Radiation-Induced transient effects in near Infrared focal plane arrays


Agenda

- Background/Problem
- Testing Goals and Strategy
- Test Data and Discussion
- Conclusions
Ionizing Particle Impacts to FPA

+ Secondaries and delta electrons are time coincident with primary and have limited range
- But, not all deltas are spatially correlated with primary

Even Small Transients can be Problematic for NIRCAM

- Read noise requirement is very low
- Essentially every primary particle and every secondary particle causes a transient that exceeds noise level
- Cosmic ray rejection algorithms can tolerate limited number of hits within integration time
- Problem is exacerbated by:
  - Crosstalk (charge spreading to neighboring pixels)
  - Multi-pixel hits (e.g., hit detector and ROIC in different pixels)
  - Secondary particles that are not spatially correlated to primary
TESTING GOALS, STRATEGY AND APPROACH

Transient Test Objectives

- Characterize proton single events as function of energy and angle of incidence
  - Pulse height distributions provide information for model calibration
- Measure charge spread (crosstalk) to adjacent pixels
  - Key parameter for determining number of disturbed pixels
- Assess transient recovery time
  - Look for long transients (collection of ionization-induced charge or persistence of radiation-induced dark current)
  - Characterize reset after hit
Devices Tested

- Test ROIC without detectors and test SCA (detectors plus ROIC) to separate effects
- Test 1024x1024 versions (H1RG and SB291)
  - Subset of identical circuitry on 2048x2048 versions

<table>
<thead>
<tr>
<th>Device</th>
<th>Test Date</th>
<th>Energies</th>
<th>Angles</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1RG ROIC</td>
<td>5-16-02</td>
<td>30, 63</td>
<td>0</td>
<td>Single event and dose</td>
</tr>
<tr>
<td>H1RG SCA</td>
<td>10-16-02</td>
<td>30, 63</td>
<td>0, 45, 67</td>
<td>Single event, dose and secondaries from Al</td>
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<tr>
<td>SB291 ROIC</td>
<td>2-11-03</td>
<td>30, 63</td>
<td>0, 45, 67</td>
<td>Single event and dose</td>
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<td>SB291 SCA</td>
<td>3-31-03</td>
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Transient Test Strategy

- Use 30 and 63 MeV protons
- Use 0, 45 and 67 degree incidence
- Use low flux for single events
  - 1e3 to 1e5 p/cm²-s range
- Use quill-mode readout of 20x100 subarray
- Multiple samples at 10 Hz (100 ms) using variable integration time Fowler-mode integrations (reset, read, read, ... read, reset)

<table>
<thead>
<tr>
<th>Mode</th>
<th>#Reads</th>
<th>Time Between Reset (ms)</th>
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<tbody>
<tr>
<td>F1</td>
<td>2</td>
<td>200</td>
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<tr>
<td>F2</td>
<td>4</td>
<td>400</td>
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<tr>
<td>F5</td>
<td>10</td>
<td>1000</td>
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<tr>
<td>F10</td>
<td>20</td>
<td>2000</td>
</tr>
</tbody>
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- Designed to capture transient recovery
20' x 100 Subarray Used for Single Event Testing

*Effectively 3408 pixel includes 2 reference columns on each side

TEST DATA AND DISCUSSION

June 21-25, 2004
Presentation at SPIE Astronomical Telescopes Conference in Glasgow, Scotland by Robert Reed
### Typical Proton-Induced Pulses

**H1RG SCA 30 MeV**

<table>
<thead>
<tr>
<th>0 Degrees</th>
<th>67 Degrees</th>
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<tbody>
<tr>
<td>5321</td>
<td>770</td>
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<tr>
<td>5222</td>
<td>558</td>
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<tr>
<td>5123</td>
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**SB291 SCA 30 MeV**

<table>
<thead>
<tr>
<th>0 Degrees</th>
<th>67 Degrees</th>
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<tbody>
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### June 21-25, 2004

Presentation at SPIE Astronomical Telescopes Conference in Glasgow, Scotland by Robert Reed
Hit Size Expected to Scale With Proton Energy and Angle of Incidence

- \( \text{dE/dX} \) (Linear Energy Transfer (LET)) is function of energy and material - lower at 63 MeV than 30 MeV
  - HgCdTe: 8.43 keV/\mu m at 30 MeV; 4.91 keV/\mu m at 63 MeV (\times 0.58)
  - InSb: 7.08 keV/\mu m at 30 MeV; 4.09 keV/\mu m at 63 MeV (\times 0.58)
  - Si: 3.42 keV/\mu m at 30 MeV; 1.92 keV/\mu m at 63 MeV (\times 0.58)
- Charge generated ~ LET * Path
- Path through device scales as cos(angle)
  - \( \times 1.41 \) at 45 degrees
  - \( \times 2.56 \) at 67 degrees

PULSE HEIGHT DISTRIBUTIONS

- Difference between first read after reset and final read
- Data histogramed into 100 e bins
- Analysis for two types of distributions:
  - Distribution of pixel charges
    - Some charge from hit pixels counted in neighboring pixels
  - Distribution of total hit charges
    - Hits identified and all charge from neighboring pixels added
SCA Pulse Height Distribution

Distribution of pixel charges

SCA Comparison at Various Angles

30 MeV

- SCA pulses are larger than ROIC pulses
- Pulses scale with angle of incidence
- H1RG pulses are larger than SB291 pulses

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TOTAL CHARGE DISTRIBUTIONS

Total Charge: Charge to hit pixel and affected neighbors summed
Peak Charge: Charge to hit pixel only

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Total Charge Peaks Scale With Angle and Energy as Expected

H1RG SCA pulses are somewhat larger than SB291SCA pulses

Measured Proton Crosstalk in H1RG SCA

- Hits randomly distributed across pixel but all at same angle
- Hits are stacked by registration to hit pixel, not to hit centroid
- In some cases, charge is still above noise even at 2 pixels out from hit pixel
Measured Proton Crosstalk in SB291 SCA

- Hits randomly distributed across pixel but all at same angle
- Hits are stacked by registration to hit pixel, not to hit centroid
- In some cases, charge is still above noise even at 2 pixels out from hit pixel

Observations

- Pulses generally scale with energy and with angle as expected
- Unipolar pulses in SB291 (same polarity as detector)
- Bipolar polarity pulses in H1RG ROIC
- Pulses are smaller in ROIC than SCA for both H1RG and SB291
- Pulses with same polarity as detector have comparable size for H1RG ROIC and SB291 ROIC
- Pulses are larger in H1RG SCA than SB291 SCA
- Crosstalk is larger in SB291 ROIC than H1RG
- Crosstalk is larger in H1RG SCA than SB291
- Hit pixel recovery <100 ms or upon reset
General Conclusions

- Whatever technology chosen, JWST will have to live with cosmic ray hits
- Overall transient responses are similar at SCA level
  - ROIC hits are larger for SB291 than H1RG
  - H1RG SCA hits are larger (apparently due to detector)
  - H1RG proton crosstalk is worse (probably related to smaller pitch)
- Note that smaller pixels would have lower hit probability in space environment but more crosstalk