CRaTER Electrical Peer Review

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Overview

- Big Picture
- System Description
- Detectors and Analog Section
- Analog->Digital Conversion
- Digital Section
- Power and Stuff
Size: 13” x 9” x 6” high; Mass: 12 lbs; Power 7.6 w

Cosmic Ray Telescope for the Effects of Radiation
System Block Diagram

Cosmic Ray Telescope for the Effects of Radiation
## System Resources

<table>
<thead>
<tr>
<th></th>
<th>Mass</th>
<th>Power</th>
<th>Data Rate</th>
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</thead>
<tbody>
<tr>
<td>PDR</td>
<td>5.2 Kg</td>
<td>5.1 w</td>
<td>515 bps / 89.0 Kbps</td>
</tr>
<tr>
<td>CBE</td>
<td>5.3 Kg</td>
<td>7.6 w</td>
<td>515 bps / 89.0 Kbps</td>
</tr>
<tr>
<td>Allocation</td>
<td>6.4 Kg</td>
<td>9.0 w</td>
<td>89.0 Kbps</td>
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<tr>
<td>Margin</td>
<td>21%</td>
<td>18%</td>
<td>n/a</td>
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### Power Calculation Details

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<thead>
<tr>
<th>Standard Contingency</th>
<th>Worst case from manufacturer</th>
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<tr>
<td></td>
<td>Nominal Volts DC</td>
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<tr>
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<td>5</td>
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<tr>
<td></td>
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<td></td>
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<tr>
<td>Single Analog Chain (ma)</td>
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<tr>
<td>Front End</td>
<td>16</td>
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<tr>
<td>Video Chain</td>
<td>9</td>
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<tr>
<td>Sum of 6 Chains</td>
<td>54</td>
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<td></td>
<td>139.2</td>
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<tr>
<td>Support (ma)</td>
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<tr>
<td>Bias supply</td>
<td>30</td>
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<td>Amptek PH300</td>
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<td>2.4</td>
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<tr>
<td>Sum of 6 peak stretchers</td>
<td>0.6</td>
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<td>14.4</td>
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<tr>
<td>Maxim 145AEUA</td>
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<td>Sum of 3 A/D</td>
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<td>General Op Amp Circuits -- 20</td>
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<td>Digital (ma)</td>
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<tr>
<td>DDC 63705X3 (25% active)</td>
<td>220</td>
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<td>FPGA</td>
<td>100</td>
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<td>SRAM</td>
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<td>Receiver (26C32)</td>
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<td>16MHz oscillator</td>
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<td>Sum of Currents (ma)</td>
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<td>193.6</td>
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<td>Sum of Power (watts)</td>
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<td></td>
<td>0.97</td>
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<td>Coverers (watts)</td>
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<td>AdvancedAnalog AMA2805S</td>
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<td>Standby power</td>
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<td>Totals (watts)</td>
<td>3.31</td>
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<td>Per Power Supply</td>
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<td>Power-reversal Diode loss (nominal: 31VDC; wc: 21VDC)</td>
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<td>Grand</td>
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## Telemetry Bandwidth & Storage

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<th>SEP</th>
<th>Unit</th>
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<td>Primary Science</td>
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<td>Secondary Science</td>
<td>176</td>
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<td>bits/second</td>
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<td>Housekeeping</td>
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<td>Totals</td>
<td>515</td>
<td>89003</td>
<td>bits/second</td>
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<td></td>
<td>6</td>
<td>961</td>
<td>MegaBytes/day</td>
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Thermal Requirements

- Instrument as Proposed

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<tr>
<td></td>
<td>50 C</td>
<td>30 C</td>
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<td>-40 C</td>
<td>-30 C</td>
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</table>

- Rationale for Operational Requirements
  - Detector <40C for noise performance
  - Instrument >-30C for ease of testing and minimizing component stress
Detectors and Analog Electronics

Bill Crain
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310-336-8530
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Introduction

- Functional Requirements
- Detector Requirements
- Signal and Noise Requirements
- Telescope Board Design
- Analog Board Design
- Analyses
- Summary
Functional Requirements

- Functional requirements unchanged since PDR
  - Measure LET of high LET particles in thin detectors
  - Measure LET of low LET particles in thick detectors
  - Combined dynamic range of 5,000 for each detector pair
  - Provide good resolution for TEP effects
  - Robust to temperature drift and environments

- Electronics
  - Telescope Board
  - Analog Processing Board (APB) in E-box

- No architectural changes since PDR
# Requirements Traceability

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<td>Amplifier strings</td>
<td>3</td>
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<td>CRaTER-L3-01</td>
<td>Board sizes</td>
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<td>Max. Energy Deposit</td>
<td>1 GeV</td>
<td>100 MeV</td>
<td>CRaTER-L3-02</td>
<td>Preamp range, closed-loop stability</td>
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<tr>
<td>Low E Threshold</td>
<td>2 MeV</td>
<td>200 keV</td>
<td>CRaTER-L3-02</td>
<td>Gain, baseline restorer, shaping time</td>
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<tr>
<td>Timing Threshold</td>
<td>&lt;1.3 MeV</td>
<td>&lt;130 keV</td>
<td>CRaTER-L3-02</td>
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<td>Noise (rms)</td>
<td>&lt;400 keV</td>
<td>&lt;40 keV</td>
<td>CRaTER-L3-02</td>
<td>Preamp, shaping time, thermal</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>CRaTER-L2-50,06,07</td>
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<td>Max. Singles Rate</td>
<td>1 kHz</td>
<td>1 kHz</td>
<td>CRaTER-L3-09</td>
<td>Shaping time, preamp time constant</td>
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<td>Non-linearity</td>
<td>0.1%</td>
<td>0.1%</td>
<td>CRaTER-L2-07</td>
<td>Preamp, shaping amp</td>
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<tr>
<td>Stability / drift</td>
<td>0.1%</td>
<td>0.1%</td>
<td>CRaTER-L3-01</td>
<td>Preamp, bias network, baseline restorer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CRaTER-L2-07</td>
<td></td>
</tr>
<tr>
<td>Internal Calibration</td>
<td>Full range</td>
<td>Full range</td>
<td>CRaTER-L3-11</td>
<td>Test pulser</td>
</tr>
</tbody>
</table>
Functional Block Diagram

Detector Boards  Telescope Board  Analog Processing Board

- Thin
- Thick
- Thin
- Thick
- Thin
- Thick

- Preamps
- Bias Networks
- Thermistor
- Detector Monitor
- Shaping / Scaling
- Baseline Restorer
- Timing Trigger
- Test Pulser
- Dosimeter

To Digital Board

Cosmic Ray Telescope for the Effects of Radiation
**Analog Interface Block Diagram**

- Documented in 32-02052 rB

![Diagram with connectors and descriptions](image)

**Cosmic Ray Telescope for the Effects of Radiation**
Detector Specification (1)

• Documented in 32-05001 rev C
• No significant changes since PDR
• Micron Semiconductor Limited
  – Lancing Sussex, UK
• 20 years experience in supplying detectors for space physics
  – CEPPAD, CRRES, WIND, CLUSTER, ACE, IMAGE, STEREO, and more…
• Detector Type
  – Ion-implanted doping to form P+ junction on N-type silicon
  – Very stable technology
  – Advantages to science include good carrier lifetime, stable to environmental conditions, and thin entrance windows
Detector Specification (2)

- Circular detectors having active area of 9.6 cm²
- Two different detector thicknesses: thin and thick
  - note: state-of-the-art is 20um for thin and 2,000um for thick detectors
- Guard ring on P-side to improve surface uniformity
- Very thin dead layers (windows) reduce energy loss, lower series resistance, and reduce noise
# Detector Specification Summary

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active area</td>
<td>9.6 cm² circular - Reference</td>
</tr>
<tr>
<td>Active dimension</td>
<td>35 mm</td>
</tr>
<tr>
<td>Active dimension tolerance</td>
<td>+/- 0.1 mm</td>
</tr>
<tr>
<td>Thickness</td>
<td>Thin = 140 um, Thick = 1000 um</td>
</tr>
<tr>
<td>Thickness tolerance</td>
<td>+/- 10 um thin, +/- 35 um thick</td>
</tr>
<tr>
<td>Thickness uniformity</td>
<td>+/- 10 um</td>
</tr>
<tr>
<td>Window implantation</td>
<td>0.1 um ohmic, 0.1 um junction</td>
</tr>
<tr>
<td>Metallization</td>
<td>Ohmic surface and junction grid 3000 Å +/- 1000 Å</td>
</tr>
<tr>
<td>Full depletion (FD)</td>
<td>Thin = 10 – 60 V, Thick = 150 – 200 V</td>
</tr>
<tr>
<td>Operating voltage max</td>
<td>Thin = Thick = FD + 30 V</td>
</tr>
<tr>
<td>Capacitance</td>
<td>Thin = 700 pF, Thick = 100 pF</td>
</tr>
<tr>
<td>Leakage current max (20°C)</td>
<td>Thin = 300 nA junction, 200 nA guard, Thick = 1,000 nA junction, 700 nA guard</td>
</tr>
<tr>
<td>Drift (max leakage @ 40°C)</td>
<td>6 x Ileak @ 20°C</td>
</tr>
<tr>
<td>Stability</td>
<td>1% Ileak @ 40°C for 168 hours</td>
</tr>
<tr>
<td>Alpha resolution (²⁴¹Am)</td>
<td>Thin = 3%, Thick = 1.5%</td>
</tr>
</tbody>
</table>

**Cosmic Ray Telescope for the Effects of Radiation**
Detector Verification Matrix

| INSERT TABLE HERE |
Signal Requirements

<table>
<thead>
<tr>
<th>Detector</th>
<th>Min Signal</th>
<th>Max Signal</th>
<th>Collection Time</th>
<th>C det</th>
<th>C fb</th>
<th>Design Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin</td>
<td>555E3 e-h pairs (88 fC)</td>
<td>275E6 e-h pairs (44 pC)</td>
<td>3 ns e-drift 9 ns h-drift</td>
<td>700 pF</td>
<td>39 pF</td>
<td>Low gm High slew rate</td>
</tr>
<tr>
<td>Thick</td>
<td>55E3 e-h pairs (8.8 fC)</td>
<td>27.5E6 e-h pairs (4.4 pC)</td>
<td>38 nsec e-drift 115 nsec h-drift</td>
<td>100 pF</td>
<td>3.9 pF</td>
<td>Optimized gm Low noise</td>
</tr>
</tbody>
</table>

![Diagram of signal requirements](image)

**Cosmic Ray Telescope for the Effects of Radiation**
Noise Requirements (1)

<table>
<thead>
<tr>
<th>Detector</th>
<th>Det. Leakage</th>
<th>Detector Capacitance</th>
<th>Circuit Capacitance</th>
<th>JFET noise</th>
<th>Series Resistance</th>
<th>Parallel Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin</td>
<td>300nA, 20°C BOL 11,200nA, 35°C EOL</td>
<td>770pF</td>
<td>88 pF</td>
<td>4 nV/RtHz</td>
<td>100 ohms</td>
<td>142 Kohms (bias</td>
</tr>
<tr>
<td>Thick</td>
<td>1,000nA, 20°C BOL 14,000nA, 35°C EOL</td>
<td>120pF</td>
<td>74.3pF</td>
<td>0.5nV/RtHz</td>
<td>100 ohms</td>
<td>192 Kohms (bias</td>
</tr>
</tbody>
</table>

\[ Q_n^2 = i_n^2 T F_i + C^2 e_n^2 \frac{1}{T} F_v \]

\[ i_n^2 = 2 q_e I_b + \frac{4 k T}{R_P} + i_{na}^2 \]

\[ e_n^2 = 4 k T R_s + e_{na}^2 \]

T=peaking time  
F=shaping factors

Reference:
Helmuth Spieler  
IFCA Instrumentation Course Notes  
2001
Noise Requirements (2)

- Thin and thick channels have same CR-RC\(^2\) shaping
- Peaking time of 1 usec +/- 20% meets requirements
- No impact on performance at hot temperature and EOL total dose
Telescope Board (1)

- Schematic 32-01010 rev B
- Detector Bias Network
  - Detector operates at FD+30V at BOL
  - Bias network designed to maintain full depletion at EOL
  - Leakage current monitor
- Preamp
  - Amptek A250 hybrid
  - External jFET

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Cosmic Ray Telescope for the Effects of Radiation
Telescope Board (2)

- Thin detector preamp
  - Interfet IF4501 jFET
  - 15 pF compensation
  - 1.25 mA bias current
  - 1 mV / MeV
- Thick detector preamp
  - Interfet IF9030 jFET
  - No compensation
  - 2.5 mA bias current
  - 10 mV / MeV

Cosmic Ray Telescope for the Effects of Radiation
Telescope Board (3)

- Preamps full-scale range is 2x below saturation onset
Analog Board (1)

- Single fixed gain linear transfer function
  - 3 pole pseudo-gaussian response (2 complex, 1 real)
- Timing discriminator used for singles counters and coincidence
- Baseline restorer corrects for offset drift
Analog Board (2)

• Shaping amplifier
  – Fast settling
  – Linear Tech RH1814 opamps
  – Meets noise requirements
  – Output scaled for PHA
**Analog Board (3)**

- **Baseline restorer**
  - Slow DC feedback to shaping stage
  - Gated signal to reduce differentiation effects from large signals
  - Linear Tech RH1078 precision opamp integrator
Analog Board (4)

- **Discriminator**
  - 5 usec pulse for each fixed threshold crossing
  - Noise occupancy in coincidence window < 0.1%
    - Threshold to noise ratio (T/N) ~ 3.2 at EOL complies with reqs.
    - Anticipated BOL T/N ratio is ~ 10

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**Cosmic Ray Telescope for the Effects of Radiation**
Analog Board (5)

- Test pulser provides capability for stimulating pre-threshold and full-scale range of each detector
  - Breadboard testing completed
Analog Board (6)

• Dosimeter
  – Provides housekeeping measurement of total dose
  – Utilizes three analog housekeeping channels
  – Fault-tolerant interface
  – 14 mA at 10 volts
Analog Board (7)

INSERT LAYOUT HERE
Digital Sub-System

Dorothy Gordon
Overview

• Requirements
• Digital Subsystem Overview/Block Diagram
• FPGA Block Diagram and Subsystem Description
• Support Functions
• Design/Implementation Status
• Next
Requirements for the Digital Sub-System

- Accept and process analog signal with 300:1 dynamic range (1000:1 goal)
- Filter the science data from the 6 detectors according to uplinked parameters
- Format the science telemetry into CCSDS packets and send out on the 1553 bus
  - Low data rate for GCR background: 3 events/sec typical .......... (312 bps)
  - High data rate for SEP flare: 1200 events/sec saturation .......... (88800 bps)
- Provide secondary science data once per second: 34 bytes .......... (272 bps) ←
  - Valid event counter, invalid event counter, total event counter, etc.
- Provide engineering data once per 16 seconds: 64 bytes .......... (32 bps) ←
- Receive 1 Hz pulse to time tag the science data to a 1 second resolution
- Receive telecommands from the 1553 bus
- Provide electrical calibration signals to the analog board
Digital Sub-System Overview

Cosmic Ray Telescope for the Effects of Radiation
Peak Conversion Timing

Cosmic Ray Telescope for the Effects of Radiation
Cosmic Ray Telescope for the Effects of Radiation
FPGA Subsystems

- **Spacecraft Interface**
  
  *Commands* – Receives/extracts commands delivered from Spacecraft via 1553 bus I/F
  o Discrete commands for test pulse on/off, biases on/off, system reset
  o Individual video chain (logical) on/off
  o Arbitrary detector coincidence map to define valid events
  o Time of next 1 Hz pulse; used to time tag data

  *Telemetry* – Packetizes (CCSDS format) and transmits to Spacecraft via the 1553 bus I/F
  o Primary Header includes Application ID, Source Sequence Count and Packet Length
  o Secondary header includes time tag and instrument serial number
    - Secondary science delivered to Spacecraft once per second as fixed CCSDS packet
      * Video chain status, calibration signal status, bias voltage status
      * Valid event counter, rejected event counter, total counter counter, etc.
    - Housekeeping delivered to Spacecraft once per 16 seconds as fixed CCSDS packet
      * A/D conversions performed every second – results are telemetered upon demand
    - Primary science - Transmits variable length CCSDS packets
      * Energy data packed as 12-bit sextuples for each valid event; 72 bits/event
      * A maximum of 48 events can be packed into a maximum length packet
      * 1 - 25 packets/second are retrieved by the Spacecraft
• **Overall Timing/Control**
  – System clock: 16 MHz – generates Internal One-Second Tick if the Spacecraft 1Hz Clock is not present and times all the FPGA subsystems
  – Reset control – Power-On reset (asynchronous assertion, synchronous deassertion)
    • Commanded reset and clear (1553 bus initiated) also available

• **Event Processing**
  – Responds to LLD (threshold crossing detect output of comparator)
  – Controls Peak Stretchers, converts events and applies Discriminator Mask Test
  – Accepted events are written into Static RAM (SRAM)
  – Counters (16 bits) track total events, rejected events and “good” events

• **Event Readout**
  – SRAM implements double buffer that swaps at the one-second tick
  – Telemetry controller packetizes data as it is read out from SRAM
• **Singles Counters**
  – Six identical 16-bit counters driven by analog subsystem triggers

• **PWM Generation**
  – Outputs LLD Threshold settings and ECAL Level (set via the command I/F)
  – Operates at 1MHz; 8 bit resolution

• **Test Mode**
  – Allows for verification of Static RAM as well as the 1553 based Telemetry I/F
Design/Implementation Status

• Parts Selection (since PDR)
  – All parts identified, ready for flight procurement
  – FPGA (Actel RT-SX72, UMC die); 1553 bus (DDC BU-63705)
  – Peak Stretcher (Amptek PH300) performance verified via breadboard
  – DC-DC – International Rectifier – one dual (+/- 5V - 12W), one single (5V - 5W)

• Schematics
  – Board Schematics: released (Drawing # 32-03003)
  – Chassis Schematics: released (Drawing # 32-03006)
  – High Voltage Power Supply (subcontracted) design complete

• Board Layout
  – Engineering layout is flight part footprint compatible
  – High Voltage Supply, implemented on hand-wired breadboard, will be integrated during the second layout stage

• FPGA Design
  – Coded in VHDL (ALDEC frontend, Synplicity compiler)
  – Top Level functional simulation complete
  – Actel Designer P&R/Timer Tools
Next

• GSE
  – 1553 Bus Controller – interfaces to Host Computer via Ethernet I/F

• Engineering Board
  – Fabricate and Populate first engineering board
  – Verify operation
  – Develop and run extensive marathon diagnostics

• Integration
  – Integrate/Test with analog subsystem board
  – Verify operation with the Spacecraft Simulator
Extra

- Event Processing Timing

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**Cosmic Ray Telescope for the Effects of Radiation**
CRaTER Electrical Peer Review
Power & Spacecraft Interfaces

Bob Goeke
Other Functions

- Provide regulated power for analog and digital functions consistent with EICD requirements
  - Design is one +/-5VDC dual supply, one +5VDC supply
  - EMC challenge is not severe being inside sealed box with standard interfaces and standard MIL power filters.
- Provide bias voltage for detectors
  - Design is 75VDC (50µa) and 225VDC (150 µa)
- Provide one passive temperature sensor for s/c use
- Survival heaters incorporated inside instrument
- No operational heaters
Grounding Diagram

Cosmic Ray Telescope for the Effects of Radiation
Bias Supply Requirements

Thin Detector Supply
Output voltage: 75 VDC
Output tolerance: +/- 3%
Output ripple: <1 volt p-p
Output current: 25 to 50 microamperes

Thick Detector Supply
Output voltage: 225 VDC
Output tolerance: +/- 3%
Output ripple: <3 volts p-p
Output current: 75 to 150 microamperes

Common Requirements
Input Voltage: 5VDC +/- 1%
Operating temperature: -30C to +30C
Survival temperature: -40C to +50C