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Gamma-ray Large Area Space Telescope (GLAST)

Large Area Telescope (LAT)

Selection of ACD Photomultiplier Tube

1. Introduction

Having concluded that a photomultiplier tube is the readout of choice for the GLAST LAT ACD, we then have to find an existing tube that meets our specific requirements. Development of a completely new tube would be prohibitively expensive, as well as raising doubts about its ability to be space qualified for a five-year mission. The principal design drivers are performance, size, and lifetime, with cost an important consideration.

2. Performance

A Minimum Ionizing Particle (MIP), the principal target for detection by the ACD, deposits approximately 2 MeV in a 1 cm thick plastic scintillator. The scintillator converts the particle energy loss to approximately 21,000 optical photons with a peak wavelength of 425 nm. The waveshifting fiber collects many of these photons and re-radiates at a peak wavelength of 490 nm. A fraction of the resultant photons are trapped in the fibers and conducted to the phototube (the collection and transmission of these photons is not easily calculated). Tests with commercial phototubes show that between 20 and 40 photoelectrons are produced at the photocathode. Because we want two phototubes per tile (in order to avoid a single-point failure), we conservatively assume 10 photoelectrons in a phototube. For a gain of 400,000 (achievable with a wide range of phototubes), these 10 photons produce 0.64 pC at the phototube output. We design our electronics to operate down to 0.1 of this signal level in order to meet our efficiency requirement. We note that this requirement is equivalent to detecting single photoelectrons. An example of signals from a tile/waveshifting fiber/phototube system, taken from the balloon flight, is shown in Fig. 1.

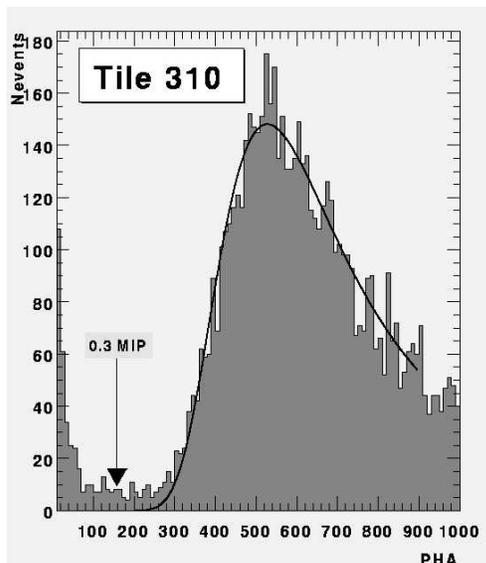


Fig. 1. Pulse height analysis spectrum from a scintillator tile with waveshifting fiber readout and a single photomultiplier tube (Hamamatsu R647), from the balloon flight. The large peak to the right is from MIPs. The peak to the left is a combination of phototube noise and signals from backplash secondaries (which are typically < 0.5 MeV photons). The key performance requirement is to be able to set the threshold in the valley between these signals, in order to have high detection efficiency for MIPs and low sensitivity to backplash.

3. Size

The phototube size is limited by mechanical dimensions – it must be large enough to collect the light but not so large as to interfere with the overall LAT dimensions:

Light Collection

- The optimal fiber spacing in the tile is 5mm, so for 34cm wide tile there will be 34 fibers per PMT.
- We are going to use 1mm round WSF and 1.2mm round clear fibers to allow for the tolerance in fiber-to-fiber connector.
- This number of fibers gives the minimum PMT photocathode diameter of 8-8.5mm
- We do not want to use the outer ~10% of the photocathode due to degraded sensitivity.
- The Hamamatsu R1635 (10mm diameter bulb) has an 8mm diameter photocathode; therefore, its useful photocathode area is too small.

Overall Size

- The ACD requires 194 phototubes; they must be arranged so that the total size of the ACD fits between the tracker and the outer envelope of the LAT
- The perimeter of the LAT is approximately 6400 cm. If only the phototube diameter were important, we could fit phototubes of up to 25mm diameter. With the required space for magnetic shielding, mechanical support, connectors, and resistor divider network, however, any tube larger than 16mm diameter would be very hard to fit into the available space, and any tube larger than 20mm diameter would almost certainly interfere with the envelope. Unless forced into a complicated mechanical design, therefore, we attempt to find a 13 mm (1/2") diameter tube, while not ruling out a 19mm (3/4") diameter alternative.
- Fig. 2 shows the mock-up details with a layout using 13mm diameter tubes.



Fig. 2. Mechanical mockup showing the phototube layout proposed for 13mm diameter tubes.

4. Lifetime

All photomultiplier tubes' performance characteristics change with operating time, and ultimately all phototubes show a degradation. In order to assure the minimum five year lifetime of the LAT, we need to find tubes whose projected useful performance life exceeds five years. In addition, we need to be able to select sets of tubes whose projected change of performance is comparable, because up to 18 tubes will be operated from a single high voltage bias supply. We can compensate for performance degradation by starting at a mid-range high voltage and then adjusting the voltage upward to maintain our required performance, but this is only practical if we have some assurance that the tubes will not have major divergences in performance with operating time.

Phototube life can be estimated by accelerated aging using higher currents than planned in flight. Fig. 3 shows a sample of performance changes for one candidate tube, the R647, using a 100 μ A (compared to the nominal 30 nA planned for the ACD tubes).

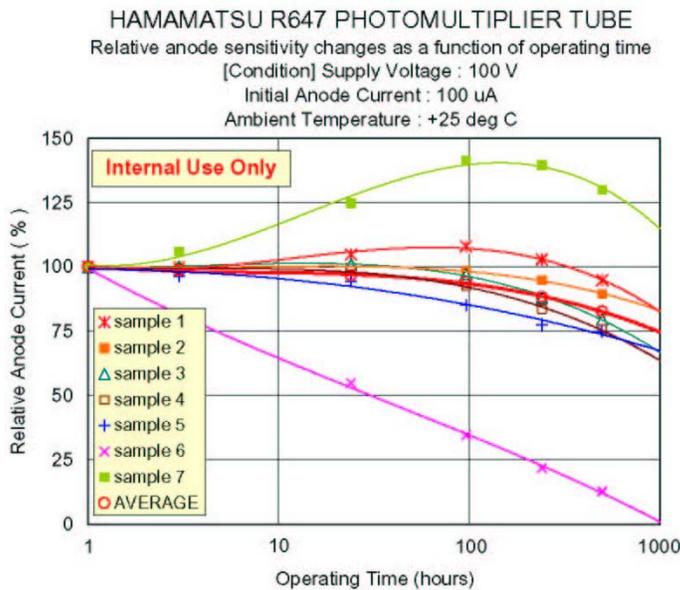


Fig. 3 – Sample accelerated life test for a number of Hamamatsu R647 tubes. A key feature is that tubes with unusual performance changes with time can be identified (and rejected if needed) with a suitable burn-in at high current.

4. Available Candidates and Development Efforts

Small photomultiplier tubes are made almost exclusively by Hamamatsu, and Hamamatsu phototubes have substantial space flight experience. Nevertheless, we conducted a market survey and ultimately a competitive procurement to search for other possible sources:

- Burle Industries is developing a $\frac{3}{4}$ " tube, but it is not ready for production. They would have no space experience with this tube.
- EMR offered to develop a $\frac{3}{4}$ " tube if we would support the research, but the cost was prohibitive. EMR tubes would be attractive, because they are extremely

rugged over a very wide temperature range, but the idea of funding an expensive development effort with no guarantee of success was not so attractive.

Hamamatsu has several candidates:

- The R1635, although its photocathode is slightly too small, has a long lifetime and good performance characteristics. The ruggedized version is more expensive than the ruggedized version of the R647.
- The R5611 is a 19mm ($\frac{3}{4}$ ") tube that is extremely rugged and has good performance characteristics, but its projected lifetime is marginal for a five year mission.
- The R647 is a 13mm tube that we have experience with. It was used for the 1997 beam test at SLAC and a follow-on test at CERN. In the several years of use, we have had no failures among the 15 of these we own. A selected set of commercial R647 tubes was used in the HEXTE experiment on RXTE. We know of one failure in the first year of that mission (out of 25 tubes). The space version of the R647 with a slightly different cathode (R4444) is still in use on the French GOLF instrument on SOHO after more than five years. In the competitive procurement, Hamamatsu proposed the R4443, the space version of the R647 with the same photocathode.

5. Conclusion

The photomultiplier tube that appears most likely to meet all our requirements is the Hamamatsu R4443.