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General photomultiplier information for pulse counting

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I have poured over as much data on photomultipliers and pulse counting techniques as I could (more than I wanted to). A small amount of the information seemed contradictory, but some was badly written and left the reader with much to sort out. Thus, I add this section not as any kind of authority, but as one who has paid some dues to get a reasonable level of user understanding.

One must, of course look at as much manufacturer information as is reasonable to determine the type of pmt device needed for the task. In the application of visible light optical SETI, it isn't too difficult to determine a proper pedigree considering the need for low dark noise, high gain, good quantum efficiency, a fairly flat spectral response centered about the visible spectrum, fast rise time, the mechanical constraints of size, side window or front window, high voltage requirements and, of course, cost and availability. For most of us low budget folks, many trips to eBay and other pmt used market websites will be required.

Grounded anode or grounded cathode mode?

After doing all of that homework, there are still important details that are hard to ferret out of the information jungle. My previous experience with pmts was using them as analog detectors and connected in the grounded anode mode. It took many weeks of fiddling about before determining that the grounded cathode mode was a far better scheme for my application with a front window tube type. The reasons are fairly simple, but sometimes a little counterintuitive. First, if the cathode is at high negative potential, there is a large gradient between the aperture plate (or other grounded metal structure) and the pmt window. Glass scintillation by stray electrons may then generate considerable spurious dark noise. When looking for non-Poisson pulse characteristics, these little bursts can be really distressing. Secondly, the outside of the pmt glass envelope in the region around the photocathode must be held at the photocathode potential. This is accommodated with painted on conductive material such as Aquadag™ or a silver conductive paint. But then the whole assembly must be well insulated from the mounting. This can lead to another frustrating source of spurious noise: corona micro discharges. These also can be detected as non-Poisson noise, coincident and otherwise. There are several techniques to mitigate these problems in the grounded anode mode, but I found none to be satisfactory for this application.

After switching to the grounded cathode mode, all of the unexpected noise issues were resolved. I found that anode DC isolation with a 100 pf capacitor terminated with 50 ohms to ground worked well. Don't forget to install fast diodes back to back to ground to protect the 1st amplifier from possible large transients. The mounting for the pmt then became simpler and the window / aperture plate spacing could be set as desired. However, here in Panama, especially during the high humidity of the rainy season, corona discharges could still be a problem around the base of the tube or across the isolation capacitor.

After adding a photometer dry air purge system there have been no recurrences of detectable corona discharges.

Recently (November, 2016) I switched to a side window tube (R3896) and was able to go back to using the grounded anode configuration with good success. The side window tube, having a photocathode deep within the glass envelope, is not as susceptible to external potential gradients.

Ringing

As suggested in several papers, a snubber at the 1st amplifier input can sometimes reduce the pulse ringing. With multiple detectors, such as with the coincidence method of detection, the physical limitations of adding snubbers along with the adjustment of the termination resistance create too many problems. However, with the single pmt detector system, a snubber is a realistic alternative. After multiple efforts on my part, there seemed only a small advantage in pulse shape, but snubbing also reduces the pulse amplitude. In this case, therefore, snubbing was not found to be advantageous. You can find more on this in at least two of the referenced papers.

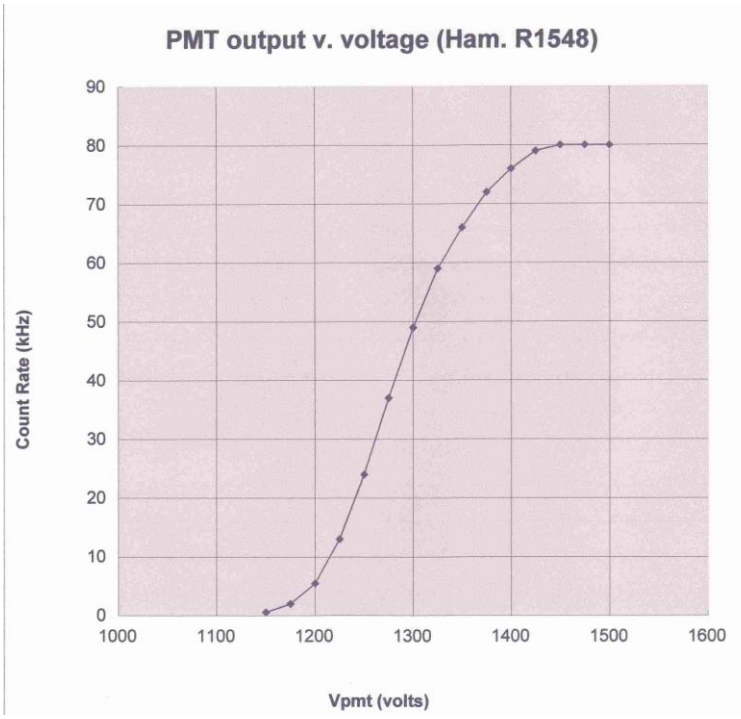
The low level persistent ringing, as seen at the output of the 1st amplifier, was down at the level of other minor noise components and is discarded via the low level discriminator.

High Voltage Settings.

PMT manufacturers specify typical and absolute maximum high voltage settings. Gain curves suggest the higher, the better, but this is only for the analog mode of operation. For setting the high voltage with pulse counting, published gain curves aren't very meaningful other than for tube to tube sensitivity comparisons. Then too, the literature isn't as clear as one might like about determining the best high voltage setting in pulsed mode. So here is a simplified version. Use a stable light source (greatly shrouded, dim LED) and generate a pmt total count v. high voltage plot. One will find that this plot develops a knee and flattens out at the high end - not to be confused with some kind of degenerate saturation. It flattens out because the incident photons have simply produced the maximum number of photoelectron output pulses. This was true for the R1548 front window tube, but the R3896 side window tube showed no signs of a plateau at up to very near the maximum allowable voltage.

Going too high in voltage increases dark counts (and possibly corona and endangers the pmt) while going lower means there will be less gain stability and reduced pulse height. Thus, for the R1548 pmt having an absolute maximum rating of -1750, the best operating point is around the knee of the curve. I chose -1400 volts erring on the side of caution and favoring a lower dark count.

I operate the R3896 at -1100 volts, 150 volts below the absolute maximum.



Discriminator Level Settings

This one is a little tricky too. The idea is to set the discriminator threshold such that true photoelectron pulses pass, but pulses not generated by photons at the photocathode and low level ringing are suppressed. Set too low, there is too much noise contamination. Set too high, there is a loss of sensitivity. If one makes a plot of total count v. pulse height threshold, it will be noted that at very low threshold levels the total count (low level noise) rises precipitously. Set the threshold at a value eliminating this noise. Though the literature drones on about this process, I found the more complicated adjustment methods to be of limited practical value.

What and where to buy photomultipliers

We amateurs don't usually have the funds to spring for new high dollar pmt tubes. But there are plenty of sources for used tubes to be found on the Internet including eBay. You might get a noisy lemon, but the expenditure can be low enough that you just try again. Worst case you'll have a bench test dog pmt for experimentation and a good one for the photometer head.

I have bought three pmts at about $50 each via eBay, from two different sources, and they have all been good, seemingly in spec. and having low dark noise. Maybe I've been lucky. I hope you will be too.

I suggest getting copies of the various manufacturer specs and start looking for just the right tube. Below is a list of Internet resources for PMT tubes, specs and pulse counting techniques in much, much greater detail than that above. Since this document is in pdf format, the links are not active - copy and paste.

Hamamatsu PMT Handbook - Chapter 6
http://www.hamamatsu.com/resources/pdf/etd/PMT_handbook_v3aE-Chapter6.pdf

Hamamatsu Photomultiplier Tubes - Construction and operating Characteristics Connections to External Circuits
https://wwwmu.mpp.mpg.de/docs/pmtconstruct.pdf

Hamamatsu Photomultiplier Tubes - Basics and Applications
https://www.hamamatsu.com/resources/pdf/etd/PMT_handbook_v3aE.pdf

Hamamatsu Photomultiplier tubes - catalog
http://ltlw3.iams.sinica.edu.tw/support/DetectorGuide/Hamamatsu-PMT.pdf

Gray Cancer Institute, Getting the best out of photomultiplier detectors
http://users.ox.ac.uk/~atdgroup/technicalnotes/Getting%20the%20best%20out%20of%20photomultiplier%20detectors.pdf

Signal Recovery with PMTs - Stanford Research Systems
http://www.thinksrs.com/downloads/PDFs/ApplicationNotes/SignalRecovery.pdf

PMT Construction and Operating Characteristics
http://sites.fas.harvard.edu/~phys191r/Bench_Notes/B4/PMT_prop.pdf

Astronomical Society of Australia - Cosmic Ray Induced Photomultiplier Noise
http://adsabs.harvard.edu/full/1976PASAu...3...38G

And here's a special bonus article that can help make your project - simple homemade scope probe - better than you can buy at any reasonable price.

http://www.signalintegrity.com/Pubs/straight/probes.htm