Experiments with a Photomultiplier

Project Aim

The purpose of this experiment is to gain experience with Photon Counting Photometry, to investigate the behaviour of a photomultiplier and to determine the best operating voltage to achieve the best signal-to-noise \( S/N \) ratio for detection of low brightness sources. Subject to progress with the experiment, the recorded statistical behaviour of photon counting might be compared with theory or a system for sequential scanning a spectrum can be investigated.

Background

A photomultiplier (PM) is a sensitive detector for use in the optical region of the spectrum. Because of its good Detective Quantum Efficiency (\( \sim 25\% \)), its stability and freedom from noise it is an excellent device for high accuracy astronomical photometry. Although it is being superseded by CCDs, particularly in the area of recording spectra, it is still preferred for the highest quality photometry of individual objects.

The basic detector comprises a cathode which produces photo-electrons when illuminated, a dynode chain for amplifying each photo-electron to a shower of electrons with gain \( \sim 10^6 \) and an anode to collect the pulses of charge for registration as a signal. The unit is contained in an evacuated glass tube with pins emerging from its base to allow the electrical connections to be made to the various elements. Different geometries are used; the tube used in the equipment provided is an EMI 9558 (tri-alkali cathode) which has an end-on semi-transparent cathode with the amplifying dynodes in the form of a series of ‘Venetian’ blind structures.

The flow of charge from the anode can be detected by various means but a preferred system involves the detection and counting of each pulse, sometimes referred to loosely as a ‘photon’. The advantage of this registration technique is that as the signal is essentially digital, it can be accessed immediately by computer and statistical tests applied – for example, checks can be made as to whether the count rate and its noise is commensurate with the random arrival of photons from a particular low brightness source.

The electronic system required to support the detector includes a high voltage (\( \sim 2 \text{ kV} \)) power pack (Extra High Tension or EHT), a preamplifier providing a gain \( \sim 10 \) and converting the high output impedance of the PM tube to a low impedance to allow the pulse to be transmitted by a long coax cable. Following a ‘line receiving’ unit (with a balanced impedance to match the cable so as to prevent pulse reflections) the pulses are fed to a counter (or scaler) which accumulates the photon number over a set integration time. The registered total can then be despatched to a computer for processing and storage. The computer controls the whole of the data acquisition, usually by a CAMAC system [see additional handout which describes the local CAMAC].

The gain of the PM depends on the voltage supplied by the EHT pack and obviously the voltage heights of the ‘photon’ pulses will increase as the EHT voltage increases. In order for a pulse to be detected, its height needs to be greater than the built-in discriminator threshold of the pre-amplifier. For a given source, as the EHT increases, it is expected that the count rate will increase until all the ‘photons’ are detected. In this voltage domain the PM tube is said to be operating on the pulse
plateau. With an EHT voltage increase, the number of detector background counts (the dark signal from the thermal background) will also rise but a plateau is not reached as dynode noise eventually gets amplified to a level that its pulses are detectable above the threshold.

After exploring some of the basic characteristics of a PM – its ‘fatigue time’ and the effect of cooling on the magnitude of the dark signal – the first aim of the project is to explore the signals associated with a light source and the detector background and to determine an optimum setting for the EHT supply.

The Electronic System

The bench layout comprises a CAMAC crate, an EHT supply, a PM cooler control and a PC. The pulse preamplifier is attached to the photometer head. A variable, stabilised light source is housed in a die-cast box from which a fibre optic emerges for feeding into the field stop plane of the photometer.

When running programmes written under QBASIC, it is impossible to guarantee that the set times for repeated integrations will be identical. For this reason the CAMAC system holds a crystal oscillator timer unit which is triggered by the software and returns a ‘time complete’ signal at the end of a preset, accurate interval. This can be set from 1s to 9s by a rotatable switch on the front panel.

The programme to run the photometric experiment is named “PHOTON.BAS” and runs under QBASIC. It is located in the PC under “C:\student”. After establishing that directory, enter “qbasic” and load the programme by the menu.

First Experiments

The aim of the first experiments is to gain familiarity with the photon counting system. Under the QBASIC Menu, check the basic operation of the data collection program.

1. Set the EHT to some nominal value $\sim 1200$ kV. With the detector shutter closed, and by taking a long run of background measurements, investigate the temporal behaviour of the counts following switch-on. Determine the time interval that is required before the PM can be considered as reasonably stable. Once this time constant has been determined, it must be remembered that the equipment must be switched on for this period before any further sensible investigations can be undertaken.

2. Determine the temperature dependence of the detector background as follows. Commencing with a high temperature on the cooling system for the PM, determine the mean count associated with the detector background. Reduce the temperature settings say by 5° in steps, waiting until the current on the cooler system has dropped to a stabilised value before making determinations of the new mean background counts. The lowest temperature on the dial corresponds to the minimum that can be achieved with Peltier cooling technology. Estimate the reduction in background count that might be achieved if dry-ice cooling $-78^\circ\text{C}$ were to be applied.
Determination of the Best SNR Condition

It can be assumed that any recorded detector count is subject to Poissonian Statistics. That means that if within an integration the number of recorded counts is \( N \), it carries an uncertainty of \( \pm \sqrt{N} \). Suppose that at some value of the EHT, the mean count when the detector ‘sees’ the illumination, \( I \), is \( N_I \) and that the corresponding background record is \( N_D \); the associated uncertainties will be \( \pm \sqrt{N_I} \) and \( \pm \sqrt{N_D} \) respectively. When \( N_D \) is subtracted from \( N_I \) to provide a determination of the source brightness its associated uncertainty is \( \pm (N_I - N_D)^{1/2} \). Hence the \( S/N \) of the determination of the source’s brightness \( S \) is given by:

\[
\frac{S}{N} = \frac{S_*}{\Delta S_*} = \frac{(I - D)}{(I + D)^{1/2}}
\]

(1)

By recording ‘photon’ count integrations for \( I \) and \( D \) determine how the \( S/N \) ratio varies with voltage and estimate what the best working voltage should be.

NEVER let the signal get too large.