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A GENERATOR OF FAST-RISING LIGHT PULSES FOR PHOTOTUBE TESTING

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Radiation Laboratory
Berkeley, California

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FOR PHOTOTUBE TESTING

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March 24, 1958

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ABSTRACT

The UCRL light-pulse generator provides flashes of light accompanied by electrical pulses generated at an impedance level of 50 ohms. The usual repetition rate is 60 cps. The primary features of interest are

- (a) that the 10% to 90% rise, both for the light and for the electrical pulse, is less than 0.5 μ sec,
- (b) that the light pulse rises and then falls to 50% peak amplitude in less than 1.5 μ sec,
- (c) that the time relation between the light and electrical pulses is fixed,
- (d) that the electrical pulse power available is large.

In conjunction with an oscilloscope, the light-pulse generator has proved useful in the testing and evaluation of multiplier phototubes and low-light-level image devices. Time resolution of 10^{-10} second is typical of measurements made with conventional fast oscilloscopes (e. g., Tektronix 517), while elaboration of technique permits relative time measurements that are better in some cases by at least three orders of magnitude. The light is emitted from a region a few mils in diameter, and thus may often be considered to come from a point source. An S4 photosurface subtending 0.1 steradian at the light source emits photoelectrically about 10^7 electrons per steradian per pulse. For convenience, three decoupled electrical output channels are provided, together with a polaroid attenuator for the light pulse.

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INTRODUCTION

The UCRL mercury-capsule light-pulse generator described in this report was developed for use in testing and evaluating the high-speed aspects of light-sensitive devices. These devices include multiplier phototubes used in scintillation and Cherenkov counters and in coincidence detectors, and low-light-level image tubes. With this pulser, tests and measurements of afterpulsing, transit time, multiplier transit-time spread, cathode transit-time spread, multiplier current saturation, etc., have been made.¹ The maximum light amplitude is great enough to current-saturate low-gain multipliers, or it may be so reduced as to release an average of one photoelectron or less per pulse from a photocathode.

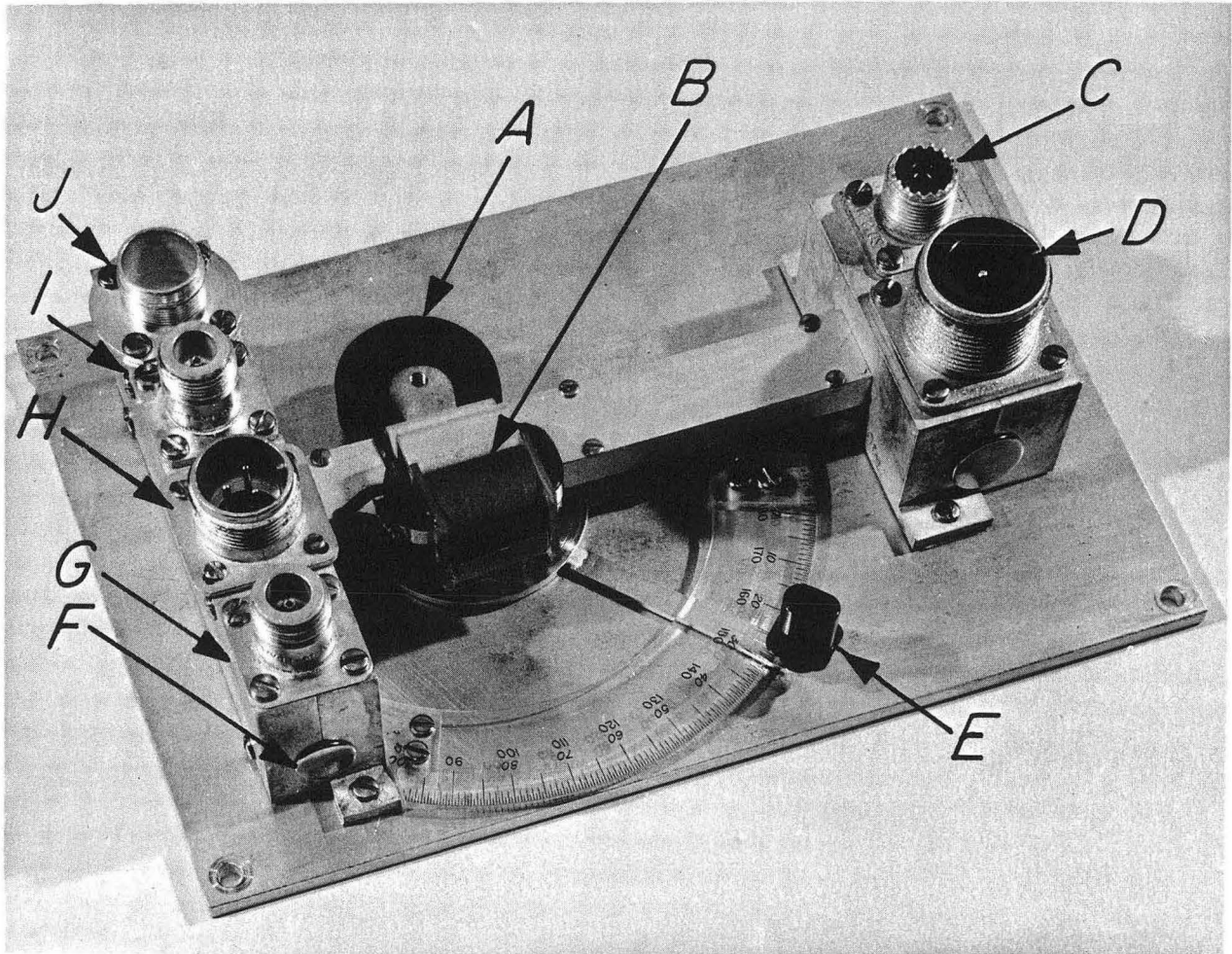
The light pulses and the electrical trigger pulses are generated simultaneously in an arc discharge, therefore the electrical pulse is conveniently used as a time reference for the light pulse.

This report describes some of the features of construction and operation of the light pulser. A number in parentheses following the first mention of any part of the pulser or any accessory or related device refers to the fabrication drawing. A list of pertinent drawings is given on pages 32 and 33.

Electrical and Mechanical Assembly

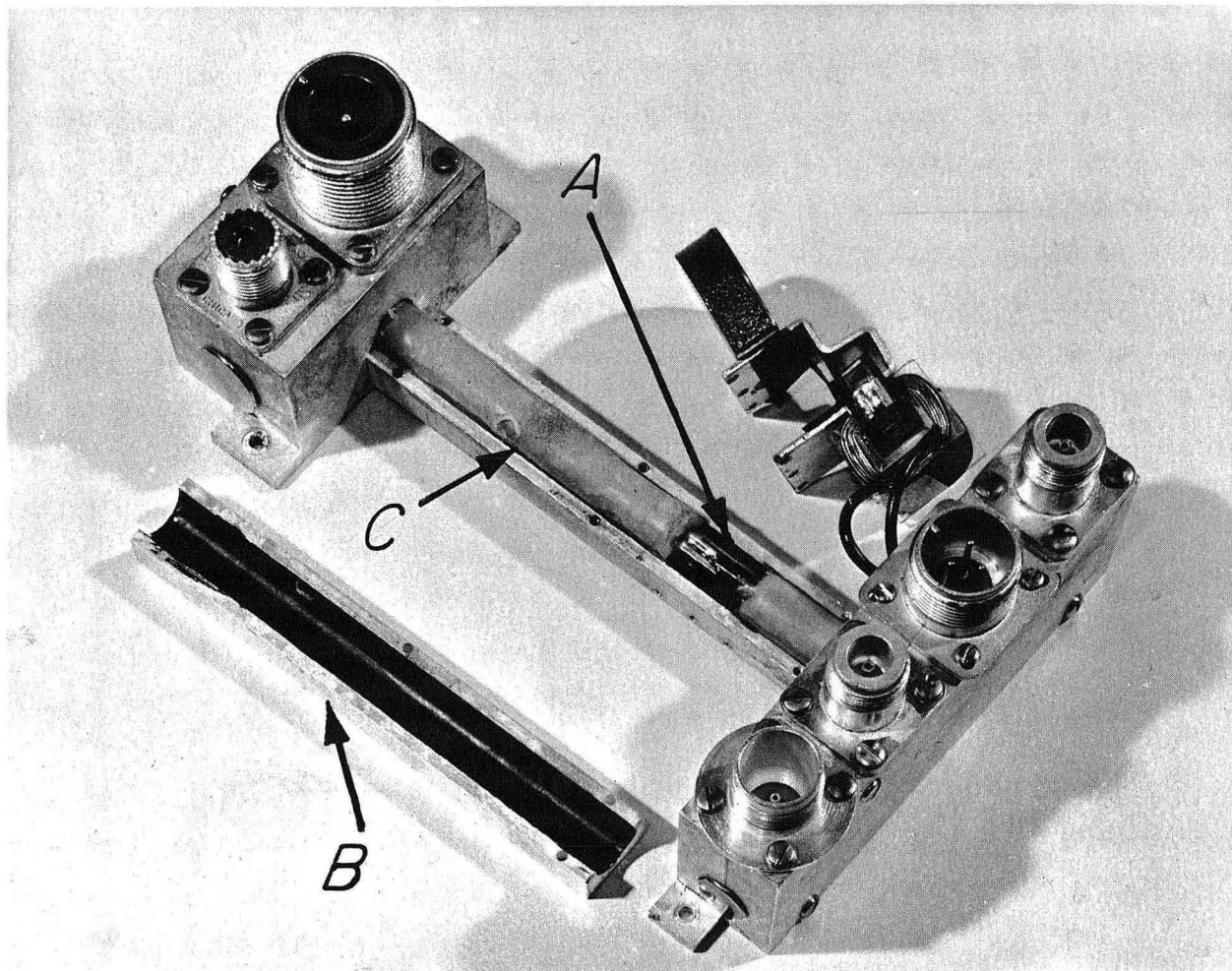
A photograph of the light pulser (4V5572) (Fig. 1) shows the rear of the pulser (the light is emitted from the front). The light pulses are produced in a mercury-wetted contact relay capsule such as is used in Western Electric 275C or Clare HG1003 relays. The source of light is the arc formed at the contacts of the capsule. The pulser is partially disassembled to show certain features in Fig. 2. The electrical assembly of the light-pulse generator is shown in Fig. 3 (4V5603B), and a schematic drawing of the light pulser in Fig. 4.

The capsule S-1 operates in a vertical position. Connectors PG-5 and PG-6 are up and PG-1, PG-2, PG-3, and PG-4 down when the generator is correctly oriented. In this position the contacts are normally open and can be closed by the magnetic field accompanying a current in the driving loop (4V5681), which is a metal strap making a single-turn secondary winding on T-1. The light-pulse generator operates most satisfactorily in a region free from strong magnetic fields or mechanical vibrations.



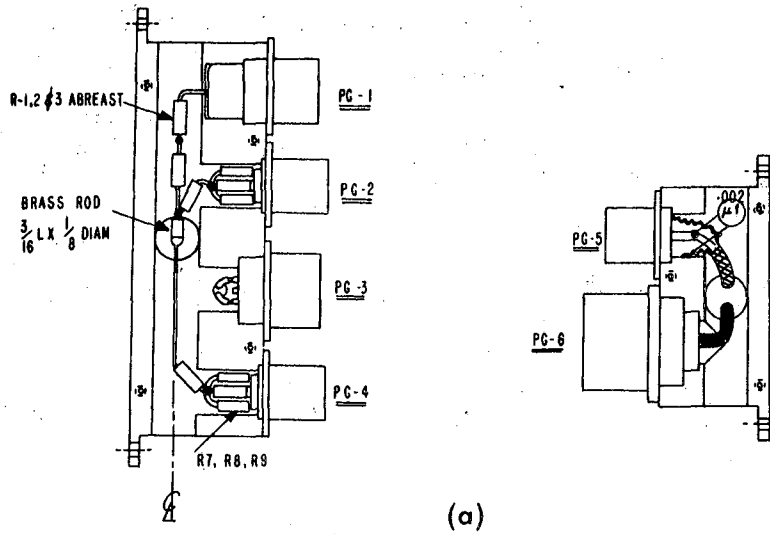
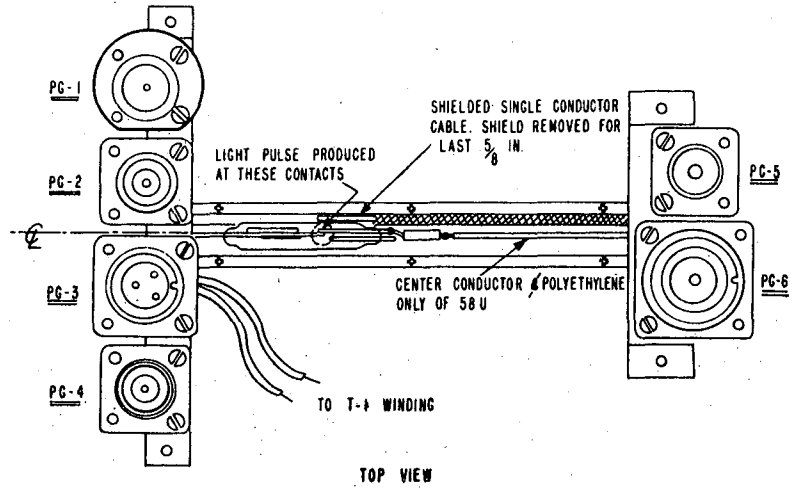
ZN-1936

Fig. 1. A rear view of the light pulser. (Light pulses are emitted from the other side.) A, permanent magnet; B, mercury-capsule driving coil; C, PG-5 monitor signal output; D, PG-6 high voltage input; E, polaroid adjustment handle; F, removable cap for high-level coaxial connection; G, PG-4 51-ohms trigger pulse; H, PG-3 driving-coil input; I, PG-2 51-ohms trigger pulse; J, PG-1 125-ohms trigger pulse.



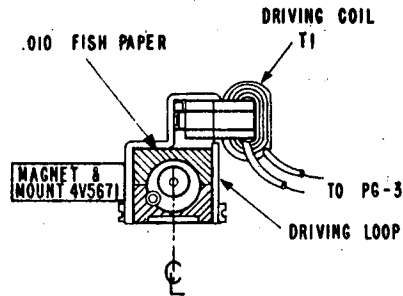
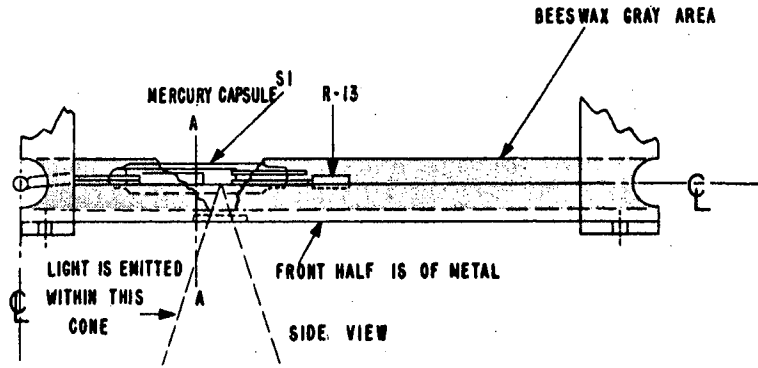
ZN-1937

Fig. 2. A rear view of the light pulser with permanent magnet, driving coil, base plate, and rear half of metal shell removed. A, mercury capsule; B, rear half of metal shell; C, beeswax.



MU-15,237

Fig. 3a



SECTION A-A (ASSEMBLED)

(b)

MU-15,238

Fig. 3b

Fig. 3. Electrical assembly of the light pulser: (a) top and end views showing placement of components; (b) side view and section through metal half shells, showing details of mounting of mercury capsule and driving coil.

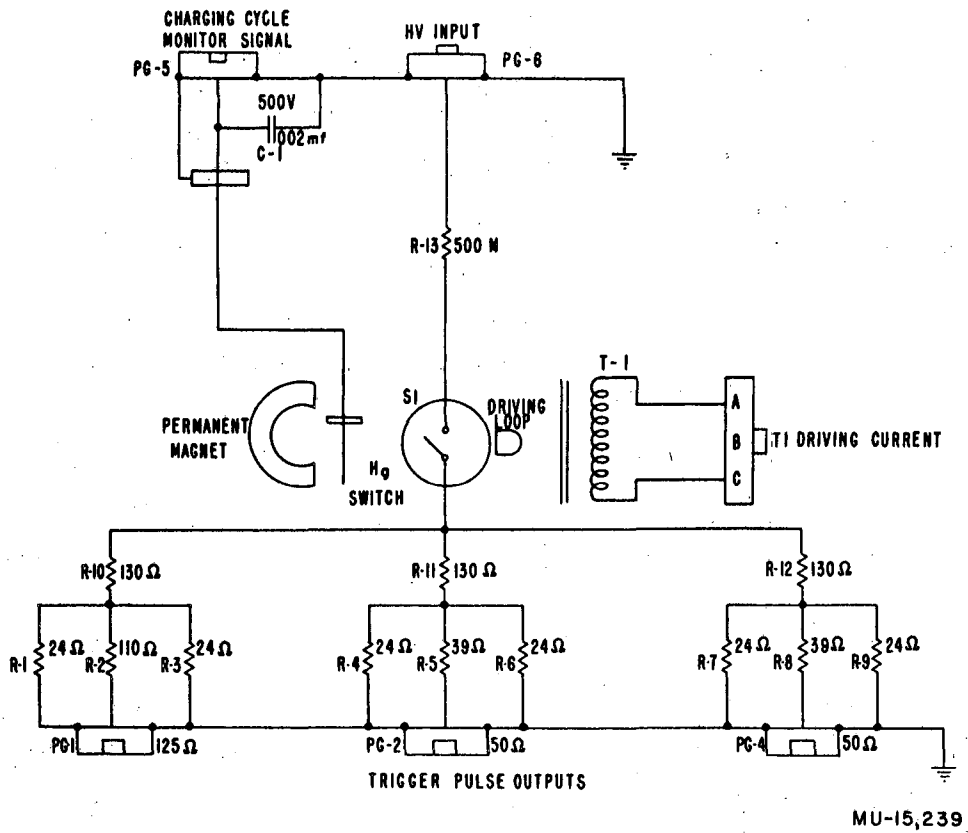


Fig. 4. Schematic drawing of the light pulser.

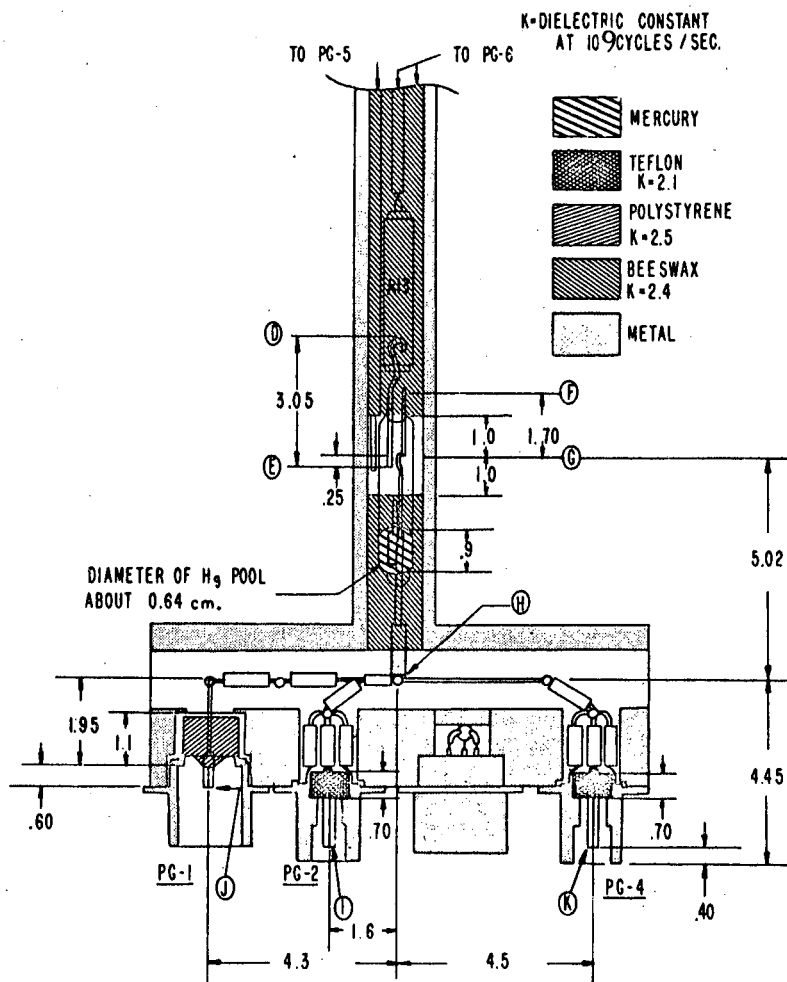
A metal shell (in two halves) (4V5612 and 4V5652) encloses S-1 to form the outer conductor of a coaxial circuit; the contacts of S-1 form the inner conductor of the circuit.

Large-amplitude high-frequency currents accompany the light pulses; these of course are the electrical trigger pulses previously mentioned. The currents are confined to the inner surfaces of the metal half shells (4V5681 and 4V5612) because of the small skin depth of the metal for high frequencies. The shielding is adequate to confine these pulses (which may exceed 100 kilowatts peak power) to the trigger channels so that the pulses do not interact with sensitive circuits that may be in the vicinity.

The magnetic field of the driving loop alternates at a low frequency, usually 60 cps, and penetrates the metal half shells with negligible attenuation. T-1 transforms the driving-loop impedance to a convenient value. The small permanent magnet bucks out a part of the built-in spring tension in the moving contact of S-1. The base plate on which the unit is assembled is a magnetic shield and should be in place when the unit is operated. This driving system gives excellent decoupling between the driving and signal circuits, plus convenient single-turn assembly and dismantling.

Electrical Pulse Geometry

Energy for both the light pulse and the electrical trigger pulse is stored in the capacitance of the stationary contact of S-1 and the short lead of the 500-megohm resistor, R-13, as indicated by DE in Fig. 5. When the contacts are open, this capacitance is recharged through R-13 which also isolates the high-voltage charging supply and cable from the discharge circuit. The energy-storage circuit DE has a capacitance of $2.8 \mu\mu\text{f}$ and thus a charging RC time constant of $500 \text{ megohms} \times 2.8 \mu\mu\text{f}$, or about 1.5 milliseconds. When the contacts are driven toward the closed position with voltage applied, an arc forms when some critical potential gradient (which depends upon pressure in the capsule) is reached. The resulting electrical pulse is propagated down the transmission line GH to the resistive attenuators at Plugs 1, 2, and 4. Since the light output can be modulated by electrical reflections, the conditions have been chosen to minimize these, although the geometry of S-1 permits only an approximation to the ideal impedance-matched configuration. The mercury-wetted contact is, however, nearly ideal from the standpoint of electrode erosion; the liquid mercury is re-formed to a reasonably smooth surface before each pulse. This process favors the attainment of a high gradient just prior to breakdown and a corresponding high rate of rise of current. Comparable dry-contact gaps have been observed to develop surface irregularities with time, whereas mercury light pulsers of the type described in this report have been in service for more than two years with no apparent deterioration.



MU-15,266

Fig. 5. Electrical pulse geometry of the light pulser. All dimensions are in centimeters.

Power Supplies

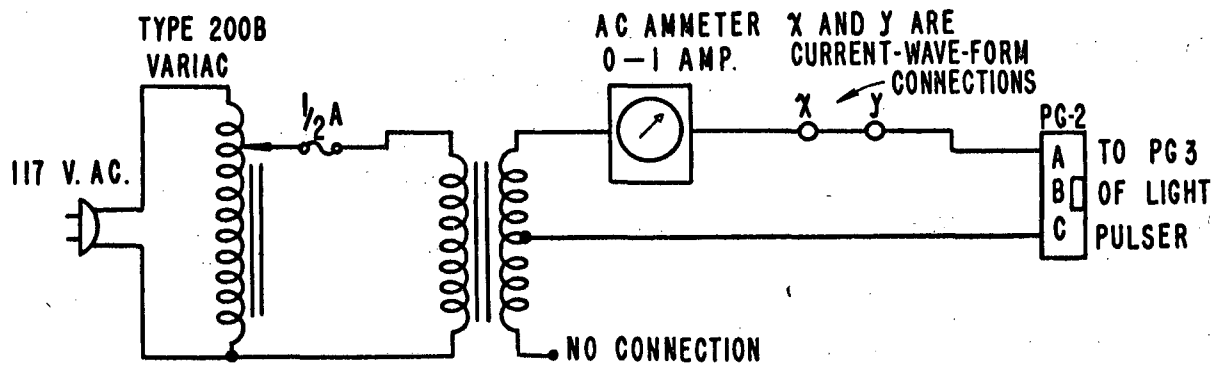
Two basic power supplies are required for operation of the light-pulse generator. One, the regulated high-voltage supply, is connected to PG-6. It should be adjustable from 100 to 5000 volts dc. Current drain is less than 20 microamperes. Either high plus or high minus operation is permissible, although the data in this report refer only to the high plus connection, for which the resulting electrical output trigger pulses at PG-1, PG-2, and PG-4 are positive. The other required power supply is an adjustable source of about 3 volts at half an ampere at 60 cps for the driving coil T-1, connected to PG-3. Figure 6 shows a suitable supply for 60-cps operation (2X8181). Figure 7 shows a supply that has been used for lower rates and when freedom from 60-cps coupling was desired (2X8791). Each supply has provision for adjusting the amplitude of the driving-coil current. It is found that a slight readjustment of driving current for each high-voltage setting may be required for maximum amplitude stability.

Monitor Signal

The signal at PG-5 is the output of a capacity divider which consists of the 0.002- μ f capacitor (C-1 of Fig. 4) and the capacity (approximately 0.1 μ f) between the unshielded end of the cable attached to PG-5 and the energy storage circuit, DE of Fig. 5, which is not accessible otherwise. The ratio of the divider is thus about 0.1 μ f divided by 0.002 μ f, or 1:20,000 for an open circuit at PG-5. An amplifier of 1-megohm input impedance shunting PG-5 modifies the picture appreciably, but the actual wave shape can be inferred to sufficient accuracy for monitoring purposes. An amplifier of purely capacitive input impedance will give about the correct wave shape except for dc level. Figure 8 shows the wave form as seen on a scope of 1 meg and 40 μ f input impedance. The hv supply setting is 2 kv. When the driving-coil supply of Fig. 7 is used, Point B occurs about 3 to 5 milliseconds after the rise of the driving-current pulse, depending on its amplitude.

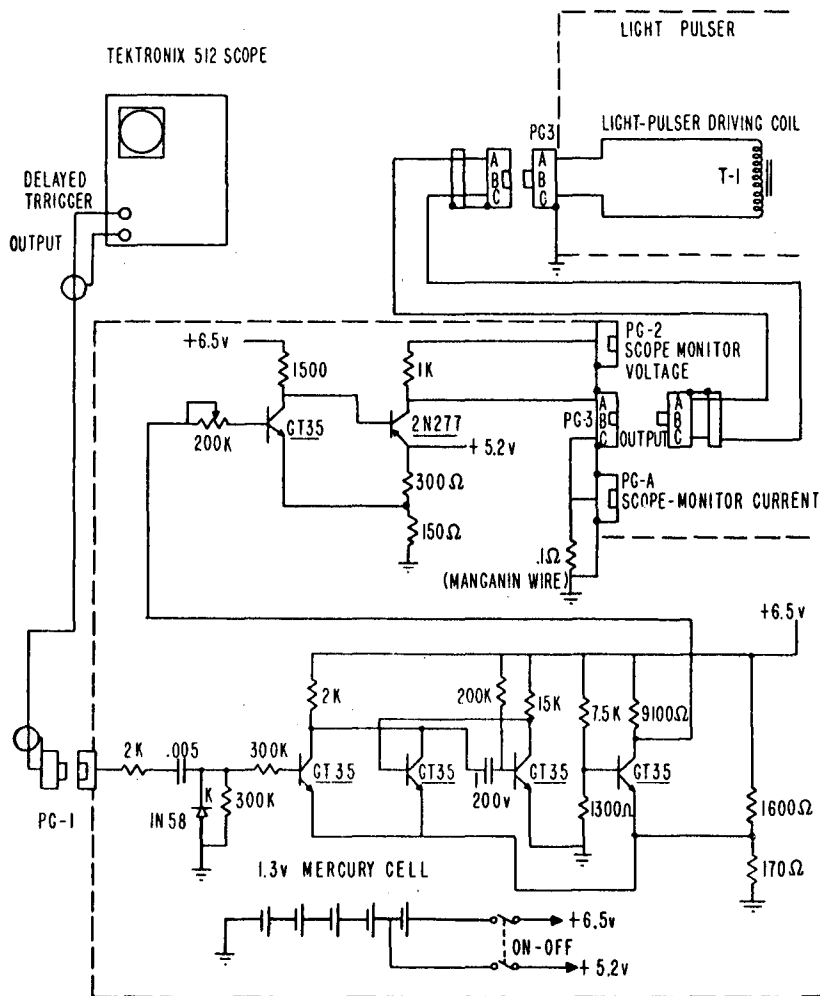
Pulse Groups

As suggested in the legend of Fig. 8, there is a structure associated with Point B in the figure. Microscopic observation of the arc shows that it occurs at a contact separation roughly proportional to voltage; the estimated critical gradient is 200 kilovolts/cm. (The hydrogen pressure in the capsule S-1 is perhaps 10 atmospheres. Capsules hold off from 8 to 10 kilovolts at maximum contact separation, and experimental pulsers have operated satisfactorily at this level.) The arc thus occurs well before the mercury surfaces are close enough to form a metallic bridge. Since the mechanical motion of the moving electrode is relatively slow, the electrodes may be considered stationary on the time scale of the arc (millimicroseconds). Oscillographic observation of the voltage on DE (Fig. 5) shows that the arc that first occurs does not completely discharge the energy-storage circuit DE. Instead, following the first arc, the contacts continue to move toward each other, at reduced voltage, and eventually a second arc occurs, and so on



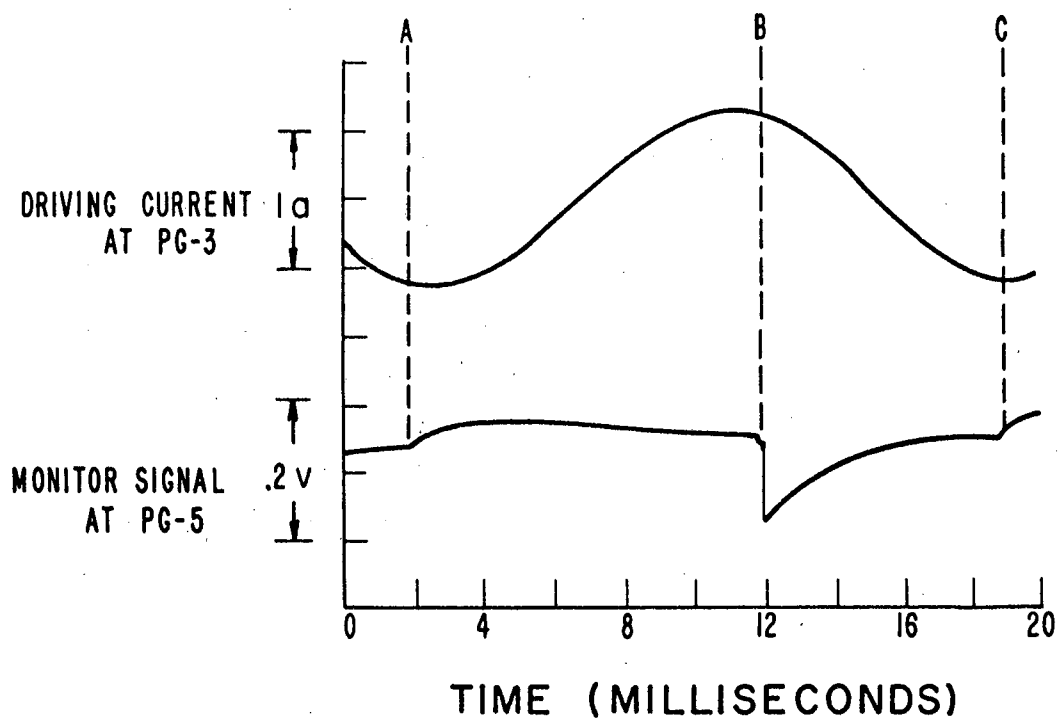
MU-15,240

Fig. 6. Light pulser driving-coil power supply for 60-cps operation. Optimum operating current for the driving coil is in the range of 0.25 to 0.7 amp (rms).



MU-15,241

Fig. 7. Light-pulser driving-coil power supply for adjustable repetition rates. The repetition rate is fixed by the sweep-repetition rate of the oscilloscope.



MU-15,242

Fig. 8. Monitor-signal wave form with 60 cps driving current as observed on an oscilloscope with 1-meg 40- μ f input termination. Point B is the time at which the arc occurs. The detailed structure following B is best observed on a shorter time base. On this basis, one may say that the contacts are closed from B to C, they open again at C, and remain open until the time corresponding to B on the next cycle. ABC is a complete cycle.

The polarity of T-1 is such that electron flow into pin C of PG-3 closes the contacts with the minimum current, i. e., the driving field aids the permanent-magnet field.

until the mercury forms a metallic bridge; the entire process may take 100 microseconds. The voltage on DE thus decays in a series of steps of decreasing size, and a group of light and electrical pulses is produced on each mechanical cycle. The nature of the group depends both on the hv setting and on the driving current (see Fig. 9). The pulses are well separated (the second pulse is delayed 2 microseconds or more after the first pulse) and may be used to trigger separate oscilloscope sweeps. The groups have been used in various ways in conjunction with auxiliary circuits to form gates, etc. Alternatively all signals after those derived from the first pulse may be gated out.

The pulse data given for both light and electrical pulses in the remaining pages refer to the first or primary pulse in the group. Below about 1 kv, usually only the primary pulse occurs.

Gate Signals

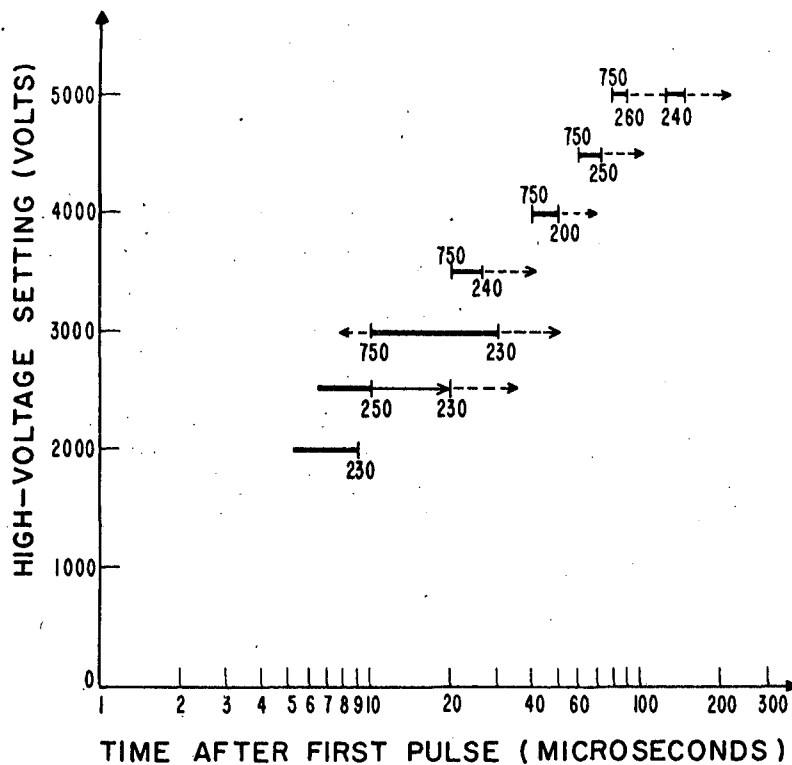
It is sometimes desired to pulse various equipment on in advance of the light pulse, which occurs at Point B (Fig. 8) of the monitor-signal wave form. Since the precise time of the pulse is not predictable, there will be a jitter time associated with such a gate signal. The magnitude of the jitter and the method of obtaining the gate depend upon the required advance in time.

As the monitor-signal wave form shows, time advances of the order of milliseconds are obtained by generating a gate timed with respect to the driving-current wave form. In this way the time of the flash can be predicted milliseconds in advance. There is a probable error of 20 microseconds with optimum driving-current settings.

Gate signals required to occur a few microseconds or less in advance of the light pulse can be generated from the monitor signal with more accuracy than from the driving signal. In this case, the timing prediction consists in measuring the capacitance increase between the contacts as they mechanically approach each other prior to the breakdown. Figure 10 shows wave forms obtained in the circuit of Fig. 11 (2X8771), designed to utilize this capacitance change to form a gate signal. When the monitor signal is used for this purpose, the capacitor C-1 in Fig. 11 is disconnected at point "x" to give the maximum signal to the amplifier. The resulting gate signal can be adjusted to turn on from zero to 10 microseconds ahead of the light pulse, with a probable error of about 0.2 microsecond. (Similar anticipator circuits have been applied to the mercury-switch electrical pulser)

Trigger Pulse

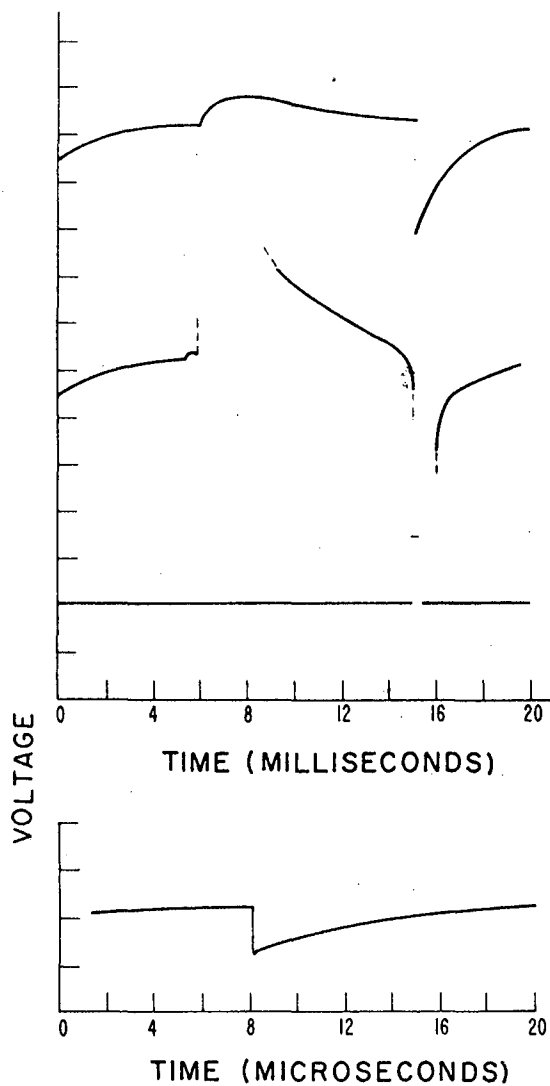
Figure 12 shows the trigger pulse available at PG-1, PG-2, or PG-4 (Points I, J, and K in Fig. 5) as viewed on a 5XP11 cathode-ray tube adapted for coaxial cable connections direct to the vertical plates. Figure 13 shows a schematic diagram (2X8801) for arrangement of 125-ohm coaxial connections to a Tektronix 517 oscilloscope. (Slightly altered values of R-2 and



MU-15;267

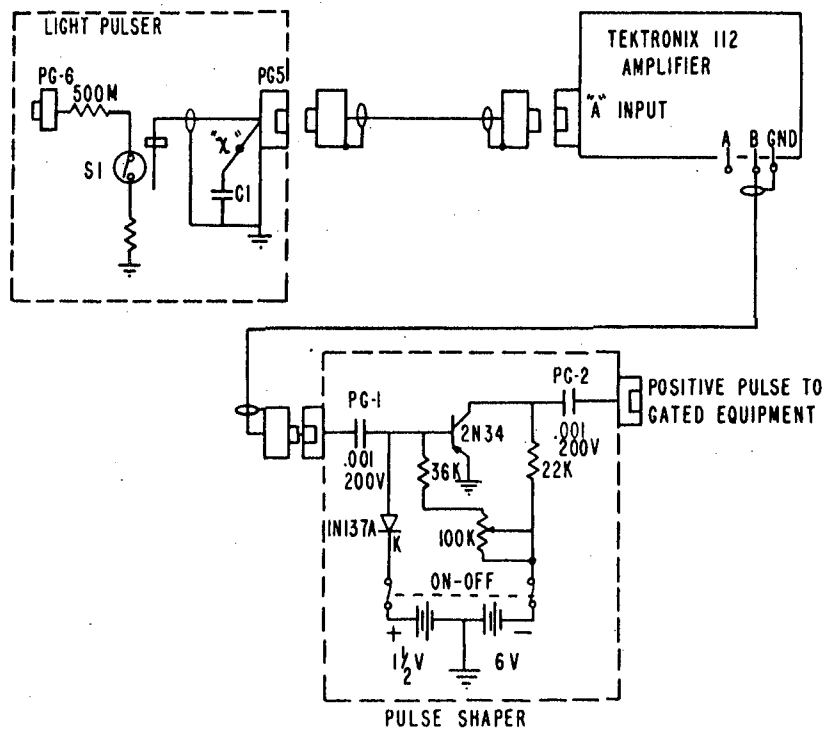
Key: Pulses occur within --- tending toward the position associated with the driving current (in ma at 60 cps) written beneath. Pulses may be made to occur within --- by forcing the driving current outside the range where stable pulses occur.

Fig. 9. Pulse groups versus high-voltage setting and driving-coil current for a typical light pulser.



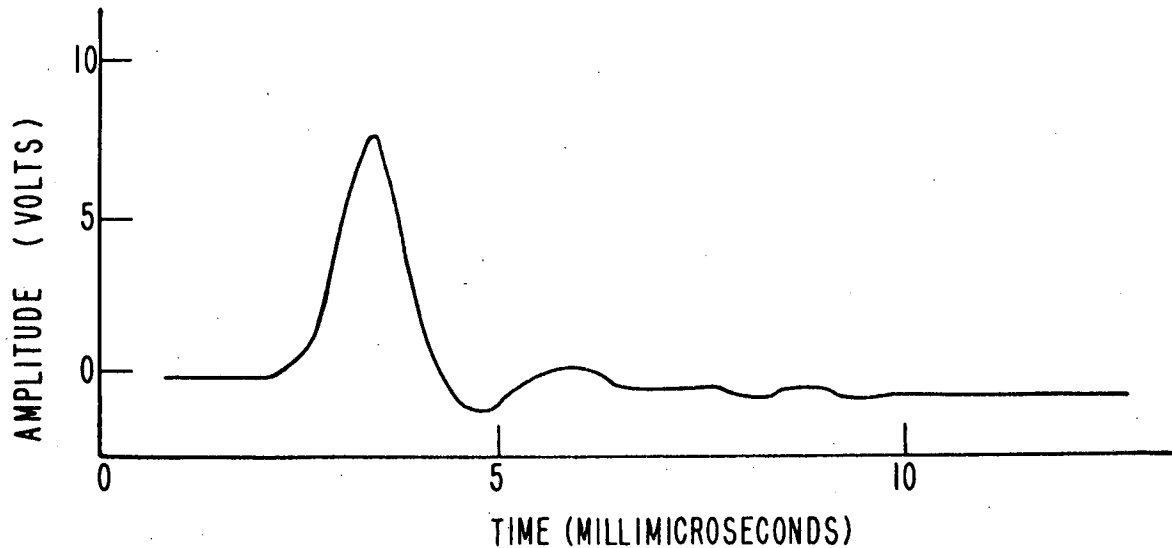
MU-15,268

Fig. 10. Wave forms of light-pulse anticipator. (a) monitor signal from PG-5 of light pulser; (b) amplified monitor signal applied to PG-1 of pulse shaper (Fig. 11); (c) output from PG-2 of pulse shaper to gated equipment; (d) stretched pulse from PG-2 of light pulser on a scope trace triggered by the anticipator output.



MU-15,243

Fig. 11. Light-pulse anticipator.



MU-15,244

Fig. 12. Trigger pulse wave form as observed on a 5XP11 cathode-ray tube.

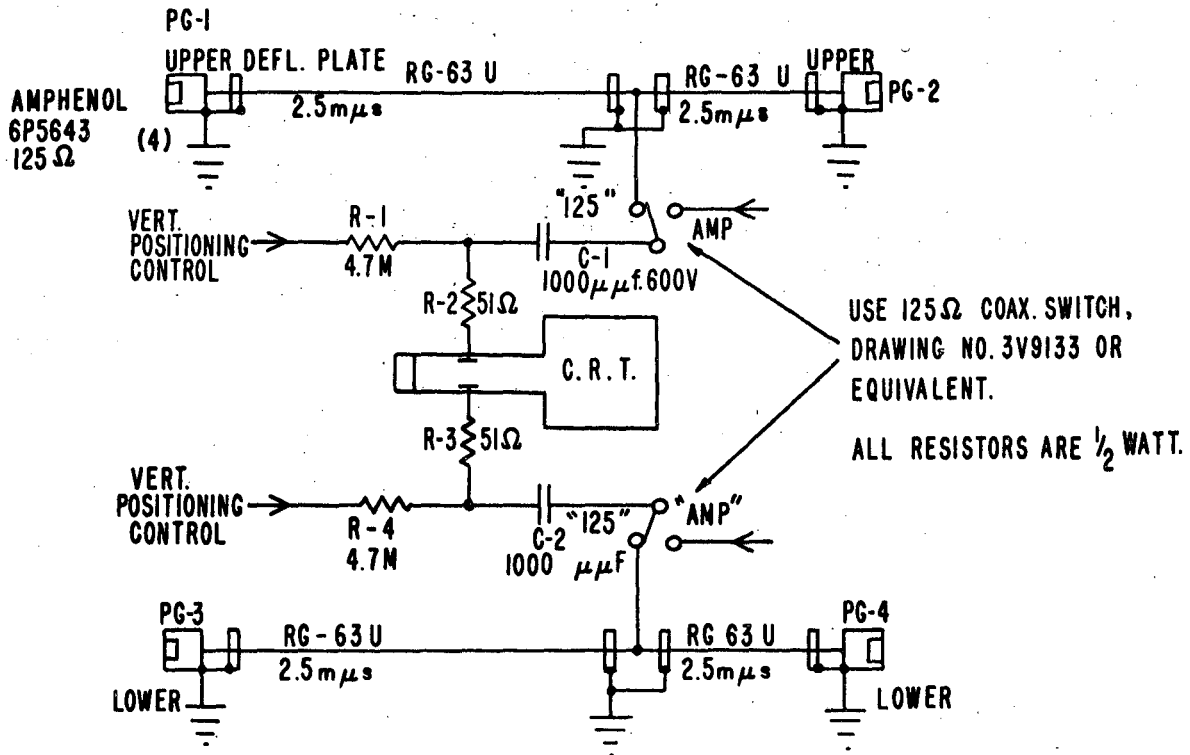
Light-pulsar high-voltage supply setting 2400 v dc.

Signal delayed through 125 millimicroseconds of RG 63U.

Signal amplitude at both the 50-ohm and the 125-ohm connectors is the same when coax lines of the appropriate impedance are connected.

Signal wave form at the 50-ohm and the 125-ohm outputs is also the same.

The arrival time of the electrical pulse at a particular connector is slightly delayed with respect to the arrival time of the light pulse at the aperture in the base plate. The electrical pulse arrives first at PG-2, and about 10^{-10} sec later at PG-1 and PG-4. The electrical pulse arriving at PG-2 may be considered to be delayed by about 3×10^{-10} sec with respect to the arrival time of the light pulse at the aperture in the base plate.



MU-15,245

Fig. 13. Schematic diagram of 125-ohm connections to Tektronix 517 oscilloscope vertical deflection plates. With care in minimizing stray capacities and inductances a rise time of about 1 μsec can be achieved with a 5XP11 cathode-ray tube.

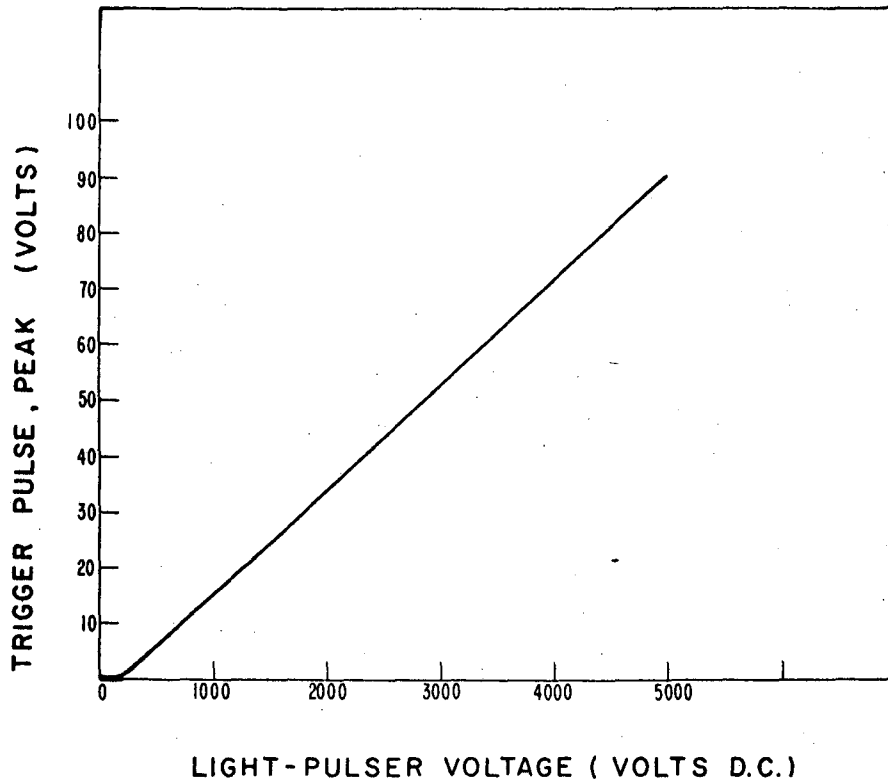
R-3 are appropriate to the 517A, and the apparent rise time is somewhat slower than that indicated in Fig. 12.) The actual trigger pulse is shorter than Fig. 12 would indicate. Figure 14 gives the measured peak voltage of the trigger pulse as a function of the high-voltage power-supply setting. The actual peak pulse voltage for Fig. 12 is about 41 volts, whereas the scope picture (which is almost the impulse response of the scope) indicates about one-fifth this amplitude and a broader pulse. Figure 15 represents the peak voltage available when the various attenuating resistors are disconnected from Point H in Fig. 5 and a single 50-ohm coax line is connected. This output is termed the high-level pulse. It is sufficiently energetic (approximately 100 kw peak power at 5 kv setting) to provide sweep and unblanking wave forms directly, and has been used in this way to make sweeps of 3×10^{-11} sec/cm synchronized with the light pulse. In this way, small time variations in the optical path can be measured down to 10^{-13} sec. The trigger pulse is short enough so that its amplitude decays to about 1/2 the initial amplitude after traversing 100 ft of RG-9/u coaxial cable.²

Light Output

Figure 16 shows the light output in terms of the response of an S-11 photocathode as a function of the high voltage for several units of the present design. For this curve, the polaroid attenuator is set for minimum attenuation. The light output increases approximately as the fifth power of the voltage at low voltages, and approximately as the square of the voltage at high voltages. The photoelectron yield is that integrated over a time of 5 μ sec and depends on the choice of driving current. Figure 17 shows the approximate light-pulse wave shape as measured by a special phototube with control grid gated by the high-level pulse.³ The trigger pulse is as observed on an oscilloscope employing the Dumont K1421 traveling-wave cathode-ray tube.⁴

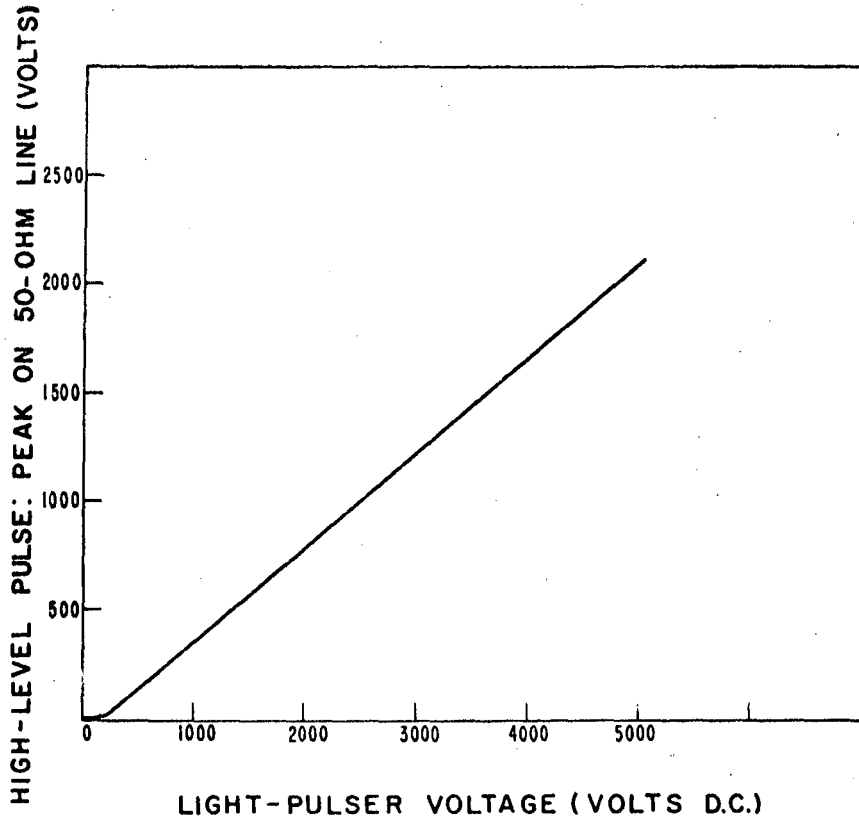
The relative timing of the pulses shown is somewhat arbitrary; timing depends on the relative optical and electrical path lengths in a given case. For this purpose, the dimensions and dielectric constants of Fig. 5 are helpful; Fig. 12 indicates the approximate timing. The jitter time between the light and electrical pulses is known to be quite small, and allows measurements in the 10^{-13} -second region when the high-level pulse is used directly to generate the oscilloscope sweep.

Observed under a medium-power microscope, the arc has an interesting and complicated structure in space and time. However, for the purposes of this report, one may consider the arc to have an effective diameter of a few thousandths of an inch, and for many purposes it may be considered a point source. The useful light output from the light-pulse generator is confined to an irregular cone of half angle approximately 10 degrees. When the mercury capsule is mounted, the attempt is to make the axis of this "cone of best visibility" normal to the base plate; for a given unit, this is approximately true, but often a somewhat better axis may be chosen by experiment. For best stability of the light-pulse amplitude the phototube should be located somewhere on this empirically determined axis. In view of the approximately point-source optics, lenses and mirrors may be used to obtain high light intensity; photoelectron current densities of several amperes per cm^2 are attainable.



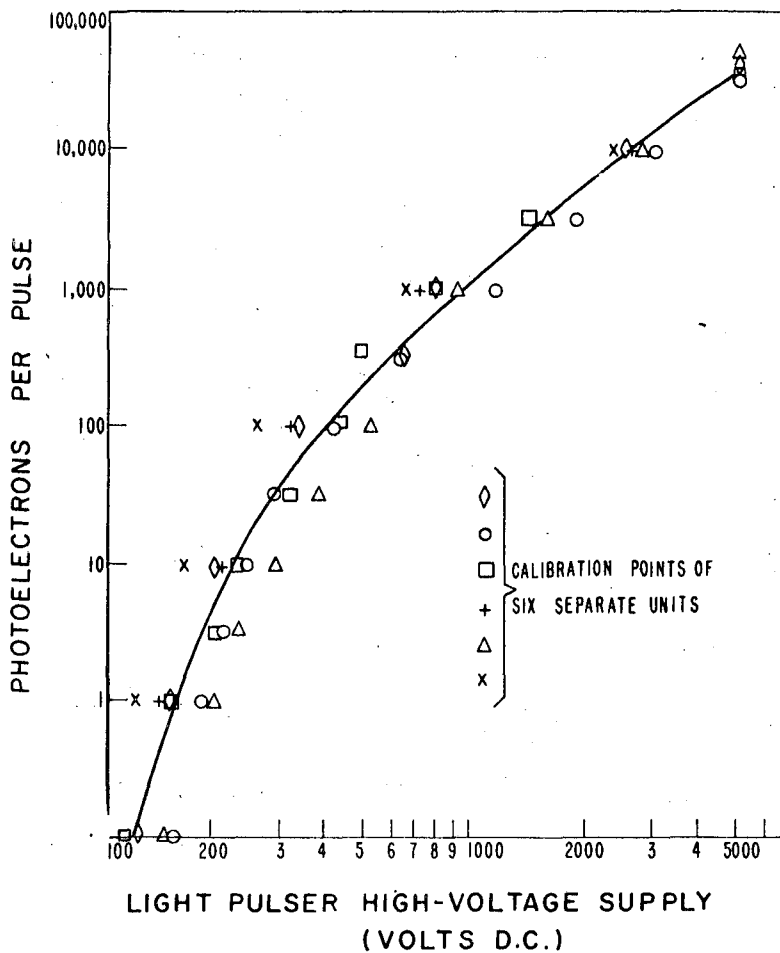
MU-15,246

Fig. 14. Trigger-pulse output voltage vs light-pulsar high-voltage setting measured at PG-1, PG-2, or PG-4.



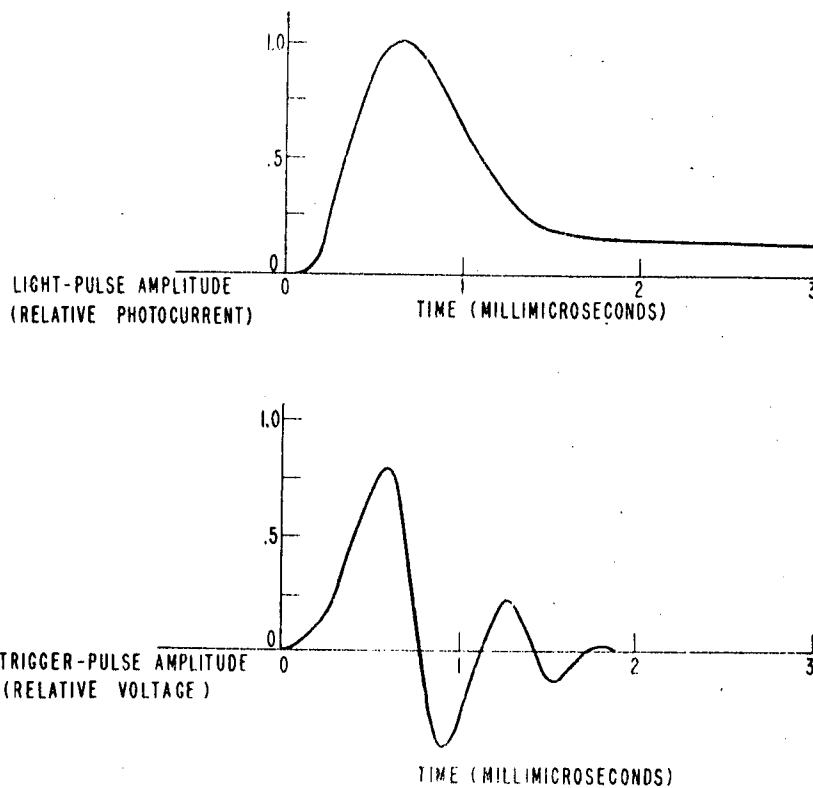
MU-15,247

Fig. 15. High-level output pulse vs light-pulsar high-voltage supply setting. The high-level pulse is obtained by removing the attenuating resistors associated with PG-1, PG-2, and PG-4 and connecting instead a 50-ohm coax.



MU-15,269

Fig. 16. The yield of photoelectrons per pulse from an S-11 cathode subtending 0.005 steradian at the light source. The polaroid attenuator is set for minimum attenuation.



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Fig. 17. (Upper) Wave shape of the light pulse as measured with a special gated phototube.

(Lower) Wave shape of the trigger pulse as observed on an oscilloscope utilizing a K1421 traveling-wave deflection cathode-ray tube.

The spectrum of the light emitted from the pulser is shown in Fig. 18.

Polaroid Attenuator

The polaroid attenuator, consisting of a stationary and a rotatable disc of Polaroid film, provides a simple way of adjusting the light amplitude without disturbing any electrical settings. It should be noted here that the light from the light pulser is partially polarized as generated; Table II illustrates this:

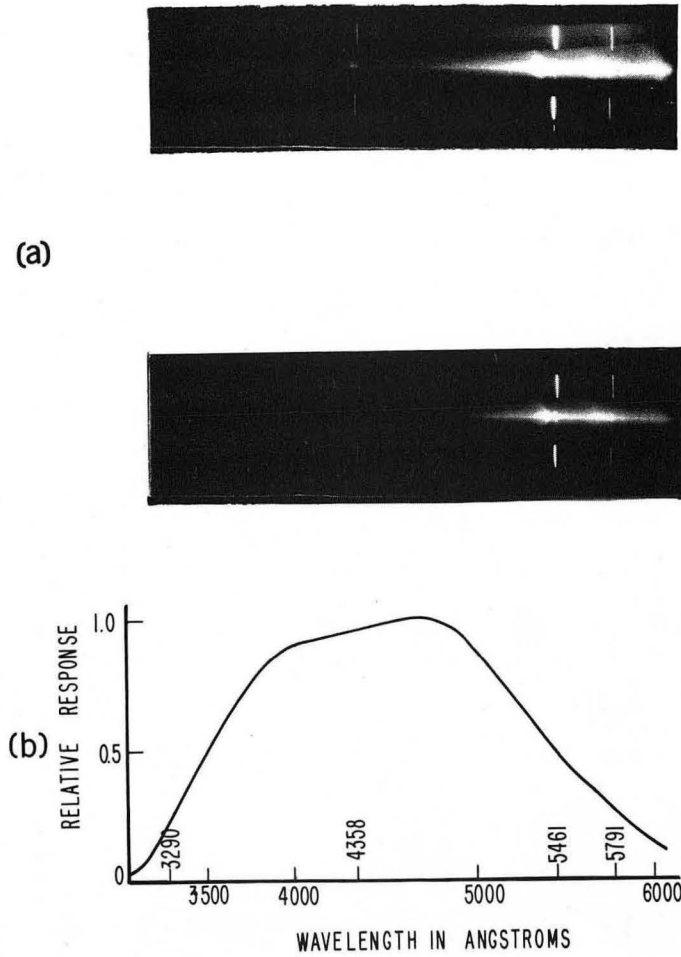
Table II

Polarization of light from the mercury capsule	
<u>Fraction of light having vertical polarization</u>	<u>High voltage setting (Volts)</u>
0.89	200
0.75	500
0.66	2000
0.57	5000

The stationary Polaroid film is oriented to pass vertically polarized light in order to take advantage of this fact. Thus when set for minimum attenuation, the attenuator readily transmits vertically polarized light. For other attenuator settings the polarizer is rotated while the analyzer remains fixed, so that the outgoing light is always vertically polarized. The polaroid films may be removed or changed by using the Waldes Truarc plier #1 to handle the retaining rings. Figure 19 is a plot of the ratio of incident to transmitted light vs the angle between polarizer and analyzer, as observed by an S-11 photocathode. The plot follows a $1/\cos^2$ function closely except near maximum attenuation when the transmitted light is attenuated by a factor of 100 over minimum attenuation.

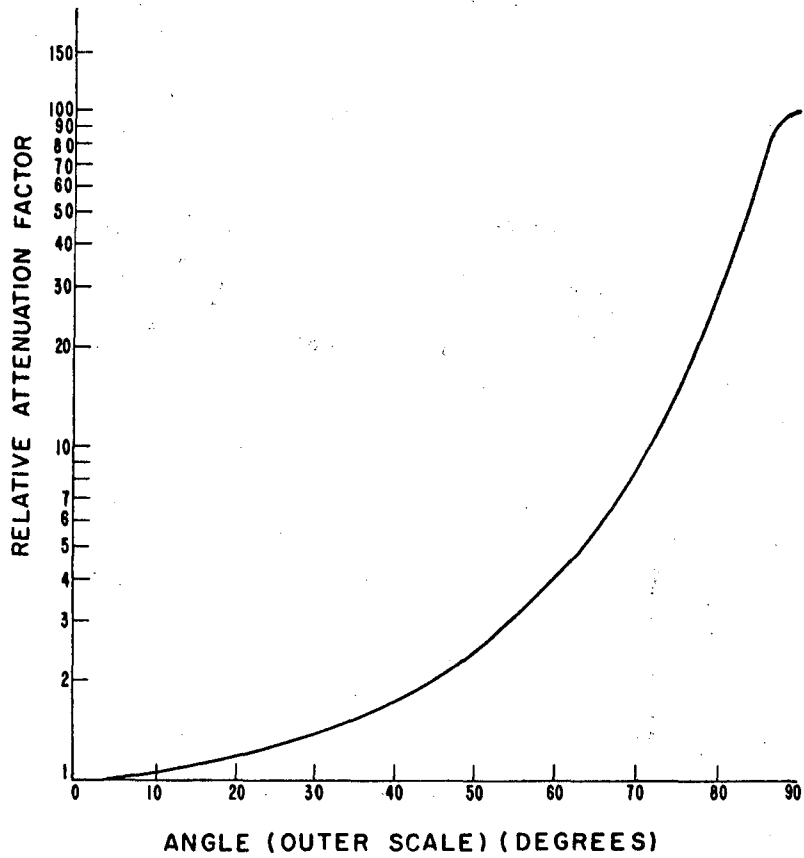
Dark Enclosure

Figure 20 (2X8493, 2X8501) shows a dark enclosure which has proved useful in connection with the light-pulse generator. The box is made of 3/4-inch plywood for which the optical attenuation factor is approximately 10^{21} . The light-pulser plugs and polaroid attenuator handle are outside the light-tight box. High-voltage leads and 125-ohm coaxial signal cables are terminated at the walls of the box with connectors mounted so as to be lighttight. For controlling focus-electrode and other voltages from outside the box,



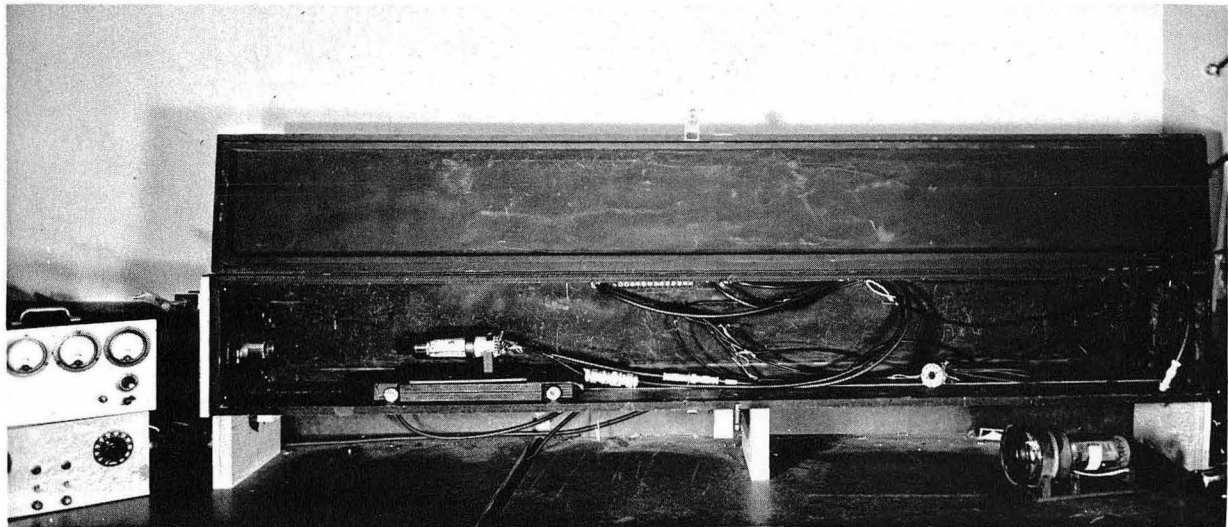
MU-15,270

Fig. 18. (a) The spectrum of the light from the pulser as photographed on a Kodak type F-1 spectrographic plate, which is most sensitive between 4500 and 6900 Å. A spectrograph with a 4 1/2-inch transmission grating was used. The two views are identical except for the contrast, which was changed in order to reproduce both ends of the spectrum more clearly. The polaroid attenuators were removed for this exposure. The calibrating marks are mercury lines at (left to right) 4358, 5461, and 5791 Å. (b) The response of an S-11 photocathode is shown on the same scale.



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Fig. 19. Relative attenuation factor of the polaroid attenuator used on the light pulser. The measurements were made with a phototube having an S-11 photocathode.



ZN-1938

Fig. 20. A dark enclosure used in conjunction with the light pulser for phototube testing. The pulser is seen attached to the left end of the box.

In this box, the phototube is mounted on a movable cart so that the light incident on the cathode can be varied in accordance with the inverse-square law. Where fixed phototube mounts are adequate, shorter boxes are used.

RG-58 cables are passed through holes drilled slightly undersize and sealed with opaque plastic material. All lighttight seals are carefully made so that the ambient light inside the box causes a photocurrent several orders of magnitude less than the photocathode dark current.

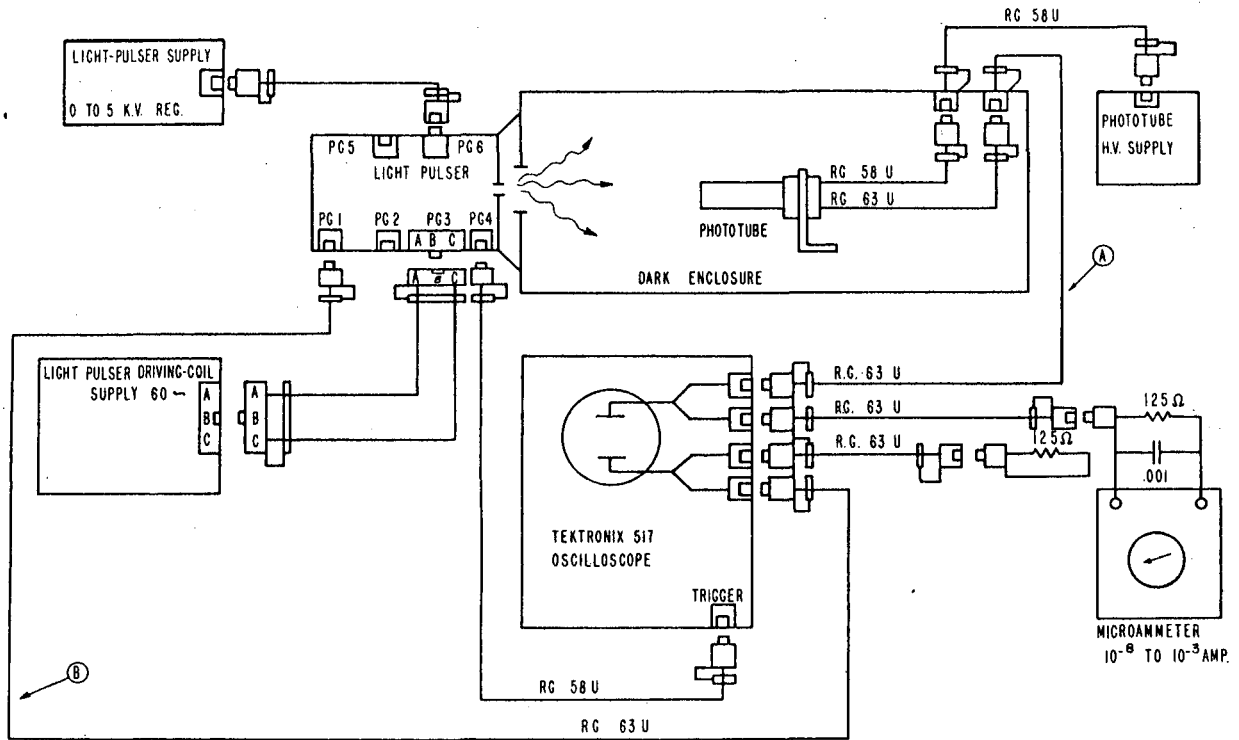
Typical Test Setup

Figure 21 shows a typical test setup (2X8812). A microswitch (not shown) on the dark enclosure cuts off the phototube hv supply when the door is opened. Several tubes may view the light source through various optical paths if desired. One of the trigger pulses may appear as a fiducial mark on the oscilloscope sweep (Cable B), another may be used for z - axis modulation, etc. The transit time of the pulse through the phototube plus the delay of Cable A should be at least 90 millimicroseconds longer than the delay through the cable that triggers the 517 scope, to allow time for the sweep circuits to start the trace. This time is also considered in determining the length of Cable B.

Sliding lines (line stretchers) are often helpful in measuring incremental time delays of tubes in the test setup. The General Radio type 874-LK or 874-LT constant-impedance adjustable lines (and other line elements) are convenient in the 50-ohm channels. (UCRL drawing # 2X6134 shows a line stretcher for use in 125-ohm impedance lines.)

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The expert assistance of Robert Reynolds, who constructed the light pulsers, is gratefully acknowledged.



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Fig. 21. Typical phototube-test setup using the light-pulse generator.

List of UCRL Drawings Pertaining to the Construction
and Use of the Light Pulser

Drawing number	Item
<u>A. Fabrication Drawings</u>	
4V5572	Electrical schematic drawing of light pulser.
4V5593	Instructions for completing the mechanical assembly of the light pulser.
4V5603	Instructions for completing the electrical assembly of the light pulser.
4V5612	Instructions for joining 4V5632, 4V5642, and 4V5652.
4V5622	Base-plate fabrication.
4V5632	Four-receptacle mount fabrication (supports PG-1, PG-2, PG-3, and PG-4).
4V5642	Two-receptacle mount fabrication (supports PG-5 and PG-6).
4V5652	Metal half-shell fabrication.
4V5661	Fabrication of parts for adjustable light attenuator.
4V5671	Permanent-magnet mounting fabrication.
4V5681	Driving-loop fabrication.
4V5691	Adjustable light-attenuator plastic scale fabrication.
4V5701	Modification of standard type N connectors for PG-2 and PG-4.
4V5711	Modification of Cannon 5-kv connector for PG-6.
4V5721	Modification of 125-ohm connector for PG-1.
4V5731	Modification of Westinghouse 1P2 pulse transformer for driving coil T-1.
<u>B. Accessory-Equipment Drawings</u>	
2X8781	Driving-coil power supply for 60-cps operation.
2X8791	Driving-coil power supply for adjustable repetition rates.
2X8771	Light-pulse anticipator.

List of UCRL Drawings Pertaining to the Construction
and Use of the Light Pulser

Drawing number	Item
<u>B. Accessory-Equipment Drawings (contd.)</u>	
2X8801	125-ohm connections to 517 oscilloscope.
3V9133	125-ohm coax switch for 517 oscilloscope.
2X8493	Dark enclosure for testing phototubes up to 5 in. in diameter.
2X8501	Suggested wiring entry into dark enclosure for testing photo- tubes.
2X8812	Typical phototube test setup with light-pulse generator.
2X6134	125-ohm line stretcher.
1X6693	Mercury-switch electrical pulser.

Light-Pulser Parts List

Part number	Specification
C-1	.002-mf 600-v ceramic condenser.
PG-1	Amphenol 82-885, modified (see 4V5721) (UCRL 125-ohm connector).
PG-2, PG-4	Amphenol UG58A/U, modified (see 4V5701).
PG-3	Amphenol 97-3102A-14S-1P-639 3-pin male chassis receptacle
PG-5	Amphenol SO-239 female receptacle.
PG-6	Cannon 3102A-18-16P, modified (see 4V5711)
R-1, 3, 4, 6, 7, 9	24-ohm 1/2-w carbon resistor.
R-2	110-ohm 1/2-w carbon resistor.
R-5, 8	39-ohm 1/2-w carbon resistor.
R-10, 11, 12	130-ohm 1/2-w carbon resistor.
R-13	500 meg 1/2-w S. S. White resistor.
S-1	Clare HG-1003 mercury switch (or equivalent).
T-1	Westinghouse 1P2 pulse transformer modified (see 4V5731).

NOTES AND REFERENCES

1. References illustrating various uses for the light pulser are available in reports prepared for internal distribution at the University of California Radiation Laboratory, as follows:
 - a. Quentin Kerns and Frederick A. Kirsten, Results of Preliminary Tests of Two RCA LE 59 Photomultiplier Tubes, UCID-18 (CRG-2), Nov. 1955.
 - b. Frederick A. Kirsten, Results of Transit-Time Measurements on Three C7187A Photomultiplier Tubes, UCID-19 (CRG-3), Dec. 1955.
 - c. Quentin Kerns, Results of Tests on Two C7232 Experimental 16-Stage Multiplier Phototubes, UCID-97 (CRG-7), Nov. 1956.
 - d. Quentin Kerns, Improved Time Response in Scintillation Counting, IRE Transactions NS-3, No. 4 (Nov. 1956), Part I.
2. Regarding the distortion of pulses transmitted in coaxial transmission lines:
 - a. Quentin Kerns, Improved Time Response in Scintillation Counting, IRE Transactions NS-3, No. 4 (Nov. 1956), Part II.
 - b. UCRL Counting Handbook, Counting Note CC2-1.
3. Frederick A. Kirsten, Measurement of the Shape of the Light Pulse Generated by Mercury Light Pulser 4V5572, Engineering Note EE548, April 1958.
4. C. Norman Winningstad, A Fractional-Millimicrosecond Oscilloscope System Utilizing Commercially Available Components, UCRL-3778, Sept. 1957.

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