Alex Loving
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Simulation of PMTs Report

Photomultiplier tubes are used extensively in experimental physics. They find wide usage to measure scintillation light and Cherenkov light. Often in those situations one finds that a very small light signal needs to be measured, and the photomultiplier tube satisfies that need by converting light into an electrical signal that can then be analyzed. Thus, understanding photomultiplier tubes, henceforth referred to as PMTs, is of the utmost importance for understanding the signals they return.

There are two main principles to how PMTs function: the photoelectric effect and secondary emission of electrons. PMTs have what is called a photocathode coated in materials with low work functions such as Cs-I, Cs-Te, Sb-Cs, and bialkalis to name a few, so that photons coming in can easily be converted into photoelectrons. Sometimes, a wavelength shifter is necessary to get into an appropriate response range of the PMT as these photocathodes have a wavelength dependent quantum efficiency, but this will lower the amount of signal that one sees. Once the photoelectron has been generated it has to be amplified to be measured. Thus, it goes through several stages called dynodes. Each stage sees an increase in voltage to accelerate the electrons, and these electrons then collide with the dynode to generate secondary-electrons. The number of dynodes differs from one PMT to another, and dynodes also have a specific configuration within the PMT which lead to different gain, response time, and secondary-electron collection efficiency.[1)]

In order to simulate the PMT, I worked entirely in C and made great use of random number generators that were already written. These number generators are optimized to be incredibly fast with as large a period as possible. They provided me with the ability to sample from a uniform distribution, a standard normal distribution, a poisson distribution, and many more.[3), 5)] The header files do not add anything to the code but instead export the functions for use elsewhere.[4), 6)] Initially, I implemented a set number of dynodes with a set of voltages corresponding to each stage in accordance with the Hamamatsu PMT R6091.[2)] I employed a static quantum efficiency for the PMT and assumed incoming photons with a wavelength of 400 nanometers. In addition, it is assumed that only one photon comes to the PMT at a time.

I utilized a uniform number generator to generate numbers between zero and one. If that value fell below the quantum efficiency of 0.25, then I would count that as a photoelectron being created. As the electron(s) moved through the stages I would iteratively calculate the number of secondary electrons produced based on the energy and number incoming. It was assumed that all generated electrons begin at rest whether they were created through the photoelectric effect or secondary emission. Therefore, the energy is simply the voltage difference between stages. In order to model the energy dependence on the secondary emission ratio, I fit a rudimentary Gaussian function to a graph provided in [7], see Equation 1. I wanted the rough behavior of the graph to match such that at energies

$$12\,e^{\frac{-(x-950)^2}{348061}}$$

Equation 1: Rudimentary Gaussian

of 20 eV the ratio would return one and at energies of 950 eV the ratio would return a maximum of twelve. I then repeated the above a million times and aggregated the ending number of electrons to form an average and a standard deviation of the gain of the PMT as can be seen in Figure 1.

Unfortunately, as it stands I have not made much more progress on my code to begin simulating how the gain changes as a function of supply voltage. I also have not begun to simulate any effects of dark current, but I plan to program in thermionic emission and eventually implement a resistor chain to include ohmic leakage. I also want to set a strict limit to the number of electrons that can be removed from the dynodes, as well as a quantum efficiency that decreases as photons are converted in order to study my original goal of gain degradation. I also have yet to add in the effect of several photons coming in simultaneously and how to best get the separation between the pedestal, one photoelectron peak, two photoelectron peak, and so on.

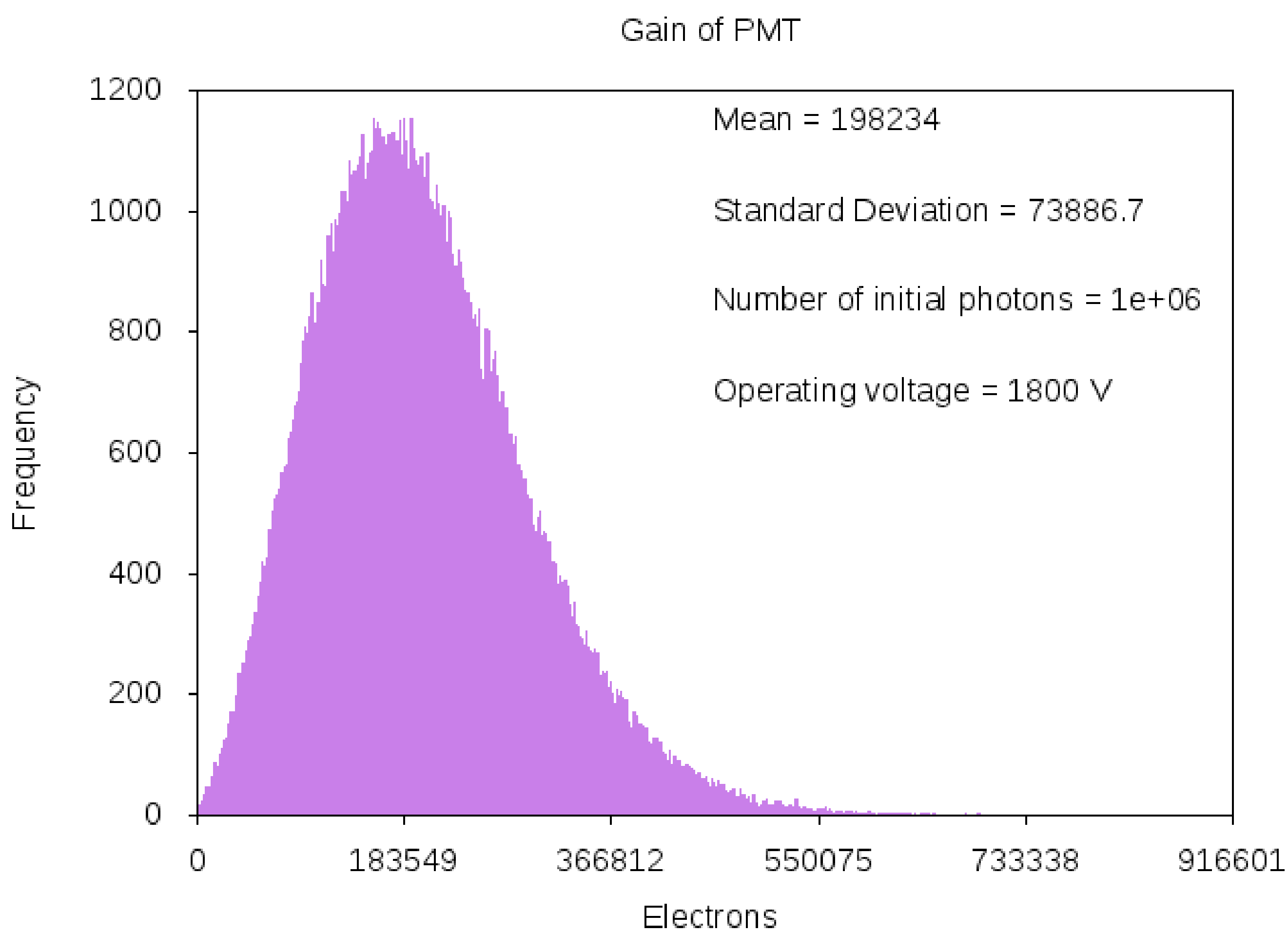

Figure 1

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References

1) Hamamatsu Photonics: PMT Handbook, Hamamatsu Photonics(2007)

2) Hamamatsu Photonics: Photomultiplier Tube R6091, Hamamatsu Photonics (1996)

3) John Burkardt: ranlib.c, http://people.sc.fsu.edu/~jburkardt/ (April, 2013)

4) John Burkardt: ranlib.h http://people.sc.fsu.edu/~jburkardt/ (April, 2013)

5) John Burkardt: rnglib.c http://people.sc.fsu.edu/~jburkardt/ (August, 2013)

6) John Burkardt: rnglib.h http://people.sc.fsu.edu/~jburkardt/ (August, 2013)

7) J.J. Scholtz, D. Dijjkkamp, and R.W.A. Schmitz: Philips J. Res. 50, 375 (1996)