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Leakage Current Prediction for GLAST Silicon Detectors

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INTRODUCTION

The GLAST experiment will fly in a low orbit and operate in a relatively low radiation environment. An upper limit estimate of 10kRad over the life of the experiment is expected. Any irradiation will have the effect of raising the leakage current in the silicon micro-strip detectors leading to increased noise. A GLAST prototype silicon detector has been irradiated at the UC Santa Cruz ^{60}C0 facility. Measurements of the leakage current for a single channel have been collected over the temperature range of $-25 < T < 25$ C. Interpolation to the conditions of the GLAST experiment are presented.

MOTIVATION

The converter/tracker of GLAST will consist of silicon strip detectors with 195μm pitch and 400μm thickness. Five detectors of 6.4cm length will be daisy-chained together to make 32cm long ladders connected to one readout chip. This increases both the parasitic capacitance and the leakage current seen by each readout channel, and both contribute to the noise of the front-end electronics. In the present amplifier design, the required low power level is reached with long shaping times of about 1.6μs which makes the total noise of the amplifier susceptible to the stochastic noise due to the leakage currents. Thus it is important to understand the amount of leakage current expected for the total dose received by GLAST and its noise contribution.

NOISE

The noise charge σ is given in terms of the capacitance C, shaping time τ, leakage current i and bias resistor R by

$$\sigma = \mathrm{sqrt}[\, (a+bC)^2 + 2i\tau/e + 4kT\tau/R \,] = \mathrm{sqrt}[\, \sigma_O^2 + 2i\tau/e + 4kT\tau/R \,]. \quad \{1\}$$

With the choice of of τ=1.6μsec as shaping time to reduce power and noise, the present GLAST prototype chip has a= 204e$^-$, b=30.3e$^-$/pF. At 31cm active length and a capacitance per unit length c =1.2pC/cm, the total capacitance is C=37.2pF and the noise with purely capacitative load is σ_O = 1330e$^-$, which sets the scale.

Other noise contribution are added in quadrature:

the bias resistors contribute $321e^-$ (5 resistors @ $50M\Omega$, at 300^oC);

a leakage current of 10nA in each of the 5 detectors contributes a noise charge of $1000e^-$.

RADIATION DAMAGE

The total radiation level for GLAST is predicted to be less than a total dose of 10kRad. If this dose were due to minimum ionizing hadrons corresponding to a fluence of $3*10^{11} p/cm^2$, the leakage current at room temperature from bulk damage would be 22nA for each 31cm long strip of the 400μ thick detectors with 195μ pitch [1]. If, for GLAST, the dose is mainly due to low energy electrons, which have a factor of at least 10 smaller displacement damage constant, the leakage current would not contribute to the noise significantly, especially if the detectors are cooled, as described below.

In addition, surface leakage currents are expected, and their temperature dependence is not know [2]. Thus a measurement of the leakage current after photon irradiation gives a reliable lower bound for the expected leakage currents.

MEASUREMENTS

The prototype GLAST silicon strip detector studied was manufactured by Hamamatsu Photonics. It is a single sided, AC coupled silicon detector with a pitch of 236 μm, and 57 μm wide implants. The detector was 5.8 cm long and 500 μm thick n-bulk with p-type strips and punch-through biasing. Bonding/probe pads are available on each strip for both the implants and metal layers.

Irradiation of the detector was carried out in two steps of 10 kRad each in the ^{60}Co source at Santa Cruz. Measurements of the leakage current on many individual strips were taken as a function of temperature a year after irradiation, i.e. after the initial annealing has taken place. It is likely much of the irradiation damage is on the surface of the detector since γ's are not expected to cause large damage to the bulk.

An insulated cold box was constructed from a one inch thick polystyrene container. The temperature was regulated by controlled flow of liquid N_2 boil-off. Temperature monitoring was provided by a digital thermometer, and a separate Resistance Thermometer Detector (RTD). Cabling for the thermometers, as well as the detector bias and strip under test (SUT), were supplied by a feed-through, which also acted as a vent for the coolant. The inlet for the Nitrogen boil-off was inserted diagonally opposed from the outlet, and the detector was placed in the middle of the cold box. We found it was necessary to completely cover the cold box with multiple layers of black cloth to eliminate background room light from the system.

The detector was mounted on a copper clad G10 board which provided a surface onto which the detector bias and strip could be connected using standard wire bonding techniques. Channel number 120 was selected as the Strip Under Test (SUT), and it's two neighboring channels (NC) were connected and their leakage currents were also measured. Both the SUT and the NC were held at ground, while the bias was applied to the back plane at 150 V and 200 V by a Keithly 237 Voltmeter. The leakage currents on the SUT and NC were measured with a 4145HP Parameter Analyzer.

The temperature was varied from room temperature (~28C) to about -25C. Difficulties were encountered in obtaining stable temperature conditions. The preferred method resulted in the Nitrogen vapor being flowed at approximately 500 cc/min. This resulted in a very quick lowering of the temperature. The flow was then stopped, and the temperature was allowed to stabilize before the measurements began. The RTD provided rapid response to temperature changes, and was calibrated with the digital thermometer (Fig 1.)

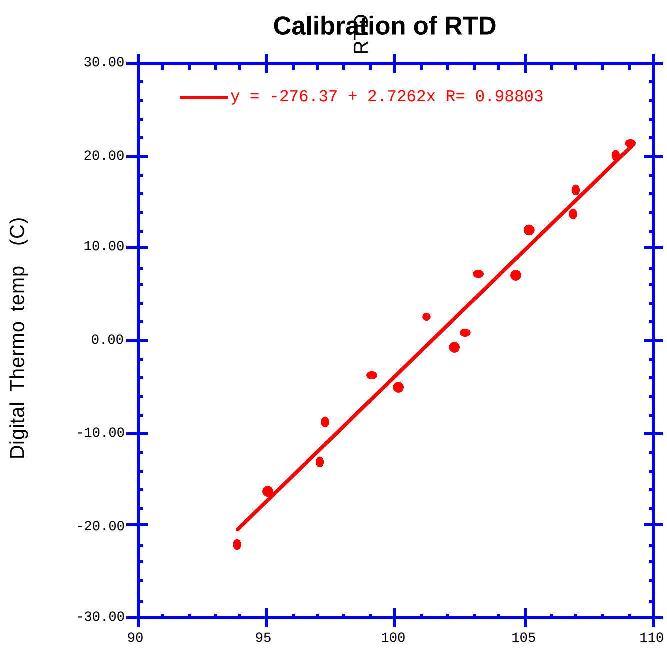

Figure 1. RTD Calibration with respect to a digitalthermometer.

After cooling to -25C the Nitrogen boil-off was terminated, and dry nitrogen at 50 cc/min was flowed at room temperature which allowed the temperature in the cold box to rise slowly. During this time the leakage currents were also measured. The dry nitrogen was needed to prevent condensation on the detector surface. The two family of curves in Fig.1 (also seen in the current measurements Figs. 2 and 3) were obtained while the cold box was being cooled, and while the temperature was allowed to rise, respectively.

RESULTS

Figures 2 and 3 show the leakage current on the SUT and on the two connected neighbors NC over the measured temperature range for 150 and 200 V bias, respectively. A fit through the single channel data is consistent with an exponential increase in leakage current as the temperature increases. E.g at 200V bias:

$$i(T) = 2.25*\exp(0.0883*T) \text{ nA, T in } {}^oC, \qquad \{2\}$$

similar to the temperature dependence of the bulk current[3]:

$$i(T)=i(T_o)*(T/T_o)^2*\exp[-0.6/kT_o+0.6/kT_o\} \quad . \quad \{3\}$$

We measure a reduction in strip current due to cooling the detector from 20^oC to 0^oC of a factor 5.9 (from 13.2nA to 2.25nA, Eq. 2), while the expected reduction factor for bulk currents is 6.6 from Eq. 3. Within the error of the measurement the reduction factors are the same. The increase in current with bias voltage increase is small, and consistent with either surface or bulk generation.

As mentioned above, the total dose of the irradiation was 20kRad. With a few plausible assumption, we can now predict the leakage current and its noise contribution in the GLAST detector. We will assume that the current is linear in dose, (which we verified experimentally), resulting in a factor 0.5. Then we will assume that the current is proportional to the strip area, which gives a factor (195/235)=0.83 for the pitch ratio and (31/5.8)=5.34 for the length ratio

Thus the expected current for a single GLAST detector strip of 31cm length as a function of temperature is

$$i(T) = 5.0*\exp(0.0883*T) \text{ nA, T in } {}^oC \quad . \quad \{4\}$$

The expected current for 10kRad total dose from photons and electrons, Eq.4, is shown in Fig. 4 as a function of the operating temperature. In the same figure, the expected total noise as a function of temperature is shown, using Eq. 1.

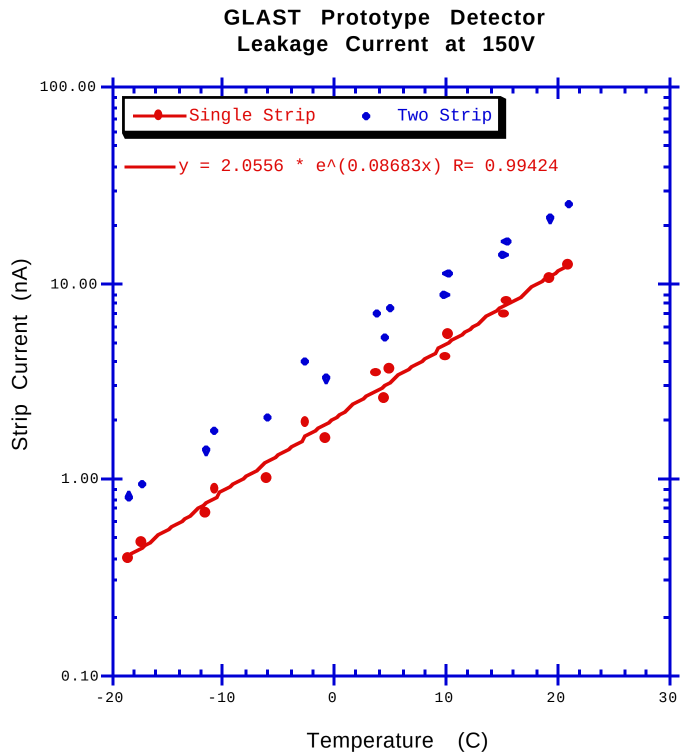

Fig. 2 Leakage current for a single strip (larger points) and two neighboring strips (small points) as a function of temperature for 150V bias voltage.

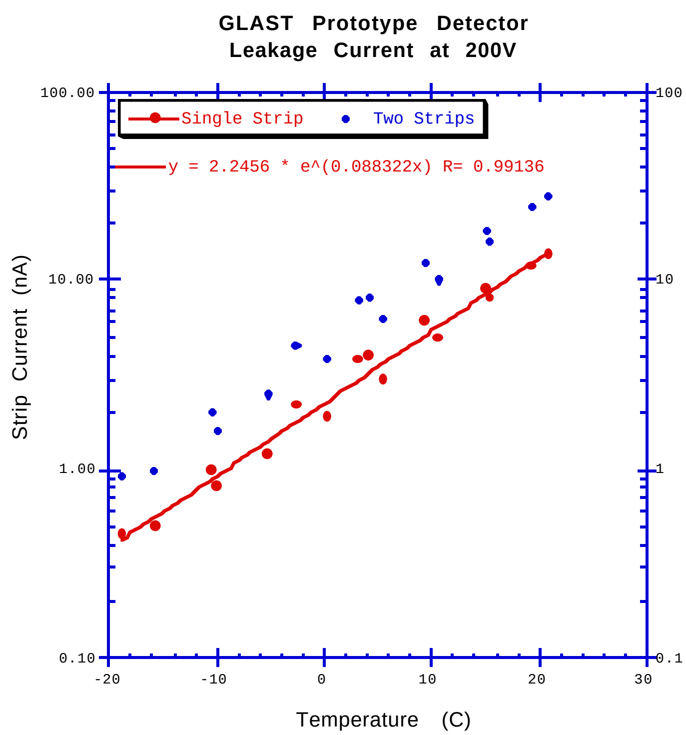

Fig. 3 Leakage current for a single strip (larger points) and two neighboring strips (small points) as a function of temperature for 200V bias voltage.

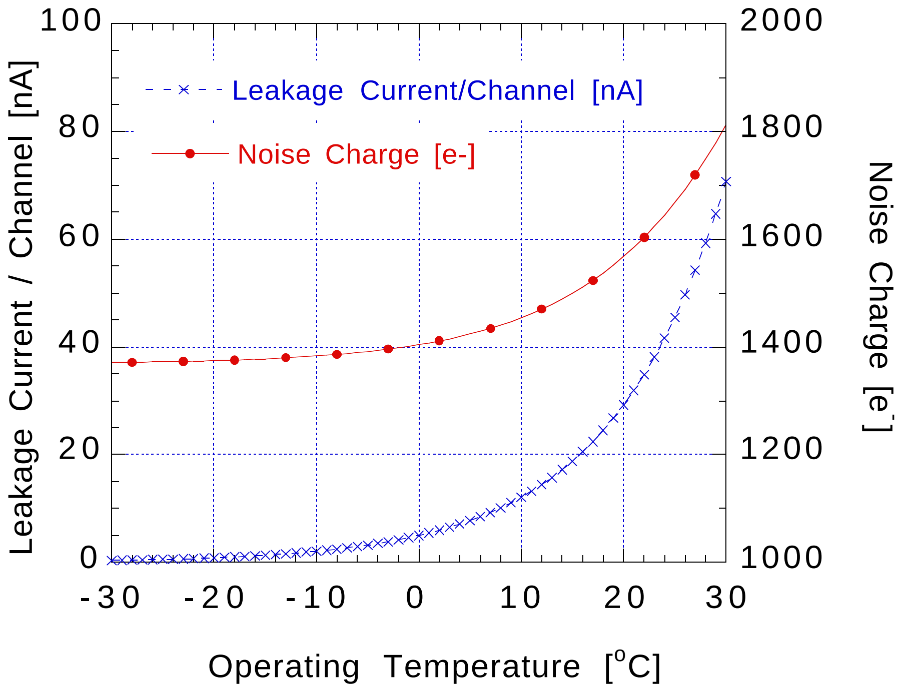

Fig. 4 Extrapolation of single strip leakage current and noise in the GLAST detector after 10kRad total dose.

As we see, the leakage starts to contribute significantly to the noise if the operating temperature is raised beyond about +10°C. At +20°C, the noise is 12% larger than at 0°C. Thus we recommend an operating temperature comfortably below +20°C for the GLAST silicon tracker.

REFERENCES

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