A new active base of photomultiplier R4125 designed for the lead tungstate calorimeter

Fernando Barbosa, Vladimir Berdnikov, Vladimir Popov, and Alexander Somov*

***Abstract*—This paper presents the design, performance, and results of radiation tests of an active base for a Hamamatsu 4125 photomultiplier tube. The active base was designed at Jefferson Lab and comprises a high voltage divider and an on-board amplifier. The photomultiplier with the active base is used to detect light from lead tungstate scintillating crystals of the forward electromagnetic calorimeter of the GlueX detector. The addition of the amplifier within the active base allows to operate the tube at lower high voltage, thereby limiting the photomultiplier anode current to a few microamperes even at a maximum counter rate of 1 MHz, while retaining the dynamic range of output signals. The performance of the active base and the calorimeter module assembly was studied using a bench test setup and a prototype positioned into a beam of photons. Measured key performance parameters such as linearity, high-rate capability, and the energy resolution verified that the active base design aligns with the detector specifications. Additionally, the resistance of the active base components to radiation was tested using a Caesium-137 source. Some damage observed during these tests required to make modifications to the original base design to improve its resilience.**

I. Introduction

The GlueX detector [1] in experimental Hall D at Jefferson Lab (JLab) was designed to perform experiments using a beam of photons incident on various targets. The JLab Eta Factory (JEF) experiment [2] will focus on measurements of various $\eta^{(\prime)}$ decays with emphasis on rare neutral modes. The experiment requires upgrading the inner part of the forward lead glass calorimeter of the GlueX detector with high-granularity high-resolution lead tungstate $PbWO_4$ scintillating crystals. The new electromagnetic calorimeter consists of 1596 $PbWO_4$ crystals [3]. Light from each crystals is detected by a Hamamatsu 4125 photomultiplier tube (PMT). The PMT is read out using an active base, which consists of a voltage divider and an amplifier positioned on the same printed circuit board. The divider design is based on the original Hamamatsu divider for this type of PMT, where two bipolar transistors are added to the last two dynodes in order to provide gain stabilization at high rate. The rate capability is also improved by using the amplifier, which allows to lower the PMT operating voltage and therefore to reduce the anode current, which also prolongs the PMT's life. The operational-based amplifier has a gain of about 3 and requires a ± 5 V power source. The active base is presented in Fig. 1. The active base design will be described at the conference.

* corresponding author A. Somov (somov@jlab.org)

Work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under contract DE-AC05-06OR23177.

Fernando Barbosa, barbosa@jlab.org, Vladimir Berdnikov berdnik@jlab.org, Vladimir Popov, popov@jlab.org, and Alexander Somov, somov@jlab.org are with Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

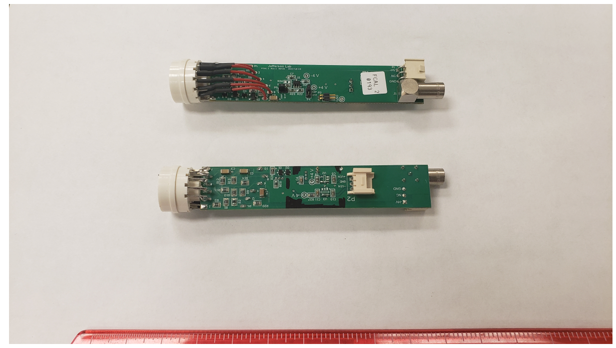

Fig. 1. Active base for Hamamatsu R4125 photomultiplier tube.

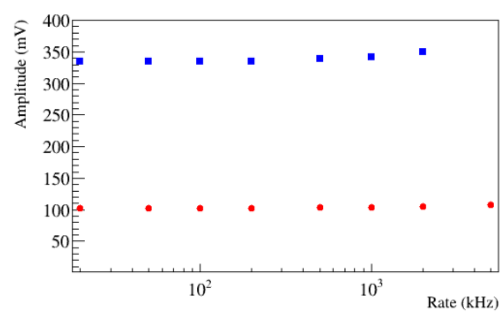

Fig. 2. Signal amplitude induced by a laser pulser as function of the rate. Measurements were performed for two amplitude values.

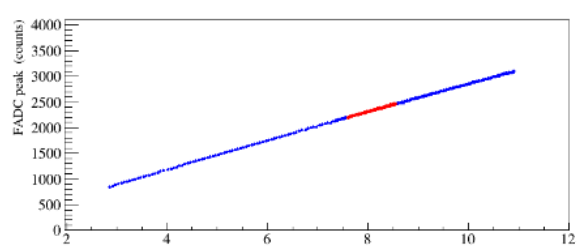

Fig. 3. Signal pulse amplitude obtained from the calorimeter module as a function of the photon beam energy (denoted as tagger energy). The amplitude is given in units of flash ADC counts.

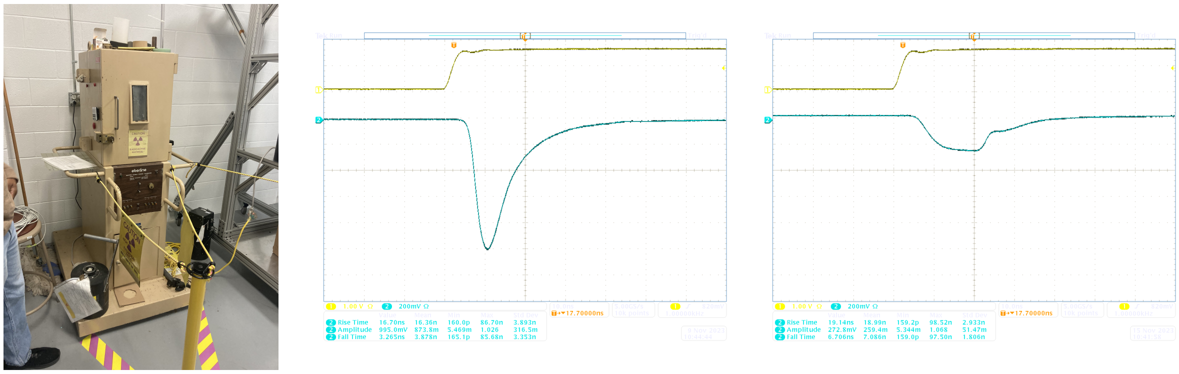

Fig. 4. Test setup used for the irradiation of active bases using Cs-137 source (left). Signal pulse induced by an LED before irradiation (middle) and after the failure of the power regulator at a dose of 20 kRad (right).

II. Test Results

The rate performance of the PMT assembly with the active base was studied using a Hamamatsu PLP-10 picosecond laser with a pulse width of 70 ps and a wavelength of 405 nm. The typical operating voltage of the assembly was 920 V, which provided the base current of 380μA. Dependence of the signal pulse amplitude as a function of the pulser rate is shown in Fig. 2. No visible degradation of the divider gain was observed up to a rate of 2 MHz.

The performance of a calorimeter module [4] instrumented with the PMT base assembly was tested using a prototype, which consisted of an array of 5x5 modules. The prototype was positioned into a beam of photons with known energy, which penetrated the central module. Signal pulses from each module were digitized using flash ADC operated at a sampling rate of 250 MHz. The signal pulse amplitude obtained from the calorimeter module as a function of the photon beam energy is presented in Fig. 3. A good linearity of the calorimeter response was observed in a wide range of energies between 3 GeV and 11 GeV; the non-linearity was found to be smaller than 1.5%.

The radiation hardness of the active base was studied using Cs-137 irradiator shown on the left plot of Fig. 4, which provided a combined beta and gamma dose of up to 0.2 kRad/hr. The irradiation tests were organized into several steps: (1) three active bases were exposed to a dose of about 3 kRad (2) The base was attached to the reference PMT, and the signal amplitude was checked using blue light emitting diodes (LED) (3) the irradiation tests were repeated. The overall accumulated dose during the test was about 50 kRad. We observed that the voltage radiator chips, which supply $\pm$ 5 V for the amplifier failed for all bases at the integrated dose of about 20 kRad. Signal pulse amplitudes induced by an LED before irradiation and after the regulator failures are presented on the middle and right plots of Fig. 4, respectively. After failure, the power regulator chips were removed from the base during subsequent tests and excluded from the final design of the base. The degradation of the signal amplitude as a function of the exposed dose is presented in Fig. 5. The amplitude decreases by about 20% for the accumulated dose of about 10 kRad. This effect was investigated and is attributed to the degradation of the transistors of the active base divider. This degradation is expected to be not very critical for the calorimeter as the maximum dose expected in the detector region around the active base is about 1 kRad per year.

III. Summary

The active base for Hamamamatsu 4125 divider was designed at Jefferson Lab. The base will be used for the instrumentation of 1596 $PbWO_4$ calorimeter modules. Tests of the active base linearity and performance at high rate demonstrated that the base's design aligns with the detector specification. The radiation tests of the base were performed and helped to finalize the design and choice of electronic components.

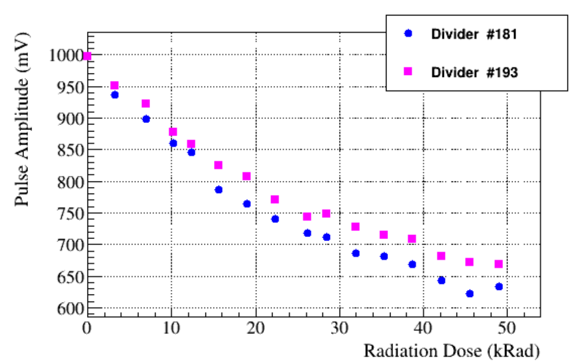

Fig. 5. Degradation of an active base amplitude induced by an LED as a fanction of the accumulated dose.

Acknowledgment

We are thankful to David Wallace and Melvin Washington from the Jefferson Lab Radiation Control department for providing the test setup and assisting us with the RadCon.

References

[1] S. Adhikari *et al.*, "The GLUEX beamline and detector," Nucl. Instrum. Meth. A **987**, 164807 (2021).

[2] A. Somov, "Jlab Eta Factory Experiment in Hall D," PoS **CD2021**, 029 (2024).

[3] T. Horn, *et al.*, "Scintillating crystals for the Neutral Particle Spectrometer in Hall C at JLab,"Nucl. Instrum. Meth. A **956**, 163375 (2020).

[4] A. Asaturyan, *et al.*, "Electromagnetic calorimeters based on scintillating lead tungstate crystals for experiments at Jefferson Lab," Nucl. Instrum. Meth. A **1013**, 165683 (2021).