United States Patent

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[54] **PULSED X-RAY CONTROL SYSTEM WITH IMPROVED FILM DARKENING**
11 Claims, 8 Drawing Figs.

[52] **U.S. Cl.** ..... **250/65 R,** 250/98, 250/99, 250/102
[51] **Int. Cl.** **H05g 1/14,** H05g 1/24, H05g 1/34
[50] **Field of Search** ..... 250/65 R, 98, 99, 102

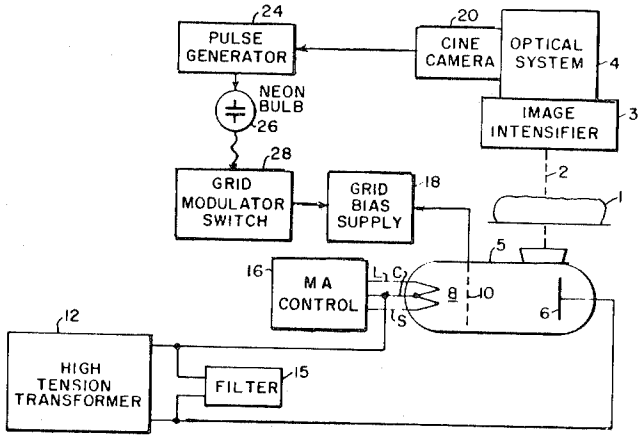
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2,879,404	3/1959	Rogers et al.	250/98
2,937,277	5/1960	Euler, Jr. et al.	250/65
3,103,591	9/1963	Rogers et al.	250/102

Primary Examiner—William F. Lindquist
Attorneys—F. H. Henson, E. P. Klipfel and S. Weinberg

ABSTRACT: A circuit for use with a grid pulse X-ray tube which is operated at its maximum rated kv. and ma. The circuit provides more film darkening than would otherwise be possible when the X-ray tube is operated under such a maximum load. The circuit includes a filter which converts the output of the high-tension transformer from a sine wave to substantially a square wave which is then fed to the input of the X-ray tube. The pulsing of the grid is controlled by other circuits in such a way that the X-ray tube conducts symmetrically about the midpoint of the sine wave. Such precise timing of the grid pulse to initiate conductivity of the X-ray tube aids the filter in its function of providing a square wave to the X-ray tube input.



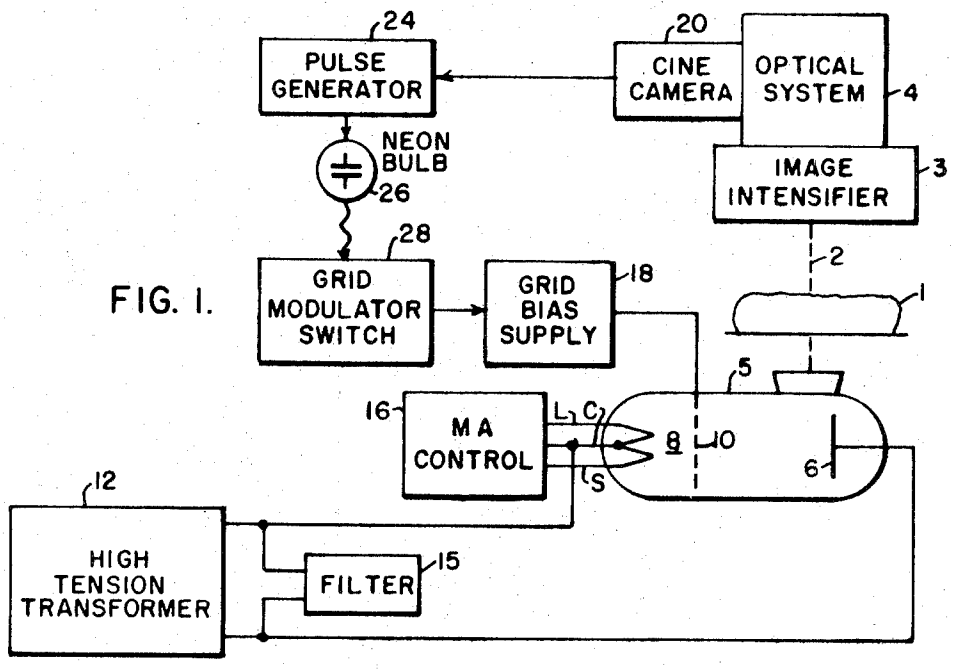

24
PULSE GENERATOR
20
CINE CAMERA
OPTICAL SYSTEM
4
NEON BULB
26
IMAGE INTENSIFIER
3
28
GRID MODULATOR SWITCH
GRID BIAS SUPPLY
18
2
1
5
16
MA CONTROL
L
C
S
8
10
6
12
HIGH TENSION TRANSFORMER
FILTER
15

FIG. 1.

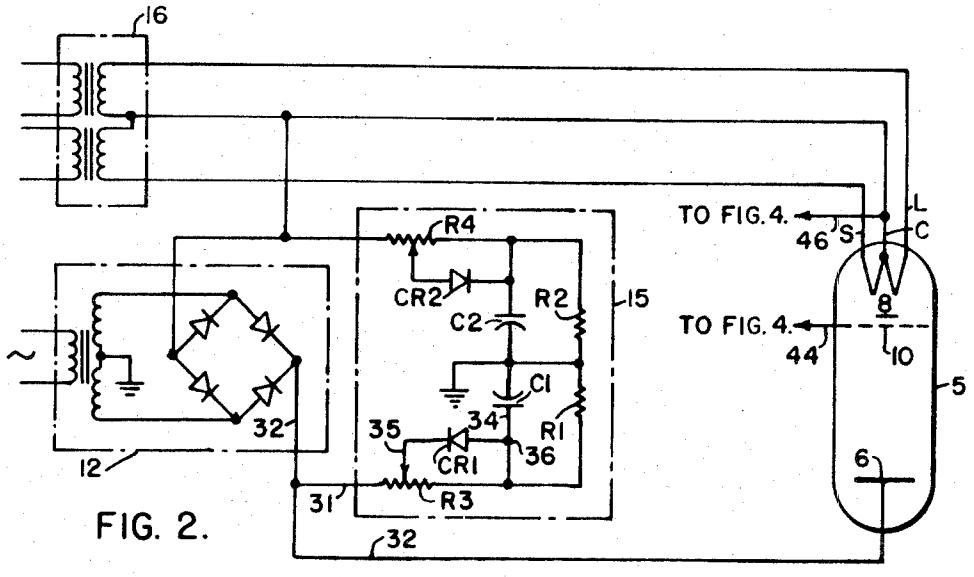
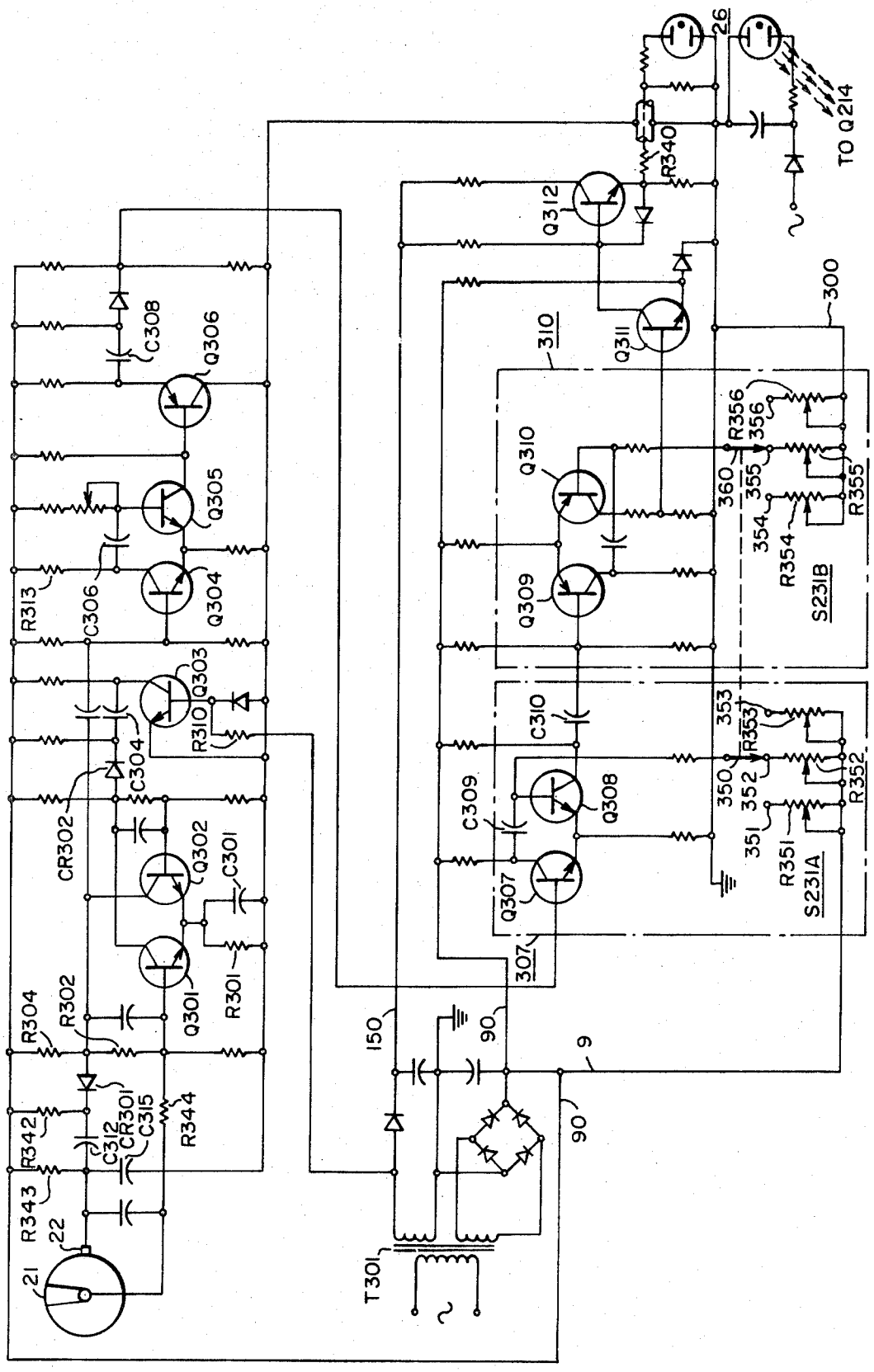

16
R4
CR2
C2
R2
15
C1
R1
CR1
R3
35
34
36
31
32
12
TO FIG. 4.
46
S
L
C
8
TO FIG. 4.
44
10
5
6
32

FIG. 2.

FIG. 3


26
TO Q214
R340
Q312
Q311
300
310
Q310
Q309
R356
356
360
355
354
R355
R354
S231B
C310
353
R353
350
352
R352
351
R351
S231A
Q308
C309
Q307
307
C308
Q306
Q305
Q304
R313
C306
Q303
R310
C304
CR302
Q302
C301
Q301
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R302
R342
C312
CR301
C315
R344
R343
22
21
T301
150
90
9

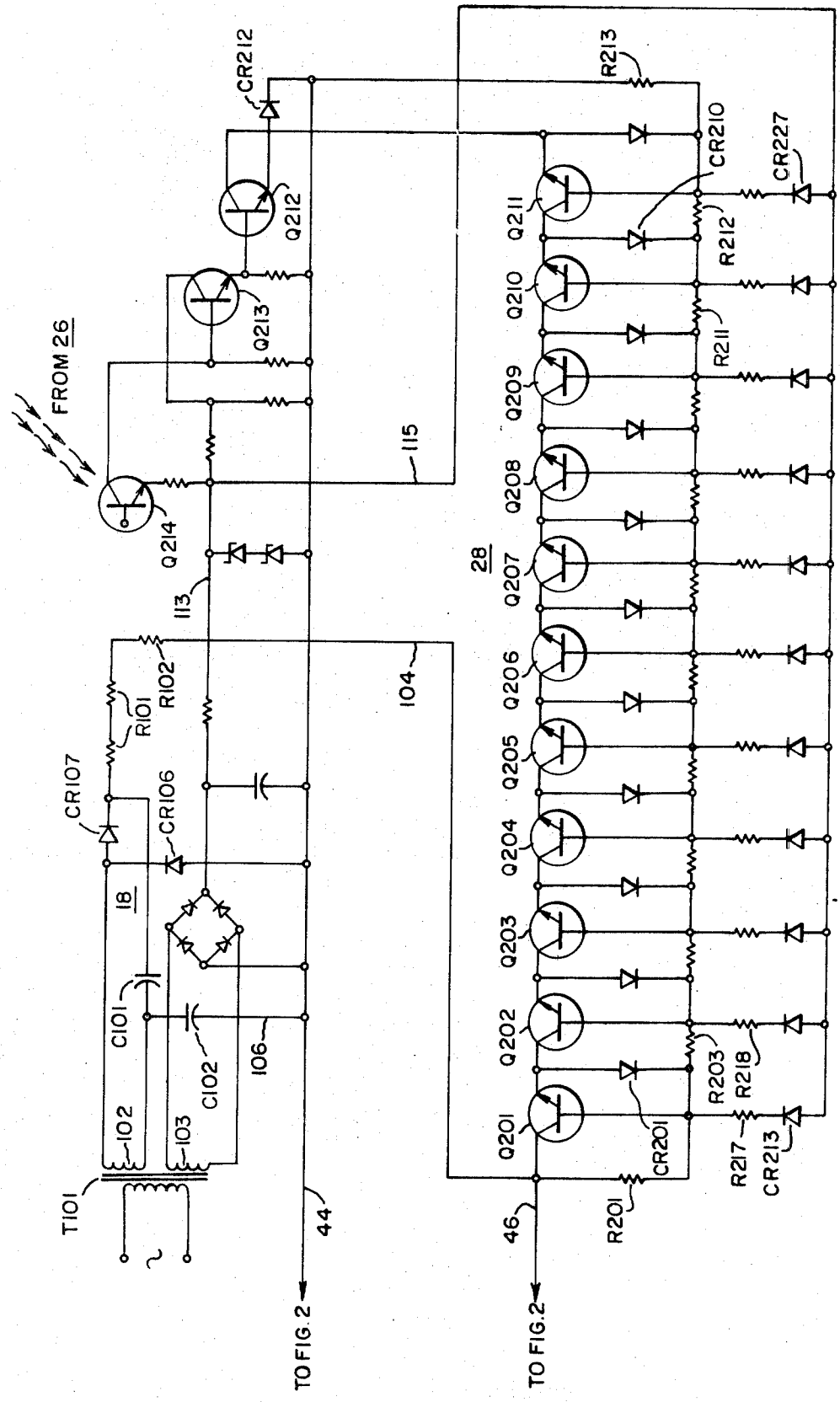

FROM 26
Q214
CR212
Q212
Q213
113
115
R101
R102
CR107
CR106
18
C101
C102
102
103
106
T101
44
TO FIG. 2
104
28
Q207
Q206
Q205
Q204
Q203
Q202
Q201
R213
CR210
CR227
Q211
Q210
Q209
Q208
R212
R211
R203
R218
R217
CR213
CR201
R201
46
TO FIG. 2

FIG. 4

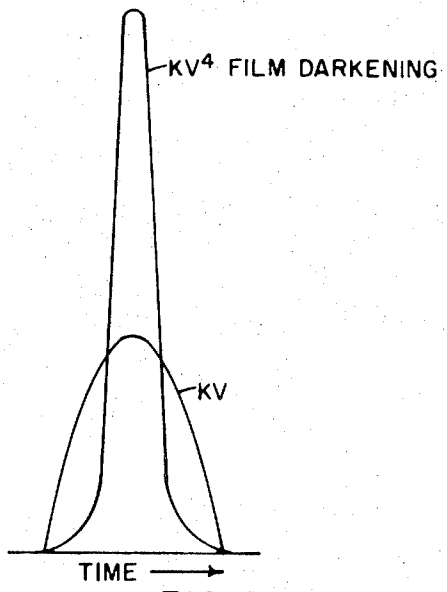


FIG. 5.

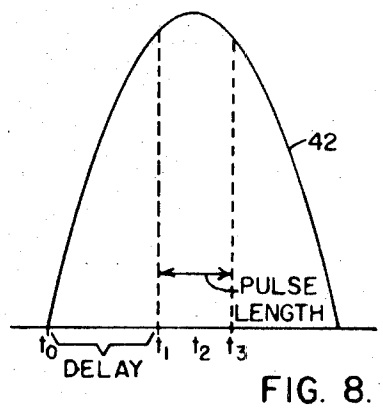


FIG. 8.

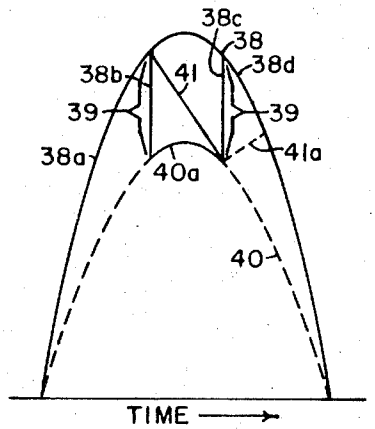


FIG. 6.

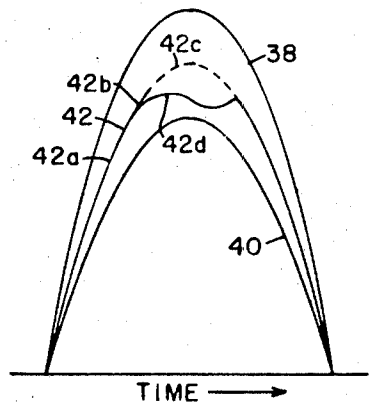


FIG. 7.

PULSED X-RAY CONTROL SYSTEM WITH IMPROVED FILM DARKENING

BACKGROUND OF THE INVENTION

1. Field of the Invention

In general, the invention relates to grid-controlled X-ray systems. More specifically, it relates to a grid control system which provides improved film darkening on photographic film which is located in a camera and which makes a permanent record of the X-ray information.

1. Description of the Prior Art

Cine radiography was first accomplished without the use of image amplifier tubes by having a cine camera photograph a fluorescent screen. Because it required so much patient radiation, it was confined to rare and short uses. Under the best conditions, it required 200 times the radiation dosage that is now required when using an image amplifier tube. Such image amplifier tubes are in wide use today.

As cine techniques improved, it became possible to reduce considerably the required dosage by pulsing the X-ray tube synchronously with the camera shutter so that an exposure is made when the cine camera shutter is opened but no exposure is made when the cine camera shutter is closed. Exposure is therefore stopped when the film is moved between frames. This type of pulsing was accomplished by pulsing the primary of the high-tension X-ray transformer. The dosage was dependent on the camera speed and the aperture of the shutter. A typical primary pulsed X-ray system is shown in the patent to Euler, Jr. et al., U.S. Pat. No. 2,937,277.

The desire of the radiologist to work with higher MA and shorter exposure times has led to the development of X-ray grid pulse generators which permit millisecond exposures. These latter systems operate by synchronously pulsing the exposure in phase with a camera shutter by using a grid bias system in the high-tension side of the X-ray tube itself to turn the exposure on and off.

A grid-controlled tube utilizes the focusing cup, which partially surrounds the tube filament, as an electrode to switch tube current on and off. This cup is usually referred to as a cathode cup. In a grid-controlled X-ray tube, the filament is electrically isolated from the cathode cup. When the cathode cup is at a sufficiently negative potential in relation to the filament, it has an electric field sufficient to completely stop the flow of electrons from the cathode to the anode of the X-ray tube. When the cathode cup is brought to the same potential as the filament, electron flow resumes and the cathode cup serves to focus the electron stream that flows across the tube to the anode in the usual manner which will be understood by those skilled in the art. The grid acts only as an "on-off" switch and does not control the magnitude of the current flow across the tube during the "on" state. As with any X-ray tube, current flow across the tube is a function of the filament temperature. Grid controlled X-ray systems are typified by the patents to Rogers et al. U.S. Pat. Nos. 2,879,404, Jacobs 3,009,079 and Rogers et al. 3,103,591.

Because X-ray tubes are very expensive, a radiologist typically does not purchase an X-ray tube which has kilovoltage (kv.) or milliamp (ma.) focal spot or dissipation characteristics which are greater than he will need in his individual, specific practice. Therefore, the radiologist will purchase an X-ray tube which, when pushed to its maximum rated kv., ma. focal spot, and temperature dissipation, will give him the maximum performance that he needs in his practice. Therefore, it is a common occurrence for the radiologist to use his X-ray equipment at its maximum allowable loading. The problem is, however, that when such equipment is used at the maximum allowable ratings, the radiologist does not obtain the greatest possible film darkening.

In order to improve film darkening, other prior art devices have used a three-phase, 12-pulse system which uses rectifiers arranged in two groups. If such a system is used at 60 cycles, for example, the ripple frequency is 12 times 60 cycles or 728 pulses per second — providing a very high ripple frequency and low amplitude. Consequently, such systems only require a small filter. However, three-phase systems are still very expensive.

Single-phase systems have also been made which used filters of size sufficient to store substantially more energy than the X-ray tube requires for a single discharge pulse. Such filters are dangerous because much energy remains after the pulse. Also, these filters are large and rather expensive. Smaller filters would not normally store enough energy to maintain the X-ray anode voltage constant enough to obtain optimum film darkening and minimum anode dissipation.

BRIEF SUMMARY OF THE INVENTION

To solve the problem of increasing film darkening when an X-ray tube is operated at its maximum capacity, certain features are added to an existing single-phase X-ray system which might include an X-ray tube, a high-voltage transformer which energizes the X-ray tube, the high-tension transformer providing a sine wave which is then rectified, and a camera with photographic film to record a permanent picture of the X-ray information.

In order to improve the film-darkening capabilities of the existing X-ray equipment, a conversion device, including a filter, converts the sine wave into substantially a flat voltage waveform — i.e., a square wave. The square wave voltage is connected to the anode of the X-ray tube in the standard manner. As part of the conversion circuitry, a delaying circuit is provided between the camera and the X-ray tube. The delay circuit includes a pulse generator which synchronizes the camera shutter to the powerline. Depending upon the length of the pulse which is desired, the pulse generator will delay transmission of the pulse from the camera to the X-ray tube for a selected period of time and will then control the pulse length so that the tube sill be conductive symmetrically with respect to the midpoint of the sine wave.

In the preferred embodiment, a grid-controlled X-ray tube is used. Normally, a bias voltage is connected to the grid to render the X-ray tube nonconductive. However, each time the pulse generator produces a pulse, a switching device renders the grid bias voltage ineffective and the X-ray tube becomes conductive over the duration of the pulse.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention, reference may be had to the preferred embodiment, exemplary of the invention, shown in the accompanying drawings in which:

FIG. 1 shows a functional block diagram of a preferred embodiment of the invention;

FIG. 2 is a circuit diagram showing how the filter is interconnected into the system;

FIG. 3 is a circuit diagram of the pulse generator;

FIG. 4 is a circuit diagram of the grid modulator switch and its relationship to the grid bias supply;

FIG. 5 is a graph showing the relationship of kv. to film darkening;

FIG. 6 is a graph comparing anode voltages under unloaded and loaded conditions;

FIG. 7 is a graph comparing anode voltages under unloaded and loaded conditions without the filter with anode voltage under loaded conditions with the filter; and

FIG. 8 is a graph showing the location of X-ray tube conduction under loaded conditions using the filter.

DETAILED DESCRIPTION OF THE INVENTION

The present invention describes a system which uses filters of minimum size thereby permitting optimum tube operation on single-phase systems. The invention is able to use an existing single-phase X-ray system. It is much cheaper to manufacture and operate than the prior art systems. Depending upon the use to which the radiologist will put his X-ray equipment, the optimum film darkening will come about as the result of an optimum balancing of the kv., ma., focal spot, and exposure

time. The kv. level will be determined by the patient geometry. For example, a patient having a large chest thickness will require a higher kv. than would be necessary for a patient having a smaller chest thickness. The focal spot required is determined by the resolution which is needed for the study which is being undertaken. For example, a picture showing the fine blood vessels of the heart will require a much smaller focal spot than a picture of the lung field. Typically, a focal spot diameter of 1mm. or less is required for heart studies.

The ma. applied to the tube is determined by taking many factors into consideration. One of the factors is, again, the patient geometry. Another factor is the thermal rating of the X-ray tube. If too much current and voltage are applied to the X-ray tube in a short period of time, the X-ray tube will be destroyed because its tungsten anode will melt. The focal spot diameter is another factor which affects the ma. If a small focal spot is required for a particular exposure, the ma. must be reduced from the value which would be permissible for a larger focal spot. The ma. must be reduced in order that the thermal rating of the X-ray tube not be exceeded because the X-ray tube can only dissipate a set amount of joules per exposure as a function of focal spot size and time.

As a general rule, radiologists use their X-ray equipment as close as possible to its maximum allowable limit. This is especially so when they are using the equipment for vascular studies, especially heart studies, where they need a high exposure rate, maximum kv., and minimum focal spot diameter.

In order to determine the maximum loading that a tube can withstand, X-ray tubes are rated in terms of the number of joules that can be dissipated by the anode of the tube during an exposure. Because the anode is substantially adiabatic (it neither radiates nor dissipates any of the heat built up in it) during each exposure pulse, there is a limit to the number of joules per exposure which can be fed to the anode as a function of the anode rating velocity and focal spot size. Consequently, there is a limit to the number of joules per exposure which can be fed to the anode as a function of the anode rotating velocity and the kv. applied to it.

The quality of the picture which is recorded by the film is directly related to the amount of film darkening. The amount of film darkening changes linearly with current. That is, if the ma. is doubled, the film darkening will also be doubled. However, film darkening is also related to the fourth power of kv. ($kv.^4$) approximately.

Referring to FIG. 5, the curve labeled kv. shows the approximate shape of an input voltage sine wave which would ordinarily be applied from the high-tension transformer to the X-ray tube anode. The curve $kv.^4$ shows the relative amount of film darkening which would be obtained as the kv. varies through the half cycle shown. FIG. 5 clearly shows that small changes in anode voltage have a very large effect on film darkening. It also shows that the maximum film darkening occurs over a very small central portion of the sine wave. Therefore, the film darkening available over most of the AC cycle is less than maximum.

The problem is, however, that when the X-ray tube is already being used at its maximum loaded value — i.e. maximum kv. and maximum ma. — the kv. cannot be increased further to increase the film darkening. However, by applying a constant voltage to the anode — that is, a flat voltage waveform — we can optimize the film darkening with respect to the $kv.^4$. Even though the ma. level will have to be reduced if a constant-voltage waveform is used in order to keep the number of joules down to a level which is acceptable for the particular tube, the use of the square wave will provide appreciably increased film darkening. At that point, the maximum amount of film darkening per unit joule of input to the tube will be attained.

FIG. 1, then, shows a functional block diagram of a circuit which will provide substantially a square wave voltage waveform at maximum tube loading. FIG. 1 shows an X-ray tube **5** having an anode **6**, a filament-cathode **8**, and a control grid **10**. The large focal spot filament wire of the cathode **8** is labeled L and the small focal spot filament wire is labeled S. High-tension transformer **12** provides a rectified sine wave voltage to the anode **6** and the common filament wire C of the cathode **8** through a filter **15** which converts the sine wave into substantially a square wave in order to maximize the film darkening for the reasons discussed above. The ma. supplied to the filament windings L and S is controlled in the usual manner by an ma. control **16**. When the X-ray tube **5** is energized by applying the proper kv. (kilovoltage) to the anode, the proper ma. (milliamps) to the filament, and the proper voltage to the grid, it will emit X-radiation as indicated at **2**. The X-radiation **2** is directed to an image intensifier **3** which changes the X-radiation not absorbed by the patient, symbolized by **1**, into visible light at its output phosphor which is optically coupled by optical system **4** to the film (not shown) in a cine camera **20**.

Normally, the grid bias supply **18** places a sufficiently negative voltage on the grid with respect to the cathode that the X-ray tube **5** is rendered nonconductive even though the high-tension transformer **12** is providing a voltage to the anode **6**. When it is desired to make an exposure and to record it with the cine camera **20**, the camera energizes a pulse generator **24** which synchronizes the camera with the AC line and generates a pulse at the proper phase point of the AC cycle. The pulsing of the pulse generator **24** energizes a neon bulb **26** which, in turn, closes a fast-acting grid modulator switch **28**. The switch **28** short circuits the grid bias supply **18** thereby removing the negative voltage from the grid **10** of the X-ray tube **5** and permitting the X-ray tube to conduct and make an exposure over the length of time that the grid modulator switch **28** is closed. When the neon bulb **26** is extinguished at the end of the pulse from the pulse generator **24**, grid modulator switch **28** returns to its deenergized or open position thereby reinstating the grid bias supply **18** on the grid **10** of X-ray tube **5**.

FIG. 2 shows a preferred embodiment of the filter **15**. In the preferred embodiment, a high-tension transformer would be supply **130** kv. across the X-ray tube, **5**—65 kv. to the anode and 65 kv. to the wire C portion of the cathode **8**. The filter **15** is divided into two symmetrical circuits. One of the symmetrical circuits is connected to the anode **6** and the second symmetrical circuit is connected to the wire C of the cathode **8**. Accordingly, only one section of the filter **12** will be described because the structure and operation of the second section is identical.

The section of the filter **15** which is connected to the anode **6** includes a resistor R3 which is connected on one end by lines **31** and **32** both to the output of the high-tension transformer **12** and to the anode **6**. The other end of resistor R3 is connected to capacitor C1 by line **34**. The other side of capacitor C1 is connected to ground. Resistor R3 is a plurality of individual resistors. Arm **35** connects a diode CR1 in a forward direction between junction point **36** and a selected point on resistor R3. The common connection point of R3 and C1 forms junction **36**. The positioning of arm **35** along resistor R3 will be described below.

As explained above, the aim of the present invention is to provide a substantially square wave to the tube. The square waveform is provided, in part, by the combination of the diode, the resistor, and the capacitor.

Referring to FIG. 6, curve **38** shows one-half of the AC cycle of the voltage which is provided by the secondary of the high-tension transformer **12** under no-load conditions. Curve **40**, including the dashed portions, shows the voltage on the secondary of the high-tension transformer **12** under load condition — i.e. when the tube is conducting — but without any filtering circuitry in between the high-tension transformer and the X-ray tube **5**. Under actual operating conditions, the voltage on the secondary of the high-tension transformer **12** would follow portion **38*a*** of curve **38** until the X-ray tube were gated on. At that point, the voltage would drop almost instantaneously along line **38*b*** to the voltage which is represented by the loaded secondary curve **40**. The voltage

would then follow portion 40*a* of the loaded secondary curve 40 until the X-ray tube were turned off when the voltage would, again, almost instantaneously, jump back up to the unloaded secondary curve along line 38*c* until it reached curve 38 which it would then follow for the remainder of the cycle.

If such a system were actually used, two undesired results would be obtained: (1) there would be approximately a 10 percent voltage deviation from the beginning to the end of tube conduction as can be seen by viewing the portion 40*a*; (2) the secondary of the high-tension transformer 12 would be subjected to a very high transient voltage as indicated by portions 39 between curves 38 and 40. In some cases the transient voltage can be as much as 30 or 40 kv. Because the transient occurs in about 50 microseconds, it can be very damaging to the secondary of the transformer.

In order to eliminate transients, the prior art placed a capacitor in parallel with the high-tension transformer and X-ray tube. This solution was tried in the aforementioned Rogers U.S. Pat. No. 2,879,404. When a capacitor is used, the unloaded secondary would again follow portion 38*a*; but when the tube is turned on, the capacitor discharges along line 41. Of course, the voltage across the X-ray tube also follows line 41. So, even though the instantaneous transient is reduced during tube conduction, the voltage shown by line 41 results in about a 20 percent deviation between the beginning and the end of tube conduction. For film-darkening purposes, such deviation is even worse than the case when no capacitor at all was used.

Referring to FIG. 7, curve 42 (including the dashed portion) shows a voltage on the secondary of the high-tension transformer 12 as it looks when filter 15 is connected to the transformer and the X-ray tube 5, but when the tube is not conducting. During the time before the X-ray tube conducts, as depicted by portion 42*a*, the capacitor C1 and the resistor R3 put a load on the transformer which is almost equal to 50 percent of the load of the X-ray tube. Most of the loading during portion 42*a* is provided by the resistor R3. If the X-ray tube does not turn on, then the voltage waveform continues along its normal course and following portion 42*c*. If the tube 5 is turned on, however, the voltage immediately drops to the voltage indicated by curve 42*d*. When the tube initially turns on, the capacitor does not provide an additional load on the transformer because the voltage on the capacitor is equal to the voltage at the output of the high-tension transformer. However, because the X-ray tube 5 continues to present a high load to the transformer secondary, the secondary voltage eventually begins to drop off. By the time the secondary voltage reaches its lowest point, the capacitor voltage is then greater than the transformer voltage and it begins to supply power to the X-ray tube thereby causing the voltage appearing on line 32 to increase, at the end of the pulse, almost back to the voltage level at which tube conduction began.

The effect of the filter 15 is to yield a much flatter voltage waveform on the tube than would be possible otherwise. In fact, under maximum load conditions (the conditions with which we are concerned here) the voltage deviation at any time during tube conduction is approximately 3 percent when the filter is used. Because the flat voltage waveform is optimal with respect to the kv.^{4} rule, we are able to get the maximum film darkening per joule of input to the X-ray tube. Furthermore, with this filter arrangement, there are no abrupt voltage changes which could damage the transformer.

The capacitor charges through resistor R3 and discharges through diode CR1. The charging rate and the discharging rate of the capacitor C1 is determined by resistor R3. A rough rule of thumb is that the capacitor should supply about 50 percent of the power and the transformer should supply about 50 percent of the power at maximum loading of the tube. In practice, the voltage across the capacitor can be measured under test conditions by using R1 and R2 as part of a resistive voltage divider to an oscilloscope. The resistor R3 can then be varied until the waveform portion 42*d* shown in FIG. 7 is as flat as possible.

In a preferred embodiment, the filter could be made up of the following components:

R3 and R4: 17 resistors, each being 1.75 k, 10 w.

CR1 and CR2: three high-voltage rectifiers, which are, together, rated 120 kv.–PIV, 500 ma.

C1 and C2: 0.075 μf., 80 kv.

If a Machlett Corporation, Dynamax HD51A grid-controlled X-ray tube were used, resistors R3 and R4 would each be set at their respective midpoints.

Throughout the discussion of the curves shown in FIGS. 6, 7 and 8, it has been assumed that tube conduction takes place symmetrically with respect to the midpoint of the portion of the sine wave which is shown in the FIGS. The circuitry for performing the function of symmetric X-ray tube conduction will be described below.

Triggering the X-ray tube 5 symmetrically about the midpoint of the curve 42 will be understood by referring to FIG. 8. It can be seen in FIG. 8 that the time between t_1 and t_2 is substantially equal to the time between t_2 and t_3. This capability is provided by the combination of the cine camera 20, pulse generator 24, neon bulb 26, and the grid modulator switch 28.

Referring to FIG. 4, the grid bias supply 18 includes one of the secondary windings 102 of the transformer T101, capacitor C101 and C102 and rectifying diodes CR106 and CR107. The configuration of these components is such that they comprise a voltage doubler. When it is energized from the main power supply (not shown), the grid bias supply 18 furnishes, in a preferred embodiment, −3,000 volts DC along lines 44 and 46. Briefly referring to FIG. 2, it will be seen that the grid bias supply is connected to the grid 10 of the X-ray tube 5 and the cathode 8. The positive voltage is supplied to the cathode from diode CR107, resistor R101, resistor R102, line 104, and line 46. The negative potential is supplied to the grid through capacitor C102, line 106, and line 44.

As explained above, the pulsing of the X-ray tube must be symmetrically placed about the midpoint of the sine wave. The camera shutter must be similarly phased. The opening of the camera shutter spans approximately 140°. The motor (not shown) of the cine camera 20 drives the shutter. Even though the camera uses a synchronous motor, frictional losses in the camera, temperature and camera age affect its rotation. Consequently, the mechanical phasing of the shutter must be arranged such that at least 80° to 90° of the 140° of the shutter opening is available during grid pulsing.

In order to mechanically phase the camera shutter with X-ray tube conduction so that both occur substantially simultaneously and symmetrically with respect to the midpoint of the sine wave, the following delaying circuitry is provided. The delay circuitry comprises the pulse generator 24. Part of the pulse generator is a contact assembly, including metal contact 21, mounted on the same drive shaft which drives the shutter. Whenever contact 21 touches contact 22, a pulse is generated. Because of the frictional losses, temperature and age of the camera, as mentioned above, the phase lag of the shutter pulse with respect to the power line will vary as much as 30° from the time when the camera is full of film to the time when the camera is very nearly empty of film. This variation is called camera "jiggle."

In order to synchronize the camera shutter with the AC line, contacts 21 and 22 send out a negative signal during the negative half cycle of the sine wave. Very nearly at the zero crossover point, as the positive half cycle of the sine wave begins to go positive, a positive signal is applied to the base of NPN-transistor Q303 from NPN-transistor T301 through resistor R310. The negative-going signal from shutter contacts 21 and 22 is coupled to the base of normally conducting NPN-transistor Q301 through capacitor C312, diode CR301 and resistor R302. The negative pulse is also connected to the collector of NPN-transistor Q302. Transistor Q301 and Q302 constitute a signal conditioner.

The negative pulse at the base of transistor Q301 and the positive pulse at the base of transistor Q303 results in capacitor C304 providing a positive pulse at the base of normally nonconducting NPN-transistor Q304.

NPN-transistor Q304 and Q305 form a multivibrator, the emitters of which are both commonly connected through resistor R341 to ground. Transistors Q304 and Q305 in conjunction with capacitor C306 cause PNP-transistor Q306 to conduct. Conduction of transistor Q306 discharges capacitor C308, resulting in a positive pulse at diode CR304. This positive pulse is conducted through multivibrator 307 which includes NPN-transistors Q307 and Q308. Multivibrator 307 determines the phase point of the sine wave at which the X-ray tube will begin to conduct by holding it for a selected period of time before it is directed to an additional multivibrator 310, including PNP-transistors Q309 and Q310 determines the length of the pulse. Multivibrator 310 conducts the pulse to the grid modulator switch over a time determined by the desired exposure time.

The effect of the last two mentioned multivibrators will be understood by briefly referring to FIG. 8. As seen in FIG. 8, the midpoint of the sine wave occurs approximately at time t_2. In order to obtain the flat voltage waveform on the anode as discussed above, it is necessary that the pulse length be symmetrically disposed about the center point t_2. That is, the time from t_1 to t_2 should equal the time from t_2 to t_3. Multivibrator 307 determines the delay from t_o, the beginning of the pulse, to t_1, the beginning of X-ray tube conduction. Multivibrator 310 determines the length of the pulse — i.e., the time from t_1 to t_3. By adjusting the time delays of multivibrators 307 and 310 properly, to obtain the timing sequences shown in FIG. 8, the flattest possible waveform will be obtained.

NPN-transistor Q307 is normally nonconducting. NPN-transistor Q308 is normally conducting. The positive pulses from CR304 causes transistor Q307 to become conductive which, in turn, causes transistor Q308 to become nonconductive. Switch S231A has a movable contact point 350 which is connected to the base of transistor Q308 through resistor R327. Switch S231A includes three stationary contacts 351, 352, and 353. Each of the stationary contacts are respectively connected to secondary 302 of transformer T301 which supplies a positive voltage through respective potentiometers R351, R352 and R353. By moving switch S231A to one of the stationary contacts, the delay and, consequently, the beginning of conduction of the X-ray tube can be varied. The delay portion of multivibrator 307, consisting of one of the potentiometers connected to movable contact 350 and capacitor C309, determines how quickly transistor Q308 turns back on.

After passing through multivibrator 307, the trigger pulse is coupled to multivibrator 310. PNP-transistor Q309 is normally nonconducting and PNP-transistor Q310 is normally conducting. Multivibrator 310 also includes a switch S231B having a movable contact 360 and a plurality of stationary contacts 354, 355, and 356. The movable contacts 350, 360 of switches S231A and S231B, respectively, are ganged together. The stationary contacts of switch S231B are connected to ground over line 300 and respective potentiometers R354, R355, and R356.

When transistor Q309 is gated on by the negative pulse resulting from the discharge of capacitor C310, the emitter voltage of transistor Q310 increases, thereby becoming nonconductive. The RC network which includes the respective chosen resistance of switch S231B and capacitor C311 determines the speed with which transistor Q310 reestablishes its conductive mode. This establishes the pulse length.

NPN-transistors Q311 and Q312 conduct the pulse from multivibrator 310 to the neon bulb configuration 26 over resistor R340. When neon bulb configuration 26 receives the pulse from the transistor Q312 it sends out a pulse of light to the grid modulator switch 28 via phototransistor Q214 which becomes conductive when it receives the light impulse from the neon bulb configuration 26. The signal supplied by phototransistor Q214 is then amplified by NPN-transistor Q213. Conduction of transistor Q213 energizes the grid modulator switch 28 which includes a plurality of cascade-connected transistors Q201 to Q212 — i.e. a plurality of transistors which are series connected via their respective collector-emitter circuits. Therefore, conduction of transistor Q213 causes NPN-transistor Q212, of switch 28, to become conductive and the process then becomes a cumulative one.

When transistor Q212 conducts it causes the emitter of NPN-transistor Q211 to drop to a low potential — i.e. the potential on line 106, thereby permitting the positive voltage from transformer secondary 103 to become effective over lines 113 and 115 to drive the base of transistor Q211 via diode CR223 and resistor R227. The process repeats stage by stage through the plurality of cascade-connected NPN-transistors Q201 to Q211. As transistor Q211 becomes conductive, the emitter of transistor Q210 drips to a very low potential and, again, the base drive will drive transistor Q210 into heavy conduction due to the bias drive applied through diode CR222 and resistor R226. The same process repeats again until all of the stages are driven into heavy conduction. When that occurs, the entire grid bias supply 18 will be short circuited in the following manner: diode CR107, resistor R011, resistor R102, line 104, transistors Q201–Q212, and line 106. When the grid modulator switch 28 becomes completely conductive, the grid bias voltage is dissipated across load resistor R101. In a preferred embodiment, load resistor R101 consists of two 100 k resistors connected in series.

At the conclusion of the light pulse applied to transistor Q214, the process works in reverse in such a way that transistor Q212 no longer is maintained in a state of conduction and, consequently, can no longer maintain the emitter of transistor Q211 at a low potential. Therefore, the base drive of transistor Q211 is no longer sufficient to maintain conduction and the other transistors become nonconductive stage by stage until the entire cascade string of transistors reverts back to their nonconducting state.

Grid modulator switch 28 is an extremely fast-acting switch. As a result, it too, aids in causing the X-ray tube to conduct symmetrically with respect to the midpoint of the sine wave.

What has been described then, is a grid-pulsed X-ray tube which is designed specifically for short-time exposure at maximum loading of the X-ray tube. In order to get the optimum film darkening at maximum loading, the invention teaches applying substantially a flat waveform voltage to the anode of the X-ray tube. This is accomplished by the combination of the filter 15, the pulse generator 24 which includes the multivibrators 307 and 310, and the fact-acting grid modulator switch 28. The input to the high-tension transformer is automatically synchronized to the input to the cine camera drive motor, the input to transformer T101, and the input to transformer T301 because all of these inputs are connected to the same source.

We claim as our invention:

1. In combination with an X-ray tube, a voltage source operably connected to said X-ray tube for causing said X-ray tube to generate X-radiation, the output of said voltage source being substantially in the form of a sine wave, means for changing said X-radiation into photoemissions, a camera, and film in said camera operable to record a permanent picture of the information provided by said photoemissions; conversion means operable to change said sine wave substantially to a square wave, said conversion means including impedance means disposed intermediate said voltage source and said X-ray tube, said conversion means further including delay means disposed intermediate said camera and said X-ray tube for causing said X-ray tube to provide X-radiation for a selected period of time and for causing said period of time to occur substantially symmetrically with respect to the midpoint of at least one-half cycle of said sine wave.

2. The combination of claim 1 wherein said delay means comprises pulse-generating means including contact means actuated by said camera for generating at least one pulse during the occurrence of said at least one-half cycle; said pulse-generating means further including holding and conducting means, said holding and conducting means being operable to delay said at least one pulse for a second selected period of time and for subsequently conducting said at least one pulse for said selected period of time.

3. The combination of claim 1 wherein said X-ray tube draws a selected amount of power, and said impedance means is connected to said voltage source and said X-ray tube, the magnitude of said impedance means being such that it supplies a selected portion of said selected amount of power to said X-ray tube.

4. The combination of claim 3 wherein said impedance means includes capacitor means, first resistive means, and second resistive means; a first conducting path including said first resistive means for charging said capacitor means and a second conducting path including said second resistive means for permitting said capacitor means to discharge through said X-ray tube.

5. The combination of claim 4 wherein said second conducting path includes a selected portion of said first resistive means.

6. The combination of claim 1 wherein said X-ray tube includes an anode, a cathode and a grid; bias voltage means; means connecting said bias voltage means to said grid; switching means connected to said bias voltage means for rendering said bias voltage means ineffective, said switching means being actuated by said delay means for said selected period of time.

7. The combination of claim 6 wherein said grid bias means normally renders said X-ray tube nonconductive; said delay means includes a pulse-generating means for generating at least one pulse during the occurrence of said at least one-half cycle; said switching means being actuated by said at least one pulse for said selected period of time.

8. The combination of claim 6 wherein said switching means includes a plurality of cascade-connected transistors.

9. The combination of claim 6 wherein said switching means includes at least one electronic switch having an input terminal and an output terminal, said terminals being operably connectable across said bias voltage supply.

10. The combination of claim 1 wherein said camera includes a shutter; said delay means includes means for synchronizing generation of X-radiation by said X-ray tube with operation of said shutter.

11. In combination with an X-ray tube, a voltage source operably connected to said X-ray tube for causing said X-ray tube to generate X-radiation, the output of said voltage source being substantially in the form of a sine wave, and film means for recording a permanent picture of the information provided by said X-radiation; conversion means operable to change said sine wave substantially to a square wave, said conversion means including impedance means disposed intermediate said voltage source and said X-ray tube, said conversion means further including delay means operable to cause said X-ray tube to generate said X-radiation for a selected period of time and for causing said period of time to occur substantially symmetrically with respect to the midpoint of at least one-half cycle of said sine wave.

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