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(54) CIRCUIT FOR DIRECT CONTROL OF THE ANODE CURRENT OF AN X- RAY TUBE WITH MONOPOLAR OR BIPOLAR POWER SUPPLY BY MEANS OF THE AUTOMATIC REGULATION OF THE GRID CURRENT

(57) A circuit that aims to control directly the anode current of a cold cathode X-ray tube by means of a feedback signal proportional to the current of the anode itself (IA) by means of the automatic regulation of the grid current (IG) of the X-ray tube, the control being carried out by means of a closed loop comprising:
- A closed loop control circuit (CLR1) that generates an amplified error signal (SMOD) that is the amplified difference between the signal proportional to the anode current (IA) and the demanded current of the anode (IDEM)
- A Digital Sequencer circuit that converts the received signal into several digital control signals,
- A grid current control circuit that receives the digital control signals from the Digital Sequencer circuit and comprises at least one set formed by an inverter (INV) and optionally a converter (DC-DC CONV) and
- A voltage and current adapter transformer (TR), whose rectified output supplies the grid intensity (IG) necessary to obtain the requested anode intensity (IA).

It avoids having to calibrate and/or characterize the curve of the anode current (IA) versus the grid current (IG), keeping the X-ray tube in perfect condition throughout its useful life.

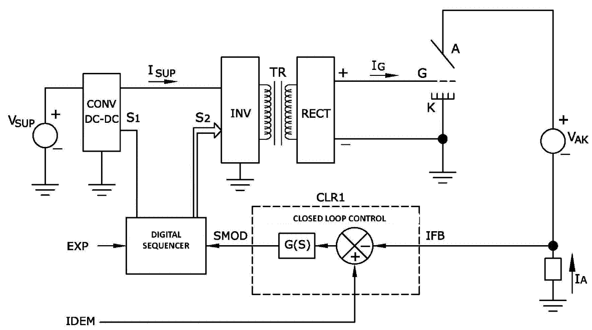

FIG.6

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Description

OBJECT OF THE INVENTION

[0001] The object of the present invention, as indicated by its title, is a circuit for direct control of the anode current of a cold cathode x-ray tube by means of automatic regulation of the grid current.

[0002] The present invention is characterised by the special design and configuration of each and every one of the elements that are part of the control circuit, so that it is possible to control the current of the X-ray anode (IA) by means of a closed loop control in which a feedback signal directly proportional to the anode current (IA) is used for the automatic regulation of the grid current (IG) of the X-ray tube.

[0003] In this way we avoid the need to calibrate and/or characterize the curve of the anode current (IA) versus the grid current (IG). The anode current (IA) is a fundamental parameter that must be controlled with great precision, because it is responsible for the amount of X-ray photons emitted by the anode of the tube.

[0004] Thanks to the characteristics of the circuit, a greater precision and stability of the radiation emitted during the entire life of the X-ray tube is achieved without having to make periodic recalibrations due to changes in the characteristics of the X-ray tube resulting from the degradation suffered in its daily use, since said degradation is compensated by the closed control loop of the circuit of the present invention.

[0005] Therefore, the present invention lies within the scope of X-ray apparatuses and specifically cold-cathode apparatuses.

BACKGROUND OF THE INVENTION

[0006] It is known in the art that the energy of X-ray radiation depends on the kV applied between the anode and the cathode, while the amount of radiation depends on the current of the anode, as well as the time of exposure.

[0007] Currently the cold or ambient temperature cathode X-ray tubes are being developed, called to distinguish them from thermionic emission tubes where an incandescent filament is needed to heat the cathode and allow it to emit electrons towards the anode. With this new cold cathode technology, the control of electron emission is realized by means of a cathode (at room temperature) formed by a series of carbon nanotubes, wherein a grid has been interposed between the cathode and the anode. Between the grid and the cathode, an electric field is applied that is high enough to extract the electrons, which are attracted and accelerated by the anode. The electrons that impact the anode cause X-ray photons to be released that are emitted by the anode with an energy determined by the voltage applied between the anode and the cathode. To control the number of electrons impacting the anode, it is necessary to control the electric field between the grid and the cathode.

[0008] Figure 1 shows a schematic diagram of a cold cathode x-ray apparatus where the x-ray tube has a monopolar power supply, comprising an anode (A) and a cathode (K) formed by a series of carbon nanotubes and arranged opposite the anode (A), between which a grid (G) has been interposed, there is a first loop formed by the anode (A), the cathode (K) and a power supply (KV) between both. Figure 1a shows the same tube, in this case with a bipolar power supply, with half of the voltage providing power supply to the anode (A) and the other half of the voltage providing power supply to the cathode (K), with the centre of both sources connected to the ground to reduce the stress in the insulations of the source itself and of the x-ray tube with respect to the ground. There is also a second loop formed by the grid (G), the cathode (K) and a power supply (V) that can be controlled by voltage or by current. Both loops share a common section, so that a current IA flows through the first loop, and a current IG flows through the second loop, while a current IA+IG flows through the common section.

[0009] Figure 2 shows a graph indicating that the anode current (IA) varies linearly with the grid current (IG), while figure 3 shows that the relationship between the anode current (IA) and the grid current (IG) with respect to the grid voltage (VG) is exponential and therefore controlling the anode current (IA) through the grid voltage is very complicated.

[0010] Figure 4 shows a diagram of a circuit for controlling the anode current (IA), where the anode is grounded through a power supply (VAG), the grid (G) is directly grounded, and the cathode (K) is grounded through a power supply (Vsup) and a MOSFET switch, across which there is a voltage drop (Vcont), and is controlled by a demand signal of the cathode current (IKDemand).

[0011] The following relationships are fulfilled in the control scheme shown in figure 4:

$$VGK = Vsup - Vcont$$

$$VAK = VAG + VGK$$

$$VAK = VAG + Vsup - Vcont$$

[0012] This control scheme carries out a linear control of the cathode current (IK) but in a very complex way. In addition, it requires a MOSFET capable of working at several thousand volts, where the voltage drop between source and drain is very large.

[0013] Another major drawback of this type of control is that the voltage between the anode and the cathode of the X-ray tube depends on the grid voltage (which varies with the ageing of the X-ray tube), directly affecting the energy of the emitted radiation.

[0014] Figures 5 and 5a shows a control of X-ray exposure by controlling the grid current, keeping the voltage between the anode and the cathode (VAK monopolar or bipolar) independent; however, this grid current has to be previously known to obtain the desired anode current. The grid current is determined by means of a previous calibration or by means of a characterization of the IA curve versus IG shown in figure 2, which can be modified by the daily use of the X-ray tube and which also varies between tubes of the same type due to the tolerances in its production process. The advantage of this type of controller is that when the required IG current is previously known, said IG can be preloaded in the DC-DC converter before starting the X-ray exposure, thus shortening the start of the X-ray exposure by a few microseconds. Shortening this time is essential for scanning techniques and for performing the X-ray exposure at the exact moment that is needed, for example in a serial production line where the objects to be X-rayed travel on a conveyor belt. Considering that, for more than 90% of radiological applications, this time is not critical, it is preferable to focus on the precision, stability and shorter stoppage time of the equipment for performing new recalibrations.

[0015] Therefore, the object of the present invention is to develop a circuit for direct control of the anode current of a cold cathode x-ray tube by means of automatic regulation of the grid current (that is, without the need to know said current by means of a previous calibration or characterization). In addition, the control circuit that powers the grid is isolated from the circuit that powers the circuit between the anode and the cathode, which establishes a constant voltage VAK (monopolar or bipolar) between the anode and the cathode that is independent of the grid control, obtaining a control circuit such as that described below.

DESCRIPTION OF THE INVENTION

[0016] The object of the present invention is essentially contained in the independent claim and the different embodiments are contained in the dependent claims.

[0017] The circuit object of the invention is designed to directly control the anode current (IA) of the X-ray exposure by means of a feedback signal proportional to the anode current, which is used to automatically control the grid current (IG) of the X-ray tube to maintain the precise and stable anode current (IA) demanded (IDEM) and which is ultimately responsible for the number of X-ray photons emitted.

[0018] The control of the anode current (IA) is carried out by a circuit that automatically supplies the grid current (IG) by means of a closed loop control, comprising:

- A closed loop control circuit in which a comparison is made between a signal proportional to the anode current (IA) and a demand signal of the anode current (IDEM) obtaining a signal that is the amplified difference between the signal proportional to the anode current and the demanded anode current,
- A digital sequencer circuit connected with the closed loop control and receiving the signal of the amplified difference between the signal proportional to the anode current and the demanded anode current and converting the received signal into several digital control signals.
- A grid current control circuit that receives the digital control signals from the Digital Sequencer circuit and which comprises at least one inverter and optionally a DC-DC converter, said digital control signals being applied to the DC-DC converter and to the inverter by means of an adapter transformer and a rectifier at its output, to achieve a grid current so as to obtain an anode current practically equal to the demanded current.

[0019] The closed loop control circuit preferably comprises, but is not limited to, a comparator having a first input that receives a signal which is proportional to the anode current (IFB) and a second input that is the demanded signal of the anode current (IDEM). The two signals are compared and amplified with a gain G(s), delivering at its output a signal of the amplified difference between the signal proportional to the anode current and the demanded current of the anode.

[0020] The grid current (IG) control circuit in a possible non-limiting embodiment comprises a connection to a power supply voltage (Vsup) connected with a DC-DC converter (DC-DC CONV), known as a "buck converter", which in turn is connected with an inverter whose output is connected to a transformer, and the output of this transformer is connected to a rectifier whose outputs are connected to the grid and to ground.

[0021] It should be noted that the DC-DC converter and the inverter could be integrated into a single inverter with a different topology than that described and controlled through voltage and/or current, obtaining a result similar to that described in the present invention. The same happens with the closed loop control, which could be analogic or digital, with almost the same results.

[0022] In one possible embodiment, when the Digital Sequencer circuit receives the exposure command (exp) it generates two signals, a first signal (S1) for the DC-DC converter and a second group of control signals (S2) for the inverter (INV).

[0023] In a preferred but non-limiting embodiment the DC-DC converter consists of a capacitor in parallel with a first switch and a first diode, and a coil and a return diode arranged in parallel with the assembly formed by the first switch and the coil.

[0024] The inverter is formed by a bridge comprising a second switch, a third switch, a fourth switch and a fifth switch, wherein the second switch and the fifth switch are in series forming a first branch, while the third switch and the fourth switch are in series forming a second branch, both branches being in parallel with each other.

[0025] Each branch is connected in its middle with a transformer whose output is connected with a rectifier bridge from where the necessary grid current is obtained, while the lower end of both branches of the inverter and the DC-DC converter are connected with ground.

[0026] Thanks to the control circuit described, an anode current control is achieved directly by controlling the power supply of the grid by means of the transformer TR. Said transformer TR could supply grid voltages of up to 15 kV or more, if necessary. As the grid control circuit is independent of the Anode-Cathode circuit, the VAK voltage is not affected at all by the grid control. Since the VAK (whether monopolar or bipolar) voltage is responsible for the emitted radiation (photons) energy, the whole emitted dose of X-rays is much more precise and stable.

[0027] The direct anode current control circuit has very important advantages that would be fundamental in any fixed or portable radiological equipment and that could be perfectly applied to equipment with tomography and/or tomosynthesis, with one or with multiple independently controlled x-ray tubes:

- Firstly, the control of the grid does not alter the anode-cathode voltage at all.
- Secondly, the grid control circuit can supply 15KV or more if necessary.
- And, thirdly, the equipment does not require any type of calibration, characterization and/or maintenance, maintaining optimal precision throughout its lifetime.

[0028] Unless indicated otherwise, all the technical and scientific elements used in this specification have the meaning usually understood by a person skilled in the art to which this invention belongs. In the practice of this invention, methods and materials similar or equivalent to those described in the specification may be used.

[0029] In the description and claims, the word "comprises" and its variants do not intend to exclude other technical characteristics, additives, components or steps. For persons skilled in the art, other objects, advantages and characteristics of the invention will be partly inferred from the description and partly from the practice of the invention.

EXPLANATION OF THE FIGURES

[0030] In order to complement the description being made herein, and with the object of aiding the better understanding of the characteristics of the invention, in accordance with a preferred practical embodiment thereof, said description is accompanied, as an integral part thereof, by a set of drawings where, in an illustrative and non-limiting manner, the following has been represented:

Figure 1 shows a schematic diagram of a cold cathode x-ray apparatus powering the x-ray tube with a monopolar power supply.

Figure 1a shows the same diagram of the cold cathode x-ray apparatus, in this case the x-ray tube being powered by a bipolar power supply.

Figure 2 shows a graph indicating that the anode current (IA) varies linearly with the grid current (IG).

Figure 3 shows the relationship between the anode current (IA) and the grid current (IG) with respect to the grid voltage (VG).

Figure 4 shows a schematic diagram of a circuit of the prior art for controlling the anode current (IA) through the cathode current (IK), which in turn affects the voltage between anode and cathode (VAK) (and therefore also affects the energy of the emitted radiation).

Figures 5 and 5a respectively show a monopolar and bipolar power supply for the circuit for controlling X-ray exposure by means of the grid current (IG), which requires a process for characterising and/or calibrating said current in order to obtain the required anode current (IA).

Figure 6 shows the block diagram of the control used in the embodiment object of the invention with monopolar power supply of the x-ray tube, which consists of directly controlling the anode current (IA) through the automatic control of the grid current (IG).

Figure 6a shows the same block diagram, but with bipolar power supply of the x-ray tube.

Figure 7 shows a non-limiting preferred embodiment of the grid current control circuit, wherein the DC-DC converter is formed by a capacitor (C) in parallel with a first switch (Q1) and a diode (D1); and by a coil (L) and a return diode (D2) in parallel with the assembly formed by the first switch (Q1) and the coil (L). The output of the DC-DC converter powers the inverter formed by the transistors Q2, Q3, Q4 and Q5 which in turn supply a high frequency alternating current to the transformer TR1. The output of TR1 is rectified to deliver direct current to the grid of the X-ray tube.

Figure 8 shows an illustrative example of the work cycle of the Digital Sequencer, working with a closed loop control of the analogic type, in the moments prior to X-ray exposure, during X-ray exposure and at the end of X-ray exposure.

Figure 9 shows a possible embodiment of a current control circuit with a pulse width modulator PWM, starting from an analogic control input (SMOD) to act directly and digitally on the DC-DC converter.

PREFERRED EMBODIMENT OF THE INVENTION

[0031] In view of the figures, a preferred embodiment of the proposed invention is described below.

[0032] Figures 1 to 5 and 5a correspond to explanations of the prior art of x-ray exposure control.

[0033] Figures 6 and 6a shows the block diagram of the direct anode current control circuit (IA), where the anode (A) is connected to a power supply (VAK with monopolar or bipolar power supply) that is connected to ground through an anode current (IA) meter, while the cathode (K) is also connected to ground; on the other hand, the grid (G) is connected through a closed control loop with the anode current, where said control loop in the preferred but not limited embodiment comprises:

- a closed loop control circuit (CLR1) PID like or equivalent, which preferably but not limited to, has a first input that receives a signal from a current (IFB) that is proportional to the anode current (IA) and a second input that is the demanded signal from the anode current (IDEM). The two signals are compared and amplified by means of a gain amplifier G(s), delivering at its output an amplified error signal (SMOD) which is the amplified difference between the signal proportional to the anode current and the demanded current of the anode (IDEM).

- A Digital Sequencer circuit, where there is a first input that is the output of the closed loop control, in particular the amplified error signal (SMOD) and a second input that is the X-ray exposure order signal (EXP). This Digital Sequencer generates a first output (S1) that controls the DC-DC Converter by means of a PWM signal and a second group of signals (S2) that sequence the operation of the inverter (INV), when the X-ray exposure signal (EXP) is received.

- A grid current (IG) control circuit that preferably, but not limited to, comprises a connection to a power supply (Vsup) connected to a DC-DC converter (DC-DC CONV), known as a "buck converter", which in turn is connected to an inverter (INV) whose output is connected to a transformer (TR), and the output of this transformer (TR) is connected to a rectifier (RECT) whose outputs are connected to the grid (G) and to ground.

[0034] In figure 6 the power supply is a monopolar power supply from a power supply (VAK) where the anode (A) is connected to the power supply (VAK) that is grounded through a shunt to measure the anode current IA, while the cathode (K) is also grounded.

[0035] In figure 6a the power supply is a bipolar power supply where the anode (A) is connected to the power supply (VAK/2) that is grounded through a shunt to measure the anode current (IA), while the cathode (K) is connected to another power supply (VAK/2) that is also grounded.

[0036] Figure 7 shows a non-limiting preferred embodiment of the above elements of the grid current control circuit, wherein the DC-DC converter is formed by a capacitor (C) in parallel with a first switch (Q1) and a diode (D1) and also by a coil (L) and a return diode (D2) in parallel with the assembly formed by the first switch (Q1) and the coil (L).

[0037] The inverter is formed by a bridge comprising a second switch (Q2), a third switch (Q3), a fourth switch (Q4) and a fifth switch (Q5), where the second switch (Q2) and the fifth switch (Q5) are in series forming a first branch, while the third switch (Q3) and the fourth switch (Q4) are in series forming a second branch, the two branches being in parallel with each other.

[0038] Each branch is connected in its middle with a transformer (TR1) whose output is connected to a rectifier bridge from where the grid current (IG) is obtained, while the lower end of both branches of the inverter and the DC-DC converter are grounded.

[0039] Figure 8 shows the example of the operation of the Digital Sequencer in different clock cycles (C1 to C12), and the state of the different switches (Q1, Q2, Q3, Q4, Q5), as well as the exposure order inputs (EXP) and the error signal, which in this example is an amplified analogic signal (SMOD).

[0040] In the cycle (C1), there is no exposure order and therefore the 5 transistors (Q1, Q2, Q3, Q4 and Q5) are off.

[0041] In the cycle (C2) the exposure command (exp) is received and the transistor (Q1) begins to modulate, according to the amplified error signal (SMOD) compared to the sawtooth signal (DS) that is synchronized with a clock signal (CLOCK) and generated in the digital sequencer itself. At the same time, the order is given to turn on the diagonal formed by the transistors (Q2) and (Q4), keeping (Q3) and (Q5) off.

[0042] In the cycle (C3), the transistor (Q1) continues to modulate in the same way as in the previous cycle, i. e. controlled by the signals (SMOD) and (DS). Now the diagonal of the transistors (Q2) and (Q4) is turned off, and the opposite diagonal (Q3 and Q5) is turned on, generating an alternating current signal to power the transformer (TR), whose output is rectified to provide the grid direct current (IG) necessary to reach the required value of the anode current.

[0043] From the cycles (C2) to (C11) the same control continues to be maintained in the transistor (Q1). The alternation in the diagonals of the inverter is also maintained, that is to say that when (Q2) and (Q4) are on, the transistors (Q3) and (Q5) are off, reversing the conducting state of the four transistors of the inverter in the next cycle.

[0044] Eventually (in this example it is in the cycle (C12)), the signal (EXP) gives the command to terminate the exposure. At that time the 5 transistors (Q1, Q2, Q3, Q4 and Q5) are switched off instantly and simultaneously. At that moment the current stops circulating towards the grid, instantly turning off the X-ray exposure. The energy stored in the inductance (L) is transferred to the power supply (Vsup) through the diodes (D1) and (D2) and everything returns to the initial state as in the cycle (C1).

[0045] Finally, figure 9 shows the circuit that converts the amplified analogic error signal (SMOD) into a digital signal which controls the transistor (Q1) and in turn controls the output current (ISUP) of the DC-DC converter. As can be seen, it comprises a flip-flop (FF1) triggered by a positive edge, which has an activation input to which an AND gate (AND1) is connected, which in turn has as inputs a clock signal (CLOCK) and an exposure start signal (EXP); and a reset signal (RES) to which a comparator (COMP1) is connected, which in turn has as inputs the amplified error signal (SMOD) and the instantaneous value of the saw tooth (DS), so that the flip-flop (FF1) will activate its output (Q) to turn on the transistor (Q1) when the inputs of the gate (AND1) are both "1", while when it reaches and/or exceeds the value of the amplified error signal (SMOD) and the instantaneous value of the saw tooth (DS) in the comparator (COMP1), it will cause its output to be "0", restarting the output (Q) of (FF1) and turning off the transistor (Q1), until it is turned on again in the next clock cycle (CLOCK).

[0046] It is noteworthy that the grid current (IG) ripple, although being directly proportional to the anode current, has no influence on the dose control of the X-ray exposure, since this depends on the amount of photons that are generated in the anode of the tube, i.e. the integral over the exposure time of the anode current, internationally known as mAs. On the contrary, the ripple of the voltage (VAK) is very important, because it generates photons of different energy, which has a very important direct impact on the emitted dose.

[0047] Having sufficiently described the nature of the present invention, in addition to the manner in which to put it into practice, it is hereby stated that, in its essence, it may be put into practice in other embodiments that differ in detail from that indicated by way of example, and to which the protection equally applies, provided that its main principle is not altered, changed or modified.

Claims

1. Direct control circuit of the anode current in an X-ray tube by means of the automatic regulation of the grid current, where the anode (A) is connected to a power supply (VAK) or (VAK/2) that is connected to ground through an anode current meter, while the cathode (K) is also connected to ground, while the grid (G) is connected by a closed control loop with the anode current, where said control loop in the preferred but not limiting embodiment shown comprises:

- A closed loop control (CLR1) circuit comprising a comparator in which a comparison is made between a signal proportional to the anode current (IA) and a demand signal of the anode current (IDEM), an amplified error signal (SMOD) being obtained which is the amplified difference between the signal proportional to the anode current (IA) and the demanded current of the anode (IDEM),
- A Digital Sequencer circuit connected with the closed loop control circuit (CLR1) receiving the amplified error signal (SMOD) and converting the received signal into various digital control signals
- A grid current control circuit that receives the digital control signals from the Digital Sequencer circuit and comprises at least one set formed by an inverter (INV) and optionally a converter (DC-DC CONV), said digital control signals being applied to the converter (DC-DC CONV) and the inverter (INV) that supplies a transformer, whose rectified output supplies a grid current (IG) such that an anode current practically equal to the demanded current (IDEM) can be obtained.

2. Control circuit according to claim 1, **characterized in that** the closed loop control circuit (CLR1) further comprises a gain amplifier G(s) arranged at the output of the comparator.

3. Control circuit according to claim 1 or 2, **characterized in that** the grid current (IG) control circuit further comprises a connection to a supply voltage (Vsup) connected to the inverter assembly (INV) and optionally to the DC-DC converter (CONV DC-DC), wherein the inverter output (Inv) is connected to a transformer (TR), and the output of this transformer (TR) is connected to a rectifier (RECT) whose outputs are connected to the grid and to ground.

4. Control circuit according to claim 3, **characterized in that** the DC-DC converter is formed by a capacitor (C) in parallel with a first switch (Q1) and a diode (D1) and, on the other hand, by a coil (L) and a return diode (D2) in parallel with the assembly formed by the first switch (Q1) and the coil (L), while the inverter is formed by a bridge comprising a second switch (Q2), a third switch (Q3), a fourth switch (Q4) and a fifth switch (Q5), where the second switch (Q2) and the fifth switch (Q5) are in series forming a first branch, while the third switch (Q3) and the fourth switch (Q4) are in series forming a second branch, both branches being in parallel with each other, so that each branch is connected in its middle to a transformer (TR1) whose output is connected to a rectifier bridge from where the grid current (IG) is obtained, while the lower end of both branches of the inverter and the DC-DC converter are grounded.

5. Control circuit according to claims 1 and 3 **characterized in that** the converter (DC-DC) and the inverter (INV) are integrated in a single inverter and controlled in voltage and/or current, obtaining very similar results.

6. Control circuit according to any of the preceding claims, **characterized in that** the Digital Sequencer circuit, when it receives the exposure command (EXP), generates two signals, a first signal (S1) for the converter (CONV DC-DC) and a second group of control signals (S2) for the inverter (INV).

7. Control circuit according to claim 6, **characterized in that** the Digital Sequencer circuit comprises a flip-flop (FF1) triggered by a positive edge, which has an activation input to which an AND gate (AND1) is connected, which in turn has as inputs a clock signal (CLOCK) and an exposure start signal (EXP); and a reset signal (RES) to which a comparator (COMP1) is connected, which in turn has as inputs the amplified error signal (SMOD) and the instantaneous value of the saw tooth (DS), so that the flip-flop (FF1) will activate its output (Q) when the inputs of the gate (AND1) are both "1", while when it reaches and/or exceeds the value of the amplified error signal (SMOD) and the instantaneous value of the saw tooth (DS) in the comparator (COMP1), its output will be "0", restarting the output (Q) of (FF1), until it is turned on again in the next clock cycle (CLOCK).

8. Control circuit according to any of the preceding claims, **characterized in that** the power supply is a monopolar power supply from a power supply (VAK) where the anode (A) is connected to a power supply (VAK) that is grounded through a shunt to measure the anode current IA, while the cathode (K) is also grounded.

9. X-ray exposure control circuit by means of a grid current, according to any of claims 1-7, **characterized in that** the power supply is a bipolar power supply where the anode (A) is connected to the power supply (VAK/2) that is grounded through a shunt to measure the anode current (IA), while the cathode (K) is connected to another power supply (VAK/2) that is also grounded.

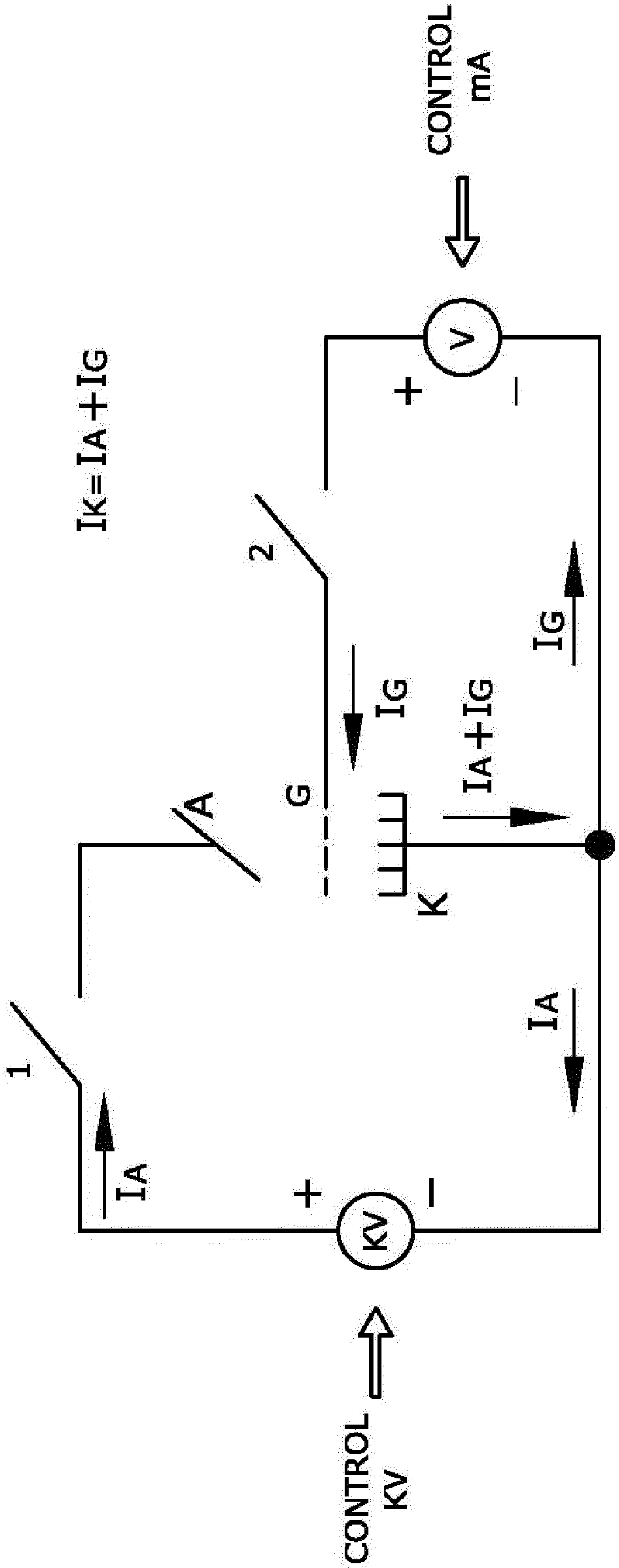

FIG.1

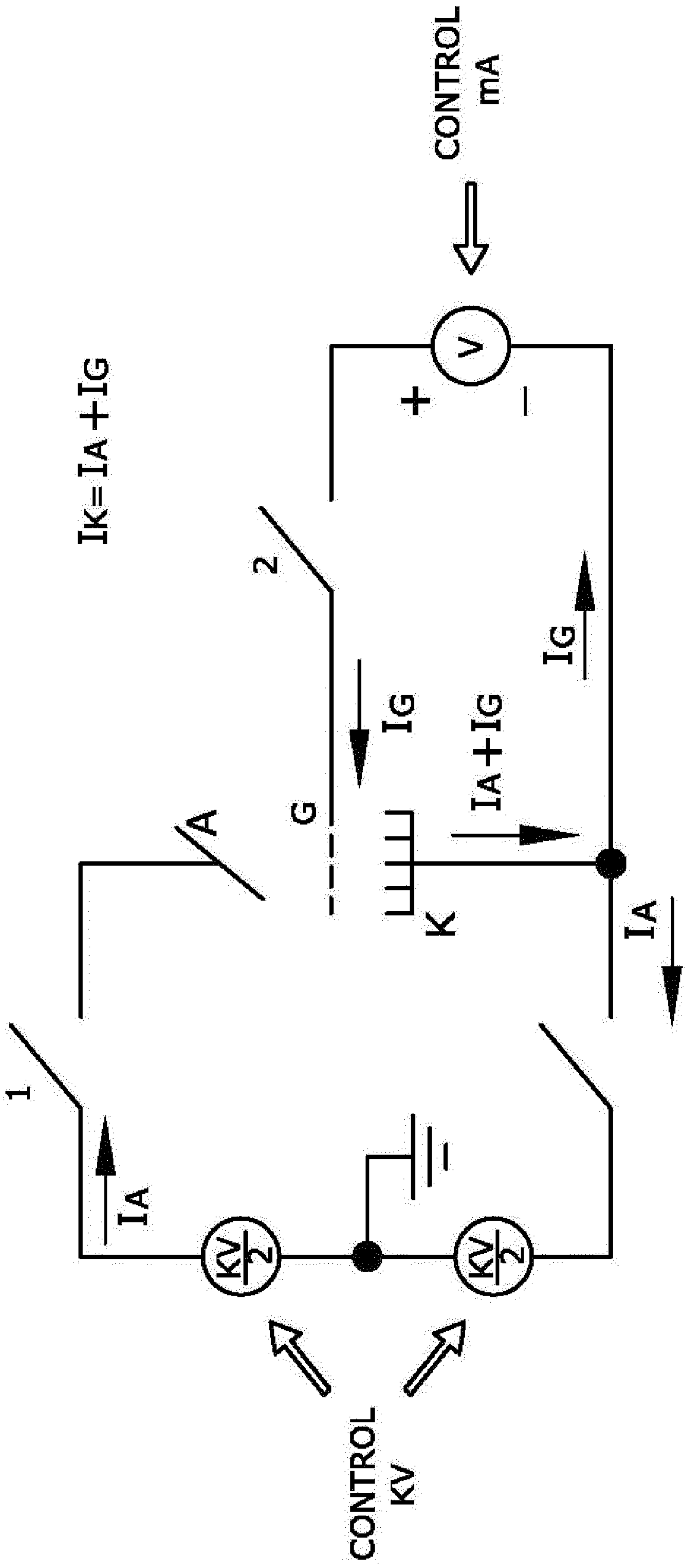

FIG.1a

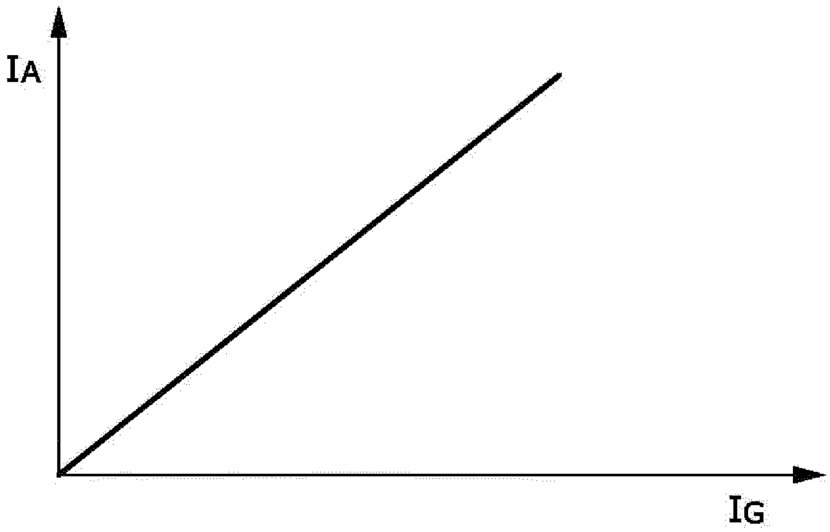

FIG.2

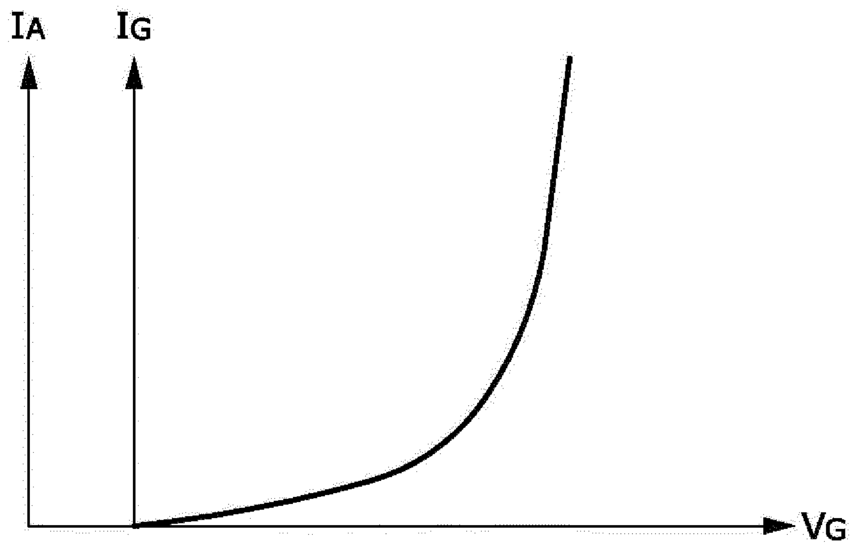

FIG.3

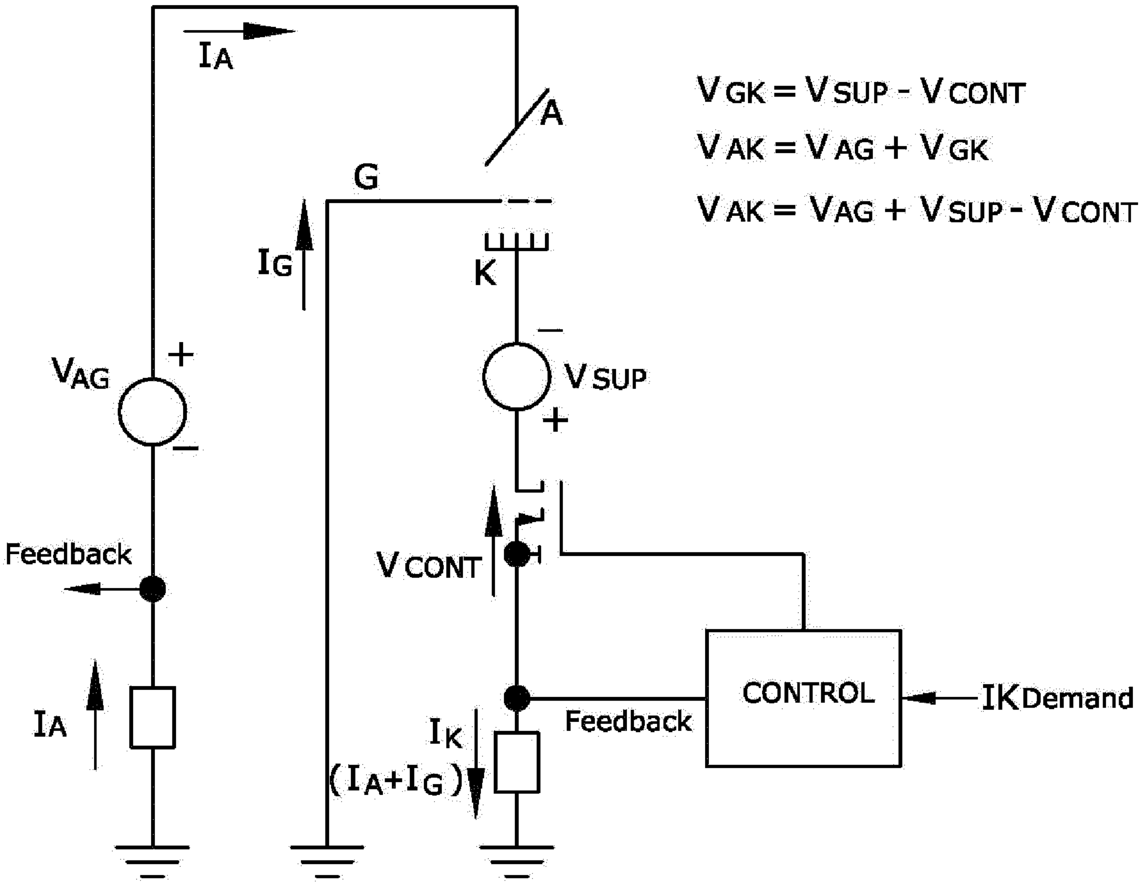
IA
A
G
IG
K
VAG
VSUP
Feedback
VCONT
IA
IK
(IA+IG)
Feedback
CONTROL
IKDemand
VGK = VSUP - VCONT
VAK = VAG + VGK
VAK = VAG + VSUP - VCONT

FIG.4

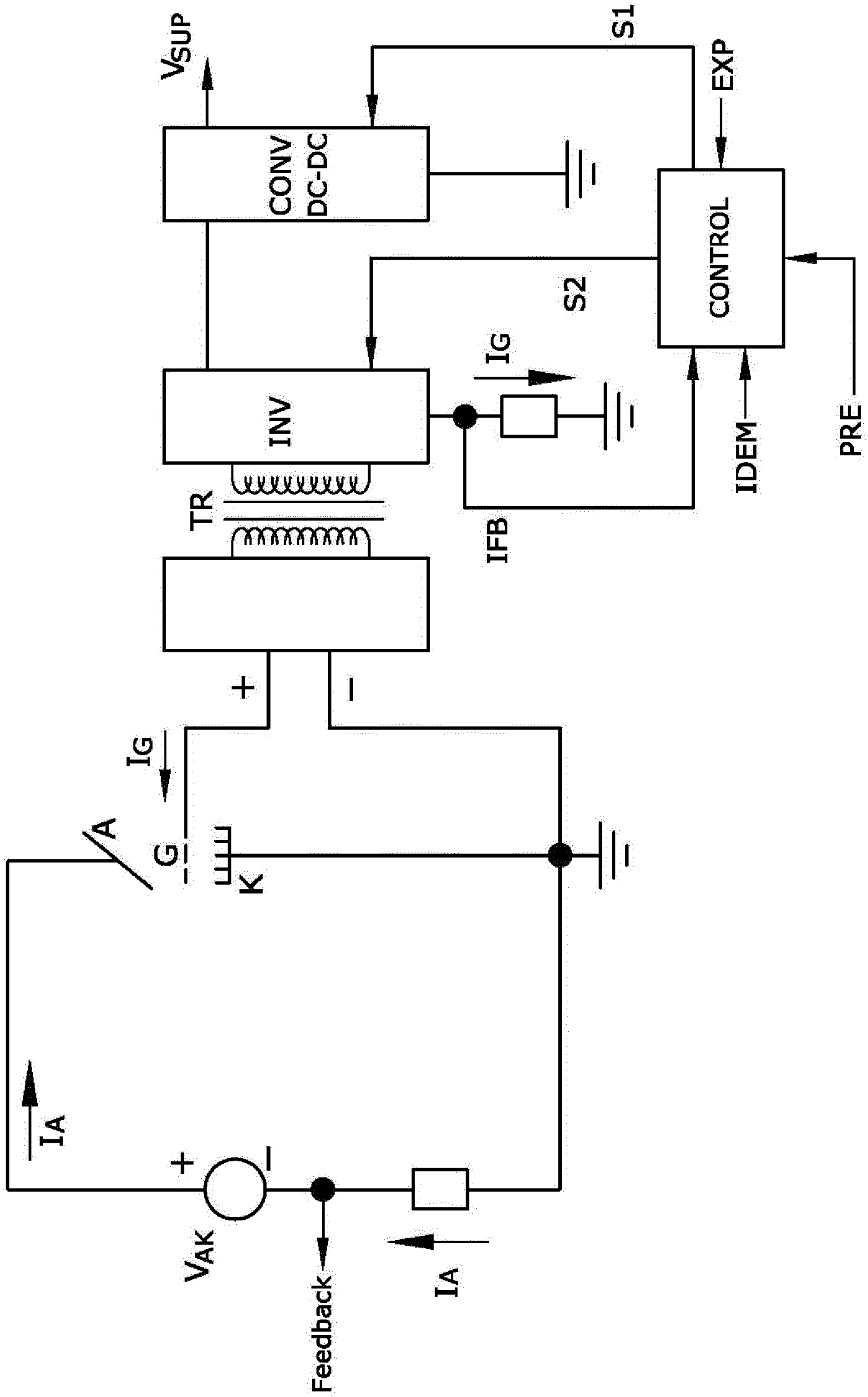
VSUP
S1
EXP
CONV
DC-DC
CONTROL
S2
IG
INV
TR
IDEM
PRE
IFB
+
−
IG
A
G
K
IA
+
VAK
Feedback
IA

FIG.5

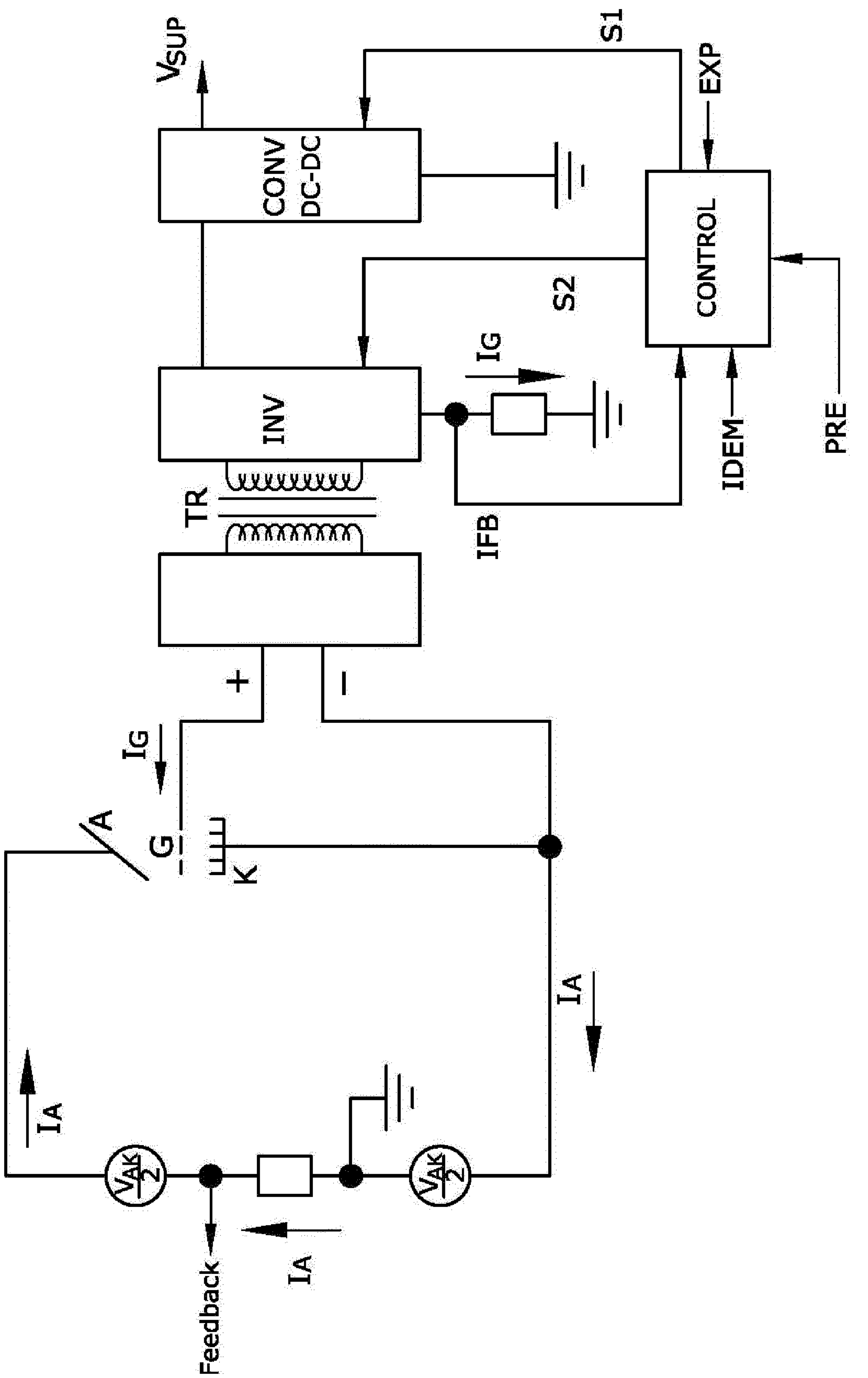
VSUP
S1
EXP
CONV
DC-DC
CONTROL
S2
INV
IG
TR
IFB
IDEM
PRE
+
−
IG
A
G
K
IA
IA
VAK/2
VAK/2
IA
Feedback

FIG.5a

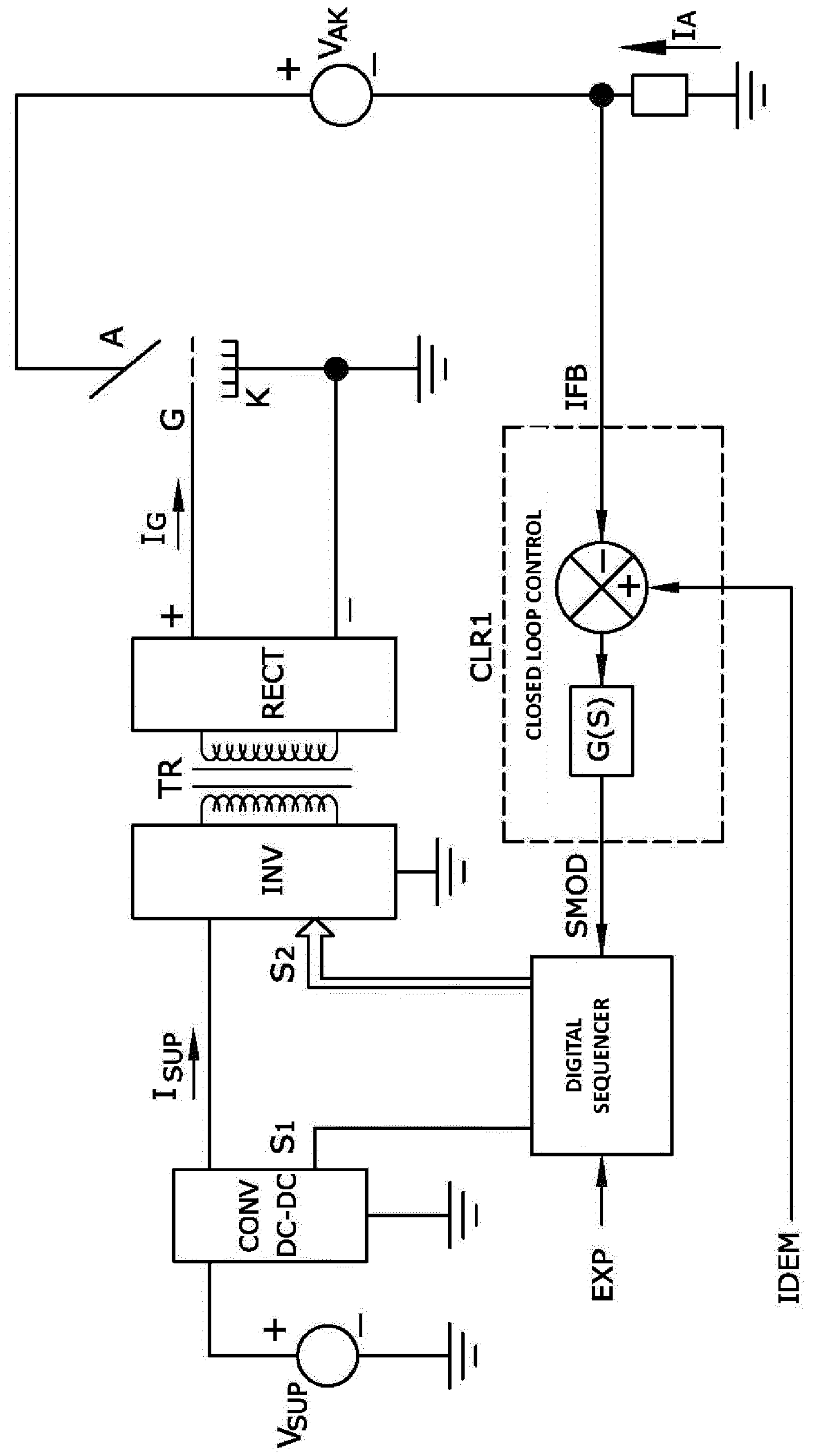
VAK
IA
A
G
K
IG
RECT
TR
INV
S2
ISUP
S1
CONV
DC-DC
VSUP
IFB
CLR1
CLOSED LOOP CONTROL
G(S)
SMOD
DIGITAL
SEQUENCER
EXP
IDEM

FIG.6

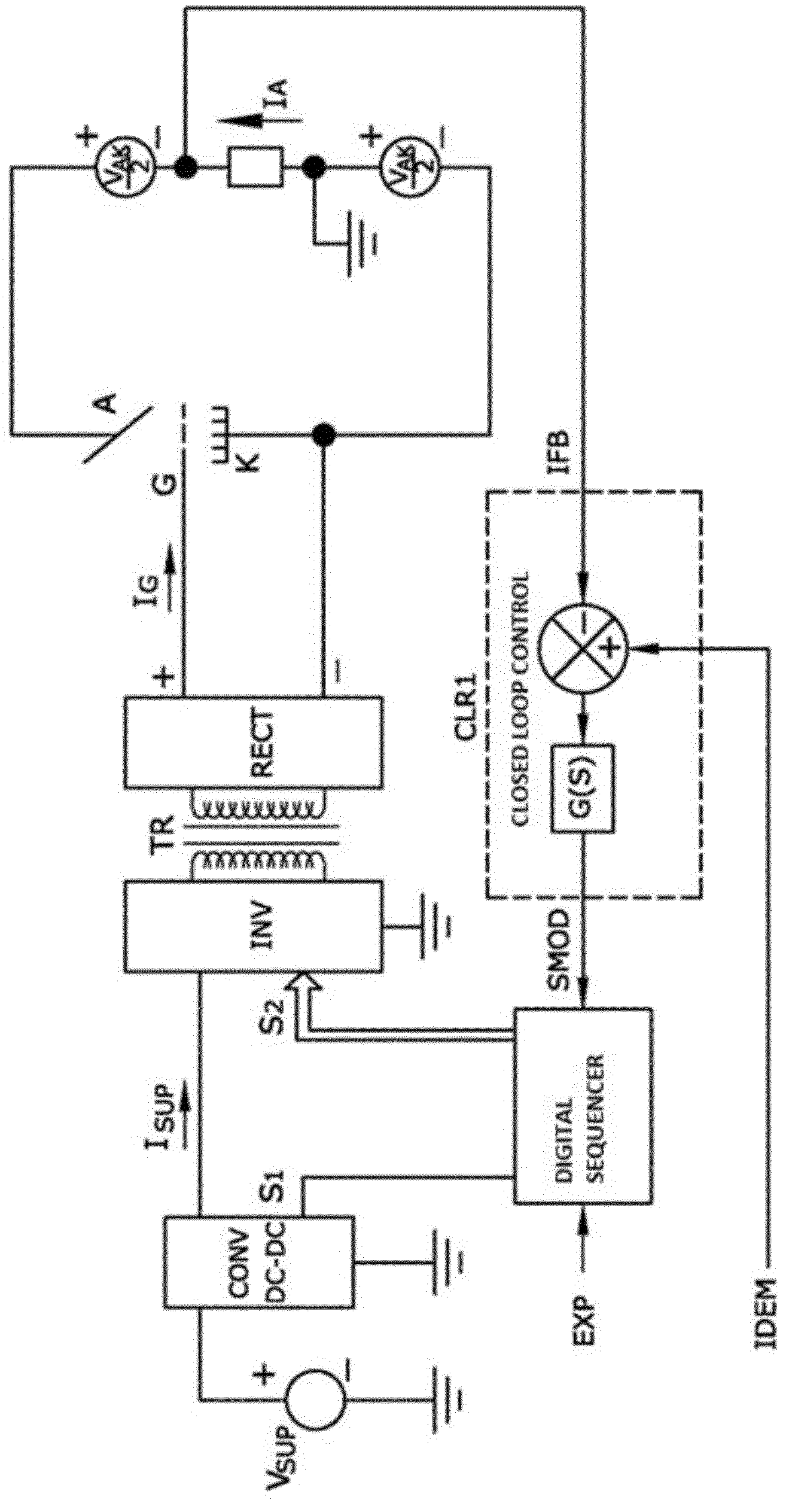
IA
A
G
K
IG
+
−
RECT
TR
INV
S2
SMOD
CLR1
CLOSED LOOP CONTROL
G(S)
IFB
DIGITAL SEQUENCER
ISUP
S1
CONV DC-DC
EXP
IDEM
VSUP

FIG.6a

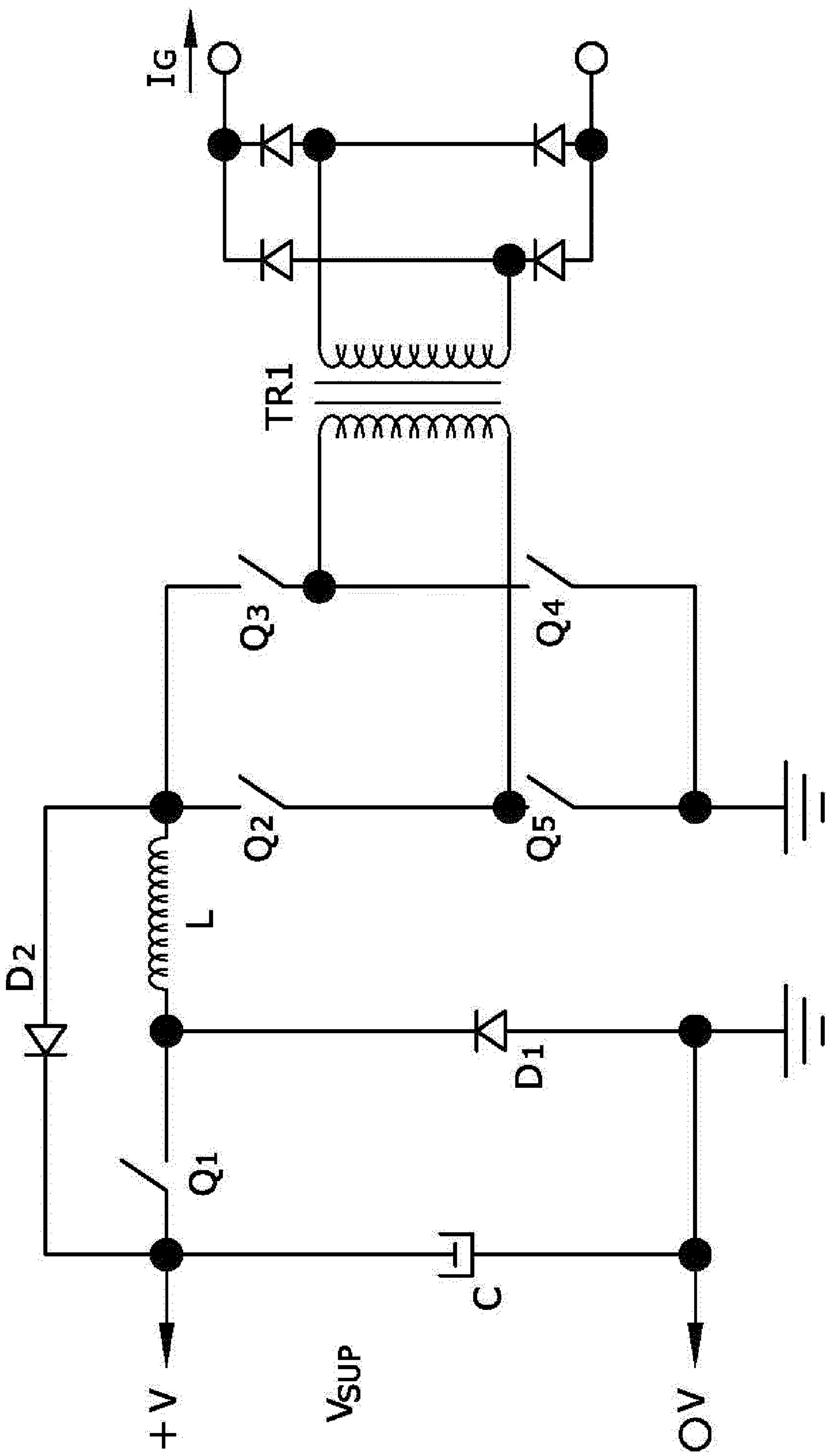

FIG.7

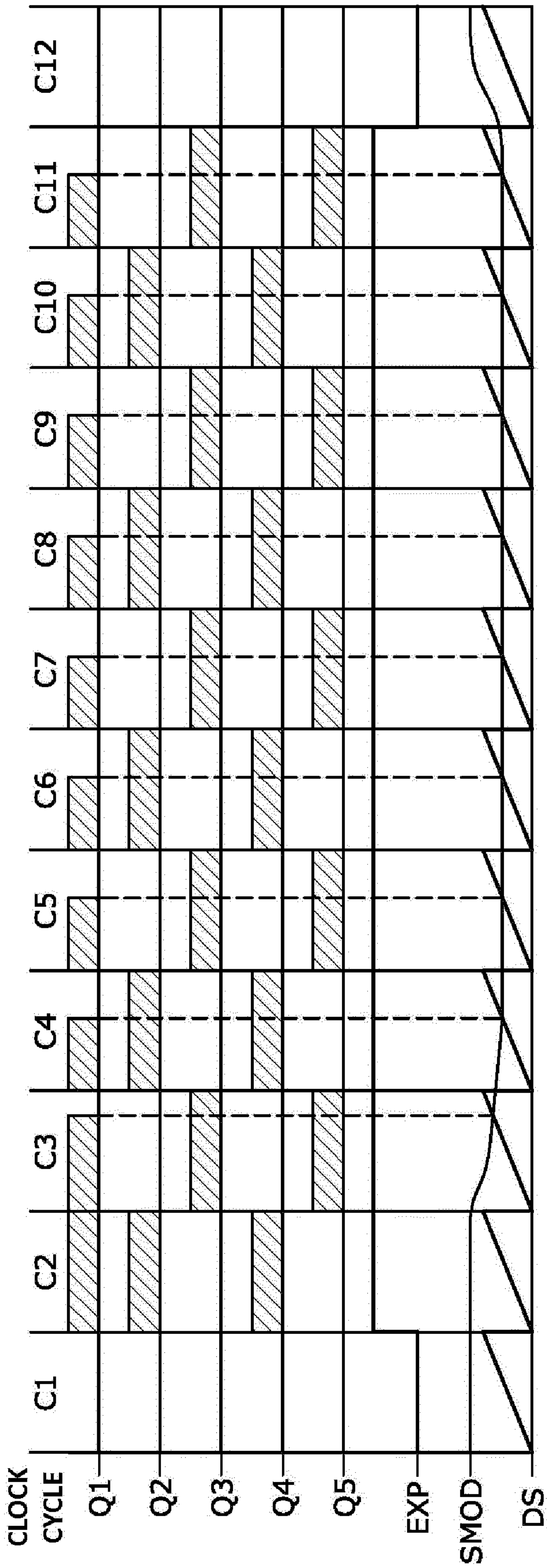
CLOCK CYCLE
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
Q1
Q2
Q3
Q4
Q5
EXP
SMOD
DS

FIG.8

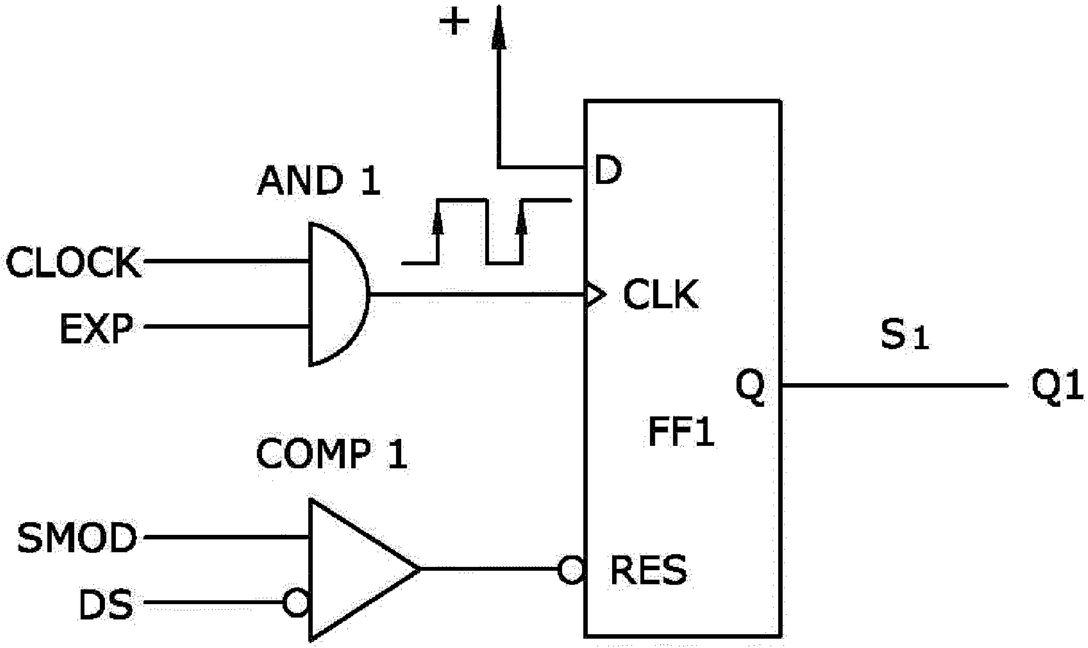

FIG.9

INTERNATIONAL SEARCH REPORT

International application No
PCT/ES2023/070286

A. CLASSIFICATION OF SUBJECT MATTER
INV. H05G1/34
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H05G H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2020/367350 A1 (FRITZ STEFAN [DE] ET AL) 19 November 2020 (2020-11-19) figures 1,8 paragraphs [0165] - [0168], [0183] -----	1-9
X	US 2012/286692 A1 (BECKMANN MORITZ [US] ET AL) 15 November 2012 (2012-11-15) figure 1 paragraphs [0011], [0014] - [0016], [0022], [0026] - [0033] -----	1-9
A	CN 109 068 468 B (GUANGZHOU HAOZHI IMAGE TECH CO LTD) 17 December 2021 (2021-12-17) the whole document -----	1

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 July 2023	08/08/2023

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Giovanardi, Chiara

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/ES2023/070286

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		EP 3677100 A2	08-07-2020
		JP 2020532089 A	05-11-2020
		US 2020367350 A1	19-11-2020
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		DE 102010043561 A1	10-05-2012
		US 2012286692 A1	15-11-2012
CN 109068468 B	17-12-2021	NONE	

Form PCT/ISA/210 (patent family annex) (April 2005)