TIDI CDR Review Meeting
April 28 - 30, 1998

TIMED DOPPLER INTERFEROMETER

TIDI

NASA • UM • CAN • UK • GER
TIDI Critical Design Review
April 28, 1998 - April 30, 1998

Presented for the
Johns Hopkins University
Applied Physics Laboratory

by the

Space Physics Research Laboratory
T. Killeen - Principal Investigator
C. Edmonson - Project Manager
W. Skinner - Instrument Scientist
H. Grassl, P. Hansen, J. Harvey - Co-Systems Engineers
CDR Data Package - Table of Contents

- Section A - Introduction
- Section B - Science & Measurement Requirements
- Section C - Systems Design
  - C.1 Systems Overview
  - C.2 Requirements Flow-down
  - C.3 Instrument Performance Modeling
  - C.4 Calibration Approach
- Section D - Telescope Subsystem
  - D.1 Overview
  - D.2 Telescopes Design
  - D.3 Fiber Optics Design
  - D.4 Telescope Servo Mechanism
- Section E - Profiler Subsystem
  - E.1 Overview
  - E.2 Optical Design
  - E.3 Mechanical Design
  - E.4 Thermal & Structural Design
  - E.5 Detector
- Section F - Electronics Subsystem
  - F.1 Overview
  - F.2 Mechanical Design
  - F.3 CCD Control Deck
  - F.4 Power Supply Deck
  - F.5 Flight Computer Deck
  - F.6 Data Acquisition Deck
  - F.7 Motor/Heater Control Deck
  - F.8 Calibration Deck
  - F.9 Telescope Servo Deck
  - F.10 Harnesses
  - F.11 Electronics Assembly & Test
- Section G - Flight Software
  - G.1 Flight Software
  - G.2 Spacecraft Simulator
- Section H - Ground Subsystem
  - H.1 Overview
  - H.2 Mission Ops Computer System
  - H.3 Mission Ops Software
  - H.4 TIDI I&T, Calibration & Qualification
  - H.5 Spacecraft Installation & I&T
  - H.6 Initial Flight Ops
- Section I - Reliability, Performance Assurance & Parts Management
  - I.1 Safety & Contamination
  - I.2 Parts & Materials
- Appendices (supplement)
# 4/28/98 Agenda

<table>
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<tr>
<th>Topic</th>
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# 4/30/98 Agenda

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Review Team
- Mark Mayr (APL) - Chair
- Josef Wonserver (GSFC) - Co-chair
- Terry Harris (APL) - Optics
- Marilyn Fortin (GSFC) - CCDs/Detectors
- Louis Fantano (GSFC) - Thermal
- Jason Budinoff (GSFC) - Mechanical
- Dan Rodriguez (APL) - Digital Electronics
- Robin Gary (APL) - Software

• APL Instrument Oversight and S/C Engineering Team:
  - Sam Yee - Mission Scientist
  - Ed Prozeller - Payload Manager
  - Doug Mehoke - Inst Tech Rep
  - Kevin Heffernan - Instrument Systems
  - Glen Cameron - S/C Systems
  - Larry Mastracci - Program Assurance
  - Al Sadilek - S/C Alignment
  - Bruce Williams - S/C Thermal
  - Ed Schaefer - S/C Structure
  - Steve Vernon - S/C Mechanical
  - Ted Sholar - Telescope Lead
  - Keith Peacock - Telescope Optics
# TIDI Engineering Support Organization

**Systems Eng.**  
Skinner, Grassl  
Harvey, Hansen

**Mechanical Design & Test**  
Harvey, Jones  
Techs: Milspaugh, TBH  
Students: Mckee, Durwin, LeMonde  
Contract: Midwest Design

**Mech. Fab.**  
Navarre  
U-M Physics Shop (CAM)  
Contracts: Creative Machine Works  
Webson, Machining, ERIM

**Parts Mgt.**  
Raygorodsky  
Students: Knoch, Fernandez, Lee  
TBH

**Ground Data Sys**  
Hardware: Gell  
AOSS Network Support Group

**Elect. Design**  
Rizor  
Contracts: Ann Arbor Engineering, Avid Design  
David Goldstein

**Detector Assy**  
Electrical: Miller  
Mech/Thermal: Harvey  
Test Protocols & Evaluation: Skinner  
Software: Marshall, Hale (student)

**Calibration**  
Gell  
Skinner, Grassl, Niciejewski  
Students: Azeem, TBH

**SC Simulator/ EGSE**  
Musko  
Software: Rego (contract)  
Hardware: Rogacki

**Mission SW**  
Gell  
Burek, Ortland, Marshall  
Student: Zhu  
Post Doc (TBH)

**Flight Assembly**  
Lee  
Huetteman, Boprie, Quada

**LVPS**  
Arnett  
Student: Haviland

TIDI CDR 4/28, 4/29/98  
A.9 Edmonson
TIDI Science Team Organization

TIMED Scientist
S. Yee (APL)

TIMED SWG
T. Killeen, TIDI PI

SPRL Science Team
W. Skinner  R. Niciejewski  Q. Wu
R. Johnson  A. Burns  D. Gell  D. Ortland
Post Doc  TBH
Graduate Students:  I. Azeem  TBH

TIDI Co-I Team
T. Fuller-Rowell
P. Hays  R. Johnson
R. Rees  S. Mende  R. Roble  W. Gault
C. Hines  B. Kennedy  A. Richmond  W. Skinner  G. Shepherd  U. von Zahn
## Design & Development Status

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TIDI CDR 4/28, 4/29/98

A.11 Edmonson
# Tall Poles - Technical & Schedule Risk Areas

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## Milestone Schedule to Delivery

<table>
<thead>
<tr>
<th>Task Name</th>
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<tr>
<td>CDR</td>
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<tr>
<td>Engineering Electronics I&amp;T</td>
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<tr>
<td>Flight SW / Electronics I&amp;T</td>
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<td>Flight Electronics I&amp;T</td>
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<td>Flight Optics Delivery</td>
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<td>Optics Breadboard &amp; Test</td>
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<tr>
<td>Filter Wheel Complete</td>
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<td>Flight Detector Complete</td>
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<td>Profiler I&amp;T</td>
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<td>Ground I&amp;T SW Complete</td>
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<td>Telescopes Delivered</td>
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<td>TIDI Instrument level I&amp;T</td>
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<tr>
<td>Final Flight SW I&amp;T</td>
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<td>TIDI Calibration</td>
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<td>TIDI Qualification</td>
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<td>TIDI Verification</td>
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**TIDI CDR 4/28, 4/29/98**
<table>
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<tr>
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<tbody>
<tr>
<td>TID-CoDR-01</td>
<td>Submit a new S/C resource requirements table which reflects the TIDI baseline instrument and the baseline measurement requirements. Add spacecraft velocity knowledge to the table.</td>
<td>H.Grassl</td>
<td>Closed</td>
<td>TIDI PDR C.17</td>
</tr>
<tr>
<td>TID-CoDR-02</td>
<td>Perform a trade study of TIDI providing the star camera function vis-a-vis APL providing an optical bench for mounting the four telescopes and the S/C star camera.</td>
<td>APL (D.Kusn...)</td>
<td>Delete</td>
<td></td>
</tr>
<tr>
<td>TID-CoDR-03</td>
<td>Trade off the following for mounting the TIDI sensor pkg: a) The current CoDR mounting configuration b) Hole in the +Y panel which exposes most of the sensor baseplate to space (55 x 30 cm). c) Mounting the sensor on the +Z panel with the telescopes.</td>
<td>APL (D.Kusn...)</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TID-CoDR-04</td>
<td>Perform an analysis to determine the expected sensitivity of the star camera. Will the star camera be capable of imaging stars dimmer than 4th magnitude in 1 second? Consider the effect of the spread of the star image over 9 fibers. Baseline requires overscan telescopes due to att errors, earth oblateness, orbit eccentricity. Assuming RT att and S/C pos info (1553), and ±25 km orbit eccentricities, redesign scan profile. Can adjacent telescopes scan common atm volume &quot;n&quot; scans apart?</td>
<td>D.Gell</td>
<td>Closed</td>
<td>Star camera eliminated</td>
</tr>
<tr>
<td>TID-CoDR-05</td>
<td>Determine how many and how often stars of 4th magnitude or brighter enter the star camera field of view.</td>
<td>T.Killeen</td>
<td>Closed</td>
<td>TIDI PDR Appendix 14</td>
</tr>
<tr>
<td>TID-CoDR-06</td>
<td>a) Describe how centroiding will be implemented? Examine b) total star movement in the 1 sec integ period. c) effect of S/C jitter. d) effect of dead fibers. e) effect of 0.05 deg Scene Selector accuracy on centroiding accuracy. The TIDI star cameras are fixed at 45 deg azimuth which makes pitch and roll separation difficult. Evaluate methods to separate pitch from roll and determine accuracy.</td>
<td>D.Gell</td>
<td>Delete</td>
<td>Star camera eliminated</td>
</tr>
<tr>
<td>TID-CoDR-07</td>
<td></td>
<td>D.Gell</td>
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<td>Star camera eliminated</td>
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<tr>
<td>TID-CoDR-08</td>
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<td>D.Gell</td>
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<td>Star camera eliminated</td>
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## Action Item Response Matrix (2)

<table>
<thead>
<tr>
<th>AI #</th>
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<th>Status</th>
<th>Response Location</th>
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<tbody>
<tr>
<td>TID-CoDR-09</td>
<td>TIDI science requirements include the measurement of O2 density to 10% accuracy and the measurement of temperature to 2 K. Demonstrate that this can be accomplished.</td>
<td>W.Skinner</td>
<td>Closed</td>
<td>TIDI PDR B.76</td>
</tr>
<tr>
<td>TID-CoDR-10</td>
<td>Examine the effect of the interference from the O2 adjacent lines and the effect of asymmetry on the overall line shape.</td>
<td>W.Skinner</td>
<td>Closed</td>
<td>TIDI PDR, Appendix 15, B.78</td>
</tr>
<tr>
<td>TID-CoDR-11</td>
<td>Determine whether O2 pressure or density data from SABER would be of use to TIDI science.</td>
<td>T.Killeen</td>
<td>Closed</td>
<td>TIDI PDR B.79</td>
</tr>
<tr>
<td>TID-CoDR-12</td>
<td>What is the electron to A/D count conversion planned to be used by TIDI and what is the effect on TIDI measurement error?</td>
<td>SPRL/Kennedy</td>
<td>Closed</td>
<td>TIDI PDR C.31, D. Mehoke e-mail 4/8/98</td>
</tr>
<tr>
<td>TID-CoDR-13</td>
<td>What is the expected intrascene dynamic range of both the Profiler and the Star Camera? Examine the impact on the 12 bit / channel telemetry (reference the 48,000 cts/channel on pg A19 of CoDR package). Specify the attitude control, determination, stability, and jitter requirements.</td>
<td>SPRL/Kennedy</td>
<td>Closed</td>
<td>TIDI PDR C.31, D. Mehoke e-mail 4/8/98</td>
</tr>
<tr>
<td>TID-CoDR-14</td>
<td>Separate the S/C requirements from the instrument and specify in &quot;not to exceed&quot; terms.</td>
<td>D.Gell</td>
<td>Closed</td>
<td>TIDI PDR Appendix 27</td>
</tr>
<tr>
<td>TID-CoDR-15</td>
<td>The current plan is to broadcast attitude data once/second: How accurately does the sample time of the attitude data being broadcast need to be known?</td>
<td>S.Musko</td>
<td>Closed</td>
<td>TIDI PDR Appendix 11</td>
</tr>
<tr>
<td>TID-CoDR-16</td>
<td>How often is attitude data stored on the tape recorder? What is the accuracy of the attitude solution broadcast onboard?</td>
<td>APL(F.Mobley, J. Perschy)</td>
<td>Closed</td>
<td>APL</td>
</tr>
<tr>
<td>TID-CoDR-17</td>
<td>In order to implement the event driven command scheme TIDI will require broadcast events. Provide a list of the required events.</td>
<td>D.Gell</td>
<td>Closed</td>
<td>TIDI PDR Appendix 28</td>
</tr>
<tr>
<td>AI #</td>
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<td>Assignee</td>
<td>Status</td>
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<td>--------------------------------------------</td>
</tr>
<tr>
<td>TID-CoDR-18</td>
<td>Will the S/C provide: a) selected HK TLM monitors and autonomous shutdown? b) an instrument heartbeat function? c) what parameters will be broadcast on the 1553 bus? d) will the S/C avoid KOZs (i.e. sun down telescope aperture) if TIDI is unpowered?</td>
<td>APL (D. Kusn)</td>
<td>Closed</td>
<td>APL</td>
</tr>
<tr>
<td>TID-CoDR-19</td>
<td>Analyze the effect of the sun in the field of view. How long before the fiber optics are affected? Any other sensitive components? If this is a problem, develop a &quot;Safe Mode&quot; concept.</td>
<td>H. Grassl</td>
<td>Closed</td>
<td>Superseded by Tel-PDR AI 3</td>
</tr>
<tr>
<td>TID-CoDR-20</td>
<td>Perform thermal analysis on telescopes. Calc worst case hot and cold temps, the effect of temp gradients on focus and alignment, and, how far the telescopes must protrude from the S/C to provide enough radiator area to maintain the temps within reason.</td>
<td>H. Grassl</td>
<td>Closed</td>
<td>TIDI PDR E.5</td>
</tr>
<tr>
<td>TID-CoDR-21</td>
<td>Update the conduction and radiation heat leaks into the CCD/TEC system to verify the total radiator area.</td>
<td>H. Grassl</td>
<td>Closed</td>
<td>TIDI PDR F.2</td>
</tr>
<tr>
<td>TID-CoDR-22</td>
<td>Determine whether the TEC for the Star Camera can be eliminated.</td>
<td>H. Grassl</td>
<td>Delete</td>
<td>Star camera eliminated</td>
</tr>
<tr>
<td>TID-CoDR-23</td>
<td>Determine the percentage of science data is lost because the sun is in the clear field of view.</td>
<td>D. Gell</td>
<td>Closed</td>
<td>TIDI PDR Appendix 29</td>
</tr>
<tr>
<td>TID-CoDR-24</td>
<td>Define envelopes and footprints for each package. If there are requirements for a thermally conductive surface or gasket, define it. The definitions of interfaces and envelopes should include any radiators or cutouts in the S/C panel. Provide a drwg that defines the total and clear fields of view for each telescope. Include dimensions to the origin from some reference pt defined by the envelope such that the S/C can establish proper placement and I/Fs to the telescopes. CCD alignment is critical. Specify the CCD alignment requirements for both the Profiler and the Star Camera and provide a procedure explaining how this will be accomplished including accessibility.</td>
<td>W. Pinkus</td>
<td>Closed</td>
<td>TIDI PDR Appendix 23 &amp; 24</td>
</tr>
<tr>
<td>TID-CoDR-25</td>
<td></td>
<td>H. Grassl</td>
<td>Closed</td>
<td>TIDI PDR Appendix 22</td>
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# Action Item Response Matrix (4)

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<tr>
<td>TID-CoDR-27</td>
<td>Define the coalignment specifications of the four telescopes. Include both the initial mechanical alignment and alignment knowledge specifications and the short and long term thermal drift requirements. The cantelevered telescope mounting concept shown in the CoDR data package is unacceptable. Provide a new mounting concept and analyze to show the design will survive vibration and maintain required pointing accuracy. Define how the telescopes and other moving mechanisms are caged and/or secured for the launch environments. If caging is not required, explain why and indicate expected loads and margins.</td>
<td>H.Grassl</td>
<td>Closed</td>
<td>TIDI PDR Appendix 19, F.1.9</td>
</tr>
<tr>
<td>TID-CoDR-28</td>
<td>Define mechanism design min torque margins. Indicate how friction thru the system will be determined and show that mtrs and/or actuators have sufficient margin to accomodate friction + loads. Show how the flexing of cables is accounted for in the margins.</td>
<td>J.Harvey</td>
<td>In review</td>
<td>See CDR Data Package D.4.7 - D.4.9, E3.10</td>
</tr>
<tr>
<td>TID-CoDR-30</td>
<td>Provide torque vs. time for each of the moving parts of the instrument. Investigate alternative mechanisms for the telescope covers. If baselining the sublimation type mechanism, look into the possible contamination and early actuation issues.</td>
<td>W.Pinkus</td>
<td>Closed</td>
<td>Superceded by IAW-05b.</td>
</tr>
<tr>
<td>TID-CoDR-31</td>
<td>Determine whether sublimation type mechanisms are acceptable for use on the TIMED S/C. The scene selector encoder has a resolution of 360/1024=0.35 deg. The accuracy requirement is 0.05 degrees. Explain how this can work.</td>
<td>APL(K. Heffernan)</td>
<td>Delete</td>
<td>TIDI PDR E.1.4</td>
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<td>TID-CoDR-32</td>
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<td>SPRL/Pinkus</td>
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<td>TID-CoDR-33</td>
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<td>W.Pinkus</td>
<td>Delete</td>
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<tr>
<td>TID-CoDR-34</td>
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<td>W.Pinkus</td>
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## Action Item Response Matrix (5)

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<tr>
<td>TID-CoDR-35</td>
<td>The angular resolution requirements of the telescope exceeds the resolution of the encoder. Explain how to obtain the resolution required with this approach.</td>
<td>SPRL/Pinkus</td>
<td>Closed</td>
<td>Angle encoders eliminated from design</td>
</tr>
<tr>
<td>TID-CoDR-36</td>
<td>Several of the mechanisms will go thru more than 10 million cycles over the life of the mission. Explain the plan for life testing of mechanisms.</td>
<td>J.Harvey</td>
<td>In review</td>
<td>See CDR Data Package D.4.7 - D.4.9, E3.10</td>
</tr>
<tr>
<td>TID-CoDR-37</td>
<td>Define the minimum resonant frequency required to avoid the highest launch loads. Define the need for instrument accessibility required (for any reason) after integration to the S/C. Discuss in particular, access required to the calibration lamps. Define a list of red tag items.</td>
<td>APL(E.Schaefer)</td>
<td>Closed</td>
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<tr>
<td></td>
<td></td>
<td>SPRL/Grassl</td>
<td></td>
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<tr>
<td>TID-CoDR-38</td>
<td>Raytrace the telescope to give the image energy distribution at each wavelength in the defocussed condition. Verify that this is adequate for centroiding which improves image location by an order of magnitude.</td>
<td>W.Pinkus</td>
<td>Closed</td>
<td>TIDI PDR C.33</td>
</tr>
<tr>
<td>TID-CoDR-39</td>
<td>Design and raytrace the Telescope and the Profiler.</td>
<td>H.Grassl</td>
<td>Closed</td>
<td>Star camera eliminated</td>
</tr>
<tr>
<td>TID-CoDR-40</td>
<td>Address the issue of dead fibers due to telescope rotation. How many can you lose before it becomes a problem for the Profiler (200 fibers total) and the star camera? How do you determine if a fiber is dead after launch?</td>
<td>H.Grassl</td>
<td>Closed</td>
<td>TIDI PDR Appendix 8 (Profiler), Appendix 9 (telescope)</td>
</tr>
<tr>
<td>TID-CoDR-41</td>
<td>Re-examine the Profiler filter bandwidths. Is the 3ang for white light rejection only? If so, what Happens if the lines of interest fall in the wrong channel?</td>
<td>D.Gell</td>
<td>Open</td>
<td>See CDR Data Package H.4.9 and Calibration Plan (CDR Appendix)</td>
</tr>
<tr>
<td>TID-CoDR-42</td>
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<td>W.Skinner</td>
<td>Closed</td>
<td>TIDI PDR Appendix 16, B.78</td>
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### Action Item Response Matrix (6)

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<tr>
<td>TID-CoDR-43</td>
<td>Determine the Surface Cleanliness specification for the telescope optics and</td>
<td>H.Grassl</td>
<td>Open</td>
<td>See &quot;Telescope Scattering Considerations&quot; memo (055-3583) and draft APL Telescope</td>
</tr>
<tr>
<td></td>
<td>the effect of this on the BRDF of the telescope.</td>
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<td>Contamination Control Plan (7372-9001) in CDR Appendix</td>
</tr>
<tr>
<td>TID-CoDR-44</td>
<td>Specify the cleanliness requirements for S/C integration. In particular, specify</td>
<td>J.Eder</td>
<td>Closed</td>
<td>TIDI PDR Appendix 4</td>
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<tr>
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<td>what class cleanroom, and any S/C surface cleanliness level and hydrocarbon</td>
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<td>requirements.</td>
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<tr>
<td>TID-CoDR-45</td>
<td>Provide pwr profile vs time for nom ops; include peak pwr. Show req'ts for</td>
<td>W.Pinkus</td>
<td>Closed</td>
<td>TIDI PDR G.1.16</td>
</tr>
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<td></td>
<td>launch, init turn-on, ops modes and deploym'ts. Include htr pwr req'ts and</td>
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<td>constraints (i.e. nightside event only). Provide full on peak pwr, and, how</td>
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<td>peak pwr is controlled.</td>
<td></td>
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<tr>
<td>TID-CoDR-46</td>
<td>Review the proposed TIDI grounding scheme.</td>
<td>APL(G. Seylar)</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Show design will meet the EMI req'ts. Concerns: worst case noise from mtr</td>
<td>SPRL/Pinkus</td>
<td></td>
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<tr>
<td></td>
<td>ops (telescope, scene select, and filter whl) when they coincide, higher freq</td>
<td></td>
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<tr>
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<td>noise due to many diff freqs and beat freqs from PWMs, resonant and piezo</td>
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<tr>
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<td>oscillators, Cal lamps, etc.</td>
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</tr>
<tr>
<td>TID-CoDR-47</td>
<td>Add two power supplies to the electronics for thermal electric cooler control.</td>
<td>W.Pinkus</td>
<td>Closed</td>
<td>TIDI PDR Section G.10</td>
</tr>
<tr>
<td>TID-CoDR-48</td>
<td>Provide the TIDI team with S/C bus voltage vs. time on a fractional orbit</td>
<td>APL(G.</td>
<td>Closed</td>
<td>T/E cooler deleted</td>
</tr>
<tr>
<td></td>
<td>basis for the life of the mission.</td>
<td>Dakermanji)</td>
<td></td>
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</tr>
<tr>
<td>TID-CoDR-49</td>
<td>Verify the mass of the flight computer electronics, board plus frame, and any</td>
<td>H.Grassl</td>
<td>Closed</td>
<td>TIDI PDR Appendix 26</td>
</tr>
<tr>
<td>TID-CoDR-50</td>
<td>added heat sinking necessary to allow 8.5 MIPS peak processing.</td>
<td></td>
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</tr>
<tr>
<td>AI #</td>
<td>Description</td>
<td>Assignee</td>
<td>Status</td>
<td>Response Location</td>
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</tr>
<tr>
<td>TID-CoDR-51</td>
<td>Update the TIDI Calibration Plan. Analyze effect on the 3 m/sec wind velocity knowledge req't of the following: a) ±1 km alt knowledge error, b) 1° roll control error on the wind reference (diff winds top to bot and left to right), c) knowledge of the free spectral range, d) stray light.</td>
<td>D.Gell</td>
<td>Closed</td>
<td>TIDI PDR Appendix 30</td>
</tr>
<tr>
<td>TID-CoDR-52</td>
<td>Demonstrate how the long term, short term and temperature drift error of 0.4 m/sec can be obtained. How can you improve the HRDI 1.7 m/sec to 0.4 m/sec for TIDI? Provide a detailed conceptual design of the focal plane detector assembly.</td>
<td>D.Gell</td>
<td>Closed</td>
<td>TIDI PDR B.56</td>
</tr>
<tr>
<td>TID-CoDR-53</td>
<td>TIDI-IAW-01 Supply purge requirements to APL including: max. time w/o purge; purity, flow rate, and launch pad purge requirements.</td>
<td>W.Skinner</td>
<td>Closed</td>
<td>TIDI PDR Appendix 36</td>
</tr>
<tr>
<td>TID-CoDR-54</td>
<td>Show the location of the analog electronics, the thermal path for the radiator, etc.</td>
<td>H.Grassl</td>
<td>Closed</td>
<td>TIDI PDR F.1.17</td>
</tr>
<tr>
<td>TIDI-IAW-02</td>
<td>Fairing environment air-conditioning information to TIDI</td>
<td>S.Vernon</td>
<td>Closed</td>
<td>Steve V 9/12 e-mail</td>
</tr>
<tr>
<td>TIDI-IAW-03</td>
<td>Review S/C cleanliness requirement, provide to APL.</td>
<td>T.Clausen</td>
<td>Closed</td>
<td>E-mail from Terry.</td>
</tr>
<tr>
<td>TIDI-IAW-04</td>
<td>Resolve clear FOV discrepancy. Verify that the telescope height used in the S/C mechanical layout is correct.</td>
<td>J.Harvey</td>
<td>Closed</td>
<td>Fax from Jon Harvey. --&gt; Vernon, Kouch, Kozuch. Waiting feedback from Vernon.</td>
</tr>
<tr>
<td>TIDI-IAW-05a</td>
<td>Torque versus time to APL (first cut)</td>
<td>T.Clausen</td>
<td>Closed</td>
<td>Email from Terry --&gt; Schaefer, Haley, Kuch</td>
</tr>
<tr>
<td>TIDI-IAW-05b</td>
<td>Torque versus time to APL (final)</td>
<td>T.Clausen</td>
<td>Closed</td>
<td>TIDI PDR E.5.12, Ed S. OK 3/27/98</td>
</tr>
<tr>
<td>TIDI-IAW-06</td>
<td>Agree on torque margin required for moments.</td>
<td>E.Schaefer</td>
<td>Closed</td>
<td>Ed Schaefer 9/20 e-mail. Torque margin required is 2.75 CoDR, 2.50 PDR, 2.25 CDR, 2.0 Accept.</td>
</tr>
<tr>
<td>AI #</td>
<td>Description</td>
<td>Assignee</td>
<td>Status</td>
<td>Response Location</td>
</tr>
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<td>---------</td>
<td>------------------------------------------------------------------------------</td>
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<td>-----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>TIDI-IAW-07</td>
<td>Produce caging analysis and qualification plan.</td>
<td>T. Sholar</td>
<td>In review</td>
<td>See CDR D.2.21 and T. Sholar e-mail 4/13/98</td>
</tr>
<tr>
<td>TIDI-IAW-08</td>
<td>Provide first cut mechanical I/F drawing, and a first cut FOV drawing by 11/15/96 for inclusion in the first TIDI SIIS draft.</td>
<td>J. Harvey</td>
<td>Closed</td>
<td>TIDI PDR Appendix 23</td>
</tr>
<tr>
<td>TIDI-IAW-09</td>
<td>Determine minimum conductance or heat leaks from telescopes into optical bench. (The ultimate objective is to define the thermal isolation point. The choices are at the deck or at the bearing interface.)</td>
<td>Ercol/Williams</td>
<td>Closed</td>
<td>D. Mehoke e-mail 4/8/98 (Heffernan)</td>
</tr>
<tr>
<td>TIDI-IAW-10</td>
<td>Provide thermal gradients and stability requirements</td>
<td>J. Harvey</td>
<td>Closed</td>
<td>D. Mehoke e-mail 4/8/98 (Heffernan)</td>
</tr>
<tr>
<td>TIDI-IAW-11</td>
<td>Review power spreadsheet</td>
<td>K. Heffernan</td>
<td>Closed</td>
<td>E-mail to Terry on 9/27. Waiting update to table.</td>
</tr>
<tr>
<td>TIDI-IAW-12</td>
<td>Provide first cut thermal I/F drawing for inclusion in the first TIDI SIIS draft.</td>
<td>J. Harvey</td>
<td>Open</td>
<td>Telescope (APL) drawings not yet complete. SPRL to release Telescope ICD drawing to APL by TIDI CDR.</td>
</tr>
<tr>
<td>TIDI-IAW-13</td>
<td>Review and tighten optical bench temperature range.</td>
<td>B. Williams</td>
<td>Closed</td>
<td>Old limits -55 C to 20C, new limits -15 C to 45 C. CDR package, thermal sec</td>
</tr>
<tr>
<td>TIDI-IAW-14</td>
<td>Answer broadcast message presentation questions.</td>
<td>TIDI (Gell)</td>
<td>Closed</td>
<td>Memo from Dave Gell (Need to distribute)</td>
</tr>
<tr>
<td>TIDI-IAW-15</td>
<td>Review GIIS for completeness of C&amp;DH memory load formats.</td>
<td>APL (Perschy)</td>
<td>Closed</td>
<td>E-mail from Musko --&gt; Perschy, Grunberger. Updated version of C&amp;DH section to IDTs on 10/2.</td>
</tr>
<tr>
<td>TIDI-IAW-16</td>
<td>Provide preferred first circuit interface information to instrument.</td>
<td>APL (Perschy)</td>
<td>Closed</td>
<td>E-mail from J. Perschy</td>
</tr>
<tr>
<td>TIDI-IAW-17</td>
<td>Determine how to bond profiler and telescopes to S/C structure.</td>
<td>J. Harvey</td>
<td>Closed</td>
<td>Fax from Jon describing details on how to bond; looking for bond locations.</td>
</tr>
</tbody>
</table>
### Action Item Response Matrix (9)

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>TIDI-IAW-18</td>
<td>Define instrument mode word.</td>
<td>TIDI (Clausen)</td>
<td>Closed</td>
<td>Superceded by TIM-07</td>
</tr>
<tr>
<td>TIDI-IAW-19</td>
<td>Review TIDI fuse(s) size and sizing philosophy.</td>
<td>D.Kooch</td>
<td>Closed</td>
<td>Kuch email 10/2. Mehoke to do e-mail on details</td>
</tr>
<tr>
<td>TIDI-IAW-20</td>
<td>Provide first cut at TIDI structural Model. Derive TIDI ops modes (day and night). Estimate measurement (derived wind/temperature) errors based on these baseline modes. Give errors as f(altitude) according to the integ times allocated for each TH. Rationale includes:</td>
<td>J.Harvey</td>
<td>Closed</td>
<td>TIDI PDR F.3.5</td>
</tr>
<tr>
<td>TIDI-PDR-01</td>
<td></td>
<td>W.Skinner</td>
<td>Closed</td>
<td>D. Mehoke e-mail 4/8/98</td>
</tr>
<tr>
<td>TIDI-PDR-02</td>
<td>Conduct stray light analysis on all emission features possibly to be used by TIDI. Perform analysis on its effect on wind and temperature retrievals based on more realistic (expected) brightness profiles and filter band widths.</td>
<td>W.Skinner</td>
<td>Open</td>
<td>See &quot;Telescope Scattering Considerations&quot; memo (055-3583) in CDR appendix</td>
</tr>
<tr>
<td>TIDI-PDR-03</td>
<td>Clarify the TIDI measurement accuracies. Are 1-3 m/sec wind accuracies and 2K temperature accuracies line-of-sight numbers or inverted numbers? There are many error sources which can contribute to the final measurement errors.</td>
<td>W.Skinner</td>
<td>Closed</td>
<td>D. Mehoke e-mail 4/8/98</td>
</tr>
<tr>
<td>TIDI-PDR-04</td>
<td>Present detailed resource requirements (requirements for spacecraft/mission operations) for TIDI star alignment calibration. Detail the yaw maneuver required, account for spacecraft settling time, integration time, the number of stars ......</td>
<td>D.Gell</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIDI-PDR-05</td>
<td>TIDI cannot obtain 4 high res emission spectra at 32 equal-wavelength channels emission spectra. Because of different binning patterns for each telescope, the wavelength grids for each of the 32-channels are different. How to deal with in data analysis?</td>
<td>W.Skinner</td>
<td>Delete</td>
<td></td>
</tr>
<tr>
<td>TIDI-PDR-06</td>
<td>The TIDI FPI has a FSR of 0.22 cm^-1 (based on a gap of 2.2 cm). For a finesse of 14.0 (only reflectivity finesse is considered), the instrument resolution (width) is ~0.22 cm^-1/14.0=0.016cm^-1. Assuming only one order of the free spectral range will ......</td>
<td>W.Skinner</td>
<td>Closed</td>
<td>CDR C.3.23 WU, D. Mehoke e-mail 4/20/98</td>
</tr>
</tbody>
</table>

TIDI CDR 4/28, 4/29/98

A.22 Edmonson
### Action Item Response Matrix (10)

<table>
<thead>
<tr>
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<th>Status</th>
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</tr>
</thead>
<tbody>
<tr>
<td>TIDI-PDR-07</td>
<td>For O2 emission, the Doppler width of an emission line is ~0.01 cm-1 (or ~0.015 cm-1 for O emission lines) at 200K and it increases to 0.022 cm-1 (or ~0.03 cm-1 for O) at 800K. How well can TIDI measure Doppler temp with an instrument res of 0.016 cm-1? ...</td>
<td>W. Skinner</td>
<td>Delete</td>
<td>D. Mehoke e-mail 4/8/98</td>
</tr>
<tr>
<td>TIDI-PDR-08</td>
<td>Determine optimum field stop size to match fiber optic focal plane. Quantify FOV broadening (throughput vs. spatial crosstalk) for the field stop chosen. Demonstrate effects of instrument FOV broadening (figure E.2.11) on wind and temp measurements.....</td>
<td>W. Skinner</td>
<td>Closed</td>
<td>D. Mehoke e-mail 4/8/98</td>
</tr>
<tr>
<td>TIDI-PDR-09</td>
<td>Re-evaluate and re-allocate pointing and alignment error budget among subsystems as necessary. Include optical axis to cube #1, cube #1 to cube #2, and effect of mag pedestal on graphite epoxy optical bench. Distinguish between short and long term errors.</td>
<td>D. Gell</td>
<td>Open</td>
<td>See CDR pages C.2.44 - C.2.49 also see the &quot;TIDI System Specification Document&quot; Section 3.3 in Appendix. Balance of issues to be addressed at APL Telescope CDR</td>
</tr>
<tr>
<td>TIDI-PDR-10</td>
<td>Regarding the purge system: provide max time w/o purge for telescopes (different from profiler), agree on time in flow to remove telescope purge lines on (or just prior to) pad, provide min. temp. which telescope can scan with purge lines in place.</td>
<td>T. Sholar</td>
<td>In review</td>
<td>See APL draft Contamination Control Plan in Appendix. To be closed at telescope CDR</td>
</tr>
<tr>
<td>TIDI-PDR-11</td>
<td>Provide a Contamination Control Plan for the telescope. Include cleanliness requirements, flowdown from science requirements, effects on spacecraft integration facilities and procedures in addition to instrument level requirements.</td>
<td>T. Sholar</td>
<td>In review</td>
<td>See APL draft Contamination Control Plan in Appendix. To be closed at telescope CDR</td>
</tr>
<tr>
<td>TIDI-PDR-12</td>
<td>Provide a test matrix that details the tests that will be run for each of the components and the TIDI instrument.</td>
<td>J. Eder</td>
<td>In review</td>
<td>Draft: 2/20/1997; Update: 9/97; Final: CDR, Go thru with Kevin H.</td>
</tr>
<tr>
<td>TIDI-PDR-13</td>
<td>Show that the thermal req'ts are met for: a) 1.5 degrees C maximum allowable temperature gradient along fiber optic entrance, and b) 1.0 degrees C maximum allowable temperature gradient from center to edge of primary mirror.</td>
<td>J. Ercol</td>
<td>Closed</td>
<td></td>
</tr>
</tbody>
</table>
## Action Item Response Matrix (11)

<table>
<thead>
<tr>
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<th>Status</th>
<th>Response Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIDI-PDR-14</td>
<td>APL to complete weight lightening study of the telescope prior to work stoppage. The results of this study can change the pivot point location and affect the optical bench design, both of which must be completed prior to restart.</td>
<td>T.Sholar</td>
<td>Closed</td>
<td>Replace by Telescope PDR action item.</td>
</tr>
<tr>
<td>TIDI-PDR-15</td>
<td>Develop an approach to protect the fiber optic cables from damage due to heavy mechanical contact or dropped objects, particularly during spacecraft integration and test. Candidate approaches are metal guards or stiff conduit. Define S/C deck temps and margins. Main concern is test temp range. Give predictions, operational and survival design ranges, and operational and survival test ranges. Define any gradient or stability reqt's in the area of TIDI. Include results in GIIS.</td>
<td>S.Vernon</td>
<td>Closed</td>
<td>Concept: 5/1/97; Final: 10/1/97; Jon and Steve agreed in telecon 9/97.</td>
</tr>
<tr>
<td>TIDI-PDR-16</td>
<td>Profiler thermal design and analysis: a) Verify environ heat loads generated by TSS with TRASYS, (with B. Williams.), b) define all heat loads from indiv sources (e.g. internal dissipation, ext envir, gains/losses thru cables, etc.) List each. c) ........</td>
<td>B.Williams</td>
<td>Closed</td>
<td>4/15/97 e-mail, CDR package, not in GIIS, rqmt's in SIIS</td>
</tr>
<tr>
<td>TIDI-PDR-17</td>
<td>Confirm FOV clearances for new CCD Radiator concepts and placement of profiler on S/C. Evaluate specifically wrt glint into telescope aperture. How should the &quot;peak&quot; peak powers be handled? Should S/C or instrument monitor current for this case? What parameters, thresholds, time exceeding threshold, and action should be taken in the event of a problem? Proper criteria for selecting fuses? ......</td>
<td>J.Harvey</td>
<td>Closed</td>
<td>a: 5/1/97; b - g: 2/1/98; will get a PDR update at the May TIM and re-evaluate the b-g due date at that time</td>
</tr>
<tr>
<td>TIDI-PDR-18</td>
<td>Reconsider not having reset command and relying on power cycle for TIDI instrument reset. Issues are: (1) undue stressing of power supply, (2) loss of configuration data in RAM.</td>
<td>D.Kouch</td>
<td>Closed</td>
<td>S. Vernon memo E-mail from Kooch, D. Mehoke to include monitoring current by inst, inst allocation includes peak, fuse sized for peak-peak</td>
</tr>
<tr>
<td>TIDI-PDR-19</td>
<td></td>
<td>D.Kooch</td>
<td>Closed</td>
<td></td>
</tr>
</tbody>
</table>

TIDI CDR 4/28, 4/29/98

A.24 Edmonson
<table>
<thead>
<tr>
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<th>Status</th>
<th>Response Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIDI-PDR-21</td>
<td>Regarding motor drive FET's, consider gate rupture susceptibility of radiation-hardened parts vs. derating a non-Rad-hard part to 50% of rated VDS. Review MIL-STD-461 test reports from HRDI to ascertain nature and magnitude of any out-of-spec conditions related to the calibration deck; work with APL EMC engineer to see if modifications or waiver are required for TIDI. APL to provide specific standard first circuit interface for 1553 bus interface circuit. Circuit should include EMI filtering required to meet EMI specifications</td>
<td>L.Liebler</td>
<td>Closed</td>
<td>Action Item not responded to, but overtaken by events. Goal was to allow input to cal deck design. Design too far along.</td>
</tr>
<tr>
<td>TIDI-PDR-22</td>
<td>Develop telescope pointing error budget using LVDT. Consider stability/repeatability of null over LVDT temp, thermal distortion of pedestal wrt telescope housing, expansion of LVDT linkage rods, etc. Consider thermal isolation, add'l htrs, Moire angle....</td>
<td>T. Sholar</td>
<td>Open</td>
<td>See CDR pages C.2.44 - C.2.49 also see the &quot;TIDI System Specification Document&quot; Section 3.3 in Appendix. Balance of issues to be addressed at APL Telescope CDR</td>
</tr>
<tr>
<td>TIDI-PDR-25</td>
<td>Provide a preliminary design for the flight software. This should define the software modules at high level. Include in this a discussion/rationale of the 16 vs. 20 Hz issue. In addition, provide timing requirements in your software req'ts spec. Provide POCC S/W Req'ts materials to APL for review. (See Steve Musko’s S/W Req'ts for flight S/W as an example.) This documentation or material should convey module requirements, timing, sizing, external interfaces, and fault tolerances and recovery. POC Ops Timeline: a. Verify that the GPS can predict orbits up to 8 wks in advance with a few minutes of accuracy. b. Verify that more than one CCSDS cmd can be sent in a cmd msg file. c. Verify that the POCs can send a week's worth of cmd msgs in advance.</td>
<td>S.Musko</td>
<td>Closed</td>
<td>submitted to R. Gary</td>
</tr>
<tr>
<td>TIDI-PDR-26</td>
<td></td>
<td>D.Gell</td>
<td>Closed</td>
<td>submitted to R. Gary</td>
</tr>
<tr>
<td>TIDI-PDR-27</td>
<td></td>
<td>R.Gary</td>
<td>Closed</td>
<td></td>
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### Action Item Response Matrix (13)

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</thead>
<tbody>
<tr>
<td></td>
<td><strong>TIDI-PDR-28</strong>&lt;br&gt;Set up FTP site for project that holds latest version of documents, such as the GHIS, SRS, and the ECT. Random e-mailing of documents/sections can get unwieldy if one is not sure of the latest version and too many copies are propagated.&lt;br&gt;There are a number of technical issues and divisions of responsibility which have not yet been cleared up between APL and SPRL. A specification with clear lines of responsibility for tasks and unambiguous requirements needs to be generated and agreed upon. 11% mass margin at this point in the telescope’s development is inadequate. Improve the mass budget by determining and tracking maturity of components, and plan on expected margin at future stages of development. Suggest that additional mass be obtained. Analyze impact of direct sunlight with the cover open for two conditions: shutter open (effect on fiber optic) and shutter closed (effect on shutter). Analyze for both thermal and optical effects.</td>
<td>K.Heffernan</td>
<td>Closed</td>
<td>(truncated @ 256 characters)</td>
</tr>
<tr>
<td></td>
<td><strong>TIDI-Tel-PDR-01</strong>&lt;br&gt;There are a number of technical issues and divisions of responsibility which have not yet been cleared up between APL and SPRL. A specification with clear lines of responsibility for tasks and unambiguous requirements needs to be generated and agreed upon. 11% mass margin at this point in the telescope’s development is inadequate. Improve the mass budget by determining and tracking maturity of components, and plan on expected margin at future stages of development. Suggest that additional mass be obtained. Analyze impact of direct sunlight with the cover open for two conditions: shutter open (effect on fiber optic) and shutter closed (effect on shutter). Analyze for both thermal and optical effects.</td>
<td>T.Sholar</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>TIDI-Tel-PDR-02</strong>&lt;br&gt;Develop a clear specification of the telescope’s development. Improve the mass budget by determining and tracking maturity of components, and plan on expected margin at future stages of development. Suggest that additional mass be obtained. Analyze impact of direct sunlight with the cover open for two conditions: shutter open (effect on fiber optic) and shutter closed (effect on shutter). Analyze for both thermal and optical effects.</td>
<td>T.Sholar</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>TIDI-Tel-PDR-03</strong>&lt;br&gt;Stray light requirement is ambiguous. Needs to be clearly defined by SPRL and agreed upon by APL. Evaluate preliminary BRDF. Does the BRDF for the mirror and baffle design give the off-axis performance which meets the TIDI requirements?</td>
<td>W.Skinner</td>
<td>Open</td>
<td>See &quot;Telescope Scattering Considerations&quot; memo (055-3583)</td>
</tr>
<tr>
<td></td>
<td><strong>TIDI-Tel-PDR-04</strong>&lt;br&gt;Stray light requirement is ambiguous. Needs to be clearly defined by SPRL and agreed upon by APL. Evaluate preliminary BRDF. Does the BRDF for the mirror and baffle design give the off-axis performance which meets the TIDI requirements?</td>
<td>T.Sholar</td>
<td>In review</td>
<td>See APL draft Contamination Control Plan in Appendix. To be closed at telescope CDR</td>
</tr>
<tr>
<td></td>
<td><strong>TIDI-Tel-PDR-05</strong>&lt;br&gt;Determine if atomic oxygen will be a problem for the primary mirror coating, or any other materials or coatings.</td>
<td>K.Peacock</td>
<td>In review</td>
<td>SRI-97-068</td>
</tr>
</tbody>
</table>
# Action Item Response Matrix (14)

<table>
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<tr>
<th>AI #</th>
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<th>Status</th>
<th>Response Location</th>
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</thead>
<tbody>
<tr>
<td>TIDI-Tel-PDR-07</td>
<td>Analyze the impact of the focal plane curvature on TIDI instrument design and performance. Determine whether to increase the slit width to 0.25 mm to increase the throughput, and if so, whether a curved or larger fiber optic bundle is required. Evaluate</td>
<td>K.Peacock</td>
<td>Closed</td>
<td>SRI-97-068</td>
</tr>
<tr>
<td>TIDI-Tel-PDR-08</td>
<td>What is the effect of the non-uniform energy distribution (in both the tangential and sagital plane direction)? Is it acceptable? What wavelength is it simulated at? How does this vary with wavelength from 5577Å to 8650 Å?</td>
<td>K.Peacock</td>
<td>Closed</td>
<td>SRI-97-068</td>
</tr>
<tr>
<td>TIDI-Tel-PDR-09</td>
<td>Perform a depressurization analysis, or, at the very least, use “rules of thumb” for vent area vs. volume. Removing the cable guard in order to install the fiber optic cable is a problem.</td>
<td>M.Kreitz</td>
<td>Closed</td>
<td>memo from M. Kreitz 2/12/98</td>
</tr>
<tr>
<td>TIDI-Tel-PDR-10</td>
<td>Resolve this design dilemma. Determine the order of integration of the various TIDI instrument components. Shielded twisted pairs for the wire cutters would add resistive torque. Investigate alternative wiring/shielding methods and whether they would be approved by the VAB Safety office. If necessary to use TSP, consider routing them in the opposite direction.</td>
<td>M.Kreitz</td>
<td>Closed</td>
<td>M. Kreitz memo</td>
</tr>
<tr>
<td>TIDI-Tel-PDR-11</td>
<td>Look into the frequency of the telescope overscanning required in flight to maintain the bearing lubrication.</td>
<td>D.Lohr</td>
<td>Closed</td>
<td>Wire replaced with flexible ribbon cable</td>
</tr>
<tr>
<td>TIDI-Tel-PDR-12</td>
<td>Design an absolute position reference method to calibrate the LVDT in orbit.</td>
<td>D. Gell</td>
<td>In review</td>
<td>See &quot;TIDI Instrument Calibration Plan&quot; in Appendix</td>
</tr>
<tr>
<td>TIDI-Tel-PDR-13</td>
<td>Analyze whether the telescope motion with the electronics unpowered will induce voltages that may cause damage to the electronics.</td>
<td>H.Grassl</td>
<td>Closed</td>
<td>C. Edmonson e-mail 4/3/98</td>
</tr>
<tr>
<td>TIDI-Tel-PDR-14</td>
<td>Determine an overall test plan for the telescope engineering model and flight units. Include a pyro test plan. Be specific as to whether the lifetest will include the cables, fiber optics, and purge lines.</td>
<td>T.Sholar</td>
<td>In review</td>
<td>See Telescope SoW (to be included in CDR appendix)</td>
</tr>
</tbody>
</table>
# Action Item Response Matrix (15)

<table>
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<tr>
<th>Al #</th>
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<th>Status</th>
<th>Response Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIDI-Tel-PDR-16</td>
<td>Update alignment error budget. a) Add telescope boresight error relative to pedestal mapping into alignment error b) Run parametric study of thermal isolation of telescopes and alignment errors. c) Look into modifying the 4 point star cam/SC mount</td>
<td>A.Sadilek</td>
<td>Open</td>
<td>To be closed at APL Telescope CDR</td>
</tr>
<tr>
<td>TIDI-Tel-PDR-17</td>
<td>A telescope internal alignment plan and assembly procedure needs to be generated. Include an alignment budget for each optical component. Review the number of items that require pinning</td>
<td>K. Peacock</td>
<td>Open</td>
<td>To be closed at APL Telescope CDR</td>
</tr>
<tr>
<td>TIDI-Tel-PDR-18</td>
<td>Determine an overall alignment test plan for the telescope engineering model and the flight units. For the flight units include both pre- and post-S/C delivery alignments. Issues that should be addressed include:</td>
<td>A.Sadilek</td>
<td>Open</td>
<td>To be closed at APL Telescope CDR</td>
</tr>
<tr>
<td>TIDI-Tel-PDR-18</td>
<td>a) Determine if mirror mock up can be placed in engineering model to look for alignment shifts during testing. b) 1G testing after telescope delivery with star cameras, IMU, and antennas in place. c) Visibility of the optical cubes on the optical bench</td>
<td>(cont)</td>
<td>(cont)</td>
<td></td>
</tr>
<tr>
<td>TIDI-Tel-PDR-22</td>
<td>Look into design of thermal control system. Determine whether to: a) provide PWM, tstat, or no control, b) have both op and sur heaters, c) add a relay for separate control of the telescope and profiler heaters, d) keep surv htrs enabled all the time</td>
<td>J. Ercol</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIDI-Tel-PDR-24</td>
<td>Define a light tight test for both the flight and GSE covers</td>
<td>K.Peacock</td>
<td>Closed</td>
<td>SRI-97-068 SPRL test (12/1/97 harvey e-mail), also monitoring current to do e-mail</td>
</tr>
<tr>
<td>TIM-11/11-01</td>
<td>Can motor survive full stall condition</td>
<td>J. Harvey</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM-11/11-02</td>
<td>What is field chromaticity cross talk between the fiber bundles, and how does this cross talk affect the measurements?</td>
<td>H. Grassl</td>
<td>In review</td>
<td>See Crosstalk analysis in CDR appendix. Final performance to be measured when optics become available</td>
</tr>
</tbody>
</table>
# Action Item Response Matrix (16)

<table>
<thead>
<tr>
<th>AI #</th>
<th>Description</th>
<th>Assignee</th>
<th>Status</th>
<th>Response Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIM-11/11-03</td>
<td>Resolve range requirement for shielding pyro cables in telescope</td>
<td>D. Mehoke</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM-11/11-04</td>
<td>Send APL latest revision of ICD drawing</td>
<td>J. Harvey</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM-11/11-05</td>
<td>Resolve RAD usage requirements for Actel parts</td>
<td>K. Heffernan</td>
<td>Closed</td>
<td>Kinnison memo, Cassanovas review of EPL</td>
</tr>
<tr>
<td>TIM-11/11-06</td>
<td>APL to send TIMED harness spec, check if NORAD orbit propagator code is available in C</td>
<td>D. Mehoke</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM5/97-01</td>
<td>Provide worst case temperatures for the telescope cables for use in the gimbal mockup temperature test.</td>
<td>J. Ercol</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM5/97-02</td>
<td>Define a drop dead date for the footprints of the TIDI hardware.</td>
<td>K. Heffernan</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM5/97-03</td>
<td>Update the mechanical ICD drawing for both the profiler and the electronics.</td>
<td>J. Harvey</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM5/97-04</td>
<td>Determine if commercial FETs from IRC can be used in TIDI.</td>
<td>K. Heffernan</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM5/97-05</td>
<td>Provide two off axis rejection plots, one perpendicular and one parallel to the slit.</td>
<td>K. Peacock</td>
<td>Open</td>
<td>To be closed at APL Telescope CDR</td>
</tr>
<tr>
<td>TIM5/97-06</td>
<td>Determine how much, if any, the electronics box can grow in height.</td>
<td>S. Vernon</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM5/97-07</td>
<td>Complete the 64 bit instrument status word.</td>
<td>S. Musko</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM5/97-08</td>
<td>Email the format of the top eight bits of the instrument status word to the instrument teams.</td>
<td>K. Heffernan</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM5/97-09</td>
<td>Provide to TIDI the name of the contact at Washington U re space fiber optics.</td>
<td></td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM5/97-10</td>
<td>Determine if APL will provide a top deck mockup to SPRL.</td>
<td>S. Vernon</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM8/97-11</td>
<td>Update the scan profile for each scan (science) type. Include both telescope and filter wheel (2) motions. Include time delays caused by filter wheel motions. (Purpose is to understand expected number of filter wheel motions, whether their is a require</td>
<td>W. Skinner</td>
<td>Delete</td>
<td>D. Mehoke e-mail 4/8/98</td>
</tr>
</tbody>
</table>
## Action Item Response Matrix (17)

<table>
<thead>
<tr>
<th>AI #</th>
<th>Description</th>
<th>Assignee</th>
<th>Status</th>
<th>Response Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIM8/97-12</td>
<td>Based on results of TIM8/97-11, update torque profile and power spreadsheet.</td>
<td>J.Harvey</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM8/97-13</td>
<td>APL to look over the CCD SOW.</td>
<td>K.Heffeman</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM8/97-14</td>
<td>Determine who is bookkeeping the weight of the FO shield.</td>
<td>K.Heffeman</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM8/97-15</td>
<td>Send a sample of the TSP and purge tube to SPRL for evaluation.</td>
<td>T.Sholar</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM8/97-16</td>
<td>APL to look over the voice coil and LVDT vendor information from a flight qualification viewpoint.</td>
<td>L.Mastracci</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM8/97-17</td>
<td>APL to start the logistics of performing the TIDI system level TV test in SSL.</td>
<td>K.Heffeman</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM8/97-18</td>
<td>Provide optical cube specifications to Al Sadilek for purchasing.</td>
<td>T.Sholar</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>TIM8/97-19</td>
<td>SPRL to perform a test of torque vs temp in which all of the cables are represented simultaneously.</td>
<td>J.Harvey</td>
<td>In review</td>
<td>See CDR D.4.8</td>
</tr>
<tr>
<td>TIM8/97-20</td>
<td>SPRL to define the electrical cable and FO cable routing and tie down points on the S/C.</td>
<td>J.Harvey</td>
<td>Closed</td>
<td>D. Mehoke e-mail 4/3/98</td>
</tr>
<tr>
<td>TIM8/97-21</td>
<td>Determine how to correlate the lab derived instrument function to the instrument function in orbit.</td>
<td>W.Skinner</td>
<td>Closed</td>
<td>D. Mehoke e-mail 4/8/98</td>
</tr>
</tbody>
</table>
Section B. Science and Measurement

Wilbert R. Skinner
voice: (734) 647-3960
fax: (734) 763-7130
EMAIL: wskinner@umich.edu
Section B Outline

- TIMED Science Objectives
- TIDI Measurements
- TIDI Measurement Techniques Overview
- TIDI Instrument Overview
- TIDI Coverage
- TIDI Requirement Summary
• **Mission Science Objectives**
  – To investigate and understand the energetics of the mesosphere and lower thermosphere (MLTI)

• **Mission Goals**
  – To determine the pressure, temperature, density, and wind structure in the MLTI region, including seasonal and latitudinal variations.
  – To determine the relative importance of various radiative, chemical, electrodynamical, and dynamical sources and sinks of energy for the thermal structure of the MLTI.
TIDI Measurement Goals

- Obtain global wind measurements from 60 km to 300 km for at least 2 years with an accuracy of a few m/s.

- Obtain global measurements of temperature and specie volume emission rates (VER) in the MLTI region.

- Derive concentrations of important minor species, such as O, O₃, and O(¹D).
TIDI Measurement Method

- Use high-resolution spectrometry to look at atomic and molecular emission lines in the visible and near IR. Doppler shifts, widths, and intensities are measured.

- Perform limb measurements using movable telescopes to probe the atmosphere in altitude.

- Use multiple telescopes and the spacecraft movement to look at the same volume of space in order to derive wind vectors.
Typical Dayglow Volume Emission Rates

Volume emission rate (photons cm$^{-3}$ s$^{-1}$)

solid=molecules, dashed=atoms, dotted=ions

Altitude (km)

TIDI CDR 4/28, 4/29/98

A.37 Edmonson
Typical Nightglow Volume Emission Rates

[Graph showing altitude (km) vs. volume emission rate (photons cm⁻³ s⁻¹) for different emissions at various wavelengths (557.7 nm, 589.3 nm, and 630.0 nm).]

- Solid lines represent molecules.
- Dashed lines represent atoms.

TIDI CDR 4/28, 4/29/98

A.38 Edmonson
<table>
<thead>
<tr>
<th>Measurement</th>
<th>Feature</th>
<th>Altitude Range</th>
<th>Statistical Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vector Wind</td>
<td>$O_2$ Atmosphere (0-1) P11</td>
<td>60 - 85 km</td>
<td>5 m/sec @ 85km</td>
</tr>
<tr>
<td></td>
<td>$O_2$ Atmosphere (0-0) P9</td>
<td>85 - 120 km</td>
<td>1 m/sec @ 85km</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 m/sec @ 120km</td>
</tr>
<tr>
<td></td>
<td>OI (557.7 nm)</td>
<td>90 - 250 km</td>
<td>4 m/sec @ 120km</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6 m/sec @ 150 km</td>
</tr>
<tr>
<td></td>
<td>OI (630.0 nm)</td>
<td>200 - 300 km</td>
<td>7 m/sec @ 150 km</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>13 m/sec @ 300 km</td>
</tr>
<tr>
<td></td>
<td>OII (732.0 nm)</td>
<td>170 - 300 km</td>
<td>20 m/sec @ 250 km</td>
</tr>
<tr>
<td>Neutral Temperature</td>
<td>$O_2$ Atmosphere (0-1) P11 and $O_2$ Atmosphere (0-1) P7</td>
<td>60 - 85 km</td>
<td>15 K @ 60 km</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12 K @ 85 km</td>
</tr>
<tr>
<td></td>
<td>$O_2$ Atmosphere (0-0) P9 and $O_2$ Atmosphere (0-0) P15</td>
<td>85 - 120 km</td>
<td>2 K @ 85 km</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7 K @ 120 km</td>
</tr>
<tr>
<td></td>
<td>OI (557.7 nm)</td>
<td>100 - 150 km</td>
<td>5 K @ 120 km</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30 K @ 150 km</td>
</tr>
<tr>
<td></td>
<td>OI (630.0 nm)</td>
<td>200 - 300 km</td>
<td>40 K @ 150 km</td>
</tr>
<tr>
<td>O$_2$ Density</td>
<td>$O_2$ Atmosphere (0-0) Volume Emission Rate</td>
<td>~100 km</td>
<td>5 - 10%</td>
</tr>
<tr>
<td></td>
<td>$O_2$ Atmosphere (0-1) and $O_2$ Atmosphere (0-0)</td>
<td>60 - 90 km</td>
<td>5% using self-absorption ratio</td>
</tr>
<tr>
<td>O Density</td>
<td>OII (732.0 nm) and OI (844.6 nm)</td>
<td>150 - 300 km</td>
<td></td>
</tr>
<tr>
<td>$O_3$ and $O^{(1D)}$ density</td>
<td>$O_2$ Atmosphere Volume Emission Rate</td>
<td>70 - 95 km</td>
<td></td>
</tr>
</tbody>
</table>
# Nightside Science

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Feature</th>
<th>Altitude Range</th>
<th>Statistical Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vector Wind</td>
<td>OH Meinel (7-3)</td>
<td>80 - 90 km</td>
<td>5 m/sec @ 85 km</td>
</tr>
<tr>
<td></td>
<td>Na D</td>
<td>85 - 95 km</td>
<td>11 m/sec @ 90 km</td>
</tr>
<tr>
<td></td>
<td>O₂ Atmosphere (0-0) P9</td>
<td>85 - 105 km</td>
<td>5 m/sec @ 95 km</td>
</tr>
<tr>
<td></td>
<td>OI (557.7 nm)</td>
<td>95 - 105 km</td>
<td>6.5 m/sec @ 95 km</td>
</tr>
<tr>
<td></td>
<td>OI (630.0 nm)</td>
<td>200 - 300 km</td>
<td>20 m/sec @ 230 km</td>
</tr>
<tr>
<td>Neutral Temperature</td>
<td>OH Meinel (7-3)</td>
<td>80 - 90 km</td>
<td>8 K @ 85 km</td>
</tr>
<tr>
<td></td>
<td>Na D</td>
<td>85 - 95 km</td>
<td>12 K @ 90 km</td>
</tr>
<tr>
<td></td>
<td>O₂ Atmosphere (0-0) P9 and O₂ Atmosphere (0-0) P15</td>
<td>85 - 105 km</td>
<td>11 K @ 95 km</td>
</tr>
<tr>
<td></td>
<td>OI (557.7 nm)</td>
<td>95 - 105 km</td>
<td>9 K @ 95 km</td>
</tr>
<tr>
<td></td>
<td>OI (630.0 nm)</td>
<td>200 - 300 km</td>
<td></td>
</tr>
<tr>
<td>O Density</td>
<td>OH Meinel</td>
<td>80 - 95 km</td>
<td></td>
</tr>
<tr>
<td></td>
<td>O₂ Atmosphere</td>
<td>85 - 100 km</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OI (557.7 nm)</td>
<td>90 - 105 km</td>
<td></td>
</tr>
</tbody>
</table>
TIDI Viewing Geometry

Limb scan through airglow layers

45°

45°

satellite velocity vector
Profiler Sampling

Telescope collects light
- Collimation optics
- High-Resolution Spectrometer
- Etalon
- Imaging optics

Reduces background

Atmospheric Emission Line
- B vs. \( \lambda \)

Counts spectrum
- CLIO
- CCD Multichannel Detector
- Spectrum
- Processing Software

Winds
- \( z \rightarrow u \)
TIDI Wind Measurements

- TIDI measures wind by measuring the Doppler shift of atmospheric emission features.
  
  - Doppler shifts are small; 10 m/s $\sim 5 \times 10^{-4}$ cm$^{-1} \sim 2 \times 10^{-5}$ nm, $\sim 17$ MHz
  
  - Accurate knowledge of pointing is required to compensate for satellite motion, $\sim 7500$ m/s
  
  - Two views of nearly the same volume from approximately orthogonal directions are required in order to form a wind vector. The two views are provided by two telescopes, one looking forward and one looking backward. The backward looking telescope sees the same volume as the forward looking one about 8 minutes later.
  
  - The telescopes’ zenith angles are adjusted to look at different altitudes.
  
  - Different emitters are used at different altitudes to cover the regions of interest.
The TIMED Doppler Interferometer

- TIDI performs a limb scan of the horizon to determine the vector-neutral wind, temperature, and selected constituent abundances.
- Vector winds are built up by combining line-of-sight Doppler measurements in four orthogonal directions with the assumption of time invariance over a period of about 8 minutes.
Effect of Wind on Emission Line

\[ \Delta \nu = (\nu_0 u) / c \]

\[ u = 1 \text{ m/s} \]
\[ \Delta \nu \approx 5 \times 10^{-5} \text{ cm}^{-1} \]
\[ \approx 2.2 \times 10^{-6} \text{ nm} \]
\[ = 1.5 \text{ MHz} \]
Example of Wind Measurement from UARS


Semidiurnal and diurnal tides are evident in these data HRDI below 110 km; WINDII above 110 km.
TIDI Temperature Measurements

• TIDI can measure temperature in two ways:
  – **Doppler width.** The spectral width of emission line is proportional to the square root of the temperature.
  – **Rotational temperature.** The ratio of the brightness of two lines in a rotational band of a molecular emission is uniquely related to the temperature.
Effect of Temperature on Emission Line

\[ \Delta \nu = 4.30 \times 10^{-7} \nu_0 \sqrt{T/M} \]

<table>
<thead>
<tr>
<th>Emitter</th>
<th>M</th>
<th>T(K)</th>
<th>(cm(^{-1}))</th>
<th>(nm)</th>
<th>(MHz)</th>
<th>(m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{O}_2(^{1}\Sigma) )</td>
<td>32</td>
<td>200</td>
<td>0.014</td>
<td>( 8.2 \times 10^{-4} )</td>
<td>420</td>
<td>320</td>
</tr>
<tr>
<td>( \text{O}(^{1}\text{S}) )</td>
<td>16</td>
<td>200</td>
<td>0.027</td>
<td>( 8.5 \times 10^{-4} )</td>
<td>820</td>
<td>450</td>
</tr>
<tr>
<td>( \text{O}(^{3}\text{D}) )</td>
<td>16</td>
<td>1200</td>
<td>0.059</td>
<td>( 2.3 \times 10^{-3} )</td>
<td>1765</td>
<td>1100</td>
</tr>
</tbody>
</table>
Rotational Temperature Method

O$_2$ (0,0) Line Strength Change with Temperature

Temperature = 180.0 K

Temperature = 250.0 K
Rotational Temperature Method
Line Strengths and Ratio as Function of Temperature

O₂ Atmospheric Line Strength

Ratio of Line Strengths
Example of Rotational Temperature Measurement from HRDI

HRDI Mean Temperatures for February

HRDI Mean Temperatures for August
Minor Species Density

- The volume emission rate is related to concentration of various components.

- A knowledge of the chemistry allows minor species density to be retrieved.

- The absolute sensitivity of the instrument must be known very well.

- Can recover O, O(1D), and O₃.
Example of Minor Specie Retrieval -
HRDI Mesosphere Ozone
TIDI Profiler Features

• High-resolution Fabry-Perot interferometer
  – well established technique to measure wind, temperature, VER from weak emissions (ground systems, DE-FPI, HRDI)

• High-quantum-efficiency CCD detector
  – about a factor of 10 better than old detectors

• Four telescopes for viewing atmosphere
  – permits two tracks on either side of the spacecraft viewing different local times

• A novel set of input optics
  – allows all four telescopes to be sampled simultaneously

• The circle to line interferometer optic (CLIO)
  – allows the CCD to be used to minimize read noise and readout time
Fabry-Perot Interferometer

- Plate
- Post
- Coating
Etalon

Incoming Light

Optical Axis

Fabry-Perot Interferometer

Imaging Lens

Image Plane
Fabry-Perot Fringe Pattern
TIDI on TIMED
TIDI Telescope
TIDI Profiler Optics Overview

8 Position filter wheel

Fixed Gap Etalon

CLIO/CCD

Imaging Cassegrain

Fiber Optic input

Collimation / expansion optics
Optical Transformation

Input field

Fixed Gap Etalon

Lens

Lens

Lens

F1

F2

Image Field
Optical Transformation (continued)

- Fiber Optic input
- 5 fields
- Lens
- Fixed Gap Etalon
- Input field
CLIO: Circle-to-Line Imaging Optics

Mirror surface

90° Conical Mirror

Focal point of the imaging optic coincident with the vertex of the cone

CCD chip surface
Demonstration of CLIO in a Lidar System

- Transforms FPI rings into linear pattern
- Allows use of linear array detector (e.g. CCD)
CCD Image Field

Image active area of CCD
~66 x 533 pixels

Etalon / Imaging optic / cone axis

Pixels/field fringe width

61 69 82 106 166
5 6 7 9 14

Max width
~66 pixels

Unused

Pixel # 0 134
Tel 1 Tel 2 Tel 3 Tel 4 Cal Field
TIDI Sensitivity

White light sensitivity: \[ S_{\text{white}} = \frac{\Delta \Omega 10^6}{4\pi} T_{\text{Top}} T_{\text{tel}} A \Delta \nu \Delta t \]

where \[ \Delta \nu = \Delta \nu_{\text{Fil}} \left( \frac{1 - R}{1 + R} \right) \]
and \[ \Delta \nu_{\text{Fil}} = \int_0^\infty T_{\text{Fil}}(\nu) d\nu \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope diameter</td>
<td>cm</td>
<td></td>
<td>7.5</td>
</tr>
<tr>
<td>Telescope effective area (each)</td>
<td>cm²</td>
<td>A</td>
<td>44.2</td>
</tr>
<tr>
<td>Field of view degrees</td>
<td>degrees</td>
<td>( \Omega )</td>
<td>0.05 x 2.5</td>
</tr>
<tr>
<td>Field of view</td>
<td>sr</td>
<td>( \Omega )</td>
<td>3.8 x 10⁻⁵</td>
</tr>
<tr>
<td>( A\Omega ) (Each telescope)</td>
<td>cm² sr</td>
<td>( A\Omega )</td>
<td>1.7 x 10⁻³</td>
</tr>
<tr>
<td>Photometric sensitivity</td>
<td>photons/s/R</td>
<td>( A\Omega 10^6/4\pi )</td>
<td>133.7</td>
</tr>
<tr>
<td>Optical Transmittance (excluding telescope and filters)</td>
<td></td>
<td></td>
<td>0.22</td>
</tr>
<tr>
<td>Peak filter transmittance</td>
<td></td>
<td>( T_{\text{fil}} )</td>
<td>0.4-0.6 (use 0.5)</td>
</tr>
<tr>
<td>Area under filter curve</td>
<td>cm⁻¹</td>
<td>( \Delta \nu_{\text{Fil}} )</td>
<td>2.5-40 (use 5)</td>
</tr>
<tr>
<td>Reflectivity</td>
<td></td>
<td>R</td>
<td>0.80</td>
</tr>
<tr>
<td>Number of channels per field</td>
<td></td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>Integration time</td>
<td>s</td>
<td>( \Delta t )</td>
<td>variable (use 1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Symbol</th>
<th>Value @ 550 nm</th>
<th>Value @ 650 nm</th>
<th>Value @ 750 nm</th>
<th>Value @ 850 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantum efficiency (^1)</td>
<td>e⁻/photon</td>
<td>Q</td>
<td>0.59</td>
<td>0.63</td>
<td>0.59</td>
<td>0.45</td>
</tr>
<tr>
<td>Telescope effective transmittance (^2)</td>
<td></td>
<td>( T_{\text{tele}} )</td>
<td>0.33</td>
<td>0.58</td>
<td>0.83</td>
<td>0.60</td>
</tr>
<tr>
<td>Sensitivity (per field)</td>
<td></td>
<td>( S )</td>
<td>14.3</td>
<td>26.9</td>
<td>36.0</td>
<td>19.9</td>
</tr>
<tr>
<td>Sensitivity (per channel)</td>
<td></td>
<td>( S )</td>
<td>0.48</td>
<td>0.90</td>
<td>1.20</td>
<td>0.66</td>
</tr>
</tbody>
</table>

Notes: 1. Estimate from SITe for T=-80°C; 2. From K. Peacock, APL

TIDI CDR 4/28, 4/29/98

A.67 Edmonson
Section B. Coverage

- Some aspects of TIDI coverage are presented here.

- In the following plots, solid symbols represent daytime observations, open symbols are nighttime. Diamonds are sun-side (warm side) and hexes are anti-sun (cold side).

- TIDI performs daytime observations when the SZA < 80 degrees at the tangent point, the SZA < 90 degrees at the spacecraft and the solar scattering angle is greater than 15 degrees.

- TIDI performs nighttime observations when the SZA > 100 degrees at the tangent point, the SZA > 90 degrees at the spacecraft and the solar scattering angle is greater than 15 degrees.
Beta Angle Description

- **β = 74.2° max**
- **β = 97.2° max**
- **β = 51.2°**

**Equinox**
- Warm side
- Cold side
- Viewing track

**Solstice**
- Warm side
- Cold side
- Viewing track
TIDI Coverage at Equinox

β Angle Near 0
TIDI Coverage at Equinox
Large Negative $\beta$ Angle

solar beta angle: -73.60 degrees

Plot produced 7-Apr-1998
vernal_views_060.dat

TIDI CDR 4/28, 4/29/98

A.71 Edmonson
TIDI Coverage at Equinox
Large Positive $\beta$ Angle

Plot produced 7-Apr-1998
vernul_views_240.dat

Local Solar Time, Hours
Geodetic Latitude, degrees
solar beta angle: 73.93 degrees
TIDI Coverage at Summer Solstice

\( \beta \) Angle Near 0

Solar beta angle: 3.18 degrees

Plot produced 7-Apr-1998

TIDI CDR 4/28, 4/29/98

A.73 Edmonson
TIDI Coverage at Summer Solstice
Large Negative $\beta$ Angle

Plot produced 7-Apr-1998
solar beta angle: -43.06 degrees

SSOLSTICE_VIEWS_000.dat

TIDI CDR 4/28, 4/29/98
A.74 Edmonson
TIDI Coverage at Summer Solstice
Large Positive $\beta$ Angle

Local Solar Time, Hours

Geodetic Latitude, degrees

Plot produced 7-Apr-1998
solar beta angle: 81.56 degrees

SSOLSTICE_VIEWS_150.dat
Warm Side Tangent Point Latitude Limits
(sc_sza<90) & (tp_sza<80) & (tp_scat>15)

Plot produced 4-Jun-1997

TIDITIDI
TIDITIDI

TIDI CDR 4/28, 4/29/98

A.76 Edmonson
Cold Side Tangent Point Latitude Limits
(sc_sza<90) & (tp_sza<80) & (tp_scat>15)

Plot produced: 4-Jun-1997
TIDI Coverage:
Forward Flight days 108 to 171

TIDI Coverage
Forward Flight - days 108 to 171

Plot produced 10-Apr-1998
# TIDI Filter Wheel #1

<table>
<thead>
<tr>
<th>Position</th>
<th>Wavelength (nm-air)</th>
<th>FWHH (nm)</th>
<th>Feature</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>867.13</td>
<td>0.3</td>
<td>O$_2$(^1S) (0-1) P11 pair (11531.7989 cm$^{-1}$ and 11536.7235 cm$^{-1}$) and Ar (866.79 nm)</td>
<td>O$_2$ and calibration filter for winds and rotational temperatures (60 - 85 km) w/ 866.12 nm</td>
</tr>
<tr>
<td>2</td>
<td>763.68</td>
<td>0.3</td>
<td>O$_2$(^1S) (0-0) P9 pair (13093.6407 cm$^{-1}$ and 13091.6958 cm$^{-1}$) and Ar (763.51 nm)</td>
<td>O$_2$ and calibration filter for winds and rotational temperatures (85 - 120 km) w/ 765.07 nm</td>
</tr>
<tr>
<td>3</td>
<td>557.8</td>
<td>0.5</td>
<td>O$_1$ (^1S) green line filter for winds (90 - 250 km) and Doppler temperatures (100 - 150 km)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>OG 515</td>
<td>N/A</td>
<td>high pass filter</td>
<td>high transmission above 515 nm, removes UV and blue light</td>
</tr>
<tr>
<td>5</td>
<td>630.1</td>
<td>0.5</td>
<td>O$_1$ (^1D) and Ne (630.48 nm)</td>
<td>red line and calibration filter winds and Doppler temperatures (200 - 300 km)</td>
</tr>
<tr>
<td>6</td>
<td>765.07</td>
<td>0.3</td>
<td>O$_2$(^1S) (0-0) P15 pair (13069.9459 cm$^{-1}$ and 13068.0662 cm$^{-1}$)</td>
<td>O$_2$ for winds and rotational temperatures (80 - 125 km) w/ 763.68nm</td>
</tr>
<tr>
<td>7</td>
<td>866.12</td>
<td>0.3</td>
<td>O$_2$(^1S) (0-1) P7 pair (11545.2971 cm$^{-1}$ and 11543.3255 cm$^{-1}$) and Ar (866.79 nm)</td>
<td>O$_2$ and calibration filter for winds and rotational temperatures (60 - 85 km) w/ 867.13 nm</td>
</tr>
<tr>
<td>8</td>
<td>892.1</td>
<td>0.5</td>
<td>OH Meinel (7-3) P1(3) pair and Ne(891.95 nm)</td>
<td>OH and calibration filter nocturnal winds and temperatures (80 - 90 km)</td>
</tr>
</tbody>
</table>
## TIDI Filter Wheel #2

<table>
<thead>
<tr>
<th>Position</th>
<th>Wavelength (nm-air)</th>
<th>FWHH (nm)</th>
<th>Feature</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OG 515</td>
<td>N/A</td>
<td>high pass filter</td>
<td>high transmission above 515 nm, removes UV and blue light</td>
</tr>
<tr>
<td>2</td>
<td>732.1</td>
<td>0.5</td>
<td>OII (2P) pair</td>
<td>plasma drift winds (170 - 300 km)</td>
</tr>
<tr>
<td>3</td>
<td>844.8</td>
<td>0.5</td>
<td>O triplet</td>
<td>auroral winds (150 - 300 km)</td>
</tr>
<tr>
<td>4</td>
<td>557.2</td>
<td>0.5</td>
<td>OI (1S) cal filter Kr (557.03 nm)</td>
<td>green line calibration filter</td>
</tr>
<tr>
<td>5</td>
<td>589.4</td>
<td>1.0</td>
<td>NaD doublet and Ne (590.25 nm)</td>
<td>sodium for nocturnal and auroral winds and temperatures (85 - 95 km)</td>
</tr>
<tr>
<td>6</td>
<td>779.5</td>
<td>0.5</td>
<td>OH Meinel (9-4) P1(2) pair</td>
<td>OH for nocturnal and auroral winds and temperatures (80 - 90 km)</td>
</tr>
<tr>
<td>7</td>
<td>764.0</td>
<td>4.0</td>
<td>O$_2$(1S) (0-0) P branch and Ar (763.51nm)</td>
<td>band brightness w/ 761.0 nm</td>
</tr>
<tr>
<td>8</td>
<td>761.0</td>
<td>2.0</td>
<td>O$_2$(1S) (0-0) R branch and Kr (760.15 nm)</td>
<td>band brightness w/ 764.0 nm</td>
</tr>
</tbody>
</table>
## Science-Driven Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy (wind)</strong></td>
<td>3 m/s l.o.s. (uninverted)</td>
</tr>
<tr>
<td>[other products do not drive design]</td>
<td></td>
</tr>
<tr>
<td><strong>Altitude coverage</strong></td>
<td>60-300 km</td>
</tr>
<tr>
<td></td>
<td>(primary 60-180 km)</td>
</tr>
<tr>
<td><strong>Vertical resolution</strong></td>
<td>2.0 km</td>
</tr>
<tr>
<td><strong>Tangent point altitude knowledge</strong></td>
<td>1 km</td>
</tr>
<tr>
<td><strong>Telescope field overlap</strong></td>
<td>~100 km</td>
</tr>
<tr>
<td><strong>Lifetime</strong></td>
<td>&gt;2 years</td>
</tr>
<tr>
<td><strong>Local time coverage</strong></td>
<td>24 hours/120 days (3¡/day)</td>
</tr>
<tr>
<td><strong>Latitude coverage</strong></td>
<td>Pole-to-pole</td>
</tr>
<tr>
<td><strong>Horizontal resolution</strong></td>
<td>~500 x 500 km</td>
</tr>
</tbody>
</table>

**BOLD** - most directly drives TIDI design
System overview

Heinz Grassl
734 763-6208
hgrassl@umich.edu
• Instrument consists of a Fabry-Perot interferometer (profiler) fed by four limb scanning telescopes
• Measure line of sight winds to 3 m/s accuracy
• Altitude coverage 60-300 km
• Altitude resolution 2 km
• Horizontal resolution 100 km
• Design lifetime 2 years
• APL is building the telescopes
  – CDR May 7
TIDI/Spacecraft configuration

Telescopes
- Sun side
- Anti-Sun side

TIDI electronics

- Y (sun) arrow
- X (Velocity) arrow
- Z (Nadir) arrow
Configuration

- **Limb scanning telescopes**
  - Fixed Azimuth ±45° and ±135° to S/C velocity vector providing simultaneous sun/anti-sun ground tracks
  - Zenith scan over the altitude range of 60 - 300 km
    - 10° operational scan range, 20° scan range for bearing lube
  - Off axis Gregorian design using low scatter primary and 11.5° sun shade
  - 0.05° x 2.5° fov (2 km x 100 km at earth limb)
  - Voice coil drive and Linear Variable Differential Transformer (LVDT) readout
  - Pyro actuated aperture cover
  - Focal plane shutter for sun avoidance
Configuration

• Profiler
  – Fabry-Perot interferometer optimized for wind measurement
  – 2 filter wheels to allow for wind, temperature, and density measurements
  – 5 shaped input fields imaged onto the CCD detector
  – Conical optic for image transformation to a rectangular array
  – Site 2000 x 800 back thinned CCD
  – passive cooling of the CCD to -80° C
  – Etalon temperature maintained at 20 ± 5° C over a beta cycle (120 days)
  – 3 point kinematic mount
  – 3 zone PWM heater control
Profiler

- Fiber optic input
- Second stage guard radiator
- CCD radiator
- Electrical connectors J301, J302, J303
- S/C mounting feet (6)
- Purge connection

TIDI CDR 4/28, 4/29/98
A.89 Edmonson
Configuration

- Electronics, 7 stackable decks
  - Power supplies
  - Flight computer, 80C51 processor
  - Data acquisition
  - CCD controller
  - Filter wheels, telescope shutters, and PWM heaters
  - Telescope servos
  - Calibration lamps
Electronics
Configuration

Telescope +45 deg
Telescope +135 deg
Calibration Sources (4)
Telescope -45 deg
Telescope -135 deg
Fiber optic 5 fields
Motor
High Res Etalon
Obj Opt
Coll Opt
FILTER WHEEL
FILTER WHEEL
CCD
Preamp
RADIATOR
BENCH COOLER

TIDI CDR 4/28, 4/29/98
A.92 Edmonson
## Instrument Parameter Summary

<table>
<thead>
<tr>
<th>Component</th>
<th>Qty.</th>
<th>Envelope in (cm)</th>
<th>Weight lb (Kg)</th>
<th>Power hot/cold W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope</td>
<td>4</td>
<td>19.2 x 12.5 x 9.5</td>
<td>33.9 (15.4)</td>
<td>6.3 / 7.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(49 x 32 x 24)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Profiler</td>
<td>1</td>
<td>28.5 x 20 x 13.5</td>
<td>34.5 (15.7)</td>
<td>3.5 / 7.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(72 x 51 x 34)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronics&amp; Harness</td>
<td>1</td>
<td>9 x 8.5 x 8</td>
<td>17.6 (8.0)</td>
<td>7.4 / 7.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(23 x 22 x 20)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>6</td>
<td></td>
<td>86.0 (39.1)</td>
<td>17.2 / 22.0</td>
</tr>
</tbody>
</table>
### Spacecraft Resources

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass</strong></td>
<td>39 kg</td>
</tr>
<tr>
<td><strong>Pointing</strong></td>
<td>45, 135, 225, 315 deg off Ram</td>
</tr>
<tr>
<td><strong>Atmospheric Region</strong></td>
<td>60 to 300 km</td>
</tr>
<tr>
<td><strong>Scan Range</strong></td>
<td>16 to 23 deg nominal</td>
</tr>
<tr>
<td><strong>Full Scan Range</strong></td>
<td>+/- 11 deg</td>
</tr>
<tr>
<td><strong>S/C Inclination</strong></td>
<td>74 degrees</td>
</tr>
<tr>
<td><strong>S/C Altitude</strong></td>
<td>625 +/- 25 km</td>
</tr>
<tr>
<td><strong>Thermal Interface</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Radiators</strong></td>
<td>Profiler, Telescope</td>
</tr>
<tr>
<td><strong>Optical Bench</strong></td>
<td>-55 to +25 C</td>
</tr>
<tr>
<td><strong>Profiler</strong></td>
<td>-20 to +40 C</td>
</tr>
<tr>
<td><strong>E-box</strong></td>
<td>-20 to +40 C</td>
</tr>
<tr>
<td><strong>Profiler Stability</strong></td>
<td>10 deg C per orbit</td>
</tr>
<tr>
<td><strong>ACDS/Nav Req</strong></td>
<td></td>
</tr>
<tr>
<td><strong>S/C Pointing</strong></td>
<td>+/- 1 deg</td>
</tr>
<tr>
<td><strong>Knowledge</strong></td>
<td>.03 deg</td>
</tr>
<tr>
<td><strong>Jitter/Stability</strong></td>
<td>.03 deg</td>
</tr>
<tr>
<td><strong>Position</strong></td>
<td>1 km</td>
</tr>
<tr>
<td><strong>Velocity</strong></td>
<td>.25 m/s</td>
</tr>
<tr>
<td><strong>Upset Torques</strong></td>
<td>5 &amp; 3 oz-in</td>
</tr>
<tr>
<td><strong>Special</strong></td>
<td>Messages</td>
</tr>
</tbody>
</table>

**TIDICDR 4/28, 4/29/98**

A.95 Edmonson
## Spacecraft Resources

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CDMS</strong></td>
<td></td>
</tr>
<tr>
<td>Commands</td>
<td>2k byte / day</td>
</tr>
<tr>
<td>Modes</td>
<td>Programmable</td>
</tr>
<tr>
<td>Data Rate</td>
<td>2494 b/s</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>100%</td>
</tr>
<tr>
<td>Interface</td>
<td>1553</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0,8,11,11</td>
</tr>
<tr>
<td>Nominal Peak</td>
<td>0,8,30,30</td>
</tr>
<tr>
<td>Peak</td>
<td>0.8,50,50</td>
</tr>
<tr>
<td>Peak Durations</td>
<td>200,1000 ms</td>
</tr>
<tr>
<td><strong>Cleanliness</strong></td>
<td></td>
</tr>
<tr>
<td>Integration Area</td>
<td>Class 100,000</td>
</tr>
<tr>
<td>S/C Surface</td>
<td>1000</td>
</tr>
<tr>
<td>Hydcarbon</td>
<td>15 ppm</td>
</tr>
<tr>
<td>Purge</td>
<td>N₂</td>
</tr>
<tr>
<td><strong>Special</strong></td>
<td></td>
</tr>
<tr>
<td>I &amp; T</td>
<td>Bench Cooler</td>
</tr>
<tr>
<td>TV</td>
<td>Radiator Cold plate</td>
</tr>
<tr>
<td>Mission</td>
<td>Yaw Man, Cover release</td>
</tr>
<tr>
<td>Radiation</td>
<td>1 uC cal lamp starter</td>
</tr>
</tbody>
</table>
Changes since PDR

• Added a second filter wheel to increase temperature and density coverage
• Revised optical design for better chromatic performance
• Revised optical design due to glass availability
• Higher radiation dose level announced
### Vendor status for major components

<table>
<thead>
<tr>
<th>IN</th>
<th>DUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVDT’s</td>
<td>EM fiber optic, May</td>
</tr>
<tr>
<td>Input optics</td>
<td>Etalons, mid May</td>
</tr>
<tr>
<td></td>
<td>CCD’s, June-July</td>
</tr>
<tr>
<td></td>
<td>Conical mirrors, July</td>
</tr>
<tr>
<td></td>
<td>Imaging optics, July-Aug</td>
</tr>
<tr>
<td></td>
<td>Voice coils, first week Aug</td>
</tr>
<tr>
<td></td>
<td>Filter wheel motors, first week Aug</td>
</tr>
<tr>
<td></td>
<td>Flight fiber optic, Sept</td>
</tr>
<tr>
<td></td>
<td>Filters, Aug</td>
</tr>
<tr>
<td></td>
<td>Telescopes, Dec</td>
</tr>
</tbody>
</table>
CDR updates

• CCD vendor production problem
  – TIDI CCD’s part of a contaminated batch (many hot spots)
  – Problem found late in production run
  – Leak in new vacuum installation found to be source of problem
  – Problem corrected

• New delivery no earlier than Oct 1 (mid Nov likely)

• Course of action
  – Proceed with I&T with engineering or grade 2 devices
  – May be able to absorb Oct 1 delivery with small schedule impact
  – Grade 2 devices may be usable as fallback

• If swap is necessary late in program
  – 1-2 mo recalibration effort
Section C. 2  
Requirements Flowdown

Wilbert R. Skinner  
voice: (734) 647-3960  
fax: (734) 763-7130  
EMAIL: wskinner@umich.edu
Section C.2 Outline

- Requirements flowdown (graphical relationships)
- Requirements (values and rationale)
- Discussion of some requirements in more detail (not possible to go over them all)
  - stray light effects
  - telescope placement accuracy
- Top level error budget
  - random and systematic
  - random breakdown
    leads to pointing requirements
• Start with the requirements on the system as driven by the measurements required to perform the science.

• Flow down through the system until a reasonable requirement can be given to the engineers:
  – adequate: keep the CCD temperature between -75 and -85°C
  – not adequate: keep the CCD noise below 10 electrons/pixel/second. [does not differentiate between a variety of noise sources]

• Some requirements are based on heritage, good engineering practice, or an experienced engineer’s judgment and not detailed analysis.
• Some requirements are implicitly derived:
  – Continuous operation implies that the instrument temperature must be controlled to such a degree that the filter drift does not cause the spectral line(s) to fall off the filter bandpass. This has significant implications for the thermal control system.
# Science-Driven Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy (wind)</strong></td>
<td>~3 m/s line of sight (uninverted)</td>
</tr>
<tr>
<td>[other products do not drive design]</td>
<td></td>
</tr>
<tr>
<td><strong>Altitude coverage</strong></td>
<td>60-300 km</td>
</tr>
<tr>
<td></td>
<td>(primary 60-180 km)</td>
</tr>
<tr>
<td><strong>Vertical resolution</strong></td>
<td>2.0 km</td>
</tr>
<tr>
<td><strong>Tangent point altitude knowledge</strong></td>
<td>1 km</td>
</tr>
<tr>
<td><strong>Telescope field overlap</strong></td>
<td>~100 km</td>
</tr>
<tr>
<td><strong>Lifetime</strong></td>
<td>&gt;2 years</td>
</tr>
<tr>
<td><strong>Local time coverage</strong></td>
<td>24 hours/120 days (3 orbits/day)</td>
</tr>
<tr>
<td><strong>Latitude coverage</strong></td>
<td>Pole-to-pole</td>
</tr>
<tr>
<td><strong>Horizontal resolution</strong></td>
<td>~500 x 500 km</td>
</tr>
</tbody>
</table>

**BOLD** - most directly drives TIDI design
TIDI Flow-Down Requirements: Measurement Accuracy

Accuracy

- Instrument resolution design
- Random errors
- Systemic errors

- Attitude errors
- Signal/Noise ratio

- Signal
- Random noise
TIDI Flow-down Requirements: Altitude Coverage

- Altitude coverage
  - Speed of telescope movement
  - Scan range of telescope
  - Emission
    - Specie
    - Geophysical conditions
TIDI Flow-Down Requirements: Random Noise

- Random noise
  - CCD radiation noise
    - CCD choice
    - CCD shielding
  - CCD read noise
    - CCD controller design
  - CCD thermal noise
    - CCD temperature

Background
  - Integration time
    - CCD thermal noise

Optics scattering
  - Cone figure
  - Filter bandwidth
  - Geophysical conditions
  - Tangent altitude

Atmospheric scattering

Telescope scattering
  - Baffle design
  - Telescope primary figure
  - Telescope cleanliness

Telescope cleanliness
TIDI Flow-down Requirements: Horizontal Resolution

- Horizontal resolution (along track)
- Time to perform 1 scan
  - Vertical scan range
  - Integration time at each altitude
  - Number of altitudes in vertical scan
- Telescope horizontal field of view
TIDI Flow-Down Requirements: Instrument Resolution

- Instrument resolution design
  - Free spectral range
    - Etalon gap
  - Finesse
    - Reflectivity finesse
      - Plate reflectivity
    - Aperture finesse
      - CCD binning pattern
      - Optical axis/CLIO alignment
        - Thermal gradient across etalon
        - Etalon manufacturing quality
        - Etalon mounting
      - Etalon figure
        - Defect finesse
TIDI Flow-down Requirements: Latitude Coverage

Latitude coverage

- Inclination of orbit
- Azimuth angle of telescopes
TIDI Flow-down Requirements: Lifetime

- Lifetime
- Altitude of orbit
- Funding
- Hardware reliability
TIDI Flow-down Requirements:
Local Time Coverage

- Local time coverage
- Local time of launch
- Precession rate
  - Inclination of orbit
  - Orbital altitude
TIDI Flow-Down Requirements: Signal

Signal flow-down requirements include:
- Integration time
- Emission brightness
  - Tangent altitude
  - Emitter specie
  - Geophysical conditions
- System throughput
  - CCD Q.E.
  - Transmission of optics, filters, and fiber optics
  - Telescope fov
  - Telescope aperture

Geophysical conditions include:
- System throughput
  - Transmission of optics, filters, and fiber optics
  - Telescope fov
  - Telescope aperture
TIDI Flow-Down Requirements: Systemic Errors

- Systemic errors
  - CCD digitalization error
    - Change in instrument function
      - Etalon figure change
        - Imaging system quality
          - Spectral channel crosstalk
            - Fiber bundle construction
    - Unknown 0-g environment effects
      - Unknown launch shift effects
        - Unknown placement uncertainties
          - Initial placement uncertainties
            - Unknown launch shift effects
              - Unknown 0-g environment effects
                - Unknown thermal drift
                  - Unknown temporal drift
                    - Unknown illumination changes
                      - Unknown attitude offsets
                        - Instrument placement uncertainties
                          - Initial placement uncertainties
                            - Unknown instrument drift
                              - Unknown temporal drift
                                - Unknown thermal drift
                                  - Zero wind position error
TIDI Flow-down Requirements:
Tangent Point Altitude Knowledge

- Tangent point altitude knowledge
  - Knowledge of Earth's shape
  - Telescope zenith angle knowledge
  - Attitude knowledge
    - Roll, pitch, and yaw knowledge
  - Knowledge of satellite location
TIDI Flow-down Requirements: Tangent Point Geographic Location

- Tangent point geographic location knowledge
  - Knowledge of Earth's shape
    - Knowledge of satellite location
  - Telescope zenith angle knowledge
  - Telescope azimuth angle knowledge
  - Attitude knowledge
    - Roll, pitch, and yaw knowledge
TIDI Flow-down Requirements: Vertical Resolution

Vertical resolution

Telescope vertical field of view

Inversion quality

Nature of atmospheric emission

Fidelity of inversion
## Etalon Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate material</td>
<td>Spectrosil-B</td>
<td>Good optical properties in visible. Used with HRDI etalons.</td>
</tr>
<tr>
<td>Post material</td>
<td>zerodur</td>
<td>Provides low thermal expansion. Always used for fixed-gap etalons.</td>
</tr>
<tr>
<td>Plate diameter</td>
<td>10.5 cm</td>
<td>Large enough for coated area and posts.</td>
</tr>
<tr>
<td>Coating diameter</td>
<td>7.5 cm</td>
<td>Required to match etendue of telescopes.</td>
</tr>
<tr>
<td>Plate thickness</td>
<td>2.65 cm</td>
<td>Want large value to minimize gradient effects, want small values to minimize mass and size. Aspect ratio from HRDI used.</td>
</tr>
<tr>
<td>Gap</td>
<td>2.2 cm</td>
<td>Optimized to provide best wind error for O$_2$ atmospheric band lines.</td>
</tr>
<tr>
<td>Reflectivity</td>
<td>0.80</td>
<td>Optimized to provide best wind error.</td>
</tr>
</tbody>
</table>
## CCD Requirements - 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel size</td>
<td>15 microns</td>
<td>At least 2 pixels are required for each spectral channel in the outermost field. Small pixel size minimizes the required focal length and hence size of the imaging optics. 15 microns is a standard size.</td>
</tr>
<tr>
<td>Area of interest</td>
<td>600 x 100 pixels</td>
<td>600 pixels are required in order to image 5 orders with at least 2 pixels per channel. 100 pixels are wider than the image and provides some margin for placement of the CLIO on the CCD.</td>
</tr>
<tr>
<td>Quantum efficiency (minimum)</td>
<td>50@400 nm, 55@500 nm, 63@600 nm, 63@700 nm, 55@800 nm, 35@900 nm</td>
<td>These values are state of the art for CCDs for use in the visible. Values correspond to -80¡ C.</td>
</tr>
</tbody>
</table>
## CCD Requirements - 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating temperature</td>
<td>-80±5°C</td>
<td>There are 3 considerations for CCD temperature:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. dark current - decreases with CCD temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. radiation effects - less significant at cold temperatures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. quantum efficiency - decreases by ~0.2%/°C</td>
</tr>
<tr>
<td>Readout noise</td>
<td>&lt;8 electrons</td>
<td>Small enough not to dominate signal-to-noise ratio</td>
</tr>
<tr>
<td>Charge transfer efficiency (CTE)</td>
<td>&gt;0.99999 at 40k e⁻/pixel</td>
<td>Parallel shifts do not matter, serial shifts do.</td>
</tr>
<tr>
<td></td>
<td>&gt;0.99995 at 1620 e⁻/pixel</td>
<td>There are a maximum of 1000 serial shifts.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.99999¹⁰⁰⁰=0.99, 0.99995¹⁰⁰⁰=0.95</td>
</tr>
<tr>
<td>Dark signal</td>
<td>&lt;0.007 e⁻/pixel/s</td>
<td>This corresponds to a maximum of 1-2 e⁻ per spectral channel/s and can be met by cooling the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CCD to &lt;-75°C and using MPP (multi-phase pinned).</td>
</tr>
</tbody>
</table>
# Telescope Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope aperture</td>
<td>7.5 cm</td>
<td>Want largest diameter possible to maximize science. All optics are proportional to this value and it largely drives the size and mass of the system (and the cost).</td>
</tr>
<tr>
<td>Telescope vertical field of view</td>
<td>0.05 degrees</td>
<td>This is about 1/2 of a scale height and maximizes the number of photons collected while minimizing the altitude smearing.</td>
</tr>
<tr>
<td>Telescope horizontal field of view</td>
<td>2.50 degrees</td>
<td>Want this to be as large as possible. Limited by horizontal gradients.</td>
</tr>
<tr>
<td>Telescope primary roughness</td>
<td>&lt;2.0 nm rms</td>
<td>The telescope primary roughness determines the amount of scattered light collected by the system. Scattered light decreases the signal-to-noise and increased the error.</td>
</tr>
<tr>
<td>Light baffle</td>
<td>baffle length = 42.76 cm, critical baffle diameter = 9.5 cm</td>
<td>Keep direct sun off the primary for sun angles of greater than 15 degrees.</td>
</tr>
<tr>
<td>Telescope f number</td>
<td>5.7</td>
<td>Required to meet the numerical aperture of the fibers.</td>
</tr>
</tbody>
</table>
## Filter Requirements - 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>0.3 - 4.0 nm, depends on spectral region</td>
<td>Want good spectral isolation to minimize background effects. Bandwidth must be wide enough to accept modest temperature changes.</td>
</tr>
<tr>
<td>Effective index of refraction</td>
<td>1.8-2.0</td>
<td>Want large to minimize angular spectral shifts. Values of ~2 are the practical limit in the visible.</td>
</tr>
<tr>
<td>Thermal drift</td>
<td>0.002 nm/°C</td>
<td>Want small values to allow filter temperature to vary. Use of refractory oxide leads to about a factor of 10 improvement over old filter types.</td>
</tr>
<tr>
<td>Blocking range</td>
<td>200-1200 nm</td>
<td>Need to be blocked over the range the CCD is sensitive.</td>
</tr>
</tbody>
</table>
Filter Requirements - 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating temp.</td>
<td>20±5°C</td>
<td>Operating range of instrument. Leads to maximum thermal drift of 0.01 nm.</td>
</tr>
<tr>
<td>Size</td>
<td>diameter = 1.370 in (+0.0/-0.01 in),</td>
<td>Clear aperture matches optics, thickness as small as possible to minimized</td>
</tr>
<tr>
<td></td>
<td>clear aperture = 1.310 in, thickness no</td>
<td>moment of inertia.</td>
</tr>
<tr>
<td></td>
<td>greater than 0.098 in</td>
<td></td>
</tr>
<tr>
<td>Field of view</td>
<td>2.25°, F/12.7</td>
<td>Matches optics.</td>
</tr>
<tr>
<td>Tilt</td>
<td>1 degree</td>
<td>Moves reflected light out of optical path.</td>
</tr>
<tr>
<td>Position</td>
<td>Wavelength (nm-air)</td>
<td>FWHH (nm)</td>
</tr>
<tr>
<td>----------</td>
<td>---------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
<td>867.13</td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>763.68</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>557.8</td>
<td>0.5</td>
</tr>
<tr>
<td>4</td>
<td>OG 515</td>
<td>N/A</td>
</tr>
<tr>
<td>5</td>
<td>630.1</td>
<td>0.5</td>
</tr>
<tr>
<td>6</td>
<td>765.07</td>
<td>0.3</td>
</tr>
<tr>
<td>7</td>
<td>866.12</td>
<td>0.3</td>
</tr>
<tr>
<td>8</td>
<td>892.1</td>
<td>0.5</td>
</tr>
</tbody>
</table>
### TIDI Filter Wheel #2

<table>
<thead>
<tr>
<th>Position</th>
<th>Wavelength (nm-air)</th>
<th>FWHH (nm)</th>
<th>Feature</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OG 515</td>
<td>N/A</td>
<td>high pass filter</td>
<td>high transmission above 515 nm, removes UV and blue light</td>
</tr>
<tr>
<td>2</td>
<td>732.1</td>
<td>0.5</td>
<td>OII (2P) pair</td>
<td>plasma drift winds (170 - 300 km)</td>
</tr>
<tr>
<td>3</td>
<td>844.8</td>
<td>0.5</td>
<td>O triplet</td>
<td>auroral winds (150 - 300 km)</td>
</tr>
<tr>
<td>4</td>
<td>557.2</td>
<td>0.5</td>
<td>OI (1S) cal filter Kr (557.03 nm)</td>
<td>green line calibration filter</td>
</tr>
<tr>
<td>5</td>
<td>589.4</td>
<td>1.0</td>
<td>NaD doublet and Ne (590.25 nm)</td>
<td>sodium for nocturnal and auroral winds and temperatures (85 - 95 km)</td>
</tr>
<tr>
<td>6</td>
<td>779.5</td>
<td>0.5</td>
<td>OH Meinel (9-4) P1(2) pair</td>
<td>OH for nocturnal and auroral winds and temperatures (80 - 90 km)</td>
</tr>
<tr>
<td>7</td>
<td>764.0</td>
<td>4.0</td>
<td>O$_2$(1Σ) (0-0) P branch and Ar (763.51 nm)</td>
<td>band brightness w/ 761.0 nm</td>
</tr>
<tr>
<td>8</td>
<td>761.0</td>
<td>2.0</td>
<td>O$_2$(1Σ) (0-0) R branch and Kr (760.15 nm)</td>
<td>band brightness w/ 764.0 nm</td>
</tr>
</tbody>
</table>
Bidirectional Reflective Distribution Function (BRDF) describes the scattering pattern

$$BRDF(\theta) = \frac{b}{\theta^c}$$

b and c are constants.

If $c = 2$, then approximately

$$\sigma = \frac{\lambda}{360} \left( \frac{\pi b}{2} \ln \left[ \frac{\theta_{\text{max}}}{\theta_{\text{min}}} \right] \right)^{\frac{1}{2}}$$

If $c \neq 2$, then

$$\sigma = \frac{\lambda}{2} \left( \frac{\pi}{180} \right)^{\frac{c}{2}} \left( \frac{b}{2 \pi (2 - c)} \left[ \theta_{\text{max}}^{2-c} - \theta_{\text{min}}^{2-c} \right] \right)^{\frac{1}{2}}$$
BRDF vs. Surface Roughness

Dotted = analytical, Solid = numerical
star = -1.5, diamond = -2, triangle = -2.5
TIS and Scattered Light

- Total Integrated Scatter (TIS) describes the total amount of scattering

\[ \text{TIS} = \left(\frac{4\pi \sigma}{\lambda}\right)^2 \]

\(\sigma\) is the roughness, \(\lambda\) is the wavelength.

- The scattered light, \(B_{scat}\), is given by (for \(c = 2\))

\[
B_{scat} (\theta_b) = 2kb \int_{-\frac{\theta_v}{2}}^{\frac{\theta_h}{2}} \int_{-\frac{\theta_v}{2}}^{\frac{\theta_v}{2}} B_{Ray} (\theta_b + \theta_v) \phi(\theta_h, \theta_v, r_{primary}, r_{baffle}, d_{baffle}) \frac{d\theta_h}{\theta_h^2 + \theta_v^2} \]

\(2\)
Total Integrated Scatter vs. BRDF

BRDF coefficient

star = -1.5, diamond = -2, triangle = -2.5
### Parameters Used in Telescope Scattering Calculation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite altitude</td>
<td>625 km</td>
</tr>
<tr>
<td>Primary radius</td>
<td>3.85 cm</td>
</tr>
<tr>
<td>Critical baffle radius</td>
<td>4.75 cm</td>
</tr>
<tr>
<td>Primary-Critical baffle distance</td>
<td>42.46 cm</td>
</tr>
<tr>
<td>b</td>
<td>0.03</td>
</tr>
<tr>
<td>c</td>
<td>2</td>
</tr>
</tbody>
</table>
TIDI Simulated Limb Brightness at 865 nm

Simulated total
Simulated scattered
Simulated direct

Simulated signal (R/cm⁻¹) vs. Altitude (km)

BRDF coefficient = 0.03

Simulated signal (R/cm⁻¹)
Simulated $O_2 (0,1)$ Signal
Tangent Altitude: 85.0 km

Solid = without scattered light, Dashed = with scattered light
Simulated $\text{O}_2 (0,1)$

Line-of-Sight Wind Errors

Solid: no scattering    Dotted $b=0.0$ (direct scattering only)
Dot-dashed: $b=0.03$ (roughness = 1 nm rms)
Dashed $b=0.1$ (roughness = 2 nm rms)
Telescope Boresite Tilt
About Telescope x Axis

• **Requirement:**

The tilt will not increase vertical extent of the field of view by more than 20%

• **Equation:**

\[ \beta < \frac{f \cdot \text{fov}_{\text{ver}}}{\text{fov}_{\text{hor}}} \]

• **Results:**

\( f=0.2; \text{fov}_{\text{ver}}=0.05^\circ; \text{fov}_{\text{hor}}=2.5^\circ \)
\( \beta<800 \text{ arc-sec}=0.23^\circ \)
Telescope Alignment:
Rotation About Telescope z Axis

• **Effects:**
  Spacecraft velocity component in measured velocity is a strong function of this angle. This is a systematic effect and is included in zero wind term.
  
  • The viewing track distance from the spacecraft changes.

\[
d \approx s \sin \alpha \\
\Delta s \cos \alpha \Delta \alpha \\
\Delta \alpha = \frac{\Delta d}{s \cos \alpha} = 3^\circ
\]

\[
s = \sqrt{(z_s - z_i)2R_e + z_f}
\]

\[
z_s = 625\text{km} \quad z_i = 60\text{km} \quad R_e = 63
\]

\[
s \approx 2700\text{km} \quad \Delta d < 100\text{km}
\]

• Position the telescopes about the spacecraft z axis to \( \sim 1^\circ \) keeps the two fields effectively overlapped.
Telescope Alignment: Rotation About Telescope y Axis

• **Effect:**
  Rotation about the y axis rotates the elevation angle. This decreases the overscan available.

• There is an overscan of 5° on either side of the operational range.

• Placing the telescopes within 0.5° in this axis uses 10% of the overscan.
TIDI Error Overview

• Errors are comprised of two types:
  – 1. Systematic - Error biases that are constant (e.g. telescope placement), change slowly (e.g. instrument drift), or are step changes that occur once (e.g. 1-g effects, launch shifts).
  – 2. Random - Errors that change from measurement to measurement and are characterized by a probability distribution, usually Gaussian.

• A error bound is a range that, to a certain probability, will include the error from an individual measurement, e.g. “the error in the measurement has a 68% chance of being within 3 m/s.”

• Most science studies combine data in some form (e.g., averaging, fitting). This has the effect of reducing random errors by approximately 1 over the square root of the number of data points.
TIDI Systematic and Random Errors

\[ V_{\text{mea}} - V_{\text{true}} \]

- error bound
- error bound
- 1\(\sigma\) precision
- systematic error

\(1\sigma\) precision
TIDI Top Level Error Budget

<table>
<thead>
<tr>
<th>Error type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random</td>
<td>2.5 m/s</td>
</tr>
<tr>
<td>Systematic</td>
<td>2.0 m/s</td>
</tr>
<tr>
<td>Error bound (68%)</td>
<td>3.2 m/s</td>
</tr>
<tr>
<td>[1-σ Gaussian uncertainty equivalent]</td>
<td></td>
</tr>
</tbody>
</table>
Systematic Errors

• Systematic effects are lumped into the “zero wind.” This is the average velocity the instrument would measure if the atmosphere were not in motion. Systematic effects cause this value to be non-zero.

• Measurement of the zero wind correction requires a long, detailed, and difficult validation process.
  – On-board lamps provide information of long-term instrument drifts, changes in instrument sensitivity, and spectral resolution.
  – Known information about geophysical conditions provides useful constraints that can get the zero wind correction close.
  – Other measurements (other satellite instruments, ground-based instruments, or in-situ measurements) can provide direct comparisons.
    
    It is essential to know the characteristics of the data used in the comparison.
## Random Noise Budget

<table>
<thead>
<tr>
<th>Effect</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon noise</td>
<td>2.0 m/s</td>
<td>Integration time can be adjusted to obtain this value. Besides counting statistics, this includes noise components such as CCD read noise, CCD thermal noise, and background (both direct and telescope scattered).</td>
</tr>
<tr>
<td>Spacecraft velocity component uncertainty</td>
<td>1.5 m/s</td>
<td>Includes precision of telescope pointing knowledge and spacecraft attitude errors.</td>
</tr>
<tr>
<td>Interferometer temperature uncertainty</td>
<td>0.5 m/s</td>
<td>Typical drift is 50 m/s/°C. A precision of 0.01 degrees is required.</td>
</tr>
<tr>
<td>total</td>
<td>2.55 m/s</td>
<td></td>
</tr>
</tbody>
</table>
Spacecraft Velocity Components and Errors

The spacecraft velocity component knowledge requirement drives the azimuth error.

The component of the spacecraft velocity along the line of sight is given by

\[
v_c = v_{sc} \left[ \cos \varepsilon \cos \alpha - \psi \cos \varepsilon \sin \alpha + \theta \sin \varepsilon \right]
\]

and the error by

\[
\sigma^2_{v_c} = v_{sc0}^2 \left[ \sigma^2_{\varepsilon \varepsilon_0} \sin^2 \varepsilon_0 \cos^2 \alpha_0 + \sigma^2_{\alpha} \cos^2 \varepsilon_0 \sin^2 \alpha_0 + \sigma^2_{\psi} \cos^2 \varepsilon_0 \sin^2 \alpha_0 + \sigma^2_{\theta} \sin^2 \varepsilon_0 + \sigma^2_{v_{sc}} \cos^2 \varepsilon_0 \cos^2 \alpha_0 \right]
\]
Tangent Altitude and Errors

The Tangent altitude knowledge requirement drives the elevation error.

The tangent altitude is given by

$$z_T = (R_e + z_s) \cos \beta - R_e$$

and the angle, $\beta$, is given by

$$\sin \beta = \sin \varepsilon + \phi \cos \varepsilon \sin \alpha + \theta \cos \varepsilon \cos \alpha$$

The error is

$$\sigma_{z_T}^2 = (R_e + z_s)^2 \left[ \sigma_\phi^2 \sin^2 \alpha_o + \sigma_\theta^2 \cos^2 \alpha_o + \sigma_\varepsilon^2 \right] \sin^2 \varepsilon_o$$
# Error Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll knowledge error</td>
<td>0.01 deg (1-σ) 36 arc-sec</td>
<td>spacecraft value</td>
</tr>
<tr>
<td>Pitch knowledge error</td>
<td>0.01 deg (1-σ) 36 arc-sec</td>
<td>spacecraft value</td>
</tr>
<tr>
<td>Yaw knowledge error</td>
<td>0.01 deg (1-σ) 36 arc-sec</td>
<td>spacecraft value</td>
</tr>
<tr>
<td>Elevation knowledge error</td>
<td>0.018 deg (1-σ) 65 arc-sec</td>
<td>required to meet altitude knowledge</td>
</tr>
<tr>
<td>Azimuth knowledge error</td>
<td>0.0083 deg (1-σ) 30 arc-sec</td>
<td>required to meet spacecraft velocity component knowledge</td>
</tr>
<tr>
<td>Spacecraft speed knowledge error</td>
<td>0.25 m/s (1-σ)</td>
<td>spacecraft value</td>
</tr>
</tbody>
</table>
# Spacecraft Velocity Component Error Budget

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spacecraft speed error component</td>
<td>0.16 m/s</td>
<td></td>
</tr>
<tr>
<td>Yaw knowledge error</td>
<td>0.85 m/s</td>
<td></td>
</tr>
<tr>
<td>Roll knowledge error</td>
<td>0.00 m/s</td>
<td>no influence to 1\textsuperscript{st} order</td>
</tr>
<tr>
<td>Pitch knowledge error</td>
<td>0.51 m/s</td>
<td></td>
</tr>
<tr>
<td>Elevation angle knowledge error</td>
<td>0.65 m/s</td>
<td>driven by altitude requirement</td>
</tr>
<tr>
<td>Azimuth angle knowledge error</td>
<td>0.71 m/s</td>
<td>only free parameter</td>
</tr>
<tr>
<td>Total velocity component error</td>
<td>1.4 m/s</td>
<td>budget value = 1.5 m/s</td>
</tr>
</tbody>
</table>
# Tangent Altitude Error Budget

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yaw knowledge error</td>
<td>0.00 km</td>
<td>no influence to 1\textsuperscript{st} order</td>
</tr>
<tr>
<td>Roll knowledge error</td>
<td>0.34 km</td>
<td></td>
</tr>
<tr>
<td>Pitch knowledge error</td>
<td>0.34 km</td>
<td></td>
</tr>
<tr>
<td>Elevation angle knowledge error</td>
<td>0.86 km</td>
<td>dominate term</td>
</tr>
<tr>
<td>Azimuth angle knowledge error</td>
<td>0.00 km</td>
<td>no influence to 1\textsuperscript{st} order</td>
</tr>
<tr>
<td>Tangent altitude precision</td>
<td>0.98 km</td>
<td>budget value = 1 km</td>
</tr>
</tbody>
</table>
End-to-End Azimuth and Elevation Errors

Azimuth error

$$\sigma_{\alpha'}^2 = \sigma_{\alpha_o}^2 + \sigma_{\psi}^2 + \sigma_{\phi}^2 \cos^2 \alpha_o \tan^2 \varepsilon_o + \sigma_{\theta}^2 \sin^2 \alpha_o \tan^2 \varepsilon_o$$

Elevation error

$$\sigma_{\varepsilon'}^2 = \sigma_{\varepsilon}^2 + \sigma_{\phi}^2 \sin^2 \alpha_o + \sigma_{\theta}^2 \cos^2 \alpha_o$$
## TIDI Azimuth and Elevation Knowledge Errors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Azimuth</th>
<th>Elevation</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll knowledge</td>
<td>11 arc-sec</td>
<td>25 arc-sec</td>
<td>Based on 0.01 deg (36 arc-sec) precision and view geometry.</td>
</tr>
<tr>
<td>Pitch knowledge</td>
<td>11 arc-sec</td>
<td>25 arc-sec</td>
<td>Based on 0.01 deg (36 arc-sec) precision and view geometry.</td>
</tr>
<tr>
<td>Yaw knowledge</td>
<td>36 arc-sec</td>
<td>0 arc-sec</td>
<td>Based on 0.01 deg (36 arc-sec) precision and view geometry.</td>
</tr>
<tr>
<td>LVDT random error</td>
<td>0 arc-sec</td>
<td>25 arc-sec</td>
<td>SPRL measurement.</td>
</tr>
<tr>
<td>Telescope random error - elevation, $\sigma_{e,1}$</td>
<td>0 arc-sec</td>
<td>25 arc-sec</td>
<td>Based on elevation angle precision in S/C frame of 65 arc sec to meet altitude knowledge requirement.</td>
</tr>
<tr>
<td>Telescope pedestal to S/C error - elevation, $\sigma_{e,2}$</td>
<td>0 arc-sec</td>
<td>25 arc-sec</td>
<td>$\sqrt{\sigma_{e,1}^2 + \sigma_{e,2}^2} \leq 60$ arc-sec</td>
</tr>
<tr>
<td>Telescope random error - azimuth, $\sigma_{a,1}$</td>
<td>0 arc-sec</td>
<td>0 arc-sec</td>
<td>Based on azimuth angle precision in S/C frame of 30 arc sec to meet S/C velocity component knowledge.</td>
</tr>
<tr>
<td>Telescope pedestal to S/C error - azimuth, $\sigma_{a,2}$</td>
<td>$\sqrt{\sigma_{a,1}^2 + \sigma_{a,2}^2} \leq 30$ arc-sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>49 arc-sec</strong></td>
<td><strong>74 arc-sec</strong></td>
<td></td>
</tr>
</tbody>
</table>
## Comparison of Alignment Requirements

<table>
<thead>
<tr>
<th>Altitude Error (km)</th>
<th>1.0</th>
<th>1.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Zenith Error = 75 arc seconds</td>
<td></td>
<td></td>
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<tr>
<td>Total Zenith Error = 100 arc seconds</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>S/C Velocity Component Error (m/s)</th>
<th>Total Random Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>2.55</td>
</tr>
<tr>
<td>2.15</td>
<td>3.00</td>
</tr>
</tbody>
</table>

| Total Azimuth Error = 50 arc seconds | 1.4 | 2.55 |
| Total Azimuth Error = 80 arc seconds | 2.15 | 3.00 |
## Variable Definition

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>$v_c$</td>
<td>component of spacecraft velocity in viewing direction</td>
</tr>
<tr>
<td>$v_{sc}$</td>
<td>spacecraft velocity (~7500 m/s)</td>
</tr>
<tr>
<td>$v_{sc,o}$</td>
<td>nominal spacecraft speed</td>
</tr>
<tr>
<td>$\Delta v_{sc}$</td>
<td>error in spacecraft speed</td>
</tr>
<tr>
<td>$\sigma_{v_{sc}}$</td>
<td>standard deviation of spacecraft speed knowledge, ~0.25 m/s</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>viewing angle depression angle (0 = horizontal viewing), nominally ~23° in the spacecraft frame</td>
</tr>
<tr>
<td>$\varepsilon_o$</td>
<td>nominal viewing depression angle, i.e. what the angle is assumed and supposed to be</td>
</tr>
<tr>
<td>$\Delta \varepsilon$</td>
<td>error in the depression angle</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>azimuth angle of observation ±45°, ±135° to x axis of spacecraft</td>
</tr>
<tr>
<td>$\alpha_o$</td>
<td>nominal azimuth angle, i.e. what the angle is assumed and supposed to be</td>
</tr>
<tr>
<td>$\Delta \alpha$</td>
<td>error in the azimuth angle</td>
</tr>
<tr>
<td>$\psi$</td>
<td>yaw of spacecraft about z axis from the local horizontal, local vertical frame</td>
</tr>
<tr>
<td>$\sigma_{\psi}$</td>
<td>standard deviation of yaw knowledge, ~0.01 degrees</td>
</tr>
<tr>
<td>$\theta$</td>
<td>pitch of spacecraft about y axis from the local horizontal, local vertical frame</td>
</tr>
<tr>
<td>$\sigma_{\theta}$</td>
<td>standard deviation of pitch knowledge, ~0.01 degrees</td>
</tr>
<tr>
<td>$\phi$</td>
<td>roll of spacecraft about x axis from the local horizontal, local vertical frame</td>
</tr>
<tr>
<td>$\sigma_{\phi}$</td>
<td>standard deviation of roll knowledge, ~0.01 degrees</td>
</tr>
<tr>
<td>$z_T$</td>
<td>tangent altitude (60-300 km)</td>
</tr>
<tr>
<td>$R_e$</td>
<td>Earth radius (mean = 6371 km)</td>
</tr>
<tr>
<td>$z_s$</td>
<td>spacecraft altitude (625 km)</td>
</tr>
<tr>
<td>$\beta$</td>
<td>angle between look direction and z axis in the local horizontal, local vertical frame</td>
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<tr>
<td>$z_{T,o}$</td>
<td>nominal tangent point altitude</td>
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</table>
# TIDI Reference Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Earth radius(^1)</td>
<td>6371.00 km (mean)</td>
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<tr>
<td></td>
<td>6378.14 km (equator)</td>
</tr>
<tr>
<td></td>
<td>6356.755 km (pole)</td>
</tr>
<tr>
<td>Satellite altitude</td>
<td>625 km</td>
</tr>
<tr>
<td>Altitude viewing range</td>
<td>60-300 km</td>
</tr>
<tr>
<td>Viewing angles (from horizon)</td>
<td>24.4 degrees (0 km)</td>
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<tr>
<td></td>
<td>23.2 degrees (60 km)</td>
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<tr>
<td></td>
<td>17.5 degrees (300 km)</td>
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<tr>
<td>Distance from spacecraft to tangent point</td>
<td>2829.3 km (0 km tangent height)</td>
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<tr>
<td></td>
<td>2690.2 km (60 km tangent height)</td>
</tr>
<tr>
<td></td>
<td>2023.0 km (300 km tangent height)</td>
</tr>
<tr>
<td>Inclination</td>
<td>74.2 degrees</td>
</tr>
<tr>
<td>Precession rate</td>
<td>~-3 degrees/day</td>
</tr>
<tr>
<td>Satellite speed</td>
<td>~7.55 km /s</td>
</tr>
<tr>
<td>Orbital period</td>
<td>~97.06 minutes</td>
</tr>
<tr>
<td>Number of orbits per day</td>
<td>~14.8</td>
</tr>
</tbody>
</table>

\(^1\) Earth radius depends on whether the measurement is compared to the equator or the poles.
System Modeling

Qian Wu
SPRL, University of Michigan
qwu@engin.umich.edu
734-647-3475
Objectives

• Assist instrument design and verify system performance
• Design operational modes
• Produce simulated data and test data analysis software
Outlines

• Simulation routines
• Operational Modes
• Rotational Temperature
Simulation Routines

- Simulation routines
Simulation Model Block Diagram

- Year, Day, Time, Location, Solar conditions
- VER Models, Wind & Temp Models
- VER, Wind and Temp Profiles
- Line of Sight Integration
- Viewing Geometry, S/C speed, Reyleigh & Telescope Scatterings, Operational mode
- Emission line Spectra (including background and Doppler Shifts)
- Line of Sight Quantities
- FPI data Analysis Algorithm
- Signal Counts
- Instrument Function

TIDI CDR 4/28, 4/29/98

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<table>
<thead>
<tr>
<th>Emission</th>
<th>Time</th>
<th>Models</th>
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</thead>
<tbody>
<tr>
<td>6300</td>
<td>day &amp; night</td>
<td>Solomon 1993</td>
</tr>
<tr>
<td>5577</td>
<td>day</td>
<td>Solomon 1993</td>
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<tr>
<td>8446</td>
<td>day</td>
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<td>7320</td>
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<td>Solomon 1993</td>
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<tr>
<td>5577</td>
<td>night</td>
<td>Greer et al. 1986</td>
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<tr>
<td>5893</td>
<td>night</td>
<td>Swider 1986</td>
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<tr>
<td>Temp</td>
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<td>MSIS90</td>
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<tr>
<td>Wind</td>
<td></td>
<td>HWM93</td>
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</tbody>
</table>
O2 Airglow Emission Calculations

**Input**
- Daytime O2 (0-0) band intensity altitude profile*
- MSIS90 temp altitude profile
- Nighttime O2 (0-0) band intensity altitude profile+

**Routine**
- Calculate O2 band line intensities (O2emiss)

**Output**
- Daytime
  - O2 (0-1) VER alt. prof.
  - O2 (0-0) VER alt. prof.
- Nighttime
  - O2 (0-1) VER alt. prof.
  - O2 (0-0) VER alt. prof.

* Heller et al., JGR, 1991
+ Greer et al., PSS, 1986

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Dayglow Volume Emission Rates

![Graph showing Dayglow volume emission rates with altitude (km) on the y-axis and volume emission rate cm⁻³ on the x-axis. Various curves indicate different emission rates at specified altitudes.]
6300 Nightglow Emission Rate

Altitude (km)

Volume Emission Rate cm$^{-3}$
Line of Sight Integration Routine

**Input**
- Temp
- Wind
- VER profiles
- S/C Speed
- Telescope Rayleigh scattering

**Routine**
- calculate line sight brightness from VER,
- add Dopper effects of wind, temp, and S/C speed; and scattering backgrounds (intadd)

**Output**
- Line of Sight Spectra for four telescopes
Line of Sight Geometry

Viewing Direction

Airglow Layer

TIDI
Line of Sight Integration Example

5577 Airglow VER & Brightness

Altitude (km)

Volume Emission Rate cm$^{-3}$ & Brightness 100.0*R

5577 VER

5577 Brightness
instrument function.

Input:
- airglow emission spectra
- instrument parameters

Routine:
- use Airy function to calculate FPI spectra for four telescopes (instru)

Output:
- FPI Signal Counts
CLIO Configuration

- Mirror surface
- 90° Conical Mirror
- Focal point of the imaging optic coincident with the vertex of the cone
- CCD chip surface
CCD Binning Pattern

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</table>

Total 187 106 82 69 61
CCD Pixel Binning

FPI Spectra (without binning)

FPI Spectra (with binning)
FPI Data Analysis Routine

Input

FPI Signal Counts

Routine

use least square fit routine to retrieve LOS quantities (Analysis)

Output

Wind
Temp
Brightness
Background Measurements & Errors
TIDI 02 (0–0) Band Spectra From The Four Telescopes

Counts

3 × 10^4
2 × 10^4
1 × 10^4

Channels

0 50 100 150

Wind 5515. Error 0.976
Wind 5598. Error 1.053
Wind 5581. Error 1.052
Wind 5574. Error 0.947
Monte Carlo Test of FPI Analysis

Wind Measurement Monte Carlo Test Wind Measurement Monte Carlo Test

-5622.5 -5618.0 -5613.5 -5609.0

Counts

Average wind -5615.458
Deviation 0.999
02 (0–0) Band

Count

5590 5595 5600 5605

Average wind 5597.955
Deviation 1.053

Wind Measurement Monte Carlo Test Wind Measurement Monte Carlo Test

-5588 -5583 -5578 -5574

Counts

Average wind -5580.659
Deviation 1.070

Count

5567.2 5571.4 5575.6 5579.8

Average wind 5573.730
Deviation 0.953
Operational Modes

• Operational Modes
Daytime Baseline Operational Mode

UT (s)

alt (km)

8672.4 $\text{O}_2(0-1)$
8662.3 $\text{O}_2(0-1)$
7637.8 $\text{O}_2(0-0)$
7651.6 $\text{O}_2(0-0)$
5577.0 $\text{O}$
6300.0 $\text{O}$
8920.0 $\text{OH}(7,3)$
8446.0 $\text{O}$
7320.0 $\text{O}^+$
5571.0 $\text{Cal Kr}$
5896.0 $\text{Na}$
7640.0 $\text{O}_2(0-0)$
7610.0 $\text{O}_2(0-0)$
Baseline Mode Errors

Wind and Temp Errors Daytime Baseline Mode

- Temperature
- Wind
- LT 12.00 hr

Errors in Temp (k) & Wind (m/s)

Alt (km)
• Rotational Temperature Measurements
O2 (0-1) Rotational Temp Errors

O2 (0,1) Rotational Temperature Error

O2 (0,1) band Intensity

Altitude (km)

K

Altitude (km)

R

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O2 (0-0) Rotational Temp Errors

O2 (0,0) Rotational Temperature Error

Altitude (km)

K

O2 (0,0) band Intensity

Altitude (km)

R

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C.4 Calibration Overview

David A. Gell
Ground System Engineer
734.763.6221 (voice)  734.763.7130 (fax)
gellda@umich.edu
• Purpose of the calibration is to characterize the instrument so that accurate retrievals of scientific data can be performed

• Calibration results in the determination of an instrument model used in data processing and analysis

• The calibration plan is documented in 055-3265B
Calibration Approach

• Two approaches to calibration
  – The instrument function can be measured directly
    Provides accurate instrument function at time of calibration
    Does not provide a way to incorporate incremental changes
    Difficult to do on orbit
  – The instrument function can be modeled and measure the model parameters
    Provides accurate instrument function
    The model allows changes in the instrument function to be incorporated as they are detected by on-orbit calibrations
    On orbit measurements of parameters are possible
Calibration
Preflight

• Goals
  – Determine instrument function
  – Characterize the CCD
  – Determine the telescope alignment

• Method
  – Component Level
    Characterize filters, etalon, fiber optic, objective telescope, & CCD
  – Assembly Level
    Characterize telescope, telescope actuator, interferometer
  – System level
    Determine line positions and normalization
    Determine the instrument sensitivity (radiometric calibration)
    Direct measurement of the instrument function
  – Spacecraft level
    Determine alignment of telescopes with respect to spacecraft
Calibration Inflight

• Goals
  – Confirm instrument stability
  – Determine zero wind line position
  – Confirm tangent altitude determination

• Methods
  – View internal lamps
    track locations of calibration lines
    track sensitivity
  – View atmosphere
    view thin emission layers to confirm LVDT calibration and tangent height determination
    view Rayleigh scattering to confirm normalization
  – Correlative measurements
    determine zero wind line position
• Preflight calibration consists of
  – developing an instrument model
  – measuring the model parameters

• Inflight calibration consists of
  – confirming the values of the model parameters
  – adjusting the values of the parameters adopted for the model

• Details of the calibration facilities and procedures will be found in section H.4
Telescope System Overview

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Telescope Systems Overview

• Telescopes are used to collect photons
  – Must define a target volume of the atmosphere
  – Efficiently collect the available photons from the volume of interest
  – Effectively reject photons from outside the volume of interest
  – Rapid step and settle times from one volume to the next
  – Accurate knowledge of the location of the target volume
  – Operate in a predictable way over all environmental conditions
Telescope Requirements

- Target volume is defined by the telescope field of view
- Collection area and fov is set to match the profiler etendue
- Low roughness mirrors to limit small angle scatter, sun shade to limit large angle contamination
  - Use high reflectivity mirrors, AR coat all lenses
- Voice coil to drive telescope to new volume position
- LVDT to read telescope boresight position
  - calibrated over operating temperature to give boresight relative to the spacecraft coordinate frame
- Athermal optical design
Telescope Requirements (cont)

• Field of view = 0.05° x 2.5°
• Clear aperture = 7.5 cm
• Operating wavelength = 550-900 nm
• Numerical aperture = 0.22 (matching fiber optic)
• Primary mirror roughness = 15-20 Å rms
Telescope interfaces

• **Mechanical interfaces**
  – Voice coil to telescope and pedestal
  – LVDT assembly to pedestal and telescope body
  – Fiber optics to cannister housing
  – Fiber optic cable connector (female) to secondary optics housing
  – LVDT preamp board to APL housing

• **Electrical interfaces**
  – Voice coil to flex circuit
  – LVDT to preamp connector
  – Control harness to LVDT connector
  – Control harness to Shutter/voice coil/ op heater connector
ICD’s

- APL drawing 7372-0010 sheet 1
  - Mass properties, mechanical
- APL drawing 7372-0010 sheet 2
  - Fields of view
- APL drawing 7372-0010 sheet 3
  - Interfaces (Fiber optic, electrical, purge, GSE)
- APL drawing 7372-0010 sheet 4
  - Spacecraft
- APL drawing 7372-0010 sheet 5
  - Thermal
Telescope Overview

Ted Sholar
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TIDI  APL Telescope Lead Personnel

- Ted Sholar  Systems & Structural
- Keith Peacock  Optics
- Mike Kreitz  Mechanical
- Jack Ercol  Thermal
- Dave Lohr  Electrical
- Al Sadilek  Alignment & Purge
- Jim Hutcheson  Assembly Technician
- Rob Gold  Science
- Larry Mastracci  Product Assurance
- John Coopersmith  Contamination
APL Task Summary

• APL responsible for designing, building and testing four earth limb scanning telescopes for the University of Michigan’s Space Physics Research Laboratory (SPRL)

• SPRL is responsible for defining the top level telescope subsystem requirements which APL flows down into detailed engineering requirements

• SPRL supplies the telescope servo (scan drive actuator, position readout device, electronics and software)

• APL will build and test a flight like Engineering Model (EM) for design verification purposes

• In essence, this is an optomechanical task - no APL electronics or software development
Telescope Clear Field Of View, Typical Four Places
Optical Bench Configuration

- GPS ANTENNA (2)
- STAR CAMERA (2)
- OPTICAL BENCH
- TIDI TELESCOPE (4)
Telescope Configuration
Design Drivers

- Optical collection area and Field Of View (FOV)
- Minimize stray/scattered light reaching fiber optic bundle (focal plane)
- Keep subsystem drag torque under 5 ounce inches
- Max weight of 4.6 kg (10.14 lbs) per telescope
- End to end alignment knowledge error not to exceed 80 arc-sec azimuth and 100 arc-sec elevation
- No mechanical launch lock - utilize static balance
Interfaces

• S/C Interfaces: Three point bolted mount
  Clear Field Of View
  Electrical Connections
  Purge line

• SPRL Interfaces: Scan drive actuator (voice coil)
  LVDT assembly
  LVDT pre-amp electronics
  Fiber Optic Cable (FOC)
  Electrical Connections
Features - Optical

- Off-axis unobscurred primary mirror
- Field stop and Lyot stop for stray light control
- Re-imaging optics to fiber optic bundle
- Radiation resistant glass re-imaging lenses
- Light-weight aluminum primary and secondary mirrors
- Low scatter gold coating on mirror reflecting surfaces
Features - Optical

- Focal plane: 7.4 mm, 0.15 mm
- Field stop (slit): 8.0 mm, 0.3 mm
- Lyot stop
- Primary Mirror
- Secondary Mirror
- Re-imaging lens
- Focal plane: 7.4 mm, 0.15 mm
Features - Mechanical

• Nominal 20.35° look down angle from S/C horizontal
• ± 5° operational scan range with a ± 11° over scan capability for bearing lubrication
• Baffled telescope housing and sunshade for stray light
• Single use deployable cover and continuous purge of primary mirror for contamination control
• Shutter mechanism in line with fiber optic bundle
• Aluminum telescope assembly mounted to a titanium bearing assembly and support base
• Operationally, telescope is cantilevered from a single pair of angular contact bearings - snubber/bushing support required to survive launch
Features - Mechanical

10.7cm (4.2") Telescope Tube O.D.

Primary Mirror

Secondary Optics
Features - Mechanical

Snubber & Cable Guard Assemblies

Bearing Assembly

Voice Coil
Features - Thermal

• Four telescopes thermally configured in pairs: sun side (-Y) & anti-sun side (+Y)

• A single non-redundant dual element heater for both operational and survival modes

• Operational temperatures maintained with a programmable setpoint electronic thermostat

• Survival temperatures maintained with a non-redundant mechanical thermostat

• Operational design range of -20°C to +50°C, survival design range of -40°C to +50°C

• At certain Beta angles, available power may limit desired operating temperature
Features - Thermal

- Silver Teflon on external sun shades 3 and 4
- Thermal isolation typical at sun shade - telescope interface
- MLI on external sun shades 1 and 2
- MLI coverage typical on telescope, bearings and brackets
  - 1 mil black kapton SiO2 coating on outer layer
  - 15 layer layup using .25 mil VDA mylar
- Titanium brackets thermally coupled to optical bench minimizing top to bottom gradients
Test Plan - Engineering Model

- Ambient & cold drag torque determination
- Alignment error over temperature
- Component level sine and random vibration:
  - Alignment launch shift
  - Drag torque variation
  - No launch lock verification
- Alignment launch shift due to 1g release
- Deployable cover release
- Thermal balance - two configurations
- Life cycles in vacuum
Test Plan - Flight Units

- Component level optical measurements
- Deployable cover release
- Ambient & cold drag torque determination
- Subsystem optical measurements - ambient
- Subsystem optical measurements - in vacuum and over temperature (includes alignment)
- LVDT calibration over temperature
- Light leak check
- Component level sine and random vibration
<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optics Procurement</td>
<td>February 23, 1998</td>
</tr>
<tr>
<td>Began EM Testing</td>
<td>February 23, 1998</td>
</tr>
<tr>
<td>Flight Fabrication</td>
<td>April 3, 1998</td>
</tr>
<tr>
<td>Instrument CDR</td>
<td>April 28, 1998</td>
</tr>
<tr>
<td>Telescope CDR</td>
<td>May 7, 1998</td>
</tr>
<tr>
<td>Complete EM Testing</td>
<td>June 26, 1998</td>
</tr>
<tr>
<td>Begin Flight Assembly</td>
<td>July 24, 1998</td>
</tr>
<tr>
<td>Begin Flight Testing</td>
<td>September 25, 1998</td>
</tr>
<tr>
<td>Delivery</td>
<td>December 10, 1998</td>
</tr>
</tbody>
</table>
• Drag Torques: Cold testing verifies that 5 oz-in requirement will be met for operational scan range but may be exceeded during overscans

• Alignment Over Temperature: Initial testing indicated substantial movement - additional testing planned to verify problem and correct if legitimate

• Vibration: Structural integrity verified, alignment shift acceptable, drag torque variation acceptable and no launch lock verified

• 1 g Release: Alignment shift is acceptable

• Weight: Current mass margin is greater than 10%
Concerns

• Alignment errors
• Stray/scattered light
• Bearing torque spikes
• Focused sunlight on slit
TIDI CDR

Fiber Optic Design

Jon Harvey
TIDI Mechanical Engineer
(734) 764-6594
jdh@engin.umich.edu
• Fiber Optic Design
  – Requirements
  – Manufacturing Issues
  – Alignment issues
    Telescope
    Profiler
  – Top Deck Routing
  – Fab and Test Flow
Fiber Optic Design

• Requirements
  – Combine 4 Telescope and 1 cal. optical inputs into a common Profiler input.
  – Optical Field
    - Telescope: 0.283 x 006 (in) 390
    - Calibration: 1.15 dia. 390
    - Profiler: 5 ea. 90° co-axial sectors 390/field
  – Packing Factor ~ 0.75
  – Fused Silica fibers with 50 µm core
  – Provide mechanical protection to the optical fibers
  – Provide 1 pixel repeatability in bundle position for mate and de-mate
  – Prevent optical fiber breakage
  – Provide flexible interface across telescope gimbal
  – Captive hardware for interface connections
  – Estimated weight = 0.75 kg
Fiber Optic Design
Fiber Optic Design

- **Manufacturing Issues**
  - Fibers purchased from: Fiberguide Inc. Poly Micro Inc.
  - Engineering F.O. mfg. by Dolan Jenner
  - Tolerance requirements
  - Sheathing
  - Deliver Schedule
    - Test cable delivered 3/4/98
    - Engineering cable delivered 4/15/98

- **Flight Cable**
  - Dolan Jenner chosen vendor
  - No Major Issues
Fiber Optic Design

- Fiber optic cable assembly details

FIBERS
TEFLON TIES
TELESCOPE FLEX JOINT
MOUNTING FLANGE

WOVEN FIBERGLASS SLEEVE
CRES MONO-COIL
B-NUT
BLACK SHRINK FIT
BAYONET
• Alignment issues
  – Repeatability requirements: 1 pixel @ detector
    1.9e-4 in @ FO
  – Repeatability measured by test on optical breadboard and Lab CCD camera.
  – Results:

![FO Repeatability Test](image)

TIDI CDR 4/28, 4/29/98
Fiber Optic Design

• Top Deck Routing
  – Final lengths to be determined by S/C engineers before flight F.O. purchase order
  – Fiber optic assembly integrated like an electrical harness
  – F.O. connections made after TIDI components installed
Fiber Optic Design
Fiber Optic Design

• Fab and Test Flow

Flight Fiber Purchase

Flight FO Fabrication P. O. 6/98

Manufacture: Dolan-Jenner

DOLAN-JENNER MFG. TESTS
1.) Geometry Measurement
2.) Packing Factor
3.) Broken fibers
4.) Random quantification

Delivery to U of M 9/98

U of M Characterization Tests
1.) Through put of each field
2.) XXXXXX

Integration To Flight Instrument SYSTEM LEVEL CALIBRATIONS
TIDI CDR

Telescope Positioning System

Jon Harvey
TIDI Mechanical Engineer
(734) 764-6594
jdh@engin.umich.edu
Telescope Subsystem

• Positioning System
  – Requirements
  – Configuration
    – Structural, Thermal, Radiation Design
    – Torque

• Drive System
  – Torque Margins
TELESCOPE MECHANISMS

• LVDT ACTUATION MECHANISM

• BEI VOICE COIL
Positioning System

- LVDT Mechanism Requirements
  - Convert rotary motion of telescope to linear motion of LVDT
  - Accuracy (Knowledge) 60 arcsec (LVDT and Mechanical)
  - Lifetime 1 million cycles (2 year life, baseline scan)
  - 5 krad 0.03 in Tantalum to susceptible components in pre-amp
  - Low Torque < 1.0 oz-in
  - Thermal Transients Sun shade/ worst case @ terminator reduced position requirement
Positioning System

- Mechanical Configuration
  - Telescope interfaces
    - Flexure mount
    - Lvdt Mount
    - Upper Sun Shade Mount
  - Ti-6Al-4V Flexure/Link rod to match Tel. Pedestal CTE
  - Alum. sun shade to reduce thermal transient effects
  - Vespel SP-3 Bushings to prevent LVDT Core rubbing LVDT ID.
Positioning System

• Structural Design
  – Fatigue life = 1 million cycles (Baseline scan ± 5 deg, 2 year life)
    Ti engineering flexure tested to 1 mil cycles (± 10 deg.)
    40 flight like samples tested to 2 mil + cycles (± 10 deg)
  – Mode shape
    0 to +10 degrees
    0 to -10 degrees
DRIVE SYSTEM

- Rotary Voice Coil, BEI Model RA68-12-001
  - Rated Peak torque: 170 in-oz
  - De-rated for TIDI to: 50 in-oz
  - Stroke (motor max.): ± 11.0 deg.
  - Average power dissipation: 0.058 watts (Baseline scan)
  - Max power dissipation: 3.0 watts (continuous stall)
  - Materials changed to comply with 1% TML and 0.1% VCM
DRIVE SYSTEM

Mechanical Model Torque Test with Flex Circuit, Fiber Optic, Purge, LVDT Installed

Temperature vs Torque
# MECHANISMS

## MECHANISM SUMMARY

<table>
<thead>
<tr>
<th>MECHANISM</th>
<th>MFG</th>
<th>MFG LIFE TEST (CY)</th>
<th>2 YEAR LIFE* (CY)</th>
<th>RATED TORQ. (OZ-IN)</th>
<th>DRAG TORQ (OZ-IN)</th>
<th>ACCEL. TORQ. (OZ-IN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TELESCOPE ACTUATOR</td>
<td>BEI</td>
<td>NA</td>
<td>650000</td>
<td>50.0**</td>
<td>5.0 max</td>
<td>45</td>
</tr>
<tr>
<td>FILTER WHEEL MOTOR</td>
<td>LITTON</td>
<td>263865 M.</td>
<td>325000</td>
<td>5.9</td>
<td>0.36</td>
<td>5.54</td>
</tr>
<tr>
<td>SHUTTER MOTOR</td>
<td>LITTON</td>
<td>263865 M.</td>
<td>&lt;&lt; Filter Wheel</td>
<td>5.9</td>
<td>0.36</td>
<td>5.54</td>
</tr>
</tbody>
</table>

* BASED ON THE BASELINE SCIENCE SCAN.
** DERATED FROM 170 oz-in.
TIDI CDR

Profiler Structural / Thermal Analysis

Bob Berry
TIDI Analysis Engineer
(203) 894-2616
berryr@svg.com
Profiler Structural & Thermal Design

• Structural Models, Description, Results Summaries
  – Profiler NASTRAN Model
    Mounting Feet
    Kinematic Mounts
    Etalon Mount
  – Thermal Models, Description, Results Summaries
    TRASYS Model
    SINDA Model
Output Set: Eigenvalue 579330.
Deformed(9.277): Total Translation
• Predicted response $f_n = 100$ Hz
  – $3\sigma$ response level = 39 g
• **Worst Case Bolt (50 g Load Factor)**
  - Max Loads (lbf):
    \[ X = 232 \]
    \[ Y = 473 \]
    \[ Z = 77 \]
  - Max Moments (lbf-in)
    \[ MX = 39 \]
    \[ MY = 66 \]
    \[ MZ = 0.0 \]
  - Max Stress (psi)
    \[ p/a = 13791 \]
    \[ Mc/I = 98053 \]
    \[ p/a + Mc/I = 111844 \]
    Bolt Yield Stress: 160 ksi
  - FS = 1.4
Profiler Housing Supported By Kinematic Mounts

- **Fixed Rod:**
  - No Translation
  - High Stiffness in bending
- **Rod:**
  - Low stiffness, 2-axis
- **Leaf**
  - Low stiffness, 1-axis
• ETALON NASTRAN MODEL
  – Predict changes in etalon gap space for:
    Adjustment sensitivity
    Temperature change
ETALON - NASTRAN MODEL

TABLE OF MECHANICAL PROPERTIES

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FUSED SILICA</td>
<td>10.64E+06</td>
</tr>
<tr>
<td>ZERODUR PROPERTY</td>
<td>13.16E+06</td>
</tr>
<tr>
<td>MODULUS OF ELASTICITY, PSI</td>
<td>3.0796</td>
</tr>
<tr>
<td>DENSITY, #/CU IN</td>
<td>0.0796</td>
</tr>
<tr>
<td>SHEAR MODULUS, PSI</td>
<td>4.02E+06</td>
</tr>
<tr>
<td>POISSON'S RATIO</td>
<td>0.17</td>
</tr>
<tr>
<td>CTE/DEG C</td>
<td>5.02E-07</td>
</tr>
</tbody>
</table>

Bob Berry

TIDI CDR 4/28, 4/29/98

A.239 Edmonson
ETALON MOUNT ADJUSTMENT SPRING

- Adjustment Spring Model

NEW ETALON SPRING DESIGN

R. BERRY, 2-16-98
• Etalon mount deflection under adjustment pre-load
  – Bottom support deflection
ETALON ADJUSTMENT RESULTS

ETALON STRUCTURAL ANALYSIS

SURFACE TO SURFACE RELATIVE MOTION (IN MICROINCHES)
DUE TO A 10 POUND PRELOAD ON EACH MOUNT (3 PLACES)

40 Microinches = 1 Micron
ETALON THERMAL STABILITY RESULTS

ETALON STRUCTURAL ANALYSIS
SURFACE TO SURFACE RELATIVE MOTION (IN MICROINCHES)
ASSEMBLED @ 25C  OPERATIONAL @ 15C (-10 DEG C DELTA TEMP)

40 Microinches = 1 Micron
STRUCTURAL ISSUES/ CONCERNS

- Finalize bench analysis
- Dynamic analysis of Etalon mount
• TRASYS Models
  – Description
  – Environment
  – Properties

• SINDA Model
  – Description
  – Power Balance
  – Cold Orbit average temp predictions
  – Hot orbit average temp predictions
  – Heater Power predictions
• TIMED Orbit, ref TIMED System Requirements Doc. APL 7363-9001
• TIDI SIIS
• TIDI Thermal Design documented in SPRL document 055-3586 TIDI Thermal Control Document
### S/C INTERFACE TEMPERATURE LIMITS

- **S/C Thermal Interface (ref. TIMED CDR)**

<table>
<thead>
<tr>
<th></th>
<th>Thermal Control Design Range</th>
<th>TEST I/F Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Operating I/F 0°C</td>
<td>Operating 0°C</td>
</tr>
<tr>
<td>TIDI Profiler (Isolated)</td>
<td>-19 to 30</td>
<td>-29 to 40</td>
</tr>
<tr>
<td></td>
<td>Non-Op 0°C</td>
<td>Non-Op 0°C</td>
</tr>
<tr>
<td></td>
<td>-24 to 50</td>
<td>-34 to 60</td>
</tr>
</tbody>
</table>
2.2.2 HOT ORBIT

Hot orbit properties listed in the TIMED CDR are as follows:

- Beta Angle: 0.0° to 88°
- Solar Constant: 1420 W/m²
- Albedo: 0.40
- Earthshine: 268 W/m²
- Optical Properties:
  - EOL
  - MLI effective emittance (sun side): 0.03
  - MLI effective emittance (cold side): 0.01
  - MLI effective emittance (small blankets): 0.05
- Internal heat dissipations: Max. orbit avg.
- Sun / Eclipse Times: 95min./ 0 min.
2.2.3 COLD ORBIT

Cold orbit properties listed in the TIMED CDR are as follows:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta Angle</td>
<td>0.0° to 88°</td>
</tr>
<tr>
<td>Solar Constant</td>
<td>1287 W/m²</td>
</tr>
<tr>
<td>Albedo</td>
<td>0.2</td>
</tr>
<tr>
<td>Earthshine</td>
<td>190 W/m²</td>
</tr>
<tr>
<td>Optical Properties</td>
<td>BOL</td>
</tr>
<tr>
<td>MLI effective emittance (front)</td>
<td>0.01</td>
</tr>
<tr>
<td>MLI effective emittance (Back)</td>
<td>0.03</td>
</tr>
<tr>
<td>MLI effective emittance (small blankets)</td>
<td>0.05</td>
</tr>
<tr>
<td>Internal heat dissipations</td>
<td>Min. orbit avg.</td>
</tr>
<tr>
<td>Sun / Eclipse Times</td>
<td>60 min. / 35 min</td>
</tr>
</tbody>
</table>
NS-43-C WHITE PAINT PROPERTIES

NS-43-C White Paint Hemispherical Emissivity vs Temp

Emissivity (ε)

-100 -80 -60 -40 -20 0 20

Temperature (C )

-0.82 -0.84 -0.86 -0.88 -0.90 -0.92
• **Profiler Thermal Requirements**

<table>
<thead>
<tr>
<th></th>
<th>OPERATIONAL TEMP.</th>
<th>SURVIVAL TEMP.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min $(\text{C}^\circ)$</td>
<td>max $(\text{C}^\circ)$</td>
</tr>
<tr>
<td>CCD</td>
<td>-75.0</td>
<td>-85.0</td>
</tr>
<tr>
<td>FPA Housing</td>
<td>-20</td>
<td>-40</td>
</tr>
<tr>
<td>Etalon</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Filters</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Optics</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Profiler Hsg</td>
<td>15</td>
<td>25</td>
</tr>
</tbody>
</table>

CCD Housing Thermally Isolated to profiler housing: $> 50\text{C/watt}$

Profiler thermal gradient:
(Along optical axis)

Orbit stability:
(Etalon housing temp)

Etalon beta cycle stability:

Thermal Isolation to spacecraft: $> 20\text{C/watt}$
EXTERIOR MODEL (TRASYS)

PROPERTIES FOR HOT CASE (EOL)
- AZ93W1 = 0.40, EZ93W1 = 0.83 $ Z93 WHITE PAINT @ -50 DEG C (95.6%)
- AZ93W2 = 0.40, EZ93W2 = 0.80 $ Z93 WHITE PAINT @ -75 DEG C (92.5%)
- AAGT2S = 0.30, EAGT2S = 0.64 $ SUN FACING SILVER FEP, 2 MIL
- AAGT2D = 0.21, EAGT2D = 0.64 $ NON-SUN FACING SILVER FEP, 2 MIL

PROPERTIES FOR COLD CASE (BOL)
- AZ93W1 = 0.20, EZ93W1 = 0.83 $ Z93 WHITE PAINT @ -50 DEG C (95.6%)
- AZ93W2 = 0.20, EZ93W2 = 0.80 $ Z93 WHITE PAINT @ -75 DEG C (92.5%)
- AAGT2S = 0.08, EAGT2S = 0.68 $ SUN FACING SILVER FEP, 2 MIL
- AAGT2D = 0.08, EAGT2D = 0.68 $ NON-SUN FACING SILVER FEP, 2 MIL

INTERIOR MODEL (TRASYS)

PROPERTIES FOR HOT CASE (EOL), $E^* = 0.01$
- AALODN = 0.40, EALODN = 0.15 $ ALODINE ON ALUMINUM
- AAGT2D = 0.21, EAGT2D = 0.64 $ NON-SUN FACING SILVER TEFOLON, 2 MIL

PROPERTIES FOR COLD CASE (BOL), $E^* = 0.03$
- AALODN = 0.40, EALODN = 0.15 $ ALODINE ON ALUMINUM
- AAGT2D = 0.08, EAGT2D = 0.68 $ NON-SUN FACING SILVER TEFOLON, 2 MIL
<table>
<thead>
<tr>
<th>SINDA MODEL DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Diffusion nodes</td>
</tr>
<tr>
<td>• Arithmetic nodes</td>
</tr>
<tr>
<td>• Boundary nodes</td>
</tr>
<tr>
<td>• Linear conductors</td>
</tr>
<tr>
<td>• Radiation conductors</td>
</tr>
</tbody>
</table>
### Internal Heat Loads

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>HOT ORBIT POWER (W)</th>
<th>COLD ORBIT POWER (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCD</td>
<td>0.058</td>
<td>0.050</td>
</tr>
<tr>
<td>CCD AUX AMP</td>
<td>0.11</td>
<td>0.09</td>
</tr>
<tr>
<td>CCD PRE AMP</td>
<td>0.08</td>
<td>0.0690</td>
</tr>
<tr>
<td>FILTER WHEEL MOTOR</td>
<td>0.33</td>
<td>0.2880</td>
</tr>
<tr>
<td>TOTAL HEAT DISSIPATION</td>
<td>0.57</td>
<td>0.4990</td>
</tr>
</tbody>
</table>

### Heater Power Estimates- Peak heater power = 1.5* orbit average

<table>
<thead>
<tr>
<th>HEATER LOCATION</th>
<th>HOT ORBIT AVERAGE POWER (W)</th>
<th>COLD ORBIT AVERAGE POWER (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GUARD HEATER</td>
<td>1.71</td>
<td>2.43</td>
</tr>
<tr>
<td>COND. TELESCOPE HEATER (P)</td>
<td>2.26</td>
<td>3.64</td>
</tr>
<tr>
<td>ETALON HEATER (L)</td>
<td>0.31</td>
<td>0.75</td>
</tr>
<tr>
<td>ETALON HEATER (R)</td>
<td>0.00</td>
<td>0.62</td>
</tr>
<tr>
<td>FILTER WHEEL HEATER</td>
<td>0.00</td>
<td>0.18</td>
</tr>
<tr>
<td>CCD HEATER</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>TOTAL (watts)</td>
<td>4.29</td>
<td>7.67</td>
</tr>
</tbody>
</table>
Selected temperature predictions

<table>
<thead>
<tr>
<th>Location</th>
<th>Node</th>
<th>HOT ORBIT</th>
<th>COLD ORBIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCD,</td>
<td>410</td>
<td>-81.70</td>
<td>-81.60</td>
</tr>
<tr>
<td>CCD RADIATOR</td>
<td>400</td>
<td>-81.80</td>
<td>-81.80</td>
</tr>
<tr>
<td>CCD HEATER</td>
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<td>-81.60</td>
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<tr>
<td>Guard Radiator</td>
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<td>-51.00</td>
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<td>Guard Shroud</td>
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<td>FPA HSG (Guard)</td>
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<td>-49.60</td>
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<td>Filter Wheel HSG.</td>
<td>221</td>
<td>15.50</td>
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<td>Baseplate</td>
<td>500</td>
<td>6.50</td>
<td>-23.90</td>
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<td>Ext. Housing</td>
<td>420</td>
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<td>-26.60</td>
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<tr>
<td></td>
<td>458</td>
<td>5.00</td>
<td>-26.80</td>
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</table>
HOT ORBIT PLOTS FROM OLD MODEL

THE UNIVERSITY OF MICHIGAN
TIDI PROFILER THERMAL ANALYSIS
WORST CASE HOT ORBIT

- Temperatures in degrees Celsius
- Time in hours

The plots show temperature variations over time for various components:
- Guard Radiator
- CCD Radiator
- Filter Wheel Heater
- Telescope Housing (Etalon, etc.)
- MLI Around Telescope Housing
- MLI Around Guard Housing
HOT ORBIT PLOTS FROM OLD MODEL
Guard Housing Cool Down Rate

GuARD COOL DOWN

- Guard Housing Cool Down Rate

TIDI - PROFILER
GUARD HOUSING COOLDOWN

The University of Michigan - Space Physics Research Laboratory

Cooldown scenario: PROFILER @ 10 deg C., All thermal nodes floating.
Radiation coupling to deep space (4 deg K.)
Development and Test

- Flow Chart

**Flow Chart**

- TIDI Thermal Model (SINDA)
  - TRASYS RADIATION COUPLINGS
  - RADIATOR GEOMETRY
  - THERMAL ISOLATOR TEST DATA
  - FPA THERMAL TEST DATA

- CDR
  - Finalize Thermal Design
  - THERMAL TEST PREDICTIONS

- Earth Sade Validation
  - INSTRUMENT LEVEL THERMAL BALANCE/ THERMAL QUAL.

- FINAL ON ORBIT PREDICTIONS

- THERMAL MODEL CORRELATIONS
THERMAL ISSUES/ CONCERNS

- CCD pre-amp temp limits
- Earth shade geometry validation
TIDI CDR
Profiler Detector Design

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CCD DETECTOR ASSEMBLY

- CCD Detector Design
  - Mechanical Design
  - Thermal Design
- CCD Detector Assembly and Test
- Status Summary - Issues/ Concerns
• Mechanical Design
  – 6061-t6 Aluminum construction
  – ~0.800 in Al radiation shield thickness
  – CCD constantan wire leads
    0.01 in dia. from bias board to adapter card
    0.005 in dia. from adapter card to CCD PWB.
  – All sensors drawings ready for final checks before sign off
  – Sensor housing can be sealed by GSE for cold operation with vacuum
  – Vibration Test Results
• Detector Assembly Figure
• Thermal Isolators
  – Max tensile load = 70,900 lbf
  – Max bending load = 10.07 lbf-in
  – Torsional stress minimized by restraining stud when nut is torqued in place
  – Ti studs to be pull tested to validate heat treat
  – Static load test of HSG isolators to 200 lbf (1σ static equiv.)
  – Full level verification vib test
VIBRATION TEST RESULTS

- Sine sweeps performed to extract modes
- $f_n$ predicted for 4 thermal isolators using vibration data

Sine Survey 5-2000 Hz

<table>
<thead>
<tr>
<th>AXIS</th>
<th>CCD ISO. $f_n$ (Hz)</th>
<th>HSG (6) ISO $f_n$ (Hz)</th>
<th>HSG (4) ISO $f_n$ (Hz) PREDICT.</th>
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<td>X</td>
<td>526</td>
<td>281</td>
<td>150</td>
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<tr>
<td>Y</td>
<td>1471</td>
<td>706</td>
<td>375</td>
</tr>
<tr>
<td>Z</td>
<td>533</td>
<td>285</td>
<td>150</td>
</tr>
</tbody>
</table>
• Sensor and Radiator assembly response prediction
• $3\sigma$ Load factor = 51g @ $f_n=150$ Hz
• $1\sigma$ Load factor = 17 g
DETECTOR ASSEMBLY

• Thermal Design
  – G-10cr and Ti-6Al-4V thermal isolators
  – Cold finger, 3 ea. thermal isolators
  – Sensor housing, 4 ea. thermal isolators
  – Polished low $\varepsilon$ gold coatings
  – CCD and CCD radiator coupled with cold finger
  – Sensor housing radiator bolts directly to sensor housing
• Thermal Test Results
  – Conductances validated
  – Reduced sensor thermal model to predict operating temps from radiator temp predictions
  – Heater sizes checked
  – Thermal time constants
Sensor Thermal Balance Test 1

- Time vs CCD Temp. (Temp. Diode)
- Time vs Cold Finger (Temp Diode)
- Time vs Pre-amp Temp. (Temp Diode)
- Time vs Sensor Housing Temp (Temp Diode)
- Time vs Housing Temp (RTD)
- Time vs -40 C Sensor HSG. Base Temp (RTD)
- Time vs -85 C CCD Base Temp. (RTD)

Heat Loads “ON”
CCD = 0.045 watts
PRE-AMP = 0.09 watts

TIDI CDR 4/28, 4/29/98
A.271 Edmonson
DETECTOR ASSEMBLY STATUS

- Preliminary assembly procedure written
- Flight thermal isolator hardware in house
- Rev. A flight part drawings signed/ released (May 1998)
- Flight parts mfg. completed (June 1998)
- Post processes on flight parts complete (July 1998)
- Flight assembly starts (Aug. 1998)
- Completed Flight Assembly (Sept. 1998)
FPA DEVELOPMENT FLOW CHART

- **Receive Flight CCD’s**
- **Build additional Flight FPA Assembly**
- **Assemble Flight FPA with eng. ccd / preamp**
- **Calibration Tests with flight FPA Assembly**
- **Final Flight FPA**
- **Full level Vibration test**
- **Send Flight parts for coatings**
- **FPA Thermal validation Test**

**Flight Parts rel. for Manufacture**
ISSUES AND CONCERNS

- Pre-amp temperature limit
- Late delivery of flight CCD
Electronics Overview

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Electronics Block Diagram

TELESCOPES

- TELESCOPE MOTORS (4)
- SHUTTER MOTORS (4)
- LVDT PREAMPS (4)
- TEMP SENSORS
- HEATERS
- CCD MOUNTING BOARD
- CCD FEEDTHRU BOARD
- CCD PREAMP BOARD
- CCD BIAS BOARD
- TEMP SENSORS
- HEATERS
- ENCODER DETECTOR BOARDS (2)

PROFILER

- FILTER WHEEL MOTORS (2)
- ENCODER EMITTER BOARDS (2)
- CCD BIAS BOARD
- CCD PREAMP BOARD
- CCD FEEDTHRU BOARD
- CCD MOUNTING BOARD

CONTROL HARNESS

- S/C INST. POWER
- S/C OP HTR POWER
- 1553 A DATA
- 1553 B DATA
- CCD TEST

ELECTRONICS STACK

TIDI
- 1553 A DATA
- 1553 B DATA
- CCD TEST

TIMED
- S/C INST. POWER
- S/C OP HTR POWER

TIDI CDR 4/28, 4/29/98

A.276 Edmonson
TIMED Electrical Interfaces

• Power
  – Separate Instrument and Operational Heater 28 VDC Power
  – Three way power isolation
    Primary to chassis
    Primary to secondary
    Secondary to chassis
  – Inrush current limited

• Communications
  – Dual redundant MIL-STD-1553B per 3.0 of the GIIS
    Remote Terminal configuration - address 10
Electronics Environment

- **Temperature (Operational) per 2.3.1 of the CES**
  - Telescopes -20 to +50 C
  - Electronics Stack -20 to +45 C
  - Profiler +15 to +25 C (CCD Preamp -40 to +25 C)

- **EMI/EMC**
  - Selected paragraphs of MIL-STD-461B per 2.6 of the CES

- **Pressure per 2.3.1 of CES - less than 10e-5 torr**

- **Vibration per 2.4.2.2 of CES**
  - Sine 8.5g Thrust, 8.5g Lateral
  - Random 0.10g^2/Hz, 100-600 Hz

- **Radiation**
  - 10 krad (si) Total Dose per 2.7.1 of the CES
Stack Pictorial
## Deck Status Summary

<table>
<thead>
<tr>
<th>Deck Assembly</th>
<th>SW I/F Spec</th>
<th>Schematic Capture</th>
<th>Parts List</th>
<th>PCB Layout</th>
<th>FPGA Design</th>
<th>Parts on Order</th>
<th>Flight Frame Design</th>
<th>EM PCB Dwg Pkg</th>
<th>EM Fab</th>
<th>EM Test</th>
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<tbody>
<tr>
<td>Power Supply</td>
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<td>Flight Computer</td>
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<td>Data Acquisition</td>
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</table>
Remote Electronics

- **Telescope Electronics**
  - LVDT Preamplifier (4)

- **Profiler Electronics**
  - CCD Mounting Board
  - CCD Feedthru Board
  - CCD Bias Board
  - CCD Preamp Board
  - Encoder Emitter Board (2)
  - Encoder Detector Board (2)
# Remote Electronics Status

<table>
<thead>
<tr>
<th>Electronic Assembly</th>
<th>Schematic Capture</th>
<th>Parts List</th>
<th>PCB Layout</th>
<th>Parts on Order</th>
<th>Flight Mech Design</th>
<th>EM PCB Dwg Pkg</th>
<th>EM Fab</th>
<th>EM Test</th>
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<td>100%</td>
<td>90%</td>
<td>50%</td>
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Power Summary

• Extensive study and estimates made for Appendix E of the TIDI SIIS - November 97
• Update for this CDR reveals very small changes to the estimates previously submitted
• Estimates generated from detailed average and peak power calculations of the current electrical designs at the component level
• Operational heater loads are factored into calculations
• Increase in operational heater power of about 25% since Nov 97
• Conservative estimate of power supply efficiency was applied to determine primary load
Power Summary (contd.)

- **Definition of Modes:**
  - **Standby** = Cal and servo supplies commanded “off”
  - **Direct Control** = Cal and servo supplies on, telescopes holding
  - **Data Collection** = Cal and servo supplies on, telescopes scanning

<table>
<thead>
<tr>
<th></th>
<th>HOT CASE</th>
<th>COLD CASE</th>
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<tbody>
<tr>
<td><strong>TIDI Electronics Power (Watts)</strong></td>
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<tr>
<td>Direct Control</td>
<td>6.6</td>
<td>6.6</td>
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</tbody>
</table>

|                        |           |           |
| **TIDI Operational Heater Power (Watts)** |          |           |
| Standby                | 8.1       | 12.9      |
| Data Collection        | 7.7       | 12.5      |
| Direct Control         | 8.1       | 12.9      |

|                        |           |           |
| **Total TIDI Power (Watts) = System + Opr Htr** |          |           |
| Standby                | 14.7      | 19.5      |
| Data Collection        | 17.2      | 22.0      |
| Direct Control         | 14.7      | 19.5      |
Harnesses

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Harness Summary

- Three harness designs
  - Bus Flex Harness
  - Deck Power Harness
  - Control Harness
Control Harness

- Provides connections between electronics stack, profiler, and four telescopes
- 182 Separate circuit functions carried by this harness
- 15 Connectors, all 311P407 or 311P409 type

**Status**
- Pin-outs defined for all but 2 connectors (MH deck & Profiler)
- Connector selection complete, ready for flight connector procurement

**Remaining design tasks**
- Transfer pin lists to wire lists
- Generate assembly drawing and parts list
- Use Spacecraft top deck mock up to determine routing, break-out points and tie downs
Power Harness

- **Functions**
  - Provide secondary power distribution between stack decks
  - Provide analog signal distribution between stack decks
  - 121 different circuit functions
  - 8 Connectors, all 311P407 types

- **Status**
  - Pinouts for all but 2 connectors defined (MH deck and PS deck)
  - Connector selection complete, ready for flight procurement

- **Remaining design tasks**
  - Transfer pin lists to wire lists
  - Generate assembly drawing and parts list
  - Use stack connector mounting plate to determine routing, break-out points and tie downs
Data Bus Flex Harness

• Functions
  – Provide digital communications between decks
    8 Bit Address bus
    16 Bit Data bus
    Bus read/write control and clock
    8 Interrupt lines
    8 Bit CCD data bus
    CCD memory control
    – Implemented with Flex-Circuit to reduce weight and provide a convenient method of shielding the many circuit connections
    – 5 Connectors, all Air-Borne WTB70 type

• Status
  – All pinouts defined
  – EM harness procured and in house
• Remaining design tasks
  – Generate assembly drawing and manufacturing parts list
Electronics Assembly & Test

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Assembly & Test Overview

• Engineering Model (EM) - Assembly & Test Flow
  – P. Hansen

• Flight Stack & Electronics - Assembly & Test Flow
  – P. Hansen

• Electronics Stack Test Systems
  – S. Musko
Typical Individual EM Board Test Sequence

• Initial power-up test
  – Lab Power Supplies
  – Bus Simulator GSE

• Flight Computer Interface Test
  – Emulator and Visual Basic Test Scripts to monitor and control board under test
  – External laboratory/custom engineering simulators for inputs/loads

• Temperature Test
  – Non operational temperature limits
  – Operational temperature cycling and performance tests
EM Stack Integration Outline

• **Support Hardware**
  – Laboratory Power Supplies
  – GSE = Emulator and Spacecraft Simulator
  – EM Harnesses
  – EM Board Fixtures
  – Laboratory Test Equipment
    Logic Analyzer, Scope, DVM, etc.

• **Begin with Flight Computer Board**
  – Establish 1553 communications

• **Integrate Data Acquisition Board**
  – Acts as Voltage/Current and Temperature monitor for boards to be added as integration proceeds
  – Contains CCD image RAM
EM Stack Integration (contd)

• Integrate CCD Controller, and EM CCD hardware
• Integrate Telescope Servo Controller and single EM Telescope
• Integrate Motor Heater Controller, EM Filter Wheel, Dummy Heater/Sensors
• Integrate Breadboard Power Supply
• First Cut at integrated control with Spacecraft Simulator
• Assemble EM Board Fixtures into EM “Stack”
• Temperature Test
Flight Stack Assembly Flow

• All flight decks will be thoroughly tested in the EM stack environment prior to Flight Stack integration
• Flight Stack Assembly is Similar to EM integration plan
• All flight decks will be subject to standard SPRL QA log book tracking per the QA plan
  – Individual deck QA tracking will continue during stack integration
• Integration flow will begin with the flight power supply deck
  – Laboratory power supplies could be used to start the integration in the event of schedule problems with the PS deck
• Flight Computer deck is next, followed by DA deck and CCD Controller
Flight Electronics Integration

START INSTRUMENT INTEGRATION

FLIGHT CONTROL HARNESS

PROFILER

FLIGHT CCD

FLIGHT TELESCOPES (4)

TEMP TEST & CALIBRATION

COMPLETED FLIGHT STACK

FLIGHT FILTER WHEELS AND HTRS
TIDI CDR

Electronics Packaging

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• Electronics Packaging
  – ICD
  – Mechanical design
  – Structural design
  – Thermal design
  – Radiation Protection
ELECTRONICS ICD

- Electronics Box ICD Summary
- Electronics Thermal Interface
ELECTRONICS PACKAGING

NOTES:
1. INTERPRET DRAWINGS PER AND 14401
2. M62 = 6.6 kg
3. MOMENTS OF INERTIA: I_x = 15, I_y = 15
4. MOMENTS OF INERTIA: I_z = 15

SECTION AA

TOP VIEW

+X

GROUND STRAP LOCATION

FORCE SUMP

CONNECTIONS TBD PER INDIVIDUAL SUBSYSTEMS

THERMAL CONTROL SURFACE MOUNTING PRESSURE SEAL

0.30 TYP, 0.25 MIN

+Z

FRONT VIEW

RIGHT SIDE VIEW

BACK VIEW

DO NOT SCALE

TIDI CDR 4/28, 4/29/98
ELECTRONICS PACKAGING
ELECTRONICS PACKAGING

• Mechanical Design
  – Individual PC board Frames
  – Cover plates between each frame and on ends
  – Stacked frames become the TIDI E-Box
  – HARDI heritage
ELECTRONICS PACKAGING

• PC Board Thermal Design

• Hot Components average power (+15%):
  – 1553  2ea.  2.3 w  HS to frame (Flight Computer)
  – CPU    1ea.  0.58 w  HS to frame (Flight Computer)
  – MOSFET  8ea.  0.17 w  HS to frame (Servo deck)
  – Pwr Hybrid 2ea.  2.3 w  Internal frame mount (PS deck)
  – MOSFET  5ea.  0.12 w  TO 254 attached to frame (PS)
  – Rectifier 2ea.  0.13 w  TO-257 attached to frame (PS)
  – Pwr switch 1ea.  0.46 w  TO-66 attached to frame (PS)

• Heat sinks
  – Integral to frame or custom part bolted in place
  – Indium foil and thermal grease at interface
ELECTRONICS PACKAGING

MOSFETS

MOSFET MOUNT/HEATSINK (ATTACHES TO CIRCUIT BOARD AND DECK ENCLOSURE)

CIRCUIT BOARD

DECK ENCLOSURE

TYP., 8 PL.

TYP., 3 PL.

TYP., 3 PL.

TYP., 4 PL.
ELECTRONICS PACKAGING

• Radiation Protection
  – Shielding to 5 krad on critical components
  – Tantalum spot shields where required
  – Tantalum Shielded Components:
CCD Imaging System

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Requirements Summary

• CCD
  – 15 micron Pixels
  – Backside Illuminated
  – Low Noise
  – Flight Heritage
  – At Least 600 x 50 Pixels

• Subsystem
  – Selectable Image Region
  – Fixed Vertical Binning
  – Variable Horizontal (Wavelength) Binning
  – Adjustable Gain
  – Adjustable Erase and Expose Times
  – Provide Adjustable Clocking Rates to CCD
  – Provide Adjustable Drive Levels for CCD Clocks
  – Provide Test Interface for Image
  – Interface with DA Deck for Image Storage
  – Provide Power Supply and Heater Synchronization
Subsystem Overview

• CCD Controller
  – Flight Computer Bus Interface
  – CCD Clock Rates
  – CCD Clock Levels
  – Post-Amp/Dual Slope Integrator
  – A/D Conversion
  – DA Deck Image Interface
  – Test Interface

• Bias Board
  – CCD Output Drain Voltage
  – Diode Temperature Sensor Interface
  – Signal Buffering/Bypassing
Substring Overview (cont.)

- **Preamp**
  - CCD Output Preamplifier
  - Profiler Survival Heater

- **Adapter**
  - Interconnection from Cold to Hot

- **CCD**
  - SITe ST005A
Subsystem Block Diagram

- Power Input: +5V, +/-15V, +26V
- FC Bus Interface
- Test Interface
- CCD Controller
- CCD Interface
- Profiler
- Sensor Housing
  - Preamp
  - Adapter
- Cryostat
- CCD
• SITe ST-005A
• 2000 x 800 Pixels
• Backside Illuminated
• 15 µm Pixels
• QE Stability
  – 53% @ 500nm
  – 63% @ 600nm
  – 35% @ 900nm
  – ±0.2% Pixel to Pixel Relative
  – ±2.0% Absolute
• CTE
  – 0.999999 at 40k Electrons/pixel
  – 0.99995 at 1620 Electrons/pixel

CCD Overview

• Full Well
  – 60k Electrons, MPP Mode
  – 600k Electrons in Serial Register
• Area of Interest
  – 600 x 100 Pixels
  – No Hot or Dark Pixels
  – Single Quadrant
  – QE within ±15% of Average
• Output Amplifiers
  – Greater than 1µV/electron
  – 30mW Power Dissipation Max.
• Readout Noise ≤ 8 electrons
CCD Region of Interest

Image Area (600 x 50)
Within Area of Interest (600x100)

Allowable Regions (677 x 400)
CCD Schematic

- Package Can Be Rotated 180°
- Output A or D
- All Parallel Clocks Common
- One Serial Register Used
CCD Statement of Work

- Updated to Revision 055-3479A
- Mostly Minor Changes to Facilitate Testing at SITe
- More Detailed Testing Specifications
- Area of Interest Increased to 600x100 (was 600x50)
- Diode Temperature Sensor (was Resistive)
CCD Procurement Status

• Engineering Grade Devices
  – Due to Equipment Problems at SITe:
    2 of 5 Engineering Grade Devices are not from Flight Lot
    Delivery Delayed from April 1, but In-House Now
    Diode Temperature Sensor Included
  – 3 of 5 Accelerated Life Test Devices From Flight Lot
    1000 Hour Tests Completed After Flight Delivery

• Grade 2 Devices
  – 2 Devices with Good Specs
  – Due In-House Now

• Flight Grade Devices
  – Delivery in October/November
Flight CCD Qualification

• SITe Accelerated Test Program
  – Lots out of Fab 5/20/98
  – Wafer and Package Test Complete 6/15/98
  – Mechanical Testing Complete (2 Devices) 7/2/98
  – Screen Testing Complete 7/8/98
  – Flight Testing Complete 7/17/98
  – 3 Flight Units Shipped to U of M 7/21/98
  – 1000 Hour Life Test Complete (3 Devices) 8/5/98
Preamp/Bias Overview

• Preamp
  – CCD Output Amplification
  – CCD Signal Bypassing, Conditioning
  – Interfaces Hot Side to Cold Side

• Bias
  – CCD Temperature Diode Conditioning
  – CCD Signal Bypassing, Conditioning
Preamp Schematic

- 15K Load R for CCD Output
- AC Coupled
- Gain of 11
- OP37 Op-Amp
CCD Controller Overview

- Flight Computer Bus Interface
- FPGA
  - Provides all Timing and Control Functions
- D/A Converters
  - High and Low Voltages for CCD Clocks
  - Bias Voltages
- Dual-Slope Integrator
  - Eliminates Reset Noise
  - Provides Post-Amp Gain
CCD Controller Overview (cont.)

• A/D Converter
  – 12-Bit AD674B
  – 15usec Max. Conversion Time

• CCD Interface
  – CMOS Switches Controlled by FPGA Create Clocks
  – DACs Provide Inputs to Switches

• DA Deck Interface
  – 8-bit Interface to Image Memory
  – 12-bit Words Split into 4/8-bit Transfers
CCD Controller FPGA Overview

• **Sequence Control**
  – Erase
  – Expose
  – Vertical Dump
  – Serial Register Dump
  – Vertical Binning
  – Horizontal Dump
  – Horizontal Binning
  – Conversion

• **Binning**
  – Fixed
  – Variable (Horizontal)
CCD Controller FPGA Overview (cont.)

• Gain Control
  – 2 Gain States for Dual-Slope Integrator
  – Fixed or Variable (Horizontal/Wavelength)

• Conversion/Shifting Rates
  – 7 Serial Clock Rates
  – 7 Parallel Clock Rates
  – 7 A/D Conversion Rates

• Image Memory Interface
  – DA Deck 8-Bit Interface
  – 2 Transfers for Each Pixel

• Test Interface
  – 12-Bit Interface
  – Spectral Images PCI Board (PC)
CCD FPGA Block Diagram

- Oscillator
- Clock Generation
  - 16.384 MHz
- Serial Clock Select
- Parallel Clock Select
- ADC Clock Select
- ADC Phase Control
- ADC Control
- DA/Test Interface Control
- SH, ADRC
- ACLK, AQEN, AQNIB
- FRAME, PIXCLK
- STS
- S1, S2, S3, S, W
- P1, P2, P3, TG
- Sync
- 512KHz
- 128KHz
- 4KHz
- 8.192 MHz
- 128KHz
- 512KHz
- Bus Interface
  - Address, Data, Control
  - Vertical Bins Register
    - Vertical Bins Counter
  - Horizontal Bins Register
    - Horizontal Bins Counter
  - Control Registers
    - Interrupt Control
  - Images Register
    - Images Counter
  - RAM Interface
    - RAM Control
    - Shared Counter
  - Sequence Control State Machine
  - RAM Interface
    - Address, Data, Control
  - DA/Test Interface
  - DCRST
  - INT+, INT-
Timing - Image Cycle

- Erase: 8 ms
- Expose: 800 ms
- VDump: 2 ms, 350 p
- RDump: 3 ms, 2030 p
- VBin: 3 ms
- HDump: 0.3 ms, 50 p
- Clamp: 0.2 ms
- HBin: 0.32 ms, 102 p
- Sample: 7 us, 5 p
- Convert: 0.32 ms, 17 us
- OScan: 0.64 ms, 1323 p

Parallel Clock = 171 KHz
Serial Clock = 683 KHz
A/D Conversion Rate = 1.6 KHz
Average Hor. Bin = 5 Pixels
600 x 50 Image Area Binned to 120 x 1
Total Conversion Time = 76 ms
Total Readout Time = 83 ms

800
2000
Subsystem Performance

- **CCD Gain:** 1.5µV/electron
- **CCD MOSFET 1/F Noise:** 8 electrons
- **Preamp Noise:** 3 electrons
- **Total Noise (RSS):** 8.5 electrons

**ADC Performance:**

<table>
<thead>
<tr>
<th>A/D Rate</th>
<th>Counts/e-</th>
<th>Readout Time (120 x 1 Image)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6 KHz</td>
<td>1.1</td>
<td>75 ms</td>
</tr>
<tr>
<td>3.2 KHz</td>
<td>0.55</td>
<td>37.5 ms</td>
</tr>
<tr>
<td>6.4 KHz</td>
<td>0.28</td>
<td>18.8 ms</td>
</tr>
<tr>
<td>12.8 KHz</td>
<td>0.14</td>
<td>9.4 ms</td>
</tr>
</tbody>
</table>
Test Flow

• Engineering Model CCD Controller Standalone Testing
• Integration with Test Camera Head
  – Prototype Bias
  – Prototype Preamp
  – Engineering Grade CCD
  – Shutter/Shutter Control
• Development of Characterization Procedures
• Integration with Engineering Electronics Stack
• Characterization of Flight CCDs
Test Setups - Functional Testing
Stand-alone CCD Controller

Diagram:
- Lab PC
- DIO-96 Digital I/O Board
- Spectral Instruments PCI Image I/F
- Differential Interface Board
- CCD Controller PCB
- CCD Test
- Lab Power Supply (+5, +15, -15, +26)
- Lab Power Supply (+26V, +5)
- CCD Lab Camera
- W1, W2, W3, W4, W5, W6, W7

Legend:
- DIO-96: Digital I/O Board
- Spectral Instruments: PCI Image I/F
- Differential Interface Board
- CCD Controller PCB
- CCD Test
- Lab Power Supply (+5, +15, -15, +26)
- Lab Power Supply (+26V, +5)
- CCD Lab Camera
- W1, W2, W3, W4, W5, W6, W7
CCD Characterization

- Bias
  - Read Noise
  - Electronics Noise
- Dark Counts
- Photon Transfer
- Flat Field
- Quantum Efficiency
- QE Stability

Diagram:
- Photodiode 1 to V
- "Air Collimator"
- Integrating Sphere
- Shutter
- CCD
- "Air Collimator"
- Computer
- A-D
- Light Source
- Interference Filter
- "Collimator"
CCD Characterization

- X-Ray CTE
Engineering Model Status

• CCD Controller Status
  – Assembled
  – Bus Interface Verified
  – Clocking Verified
  – RAM Access Verified
  – Basic Sequencing Verified
  – ADC Control Verified
  – ADC Trimmed for 0 to 10V Operation
  – DAC Operation Verified
  – Test Interface Operation Verified

• CCD Controller EM Checkout Remaining
  – Verify CCD Clock Timing
  – Test Dual-Slope Integrator
Engineering Model Status (cont.)

• Lab Camera Status
  – PCB in Manufacturing
  – Camera Head Assembled
  – Engineering CCDs In-House

• Lab Camera Checkout Remaining
  – Verify Preamp/Bias Operation
  – Verify Connections to CCD
  – Verify Shutter Operation
  – Integrate and Test CCD
Engineering Model Status (cont.)

- **Image Processing Software Status**
  - Basic User Interface Complete
  - CCD Controller Setup Complete
  - Basic Image Acquisition (via Test Interface) Complete

- **Image Processing Software Tasks Remaining**
  - “Image Manager” Interface
  - Support for Multiple Images
  - User Settable Region of Interest with Statistics
  - Automatic Flat-Fielding Support
Planned Milestones

- EM Controller Checkout Complete  Mid May
- EM Preamp/Bias Checkout        Late May
- Image Processing Software      Late May
- Engineering CCD Test Complete  Mid June
- Incorporate Design Changes     Late June
- Manufacture Flight PCBs        Mid July
- Assemble Flight PCBs           Early August
- Begin Testing Flight Components Early August
ADC Calculations

\[
\text{Counts} \equiv \left( \frac{4096}{10 \text{ V}} \right) \cdot \frac{G_{\text{ccd}} \cdot G_{\text{Preamp}}}{R \cdot C} \int_{0}^{T} 1 \, dt
\]

Where:

\[G_{\text{ccd}} := \frac{1.5 \cdot \text{uV}}{e}\]

\[G_{\text{Preamp}} := 11\]

\[R := 500 \Omega\]

\[C := 2700 \text{pF}\]
LOW VOLTAGE POWER SUPPLY

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TIDI PS is intended to meet specifications put forth in TIMED Component Environmental Specification 7363-9010 and TIMED EMC Control Plan and EMI Performance Requirements Specification 7363-9038

- Key Requirements:
  - Bus Voltage +22VDC to +35VDC
  - Transients: +/-28V peak for <200mS (+56V max., -2V min.)
  - Fault: 0 to 40V
  - In-rush current 10A max for 10uS, 2.5A for 200mS
  - Survive short circuit across primary power inputs
  - 1Megohm isolation between Primary Power, Secondary Power, Heaters and Chassis Ground
  - Separate EMI/EMC control for Heater Power
• **Output Requirements**
  – Provide low voltage outputs
    + +/-15 Volts - Pulsed Loads
    + +/-15 Volts - Quiet
    + 5 Volts - Logic
    + 26 Volts - CCD FET Boost
    + 28 Volts - Calibration Supply
    + +/-6 Volts - Servo Supply
  – Temperature monitor
  – Current sense for Primary Power and Heater Power
  – Provide Power On Reset signal
OUTPUT PEAK LOAD REQUIREMENTS

<table>
<thead>
<tr>
<th>Polarity</th>
<th>OUTPUT VOLTAGE</th>
<th>Note 3</th>
<th>Note 3</th>
<th>Note 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>Plus</td>
<td>Minus</td>
<td>Plus</td>
<td>Minus</td>
</tr>
<tr>
<td>Value</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Type</td>
<td>Pulsed</td>
<td>Pulsed</td>
<td>Quiet</td>
<td>Quiet</td>
</tr>
</tbody>
</table>

Electronic Subsystem

- CCD Controller (CD) 28.0 35.0 41.0 4.0
- Flight Computer (FC) 260.0
- Data Acquisition (DA) 22.0 22.5 30.0
- Filter Wheel/Motor/Heater (MH) 662.0
- Telescope Servo Controller (TS) 78.5 76.5 20.0 4440.0 0.0
- Calibration Lamp PS (CAL) 50.0 150.0

Total Load Current (mA) 662.0 260.0 128.5 134.0 524.0 4.0 150.0 4440.0 0.0
Total Load Power (W) 9.93 3.90 1.93 2.01 2.62 0.10 4.20 26.64 0.0

Grand Total PS Peak Load Power 51.33 Watts from either +6 or -6, not simultaneous
Peak PS Input Power @ .7 Eff 73.33 Watts 4.44 amps assumes 4 telescopes slewing, scan mode
Operational Heater Power 13.87 Watts (Cold Case, 100% DF, 26V)
Total TIDI Peak Load Power @ 26V 87.20 Watts Note 2: Cal lamp peak current may be drawn continuously during ground testing/calibration
TIDI Peak Input Current @ 22V 3.78 Amps
TIDI Peak Input Current @ 26V 3.35 Amps Note 3: Voltage is On/Off Commandable
TIDI Peak Input Current @ 35V 2.81 Amps Note 4: Normal peak -15V current (260 ma) for 1553 activity lasts 3 ms each second (0.3% DF). The value shown would represent 100% activity by 1553 i.e babbling

SC Input Voltage 22 26 35
Instrument Peak Current 3.33 2.82 2.10 Amps Note 5: Peak current is duty cycled, 6.5 sec on,
Operational Heater Peak Current 0.45 0.53 0.72 Amps 6.5 sec off so maximum "average" peak power is
Total Peak Current 3.78 3.35 2.81 Amps 26.64/2=13.32W
DESIGN STRATEGY

• Input filter includes common mode and EMI filters
  – Soft start control used to restrict in-rush current and ensure filter is fully charged prior to PWM start-up

• Switching frequencies synchronized with CCD sample clock for system noise suppression

• Interpoint DC/DC converters for +5, +/-15V outputs

• Boost converters for +26CCD, +28Cal supplies
  – +26CCD derived from +15
  – +28Cal derived from +5

• Custom PWM supply for +/-6 Servo
  – Similar in concept to design used on TOMS
DESIGN DETAILS

• +5, +/-15V outputs generated by Interpoint hybrids MTR2805SF and MTR2815DF
  – Two hybrids used due to peak load demands; ensures adequate margin over load and temperature
  – Synchronized to 512KHz provided by CCD Controller
  – Hybrids inhibited at turn-on by soft start circuit until input filter charged
  – Separate output filters for +/-15V Quiet and +/-15V Pulse outputs

• Boost converters used for +26CCD, +28CAL
  – +26CCD derived from +15V
  – +28CAL derived from +5V
  – Each synchronized to 128KHz provided by CCD Controller

• Power On Reset is an active low signal; clears 160mS after +5V output reaches 4.7V; triggers when +5V output drops below 4.5V
• +/-6 Servo power supply is a custom PWM design
  – Power stage consists of 128KHz PWM pre-regulator followed by a phase-locked 64KHz driven inverter
    128KHz clock provided by CCD Controller
  – SG1524B control chips used for PWM and inverter
  – Transformer is custom built on ferrite torroid
    Same construction techniques as used on MSX-CEMS, Cassini INMS, Huygens Probe GCMS, TOMS EP
    Control power and regulator feedback provided by dedicated winding
  – Design similar in concept to power supply built for TOMS
CHANGES SINCE PDR

- +/-12V output changed to +/-15V for adequate margin for 10V references, op-amps
- Separate EMI/EMC filters provided for SC_28V_MAIN and SC_28V_HTR
- Power On Reset signal added
IMPLEMENTATION PLANS

- Breadboard Testing complete: Mid-late May
- PCB Layout Complete: Mid June
- Magnetics Manufacture Start: June
- Manufacture Flight PCB
- Flight Unit Assembly Complete: Late July
  - Contingency plan calls for installation of prototype hybrids if flight hybrids are not available
- Flight Unit Testing Complete: Mid August
  - Contingent upon flight hybrid delivery
INTERPOINT CONCERNS

- **Use of multilayer ceramic capacitor in hybrid**
  - Input capacitor for MTR series is a 6uF “high-fire” Presidio multilayer ceramic (PN HRS301X7R605M2J3HA)

- **Use of opto-isolators**
  - MTR series does not use opto-isolators; magnetic feedback is utilized for regulation/isolation

- **Stability margin**
  - Converter stability will be rigorously tested on the breadboard model over load, line, and temperature. Inhibit will be set to ensure EMI filter is fully charged prior to converter start-up.

- **Sync signal failure**
  - In the event of a sync signal failure (high or low) converters will free run at their nominal frequency (625KHz typical)
Flight Computer

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734-763-5373
Requirements Summary

• **Spacecraft Requirements**
  – MIL-STD-1553B Interface
  – Radiation Hardened, Qualified Components

• **Instrument Requirements**
  – Boot PROM
  – Data and Program RAM
  – EEPROM for Code and Data Storage
  – Watchdog Timer
  – Power-On Reset
  – Discrete Digital Output
  – Bus Interface for Control of Other Decks
  – Bench Test Features (Reset, Watchdog Disable)
Subsystem Overview

• CPU
  – UTMC 69RH051 (Rad-Hard 80C51)
  – 16 MHz Clock

• Memory
  – 16K Boot PROM
  – 64K Program RAM
  – 64K Data RAM
  – 128K EEPROM

• Spacecraft Interface
  – MIL-STD-1553B (Transformer Coupled)
  – DDC BU61582
Subsystem Overview (cont.)

• **Instrument Control Bus**
  – 16-bit Address
  – 8-bit Data
  – Read, Write, Reset, 8 Interrupts, 2 MHz Bus Clock

• **General**
  – Paged Memory
  – Watchdog Timer
  – Cal Lamp Control, Cal & Servo Power Supply Control
  – Bench Test (Reset, Watchdog Disable)
Operational Description

• 8051 Memory Space
  – 64K Data Space
  – 64K Program Space

• Memory Paging
  – Allows More than 64K For Data Access
  – 16K Window in Data RAM
  – Page Register Controls Actual Memory Accessed via 16K Window

• Bootup
  – 16K PROM Available for Program Execution
  – 48K Program RAM Available for Program Execution
  – All Program RAM (64K) is Read/Write via Page Register
Operational Description (cont.)

• Control Register
  – Disable PROM
  – Enable Read/Write access to Program RAM

• Watchdog Timer
  – FPGA State Machine
  – No Sequential Modules
  – 2.09 Second Timeout
  – Generates 131ms Reset Pulse
Bus Timing Diagrams

External Bus Read Cycle (16 MHz)

- A15, A14
- A13..A0
- RD/
- D0..D7 (IN)

Timing:
- 275 ns
- 119 ns
- 283 ns

External Bus Write Cycle (16 MHz)

- A15, A14
- A13..A0
- WR/
- D0..D7 (OUT)

Timing:
- 130 ns
- 275 ns
Memory Map

16K PROM

64K Program RAM

Internal RAM/Registers

64K Data RAM

PROM is decodable after Reset. Can be disabled by CPU using Control Register.

Program RAM above 0x4000 is decodable after Reset. Page Window access can be enabled by CPU using Control Register.

Internal RAM/Registers are always accessible using appropriate 8051 addressing modes.

Actual memory space accessed using Data RAM addresses C000..FFFF is dependent on value of Page Register.
## On-Board Register List

<table>
<thead>
<tr>
<th>On-Board Address (Hex)</th>
<th>On-Board Device</th>
<th>Register Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000..003F</td>
<td>1553 Registers</td>
<td>16 bits</td>
</tr>
<tr>
<td>80</td>
<td>Page Register</td>
<td>8 bits</td>
</tr>
<tr>
<td>81</td>
<td>Control Register</td>
<td>8 bits</td>
</tr>
<tr>
<td>82</td>
<td>Status Register</td>
<td>8 bits</td>
</tr>
<tr>
<td>83</td>
<td>Watchdog Reset</td>
<td>8 bits</td>
</tr>
<tr>
<td>84</td>
<td>Interrupt Register</td>
<td>8 bits</td>
</tr>
<tr>
<td>85</td>
<td>Digital Output</td>
<td>8 bits</td>
</tr>
</tbody>
</table>
# Page Register Definitions

<table>
<thead>
<tr>
<th>Page Register Value (Hex)</th>
<th>Device Accessed</th>
<th>Device Address (Hex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Data RAM</td>
<td>C000..FFFF</td>
</tr>
<tr>
<td>01</td>
<td>Program RAM</td>
<td>0000..3FFF</td>
</tr>
<tr>
<td>02</td>
<td>Program RAM</td>
<td>4000..7FFF</td>
</tr>
<tr>
<td>03</td>
<td>Program RAM</td>
<td>8000..BFFF</td>
</tr>
<tr>
<td>04</td>
<td>Program RAM</td>
<td>C000..FFFF</td>
</tr>
<tr>
<td>05</td>
<td>Data EEPROM</td>
<td>0000..3FFF</td>
</tr>
<tr>
<td>06</td>
<td>Data EEPROM</td>
<td>4000..7FFF</td>
</tr>
<tr>
<td>07</td>
<td>Data EEPROM</td>
<td>8000..BFFF</td>
</tr>
<tr>
<td>08</td>
<td>Data EEPROM</td>
<td>C000..FFFF</td>
</tr>
<tr>
<td>09</td>
<td>Data EEPROM</td>
<td>10000..13FFF</td>
</tr>
<tr>
<td>0A</td>
<td>Data EEPROM</td>
<td>14000..17FFF</td>
</tr>
<tr>
<td>0B</td>
<td>Data EEPROM</td>
<td>18000..1BFFF</td>
</tr>
<tr>
<td>0C</td>
<td>Data EEPROM</td>
<td>1C000..1FFFF</td>
</tr>
<tr>
<td>0D</td>
<td>1553 RAM</td>
<td>0000..3FFF</td>
</tr>
<tr>
<td>0E</td>
<td>1553 RAM</td>
<td>4000..7FFF</td>
</tr>
<tr>
<td>0F</td>
<td>Boot PROM</td>
<td>0000.3FFF</td>
</tr>
<tr>
<td>80</td>
<td>CCD Controller Deck (Bus)</td>
<td>0000..3FFF</td>
</tr>
<tr>
<td>81</td>
<td>Motor/Heater Deck (Bus)</td>
<td>4000..7FFF</td>
</tr>
<tr>
<td>82</td>
<td>ADC Deck</td>
<td>(Bus) 8000..BFFF</td>
</tr>
<tr>
<td>83</td>
<td>Servo Deck</td>
<td>(Bus) C000..FFFF</td>
</tr>
</tbody>
</table>
Design Status

• Changes Since PDR
  – No significant changes

• Design Complete

• Engineering Model
  – PCB Assembled
  – Partially Tested
    Memory Decoding
    Memory Paging
    On-Board Registers, 1553 Registers
    Clocks
    Program Execution
Design Status (cont.)

• Remaining Testing
  – 1553 Interface
    Interconnection with Spacecraft Simulator
    Message Transfer
    Electrical Verification of Interface to MIL-STD-1553
  – External Deck to Deck Bus
    Addressing
    Timing
  – Timing Verification
    Decoder Performance
    Memory Access Timing Margins
  – Temperature Test
    Full Functional Test with PROMs (EEPROMs)
Planned Milestones

• Complete Engineering Model Tests  Early May
• Release Flight Computer to S/W Dev.  Mid May
• Incorporate Design Changes  Mid May
• Procure Flight PCB  Late May
• Assemble Flight PCB  Early June
• Test Flight PCB  Mid June
Data Acquisition Deck

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DA Deck Block Diagram

HOUSEKEEPING

16 X 1 MUX

WIDE SPAN TEMP SCALING AMP

4 X 1 MUX

NARROW SPAN TEMP SCALING AMP

8 X 1 MUX

12 BIT A/D CONV

80 SINGLE ENDED ANALOG INPUTS

42 DIFF AMPS

ANALOG SIGNAL CONDITIONING

UP TO 16 AD590's

UP TO 4 AD590's

UP TO 6 DIFF I & V MON

48 X 6 MUX

UP TO 16 AD590's

SCIENCE

64K x 8 SRAM CCD BUFFER

60 SINGLE ENDED ANALOG INPUTS

42 DIFF AMPS

ANALOG SIGNAL CONDITIONING

UP TO 4 AD590's

UP TO 6 DIFF I & V MON

48 X 6 MUX

UP TO 16 AD590's

SCIENCE

DIGITIZED DATA AND CONTROL SIGNALS FROM CCD CONTROLLER DECK

120 SAMPLES AT UP TO 50 KHZ CONVERSION RATE EACH

ONE SECOND INTEGRATION PERIOD (150 SAMPLES @ CAL)

SENSE SAMPLE RATE = 1 SPS

SENSOR SAMPLE RATE = 1 KHZ

A/D CONVERSION RATE = 1 KHZ

INTEGRATION TIME PERIOD (1.5 S)

SET TIME PERIOD (150 SAMPLES @ CAL)

120 SAMPLES AT UP TO 50 KHZ CONVERSION RATE EACH

ONE SECOND INTEGRATION PERIOD (150 SAMPLES @ CAL)

RESET

R/W CTRL

2 MHZ CLK

INT

DATA 8

ADR 15

CTRL 4

DATA 8

CTRL 3

BUS INTERFACE UNIT

FPGA

120 SAMPLES AT UP TO 50 KHZ CONVERSION RATE EACH

ONE SECOND INTEGRATION PERIOD (150 SAMPLES @ CAL)

SET TIME PERIOD (150 SAMPLES @ CAL)

120 SAMPLES AT UP TO 50 KHZ CONVERSION RATE EACH

ONE SECOND INTEGRATION PERIOD (150 SAMPLES @ CAL)

SET TIME PERIOD (150 SAMPLES @ CAL)
Telemetry Measurement Points

• Telescope Temps (4)
  – Optics Housing*
  – Pedestal Mount
  – LVDT Preamp

•Profiler Temps
  – Profiler base plate
  – Filter wheel housing*
  – CCD Substrate*
  – CCD Preamp
  – Sensor Window*
  – Profiler Rod*
  – Profiler Leaf*
  – Profiler Post*

• Stack Temps
  – PS Deck
  – Flight Computer Deck
  – Data Acquisition Deck

• Spacecraft Interface
  – Primary Voltage
  – Primary Instrument Current

• Telescope Position (4)
  – Position
  – Position Error

• Telescope Servo (4)
  – Telescope holding current

* Indicates Heater Control Point
• CCD Controller
  – Drive Level D-A’s (14)

• Power Supply Secondary
  – Voltages
    +5, +15, -15, +6, -6, +26, +28
  – Currents
    +6 Total Avg Servo Current
    -6 Total Avg Servo Current
    +28 Cal Lamp Total Current
Performance Requirements & Goals

- **Maintain 1 Megohm Isolation for the 3 Spacecraft Primary current and voltage measurements**
  - Provided by 3 differential amplifiers, each having a common mode input impedance of 5 Megohms

- **Filter critical measurements as close to Nyquist criteria as possible (Sensor sample rate = 1 Hz)**
  - 1 KHz burst rate multiplexing requires that all 1 Hz Nyquist filtering be performed at the input to the multiplexer
  - Reasonable physical size capacitance values limited to 0.1uF
  - Differential amplifiers for servo total current and S/C primary measurements will achieve 0.09Hz BW, 3 pole roll off
  - Other critical measurements are filtered at the source

  Telescope servo position errors are heavily filtered at the servo deck output
Performance Requirements & Goals contd.

• Analog signal conditioning will not degrade temperature performance of A-D converter.
  – Analysis of all interface circuits indicates less than 1 LSB error contribution to A-D conversion process
  – Specified absolute accuracy (combined span and zero) for Analog Devices AD674B converter is 7 LSB over full -55 to +125 C mil temperature range
  – Measurement of data acquisition board temperature at or near the A/D converter will be provided to permit calibration of systematic error

• Provide 64K of SRAM buffer memory for the CCD data
Remaining Design Tasks

- Add 4 additional temperature monitors for telescopes
- Add internal temperature monitor near A/D
- Complete the FPGA design
- Derating Inspection and Calculations
- Update Software Interface Document
- Conduct internal final design review
Motor / Heater Deck

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rogacki@umich.edu
Motor / Heater Deck
Requirements Summary

• Control position of 2 filter wheels, inertia 15 oz-in² each
  – 8 filters per wheel, spaced 45 degrees apart
  – use closed-loop control algorithm to minimize time to index

• Control 4 step motors for telescope shutters
  – use open-loop control algorithm
  – motors driven into physical endstops

• Provide opto-isolated pulse width modulated power for 10 heaters
  – 4 telescope operational heaters
  – 3 profiler heaters
  – 1 filter wheel heater
  – 1 CCD heater
  – 1 CCD window heater

• Inhibit PWM switching when CCD is taking data
Motor / Heater Deck Subsystem Overview

- **Field Programmable Gate Arrays, FPGA for digital logic (2 req’d)**
  - Flight computer interface, address decoding and data latches
  - Pulse generation for motors and heaters
  - Filter wheel closed-loop motion control
  - Each of 2 FPGA’s will control one filter wheel motor, two telescope shutters, and 5 heaters
  - Switching delays in logic to prevent H-bridge cross-conduction
  - Use combinatorial logic for H-bridge signal generation to prevent SEU from causing cross-conduction

- **Motor drivers for control of stepper motors**
  - H-bridges use discrete JANTXV2N7336 N and P channel MOSFETS
  - Level shifters convert logic signals to gate drives
Motor / Heater Deck
Subsystem Overview - cont

- **Power switches for control of heaters**
  - Heaters powered from 28 volt bus
  - Optoisolation required, use 6N140A quad optocoupler
  - High side drivers for ground referenced loads
  - Use discrete P-channel MOSFETs, quad JANTXV2N7335

- **Filter wheel encoders**
  - Preamplifiers located in profiler
  - 200 ppr matches step motor
  - 2 channels with 90 degree quadrature
  - Index channel
  - Encoders individually powered-down by Motor / Heater Deck when not moving to conserve power
Motor / Heater Deck
FW Motor Control

Clock and Direction
Logic Sequencer
Bridge Logic and Commutation Delay
H-Bridge
Encoder
Motor
Filter Wheel

Position Error Register
Over/Undershoot Latch
Slowdown Position Register
Present Position Register and Index latch
Mode Control Logic
Mode

Flight Computer
Flight Computer Interface Logic
Hold Current Setting Register

ERR>0
ERR<0
= 0

+15 VDC Power
Encoder Power Switch
+5 VDC Power

Interrupt
Inhibit PWM
## Motor / Heater Deck

### FW Motor Mode State Diagram

**Mode CW**
- **Stop**
- **DAMP CW**
- **ACCEL CW**
- **DECEL CW**
- **REV CW**

**Mode CCW**
- **Stop**
- **DAMP CCW**
- **ACCEL CCW**
- **DECEL CCW**
- **REV CCW**

### Lead in Motor Steps and Phases

<table>
<thead>
<tr>
<th>Mode CW</th>
<th>Mode CCW</th>
<th>Lead in Motor Steps</th>
<th>Phases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop</td>
<td>Stop</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>DAMPCW</td>
<td>DAMPCCW</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>REV CW</td>
<td>REV CCW</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>ACCEL CW</td>
<td>ACCEL CCW</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>DECEL CW</td>
<td>DECEL CCW</td>
<td>-0.5</td>
<td>1</td>
</tr>
</tbody>
</table>

- **OFF**
- **HOLD**
- **ACCEL CW**
- **DECEL CW**
- **REV CW**
- **DAMP CW**
- **DAMP CCW**
- **Encoder Edge CCW**
- **Encoder Edge CW**
- **TIMEOUT or Encoder Edge**
- **ERR < 0**
- **ERR > 0**
- **DIR = CCW**
- **DIR = CW**
- **SLOWDOWN = 0**
- **SLOWDOWN > 0**
- **GO, and ERR < 0**
- **GO, and ERR > 0**
- **REPORTED OVERSHOOT**

**TIMEOUT**
- **HOLD CURRENT REGISTER**
- **TIMEOUT**
- **Encoder Edge CCW**
- **Encoder Edge CW**

### CW Move Profile with Overshoot

- **CW**
- **CCW**

**Encoder Edge CCW**
- **Encoder Edge CW**
- **TIMEOUT or Encoder Edge**
- **ERR < 0**
- **ERR > 0**
- **DIR = CCW**
- **DIR = CW**
- **SLOWDOWN = 0**
- **SLOWDOWN > 0**

**DAMPING TIMEOUT** = 100 ms
Motor / Heater Deck
FW Motor Control

Acceleration Move Profile, 2 phase equilibrium switching

<table>
<thead>
<tr>
<th>Position (100 steps = 45 deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>150</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>250</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>time (2000 = 100 ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>1000</td>
</tr>
<tr>
<td>2000</td>
</tr>
<tr>
<td>3000</td>
</tr>
<tr>
<td>4000</td>
</tr>
<tr>
<td>5000</td>
</tr>
</tbody>
</table>

- 1.0 step lead
- 1.5 step lead
- 2.0 step lead
Motor / Heater Deck
FW Motor Control Description

• Motor phase currents are switched at 2-phase equilibrium points.
  – 1-phase equilibrium was tested and total move times were similar, but 2 motor windings must be energized to hold position.
  – Encoder position is phase adjusted to match motor.

• Use 2.0 phase lead acceleration.
  – Provides greater torque than 1.0 or 1.5 phase lead modes.

• Use 3.5 (-0.5) phase lead deceleration.
  – Mode 0 phase lead decel provides slightly faster deceleration, but does not ensure direction reversal and uses twice the power.
  – Adequate deceleration and direction reversal is automatic.
Motor / Heater Deck
FW Motor Control Description

• Active damping pulses are used to speed settling time
  – Used in STOP mode with decreasing amplitude during 100 ms damping interval.
  – Used in REVCW and REVCCW to provide rate limiting.

• Slowdown position is specified to 1/800 rev
  – 1/200 rev does not provide enough resolution for optimal move profile
  – The optimal slowdown point is variable for different moves, but consistent for a particular move.
  – The desired endpoint will be reached even if the slowdown position is not optimal. Move time will be increased.
Motor / Heater Deck
Filter Wheel 45 deg Move Profile

Tidi Filter Wheel Step

45 deg step

Position (deg)

0 10 20 30 40 50

Time (ms)

0 100 200 300 400

Filter Wheel Inertia = 15 oz in^2
Two Phase On accel
One Phase On decel
2 Step accel lead angle
-0.5 Step decel lead angle
Damp Pulse = 2 ms
Motor / Heater Deck
Filter Wheel 180 deg Move Profile

Tidi Filter Wheel Step

180 deg step

Position (deg)

0 20 40 60 80 100 120 140 160 180 200

Time (ms)

0 200 400 600 800 1000

Filter Wheel Inertia = 15 oz in²
Two Phase On accel
One Phase On decel
2 Step accel lead angle
-0.5 Step decel lead angle
Demp Pulse = 2 ms

TIDI CDR 4/28, 4/29/98

A.385 Edmonson
Motor / Heater Deck
Operational Description

• Move Filter Wheel

1. The FC writes to the mtr_ena register to enable the filter wheel motor.

2. The FC writes values to fwx_accel and fwx_move to specify acceleration distance and incremental movement parameters.

3. The FC writes to fwx_cntl to initiate motion.

4. The MH turns on power to the encoder and loads the position error register to begin motion, then clears the fwx_hold bit in fw_stat to indicate that motor power is on.

5. The MH sets the fwx_move bit in fwx_stat to indicate that the position error is greater than zero.

6. The MH generates signals to operate the filter wheel motor according to the parameters set by the FC and to drive the position error register to zero. Even if the deceleration point is not optimal, the desired position will be reached.
7. The initial over or undershoot is latched at the point of first direction reversal. Whenever position error is zero, the fwx_move bit is set to zero.

8. When the position error is zero for at least 100 ms, the MH turns on a holding current as set by the fwx_holdpw register to one phase of the motor to maintain the present position. Power to the encoder is turned off and the the fwx_hold bit is set.

9. If the int_ena bit was set in the mtr_ena register by the FC, The MH sends an interrupt to the FC when the position error first becomes zero. With a reasonable deceleration point, further motion will be minimal.

10. The FC reads the fwx_err bit in fw_stat to determine whether an error occurred.

11. The FC reads the fwx_over register and if greater than 1, or -1, adjusts the length of acceleration for the next move. The absolute position register, fwx_posn may be read at any time.

12. Motor holding currents are turned off while the CCD read signal is active.
• Move Shutter Motor

1. The FC writes to mtr_ena to enable the telescope shutter motor.
2. The FC writes to ts_step to specify the number of steps to move the motor.
3. The FC writes to ts_cntl to specify the direction of movement of the shutter and to start the motor.
4. The MH turns on power to the motor and sets the ts_move bit in ts_stat to indicate that motor power is on.
5. The MH generates signals to move the motor as specified by the FC.
6. The MH turns off power to the motor and clears the tsx_move bit in ts_stat and, if enabled, sends an interrupt to the FC to indicate that movement has stopped and power is off.
• Set Heater Power
  1. The FC loads the zzz_pw registers to indicate the heater duty cycles as an 8 bit value.
  2. The MH generates pulses to operate the heater.
  3. The FC monitors temperatures through other channels and updates the zzz_pw registers every second. If a value of zero is loaded, that heater is off.
  4. Heater currents are turned off while the CCD read signal is active.

• Find Index
  1. The FC writes to the mtr_ena register and clears the filter wheel index bit.
  2. The FC commands either a 200 step move or a series of smaller moves.
  3. After each move, the FC checks the fwx_index bit in the fw_stat register. If set, the index pulse was detected and the position register is set to the absolute position.
# Motor / Heater Deck
## Control and Status Register List

### Telescope shutter motors

<table>
<thead>
<tr>
<th>Address</th>
<th>R/W</th>
<th>Byte name</th>
<th>Bit no.</th>
<th>Bit name</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>base+30H</td>
<td>W</td>
<td>ts1_step</td>
<td>0-7</td>
<td>ts_go</td>
<td>TS no. of steps to move</td>
</tr>
<tr>
<td>base+31H</td>
<td>W</td>
<td>ts1_cntl</td>
<td>0</td>
<td>ts_go</td>
<td>TS start movement:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 = stop</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 = start</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>ts_dir</td>
<td>TS direction:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 = open</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 = close</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2-7</td>
<td></td>
<td>Not used</td>
</tr>
</tbody>
</table>

### Heaters

<table>
<thead>
<tr>
<th>Address</th>
<th>R/W</th>
<th>Byte name</th>
<th>Bit no.</th>
<th>Bit name</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>base+40H</td>
<td>W</td>
<td>th1_pw</td>
<td>0-7</td>
<td></td>
<td>TH1 byte for pulse width</td>
</tr>
<tr>
<td>base+42H</td>
<td>W</td>
<td>th2_pw</td>
<td>0-7</td>
<td></td>
<td>TH2 byte for pulse width</td>
</tr>
<tr>
<td>base+44H</td>
<td>W</td>
<td>th3_pw</td>
<td>0-7</td>
<td></td>
<td>TH3 byte for pulse width</td>
</tr>
<tr>
<td>base+46H</td>
<td>W</td>
<td>th4_pw</td>
<td>0-7</td>
<td></td>
<td>TH4 byte for pulse width</td>
</tr>
<tr>
<td>base+48H</td>
<td>W</td>
<td>ph1_pw</td>
<td>0-7</td>
<td></td>
<td>PH1 byte for pulse width</td>
</tr>
<tr>
<td>base+4AH</td>
<td>W</td>
<td>ph2_pw</td>
<td>0-7</td>
<td></td>
<td>PH2 byte for pulse width</td>
</tr>
<tr>
<td>base+4CH</td>
<td>W</td>
<td>ph3_pw</td>
<td>0-7</td>
<td></td>
<td>PH3 byte for pulse width</td>
</tr>
<tr>
<td>base+4EH</td>
<td>W</td>
<td>fwh_pw</td>
<td>0-7</td>
<td></td>
<td>FWH byte for pulse width</td>
</tr>
<tr>
<td>base+50H</td>
<td>W</td>
<td>ccdh_pw</td>
<td>0-7</td>
<td></td>
<td>CCDH byte for pulse width</td>
</tr>
<tr>
<td>base+52H</td>
<td>W</td>
<td>shh_pw</td>
<td>0-7</td>
<td></td>
<td>SHH byte for pulse width</td>
</tr>
</tbody>
</table>
### Motor / Heater Deck
#### Control and Status Register List

**Master Control and Status**

<table>
<thead>
<tr>
<th>Address</th>
<th>R/W</th>
<th>Byte Name</th>
<th>Bit no.</th>
<th>Bit name</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>base + 00H</td>
<td>W</td>
<td>mtr_ena</td>
<td>0-2</td>
<td></td>
<td>3-bit value for selecting motor:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 = FW 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 = FW 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 = TS 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 = TS 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4 = TS 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 = TS 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6 = Clear</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>fw1_index bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7 = Clear</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>fw2_index bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>int_ena</td>
<td>3</td>
<td></td>
<td>interrupt generation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 = disable</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 = enable</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4-7</td>
<td></td>
<td>Not used</td>
</tr>
<tr>
<td>base + 01H</td>
<td>R</td>
<td>fw_stat</td>
<td>0</td>
<td>fw1_move</td>
<td>FW1 movement:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 = in progress</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 = done</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>fw1_hold</td>
<td>FW1 hold current:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 = on</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 = off</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>fw1_err</td>
<td>FW1 error:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 = no error</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 = error</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>fw1_index</td>
<td>FW1 index pulse</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 = not detected</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 = detected</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>fw2_move</td>
<td>FW2 movement</td>
</tr>
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<td></td>
<td></td>
<td>5</td>
<td>fw2_hold</td>
<td>FW2 hold current</td>
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<td></td>
<td></td>
<td></td>
<td>6</td>
<td>fw2_err</td>
<td>FW2 error</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td>fw2_index</td>
<td>FW2 index pulse</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 = not detected</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 = detected</td>
</tr>
</tbody>
</table>
## Filter Wheel Motors

<table>
<thead>
<tr>
<th>Address</th>
<th>RW</th>
<th>Byte Name</th>
<th>Bit no.</th>
<th>Bit Name</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>base+10H</td>
<td>W</td>
<td>fwl_move</td>
<td>0-7</td>
<td></td>
<td>FW1 no. of steps to move (signed 2’s complement)</td>
</tr>
<tr>
<td>base+11H</td>
<td>W</td>
<td>fwl_holdpw</td>
<td>0-7</td>
<td></td>
<td>Pulse width for hold current</td>
</tr>
<tr>
<td>base+12H</td>
<td>W</td>
<td>fwl_accel</td>
<td>0-7</td>
<td></td>
<td>FW1 no. of steps to accelerate (signed 2’s complement)</td>
</tr>
<tr>
<td>base+13H</td>
<td>W</td>
<td>fwl_ctl</td>
<td>0</td>
<td>fwl_go</td>
<td>FW1 start movement: 0 = stop, 1 = start</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1-7 Not used</td>
</tr>
<tr>
<td>base+14H</td>
<td>R</td>
<td>fwl_posn</td>
<td>0-7</td>
<td></td>
<td>FW1 actual motor position</td>
</tr>
<tr>
<td>base+15H</td>
<td>R</td>
<td>fwl_over</td>
<td>0-7</td>
<td></td>
<td>FW1 maximum overshoot or undershoot for last move (signed 2’s complement)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Address</th>
<th>RW</th>
<th>Byte Name</th>
<th>Bit no.</th>
<th>Bit Name</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>base+20H</td>
<td>W</td>
<td>fwl2_move</td>
<td>0-7</td>
<td></td>
<td>FW2 no. of steps to move (signed 2’s complement)</td>
</tr>
<tr>
<td>base+21H</td>
<td>W</td>
<td>fwl2_holdpw</td>
<td>0-7</td>
<td></td>
<td>Pulse width for hold current</td>
</tr>
<tr>
<td>base+22H</td>
<td>W</td>
<td>fwl2_accel</td>
<td>0-7</td>
<td></td>
<td>FW2 no. of steps to accelerate (signed 2’s complement)</td>
</tr>
<tr>
<td>base+23H</td>
<td>W</td>
<td>fwl2_ctl</td>
<td>0</td>
<td>fwl2_go</td>
<td>FW2 start movement: 0 = stop, 1 = start</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1-7 Not used</td>
</tr>
<tr>
<td>base+24H</td>
<td>R</td>
<td>fwl2_posn</td>
<td>0-7</td>
<td></td>
<td>FW2 actual motor position</td>
</tr>
<tr>
<td>base+25H</td>
<td>R</td>
<td>fwl2_over</td>
<td>0-7</td>
<td></td>
<td>FW2 maximum overshoot or undershoot for last move (signed 2’s complement)</td>
</tr>
</tbody>
</table>
• Preamplifier for each filter wheel located in profiler.
• Differential design reduces sensitivity to opto-coupler degradation.
• 200 ppr for non-ambiguous step-motor commutation.
• Opto components shielded for 5 krad exposure.
• 50% light/dark ratio for encoder disk, 2 stationary masks
Motor / Heater Deck Status

- Filter wheel encoder design finalized
- Filter Wheel stepper motor control algorithm is determined
- Interface specification document has been revised
- Electrical schematic is 30% complete
- FPGA design is 20% complete
- All major component parts identified
Changes in filter wheel encoder design since last review

• Analysis of the single-ended design
  – Expect large CTR degradation due to radiation effects and aging
  – Change in output duty cycle could lead to loss of quadrature

• Use a differential design
  – Two emitters and detectors per channel to reduce the sensitivity to degradation.
  – Requires 50% more power than original design.

• Use 200 ppr rather than 400 ppr
  – No commutation ambiguity on power-up
  – Adequate resolution for motion control and damping
  – Increased reliability, less sensitive to phase shift
  – Will be powered-down when not moving
Changes in filter wheel motor control since last review

- Litton motor is determined to be acceptable
- Motion algorithm has been finalized
  - The motor has 50 power-off detents per revolution and may move off the desired position when powered down. A holding current of approximately 10 mA through a single motor phase overcomes the detent torque and maintains position, allowing the encoder to be powered down when not moving. This holding current is controlled using PWM on the H-bridge and does not require additional hardware to implement.
  - Active damping is used to reduce the settling time
- Power profiles have been updated
- Interface document has been revised
Calibration Deck

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Cal Deck Overview

• HRDI Design Heritage
  – Cal lamps have worked well throughout their expected lifetime
  – No electronic malfunctions to date
• Provide RF power for two rare-gas calibration lamps
• Provide DC power for two incandescent calibration lamps
• Provide two radioisotope lamp starters
• Provide lamp image to Profiler via fiber-optic cable
• Separate EMI filtering on each I/O lead
• RF oscillators for rare-gas lamp power
  – 5 MHz sine wave, 800 V p-p
• DC supplies for incandescent lamp power
  – 5V @ 115 mA
  – Pulse-width modulator, 80 kHz, 0.2 to 0.25 duty factor
• Calibration lamp sources
  – 1 helium-argon-krypton (HAK) lamp
  – 1 neon lamp
  – 2 incandescent lamps
• Radioisotope lamp starters
  – 1 uC $^{152}$Eu for each rare-gas lamp
Cal Deck PCB Layout
Telescope Servo

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Telescope Servo Design Requirements

• Control Position of 4 single axis telescopes
  – All 4 telescopes can be stepped simultaneously or independently

• Store Parameters for single step, flight computer will maintain table of scan parameters.

• Scan Range
  – Normal range of ±5 degrees
    Minimum Step size 0.05 degrees
    Servo Position Accuracy ±0.01 degrees (±36 arc sec)
  – Over scan of ±10 degrees for bearing lubrication

• Maintain position accuracy with static friction of 5 oz in
• Elevation Knowledge
  - Telescope Bore Sight to Alignment cube
    Total $1\sigma$ error: 65 arc sec over $\pm5^\circ$ scan range
    
    Electronics 25 arc sec
    LVDT Pre-amp  15 arc sec
    Servo          8 arc sec
    Data Acq       18 arc sec (1 LSB)

    LVDT and Mechanical 60 arc sec

• Limit voice coil power dissipation if telescope is driven into the stops
Telescope Servo
System Overview

- Two Field-programmable gate arrays (FPGA) for flight computer interface, and telescope drive timing control.
  - Gate arrays are identical, each controls 2 telescopes
- Analog PID loop with Dither
  - Analog PID steps and holds telescope position
  - Dither uses lead lag error signals to overcome static friction
- LVDT for position feedback
- Rate feedback from LVDT for damping and velocity limit
- Latched position error signals to processor for position monitor
- Interrupt processor on step completion
Telescope Servo
Changes Since PDR

- **Eliminated Feedforward and Hold Drive Currents**
  - Difficult to calibrate Feedforward times and hold currents for all step sizes over temperature
  - Analog Servo can meet step time and position error requirements with reasonable gains

- **Dither uses error flags to determine pulse polarity**
  - Previous design used square wave drive to linearize static friction
    - Settle times of 100 - 200 ms were necessary to reduce error
    - Wastes Power - dither current doesn’t drive telescope
  - Present design monitors position error flags and sets dither to drive position error towards zero
    - Settle times of 25 - 30 ms
  - Uses less power - Dither pulses are only produced if excessive position error exists. Pulses drive telescope to desired position
Telescope Servo
Changes Since PDR (Cont)

• Added over current detect to reduce power dissipated in the voice coil if telescopes are driven into the stops.
  – Maximum on duty cycle is 50% at max current
  – Reduces max voice coil power from 6 to 3 watts

• Flight Computer can independently disable the voice coil drive to each telescope.
  – Telescope drive / bearing failure can be disabled to reduce power consumption and let other telescopes operate normally
  – No additional hardware - uses same circuitry as voice coil over current detect.
Telescope Servo
Analog Servo Loop

Controller
Actel 1280

DAC 8 bit
Latch

DAC 12 bit
Latch

GAIN

INTEGRAL

RATE

DITHER

HSK A/D

LAG

LEAD

Add/Data

Step Int

BUS

LVDT & Pre-amp

Gain Control

Sum

Diff

Current Amp

Voice Coil

Voice Coil

Current

HSK A/D

Voice Coil

Current

HSK A/D

DAC 8 bit

Latch

DAC 12 bit

Latch

DITHER

+1 -1

X

HSK A/D

Latch

DAC 8 bit

Latch

DAC 12 bit

Latch

GAIN

INTEGRAL

RATE

DITHER

+1 -1

X

HSK A/D

Latch

DAC 8 bit

Latch

DAC 12 bit

Latch

GAIN

INTEGRAL

RATE

DITHER

+1 -1

X

HSK A/D
Telescope Servo
LVDT Pre-Amp Block Diagram

Telescope Servo
LVDT Drive
Telescope Position
Telescope Rate
Data Acquisition
LVDT Pre-Amp
Temperature
AD590
Telescope Mount Temperature
AD590

Reference Voltage
A + B
A - B
Peak Detector
Peak Detector
Amp
Buffer
LVDT
PRI
A-SEC
B-SEC
LVDT Pre-Amp
AD590
Telescope Servo Modelin / Simulation

• Telescope motion simulated using difference equations in Mathcad
  – Models effects of static friction
  – Simulates analog PID controller
  – Dither effects modeled
  – Models component limits
    Motor Current
    Op-amp saturation
• Model used to estimate power required to step telescope
• Simulation used to pick servo parameters
  – Good correlation between measured and simulated responses
Telescope Servo
Design Specifications

• Telescope Step Parameters
  – Position set point: 12 bit DAC, Range ±10.5°, Resolution 0.0051°
  – Step Time: 16 bit timer, Range 0 - 6.5535 sec, Resolution 0.1 ms
  – Settle Time: 12 bit timer, Range 0 - 409.5 ms, Resolution 0.1 ms
  – Dither Force: 8 bit DAC, Range 0 - 1.24 amps, Resolution 4.8 ma
  – Dither PW: 8 bit timer, Range .2 - 25.6 ms, Resolution 0.1 ms

• Integral Amp Modes
  Integrator off all the time
  Integrator on during Step and Settle times (normal mode)
  Integrator on all the time

• Dither Modes
  Off all of the time (set Dither PW to 0)
  On during Settle time (normal mode)
  On all of the time
Telescope Servo
Design Specifications (Cont)

• **Servo Position Accuracy**
  – Lossy Integrator acts like a proportional gain at steady state
  – The max position error of servo loop is ±0.0085° for 5 oz in of friction
  – Dither error threshold set to ±0.005°

• **Rate feedback limits max velocity to 22°/sec**
  – The telescope moves at constant velocity for steps over 1°

• **Motor power limit has 6.5 sec on/off cycle**

• **LVDT Sensitivity is 0.48 V/deg**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Telescope</th>
<th>LVDT</th>
<th>LVDT Pre-Amp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scan Range</td>
<td>± 10.5 Deg</td>
<td>±0.525 in</td>
<td>±5.00V</td>
</tr>
<tr>
<td>Minimum Step Size</td>
<td>0.05 Deg</td>
<td>2.5 mil</td>
<td>23.9 mV</td>
</tr>
<tr>
<td>Position Accuracy</td>
<td>±0.01 Deg</td>
<td>±0.5 mil</td>
<td>±4.8 mV</td>
</tr>
</tbody>
</table>
Telescope Servo
Operating Sequence

• Flight Computer Tasks
  – Load step parameters for all telescopes to be moved
    Telescope Position  Dither Pulse Width
    Step Time          Dither Current
    Settle Time
  – Check for any latched position errors from previous step
  – Issue command to start the telescope step
  – Clear latched position error register before step is completed

• Servo Deck Tasks
  – Moves telescope using analog servo during “Step Time”
  – Applies dither, if necessary, during “Settle Time”
  – Interrupt flight computer after “Settle Time” expires
  – Monitor and latch any position errors after “Settle Time”
Telescope Servo
Step Position Time Profile

0.05 Degree Telescope Step

0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1

Position (deg)

Time (s)

STEP
SETTLE
DITHER ENABLED
INTEGRAL ENABLED
Dwell
Telescope Servo
Step Current Time Profile

0.05 Degree Telescope Step

Motor Current (A) vs. Time (s)

- STEP
- SETTLE
- DWELL
- DITHER ENABLED
- INTEGRAL ENABLED
Telescope Servo
Step Time

Inertia = 125 oz in²
$K_p = 35$
$K_i = 75$
$K_d = 2.1$
Telescope Servo
LVDT Pre-Amp Test Data
LVDT Temperature Test

LVDT core mounted on 0.4" Titanium rod attached to end of LVDT

Std dev of error to the linear regression line is 2.3 arc sec

Run 1: +50 to -40
Run 2: +50 to -40
Run 3: -40 to +50

Linear Regression

15 arc sec error band
Telescope Servo
Position Knowledge Calibration

- Telescope Position vs LVDT readout requires calibration to achieve position knowledge requirement
  - Electronics Temperature Drift (LVDT Pre-amp, Data Acquisition and Telescope Servo Decks)
    Calibrate Data Acquisition and Telescope Servo during deck level temperature tests
    Characterize LVDT Pre-amp over temperature with telescope model
  - LVDT and mechanical non-linearities
    Calibrate using Autocollimator and Theodolite
  - Telescope mechanical, LVDT, and Pre-Amp Temperature drift
    Calibrate Telescope, LVDT and Pre-Amp using Theodolite to measure position with telescopes in temperature chamber
Telescope Servo Calibration Method / Test Matrix

- Measure angular position change of two reference mirrors over operational temperature range
  - On telescope barrel, 3 facets 5° apart (rotating mirror)
  - On telescope mount (fixed mirror)

<table>
<thead>
<tr>
<th>Test Condition</th>
<th>Position (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20°C *</td>
<td>-5.0 0.0 5.0</td>
</tr>
<tr>
<td>-10°C *</td>
<td>-5.0 0.0 5.0</td>
</tr>
<tr>
<td>0°C *</td>
<td>-5.0 0.0 5.0</td>
</tr>
<tr>
<td>10°C *</td>
<td>-5.0 0.0 5.0</td>
</tr>
<tr>
<td>20°C *</td>
<td>-5.0 0.0 5.0</td>
</tr>
<tr>
<td>30°C *</td>
<td>-5.0 0.0 5.0</td>
</tr>
<tr>
<td>40°C *</td>
<td>-5.0 0.0 5.0</td>
</tr>
<tr>
<td>Room Temp **</td>
<td>-5.0 to 5.0 each degree</td>
</tr>
<tr>
<td>Room Temp ***</td>
<td>-5.0 to 5.0 each 0.05 degree</td>
</tr>
<tr>
<td>Room Temp ***</td>
<td>-10 to 5 and 5 to 10 each degree</td>
</tr>
</tbody>
</table>

* Temperature chamber and autocollimating theodolite
** Autocollimating theodolite
*** Digital autocollimator
Telescope Servo Status / Implementation Plans

- Prototype of analog servo and LVDT pre-amp assembled and tested
- Engr Model Servo and LVDT pre-amp assembled

- Engr Model testing complete Late May
- Engr Model integration complete Mid June
- Flight unit fab start Late June
- Flight board test complete Late July
- Integration with telescope start Mid Sept.
Flight Software

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Flight Software Topics

- Development Process & Documents
- Status
- Software Development and Test System
- Requirements
- Design
- Memory Usage and Performance
- Test Plan
- Changes from PDR
Flight Software
Development Process & Documents

1. Prepare FS Development Plan
   - Review
2. Prepare FS Requirements Spec
   - Review
   - Prepare FS Test Plan
     - Review
   - Prepare FS Design Spec
     - Review
3. Write Code Unit
   - Test Code Unit
4. Execute FS Test Procedure
   - Passed
   - Failed
   - Prepare FS Test Procedure
4.1. Update FS Test Procedure
4.2. Review Code
4.3. Freeze Candidate FS Version
5. Prepare FS Release Package
   - Release FS
Flight Software Status

• Requirement Spec completed
• Design Spec completed
• Coding and Unit Test 50% completed - will be completed 9/1/98
• Test Plan completed
• Test Procedure will be completed 12/1/98
Flight Software Bench Test System

Deck Bench Test PC
- Software
  - 8051 Emulator SW
  - TIDI Flight SW
- Emulator Board
- Trace Board

S/C Simulator PC
- Software
  - S/C Simulator SW
- 1553 I/F Board
- DIO & ADC Board
- GPIB I/F Board

TIDI Electronics Stack
- 8051 Emul Pod
- 1553 Bus
- Surv. Htrs. etc.

S/C Simulator I/F Box
- HP GPIB Power Supply

Deck-Specific Test Equipment

Ethernet
Flight Software Development Tools

- Keil 8051 C Compiler
- Keil 8051 Simulator
- MKS Source Integrity Version Control System
- Opus Make
- Codewright Editor
Flight Software Requirements

- Execute commands from 1553 bus
- Execute Control Program
- Control Scanning
- Control Temperatures
- Control shutters and telescope positions for Sun avoidance
- Read housekeeping sensors
- Sync instrument time with S/C time
- Format and transmit science and engineering TM
- Respond to spacecraft warnings
  - Solar panel rotation
  - Loss of attitude control
  - Power down
- Limit check critical houskeeping values
Flight Software
Telemetry Packetization

Packet Primary Header
6 bytes

Packet Data Field
256 bytes

Version No.
Packet ID
Packet Sequence Control
Packet Data Length
Packet Sec Header
Application Data

Type Indicator
Pkt. Sec. Hdr. Flag
Application Process ID
Grouping Flags
Sequence Source Count

=000
=0
=1
11 Bits
14 Bits
16 Bits
6 bytes

TIDI TM Packet
Sync Code
2 Bytes
Pkt Type
1 Byte
Pkt Length
2 Bytes
Pkt Time
4 Bytes
Packet Data Field
0 to 512 Bytes
Pkt Checksum
1 Byte

CCSDS Source Packet

Stream of TIDI TM Packets

TIDI TM Packet

TIDI CDR 4/28, 4/29/98
A.432 Edmonson
## Flight Software Command Packetization

**Packet Primary Header**

<table>
<thead>
<tr>
<th>Version No.</th>
<th>Packet ID</th>
<th>Packet Sequence Control</th>
<th>Packet Data Length</th>
<th>Application Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>=000</td>
<td>=1</td>
<td>=0</td>
<td>=0AH</td>
<td>=11</td>
</tr>
<tr>
<td>3 Bits</td>
<td>1 Bit</td>
<td>1 Bit</td>
<td>11 Bits</td>
<td>2 Bits</td>
</tr>
<tr>
<td></td>
<td>14 Bits</td>
<td>16 Bits</td>
<td></td>
<td>1 to 248 Bytes</td>
</tr>
</tbody>
</table>

**Packet Data Field**

<table>
<thead>
<tr>
<th>Command Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>- One or more TIDI Commands</td>
</tr>
<tr>
<td>1 to 248 Bytes</td>
</tr>
<tr>
<td>2 Bytes</td>
</tr>
</tbody>
</table>

**TIDI Command**

<table>
<thead>
<tr>
<th>Command ID</th>
<th>Command Arguments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Byte</td>
<td>0 to 247 Bytes</td>
</tr>
</tbody>
</table>

**CCSDS Telecommand Packet**

**TIDI**

**Flight Software**

**Command Packetization**

---

*TIDI CDR 4/28, 4/29/98*

*A.433 Edmonson*
Flight Software Instrument Status Word

- 64 bits of instrument status that is inserted in S/C real time telemetry
- Not packetized
- Transmitted to S/C via dedicated 1553 subaddress
- Updated by the instrument at 1 Hz.

- Status Word Values
  - Aliveness Toggle 1 bit
  - Inst. Autonomy Bit 1 bit
  - CMD Packet Count 3 bits
  - Cmd Reject Count 3 bits
  - Error Count 4 bits
  - Error Pkt. Sent 1 bit
  - Reboot Flag 1 bit
  - Limit Flags 10 bits
  - Position Error Flags 6 bits
  - Filter & Shutter Pos. 10 bits
  - Boot Code Flag 1 bit
  - Mechanism Moved 1 bit
  - Cal. Lamp States 4 bits
  - Spare 18 bits
Flight Software
Boot Code vs. Instrument Software

• Boot Code
  – Executes after CPU reset
  – Stored in PROM
  – Executes out of PROM
  – Automatically boots the Instrument Software
  – Limited command set
  – Special version for thorough memory testing

• Instrument Software
  – Stored in EEPROM (uploadable)
  – Executes out of RAM
  – Full command set
Flight Software
Boot Code Commands

- Disable Autoboot
- Boot Now
- Write Memory
  - RAM
  - EEPROM
  - I/O Registers
- Dump Memory
  - PROM
  - RAM
  - EEPROM
  - I/O Registers
- Calculate Cyclic Redundancy Check (CRC)
- Execute RAM Code
- No Operation
Flight Software
Instrument Software Commands

• Control Program Execution
  – Start Control Program
  – Stop Control Program
  – Clear Control Program Buffer
  – Append to Control Program Buffer
  – Jump
  – Jump if Equal
  – Jump if Not Equal
  – Jump if Greater Than
  – Jump if Less Than
  – Wait
  – Call Subroutine
  – Return from Subroutine

• Parameter Manipulation
  – Load Parameter
  – Add Parameter
  – Subtract Parameter
  – Increment Parameter
  – Decrement Parameter
  – Compare Parameter
Flight Software
Instrument Software Commands (cont)

- **Hardware Control**
  - Load Scan Table
  - Start Scanning
  - Stop Scanning
  - Set Filter Wheel Position
  - Set Calibration Lamp States
  - Set Telescope Elevation
  - Set Shutter Position
  - Clear CCD Binning Table
  - Append to CCD Binning Table

- **Miscellaneous**
  - Write Memory
  - Dump Memory
  - Calculate CRC
  - Execute RAM Code
  - No Operation
  - Let Watchdog Timeout
Flight Software
Instrument Control Program

• Control Program
  – Comprises a block of commands
  – Loaded with Append to Control Program command
  – Executed continuously by the Instrument Software
  – Has access to the Instrument Parameter Table

• 1553 commands have priority over the Control Program

• Default Control Program is stored in EEPROM
  – Loaded and executed at initialization
  – Used for parameter set up, default scan control etc.
Flight Software
Commandable Instrument Parameters

• Commandable Parameters
  – PI Temp Controller Parameters
  – Heater Duty Cycles (when PI temp control is disabled)
  – Sun Avoidance Mode Entry Sun Angle
  – Sun Avoidance Mode Exit Sun Angle
  – CCD Control Parameters
  – Telescope Control Parameters
  – Earth Oblateness Comp. On/Off
  – Control Program Global Variables
  – Status TM Packet Rate
  – Control Program Execution Time
  – Red and Yellow Limits
Flight Software
Non-commandable Instrument Params

• Instrument Status
  – Analog Sensor Readings
  – Filter Wheel Positions
  – Telescope Positions
  – Current Scan Table ID
  – Commanded Shutter Positions
  – Filter Wheel Position Error Flags
  – Telescope Position Error Flags
  – Latched Reboot Flag
  – Scanning Flag
  – Executing Control Program Flag
  – Other miscellaneous status

• Spacecraft Status
  – Most Recent Terminator Crossing
  – Most Recent Node Crossing
  – Universal Time
  – Latitude, Longitude, Altitude
  – Velocity
  – Yaw, Pitch, Roll
  – Sun Vector
  – Latched Warning Flags
    Solar Panel Rotation
    Yaw Manuever
    Loss of Attitude Control
    Power Down
• Scanning is the coordinated control of:
  – Telescope, Filter Wheel and Shutter Positions
  – Calibration Lamp states
  – CCD Erase and Exposure Times
  – CCD ADC Gain
  – Science Data Mode

• Scan timing is controlled by the Scan Table
• Scanning is started and stopped via command

One CCD Erase-Expose-Read Cycle

Erase Time
Mechanisms are moved during the Erase Time
Exposure Time
CCD Data is read at the end of the Exposure Time
Flight Software
Science Data TM Packets

- 4 Science Data TM Packet Types
  - Spectral Science Data TM Packets contain 120 14-bit channel values
  - Calibration Science Data TM Packets contain 150 14-bit channel values
  - CCD Image Science Data TM Packets contain 50 x 300 14-bit pixel values
  - Photometric Science Data TM Packets contain 5 14-bit photometric values
- All Science Data TM Packets contain:
  - Data Validity Flags
  - Mechanism Positions and Position Error Flags
  - Calibration Lamp States
  - Instrument Time at start of CCD exposure
  - Scan Table ID
  - Exposure Count
Flight Software
Miscellaneous TM Packet Types

- Status TM Packet
  - Contains all Instrument Parameter Values except Control Program Global Variables
  - Programmable packet transmission rate (1 pkt/sec or slower)
- Command Confirmation Packet
- Memory Dump Packet
- Control Program Global Variable Dump Packet
- CRC TM Packet
- Error Report Packet
- Null Packet
<table>
<thead>
<tr>
<th>TIDI TM Pkt Size (bits)</th>
<th>TIDI TM Pkt Rate (pkts/sec)</th>
<th>TIDI TM Pkt Bit Rate (bits/sec)</th>
<th>CCS DS Source Pkt Overhead (bits/sec)</th>
<th>Total TM Rate (bits/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Science Data TM Packet</strong></td>
<td>1872</td>
<td>1</td>
<td>1872</td>
<td>74</td>
</tr>
<tr>
<td><strong>Status TM Packet</strong></td>
<td>2704</td>
<td>0.1</td>
<td>270</td>
<td>11</td>
</tr>
<tr>
<td><strong>Margin</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total**: 2494
Flight Software
Top Level Design

- Code is divided into
  - Interrupt code (High Priority)
    - Interrupt Service Routines
    - Event Service Routines
  - Non-interrupt code (Low Priority)
    - Main Loop
    - Tasks
    - Utility Routines

- Tasks are state machines called from a main loop
  - Each task limits its own execution time

- Tasks share the CPU through cooperative multitasking
- Same architecture used for TOMS/Earth Probe flight SW
Flight Software ISRs and ESRs

• Interrupt Service Routines
  – Millisecond ISR
  – 1553 ISR
  – I/O Bus ISR
  – ADC Timer ISR

• Event Service Routines
  – Centisecond ESR
  – Command Message ESR
  – TM Message ESR
  – S/C Status Message ESR
  – Start of Second ESR
  – Time Code ESR
  – Motor Heater Deck ESR
  – CCD Data Available ESR
  – Filter Wheel Position ESR
  – Shutter Position ESR
  – Telescope Position ESR
Flight Software Tasks

- Prepare Commands
- Execute Commands
- Control Motors
- Send Source Packets
- Load Scan Control Block
- Build Science Data Packet
- Sync Instrument Time
- Send Status Packet
- Read S/C Status
- Do Housekeeping
Flight Software
Projected Total Memory Usage

- The following memory estimates are based on the design specification and the code already written
  - PROM
    16K total available, 13K will be required for Boot PROM code
  - Data RAM
    64K total available, 48K will be required for program variables
  - Program RAM
    64K total available, 22K will be required for Instrument Software
  - EEPROM
    128K total available, 76K will be required for Instrument Software and Default Control Program
• Critical Tasks and ISRs are coded and tested.
  – Instrument timekeeping
  – CMD reception
  – TM production and transmission
  – Instrument parameter access
• No performance concerns to date although tight coding has been required
• Almost all deadlines are handled by ISR code allowing the tasks to use up to 75 msec per invocation
• The most demanding task code deadline is 975 msec (Spacecraft Start of Second message)
• Design Spec CPU Load Estimate has held up so far at approximately 30% CPU utilization
Flight Software Test Plan

- Visually inspect code
- Unit Test with 8051 simulator on PC
- Unit Test with 8051 emulator on the engineering model electronics stack (100% coverage)
- System Testing
- Stress Testing
  - Try to crash the flight software with high command rates
  - Try to crash the flight software with invalid commands
- Code Review
- Formal Test Procedure - Test all requirements. Executed on the flight model before instrument calibration begins.
Flight Software

Significant Changes from PDR

• Sun avoidance now requires moving telescopes to lowest elevation
• Modified commands and status for 2nd filter wheel
• Eliminated programmable format for Status TM packets. Status TM packet size now fixed.
• Added “Allocate Local Vars” and “Deallocate Local Vars” commands
• Removed autonomous bearing lube overscanning.
• Changed temp control from PID to PI
• Removed “Optimize Telescope Movement” and “Optimize Filter Wheel Movement” commands
Flight Software
CCD Binning

- Multiple binning tables are stored in RAM
- CCD Binning is controlled by the current Binning Table
- Current Binning Table is selected in the Scan Table
  - Can be changed many times during a scan
- Binning Table contains one entry for each horiz. bin (up to 256 bins)
- Each Binning Table entry contains a bin width (1 to 255 pixels), a bin gain (4 ranges) and a "discard bin" bit
Spacecraft Simulator

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S/C Simulator
Requirements Summary

• Provide a ground-based testing platform
  – Variable DC power source, with GPIB interface to simulate S/C and supply instrument power
  – Controlled on/off interface to survival heaters
  – Interface to RTD temperature sensors
  – Serial interface to flight computer
  – Differential CCD test interface
  – Emergency stop switches (3) to interrupt TIDI power
  – Interface box to be located next to TIDI instrument
S/C Simulator
Requirements Summary - cont

• S/C simulator computer to be located up to 35 feet away
  – Transmit commands, receive TM via 1553 bus
  – Display real-time science TM, Histograms, CCD Images, numerical values, etc.
  – Display real-time engineering TM
    Strip charts of analog values
    Command confirmations, error reports, memory dumps
  – Provide GUI for easy single command control
  – Transmit all TM to the GSE Workstation
The S/C Simulator consists of four major components

- **S/C Simulator I/F Box in a transportable 19” rack**
  - GPIB 200 watt power supply, 0-35V, 0-6A with inhibit input
  - 19” chassis for power control, data acquisition, and interface circuitry
  - Power distribution outlet strip

- **S/C Simulator Computer**
  - Spectral Instruments PDCI (Parallel Digital Camera Interface) for PCI bus
  - Serial interface for communication with the Flight Computer processor
  - DDC 1553 interface board
  - National Instruments Analog/Digital IO board, 8 differential analog inputs, 8 digital I/O
  - GPIB interface board
  - Optional Ethernet board
• Cabling to connect Simulator I/F Box to S/C Computer
  – Allow 35 ft separation for computer to reside outside the clean room
• Cabling between TIDI and the Simulator I/F Box
  – TIDI will be located inside a vacuum chamber
  – Interface through 3 Varian connectors, 20 conductors each
S/C Simulator I/F Box

- **Buffer and level converter board**
  - converts single ended CCD signals to differential
  - provides RS232 level conversion

- **Data Link couplers for the 1553 Bus**
  - high impedance stubs connect to TIDI
  - low impedance busses connect to S/C Simulator computer

- **RTD interface, independent 1 mA current sources**
  - 4 telescope sensors
  - 2 profiler sensors
  - RTDs are 1000 ohm @ 0 deg C, +3.85 ohm/deg C
  - Analog input board with 12 bit A/D and 0-5V range gives 0.3 degree resolution
S/C Simulator Subsystem Overview - cont

• Relay board under S/C Simulator Computer control
  – control main 28 V bus
  – control each of 5 survival heaters

• Emergency Stop switches (3)
  – one on front of 19” rack, 2 remote
  – immediate interruption of the 28 V power supply
  – indication through GPIB that E-stop has been pressed
  – opens a 12 v inhibit relay

• Linear power supply, +5 V, +12V

• Single point connection from DC common to chassis ground
S/C Simulator Status

- Design completed
- All parts on order
- CCD interface built and tested
- Remaining assembly to be completed by mid May
Ground Subsystem
H.1 Overview

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Ground System Overview

Outline

- H.1 Overview (Gell)
- H.2 Mission Operations Computer System (Gell)
- H.3 Mission Operations Software (Gell)
- H.4 Instrument Level I&T, Calibration and Qualification (Grassl)
- H.5 TIDI-Spacecraft I&T (Gell)
- H.6 Mission Operations (Gell)
Ground System Overview

- Ground system consists of the elements required to
  - Operate the instrument during calibration and qualification spacecraft I&T flight operations
  - Reduce the measurements to scientifically useful quantities
  - Archive, catalog and serve the data products
Mission Operations Concept

- Mission Operations Consists of all the functions that the ground system is called upon to perform
  - Uplink Operations
    - Command Planning
    - Command Generation
    - Command Transmission
  - Downlink Operations
    - Instrument Health and Safety Monitoring
    - Operations Monitoring
    - Data Logging
  - Anomaly Resolution
  - Data Processing and Distribution
    - Data Generation
    - Archive Maintenance
Mission Operations
Data Flow

Overview of the data flow in the TIDI mission operations

- Correlative Sites
- Overpass Predictions
- APL TIMED MOC
- CCSDS Telecommands
- APL TIMED MDC
- Telecommand

Data Flow:
- Data Users
- Production Data Archive
- UM TIDI POC
- Telemetry

Production Data Archive

A.468 Edmonson
Ground System Components

• Software
  – Command Planning and Generation
  – Instrument Evaluation
  – Data Production
  – Data Display

• Hardware
  – Computers
  – Data Storage
  – Communications

• Procedures
  – Planning
  – Instrument Operations
  – Anomaly identification and resolution
Ground Subsystem
H.2 Mission Operations Computer System

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Mission Operations Computer System

Functions

• Payload Operations Center (POC)
  – Command Generation and Transmission
  – Real-Time Instrument Evaluation
  – Telemetry Acquisition and Logging

• TIDI Science Data Processing
  – Production Data Processing
  – Data Storage
  – Data Service
Mission Operations Computer
System Requirements

• Data Storage
  – 12 Gbytes per year, 2 year mission with extensions possible

• Communications
  – Local Area Network access for printing and file transport
  – Wide Area Network access for communications with the TIMED MDC/MOC

• Software Compatibility Requirements
  – OASIS/CC Control and Display Software
  – IDL Graphics

• Field Operations Requirements
  – A fully functional computer must accompany the instrument to APL
  – Communications to UM/SPRL and to TIMED MDC/MOC must be maintained in the field
Mission Operations POC

- Communications with instrument through TIMED MOC/MDC
- System located at Michigan within the TIDI POC
- Components include
  - 2 HP workstations
  - Disk array
  - Tape backup systems
  - Uninterruptable power supplies
  - Printers
Mission Operations Computer System Configuration

- TIDI01: HP C180, 128 MB ra, 4 GB disk, CDROM
- TIDI02: HP C200, 128 MB ra, 9 GB disk, CDROM, Diskette
- Storage Array: 9 GB Disk
- LAN
- B&W Printer
- Color Printer
- SE SCSI-2: 9 GB Disk, 9 GB Disk, 9 GB Disk
- 1300 VA UPS
- DAT-3
- FWD SCSI
- Tape Stacker
- DAT Stacker
- FWD SCSI
Instrument Calibration POC

- Communications with instrument through Local Area Network and TIMED spacecraft emulator
- System components located at Michigan
  - One workstation located to act as test conductors console
  - One workstation, disk array and other peripherals located within the TIDI POC
- Additional hardware used to operate calibration systems
  - HP data acquisition switch
  - dye laser controller
Calibration System
Field Operations and Test POC

- Communications with the instrument via the TIMED test MOC
- System components located at the test site forming test POC
  - Workstation
  - tape system
  - UPS
- System components located at Michigan forming flight POC
  - Workstation
  - disk array
  - tape system
- POC and Test POC communicate via Internet
Spacecraft I&T and Field Ops Configuration

Field Site

TIDI01
HP C180
128 MB ra,
4 GB disk
CDROM

DAT-3
1300 VA
UPS

SE SCSI-2

TIDI02
HP C200
128 MB ra,
9 GB disk
CDROM
Diskette

DAT-3
1300 VA
UPS

Tape
Stacker

STORAGE
ARRAY

9 GB
Disk
9 GB
Disk

FWD SCSI

LAN
WAN
LAN

B&W
Printer

Color
Printer

B&W
Printer

Color
Printer

SE SCSI-2

University of Michigan

TIDI CDR 4/28, 4/29/98
A.479 Edmonson
H.3 Mission Operations Software

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Introduction

• Uplink Software
  – Purpose and Requirements
  – Components
  – Data Flow
  – Data Products
  – Status
  – Changes since PDR

• Downlink Software
  – Purpose and Requirements
  – Components
  – Data Flow
  – Data Products
  – Status
  – Changes since PDR

• Real Time Software
  – Purpose and Requirements
  – Components
  – Data Flow
  – Data Products
  – Status
  – Changes since PDR
Uplink Software
Purpose and Requirements

• Purpose
  – Provide tools for planning instrument operations
  – Provide tools for command generation and transport
  – Provide tools for testing instrument programs

• Requirements
  – All tools must operate in the TIDI POC environment
    HP C-class workstations, HP-UX v10.20
    Component programs communicate via files
  – All interfaces must comply with the TIMED GIIS and TIDI SIIS
  – Each component will perform an orderly shutdown upon receipt of a SIGTERM signal
  – Programming will be performed in C, FORTRAN, or IDL as appropriate to the problem
Uplink Software Data Flow

1. Compile
   - Command Block File
   - TICL Listing File

2. Package Cmd Message
   - Encrypted Cmd Messages

3. Simulate Instrument
   - Telemetry Packet File

4. Predict Overpasses
   - Station Overpass Predictions
   - Viewing Condition Predictions

5. Visualize Scan
   - Scan Table File

6. Predict Viewing Geometry
Uplink Software
Planning and Testing Components

• **VisualizeScan**
  - Displays scan performance and timing
  - Shows mechanism activity
  - Estimates resources required for scan

• **ViewPredict**
  - Determines viewing geometry
    sza, scattering, local solar time

• **OverPassPredict**
  - Determines coincidences with ground stations

• **Simulator**
  - Generates simulated TM based on an instrument control program
Uplink Software
Command Processing

1. Compile
   - Control Program Source File
   - Scan Table File
   - CCD Bin Definition File
   - TCL Listing File

2.1 Create Cmd Message
   - Cmd Block File
   - Cmd Packaging Options

2.2 Encrypt Cmd Message
   - Command Message File
   - Encrypted Cmd Message File

§ Command Delivery Times
Script Information
Purpose (override)
Uplink Software
Command Generation Components

• Compile
  – Combines scan definition, control program, and binning definition
  – Creates a file containing a stream of instrument commands

• Package
  – Forms one or more command message files from the output of COMPILE
  – Maintains log of CCSDS sequence numbers, processing times, and command enable times
  – Encrypts command message files and transmits to the TIMED MOC
• **Command Block File**
  – Contains the instrument commands resulting from the compilation of a control program or an immediate command sequence
  – Contains descriptive information for the command message file header
  – Stored for re-use by scripts

• **Command Message File**
  – Contains the descriptive header and instrument command data
  – Each contains a unique CCSDS sequence number

• **Encrypted Command Message File**
  – PGP encrypted version of the command message file
  – Encrypted using the MOC public key and the TIDI private key
Uplink Software
Example Control Program

; file: example.ticl
; date: 1-Apr-1998

; method
;
; global usage
; global_01 telescope id to exercise for bearing lub
;
; change history:
; 1-Apr-1998 D. Gell Initial coding
;
; purpose "example ticl program"
;
; program 0 ; set program ID in telemetry
;
; local isDay
; define dayside 1

store global_01 1 ; initialize telescope counter
;
; top:
; store isDay spacecraft_dayNight_status
; compare isDay dayside
; jump_eq doday
; jump donight

; odoy:
; load_scan_table "/tidi/sequences/baseline.scan"
; start scan
; jump wait_term

; donight:
; load_scan_table "/tidi/sequences/mtnwind0.scan"
; start scan
; jump wait_term

; wait_term
; wait 10 ; wait ten seconds
; compare isDay spacecraft_dayNight_status
; jump_eq wait_term

; stop scan_end

; terminator crossing occurred, exercise telescopes
; one at each terminator crossing
;
; call bearingOverScan
; compare global_01 5
; jump_eq top
;
; ; perform cal every 4th terminator crossing
; load_scan_table "/tidi/sequences/cal_mode"
; start_scan
; wait 1
; stop scan_end
; jump top

end

bearingOverScan: subroutine
; subroutine to exercise telescope
;
; ; global usage
; ; global_01 telescope to exercise
;
; ; define maxEl 28
; ; define minEl 18

; ; test telescope count and reset if greater than 4
; compare global_01 5
; jump_lt doit
; load global_01 1

; doit: tele global_01 maxEl
; wait 2 ; wait 2 seconds
; tele global_01 minEl
; wait 2
; inc global_01
; return

end

TIDI CDR 4/28, 4/29/98

A.488 Edmonson
# Baseline Scan Table

**Uplink Software**

<table>
<thead>
<tr>
<th>start</th>
<th>end</th>
<th>step</th>
<th>waveln</th>
<th>fw1</th>
<th>fw2</th>
<th>tex</th>
<th>ter</th>
<th>cal</th>
<th>shutter</th>
</tr>
</thead>
<tbody>
<tr>
<td>57.5</td>
<td>87.5</td>
<td>2.5</td>
<td>867.24</td>
<td>1</td>
<td></td>
<td>1.0</td>
<td>0.1</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>90.0</td>
<td>107.5</td>
<td>2.5</td>
<td>763.74</td>
<td>2</td>
<td></td>
<td>1.0</td>
<td>0.1</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>110.0</td>
<td>142.5</td>
<td>2.5</td>
<td>557.70</td>
<td>3</td>
<td></td>
<td>1.0</td>
<td>0.2</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>160.0</td>
<td>160.0</td>
<td>20.0</td>
<td>630.00</td>
<td>5</td>
<td></td>
<td>1.0</td>
<td>0.2</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>180.0</td>
<td>320.0</td>
<td>-20.0</td>
<td>732.00</td>
<td>4</td>
<td></td>
<td>1.0</td>
<td>0.2</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>320.0</td>
<td>320.0</td>
<td>-20.0</td>
<td>732.00</td>
<td>4</td>
<td></td>
<td>1.0</td>
<td>0.2</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>300.0</td>
<td>160.0</td>
<td>-20.0</td>
<td>732.00</td>
<td>4</td>
<td></td>
<td>1.0</td>
<td>0.2</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>142.5</td>
<td>142.5</td>
<td>-2.5</td>
<td>557.70</td>
<td>3</td>
<td></td>
<td>1.0</td>
<td>0.2</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>140.0</td>
<td>110.0</td>
<td>-2.5</td>
<td>557.70</td>
<td>3</td>
<td></td>
<td>1.0</td>
<td>0.2</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>107.5</td>
<td>107.5</td>
<td>-2.5</td>
<td>765.16</td>
<td>6</td>
<td></td>
<td>1.0</td>
<td>0.3</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>105.0</td>
<td>90.0</td>
<td>-2.5</td>
<td>765.16</td>
<td>6</td>
<td></td>
<td>1.0</td>
<td>0.2</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>87.5</td>
<td>57.5</td>
<td>-2.5</td>
<td>866.23</td>
<td>7</td>
<td></td>
<td>1.0</td>
<td>0.2</td>
<td>off</td>
<td>open</td>
</tr>
</tbody>
</table>
Uplink Software
Baseline Scan

Visualized Scan Table
name: daybase (id: 001) version:09-Sep-1997
source file: /tidi/sequences/baseline.scan
baseline daytime wind sequence

- 857.240 nm
- 763.780 nm
- 557.770 nm
- 553.000 nm
- 650.000 nm
- 765.180 nm
- 866.230 nm

scanning duration (sec): 103.70
total integration time (sec): 88.00 (88.49)
altitude range (km): 57.20 to 320.00
angle range (deg): 16.672 to 23.225

TIDI CDR 4/28, 4/29/98
A.490 Edmonson
Uplink Software
Baseline Scan Mechanism Motion

Visualized Scan Table
name: daybase (id: 001) version:09-Sep-1997
source file: /tidi/sequences/baseline.scan
baseline daytime wind sequence

TIDI CDR 4/28, 4/29/98
A.491 Edmonson
### Uplink Software
#### Nighttime Scan Table

**.name:** mlt wind0  
**.id:** 3  
**.description:** Measures the wind in the MLT region at night  
**.approved:** 15-Sep-1997  
**.scan:** altitude

---

#### Change History

- **DAG** 15-Oct-1997 entered from specification 055-3431A

---

#### Scan Parameters

<table>
<thead>
<tr>
<th>Start</th>
<th>End</th>
<th>Step</th>
<th>Wavelength</th>
<th>Filter Width 1</th>
<th>Filter Width 2</th>
<th>Exposure</th>
<th>Retarder</th>
<th>Cal</th>
<th>Shutter</th>
</tr>
</thead>
<tbody>
<tr>
<td>107.5</td>
<td>90.0</td>
<td>-2.5</td>
<td>557.70</td>
<td>3</td>
<td>1</td>
<td>4.0</td>
<td>0.1</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>87.5</td>
<td>87.5</td>
<td>-2.5</td>
<td>892.00</td>
<td>8</td>
<td>1</td>
<td>4.0</td>
<td>0.4</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>85.0</td>
<td>75.0</td>
<td>-2.5</td>
<td>892.00</td>
<td>8</td>
<td>1</td>
<td>4.0</td>
<td>0.1</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>75.0</td>
<td>87.5</td>
<td>2.5</td>
<td>892.00</td>
<td>8</td>
<td>1</td>
<td>4.0</td>
<td>0.1</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>90.0</td>
<td>90.0</td>
<td>2.5</td>
<td>763.78</td>
<td>2</td>
<td>1</td>
<td>4.0</td>
<td>0.4</td>
<td>off</td>
<td>open</td>
</tr>
<tr>
<td>92.5</td>
<td>107.5</td>
<td>2.5</td>
<td>763.78</td>
<td>2</td>
<td>1</td>
<td>4.0</td>
<td>0.1</td>
<td>off</td>
<td>open</td>
</tr>
</tbody>
</table>
Uplink Software
Nighttime Scan
Example Command Block File

`.FFVID 101
.TIDL /tidi/ticl/example.ticl
.TCMD /tidi/tcmd/example.tcmd
.CTIME 19980912050
.CPROG /tidi/software/bin/compile
.CNODE tidi01
.CCMD ticl example.ticl
.PURPOSE example ticl program
.MODEL stored
12 26 B0 00 00 31 41 59 26 53 58 97 93 23 84 62 64 33 83 ...
# Uplink Software Status

<table>
<thead>
<tr>
<th>Element</th>
<th>Requirements Specification</th>
<th>Design</th>
<th>Code</th>
<th>Test</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compiler</td>
<td>1 Jun 98 DAG</td>
<td>1 Jul 98 CP</td>
<td>1 Aug 98 CP</td>
<td>15 Aug 98 CP</td>
<td></td>
</tr>
<tr>
<td>Package</td>
<td>1 Jun 98 DAG</td>
<td>1 Jul 98 DAG</td>
<td>15 Jul 98 DAG</td>
<td>1 Aug 98 DAG</td>
<td></td>
</tr>
<tr>
<td>ViewPredict</td>
<td>na</td>
<td>15 May 98 DZ</td>
<td>15 Jun 98 DZ</td>
<td>1 Jul 98 DZ</td>
<td>port from HRDI</td>
</tr>
<tr>
<td>OverPassPredict</td>
<td>na</td>
<td>1 Apr 98 DZ</td>
<td>1 May 98 DZ</td>
<td>15 May 98 DZ</td>
<td>port from HRDI</td>
</tr>
<tr>
<td>SGP4 Propogator</td>
<td>na</td>
<td>15 Mar 98 DZ</td>
<td>1 Apr 98 DZ</td>
<td>30 Apr 98 DZ</td>
<td>reproduces test cases provided in spacetrack report 3</td>
</tr>
<tr>
<td>Visualize Scan</td>
<td>3 Sep 97 DAG</td>
<td>22 Oct 97 DAG</td>
<td>1 Nov 97 DAG</td>
<td>11 Nov 97 DAG</td>
<td>complete</td>
</tr>
<tr>
<td>Simulate</td>
<td>1 Feb 99 DAG</td>
<td>1 Mar 99</td>
<td>1 May 99</td>
<td>15 Jun 99</td>
<td>to be completed 6 months prior to launch</td>
</tr>
</tbody>
</table>

DAG-David Gell       MJB-Michael Burek       ARM-Alan Marshal       DZ -Dapeng Zu       CP-Contract Prgmr
Uplink Software
Changes Since PDR

- Merge function included in the compiler
- PGP specified for command encryption
Downlink Software

Purpose

• Provide tools to monitor the performance of the instrument
• Transform instrument measurements into geophysically useful data
• Archive and serve results to the community
• Support correlative measurements
Downlink Software Requirements

• Environment
  – All components will execute on the TIDI data processing system
    Hewlett-Packard C180 Workstation
    HP-UX v10.20 (or later) operating system
  – Each component will perform an orderly shutdown upon receipt of a SIGTERM signal
  – Programming will be performed in C, FORTRAN, or IDL as appropriate to the problem

• Interfaces
  – All interfaces comply with the TIMED GIIS and TIDI SIIS
  – Scientific data products will be stored in netCDF files
  – netCDF files will include the project defined global attributes (GIIS section 8)
Software Components — I

- **TMLLogger**
  - Acquires real time or playback TM
  - Produces a level 0 file, TIDI TM Packet File

- **Retrieve**
  - Converts measured spectra from instrument units into radiometric units, correcting for instrument artifacts and applying radiometric calibration
  - Determines actual viewing geometry
  - Produces a Level 1B file, TIDI Line of Sight file

- **Invert**
  - Inverts spectra producing profiles of wind, temperature and volume emission rate
  - Computes ancillary data for each profile
• **Events**
  – Creates detailed log and daily summary
  – logs and counts limit transitions
  – logs changes of scan table
  – detects and logs contaminated spectra
  – detects and logs flight software error reports

• **Trend**
  – Produces a history of selected TM values
  – Creates a trend file for each selected item

• **OverPassDetect**
  – Compares profile locations with a ground station
  – Reports geographical coincidences
Downlink Software
Data Flow

1. RECORD TM
2. RETRIEVE
3. INVERT
4. ARCHIVE
5. LOG EVENTS
6. EXTRACT TRENDS
7. EVALUATE CAL
8. EVALUATE CAL
9. DETECT OVER-PASS

Instrument Event Log
TIDI TM Packets
S/C TM Packets
TM Packet Storage
LOS Quantities
Profiles
Catalog

Daily Summary
Trend Histories
Calibration Reports
Instrument Parameters
Overpass Logs

Data Requests
Data Sets

Packets
Packets
Storage
Trend Histories
Calibration Reports
Instrument Parameters
Overpass Logs

Records
Events
Invert
Archive
Extract Trends
Evaluate Cal
Detect Over-Pass

Profiles
Catalog

Data Requests
Data Sets

TIDI CDR 4/28, 4/29/98
A.501 Edmonson
Downlink Software
Major Data Products

• TM Packet File
  – Routine Level 0 Product
  – Contains TIDI and Spacecraft Data
  – Custom direct access file format

• Line of Sight File
  – Routine Level 1B Product
  – Contains spectra in photometry units (rayleigh)
  – Contains ancillary data for each spectra
  – netCDF file

• Profile File
  – Routine Level 2 Product
  – Contains profiles of wind, temperature and VER
  – Contains ancillary data for each profile
  – netCDF file
# Downlink Software

## Data Volume

<table>
<thead>
<tr>
<th>File Level</th>
<th>File Type</th>
<th>Annual Production (Mbytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Packet Storage</td>
<td>9,463.</td>
</tr>
<tr>
<td>1B</td>
<td>LOS Quantities</td>
<td>3,016.</td>
</tr>
<tr>
<td>2</td>
<td>Profiles</td>
<td>244.</td>
</tr>
<tr>
<td>Ñ</td>
<td>Trend</td>
<td>4.</td>
</tr>
<tr>
<td>Ñ</td>
<td>Instrument Event Log</td>
<td>3.4</td>
</tr>
<tr>
<td>Ñ</td>
<td>Overpass Log</td>
<td>7.5</td>
</tr>
<tr>
<td>Ñ</td>
<td>Catalog</td>
<td>0.75</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>12,700.</td>
</tr>
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</table>
## Downlink Software Status

<table>
<thead>
<tr>
<th>Element</th>
<th>Requirements Specification</th>
<th>Design</th>
<th>Code</th>
<th>Test</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TMLogger</strong></td>
<td>11 Feb 98 DAG</td>
<td>15 Apr 98 MJB</td>
<td>1 May 98 MJB</td>
<td>15 May 98 MJB</td>
<td></td>
</tr>
<tr>
<td><strong>Retrieve</strong></td>
<td>11 Feb 98 DAG</td>
<td>1 Jul 98 ARM/DAO</td>
<td>1 Sep 98 ARM</td>
<td>15 Jun 99 ARM</td>
<td>Data processing software to be ready six months prior to launch</td>
</tr>
<tr>
<td><strong>Invert</strong></td>
<td>11 Feb 98 DAG</td>
<td>1 Jul 98 ARM/DAO</td>
<td>1 Sep 98 ARM</td>
<td>15 Jun 99 ARM</td>
<td>Data processing software to be ready six months prior to launch</td>
</tr>
<tr>
<td><strong>Events</strong></td>
<td>11 Feb 98 DAG</td>
<td>1 Jul 98 DAG</td>
<td>15 Aug 98 DAG</td>
<td>25 Sep 98 MJB</td>
<td></td>
</tr>
<tr>
<td><strong>Trend</strong></td>
<td>11 Feb 98 DAG</td>
<td>15 Aug 98 MJB</td>
<td>1 Sep 98 MJB</td>
<td>25 Sep 98 MJB</td>
<td></td>
</tr>
<tr>
<td><strong>OverPassDetect</strong></td>
<td>11 Feb 98 DAG</td>
<td>1 May 99 DAG</td>
<td>1 Jun 99 DAG</td>
<td>15 Jun 99 MJB</td>
<td>Data processing software to be ready six months prior to launch</td>
</tr>
<tr>
<td><strong>Level0 Access API</strong></td>
<td>11 Feb 98 DAG</td>
<td>30 Apr 98 MJB</td>
<td>15 May 98 MJB</td>
<td>15 Jun 98 MJB</td>
<td></td>
</tr>
<tr>
<td><strong>TM Query Extractor</strong></td>
<td>11 Feb 98 DAG</td>
<td>23 Jun 98 MJB</td>
<td>15 Jul 98 MJB</td>
<td>1 Aug 98 MJB</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- DAG-David Gell
- MJB-Michael Burek
- ARM-Alan Marshal
- DAO-David Ortland
• Profiles obtained directly from spectra without intermediate line of sight quantities
  – Level 1B file no longer contains line of sight winds, brightness …
  – RETRIEVE simplified

• Overpass detection separated from the event logging function

• Telemetry values are stored as TIDI packets
  – stored as raw values
  – Level 0 Access routines provide conversion to engineering units

• Identified requirement for TM Query Extractor
Real-Time Software

• Purpose
  – Provides display of instrument status information
  – Provides real-time command interface for I&T and orbital operations
  – Logs data during tests and provides “ad-hoc” reports

• Requirements
  – Display and operator interface is to be implemented using the OASIS-CC package, unmodified
  – All elements must operate in the TIDI POC environment
  – All interfaces must comply with the TIMED GIIS and TIDI SIIS
Real-Time Software Components

- **OASIS-CC**
  - Command and Display elements built on this product

- **Downlink Software Components**
  - TMLLogger, Events and Trend
    - Provide data logging, trend analysis and event detection
  - TM Query Extractor
    - Extracts engineering values from the TM Packet file
    - Formats “ad-hoc” reports

- **Uplink Software Components**
  - Package
    - Provides message file creation and encryption of previously compiled command programs
    - Ensures unique CCSDS sequence numbering
Real-Time Software
Data Products

• The Real-Time software produces the same products as the Downlink software
• TM Value reports and limit reports will be generated as needed from the level 0 data and the event logger report
Real-Time Software Status

- OASIS
  - OASIS and TAE Software installed
  - Table Definitions
    Data Handling
    Engineering data definitions complete using automation
    Science packets need to be defined
  External Communications
    Link definition in progress
  Command and User Interface remain
• Requirement for unique CCSDS sequence numbers in message files
I&T, Calibration & Qual flow

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TIDI Calibration

12/16/98
- Flight Electronics stack complete
- Flight Profiler complete
- Flight Cal SW complete
- GSE complete
- Flight telescopes complete

1/2/99
- Start final calibration

1/4/99
- Finalize EPET procedures

1/6/99
- Throughput w/o telescopes

1/11/99
- Instrument function scans (dye laser)

2/8/99
- Thermal drift coefficients

2/15/99
- Determine normalization constants w/ telescopes

2/22/99
- Throughput w/ telescopes

3/1/99
- Thermal stability test

3/19/99
- TIDI ready for qual testing

3/8/99
- 250 hrs of continuous operation

1/3/99
- Throughput w/ telescopes

2/22/99
- Throughput w/ telescopes

3/19/99
- TIDI ready for qual testing

3/8/99
- 250 hrs of continuous operation

All functions will include EPET's

TIDI CDR 4/28, 4/29/98

A.514 Edmonson
Telescope I&T

- Voice coil and LVDT and preamp to be fully tested at SPRL and integrated at APL
- Calibration of the LVDT at APL in conjunction with the boresight measurements
  - SPRL to arrive at APL with GSE to read LVDT while telescope is undergoing temperature test and boresight is monitored
- Telescopes will be fully exe/orcized at SPRL during TIDI I&T
  - primarily testing the flight s/w
- Telescopes will be calibrated for throughput at SPRL
Telescope LVDT calibration

- APL OCF
- Window
- Boresight
- Theodolite
- Tel ref.
- Electrical feedthru
- Voice coil drive & LVDT
Telescope throughput

30 cm Φ Integrating sphere

Source inputs:
NBS Tungsten lamp
Laser
Spectral lamps
Cal lamps

Air collimator

reference diode

Calibrated photo diode measures input signal to telescope

Telescope

reference diode

Calibrated photo diode measures telescope output

Tests will be performed on each telescope with/without fiber optic
Tests at SPRL

- Telescopes will be mated to profiler with fiber optics
- Integrating sphere will be mounted to telescope with full aperture window in place.
  - Measure total system throughput vs $\lambda$
  - Measure CCD channel normalization vs $\lambda$
  - Repeat for fiber optic mate / demate (cycle 10X)

- Repeat with deployable cover (small window) in place
  - This will provide the reference values to be carried to the spacecraft (signal/channel/ in each of the five fields)
Telescope / FO integration

At Spacecraft I&T w/ TIDI fully integrated

Repeat SPRL transfer test case

- Total # fibers/channel = 13

<table>
<thead>
<tr>
<th>Field</th>
<th>channel width (fiber)</th>
<th>Channel height (fiber)</th>
<th>throughput loss/channel (1 broken fiber) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tele 1</td>
<td>0.16</td>
<td>80</td>
<td>1.2</td>
</tr>
<tr>
<td>Tele 2</td>
<td>0.18</td>
<td>70</td>
<td>1.4</td>
</tr>
<tr>
<td>Tele 3</td>
<td>0.22</td>
<td>59</td>
<td>1.7</td>
</tr>
<tr>
<td>Tele 4</td>
<td>0.28</td>
<td>46</td>
<td>2.2</td>
</tr>
<tr>
<td>Cal</td>
<td>0.44</td>
<td>27</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Action

0- 10 % / channel : no action on ground, normalize on orbit

>10% / channel : Consider swapping fiber cable and rerunning throughput tests
Profiler I&T

• Integration will begin in May
  – optical bb test bed will be converted to flight bb test bed by September as optics arrive

• Input optics testing
  – verify filter collimator efl, spot size, beam size, throughput
  – verify etalon collimator efl, spot size, beam size, throughput

• EM fiber optic
  – verify configuration
  – image onto CCD
  – measure throughput
  – measure field-to-field crosstalk

• Etalon testing
  – Finesse, FSR (pressure scanning)
• Objective optics
  – measure efl, spot size, throughput

• End-to-end throughput
  – from fiber optic input to CCD

• End-to-end imaging
  – Characterize flight fiber optic fields at the CCD
  – Measure flight fiber optic field crosstalk

• Characterize circular field transformation into rectangular array (CLIO)

• Repeat end-to-end tests
  – With CLIO
  – With telescopes
Optics test bed

TIDI optical breadboard

**Test list**
- Fiber optic positioning repeatability test
- Etalon Finesse measurements
- Input optics characterization
- Imaging optics characterization
- Throughput

**Light sources**
- 1 NBS
- 2 single freq. HeNe
- 3 Spectral lamps
- 4 Cal deck

**5 port fiber adaptor**
- Newport 818-SL diode
- Newport 1825-C optical power meter

**Input optics**
- Currently HRDI lenses w/ 160 mm efl
- To be replaced with TIDI lenses w/ 167 mm efl

**Etalon**
- Currently 1 cm
- to be replaced w/ 2.2 cm

**600 mm PCX imaging optic**

**Pressure piston**
- Etalon pressure vessel.
  (Removed for fiber placement testing)

**To be replaced by TIDI Cassegrain**

**Initial camera use w/o CLIO**
- Pix Vis CCD camera
- Pix Vis camera controller
- NEC MultiSync 5FGe
- NEC 2020

**Stepper control**

**Fiber optic, 50 micron single fiber or flight fiber cable**

**Rigid FO mount**
- Female FO receptacle
- Male FO connector

**Integrating sphere**
- Newport 818-SL diode
- Newport 1825-C optical power meter

**Aperture masks**
H.5 TIDI — Spacecraft Integration and Test

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I&T Plans - Flow I

• Pre-Ship
  – Function test performed at Michigan
  – Packed and shipped to APL

• Post-Ship
  – Unpacked at APL, set up on bench (2 to 3 days)
  – Functional test repeated (2 days)

• Installation on spacecraft
• Interface Tests
I&T Plans - Flow II

• **Spacecraft Qualification**
  – Functional test repeated as required
    before environmental test
    after environmental tests
    during thermo-vac
  – Support anomaly resolution as required

• **Mission simulations**
  – Full data paths exercised
    Command Flow from TIDI POC through all elements to spacecraft
    TM flow from spacecraft through all elements to TIDI POC
  – Major activities tested
    Spacecraft activation
    Instrument activation
    Routine data collection
I&T Plans - Operational Activities
(A day in the life of the TIDI I&T Staff)

• Activities controlled by the S/C I&T Plan
  – Functional tests performed to support S/C goals
  – Instrument monitoring whenever power is applied

• Functional Test
  – Command Preparation
    select a prepared command message
  – Command Transmission
  – Monitor instrument operation in real time
  – Test evaluation
    use analysis tools to determine success of test
    simple tests are evaluated by the instrument computer
    transmit alarm logs to test conductor
  – Anomaly resolution (as required)
    generate Housekeeping log
    review logs from involved subsystems
Flight POC Testing

• Test and Flight POC consist of identical hardware and software

• Testing will include
  – Execution of the accepted test plan per SDP
  – Usage during instrument integration and test
  – Mission Simulations
H.6 Activation and Flight Operations

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Activation and Flight Operations
Outline

• Mission Operations Concept
• Initial Operations
Mission Operations Concept

- Overview
- Uplink Activities
- Downlink Activities
- Data Processing
Mission Operations Concept Overview

- Mission Operations Consists of
  - Uplink Operations
    - Command Planning
    - Command Generation
    - Command Transmission
  - Downlink Operations
    - Instrument Health and Safety Monitoring
    - Operations Monitoring
    - Data Logging
  - Anomaly Resolution
  - Data Processing and Distribution
    - Data Generation
    - Archive Maintenance
Mission Operations Concept
Data Flow Diagram, General
Mission Operations Concept

Uplink

- **Mission Planning**
  - Develop TIDI observation plan, implementing TIMED science goals
  - Coordinate Special Campaigns

- **Command Planning**
  - Develop detailed observation program
  - Specify, Code and Test instrument control programs
  - Coordinate with correlative measurement sites, particularly rocket measurements

- **Command Execution**
  - Transfer command loads to spacecraft control center
  - Verify receipt and execution
## Mission Operations Concept
### Uplink Operations Timeline

<table>
<thead>
<tr>
<th>Time</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>D – 8 weeks</td>
<td>Receive predicted orbital ephemerides</td>
</tr>
<tr>
<td>D – 4 weeks</td>
<td>Produce viewing geometry predictions</td>
</tr>
<tr>
<td></td>
<td>Specify measurements</td>
</tr>
<tr>
<td>D – 4 weeks</td>
<td>Determine correlative measurement opportunities</td>
</tr>
<tr>
<td></td>
<td>Transmit overpass predictions to correlative sites</td>
</tr>
<tr>
<td>D – 3 weeks</td>
<td>Complete specification of instrument control program</td>
</tr>
<tr>
<td>D – 2 weeks</td>
<td>Complete coding and simulator verification of control program</td>
</tr>
<tr>
<td>D – 1 week</td>
<td>Transfer control program to TIMED control center for upload</td>
</tr>
<tr>
<td>D – 1 day</td>
<td>MOCC uploads TIDI control program at any time during the day</td>
</tr>
<tr>
<td>0</td>
<td>Operational Day, execute command program currently in instrument</td>
</tr>
</tbody>
</table>
Mission Operations Concept Downlink

- Monitors the instrument health
  - Uses automated procedures
  - reports limits violations
  - maintains trends of important parameters

- Monitors instrument operation
  - confirms receipt of command loads at TIMED MOCC
  - confirms receipt of command loads at the instrument
  - confirms measurements are as planned

- Anomalies are recognized and resolution activities begun
### Mission Operations Concept
#### Downlink Operations Timeline

<table>
<thead>
<tr>
<th>Time</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Receive near real time (NRT) data</strong>&lt;br&gt;<strong>Receive previous day’s playback (PB)</strong></td>
<td></td>
</tr>
<tr>
<td>Data Receipt + 1 hour</td>
<td>Complete automated limit checking completed on NRT data</td>
</tr>
<tr>
<td>Data Receipt + 1 hour</td>
<td>Confirm receipt of uploads in NRT data</td>
</tr>
<tr>
<td>Data Receipt + 2 hours</td>
<td>Complete automated production of quicklook plots and review</td>
</tr>
<tr>
<td>Data Receipt + 12 hours</td>
<td>Complete limit checking on PB data</td>
</tr>
<tr>
<td>Data Receipt + 24 hours</td>
<td>Complete routine processing of PB data</td>
</tr>
<tr>
<td>Data Receipt + 24 hours</td>
<td>Examine diagnostic plots:&lt;br&gt; mechanism state plots&lt;br&gt;engineering trend data&lt;br&gt;sample spectra&lt;br&gt;daily wind maps</td>
</tr>
</tbody>
</table>
Mission Operations Concept
Quicklook Analysis

• Provides tools for instrument health and safety monitor
• Examines a short data sequence from each contact
• Reports
  – limit violations
  – instrument configuration
• Extracts
  – engineering trend data
  – state sequence information
• Produces plots
Mission Operations Concept
Data Processing

- Produces routine data products
- Archives routine products
- Satisfies data requests
- Produces summary products used for operational monitoring of the instrument
Mission Operations Concept
Data Processing Software

- Transforms TM data to geophysical quantities
- Archives data
- Analyzes instrument performance (calibrations)
- Provides input data for scientific analysis
- Provides catalog and data distribution services
- Data stored in self-documenting files (netCDF)
Activation
Initial Operations

• Goals
  – Confirm that the instrument has not been affected by launch
  – Configure instrument for initial operations

• Phases
  – Outgasing
  – Initial Turn on and Checkout
  – Initial Data Collection
  – Routine Operations
Initial Operations
Outgasing

• Outgasing is required
  – to maintain optical cleanliness
  – to avoid corona discharge in the gas discharge calibration lamp power supply
• 14 days is desired duration
• Instrument is off, survival heaters active
• Instrument health monitored with passive temperature monitors
Initial Operations
Turn On & Checkout

- Timeline depends on frequency of communications during initial operations period
- Steps include
  - Aliveness Test
  - Computer Self Test
  - Detector Map
  - Mechanism Functional Test
  - Optical Calibration
  - Release Telescope Covers
  - Optical Continuity Test
- Normal TM contains enough information to evaluate each step
- Each step is evaluated prior to advancing to the next
Initial Data Collection

• Provides first “real” data to data processing system
• Results examined to confirm validity of assumptions in data collection
  – Signal level
  – Altitude distribution
  – Geographic distribution
• Each data collection program defined at launch exercised
  – Confirm the operation of the data processing with actual data
• Routine Operations continue with data collection