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ABSTRACT

This mercury-capsule light-pulse generator was developed to test and evaluate the high-speed features of multiplier phototubes and low-level image tubes. Light pulses and electrical trigger pulses are generated simultaneously in an arc discharge at a usual repetition rate of 60 per second. The electrical pulse is used as a time reference for the light pulse. The time required for both the light and the electrical pulse to rise from 10% to 90% of peak amplitude is less than 5×10^{-10} sec. The light pulse rises to a maximum and falls to 50% peak amplitude in less than 1.5×10^{-9} sec. The electrical pulse power available is large. Time resolution of 10^{-10} sec is typical of measurements made with conventional fast oscilloscopes, 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 sterad at the light source emits photoelectrically about 10^7 electrons per sterad per pulse. For convenience, three decoupled electrical output channels are provided, together with a polaroid attenuator for the light pulse.

5451

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INTRODUCTION

The light-pulse generator described in this paper was developed for testing the high-speed characteristics 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 have been made of afterpulsing, transit time, multiplier transit-time spread, cathode transit-time spread, multiplier current saturation, and certain other features.[1] Information of this detail is ordinarily unavailable from manufacturers. However, when designing instrumentation for use in particle detectors it is desirable to know the constants involved in a designated tube. Once a particular experiment is in progress, it is convenient to have replacement tubes available for which these values are known, so that time will not be lost in recalibrating or redesigning equipment after installing a new tube.

This paper is a summary presentation; for a more detailed discussion see UCRL-~~8277~~ 8227.[2]

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*Work was done under the auspices of the U.S. Atomic Energy Commission.

ELECTRICAL AND MECHANICAL ASSEMBLY

Arrangement

Figure 1 shows the external arrangement of the light pulser. Figure 2 indicates the electrical and mechanical assembly. The light pulses and the electrical trigger pulses are produced simultaneously in a mercury-wetted contact relay capsule S-1. This capsule is contained in a metal shell that forms the outer conductor of a coaxial circuit; the contacts MC and SC form the inner conductor of the circuit. The source of light is the arc formed at these contacts. The light is emitted through an aperture located in the rear of the base plate into a lighttight box containing the phototube being tested. A polaroid attenuator, consisting of a stationary and a rotatable disc of Polaroid film, provides a simple means of adjusting the light amplitude without disturbing any electrical setting.

The magnetic field of the driving loop alternates at low frequency, usually 60 cps, and penetrates the metal shell with negligible attenuation. The driving loop is a single-turn copper strap which surrounds the metal shell and is the secondary of T-1. The multiturn primary winding (the driving coil) of 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 MC.

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 is adjustable from 100 to 5000 v dc. Current drain is less than 20 μamp. Either high-plus or high-minus operation is permissible, although the data in this paper 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 v at 1/2 amp at 60 cps for the driving coil of T-1, connected to PG-3. The pulser will operate at any lower repetition rate by putting in a 15-msec pulse of the required volt-sec product at the terminals of the driving coil. A suitable supply will have provision for adjusting the amplitude. It is found that a slight readjustment of driving current for each high-voltage setting may be required for maximum amplitude stability.

FORMATION OF LIGHT AND ELECTRICAL PULSES

Energy for both the light pulse and the electrical trigger pulse is stored in the capacitance of the stationary contact, SC, of the capsule and the short lead of the 500-meg resistor, R-13, as indicated by DE in Fig. 2. 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 μμf and thus a charging RC time-constant of 500 meg × 2.8 μμf, or about 1.5 msec. 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 PG-1, PG-2, and PG-4. Because 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 here have been in service for more than two years with no apparent deterioration.

PERFORMANCE

Monitor Signal

The signal at PG-5 is the output of a capacity divider. The divider consists of the 0.002-μf capacitor C-1 and the capacity (approximately 0.1 μμf) between the unshielded end of the cable attached to PG-5 and the energy storage circuit, DE, which is not accessible otherwise (Fig. 2). The ratio of the divider is thus about 0.1 μμf divided by 0.002 μf, or 1:20,000 for an open circuit at PG-5. An amplifier of 1-meg 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 3 shows the wave form as seen on a scope of 1 meg and 40-μμf input impedance. The hv-supply setting is 2 kv. Point B occurs about 3 to 5 msec after the rise of the driving-current pulse, depending on its amplitude.

Pulse Groups

As suggested in the legend of Fig. 3, 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 kv/cm. (The hydrogen pressure in the capsule S-1 is perhaps 10 atmospheres. Capsules hold off from 8 to 10 kv 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. Because the mechanical motion of the moving electrode is relatively slow, the electrodes may be considered stationary on the time scale of the arc (nanosec). Oscillographic observation of the voltage on DE (Fig. 2) 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 until the mercury forms a metallic bridge; the entire process may take 100 μsec. 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. 4). The pulses are well separated (the second pulse is delayed 2 μsec 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 and control signals. 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. 3) 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 μsec 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 5 shows wave forms obtained in a circuit 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. 2 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 μsec ahead of the light pulse, with a probable error of about 0.2 μsec. (Similar anticipator circuits have been applied to the mercury-switch electrical pulser.)

Trigger Pulse

Figure 6 shows the trigger pulse available at PG-1, PG-2, or PG-4 as viewed on a 5XP11 cathode-ray tube adapted for coaxial-cable connections direct to the vertical plates. The actual trigger pulse is shorter than Fig. 6 would indicate. Figure 7 gives the measured peak voltage of the trigger pulse as a function of the hv power-supply setting. The actual peak pulse voltage for Fig. 6 is about 41 v, whereas the scope picture (which is almost the impulse response of the scope) indicates about one-fifth this amplitude and a broader pulse. Figure 8 represents the peak voltage available when the various attenuating resistors are disconnected from point H in Fig. 2 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.[3]

Light Output

Figure 9 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 nanosec and depends on the choice of driving current. Figure 10 shows the approximate light-pulse wave shape as measured by a special phototube with control grid gated by the high-level pulse.[4] The trigger pulse is as observed on an oscilloscope employing the Dumont K1421 traveling-wave cathode-ray tube.[5]

The light pulse and the trigger pulse are generated simultaneously at the arc. The timing between the light and electrical pulses depends on the relative optical and electrical path lengths in a given case. Figure 10 indicates the approximate time relation between light arriving at a surface 3 in. from the arc, and the trigger pulse on PG-2. The jitter time between the light and electrical pulses is known to be quite small, and allows measurements in the 10^{-13}-sec 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 paper, 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 amp/cm^2 are attainable.

The spectrum of the light emitted from the pulser is shown in Fig. 11. The wave shape of the light pulse shown in Fig. 10 is that obtained using the spectrum of Fig. 11b. By selecting and using narrower spectral regions, some changes in waveshape can be obtained, particularly in regard to the decay of the light pulse.

ACKNOWLEDGMENT

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

NOTES AND REFERENCES

1. References illustrating various uses for the light pulser are:
    a. Quentin Kerns and Frederick A. Kirsten, Results of Preliminary Tests of Two RCA LE 59 Photomultiplier Tubes, UCID-18, Nov. 1955.
    b. Frederick A. Kirsten, Results of Transit-Time Measurements on Three C7187A Photomultiplier Tubes, *UCID-19,* Dec. 1955.
    c. Quentin Kerns, and Frederick A. Kirsten, Results of Tests on Two C7232 Experimental 16-Stage Multiplier Phototubes, UCID-97, Nov. 1956.
    d. Quentin Kerns, Improved Time Response in Scintillation Counting, IRE Trans., *NS-3,* No. 4 (Nov. 1956), Part I.
2. Kerns, Kirsten, and Cox, A Generator of Fast-Rising Light Pulses for Phototube Testing, UCRL-8227, March 24, 1958
3. Regarding the distortion of pulses transmitted in coaxial transmission lines:
    a. Quentin Kerns, Improved Time Response in Scintillation Counting, IRE Trans., *NS-3,* No. 4 (Nov. 1956), Part II.
    b. UCRL Counting Handbook, Counting Note CC2-1, UCRL-3307, Mar. 1, 1956.
4. Frederick A. Kirsten, Measurement of the Shape of the Light Pulse Generated by Mercury Light Pulser 4V5572, UCID-224 April 1958.
5. C. Norman Winningstad, A Fractional-Millimicrosecond Oscilloscope System Utilizing Commercially Available Components, Rev. Sci. Instr. *29,* 578-584 (1958).

LEGENDS

Fig. 1. The light pulser. A, permanent magnet; B, polaroid-attenuator adjustment handle; C, removable cap for high-level coaxial connection; T-1: primary driving coil, driving loop, and Hypersil core; Plugs: PG-1, 125-ohm trigger output; PG-2, 51-ohm trigger output; PG-3, driving-coil input; PG-4, 51-ohm trigger output; PG-5, monitor signal output; PG-6, high-voltage input.

Fig. 2. Electrical and mechanical arrangement of the light pulser. (Values not shown: R-1=24Ω, R-2=110Ω, R-3=24Ω, R-4=24Ω, R-5=39Ω, R-6=24Ω, R-7=24Ω, R-8=39Ω, R-9=24Ω.)

Fig. 3. Monitor-signal wave form with 60 cps driving current as observed on an oscilloscope with 1-meg 40-μμf 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.

Fig. 4. Pulse groups vs hv setting and driving-coil current for the light pulser. 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. 5. 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; (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.

Fig. 6. Trigger-pulse wave form as observed on a 5XP11 cathode-ray tube. Light-pulser hv-supply setting 2400 v dc. Signal delayed through 125 nanosec of RG 63U cable. 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 0.1 nanosec later at PG-1 and PG-4. The electrical

pulse arriving at PG-2 may be considered to be delayed by about 0.3 nanosec with respect to the arrival time of the light pulse at the aperture in the base plate.

Fig. 7. Trigger-pulse output voltage vs light-pulser hv setting measured at PG-1, PG-2, or PG-4.

Fig. 8. High-level output pulse vs light-pulser hv 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.

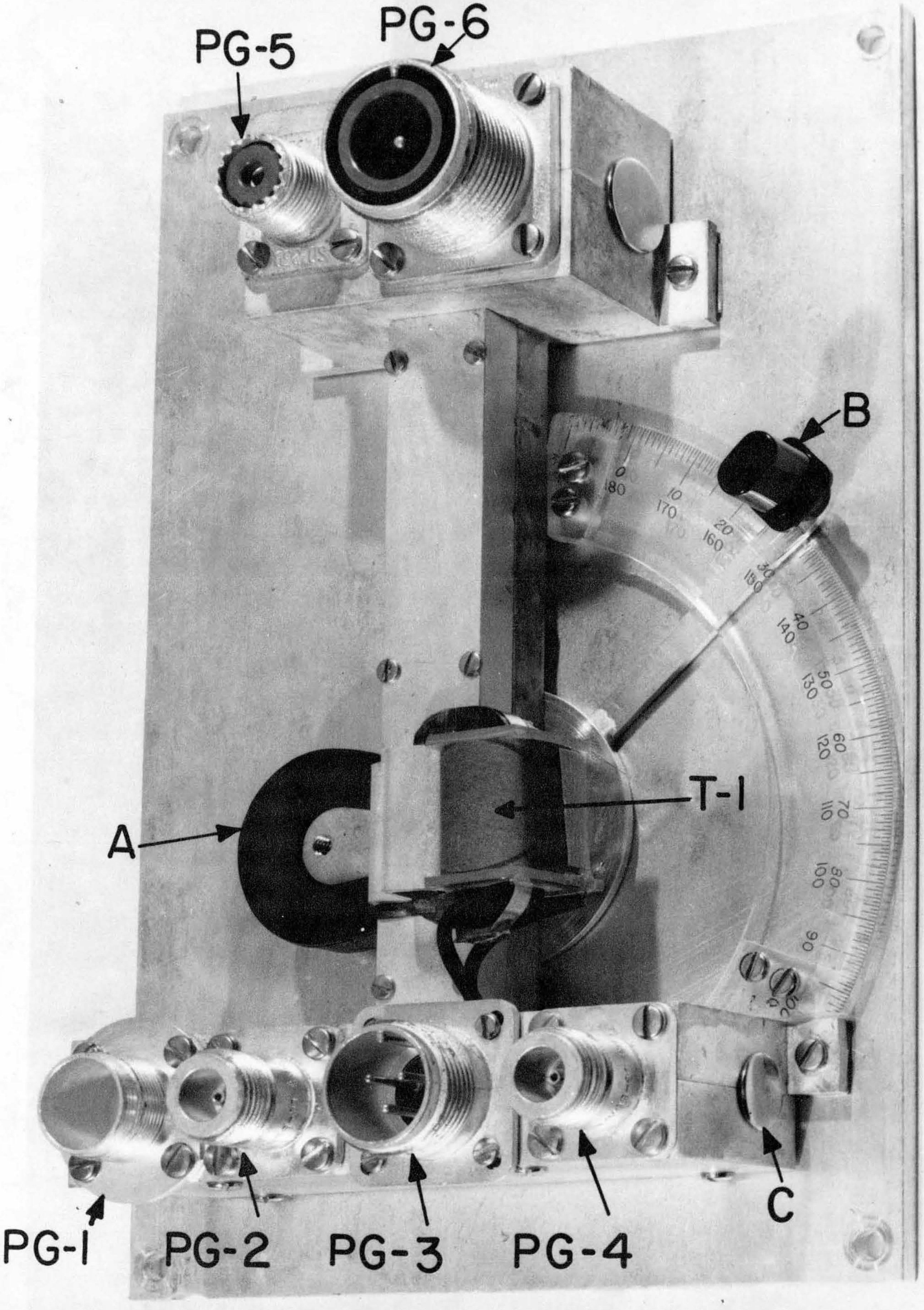
Fig. 9. The yield of photoelectrons per pulse from an S-11 cathode subtending 0.005 sterad at the light source. The polaroid attenuator is set for minimum attenuation.

Fig. 10. (Upper) Wave shape of the light pulse as measured with special gated phototube.

(Lower) Wave shape of the trigger pulse as observed on an oscilloscope utilizing a K142[illegible] traveling-wave deflection cathode-ray tube.

Fig. 11. (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 A. 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 A.

(b) The response of an S-11 photocathode is shown on the same scale.



7-1

GPR-1610-A

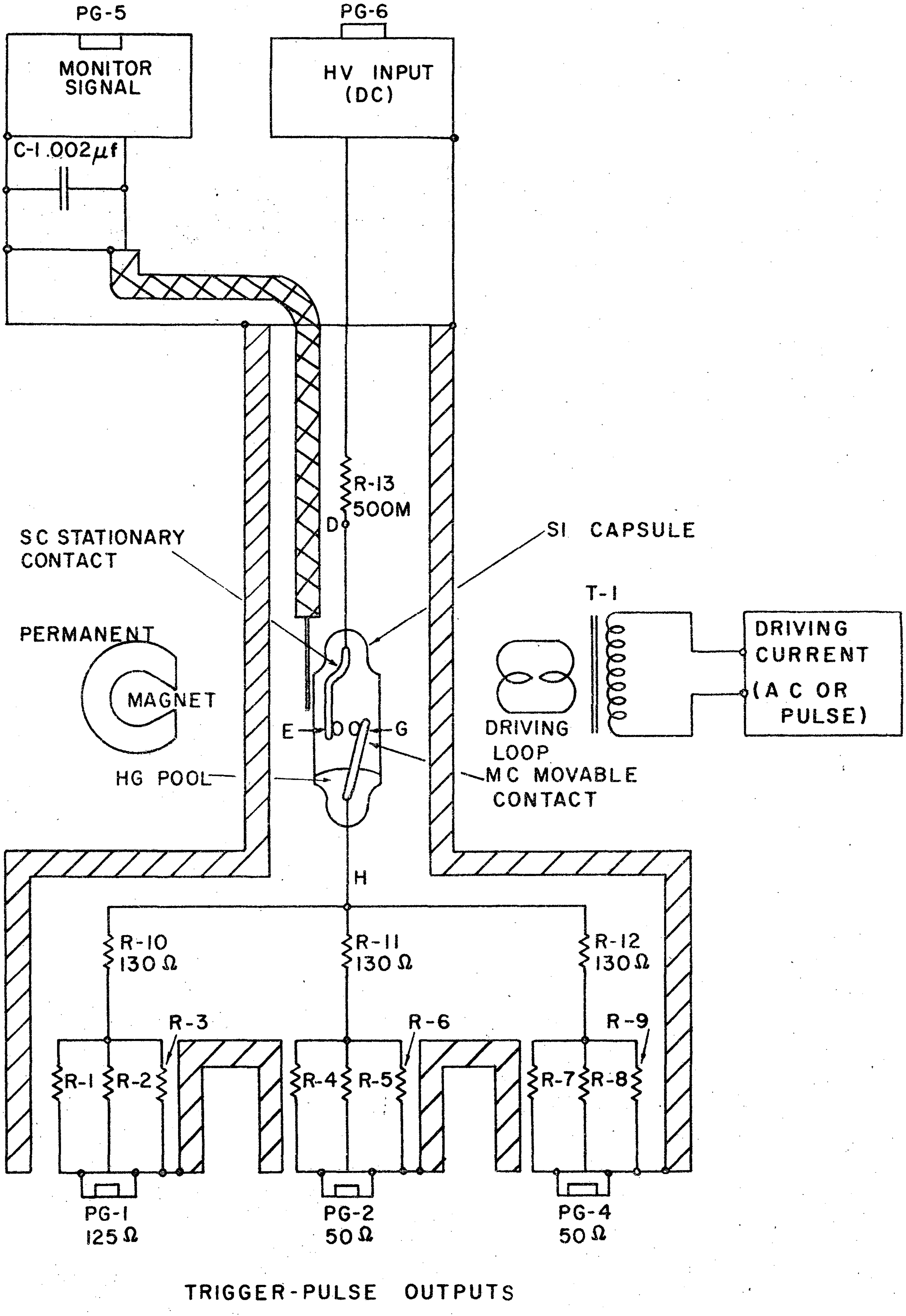

PG-5
MONITOR SIGNAL
PG-6
HV INPUT (DC)
C-1 .002µf
R-13 500M
D
SC STATIONARY CONTACT
SI CAPSULE
T-1
PERMANENT MAGNET
DRIVING CURRENT (A C OR PULSE)
E
G
DRIVING LOOP
HG POOL
MC MOVABLE CONTACT
H
R-10 130 Ω
R-11 130 Ω
R-12 130 Ω
R-3
R-6
R-9
R-1
R-2
R-4
R-5
R-7
R-8
PG-1 125 Ω
PG-2 50 Ω
PG-4 50 Ω
TRIGGER-PULSE OUTPUTS

Fig 2

51,114-2

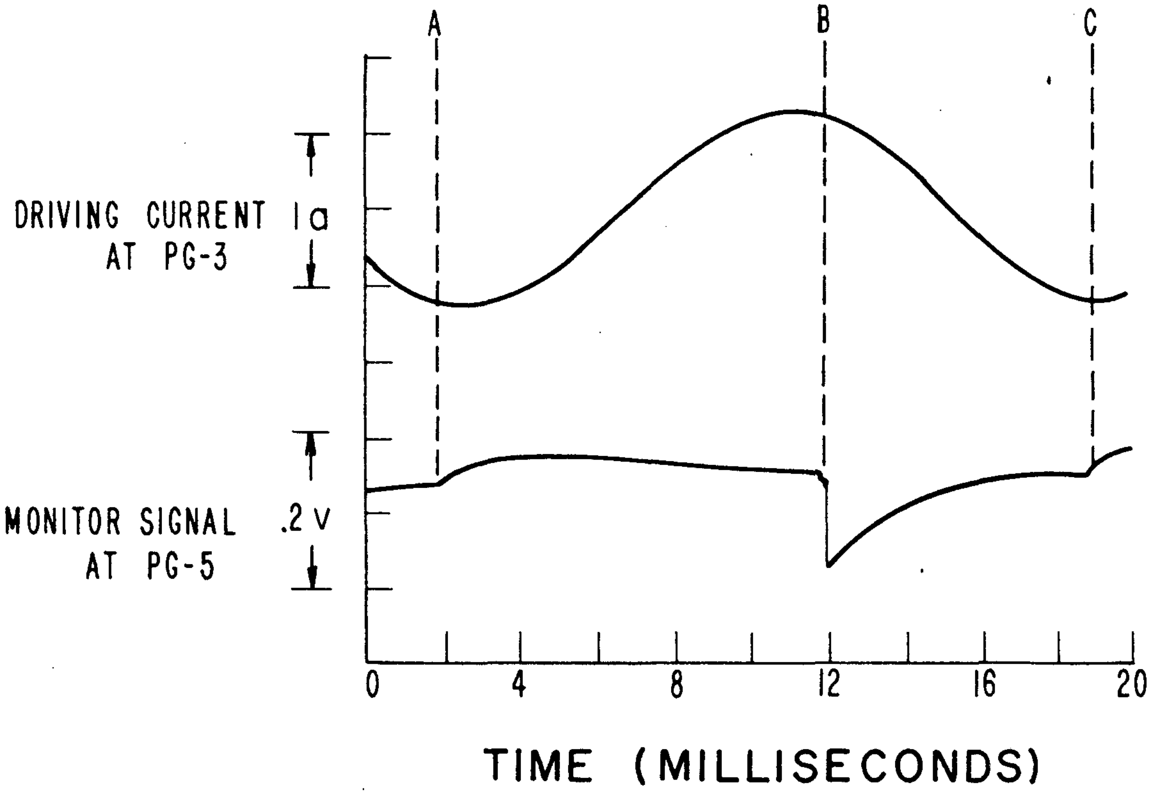

A
B
C
DRIVING CURRENT AT PG-3
1a
MONITOR SIGNAL AT PG-5
.2 v
0
4
8
12
16
20
TIME (MILLISECONDS)

Fig 3

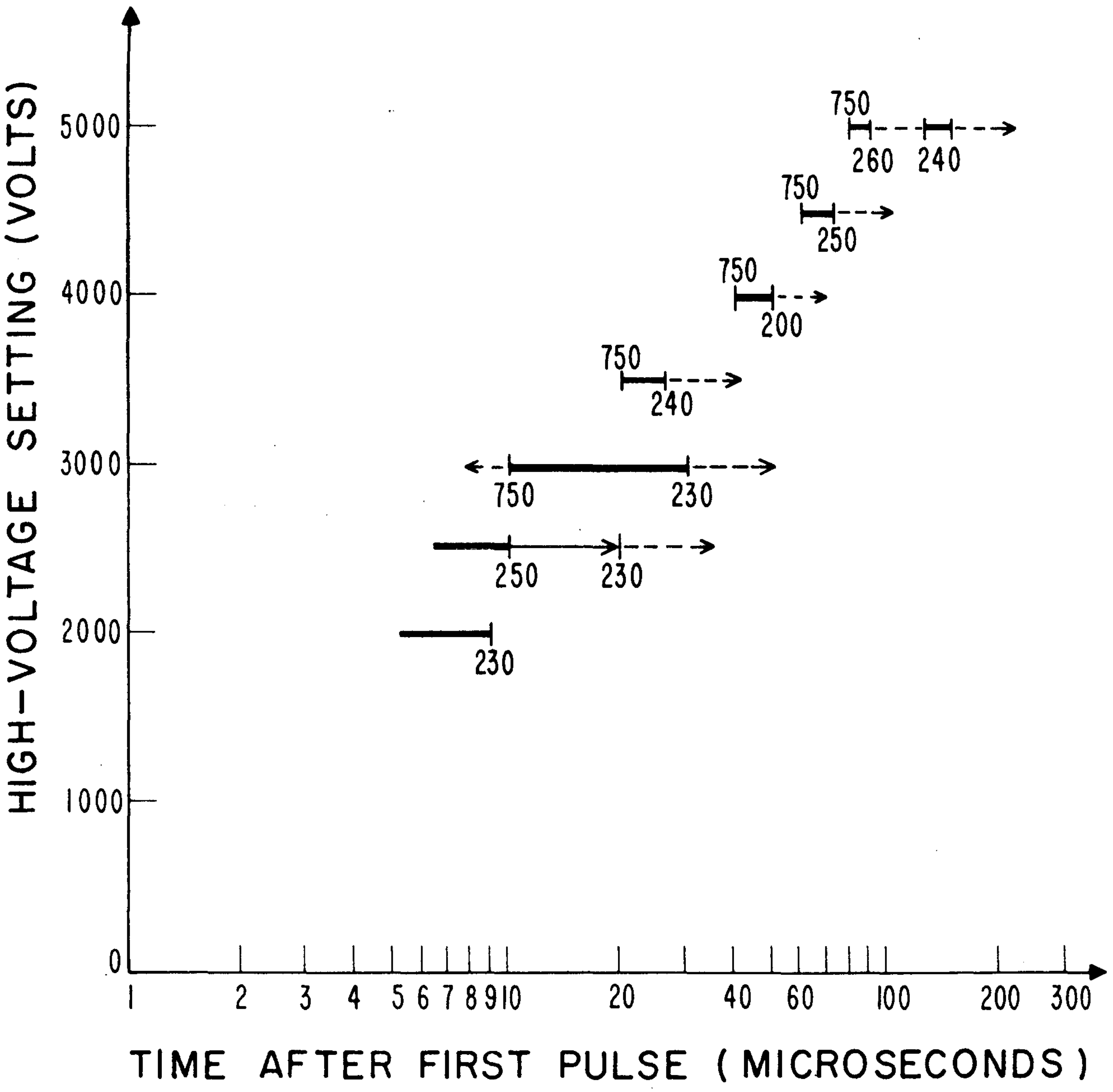
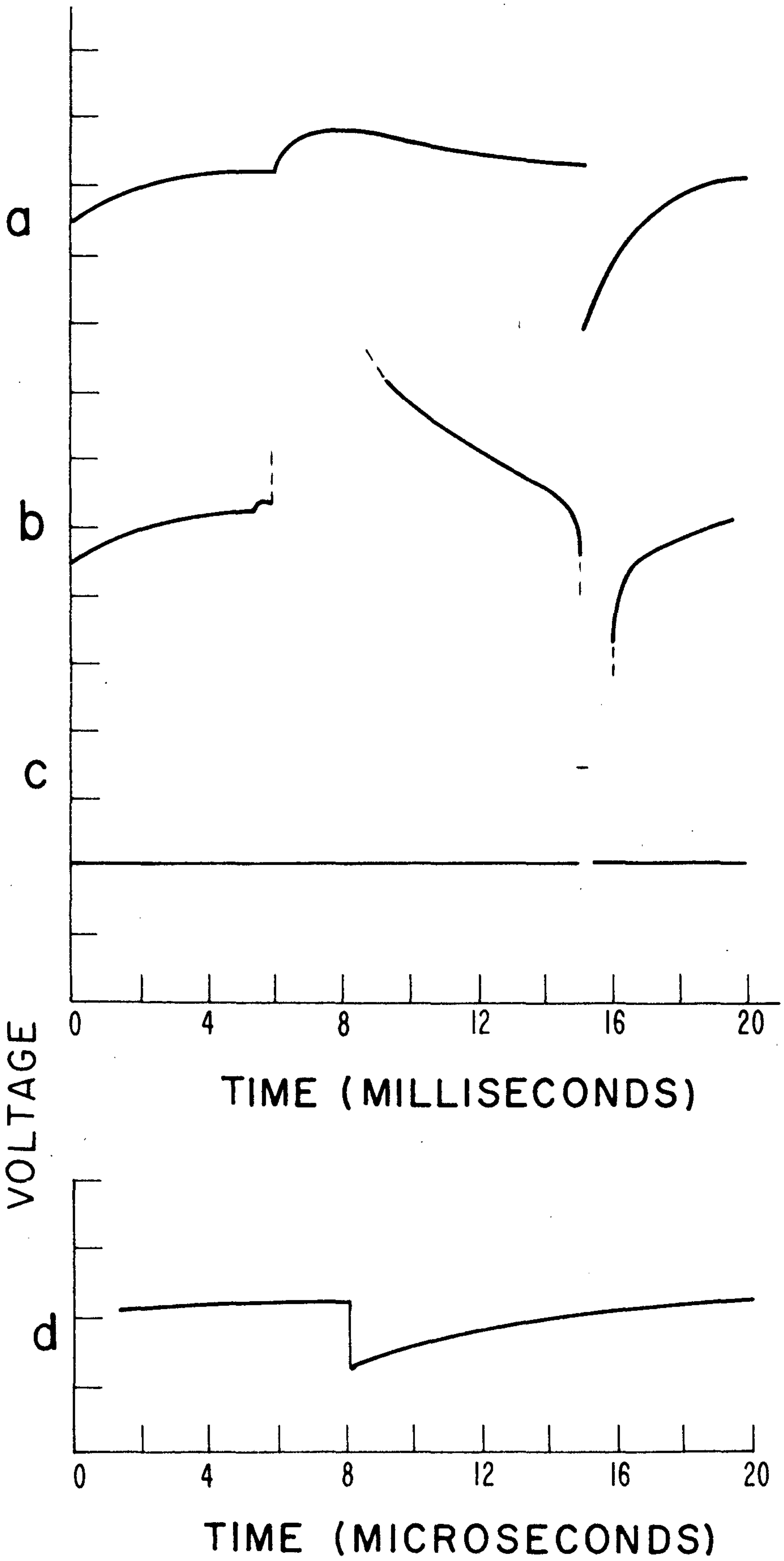

HIGH-VOLTAGE SETTING (VOLTS)
0
1000
2000
3000
4000
5000
TIME AFTER FIRST PULSE (MICROSECONDS)
1
2
3
4
5
6
7
8
9
10
20
40
60
100
200
300
750
260
240
750
250
750
200
750
240
750
230
250
230
230

Fig 4

50,828-1


a
b
c
d
VOLTAGE
0
4
8
12
16
20
TIME (MILLISECONDS)
0
4
8
12
16
20
TIME (MICROSECONDS)

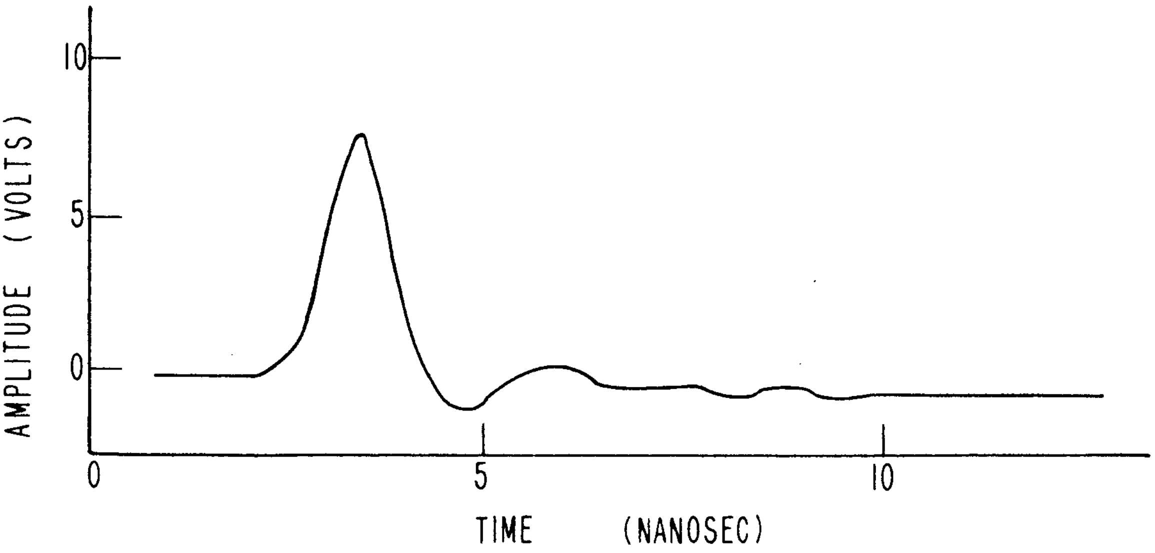


Fig 6

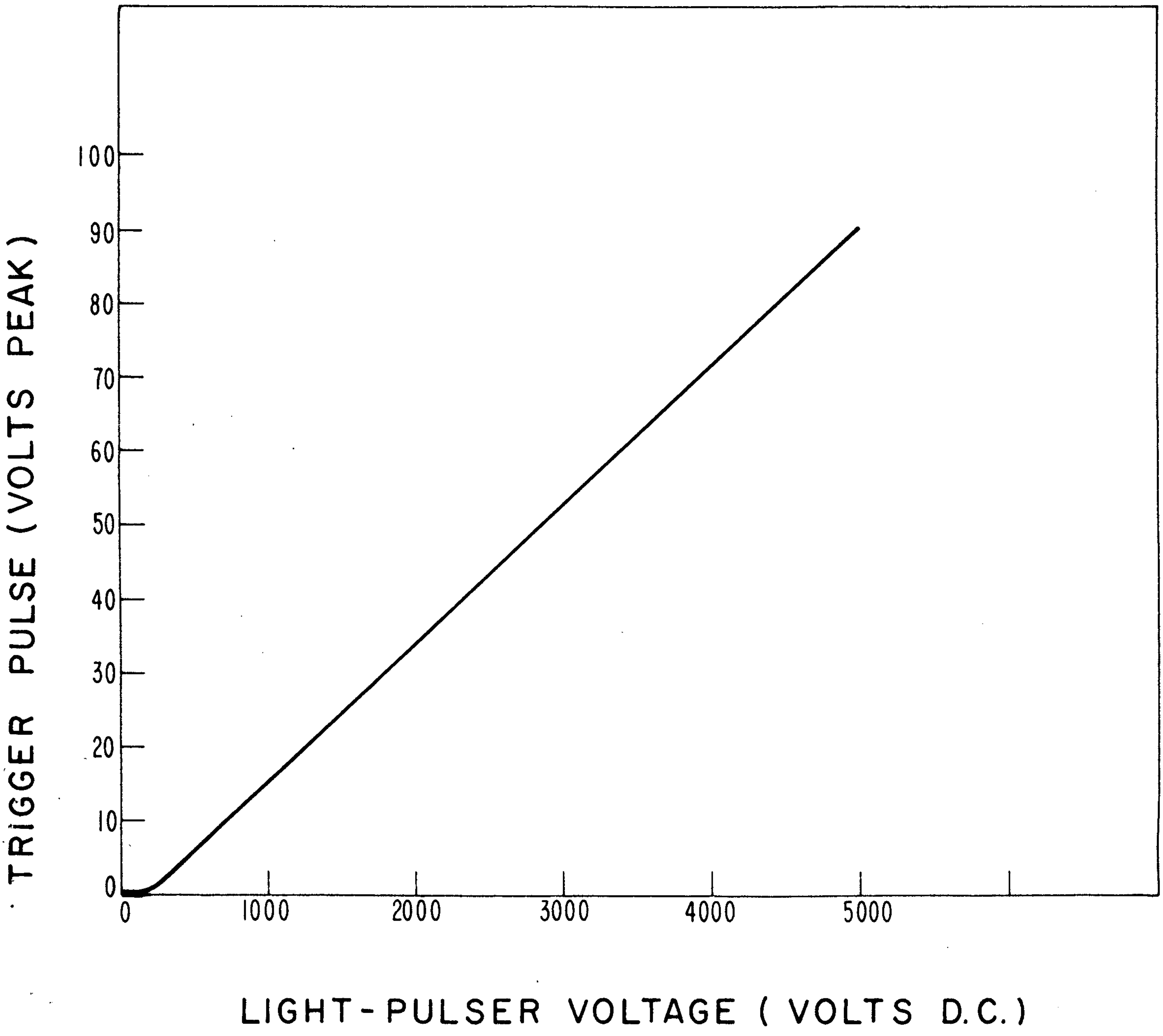

TRIGGER PULSE (VOLTS PEAK)
100
90
80
70
60
50
40
30
20
10
0
0
1000
2000
3000
4000
5000
LIGHT-PULSER VOLTAGE (VOLTS D.C.)

Fig 7

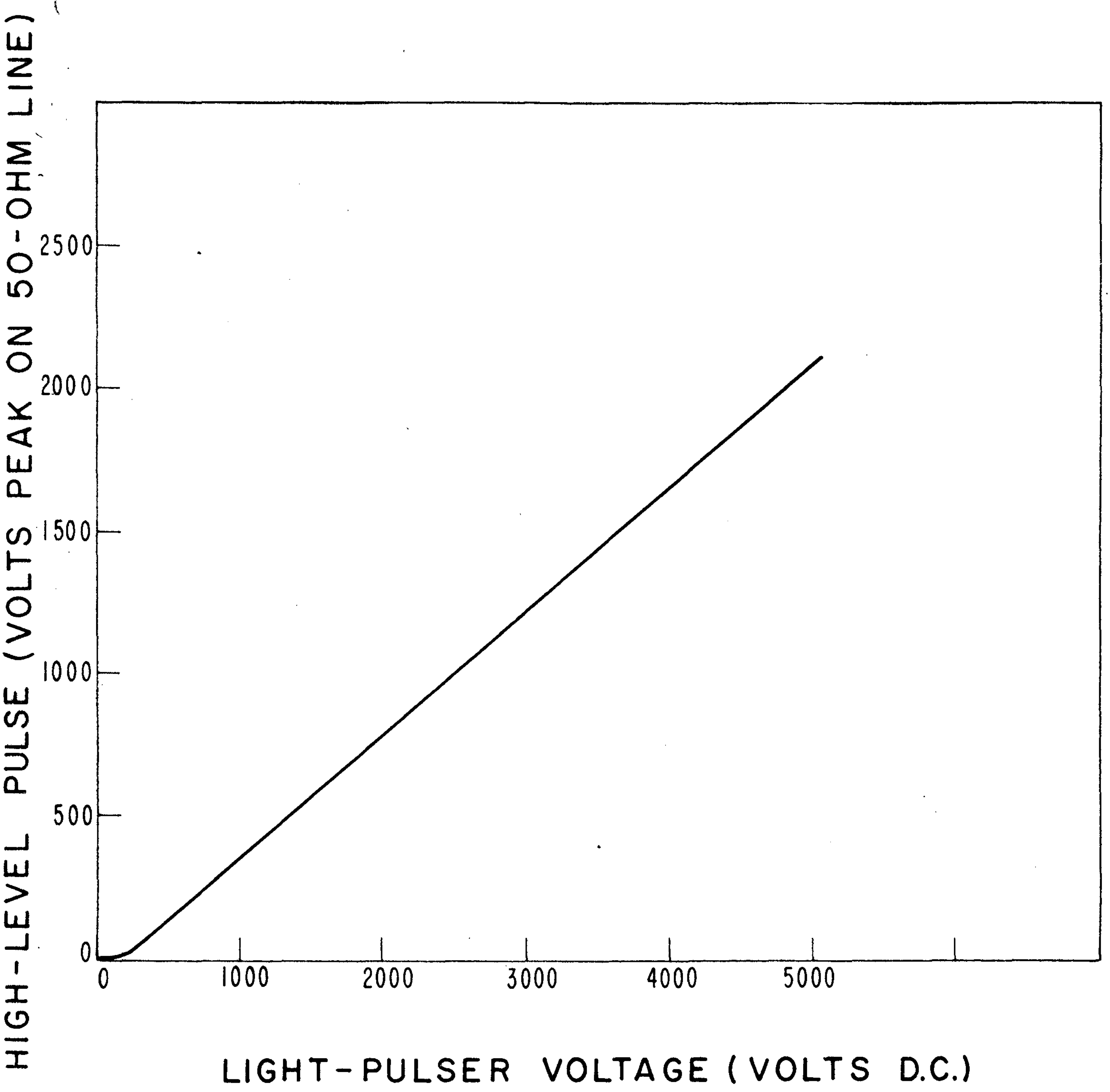

HIGH-LEVEL PULSE (VOLTS PEAK ON 50-OHM LINE)
2500
2000
1500
1000
500
0
0
1000
2000
3000
4000
5000
LIGHT-PULSER VOLTAGE (VOLTS D.C.)

Fig 8

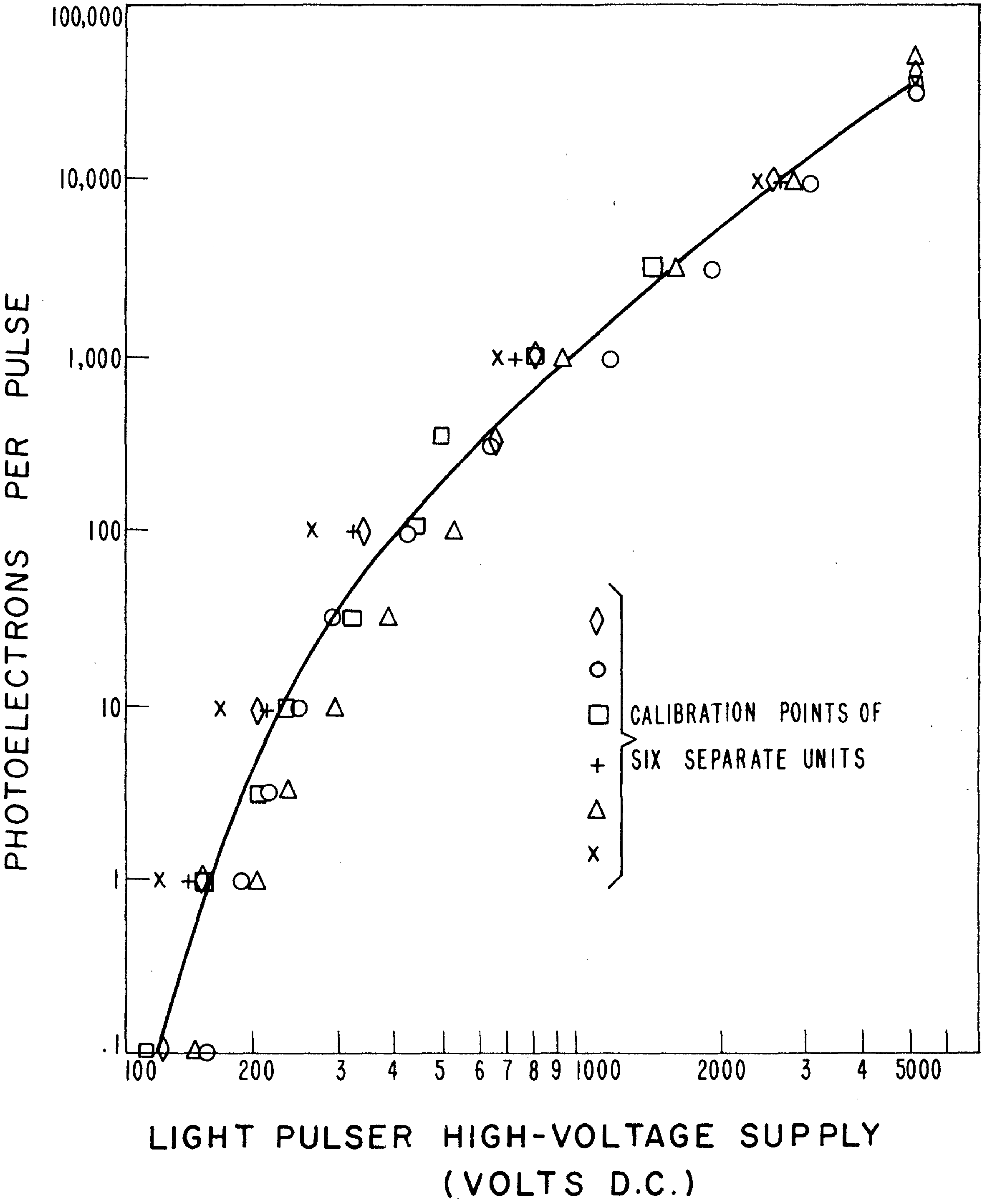
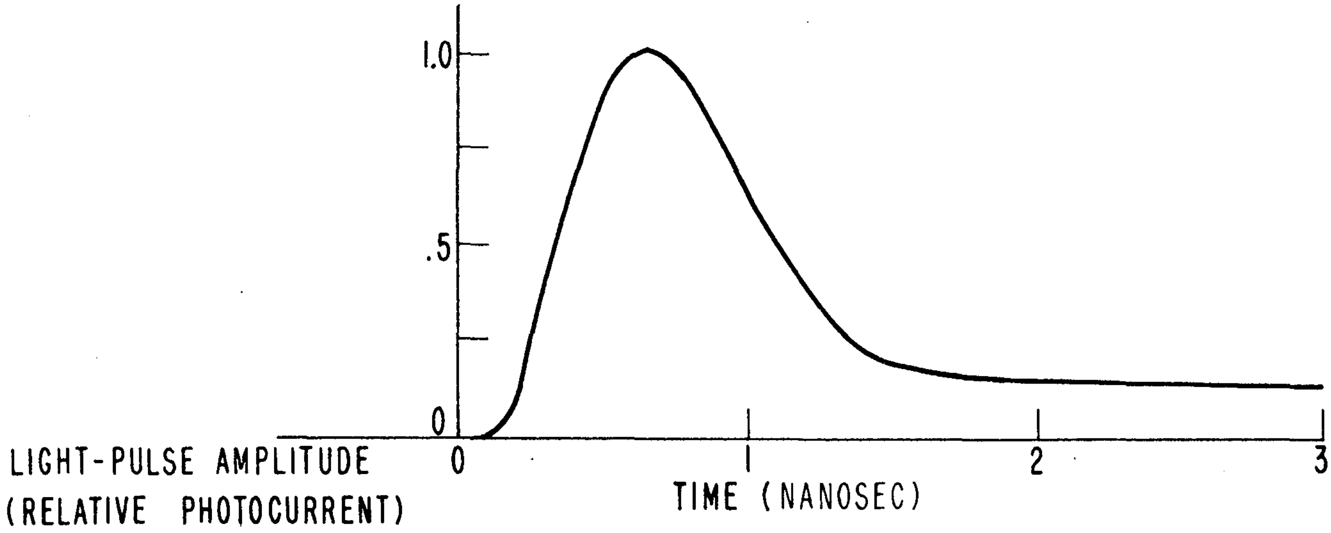

PHOTOELECTRONS PER PULSE
100,000
10,000
1,000
100
10
1
.1
100
200
3
4
5
6
7
8
9
1000
2000
3
4
5000
◊
○
□
+
△
x
CALIBRATION POINTS OF SIX SEPARATE UNITS
LIGHT PULSER HIGH-VOLTAGE SUPPLY
(VOLTS D.C.)

Fig 9

50,827-1



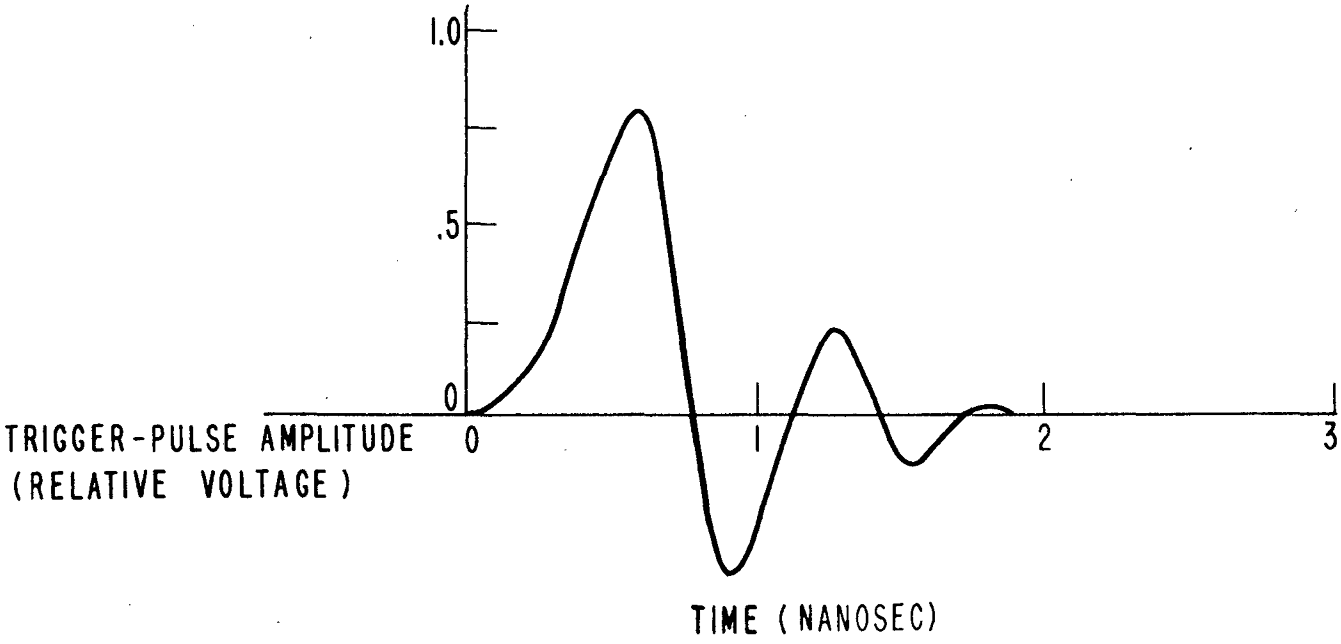
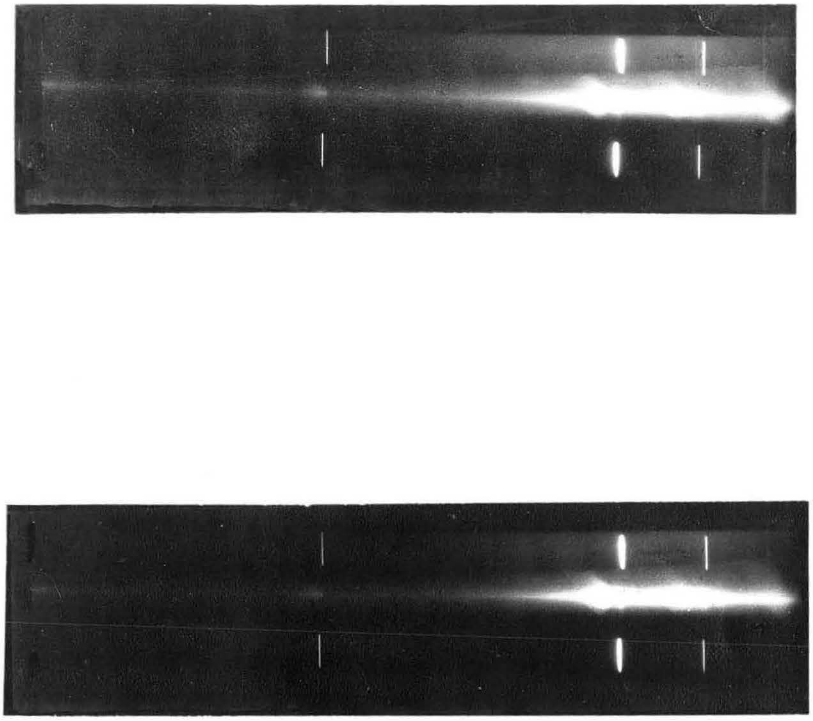
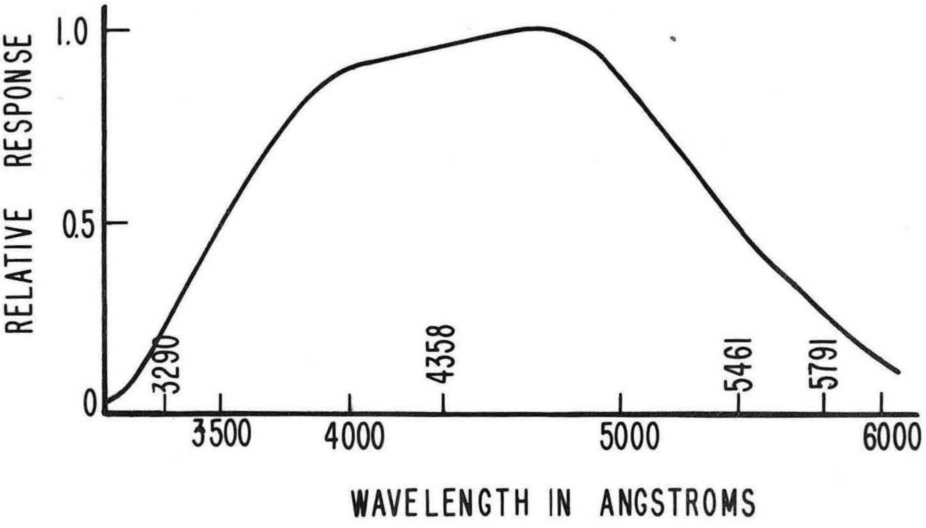


Fig10

50816-1



(a)



(b)

RELATIVE RESPONSE
1.0
0.5
0
3290
4358
5461
5791
3500
4000
5000
6000
WAVELENGTH IN ANGSTROMS

Mu-15270-A
Fig 11