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(54) X-RAY SCANNING CONTROL SYSTEM

(57) X-ray scanning system comprising a plurality of emitters and at least one receiver arranged opposite each other where only one emitter can be emitting at a certain time and so on until the exposure is performed, wherein each X-ray emitter comprises an anode (A) connected to a single power source (Aps) as well as a grid (G) and a cathode (K), where connected to each cathode there is at least one controller (CLR1) that controls the anode current (IA) and where each controller (CLR1) comprises a comparator (COMP) that has as reference the current demand of the anode (DIA), and the feedback of the comparator (COMP) is the actual anode current (IA). This allows avoiding the calibration of the cathode current demand value, maintaining the precision state in all X-ray emitters and shortening the activation and deactivation transition times.

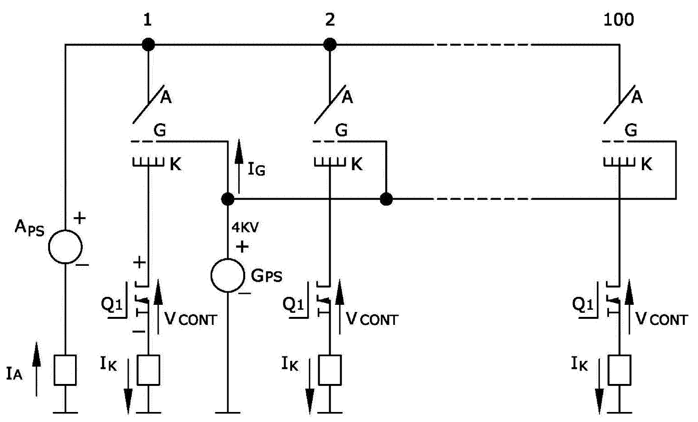


FIG.6

EP 4 426 071 A1

Description

OBJECT OF THE INVENTION

[0001] The present invention, as the title of the invention indicates, relates to an X-ray scanning control system composed of a multiplicity of emitters and at least one X-ray receiver arranged in such a way that an object is placed between the multiplicity of emitters and the at least one receiver to take an image thereof, where only one emitter can be emitting at a given instant in order not to distort the image obtained, so that once the emission by one X-ray emitter has been made and completed, the emission by another emitter begins, and the next emission does not begin until the previous emission is completed or deactivated.

[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 scanning system, and particularly of the activation and deactivation system of each one of the X-ray emitters, in order to increase the scanning speed.

[0003] By means of the control system, 3D scans and/or tomosynthesis or any other type of scan can be performed.

[0004] Therefore, the present invention belongs to the field of control means, and particularly those used by X-ray machines.

BACKGROUND OF THE INVENTION

[0005] X-ray images are one of the most commonly used techniques for visualizing the internal structures of an object and are used in a variety of applications, such as health care, security control, non-destructive testing, etc. One of the known limitations of flat 2D images is that there is structural noise in the image caused by the overlap of several objects (or tissues in the case of medical images) in the X-ray beam. To avoid this effect, several techniques (such as computed tomography and tomosynthesis) are used to create 3D or multi-slice images of the object.

[0006] These methods require repetitive imaging of the object of interest from a variety of angles, typically ranging from 15° (in the case of tomosynthesis) to 360° (in the case of computed tomography). Typically, this variety is achieved by the rotation (or other geometrical shifting) of an X-ray source around the object with a cyclic imaging process repeatedly for subsequent processing and reconstruction of 3D or multi-slice images.

[0007] The invention disclosed herein is based on another principle: the use of multiple X-ray sources, positioned in a predefined way, with a rapid change between them to obtain the predefined number of images and subsequent processing thereof for the reconstruction of 3D or multi-slice images.

[0008] To make this type of 3D or multi-slice images, a very rapid switch between multiple X-ray sources is required, typically in the range of 5 μs to 15 μs. This is usually done using cold-cathode X-ray tubes, which typically comprise an anode, a cathode and an emission control grid.

[0009] In addition, and in a complementary manner, the scanning system faces several problems inherent to the physics of the X-ray emitter:

- The positive bias voltage of the grid with respect to the cathode is several kV (between 0.5kV and 10kV) and must be controlled from the ground level.
- The high voltage power supply that feeds the anode is in the order of 20KV-180 KV, and also has to be referred to the ground to be able to measure the anode current quickly, easily and safely.

[0010] A first solution of the prior art is shown in figures 1 to 5.

[0011] Figure 1 shows a series of X-ray emitter-receiver sets where all of them share a same power supply (Aps) attached to each of the anodes (A) and where all the grids (G) are connected to the ground, while the cathodes (K) each have a current controller and a power supply of several kV; therefore, there are as many current controllers and power supplies (Gps) as there are emitter-receiver sets (1,2,...,100).

[0012] Figure 1 shows that this solution consists of arranging all the grids connected to ground, so that as many current controllers and power supplies as there are pairs of emitter-receivers are needed.

[0013] The way to do this is by directly controlling the cathode current (IK) with a cathode current demand value (DIK), which has been pre-calibrated in a separate process, which in turn will control the anode current (IA), which is the one that produces the X-ray emission.

[0014] Figure 2 shows the block diagram of this prior art embodiment can be seen. Where a cathode current demand value (DIK) obtained by a previous calibration process is used to obtain the desired value of the anode current (IA), said cathode current demand value (DIK) being used as the reference for a controller (CLR1). The output of the controller (CLR1) attacks the gate of a high voltage transistor (Q1) (Mosfet or IGBT), which controls the cathode current (IK), according to the current demand value (DIK) at its input. The controller (CLR1) uses the cathode current (IK) as the feedback value for the transistor gate current control (Q1).

[0015] The controller (CLR1) will preferably be of the integrator type, but could be of another similar type.

[0016] In Figure 3 a very determining factor is represented in detail that must be taken into account. This determining factor is the parasitic capacity between the grid and the cathode (CGK) of the X-ray tube. This capacity has a typical value between 15pF and 30pF; although this would appear to be a practically negligible value, as it has to be charged typically between 0.5kV and 10kV and in a typical time between 5μs to 15μs, it requires a constant load current of 10mA-100mA. Considering that the typical maximum value of the anode current (IA) is 100mA, the value of said parasitic capacity is not negligible at all.

[0017] Figure 3 also shows how a large part of the cathode current (IK) is the current (IC) that is derived to charge the parasitic capacity between the grid and the cathode (CGK), stealing current from the grid (IG) and therefore causing the anode to also emit a lower anode current (IA).

[0018] Figure 4 shows how the controller (CLR1) perfectly controls the cathode current (IK), with a transition time of 5μs, as required by the 3D scanner.

[0019] However, in Figure 5 we see what happens with the anode current (IA) due to the effect of the parasitic capacity between the grid and the cathode (CGK).

[0020] The anode current (IA) rise or activation transition time is slower than expected, because some of the grid current (IG) has been derived to the parasitic capacity between the grid and the cathode (CGK). Until the parasitic capacity between the grid and the cathode (CGK) has been fully charged, the expected anode current (IA) value will not be reached, which makes the activation transition time substantially longer than expected.

[0021] On the other hand, the fall transition time or deactivation time is the expected time of 5-15μs, because it is the response time of the controller (CLR1) with the transistor (Q1), which directly cuts the total current of the circuit, including the anode current (IA).

[0022] This realization inherently presents four important problems:

1. The necessary calibration of the individual current demand value (DIK) for each of the multiple X-ray emitters that make up the 3D scanner.
2. Maintaining the state of accuracy in each and every one of the X-ray emitters, regardless of their degradation due to the mode and time of use.
3. Shortening the activation transition time or rise time of the anode current (IA), due to the parasitic capacity between grid and cathode (CGK).
4. Shortening the transient deactivation time or fall time of the anode current (IA), due to the response time of the controller (CLR1).

[0023] Therefore, the object of the present invention is to develop an X-ray scanning control system which overcomes the problems described above by means of a scanning control system such as the one described below, the essence of which is contained in claim 1.

[0024] Another solution is shown in figure 6 and consists of connecting all the grids to the positive terminal of a single power supply while the negative terminal of said power supply is connected to ground, so there would only be as many independent current controllers as pairs of emitters-receivers, with only a single power supply for all of them.

DESCRIPTION OF THE INVENTION

[0025] The object of the present invention is essentially contained in the independent claim and the different embodiments are contained in the dependent claims.

[0026] The object of the present invention is the control of an X-ray scanning system by means of the direct control of the anode current through the grid control, which comprises a plurality of emitters and at least one receiver arranged opposite each other and where only one emitter can be emitting at a certain moment, that is, once the emission by one X-ray emitter has been made and completed, the emission by another emitter begins, and until said emission ends or is deactivated the next emission will not begin.

[0027] By means of the control system, 3D scans and/or tomosynthesis or any other type of scan can be performed.

[0028] The geometry adopted by the plurality of emitters and the at least one receiver may be any of the known ones, and is in no case limiting, such that the object to be scanned is located between the plurality of emitters and the at least one receiver.

[0029] In short, it is a scanning system with multiple X-ray emitting sources, where the geometry in which the multiple emitting sources are arranged is not limiting.

[0030] For this reason, the emission time of each emitter must be extremely short, in the order of 5μs-15μs. Likewise, the activation and deactivation transition times of the emitters must be as short as possible, always less than 5μs. To do this, the quickest and most efficient way is to use a linear controller of the grid current, which in turn is controlled and corrected by the real-time measurement of the anode current.

[0031] The solution proposed in the present invention is to connect all the grids to the positive terminal of a single power supply while the negative terminal of said power supply is grounded, so there would be as many independent current controllers as there are pairs of transmitters-receivers, but only a single power supply.

[0032] Furthermore, the main idea of the invention is to directly control the anode current instead of the cathode current to avoid the deleterious effects described above.

[0033] To this end, the control system has a controller that has as reference the current demand of the anode, which produces the emission of X-rays, while the feedback of the controller is the actual current of the anode. This control avoids the need to calibrate the current demand of the cathode based on the current of the anode.

[0034] The controller avoids the need to recalibrate the emitters due to degradation thereof due to the type and time of use, by keeping each and every one of the emitters in perfect state of precision at all times due to the closed loop control.

[0035] The controller is preferably of the PID type, but another type of control could be applied.

[0036] The integral part of the controller corrects errors and adjusts the accuracy of the anode current (IA), while the differential part makes the charge of the parasitic capacity between the grid and the cathode faster, considerably improving the activation transition time or rise time.

[0037] Additionally, in order to improve the speed of the activation and deactivation times, the deactivation times or fall times are reduced by a signal applied to a buffer causing the gate of the control transistor to be short-circuited, without having to wait for the response of the CLR1 controller.

[0038] Moreover, complementarily and additionally the CLR1 controller may apply an overcurrent during the rise time of the cathode current, to rapidly charge the parasitic capacity between the grid and the cathode. That overcurrent ceases when the CGK capacitor is fully charged and in steady state.

[0039] The means described above achieves:

- Avoiding the necessary calibration of the individual cathode current demand value (DIK) for each of the multiple X-ray emitters.
- Maintaining the state of accuracy in each and every X-ray emitter.
- Shortening the activation transition time or rise time.
- Shortening the deactivation transition time and thus considerably reducing the scanning time on the order of 25% relative to the time required for a current controller without means of shortening the activation and deactivation times.

[0040] 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.

[0041] 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

[0042] To complement the present description, and to help to better understand the characteristics of the invention according to a preferred practical embodiment thereof, the said description is accompanied, as an integral part thereof, by a set of drawings where the following has been represented in an illustrative and non-limiting manner:

Figure 1 shows an embodiment of the prior art in which the grid is grounded, requiring as many power supplies and current controllers as there are emitter-receiver pairs.

Figure 2 shows the block diagram of the cathode current control (IK) of the prior art embodiment shown in figure 1.

Figure 3 shows in detail the parasitic capacity between the grid and the cathode (CGK) of the X-ray tube.

Figure 4 shows the graph of the cathode current (IK) and how the controller (CLR1), perfectly controls the cathode current (IK).

Figure 5 shows the graph of the anode current (IA) with respect to time and how the time required to reach a desired value is increased due to the effect of the parasitic capacity between the grid and the cathode (CGK).

Figure 6 shows the proposed embodiment according to the invention in which all the grids are connected to a single power supply.

Figure 7 shows the block diagram of the control used in the embodiment object of the invention which consists of directly controlling the anode current (IA).

Figure 8 shows in detail the deactivation of the exposure, by means of an EXP signal.

Figure 9 shows a graph of the cathode current (IK) with respect to time and how the CLR1 controller applies an overcurrent during the rise time (t1) of the cathode current (IK), to quickly charge the parasitic capacity between the grid and the cathode (CGK).

Figure 10 shows a graph of the anode current (IA) with respect to time where the reduced activation time (t1) and deactivation time (t3) achieved can be seen, comparing figures 5 and 10.

PREFERRED EMBODIMENT OF THE INVENTION

[0043] In view of the figures, a preferred embodiment of the proposed invention is described below.

[0044] Figures 1 to 5 show an embodiment of the prior art explained in the background section of the invention.

[0045] Figure 6 shows the embodiment object of the invention, where all the grids (G) are connected to the positive terminal of a single power supply (Gps), while the negative terminal of said power supply (Gps) is connected to ground, requiring as many current controllers as there are X-ray beam emitter-receiver pairs, where said current controllers comprise at least one transistor (Q1) and a controller (CLR1) where the anode current (IA) is controlled instead of the cathode current (IK), to avoid the very negative effects described above.

[0046] Figure 7 shows a possible embodiment of the control of the anode current (IA), in which the controller

(CLR1) comprises a comparator (COMP) that has as reference the current demand of the anode (DIA), which is the one that produces the emission of the X-rays, while the feedback of the comparator (COMP) is the actual anode current (IA), further comprising a control (G(s)) where the output of said controller (CLR1) can be applied directly to the gate of the transistor (Q1) that controls the cathode current (IK).

[0047] The controller (CLR1) avoids the need to calibrate the cathode current demand (DIK) based on the anode current (IA).

[0048] The presence of the controller (CLR1) avoids having to recalibrate the emitters due to their degradation due to the type and time of use, because it always keeps each and every one of the emitters in perfect precision state due to the closed control loop.

[0049] The control (G(s) of the controller (CLR1) may be of the PID type, but another type of control could be applied.

[0050] The integral part of the controller corrects errors and adjusts the accuracy of the anode current (IA), while the differential part makes the charging of the parasitic capacity between the grid and the cathode (CGK) faster, considerably improving the activation transition time or rise time.

[0051] Additionally and in a complementary manner, between the output of the controller (CLR1) and the input gate of the transistor (Q1) a buffer can be provided in charge of delivering the necessary current to the transistor gate (Q1), to improve its response time in both the activation and in the deactivation of the X-ray exposure.

[0052] Figure 8 shows the buffer in detail, which comprises a signal (EXP). The controller (CLR1) has a response time similar to the activation time, i.e. 5μs. However, this time can be drastically reduced to the nanosecond range short-circuiting the Q1 gate by means of the buffer when the signal (EXP) is turned off without needing to wait for the response of the CLR1 controller.

[0053] Figure 9 shows how the controller (CLR1) can apply an overcurrent during the rise time (t1) of the cathode current (IK), to quickly charge the parasitic capacity between the grid and the cathode (CGK). That overcurrent ceases when the parasitic capacity between the grid and the cathode (CGK) is fully charged and in a steady state, which is represented by the stabilization time (t2).

[0054] Figure 10 shows that the anode current (IA) rises optimally during the rise time (t1), until it stabilizes at its nominal value during the stabilization time (t2).

[0055] During the stabilization time (t2), the cathode (IK) and anode (IA) current remain stable.

[0056] During a fall or deactivation time (t3) the control system receives the end of exposure end signal, wherein the transistor gate (Q1) is short-circuited by the buffer and its current (including IA) is optimally extinguished in nanoseconds.

[0057] 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. X-ray scanning control system **characterized in that** it comprises a multiplicity of emitters and at least one receiver arranged opposite each other, where only one emitter can be emitting at a certain time, where once the emission by one X-ray emitter is performed and finishes the emission by another emitter begins and until such emission ends or is deactivated, the next emission will not begin, where each X-ray emitter comprises an anode (A) connected to a single power supply (Aps), a cathode (K) and a grid (G), where all the grids (G) are connected to the positive terminal of a single power supply (Gps), while the negative terminal of said power supply (Gps) is grounded, in addition in each cathode (K) there is at least one controller (CLR1) that controls the anode current (IA) and where each controller (CLR1) comprises a comparator (COMP) that has as reference the current demand of the anode (DIA), and the feedback of the comparator (COMP) is the actual anode current (IA), further comprising a control (G(s)) where the output of said controller (CLR1) is connected on the gate of the transistor (Q1) that controls the cathode current (IK).

2. X-ray scanning control system according to claim 1, **characterized in that** between the output of the controller (CLR1) and the input gate of the transistor (Q1) a buffer is available in charge of delivering the necessary current to the gate of the transistor (Q1), to improve its response time both in the activation and deactivation of the X-ray exposure, where said buffer comprises a signal (EXP)

3. 3D X-ray scanning control system according to claim 1, **characterized in that** the controller (CLR1) applies an overcurrent during a rise time (t1) of the cathode current (IK), to quickly charge a parasitic capacity between the grid and the cathode (CGK), where said overcurrent ceases, when the parasitic capacity between the grid and the cathode (CGK) is fully charged and in a steady state.

4. X-ray scanning control system according to any of the preceding claims, **characterized in that** the control (G(s)) of the controller (CLR1) is of the PID type.

Amended claims under Art. 19.1 PCT

1. X-ray scanning control system **characterized in**

that it comprises a multiplicity of emitters and at least one receiver arranged opposite each other, where only one emitter can be emitting at a certain time, where once the emission by one X-ray emitter is performed and finishes the emission by another emitter begins and until such emission ends or is deactivated, the next emission will not begin, where each X-ray emitter comprises an anode (A) connected to a first single power supply (Aps), a cathode (K) and a grid (G), where all the grids (G) are connected to the positive terminal of a second single power supply (Gps), while the negative terminal of said power supply (Gps) is grounded, in addition in each cathode (K) there is at least one controller (CLR1) that controls the anode current (IA) and where each controller (CLR1) comprises a comparator (COMP) that has as reference the current demand of the anode (DIA), and the feedback of the comparator (COMP) is the actual anode current (IA), further comprising a control (G(s)) where the output of said controller (CLR1) is connected on the gate of the transistor (Q1) that controls the cathode current (IK).

2. X-ray scanning control system according to claim 1, **characterized in that** between the output of the controller (CLR1) and the input gate of the transistor (Q1) a buffer is available in charge of delivering the necessary current to the gate of the transistor (Q1), both in the activation and deactivation of the X-ray exposure, where said buffer comprises a deactivation of the exposure signal (EXP)

3. X-ray scanning control system according to claim 1, **characterized in that** the controller (CLR1) applies an overcurrent during a rise time (t1) of the cathode current (IK), to quickly charge a parasitic capacity between the grid and the cathode (CGK), where said overcurrent ceases, when the parasitic capacity between the grid and the cathode (CGK) is fully charged and in a steady state.

4. X-ray scanning control system according to any of the preceding claims, **characterized in that** the control (G(s)) of the controller (CLR1) is of the PID type.

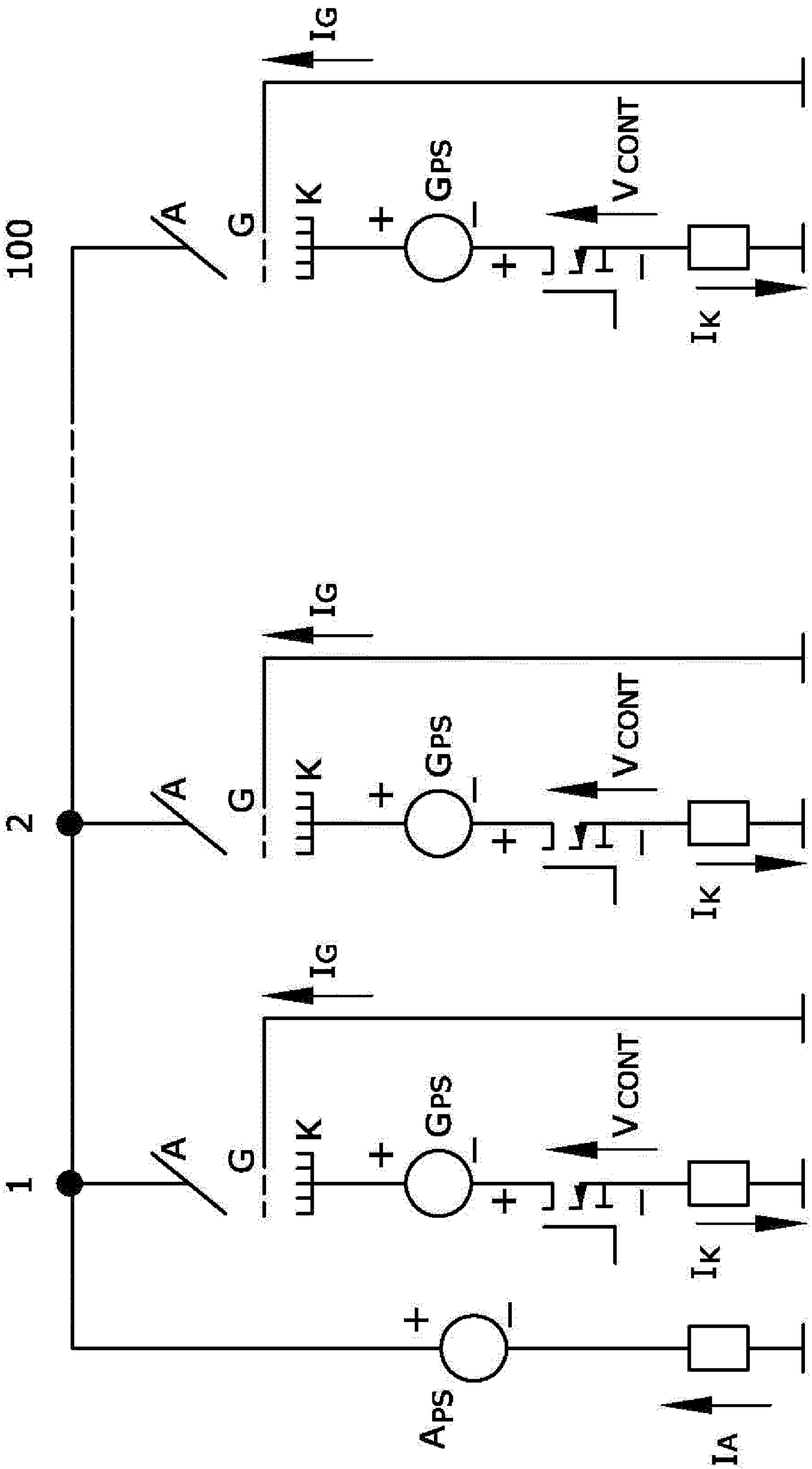


FIG.1

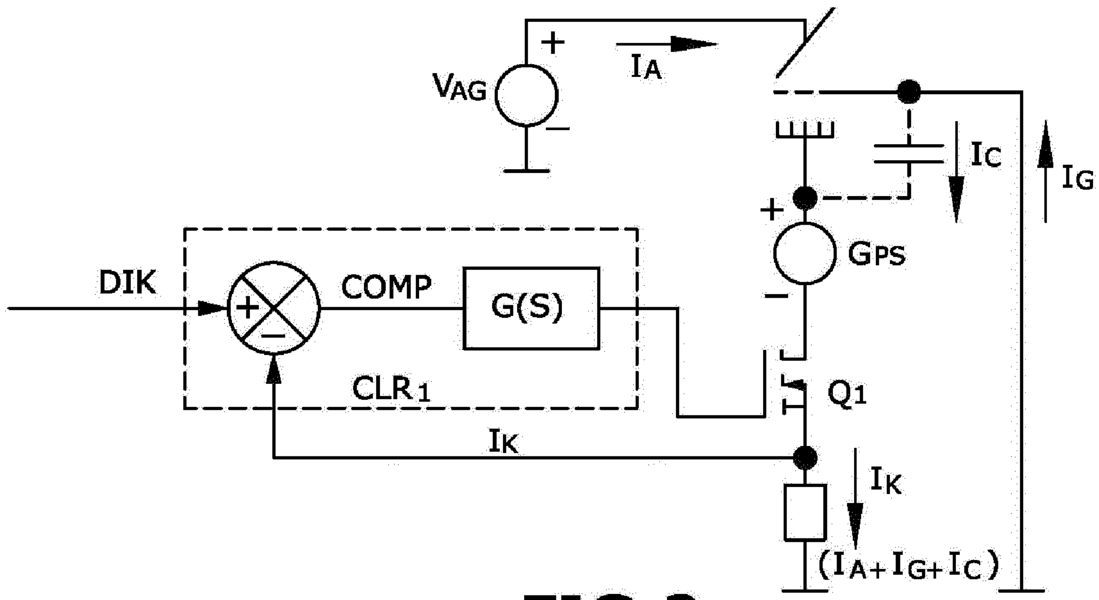

VAG
+
−
IA
IC
IG
+
GPS
−
DIK
COMP
G(S)
CLR1
Q1
IK
IK
(IA+IG+IC)

FIG.2

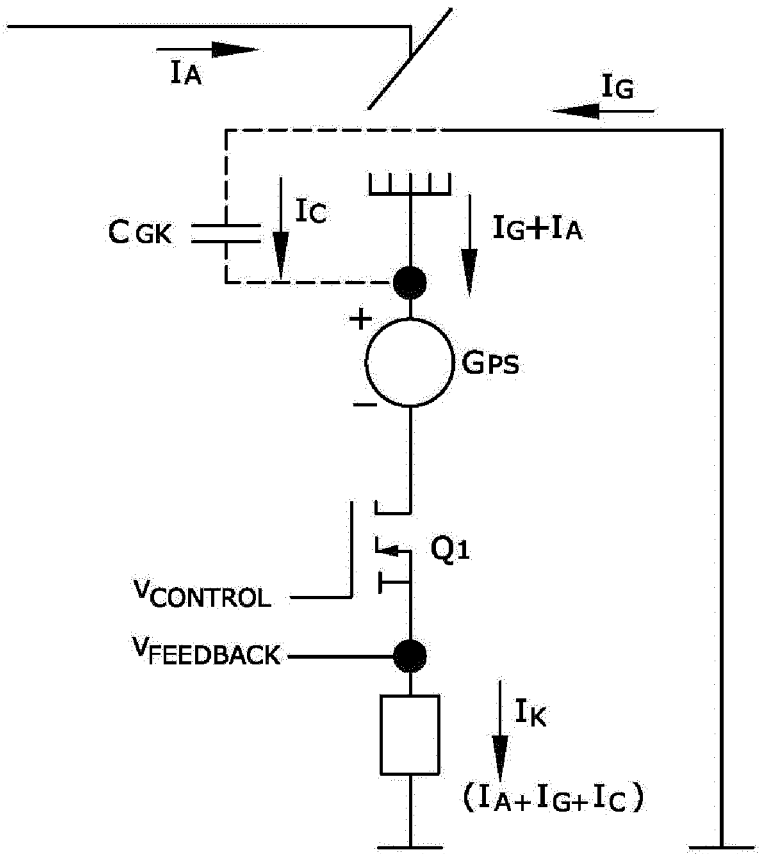

IA
IG
CGK
IC
IG+IA
+
GPS
−
Q1
VCONTROL
VFEEDBACK
IK
(IA+IG+IC)

FIG.3

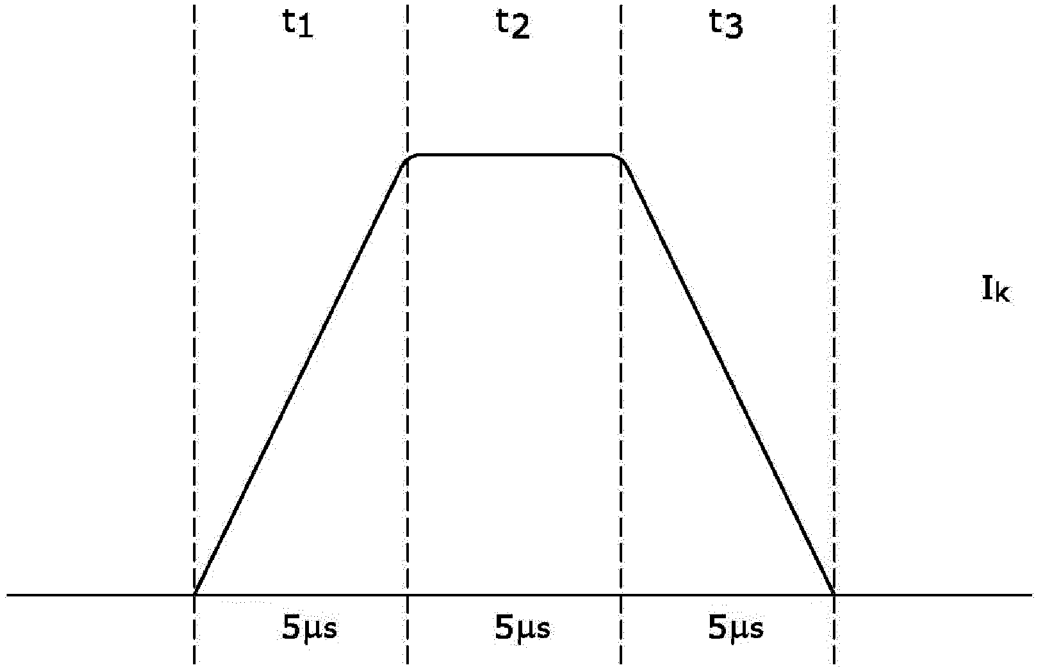


FIG.4

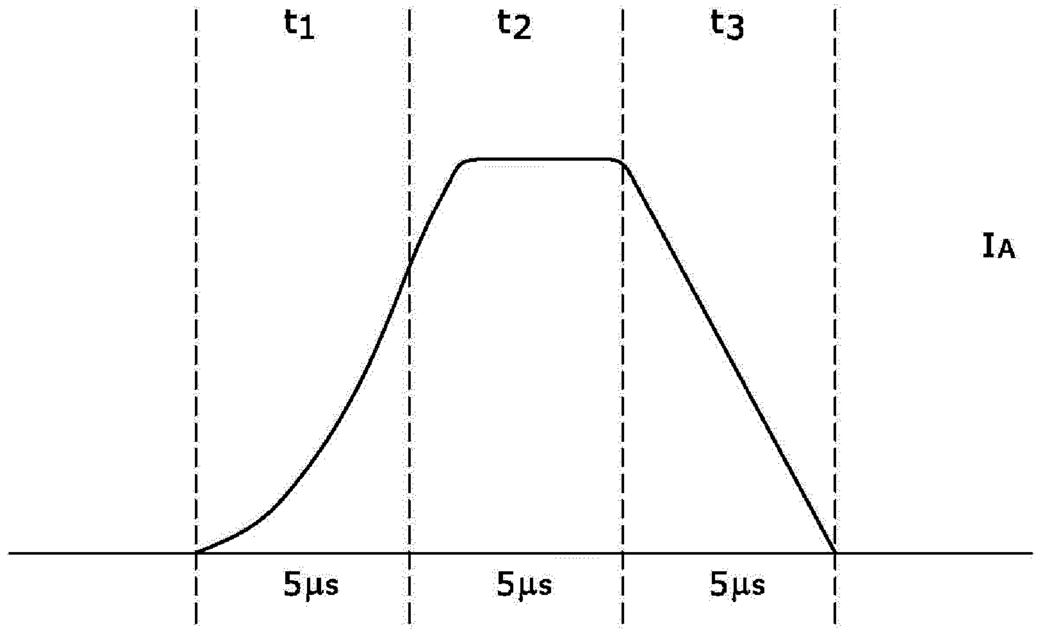


FIG.5

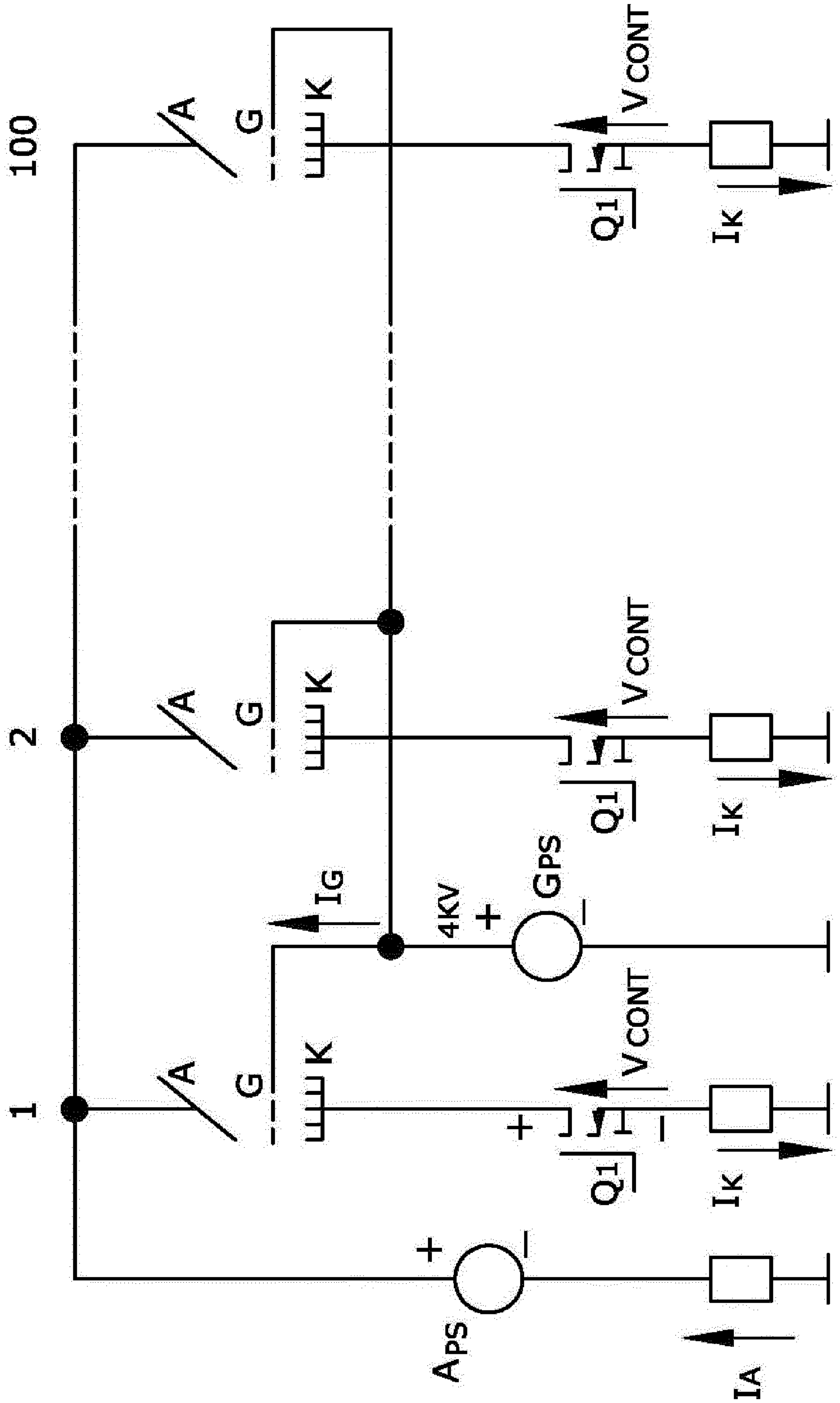
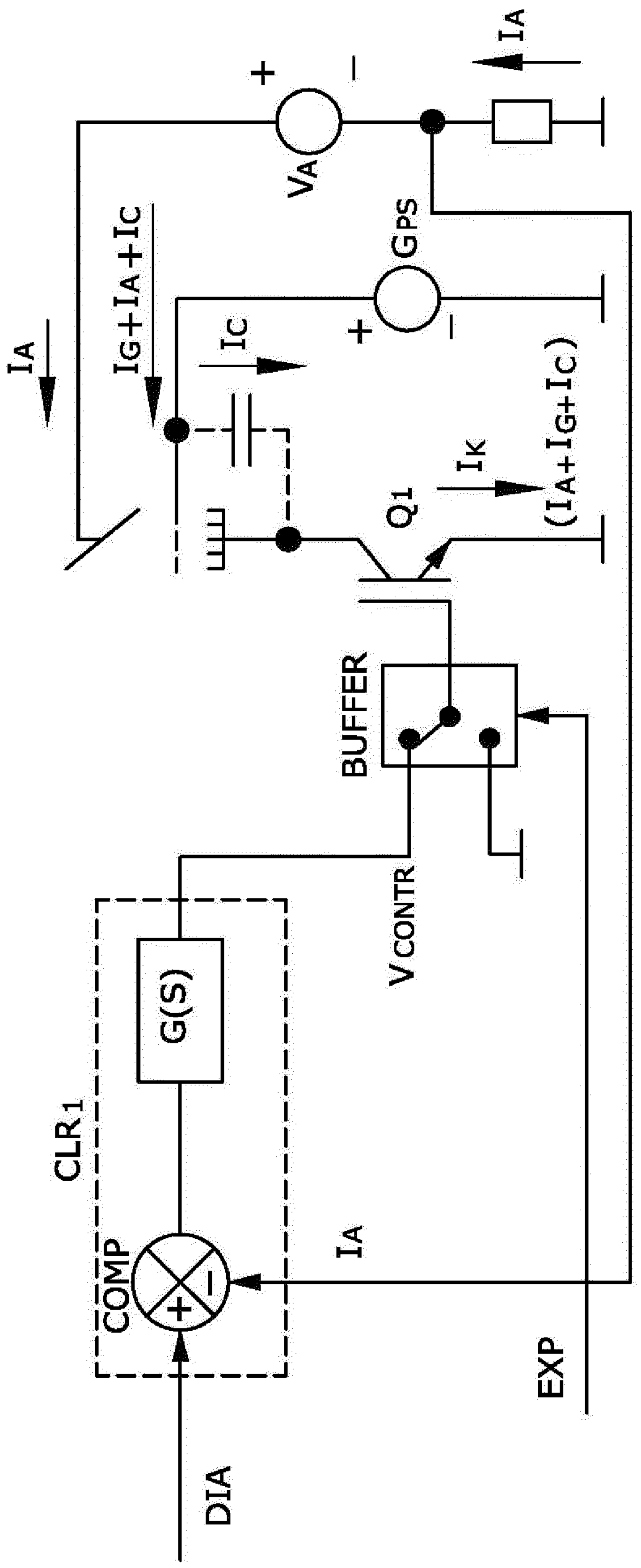


FIG.6



IA
VA
GPS
IG+IA+IC
IC
IK
Q1
(IA+IG+IC)
BUFFER
VCONTR
G(S)
CLR1
COMP
DIA
EXP

FIG.7

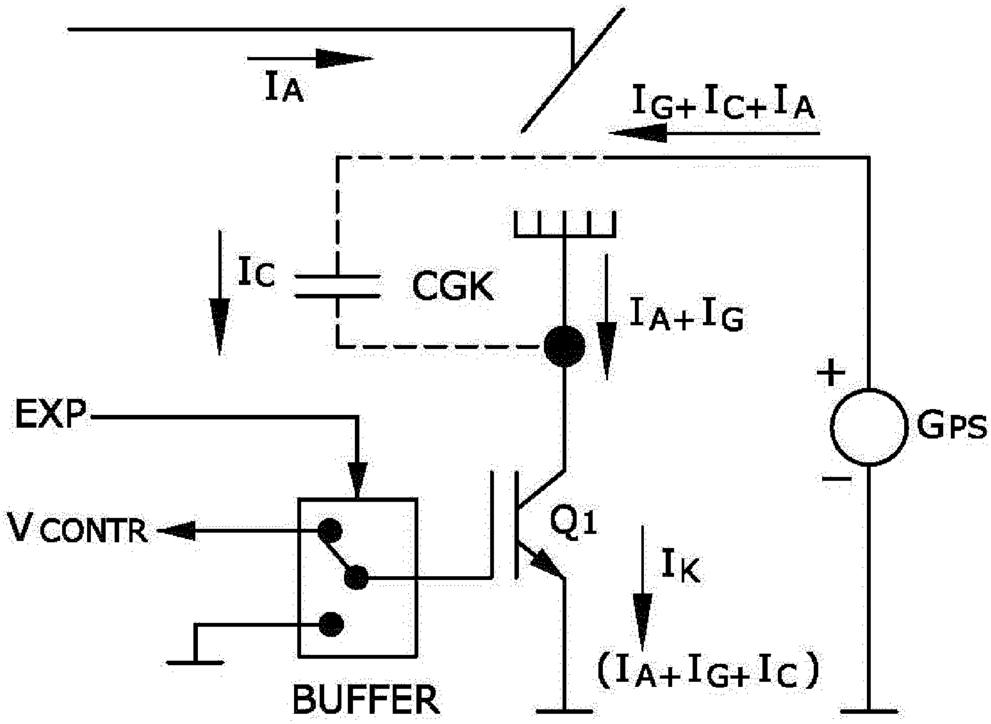


FIG.8

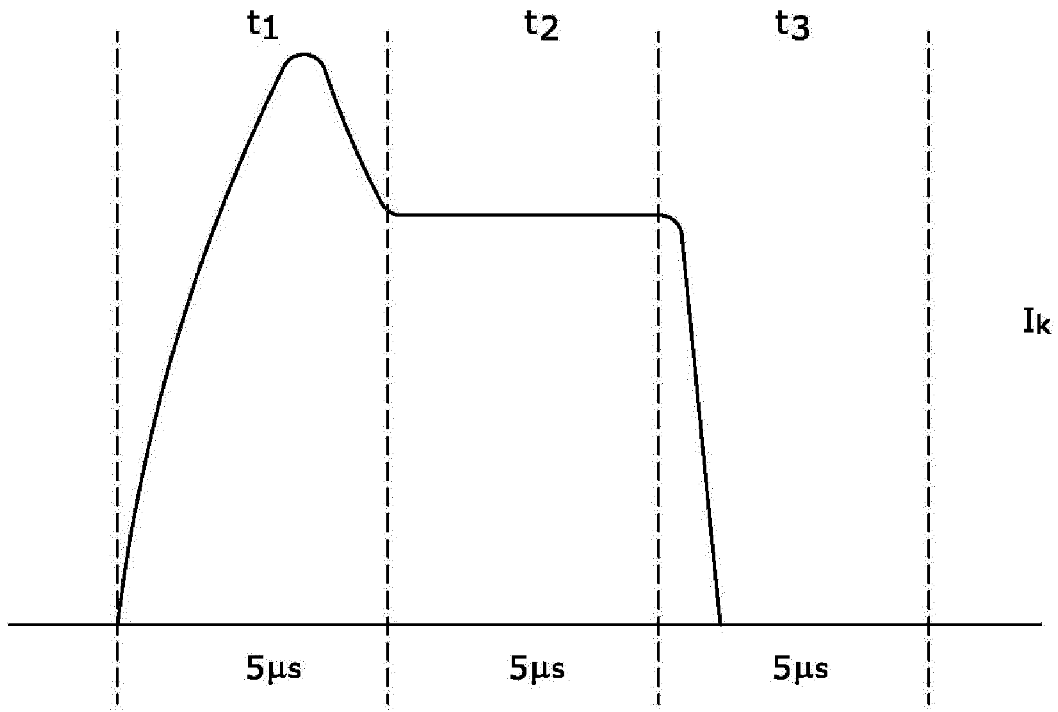


FIG.9

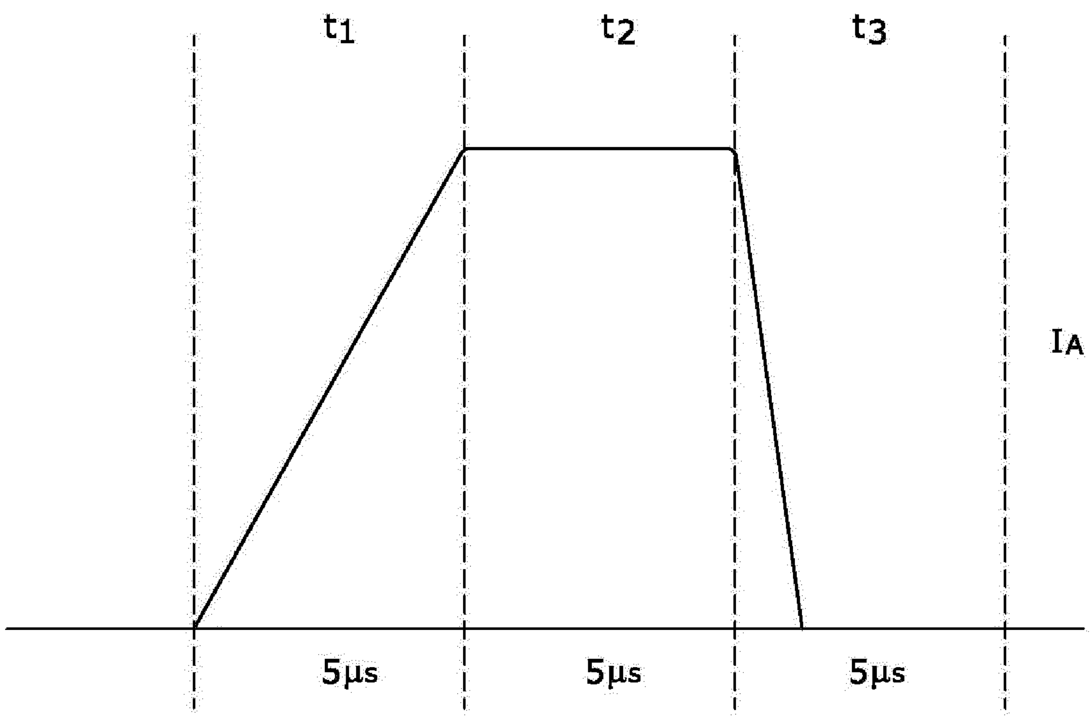


FIG.10

INTERNATIONAL SEARCH REPORT

International application No
PCT/ES2022/070576

A. CLASSIFICATION OF SUBJECT MATTER
INV. H05G1/08 H05G1/70
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

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 2009/022264 A1 (ZHOU OTTO Z [US] ET AL) 22 January 2009 (2009-01-22)	1,3,4
Y	figures 1,11b,12,15 paragraphs [0032], [0033], [0041], [0046], [0052] paragraphs [0069] - [0074] paragraphs [0080] - [0082] -----	2
Y	US 2018/184990 A1 (SHIN SEUNGHUN [KR] ET AL) 5 July 2018 (2018-07-05)	2
A	figures 3,7,8 paragraphs [0054] - [0056], [0059], [0061] paragraphs [0070] - [0075] -----	1
X	US 9 390 880 B2 (KOREA ELECTRONICS TELECOMM [KR]) 12 July 2016 (2016-07-12) the whole document -----	1,3,4
	-/--	

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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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
24 April 2023	09/05/2023

Name and mailing address of the ISA/	Authorized officer
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2

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