Technical Note:
Estimating and Measuring Photomultiplier Anode Current

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Alpha Spectra, Inc.

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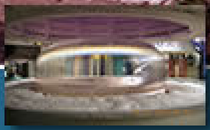

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Technical Notes

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PMT Anode Current Measurements in Scintillation Detectors.

In some scintillation detector applications, the PMT anode current can be a useful parameter to know. The anode current can be easily estimated or it can be measured. Some scintillation detectors are designed to operate either in the negative high voltage (-HV) or in the positive high voltage (+HV) mode of operation. This depends on the intended application. The configuration of the detector's PMT and/or the design of the voltage divider network (VDN) must be taken into account. The scintillation detector should be properly labeled to indicate the mode of high voltage operation it was designed to accommodate. Each mode of operation has its own advantage and disadvantage.

When the PMT is operated in the -HV mode, the photocathode is at negative HV potential and the anode is at earth ground potential (system ground). In the –HV mode VDN need not contain a blocking capacitor between the anode and output signal of the scintillation detector. The measurement of anode current may be obtained by simply connecting a multi-meter or electrometer to the anode output for a given excitation condition of the detector. Some advantages in using the -HV mode of operation are simple operation at high count rates and the relative absence of contribution to the pulse shaping time constants of the detection system. Some disadvantages are sensitivity to DC shifts and the inability to distinguish the signal from such noise components such as dark current.

When the PMT is operated in the +HV mode, the photocathode is at earth ground potential and the anode is at positive potential. The VDN almost always contains a "blocking" capacitor between the anode and output signal of the scintillation detector. The purpose of the blocking capacitor is to prevent +HV potential from occurring at the output of the scintillation detector. Only charge pulses can pass through the blocking capacitor – DC currents are blocked. Some advantages in using the +HV mode are relative insensitivity to DC shifts and the ability to discriminate against sources of DC noise such as dark current. Some disadvantages are the inability to directly measure the DC anode current because of the blocking capacitor and contribution to the pulse shaping time constants of the detection system.

Methods of estimating the detector output current in the +HV mode of operation are suggested below.

1. Method for Estimating the PMT Anode Current at a Given Count Rate.

The simplest method to estimate the average anode current is as follows:

Current_{avg} = (Energy (MeV)) x (Photons Scintillator/pulse-MeV) x (Number of photons impinging on photocathode per scintillation pulse) x (Quantum Efficiency of photocathode) x (charge per electron) x (Gain of PMT) x (pulses per second).

Energy = Gamma ray energy in MeV, (E_γ = 0.662 MeV for Cs-137).

For NaI(Tl), the number of photons per pulse is approximately 40,000 photons/MeV.

Assume that the optical collection efficiency (Number of photons from the scintillator impinging on photocathode per pulse) is 0.8.

Quantum efficiency photocathode ≈ 0.25 (NaI(Tl), it may be different for other scintillators and PMTs depending on the wavelength of the spectral emission curve and the spectral sensitivity of the photocathode).

Charge per electron = 1.6 x 10(-19) coulomb.

Gain PMT = dependent on high voltage and voltage divider network (VDN).

Pulses per second = count per second.

This method estimates the value of the average anode current, but not the peak anode current which is dependent on the temporal pulse characteristics of the scintillator.

The peak anode current can be estimated by:

Peak anode current = (Energy (MeV)) x (Photons Scintillator/pulse-MeV) x (Number of photons impinging on photocathode per pulse) x (Quantum Efficiency of photocathode) x (charge per electron) x (Gain of PMT) / (Decay time of scintillator).

Exercise caution to insure that the peak anode current of the PMT is within the limits set by the PMT manufacturer.

2. Method for Estimating the PMT Total Anode Current Using an Oscilloscope. PMT is Operated in +HV Mode.

The following method assumes that:

a. **Time constants involved in the measurement circuit are taken into account.**

The amount of charge collected during the rise time is negligible compared to the amount of charge collected during the decay time. The decay of the pulse current is given by:

$$I(t) = I_0 e^{-t/\lambda}$$

where λ = 1/e decay time constant of the scintillation pulse (for NaI(Tl), λ = 230 nsec). An example of the decay of a current pulse from a NaI(Tl) scintillator is shown in Figure 1.

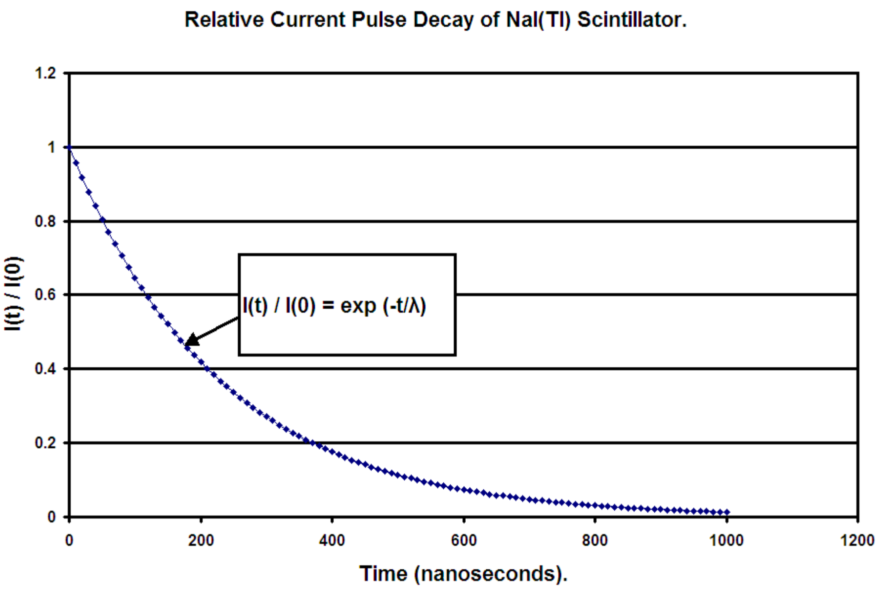

Figure 1. Pulse Decay Neglecting Rise Time.

The charge Q in 1 pulse can be estimated by:

$$Q = \int^{(t=0\text{ to }\infty)} I(t)dt$$

Therefore:

$$Q = \int^{(t=0\text{ to }\infty)} I_0e^{-t/\lambda}dt$$
$$= -\lambda I_0\ (0 - 1)$$
$$= \lambda I_0$$

By observing the pulse across a resistor R, at the input of an oscilloscope, and assuming that the input capacitance is very small, then:

$$Q = \lambda V_0/R$$

where V_0 is the maximum observed voltage pulse on the oscilloscope. In this type of measurement, the voltage is typically measured across a 50 ohm resistor at the input of an oscilloscope. Sometimes this is referred to as a 50 ohm termination. Then R is 50 Ω and V_0 is the voltage pulse maximum in volts.

If there are n pulses per one second, then:

$$I = Q/t = \lambda nV_0/R$$

where I is the estimated current due to a train of charge pulses and is measured in amperes.

Table 1 shows the estimated current in amperes assuming the gain of the PMT is adjusted to give a 50 mV output at different count rates.

Count rate cps	Source	V (V across 50 ohms)	Lambda (NaI)	Current (Amperes)	Current (uAmperes)
1.00E+03	Cs-137	5.00E-02	2.30E-07	2.30E-07	2.30E-01
5.00E+03	Cs-137	5.00E-02	2.30E-07	1.15E-06	1.15E+00
1.00E+04	Cs-137	5.00E-02	2.30E-07	2.30E-06	2.30E+00
5.00E+04	Cs-137	5.00E-02	2.30E-07	1.15E-05	1.15E+01
1.00E+05	Cs-137	5.00E-02	2.30E-07	2.30E-05	2.30E+01
5.00E+05	Cs-137	5.00E-02	2.30E-07	1.15E-04	1.15E+02
1.00E+06	Cs-137	5.00E-02	2.30E-07	2.30E-04	2.30E+02

Table 1. Estimated Anode Current Caused by Charge Pulses at Different Count Rates for a Scintillation Detector Operated in the +HV Mode and at a Constant Gain.

3. Method for Estimating the Anode Current by Integrating Charge Pulses for a Known Time Period in the +HV Mode of Operation.

The anode current resulting from a train of charge pulses with the scintillation detector operating in the +HV mode may be estimated by integrating the charge pulses over a known period of time. The anode current may then be estimated by dividing the total integrated charge by the time period.

Multi-meters and electrometers that are capable of integrating charge pulses to measure total integrated charge in coulombs are commercially available. The selection of which device to use is at the discretion of the user.