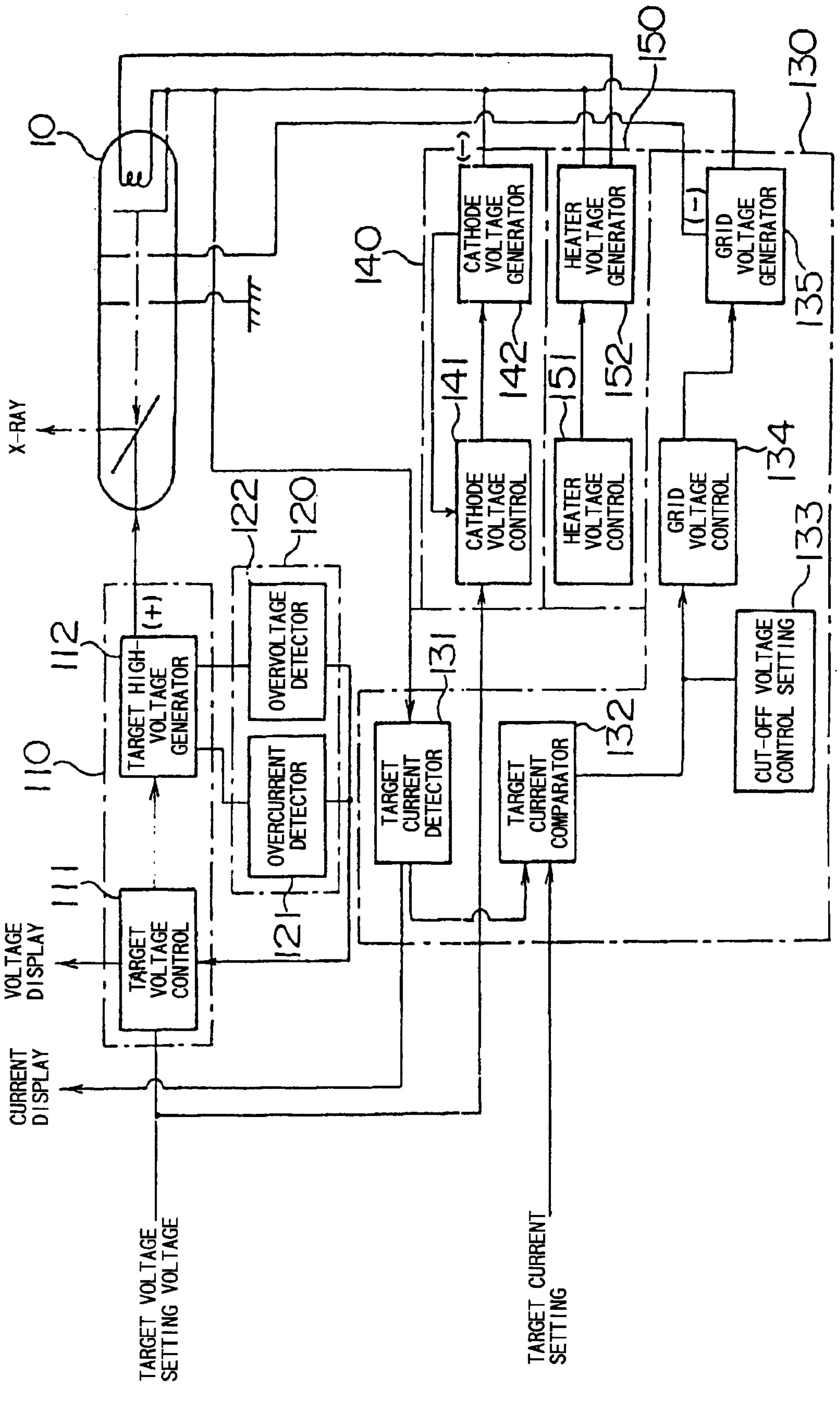

X-RAY
10
TARGET VOLTAGE SETTING VOLTAGE
TARGET CURRENT SETTING
CURRENT DISPLAY
VOLTAGE DISPLAY
110
111
TARGET VOLTAGE CONTROL
112
TARGET HIGH-VOLTAGE GENERATOR
(+)
120
121
122
OVERCURRENT DETECTOR
OVERVOLTAGE DETECTOR
130
131
TARGET CURRENT DETECTOR
132
TARGET CURRENT COMPARATOR
133
CUT-OFF VOLTAGE CONTROL SETTING
134
GRID VOLTAGE CONTROL
135
GRID VOLTAGE GENERATOR
(−)
140
141
CATHODE VOLTAGE CONTROL
142
CATHODE VOLTAGE GENERATOR
(−)
150
151
HEATER VOLTAGE CONTROL
152
HEATER VOLTAGE GENERATOR

FIG. 8

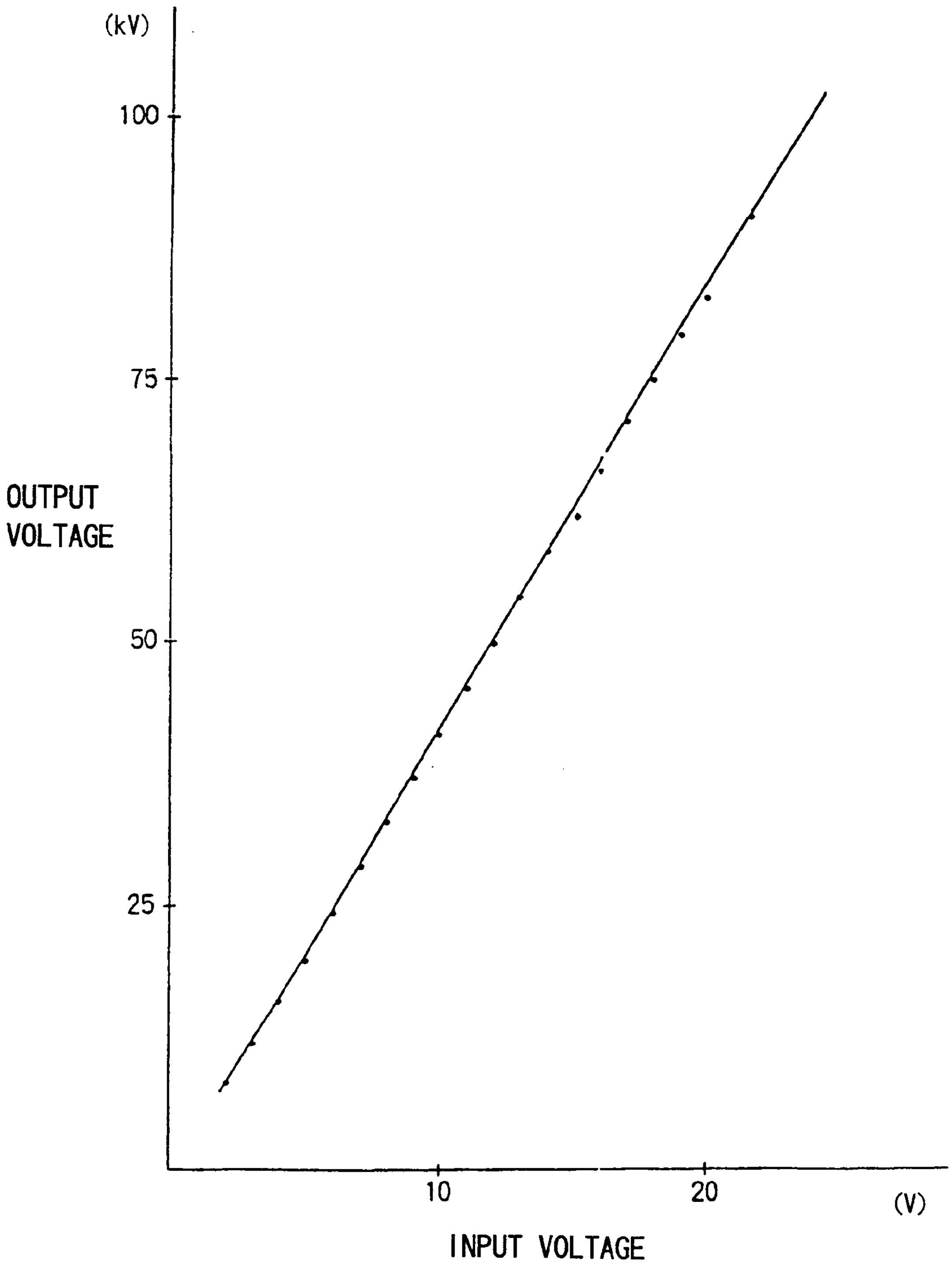


FIG. 9

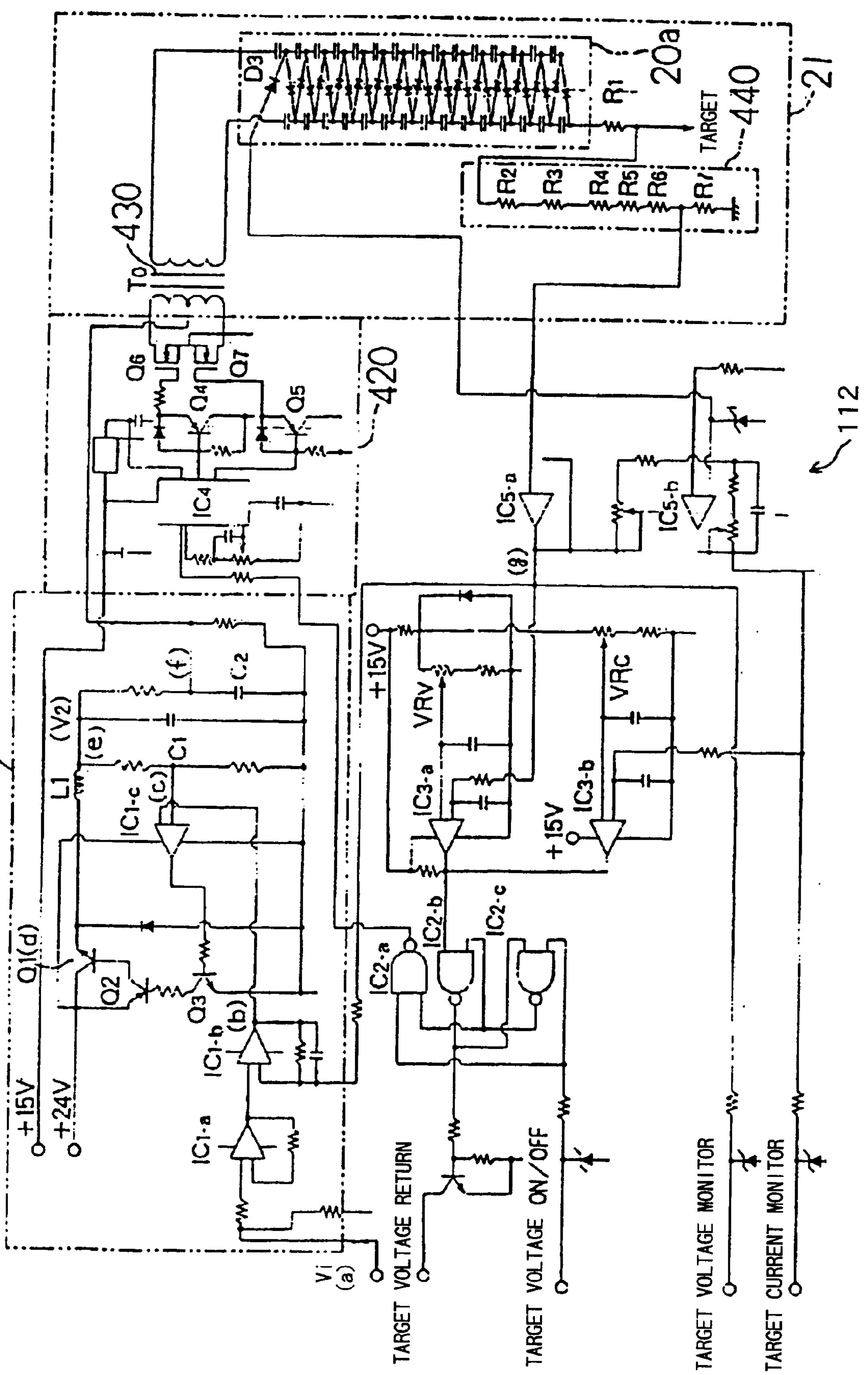

410
420
430
440
20a
21
112
+15V
+24V
Vi
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(V2)
IC1-a
IC1-b
IC1-c
IC2-a
IC2-b
IC2-c
IC3-a
IC3-b
IC4
IC5-a
IC5-b
Q1
Q2
Q3
Q4
Q5
Q6
Q7
L1
C1
C2
VRV
VRC
T0
D3
R1
R2
R3
R4
R5
R6
R7
TARGET
TARGET VOLTAGE RETURN
TARGET VOLTAGE ON/OFF
TARGET VOLTAGE MONITOR
TARGET CURRENT MONITOR

FIG. 10

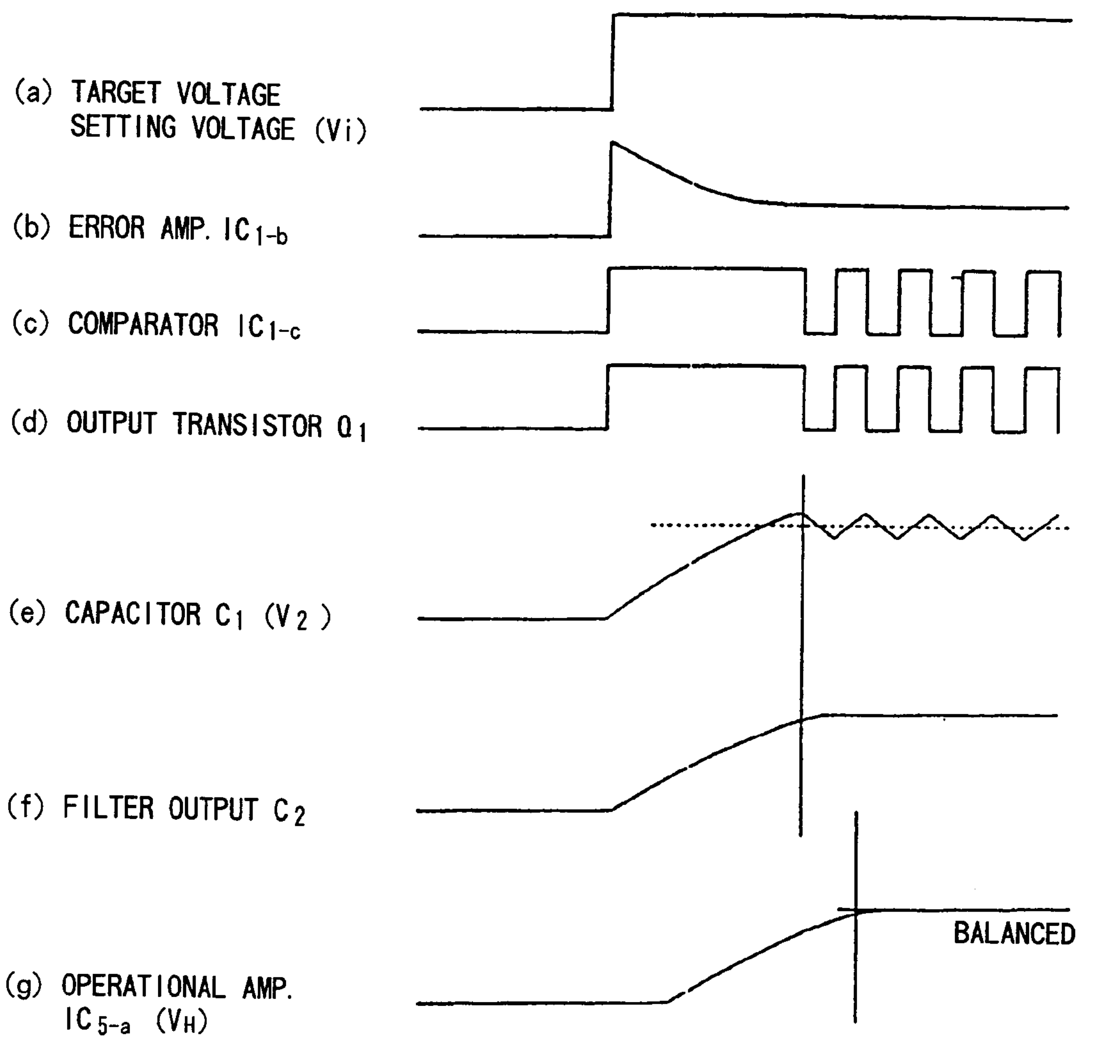

(a) TARGET VOLTAGE SETTING VOLTAGE (Vi)
(b) ERROR AMP. IC1-b
(c) COMPARATOR IC1-c
(d) OUTPUT TRANSISTOR Q1
(e) CAPACITOR C1 (V2)
(f) FILTER OUTPUT C2
(g) OPERATIONAL AMP. IC5-a (VH)
BALANCED

FIG. 11

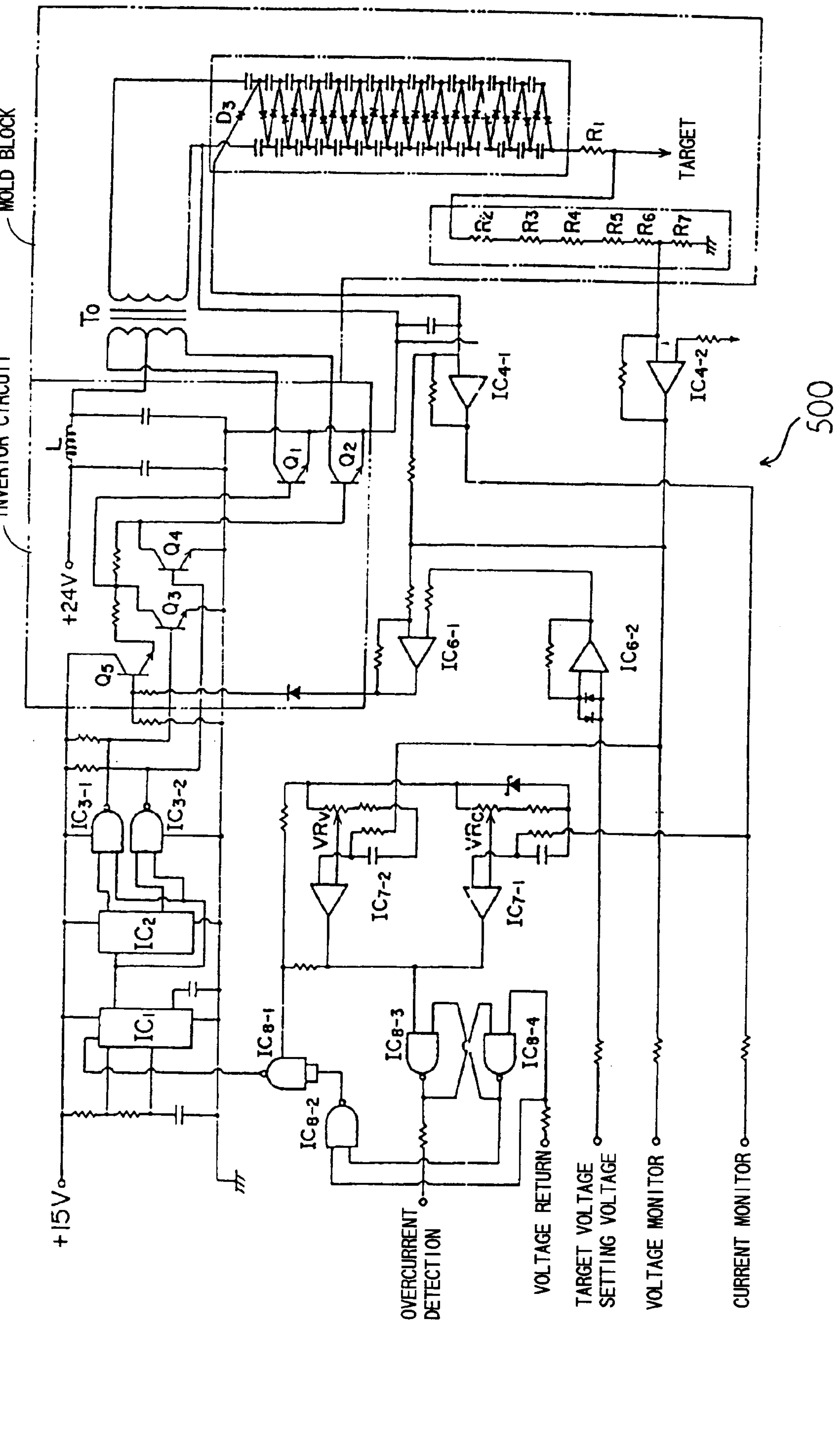

MOLD BLOCK
INVERTOR CIRCUIT
TARGET
To
L
D3
R1
R2
R3
R4
R5
R6
R7
Q1
Q2
Q3
Q4
Q5
+24V
+15V
IC1
IC2
IC3-1
IC3-2
IC4-1
IC4-2
IC6-1
IC6-2
IC7-1
IC7-2
IC8-1
IC8-2
IC8-3
IC8-4
VRV
VRC
OVERCURRENT DETECTION
VOLTAGE RETURN
TARGET VOLTAGE SETTING VOLTAGE
VOLTAGE MONITOR
CURRENT MONITOR
500

FIG. 12 (a)

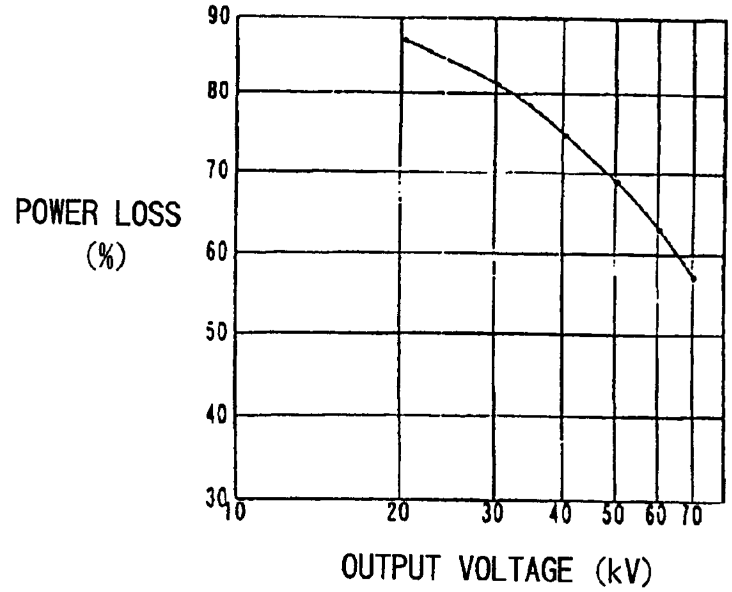


FIG. 12 (b)

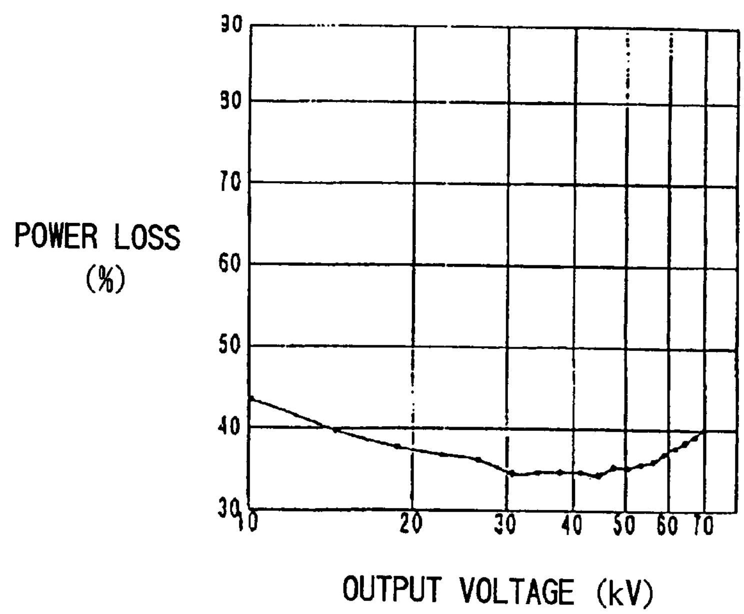


FIG. 13 (a)

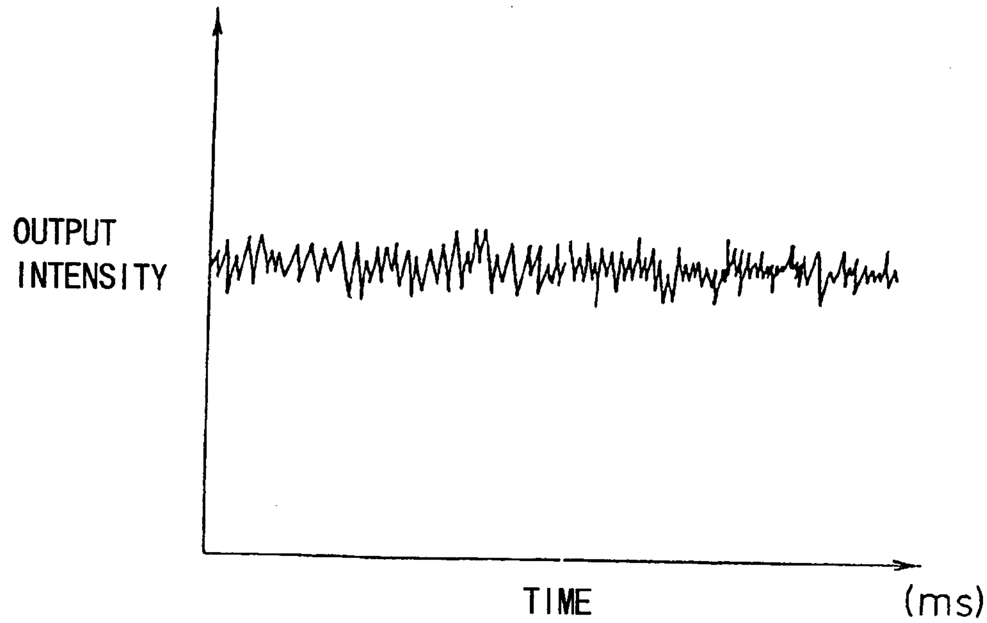
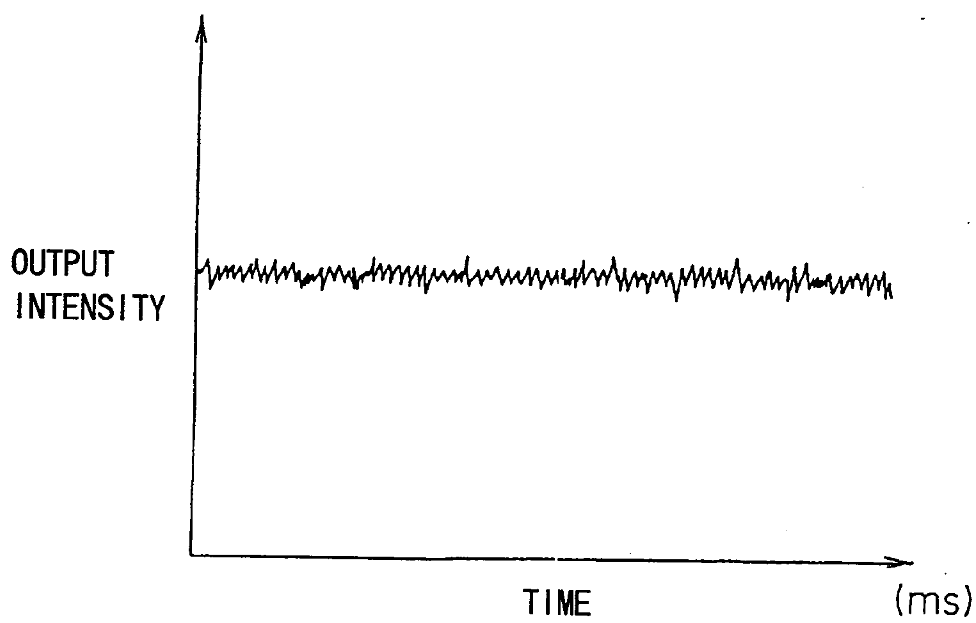


FIG. 13 (b)



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 30 4735

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	DE-A-38 33 148 (KABUSHIKI KAISHA TOSHIBA) * abstract * * column 3, line 10 - column 4, line 62; figure 2 * ---	1,3	H05G1/06 H05G1/20 H05G1/32
A,D	US-A-5 077 771 (B. SKILLICORN ET AL.) * abstract * * column 2, line 38 - column 5, line 2; figures 5,7A * ---	1,3,7,8	
A	US-A-5 272 612 (T. HARADA ET AL.) * column 7, line 47 - column 9, line 68 * * column 12, line 9 - column 14, line 14; figures 16,17 * ---	1,3	
A	DE-A-43 35 708 (STADLER ELEKTRONIK AG) * abstract * * column 1, line 3 - line 51 * ---	1,3	
A	EP-A-0 108 336 (GENERAL ELECTRIC COMPANY) * page 9, line 8 - page 20, line 12; figures 1A,4-6 * ---	1,3	TECHNICAL FIELDS SEARCHED (Int.Cl.6) H05G
A	EP-A-0 047 957 (TOKYO SHIBAURA DENKI KABUSHIKI KAISHA) * page 1, line 2 - page 4, line 19; figure 1 * -----	1,3	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	6 October 1995	Horak, G

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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