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A radiation tolerant light pulser for particle physics applications

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A B S T R A C T

A light emitting diode (LED) pulser has been developed that can be used for tests or calibration of timing and amplitude sensitivity of particle physics detectors. A comparative study is performed on the components and pulser output characteristics before and after application of 800 MeV protons and cobalt-60 gammas. This device is demonstrated to be tolerant to fluences up to 6.7×10^{13} 800-MeV-p/cm^2 and gamma doses up to 5 Mrad.

1. Introduction

Optical pulsers are frequently needed as in-situ time and amplitude calibrators in particle physics experiments. In applications with no significant radiation field, approaches [1–8, and references therein] to calibration based on radioluminescence sources, optoelectronics with LEDs or lasers, and gas-discharge (lamps) have been employed. A circuit has been developed on the model of Kapustinsky [9] and has been implemented in the design of a pulser for use in radiation fields, for example during commissioning of systems that provide precision timing of particle transit near an interaction point at a hadron collider.

2. Design of the pulser

The circuit, see Fig. 1, uses eight off-the-shelf components plus (at Output) the Thorlabs LED465E, which has a 465 nm wavelength (blue) output. Light pulse intensity is varied by setting the V_{IN} which charges a 100 pF capacitor. Fast discharge of the capacitor through the LED is achieved with a low impedance transistor switch (complementary pair of RF bipolar junction transistors) which is triggered by an externally generated trigger pulse. The circuit was implemented in pairs on laminated glass epoxy boards with finished thickness $0.06''$, dimensions $1.5'' \times 1.95''$, surface mount components, and 1-oz. copper trace layers.

3. Characterization

Pulsers were characterized before and after exposure to a proton beam or to cobalt-60 gammas. Signals from a photomultiplier tube (PMT) were read by a Tektronix TDS7354B 2.5 GHz oscilloscope. Fig. 2 shows the experimental setup. The distance from LED to PMT is 60 cm. The PMT used for measurements before and after gamma irradiation is a Hamamatsu R7400U. The PMT used for measurements before and after proton irradiation is a Photonis 85001-501. The effects of the R7400U PMT and the TDS7354B oscilloscope on the width of the signal from the pulser range from 0.3% at $V_{\mathrm{IN}} = 4$ V to 0.03% at $V_{\mathrm{IN}} = 24$ V; these values are calculated using the transient time spread (TTS) of the PMT (230 ps) and the effect of the oscilloscope bandwidth (176 ps). The same values were assumed for the Photonis 85001-501 PMT. The standard deviation of the pulse width of a typical non-irradiated LED ranges from 6.2% at $V_{\mathrm{IN}} = 4$ V to 7% at $V_{\mathrm{IN}} = 24$ V. In Fig. 3 we show a typical measurement of a normalized pulse width at two different values of V_{IN}. This measurement technique is sufficient for comparative measurements. An absolute timing measurement [10] would require single photon counting using a constant fraction discriminator (CFD).

4. Proton irradiations

Three pulser boards, including all their components, were exposed to 800 MeV protons at the Los Alamos LANSCE facility in 2013. The protons were applied at room temperature over a period of less than an hour. Two boards received 1.5×10^{13} p/cm^2 and one received 6.7×10^{13} p/cm^2. Fig. 4 indicates the effect of the proton fluences upon the pulse width, as a function of input voltage. The error bars shown reflect variations of the V_{IN} (0.5%), angle and distance of the LED with respect to the PMT (0.03%), and oscilloscope precision (1%), as well as the PMT TTS and oscilloscope bandwidth. Also included in the error is the statistical variation in the typical pulse width of an LED465E previously mentioned. After irradiation with 1.5×10^{13} p/cm^2, the pulse shape and

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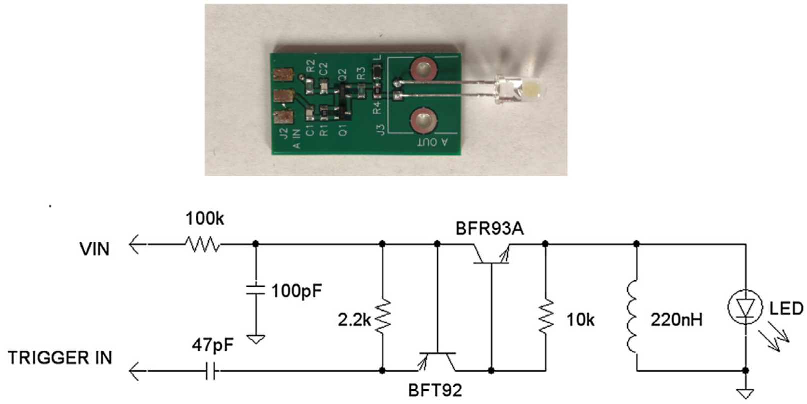

Fig. 1. The pulser circuit and board.

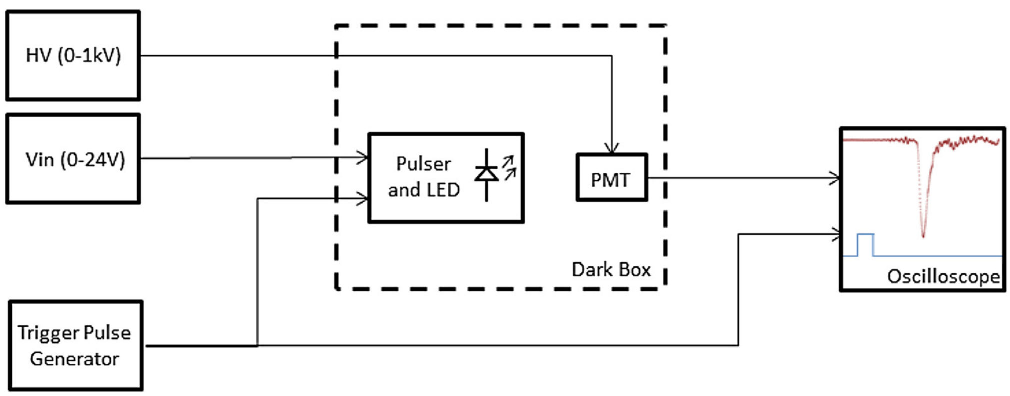

Fig. 2. The measurement setup.

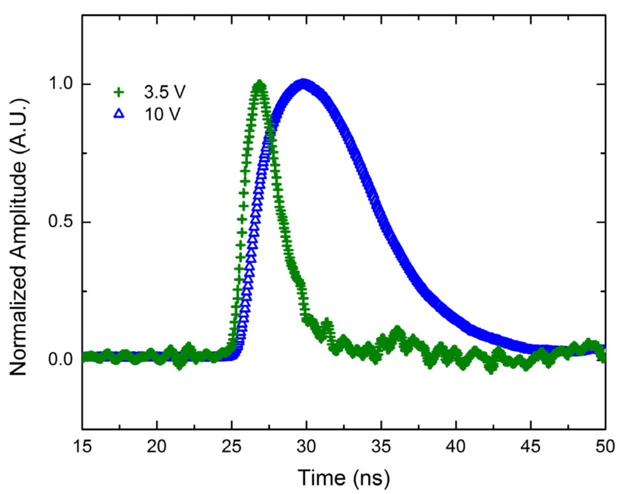

Fig. 3. Output pulse width of a non-irradiated pulser board at $V_{IN} = 3.5$ V and $V_{IN} = 10$ V.

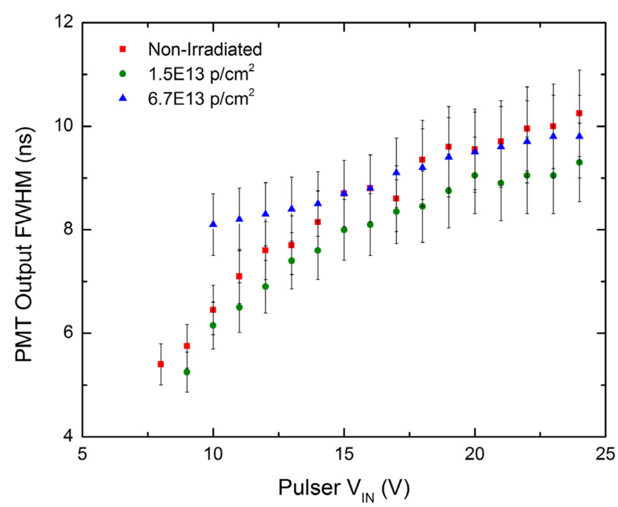

Fig. 4. Pulse width of the pulser before and after proton irradiation to fluences of 1.5×10^{13} and 6.7×10^{13} 800-MeV-p/cm^2.

minimum width are similar to the pre-irradiated values. The minimum pulse width rises from 5 to 8 ns after application of 6.7×10^{13} p/cm^2. The minimum V_{IN} at which signal output is achievable increases with dose. Pulse width increases as V_{IN} increases in each set of data. Fig. 5 shows the pulse amplitude (V_{OUT}) as a function of input voltage for the same devices. Contributing factors to the error are variations of the V_{IN} (ranging from 12% at $V_{IN} = 7$ V to 0.3% at $V_{IN} = 24$ V), angle and distance of the LED with respect to the PMT (0.1%), and oscilloscope precision (1%). Although the amplitude is diminished in the proton-irradiated devices, over 50% of the light output is retained in the upper half of the input voltage range.

5. Gamma irradiations

Ten pulsers were exposed to gammas at the Sandia Gamma Irradiation Facility in 2017, with two each receiving doses of 100 krad,