Version 5e

April 26, 2017

Photocurrent Measurement for a PMT With Resistive HV Divider

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Abstract

We had measured the quantum efficiency of the photocathode of a microchannel plate photomultiplier in which high voltage is supplied by a resistive divider to the successive amplification stages by measuring the change in total current induced by illumination. However, a simple circuit analysis showed that this technique results in a large underestimate of the quantum efficiency, since the first stage of the resistive divider "shorts out" the photocurrent. The change in total current is reduced by a factor of $R_{divider}/R_{gap}$, where $R_{divider}$ is the total resistance of the divider and R_{gap} is the resistance across the gap between the photocathode and the first dynode.

1 Introduction

Vacuum-tube photomultipliers (PMTs) are a mature work-horse technology in wide use due to their gain-bandwidth, low noise, and simplicity of use. The gain is achieved by multiplication from successive electron collisions with dynodes (in conventional PMTs) or emissive layers on the walls of capillary pores (in Microchannel Plate Photomultipliers, MCP-PMT). The accelerating potentials needed to supply electron energy between collisions result in PMTs typically requiring high voltage (HV) distributed to each dynode or to each MCP plate. One simple solution for providing a series of HV values is a resistive voltage divider, usually 'stiffened' by the inclusion of diodes and capacitors in the higher current stages [1, 2].

The LAPPD$^{\text{TM}}$ is an 8.66" x 8.66"-square MCP-based PMT being developed[3, 4, 5, 6] for large-area applications for which psec time resolution coupled with sub-mm space resolution [7, 8] would allow new capabilities [9, 10, 11, 12, 13, 14, 15, 16, 17].

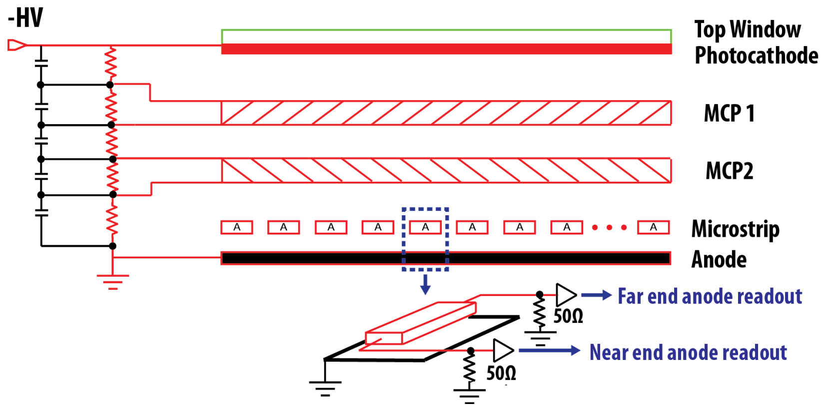

Figure 1: A schematic circuit diagram for the LAPPD™ PMT with an internal HV divider.

An implementation intended for high-volume production of the LAPPD distributes HV applied to the photocathode to each of two MCP plates via a resistive divider that begins at the photocathode and ends at the anode plane, as shown in Figure 1 [18]. High temporal and spatial resolution can be provided by capacitively coupling the fast signal through a thin metal anode film to a user-specified signal pickup comprising a 1-dimensional array of microstrip transmission lines or a 2-dimensional array of pixels (a.k.a. pads) [8].

In this implementation of the LAPPD™ , the resistive divider is internal to the vacuum volume, and consists of two resistive MCPs and 3 layers of thick-film resistors, printed on ceramic spacers. The only electrical feedthroughs connect to the anode and cathode, thus the implementation is effectively a two terminal device. In order to extract photocurrent, the LAPPD must be given a DC bias voltage, which causes a DC bias current through the resistive string in addition to biasing the photocathode-to-first-MCP vacuum gap (see Fig. 1). In order to determine the photocurrent, we expose the LAPPD to a periodic light source and measure the resulting periodic current, which is superposed on the DC bias current, by lock-in detection. Here we derive the relationship between the measured oscillating current and the photocurrent emitted by the photocathode.

2 The Measurement Circuit

Fig. 2 is a block diagram of the measurement apparatus. A high voltage power supply is used to bias the tile so that photocurrent may be extracted. The bias voltage is chosen so that the voltage across the first gap is 10-20 V, in order to efficiently extract photocurrent

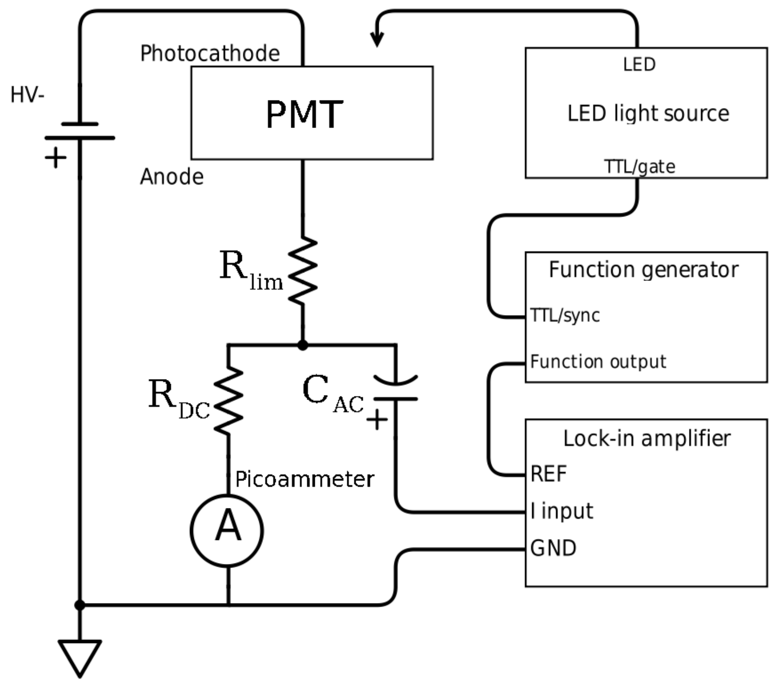

Figure 2: A block diagram of the circuit used to measure photocurrent from an LAPPD^{TM} PMT, here labeled as "PMT". The HV divider is internal to the PMT vacuum envelope.

without any secondary electron emission.

As shown in Fig. 2,light from an LED light source [19], flashing at 350 Hz, illuminates a PMT via an optical fiber, driving a periodic photocurrent. The LED is controlled by the TTL logic output of a function generator, which also sends a synchronous sine wave via the function output to a lock-in amplifier [20], which references the sine wave for lock-in detection of the photocurrent.

The current output of the MCP-PMT is coupled into the lock-in amplifier and a picoammeter [21] through an RC filter. A 1 mF electrolytic capacitor (C_{AC}) couples the oscillating part of the current into the lock-in amplifier, while a 10 kΩ resistor (R_{DC}) couples the DC bias current into the picoammeter, allowing simultaneous measurement of both. The corner frequency f_C=1.6$\times$10^{-2} Hz of this filter was chosen to allow the possibility of detection at a range of frequencies. A current-limiting resistor (R_{lim}) protects the measuring instruments against overcurrent.

3 Relating Photocurrent to Measured Current

To analyze the performance of the measurement circuit, we construct an abstraction, depicted in Fig. 3. The current-measurement apparatus is represented by a single ammeter which measures current I_{out}. The resistive divider is reduced to two stages, Z_1 and Z_2, where Z_1 is the stage between the photocathode and the first MCP, and Z_2 stands in for the remainder of the divider and the external current-limiting resistor. This partitioning is chosen so that the vacuum gap traversed by the photocurrent, represented by ideal current source I_1 is paralleled by Z_1 only. The HV power supply is represented by ideal voltage source V_1.

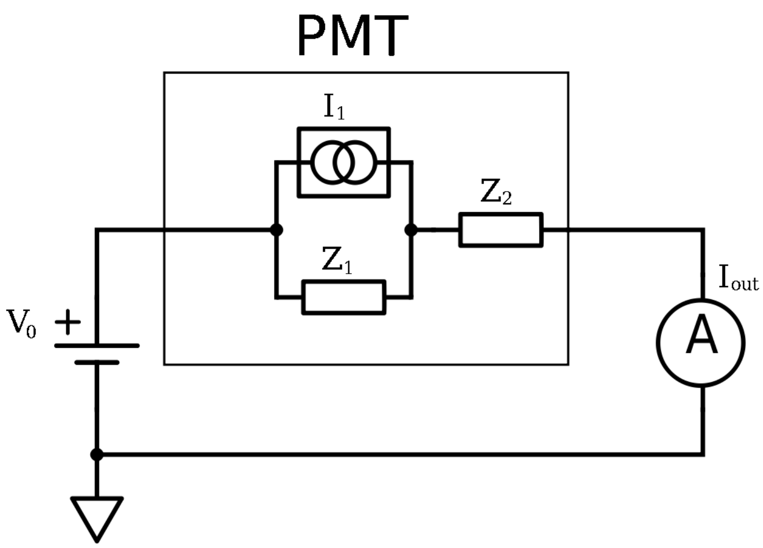

Figure 3: A simplified schematic diagram of the photocurrent measurement circuit. The current I_{out} is measured by an ideal ammeter, the resistive divider has two stages, Z_1 and Z_2, the bias is supplied by ideal voltage source V_0 and the photocurrent is represented by ideal current source I_1.

Treating the whole tile as a non-ideal current source with output current I_{out} and output impedance Z_{out}, one obtains:

$$I_{out} = -\frac{V_0}{Z_1 + Z_2} - \frac{Z_1}{Z_1 + Z_2} I_1 \tag{1}$$

$$Z_{out} = Z_1 + Z_2 \tag{2}$$

Although the photocurrent is a high-impedance current signal, it is paralleled by Z_1, which reduces the output impedance of that stage to Z_1. Since this current signal is passed through

Z_2 before reaching the output of the tile, it is attenuated by $\frac{Z_1}{Z_1+Z_2}$. The full current is not externally available in any measurement scheme which treats the PMT and its resistive divider as a two-terminal device.

4 Conclusions

When a PMT with HV sourced from a single resistive divider is operated below gain voltage, the output current is lower than the photocurrent by a factor of $R_{divider}/R_{gap}$, where R_{gap} is the resistance bridging the gap crossed by photoelectrons. This effect occurs because the resistive divider presents a load impedance $R_{divider}$, while the gap resistor reduces the effective source impedance to R_{gap}. Although it is customary to disconnect the cathode from the resistive divider when making quantum efficiency measurements [2], in our implementation the divider was internal, so we were unable to isolate the cathode.

5 Acknowledgments

I would like to thank Evan Angelico, Andrey Elagin and Henry Frisch, without whom this work would be impossible and largely unimaginable.

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