April 8, 2004

GLAST LAT ACD Phototube Lifetime Protection

1. Introduction

All photomultiplier tubes have performance changes with time, depending on the running time and electrical current flowing through the tubes. The GLAST LAT ACD phototubes are designed to have ample margin against the decreasing gain that is characteristic of aging phototubes. The present document is a summary of the considerations related to the ACD phototube design and operating plan.

Some basic information:

- The phototubes are connected to plastic scintillators, which are expected to see typically 1 KHz of minimum ionizing particles (MIPs) in orbit. The maximum expected rate under normal conditions is 5 KHz.
- With the light collection scheme using wave-length shifting fibers, each phototube sees about 20 photoelectrons (pe) per MIP.
- Assuming a typical gain (at launch) of 400,000, the charge produced by the phototube was expected to be 10 pe^- x 1.6022 x 10^{-19} Coulombs x 4 x 10^5 = **0.64 pC per MIP.** In practice, we are seeing 20 pe at the phototubes, so we have the option of running at lower gain or higher current. As noted below, a factor of 2 higher current has no effect on the performance change of the tubes.
- For the expected rate of 1 KHz, this charge results in a current of 0.64 nA, or 3.2 nA for the maximum expected rate (or twice these values if we operate at higher gain).

2. Lifetime Considerations

The Hamamatsu R4443 phototube is a ruggedized version of the R647 tube, whose properties have been studied in detail. The lifetime is measured at a high current, and then a correction is applied as a function of the current. Measurements and calculations (see the Hamamatsu proposal) show that

- At a current of 100 microA, the average gain degradation in 1000 hours is about 23%.
- For any currents of 30 nA or less, the lifetime is extended by a factor of 50 compared to the measurements at 100 microA. In terms of lifetime, there is no significant benefit to making currents less than 30 nA.
- For our tubes, operating at currents of 7 nA or less, we can therefore expect 50,000 hours (5.7 years) before seeing the 23% degradation.
- About 16% of the ACD tubes could see a degradation of 40% or more by the end of 50,000 hours.

3. Design considerations

Although the normal operating conditions present no threat to the ACD phototubes, there are other factors that influence the design. In particular,

- Some correction capability is needed for any changes in gain that are seen. For this reason, tubes are selected to have the nominal gain of 400,000 at a relatively low voltage (nominally 800 V), so that gain can be restored by increasing the high voltage when needed. All the tubes have a gain of at least 2×10^6 at their maximum rated voltage, giving significant margin for gain changes. Because up to 17 phototubes are powered from a single High Voltage Bias Supply, such adjustments would have to be made based on the weakest tube (although they are matched).

- The particle fluxes in the South Atlantic Anomaly (SAA) are many orders of magnitude higher than the fluxes seen over most of the orbit. GLAST will pass through the SAA typically eight or nine times a day, with each passage lasting from a few to 30 minutes. In the SAA passage, the current in the phototubes will increase to the maximum allowed by the biasing network.

Because high currents in the phototubes during SAA crossings would shorten the tube life, we take two approaches to mitigating the effect, one active and one passive:

- The active approach is to reduce the high voltage on the tube during the SAA passage to a low enough value that the tube effectively has no gain. Voltages of about 400 V achieve this effect. The operating plan is to command the High Voltage Bias Supplies into this low value before entering the SAA and restore the voltage after exiting from it.

- The passive approach is to limit the current that can flow through the tubes even if the voltage on the tubes is not reduced. By making the total resistance of the phototube voltage divider 800 Mohms, the maximum current that can flow at 800 V is about 1 microA (1.6 microA at the maximum voltage of 1250 V). This current is far higher than the tube needs in normal operation, but low enough that the tube would not suffer immediate damage (the maximum rated current for these tubes is 100 microA). Nevertheless, repeated passages through the SAA even at 1 microA would shorten the effective life of the tubes. The 1 microA current is about a factor of 3 worse than the nominal current in the tubes in terms of aging effects (see the Hamamatsu proposal), so the 50,000 hour milestone would be reached at about 43,000 hours (< 5 years) if the voltage were never reduced, assuming 20% of the time is spent in the SAA. The current limitation is, therefore, a backup to the active approach of reducing the voltage.

4. Summary

The ACD phototube design balances the need for having enough phototube current to achieve the scientific goals (see the Appendix) against the lifetime effects of having so much current, especially in the SAA, that the tube lifetime is impacted.

APPENDIX

AM, 11/25/2002

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How the ACD PMT low-current divider handles the particle rate?

ACD PMT divider is designed to minimize the power consumption through the HV line. The maximum estimated single-charged particle rate on the orbit is 1-2 kHz, ACD Level III requirements require the maximum rate of 3 KHz to be handled by ACD. Assuming 1 pC per pulse and rate of 3 KHz, the average anode PMT current is ~3 nA. The divider has to provide at least factor of 100 higher current. Our divider is designed to provide ~ 1 mkA at 800 V.

How the PMT output changes with the particle rate is the subject of these notes. The signals were imitated by LED placed at the PMT face, with the signals from PMT to look similar to that produced by real particles – here cosmic muons.

Rate_rate.ps

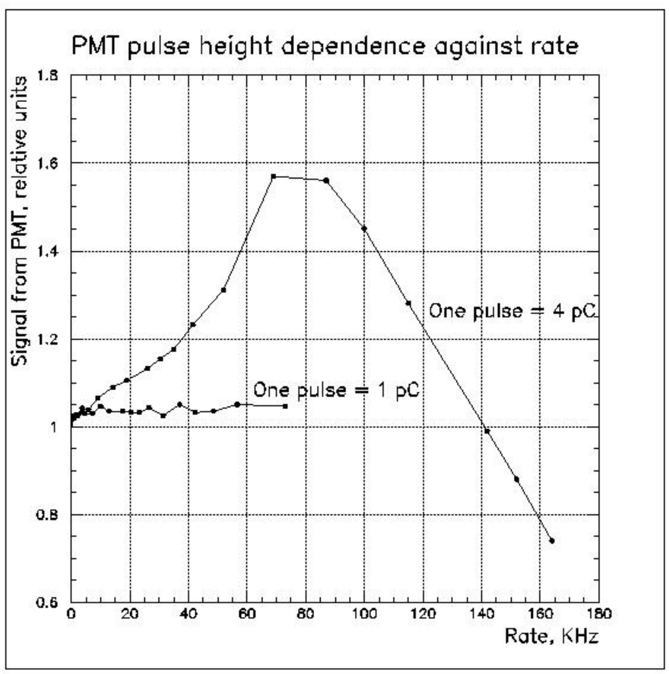

Fig.1. PMT signal change vs. the rate. Measured for two values of signal – 1 pC and 4 pC. The real signals from ACD tile is 0.6-1 pC.

Rate_current_1.ps

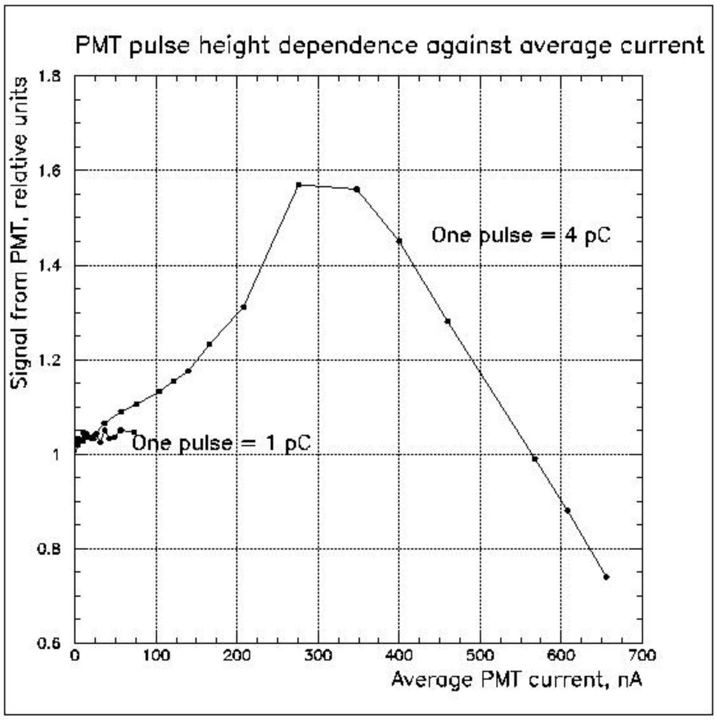

Fig.2. The same data as in Fig.1, but plotted against the average PMT anode current

Rate-current_2.ps

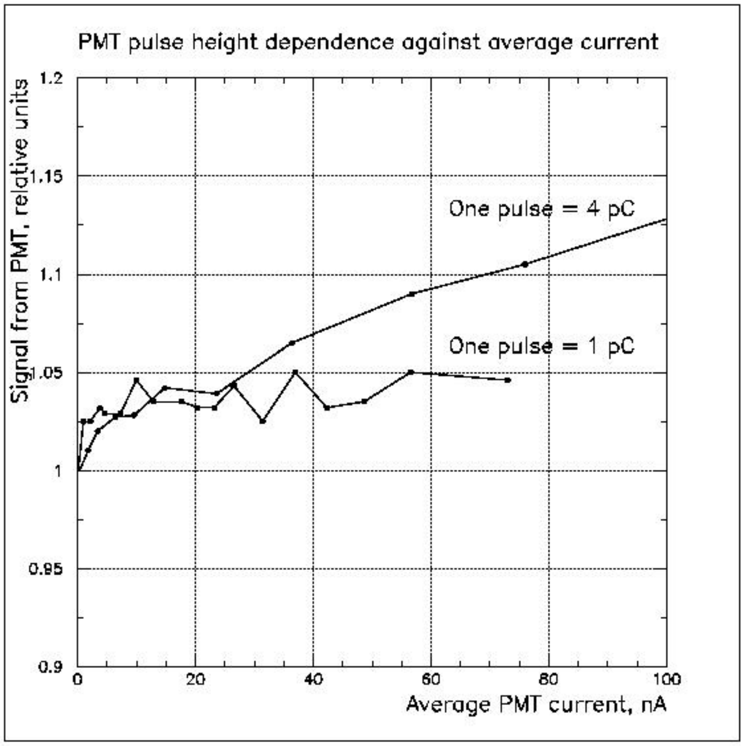

Fig.3. same as Fig.2, but expanded X-axis

Conclusion. Fig.1 shows that up to several tens of KHz there will no visible change of PMT performance for the signals of ~ 1pC. For larger signals we see the effect of signals increase, and after that decrease (saturation). Fig. 2 and 3 (expanded view) show the same results but plotted against the average PMT anode current. It can concluded that our PMT divider performs properly in required rate/anode current range