TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

8 May 96
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

INTRODUCTION

Scope of Review

Action Item Status

Agenda
SCOPE OF REVIEW

CRITICAL DESIGN REVIEW (CDR) OF TELESCOPE READ-OUT

TRE Detector
- Electrical Design
  - Photo-diode sensor
  - Pre-amplifier
- Packaging
  - Thermal Mount
  - Detector Package

TRE Forward Electronics
- Electrical Design
  - Charge-Locked Loop
  - Detector Support Functions
- Cables
- Interfaces
- Enclosure
ACTION ITEM STATUS

TRE PDR: 35 Items

11  Closed
13  Recommend Closure

OPEN ITEMS (11 total):
1  Specification Items Still In Work
22) Scrub Total Weight In Front-End

2  Test Program Items Still In Work
19) Schedule EMI Test Milestones For Electronics Boxes
31) Define Test Chamber And Joint TRE/Telescope Test Plan

3  Simulation/Modeling Items
8) How Well Can We Calibrate Scale Factor On-Orbit With Rate Gyros
17) TRE Implications For Data Reduction
26) Generate A Detailed Error Analysis Of How Scale Factor, Bias, etc. Get To ATC System.

1  Thermal Item 14) Have Thermal Working Group Look At Probe Wires

4  System Engineering Items (# 18, 30, 32, 34)
Will be addressed by Stanford Systems Engineering

May 8, 1996
TRE IDR: 18 Items

7 Recommend Closure (#1, 4, 5, 7, 8, 10, 17)

OPEN ITEMS STILL IN WORK (11 total):

3 Specification Items Still In Work
   2) Add Max. Field Of View Spec (Exclude HR5110 Companion)
   3) PCB Change T002 And T003 Linearity - “Stable And Calibratable”
   16) Estimate Thermal Gradient Values

3 Test Program Items Still In Work
   13) Collect JFET Noise down to 0.1 Hz
   15) Scheduling Tests To Verify Charge Trapping, etc.
   18) Test Plan For Telescope System Tests

2 Simulation/Modeling Items
   6) System model for Pointing Control Sim.
   14) Det. Noise characteristics to be put into models

3 Miscellaneous
   11) How to match Feedback Capacitors?
   12) FET Guard ring?
   9*) System Engineering Item (RF Interference From SE Asia)
       (Will be addressed by SU Systems Engineering)
AGENDA

8:30   Introduction
8:40   Functional Overview and Performance Issues
10:00  Detector Electrical Design
10:50  Detector Mount Design
11:10  Detector QA and Parts Selection
11:20  Detector to Telescope Integration
11:30  TRE Forward Electronics Design
12:15  Lunch
12:45  Forward Electronics Enclosure
1:00   TRE Manufacturing and Test Flow
1:10   Forward electronics QA and Parts Selection
1:20   Verification Plan and Test Matrix
1:40   Schedule
1:50   Development Tests
2:05   Error Budget and Predicted Performance
2:20   Wrap-up

P. Ehrensberger
J. Goebel
M. Sullivan
F. Berkowitz
S. Wang
R. Farley

R. Ajitomi
G. Swart
G. Swart
Mark Tapley
J. Burns
H. Demroff
K. Coleman
P. Ehrensberger
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

TRE FUNCTIONAL OVERVIEW
AND
PERFORMANCE ISSUES

P. Ehrensberger

Specifications/Requirements
   Detectors
Interface Between Detector and Fwd Electronics
   Forward Electronics
   Data Acquisition
Command, Telemetry, and Software
   ATC Interface
   Science Data Interface
GP-B SCIENCE TELESCOPE

Guide Star

Candidates:
HR5110
IM Peg
HR1099

SCIENCE TELESCOPE PROVIDES:
- POINTING REFERENCE FOR SPACECRAFT
- POINTING DATA FOR SCIENCE

Important Performance Requirements:
Random Pointing
< 20 marcsec RMS
Unobservable Pointing Bias
< 0.1 marcsec
OVERVIEW OF TELESCOPE READ-OUT ELECTRONICS

PROBE

Guide Star

X-Axis Detector

Y-Axis Detector

Each detector contains a pair of Si photo-diodes and Si J-Fet pre-amps

FORWARD EQUIP AREA

TRE-A

X-AXIS

Y-AXIS

FWD SRE-A

power
digital
analog

AFT EQUIP AREA

AFT SRE-A

1773 to SC

AFT SRE-B

1773 to SC

Aft SRE is cold redundant

TRE-B

X-AXIS

Y-AXIS

FWD SRE-B

Cross-strapped Power and Digital I/F

Charge-locked Loops Analog Signal Conditioning Detector Support

A/D Conversion Timing Signals Power Switching

Digital Signal Processing Command Handling

PRIMARY AND REDUNDANT TRE'S ARE OPERATED CONTINUOUSLY
FLOW DOWN FOR TRE SPECIFICATION

From 12 Fundamental Science Requirements (T002)
- 7. Science Telescope (ST): After appropriate filtering and calibration, the linearity shall not exceed 3 arcsec within the +/- 60 arcsec range. The output will be stable to 0.1 arcsec.
- 8. Pointing: The pointing system shall keep the ST aligned with the reference star to within 20 arcsec rms.
- 11. Telemetry and Data Processing: The Science Gyro and ST signals shall be conditioned, sampled and processed so that they can be differenced on the ground with an added error of less than 0.1 arcsec.

Spacecraft ATC requirements
Acquisition range
Noise performance

Guide star Candidates
Magnitude and Color
HR5110
IM Peg
HR1099

System Design and Performance Requirements (T003)
7.2 Range
7.5 Noise
7.6 Signal Processing

Allocation of bias error between telescope optics and TRE is 50/50.

Telescope Readout Electronics
PLSE-13, Pt 3.2

Detailed Performance Specifications for:
DETECTORS
FORWARD ELECTRONICS
INTERFACES

TRE Specification is derived from worst case assumptions:
Guide Star - HR1099; Optics Transmission - 20%; and Strehl - 50%. 
ELEMENTS OF TELESCOPE PERFORMANCE

TRE SPECIFICATION STATUS

- Held Spec Sign-off Meeting: Most specs in database.
  - PCB 227: Change leakage current specs in probe cables.
  - PCB 234: TRE spec update (includes ATC interface specs, and other previously unsigned pages).
  - PCB 231: Change Probe TRE pin-outs.
  - PCB 233: Add capability to switch between primary and redundant channels for SC pointing.
- Software for Science Data and ATC are covered in SE-15 and -16.
- Data Acquisition and SRE interface is covered in TRE Specification.
- Filters covered in Filter Specification (#5833851).
- FEE Cables in separate FEE Cable Specification.
- Probe Cables are covered in SIA Specification.

The most difficult performance specifications are random noise and bias stability.
TRE RANDOM NOISE

Requirement: < 10 marcsec/rtHz single-sided (Goal is to achieve photon-limit)
Influence on SC random-pointing error - especially important for back-up Mode.

Noise is dominated by first stage of detector preamp.
Important elements for noise:
• detector capacitance - driven by size to accommodate alignment and acquisition range
• transistor capacitance
• parasitic capacitance
• transistor input-referred voltage noise

Demonstrated performance to date (based on 10 second acquisition time):
Standard deviation of 100 mS estimates is 26 marcsec => 8.2 marcsec/rtHz average over DC to 5 Hz.

For reference photon noise implies:
Standard deviation of estimates 7.9 marcsec => 2.48 marcsec/rtHz

REQUIREMENT WILL BE MET
Development continues to achieve the photon-limit goal.
TRE Bias Stability

T003 Requirement 7.6.2.1:

\[ \frac{1}{T_d} \int z(t) \frac{t}{T_d} \left[ \frac{\cos(w_r t)}{\sin(w_r t)} \right] d(t) < 0.1 \text{ marsec} \]

Modified by 50% allocation and change to absolute stability rather than “change over year”

TRE Requirement:

\[ \frac{1}{T_d} \int z(t) \left[ \frac{\cos(w_r t)}{\sin(w_r t)} \right] d(t) < 0.05 \text{ marsec} \]

\( w_r \) is roll (1 to 10 min period), SQUID Calibration, or dither (20 sec to 45 min period).

\( w_o \) is orbital frequency and \( T_d \) is annual period.

Error contributions dominated by temperature changes. This then bounds the temperature coefficients of the TRE.

Additional requirements (T003 7.6.2.2 and 3) bound the bias errors at \( w_r \) modulated by annual and orbital frequencies. These are easily meet by requiring that the temperature coefficients never exceed the values required to meet the previous requirements over the temperature ranges at orbital and annual.

TRE TEMPERATURE COEFFICIENTS WILL MEET THIS REQUIREMENT
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

TRE DETECTORS

Design Overview
Photo-diodes and Alignment
Optical Signal Level
Ionizing Radiation
Thermal Interface to SIA
TELESCOPE DETECTOR PACKAGE ASSEMBLY

- Thermal Washer
- Detector Mount Assembly
- Photodiode Detectors
- Local EMI Shield
- Thermal/Electrical Isolator
- Detector Package Body
- Beamsplitter Holder Assembly
- Plano-Convex Lens
Each Detector consists of a pair of photodiodes and pre-amps (a "bi-cell" for one axis)
- Each Detector Package includes a primary and redundant detector.
- Full complement is two detector packages
- Thermal mount provides standoff between 2 K ambient and 50-80 K detector.

This design minimizes thermal differentials that lead to bias variation
Alignment Error Summary
Total alignment error tolerance < 70 μm
Expected rms alignment error < 35 μm

Defocused Spot = 40 to 60 μm
Focused Spot = 6 μm

Acquisition Field, 1 Arc-min Size = 360 μm
Photodiode Size = 500 μm
### Telescope Through-Put & Tracking Performance Estimate

<table>
<thead>
<tr>
<th>Parameter / Guide Star Name</th>
<th>HR 5110</th>
<th>HR 1099</th>
<th>IM Peg</th>
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<tbody>
<tr>
<td>Ecliptic Latitude (deg)</td>
<td>43.00</td>
<td>-18.30</td>
<td>22.10</td>
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<td>Star Temperature (K)</td>
<td>6700</td>
<td>4490</td>
<td>4500</td>
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<tr>
<td>Companion Temperature (K)</td>
<td>4800</td>
<td>5733</td>
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<tr>
<td>Visual Magnitude</td>
<td>4.98</td>
<td>5.71</td>
<td>5.64</td>
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<td>Star/Companion Flux Density Ratio</td>
<td>0.233</td>
<td>0.396</td>
<td>0</td>
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<td>Incident Photons/sec (400 nm to 1000 nm)</td>
<td>6,834,710</td>
<td>4,289,492</td>
<td>4,841,490</td>
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<td>Detected Photo-electrons for 1 Itek Window</td>
<td>4,865,493</td>
<td>3,680,146</td>
<td>3,481,800</td>
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<tr>
<td>Detected Photo-electrons for 2 Itek Windows</td>
<td>4,326,539</td>
<td>2,738,879</td>
<td>3,095,362</td>
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<td>Telescope High Transmission Efficiency (%)</td>
<td>53.36</td>
<td>53.36</td>
<td>53.36</td>
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<tr>
<td>High Single Detector Signal (fA)</td>
<td>51.92</td>
<td>32.87</td>
<td>37.16</td>
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<tr>
<td>Low Single Detector Signal (fA)</td>
<td>18.72</td>
<td>11.85</td>
<td>13.39</td>
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<tr>
<td>Telescope High Strehl Ratio</td>
<td>0.65</td>
<td>0.65</td>
<td>0.65</td>
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<tr>
<td>Telescope Low Strehl Ratio</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>High Tracking Signal (aA/marc-s)</td>
<td>101.25</td>
<td>64.10</td>
<td>72.46</td>
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<tr>
<td>Low Tracking Signal (aA/marc-s)</td>
<td>28.07</td>
<td>17.77</td>
<td>20.08</td>
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</tbody>
</table>

- Thermal spectrum used for guide star and companion.
- Star data obtained from Lange, GP-B TR S0225, 2-4-'94.
- Multi-spectral star image used to calculate detector and tracking signal.
- Wavefront errors degrade telescope Strehl ratio and tracking signal together.
- Change shape of focused spot but detector signal unchanged.
DETECTOR RESPONSE TO IONIZING RADIATION

Sensitive Elements:
• Photo-diode
• Feedback Capacitor
• Transistors

TRANSIENT EFFECTS

Short-term transients (i.e. “cosmic-ray hits”) can blind telescope.
“Hit-rate” is less than 10 per hour (per photo-diode) outside SAA.
Software “sanity check” will detect and veto events.
Resets effectively limit persistence of transient on subsequent measurements.
Guide-star Invalid mode will be used during SAA transit.

Long-term relaxation effects (from passing through SAA or magnetic poles) could cause bias variation.
Expected to be small. Will not to occur at sensitive frequencies.

INTEGRAL EFFECTS

Total dose is low. No problem wrt device damage.
“Charge-trapping” not expected to be a problem.

INTEGRAL AND TRANSIENT EFFECTS WILL BE CONFIRMED IN RADIATION TEST PROGRAM

VERY-LOW ENERGY SCATTERED RADIATION

Bias error from very-low energy scattered radiation is possible. Judged very unlikely.
Analysis must be made to confirm.
Overview of SAA Effects on Telescope Detectors
- GP-B will pass through SAA several times every 12 hours; Maximum duration in SAA ~16 min
- Minimum shielding at location of Telescope Detectors is 5.7 g/cm²
- Proton flux at Telescope Detectors during SAA passage will be approximately $10^3 / \text{cm}^2 / \text{s}$
- Latchup is not a problem: no structures susceptible to latchup are used
- Because of their large area, the Detector Diodes dominate the Telescope Detector response to the SAA
- Total Detector Diode area is $40 \times 10^{-3} \text{ cm}^2$: Therefore, the estimated hit rate on the Telescope Detector Diodes in the SAA is 40 / s
- We must assume that the Science Telescope will be effectively blind in the SAA

Resulting Effect on ATC System:
- Not a problem: Use Guide Star Invalid pointing mode
- Proton Detector data, sanity checks on Telescope data, and Ephemeris data are used to know when to disregard the Telescope data

Resulting Effect on Science Data:
- Not a problem: 95% of the total Science Data which would be available were it not for the SAA will still be available despite the SAA
- Proton Detector data, sanity checks on Telescope data, and Ephemeris data are used to know when to disregard the Telescope data
THERMAL INTERFACE BETWEEN SIA AND TRE DETECTOR

• Detector power dissipation
  1 mW max per detector (4 mW total)
  0.75 mW allocated to circuit and 0.25 mW to heater

• SIA Temperatures
  QBS temperatures: QBS fingers 2.45 K; Spider 2.49 K
  Meets requirement.

• Temperature Stability
  The mount base temp bounded to 3.5 mK peak to peak @ roll via static analysis.
  Detector electronics temp change at least 20 times less (< 0.2 mK).
  Error budget performed using 2mK variation.

BASE-LINE IS TO USE OPEN-LOOP TEMP CONTROL OF DETECTOR CLOSED-LOOP OPTION IS AVAILABLE.
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

INTERFACE BETWEEN
DETECTOR AND FWD ELECTRONICS

Signal Transmission Methods
Signal Levels
Interface design controls contributors to bias error
(e.g. leakage currents, filter attenuation, thermocouples, etc.)
to acceptable levels.
TELESCOPE READ-OUT SIGNAL LEVELS

<table>
<thead>
<tr>
<th>I&lt;sub&gt;signal&lt;/sub&gt;</th>
<th>Min</th>
<th>Max</th>
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<tbody>
<tr>
<td>total</td>
<td>75k e/s</td>
<td>325k e/s</td>
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<tr>
<td>per marcs</td>
<td>110 e/s</td>
<td>631 e/s</td>
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<table>
<thead>
<tr>
<th>V&lt;sub&gt;signal&lt;/sub&gt;</th>
<th>Min&lt;sup&gt;*&lt;/sup&gt;</th>
<th>Max&lt;sup&gt;*&lt;/sup&gt;</th>
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<tbody>
<tr>
<td>Range</td>
<td>60e-6 V</td>
<td>867e-6 V</td>
</tr>
<tr>
<td>delta/marcs</td>
<td>90e-9 V</td>
<td>1.7e-6 V</td>
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<table>
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<tr>
<th>I&lt;sub&gt;drive&lt;/sub&gt;</th>
<th>Min&lt;sup&gt;*&lt;/sup&gt;</th>
<th>Max&lt;sup&gt;*&lt;/sup&gt;</th>
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<tbody>
<tr>
<td>Range</td>
<td>150e-9 A</td>
<td>2.2e-6 A</td>
</tr>
<tr>
<td>delta/marcs</td>
<td>230e-12 A</td>
<td>4.4e-9 A</td>
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<tr>
<th>V&lt;sub&gt;feedback&lt;/sub&gt;</th>
<th>Min</th>
<th>Max</th>
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<tr>
<td>Range</td>
<td>2.4e-3 V</td>
<td>10.4e-3 V</td>
</tr>
<tr>
<td>delta/marcs</td>
<td>3.5e-6 V</td>
<td>20e-6 V</td>
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<table>
<thead>
<tr>
<th>V&lt;sub&gt;out&lt;/sub&gt;</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>6 V / 20 K bits</td>
<td>18 V / 60 K bits</td>
</tr>
<tr>
<td>delta/marcs</td>
<td>9e-3 V / 29 bits</td>
<td>35e-3 V / 113 bits</td>
</tr>
</tbody>
</table>

* Open-loop equivalents

Each estimate is made by using ~200 samples. Min values based on 20% transmission, 50% strehl, and HR1099. Max signals based on 50% transmission, 65% strehl, and HR5110.
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

TRE FWD ELECTRONICS

Partition
Grounding and Shielding
Power Distribution
TRE PARTITIONING

Forward Electronics

Detectors

X+ → Charge-Locked Loop circuits → Analog signal conditioning → X+ To SRE

X- → Charge-Locked Loop circuits → Analog signal conditioning → X- To SRE

X-AXIS ANALOG PCB

Detector support circuits → Engr data → To SRE

Digital circuits

X-AXIS DIGITAL PCB

Y-AXIS ANALOG PCB

Y-AXIS DIGITAL PCB

FORWARD TRE CONSISTS OF 4 CIRCUIT BOARD (TWO DESIGNS)
TRE GROUNDING AND SHIELDING

Grounding Scheme follows “good-practice” rules and allows use of shared Data Acquisition System in SRE
SRE/TRE POWER DISTRIBUTION
BLOCK DIAGRAM

- ALL DC/DC CONVERTERS ARE REDUNDANT.
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

DATA ACQUISITION

Configuration
Block Diagram
Features
SRE/TRE DATA ACQUISITION SYSTEM

BLOCK DIAGRAM

SQUID 1 LOW FREQ
SQUID 3 LOW FREQ
SQUID 1 HIGH FREQ
SQUID 3 HIGH FREQ
TRE A +X SIGNAL
TRE A -X SIGNAL
TRE A +Y SIGNAL
TRE A -Y SIGNAL
TRE A X HEALTH & STATUS
TRE A X HEALTH & STATUS

PRIMARY
MULTIPLEXER

ANALOG BUFFER

16 BIT ANALOG-TO-DIGITAL CONVERTER
ADS7805

CONVERTER CONTROL GATE ARRAY

TO FWD/AFT INTERFACE

SRE HEALTH & STATUS

SECONDARY
MULTIPLEXERS

PRIMARY
MULTIPLEXER

May 6, 1996 Stanford University

Functional Overview and Performance Issues
Design Features to meet the requirements

- DATA REDUCTION CIRCUITS IN THE FORWARD ENCLOSURE
  - TO PROVIDE A MORE CONSTANT THERMAL ENVIRONMENT
  - TO REDUCE THE DISTANCE TRAVELED BY DELICATE ANALOG SIGNALS

- IDENTICAL CIRCUITS FOR TRE AND SRE IN THE SAME ENCLOSURE
  - TO MAKE THE SQUID AND TELESCOPE READOUT SIGNAL PROCESSING AS SIMILAR AS POSSIBLE
  - TO PUT ALL THE COMPONENTS IN THE SAME THERMAL ENVIRONMENT

- ALL SIGNALS PROCESSED BY TWO ANALOG-TO-DIGITAL CONVERTERS
  - TO PROVIDE A REASONABLE TRADE BETWEEN REDUNDANCY AND COMPLEXITY
  - TO REDUCE THE CHANCE OF SYSTEMATIC ERRORS

- READOUT ERRORS CONTRIBUTED BY DATA ACQUISITION SYSTEM:
  - BIAS STABILITY ERROR < 0.002 mARCS.
  - RANDOM NOISE < 0.1 mARCS/RT HZ
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

COMMAND, TELEMETRY, AND SOFTWARE

Overview
Command Items
Telemetry Items
Software Elements
TRE Command/Telemetry and Software Overview

TRE Fwd. Electronics

TRE Detectors

Digital Command Words (nx16 bits)

Analog Signals (Pointing Data, Muxed Housekeeping Data)

TRE Command/TLM Interface with SRE

DAS

Fwd SRE

GPBPP

Fore/Aft Bus (FAB)

Aft SRE

TRE SW

1773 Bus

Commands

Telemetry

CCCA
# TRE Commands

<table>
<thead>
<tr>
<th>Command Name</th>
<th>Command Function</th>
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<tbody>
<tr>
<td>TRE_s_Digital_On</td>
<td>Turns Digital Power On/Off to the TRE axis</td>
</tr>
<tr>
<td>TRE_s_Digital_Off</td>
<td></td>
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<tr>
<td>TRE_s_Analog_On</td>
<td>Turns Analog Power On/Off to the TRE Axis</td>
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<tr>
<td>TRE_s_Analog_Off</td>
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<tr>
<td>STz_Monitor</td>
<td>Sets the TRE Control Register</td>
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<tr>
<td>STz_TIA_Disable</td>
<td>Enables/Disables Transimpedance Mode</td>
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<tr>
<td>STz_TIA_Enable</td>
<td></td>
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<tr>
<td>STz_Temp_Disable</td>
<td>Enables/Disables Local Closed Loop Temperature Control</td>
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<tr>
<td>STz_Temp_Enable</td>
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<tr>
<td>STz_Diagnostic_Mode_n</td>
<td>Invert Reset, Invert Gate, TIA Mode, Inhibit Reset Clock</td>
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<tr>
<td>STz_Detector_Power_On</td>
<td>Turns TRE Detector Power On/Off</td>
</tr>
<tr>
<td>STz_Detector_Power_Off</td>
<td></td>
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<tr>
<td>STz_Local_Temp_SP</td>
<td>Sets TRE z Local Closed Loop Temperature Setpoint</td>
</tr>
<tr>
<td>STz_Detector_Heater</td>
<td>Sets TRE z Detector Heater</td>
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<tr>
<td>STz_Clamp+</td>
<td>Sets TRE z +/- Clamp Voltage</td>
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<td>STz_Clamp-</td>
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<tr>
<td>STz_Gain+</td>
<td>Sets TRE z +/- Gain and/or PhotoDiode Bias Voltage</td>
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<tr>
<td>STz_Gain-</td>
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<tr>
<td>STz_Primary_Bias</td>
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<tr>
<td>STz_Secondary_Bias+</td>
<td>Sets Second Stage Bias Control</td>
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<tr>
<td>STz_Secondary_Bias-</td>
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## TRE Telemetry

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<tr>
<th>Telemetry Monitor</th>
<th>Telemetry Type</th>
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<tbody>
<tr>
<td>Slope Estimation (ATC)</td>
<td>ATC TLM output on 1773 at 10 Hz</td>
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<tr>
<td>Slope Estimation (Science)</td>
<td>Science TLM output on 1773 at 10 Hz</td>
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<tr>
<td>Transimpedance Signal Amplifier Voltage</td>
<td>Engineering TLM output on 1773 at 0.5 Hz</td>
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<td>Transimpedance Reference Amplifier Voltage</td>
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<td>Offset DAC Output</td>
<td>Engineering TLM output on 1773 at 0.5 Hz</td>
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<td>Direction Feedback Point</td>
<td>Engineering TLM output on 1773 at 0.5 Hz</td>
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<td>Reset Drive Level</td>
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<td>Diode Bias</td>
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<td>Signal Common 0, 1, 2</td>
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<td>Detector Temperature</td>
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<td>Local Box Temperature</td>
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</tr>
<tr>
<td>Temperature Command DAC</td>
<td>Engineering TLM output on 1773 at 0.5 Hz</td>
</tr>
<tr>
<td>Temperature Servo Error Voltage</td>
<td>Engineering TLM output on 1773 at 0.5 Hz</td>
</tr>
<tr>
<td>+12V, -12V, +5V</td>
<td>Engineering TLM output on 1773 at 0.5 Hz</td>
</tr>
<tr>
<td>Reference +0.5V, +5V, +4V, -10V</td>
<td>Engineering TLM output on 1773 at 0.5 Hz</td>
</tr>
<tr>
<td>Second Stage Bias</td>
<td>Engineering TLM output on 1773 at 0.5 Hz</td>
</tr>
<tr>
<td>Analog Clock 1, 2 Monitor</td>
<td>Engineering TLM output on 1773 at 0.5 Hz</td>
</tr>
</tbody>
</table>
# TRE Software

<table>
<thead>
<tr>
<th>Software Component</th>
<th>Algorithm</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheduler</td>
<td>Identical to scheduler in CCCA</td>
<td></td>
</tr>
<tr>
<td>Command Routing</td>
<td>Commands received from CCCA at 10 Hz</td>
<td>Comprehensive list documented in Section 9 of the Software Design Document SE-16</td>
</tr>
<tr>
<td></td>
<td>Commands transmitted to Fore SRE at 10 Hz to mitigate SEUs</td>
<td></td>
</tr>
<tr>
<td>ATC Slope Estimator</td>
<td>ATC Slope Fit</td>
<td>Requirements definition complete. Awaiting customer sign-off.</td>
</tr>
<tr>
<td>Science Slope Estimator</td>
<td>Science Slope Fit</td>
<td>Requirements definition complete. Prototyping in progress</td>
</tr>
<tr>
<td>Engineering Data Filter</td>
<td>Low Pass</td>
<td>Preliminary specification complete.</td>
</tr>
<tr>
<td>Digital Closed Loop Thermal Control</td>
<td>PID</td>
<td>Preliminary specification complete</td>
</tr>
<tr>
<td>Telemetry Processing</td>
<td>Pointing TLM available at 10 Hz</td>
<td>Comprehensive list documented in Section 9 of the Software Design Document SE-16</td>
</tr>
<tr>
<td></td>
<td>Engineering TLM available at 0.5 Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Snapshot TLM available on demand or on event</td>
<td></td>
</tr>
</tbody>
</table>
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

ATC INTERFACE
Block diagram
Requirements
Telescope processing model
ATC Interfaces

- ATC data flow well defined
- Aft SRE performs error check on high frequency data
- Attitude control law supports multiple modes
  - Observer
  - Direct
  - Gyroless

Guide Star

Science Telescope (ST)

Photons

Cold Detectors & Preamps

Analog Signals

Warm TRE Electronics

Analog Signals

SRE Forward Electronics

Digital Samples @ 2.2 kHz

SRE Aft Electronics

ATC Slope Estimates @ 10 Hz

True SV Pointing Angle

Plant $\frac{1}{s^2}$

Space Vehicle (SV)

Attitude Control Law

Modes include observer direct gyroless

Curve Fit Polynomial coefficients to be documented in SE-16

Compute Normalized Pointing Angle

$\frac{(x_+ - x_-)(x_+ + x_-)}{(y_+ - y_-)(y_+ + y_-)}$

CCCA (Spacecraft Computer)
## ATC ST requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) The science telescope shall provide the slope fit to the integrated pointing error from the plus and minus sides of the yaw and pitch detectors. Signal filtering shall be greater than 100 Hz.</td>
<td>Design</td>
</tr>
<tr>
<td>2) The science telescope noise, after a 10 Hz slope fit, shall be less than 10 marcs/√Hz (one-sided).</td>
<td>Test</td>
</tr>
<tr>
<td>3) The science telescope signals shall allow determination of the star magnitude to within ±0.2 Mv (20%).</td>
<td>Test</td>
</tr>
<tr>
<td>4) Resets shall occur on 10 Hz boundaries.</td>
<td>Test</td>
</tr>
<tr>
<td>5) The science telescope quantization shall be less than or equal to 0.25 marcs (12 bits over ±500 marcs).</td>
<td>Test</td>
</tr>
<tr>
<td>6) The science telescope shall provide more than 75% full reading when beyond ±500 marcs and within the total field-of-view of ±60 arcsec.</td>
<td>Test</td>
</tr>
<tr>
<td>7) The science telescope shall be linearizable over the range of ±500 marcs (see 8 for error).</td>
<td>Test</td>
</tr>
<tr>
<td>8) The residual linearization error of the science telescope shall be less than 6% over any 5 marcs range within ±60 marcs and less than 15% from 60 marcs to 500 marcs.</td>
<td>Test</td>
</tr>
<tr>
<td>9) The ATC data shall be available after receipt of the 10 Hz ATC strobe.</td>
<td>Test</td>
</tr>
</tbody>
</table>

*Telescope data word format is controlled in Flight Software Specification, SE-16, Section 9
*PCB to add these requirements to TRE Spec is in data package
TELESCOPE PROCESSING MODEL

file: bdelti.m
# TELESCOPE PROCESSING MODEL RESULTS

<table>
<thead>
<tr>
<th>dt</th>
<th>0.1 sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cf</td>
<td>5.00E-13 F</td>
</tr>
<tr>
<td>beta</td>
<td>0.0015 1/mas</td>
</tr>
<tr>
<td>el</td>
<td>1.60E-19 C</td>
</tr>
<tr>
<td>run time</td>
<td>100 sec</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>transient</th>
<th>12 samples</th>
<th>V/sec</th>
<th>Individual Channels</th>
<th>Combined bi-cell meas.</th>
</tr>
</thead>
<tbody>
<tr>
<td>eNps</td>
<td>Iodt</td>
<td>teta</td>
<td>sig_vy</td>
<td>sig_vn</td>
</tr>
<tr>
<td>-----------</td>
<td>------</td>
<td>------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>100</td>
<td>1.19E-14</td>
<td>60</td>
<td>0.0012</td>
<td>0.0012</td>
</tr>
<tr>
<td>50</td>
<td>1.19E-14</td>
<td>60</td>
<td>0.000672</td>
<td>0.000655</td>
</tr>
<tr>
<td>50</td>
<td>1.19E-14</td>
<td>60</td>
<td>0.000677</td>
<td>0.000636</td>
</tr>
<tr>
<td>20</td>
<td>1.19E-14</td>
<td>60</td>
<td>0.000405</td>
<td>0.000371</td>
</tr>
<tr>
<td>10</td>
<td>1.19E-14</td>
<td>60</td>
<td>0.000335</td>
<td>0.000321</td>
</tr>
<tr>
<td>2</td>
<td>1.19E-14</td>
<td>60</td>
<td>0.000311</td>
<td>0.000291</td>
</tr>
<tr>
<td>1</td>
<td>1.19E-14</td>
<td>60</td>
<td>0.000329</td>
<td>0.000298</td>
</tr>
<tr>
<td>0.1</td>
<td>1.19E-14</td>
<td>60</td>
<td>0.000319</td>
<td>0.000297</td>
</tr>
<tr>
<td>0.01</td>
<td>1.19E-14</td>
<td>60</td>
<td>0.000311</td>
<td>0.000279</td>
</tr>
<tr>
<td>20</td>
<td>0.00E+00</td>
<td>60</td>
<td>0.000233</td>
<td>0.000233</td>
</tr>
<tr>
<td>50</td>
<td>1.70E-14</td>
<td>60</td>
<td>0.000702</td>
<td>0.00072</td>
</tr>
</tbody>
</table>

---

**Electronics Noise Effects**

- Channel_1
- Channel_2
- Tscope-out
- Photon

- Individual Channels
- Combined bi-cell measurement
- Photon Noise

**Transistor Input Voltage Noise [nV/Hz]**

![Graph showing noise effects and transistor input voltage noise](image-url)
ST SCIENCE DATA INTERFACE

Calibration inputs: e.g., dither, limb observation, GS scan.

Telescope Optics

Thermometers

Proton Monitor → ECU

TRE Ground Telemetry:
Individual photo-diode currents
TRE Engr data used for verification:
  Detector temperatures
  Fwd Elect temperatures
  Measured set-point values

Primary and redundant signals are in telemetry stream.

TRE SUPPORTS ALL SCIENCE DATA PROCESSING AND VERIFICATION REQUIREMENTS
<table>
<thead>
<tr>
<th>Spec # / Parameter</th>
<th>Regmmt.</th>
<th>Design for Compliance</th>
<th>Verification Methods</th>
<th>Achieved to Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>T003 7.5 Random Noise</td>
<td>&lt; 10 marcs /√Hz (1-sided)</td>
<td>Cold low-noise JFET 1st stage amplifiers Capacitive feedback in CLL avoids Johnson noise in feedback</td>
<td>Measured in detector acceptance test, integrated P/L test, S/V thermal vac On-orbit check of dark noise with shutter closed during GI</td>
<td>8.2 marcs /√Hz (lab test)</td>
</tr>
<tr>
<td>3.2.15.2 Bias Variation</td>
<td>&lt; 0.05 marcs at critical frequencies</td>
<td>Bi-cell photodiode detectors and preamps co-located on temp. stable sapphire platform CLL minimizes dynamic range of voltage on photodiodes and JFETs</td>
<td>Dev. &amp; acceptance test with unfocused light System test with Artificial Star &amp; Telescope in GTU-2 and integrated P/L On-orbit check between redundant sides of TRE</td>
<td>Designed to meet spec.</td>
</tr>
<tr>
<td>3.2.15.3 Scale Factor Variation</td>
<td>&lt; 1%</td>
<td>Both halves of bi-cell read out; signal normalized $(x^+ - x^-) / (x^+ + x^-)$</td>
<td>Dev. &amp; acceptance test with unfocused light System test with Artificial Star &amp; Telescope in GTU-2 and integrated P/L On-orbit check using S/V dither On-orbit check between redundant sides of TRE</td>
<td>Designed to meet spec.</td>
</tr>
<tr>
<td>3.2.15.6 Transfer Function Stability</td>
<td>&lt; 0.01 rad.</td>
<td>High rate (&gt;2kHz) sampling with critical filtering performed digitally makes pre-sample analog filters non-critical</td>
<td>Direct measurement in lab vs. temperature variation of electronics On-orbit verification using S/V dither</td>
<td>Designed to meet spec.</td>
</tr>
<tr>
<td>3.2.1 EMI</td>
<td>Operate within spec with TLM xmr ON</td>
<td>Shielding of cables in Probe. Internal shield around detector platforms referenced to TRE signal ground.</td>
<td>EMI tests in on TRE boxes and detector packages; in GTU-2, during P/L integration and during S/V integration</td>
<td>Designed to meet spec.</td>
</tr>
<tr>
<td>3.2.2, 3.3 Ionizing Radiation</td>
<td>Operate within spec in spec'd environment (PCB for exception in SAA)</td>
<td>Loss of data in SAA acceptable to system High rate (&gt;2kHz) sampling allows detection of high-energy events Resets (10Hz) limit persistence of events</td>
<td>Electronic development tests in lab Total dose ($\gamma$) and transient (protons from cyclotron) test program Correlate with Proton Monitor data on orbit</td>
<td>Designed to meet spec.</td>
</tr>
<tr>
<td>3.2.5 Detector Mount</td>
<td>$f_0 &gt; 100$ Hz Alignment wrt light spots</td>
<td>Very stiff Adjustable within package for alignment</td>
<td>Development / acceptance test in lab</td>
<td>Designed to meet spec.</td>
</tr>
<tr>
<td>3.2.6 Detector Power</td>
<td>1 mW / platform</td>
<td>Nominal dissipation 1 mW/detector (4 mW total) 75% for circuit operation, 25% for heater Heater power commandable in flight</td>
<td>Development / acceptance test in lab Temperature measurements on orbit</td>
<td>Designed to meet spec.</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>3.2.7 Operation Range</td>
<td>10 fA 10 pA 1 μA</td>
<td>TIA mode allows operation at warm temperature and high current for test modes</td>
<td>Development / acceptancetest in lab</td>
<td>Designed to meet spec.</td>
</tr>
</tbody>
</table>
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

ELECTRICAL DESIGN OF TRE DETECTOR

J. GOEBEL

Schematics
Layout
Specifications
SAA Effects on TRE
Test Program
Critical Design Review Telescope Readout Electronics

Detector Mount Assembly

May 8, 1996
Critical Design Review Telescope Readout Electronics

Detector Mount

May 8, 1996
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Detector (Layout)

May 8, 1996
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One-Half of Differential Amplifier

May 8, 1996
# Telescope Readout Electronics Critical Design Review

## TRE Detector Component Parametric Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Simulation</th>
<th>Test Program</th>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark Current</td>
<td>$I_{dark} \leq 0.01 \text{ fA}$</td>
<td>In progress</td>
<td>In Preparation Area of Concern</td>
<td>June 1</td>
</tr>
<tr>
<td>Si Photodiode External Quantum Efficiency @ 550-900 nm</td>
<td>$\eta_{ext} \geq 80%$</td>
<td>In progress</td>
<td>In Preparation Area of Concern</td>
<td>&gt; GTU-2</td>
</tr>
<tr>
<td>Diameter of Photoactive Area</td>
<td>TBD $0.5 \leq D_{Det} \leq 0.8 \text{ mm}$</td>
<td>Centronic Blueprint</td>
<td>Suwen</td>
<td>Available</td>
</tr>
<tr>
<td>Sense Node Capacitance</td>
<td>$C_T \leq 20 \text{ pF}$</td>
<td>In progress</td>
<td>In Preparation</td>
<td>June 1</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>TBD $40 &lt; T_{op} &lt; 120 \text{ K}$</td>
<td>In progress</td>
<td>In Preparation Area of Concern</td>
<td>June 1</td>
</tr>
<tr>
<td>Sense Node Referred Noise</td>
<td>$N_{EQ} \leq 50 \text{ e}/T_{\text{int}}$</td>
<td>In progress</td>
<td>In Preparation Area of Concern</td>
<td>Aug 1</td>
</tr>
<tr>
<td>Component Si-JFET Transconductance</td>
<td>$g_m \geq 0.3 \text{ mS}$</td>
<td>In progress</td>
<td>In Preparation</td>
<td>June 1</td>
</tr>
</tbody>
</table>
## Telescope Readout Electronics Critical Design Review

**TRE Detector Parametric Performance**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Simulation</th>
<th>Test Program</th>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Stability @ roll</td>
<td>$\Delta T \leq 2$ mK</td>
<td>In progress</td>
<td>In Preparation Needs Confirmation</td>
<td>&gt; GTU-2</td>
</tr>
<tr>
<td>Power Dissipation per Platform</td>
<td>$P_{Plat} \leq 1$ mW</td>
<td>In progress</td>
<td>In Preparation Needs Confirmation</td>
<td>June 1</td>
</tr>
<tr>
<td>CTIA Sense Node Capacitance</td>
<td>$C_T \leq 20$ pF</td>
<td>Howard Demroff</td>
<td>In Preparation</td>
<td>June 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bob Farley</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>$40 &lt; T_{op} &lt; 120$ K</td>
<td>In progress</td>
<td>In Preparation Needs Confirmation</td>
<td>June 1</td>
</tr>
<tr>
<td>CTIA Sense Node Referred Noise</td>
<td>$\sqrt{S_{CTIA}} \leq 100$ nV/$\sqrt{\text{Hz}}$</td>
<td>In progress</td>
<td>In Preparation</td>
<td>&gt; GTU-2</td>
</tr>
<tr>
<td>FET Threshold Voltage Matching</td>
<td>$</td>
<td>\Delta V_{TH}/V_{TH}</td>
<td>\leq 1%$</td>
<td>In progress</td>
</tr>
<tr>
<td>FET Threshold Voltage Temperature Coefficient Matching</td>
<td>$</td>
<td>\Delta(\partial V_{TH}/\partial T)/(\partial V_{TH}/\partial T)</td>
<td>\leq 1%$</td>
<td>In progress</td>
</tr>
<tr>
<td>Channel Gain Matching Temperature Coefficient Matching</td>
<td>$</td>
<td>\Delta(\partial G/\partial T)/(\partial G/\partial T)</td>
<td>\leq 5%$</td>
<td>In progress</td>
</tr>
<tr>
<td>EMI</td>
<td>TBS</td>
<td>In progress</td>
<td>In Preparation Area of Concern</td>
<td>&gt; GTU-2</td>
</tr>
</tbody>
</table>
Critical Design Review Telescope Readout Electronics

- Test Plan for Si-PD External Quantum Efficiency
  - Determine $\eta(T)$
  - $\eta(300K) = 82\%$
  - $\eta(77K) = ???$
  - Bias Dependence
  - Trade with Noise

Detector Mount Assembly at Top

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Model</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 80%</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

May 8, 1996
Critical Design Review Telescope Readout Electronics

- Test Plan for Si-PD Dark Current
  - Determine $I_D(T)$
  - $I_D(300K)$ =
  - $I_D(77K)$ = ?
  - Bias Dependence
  - Trade with $\eta(T)$

Detector Mount Assembly at Top

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Model</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.01 fA</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

Figure 10.3. The PIN photodetector: (a) the $I$–$V$ characteristic (1—in the dark, 2—with light); (b) PIN diode structure; (c) the equivalent circuit; (d) standard circuit symbol.

May 8, 1996
Critical Design Review Telescope Readout Electronics

- Test Plan for Platform Leakage Current
  - Determine $I_L(T)$
  - $I_L(300K) = $?
  - $I_L(77K) = $?
  - Bias Dependence

Detector Mount Assembly at Top

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Model</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.01 fA</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

May 8, 1996
Critical Design Review Telescope Readout Electronics

- Test Plan for Si-JFET Gain
  - Determine $g_m$
  - $g_m(300\text{K}) =$
  - $g_m(77\text{K}) = ?$
  - Bias Dependence
  - Trade with Noise and Power Dissipation

Detector Mount Assembly at Top

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Model</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 $\mu$S</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

Figure 12.3. (a) The JFET drain characteristics determined by \((12.8)\) up to the pinch-off point; (b) the depletion layer for $V_{dss} > V_{DS(sat)}$. 

May 8, 1996
Critical Design Review Telescope Readout Electronics

- Test Plan for Si-JFET Threshold Voltage
  - Determine $V_{TH}$
  - $V_{TH}(300K) = 1.1V$
  - $V_{TH}(77K) = 1.1V$
  - Current Dependence

Detector Mount Assembly at Top

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Model</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 V</td>
<td>TBD</td>
<td>1.1V</td>
</tr>
</tbody>
</table>

Figure 3.11

May 8, 1996
Test Plan for Si-PD Component Capacitance

- Determine $C(T)$
- $C(300K) = 0.5 \, \text{pF}$
- $C(77K) = ?$
- FETs, PD, $C_F$
- Trade with Noise and CTIA Gain
- Bias Dependence

Detector Mount Assembly at Top

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Model</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5 pF</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>
Critical Design Review Telescope Readout Electronics

- Test Plan for Sense Node Capacitance
  - Determine $C_T(T)$
  - $C_T(300K) = ?$
  - $C_T(77K) = ?$
  - Trade with Noise and CTIA Gain
  - Bias Dependence

Detector Mount Assembly at Top

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Model</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 20 pF</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>
Critical Design Review Telescope Readout Electronics

- Model of Thermal Dynamics
  - Thermal Time Constant
  - Radiation Sensitivity

- Model ID: ThermalDyn1.0
  - Status: Under Development
  - Question: Is the platform stable against perturbation?
  - Answer: Complex

May 8, 1996
Critical Design Review Telescope Readout Electronics

- Test Plan for Thermal Stability and Control
  - Determine $Z(T)$
  - $Z(300K) = N/A$
  - $Z(77K) = ?$
  - Bias Dependence
  - Trade with Power Dissipation

**Detector Mount Assembly at Top**

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Model</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 2 \text{ mK}$</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>
Critical Design Review Telescope Readout Electronics

- Test Plan for Component Noise
  - Determine $S(T)$
  - $S(300\text{K}) =$
  - $S(77\text{K}) =$?
  - Bias Dependence
  - Trade with Power Dissipation

Detector Mount Assembly at Top

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Model</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 100 nV/√Hz</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

Figure 4.8 Typical photoconductor mean square noise spectrum.

May 8, 1996
Critical Design Review Telescope Readout Electronics

- Test Plan for Si-PD Preamp Noise
  - Determine $S(T)$
  - $S(300K) =$
  - $S(77K) =$
  - Bias Dependence
  - Trade with Power Dissipation

Detector Mount Assembly at Top

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Model</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 300 \text{ nV/}\sqrt{\text{Hz}}$</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

May 8, 1996
Critical Design Review Telescope Readout Electronics

- Test Plan for Optimum Operating Temperature
  - Determine $T_{op}$
  - Noise Trade
  - Signal Trade
  - Stability Trade

Detector Mount Assembly at $T_{op}$

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Model</th>
<th>Test</th>
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</thead>
<tbody>
<tr>
<td>&lt; 120 K</td>
<td>TBD</td>
<td>TBD</td>
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</tbody>
</table>
Test Plan for EMI

- Determine Detector & Preamp Bandwidth with Shielding
- Diode can be made resistive
- Bias line can be filtered at detector

Detector Mount Assembly at Top

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Model</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>?</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

Figure 3-11 Detector equivalent circuit.

May 8, 1996
Critical Design Review Telescope Readout Electronics

- Test Plan for Ionizing Radiation
  - Need ~100 Mev protons
  - Can do preliminaries with γ-rays
  - PD, FETs, and Capcitors most sensitive
  - Bias Dependence

Detector Mount Assembly at Top

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Model</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>?</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>
Critical Design Review Telescope Readout Electronics

- Test Plan for CTIA Performance
  - Integration of above tests
  - Coupled to warm electronics
  - Long leads used in GTU-2

Detector Mount Assembly at Top

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Model</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; $\sqrt{7,500}$ e-/read</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

May 8, 1996
Critical Design Review Telescope Readout Electronics

- Manufacturing Plan DMA
  - Assemble Sapphire Hybrid
  - Construct Kapton Thermal Isolator
  - Construct Base Assembly
  - Construct Rigidizer
  - Construct Cable-Connector Assembly
  - Integrate Cable-Base Assembly
  - Integrate Cable-Base-Isolator Assembly
  - Integrate Hybrid, Isolator and Cable-Base

May 8, 1996
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

DESIGN OF TRE DETECTOR PACKAGE AND MOUNT

M. SULLIVAN

Specification/Requirements
Baseline Design
Hardware Status
Additional Development
TELESCOPE DETECTOR PACKAGE ASSEMBLY

REQUIREMENTS

- Provide stable structural mounting for Telescope Detectors
- Thermally isolate 75 K JFETs from 3 K Telescope optics
- Provide isothermal platform to minimize temperature-induced JFET scale factor mismatch
- Provide electrical connection from cryogenic Telescope Read-Out electronics to Probe Top Hat
- Provide EMI shielding
TELESCOPE ASSEMBLY
TELESCOPE DETECTOR PACKAGE ASSEMBLY

THERMAL WASHER
DETECTOR MOUNT ASSEMBLY
PHOTODIODE DETECTORS
LOCAL EMI SHIELD
THERMAL/ELECTRICAL ISOLATOR
DETECTOR PACKAGE BODY
BEAMSLITTER HOLDER ASSEMBLY
PLANO-CONVEX LENS
DETECTOR MOUNT ASSEMBLY

**Thermal Platform**
- Synthetic Sapphire
- 2 Photodiode Detectors
- Isothermal platform

**Thermal Isolator**
- .002" thick Kapton
- .400" OD
- Copper Traces with Gold Overcoat
- Thermal isolation
- Electrical connections

**Predicted Performance**
- $f_0 = 500 \text{ Hz}$
- $q = 1 \text{ mW for } \Delta T = 72 \text{ K}$

**Base**
- Titanium
- Interface to Detector Package
Detector Mount (Thermal Isolator)
- .002" Kapton sheet
- Pattern cut by reactive ion etch in flat form
- Electrical Leads photolithographically placed
  - > 2500 angstroms Cu
  - > 500 angstroms Au
- Rolled & glued
- Traces wire bonded to electrical contacts on top
- Wire bundle soldered to traces on bottom
DETECTOR MOUNT ASSEMBLY (DMA)

- Dual Photodiode Detector
- Detector Circuit (Metalized onto Sapphire)
- Thermal Platform (Synthetic Sapphire)
- Thermal Isolator (Kapton)
- Base (Titanium)
- 20x Wire Bonds
- 4x5-20 Copper/Gold Traces
- 20x Solder Connections
## DETECTOR PACKAGE REQUIREMENTS

<table>
<thead>
<tr>
<th>Specification Number</th>
<th>Parameter Name</th>
<th>Required Value</th>
<th>Verification</th>
<th>Test Description</th>
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<tr>
<td>3.2.4, 3.2.5.1</td>
<td>Vibration</td>
<td>$f_0 \geq 100$ Hz</td>
<td>A &amp; T</td>
<td>Shake table (ARC) &amp; GTU-2</td>
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<tr>
<td>3.2.5.2.1, 3.2.5.2.2, 3.2.5.2.3</td>
<td>Alignment</td>
<td>Tip/Tilt $\leq 5$ degrees</td>
<td>I &amp; T</td>
<td>Room temperature mechanical &amp; optical inspection; cryo qualification testing &amp; GTU-2</td>
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<tr>
<td></td>
<td></td>
<td>Defocus $\leq 200$ μm</td>
<td>I &amp; T</td>
<td>Room temperature mechanical &amp; optical inspection; cryo qualification testing &amp; GTU-2</td>
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<td>Decenter $\leq 100$ μm</td>
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<td>Room temperature mechanical &amp; optical inspection; cryo qualification testing &amp; GTU-2</td>
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<td>Allowable Heat Transfer</td>
<td>$\leq 1$ mW</td>
<td>A &amp; T</td>
<td>Cryo qual testing &amp; GTU-2</td>
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<tr>
<td>3.2.5.3</td>
<td>Platform Temperature Variation</td>
<td>$\leq 2$ mK</td>
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<td>3.2.5.4</td>
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<td>3.2.5.5</td>
<td>Electrical Lead Resistance</td>
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<td>3.2.5.6.1, 3.2.5.6.2, 3.2.5.6.3</td>
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<td>Operational $2$–$80$ K</td>
<td>T</td>
<td>RT &amp; cryo qual testing &amp; GTU-2</td>
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<td>Test $2$–$372$ K</td>
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<td>3.2.5.7</td>
<td>EMI</td>
<td>TBS</td>
<td>T</td>
<td>EMI test booth &amp; GTU-2</td>
</tr>
</tbody>
</table>
DETECTOR PACKAGE HARDWARE STATUS

DESIGN

- Detector Mount Assembly (DMA) design completed
  - Base, Thermal Isolator, & Thermal Platform drawings released
  - Assembly drawings in review

- Detector Package Assembly (DPA) design completed
  - Metallic & optical part drawings released
  - Assembly drawings in review

- Detector Cable Assembly (DCA) design in process
  - Thermal & electrical grounding paths determined
  - Interfaces coordinated with Lockheed-Martin
  - Detailed design underway
DETECTOR PACKAGE HARDWARE STATUS (cont’d)

FABRICATION

- All Detector Mount Assembly parts expected by May 10
  - Additional Thermal Isolators being made as backup

- All Detector Package Assembly parts expected by May 15
  - 982 piece parts (many spares) currently being delivered by Watts Machining and FM Industries (flight-approved vendors)
  - Mechanical & magnetic inspection to be done in parallel with Integration & Testing

- Detector Cable Assembly parts being developed
  - GTU-2 Cable interfaces are different than for Science Mission
    ▶ GTU-2 uses Probe B
    ▶ SM uses Probe C
  - GTU-2 Detector Cable Assembly will be made to support a single Detector Package channel (no redundancy)
  - SM DCA will support 4 DPA channels
## DETECTOR PACKAGE HARDWARE STATUS (cont'd)

## HARDWARE SUMMARY

<table>
<thead>
<tr>
<th>Part #</th>
<th>Part Name</th>
<th>Design Comp'd</th>
<th>Dwg Released</th>
<th>Material Ordered</th>
<th>Material Rec'd</th>
<th>Material Appr'd</th>
<th>Material Issued</th>
<th>Parts Ordered</th>
<th>Parts Rec'd</th>
<th>Parts Insp'd</th>
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<td>2507-1-101</td>
<td>Body, Detector Package</td>
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<td>2545-8-101</td>
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<td>2545-8-104</td>
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<td>2545-8-108</td>
<td>Washer, Belleville, #6</td>
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<td>2546-8-101</td>
<td>Screw, Shoulder, Det Pack</td>
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<td>Screw, Captive, DPA</td>
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<td>2548-8-101</td>
<td>Washer, Captive, DPA</td>
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<td>2548-8-101</td>
<td>Key, Beam splitter mount</td>
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</tbody>
</table>
DETECTOR PACKAGE HARDWARE STATUS (cont’d)

INTEGRATION & TESTING

- Assembly of Detector Package in process
  1. Mechanical assembly of Detector Mount Assembly
     ➤ Glue Base, Isolator, & Platform (Stycast 1266 epoxy)
     ➤ Solder cable wires to traces (Indalloy #1 solder)
     ➤ Wire bond traces to circuit (Gold wire)
  2. Electrical testing of DMA
  3. Assemble Package parts
  4. Opto-mechanical alignment—Phase 1
     ➤ Plano-convex lens centered in Package Body
     ➤ Beamsplitter Assembly installed
  5. Detector Mount Assemblies integrated with Detector Package Assembly
  6. Opto-mechanical alignment—Phase 2
     ➤ Detectors aligned with plano-convex lens and beamsplitter
  7. Final electrical test
  8. Detector Package Assembly ready for integration with Telescope

- Fully integrated Detector Package expected June 21
DETECTOR PACKAGE ASSEMBLY DEVELOPMENT

FUTURE EFFORTS

• Thermal Isolator fabrication
  – Refine epoxy bonding application
    ▶ Investigating precision dispensers
  – Improve gold passivation of copper traces
    ▶ Oromerse
    ▶ Titanium barrier layer
  – Develop assembly and alignment jigs
  – Evaluate alternate wire bond materials
    ▶ Lead/Tin/Gold
    ▶ Aluminum

• Cryogenic thermal cycling

• Thermal modelling of DMA and DPA/SIA system

• Vibration testing of Detector Package Assembly

• EMI testing of Detector Cable Assembly prototype
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

QUALITY ASSURANCE AND RELIABILITY
FOR TRE DETECTOR

F. BERKOWITZ

Quality Provisions
Fabrication
Procurement
Status
Quality Provisions per SU's "Science Mission Quality Plan" P0108

Configuration Control per "Science Mission Configuration Management Plan" P0098
- Drawings Release through Drawing Release Review and Change Control (ECB)
- Drawing tree updated as required; controlled through drawing release process
- Changes of requirements through Program Change Board (PCB)
- Changes of Drawings through Engineering Change Board (ECB)

Fabrication Control:
- Identification, Traveler, As-Built Configuration
- Workmanship
- Special Processes: Per written procedures
- ESD Control per MIL-STD-1686A
- Authorized fabricators complete specialized training (e.g. soldering course)
• Inspection and Tests:
  • Incoming inspection for workmanship and functional
  • Dimensional Inspection: 100% per the approved drawings
  • Tests: Per written and approved procedures
  • Periodic calibrated equipment for RE defined final/specs tests

• Configuration and Test Database
  • Database includes:
    Requirements, Specs and other documents, Reviews and Action Items, PCBs
  • Inclusion in process:
    ECOs, DR’s, Drawing Tree, Components, As-Built Configuration, Tests Plans and Tests Results etc.

• Nonconformance Control:
  • Discrepancy Reports including Analysis and Corrective Action.
  • Disposition by Material Review Board (MRB).
• **Procurement Control**
  - Vendors selection from SU Approved Vendors List
  - Vendors Quality System meets the requirements of MIL-I 45208A
  - Procurement document reviewed by the Quality Engineer

• **Reliability:**
  - FMECA to be completed.

• **Reports:**
  - All Discrepancy Reports (DRs) and Engineering Changes ECOs are reported to NASA in the Monthly Reviews
## Parts Status for Telescope Read Out Detector

As of 5/2/96

<table>
<thead>
<tr>
<th>#</th>
<th>Part Title</th>
<th>Qty per Assy</th>
<th>Vendor</th>
<th>Qty ordered</th>
<th>RFQ date</th>
<th>Date ordered</th>
<th>Promised date</th>
<th>Recvd date</th>
<th>PO #</th>
<th>Total Cost</th>
<th>notes</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Photodiode die</td>
<td>2</td>
<td>Centronics</td>
<td>100+100</td>
<td>3/14/95</td>
<td>6/19/95</td>
<td>7/3/95</td>
<td>E035220</td>
<td>$40,600.00</td>
<td>Extra 50 units, for assembly practice have been received (free of charge) on 7-24-95</td>
<td></td>
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<tr>
<td>1.1</td>
<td>Photodiode die - 100 of each (.8 and .5)</td>
<td>2</td>
<td>Centronics</td>
<td>100+100</td>
<td>12/4/95</td>
<td>6 WEEKS</td>
<td>~1/1/1996</td>
<td>E405660</td>
<td>$17,700.00</td>
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<tr>
<td>2</td>
<td>Differential FET die</td>
<td>4</td>
<td>NASA Goddard</td>
<td>160 a</td>
<td>2/2/95</td>
<td>4/1/95</td>
<td>8/24/95*</td>
<td>E13523</td>
<td>$60,000.00</td>
<td>Kim Barlow will call on 8-29-95 for new delivery date</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Current source resistor, die</td>
<td></td>
<td>Mini System Inc.</td>
<td>440 d</td>
<td>same 6</td>
<td>7/21/95</td>
<td>partially</td>
<td>E13523</td>
<td>$7,635.00</td>
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<tr>
<td>4</td>
<td>Reset FET die</td>
<td>2</td>
<td>InterFet</td>
<td>180</td>
<td>5/22/95</td>
<td>Original: 7/21/95</td>
<td>2/2/96</td>
<td>E13516</td>
<td>$1,257.00</td>
<td>Shipment problems, can't pack as req., will agree and proceed</td>
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</tr>
<tr>
<td>5</td>
<td>Capacitor die</td>
<td>2</td>
<td>Electro Films Inc.</td>
<td>10000 b</td>
<td>4/25/95</td>
<td>5/16/95 c</td>
<td>9/30/95</td>
<td>E09523</td>
<td>$1,020.00</td>
<td>8-28-95: RFQ was faxed to second source: California Micro Devices</td>
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<td>5.1</td>
<td>Capacitor die UNCA-129-50000Dl</td>
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<td>Electro Films Inc.</td>
<td>10000 b</td>
<td>2/5/96</td>
<td>2/8/96</td>
<td>12 weeks</td>
<td>E508200</td>
<td>$485.00</td>
<td># dice, Expected: end May</td>
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<td>6</td>
<td>Heat Resistor</td>
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<td>same as item 6</td>
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<td>7/21/95</td>
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<td></td>
<td>$7,635.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.1</td>
<td>Resistor#MSTF 2SN-80000B-X, 10000, 12001</td>
<td>1</td>
<td>Mini System Inc.</td>
<td>110*3</td>
<td>1/10/96</td>
<td>1/29/96</td>
<td>8w + 4w</td>
<td>E435150</td>
<td>$4,423.00</td>
<td>Expected: 5-10-96</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Si Temperature sensor</td>
<td>1</td>
<td>Univ. of Southampton, Inst. of Cryogenics,</td>
<td>100</td>
<td>7/12/95</td>
<td>7/21/95</td>
<td>U3XD</td>
<td>E21192</td>
<td>$1,600.00</td>
<td>Initial order not including tests.</td>
<td></td>
</tr>
<tr>
<td>7.1</td>
<td>Si Temperature sensor</td>
<td>1</td>
<td>Univ. of Southampton, Inst. of Cryogenics,</td>
<td>200</td>
<td>12/22/95</td>
<td>2/1/96</td>
<td>?</td>
<td>E09139</td>
<td>$9,628.00</td>
<td>ordered</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Thermal platform disc</td>
<td>1</td>
<td>Mill Optics</td>
<td>250</td>
<td>4/21/95</td>
<td>6/19/95</td>
<td>7/13/95</td>
<td>E09139</td>
<td>$2,287.00</td>
<td>Mark - received 20, sent 5 to Goddard</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Support tube</td>
<td>16</td>
<td>IR Laboratories</td>
<td>17</td>
<td>6/8/95</td>
<td>7/14/95</td>
<td>U3XD</td>
<td>E155880</td>
<td>$1,882.00</td>
<td>Non flight parts.</td>
<td></td>
</tr>
</tbody>
</table>

**Total cost for parts:** $156,152

**Notes**

- a. Fourth wafer, the first to meet room temp. requirements.
- b. Whole wafer
- c. Without life test
- d. 110 of 4 different resistance values flight chips + 100 x 4 non-flight.
- e. Passed promised date
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

TRE DETECTOR TO TELESCOPE INTEGRATION

S. WANG
TRE Detector to Telescope Integration and Testing

Telescope Electronics CDR

May 8, 1996

TRE Detector Integration Test Flow

Detector Electronics Test

Probe Wiring Check

Optical Alignment

Mating Connector Check

Detector Telescope Integration

Integrated Detector Test
I. Pre-integration:

- Qualification Testing Before Integration:
  - Radiation
  - Magnetics
  - Calibration of Thermometers on the Thermal Platforms
  - Temperature on Thermal Platform Measured as a Function of Heating Power
  - Functional Performance of TIA Mode
  - Cross Talk Between the Channels
  - Calibration of Output as a Function of Photo Current
  - Test Results of Noise, Linearity, Sensitivity and Photodiode Surface Uniformity
  - Thermal Cycle Reproducibility
Qualification Testing Before Integration (Cont'd)

- Long Term Stability of Better Than 0.05% for At Least Hours*
- Output Sensitivity on Temperature of the Thermal Platform
- Room Temperature Dependence of the Output
- Operational at 10 fA, 10 pA and 10 nA Photo Current Levels at 4.2 K and 2 K Ambient Temperature
- Operational at 10 pA Photo Current at Temperatures Ranging from 300 K to 4.2 K Ambient

Confirm The Optical Alignment of Detectors Packages

- Raster Scan Results to Show the Centering of Light Spots on the Photodiodes

Check Mating Connector on the Telescope Probe -- Magnetics, Continuity
TRE Detector to Telescope Integration and Testing

Telescope Electronics CDR May 8, 1996

♦ Check Wiring on the Telescope Probe -- Continuity

II. Integration Process

♦ Integration Procedure
  • Performed In Class 10 Clean Room
  • Non Magnetic Tools for Flight Parts
  • Proper Thermal and Mechanical Anchoring of Wires
  • Limit Light Input Through Telescope Aperture to Non-Collimated Room Levels for the Protection of Detectors

III. Integrated Tests

♦ Verification of Noise Performance
♦ Verification of Cross Talk
TRE Detector to Telescope Integration and Testing

Telescope Electronics CDR May 8, 1996

- Measurement of Temperature Stability of the Thermal Platform
- Temperature Control of Room Temperature Electronics *
TRE Detector to Telescope Integration and Testing

Telescope Electronics CDR May 8, 1996

*

♦ NEED A FEW HOURS TO PERFORM A LINEARITY SCAN ON TELESCOPE
♦ THE ELECTRONICS OUTPUT NEEDS TO BE STABLE TO 0.05% DURING THE SCAN
♦ AIR CONDITIONER CAN CONTROL TEMPERATURE TO 1 DEGREE WITH A PERIOD OF 20 MIN.
♦ DRIFT OF ELECTRONICS IS MOSTLY FROM TEMPERATURE FLUCTUATIONS

⇒ NEED TEMPERATURE CONTROL OF ROOM TEMPERATURE ELECTRONICS TO ACHIEVE READOUT STABILITY
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

TRE FWD ELECTRONICS DESIGN

R. FARLEY

Partition
Charge-locked loop
Signal paths
Operation Modes
Detector Support Functions
FEE Cables
TRE FWD

Primary

Redundant

Analog  Digital
+ Dir  X-axis
- Dir

Analog  Digital
+ Dir  Y-axis
- Dir

Analog  Digital
+ Dir  X-axis
- Dir

Analog  Digital
+ Dir  Y-axis
- Dir
A layout aid used for assigning connector pins.
• Linear regulators are located on the Analog Board.

• Regulators will require heat sinks.

• Five volts used mostly on the Digital Board.
The Charge Locked Loop

Simplified Schematic
Analog Signal Path

Open loop beyond the CLL

- The +direction signal and the -direction signal paths must have very high gain stability to minimize errors.

- With no attenuation, the Detector Signal Transfer gain is estimated to be $\approx 5.1 \text{ v/(sec-fA)}$
The Charge Locked Loop Reset Cycle

- The rising edge of the 2.2 kHz Data Acquisition clock after the rise of the ATC strobe initiates a data hold period at the input of the 500 Hz low pass filter.

- The detector feedback loop is opened, and the CLL output level is driven to a programmed offset voltage sufficient to cause the closed loop output level to be near zero volts.

- The reset JFET is activated, discharging the photodetector, and preloading the feedback capacitor.

- The reset JFET is turned off, dumping a small amount of charge onto the photodetector anode.

- The feedback loop is closed, and a transient decays.

- The track/hold returns to its input following state, minimizing the transient applied to the low pass filter input.

Simulated waveform after the Track / Hold circuit
Open Loop Transfer Function of the CLL

\[ F(s) = \frac{R_1}{1 + C_1 s R_1} \frac{R_2 \left( R_3 C_2 s + 1 \right) \left( 1 + C_4 s R_2 \right)}{\left( R_3 C_2 s + R_4 C_2 s + 1 \right) R_2} \frac{R_5 + R_6 + R_6 s C_5 R_5}{\left( 1 + s C_5 R_5 \right) R_6} \frac{R_7}{1 + R_7 C_3 s} \]
Gain Control Implementation

- Each detector channel gain is selectable over a range of 256 to 1 in 3dB steps.

- Gain control allows optimal matching of input signal to A/D converter for alternative sources; not intended for plus / minus direction channel matching.

- Resistor ladder network provides $1/\sqrt{2}$ gain per tap. Node resistance is 1.71KΩ. A rad hard 16 Channel Analog Multiplexer selects output tap. Constant impedance at each tap implies uniform frequency response for region of interest.

- This approach uses fewer control bits and less power than a multiplying DAC.

- Design approach is practical, and can achieve good matching between channels by using stable, accurate components.
  - Custom resistor packs from Vishay with ±0.02% absolute tolerance, ±0.6 ppm/°C absolute TCR.
  - 16-pin dual in-line package is symmetrical with optional terminating resistors at each end to allow cascading, and layout flexibility.
Analog Signal Conditioning

Ladder Networks

Analog Multiplexer

Track and Hold Amplifier

from CLL Input Selection to Filter Input

1.0K 30.9K

HOLDUT

HS-0420RH 1000pF

Multiple Feedback Low Pass Filter

from Track and Hold to Line Driver

26.5K 41.2K

0.022uF 20.5K

102K 2.2nF

OP497

10

-10

-20

120

1000

10000

MFB Low-Pass Filter

SSGAIN2.DOC
Control Modes Allow Diagnostics

- The Charge Locked Loop options:
  - Normally the detectors are reset at a periodic rate (ATC Strobe). The feedback is through the 0.5 pF capacitor.
  - Detector Power Enable—connects the -10 volt reference to the source resistors.
  - TIA Mode—The periodic reset cycle is halted. Feedback to the detector node is via the turned-on reset JFET through a 1 MΩ resistor.
  - Inhibit Cycle—a diagnostic mode that inhibits the reset clocks, but the 1 MΩ resistor is not connected.
  - Two control bits invert the sense of the reset clock and the output clamp switch.
    - When INVGAT=0, the TIA amplifier output is driven from the focal plane module; when INVGAT=1, the TIA output is driven from the offset (clamp voltage) DAC.
    - When INVRST=0 the gate drive to the reset JFETs turns the device on; when INVRST=1 the reset JFET is turned off.

- The Engineering Data channel options:
  - The analog multiplexer is normally sequenced through up to 27 signals during the 1/10th second interval.
  - Setting a control bit causes the multiplexer to monitor a specific channel for the whole period. The channel is selected by five address bits.
- Open Loop Control drives heater dac with 12 bit value received from SRE.

- Local Closed Loop Control drives heater dac from an up/down counter, updated on temperature error.
TRE Box Temperature Measurement

- Uses the Temperature output of the REF02 that generates the +5 volt reference voltage.
- Output is amplified with low offset voltage non inverting amplifier.

Plot from the data sheet.

Voltage as indicated by Engineering Data A/D Converter
The Engineering Data Channel
Multiplexed analog voltages

- 23 of the 27 available periods have monitored signals, the remaining channels are grounded.

<table>
<thead>
<tr>
<th>signal name</th>
<th>gain*</th>
<th>signal name</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRE-A/B +X/Y Transimpedance Signal Voltage</td>
<td>0.6667</td>
<td>TRE-A/B X/Y Temperature Command</td>
</tr>
<tr>
<td>Voltage</td>
<td></td>
<td>TRE-A/B X/Y Temperature servo DAC</td>
</tr>
<tr>
<td>TRE-A/B +X/Y Transimpedance Reference Voltage</td>
<td>0.6667</td>
<td>error</td>
</tr>
<tr>
<td>TRE-A/B +X/Y Offset DAC Output</td>
<td>2.0000</td>
<td>TRE-A/B X/Y +12V</td>
</tr>
<tr>
<td>TRE-A/B +X/Y Direction Feedback Point</td>
<td>0.6667</td>
<td>TRE-A/B X/Y -12V</td>
</tr>
<tr>
<td>TRE-A/B -X/Y Transimpedance Signal Voltage</td>
<td>0.6667</td>
<td>TRE-A/B X/Y +5V</td>
</tr>
<tr>
<td>TRE-A/B -X/Y Transimpedance Reference Voltage</td>
<td>0.6667</td>
<td>TRE-A/B X/Y Diode Bias</td>
</tr>
<tr>
<td>Voltage</td>
<td></td>
<td>TRE-A/B X/Y Reference +5V</td>
</tr>
<tr>
<td>TRE-A/B -X/Y Offset DAC Output</td>
<td>2.0000</td>
<td>TRE-A/B X/Y Reference -4V</td>
</tr>
<tr>
<td>TRE-A/B -X/Y Direction Feedback Point</td>
<td>0.6667</td>
<td>TRE-A/B X/Y Reference -10V</td>
</tr>
<tr>
<td>TRE-A/B X/Y Detector Temperature (Silicon Diode Voltage)</td>
<td>6.0026</td>
<td>TRE-A/B X/Y Reset Drive Level</td>
</tr>
<tr>
<td>TRE-A/B X/Y Local Box Temperature (REF02 temperature output)</td>
<td>11.280</td>
<td>TRE-A/B X/Y Reference +0.5V</td>
</tr>
<tr>
<td>TRE-A/B X/Y Heater Voltage</td>
<td>0.6667</td>
<td>TRE-A/B X/Y Reference +5, +0.5, -4, -10</td>
</tr>
</tbody>
</table>

Bias Reference Voltages generated are: +5, +0.5, -4, -10
Box Temperature readout resolution: ≈77 counts/K
Photo Diode Bias DAC range: +3 to -12 v
Detector Temperature readout resolution: ≈35.6 counts/K
Temperature servo error readout resolution: ≈2420 counts/K

*Voltage gain between the monitored point and the differential output.
Digital Logic Functions

- Differential Line Receivers
  Five channels received
- Shift and Storage Registers
  Six groups of 20 bits
- DAC Data Handling
  Six DACs on Analog Board
- Analog Gain Control
  Two 16-input Analog Multiplexers on Analog Board
- Reset Interval Timing
  Three nested intervals required
- Analog Multiplexer Control
  Sequence through 27 channels, or Random Access Selection
- Temperature Servo Integrator
  Closed loop control uses an up/down counter as a digital integrator,
  Open Loop allows direct control of DAC
- Temperature Servo Timing Selector
  Integration timing selectable as ATC Strobe or Seven higher rates
- Mode Control
  Five bits provide test or control options
Timing and Data Definitions

ATC Strobe (10 Hz)
Enable X Data
Enable Y Data

(expanded scale)
68.2KHz Clock
Data transitions on rising edge of clock, stable on falling edge.

Enable

20 Data bits per group.

Data stored on next edge.

Shift Register Clock

Data
Leading '1' 3 address bits 16 bits beneficial data Don't care

Simple Gating assures no glitches.

Clock NAND AND
Enable

SSTIMNG.DOC
Startup Conditions

Before a complete command set is received

- A power-on reset clears all shift register cells to zero.

- Power to the mode decoder is delayed so the temporary storage registers will also be loaded with zeros. The end of the power on reset triggers a load pulse to initialize all of the output registers.

- Heater integrator is zeroed by the power-on reset.

- The temperature Servo mode is open loop.

- All DAC output voltages are scaled to be safe for any input code.

- The first rise of the ATC strobe after all six serial command groups are received begins commanded operation.
## Analog / Digital Partitioning

Separating the functions to minimize interference.

<table>
<thead>
<tr>
<th>Analog Board</th>
<th>Digital Board</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Filter, Line Drivers</td>
<td>--</td>
</tr>
<tr>
<td>• Voltage Regulators and Fixed Analog Biases</td>
<td>--</td>
</tr>
<tr>
<td>• Analog Switch</td>
<td>• Logic Driver</td>
</tr>
<tr>
<td>• Attenuator Multiplexer &amp; Track/Hold</td>
<td>• Channel logic selection &amp; Logic driver</td>
</tr>
<tr>
<td>• JFET reset driver</td>
<td>• Logic for switch control</td>
</tr>
<tr>
<td>• TIA Mode analog switch</td>
<td>• Logic driver</td>
</tr>
<tr>
<td>• Offset DACs</td>
<td>• Latched command word</td>
</tr>
<tr>
<td>• Photodiode bias DAC</td>
<td>• Latched command word</td>
</tr>
<tr>
<td>• Temperature Command DAC</td>
<td>• Latched command word</td>
</tr>
<tr>
<td>• Temperature sensor bias generator, voltage sensing, comparison, gain, error sense.</td>
<td>• Count command, clock, up/down counter, Heater DAC.</td>
</tr>
<tr>
<td>• Housekeeping multiplexer and line driver</td>
<td>• Sequencer control</td>
</tr>
</tbody>
</table>

ADPART.DOC
Parts Selection

Parts must be reliable, accurate, stable, and radiation tolerant.

- **Stable Capacitors for Filters, Loop compensation**
  Hermetically-Sealed, Metalized Polycarbonate, ±1% tolerance, S failure rate
- **Stable Capacitors for Loop compensation, amplifier compensation**
  Ultra-stable Ceramic (CCROx-)
- **Bypass Capacitors for Power decoupling**
  CK0xBX Ceramic
- **Filter Capacitors for Voltage regulator filtering.**
  Solid electrolyte Tantalex®, Hermetically Sealed, Metal Cased, Tubular, B failure rate.

- **Stable Precision Resistors for Critical gain sensitive locations**
  Vishay S102C Bulk Metal® Foil, ±0.6ppm/°C TCR, ±0.1% tolerance, very stable.

- **Precision Resistors used for General applications, isolation**
  RN55C Metal Film, ±1% tolerance, ±50ppm/°C

- **Power isolation Resistor**
  RWR81S Molded Wirewound

- **Semiconductors**
  Packages: Ceramic DIP or Metal Can
  Harris Rad Hard SOS HCSxx or HS-xxxx
  Analog Devices DI or LC²MOS or Bi-polar
  Burr-Brown Difet®
  National Semiconductor LM140H & LM120H voltage regulators
CABLE DESIGN

EMI FILTER/CONNECTOR - DESIGNED & MANUFACTURED BY JERRIK
CABLE AND ATTENUATION COVER - DESIGNED & MANUFACTURED BY GLENAIR

TOPHAT

TRE

ECU
Cable Manufacturing Specifications

- **LAC SPEC 3200 Fabrication and Assembly of Harness and Cable**
  - Proper installation of Foil Sheath

- **LAC SPEC 0411 Termination of Shielded Cables**
  - Requirements for termination of shields on shielded cables

- **MPS627-076 (Material Process Specification)**
  - Round Braid Shield Termination

- **MPS627-091**
  - Shield and Overwrap Termination

- **MPS627-092**
  - Terminate Harness Shield and Overwrap (rectangular connectors)
Open Issues

- Need values of JFET capacitances (influences the CLL compensation).
  — Resolution: will measure when equipment arrives.

- Selecting method for balancing the differential gain stage.
  — Resolution: review and select among the following options.
    - A commandable DAC to allow slightly offsetting the -4 volts to the reference gate.
    - Laser trimming the cold resistors.
    - Both of the above.

- Verification of frequencies used for updating the temperature controller (local closed loop control).
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

TRE FORWARD ELECTRONICS ENCLOSURE

R. AJITOMI
FWD TRE ELECTRONICS LOCATION

- Telescope Readout Electronics (TRE) A located 22.5 deg from +X axis
  - TRE B located 90 deg from TRE A

- Location determined by:
  - Shortest cable length
  - 90 deg separation
  - Increase in FWD GSU/PMSU height
    » From 4” to 7.75”
  - FWD SRE located for max. thermal radiation
• Top Hat to FWD TRE
  – 79 pin cylindrical connector, P/N# D38999/24FG35SN
• FWD TRE to FWD SRE
  – 22 pin cylindrical connector, digital cable, P/N# D38999/24FC35PN
  – 37 pin cylindrical connector, analog cable, P/N# D38999/24FD35PN
## MECHANICAL DESIGN/REQUIREMENTS

<table>
<thead>
<tr>
<th>Spec Section Number</th>
<th>Parameter Name</th>
<th>Required Value</th>
<th>Verif.</th>
<th>Design Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3.8.8</td>
<td>POWER</td>
<td>10W</td>
<td>T</td>
<td>10W</td>
</tr>
<tr>
<td>3.2.8.2</td>
<td>WEIGHT</td>
<td>6.25kg</td>
<td>I</td>
<td>6.25kg</td>
</tr>
<tr>
<td>3.2.8.1</td>
<td>LENGTH</td>
<td>17 in.</td>
<td>I</td>
<td>17 in.</td>
</tr>
<tr>
<td>3.2.8.1</td>
<td>WIDTH</td>
<td>9.7 in.</td>
<td>I</td>
<td>9.7 in.</td>
</tr>
<tr>
<td>3.2.8.1</td>
<td>HEIGHT</td>
<td>3.0 in.</td>
<td>I</td>
<td>3.0 in</td>
</tr>
<tr>
<td>3.2.8.3</td>
<td>Relative Clocking Angle</td>
<td>90°</td>
<td>I</td>
<td>90°</td>
</tr>
</tbody>
</table>

- Material - Aluminum 6061-T651
- Manufacturing Process - Machining (hog out)
- Flat Black Silicone on box exterior per LAC SPEC 37-4777-0300
  - Emissivity of .89
## Thermal Requirements

<table>
<thead>
<tr>
<th>Spec Number</th>
<th>Parameter Name</th>
<th>Required Value</th>
<th>Achieved to Date</th>
<th>Verif.</th>
<th>Test Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2.8.4</td>
<td>Roll; Box pk to pk Max temp variation</td>
<td>0.1 K</td>
<td></td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>3.2.8.5</td>
<td>Roll; Board Max gradient pk to pk temp variation</td>
<td>0.025 K</td>
<td></td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>3.2.8.6</td>
<td>Orbital; Box pk to pk Max temp variation</td>
<td>2 K</td>
<td></td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>3.2.8.7</td>
<td>Annual; Box pk to pk Max temp variation</td>
<td>20 K</td>
<td></td>
<td>T</td>
<td></td>
</tr>
</tbody>
</table>

## Thermal Design
- Operating Temperature Range: 286-294K
  - Analysis done with FWD GSU at 2 watts
- Hog out Maximizes Thermal Uniformity of Enclosure
- Requires Forward Equipment Enclosure (FEE)
  - Passive thermal control design
  - 0.05 deg Box pk to pk variation at roll with FEE (preliminary thermal study 20 July 1994)
OPEN ISSUES

• Thermal Study
  - Detailed Thermal Analysis to be Performed After PC Board Layout is Completed

• Ionizing Radiation
  - Natural Orbital Environmental Spec. P0149
    » Stanford System Engineering will Analyze Enclosure Design for Survivability
TRE DETECTOR & ASSEMBLY MANUFACTURING FLOW

@ STANFORD

- KAPTON MANUFACTURE
  - @ WATTS MACHINING
    - TITANIUM MACHINING

@ STANFORD

- ASSEMBLY

@ GENERAL OPTICS

- BEAMSPLITTER
  - @ WATTS MACHINING
    - TITANIUM MACHINING

@ LMMS

- ALIGNMENT PERFORMANCE TEST
  - @ LMMS
    - ALIGNMENT PERFORMANCE TEST
    - DELIVER

@ STANFORD

- ASSEMBLY
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

QUALITY ASSURANCE AND RELIABILITY
FOR FORWARD ELECTRONICS

G. SWART
ELECTRONICS
FABRICATION, ASSEMBLY, TEST
OBJECTIVES

BUILD MISSION-CAPABLE ELECTRONICS HARDWARE

- PROVIDE OPERATIONAL MARGINS VERIFIED BY ANALYSIS OR TEST
- PROVIDE DOCUMENTATION PER APPLICABLE SPECIFICATIONS
- USE TAILORED MIL-SPEC AND NHB-5300.4 PROCESSES
- USE TAILORED CONFIGURATION CONTROL

FABRICATION & ASSEMBLY FACILITIES

The Space Payloads and Dynamics & Control Electronics Laboratories (buildings 255/250) are well qualified, experienced, certified and equipped for flight electronics hardware assembly, with over 5,000 square feet of process/test area.
- Workstations, Personnel, Certifications
- Equipment, Cleanliness, Electrostatic Discharge Protection

LGB-2
MANUFACTURING

CONFIGURATION CONTROL
MIL-STD-130, NHB5300.4 (1C),(3K)  
MSFC STD 506 C

HANDLING & STORAGE
JA-447B, MSFC-STD-506C, NHB5300.4 (1C)

ELECTROMAGNETIC COMPATIBILITY
MSFC-SPEC-461D

ELECTROSTATIC DISCHARGE PROTECTION
MSFC-STD-506C  
NHB5300.4 (3A-1)

CLEANING
MSFC-STD-506C

CERTIFICATIONS
NHB5300.4 (3H), (3A-1), MSFC STD 506 C

INSPECTION
NHB5300.4 (1C), (3A-1), (3H)

ELECTRONICS DOCUMENTATION
NHB5300.4 (3K)
MANUFACTURING

SPECIAL PARTS CONSIDERATIONS
MIL-STD-975, MIL-STD-883B

MATERIAL & PROCESSES
MSFC-STD-506C

BOARD FABRICATION
NHB 5300.4 (3I), MIL-P-55110C

CONFORMAL COATING
NHB5300.4 (3J)

BOARD ASSEMBLY
NHB5300.4 (3I), (3H), (3G), (1C), (3K), (3A-1)

VERIFICATION AND TEST
MSFC-SPEC-1198C, MSFC-SPEC-521 B
MSFC-HDBK-1453

ENVIRONMENTAL TESTING
JA-418-A, MSFC-HDBK-1453
PRODUCT ASSURANCE

Requirements:
PRODUCT ASSURANCE REQUIREMENTS HAVE BEEN TAILORED TO THE NEEDS OF THE GP-B PROGRAM DESCRIBED IN STU ELECTRONICS PRODUCT ASSURANCE PLAN, DATED 14 AUG 92

Implementation:
LMSC SAFETY, RELIABILITY, MAINTAINABILITY AND PRODUCT ASSURANCE PLAN, (F428533, FOR GP-B PROGRAM)

Reliability

Paragraphs 1C201 through 1C311 of NHB 5300.4 (1C):
☆ Inspection System Plan, ☆ Handling, Packing, Packaging Procedures
☆ Government Property Records, ☆ Procurement Documents
☆ Raw Material Test Reports, ☆ Inspection and Test Procedures
☆ Inspection and Test Records, ☆ Process Control Procedure
☆ Process Control Records, ☆ Nonconformance Documentation
☆ Metrology System Procedures, ☆ Sampling Plans
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

VERIFICATION AND TEST PLAN FOR TRE

M. TAPLEY

Matrix
Environmental Tests
EMC
Radiation Tests
Subsystem Tests
Integrated Payload Tests
Space Vehicle Tests
VERIFICATION MATRIX

• Verification Matrix Integrated With Spec In Database

• Derived Performance Specs Have Driven Design Analyses; Critical Derivations (ie Annual Drift) Will Be Written Up As P-Documents

• T003 Flow-Down For Critical Parameters Captured In TRE Requirement Text Will Be Entered As Links In Database

• Complete Flow-Down Analysis (T003, Payload Spec, SIA Spec) Presented In Data Package This Review
TEST PLAN

General Environmental Compatibility

- Flight Unit Box Thermal Testing
  - Operation And Survival Ranges From FEE Thermal Specs
  - Variations At Roll And Orbital Rates Defined In FEE Thermal Specs
    - Test Will Include Detector Or Dummy Load (See Below)
  - Verifies Thermal Coefficients Computed From Part Data

- Flight Unit Vibration Testing
  Vibration Profile In Specification

- Meteoroid And Debris Specs Will Be Verified By Analysis

- Vacuum/Neutral Gas Environment
  Verified In Thermal-Vac Testing (Subsystem And Integrated SV)
  Plasma N/A Due To FEE Enclosure

May 8, 1996
Electromagnetic Compatibility

- EMI Tests On Box Will Be Carried Out According To EMI Test Plan
  - EMITP Modified From MIL-STD-461D (More Stringent For GP-B)

- Engineering Unit EMI Test Suite Approx. 1Q97

- EMI Effect On Detector - GTU2 EMI Tests And Bench Tests In LN$_2$ (1Q97)
  - Sunshade Attenuation Tested Separately

- EMI / Grounding / Shielding Review May 14 Will Give More Details

Radiation Tests

- Parts Individually Tested Or Vendor Radiation Test Data Used

- Integrated Detector Package Exposed To Proton Bombardment 4Q96

- Charge Trapping, etc. Will Be Tested In Parts Tests

May 8, 1996
Subsystem Tests

- JFET Noise To Be Characterized In Dewar And RT Tests Down To 0.1 Hz

- Detector Testing In Test Dewar 2Q 1996
  - Verified Detector Functionality Cold
  - Verified Performance Against LED Light Source.

- Detector + Telescope 2 Testing 3Q 1996 With AS #2
  - Verify System Assembly/Alignment And Detector Performance (PDR 31)
  - Indicates Linearity. (IDR 18)

- Engineering Unit Box Testing 4Q 1996/1Q 1997

- Flight Unit Box Testing 4Q 1997
Subsystem Tests (cont.)

- Phase Delay As A Function Of Temperature
  - Precisely Quantify Delays (Phase Shifts) In TRE Data System
Integrated Payload Tests

- Artificial Star 3 Tests In SP Integrated Testing
- Box Fuctionality Testing 2Q97 (Engineering Unit) 1Q98 (Flight Unit)

Space Vehicle Tests

- Integrated Space Vehicle Testing Confirms Box And Detector Aliveness
- On-Orbit Verification Confirms Noise Numbers
- On-Orbit Dither Against Rate Gyros
  - Provides Additional Data And Confirms Pointing Simulations
- GS-Invalid Periods During SM
  - Dark Signal Calibrates Radiation Influence On Detectors And Elx.
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

SCHEDULE

J. BURNS
## TELESCOPE ELECTRONICS

### OVERVIEW SCHEDULE

<table>
<thead>
<tr>
<th></th>
<th></th>
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<td>1</td>
<td>2</td>
<td>3</td>
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<td>2</td>
</tr>
</tbody>
</table>

**TELESCOPE READOUT ELECTRONICS**

**TRE BREADBOARD DEVELOPMENT**

- **9/30/94:** TSCOPE ELX PRELIM. DESIGN & TESTING
- **10/5/94:** TSCOPE BREADBOARD COMPLETE
- **11/15/94:** DESIGN & FAB TSCOPE ELX BREAD BOARD (Rev.B)
- **12/12/94:** TRE BREADBOARD (REV.B) COMPLETE

**TRE ENGINEERING UNIT DEVELOPMENT**

- **3/1/95:** DETECTOR PKG ASSEMBLY
- **3/15/95:** TSCOPE ELX ENG. UNIT DESIGN, FAB & TEST
- **4/15/95:** TSCOPE ENGINEERING UNIT COMPLETE

**TRE FLIGHT HARDWARE DEVELOPMENT**

- **5/28/95:** TSCOPE READOUT ELECTRONICS CDR
- **6/1/95:** TRE DETECTOR CDR
- **6/30/95:** FLIGHT DETECTOR QUALIFICATION TESTING
- **6/30/95:** FLIGHT DETECTOR PKG ASSEMBLY
- **6/30/95:** FLIGHT READOUT MODULES AVAILABLE
- **7/1/95:** TSCOPE READOUT FLT MODEL DESIGN
- **7/31/95:** TRE FLIGHT HARDWARE FAB
- **8/1/95:** TRE FLIGHT HARDWARE TEST
- **8/15/95:** TRE FLIGHT HARDWARE DELIVERY

**GROUND TEST UNIT 2 (PROBE B & SMD)**

- **8/1/95:** GTU 2 INTEGRATION & TEST

**SM PAYLOAD FLIGHT VERIFICATION (PROBE C / SMD)**

- **9/1/95:** SM FLIGHT VERIFICATION INTEGRATION & TEST

### LEGEND

- CRITICAL MILESTONE
- MAJOR MILESTONE
- TECHNICAL MILESTONE
- PROGRAM ACTIVITY
- PROGRESS ON ACTIVITY
- CURRENT CHANGES TO
  START OR COMPLETE DATES

**Rev. Number:** R-8  
**Data Date:** 29APR96
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

DEVELOPMENT TESTS

H. DEMROFF
1) LIQUID NITROGEN DEWAR  4 LITER
2) BREADBOARD ELECTRONICS
   A) TEMPERATURE SENSE AND BIAS CARD
   B) TIMING AND RESET CARD
   C) 2 DETECTOR AMPLIFIER CARD FOR X+ AND X-, Y+ AND Y-
3) SR 760 FFT SPECTRUM ANALYZER
4) TEKTRONIX TDS 540 FOUR CHANNEL DIGITAL SCOPE WITH 15 BIT RESOLUTION
5) GPIB INTERFACE CARD (IEEE 488.2) FOR AUTOMATED DATA ACQUISITION
TRE OUTPUT FOR EXPECTED MINIMUM LIGHT INTENSITY
These oscilloscope traces show the reset pulse occurring within the output clamp.
Measured Leakage Current 0.01fA  Photodiode Bias 4.1 volt

Meets Requirement TRE PLSE-13, Pt 3.2.18.3
Measured Leakage Current < .005 fA  Photodiode Bias 0 volt
TELESOCPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

ERROR BUDGET AND PERFORMANCE PREDICTION

K. COLEMAN

Bias Variation Estimation
SPICE Model
Error Tree
TRE BIAS VARIATION ESTIMATE

Example:

<table>
<thead>
<tr>
<th>Error Source</th>
<th>Excitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vgs mismatch</td>
<td>Delta Temp 2mK Peak</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset Value (mV/K @ roll)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>marcs/offset</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bias error Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02 marcs</td>
</tr>
</tbody>
</table>

- ERRORS ARE WORST CASE AT ROLL
- TRE CIRCUIT SENSITIVITIES ARE DETERMINED IN SPICE
BIAS VARIATION ERROR TREE

Bias Variation

Allocation: 0.05 marcs
Estimate:

Detector 0.03 marcs

Detector Interface 0.03 marcs

Forward Electronics 0.02 marcs

Data Acquisition System 0.002 marcs
Bias Stability in TRE Spec

1st Stage Amplifier 0.025 marcs

Photodiode 0.02 marcs

Detector Contributions to Bias Variation
* Vgs of Preamp Mismatch in FET
* Differential Leakage Current @Summing Node

Feedback Line 0.005 marcs

Photodiode Cathode Voltage 0.02 marcs

1st Stage Reference Voltage 0.02 marcs

Leakage Currents 0.01 marcs

Amplifier Offset Voltage 0.001 marcs

Amplifier Input Bias Current 0.001 marcs

Forward Electronics Contributions to Bias Variation Temperature Coefficient
* Component Temperature Coefficients
* Thermocouple Voltages

Interface Contributions to Bias Variation Temperature Coefficient
* Thermocouple Voltages
* Leakage Currents
* Filter Attenuation
* EMI Rectification

* ERRORS ARE WORST CASE AT ROLL
* TRE CIRCUIT SENSITIVITIES ARE DETERMINED IN SPICE
BIAS VARIATION ERROR TREE

Detector

Allocation: 0.03 marcs
Estimate:

1st Stage Amplifier 0.025 marcs

Vgs Mismatch 0.02
<1% Temp Co. mismatch

Leakage Current @ summing node 0.005
Leakage current Temp Co. matched to < 500 e-/s/K

Photodiode 0.001 marcs

QE Mismatch 0.001
QE differential change < 1% Temp Co. Mismatch

* ERRORS ARE WORST CASE AT ROLL
* TRE CIRCUIT SENSITIVITIES ARE DETERMINED IN SPICE
BIAS VARIATION ERROR TREE

Detector Interface

Allocation: 0.03 marcs
Estimate:

Feedback Line 0.005

Photodiode Cathode Voltage 0.02

1st Stage Reference Voltage 0.02

Leakage Current 0.01

Probe Cables 0.005

300pA @ Roll

Top Hat Connector 0.005

300pA @ Roll

Filter Attenuation 0.01

0.001% Stability

Thermocouple Voltages 0.01

Peak Thermocouple voltage @ roll ~ 10μV/K

EMI Rectification 0.005

Peak Thermocouple voltage @ roll ~ 10μV/K

TRE Electrical Temp Co 0.01

< 1% Temp Co. mismatch

Filter Attenuation 0.01

0.001% Stability

Thermocouple Voltages 0.01

Peak Thermocouple voltage @ roll ~ 10μV/K

TRE Electrical Temp Co 0.01

< 1% Temp Co. mismatch

Filter Attenuation 0.005

300pA @ Roll

FEE Cable 0.005

300pA @ Roll

TRE Connector 0.005

300pA @ Roll

* ERRORS ARE WORST CASE AT ROLL
* TRE CIRCUIT SENSITIVITIES ARE DETERMINED IN SPICE
BIAS VARIATION ERROR TREE

Forward Electronics

Allocation: 0.02 marcs
Estimate:

Amplifier Offset Voltage 0.025marcs

Input Offset Voltage Temp Co. 0.025marcs

5uV/deg C

Amplifier Input Bias Current 0.025marcs

Input Bias Current Temp Co. 0.02marcs

4.8fA/deg C

Radiation Induced Bias Current Changes 0.02marcs

* ERRORS ARE WORST CASE AT ROLL
* TRE CIRCUIT SENSITIVITIES ARE DETERMINED IN SPICE
TELESCOPE READ-OUT ELECTRONICS
CRITICAL DESIGN REVIEW

WRAP-UP

P. EHRENSBERGER

On-orbit Verification
Mission Time Line
ON ORBIT VERIFICATION

Pre-mission:
Large and small amplitude dither operations - scale-factor measurement and look for anomalous response.
Detector thermal control evaluation - test thermal control modes for detector and select one. Observation of guide star and neighbors - verify calibration of magnitude signal
Monitor redundant electronics during roll-up - study temp coef of bias in forward electronics.
Sunshade performance evaluation - verify that sunshade is performing adequately.
(method not identified to date)

Mission:
Guide Star Invalid mode provides data to verify bias variation in TRE (detector and fwd). Redundant channel read out provides a way to evaluate bias variation due to temperature and/or or radiation effects in forward electronics during Guide Star Valid. Monitor magnitude signals to verify sunshade performance.

Post-mission:
Enhance temperature variation in forward electronics to verify temperature coef (no method identified to date).
Enhance temperature variation in detector to verify temperature coef.
<table>
<thead>
<tr>
<th>Time</th>
<th>Task Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>210</td>
<td>Turn on other Payload exel.</td>
</tr>
<tr>
<td>260</td>
<td>Turn on telescope detector heaters</td>
</tr>
<tr>
<td>280</td>
<td>Power detectors (30 min. after heaters turned on)</td>
</tr>
<tr>
<td>300</td>
<td>Telescope reset sequence</td>
</tr>
<tr>
<td>321</td>
<td>Turn ON Proton Monitor</td>
</tr>
<tr>
<td>340</td>
<td>Bake out of windows 1 - 4</td>
</tr>
<tr>
<td>410</td>
<td>Activate Shutter to Normal Operation</td>
</tr>
<tr>
<td>550</td>
<td>Limb shutter operation (2 orbits)</td>
</tr>
<tr>
<td>600</td>
<td>Return to normal shutter operation</td>
</tr>
<tr>
<td>610</td>
<td>Scan for Guidestar and neighboring stars</td>
</tr>
<tr>
<td>620</td>
<td>Initiate fine Guidestar</td>
</tr>
<tr>
<td>660</td>
<td>Check Guidestar telemetry</td>
</tr>
<tr>
<td>670</td>
<td>Validate Guidestar</td>
</tr>
<tr>
<td>680</td>
<td>Large Inertial Amp Dither (200marcs)</td>
</tr>
<tr>
<td>710</td>
<td>Small Amp Dither (35marcs)</td>
</tr>
<tr>
<td>715</td>
<td>Inertial Dither (200marcs)</td>
</tr>
<tr>
<td>720</td>
<td>Albedo Assessment/Calibration</td>
</tr>
<tr>
<td>725</td>
<td>Monitor redundant exel. while increasing roll rate (T/S-D)</td>
</tr>
<tr>
<td>790</td>
<td>Telescope Thermal Control Evaluation</td>
</tr>
<tr>
<td>810</td>
<td>Sunshade Performance Evaluation</td>
</tr>
<tr>
<td>1122</td>
<td>Large Inertial Amp Dither (200marcs)</td>
</tr>
</tbody>
</table>

----------LOW TEMPERATURE BAKE-OUT----------

1870: Turn on all probe heaters (warm-up) - 6 hours
1880: Maintain "low temp bake-out" thermal env. (4 hours)
1890: Close probe gate and SG exhaust valves
1900: Test back-up mode: "rate-gyroless" (Telescope Cal.)
1910: Final exel. set point check (Telescope Cal.)
# RELATIVITY MISSION TIMELINE DATASET - 
## TELESCOPE SUBSET (COMMANDS AND TELEMETRY)

<table>
<thead>
<tr>
<th>Event #</th>
<th>Associated Commands</th>
<th>Associated Telemetry</th>
<th>Event #</th>
<th>Associated Commands</th>
<th>Associated Telemetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1.0</td>
<td>HLD from CCCA to Alt SPRE A</td>
<td>TRE A x DTemp, TRE A y DTemp</td>
<td>6.8.0</td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td>2.6.0</td>
<td>Set x detector heater A</td>
<td>TRE A x DTemp</td>
<td>6.9.0</td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td></td>
<td>Set x detector heater B</td>
<td>TRE B x DTemp</td>
<td></td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td></td>
<td>Set y detector heater A</td>
<td>TRE A y DTemp</td>
<td></td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td></td>
<td>Set y detector heater B</td>
<td>TRE B y DTemp</td>
<td></td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td>2.8.0</td>
<td>Power x detector A</td>
<td>TRE A x DTemp</td>
<td>7.1.0</td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td></td>
<td>Power x detector B</td>
<td>TRE B x DTemp</td>
<td></td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td></td>
<td>Power y detector A</td>
<td>TRE A y DTemp</td>
<td></td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td></td>
<td>Power y detector B</td>
<td>TRE B y DTemp</td>
<td></td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td>3.0.0</td>
<td>asynchronous reset, set snapshot monitor mode</td>
<td>Snapshot: detector signal telemetry</td>
<td>7.1.5</td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td>3.2.1</td>
<td>PDU: Proton Monitor On</td>
<td>SF DITHERAMP</td>
<td></td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td>3.4.0</td>
<td>SP Dither</td>
<td>SF DITHER</td>
<td></td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td>4.1.0</td>
<td>Remove power to shutter to disable closed (TBD) : Lim Mar</td>
<td>Detector signals: TRE A (+x) (-x), TRE B (+x) (-x)</td>
<td>7.2.0</td>
<td>set snapshot monitor mode</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRE A (+x)DET, TRE A (-x)DET</td>
<td></td>
<td>open and close shutter to given angle</td>
<td>Shutter Open/close detectors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRE B (+x)DET, TRE A (-x)DET</td>
<td>7.2.5</td>
<td></td>
<td>Shutter Open/close detectors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRE B (+y)DET, TRE A (+y)DET</td>
<td>7.5.0</td>
<td></td>
<td>Shutter Open/close detectors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRE B (+y)DET, TRE A (+y)DET</td>
<td>8.1.0</td>
<td>Switch to gyro pointing</td>
<td>Std Tm : TBD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRE B (-y)DET, TRE A (-y)DET</td>
<td></td>
<td>Point Telescope at large star-free area of space</td>
<td>Std Tm : TBD</td>
</tr>
<tr>
<td></td>
<td>Shutter lim (TBD)</td>
<td></td>
<td></td>
<td>Return to Guider pointing</td>
<td>Std Tm : TBD</td>
</tr>
<tr>
<td>5.5.0</td>
<td>set snapshot monitor mode</td>
<td>Detector signals: (as in 410)</td>
<td>11.2.0</td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td></td>
<td>open and close shutter to given angle</td>
<td>Shutter Open/close detectors</td>
<td></td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td>6.0.0</td>
<td>set snapshot nominal mode</td>
<td>Detector signals: (as in 410)</td>
<td>11.2.0</td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td></td>
<td>open and close shutter to given angle</td>
<td>Shutter Open/close detectors</td>
<td></td>
<td>SF DITHERAMP</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td>6.1.0</td>
<td>Detector signals: (as in 410)</td>
<td>SF DITHERAMP</td>
<td>11.3.0</td>
<td>Detector signals: (as in 410)</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td>6.2.0</td>
<td>Initiate guider star acquisition</td>
<td>SF DITHERAMP</td>
<td>11.4.0</td>
<td>Detector signals: (as in 410)</td>
<td>Detector signals: (as in 410)</td>
</tr>
<tr>
<td>6.9.0</td>
<td>Detector signals: (as in 410)</td>
<td>SF DITHERAMP</td>
<td>11.5.0</td>
<td>Detector signals: (as in 410)</td>
<td>Detector signals: (as in 410)</td>
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<tr>
<td>6.7.0</td>
<td>PP GSV</td>
<td>11.6.0</td>
<td>Change mode to gyroless</td>
<td>19.1.0</td>
<td></td>
</tr>
</tbody>
</table>