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CONSTANT-AMPLITUDE LIGHT-FLASH GENERATOR FOR GAIN STABILIZATION OF PHOTOSENSITIVE SYSTEMS

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Quentin A. Kerns and Robert F. Tusting

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ABSTRACT

Gain variations of an uncontrolled nature may occur in photosensitive systems, and are particularly undesirable when numerical evaluation of signal amplitude is required. Effective gain stabilization can be achieved by a control loop in which the photosensitive device is interrogated by a known-amplitude light flash, the response is measured, and an appropriate adjustment is made to compensate for the system gain shift.

This paper describes a pulsed light source designed for stabilization applications. The light flash is typically phased to occur in the off-time of pulsed particle accelerators. The light source has been found useful also in connection with pulsed optical spectrometry, studies of phototube fatigue effects, in the evaluation of vidicons, and in the adjustment of pulse-shape discrimination circuitry and gated phototubes.

In this way the overall amplitude performance of the system was checked automatically: the gain was sampled and stabilized 64 times per second during the off time of the accelerator.* The feedback system used in this experiment is discussed by Brown.[9] The present paper describes the constant-amplitude light-flash generator.

PRINCIPLE

An argon-filled glow lamp produces an amplitude-stable light pulse when energized by a voltage pulse, provided there exists an abundance of electrons near the lamp cathode to start a discharge. Before describing the electron source actually used, it is instructive to consider alternative methods of providing an electron cloud.

(a) Radioactive sources are sometimes used to supply free electrons, but a radioactive source of any conceivable tolerance level is still too weak for precise amplitude stability. A 1-curie source has a disintegration rate of 3.7 disintegrations per 100 psec. Even this rate, considering a solid-angle utilization factor of less than 4π steradians and range straggling of emitted particles, appears insufficient for stabilization to the required accuracy. A disadvantage of radioactive material in the lamp is the probability that spurious counts will be recorded by the nearby detector.

(b) A photon source which ejects photoelectrons from the cathode is actually quite feasible, and has been used for the 1-μsec light pulser described in LRL Counting Research Group report No. 38, June 12, 1958. A microampere of photoelectron current supplies approximately 600 electrons per 100 psec.

(c) Field-emitted electrons are used in the corona lamp; see UCRL-9269, October 1960 or reference 10.

(d) A thermionic emitter would be an adequate source of electrons, but would mean the additional complication of a filament or heater-cathode, plus a heater supply with its wiring and control circuits.

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*For use with a cw accelerator the gain stabilization cycle should include a measurement of the difference in photodetector output before and during the light flash, as well as gating off data storage during the light flash.

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INTRODUCTION

Gain variations of an uncontrolled nature may occur in photosensitive systems, and are particularly undesirable in equipment concerned with pulse-height analysis. Effective gain stabilization can be achieved by a control loop in which the photosensitive device is interrogated by a known-amplitude light flash, the response is measured, and an appropriate adjustment is made to compensate for the system gain shift.

Multiplier phototubes, as an example, are commonly used in nuclear instrumentation systems. Unfortunately the gain of a photomultiplier varies with time, temperature,[1,2] counting rate,[3-6] magnetic field,[7] radiation level, and other factors that are not easy to predict or control. In a recent experiment[8] at the LRL 184-inch cyclotron it was found that the gain of several RCA 7046 photomultipliers changed by approximately 50% with the counting rates produced by a 20-pA cyclotron beam current. To improve the resolution of the experiment it was decided that the gain of each of several detector systems should be stabilized to within a few percent by:

(a) Flashing a constant-amplitude light source, which illuminates the photomultiplier cathode, during the interval between beam bursts of the cyclotron.

(b) Passing the output pulse of each photomultiplier through the amplifiers, gates, etc., which comprise the system, and measuring the amplitude of the resulting pulse.

(c) Holding the photomultiplier gain constant by varying the supply voltage automatically to compensate for any system gain shift.*

*Arrangements can be made to vary potentials on the PMT so gain is adjustable without affecting transit time.

SOLID-STATE SOURCES

It is worth noting that the measured light output from various silicon solid-state junctions in avalanche is about 1 photon/10^{10} electrons; i.e., the quantum efficiency is 1×10^{-10}. Thus an enormous current is necessary in such a solid-state junction to obtain enough light to be free from photostatistical limitations. A semiconducting material of higher band gap such as gallium phosphide is more efficient in generating visible photons when avalanched. The injection lasers have quantum efficiencies of 1×10^{-4} to 1×10^{-3} at room temperature. They emit energy in the red region (9000 Å for Ga-As, and 7700 Å for Ga-As—Ga-P). The large dependence of quantum efficiency with temperature is a limitation of these lamps for our purpose. Low-temperature operation improves the efficiency but would certainly complicate the lamp holder. Further solid-state development may result in a suitable lamp for precision illumination, but presently none is available.

DESCRIPTION

The light source is packaged in an aluminum barrel similar to that of the UCRL corona lamp, which is shown in Fig. 1.[10] A General Radio type 874 connector is provided for the electrical input, which is supplied to the light source through a 50-Ω transmission line. The end of the housing at which the light flash emerges has a 1/2-20 thread for mounting the assembly. A picture of the light source is given in Fig. 2 and a schematic in Fig. 3.

The lamp is a commercially available AR-4 glow lamp,* but the bayonet base has been replaced by a molded base of foam silicone rubber** to cushion the lamp against mechanical shock and ensure that the lamp remains stably positioned in the barrel. Mechanical stability of the lamp and of the optical path from lamp to detector is essential to the use of the source as a constant-amplitude light flasher; an apparent amplitude shift of ≈ 1% results from a 0.001-in. displacement of the lamp relative to the phototube.

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*General Electric and Signalite Inc., for example.

**Dow-Corning Silastic RTV S-5370.

The method used here is that of a small dc keep-alive current flowing at all times in an argon glow lamp. Thus, when the pulse from the pulse generator arrives, there is a continuous source of electrons to provide the starting point for a rapid current buildup. Both the time and amplitude jitter of the resulting light flash are minimized. Because of the lamp electrode symmetry, either positive or negative pulses can be used, but it is necessary that the polarity of the keep-alive current be the same as that of the main pulse.

The operation of the lamp depends upon electrons, accelerated in the electric field between anode and cathode, exciting atoms and molecules that subsequently emit light in decaying from their excited states. One would expect of the order of a few photons to be produced for each electron that works its way from cathode to anode. We measure a useful-photon output to an S11 photosurface of approximately one-half photon per electron traversing the discharge path. By useful photons, we mean those with wavelength λ within the range of photocathode spectral sensitivity, and emitted within a solid angle of 1/3 steradian; larger solid angles than this tend to be impractical for general use. One obtains several photons per electron if the light is collected with 4π geometry. Thus one is justified in saying that the quantum efficiency of the lamp described here is about unity.

A number of workers have used noble-gas lamps of various types: Wright and Garlick to check photomultiplier pulse amplitude spread,[11] and Ghiorso, to provide a reference peak on a PHA spectrum.[12]

Argon lamps have advantages over neon for the present purpose: the decay tail of the light pulse is shorter (the decay is that of a number of separate spectral lines and is therefore compound rather than a simple exponential decay), and the light output is greater in the blue and ultraviolet (where the photosurface is most sensitive). Of special importance is the fact that argon will sustain a small keep-alive glow without oscillation, whereas for the neon lamps examined, no stable low-current operating point could be found, but instead, negative resistance oscillations developed. We use AR-4 argon lamps with a keep-alive current of 1 μA dc. The residual light output due to the continuous small glow has not proved a serious disadvantage thus far; the residual output is $< 1 \times 10^{-6}$ of the peak light output.*

*Since there are differences in the relative intensities of the spectral lines excited by the keep-alive current and those excited during the pulse, narrow-band optical filters could be used to further reduce the residual light output.

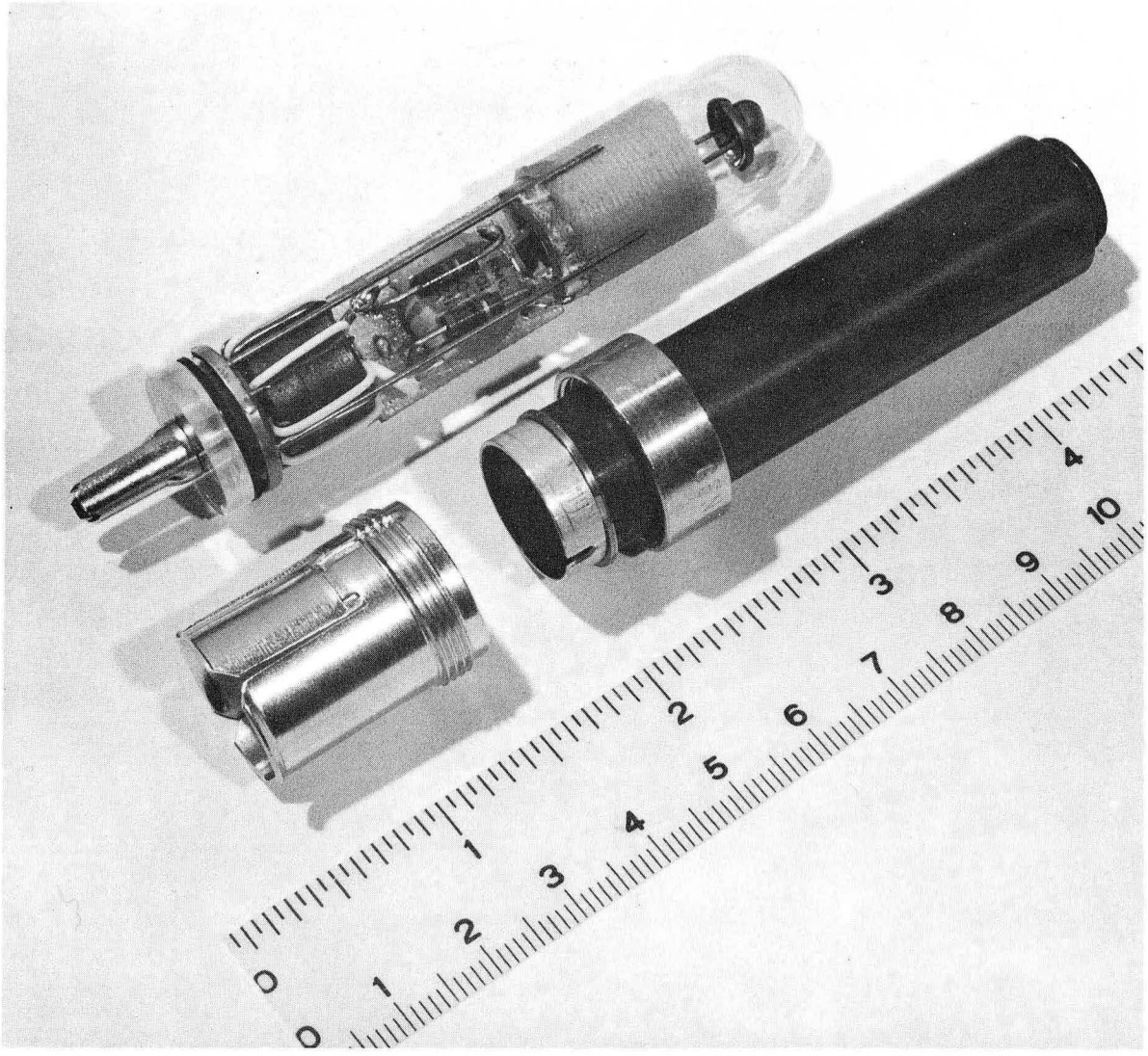

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Fig. 2. Constant-amplitude light source.

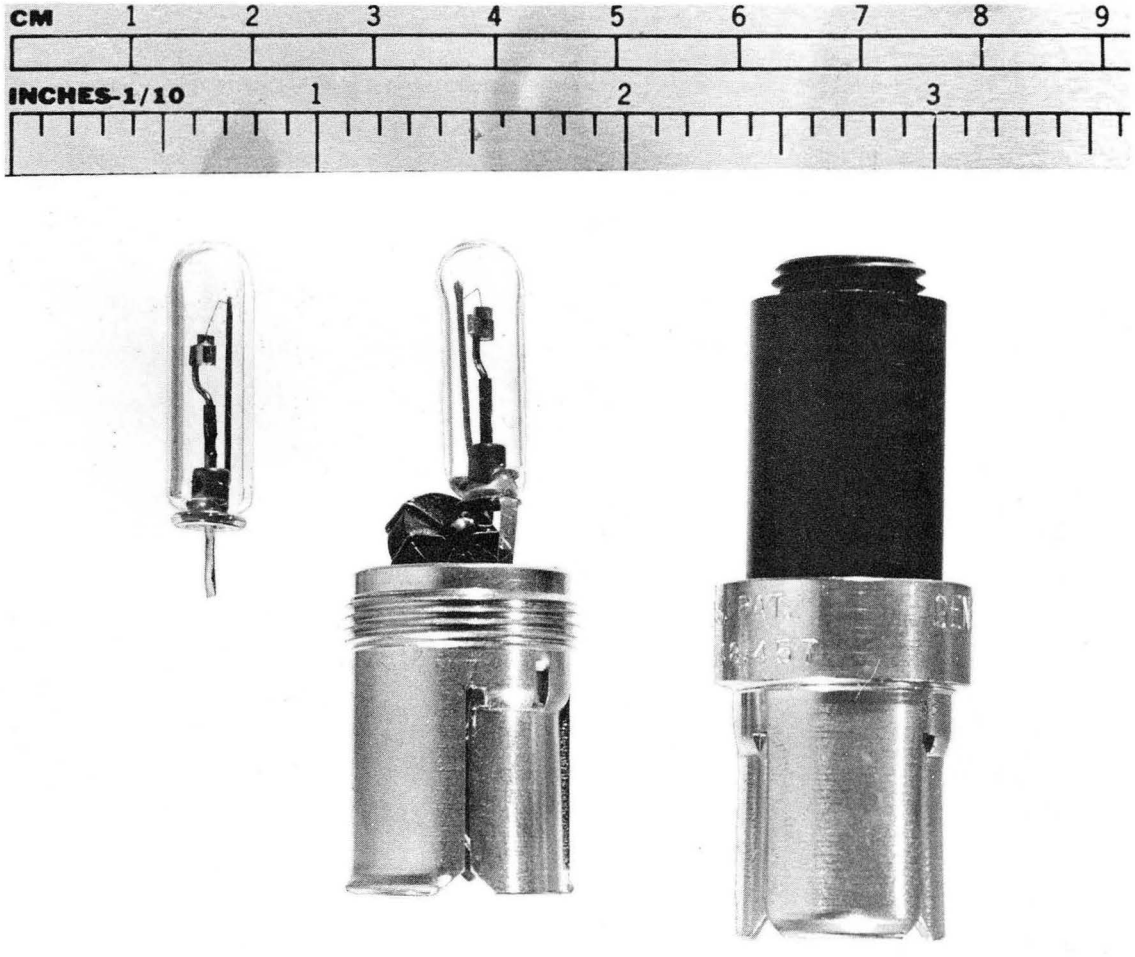

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Fig. 1. UCRL corona lamp.

A 4:1 step-up transformer is employed to reduce the pulse power required to energize the lamp, since for a fast pulse the lamp impedance is much higher than 50 Ω. The 22-MΩ resistor carries the keep-alive current from the transmission line to the lamp.

To prevent relaxation oscillation of the dimly glowing lamp, the value of the coupling capacitor is made appropriately small (10pF), which restricts the energizing pulse width to approximately 20 nsec or less. The 0.01-μF capacitor and 62-Ω resistor in series provide a termination for the pulse to prevent reflections which could retrigger the light. Most of the electrical pulse energy is dissipated in the termination resistor, and in the present design its power rating limits the maximum pulse repetition rate to approximately 2000 pps.

A block diagram of a typical experimental arrangement is given in Fig. 4. The power supply consists of a short-rise-time pulse generator* and the keep-alive current supply. The generator, by way of an internal splitting transformer, supplies each of several light sources (six in the present design) with an amplitude-stable positive pulse. A larger number of light sources can be excited sequentially by interposing a commutator between the generator and lamps. Reed switches have been used to make such a commutator,[13] but solid-state switches could also be used. The amplitude of the pulse from the generator described is adjustable from 100 to 500 V. A precisely synchronized trigger pulse is provided by taking a fraction of the main pulse. Both the main pulse and the keep-alive current are transmitted to the light source through a 50-Ω coaxial line. Double-shielded cables are normally used to reduce the possibility of radio-frequency interference. Low-loss cables are used when there is a long distance between the light source and the power supply (50 ft of RG 9/U reduces the light output ≈ 10%). The Andrew Corp. makes foam Heliax coaxial cable which is low loss and well shielded. (The cable is semiflexible.) If the choice of phototube signal levels is such that electrical interference would be a problem, we recommend Heliax cable for transmitting pulses to the lamps. Similarly, we have found Heliax cable quite useful for transmitting phototube signals through an electrically noisy environment.

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*To be described in a separate report.

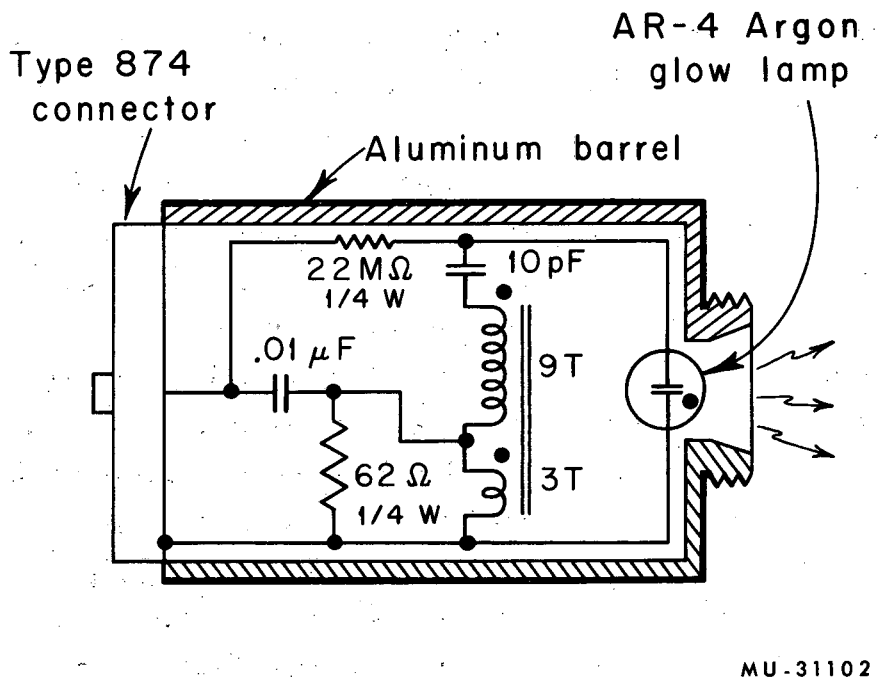


Fig. 3. Schematic drawing of the constant-amplitude light source.

LIGHT OUTPUT

The total usable output of the light flasher in the range 3000 to 5000 Å is approximately 10^{10} photons per pulse. Figure 5 shows a graph of the photon output as a function of pulse voltage for a 15-nsec-wide rectangular pulse. Figure 6 shows the spectral composition of the light flash as measured with a monochrometer adjusted to have 50-Å resolution. The General Electric AR-4 lamps contain about 15% N_2 in addition to the argon, and most of the light output can be identified as molecular nitrogen bands rather than argon lines.

The shape of the light pulse is a function of the amplitude and width of the voltage pulse and of the spectral range over which the light is observed. With a 300-V 15-nsec-wide rectangular pulse applied to the light flasher, the light output has a rise time of ≈ 3 nsec and a compound decay consisting of an approximately 50-nsec portion and a lower-amplitude 3-μsec tail. Refer to Fig. 7 for the pulse shape as seen by a 1P21 photomultiplier (S-4 cathode). When the peaks of the spectral distribution curve (Fig. 6) were observed individually it was found that the light pulse was different for each peak. In particular, the long (3-μsec) tail is absent in the light observed from the peaks at 3900, 4250, 4580, and 4750 Å. The light pulse from the other peaks is similar in shape to that of the total light output.

In some applications the long decay tail of the light pulse is undesirable. A relatively short flash (≈ 30 nsec) can be obtained at the expense of total light output by using a short electrical pulse (≈ 5 nsec) to energize the lamp and by employing an optical filter that strongly attenuates the slow-decay components in the ultraviolet. Polaroid polarizing film (HN32) and lucite light-piping rods have been used as uv attenuators, but a sharp-cutoff yellow filter such as a Corning type C. S. 3-73 should be more effective.

STABILITY OF LIGHT OUTPUT

The histogram of pulse-to-pulse amplitude jitter of the integrated light flash (when the lamp is driven by a stable-electrical-pulse generator) is approximately 0.3% full width at half maximum. The long-term average light output per pulse has been measured to be constant to within approximately 1% when operated at 60 pps for several weeks. There are no measurable effects of aging. In order to utilize the full stability of the light source, the

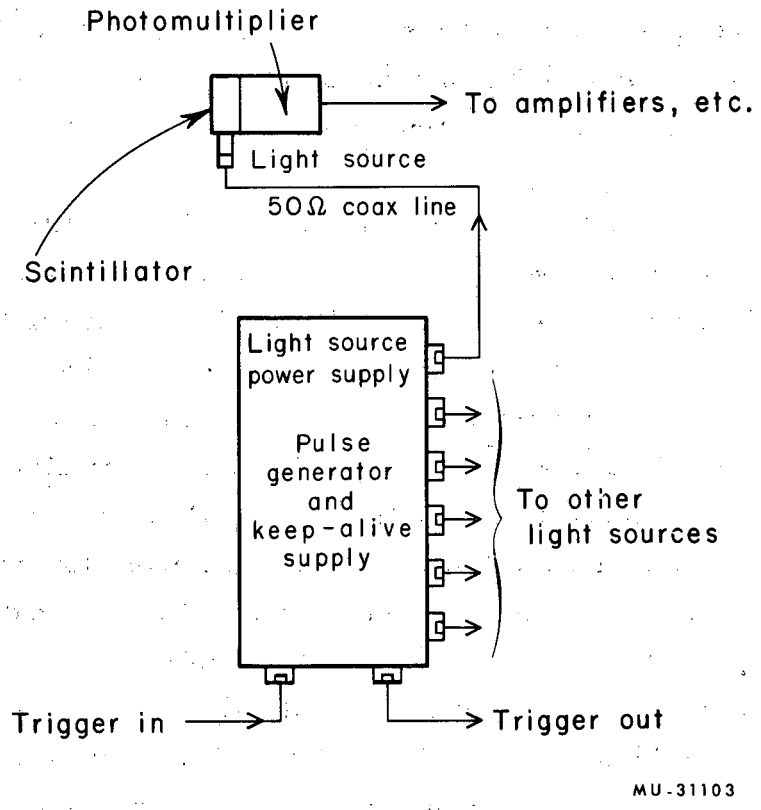


Fig. 4. Block diagram of a typical experimental arrangement using the constant-amplitude light-flash generator.

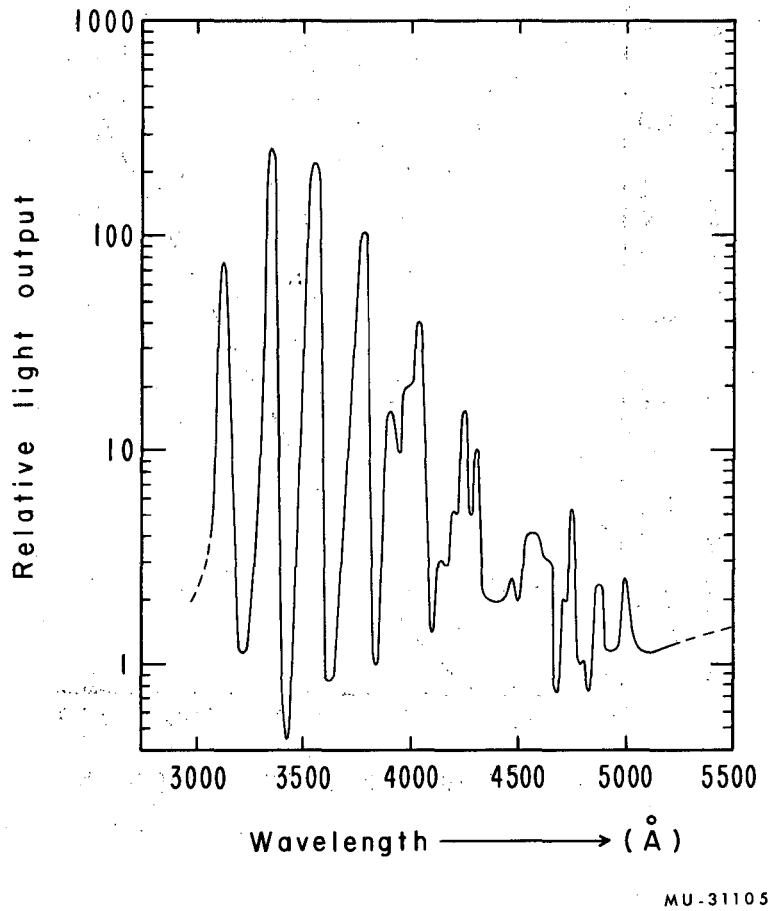


Fig. 6. Spectral composition of the light flash as measured with a 50-Å resolution monochrometer.

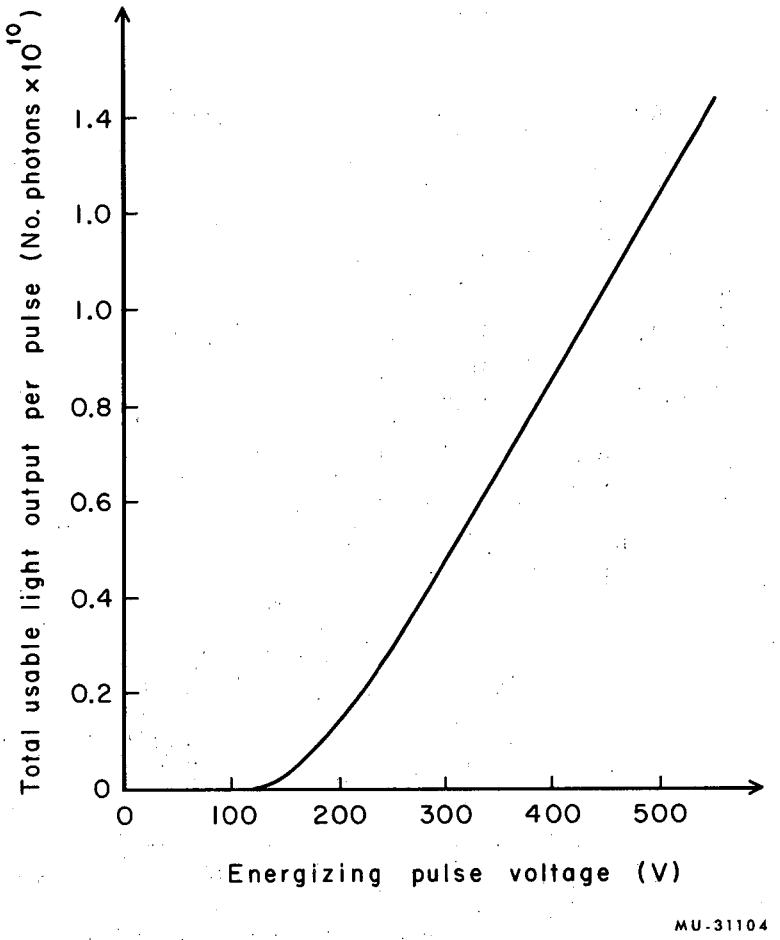


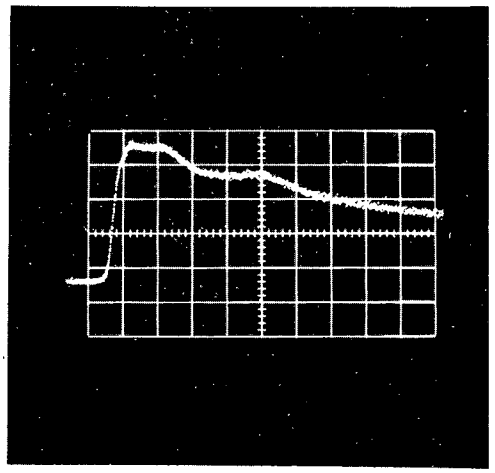
Fig. 5. Photon output of the light flasher as a function of pulse voltage for a 15-nsec pulse.

arrangement for coupling the light to the photodetector must be highly stable. In addition, the amplitude of the energizing pulse should be two to three times above threshold (the "knee" of Fig. 5) and be stable to 0.1%. Large adjustments in light level are preferably obtained by suitable optical attenuators, such as Kodak diffuse or neutral density filters, while small adjustments (less than 50%) can be made by varying the amplitude of the electrical pulse. Some applications may require a light level so low (e.g., a few photons per flash) that amplitude fluctuations at the photocathode are determined by statistics rather than the amplitude fluctuation at the light source. The low light level is obtained by interposing an optical attenuator between lamp and photodetector. The long-term stability of the average light output per pulse is not degraded by such optical attenuation.

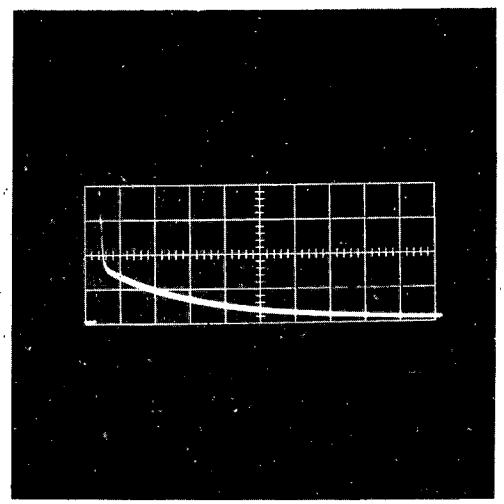
Jitter in the rise time of the light flash, relative to the driving pulse, is less than 50 psec. The temperature coefficient of the light output is approximately +0.1%/°C.

SUMMARY AND CONCLUSIONS

Amplitude-stable light flashes have a variety of practical uses: we mention a few here. An optical system for measuring the dynamic properties of a hydrogen plasma[14] employed a number of EMI 6255B phototubes whose sensitivity required standardization at intervals; an AR-4 light source proved effective for the purpose. In a counter experiment involving about 40 phototubes, an AR-4 light source was attached to each phototube for gain monitoring and to verify the long-term timing stability. Solid-state detectors are generally quite light-sensitive and can be illuminated with the AR-4 lamp to introduce a test charge for calibration or circuit-development purposes. Recently we have used the AR-4 lamp to measure the quantum sensitivity and the signal-to-noise properties of a vidicon tube with its associated video amplifier. We find that photomultiplier fatigue and gain-shift effects become straightforward to measure if one has a stable light source. The combination of a corona lamp[10] and the AR-4 flashed with an adjustable relative time delay simplifies measurement of space charge effects in the output stages of an electron multiplier. The combination of corona lamp and AR-4 lamp has been used also to develop pulse-shape discrimination circuits. The corona lamp can be flashed before, during, or after the AR-4 lamp to establish the desired light-flash shape. Figure 8 shows the light-flash shape from a corona lamp.



10 nsec / cm →



500 nsec/cm →

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Fig. 7. Light-flash shape from the constant-amplitude light source for a 300-V 15-nsec energizing pulse.

In view of the uses mentioned above, plus the additional ones that may occur to the reader, we conclude that the introduction of a small keep-alive current in the argon lamp greatly increases its possibilities as a pulsed light source. To realize the full stability inherent in the lamp, the entire optical system must be mechanically stable, and the electrical pulse generator must provide a reproducible pulse. It would appear that a lamp specifically developed as a keep-alive lamp could have special modifications; e.g., smaller physical size, greater on-to-off ratio in light output, modified spectral intensity distribution, flatter temperature coefficients of light output, quenching gases to reduce the decay time constant, etc. Another relatively unexplored field is that of flexible wide-range pulse generators to drive the lamps. The problem is not trivial because of the amplitude precision required, but we believe it can be solved effectively by using sampled-data feedback techniques at the generator.

For the convenience of those wishing to construct similar light sources, prints are available. These are listed as the 10X101... series, "Stabilized Light Source."

ACKNOWLEDGMENTS

We would like to thank Dr. G. J. Igo, who called our attention to the usefulness of a constant-amplitude light source and encouraged its development.

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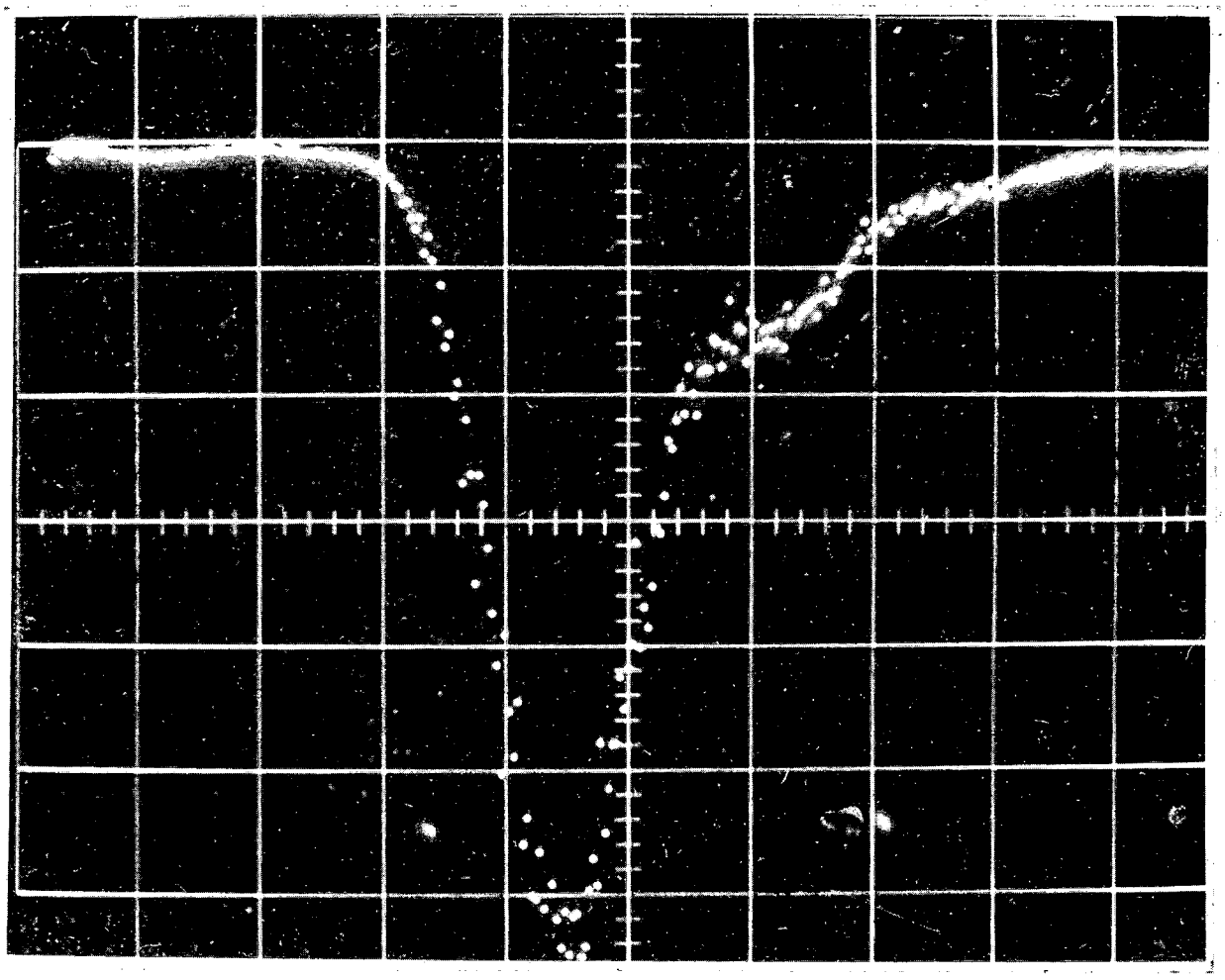

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Fig. 8. Light-flash shape from the corona lamp. Time scale, 2 nsec per major division.

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