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(54) X-RAY IMAGING WITH FAST KVP-SWITCHING

(57) The invention relates to X-ray imaging with fast kVp-switching. The invention provides a voltage generator (100) for X-ray imaging with fast kVp-switching between at least a first voltage level and a second voltage level different to the first voltage level. The voltage generator (100) comprises a voltage input (110), a voltage output (120), a voltage multiplier circuit (130), connected to the voltage input (130) and to the voltage output (120), and comprising a network of a push-pull capacitance (131) and at least one diode (132), and configured to provide, in response to a input voltage received via the voltage input (110), at least the first voltage level and the second voltage level at the voltage output (140) in an alternating manner, and a buffer capacitance (140) arranged with respect to the voltage output (120). Thereby, a ratio of push-pull capacitance to buffer capacitance is between 0.5 and 3.

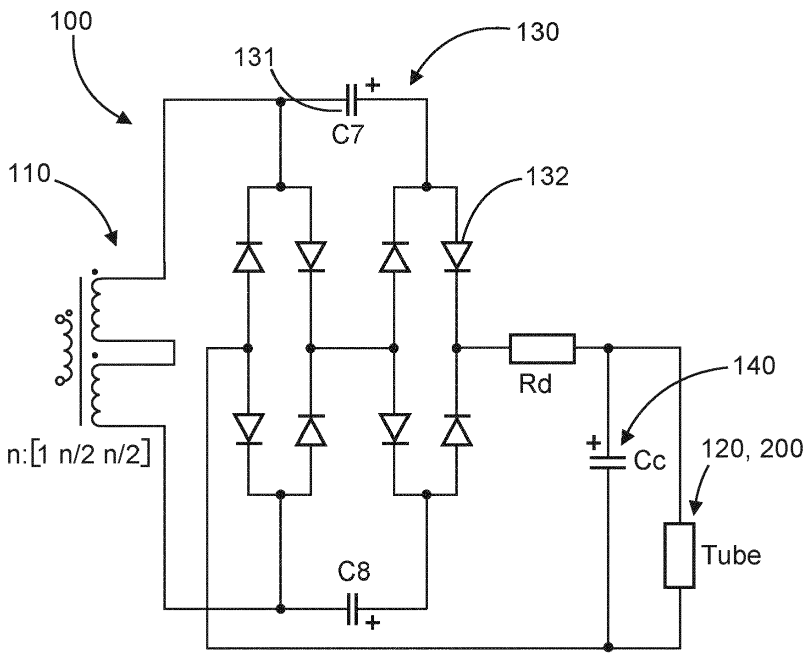


FIG. 2

Description

FIELD OF THE INVENTION

[0001] The invention relates to X-ray imaging with fast kVp-switching.

[0002] In particular, the invention relates to a voltage generator for X-ray imaging with fast kVp-switching between at least a first voltage level and a second voltage level different to the first voltage level. Further, the invention relates to an X-ray imaging system, and a method of controlling X-ray imaging with fast kVp-switching.

BACKGROUND OF THE INVENTION

[0003] So-called Fast kVp-switching is a dual energy acquisition technique in X-ray imaging, particularly in computed tomography (CT), in which technique alternating views correspond to the switched low and high tube voltages, i.e. utilizing scans at different voltage and/or energy levels, "low-kV" and "high-kV". For example, projections may be acquired at a first, high(er) voltage of about 120 to 150 kilovolts (kV) and or another suitable value or range, and at a second, low(er) voltage of e.g. 70 to 100 kV or another suitable value or range, e.g. switching between the different voltage levels at every few or fractions of milliseconds. In this way, spectral imaging can be performed using fast kVp-switching.

[0004] Fast kVp-switching is, however, associated with a larger ripple in the output voltage to be applied to an X-ray tube, which ripple may compromise image quality. Therefore, it is desirable to find a suitable compromise between ripple and speed. Thereby, large values of buffer or smoothing capacitance are expected to decrease the ripple of the tube voltage at the expense of longer transition times between the low and high kV level. Vice versa, small values of the buffer capacitance are expected to yield speed but are also expected to introduce more ripple into the waveform which would degrade image quality if left uncorrected.

SUMMARY OF THE INVENTION

[0005] There may, therefore, be a need for improving kVp-switching in terms of at least decreasing ripple in an output voltage to be provided to an X-ray source in X-ray imaging. The object of the present invention is solved by the subject matter of the independent claims, wherein further embodiments are incorporated in the dependent claims.

[0006] According to a first aspect, there is provided a voltage generator for X-ray imaging with fast kVp-switching between at least a first voltage level and a second voltage level different to the first voltage level. The voltage generator comprises a voltage input, and a voltage output. Further, the voltage generator comprises a voltage multiplier circuit, connected to the voltage input and to the voltage output, and comprising a network of a push-pull capacitance and at least one diode, and configured to provide, in response to a input voltage received via the voltage input, at least the first voltage level and the second voltage level at the voltage output in an alternating manner. Further, the voltage generator comprises a buffer capacitance arranged with respect to the voltage output. Thereby, a ratio of push-pull capacitance to buffer capacitance is between 0.5 and 3.

[0007] In this way, fast kVp-switching can be performed with reduced ripple in the output voltage. In addition, a high speed of kVp-switching can also be achieved. Therefore, the voltage generator can provide a good compromise between ripple and speed. It is noted that a large value of buffer or smoothing capacitance typically decreases the ripple of the output voltage at the expense of longer transition times between the low and high kV level. Vice versa, small values of the buffer capacitance will yield speed but will introduce more ripple into the waveform which would degrade image quality if left uncorrected. The above voltage generator, however, allows the push-pull capacitance to be reduced in addition to a reduced buffer capacitance to decrease the ripple in the output voltage. Thereby, it would normally be expected that a reduced push-pull capacitance also contributes to a higher ripple. However, while the voltage ripple across the push-pull capacitance itself increases indeed, the ripple in the output voltage does not if the value of the push-pull capacitance is intentionally or carefully selected. If the amount of charge stored in the push-pull capacitance at least substantially matches the charge stored in the buffer capacitance, the deviation of the output voltage from an ideal trapezoidal shape will be less severe. Thus, the ripple in the output voltage across a load at the voltage output can be reduced even with a reduced value of push-pull capacitance.

[0008] In other words, a large push-pull capacitance typically leads to a small ripple across the push-pull capacitance. Therefore, it would be expected that this would lead to a smaller ripple in the output voltage as well. However, the inventors have been found in a non-obvious way that this is not the case which may be counterintuitive at first sight. As the reason for this effect, it has been found a pronounced charge imbalance in the generator at the time instant when the transition from high kV to low kV is just finished and voltage generation is turned on again to maintain the low kV voltage level. During the transition from high to low kV, the one or more high voltage diodes are not conducting. Hence, an electrical current provided to an X-ray tube connected to the voltage output has discharged the buffer capacitance only. The voltage across the push-pull capacitance still corresponds to the high kV level because no charge was being removed. At the instant when the voltage generation is turned on, there is a charge imbalance between buffer and push-pull capacitance. The one or more high voltage diodes start conducting and a transient process occurs that eliminates this charge imbalance at the expense of a high voltage overshoot even if the generator injects energy only for a single half period of the resonant current. This can cause a large ripple in the output voltage and distorts the fidelity of the kVp-switching waveform. It has been found that a smaller value of the push-pull capacitance can reduce this effect in two ways. First, the voltage overshoot when the voltage generation is turned on, is smaller. Second, the smaller amount of charge can be removed faster during the transient.

[0009] As used herein, the term "fast kVp-switching" means a dual energy acquisition technique in X-ray imaging, particularly in computed tomography (CT), in which technique the X-ray source voltage is switched between different voltage and/or energy levels, "low-kV" and "high-kV", between individual projections. The X-ray source, e.g. X-ray tube, may be connected to, via a connector, high-voltage cable, etc., or may form the voltage output, so that the voltage output may also be referred to as a "tube". Accordingly, a preferred application or use of the voltage generator is an X-ray imaging device or system for CT applications configured to provide fast kVp-switching, wherein "fast kVp-switching" may be understood as the tube voltage is changed between individual projections of the scanning procedure.

[0010] Further, as used herein, the smallest amount of ripple in the output voltage may be obtained if the push-pull capacitance equals exactly the buffer capacitance. However, it is not trivial to determine exactly this amount of capacitance. Therefore, it is not trivial neither to match exactly the push-pull capacitance to this residual buffer capacitance. Thus, a suitable range is therefore selected and the push-pull capacitance may be selected or chosen between approx. 50% up to approx. 300% of buffer capacitance, i.e. with a factor between approx. 0,5 to approx. 3 of buffer capacitance. It is noted that if the push-pull capacitance is larger than 300% of the buffer capacitance the voltage peaks can become too large and if the push-pull capacitance is smaller than 50% of the buffer capacitance the power density of the voltage generation can become too low.

[0011] As used herein, the voltage multiplier circuit may be broadly understood as an electrical circuit that is configured to convert electrical power, particularly AC electrical power, from a lower voltage to a higher DC voltage, typically using a network of one or more capacitors and one or more diodes. For example, the voltage multiplier circuit may be formed unipolar or bipolar. Further, by way of example, the voltage multiplier circuit may comprise multiple high-voltage cascades, which may be formed as e.g. a Cockcroft-Walton generator, Villard multiplier circuit or Siemens circuit, or the like.

[0012] Further, as used herein, the buffer capacitance may also be referred to as a smoothing capacitance, since the buffer capacitance smooth the output voltage, thereby reducing ripple. Further, the buffer capacitance may be broadly understood as a total capacitance measured from the X-ray source position, e.g. X-ray tube position, where all diodes are in a non-conducting state.

[0013] As used herein, the push-pull capacitance may be broadly understood as a series connection of all, i.e. one or more, capacitors arranged within or along a single leg of the voltage multiplier circuit, which leg is defined as the series connection of one or more push-pull capacitors needed for the push-pull action of the voltage multiplier circuit. A voltage multiplier circuit may have a number of legs. For example, the voltage multiplier circuit may be configured with only one single leg or with two, three or more legs. Thereby, the push-pull capacitance means the series connection of all capacitors in one leg.

[0014] In at least some embodiments, the output voltage may have a trapezoidal signal shape, at least approximately. It is noted that an ideal square signal is not possible in practice for physics reasons.

[0015] According to an embodiment, switching and/or changing the voltage between the first voltage level and the second voltage level may be in an order of at least 100 mega volts per second (MV/s), preferably of at least 300 MV/s, and most preferably of 1000 MV/s, or even more MV/s. In a respective embodiment, this may be understood as "fast kVp-switching".

[0016] In an embodiment, the buffer capacitance may be below 1000 pikofarad (pF), preferably below 300 pF, further preferably below 150 pF, and most preferably below 50 pF. In this way, the buffer capacitance, and in turn the push-pull capacitance, are particularly small, thereby increasing the speed of switching while still reducing the ripple.

[0017] According to an embodiment, the push-pull capacitance may comprise a number of capacitors arranged in one or more high-voltage cascades. For example, the voltage multiplier circuit may comprise multiple high-voltage cascades, e.g. two, three, four, five, or more. In this way, the voltage generator may be provided to a wide range of applications.

[0018] In an embodiment, the buffer capacitance may comprise a high voltage cable capacitance, wherein the high voltage cable is connectable or connected to the voltage output. In other words, fast kVp-switching may further be improved in terms of speed by removing all dedicated buffer capacitors and rely only on some residual and/or parasitic, quasi unavoidable, buffer capacitance of the voltage generator and/or X-ray or CT imaging device or system. This residual or unavoidable capacitance is inherent to the high voltage cable that connects to the X-ray tube of the X-ray or CT imaging device. In this way, the speed of kVp-switching may be increased, and the number of dedicated buffer capacitors may be reduced or their need may be eliminated or omitted at all.

[0019] According to an embodiment, the buffer capacitance may comprise a high voltage measurement divider capacitance, wherein the high voltage measurement divider is connectable or connected to the voltage output. In other words, fast kVp-switching may further be improved in terms of speed by removing all dedicated buffer capacitors and rely only on some residual and/or parasitic, quasi unavoidable, buffer capacitance of the voltage generator and/or X-ray or CT imaging device or system.

This residual or unavoidable capacitance is inherent to the high voltage measurement divider that connects to the voltage output. In this way, the speed of kVp-switching may be increased, and the number of dedicated buffer capacitors may be reduced or their need may be eliminated or omitted at all.

[0020] In an embodiment, the buffer capacitance may comprise at least one, preferably dedicated, capacitor. For example, one or more capacitors may be included in the voltage multiplier circuit. In this way, the buffer capacitance can be increased, for example, to obtain a more smooth output voltage.

[0021] According to an embodiment, the buffer capacitance is solely formed by one or more residual and/or parasitic capacitances. In other words, the voltage multiplier circuit may omit a dedicated buffer capacitor etc., wherein the push-pull capacitance may be adjusted to the residual and/or parasitic capacitance(s). For example, the capacitance of a high-voltage cable of the X-ray imaging system may be determined by measurement, modelling, calculation based on a datasheet or the like, experience, etc., and the push-pull capacitance may be adjusted by selecting or choosing one or more suitable capacitors or the like. In this way, the buffer capacitance can be reduced to a minimum value, since the buffer capacitance utilized is inherent to the voltage generator and/or X-ray or CT imaging device or system.

[0022] In an embodiment, the voltage multiplier circuit may comprise a number of high-voltage cascades comprising a number push-pull capacitors forming the push-pull capacitance, without a dedicated buffer capacitor. In this way, the speed of kVp-switching can be increased and at the same time the ratio of push-pull capacitance and buffer capacitance can be well adjusted.

[0023] According to an embodiment, the voltage multiplier circuit may comprise a unipolar or bipolar multi-stage high-voltage cascade. In this way, the voltage generator may be provided to a wide range of applications.

[0024] In a second aspect there is provided an X-ray imaging system that is configured for fast kVp-switching between at least a first voltage level and a second voltage level different to the first voltage level. The X-ray imaging system comprises a voltage generator according to the first aspect, and an X-ray source, connected to a voltage output of the voltage generator to receive a voltage signal switching between the first voltage level and the second voltage level.

[0025] In this way, fast kVp-switching can be performed with reduced ripple in the output voltage. In addition, a high speed of kVp-switching can also be achieved. For further advantages reference is made to the first aspect.

[0026] Optionally, the X-ray imaging system may comprise a gantry, and the X-ray source may be arranged in the gantry. Further optionally, the X-ray imaging system may comprise a detector, and the X-ray source may be configured to project a beam of X-rays toward the detector on an opposite side of the gantry.

[0027] Optionally, the X-ray imaging system may comprise a controller configured to control the voltage generator to change the X-ray source voltage utilizing the fast kVp-switching technique.

[0028] In an embodiment, the X-ray imaging system may be a computed tomography system further comprising a controller configured to control the voltage generator to change the X-ray source voltage between individual projections. In this way, fast kVp-switching in CT can be used for e.g. spectral tomography. Optionally, the X-ray imaging system may be a CT scanner utilizing the fast kVp-switching technique.

[0029] Optionally, the voltage generator may be configured to control switching between and/or changing the first voltage level and the second voltage level in an order of at least 100 MV/s, more preferably 300 MV/s, and most preferably 1000 MV/s.

[0030] As used herein, the term "fast kVp-switching" may be understood as changing the X-ray source voltage, e.g. the tube voltage, between individual projections.

[0031] For example, the X-ray source may comprise or be formed as an X-ray tube, which may be a vacuum tube configured to convert an electrical input power into X-rays.

[0032] By way of example, the input signal may be provided by an AC voltage source, such as a transformer or the like, or any other suitable voltage generator.

[0033] Optionally, the X-ray imaging system may comprise a high-voltage cable connecting a voltage output of the voltage generator and the X-ray source to each other. The high-voltage cable inherently comprises a residual and/or parasitic, quasi unavoidable, buffer capacitance.

[0034] According to an embodiment, a buffer capacitance of the voltage generator and/or the X-ray imaging system comprises a high voltage cable capacitance, wherein the high voltage cable connects the voltage output of the voltage generator to the X-ray source. In this way, a dedicated buffer capacitor can be omitted, still allowing reducing ripple in the output voltage.

[0035] Optionally, the X-ray imaging system may comprise a high voltage measurement divider that is connectable or connected to the voltage output of the voltage generator. The high voltage measurement divider inherently comprises a residual and/or parasitic, quasi unavoidable, buffer capacitance.

[0036] In an embodiment, a buffer capacitance may comprise a high voltage measurement divider capacitance, wherein the high voltage measurement divider connects the voltage output of the voltage generator. In this way, a dedicated buffer capacitor can be omitted, still allowing reducing ripple in the output voltage.

[0037] In a third aspect, there is provided a method of controlling X-ray imaging for fast kVp-switching between at least a first voltage level and a second voltage level different to the first voltage level. The method comprises:

providing a voltage multiplier circuit, comprising a network of a push-pull capacitance and at least one diode, and configured to provide, in response to a driver signal received via a driver signal input, at least a first voltage level and a second voltage level at a voltage output;

providing a buffer capacitance with respect to the voltage output;

wherein at least the push-pull capacitance is selected to provide a ratio of push-pull capacitance to buffer capacitance between 0.5 and 3; and

driving the voltage multiplier circuit to generate an output voltage at the voltage output.

[0038] In this way, fast kVp-switching can be performed with reduced ripple in the output voltage. In addition, a high speed of kVp-switching can also be achieved. For further advantages reference is made to the first aspect and/or second aspect.

[0039] Preferably, the method may be applied to the voltage generator of the first aspect and/or the X-ray imaging system of the second aspect.

[0040] According to an embodiment, the push-pull capacitance is selected to at least substantially match a residual and/or parasitic capacitance forming the buffer capacitance. For example, the buffer capacitance below 1000 pF, preferably below 300 pF, further preferably below 150 pF, and most preferably below 50 pF. In this way, the buffer capacitance, and in turn the push-pull capacitance, are particularly small, thereby increasing the speed of switching while still reducing the ripple.

[0041] It is noted that the above embodiments may be combined with each other irrespective of the aspect involved. Accordingly, the method may be combined with structural features of the device and/or system of the other aspects and, likewise, the device and the system may be combined with features of each other, and may also be combined with features described above with regard to the method.

[0042] These and other aspects of the present invention will become apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0043] Exemplary embodiments of the invention will be described in the following drawings.

Fig 1 shows an exemplary X-ray imaging system for fast kVp-switching according to an embodiment.

Fig. 2 shows in an exemplary circuit diagram a voltage generator for fast kVp-switching according to another embodiment.

Fig. 3 shows in an exemplary circuit diagram a voltage generator for fast kVp-switching according to another embodiment.

Fig. 4 shows in an exemplary circuit diagram a voltage generator for fast kVp-switching according to another embodiment.

Fig. 5 shows in a tube voltage/kV - time - diagram an exemplary output voltage waveform during kVp-switching.

Fig. 6 illustrates in a flow chart a method of controlling X-ray imaging for fast kVp-switching according to an embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS

[0044] Fig. 1 shows an exemplary X-ray imaging system 1 that is configured for fast kVp-switching between at least a first voltage level and a second voltage level different to the first voltage level. For example, the X-ray imaging system is a computed tomography (CT) system in which the X-ray source voltage can be switched and/or changed between individual projections.

[0045] The X-ray imaging system according to Fig. 1 comprises a voltage generator 100, an X-ray source 200, e.g. an X-ray tube, a gantry 300, a detector 400, a controller 500, and, optionally, a high voltage measurement divider 600.

[0046] For example, the voltage generator 100 is configured to switch between the first voltage level and the second voltage level is in an order of at least 100 MV/s, more preferably 300 MV/s, and most preferably 1000 MV/s. In at least some embodiments, the X-ray source 200 is arranged in the gantry. The X-ray source 200 is configured to project a beam of X-rays toward the detector 400 on an opposite side of the gantry 300. The controller 500 is configured to control the voltage generator 100 to change the X-ray source voltage, i.e. the voltage provided by the voltage generator 100 to the X-ray source 200 utilizing the fast kVp-switching technique. The voltage generator 100 and the X-ray source 200 are connected via a high-voltage cable, which is indicted in Fig. 1 by an arrow. The optional high voltage measurement divider 600 may be arranged in a different way as illustrated in Fig. 1, however, if applicable, both the high-voltage cable and the high voltage measurement divider 600 may contribute to a buffer capacitance with respect to the voltage generator 100 and/or the X-ray source 200.

[0047] Referring now to Fig. 2, which shows an exemplary voltage generator 100, which is configured for X-ray imaging with fast kVp-switching between at least a first voltage level and a second voltage level different to the first voltage level.

[0048] The voltage generator 100 comprises a voltage input 110, such as a transformer or the like, and a voltage output 120, which is connected to the X-ray source 200, e.g. via the high-voltage cable. A voltage multiplier circuit 130 is connected to the voltage input 110 and to the voltage output 120, and configured to provide, in response to a input voltage received via the voltage input 110, at least the first voltage level and the second voltage level at the voltage output 120 in an alternating manner. According to Fig. 2, in at least some embodiments, the voltage generator 100 and/or voltage multiplier circuit 130 may be bipolar, and may comprise or may be formed of a high-voltage cascade, wherein this exemplary embodiment comprises two cascade stages.

[0049] The multiplier circuit 130 comprises a network of a push-pull capacitance 131 and at least one diode 132, wherein in Fig.2 only an exemplary one of each is designated by the respective reference sign, for better illustration. The push-pull capacitance 131 according to Fig.2 comprises push-pull capacitors C7 and C8. It is noted that the multiplier circuit 130 comprises a total of two legs, wherein a leg may be understood as the series connection of push-pull capacitors needed for the push-pull action of the voltage multiplier circuit 130. Further, the push-pull capacitance 131 may be understood as the series connection of all capacitors in one leg. Therefore, the push-pull capacitance 131 may also be referred to and/or considered as leg-wise push-pull capacitance 131.

[0050] Further, the voltage generator 100 according to Fig. 2 comprises a buffer capacitance 140, configured to smooth the output voltage and arranged with respect to the voltage output 120 and/or the X-ray source 200. According to Fig. 2, in at least some embodiments, the buffer capacitance 140 is solely formed by the residual and/or parasitic capacitance of the high voltage cable connecting the voltage output 120 and the X-ray source 200. In this case, a further, dedicated buffer capacitor can be omitted.

[0051] A ratio of push-pull capacitance to buffer capacitance is chosen to be between 0.5 and 3. It is noted that a value of the buffer capacitance 140 may be obtained by measurement, calculation, modelling, or the like, so that the push-pull capacitance 131 can be chosen in a suitable manner fulfilling the above ratio of 0.5 to 3. In other words, the push-pull capacitance 131 may be chosen between 50 % up to 300 % of the buffer capacitance 140. For example, the buffer capacitance is below 1000 pF, preferably below 300 pF, further preferably below 150 pF, and most preferably below 50 pF. It is noted that the buffer capacitance may be understood as the total capacitance measured from the x-ray tube position where all diodes are in a non-conducting state.

[0052] For example and better illustration, in the exemplary voltage generator 100 according to Fig. 2, the push-pull capacitor C7 has a value of 0.5 until 3 times the value of parasitic high-voltage cable capacitance, which in Fig. 2 is designated by Cc.

[0053] If the amount of charge stored in the push-pull capacitance 131 matches the charge stored in the buffer capacitance 140, e.g. the high voltage measurement divider and/or the charge stored in the capacitance of the high voltage cable, the deviation of the output voltage from an ideal trapezoidal shape is less severe.

[0054] Fig. 3 shows a further configuration of the voltage generator 100, which working principle is the same as described above, and which ratio of push-pull capacitance to buffer capacitance is also chosen to be between 0.5 and 3. Deviating from the above, the voltage generator 100 according to Fig. 3 comprises or is formed as an unipolar three stage high-voltage cascade. The voltage multiplier circuit 130 comprises push-pull capacitors C1, C4 and C7, and capacitors C2, C5 and C8 as push-pull capacitances 131, and dedicated buffer capacitors C3, C6 and C9 contributing to the buffer capacitance 140, which may further comprise the residual and/or parasitic capacitance of the high voltage cable. According to Fig. 3, the voltage multiplier circuit 130 comprises two legs, a leg defined as the series connection of push-pull capacitors needed for the push-pull action of the voltage multiplier circuit. The push-pull capacitance 131 is the series connection of C1, C4, and C7 for one leg. For the other leg, the push-pull capacitance 131 is the series connection of C2, C5, and C8. Further, according to Fig. 3, the buffer capacitance 140 is formed of the parallel connection of Cc with the series connection of C3, C6, and C9.

[0055] If the amount of charge stored in the push-pull capacitance 131, i.e. the push-pull capacitors C1, C4 and C7, and/or capacitors C2, C5 and C8 matches the charge stored in the residual buffer capacitance, i.e. the parallel connection of Cc with the series connection of C3, C6, and C9, the deviation of the output voltage from an ideal trapezoidal shape will be less severe. Thus, the ripple in the output voltage across the load, i.e. X-ray source 200, can be reduced even with a reduced value of push-pull capacitance 131.

[0056] Fig. 4 shows a further configuration of the voltage generator 100, which working principle is the same as described above, and which ratio of push-pull capacitance to buffer capacitance is also chosen to be between 0.5 and 3. Deviating from the above, the voltage generator 100 according to Fig. 4 comprises or is formed as a bipolar high-voltage cascade. Further, the voltage multiplier circuit 130 according to Fig. 4 may be distinguished into two independent voltage multipliers connected differentially across the X-ray source 200, e.g. tube, and/or the voltage output 120. Accordingly, each one of the two independent voltage multipliers has a single leg, one leg comprising the push-pull capacitor C1 as the push-pull capacitance 131, the other leg comprising the push-pull capacitor C2 as the push-pull capacitance 131. Further, in Fig. 4, two buffer capacitances 140A, 140B may be distinguished. The first buffer capacitance 140A is made of the parallel connection of dedicated buffer capacitor C3 with the parasitic high-voltage cable capacitance, which in Fig. 4 is designated by CcAnode. The second buffer capacitance 140B is made of the parallel connection of dedicated buffer capacitor C6 with parasitic cable capacitance, which in Fig. 4 is designated by CcCathode. The push-pull capacitor C1 may be selected to have a value of 0.5 to 3 times the value of the first buffer capacitance 140A defined above. The push-pull capacitor C2 may be selected to have a value of 0.5 to 3 times the value of the second buffer capacitance 140B.

[0057] Fig. 5 shows in a tube voltage / kV - time - diagram an exemplary output voltage waveform during kVp-switching. The output voltage may be provided at the X-ray source 200, i.e. the tube. The output voltage waveform could ideally have a rectangular shape as drawn with dashed line in the diagram, which in practice is physically approximated by a rather trapezoidal shape. Further, in Fig. 5, arrows A indicate a number of undesired voltage spikes appearing during kVp-switching, which may also be referred to as ripple, degrading image quality if left uncorrected.

[0058] With the above voltage generator 100, the undesired spikes indicated in Fig. 5 by arrows A can be reduced by choosing an appropriate ratio of push-pull capacitance 131 to buffer capacitance 140, wherein the ratio is chosen to be between 0.5 and 3, i.e. the push-pull capacitance 131 has a value of 0.5 until 3 times the value of the buffer capacitance 140. It is noted that it has been found that reducing both the buffer capacitance 140 and also the push-pull capacitance 131 decreases the ripple in the output voltage with a good compromise between ripple and speed.

[0059] Fig. 6 shows in a flow chart a method of controlling X-ray imaging for fast kVp-switching according to an embodiment. The method may be carried out by the above X-ray imaging system 1 and/or the voltage generator 100.

[0060] In step S1, the method comprises providing the voltage multiplier circuit 130, connected to the voltage input 130 and to the voltage output 120, and comprising the network of a push-pull capacitance 131 and at least one diode 132, and configured to provide, in response to a input voltage received via the voltage input 110, at least the first voltage level and the second voltage level at the voltage output 120 in an alternating manner.

[0061] In a step S2, the method comprises providing a buffer capacitance 140 with respect to the voltage output 140.

[0062] Thereby, at least the push-pull capacitance 131 is selected to provide a ratio of push-pull capacitance to buffer capacitance between 0.5 and 3.

[0063] In a step S3, the method comprises controlling the voltage multiplier circuit 130 to generate an output voltage at the voltage output 120.

[0064] It is noted that embodiments of the invention are described with reference to different subject matters. In particular, some embodiments are described with reference to method type claims whereas other embodiments are described with reference to the device type claims. However, a person skilled in the art will gather from the above and the following description that, unless otherwise notified, in addition to any combination of features belonging to one type of subject matter also any combination between features relating to different subject matters is considered to be disclosed with this application. However, all features can be combined providing synergetic effects that are more than the simple summation of the features.

[0065] While the invention has been illustrated and described in detail in the drawings and the 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. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing a claimed invention, from a study of the drawings, the disclosure, and the dependent claims.

[0066] 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 re-cited in the claims. The mere fact that certain measures are re-cited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

LIST OF REFERENCE SIGNS:

[0067]

1	X-ray imaging system, e.g. CT imaging system
100	voltage generator
110	voltage input
120	voltage output
130	voltage multiplier circuit
131	push-pull capacitance
140	buffer capacitance
200	X-ray source 200, e.g. X-ray tube,
300	gantry 300
400	detector 400
500	controller
600	high voltage measurement divider

Claims

1. A voltage generator (100) for X-ray imaging with fast kVp-switching between at least a first voltage level and a second voltage level different to the first voltage level, comprising:

   a voltage input (110);
   a voltage output (120);
   a voltage multiplier circuit (130), connected to the voltage input (130) and to the voltage output (120), and comprising a network of a push-pull capacitance (131) and at least one diode (132), and configured to provide, in response to a input voltage received via the voltage input (110), at least the first voltage level and the second voltage level at the voltage output (140) in an alternating manner;
   a buffer capacitance (140) arranged with respect to the voltage output (120);
   wherein a ratio of push-pull capacitance to buffer capacitance is between 0.5 and 3.

2. The voltage generator of claim 1, further configured to switch between the first voltage level and the second voltage level is in an order of at least 100 MV/s, more preferably 300 MV/s, and most preferably 1000 MV/s.

3. The voltage generator of claim 1 or 2, wherein the buffer capacitance is below 1000 pF, preferably below 300 pF, further preferably below 150 pF, and most preferably below 50 pF.

4. The voltage generator of any one of the preceding claims, wherein the push-pull capacitance (131) comprises a number of capacitors arranged in one or more high-voltage cascades.

5. The voltage generator of any one of the preceding claims, wherein the buffer capacitance comprises a high voltage cable capacitance, and wherein the high voltage cable is connectable or connected to the voltage output (120).

6. The voltage generator of any one of the preceding claims, wherein the buffer capacitance comprises a high voltage measurement divider capacitance, and wherein the high voltage measurement divider (600) is connectable or connected to the voltage output (120).

7. The voltage generator of any one of the preceding claims, wherein the buffer capacitance (140) is solely formed by one or more residual and/or parasitic capacitances.

8. The voltage generator of any one of claims 1 to 6, wherein the buffer capacitance (140) comprises at least one capacitor.

9. The voltage generator of any one of the preceding claims, wherein the voltage multiplier circuit (130) comprises a number of high-voltage cascades comprising a number push-pull capacitors forming the push-pull capacitance, without a dedicated buffer capacitor.

10. The voltage generator of any one of the preceding claims, wherein the voltage multiplier circuit (120) comprises a unipolar or bipolar multi-stage high-voltage cascade.

11. An X-ray imaging system (1) configured for fast kVp-switching between at least a first voltage level and a second voltage level different to the first voltage level, comprising:

a voltage generator (100) according to any one of the preceding claims; and
an X-ray source (200), connected to a voltage output (140) of the voltage generator (100) to receive a voltage signal switching between the first voltage level and the second voltage level.

12. The X-ray imaging system of claim 11, wherein the x-ray imaging system is a computed tomography system further comprising a controller (500) configured to control the voltage generator to change the X-ray source (200) voltage between individual projections.

13. The X-ray imaging system of claim 11 or 12, wherein a buffer capacitance of the voltage generator (100) comprises a high voltage cable capacitance, and wherein the high voltage cable (160) connects the voltage output (140) of the voltage generator (100) to the X-ray source (200).

14. The X-ray imaging system of any one of claims 11 to 13, wherein a buffer capacitance comprises a high voltage measurement divider capacitance, and wherein the high voltage measurement divider (170) connects the voltage output (140) of the voltage generator (100).

15. A method of controlling X-ray imaging for fast kVp-switching between at least a first voltage level and a second voltage level different to the first voltage level, the method comprising:

a voltage multiplier circuit (130), connected to a voltage input (130) and to a voltage output (120), and comprising a network of a push-pull capacitance (131) and at least one diode (132), and configured to provide, in response to a input voltage received via the voltage input (110), at least the first voltage level and the second voltage level at the voltage output (120) in an alternating manner;
providing a buffer capacitance (140) with respect to the voltage output (140);
wherein at least the push-pull capacitance (131) is selected to provide a ratio of push-pull capacitance to buffer capacitance between 0.5 and 3; and
controlling the voltage multiplier circuit (130) to generate an output voltage at the voltage output (120).

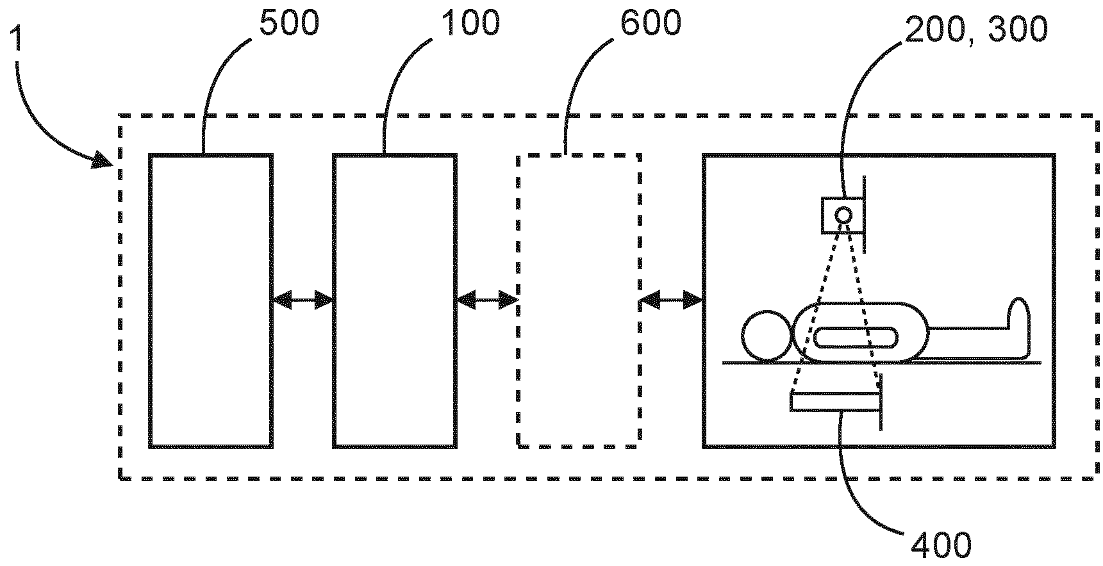

1
500
100
600
200, 300
400

FIG. 1

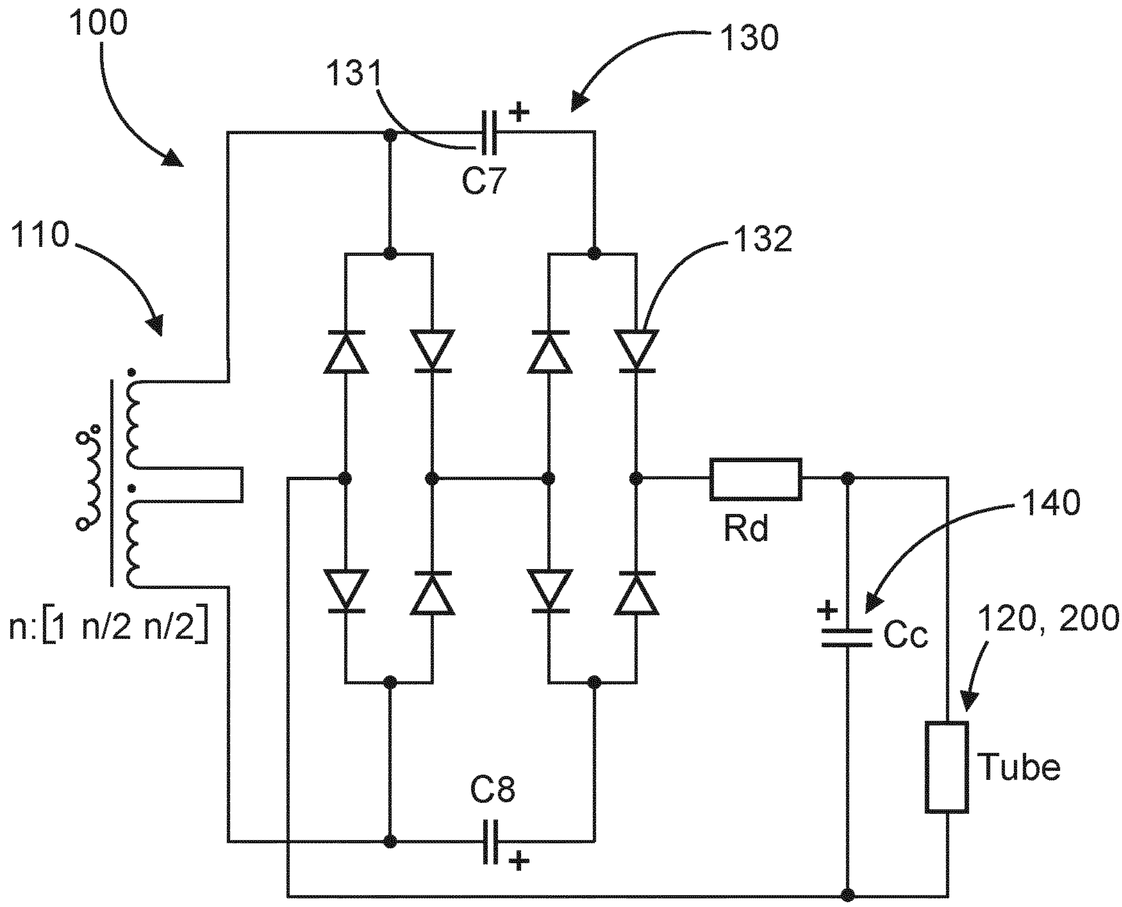
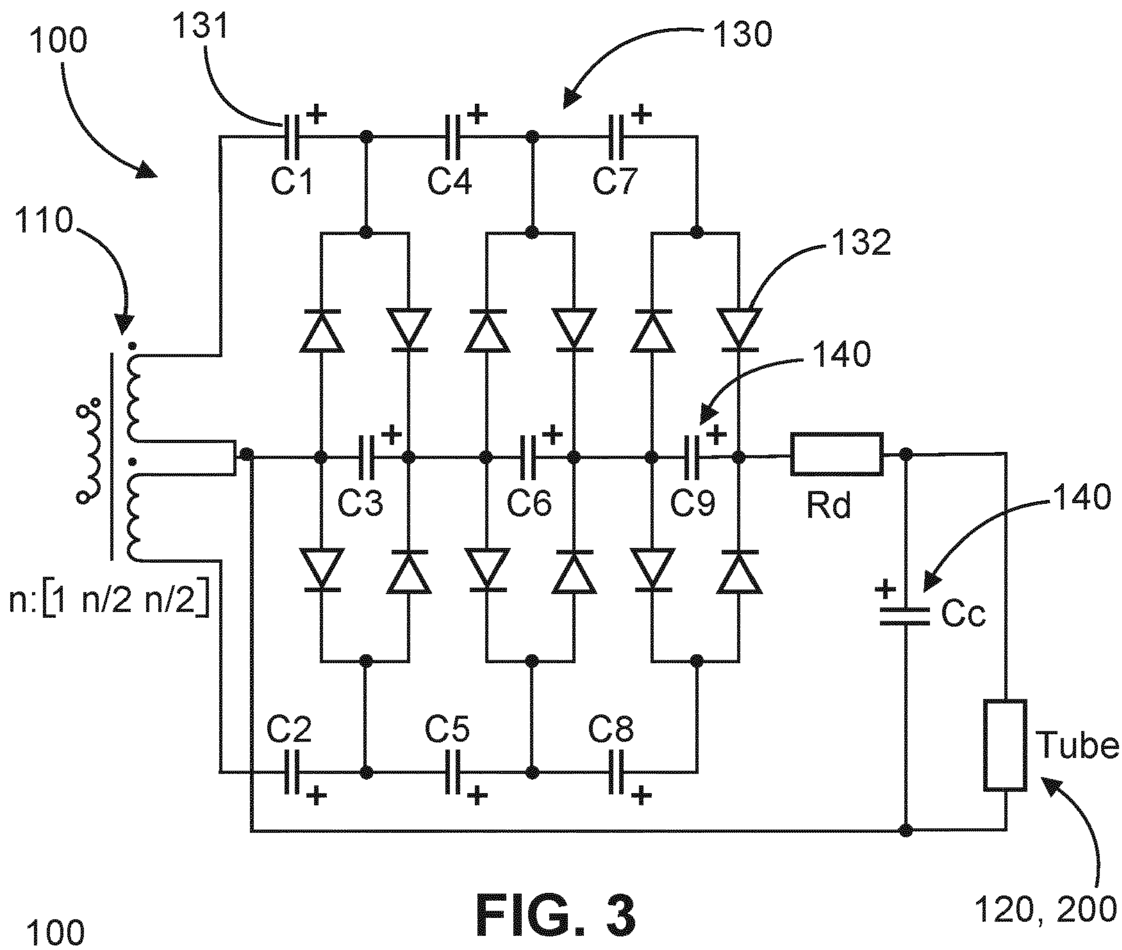
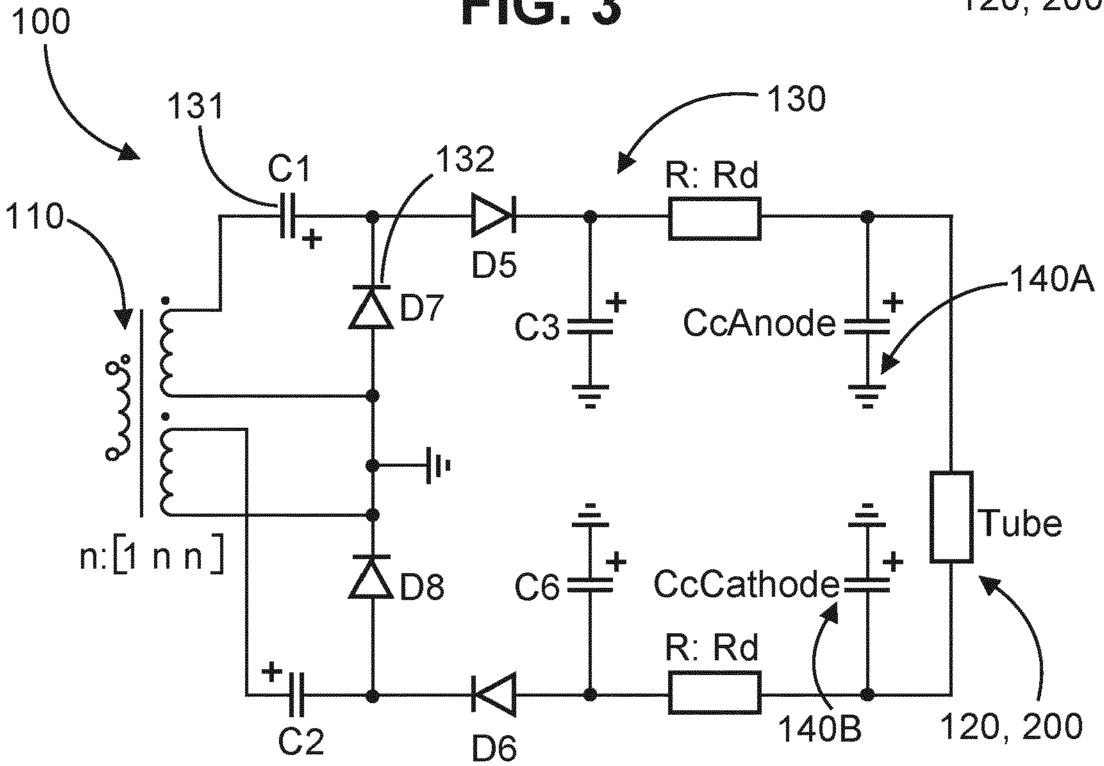

100
131
130
C7
110
132
n:[1 n/2 n/2]
Rd
140
Cc
120, 200
Tube
C8

FIG. 2



100
131
130
C1
C4
C7
110
132
140
C3
C6
C9
Rd
140
n:[1 n/2 n/2]
Cc
C2
C5
C8
Tube
120, 200

FIG. 3



100
131
130
C1
132
R: Rd
110
D5
D7
C3
CcAnode
140A
n:[1 n n]
D8
C6
CcCathode
Tube
R: Rd
C2
D6
140B
120, 200

FIG. 4

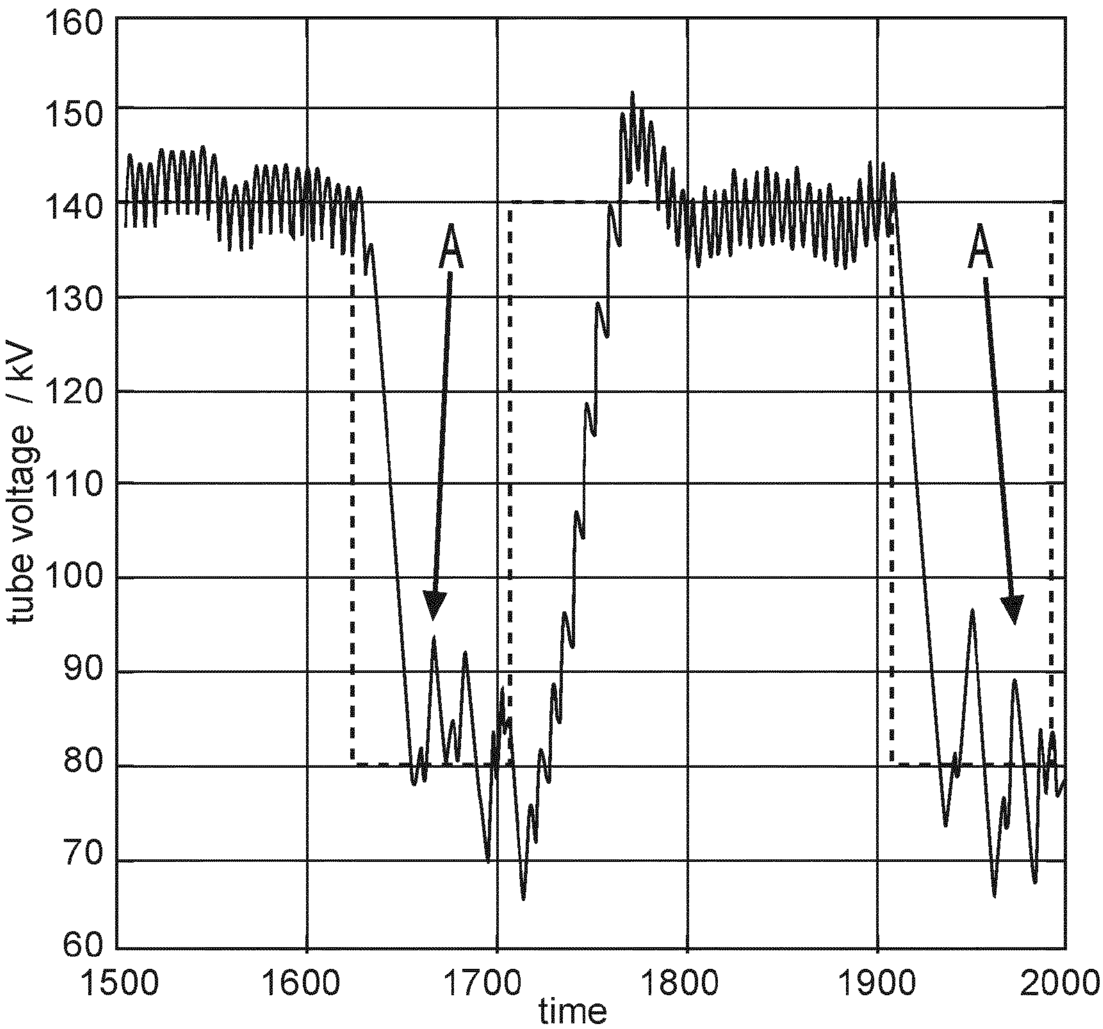

160
150
140
130
120
110
100
90
80
70
60
tube voltage / kV
1500
1600
1700
1800
1900
2000
time
A
A

FIG. 5

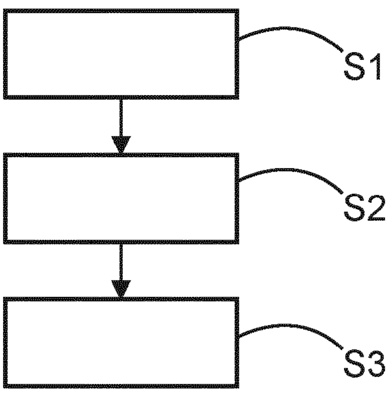

S1
S2
S3

FIG. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 21 18 5350

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2017/245356 A1 (ZYWICKI JANUSZ [GB] ET AL) 24 August 2017 (2017-08-24) * see fig. 2, and also fig. 3 and the description thereof * -----	1,2,4,5, 8,10-13, 15	INV. H05G1/10 H05G1/22

TECHNICAL FIELDS SEARCHED (IPC)

H01J
H05G

1

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	1 December 2021	Angloher, Godehard

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

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Application Number
EP 21 18 5350

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

- [ ] Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

- [ ] No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

- [ ] All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

- [ ] As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

- [ ] Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

- [x] None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

  1, 2, 4, 5, 8, 10-13, 15

- [ ] The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

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LACK OF UNITY OF INVENTION SHEET B

Application Number
EP 21 18 5350

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1, 2, 4, 5, 8, 10-13, 15

A voltage generator according to claim 1;
additional features of claim 2:
configured to switch between the first voltage level and the second voltage level ... in an order of at least 100 MV/s, more preferably 300 MV/s, and most preferably 1000 MV/s;
(additional) features common to claims 11 and 12;
An X-ray imaging system (1) configured for fast kVp-switching between at least a first voltage level and a second voltage level different to the first voltage level, comprising:
a voltage generator (100) according to e.g. claim 1; and
an X-ray source (200), connected to a voltage output (140) of the voltage generator (100) to receive a voltage signal switching between the first voltage level and the second voltage level.
claim 15:
A method of controlling X-ray imaging for fast kVp-switching between at least a first voltage level and a second voltage level different to the first voltage level, the method comprising:
a voltage multiplier circuit (130), connected to a voltage input (130) and to a voltage output (120), and comprising a network of a push-pull capacitance (131) and at least one diode (132), and configured to provide, in response to a input voltage received via the voltage input (110), at least the first voltage level and the second voltage level at the voltage output (120) in an alternating manner;
providing a buffer capacitance (140) with respect to the voltage output (140);
wherein at least the push-pull capacitance (131) is selected to provide a ratio of push-pull capacitance to buffer capacitance between 0.5 and 3; and
controlling the voltage multiplier circuit (130) to generate an output voltage at the voltage output (120).

1.1. claims: 4, 5, 8, 10, 13

see the corresponding features;

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2. claims: 3, 7, 9

A voltage generator according to e.g. claim 1;
special technical feature of claim 3:
the buffer capacitance is below 1000 pF, preferably below 300 pF, further preferably below 150 pF, and most preferably below 50 pF;
special technical feature of claim 7:
the buffer capacitance (140) is solely formed by one or more

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LACK OF UNITY OF INVENTION SHEET B

Application Number
EP 21 18 5350

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

residual and/or parasitic capacitances;
special technical feature of claim 9:
the voltage multiplier circuit (130) comprises a number of high-voltage cascades comprising a number push-pull capacitors forming the push-pull capacitance, without a dedicated buffer capacitor;

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3. claims: 6, 14

A voltage generator according to e.g. claim 1 / An X-ray imaging system according to e.g. claim 11;
special technical feature of claim 6:
the buffer capacitance comprises a high voltage measurement divider capacitance, and ... the high voltage measurement divider (600) is connectable or connected to the voltage output (120);
special technical feature of claim 14:
a buffer capacitance comprises a high voltage measurement divider capacitance, and ... the high voltage measurement divider (170) connects the voltage output (140) of the voltage generator (100);

Please note that all inventions mentioned under item 1, although not necessarily linked by a common inventive concept, could be searched without effort justifying an additional fee.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 21 18 5350

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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01-12-2021

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2017245356 A1	24-08-2017	CN 107079571 A	18-08-2017
		EP 3199000 A1	02-08-2017
		JP 6538156 B2	03-07-2019
		JP 2017535916 A	30-11-2017
		US 2017245356 A1	24-08-2017
		WO 2016045905 A1	31-03-2016

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82