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IMAGE CONVERTER CAMERA FOR 0.5 TO 10,000 MICROSECOND PHOTOGRAPHS

By
H. L. Miller

October 1964

Plasma Physics Laboratory
Princeton University
Princeton, New Jersey

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0.5 to 10,000 Microsecond Photographs

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ABSTRACT

Equipment is described for making photographs using an image converter tube as an electronic shutter. When operating in the framing mode, the camera will take three frames 10 to 10,000 μsec apart with exposure times from 0.5 to 2000 μsec . Each frame has a maximum diameter of 25 mm. When operating in the streak mode, the camera has streak times from 10 to 10,000 μsec . The streak picture is about 60 mm long and 25 mm wide. The equipment uses the RCA 73435D image converter tube. A standard oscilloscope camera is used to record the images. Design of the equipment is discussed and circuits for controlling and timing the photographs described.

1.0 INTRODUCTION

1.1 Purpose.

The image converter camera was developed for taking photographs of the ionized gas in plasma physics¹ experiments.

There is a need for ordinary two dimensional pictures or frames in rapid sequence (the framing mode of operation) and also for the streak mode of operation wherein time is one dimension and displacement along a slit in either image or object plane is the other dimension. The streak mode seems to be more useful in plasma physics. Streak times from 10 to 10,000 μ sec have been useful. A sequence of three framing mode pictures spaced from 10 to 10,000 μ sec apart at their leading edges and having exposure time of 0.5 to 2000 μ sec seemed appropriate for the time duration of stellarator experiments.

The image converter was chosen as an addition to a locally developed drum camera, instead of other cameras, because of the low light intensity in experiments here. The advantages of an image converter when light is low have been discussed by Clark.² The RCA 4449 image converter tube has a minimum radiant power gain of 50. Use of an image converter requires a second lens system which reduces the light intensity a factor of 10 to 60. This still leaves the image converter camera at least equal to, and usually more sensitive than the drum camera, in addition to permitting the convenience of Polaroid film. The rotating mirror or prism cameras require long focal length lenses not readily

available in large apertures. The Kerr cell and magneto-optical shutters transmit only about 10% of the incoming light when fully open.

1.2 History

The use of image converters as fast camera shutters has a history going back to 1948³ or earlier, as may be seen from the attached bibliography.^{4, 5, 6, 7, 8} In recent years image converter cameras have become available from STL Products Division of Space Technology Laboratories, Precision Technology Division of General Precision Equipment Corporation, Electro-Optical Instruments, Advanced Kinetics Incorporated, and Beckman and Whitley.

2.0 DESCRIPTION OF CAMERA

2.1 Image Converter Tubes

The RCA 4449 (developmental 73435B) was developed for use as a high speed shutter.⁹ It is packaged in a glass and metal envelope 9-7/8 inches long and 4 inches in diameter. The light image is focused on one end of the tube which has a photocathode on its inner surface. The electrons are emitted from the photocathode in the same pattern as the light image formed on it. The electrons then pass between the wires of a wide spaced control grid. This grid is at about 160 volts positive relative to the cathode when the tube is on; however, if the grid is about 80 volts negative relative to the cathode the electron flow will be cut off by the grid. The electrons then pass through a cylindrical focusing electrode at about

1400 volts, then through a small hole at the apex of the conically shaped anode which operates at 15,000 volts. The electrons pass between a pair of deflection plates immediately after the anode hole. The plates should operate at an average potential equal to that of the anode and require a voltage between them of about 1200 volts to deflect the image one inch. After passing the deflection plates the electrons hit a fluorescent screen (P-11) which is at the same potential as the anode. The screen is three inches in diameter, permitting three images almost an inch in diameter to be positioned by the deflection plates. The images are reduced in size while going through the tube from a 1-3/8 diameter cathode. When in streak mode, the streak can be about 2.4 inches long and almost 1 inch wide.

The 4449 has a flat cathode with S-11 response. The tube is also available with S-20 response as the 73435D, and other options are said to be available. The S-20 cathode has been used most here because red light predominates in our sources. The quantum efficiency of the S-20 cathode is between 10 and 20%.

Photon gain of the tube can be calculated as follows: Electrons leave the cathode with an energy of about 2.5 volts and have been accelerated to 15,000 volts when they hit the screen. If we assume a 10% efficiency for the screen in converting electrons to 2.5 eV photons, the maximum photon gain would be:

$$\frac{15,000 \text{ eV} \times 0.2 \times 0.1}{2.5 \text{ eV}} = 120$$

Resolution of the tube at the center of the screen is specified as 17 or more line pairs per mm.

2.2 Camera Lens

The lens which images the object on the image converter cathode is called the camera lens. The focal length necessary for it is computed from the formula:

$$F = mu/(m + 1)$$

where F is focal length

m is magnification from object to image

u is distance from object to lens.

The magnification should be chosen to nearly fill the cathode in order to get maximum information. It may be desirable to build the camera case to accommodate the interchangeable lens systems of one of the 35 mm camera manufactures, although we did not do so. Our camera is equipped with an $f/1.5$, 125 mm Taylor-Hobson Anastigmat lens, and has an $f/4.3$, 220 mm lens in reserve.

If the distance from object to camera is so large that a practical compromise between f /number and focal length to produce the proper size image is not possible, an additional lens can be used. It is placed between the object and camera lens to form a real image in space at a point where the camera lens can focus on the image and produce another image of the right size on the photocathode. This process can be repeated several times if needed to produce a large enough image. The simple lens train described so far will usually lose considerable light, producing an image that is dimmer at the edge than the center. The light economy is

corrected with "field" lenses which are located at each real image (the lens must be larger than the real image) and with focal lengths chosen to focus an image of the preceding lens on the following lens. If transmission and reflection losses in the lens train are ignored, the brightness of the image formed by the camera lens alone will not be diminished by adding the train, provided the image of the first lens on the camera lens is as large, or larger, than the camera lens. If the image of the lens is smaller, there will be a loss of brightness; if larger, the image formed by the camera lens will be smaller. It is not necessary to use high quality anastigmat lenses in such a lens train if the lenses' f/number is larger than 6, and the images formed are much larger than the one finally formed on the photocathode. Telescope objective lenses have been satisfactory here.

2.3 Back Lens and Recording Camera

The back lens is required to transfer the light image on the image converter screen to film for final recording. A convenient and fairly satisfactory system is the DuMont Fairchild 450 oscilloscope camera equipped with an Oscillo-Raptar $f/1.9$, 75 mm lens and operated at a magnification of 1.1. This lens loses resolution very noticeably when going from $f/4.0$ to $f/1.9$. Possibly, better results could be obtained if a special lens system and coupling to a film holder were built.

Usually, Polaroid prints are used in order to get immediate results. When automatic or remote operation is needed, a Beattie-Coleman oscilloscope camera with 50 mm lens and 35 mm film is used.

Reference 2 shows that a lens reduces power per unit area in the image from that in the object (considering only geometry) by the following factor:

$$4 (f/)^2 (1 + m)^2$$

where $f/$ is f-number and m is magnification.

The $f/1.9$ lens at a magnification of 1.1 reduces the power per unit area by a factor:

$$4 \times 1.9^2 (1 + 1.1)^2 = 63.7$$

2.4 Image Converter Tube Case

The case must be large enough to provide space for the final deflection amplifier and for the high voltage biasing circuits of the image converter. In order to prevent corona, it was found necessary to mount parts which have a 15 kV potential difference at least 1-1/8 inches apart. It was also necessary to use corona rings made of No. 12 wire.

The case is a box 12 inches in each inside dimension. Four of the sides are made of 1/4 inch thick aluminum welded together for best electromagnetic shielding. The other two sides of the box are of 1/16 inch aluminum bolted to the welded sides. To provide additional magnetic shielding, the box is surrounded by two layers of "Mu-Metal" with aluminum between the layers.

The box has a threaded hole so it can be mounted on a heavy duty camera tripod with the standard screw. The lens is mounted on the front side of the box and an oscilloscope bezel for mounting an oscilloscope camera

is on the back side of the box. A heavy lucite panel is between the bezel and the screen end of the image converter to protect viewers from the 15 kV potential on the tube screen and end. A photograph of the assembly appears as Fig. 1.

3.0 ELECTRICAL SYSTEM

3.1 Image Converter Tube Biasing Circuits

Design of the biasing circuits (Fig. 2) was based on the need to have all of the voltages on the tube change in the same proportion if the supply voltage changed. Also, when the centering control changes the voltage between deflection plates, they must change equally and remain at the same average potential as the screen and anode. It is necessary that the 60 cycle line voltage not appear in sufficient strength (2 volts p-p) between the deflection plates to cause image blurring. When the cathode is pulsed to turn the tube on, the other tube voltages must be held constant by capacitors to ground.

The tube is operated with the screen at 15 kV above ground instead of the cathode 15 kV below ground because this makes the cathode pulsing circuit design easier, but has little effect on the deflection amplifier design.

The focus electrode voltage must be adjusted for best focus and the control grid voltage for least visibility of grid wires. Some reiteration with these controls is necessary.

A power supply capable of 0.5 mA at 15 kV with ripple less than 0.5% is required. The supply used here is based on a commercial unit to which controls must be added. It is shown in Fig. 2.

3.2 Image Converter Tube Driving Circuits

It would be desirable to keep all heat generating parts out of the image tube case because the tube is sensitive to heat and cannot be exposed to more than 75° C. Despite this, it is necessary to have the final deflection amplifier in the image tube case in order to minimize the capacitance the amplifier must drive. There should be a partition between the amplifier and image tube to shield the tube from the amplifier's heat and light.

The demands made on the final deflection amplifier are severe. When in the framing mode it must produce equal positive and negative staircase pulses having two steps of 540 volts each. The minimum time between frames is set by the rise time of the steps, so it is necessary that the complete rise time of the steps be less than 10 μ sec. The top of the steps must be flat within 0.4% (~ 2 volts) during the exposure period or the image sharpness will suffer. The flatness is achieved by use of a large coupling RC time constants and by inverse feedback from plate to grid of the final deflection amplifier tubes. The coupling capacitor in this feedback path is sized so there is less inverse feedback during the later part of the pulse so that droop is compensated. The droop observed is 2 to 3% in 10,000 μ sec.

The rise time of the steps is speeded by the 7 to 45 pF capacitor between grid of V23 and ground. This effects the first 10 μ sec of the step most.

The 1.5 to 7 pF capacitor affects the first 50 μ sec. They must be adjusted alternately so as to get the step up to its full height in 10 μ sec or less with overshoot less than 0.4%. The 1.5 to 7 pF capacitor at the grid of V22 must then be adjusted for fastest rise time with overshoot less than 0.4% at the plate of V22. Each capacitor will affect the signals at both plates, so some iteration is necessary to get the signals at both plates to have the fastest rise time. It is essential that the feedback resistors have a small voltage coefficient of resistance because of the large pulse voltage present.

The grid bias of V23 must be adjusted so that its plate is at 400 volts when well warmed up or 550 volts when cold.

The neon bulb on the plate resistor of V22 is a convenience feature which shows when the camera has responded to an initiating pulse.

A power supply capable of 20 mA at 3.6 kV is required. Ripple should be less than 0.1% rms. A Sorenson-Beta Model 1005-50 supply is used here.

The image converter tube is kept turned off by holding its cathode about 150 volts positive with respect to the control grid. It is turned on by driving the cathode negatively to ground. Diodes between cathode and ground prevent the cathode being driven below ground potential and serve to square the pulse.

An earlier version used a 180 ohm resistor as the termination of a 185 ohm cable driven by a pair of 6DQ5 tubes in parallel. Such an arrangement is necessary if there is to be a long cable between 6DQ5 tubes and

image converter tube. However, we are using a cable only 15 feet long so the reflection time is 31 nanoseconds for the round trip. This time is shorter than the rise time, so it has a small effect noticeable only for the shortest pulses.

When the plate load resistor for the 6DQ5 (V10) was located in the camera case with the image tube, a ground loop caused the exposure pulse to appear with the staircase pulse. This was corrected by putting the load resistor in the control unit chassis (Fig. 3) where the 6DQ5 tube was located. This leaves the cable essentially unterminated at the image tube end. The load resistor should be a 680 ohm metal film type if exposures are usually longer than 10 μ sec. If exposures will often be shorter than 10 μ sec, the resistor should be about 470 ohms, which will shorten the pulse fall time. The increased current drawn when a 470 ohm plate load is used will discharge the two 250 μ f capacitors at the cathode of V10 during a 1000 μ sec or longer pulse. If one works at both extremely fast and slow speeds constantly, a 200 ohm resistor could be installed in series with the 470 ohm resistor and shorted by a switch when short exposures are being used.

3.3 Timing Circuits

The timing circuits in the exposure control unit are required to generate an exposure pulse with a 10 to 90% rise and fall time of $< 0.1 \mu$ sec. The pulse must be adjustable in duration in steps from 0.5 to 10,000 μ sec. When operating in streak mode there must be a simultaneous ramp pulse generated with good linearity for the image deflection circuit.

When operating in the framing mode, three exposure pulses must be generated with the time from leading edge of one to leading edge of the next accurately and continuously variable from less than 10 μsec to 10,000 μsec . At the end of each exposure pulse, a step in a staircase pulse must be generated for the image deflection circuit.

The operation of the exposure control unit in detail is as follows.

An electrical initiating pulse comes from the experimental device's program timer, either directly or through the delay circuit. The initiating pulse may also be generated by a push button on the exposure control unit front panel. The electrical pulse goes directly to the second exposure delay multivibrator V1 of Fig. 3. (There is no delay for the first exposure except when the delay unit of Fig. 2 is used.) The positive pulse from V1 is differentiated and its leading edge amplified in V11, then sent to the exposure pulse generator V3. The trailing edge is not used when in the streak mode, which we shall now discuss.

A monstable multivibrator is formed by V3 and V4. Its natural period is much longer than 10,000 μsec , the maximum pulse duration required from the multivibrator, so the actual pulse duration is determined by the ramp generator V5. The negative pulse at the plate of V4 cuts off the quiescent current in the two diodes between V4 and V5. When the diode currents are cut off, one of the timing capacitors of SW-4 can charge through the grid resistor of V5. The charging current in the grid resistor makes the grid go negative, which makes the plate go positive. The plate pulse, or ramp,

is coupled to the grid through the timing capacitor and acts to keep the grid voltage from dropping more than one volt of the 148 across the grid resistor, so that current through the grid resistor changes less than 1%, and the timing capacitor voltage is a very linear ramp. The plate of V5 is actually coupled to the timing capacitor through a neon bulb to lower the dc level, and then through a cathode follower V6. (The circuit must be credited to the Tektronix 555 oscilloscope.)

The ramp voltage is also coupled through the left cathode follower of V7 and a disconnect diode to the grid of V3. When the ramp voltage becomes 17 volts more positive than the grid voltage of V3, it turns on V3 and returns the multivibrator to its quiescent state, ending both the exposure pulse and the ramp. The next pulse will be shortened if it follows closer than one-half pulse length after the preceding.

The ramp voltage is coupled through the right cathode follower of V7 to a variable attenuator, then to SW-3 and then to the cable to the deflection amplifier of Fig. 2. The ramp uniformity trimmer capacitor is used to compensate the attenuator for the cable capacitance. Possibly, a better design would have put the attenuator earlier, so the cathode follower could go directly to the cable. The positive rectangular pulse at the plate of V3 is sent to the grid of V10, the exposure pulse amplifier, and thence to the cathode of the image converter tube.

When in the framing mode of operation, all of the circuitry previously described for streak mode is still in action, except that the right half of V7

is disconnected from the sweep output by SW-3. In framing mode, SW-3 allows the third exposure multivibrator to operate.

The trailing edge of the positive pulse from V1 is amplified in the left side of V11 and then sent to trigger V2. The positive pulse from V2 is differentiated and its leading edge sent to the right half of V11 for amplification. The negative pulse from V2 is differentiated and its trailing edge sent to the right half of V11 for amplification along with the leading edge pulses from V1 and V2. These three pulses go from the right plate of V11 to the grid of V3 where each triggers the exposure pulse for one frame.

The staircase generator monostable multivibrator, V8, gets its initiating pulse from the trailing edge of the pulse from the plate of V3. The multivibrator has a $0.47 \mu\text{f}$ capacitor between its quiescently cutoff plate and ground. During the quasi-stable state of the multivibrator the capacitor is charged to about 0.5 volts in 4 to 5 μsec which becomes the rise time. The capacitor discharges with a 0.235 second time constant through the plate load resistor of V8 and the grid resistor of V9. The pentode section of V9 amplifies the steps to about 24 volts each. The staircase next goes through a variable attenuator, then to switch SW-3, and then to the cable to the deflection amplifier.

Layout of the exposure control chassis should be done so there is minimum chance for the exposure pulse to couple into the sweep circuits. In general, any layout must put V3 in about the center because it is connected to V4, V7, V8, V10 and V11. The $80 \mu\text{f}$ capacitor from plate power to ground

must be located near the plate resistor of V10. The grid wiring of V1, 2 and 3 should be kept as short as possible. A shield was necessary on V9.

The negative 300 volt supply was built as shown in Fig. 2; however, a commercially available supply could equally well have been used. The positive 300 volt supply and 6.3 volt ac supply was a Lambda Model C881 regulated supply. The +300 volts should not be on unless the -300 volts is on.

3.4 Delay Circuit

The delay circuit is used when it is necessary to delay the first frame or the streak beginning from the initiating pulse. It is also used when the initiating pulse is not ideal, e.g., contains contact bounce or noise. The circuit is shown in Fig. 2. A push button for testing or manual operation is included. A cathode coupled amplifier, V31, with input to both grids permits use of initiating pulses of either polarity. A 24 volt pulse is large enough to trigger it, and the amplifier is able to deal with much larger pulses without overloading. A monostable multivibrator, V32, stops incoming pulses for 14 to 16 msec after an initiating pulse. This is to prevent triggering on contact bounce, etc. A monostable multivibrator, V33, is used to generate the delay adjustable from 3 to 10,000 μ sec. The positive output pulse of V33 is sharply differentiated and then the trailing edge is amplified in the left half of V34. The right half of V34 is a paraphase amplifier giving both a positive and negative output pulse of 40 volts.

4.0 RESULTS

Figures 4 and 5 were made from Polaroid type 46 L transparency film which has a speed of only ASA 800, but is easier to make copies of than the ASA 3000 Polaroid. Figure 4 shows three photographs in the framing mode of an NBS 1952 resolution chart illuminated by a 60 watt bulb and 20 inches from the lens. The chart is not at the distance for its scale to be direct reading; however the resolution can be approximated by direct measurement of the photograph. Using the best set of horizontal lines, at 1000 μ sec exposure, and allowing for the 2.25 magnification from the screen to the illustration, one observes 11 line pairs per mm, referred to the image converter screen. If the original photographs are used the resolution is a step (41%) better. It is necessary to photograph the bare filament of a 6 watt bulb to have sufficient intensity at 1.0 μ sec. The vertical bars are caused by the control grid wires.

Figure 5 shows two photographs of the resolution chart with a 5/8 inch wide slit which eliminated the vertical lines. The grid wires are slightly visible in the second of these, and in the next photograph of the 6 watt filament without a slit. The fourth picture is of the stellarator light.

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Fig. 1. Power Supplies and Control Circuits with Image Converter Camera.

ADJUSTMENTS

1. "RAMP AMP" SO THAT STREAK ON IMAGE TUBE ALMOST COVERS SCREEN.
2. "RAMP UNIFORMITY" SO THAT STREAK ON IMAGE TUBE IS AS LONG AT 20 μ S AS AT 2000 μ S.
3. "PULSE AMPLITUDE" SO THAT PULSE AMPLITUDE AT GRID ON VIO EQUALS GRID BIAS THIS ALSO AFFECTS PULSE DURATION.
4. "STEP RISE" SO THAT WHEN STAIRSTEP AMP IS WITHIN 15° OF FULL SCALE THE THREE FRAMES WILL ALMOST FILL TUBE SCREEN.
5. "STAIRSTEP AMP" USED FOR QUICK FINE ADJUSTMENTS IN FRAME SPACINGS.
6. "90% CALIBRATION" AT 9000 μ S LEADING EDGE TO LEADING EDGE OF EXPOSURE PULSE.
7. "10% CALIBRATION" AT 1000 μ S.

NOTES

1. RESISTORS $\pm 10\%$ 1/2 W UNLESS OTHERWISE NOTED.
2. CAPACITOR VALUES > 1 IN PF UNLESS OTHERWISE MARKED.
3. MOUNT 7044 TUBES WITH PINS 5 8 9 IN VERTICAL LINE.

EXPOSURE CONTROL UNIT

Fig. 3. Exposure Control Unit Schematic Diagram.

1,000 μ sec. exposure, 10,000 μ sec apart
f/2.8 and f/4.0

200 μ sec exposure, 1,000 μ sec apart
f/1.5 and f/1.9

20 μ sec exposure, 50 μ sec apart
f/1.5 and f/1.9

1 μ sec. exposure, 10 μ sec apart
f/1.5 and f/1.9

Fig. 4. Photographs Taken in Framing Mode of Operation.

10,000 μ sec.
f/2.8 and f/4.0

500 μ sec.
f/1.5 and f/1.9

20 μ sec. 6W filament
f/1.5 and f/1.9

1000 μ sec. Model C Stellarator

Fig. 5. Photographs Taken in Streak Mode of Operation.

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APPENDIX

OPERATION

The camera can be operated in normal room light except when very long exposures (> 1 millisecond) are being used.

If the device being photographed has a program timer generating synchronizing pulses larger than 40 volts and with adjustable delay, it will probably not be necessary to use the delay circuit. If not, the delay generator output must be connected to the input of the exposure control.

The interconnection diagram of Fig. 2 shows how the various units are connected. The block diagram gives an idea of the operation of the circuits.

In streak mode operation the following adjustments are made:

1. Turn SW-3 to streak.
2. Turn SW-4 to the overall streak time desired.

In framing mode the following adjustments are made:

1. Turn SW-3 to frame.
2. Turn SW-4 to the exposure time desired.
3. Turn SW-1 and the second exposure delay control to the desired delay between leading edge of the first frame exposure pulse and the second frame exposure pulse. SW-1 acts as a multiplier for the control. The time cannot be less than $6 \mu\text{sec}$, or less than $1\frac{1}{2}$ times the exposure time, whichever is longer.

4. Turn SW-2 and the third exposure delay control to the desired delay between leading edge of the second frame exposure pulse and the third frame exposure pulse. The time cannot be less than $6 \mu\text{sec}$, or less than $1\text{-}1/2$ times the exposure time, whichever is longer.

The turn-on procedure is as follows:

1. Turn on 6.3 volt ac supply.
2. Turn on 15 kV supply and raise voltage slowly to 15 kV.
3. Take a picture of the apparatus in room light so that pictures of the light emitted will have a reference to the apparatus.
4. Turn on -300 volt supply then +300 volt supply.
5. Turn on 3.6 kV and set at 3.6 kV.

The turn-off procedure is as follows:

1. Turn voltage control of 3.6 kV supply to zero and shut off.
2. Turn off +300 volts then -300.
3. Turn off 6.3 volt ac supply.
4. Take a room light picture to disclose any movement of camera since step 3 of turn on procedure.
5. Turn voltage control on 15 kV supply to zero and switch off.

CALIBRATION

Image Tube Bias

1. Only turn on 15 kV supply and adjust to 15 kV.
2. Aim camera at a resolution chart at a distance that permits the chart to fill the image and adjust lens for best focus.

3. Adjust "centering" control so the image is as near the edge of the screen as it can be without distortion.
4. Adjust the "focus" voltage control for best resolution of both vertical and horizontal lines, but keep size of image just below $1/3$ of screen diameter.
5. Adjust "grid bias" control until the grid wires are least visible.
6. Repeat steps 4 through 5 until no further improvement results.
7. Turn the control on the 15 kV supply to zero.

Exposure Pulse Adjustments

1. Set SW-3 for "streak".
2. Put scope probe at the exposure pulse input, on the camera case.
3. Use test pulser to initiate pulses and adjust "pulse amplitude" control for -300 volt pulses properly limited by the diodes.
4. Set "exposure time" SW-4 to 10,000 μsec . Adjust "ramp and sweep calibrate" control for a 10,000 μsec pulse at exposure pulse input.
5. Set exposure time switch to other times and adjust trimmer capacitors for correct pulse duration.

Second and Third Exposure Delay Calibration

1. Set SW-3 for "frame".
2. Set SW-1 and the "second exposure delay" control for 9000 μsec .
3. Adjust the "90% cal." control for 9000 μsec between leading edges of first and second exposure pulses.
4. Set the second exposure delay control at 1000 μsec (10% of full scale).

5. Adjust the "10% cal." control for 1000 μ sec between leading edges of second exposure pulses.
6. Set the trimmer capacitors on SW-1 for the correct time between leading edge of first and second exposure pulses when the second exposure delay control is at 90% of full scale.
7. Follow the same procedure for calibrating the third exposure delay circuit with the time between leading edges of the second and third exposure pulses.

Stairstep Sweep Adjustments

1. Turn on the 3.6 kV supply and adjust its output to 3.6 kV.
2. While the circuitry is still cold, adjust the "sweep bias" control so the plate voltage of V23 is 550 volts. When hot this voltage must be no less than 400.
3. Set timing circuits for 1000 μ sec exposure pulses, 3000 μ sec apart.
4. Set the stairstep amplitude control about 10% of a turn from fully clockwise.
5. Turn voltage control on 15 kV supply to 15 kV.
6. Adjust the trimmer capacitor of V8 so the three frames will appear properly spaced on the image tube screen. If frame spacing needs adjustment in usage as tubes age, the "stairstep amplitude" control should be used.
7. Turn off the 15 kV supply.
8. Adjust the 1.5 to 7 pf capacitor at the grid of V23 for best flatness between 10 and 50 μ sec after the step pulse begins at the image tube deflection plate connected to V23.

9. Adjust the 7 to 45 pf capacitor at the grid of V23 for shortest rise time of the first 10 μ sec of the step pulse (keeping overshoot less than 0.4%), at the image tube deflection plate connected to V23.
10. Adjust the 1.5 to 7 pf capacitor at the grid of V22 for shortest rise time (with less than 0.4% overshoot), at the image tube deflection plate connected to V22.
11. Repeat steps 8 through 10 until no further improvement results.

Streak Sweep Adjustments (Must not be done before stairstep adjustments.)

1. Set SW-3 for "streak" and SW-4 "exposure time" for 10,000 μ sec.
2. Turn on 15 kV supply at 15 kV.
3. Adjust the "ramp amplitude" control so the streak on the image converter screen is just a little shorter than the diameter of the screen.
4. Set SW-4 "exposure time" for 20 μ sec, then adjust "ramp uniformity" so the streak on the image tube screen is the same length as in step 3. If there is not enough light conveniently available for this, the adjustment can be made with an oscilloscope viewing the deflection plate ramp pulses.

Delay Circuit Calibration

1. Connect the oscilloscope external trigger input to the positive input of the delay circuit. This will provide a positive trigger to the oscilloscope whenever the test button is pushed.

2. Set the helipot and range switch for 10,000 μ sec and adjust the "10 ms cal." for 10,000 μ sec delay at the output.
3. Set the helipot for 1000 μ sec (10% of full scale) and adjust the 1 ms cal." for 1000 μ sec delay at the output.
4. Set the helipot to full scale and adjust the trimmer capacitor on the X1.0 and X0.1 switch positions for proper delay.