

CRaTER Analog Processing Worst Case Analysis

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CRaTER

Analog Processing Electronics

Worst Case Analysis

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Revision 01

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1. Scope

A worst case analysis of the CRaTER detector electronics was performed and documented in this report. The CRaTER detector electronics consists of two printed circuit boards: Telescope Board (TB) and Analog Processing Board (APB).

The worst-case analysis considered the following:

- a) Circuit effects due to detector leakage current under worst case temperature and radiation dose
- b) Circuit effects due to highest LET particle impacting detector
- c) Circuit effects due to opamp leakage currents under worst case temperature and radiation dose

2. Applicable Documents

- 1) 32-05001 Detector Specification
- 2) 32-01002 LRO Radiation Requirements
- 3) 32-03004 Analog Board Schematic
- 4) 32-03005 Telescope Board Schematic
- 5) 32-01205 Instrument Requirements Document

3. Detector Leakage Current

3.1. Worst Case Prediction

Leakage current will increase by a factor of 2 for every 8 deg C rise in temperature (Ref 1). Radiation damage will result in an increase in leakage current by approximately 1 nA / cm² / 100 Rads (Ref 1). This is a worst-case prediction with no consideration for annealing affects, which will likely result in a much lower rate. The combination of temperature-drift and radiation degradation results in a worst-case prediction for each detector.

3.1.1. Thin Detector Prediction

The temperature prediction is as follows. The specified maximum leakage current through the active contact of the thin detector is 0.3 uA at 20 C (Ref 1). The maximum operating temperature of the detectors is specified at 35 C. Therefore, the maximum leakage current due to temperature effects is 1.2 uA.

The radiation effects are estimated as follows. The detectors are located behind at least 30 mils of Aluminum. The radiation dose behind this amount of shielding is no greater than 100 kRads (Ref 2). The thin detector active area is 9.8 cm². Then, 9.8 cm² x 1 nA/cm²/100Rads x 100,000 Rads Si results in a maximum leakage current of 10 uA.

The resulting worst-case estimate is the sum of these two currents: 11.2 uA.

3.1.2. Thick Detector Prediction

The temperature prediction is as follows. The specified maximum leakage current through the active contact of the thin detector is 1 uA at 20 C. The maximum operating temperature of the detectors is specified at 35 C. Therefore, the maximum leakage current due to temperature effects is 4 uA.

The radiation effects are the same as the thin detector, 10 uA.

The resulting worst-case estimate is the sum of temperature and radiation effects: 14 uA.

3.2. Effects on Detector Bias

The allowable safe bias region for the detectors is in the range: $FD < V_b < FD + 30V$, where V_b is the voltage across the detector active junction and FD is the measured full depletion voltage. At the time of launch, the voltage bias will be set to $FD+30$ for each detector.

3.2.1. Thin Detector Bias

The total equivalent resistance from the bias supply to the detector junction is chosen so that no more than 25 volts drop in the detector bias is incurred from the worst-case leakage current of 11.2 uA. ***The value of R in this case must be < 2.2 MegOhm (Ref 4)***

3.2.2. Thick Detector Bias

The total equivalent resistance from the bias supply to the detector junction is chosen so that no more than 25 volts drop in the detector bias is incurred from the worst-case leakage current of 14 uA. ***The value of R must be < 1.7 MegOhm (Ref 4).***

3.3. Effects on Noise

Higher leakage current from temperature and radiation effects along with small bias resistors for low IR drop has the effect of higher noise. The graph of figure 1 was obtained from the values in Table 1, and it illustrates the best and worst-case noise for both thin and thick detectors as a function of pulse shaping time. The circuits are designed for 800 ns shaping.

3.3.1. Thin Detector Noise

The thin detector noise at a pulse shaping time of 800ns at 20C, BOL (begin-of-life), will be 38 KeVrms. The noise at 35C, EOL (end-of-life), will be 49 KeVrms. The limit on tolerable noise for the thin detector circuit is 400 KeVrms (Ref 5). ***Because the added noise is still much lower than the required limit, there will be virtually no discernable impact on performance.***

3.3.2. Thick Detector Noise

The thick detector noise at a pulse shaping time of 800ns at 20C, BOL, will be 12 KeVrms. The noise at 35C, EOL, will be 36 KeVrms. The limit on tolerable noise is 40 KeVrms (Ref 5). ***Because the hot EOL prediction is still below the noise limit, there should be no discernable performance degradation from the added noise.***

Table 1. CRaTER Noise Model Inputs

Detector	Det. Leakage	Detector Capacitance	Circuit Capacitance	JFET noise	Series Resistance	Parallel Resistance
Thin	300nA, 20C BOL 11,200nA, 35C EOL	770pF	88 pF	4 nV/RtHz	100 ohms	142 Kohms (bias feedback)
Thick	1,000nA, 20C BOL 14,000nA, 35C EOL	120pF	74.3pF	0.5nV/RtHz	100 ohms	192 Kohms (bias feedback)

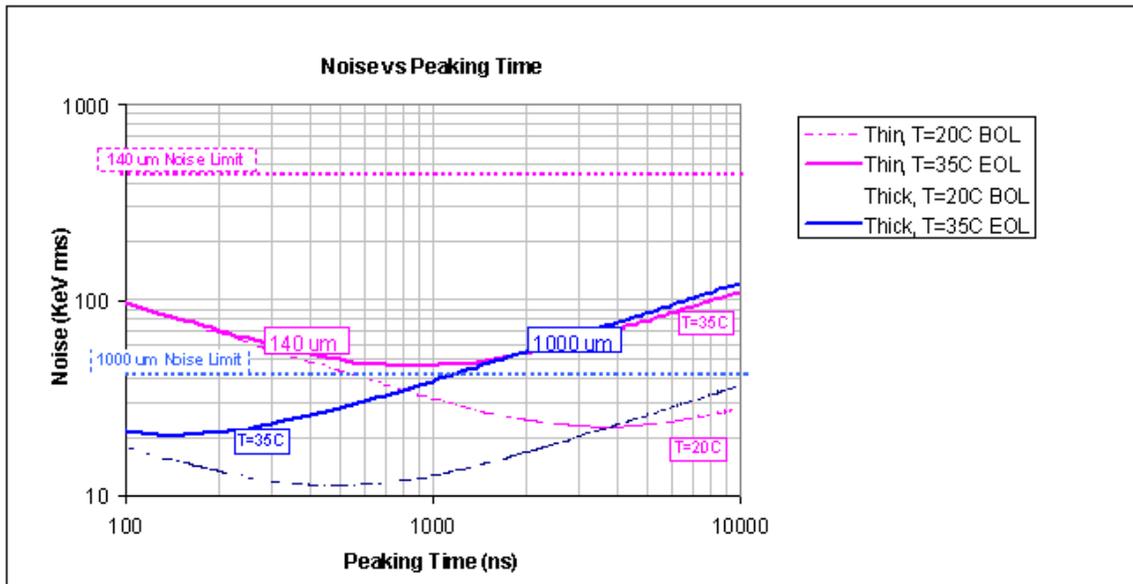


Figure 1: CRaTER Noise vs Amplifier Peaking Time

4. High-Z Particle Impact

4.1. Worst case prediction

Ions up to Uranium into the 140 & 1000 micron detectors at normal incidence were simulated by J. Mazur. The max deposit is about 14 GeV in the thick silicon, representing the worst-case deposited energy. Natural abundances fall off many orders of magnitude for ions heavier than iron. In the galactic cosmic rays, these ultra-heavy ions are on the order of 10^{-5} of iron, so the likelihood of ever seeing one in our mission is quite small ($\sim 10^{-8}$ / (m²-sec-sr-MeV/n)). In some solar flares the ultra-heavies are enriched by a factor of 1000, but they are much lower energy hence their peak deposit is down by at least a factor of 10.

The probability of getting hit by a micrometeoroid is higher than the probability of seeing such large deposits from ionizing particles. By rough calculation the ultra-heavy flux is comparable to the micrometeoroids above 10^{-8} g, where you see about $10^{-4}/(\text{cm}^2\text{-year})$. While the probability of impact on the detectors is very small, the analysis below demonstrates the effect of such particles on the analog processing system.

4.2. Effects on Thin Detector

As shown in the figure below, the maximum energy deposit in the thin detector due to an abnormally large LET particle is 4 GeV.

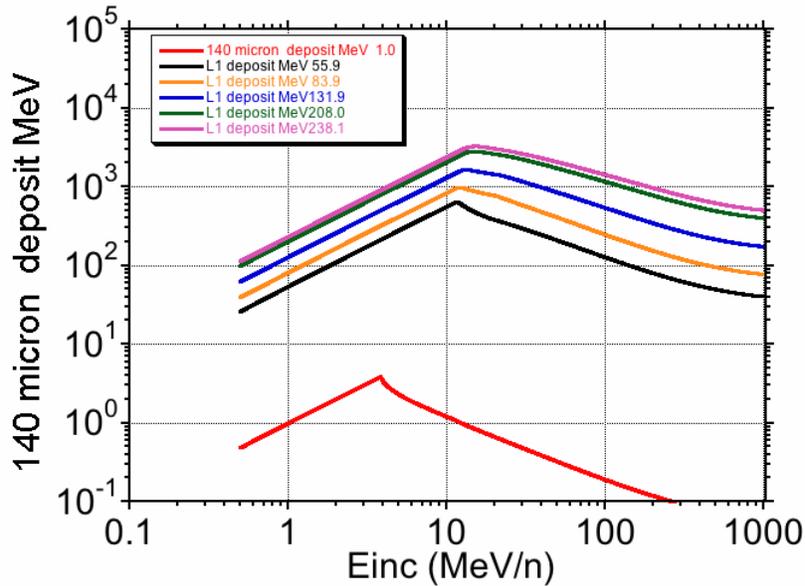


Figure 2: Thin Detector W/C Energy Deposit for Known Heavy Ions

At this energy, the preamp will be saturated and overdriven by a factor of 2 (note: the preamp is designed for 1V/GeV and there is a 2 volt linear signal range). Under this saturated condition, the voltage on the input to the jFET will rise positively by an amount equal to the total detector charge divided by the total input capacitance ($V = Q_{det}/C$).

$$V_{in} = (4 \text{ GeV} - 2 \text{ GeV}) \times (1 \text{ e-h pair} / 3.6 \text{ eV}) \times 1.6\text{E-}19 \text{ Coul/e-h} / 800\text{pF}$$

V_{in} = 0.11 Volt

This change in voltage is negligible and will not damage the jFET. The amount of time to recover from such a large saturation is determined mainly by the preamp feedback resistance.

$T_{rec} = Q / ((V_{sat} - V_{in}) / R_f)$, where V_{sat} is equal to the preamp saturation voltage of say 5 volts and R_f is the feedback resistance of 499Kohms.

$$T_{rec} = (4 \text{ GeV} - 2 \text{ GeV}) \times (1 \text{ e-h pair} / 3.6 \text{ eV}) \times 1.6\text{E-}19 \text{ Coul/e-h} / (5 / 499\text{E}3)$$

Trec = 8.9 usecs

This recovery time is less than the required 100 usecs for a 10 KHz singles counting rate. See Ref 4.

4.3. Effects on Thick Detector

As shown in the figure below, the maximum energy deposit in the thick detector due to an abnormally large LET particle is 14 GeV.

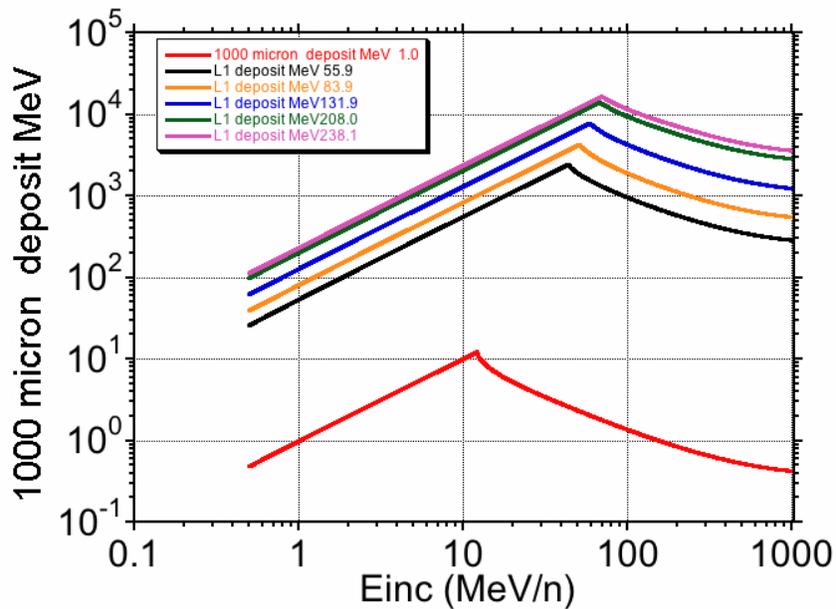


Figure 3: Thick Detector W/C Energy Deposit for Known Heavy Ions

At this energy, the preamp will be highly saturated and overdriven by a factor of more than 2 (note: the preamp is designed for 1V/100MeV and there is a 2 volt linear signal range). Under this saturated condition, the voltage on the input to the jFET will rise positively by an amount equal to the total detector charge divided by the total input capacitance ($V = Q_{det}/C$).

$$V_{in} = (14 \text{ GeV} - 0.2 \text{ GeV}) \times (1 \text{ e-h pair} / 3.6 \text{ eV}) \times 1.6\text{E-}19 \text{ Coul/e-h} / 200\text{pF}$$

Vin = 3.1 Volts

This change in voltage will not damage the jFET. The amount of time to recover from such a large saturation is determined mainly by the preamp feedback resistance.

$T_{rec} = Q / ((V_{sat} - V_{in}) / R_f)$, where V_{sat} is equal to the preamp saturation voltage of say 5 volts, V_{in} is the jFET input voltage calculated above, and R_f is the feedback resistance of 4.99 Mohms.

$$T_{rec} = (14 \text{ GeV} - 0.2 \text{ GeV}) \times (1 \text{ e-h pair} / 3.6 \text{ eV}) \times 1.6 \times 10^{-19} \text{ Coul/e-h} / ((5 - (-3.1)) / 4.99 \times 10^6)$$

T_{rec} = 361 usecs

This recovery time is greater than the desired 100 usecs for a 10 KHz singles counting rate, but the probability of occurrence is near zero. See Ref 4.

There are no damage risks due to high Z particle impacts on either the thin or thick detectors.

Table 2: Summary of Worst Case High Z Deposit Effects

Detector	Max E deposit	Max Vin	Max Recovery	Impact
Thin	4 GeV	0.11 V	8.9 usecs	None
Thick	14 GeV	3.1 V	361 usecs	None

5. Op-amp Input Offset

5.1. Worst Case Prediction

Without a baseline restorer, the zero level of the analog pulse output signal would drift nearly 30 mV due to opamp input offset voltage and bias current offset drift from temperature and radiation. Even worse, the input to the low energy discriminator would drift by as much as 310 mV. This situation would result in a significant loss of low energy threshold capability. For the thin detector, a baseline shift of 310 mV corresponds to about 10 MeV, a factor of over 5 higher than the required low energy threshold of 2 MeV (Ref 5). The same is true for the thick detector.

5.2. Effects on Low Energy Discriminator Singles Counters

To mitigate this offset drift, a baseline restorer circuit is implemented as a slow opamp integrator of the discriminator input signal that is fed back to the non-inverting input of the shaping amplifier (Ref 3). The RH1078 opamp used in the integrator has negligible input offset characteristics. The baseline is accurately controlled to within a few hundreded microvolts at the input to the low energy discriminator, an order of magnitude lower than the required threshold. ***As a result, there will be negligible shift in the baseline at the input to the discriminator.***

5.3. Effects on Pulse Signal to A/D Converter

The signal going to the A/D converter is upstream through a x10 amplifier comprised of a RH1814 opamp. The pulse baseline stabilization is dependent on the input offset effects of this opamp circuit only. The worst-case input offset is $V_{os}=4\text{mV}$ and $I_{os}=1\text{uA}$ (from RH1814 datasheet at 20 krads and 125C). Because the input resistances are matched on both opamp inputs, only the voltage offset and input offset current are considered, and not the input bias current. The total offset calculates to 5 mV. This corresponds to a slight reduction in dynamic range on the A/D converter, from a goal of 1000 to a worst-case of 600. ***This is still 2x wider dynamic range than the requirement of 300 stated in Ref 5.***