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(54) **VOLTAGE STABILIZED X-RAY POWER SUPPLY**

(57) Disclosed is a medical instrument (100, 200, 300, 400, 500, 700, 900) comprising an X-ray power supply (102, 102'). The X-ray power supply is configured to provide an output voltage that repeatedly switches between a first voltage and a second voltage. The X-ray power supply is configured for powering an X-ray tube (106) with the output voltage to produce X-rays, wherein switching between the first voltage and the second voltage generates an oscillating impulse voltage superimposed on output voltage. The oscillating impulse voltage has a ripple frequency. The medical instrument further comprises at least one voltage stabilizer circuit (104, 104', 104") for stabilizing the first voltage and the second voltage. The at least one voltage stabilizer circuit comprises an oscillator (110) and a transformer (112) configured for coupling to the output voltage. The oscillator is configured for oscillating at a voltage stabilizer frequency that matches the ripple frequency. The transformer comprises a magnetic core (112) configured for limiting coupling of the oscillating impulse voltage to the at least one voltage stabilizer circuit.

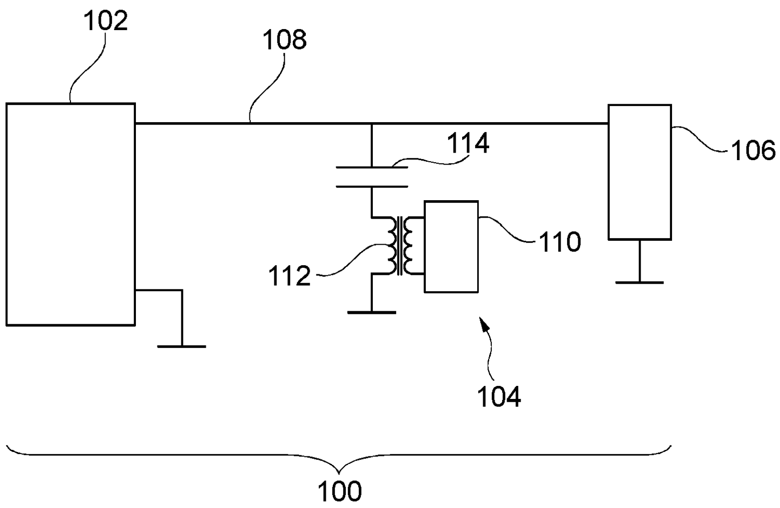

Fig. 1

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Description

TECHNICAL FIELD

[0001] The invention relates to Computed Tomography, in particular to multi-spectral tomography.

BACKGROUND OF THE INVENTION

[0002] In Computed Tomography X-ray measurements are taken from a variety of angles and used to reconstruct a tomographic image. The attenuation of the X-rays by different body structures and tissue types is dependent upon the energy of the X-rays. A recent trend is to obtain additional information by acquiring multiple measurements using X-ray beams with different energy spectra. This is typically achieved by varying the tube voltage of the X-ray tube.

[0003] United States patent application publication US 2013/0170608 discloses techniques and/or systems for reducing a voltage ripple in an electric signal. In this way, in radiographic imaging modalities, for example, undesired fluctuations in an output of a radiation source (e.g., undesirable fluctuations in an energy level of emitted photons) may be reduced. To reduce the voltage ripple, a (ripple reducing) electric signal is generated that comprises properties substantially similar to the voltage ripple, but opposite in phase. The (ripple reducing) electric signal is then combined with the original electric signal to generate a combined electric signal with a voltage ripple that is reduced relative to the voltage ripple of the electric signal as initially generated.

SUMMARY OF THE INVENTION

[0004] The invention provides for a medical instrument and a method in the independent claims. Embodiments are given in the dependent claims.

[0005] When performing multi-spectral computed tomography, the voltage applied between the anode and the cathode is varied or switched to produce X-ray beams with different energy spectra. Between the anode and the cathode X-ray tube can be effectively be modeled as a capacitance. This means that as the tube voltage is switched between a first voltage and a second voltage there is a ringing effect or an oscillating impulse voltage that has a ripple voltage. There is not only a ripple voltage when switching, but the X-ray power supply regularly produces a ripple voltage during constant energy operation. This ripple voltage is typically not a problem when performing non-spectral imaging, but spectral CT may be more sensitive to this ripple voltage, depending upon the details of the implementation of the reconstruction and the availability of supplemental measurements for compensating this effect. This oscillating impulse voltage is therefore undesirable, because it causes the spectra of X-rays emitted from the X-ray tube to vary.

[0006] Herein references are made to the output voltage of an X-ray power supply. It is understood that the output voltage of the X-ray power supply is configured to supply the tube voltage to an X-ray tube. To counteract the oscillating impulse voltage, a voltage stabilizer circuit can be coupled to the output voltage of the X-ray power supply. A difficulty is that the oscillating impulse voltage initially has a strong voltage variation and then decreases in strength. The initial impulse can be damaging to voltage stabilizer circuit, especially if a fault condition in the X-ray tube occurs like an arc discharge. To protect the voltage stabilizer circuit the voltage stabilizer circuit can be coupled to the output voltage using a transformer with a magnetic core that saturates to limit the coupling of the oscillating impulse voltage. This solution is cost effective and may enable the X-ray power supply to switch between the first voltage and the second voltage for an extended duration or continuously.

[0007] In one aspect the invention provides for a medical instrument that comprises an X-ray power supply. The X-ray power supply is configured to provide an output voltage that repeatedly switches between a first voltage and a second voltage. The X-ray power supply is configured for powering an X-ray tube with the output voltage in order to produce X-rays. Switching between the first voltage and the second voltage generates an oscillating impulse voltage superimposed on the output voltage. The oscillating input voltage has a ripple frequency.

[0008] The medical instrument further comprises at least one voltage stabilizer circuit for stabilizing the first voltage and the second voltage. The at least one voltage stabilizer circuit comprises an oscillator and a transformer. The transformer is configured for coupling the at least one voltage stabilizer circuit to the output voltage. The oscillator is configured for oscillating at a voltage stabilizer frequency. The voltage stabilizer frequency matches the ripple frequency. The transformer comprises a magnetic core configured for limiting coupling of the oscillating impulse voltage to the at least one voltage stabilizer circuit.

[0009] The use of the magnetic core in the transformer may be beneficial because saturation of the transformer core will naturally limit large impulses in the voltage or current coupling into the voltage stabilizer circuit. In such X-ray power supplies the voltage oscillates rapidly between the first voltage and the second voltage. The magnetic core prevents the very large voltages from being coupled into the oscillator. This may enable a simple circuit to be used for the at least one voltage stabilizer circuit.

[0010] The X-ray power supply may, in some cases, produce a ripple voltage that contains more than one spectral component. In this case the oscillator may be configured to oscillate such that the spectral output of the oscillator matches that of the ripple voltage.

[0011] The at least one voltage stabilizer circuit may in some examples further comprise a voltage sensor and a voltage controller that is configured to control the output of the oscillator such that the voltage output of the at least one voltage stabilizer circuit has an opposite amplitude to the oscillating impulse voltage. In this case the voltage controller controls the oscillator so that it cancels the ripple voltage.

[0012] In another embodiment the medical instrument further comprises a computer tomography system. The computer tomography system is configured for acquiring first CT data when the X-ray tube is supplied with the first voltage and for acquiring second CT data when the X-ray tube is supplied with the second voltage. By varying the voltage applied to the X-ray tube the spectra of the X-ray as emitted by the X-ray tube also vary. The first CT data and the second CT data are then acquired with a different spectrum of X-rays generated by the X-ray tube. This then may provide more detailed data about the structure of the subj ect.

[0013] In another embodiment the medical instrument further comprises a processor for controlling the computer tomography system. The medical instrument further comprises a memory for storing machine-executable instructions. Execution of the machine-executable instructions causes the processor to reconstruct a multispectral CT image using the first CT data and the second CT data. This embodiment may be beneficial because the voltage stabilizer circuit may provide for a better separation of the X-ray spectral data into the first CT data and the second CT data.

[0014] In another embodiment the at least one voltage stabilizer circuit comprises an H-bridge amplifier. An H-bridge circuit as used herein encompasses a circuit that uses four switches to reverse the polarity of a power supply which is connected. The H-bridge amplifier may then provide an inexpensive means of providing the oscillator.

[0015] In another embodiment the at least one voltage stabilizer circuit comprises a half H-bridge amplifier. A half H-bridge amplifier is similar to an H-bridge amplifier but in this case only two switches are needed. Instead of reversing the polarity of the amplifier connected the half H-bridge amplifier is connected using the same polarity but only for a portion of the wave cycle.

[0016] In another embodiment the X-ray power supply is unipolar power supply with a single output to provide the output voltage. The at least one voltage stabilizer circuit is a single voltage stabilizer circuit. The voltage stabilizer circuit is capacitively coupled to the single output. For example, the transformer of the voltage stabilizer circuit may be coupled to the single output via a capacitor.

[0017] In another embodiment the X-ray power supply is a bipolar power supply with a first output and a second output to provide the output voltage. The at least one voltage stabilizer circuit is a first voltage stabilizer and a second voltage stabilizer circuit. The first voltage stabilizer is capacitively coupled to the first output. The second voltage stabilizer is capacitively coupled to the second output.

[0018] In another embodiment the medical instrument comprises a voltage controller configured for controlling the amplitude and the phase of the oscillator of each of the at least one voltage stabilizer. For example, the voltage controller may control the oscillator such that it amplitude of the voltage produced is the opposite of the amplitude of the ripple voltage. The ripple voltage will be cancelled then. Equivalently the voltage controller may also be used for controlling the duty cycle if the voltage stabilizer circuit comprises H-bridge or half H-bridge amplifiers. The voltage controller comprises a voltage sensor configured for measuring the oscillating input impulse voltage. The voltage sensor may be implemented in different ways but a very typical means is to use a capacitive voltage divider. The voltage controller is configured for adjusting the amplitude of the at least one voltage stabilizer to minimize the oscillating input voltage. This embodiment may be beneficial because it may provide for a better stabilization of the first voltage and the second voltage.

[0019] In another embodiment the magnetic core is a nanomagnetic core.

[0020] In another embodiment the magnetic core is an amorphous alloy core.

[0021] In another embodiment the magnetic core is a permalloy core.

[0022] In another embodiment the magnetic core has a relative permeability greater than 5,000. Having a relative permeability greater than 5,000 may be beneficial because this may provide for a transformer core which saturates early enough to protect the oscillator circuits from the oscillating input impulse voltage.

[0023] In another embodiment the magnetic core has a relative permeability greater than 20,000. This embodiment may be even better at protecting the oscillator circuits than when the relative permeability is greater than 5,000.

[0024] In another embodiment the ripple frequency is between 30 kHz and 200 kHz.

[0025] In another embodiment the ripple frequency is between 50 kHz and 150 kHz.

[0026] In another embodiment the ripple frequency is between 75 kHz and 100 kHz.

[0027] In another embodiment the first voltage is between 50 kV and 105 kV. The second voltage is between 110 kV and 200 kV.

[0028] In another embodiment the first voltage is between 70 kV and 90 kV. The second voltage is between 120 kV and 160 kV. The voltage range between 70 and 90 kV for the first voltage and the second voltage being between 120 and 160 kV may be beneficial because it may provide for a good separation between the X-ray spectral data acquired at the first voltage and the second voltage.

[0029] In another embodiment the medical instrument further comprises a tube arc protection circuit in parallel with the transformer. This may be beneficial because it may provide for an additional means of protecting the voltage stabilizer circuits. For example, diodes may be used in case the voltage exceeds a value which might damage the at least one voltage stabilizer circuit.

[0030] In another embodiment the tube arc protection circuit is a rectifier circuit. The use of a rectifier circuit may be beneficial because it provides a cost-effective circuit which may provide excellent ability to protect the at least one voltage stabilizer circuit.

[0031] In another embodiment the medical instrument comprises an X-ray power supply high voltage isolation tank. The amplifier is within the X-ray power supply high voltage isolation tank. The at least one voltage stabilizer circuit is within the X-ray power supply voltage isolation tank. This embodiment may be beneficial because the at least one voltage stabilizer circuit may for example be powered by the power for the X-ray power supply. This may also provide an effective means of upgrading an existing system. The X-ray power supply and the additional functionality of the at least one voltage stabilizer circuit can be added at the same time.

[0032] In another embodiment the medical instrument comprises an X-ray tube high voltage isolation tank. The X-ray tube high voltage isolation tank is configured to receive the X-ray tube. The at least one voltage stabilizer circuit is within the X-ray high voltage isolation tank. This embodiment may be beneficial because the voltage stabilizer circuits are provided directly at the point where the X-ray tube is.

[0033] In another embodiment the at least one voltage stabilizer circuit comprises an energy extraction circuit configured for powering the at least one voltage stabilizer circuit from changes between the first voltage and the second voltage. This embodiment is beneficial because the voltage stabilizer circuits can be added to the medical instrument without any additional power supply being needed. This for example may be particularly beneficial when the at least one voltage stabilizer circuit are added within the X-ray tube high voltage isolation tank.

[0034] In another aspect the invention provides for a method of operating a medical instrument. The medical instrument comprises an X-ray power supply. The X-ray power supply is configured to provide an output voltage that repeatedly switches between a first voltage and a second voltage. The X-ray power supply is configured for powering an X-ray tube with the output voltage to produce X-rays. Switching between the first voltage and the second voltage generates an oscillating input impulse voltage superimposed on the output voltage. The oscillating input voltage has a ripple frequency.

[0035] The medical instrument further comprises at least one voltage stabilizer circuit for stabilizing the first voltage and the second voltage. The at least one voltage stabilizer circuit comprises an oscillator and a transformer. The transformer is configured for coupling the at least one voltage stabilizer circuit to the output voltage. The oscillator is configured for oscillating at a voltage stabilizer frequency. The voltage stabilizer frequency matches the ripple frequency. The transformer comprises a magnetic core configured for eliminating coupling of oscillating impulse voltage to the at least one voltage stabilizer circuit.

[0036] The method comprises powering the X-ray tube by using the X-ray power supply to supply the output voltage. The method further comprises reducing the oscillating impulse voltage using the at least one stabilizer circuit.

[0037] It is understood that one or more of the aforementioned embodiments of the invention may be combined as long as the combined embodiments are not mutually exclusive.

[0038] As will be appreciated by one skilled in the art, aspects of the present invention may be embodied as an apparatus, method or computer program product. Accordingly, aspects of the present invention may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, microcode, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a "circuit," "module" or "system." Furthermore, aspects of the present invention may take the form of a computer program product embodied in one or more computer readable medium(s) having computer executable code embodied thereon.

[0039] Any combination of one or more computer readable medium(s) may be utilized. The computer readable medium may be a computer readable signal medium or a computer readable storage medium. A 'computer-readable storage medium' as used herein encompasses any tangible storage medium which may store instructions which are executable by a processor of a computing device. The computer-readable storage medium may be referred to as a computer-readable non-transitory storage medium. The computer-readable storage medium may also be referred to as a tangible computer readable medium. In some embodiments, a computer-readable storage medium may also be able to store data which is able to be accessed by the processor of the computing device. Examples of computer-readable storage media include, but are not limited to: a floppy disk, a magnetic hard disk drive, a solid state hard disk, flash memory, a USB thumb drive, Random Access Memory (RAM), Read Only Memory (ROM), an optical disk, a magneto-optical disk, and the register file of the processor. Examples of optical disks include Compact Disks (CD) and Digital Versatile Disks (DVD), for example CD-ROM, CD-RW, CD-R, DVD-ROM, DVD-RW, or DVD-R disks. The term computer readable-storage medium also refers to various types of recording media capable of being accessed by the computer device via a network or communication link. For example, a data may be retrieved over a modem, over the internet, or over a local area network. Computer executable code embodied on a computer readable medium may be transmitted using any appropriate medium, including but not limited to wireless, wire line, optical fiber cable, RF, etc., or any suitable combination of the foregoing.

[0040] A computer readable signal medium may include a propagated data signal with computer executable code embodied therein, for example, in baseband or as part of a carrier wave. Such a propagated signal may take any of a variety of forms, including, but not limited to, electro-magnetic, optical, or any suitable combination thereof. A computer readable signal medium may be any computer readable medium that is not a computer readable storage medium and that can communicate, propagate, or transport a program for use by or in connection with an instruction execution system, apparatus, or device.

[0041] 'Computer memory' or 'memory' is an example of a computer-readable storage medium. Computer memory is any memory which is directly accessible to a processor. 'Computer storage' or 'storage' is a further example of a computer-readable storage medium. Computer storage is any non-volatile computer-readable storage medium. In some embodiments computer storage may also be computer memory or vice versa.

[0042] A 'processor' as used herein encompasses an electronic component which is able to execute a program or machine executable instruction or computer executable code. References to the computing device comprising "a processor" should be interpreted as possibly containing more than one processor or processing core. The processor may for instance be a multi-core processor. A processor may also refer to a collection of processors within a single computer system or distributed amongst multiple computer systems. The term computing device should also be interpreted to possibly refer to a collection or network of computing devices each comprising a processor or processors. The computer executable code may be executed by multiple processors that may be within the same computing device or which may even be distributed across multiple computing devices.

[0043] Computer executable code may comprise machine executable instructions or a program which causes a processor to perform an aspect of the present invention. Computer executable code for carrying out operations for aspects of the present invention may be written in any combination of one or more programming languages, including an object oriented programming language such as Java, Smalltalk, C++ or the like and conventional procedural programming languages, such as the "C" programming language or similar programming languages and compiled into machine executable instructions. In some instances the computer executable code may be in the form of a high level language or in a pre-compiled form and be used in conjunction with an interpreter which generates the machine executable instructions on the fly.

[0044] The computer executable code may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider).

[0045] Aspects of the present invention are described with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products according to embodiments of the invention. It is understood that each block or a portion of the blocks of the flowchart, illustrations, and/or block diagrams, can be implemented by computer program instructions in form of computer executable code when applicable. It is further under stood that, when not mutually exclusive, combinations of blocks in different flowcharts, illustrations, and/or block diagrams may be combined. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

[0046] These computer program instructions may also be stored in a computer readable medium that can direct a computer, other programmable data processing apparatus, or other devices to function in a particular manner, such that the instructions stored in the computer readable medium produce an article of manufacture including instructions which implement the function/act specified in the flowchart and/or block diagram block or blocks.

[0047] The computer program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other devices to cause a series of operational steps to be performed on the computer, other programmable apparatus or other devices to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide processes for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

[0048] A 'user interface' as used herein is an interface which allows a user or operator to interact with a computer or computer system. A 'user interface' may also be referred to as a 'human interface device.' A user interface may provide information or data to the operator and/or receive information or data from the operator. A user interface may enable input from an operator to be received by the computer and may provide output to the user from the computer. In other words, the user interface may allow an operator to control or manipulate a computer and the interface may allow the computer indicate the effects of the operator's control or manipulation. The display of data or information on a display or a graphical user interface is an example of providing information to an operator. The receiving of data through a keyboard, mouse, trackball, touchpad, pointing stick, graphics tablet, joystick, gamepad, webcam, headset, pedals, wired glove, remote control, and accelerometer are all examples of user interface components which enable the receiving of information or data from an operator.

[0049] A 'hardware interface' as used herein encompasses an interface which enables the processor of a computer system to interact with and/or control an external computing device and/or apparatus. A hardware interface may allow a processor to send control signals or instructions to an external computing device and/or apparatus. A hardware interface may also enable a processor to exchange data with an external computing device and/or apparatus. Examples of a hardware interface include, but are not limited to: a universal serial bus, IEEE 1394 port, parallel port, IEEE 1284 port, serial port, RS-232 port, IEEE-488 port, Bluetooth connection, Wireless local area network connection, TCP/IP connection, Ethernet connection, control voltage interface, MIDI interface, analog input interface, and digital input interface.

[0050] A 'display' or 'display device' as used herein encompasses an output device or a user interface adapted for displaying images or data. A display may output visual, audio, and or tactile data. Examples of a display include, but are not limited to: a computer monitor, a television screen, a touch screen, tactile electronic display, Braille screen,

[0051] Cathode ray tube (CRT), Storage tube, Bi-stable display, Electronic paper, Vector display, Flat panel display, Vacuum fluorescent display (VF), Light-emitting diode (LED) displays, Electroluminescent display (ELD), Plasma display panels (PDP), Liquid crystal display (LCD), Organic light-emitting diode displays (OLED), a projector, and Head-mounted display.

[0052] Computed Tomography (CT) data is defined herein as being the recorded X-ray measurements. CT data may be reconstructed by a computer into one or more tomographic images, which can be visualized using a computer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0053] In the following preferred embodiments of the invention will be described, by way of example only, and with reference to the drawings in which:

- Fig. 1 illustrates an example of a medical instrument;
- Fig. 2 illustrates a further example of a medical instrument;
- Fig. 3 illustrates a further example of a medical instrument;
- Fig. 4 illustrates a further example of a medical instrument;
- Fig. 5 illustrates a further example of a medical instrument;
- Fig. 6 illustrates an example of a voltage stabilizer circuit;
- Fig. 7 illustrates a further example of a medical instrument;
- Fig. 8 shows a flow chart which illustrates a method of operating the medical instrument of Fig. 1, 2, 3, 4, 5, 6, or 8; and
- Fig. 9 illustrates a further example of a medical instrument.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0054] Like numbered elements in these figures are either equivalent elements or perform the same function. Elements which have been discussed previously will not necessarily be discussed in later figures if the function is equivalent.

[0055] Fig. 1 illustrates an example of a medical instrument 100. The medical instrument is shown as comprising an X-ray power supply 102. The medical instrument also comprises a voltage stabilizer circuit 104. Additionally, an X-ray tube 106 is shown. The X-ray power supply 102 has a single output 108 that is connected to the X-ray tube 106. The X-ray power supply 102 is configured for powering the X-ray tube 106 by producing a voltage supply that switches between a first voltage and a second voltage. This causes a difference in the spectra of X-rays emitted by the X-ray tube 106.

[0056] The oscillation between the first voltage and the second voltage causes an oscillating impulse voltage that is superimposed on the output voltage on the single output 108. Voltage stabilizer circuit 104 reduces this effect. The voltage stabilizer circuit 104 comprises an oscillator 110 and a transformer with a core 112. The transformer with the core 112 is used to couple the oscillator 110 to the single output 108. In this example the transformer 112 is coupled to the single output 108 using a coupling capacitor 114.

[0057] Fig. 2 illustrates an additional example of a medical instrument 200. The example illustrated in Fig. 2 is similar to that illustrated in Fig. 1. In Fig. 2 the dashed line 202 represents the X-ray tube high voltage isolation tank 202. In this example the voltage stabilizer circuit 104 is located within the X-ray tube high voltage isolation tank 202. In some examples there may be an external power supply provided to the oscillator 110. In other examples there may be a rectifier circuit attached to the transformer with the core 112 so that the oscillations between the first voltage and the second voltage on the single output 108 may be used to generate or self-power the voltage stabilizer circuit 104. This would be particularly advantageous as the voltage stabilizer circuit 104 can be integrated into the X-ray tube high voltage isolation tank 202 without needing an additional power supply.

[0058] Fig. 3 illustrates a further example of the medical instrument 300. The example illustrated in Fig. 3 is similar to the example as illustrated in Figs. 1 and 2. However, in Fig. 3 the dashed line 302 represents the X-ray power supply high voltage isolation tank 302. In this example the voltage stabilizer circuit 104 is located within the X-ray power supply high voltage isolation tank 302. In this example the voltage stabilizer circuit 104 could be self-powered but there will also be power for the X-ray power supply 102 which is available. Fig. 3 may be a convenient means of upgrading an existing system with an improved power supply comprising a voltage stabilizer circuit 104.

[0059] Fig. 4 illustrates a further example of a medical instrument 400. The example shown in Fig. 4 is similar to the previous examples 1, 2 and 3 except in this example the X-ray power supply 102' is a bipolar power supply which has a first output 108' and a second output 108". The X-ray power supply 102 in Figs. 1, 2 and 3 is a unipolar power supply.

[0060] In the example illustrated in Fig. 4 there is a first voltage stabilizer circuit 104 that is capacitively coupled to the first output 108' and there is a second voltage stabilizer circuit 104" that is capacitively coupled to the second output 108".

[0061] The X-ray tube 106 in the example in Fig. 4 is configured for being powered by the bipolar X-ray power supply 102'.

[0062] The first and second voltage stabilizer circuits 104' and 104" may be placed within the X-ray tube high voltage isolation tank 202 as is illustrated in Fig. 2 or the X-ray power supply high voltage isolation tank 302 as is illustrated in Fig. 3.

[0063] Fig. 5 illustrates a further example of a medical instrument 500. The example illustrated in Fig. 5 is a modification of the example illustrated in Fig. 1. In this example there is a tube arc protection circuit 502 that is attached in parallel to the transformer with the core 112. Additionally, between the coupling capacitor 114 and the transformer 112 is an additional resistive element 504. The resistive element 504 may for example be an inductance, a resistance or a combination (preferably in series) of a resistance and an inductance. The tube arc protection circuit 502 and the resistive element 504 help to protect the voltage stabilizer circuit 104 from over-voltages in the single output 108. The tube arc protection circuit 502 may for example include a rectifier circuit comprising at least one relatively large capacitance to limit, also by the use of an inductance in 504 limiting the maximum current to for example a few kA, the maximum voltage building up to a normal maximum operating voltage over the terminals of 502 in case of a voltage peak on 108. Such a circuit can be built from a 4-diode rectifier and a single capacitor, or two individual (opposite in relation to each other) circuits each consisting of a single capacitor in series with a single diode. Such a protection circuit may not be needed if sufficient damping is available.

[0064] Fig. 6 illustrates an example of the voltage stabilizer circuit 104. In this example the voltage stabilizer circuit is a self-powered H-bridge circuit. The transformer of the core 112 is connected to a group of switches 600, 602, 604, 606 and diodes 608. The switches 600, 602, 604, and 606 are the switches for the H-bridge circuit, and can for example be transistors or MOSFETs. The diodes 608 form a rectifier that may be used for powering the H-bridge circuit 620. There is a storage capacitor 610 which is used to store energy. Also connected is 612 which is the transistor gate electronics used to control the switches 600, 602, 604, and 606. At start up for example, the switches 600, 602, 604, and 606 may all be left open and a voltage will build up on the capacitor 610. After a few volts of the DC link voltage have built up, the pair of switches 604 and 606, or the pair of switches 600 and 602, or the pair of switches 600 and 606, or the pair of switches 602 and 604 may be closed to start operation of the H-bridge formed by switches 601-604; subsequently the selected pair of switches as determined by transistor gate electronics 612 will be activated in order to produce a counteracting ripple. As the operation drains the capacitor 610, periodically the operation of the H-bridge may be interrupted until enough power for the operation of the entire H-bridge circuit is available, preferably at times where the circuitry is not needed or when the ripple is below a certain threshold.

[0065] Fig. 7 illustrates a further example of a medical instrument 700. The medical instrument 700 is similar to the medical instrument 500 in Fig. 5. Additionally, there is a voltage sensor 702 to measure the current voltage on the single output 108. There is also a voltage controller 704 which may contain a processor or other control circuitry to control the amplitude of the signal produced by the oscillator 110. The voltage sensor 702 could for example be a capacitive voltage divider or resistive voltage divider. The voltage controller 704 may also be incorporated into the transistor gate electronics 612 (inside 104) of Fig. 6. The voltage controller 704 may be advantageous because it may be used to measure and be used to more accurately correct for the oscillating impulse voltage.

[0066] Fig. 8 shows a flowchart which illustrates a method of operating the medical instrument 100, 200, 300, 400, 500, or 700, illustrated in any of Figs. 1-7. In step 800 the X-ray tube is powered using the X-ray power supply 102, 102' to supply the output voltage. This output voltage is going between a first voltage and a second voltage. This switching between the first voltage and the second voltage results in an oscillating input voltage that has a ripple frequency. Next in step 802 the oscillating impulse voltage is reduced by using the at least one voltage stabilizer circuit 104, 104', 104". The method illustrated in Fig. 8 may for example be useful for powering an X-ray tube on a CT or computer tomography system using multiple X-ray spectrums. The change in the voltage between the first voltage and the second voltage causes the emitted spectra of the X-ray tube 106 to change.

[0067] Fig. 9 illustrates a further example of a medical instrument 900. The medical instrument contains circuitry similar to that illustrated in Figs. 1, 2, 3, 4, 5, 7. However, the medical instrument 900 additionally comprises a CT or computer tomography system 902. The CT system 902 comprises a rotating gantry 904. The gantry 904 rotates about an axis of rotation 906. There is a subject 908 reposing on a subject support 910. Within the gantry 904 is the X-ray tube high voltage isolation tank 202. In one variation, this is the location of the X-ray tube 106 and the voltage stabilizer circuit 104. This is however only exemplary. In another variation the voltage stabilizer circuit 104 could be located within the X-ray power supply 102 as is illustrated in Fig. 3 or it may be located external to both the X-ray power supply 102 and the X-ray tube high voltage isolation tank 202.

[0068] The X-ray tube 106 produces X-rays 914 that pass through the subject 908 and are received by a detector 912. Within the area of the box 916 is an imaging zone where CT or computer tomography images of the subject 908 can be made. The CT system 902 is shown as being controlled by computer system 920. The computer 920 comprises a processor 922. The processor is in communication with a hardware interface 924, a user interface 926 and a memory 928. The hardware interface 924 allows the processor 922 to exchange messages and control the CT system 902.

[0069] The memory 928 is shown as containing machine-executable instructions 930. The machine-executable instructions 930 enable the processor 922 to control the CT system 902 as well as perform various data analysis and computing functions. The memory 928 is further shown as containing CT system control commands 932. The CT system control commands 932 are used by the processor 922 to control the CT system 902 to acquire computer tomography data. The memory 928 is shown as containing first CT data 934 and second CT data 936 that were acquired by controlling the CT system 902 with the CT system control commands 932. The first CT data 934 was acquired when the X-ray power supply 102 was supplying the first voltage to the X-ray tube 106. The second CT data 936 was acquired when the X-ray power supply 102 was supplying the second voltage to the X-ray tube 106. The memory 928 further shows a multispectral CT image or data 938 that has been reconstructed from the first CT data and the second CT data 934, 936 respectively. An advantage of using the voltage stabilizer circuit 104 is that the quality of the multispectral CT image 938 may be improved.

[0070] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments.

[0071] Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measured cannot be used to advantage. A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems. Any reference signs in the claims should not be construed as limiting the scope.

LIST OF REFERENCE NUMERALS

[0072]

100 medical insturmnet
102 X-ray power supply
102' bipolar X-ray power supply
104 voltage stabilizer circuit
104' first voltage stablizer circuit
104" second voltage stablizer circuit
106 X-ray tube
108 single output
108' first output
108" second output
110 oscillator
112 transformer with core
114 coupling capacitor
200 medical instrument
202 X-ray tube high voltage isolation tank
300 medical instrument
302 X-ray power supply high voltage isolation tank
400 medical instrument
500 medical instrument
502 tube arc protection circuit
504 resistive element
600 switch T1
602 switch T2
604 switch T3
606 switch T4
608 diodes
610 storage capacitor
612 transistor gate electronics
700 medical instrument
702 voltage sensor
704 voltage controller
800 powering the X-ray tube by using the X-ray power supply to supply the output voltage
802 reducing the oscillating impulse voltage using the at least one voltage stabilizer circuit
900 medical instrument
902 CT system
904 gantry
906 axis of rotation
908 subject
910 subject support
912 detector
914 X-rays
916 imaging zone
920 computer
922 processor
924 hardware interface
926 user interface
928 memory
930 machine executable instructions
932 CT system control commands
934 first CT data

936 second CT data
938 multi spectral CT image

Claims

1. A medical instrument (100, 200, 300, 400, 500, 700, 900) comprising an X-ray power supply (102, 102'), wherein the X-ray power supply is configured to provide an output voltage that repeatedly switches between a first voltage and a second voltage, wherein the X-ray power supply is configured for powering an X-ray tube (106) with the output voltage to produce X-rays, wherein switching between the first voltage and the second voltage generates an oscillating impulse voltage superimposed on the output voltage, wherein the oscillating impulse voltage has a ripple frequency,
wherein the medical instrument further comprises at least one voltage stabilizer circuit (104, 104', 104") for stabilizing the first voltage and the second voltage, wherein the at least one voltage stabilizer circuit comprises an oscillator (110) and a transformer (112), wherein the transformer is configured for coupling the at least one voltage stabilizer circuit to the output voltage, wherein the oscillator is configured for oscillating at a voltage stabilizer frequency, wherein the voltage stabilizer frequency matches the ripple frequency, wherein the transformer comprises a magnetic core (112) configured for limiting coupling of the oscillating impulse voltage to the at least one voltage stabilizer circuit.

2. The medical instrument of claim 1, wherein the medical instrument further comprises a computed tomography system (902), wherein the computed tomography system is configured for acquiring first CT data (834) when the X-ray tube is supplied with the first voltage and for acquiring second CT data (936) when the X-ray tube is supplied with the second voltage.

3. The medical instrument of claim 1 or 2, wherein the at least one voltage stabilizer circuit comprises any one of the following: an h-bridge amplifier and a half h-bridge amplifier.

4. The medical instrument of any one of the preceding claims, wherein any one of the following:

   - the X-ray power supply is a unipolar power supply (102) with a single output (108) to provide the output voltage, wherein the at least one voltage stabilizer circuit is a single voltage stabilizer circuit (104), and wherein the voltage stabilizer circuit is capacitively coupled to the single output; and
   - the X-ray power supply is a bipolar power (102') supply with a first output (108') and a second output (108") to provide the output voltage, wherein the at least one voltage stabilizer is a first voltage stabilizer (104') and a second voltage stabilizer (104"), wherein the first voltage stabilizer is capacitively coupled to the first output, and wherein the second voltage stabilizer is capacitively coupled to the second output.

5. The medical instrument of any one of the preceding claim, wherein the medical instrument comprises a voltage controller (704) configured for controlling the amplitude and the phase of the oscillator of each of the at least one voltage stabilizer, wherein the voltage controller comprises a voltage sensor (702) configured for measuring the oscillating impulse voltage, wherein the voltage controller is configured for adjusting the amplitude and the phase of the at least one voltage stabilizer to minimize the oscillating impulse voltage.

6. The medical instrument of any one of the preceding claims, wherein the magnetic core is any one of the following: a nano-magnetic core, an amorphous alloy core, and a permalloy core and/or wherein the magnetic core has a relative permeability greater than 5000, preferably greater than 20000.

7. The medical instrument of any one of the preceding claims, wherein the ripple frequency is any one of the following: between 30 kHz and 200 kHz, between 50 kHz and 150 kHz, and between 75 kHz and 100 kHz.

8. The medical instrument of any one of the preceding claims:

   - wherein the first voltage is between 50 kV and 105 kV, wherein the second voltage is between 110 kV and 200 kV; and
   - wherein the first voltage is between 70 kV and 90 kV, wherein the second voltage is between 120 kV and 160 kV.

9. The medical instrument of any one of the preceding claims, wherein the medical instrument further comprises a tube arc protection circuit (502) in parallel with the transformer.

10. The medical instrument of claim 9, wherein the tube arc protection circuit is a rectifier circuit.

11. The medical instrument of any one of the preceding claims, wherein the medical instrument comprises an X-ray power supply high voltage isolation tank (302) wherein the amplifier is within the an X-ray power supply high voltage isolation tank, and wherein the at least one voltage stabilizer circuit is within

the X-ray power supply high voltage isolation tank.

12. The medical instrument of any one of the preceding claims, wherein the medical instrument comprises an X-ray tube high voltage isolation tank (202), wherein the X-ray tube high voltage isolation tank is configured to receive the X-ray tube, and wherein the at least one least one voltage stabilizer circuit is within the X-ray high voltage isolation tank.

13. The medical instrument of any one of the preceding claims, wherein the at least one voltage stabilizer circuit comprises an energy extraction circuit (608, 610) configured for powering the at least one voltage stabilizer circuit from changes between the first voltage and the second voltage.

14. A method of operating a medical instrument (100, 200, 300, 400, 500, 700, 900), wherein the medical instrument comprises an X-ray power supply (102, 102'), wherein the X-ray power supply is configured to provide an output voltage that repeatedly switches between a first voltage and a second voltage, wherein the X-ray power supply is configured for powering an X-ray tube (106) with the output voltage to produce X-rays, wherein switching between the first voltage and the second voltage generates an oscillating impulse voltage superimposed on output voltage, wherein the oscillating impulse voltage has a ripple frequency,
wherein the medical instrument further comprises at least one voltage stabilizer circuit (104, 104', 104") for stabilizing the first voltage and the second voltage, wherein the at least one voltage stabilizer circuit comprises an oscillator and a transformer (112), wherein the transformer is configured for coupling the at least one voltage stabilizer circuit to the output voltage, wherein the oscillator is configured for oscillating at a voltage stabilizer frequency, wherein the voltage stabilizer frequency matches the ripple frequency, wherein the transformer comprises a magnetic core (112) configured for limiting coupling of the oscillating impulse voltage to the at least one voltage stabilizer circuit;
wherein the method comprises:

- powering (800) the X-ray tube by using the X-ray power supply to supply the output voltage; and
- reducing (802) the oscillating impulse voltage using the at least one voltage stabilizer circuit.

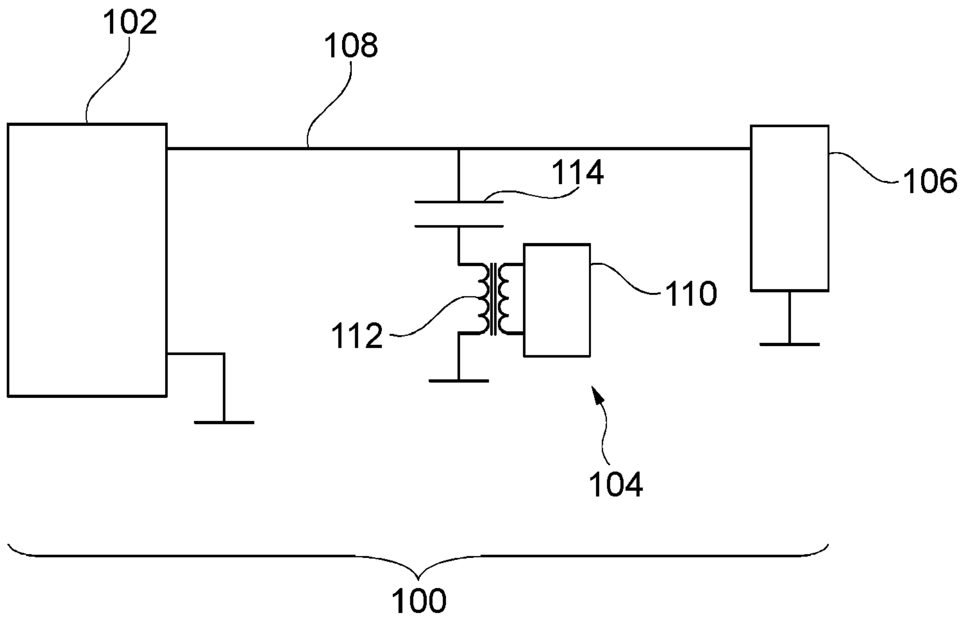

Fig. 1

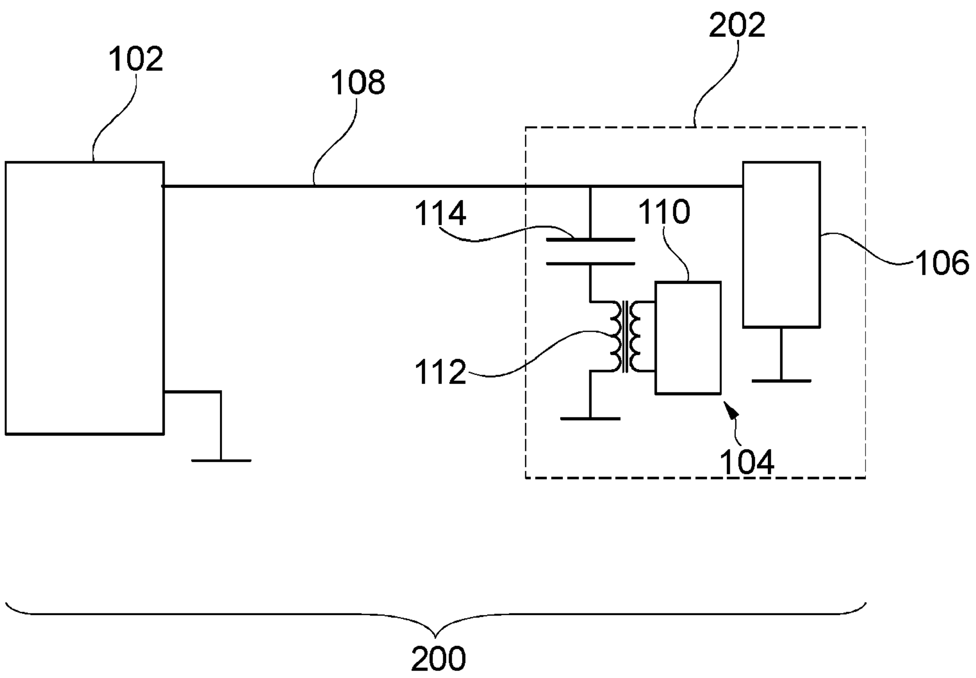

Fig. 2

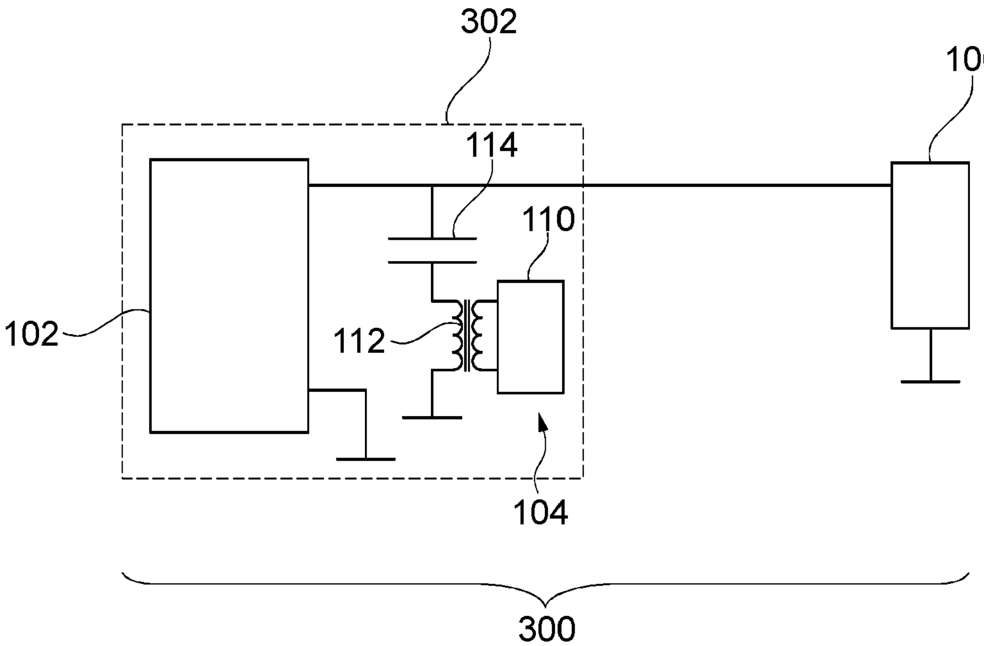

Fig. 3

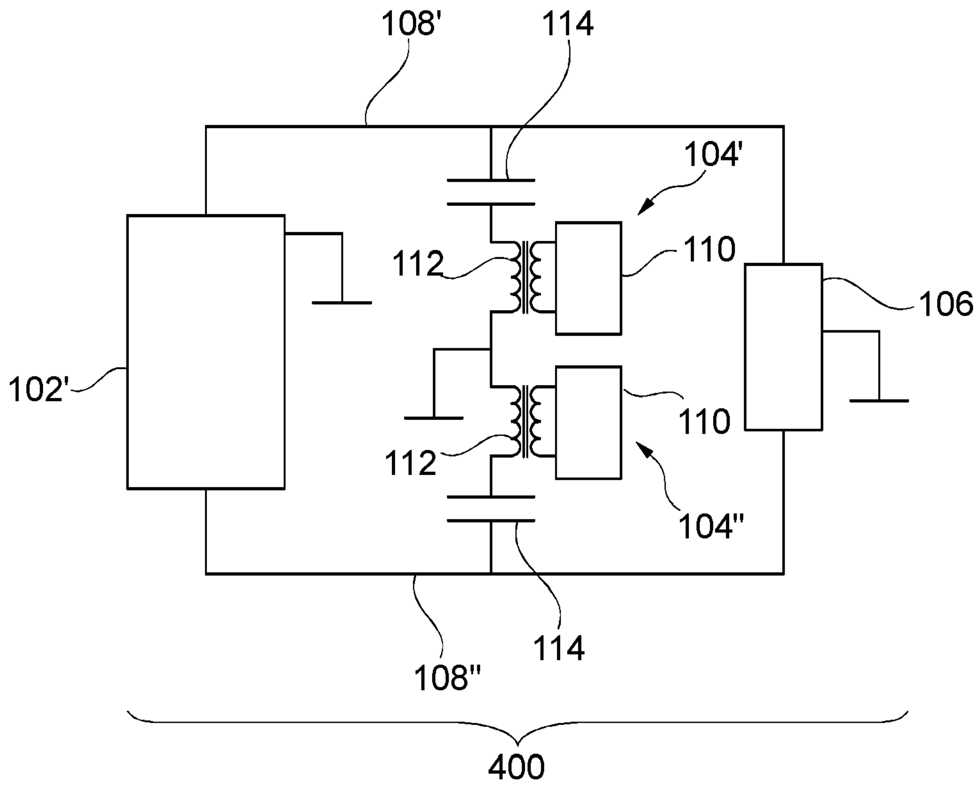

Fig. 4

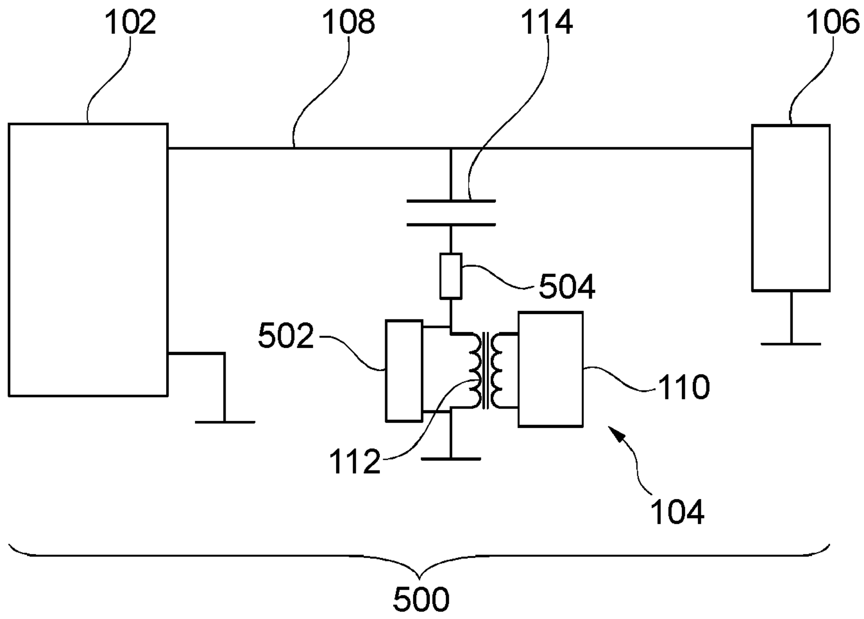

Fig. 5

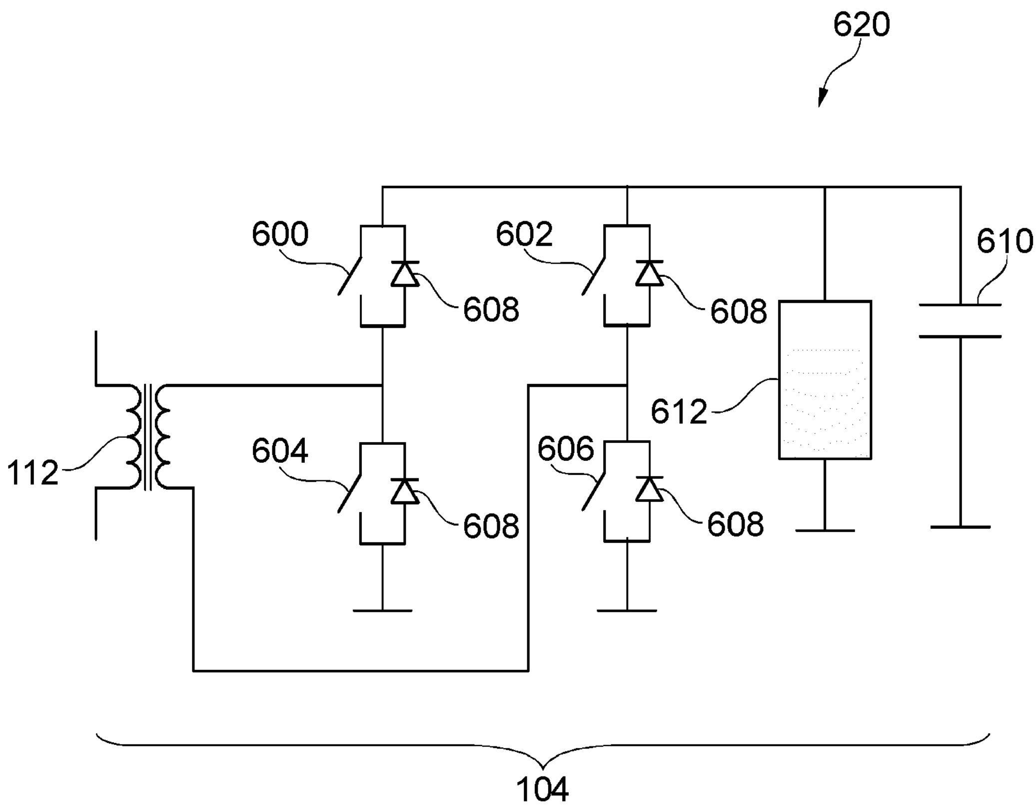

Fig. 6

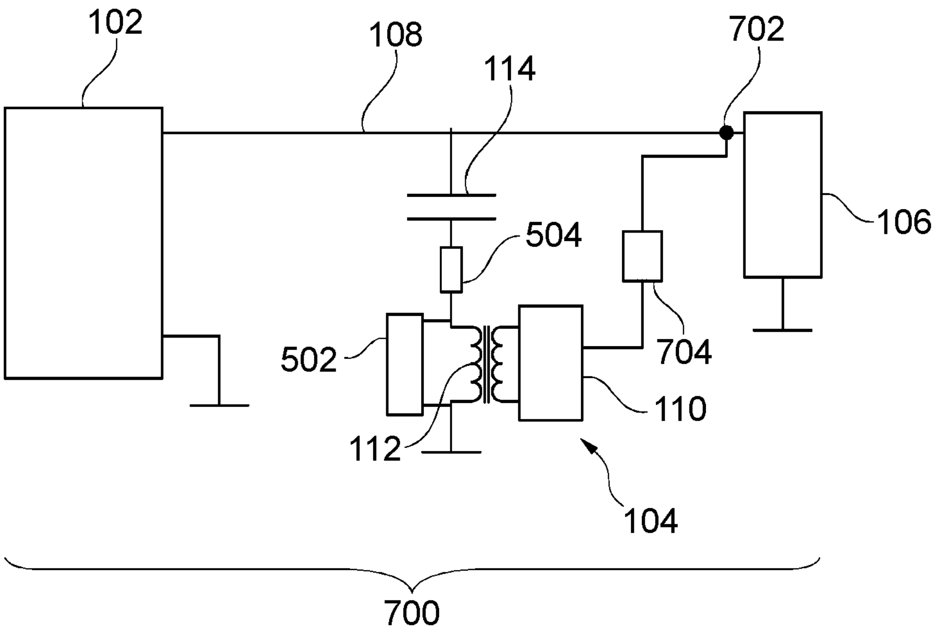

Fig. 7

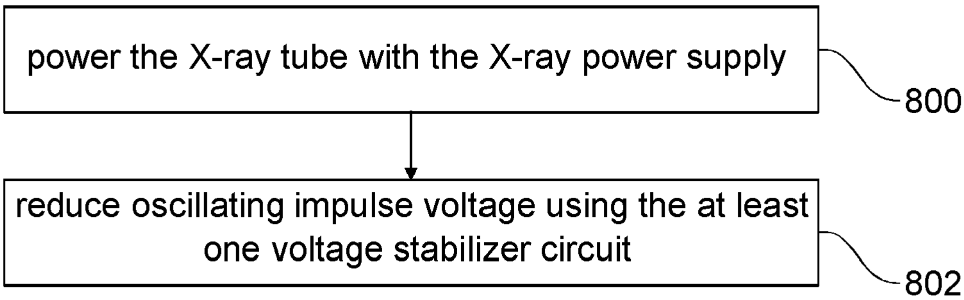
power the X-ray tube with the X-ray power supply
800
reduce oscillating impulse voltage using the at least one voltage stabilizer circuit
802

Fig. 8

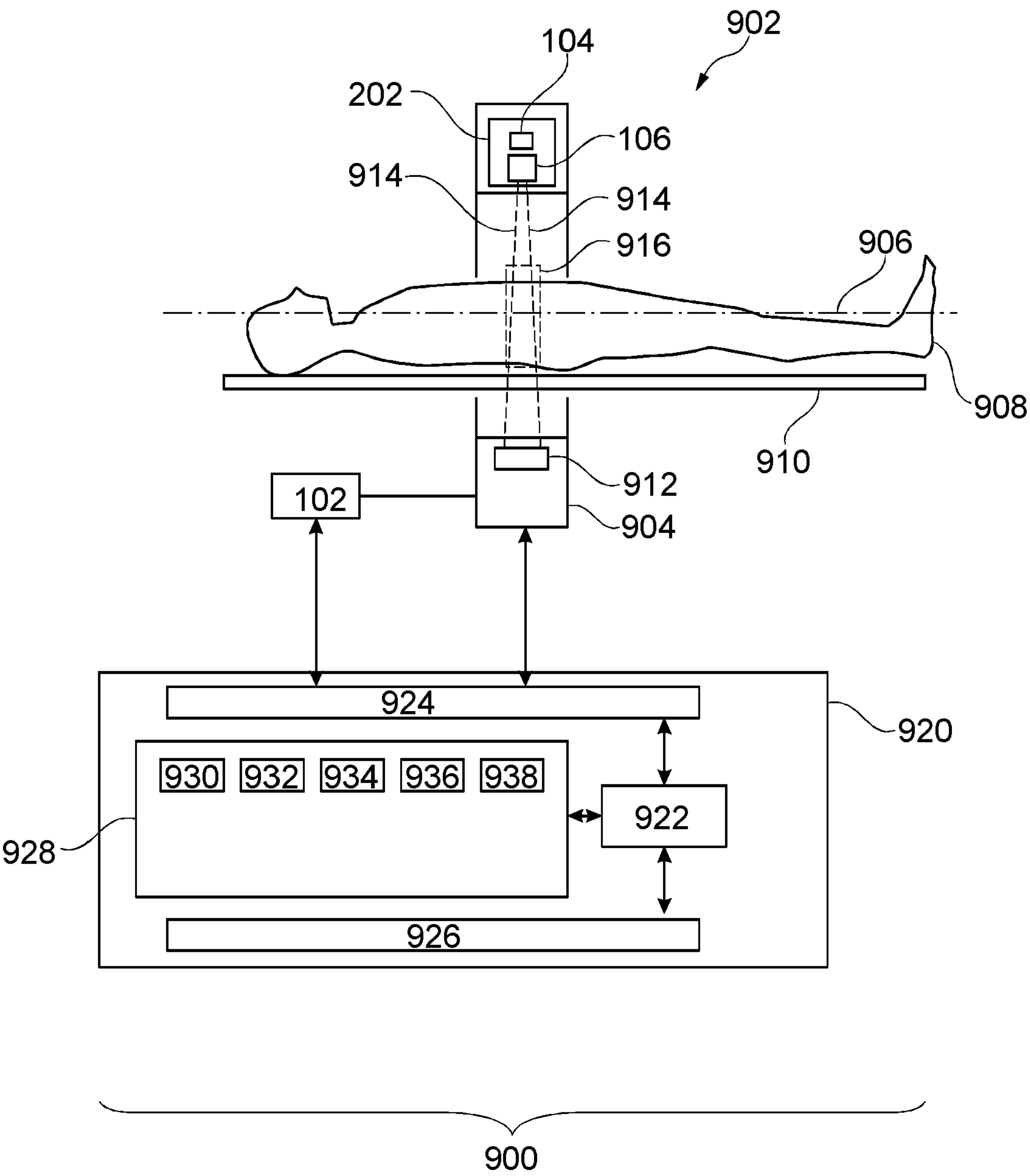
902
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Fig. 9

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EUROPEAN SEARCH REPORT

Application Number
EP 19 21 7858

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	US 2013/170608 A1 (WEEDON HANS J [US]) 4 July 2013 (2013-07-04) * see fig. 1 - 3 and the description thereof * -----	1-8, 11-14	INV. H05G1/20 H05G1/26 H05G1/32
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H05G
H01J
A61B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	8 June 2020	Angloher, Godehard

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