Characterization of Photomultiplier Tubes

Michael Kennedy*, Dept. of Physical Sciences, Suffolk County Community College, Selden, NY; Garrett Stoddard*, Dept. of Physics, Stony Brook University; Aiwu Zhang PhD and David Jaffe PhD, Electronic Detector Physics Department, Brookhaven National Laboratory; Raul Armendariz PhD, Department of Physics, Queensborough Community College, Bayside, NY; students

* students

Abstract

We would like to thank Dr. Steve Kettell and Dr. Milind Diwan from the Electronic Detector Group at Brookhaven National Laboratory and Dr. David Johnson from the Department of Physics at Queensborough Community College.

Testing photomultiplier tubes for two projects

Cosmic ray detectors are being developed using plastic scintillators at Queensborough Community College. To achieve this goal, photomultiplier tubes (PMTs) with excellent response is required. A PMT characterization system has been set up with the electronic detector group in the BNL physics department. PMTs will be evaluated by measuring their gain, relative quantum efficiency, dark current, etc. This system achieves certain criteria will be selected for cosmic ray detector applications.

Collaborations from BNL Chemistry and Physics have developed a 1 Ton detection system for water-based liquid scintillator (WLS) feasibility studies for very large scale (~10^6 ton) detectors for particle physics. In these studies, photomultiplier tubes (PMTs) with single photon detection capability are required. Various PMTs will be characterized by measuring their gain, single photon-electron resolution (SPEL) peak to valley (PV) ratio, dark current rate, etc. Based on the measurements, satisfactory PMTs will be identified and used for WLS research.

Accomplishments

A dark loss has been set up which can test 4 PMTs simultaneously at a distance of about 32 inches from a flashing LED driven by a pulse generator set at ±2 V, 110 Hz, frequency 5 to 10 Hz. A four-channel oscilloscope are taken from a Tektronix 4104 oscilloscope for a 100% display. The data rate is around 1.6 KHz. The data were taken from 1200 V. To measure a gain near 10 V, a single PMT was tested. The PMT was placed within 5 cm of the LED and the PV ratio could be studied. A diode was also used to measure dark current as a function of high voltage.

Photon multiplier tubes work as if the photonic effect, unlike photodiodes, a photomultiplier tube has dynodes that create an electronic cascade which allows for detection of even single photons.

Photon Multipliers and CATHEDRAL

There are two general types of PMTs: photocathode and intrinsically-coupled. Photomultipliers use a photocathode, a material that emits electrons when struck by light. The light is converted to electrons, which are then multiplied as they pass through a series of multipliers. Each multiplier is called a dynode. The dynodes are biased at a higher voltage than the previous one, allowing the electrons to be accelerated and multiplied. The process continues until the final dynode is reached, where the electrons are collected and their signals are amplified.

PMT Calculations: understanding PMT signal detection

1. Gain of PMT

The number of electrons emitted by anode

\[ g = N_e \]

2. Charge emitted by anode

\[ I_R = \frac{q}{t} \]

3. Dark Current emitted by anode

\[ I_D = \frac{q}{t} \]

Signal over noise: minimum light detection over PMT dark current

The minimum amount of light detectable by a PMT is determined by its dark current, gain, and quantum efficiency. In order for the PMT anode output to be above its dark current \( I_D \), the signal \( I_R \) must be greater than \( I_D \).

\[ I_R > I_D \]

where \( I_R = \frac{q}{t} \) is the incident light current on the photocathode.

Using the above relationship, the incident light power on the photocathode should be:

\[ P = \frac{q^2}{2t} \]

or, for a single photon of \( \lambda = 420 \text{ nm} \) and a PMT with \( I_D = 100 \text{nA} \), \( Q = 0.2 \), and \( g = 2.5 \times 10^9 \), the incident light power required for detection is:

\[ P_{\text{required}} > \frac{q^2}{2t} = \frac{2.5 \times 10^9}{2 	imes 10^{-15}} \]

or, for 100 photons per Watt:

\[ 100 \text{ photons per Watt} \]

References