Radiation-Induced Charge Collection in Detector Arrays*


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Outline

• Background
• Ionizing Particle Environment
• Array Charge Collection Model
• Model Calibration With Test Data
• Comparison to Available Data
Radiation Effects Challenge for IR Astronomy

- Exposure to galactic cosmic rays and solar particle events
- Very low noise required
  - 10 electrons or less
- Very long integration time required
  - Hundreds to thousands of seconds
- Single event transients increase output level of individual pixels
  - Transients are “latched in” until reset
  - “High” level events can be filtered
  - “Low” level events increase noise
Radiation-Induced Charge in NICMOS

256x256 HgCdTe Array

Cosmic Ray charge deposits after ~30 minutes of dark-field viewing
Ionizing Particle Impacts to FPA

- Deltas are not spatially correlated

+ Secondaries and delta electrons are time coincident with primary and have limited range

natural radioactivity

surrounding material

induced radioactivity

(latent emission)

FPA

secondary

delta

primary
General Approach

Space Environment

Spacecraft Model and Materials

Environment Transport Calculations

Secondary and Transported Primary Environment protons, electrons, neutrons, photons

Activation Studies

Array Charge Transport Model

Presented by J.C. Pickel, NASA/GSFC Consultant

2002 IEEE Nuclear and Space Radiation Effects Conference, Phoenix, AZ
Both the Detector Array and the ROIC Contribute to Charge Collection in Hybrid FPA

- Charge collected by drift in high-field regions
- Charge collected by diffusion in low-field regions

[Diagram of hybrid FPA with labels for detector array, substrate, diffusion region, and depletion region.]
Charge Collection Modeling Approach

- Starting point is charge collection model for proton hits to CCDs developed and validated at Aerospace Corporation

- Add enhancements
  - secondary particles generated externally and internally
  - activation/decay and inherent radioactivity
  - multiple layers
  - sub-regions within layers
  - LET variation along path
  - large angle scatter (electrons)
  - drift-assisted diffusion
Array Charge Collection Model

- Initial line source based on particle LET and trajectory
- All charge that is generated in or diffuses to high-field region is collected
- Particle history ends when either collected or recombines
Charge Collection by Diffusion in Low Field Regions

- Analytic model by Kirkpatrick calculates charge distribution on a uniform collection surface from a line-source
  - Solves 3-D diffusion equation assuming semi-infinite medium and assuming point source at given depth
    - \( Q_{ps}(x,y) \)
      - Integrates \( Q_{ps}(x,y) \) along line with trajectory \((\theta,\phi)\) through diffusion region to effective diffusion length \((L)\) to give surface charge density
    - \( Q_{ls}(x,y,\theta,\phi,L) \)
- Charge collected by each pixel obtained by numerical integration over pixel area at diffusion-depletion boundary
  - \( Q_{n,m} = \sum\sum Q_{ls}(x,y)dx\,dy \)
Charge Collection by Drift and Diffusion in Moderate Field Regions

- Hybrid Monte Carlo solution to transport equation
- 3-D random walk with spatially dependent drift
- Follows approach used by Sai-Halasz to model alpha particle effects in ICs
Charge Spread for Various Particles

300 keV electron

10 GeV proton

30 MeV proton

600 MeV Argon

Presented by J.C. Pickel, NASA/GSFC Consultant
2002 IEEE Nuclear and Space Radiation Effects Conference, Phoenix, AZ
Simulation for Effect of Angle
20 MeV Proton Hits

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Typical Simulation Result

100x100 array, pitch=20 um
HgCdTe, Zdepl=1 um, Zdiff=10 um
100 random hits, omnidirectional
GeV protons
Pulse Height Distribution

Compare test data to simulation to infer model parameters

- $Q_{av}$ and $Q_{max}$ related to charge collection volume geometry
- PHD shape dependence in cross-talk tail related to diffusion layer thickness
Comparison to NICMOS Data

On-Orbit Data

Simulation
Comparison to APS Data
600 MeV Ar at 0 and 60 Degrees
2 pixel designs
Summary

• Simulation tools for charge collection in detector arrays have been developed using a combination of analytical and Monte Carlo approaches

• Simulation addresses:
  – secondary particles and radioactivity
  – multiple layers and sub-regions within layers
  – variation of LET
  – secondary electron scattering
  – drift
  – free-field diffusion
  – field-assisted diffusion

• Model parameters can be calibrated with experimental data

• Applicable to all semiconductor detector arrays