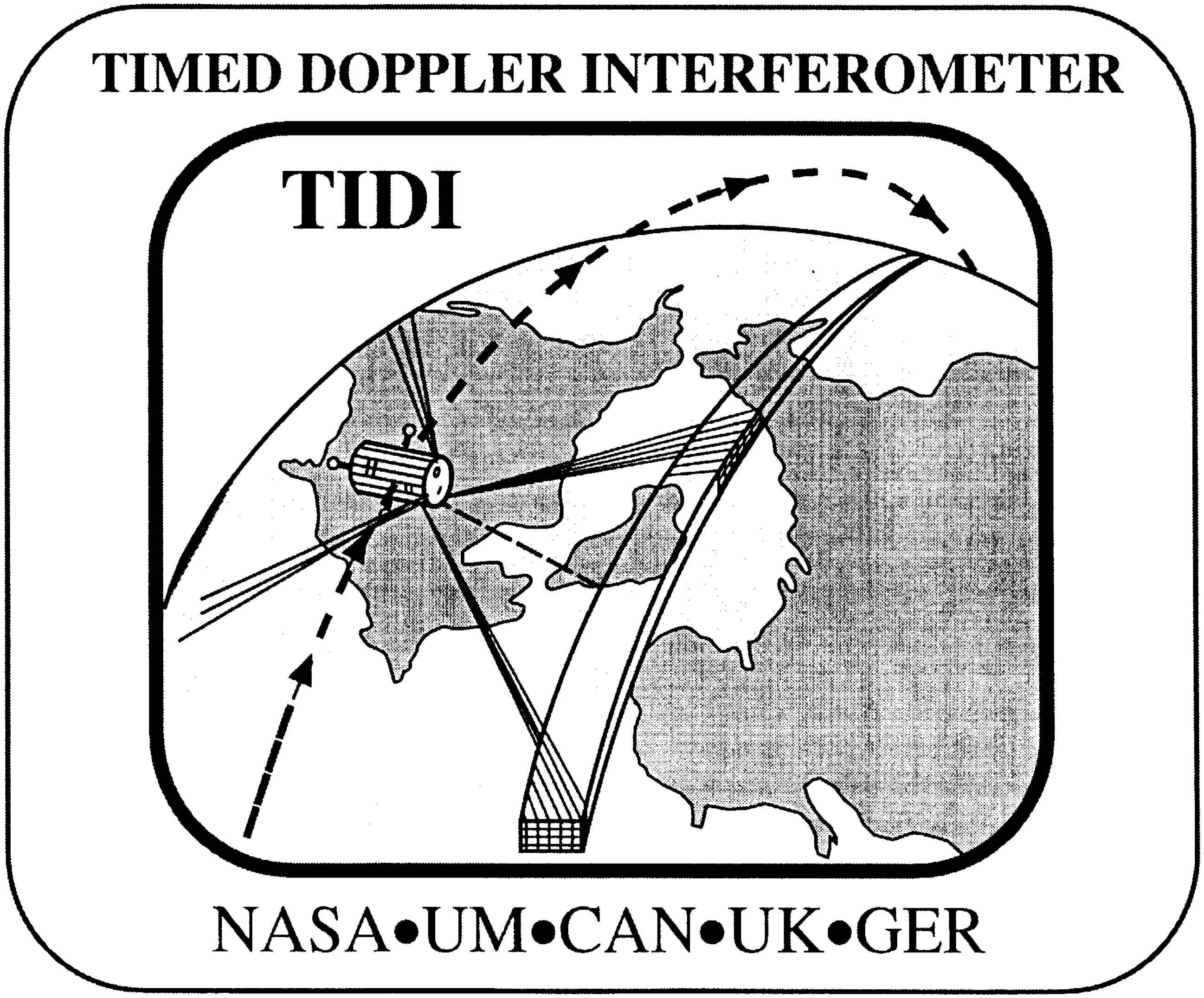
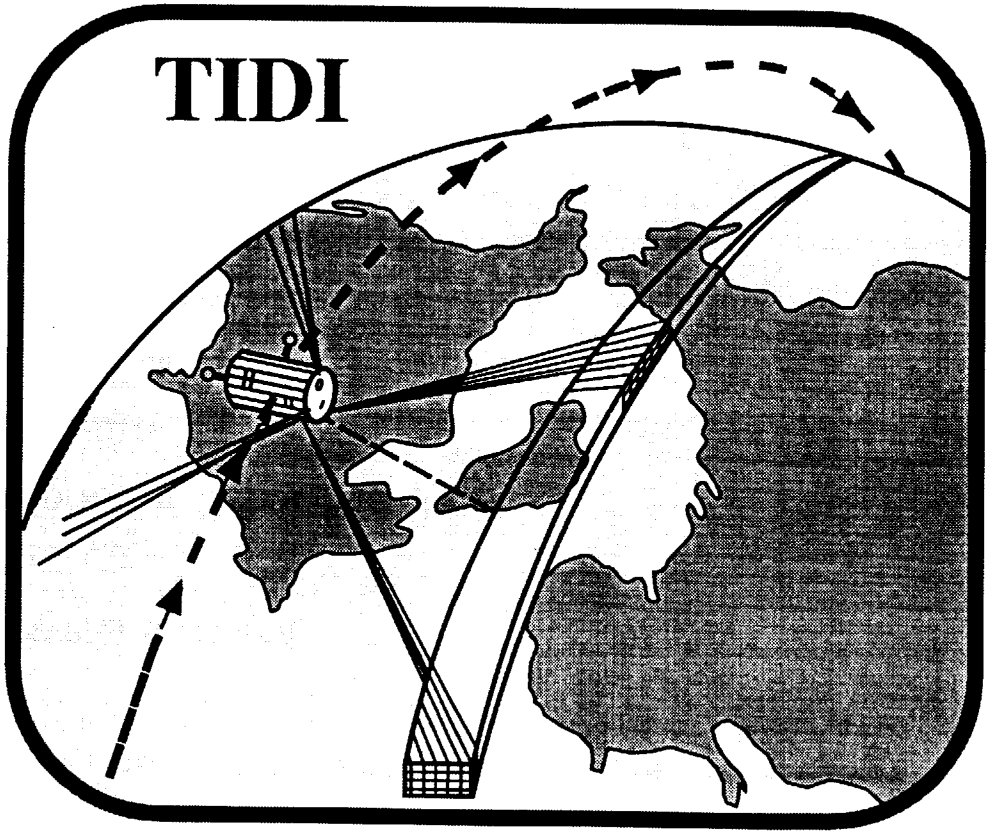
NASA-CR-201893

TIDI CoDR Review Meeting
Oct 31- Nov 1, 1995



TIDI CoDR Review Meeting
Oct 31- Nov 1, 1995

TIMED DOPPLER INTERFEROMETER



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TIDI CoDR Table of Contents

Conceptual Design Review

October 31, 1995 - November 1, 1995

Space Physics Research Laboratory
University of Michigan
Principal Investigator - Timothy L. Killeen
Project Manager - Charles J. Edmonson

TIDI

SPRL Team Members

Science	Engineering
Timothy Killeen - Leader	Charles Edmonson - Leader
Roberta Johnson - Coverage and Tides Modeling	Brian Kennedy - Systems Engineer
Wib Skinner - Instrument Modeling	Walter Pinkus - Electrical Engineer
Alan Burns - Theoretical Analysis	Heinz Grassl - Mechanical/ Optical Engineer
Rick Niciejewski - InstrumentParameter Optimization	Stephen Musko - Software Engineer
Qian Wu - Instrument Simulation	Kenneth Arnet - Power Supply Engineer
David Rees - Etalon Studies	David Gell - Ground Systems Engineer
Stephen Mende (LMPARL) - ImagerDesign Studies	John Eder - R&QA and Parts Engineer
	Alan Delamere (BASD) - Circular CCD
	Wayne Frame (BASD) - Circular CCD
	Bill Roybal (BASD) - Telescope Design
	Joe Walunas (Student) - CCD Test Lab

TIDI Review Team

Glen Cameron - Mission Engineer

Dave Grant - Project Manager

Kevin Heffernan - PayloadSystems Engineer (chair)

Rick Howard - NASA Program Manager

Dave Kusnierkiewicz - Spacecraft Systems Engineer

Fred Mobley - Attitude Control Engineer

Keith Peacock - Optics Engineer

Jim Pershey - C&DH Engineer

Ed Prozeller - Payload Manager

Steve Vernon - Mechanical Engineer

Bruce Williams - Thermal Engineer

Sam Yee - Project Scientist

TIDI

CoDR Agenda, October 12, 1995

08:55 - 09:00 Introduction & Agenda - Edmonson

09:00 - 10:00 Science & Measurements - Killeen

10:00 - 10:10 Break

10:10 - 11:10 Systems Design - Kennedy

11:10 - 11:45 Calibration & Error Sources - Gell

11:45 - 13:00 Lunch

13:00 - 13:30 Optical Design - Grassl

13:30 - 13:45 Mechanical Design - Grassl

13:45 - 14:00 Thermal Design - Grassl

14:00 - 14:30 Mechanisms Design - Pinkus

14:30 - 15:10 Detector Design - Kennedy

15:10 - 15:20 Break

15:20 - 15:50 Electronics Design - Pinkus

15:50 - 16:20 Microprocessor/Flight Software Design - Musko

16:20 - 16:45 Ground Segment - Gell

16:45 - 16:55 Quality Assurance & Parts Management - Eder

16:55 - 17:00 Proposed Baseline Enhancement Studies - Kennedy

TIDI **CoDR Agenda, October 13, 1995**

09:00 - 10:00	**APL Review Comments**
10:00 - 11:00	**Discussion**
11:00 - 11:15	**Action Item Review**
11:15 - 12:00	**Facility Tour**
12:00	**Adjourn**

Science/Measurement
Timothy L. Killeen

TIDI Investigator Team

Principal Investigator:
Dr. Timothy L. Killeen
Professor of Atmospheric and Space Sciences
The University of Michigan

Co-Investigators:

Dr. Timothy J. Fuller-Rowell
CIRES/University of Colorado

Dr. Paul B. Hays
University of Michigan

Dr. Roberta M. Johnson
University of Michigan

Dr. Stephen Mende
Lockheed Palo Alto Research Laboratory

Dr. Arthur D. Richmond
National Center for Atmospheric Research

Dr. Gordon G. Shepherd
York University
Canada

Dr. William A. Gault
York University, Canada

Dr. Colin O. Hines
York University, Canada

Mr. Brian C. Kennedy
University of Michigan

Dr. David Rees
University College London
United Kingdom

Dr. Raymond G. Roble
National Center for Atmospheric Research

Dr. Wilbert R. Skinner
University of Michigan

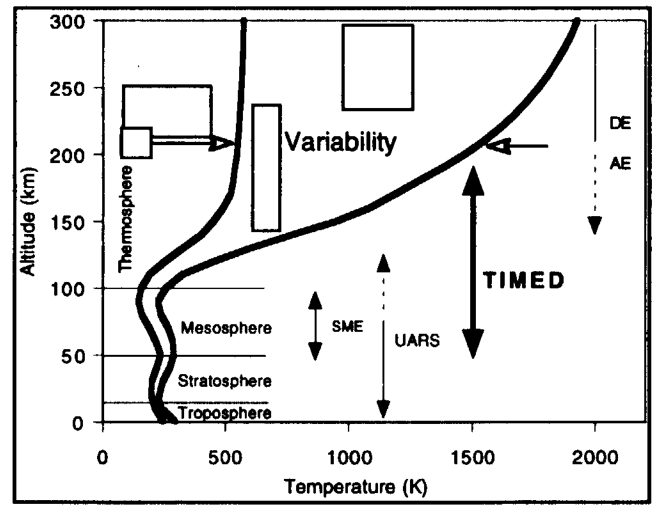
Dr. Ulf von Zahn
Bonn University,
Germany

TIMED Science

Science Objectives:

"A NASA Mission to Study the Last Frontier in our Exploration of the Earth's Atmosphere"

- To determine the spatial and temporal variations of temperature, major constituent densities, and winds.
- To determine the importance of radiation, chemistry and atmospheric motions for the energy balance.
- To determine the sources and magnitudes of atmospheric waves and tides, and their interactions.
- To determine the spatial and temporal variations of minor species such as CO_2, O_3, NO and H_2O - which are important for the energy balance.
- To determine the importance of electric fields and winds for the atmosphere and ionosphere.
- To investigate the processes responsible for the anthropogenic effects and to establish a baseline set of observations for future investigation.



"The Earth's Mesosphere and Lower Thermosphere are the Least Explored Regions of the Earth's Atmosphere"

National Academy of Sciences, 1988

NOTES:

TIDI Science Objectives

1. Study the dynamical and thermal structures, and constituent distributions of the MLTI region (60-180 km)
2. Study the energetics balance of the MLTI region

TIDI will:

- Accurately and precisely determine the global vector MLTI wind, temperature, and density profiles.
- Measure characteristics of the gravity wave and planetary wave spectra.
- Determine the tidal characteristics of temperature, density and wind in the MLTI.
- Measure neutral and ion winds to characterize the electrodynamical behavior of the MLTI.
- Measure O and O_2 abundances and nocticulent cloud activity.

NOTES:

TIDI Driving Measurement Requirements

- **Line of Sight Winds from 60-180 km with an absolute accuracy $\leq$ 3 m/sec (1 m/sec goal).**
- **Kinetic/Rotational Temperature profiles with an absolute accuracy of 2K**
- **<10% O_2 Density 60-120 km; O density 250 - 300 km (day), 85-95 km (night); total density 60-100km (day)**
- **Limb Wave and Airglow Intensity data, ~20-40 km horizontal x 3 km vertical**
- **Vector Wind Coverage over several hours LT along orbital track**
- **Δt Resolution, better than 1.5 minutes per profile (to retain vector wind capability)**
- **Δh Resolution, better than 3 km for lowest altitudes (~ atmospheric scale heights)**

NOTES:

Instrument Requirements

Scales and Ranges

Phenomena	Horizontal Scale	Vertical Scale	Velocity Range	Temp. Range
Global Circulation	500-5000 km	10-50 km	5-200 m/s	150 - 2000 K
Planetary Waves	100-1000 km	4-20 km	1-100 m/s	150 - 2000 K
Gravity Waves	10-500 km	2-20 km	1-100 m/s	150 - 2000 K
Tides	1000+ km	10+ km	1-100 m/s	150 - 2000 K

Accuracies

TIDI Channel	Horizontal Resolution	Vertical Scale	Velocity Range	Temperature Range	Wind accuracy	Temp. accuracy
Profiler	100+ km	2+ km	1-1000 m/s	120-2000 K	1-3* m/s	2 K
Imager	40-100 km	2-100 km	N/A	120-2000 K	N/A	5-10 K

*** 3 m/sec is the requirement; 1 m/sec is strongly desired**

NOTES:

TIDI Science Requirement Flowdown

Wind, Temperature, Densities and Waves
accuracies of 3m/sec, 2 K; profiles in <1.5 min; Δh~2km; Δl~100km; max. possible LT coverage

↓ Proven Instrumental Approaches
Heritage
Spectral Resolution

High-sensitivity, limb-scan Fabry-Perot interferometer
resolving power ~40,000; stability knowledge ~0.5 m/sec; minimum integration period 0.25 sec -> etendue > 10^{-3} cm^2 sr, scanning telescopes, selectable emissions)

↓ Sensor technology, availability, heritage
Instrument Requirements
Observation Scenario

Limb Scan
4 articulated telescopes; fiber-optic coupling aperture >7.5cm, baffles

Spectral Analysis
high res and tunable low res. high-stability etalons 8-position filter wheel

Detector
high-sensitivity CCD 500-900nm; photon-counting; low noise

Errors
Precise knowledge of pointing. star imaging system; calibration plan

↓ Power requirements
Telemetry requirements
Heritage
Optimize science

Two Channels
FPI and filtered CCD Star camera; shared resources; enables wave science

Flight Computer
t/m requirement, on-board compression, baseline Lockheed 95RH; >3 MIPS.

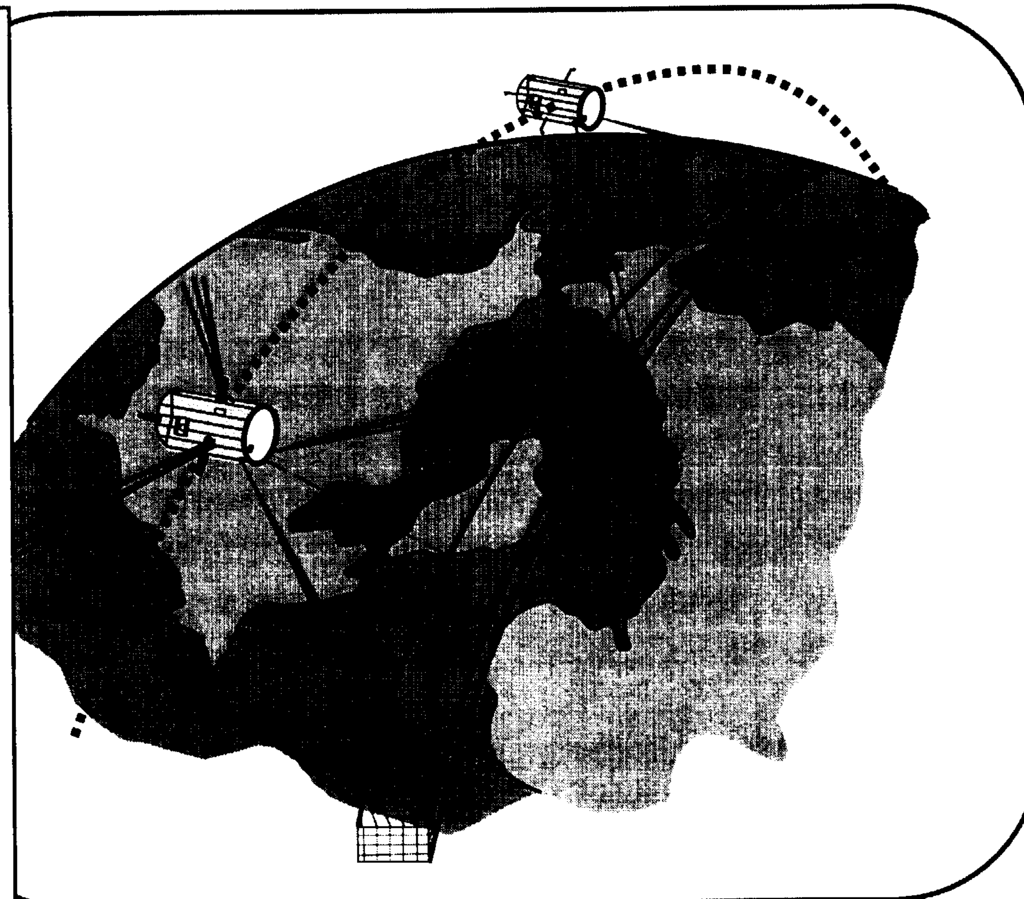
Power/Thermal
S/C 28V; regulated instrument voltages; thermal isolation of interferometer sensor; CCD radiator profiler 20±5°

Calibration System
on-board cal. lamps star position monitoring; attitude, alignment knowledge 0.03° (3σ).

NOTES:

TIDI 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
- A bore-sighted star imager provides attitude knowledge and information on gravity waves in the atmosphere



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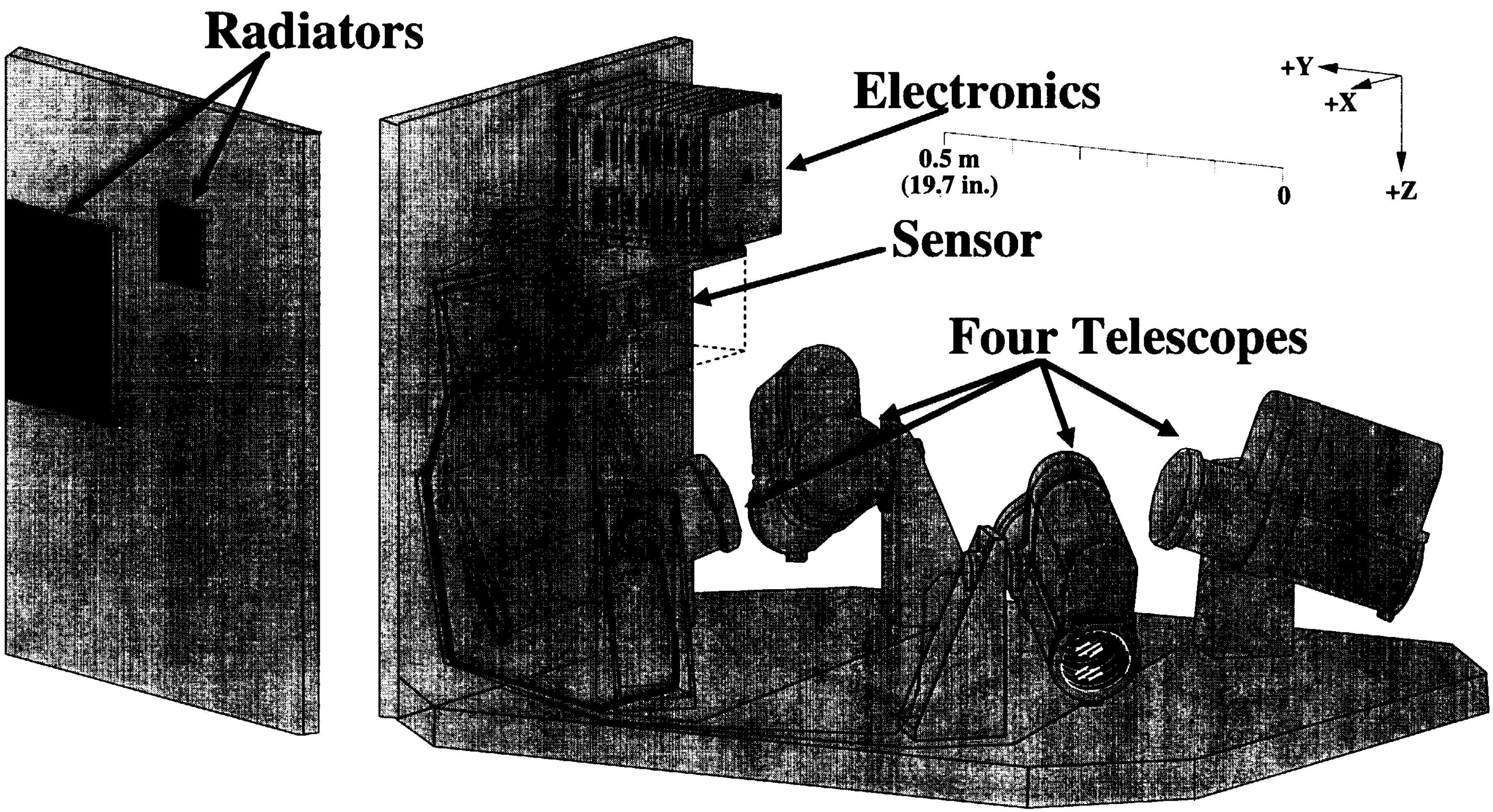
NOTES:

TIDI Baseline Instrument

- Twin etalon Fabry-Perot Profiler; fixed gap high resolution etalon; variable gap low resolution etalon
- One combined Star Camera/Wave Imager replaces Canadian Michelson for bore-sight alignment knowledge through telescopes
- Four telescopes with single axis gimbals
- Two 8-position filter wheels
- Two scene selectors
- Two rectangular CCDs each with TECs and passive radiators
- 95 RH (R3000 class) flight computer
- No dove prisms; fiber optics rotate $\pm 3.75°$

NOTES:

TIDI Mechanical Overview



NOTES:

Two Channels

Two TIDI channels will share common electronics and optics. TIDI views the limb through four orthogonal telescopes which enable the line-of-sight wind measurements to be combined to provide the full vector wind. An imaging channel will provide simultaneous star images through the TIDI optics to provide accurate pointing knowledge. The TIDI wind accuracy requirement is ±3 m/sec, with a goal of ±1 m/sec

- Profiler Channel:
  A twin-etalon Fabry-Perot interferometer primarily measures horizontal vector neutral winds and temperatures from 60-300 km, with a vertical resolution of 2 km and accuracies of ~3m/sec and ~2K, respectively.
- Imager Channel:
  A filtered CCD imaging channel provides a 2.5x2.5° field of view image, corresponding to 100km x 100km spatial resolution. This channel will be used to provide numerous star sightings per orbit as well as providing ancillary science information on airglow fluctuations associated with gravity waves and mesospheric temperatures (40 km horizontal and 3 km vertical resolution).

Baseline instrument: Profiler and Imager channels with four telescopes

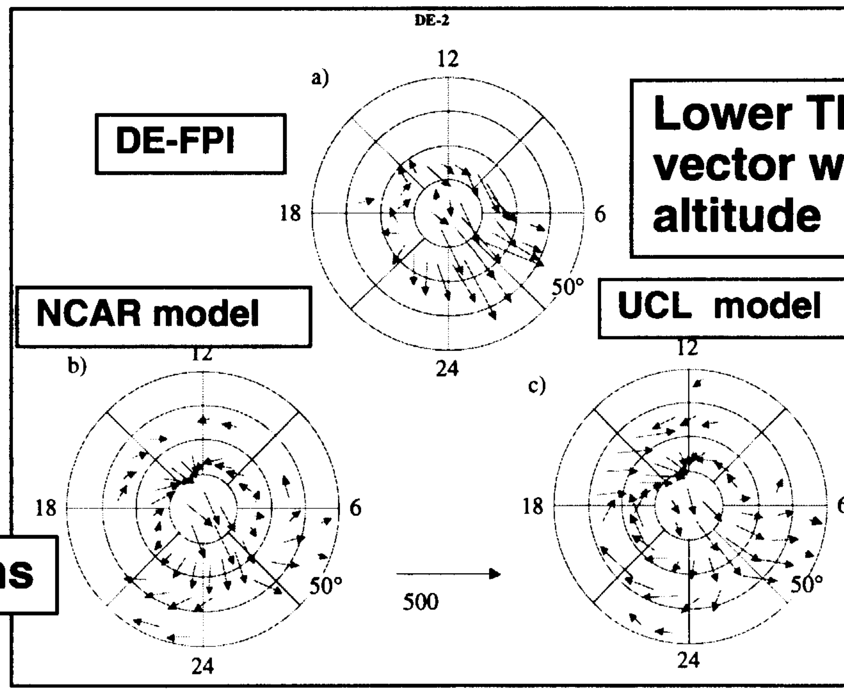
NOTES:

TIDI Dynamics Explorer Heritage

DE-FPI was a single-etalon interferometer optimized for the upper thermosphere. It operated from Feb 1981-March 1983.

Lower Thermospheric vector winds at 97 km altitude

Model comparisons

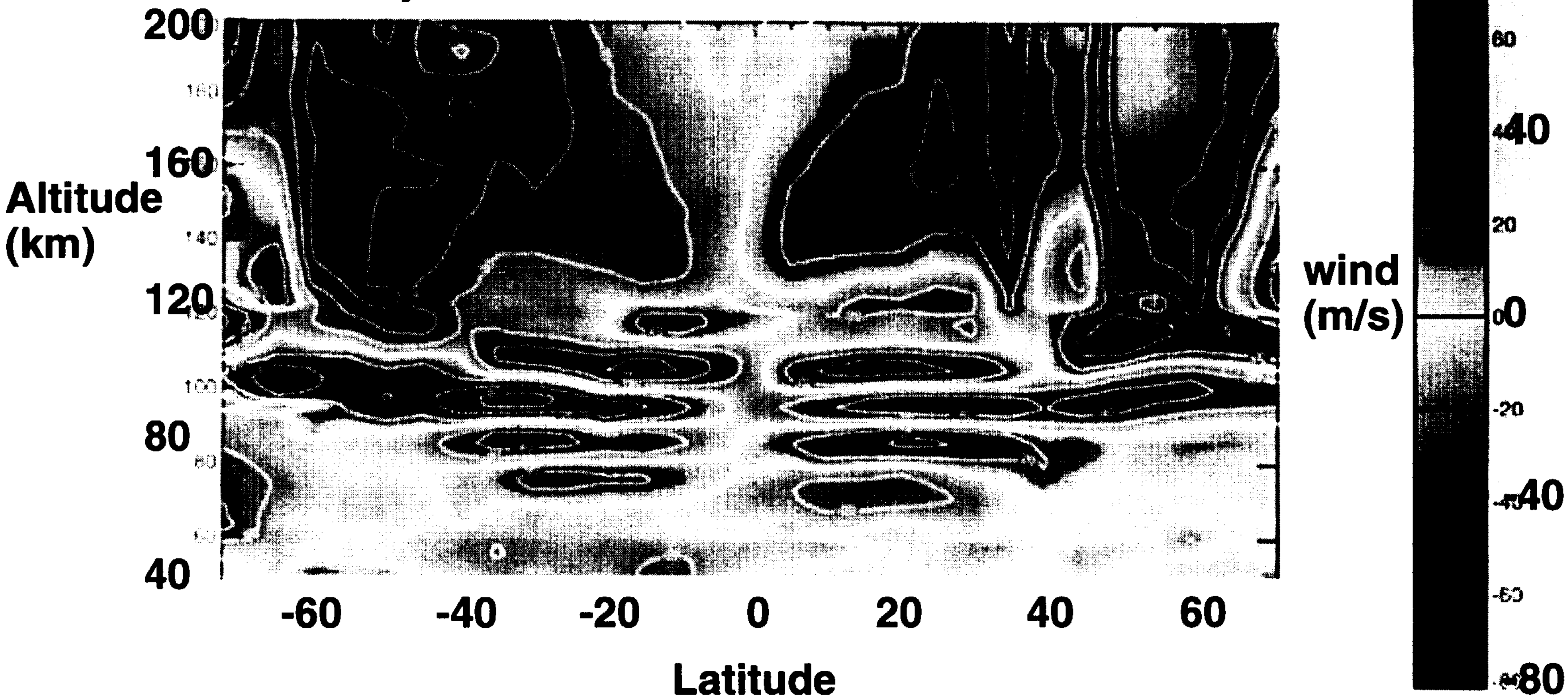


From Killeen et al., GRL, 1993

NOTES:

TIDI The UARS Heritage

Combined HRDI and WINDII meridional wind measurements. Monthly means from March 1993 and March 1994



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

NOTES:

TIDI

TIDI/HRDI Sensitivity Comparison

White light sensitivity:

$$S_{white} = \frac{A\Omega 10^6}{4\pi} T_{op} T_{fil} Q \Delta\bar{\nu}$$

where

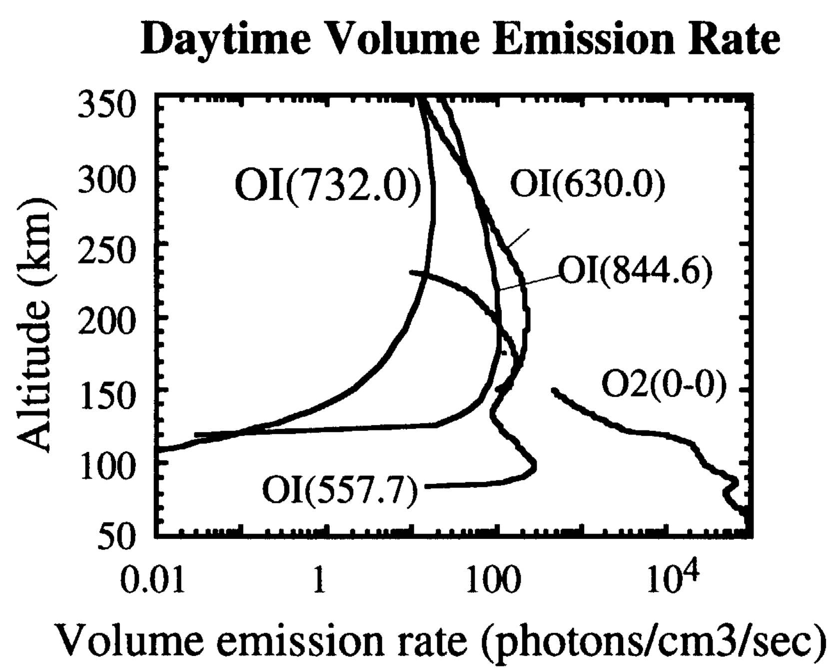
$$\Delta\bar{\nu} = \Delta\nu_{FSR}\left(\frac{1-R}{1+R}\right)$$

TIDI/HRDI = 3.87

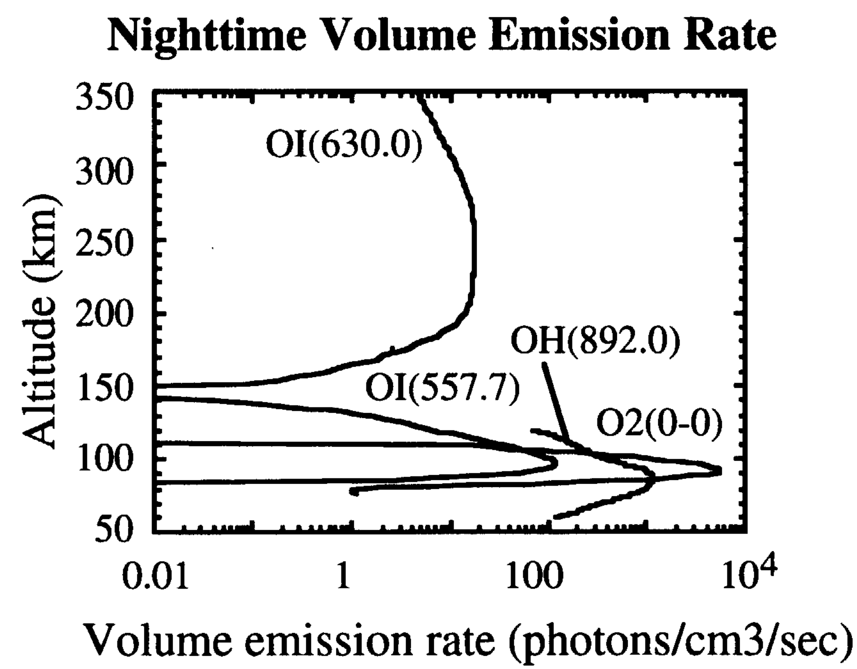
Item	Units	Symbol	HRDI	TIDI
Telescope diameter	cm		17.78	7.5
Telescope effective area	cm^2	A	248.3	44.2
field of view	degrees		0.13 x 1.3	0.05 x 2.5
field of view	sr	Ω	5.1 x 10^{-5}	3.8 x 10^{-5}
$A\Omega$	cm^2 sr	$A\Omega$	1.3 x 10^{-2}	1.7 x 10^{-3}
Photometric sensitivity	photons/s/R	$A\Omega 10^6/4\pi$	1007.7	133.7
Peak filter transmittance		T_{fil}	0.5	0.5
Optical Transmittance		T_{op}	0.10	0.14
Q. E. at 760 nm		Q	0.03	0.77
HRE gap	cm		1.00	1.26
Free spectral range	cm^{-1}	$\Delta\nu_{FSR}$	0.50	0.40
Reflectivity at 760 nm		R	0.90	0.90
Effective bandwidth	cm^{-1}	$\Delta\nu$	0.026	0.021
Number of channels			32	30
Instrument sensitivity	event/s/R/cm^{-1}	S_{white}	0.039	0.151
Channel sensitivity	event/s/R/cm^{-1}	S_{white}	0.001	0.005

NOTES:

TIDI Observed Features



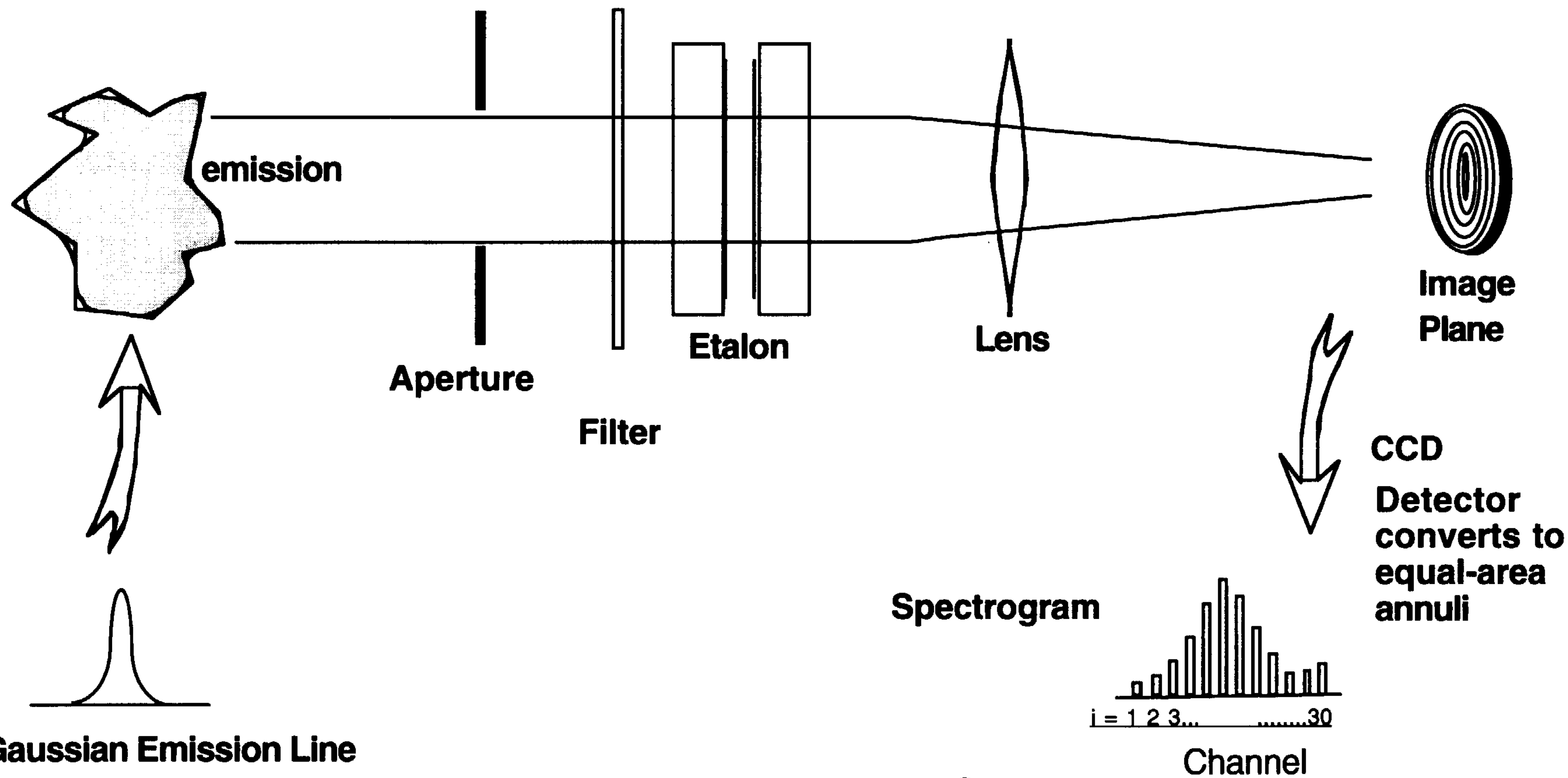
Daytime emissions cover the full TIMED altitude range



Nighttime emissions provide excellent coverage from 80-110 km and above ~200 km

NOTES:

TIDI Profiler Sampling



$$N_i = C_{01} t \, T_{F0} \int_0^{\infty} \Psi_i(\lambda) \, Y(\lambda) \, d\lambda + B_i$$

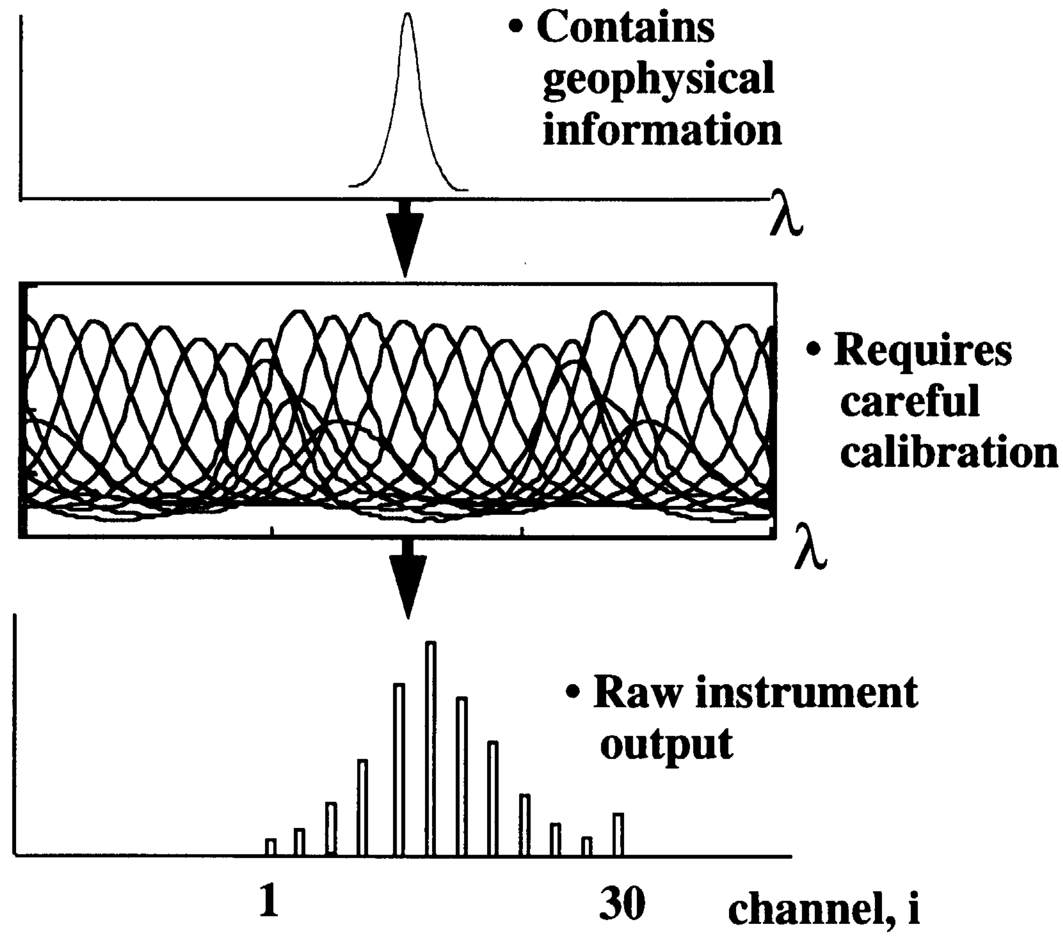
NOTES:

Profiler Spectrogram (example)

Emission Line: B

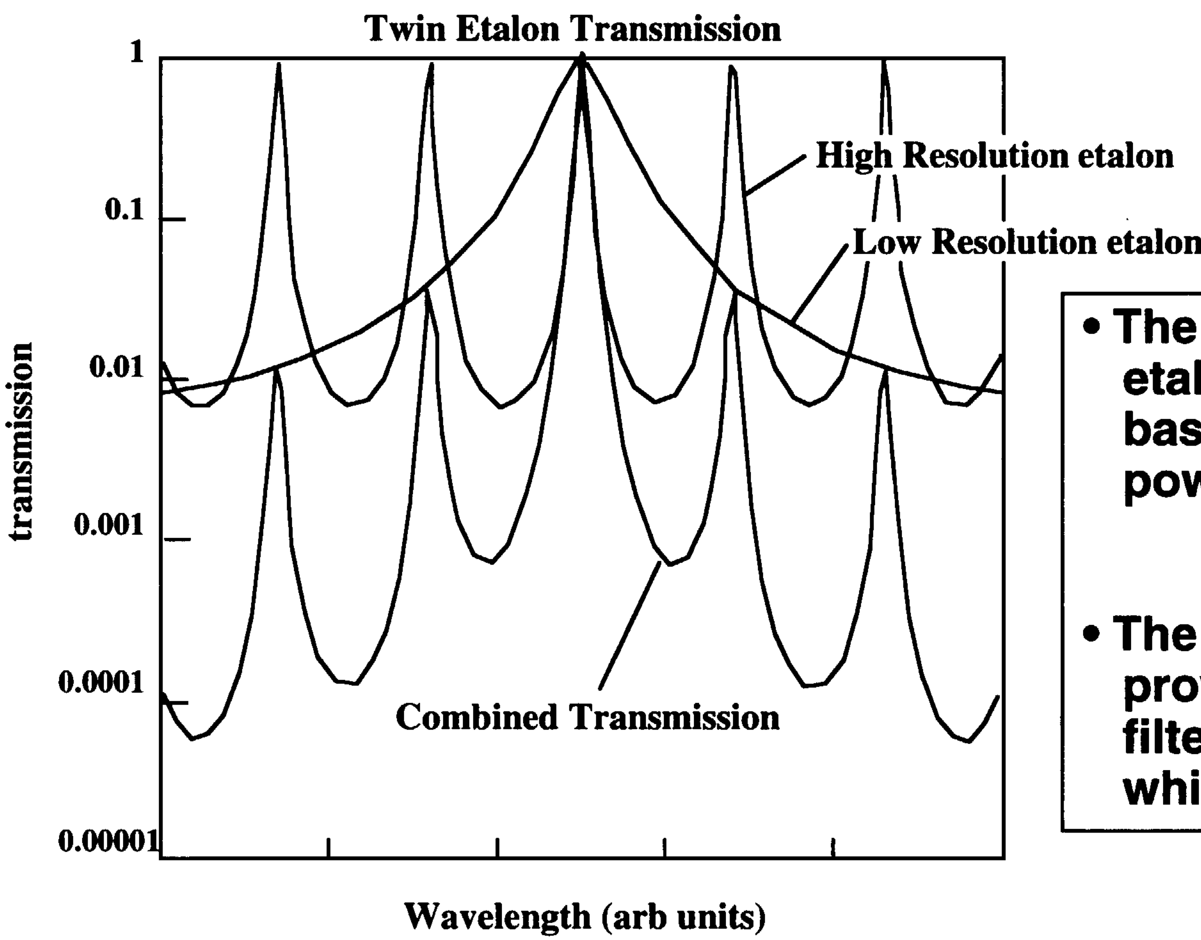
Instrument Transfer Function: Ψ_i

Spectrogram: N_i



NOTES:

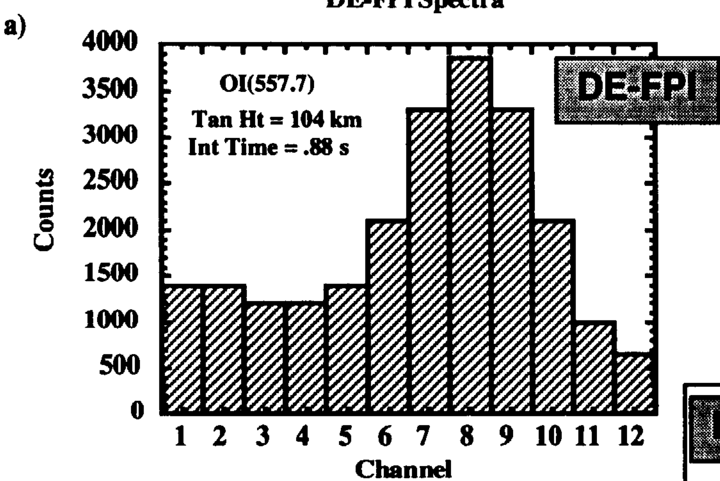
Profiler Dual Etalon Filtering

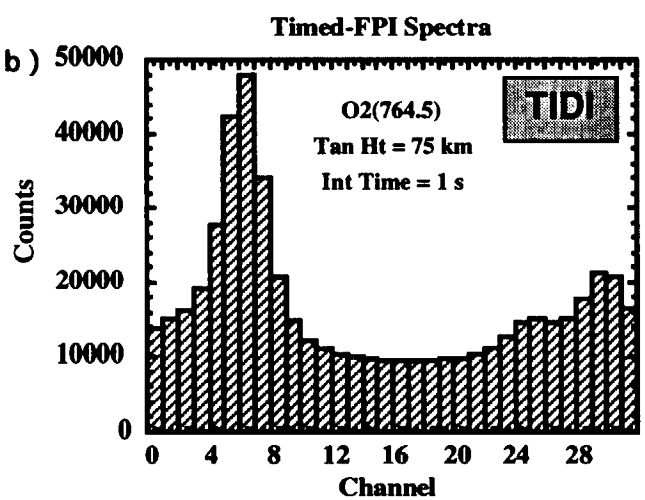


- The High Resolution etalon provides the basic spectral resolving power.
- The Low Resolution etalon provides additional off-band filtering, needed to cut down white light in sidebands.

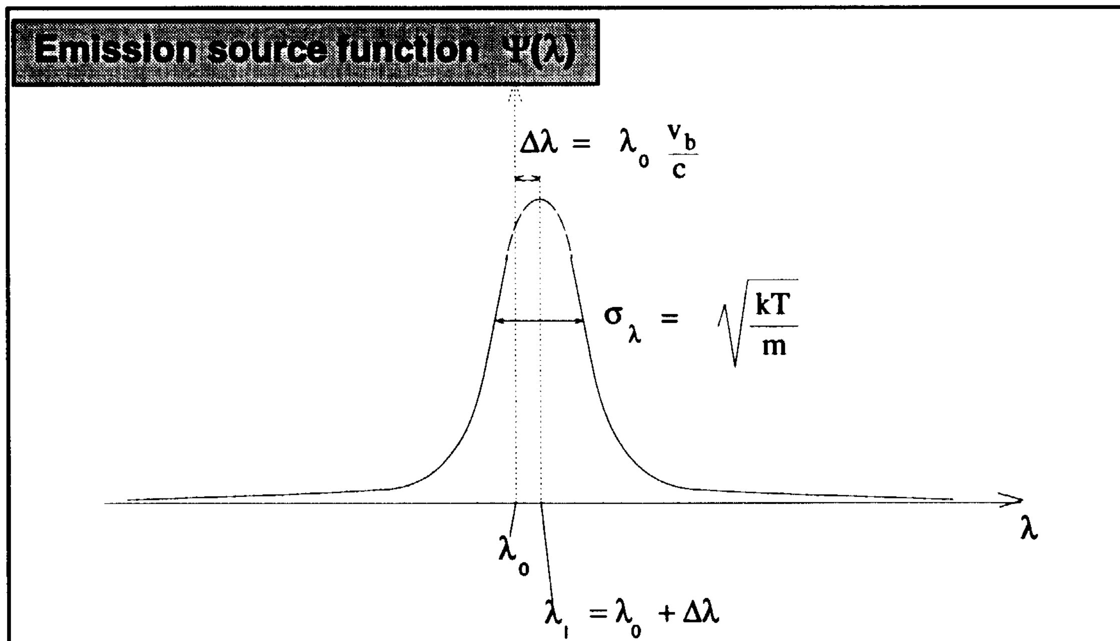
NOTES:

TIDI Profiler Doppler Emission Line Analysis





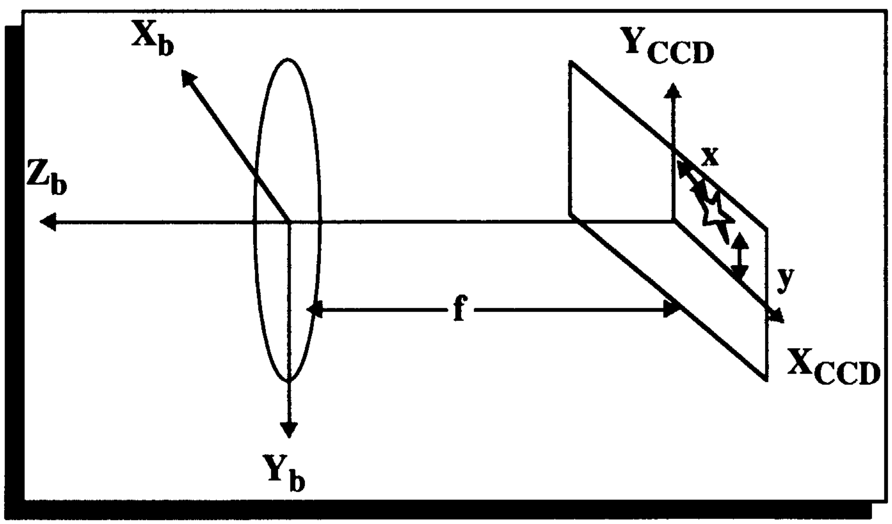
Fringe Pattern measured using a bare CCD interferometer viewing the nocturnal oxygen red line emission over Ann Arbor



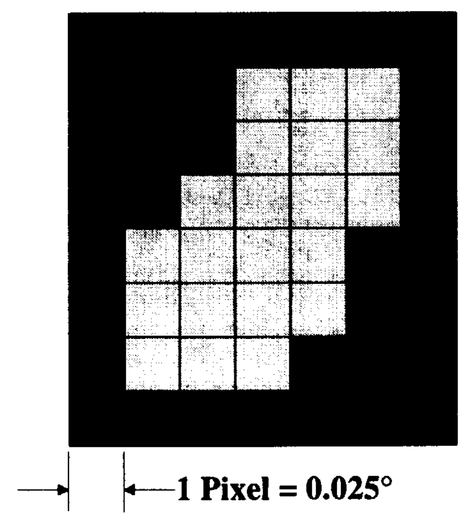
NOTES:

Imager Alignment Measurement

- The position of an identified star in the boresight is measured as a function of time.
- The star image is intentionally blurred over 3 fibers.
- In a one second integration the image moves another 3 fibers.
- The centroid of the image gives the position of the star at the midpoint of the integration period.

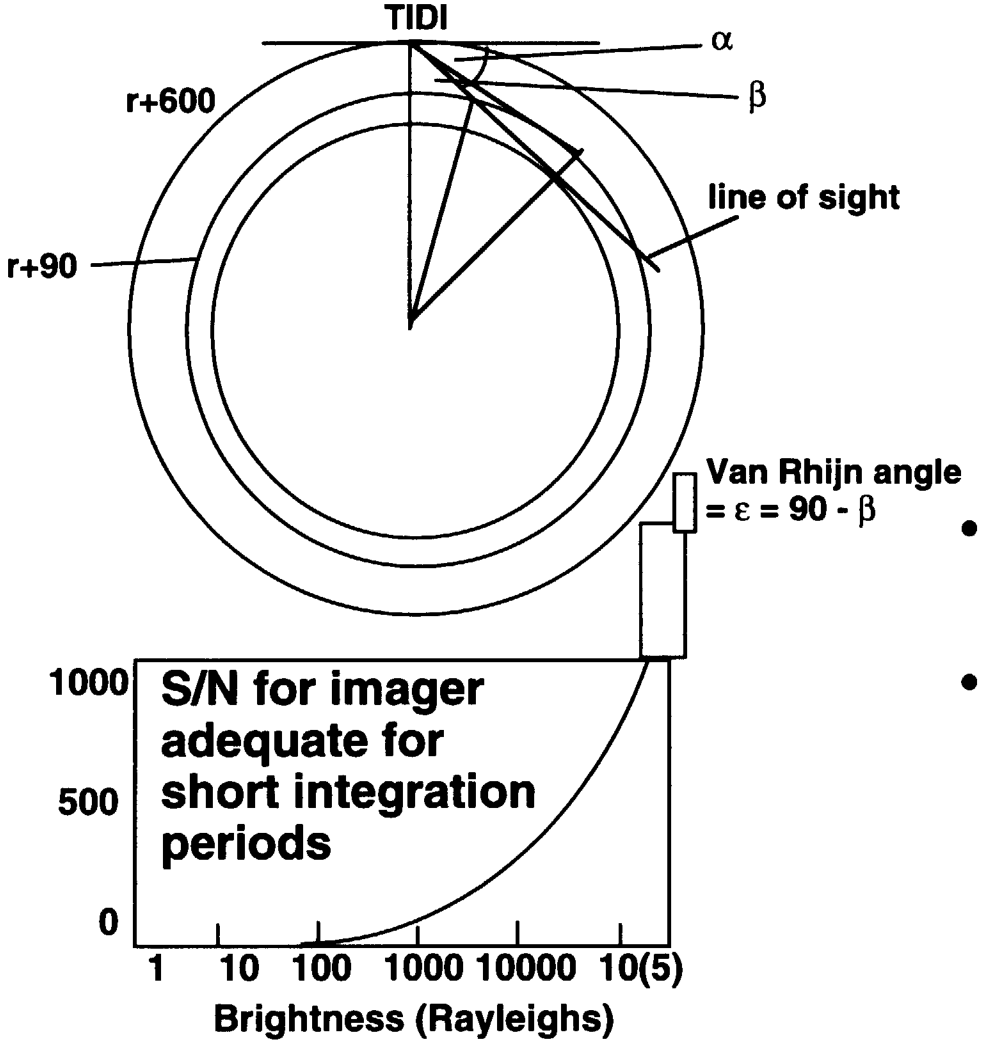


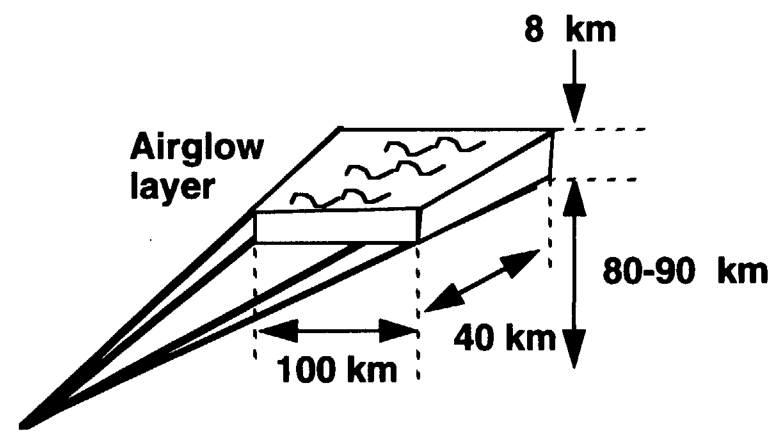
Defocused Star Image Path



NOTES:

Imager Science





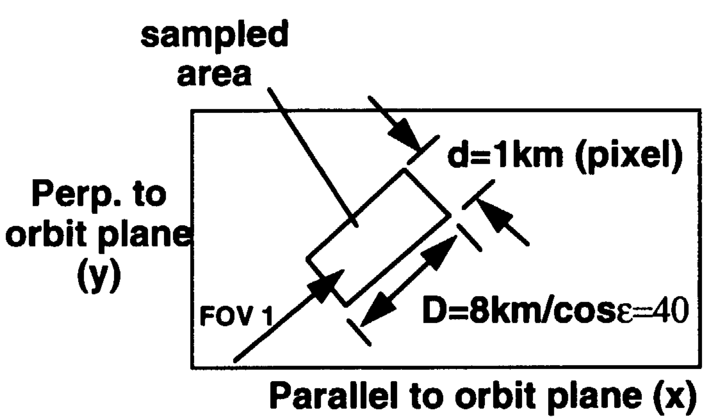
- Channel design driven by star position measurement requirement (wind accuracy)
- Wave Science (originally proposed in conjunction with Canadian imager) possible with modifications.
  - more filters
  - t/m availability (945 bps - less than originally planned for Michelson)
  - on-board image compression
  - fixed prism

NOTES:

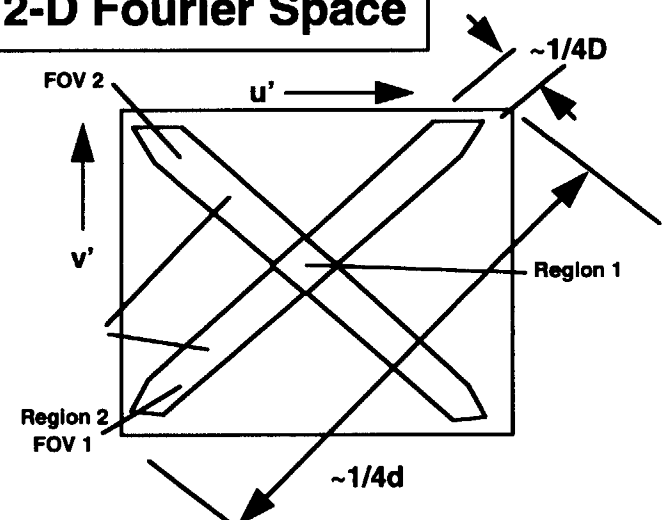
TIDI — Imager Science Mode

- Baseline: Imager viewing through "idle" telescopes at lowest elevation
  - 2 64 x 8 images each with 3-sec integration. 24 times every 104 sec.
  - 945 bps with 2:1 image compression
  - no motion compensation required
  - Dual filters with two images allow for spectral ratio studies
  - Blurring due to spacecraft motion: ~24 km
  - Horizontal resolution ~40 km, vertical resolution ~ 2 km.

Physical Space



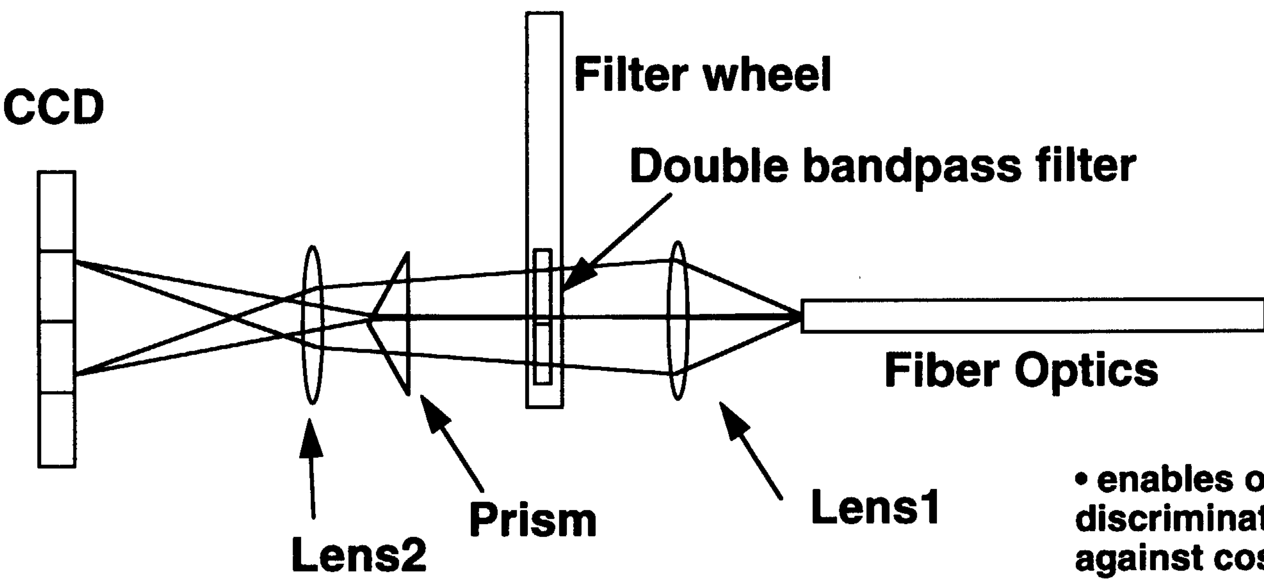
2-D Fourier Space



- Primary product is a complete specification of the long waves regardless of directionality (region 1)
- Secondary product is a specification of shorter waves that happen to be perpendicular to one of the two view directions (regions 2)

NOTES:

TIDI Imager Dual Wavelength Implementation



• enables on-board discrimination against cosmic ray hits

Filter	A	B	Function
1	7608 (12)	7624 (12)	O_2 (0,0) temp.
2	7620 (12)	8626 (12)	O_2 density
3	5577 (12)	5700 (12)	Green line waves
4	8400	8420	OH P1 P2 temp.
5	8656	8625	O_2 (0,1) temp.
6	6300	5700	Red line waves
7	OH	OH Bg	OH total
8	red block	red block	stars

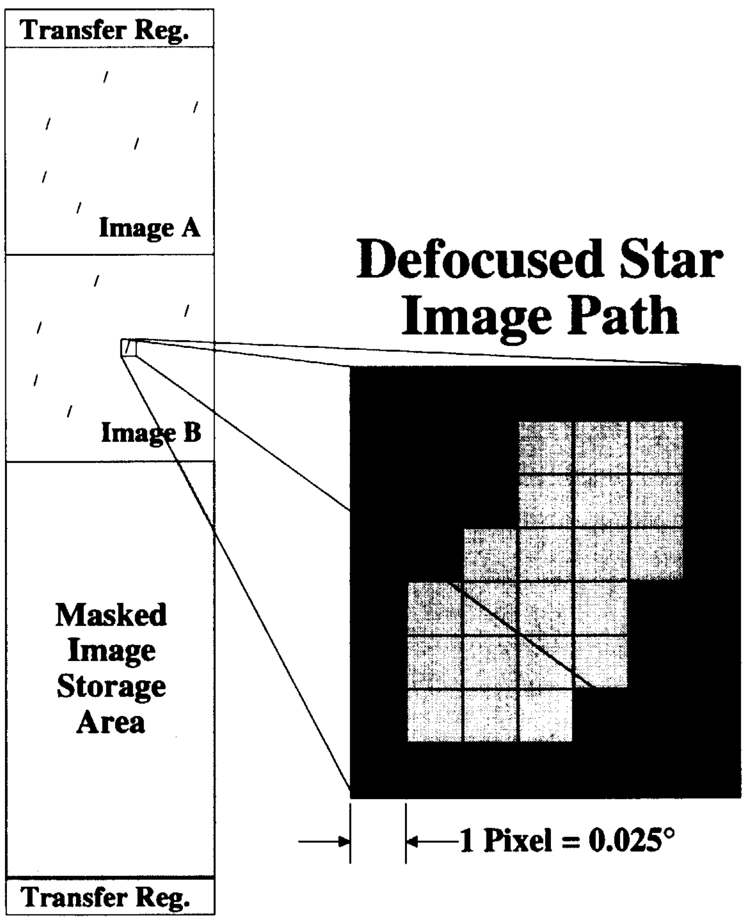
Products:

Waves 40-40,000 km O_2 temperatures
Waves 40-40,000 km O_2 intensity, density
Waves 40-40,000 km Green line
Waves 40-40,000 km OH temperatures
Waves 40-40,000 km OH intensity
Temperature map averaged per 1°lat
Gravity wave index 1 per 5° lat.
Alt. profiles of temperature per 1° lat.

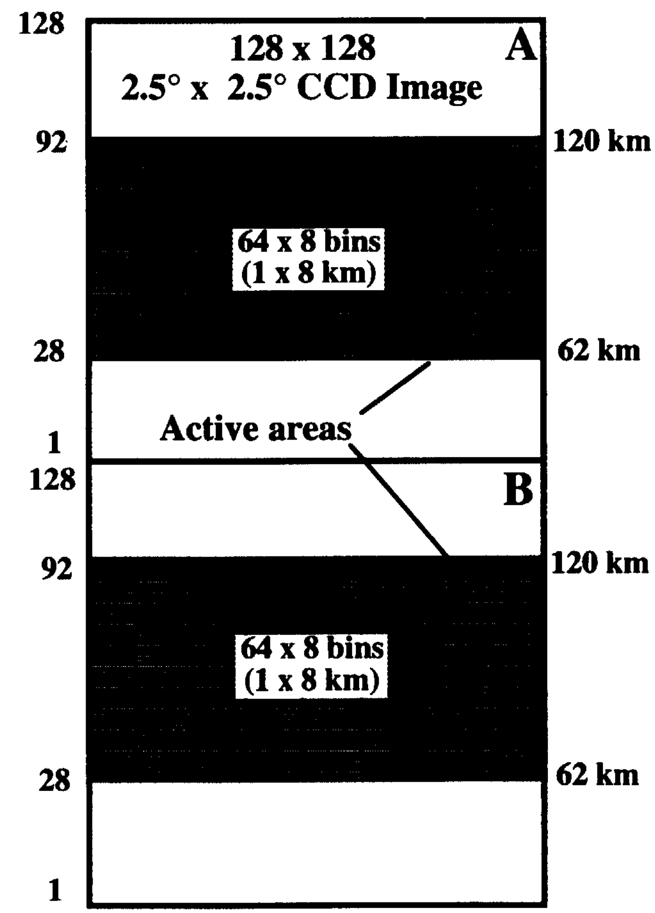
NOTES:

TIDI Imager CCD Formats

Star Measurement



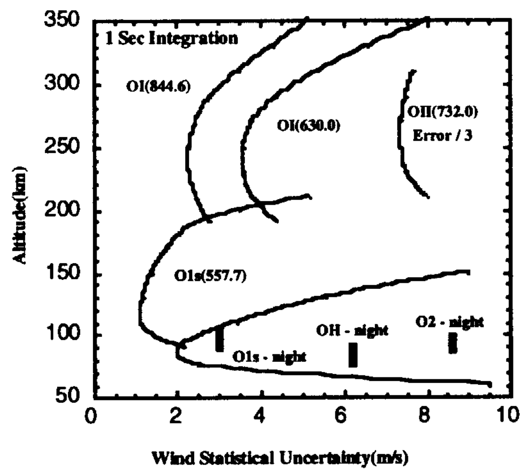
Waves Measurement



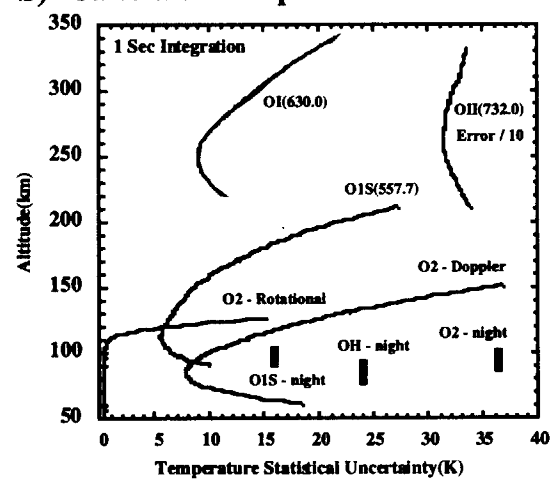
NOTES:

TIDI Calculated Uncertainties

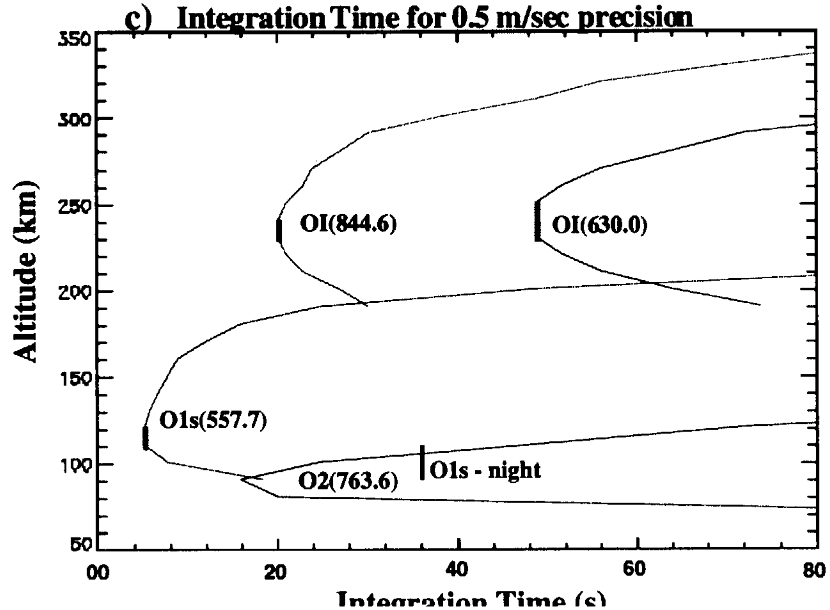
a) Calculated Wind Uncertainties



b) Calculated Temperature Uncertainties



c) Integration Time for 0.5 m/sec precision



NOTES:

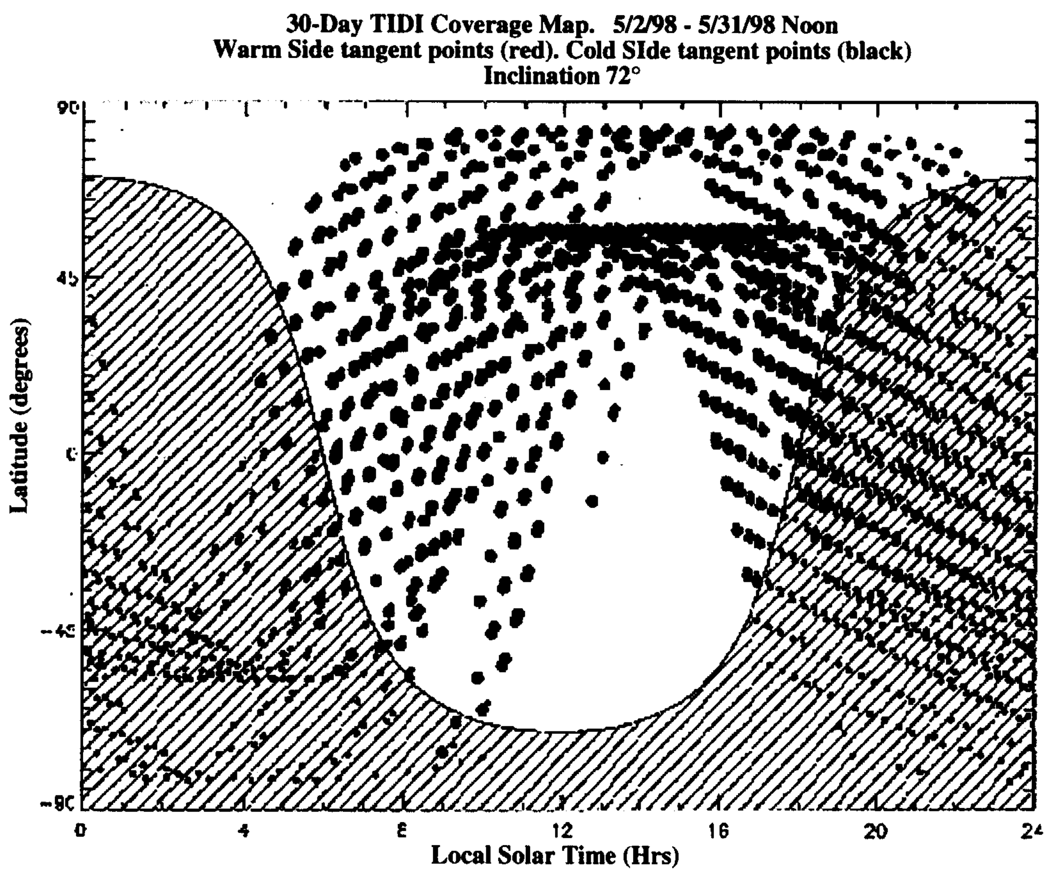
TIDI Measurement Set

1. Vector Wind	Day	Night
Doppler Winds from O_2 (0-0) band @~763.6, 764.5, 765.9 nm	60 - 120 km	85 - 105 km
Doppler Winds from OI 557.7 nm	90 - 250 km	95 - 105 km
Doppler Winds from OI 630.0 nm	200 - 300 km	200 - 300 km
Doppler Winds from OH 892.0 nm	N/A	80 - 110 km
Doppler Ion Drift from OII 732.0 nm	170 - 300 km	N/A
2. Temperature		
Rotational temperature from O_2 (0-0)	90 - 150 km	85 - 105 km
Rotational Temperature from O_2 (0.1)	60 - 100 km	
Kinetic Temperature from OI 630.0 nm	200 - 300 km	200 - 300 km
Kinetic Temperature from OI 557.7 nm	100 - 150 km	95 - 105 km
3. Density		
O_2 density from (0-0) band extinction	60 - 120 km	N/A
O density from simultaneous OII 732.0 and OI 844.6 nm	150 - 300 km	N/A
O Density from O_2 (0-1) 866.0 nm		85-95 km
Total density from Rayleigh Scatter	60 - 100 km	
4. Waves		
Wave field 40 km horizontal; 3 km vertical resolution	60 - 120 km	95 - 105 km

NOTES:

TIDI Monthly Coverage Plot

Red: dayside
Black: nightside

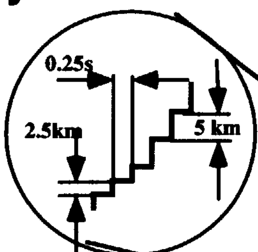


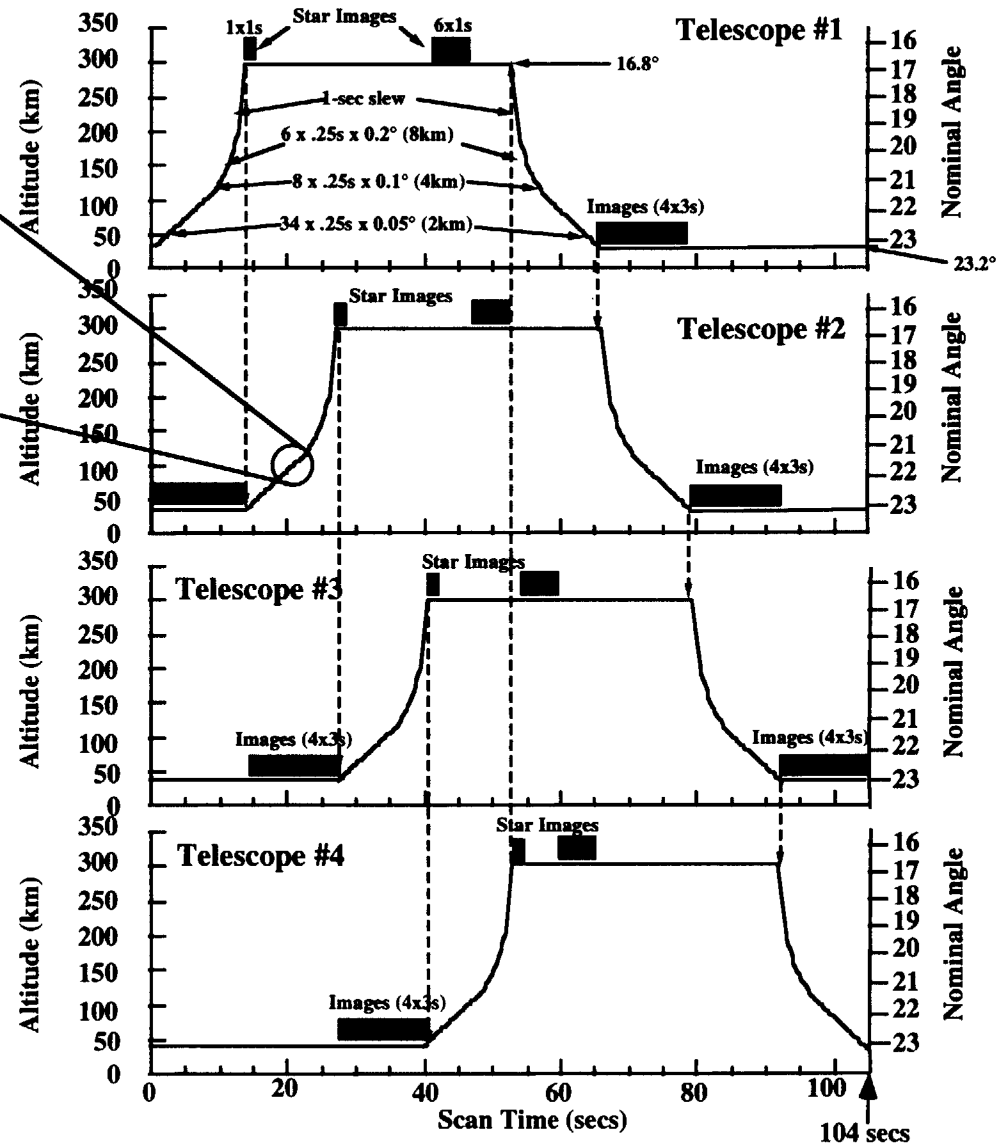
NOTES:

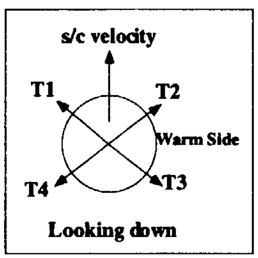
TIDI

Baseline Mode

Repeating 104-sec cycle





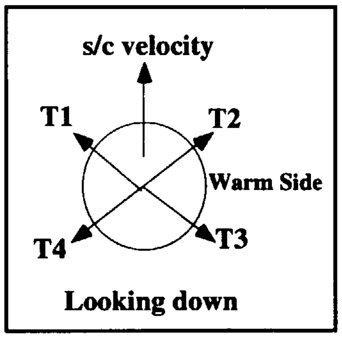


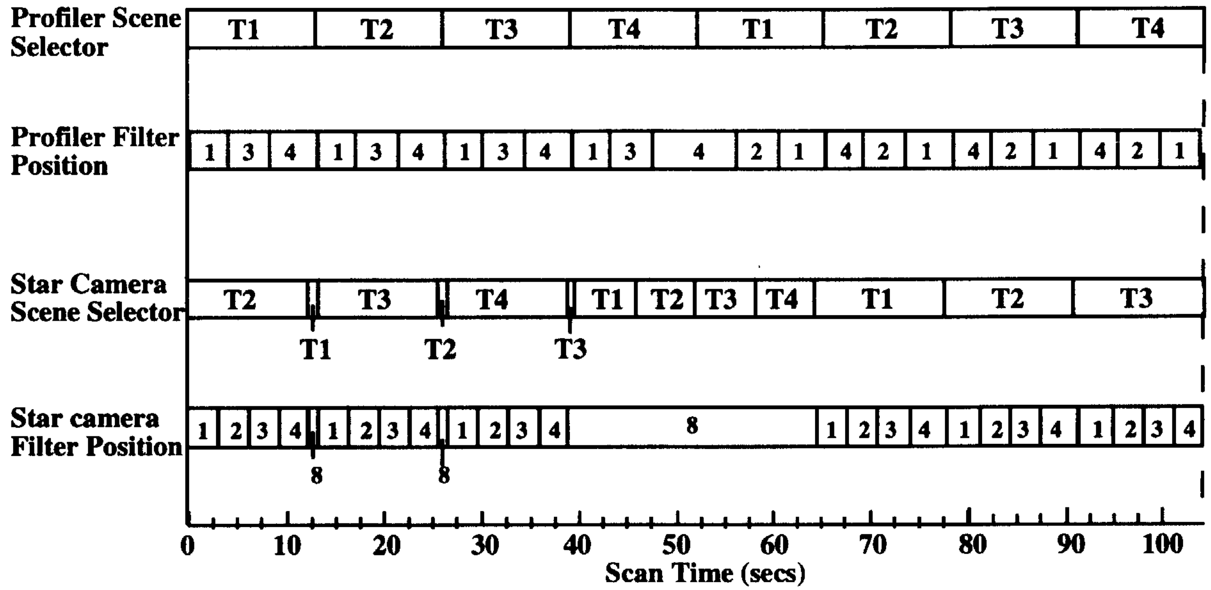
Earth Oblateness ±0.25° adjusts look angle using on-board look-up

Placement error accounted for by ±0.5° overscan (leads to longer scan period by ~40%).

NOTES:

TIDI Baseline Mode Scene and Filter Selects





Profiler Filter Wheel Allocation

Filter	λ(Å)	Function
1	7636 (3)	O_2 optically thin 60-80 km
2	7645 (3)	O_2 optically thin 80-110 km
3	7659 (3)	O_2 optically thin 80-120 km
4	5577 (3)	Green line 90-250 km
5	6300 (3)	Red line 300 km
6	7320 (3)	Ion drifts 300 km
7	8920 (3)	OH winds 80-110 km
8	8446 (3)	OI auroral winds 150-300 km

Star Camera Filter Wheel Allocation

Filter	A	B	Function
1	7608 (12)	7624 (12)	O_2 (0,0) temp.
2	7620 (12)	8626 (12)	O_2 density
3	5577 (12)	5700 (12)	Green line waves
4	8400	8420	OH P1 P2 temp.
5	8656	8625	O_2 (0,1) temp.
6	6300	5700	Red line waves
7	OH	OH Bg	OH total
8	red block	red block	stars

NOTES:

TIDI

Other TIDI Modes

- The Baseline mode represents the most resource-intensive in terms of mechanism activations and on-board computation
- If the placement error for the s/c can be tightened, the baseline mode will be shortened (optimally 64 sec repeating sequence).
- Mesopause Wind Mode: concentrates on 90-100 km altitude range, day and night winds. Longer integration times, fewer filter wheel steps, fewer telescope steps
- Residual Circulation Mode: concentrates on 60-100 km altitude. Longer integration times fewer telescope and filter wheel steps
- Calibration modes for zero wind measurement; single filter, long integration times (minutes)

NOTES:

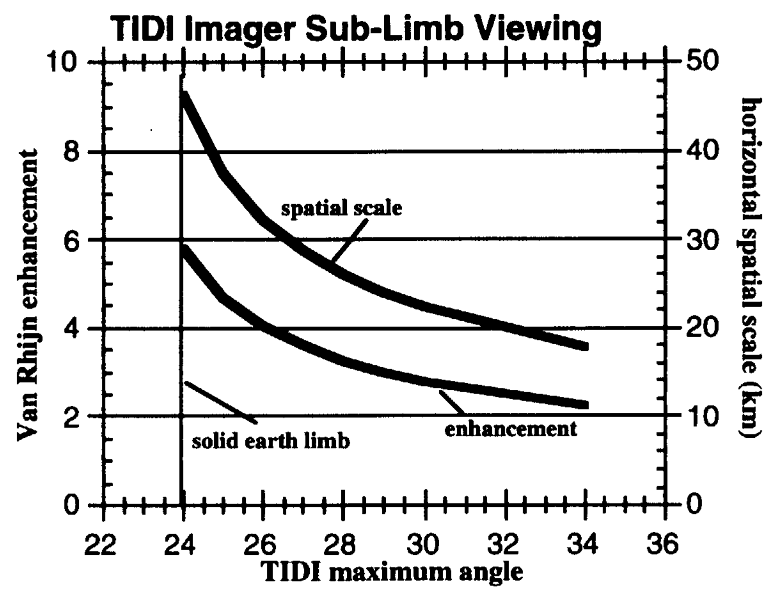
TIDI Risk Reduction Study - Major Outcomes

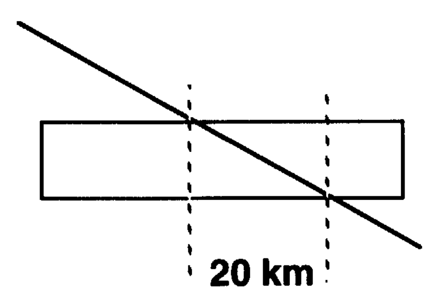
- Baseline Instrument better defined
- Four articulated telescope implementation
- Study concentric ring CCD, hold rectangular CCD in baseline
- Bore-sighted star imager using coherent fiber bundle replaces Canadian Michelson channel, enables required pointing accuracy knowledge for end-to-end instrument
- Detailed calibration plan for 1 m/sec accuracy involves s/c manoevers including nadir views
- Duplicate 8-position filter wheels for profiler and imager
- RH 95 Flight Computer implementation
- Imager channel can contribute to TIMED science
- Resonance, Ltd. lamps can be used to provide on-board emission line calibration (good for ~3m/sec accuracy)

NOTES:

TIDI TIDI Option for Sub-Limb Viewing

- **Horizontal resolution for the imager wave imaging can be improved by extending the telescope motion to view below the Earth's limb**
- **Sub-limb viewing reduces the signal level due to reduced Van Rhijn effect**
- **Option:**
  - **Extend telescope lower limit angle from 23.2° to 32°.**
  - **This would reduce horizontal resolution to about 20 km, with a factor of 2 reduction in signal to noise**
  - **Current baseline range is from 16.8° to 23.2° (6.4° total). New range would be from 16.8° to 32° (15.2° total)**
  - **Impact would include larger clear FOV requirements.**





NOTES:

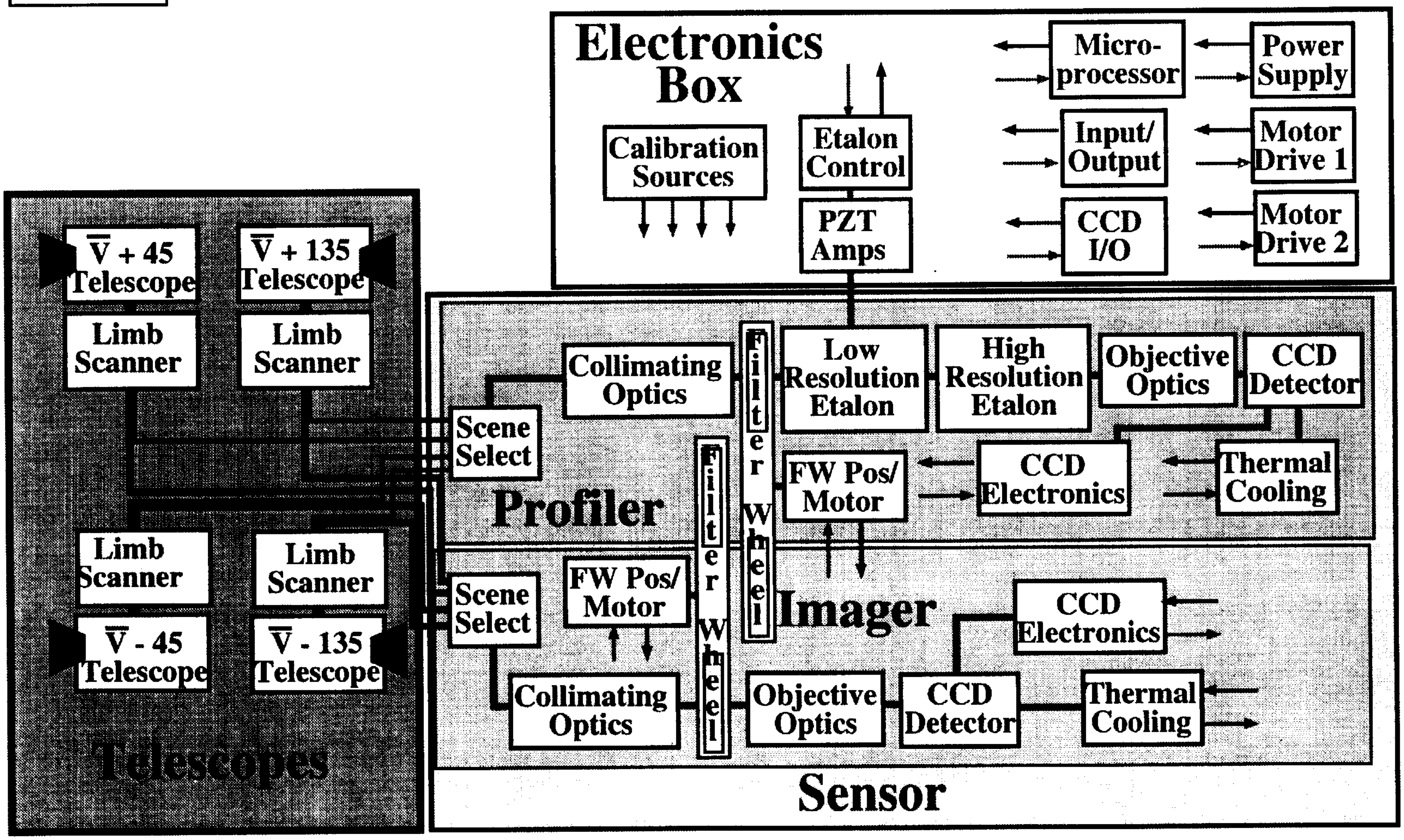
Systems
Brian C. Kennedy

Baseline from Proposal to Current

Item	Proposal	Current	Comment
Imager	Michelson	Stars/Waves	Need Attitude, get Waves
Cal Lamps	HAK & Neon	$O^1(s)$ & O_2	Matches Observed Lines
Telescopes	Two	Four	Improved Tides
Telescopes	Scan Mirror	Articulated	Improved Scattering
Telescopes	Schaeffer Type 1	Type 2	Larger Hole for F.O.
Filter Wheel	One, Shared	Two	Faster Step, More Flexible
Scene Selectors	Four Motors	Two Motors	Simpler Interface
Profiler CCD	Tektronix	Loral	Tektronix too Slow
Imager CCD	Tektronix	Loral	Tektronix too Slow
Flight Computer	80C86	95 RH	80C86 too Slow
Profiler xmit # of Ch's	16 x16 bit	30 x 12 bit	To monitor 2nd Order Effects

NOTES:

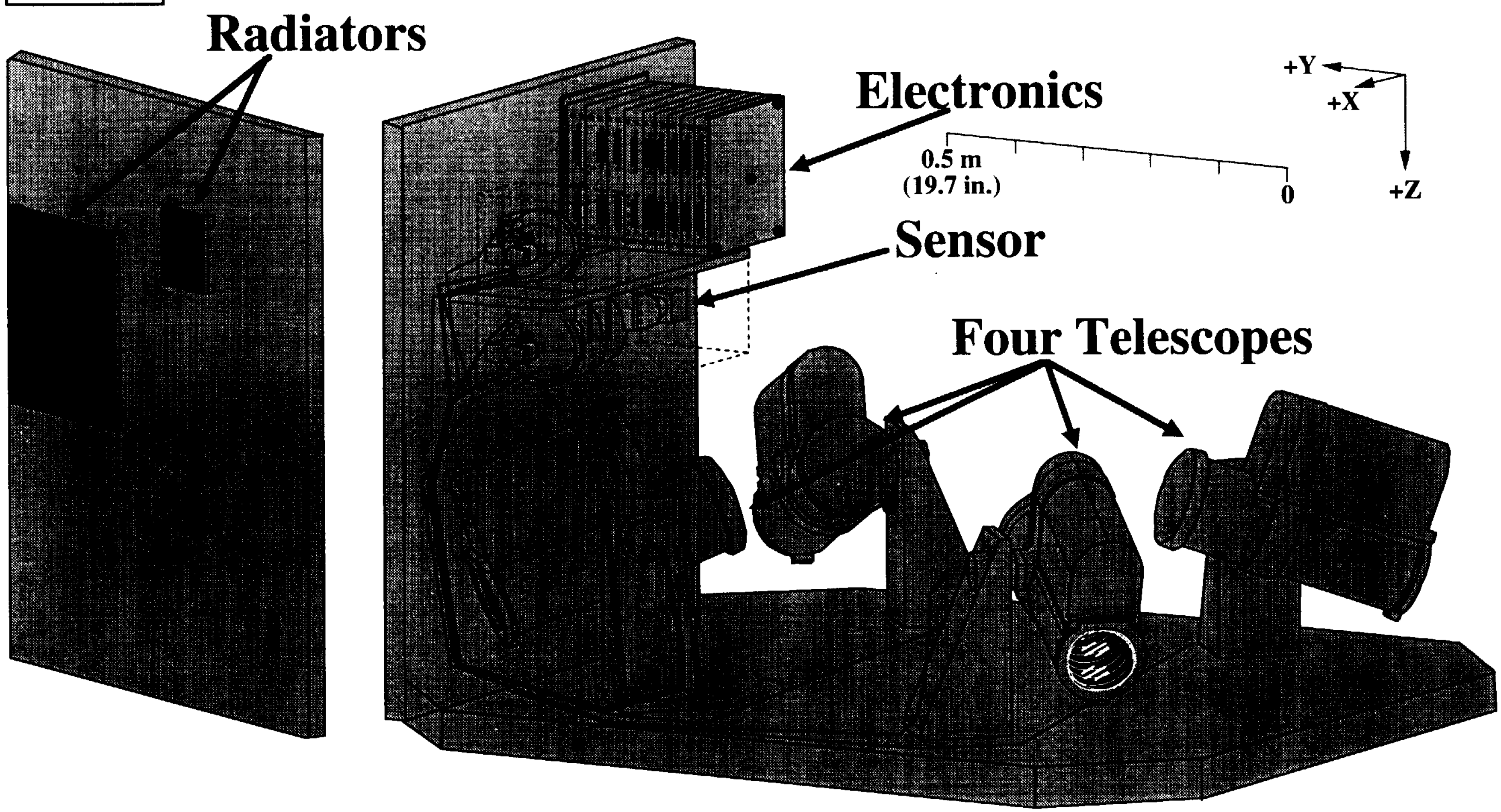
TIDI Instrument Block Diagram



NOTES:

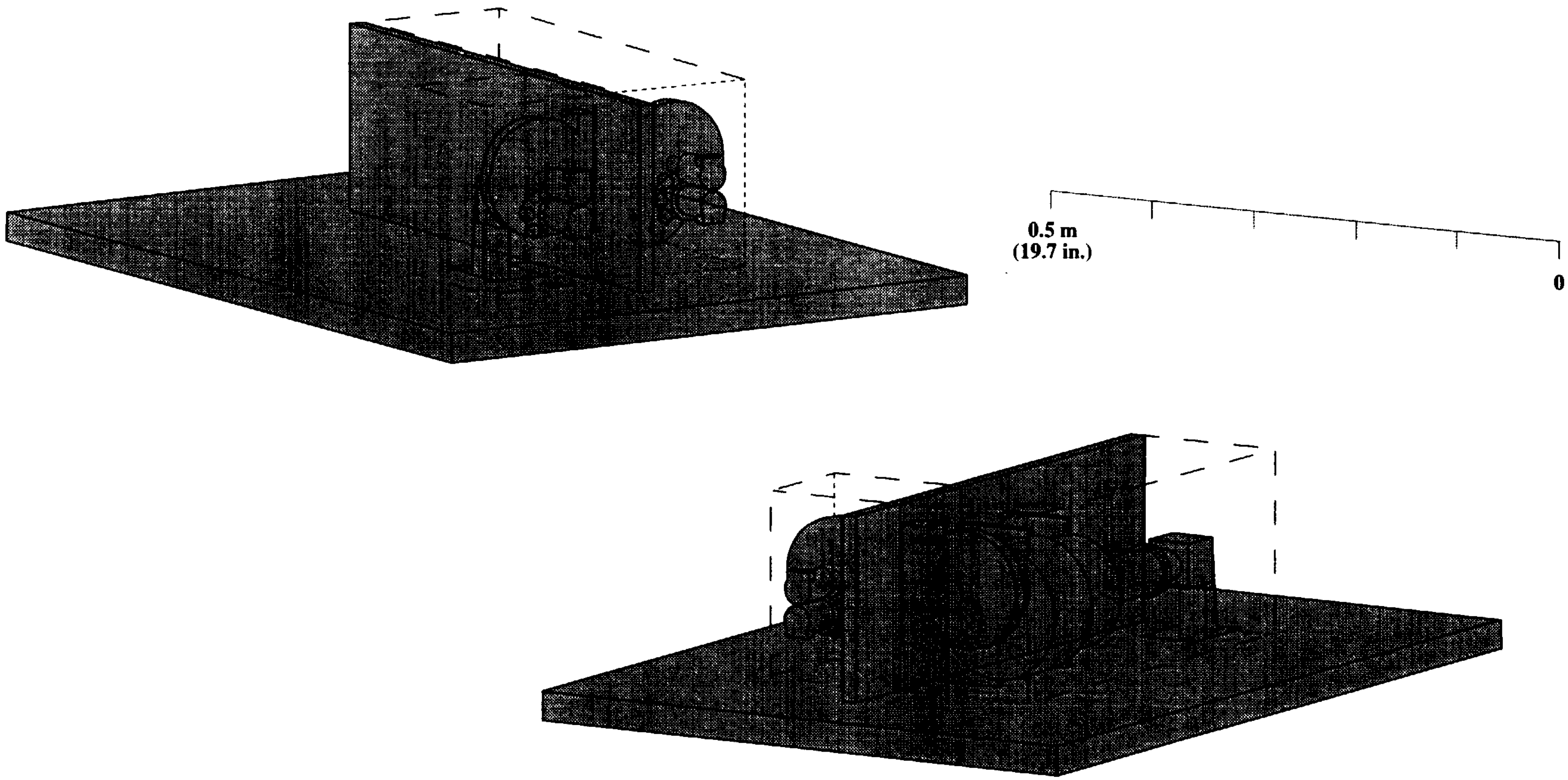
TIDI

Mechanical 3D Overview



NOTES:

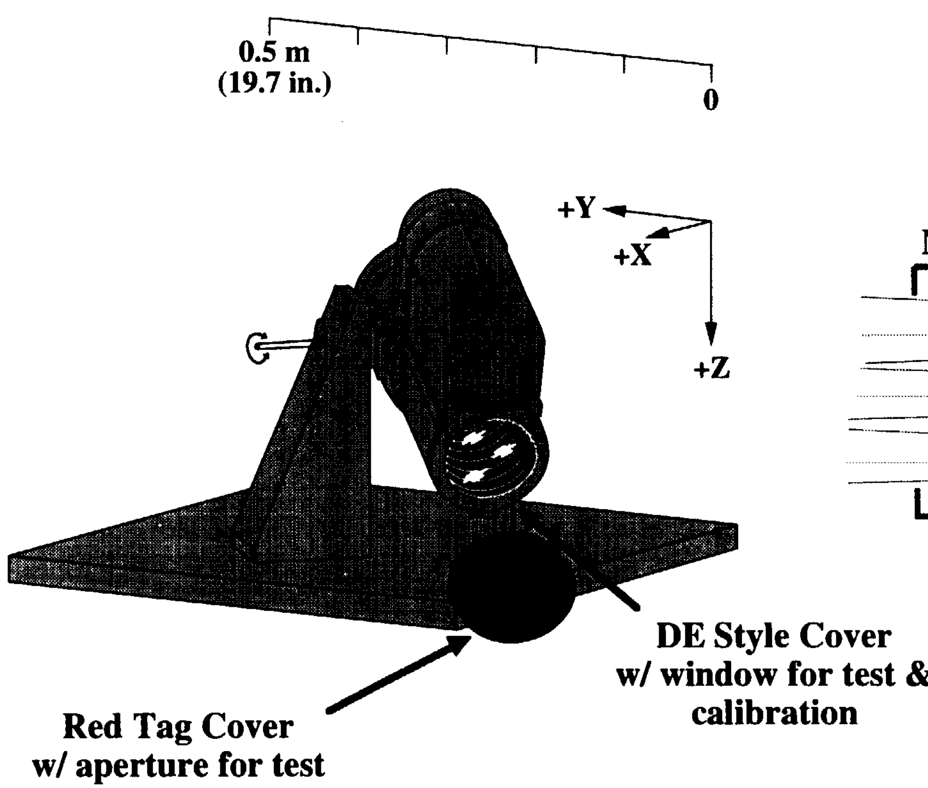
Mechanical 3D Sensor



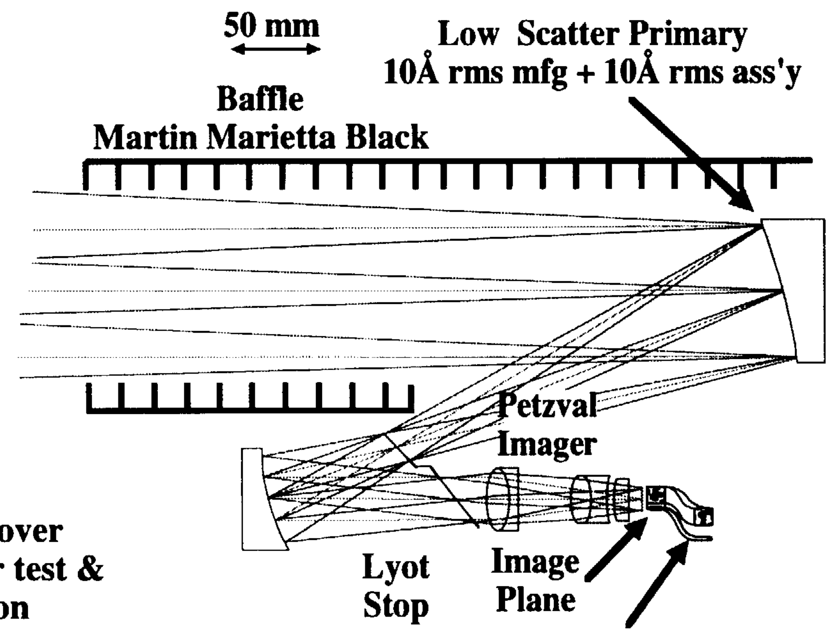
NOTES:

TIDI

Mechanical 3D Telescope



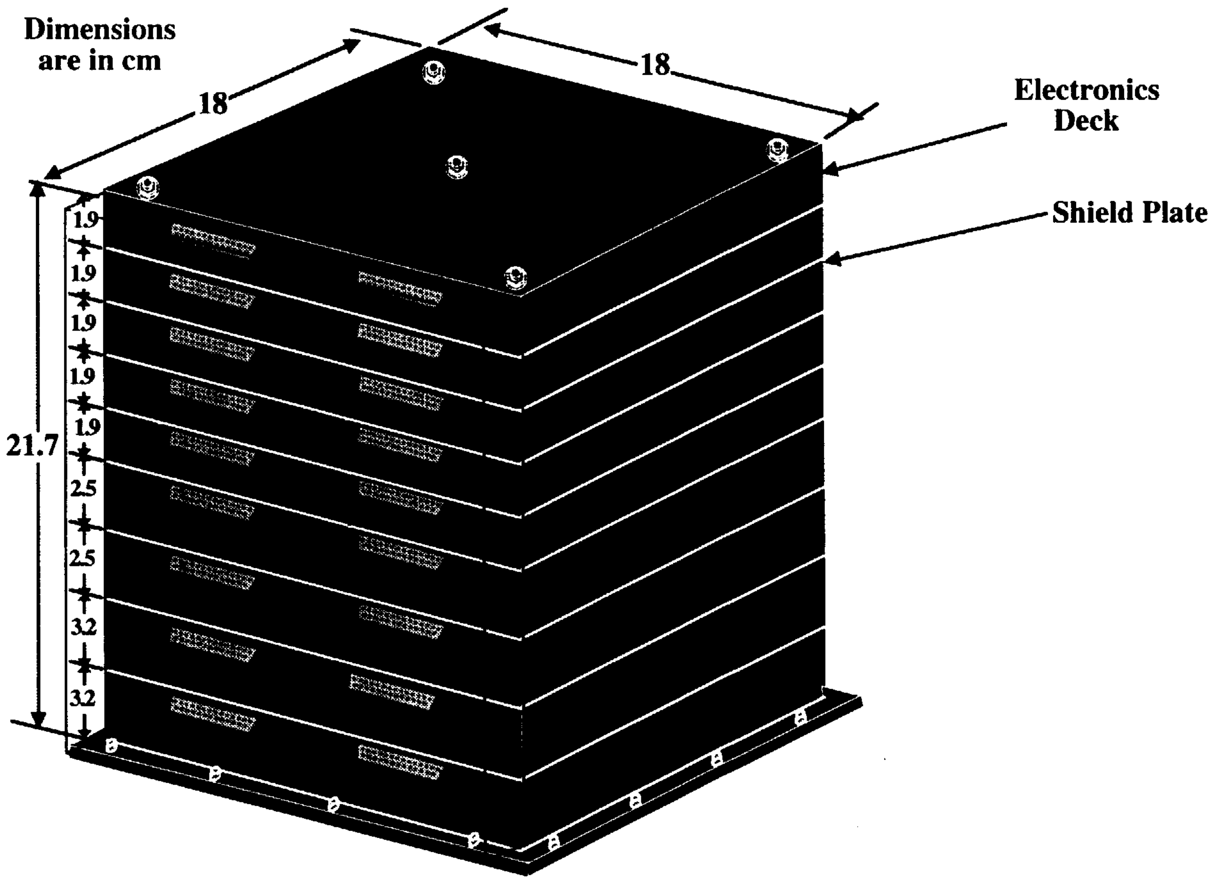
Low Scatter Parabolic Off
Axis Gregorian
with Petzval Imager



Fiber size = 55 micron,
50 micron core
fo length = 1.5m
NA > 0.28

NOTES:

Mechanical 3D Electronics



NOTES:

Subsystem Heritage & Risk

Name	Heritage AE	DE	UARS	Risk Elements
Telescope			x (H)	Simpler version of HRDI
Structure	x	x	x	Simple, aluminum
Optical Bench		x		Kinematic design
Scene Selector	x	x	x	Same motor, newer control
Fiber Optics			x	based on HRDI design
Calibration		x	x	DE/HRDI design w/ new spectral lines
Collimator		x	x	DE design
Etalons		x	x (H)	DE design, with HRDI LRE design
Imager			x (W)	Miniature, simpler version of WINDII, with no moving parts, compensated for single spectral region
Objective	x	x	x	based on DE design
CCD			x (W)	UARS-WINDII derivative
Cooler			x (W)	UARS-WINDII derivative
Radiator			x (W)	UARS-WINDII derivative
Electronics	x	x	x	DE, TOMS I/O, 95 RH Computer

NOTES:

Instrument Parameter Summary

- Included as an Appendix
- Intended to Contain Every Number Associated with TIDI
- Is done in a Spreadsheet to Perform Arithmetic and Searching
- Is Located on Our Server so Everyone has Access to Read or Modify
- Is Backed Up Daily to Recover from Mistakes, etc.

NOTES:

Mass & Power by Subsytem

Power & Mass Subsytem Sum.	W	Kg
Telescope subass'y, 1	0.64	3.60
Scene selectors 1	0.05	0.45
FW, Profiler	0.65	0.29
FW, Imager	0.85	0.29
Profiler CCD Elect	0.50	0.15
Profiler TEC	0.56	0.35
Profiler CCD Radiator		1.10
Imager CCD Elect	0.50	0.15
Imager TEC	0.32	0.35
Imager CCD Radiator		0.65
LRE PZT Amp	0.4	0.48
LRE PZT Control	0.4	0.47
CCD I/O	0.45	0.50
SC I/O	1.00	0.50
uP	3.2	0.50
Motor Drive 1	0.2	0.50
Motor Drive 2	0.2	0.50
Calibration Lamps	0.02	0.77
LVPS Eficiency	0.75	1.00
Harnesses		0.50
Fiber Optics, Profiler		0.13
Fiber Optics, Imager		0.60
Profiler, etalon, optics, etc		0.97
Imager, optics		0.02
Sensor Structure		3.22
Sensor Thermal Blanket		0.57

Total Mass 29.8 Kg
SC Margin 13%
75.4 Kg

Total Power 13.3 W
SC Margin 25%
57 W

NOTES:

SC Resource Requirements 1

Heritage	DE FPI, HRDI & WINDII/UARS
Satellite Nominal Design Altitude	600 ±25 km
Satellite inclination	74.1±0.1°
Mission Lifetime	2 years
Atmospheric Region	60 - 300 km
Look directions, Azimuth	45°, 135°, 225°, & 315° (Velocity = 0°)
Look directions, Depression Angle	16° to 23° (Horiz. = 0°)
Instantaneous Field of View	2.5° V x 2.5° Imager 0.05° V x 2.5° Profiler
Placement, R, P,Y, 3σ (Inst + SC)	±0.5°
Knowledge, R,P, Y 3σ	0.03° (Inst + SC)
Jitter	0.03°/0.25sec
Stability	0.03°/10sec
Absolute Time, UTC	1 sec ±2.5 msec
Orbit; Height, Along Trk, X Trk	±1, ±1, ±1 km
Avoidance Cone, Θ1/2wrt boresight	17.5° (4 look directions)
Detector Radiator Area	25 x 25 cm Profiler CCD 10 x 10 cm Imager CCD
Detector Radiator Location	Anti-sun 2π Sr Clear Field of View

NOTES:

TIDI SC Resource Requirements 2

Operating Temperature Range	
Electronics & Telescopes	-20 to +40°C
Sensor	20± 5°C, 0.1°C/orbit
Survival Temperature Range	
Telescopes	-30 to +50°C
Sensor & Electronics	-40 to +60°C
Magnetic Field	Non Critical, < 5 Gauss
Electric Field	Non Critical
Mass	29.8 Kg
Power	13.3 W
Serial Commands 16Bit	2 KBytes/day
Relay Commands	1 @ 1/mission
Integration Time	0.25 Sec min
Data Rate with Housekeeping	2336 bps
Duty Cycle	100%
Contamination, particulate	Flight Covers, normal handling
Contamination, molecular	Purge required
Mechanical Disturbances, °/step, step time, Moment of Inertia	
Telescopes	0.05°, 20 ms, 0.0166 Kg/M^2
Filter Wheels	45°, 50 ms, $8.8x10^{-5}$ Kg/M^2
Scene Selectors	45°, 10 ms, 10^{-6} Kg/M^2

NOTES:

TIDI

Profiler Performance

• Lifetime	2 years	Meets; Radiation, Lubrication, FO
• Altitude Coverage	60 - 300 km	Meets; 16 - 23° scan @ 600Km
• Altitude Resolution	2.5 km	Meets; 0.05° VFOV @ 600Km
• Look Directions	±45° & ±135°	Meets; 4 Telescopes
• Horizontal Resolution	100 km	Meets; 2.5° HFOV @ 600Km
• Spectral Region	550 to 900 nm	Meets; Coatings, filters, Det.
• LOS accuracy	3 m/s	Meets; see Errors section
• Temperature accuracy	2 °K	Meets; Proposal Fig 1.5-1
• Minimum sample time	0.25 Sec	Meets; Design
• Density, O_2, O, total	<10%	Meets; O_2 A band, Hays, 1988
• Vector Wind	Several hrs LT	Meets; Orbit precession
• Δt Resolution/Profile	1.5 Minutes	Meets; see Operating mode

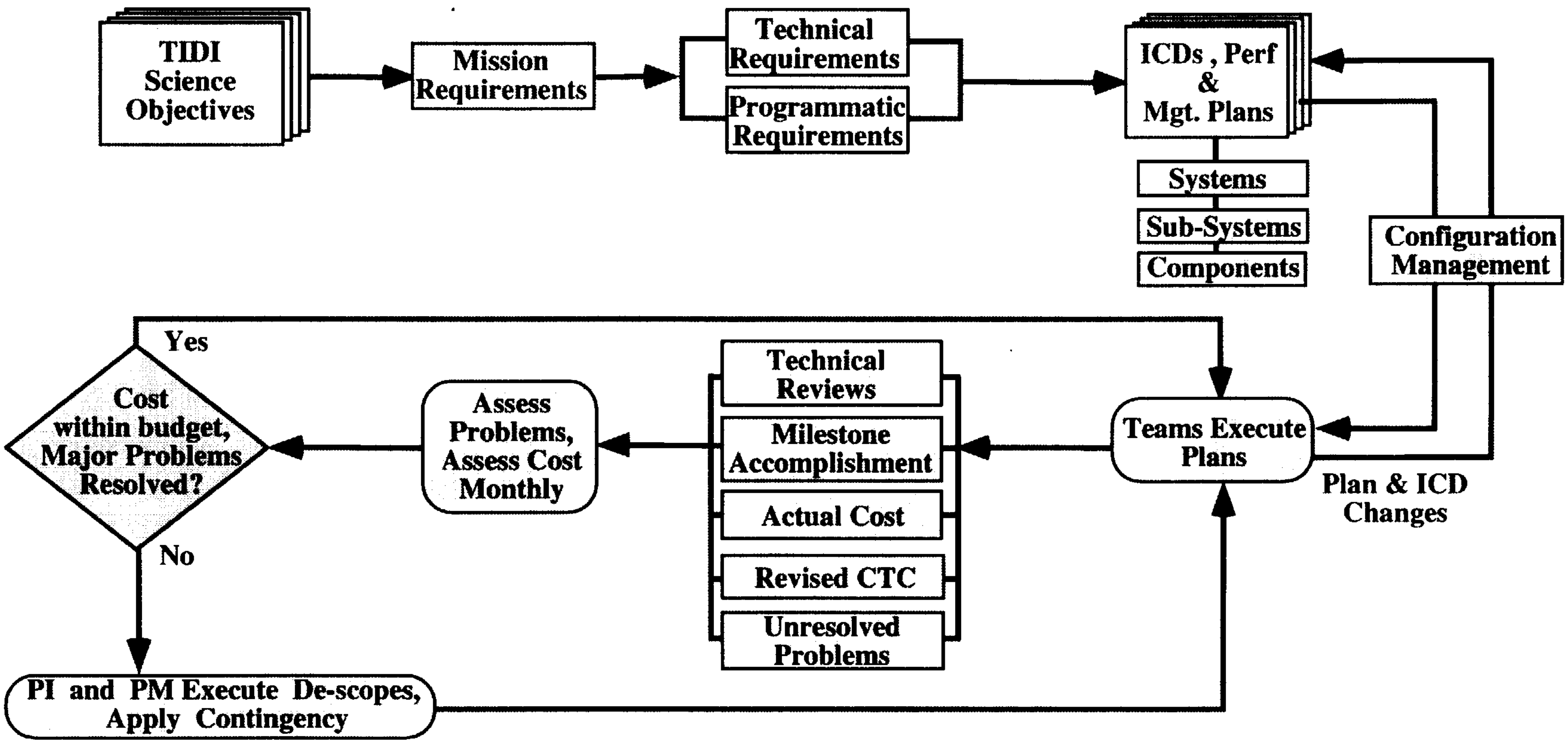
NOTES:

Imager Performance

• Lifetime	2 years	Meets; Radiation, Lubrication, FO
Star Sensing		
• Knowledge, R,P, & Y	0.03°, 3σ	Meets; Design, Signal, Geometry
• Spectral region	550 - 900 nm	Meets; Coatings, Filters, Detectors
• Look Directions	±45° & ±135°	Meets; 4 Telescopes
• Horizontal FOV	2.5°	Meets; Design
• Vertical FOV	2.5°	Meets; Design
• Sample time	1 Second	Meets; Design
Wave Sensing		
• Temperature accuracy	2 °K	Meets; Kinetic/rotational O_2
• Minimum sample time	3 Sec	Meets; Design
• Along line of sight	40 Km	Meets; Geometry
• Vertical resolution	3 Km	Meets; Less than stars

NOTES:

TIDI — The Design Process



- Well defined (frozen/capped) instrument requirements cannot grow
- Involvement ensures team committment
- Clear lines of responsibility, authority, accountability
- Frequent communications among teams & with Program Office

NOTES:

Make or Buy?

GUIDELINES -> Expertise -> Quality -> Schedule -> Cost

- **Electronics:**

Design	In house, consultants. PCB Layout
EEE Parts	Buy From Qualified Suppliers
PC Boards	Buy From Qualified Suppliers
Transformers & Inductors	In house
Harnesses, GSE & Flight	In house
Mechanisms	Buy From Qualified Suppliers
Electronics Assembly	In house, except for schedule

- **Optical:**

Design, conceptual,	In house
Design, detailed	In house, consultants
Fabrication	Buy From Qualified Suppliers
Assembly	In house, Buy From Qualified Suppliers

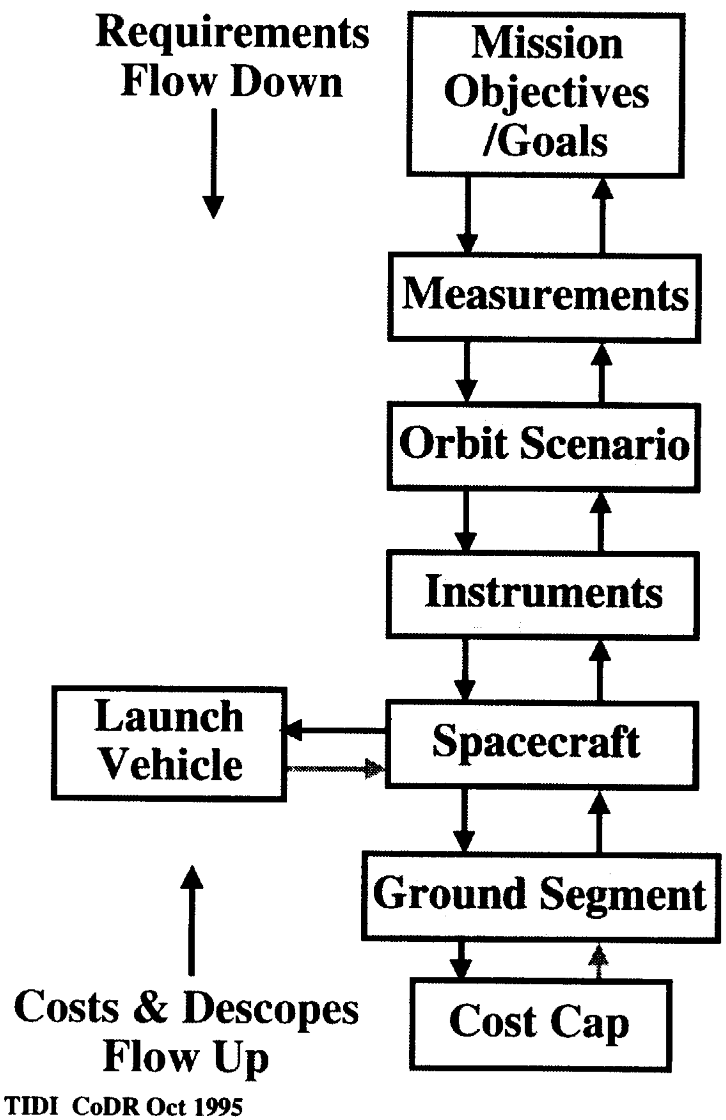
- **Mechanical/Thermal:**

Design	In house Occasional consultant
Fabrication	Both, schedule
Assembly	In House

NOTES:

TIDI

Requirements Flow Down



For Example,

- 3 M/S Line of Sight Winds
  - Error table e.g
- Detector statistics, 0.5 m/s
- Etendue of 1 x $10^{-3} cm^2$ sr
  Optical transmission, 0.1
  QE, 60%
  Finesse, 10
  FSR, 7,500 m/s
  Detector background < 0.01 e/bin/sec
  Detector read noise, < 10 e
- $O(^1S)$ 2 557.7 nm,
  Integration time, 2 seconds

NOTES:

TIDI

Requirements Flowdown to Telescope 1

Driving Requirements	Req./Sys Spec.	Description
Atmospheric Region 60 - 300 km, SC altitude - 600 km, $\pm.5^\circ$ placement, earth's oblateness	Sys Spec	Telescope vertical angular scan range 16° to 23° depression angle
Spectral response, 550 to 900 nm	Sys Spec	Optimize optical coatings and FO optic materials
Vertical resolution, 2.5 km	Sys Spec	0.05° vertical FOV, 0.05° steps
Horizontal resolution, 100 km, match etendue	Sys Spec	Horizontal FOV, 2.5°
With 0.05° x 2.5° angular FOV. match etendue	Sys Spec	Aperture diameter, 7.5 cm
Minimize background contribution due to earth scattered light	Sys Spec	Off axis Gregorian optical configuration, with low scatter primary, 20Å rms, Lyot stop
Solar light contamination to less than 10 R/Å at 15°, $\theta_{1/2}$	Sys Spec	Baffle L/D -> $\theta_{1/2} = 15^\circ$
Optimize the measurement of Tides	Sys Spec	Look directions in azimuth, $\pm45^\circ$ & $\pm135^\circ$

NOTES:

TIDI

Requirements Flowdown to Telescope 2

Driving Requirements	Req./Sys Spec.	Description
Keep scattering from SC surfaces to < 10 R/Å	Sys Spec	Avoidance Cone, $\theta_{1/2} > 17.5^\circ$
From 3 m/s, maintain pointing to 0.005°	Sys Spec	Step & settle to 0.005°, utilize all aluminum thermal matching design
Provide adequate FOV for star sensing	Sys Spec	2.5° x 2.5° FOV for imager
Scramble profiler image maximally with minimal transmission loss	Sys Spec	Optimize FO size ~ 50 u
Maximize operating temperature for ease of thermal design	Sys Spec	Actuator operating temp -20 to +50°C Telescope operating temp -20 to +80°K
Maximize survival temperature for ease of thermal design	Sys Spec	Actuator, -40 to +50°K Telescope, - 40 to +80°K

NOTES:

TIDI

Requirements Flowdown to Profiler

Driving Requirements	Req./Sys Spec.	Description
Cosmic ray cross section, readout speed, CTE, thermal load	Sys Spec	Detector - CCD, 128 x 128 pixels
Dark current, radiation effects, CTE	Sys Spec	Detector Temp - 200°K Detector Radiator Area - 25 x 25 cm
Geophysical lines, physical size constraints	Sys Spec	# of filters, transmission characteristics
Control filter wavelength drift	Sys Spec	Operating Temp (+20±5°C)
Mission requirement	Req	Survival Temp -40 to +60°C
S/N, temporal resolution	Sys Spec	HRE size
Peak always on detector, always determine background	Sys Spec	Maintain 1.1 orders min on CCD for all wavelengths
Profiler temp range	Sys Spec	LRE post tuning range, 8,000Å min

NOTES:

Requirements Flowdown to Imager

Driving Requirements	Req./Sys Spec.	Description
Determine telescope misalignment to 0.01°	Sys Spec.	Detector - CCD, Size 256 x 1024 pixels, star image update rate
Dark Current, Radiation Effects, CTE	Sys Spec.	Detector Radiator Area - 10 x 10 cm Detector Temp 238°K
Ancillary science requirements, Filter Wavelength Drift	Sys Spec.	Operating Temp (+20±5°C)
Mission Requirement	Req	Survival Temp -40 to +60°C

NOTES:

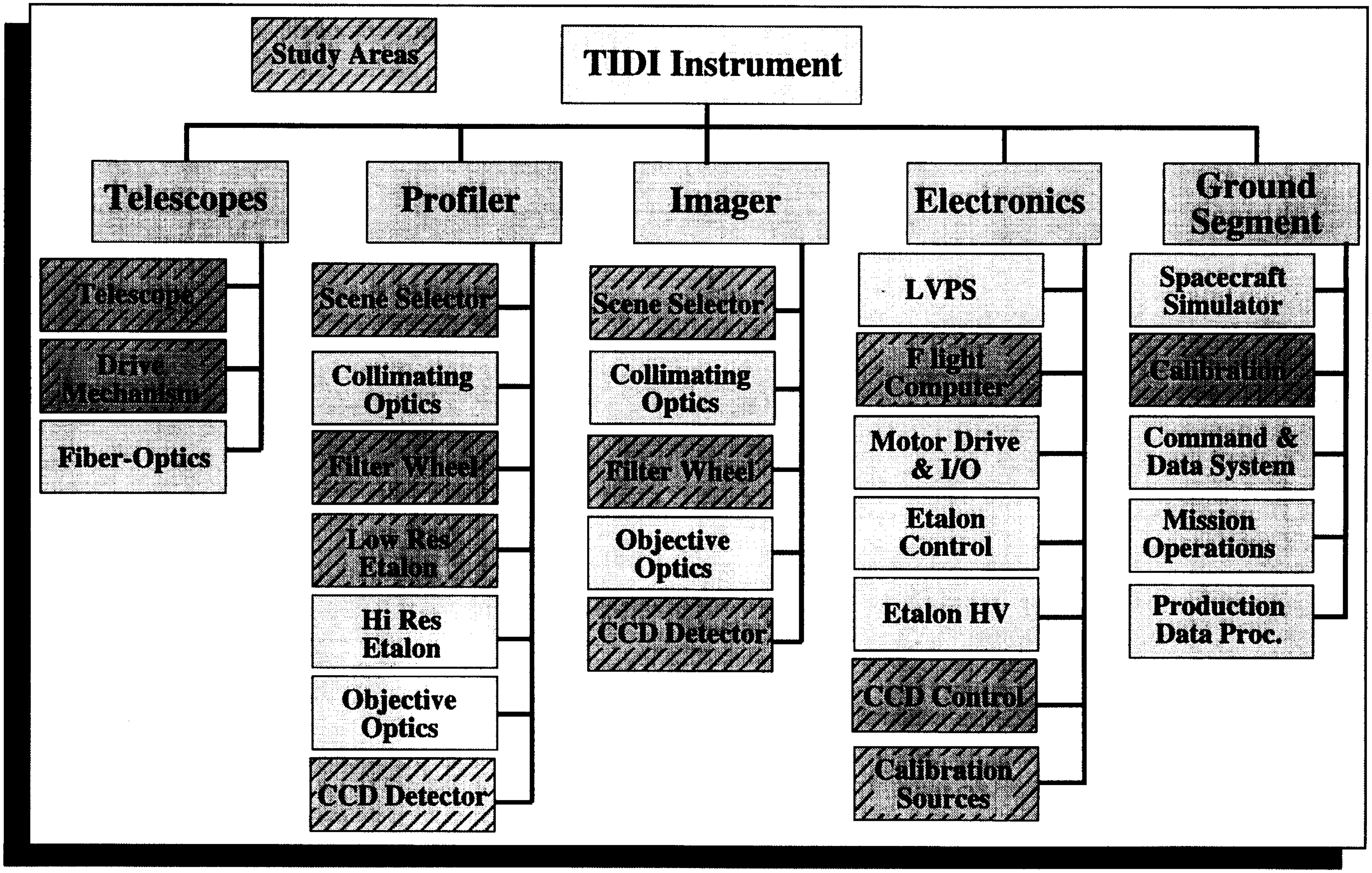
Requirements Flowdown to Calibration

Driving Requirements	Req./Sys Spec.	Description
Generate Vector Winds	Req	Placement, R, P, Y, 3σ (Inst+S/C) - 1° Orbit Height along trk, cross trk ±1, ±1, ±1 km
Wind Accuracy of 3 m/sec (1 m/sec goal)	Req	Knowledge, R, P, Y, 3σ (Inst+S/C) - 0.03° Jitter - 0.03°/0.25sec Stability - 0.03°°/~10sec
Star Alignment	Req	Absolute Time, UTC - 1 sec ±2.5 msec

NOTES:

TIDI

Subsystem Breakdown



NOTES:

Risk Reduction Trade Studies Review

	Baseline	ΔKg	ΔW	ΔKbps
1. Michelson to CCD Imager	Yes	-2.5	0	-0.5
2. Dual Imager	Yes	0.1	0	0
3. Residual Circulation, 1 m/s	Future	0	0	0
4. Calibration Lamp Spectral Lines	Yes	0	0	0
5. Telescopes 2 to 4	Yes	7.2	0.12	0
6. Telescopes Scan Method	Yes	-4.0	0	0
7. Telescope Drive	Yes	0.5	0	0
8. Telescope Thermal	Yes	0.1	0	0
9. Filter Wheel, One to Two	Yes	0.46	0.78	0
10. Scene Selector, Simpler	Yes	-.2	-0.1	0
11. Low Resolution Etalon, Posts	Yes	0.2	0	0
12. Sensor Thermal	Future	0	0	0
13. Profiler Detetor	Yes	0	0	0
14. Imager Detector	Yes	0	0	0
15. Detector Thermal	Yes	0.5	0.5	0
16. Flight Computer	Yes	0	2.8	0
17. Profiler # of Ch's Transmitted	Yes	0	0	0.45

NOTES:

1. Michelson to Star/Wave Imager

- Proposed Concept: Canadian Michelson Interferometer for waves and star sensing
- Current Design: Filtered CCD Imager
- Trade-offs: +Reduced complexity; +Reduced mass;
  -Loss of science (retains as much science as possible);
  -Increased cost (Michelson was no-cost item)
- Resource Changes: +Reduced mass (2.5 kg) , +reduced TM
  -500 bps

NOTES:

TIDI

2. Dual Filter Imager

- Current Baseline:Simple, Filtered CCD
- Potential Change: Dual λ Imager Filters
- Trade-offs:+improved science (atmospheric temperature); +cosmic ray discrimination;- added cost for prism and filters
- Resource Changes: Small mass increase

NOTES:

TIDI 3. 1 m/s Meridional Global Circulation

- Proposed Concept: 1 m/s line of sight accuracy to determine Differential Meridional Global Circulation

- Current Design: 3 m/s requirement

- Trade-offs: +Improved science; -probable need for nadir looking zero wind determination, -better boresight knowledge, -better stability

- Resource Changes: Ability to do nadir view, 0.01° knowledge SC and Imager,

NOTES:

TIDI

4. Calibration Lamps

- **Proposed Concept: Use of DE/HRDI style calibration lamps (neon, HAK) with selection of nearest line to actual measurement**
- **Current Design: Use custom spectral lamps which provide the actual spectral lines used for geophysical measurements**
- **Trade-offs: +Reduces zero wind line position error**
- **Resource Changes: None**

NOTES:

TIDI

5. Telescope, Two to Four

- Proposed Concept: 2-telescopes, located +45° and +135°
- Current Design: 4-telescopes ±45° and ±135°
- Trade-offs: +Improved geographic coverage, +Tides;
  -Increased cost; -Increased mass; -Increased number of fiber-optic cables
- Resource Changes: Increased mass (7.2 kg); Increased S/C CFOV requirement

NOTES:

6. Telescope, Articulated

- Proposed Concept: Telescopes with internal scan mirrors, large baffle acceptance angles
- Current Design: 1 -axis, externally articulated telescopes
- Trade-offs: +Improved white light scattering; +simplified telescope design; +reduced cost (off-the-shelf), +reduced mass; -larger moment of inertia
- Resource Changes: Reduced CFOV requirement; S/C must accommodate telescope motion envelope, reduced mass, 4 Kg

NOTES:

7. Telescope Drive

- Proposed Concept: Schaeffer Type-1 motor for scanning control
- Current Design: Schaeffer Type-2 motor for scanning control
- Trade-offs: Type 1 through hole is too small for fiber optic
- Resource Changes: Increased mass, 0.5 Kg

NOTES:

8. Telescope thermal design

- Proposed Concept: Thermally decouple telescope from scan actuator, conductively couple to spacecraft
- Current Design:HRDI design with telescope nominally coupled to actuator
- Trade-offs: +Prevents overheating when near a terminator orbit; -slight mass increase, - 2 x 6 thermal watts coupled to spacecraft
- Resource Changes: Increased mass (.1kg)

NOTES:

9. Filter Wheel, One to Two

- Proposed Concept: One filter wheel for Profiler and Imager
- Current Design: Individual, identical filter wheels loaded w/ optimized filters for Star Imager and Profiler
- Trade-offs: +Simplifies packaging design,+Enables optimized science; -Increases mass; -Adds a mechanism
- Resource Changes: Increased mass (.29kg)

NOTES:

10. Scene Selector, Simpler

- Proposed Concept: Dual moter, dual scene selectors for Profiler and Imager based on HRDI design
- Current Design: Single motor scene selectors
- Trade-offs: +Reduces number of mechanisms,+reduces mass, +reduces cost
- Resource Changes: Less mass, 0.2 kg

NOTES:

TIDI

11. Low Resolution Etalon, Size

- Proposed Concept: 5 cm diameter, new post design
- Current Design: 7 cm diameter, HRDI post design
- Trade-offs: +Less cost, +Proven performance
- Resource Changes: Increased mass, 0.2 Kg

NOTES:

TIDI

12. Sensor Thermal Design

- Proposed Concept:Entirely passive, SC thermal control is adequate
- Current Design: Instrument assumes thermal design, electronics and sensor are combined with HRDI style approach
- Trade-offs: +Simpler SC interface +Proven proven performance + less SC cost; -more cost at instrument
- Resource Changes: Instrument mass increase offset by SC mass decrease

NOTES:

TIDI

13. Profiler Detector

- **Proposed Concept: SiTE (Tektronix) TK-1024 CCD for Profiler**
- **Current Design: Loral 1024 x 1024 for Profiler**
- **Trade-offs:+Loral provides needed frame transfer speed**
- **Resource Changes: None**

NOTES:

14. Imager Detector

- **Proposed Concept: SiTE (Tektronix) TK-1024 CCD for Imager**
- **Current Design: Loral 1024 x 1024 for Imager**
- **Trade-offs:+Loral provides needed frame transfer speed**
- **Resource Changes: None**

NOTES:

15. Detector Thermal

- Proposed Concept: Thermo Electric Cooler and simple anti - sun radiator
- Current Design: Same
- Trade-offs: +Still simplest approach
- Resource Changes: Refined design changes power and radiator size, - 0.5 W, +0.5 Kg

NOTES:

16. Flight Computer

- Proposed Concept: 80C86-based SPRL-designed microprocessor (TOMS)
- Current Design: Lockheed 95 RH processor board (8.3MIPS)
- Trade-offs: +Provides adequate speed+Reduced cost; +Reduced risk; +Higher performance margin; -Increased power
- Resource Changes: Increased power (2.8 w)

NOTES:

TIDI

17. Profiler Number of Transmitted Channels

- Proposed Concept: Telemeter Profiler data at 16 channels at 16 bits each
- Current Design: Telemeter 30 channels at 12 bits each
- Trade-offs: Improves ability to detect and correct for second order changes in FPI response
- Resource Changes: None, 416 bps Profiler increased more than compensated by Imager decrease

NOTES:

On Orbit Radiation

- Special Cases will be Described in the Appropriate Sections
  All Aspects of TIDI Designs are Examined for the Following:
- Cosmic Ray inputs - we have an Analysis above the Magnetosphere, we need this for our Orbit of Particular Interest in CCD's and Single Event Effects
- Total Dose - Need Total Dose in Rads, Currently 5,000 for Electronic Part and Optical Component Selection
- Proton Dose - Need for CCD Charge Transfer Efficiency Calculations and Device Testing
- Electron Dose - Need for Shielding Calculations

NOTES:

Systems, Future Activities

- CTE Design for CCD's - use Consultant for Cross Check
- Thermal Design - work with SPRL & APL
- Parameter Summary Table - Continue to Review & Update
- Interface Control Document - Interface with APL in Preparation
- Instrument Operations - Interface with Scientists, Engineers, & APL
- Budget - Participate in Budget Refinement and Review
- Schedule - Participate in Schedule Refinement and Review

NOTES:

Measurement Error Sources

Calibration

David A. Gell

TIDI

Line of Sight Wind Determination

$$v_m = v_{los} + v_0(\nu, \phi) + \alpha(T - T_0) + f(t) + v_s \cos\varepsilon \cos\phi + \frac{2\pi R_E}{T_e} \sin\psi \cos\theta$$

- **Line of Sight (LOS) Wind is determined by accounting for shifts in the measured line position due to**
  - **Temperature**
  - **Long Term Drifts**
  - **Spacecraft Velocity Component**
  - **Earth's Rotation**
- **With accurate knowledge of the zero wind position, the LOS wind may be determined**

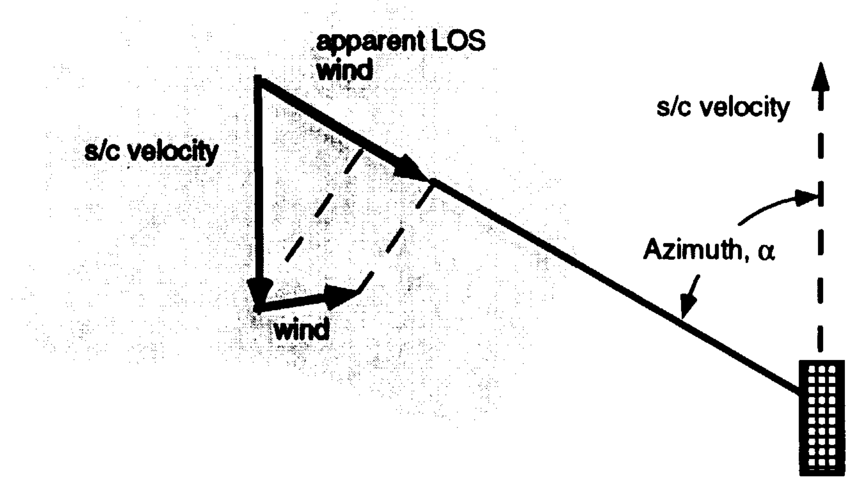
notes:

The line of sight (LOS) wind is determined by measuring the position of a spectral feature on the detector. The spectral feature is shifted from its rest position due to Doppler shifts and instrumental shifts. The Doppler shifts are due to the wind, the spacecraft velocity, and the earth's rotation. The instrumental shifts are due to temperature and long term changes in the instrument.

Calibration and accurate knowledge of the spacecraft attitude and velocity permit all of the Doppler shifts and instrument shifts to be accounted for. The difference between the corrected line position and the zero wind position is the Doppler shift due to the winds. The zero wind line position must be accurately measured to obtain an accurate wind.

Alignment Error Effects

- Pointing uncertainty affect wind accuracy and tangent point location accuracy.
- The alignment between the telescopes and the spacecraft attitude system will be measured prior to launch.
- After launch, the alignment can change so it is measured in flight.
- Measurement frequency depends on stability of spacecraft structure:
  The more rapidly the structure can deform due to thermal changes, the more often the measurement is required.



notes:

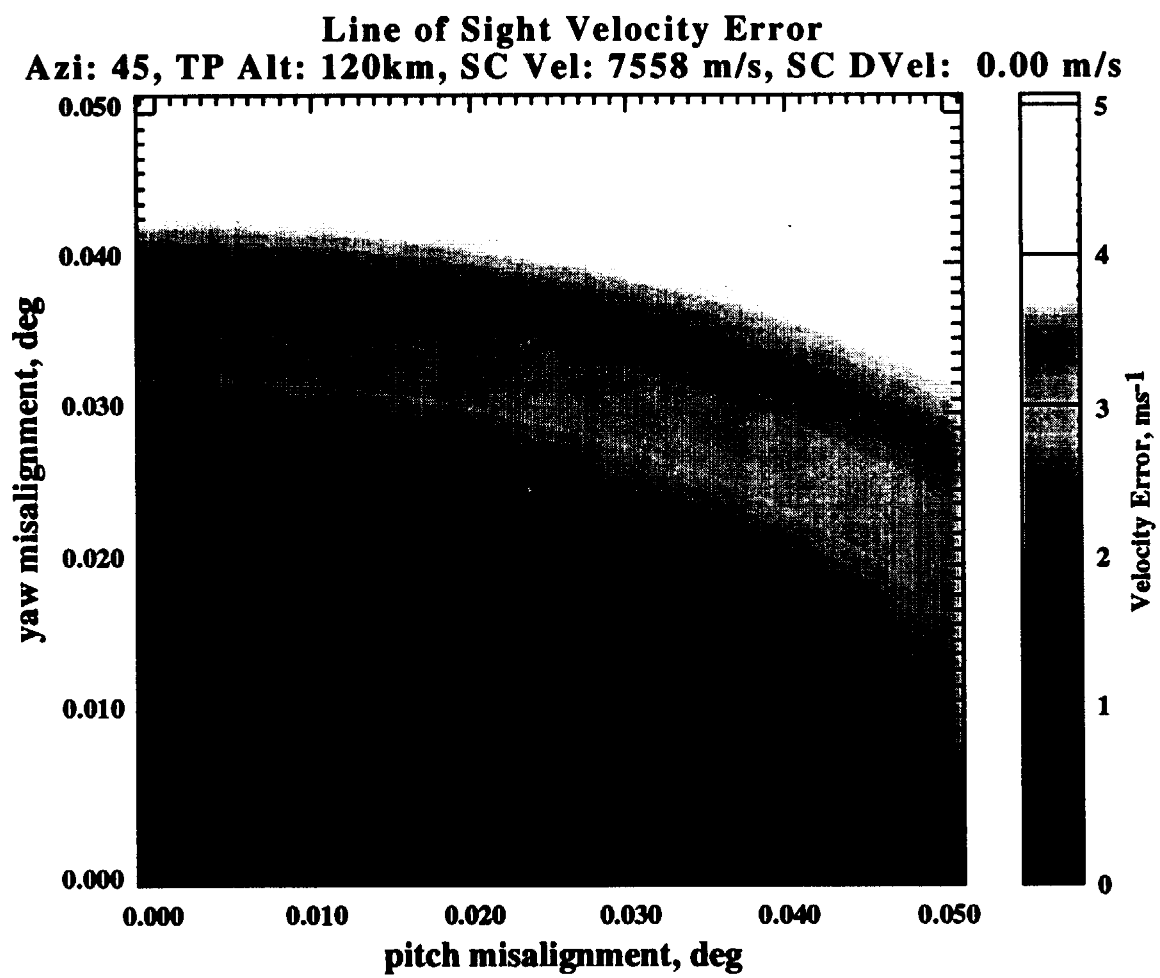
The apparent line of sight wind is the sum of the components of the spacecraft velocity and the wind along the line of sight as illustrated in the accompanying figure. In order to determine the geophysical wind, the spacecraft velocity component must be accounted for.

The determination of the spacecraft velocity component along the instrument line of sight requires accurate knowledge of both the spacecraft velocity and of the instrument boresight directions. The spacecraft velocity component along the line of sight is the vector dot product of the velocity vector and a unit vector in the line of sight direction. An error in either the direction of the velocity or the direction of the boresight results in an error in the spacecraft velocity component along the instrument line of sight.

To control this error, the telescope alignment will be measured before and during flight. The inflight measurement will be described in a subsequent chart.

TIDI

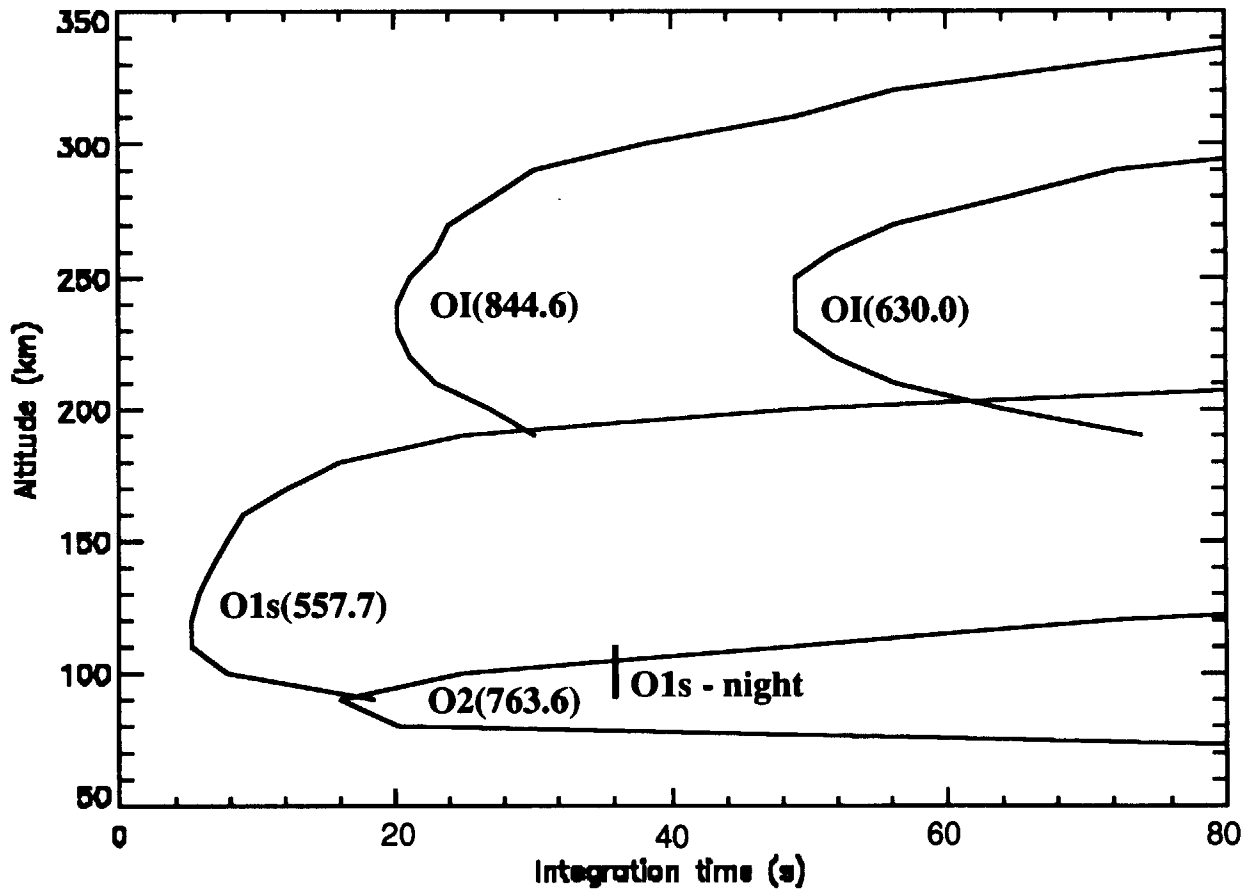
Wind Uncertainty Estimate



notes:

Detector Statistics

- Integration period for 0.5 ms^{-1} accuracy
- 10 electron read noise
- Negligible dark counts



notes:

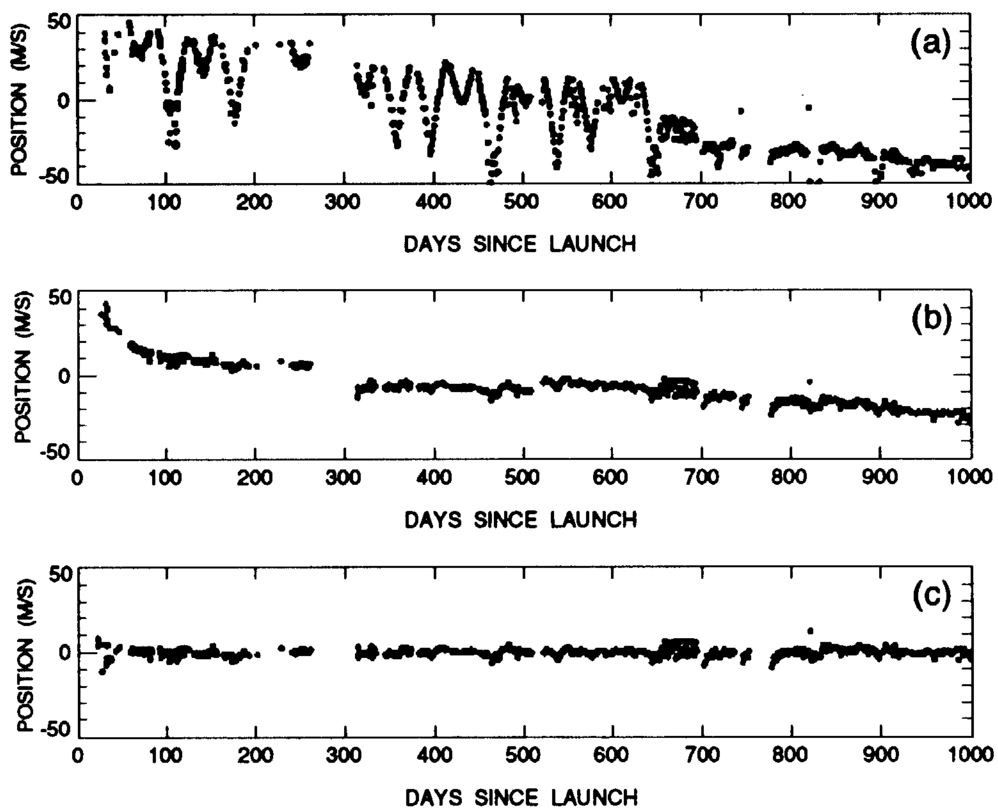
A major component of the error budget is the statistical errors resulting from the photon counting operation of the detector. The accompanying chart illustrates the integration time required to obtain the budgeted detector error. The chart was prepared under the assumptions that the CCD is cooled sufficiently to make the dark counts negligible and that the CCD read noise is $10e^{-}$ RMS.

The chart shows that for the $O(^1s)$ emission at 557 nm, an integration period of 10 seconds provides better than 0.5 ms^{-1} detector errors.

TIDI Long Term Drift

HRDI Calibration Line Location

693 nm (14427 cm^{-1})



As Measured

Temperature Correction Applied

Corrected for Drift 1.7 ms^{-1} 1σ

notes:

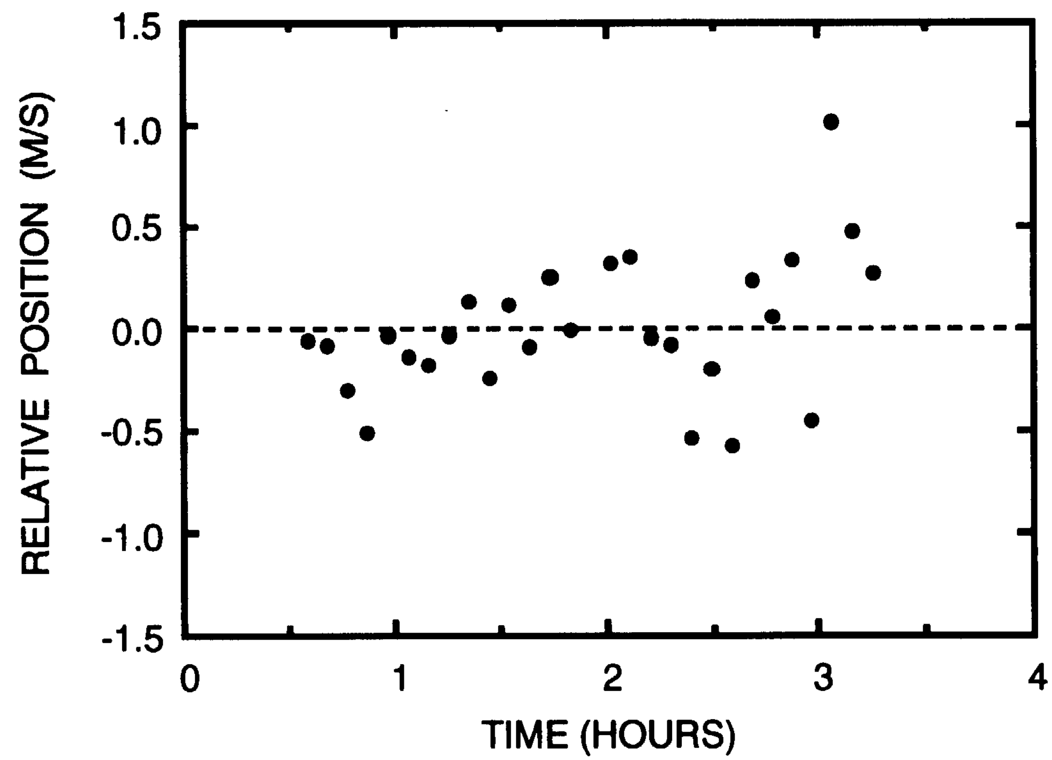
The accompanying figure shows HRDI in-flight calibration data. The upper panel is a history of the measured position of the 14427 cm^{-1} (693 nm) neon calibration lamp line. In this figure, both long term trends and thermal trends are evident. The change in the character of the data at approximately day 650 is the result of a change in the way the thermal control subsystem was operated.

The middle panel shows the line position corrected for thermal effects. This data was used to determine the long term drift f(t) in the line of sight wind equation shown on the first chart. With the long term drift effect removed, the lower panel shows that the line position is know to better than 2 meters per second, sufficient for the HRDI goal of 5 meters per second.

Short Term Stability

- **Position of calibration line measured repeatedly over 2 orbits**
- **Stability (1-σ): 0.1 ms^{-1}**

HRDI Calibration Line Position
693 nm (14427 cm^{-1})



notes:

The accompanying figure displays the result of a measurement of the short term stability of the HRDI instrument made in flight. In this measurement, HRDI was repeated tuned to a calibration line. The line position while tuned was measured. The procedure was continued for approximately two orbits, during which the instrument temperature varied by 0.1°K.

The results demonstrate that over orbital periods HRDI was stable to approximately 0.1 ms^{-1}.

Zero Wind Line Position

- The measured line position is a function of the line of sight wind and additional terms:

$$v_m = v_{los} + v_0(\nu,\phi) + \alpha(T - T_0) + f(t) + v_s \cos\varepsilon \cos\phi + \frac{2\pi R_E}{T_e} \sin\psi \cos\theta$$

- Spectral lamps provide measurement of drift terms f(t) and $a(T-T_0)$
- Zero wind line position , v_0, is obtained
  - Application of geophysical constraints (~10 ms^{-1})
  - Correlative measurements
  - Spectral Lamps
  - Nighttime nadir viewing

notes:

It is important to be able to make an accurate estimate of the zero wind line position. One way to measure this parameter is to have a calibration lamp that emits the spectral line used in the geophysical measurement. A line at a different wavenumber could, in principle, be used, however the accuracy of the determination of the position of the geophysical line is limited by the accuracy with which the etalon gap is known.

Use of a lamp line is also limited by how well the lamp illuminates the etalon. If the illumination of the etalon by the lamp is different than that of the sky viewed through the telescope, the measured line shapes will be different. Any inconsistency in the line shape between the sky and the lamp results in an error in the line position measured by the lamp.

The zero position can be determined in a number of different ways, which will be fully discussed as part of the calibration plan. Our experience with HRDI indicates that a zero wind location accuracy of approximately 2 ms^{-1} can be achieved by means of correlative measurements. Improvements to this will be discussed in the calibration section.

Baseline Error Budget

error source	error magnitude 1σ		equivalent wind error ms
Spacecraft Velocity Knowledge, one axis	0.06	ms^{-1}	0.10
Spacecraft Attitude Knowledge			
Roll	0.01	deg	neg
Pitch	0.01	deg	0.86
Yaw	0.01	deg	0.93
Telescope Misalignment			
Roll	0.01	deg	neg
Pitch	0.01	deg	0.86
Yaw	0.01	deg	0.93
Gimbal Precision	0.003	deg	0.26
Instrument Knowledge			
Long Term Drift	0.4	ms^{-1}	0.40
Temperature Drift	0.5	ms^{-1}	0.50
Short Term Stability	0.4	ms^{-1}	0.40
Zero Wind Line Position	2.0	ms^{-1}	2.00
Detector Statistics	0.5	ms^{-1}	0.50
Root-Sum-Square			2.85

notes:

The errors that effect the determination of the line of sight wind may be divided in geometric errors, zero wind position errors, and detector errors.

The geometric errors are errors in determining the magnitude of the spacecraft velocity component in the line of sight. These errors are errors in knowledge of the spacecraft velocity, the spacecraft attitude, and the alignment of the instrument bore-sight with the spacecraft attitude reference.

The error in the zero wind position is the error in the determination of the location of the line on the detector in the absence of any Doppler shift.

The detector errors are the result of the counting statistics. This error may be reduced by increasing the integration period and by reducing background and read noise.

The accompanying chart provides an error budget which results in a line of sight error meeting our goal of a 3 ms^{-1} line of sight error. Note that the major error components are the geometric errors and the zero wind line position error.

Data Retrieval Error Sources

- inversion
  - noise amplification
  - constraint applications
  - forward model limitations
- other considerations
  - scattered light
  - atmospheric non-homogeneity
  - field of view

notes:

Obtaining the line of sight Doppler shift is just the first step in determining a wind profile. The wind profile is obtained by inverting the integral equation that relates the altitude profile of the wind to the observed line of sight Doppler Shifts:

$$v_i = \int_0^{\infty} W_i(z)P(z)dz + \varepsilon_i$$

where v_i is the line of sight wind at the i^{th} tangent point, ε_i is the measurement error, W_i is the weighting function that expresses how the atmospheric profile P(z) contributes to the line of sight measurement.

Inverting this equation has the effect of amplifying the measurement noise. To control this effect, the inversion must be constrained. These constraints may have the effect of masking geophysical signals of interest. Selecting appropriate constraints requires a compromise between the physical problem being studied and the noise amplification that is acceptable.

In addition to the effects of noise and constraints, the inversion accuracy is affected by the forward model used to obtain the waiting functions W_i.

Other considerations include the effect of light scattered into the field of view from other points in the atmosphere. This has the effect of broadening the weighting functions. In addition the horizontal width of the field of view results in a variation of the spacecraft velocity correction across the field of view. Both of these effects can be reduced by careful analysis and data retrieval.

A final consideration in the data retrieval process is the effects of atmospheric non-homogeneity. Inversion methods assume that the atmosphere is spherically symmetric, the properties of the atmosphere are only a function of altitude. In the presence of waves, for example, this assumption may not hold and the interpretation of the inversion results must consider this.

Attaining 1 ms^{-1} Accuracy

- Major error sources are
  - pointing knowledge
  - zero wind line position knowledge
- 1 ms^{-1} accuracy can be obtained by
  - improving the pointing knowledge from 0.01 to 0.003 degrees (1-σ)
  - improving the zero wind line position from 2.0 to 0.5 ms^{-1}
- Both improvements are achievable

notes:

The science return provided by TIDI could be enhanced by improving the wind determination accuracy. For example, one area of current research activity pertains to the residual mean meridional flow. Improving the TIDI wind recovery accuracy permits estimates of this field.

Recall that the major sources of error in the line of sight budget are the uncertainties in the boresight pointing and in the zero wind position. A sufficient improvement in the pointing direction knowledge accuracy and in the zero wind position knowledge results in attaining 1 ms^{-1} line of sight wind accuracy.

To obtain 1 ms^{-1} accuracy, the pointing knowledge must be improved by improving both the spacecraft attitude knowledge and the telescope alignment knowledge from 0.01° to 0.003°.

In addition to the pointing knowledge improvement, the zero wind line position knowledge must be improved from 2.0 ms^{-1} to 0.5 ms^{-1} which we believe is achievable through the use of appropriate calibration lamps and nadir viewing observations of the night airglow layers. These calibrations will be more completely described in a subsequent section.

Improved Error Budget

error source	error magnitude 1σ	equivalent wind error ms
Spacecraft Velocity Knowledge, one axis	0.06 ms^{-1}	0.10
Spacecraft Attitude Knowledge		
Roll	0.003 deg	neg
Pitch	0.003 deg	0.26
Yaw	0.003 deg	0.28
Telescope Misalignment		
Roll	0.003 deg	neg
Pitch	0.003 deg	0.26
Yaw	0.003 deg	0.28
Gimbal Precision	0.003 deg	0.26
Instrument Knowledge		
Long Term Drift	0.2 ms^{-1}	0.20
Temperature Drift	0.2 ms^{-1}	0.20
Short Term Stability	0.2 ms^{-1}	0.20
Zero Wind Line Position	0.5 ms^{-1}	0.50
Detector Statistics	0.5 ms^{-1}	0.50
Root-Sum-Square		1.00

notes:

Calibration Plan

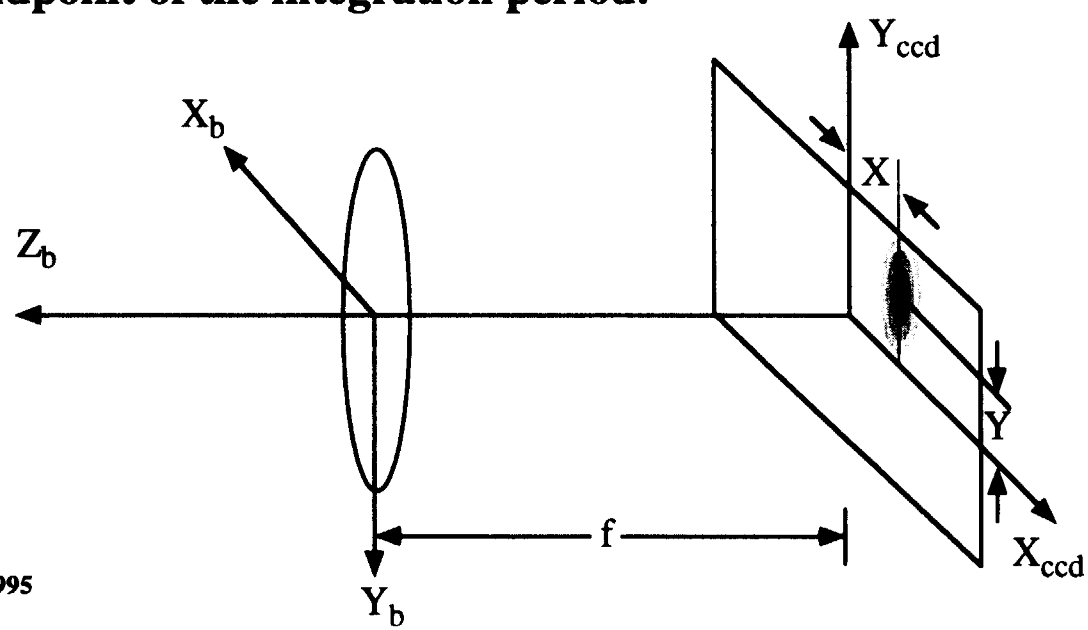
$$v_m = v_{los} + v_0(\nu,\phi) + \alpha(T - T_0) + f(t) + v_s \cos\varepsilon \cos\phi + \frac{2\pi R_E}{T_e} \sin\psi \cos\theta$$

- **Preflight**
  - **Measure instrument function**
    - » **model instrument and measure parameters**
    - » **measure instrument function directly**
  - **Characterize CCD**
  - **Radiometric calibration**
  - **Alignment measurement**
  - **Instrument flat fielding**
- **In-flight**
  - **Verify instrument model parameters, spectral lamp source**
  - **Monitor radiometric calibration, incandescent lamp source**
  - **Measure telescope alignment, stellar source**
- **Determine Zero Wind Position**

notes:

Alignment Measurement

- **The position of an identified star in the boresight is measured as a function of time.**
- **The star image is intentionally blurred over 3 fibers.**
- **In a one second integration the image moves another 3 fibers.**
- **The centroid of the image gives the position of the star at the midpoint of the integration period.**



notes:

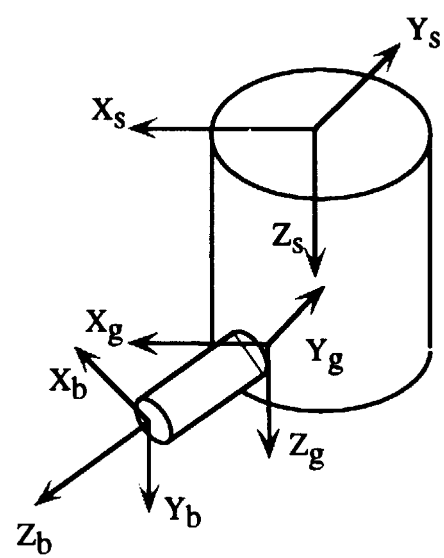
Alignment Analysis

- Consider four coordinate frames:
  - The inertial frame (ECI)
  - The spacecraft frame (s)
  - The telescope gimbal frame (g)
  - The telescope boresight frame (b)
- Instrument pointing is given by

$$\hat{s}^{(eci)} = T_{\frac{eci}{s}}(t) T_{\frac{s}{g}} T_{\frac{g}{b}}(\alpha, \varepsilon) \hat{s}(t)^{(b)}$$

- Goal is to determine the misalignment matrix

$$T_{\frac{s}{g}} = \begin{bmatrix} 1 & \theta_{yaw} & -\theta_{pitch} \\ -\theta_{yaw} & 1 & \theta_{roll} \\ \theta_{pitch} & -\theta_{roll} & 1 \end{bmatrix}$$



- The measurement is the star position s_b at time t.
  - Every term in the instrument pointing equation is known at the time of the measurement except the misalignment, $T_{s/g}$.
  - The pointing equation is solved by a sequential estimator, accounting for measurement and state errors

notes:

Alignment Accuracy

- Measurement is
  - position of star image
  - time of image
  - attitude of spacecraft in ECI
- Measurement error contributions include
  - signal level

    ~100 cs^{-1} M_v=4, T=5000°K using 6500Å cut on filter
  - image size, pixel size
  - time base
  - cosmic ray discrimination
- Star Position in boresight frame
  - fiber size, 0.025 degree
  - centroiding can improve to 0.003 degree

notes:

TIDI Zero Wind Line Position

- **The measured line position is a function of the line of sight wind and additional terms:**

$$v_m = v_{los} + v_0(\nu,\phi) + \alpha(T - T_0) + f(t) + v_s \cos\varepsilon \cos\phi + \frac{2\pi R_E}{T_e} \sin\psi \cos\theta$$

- **Spectral lamps provide measurement of drift terms f(t) and a(T-T_0)**
- **Zero wind line position , v_0, is obtained**
  - **Application of geophysical constraints (~10 ms^{-1})**
  - **Correlative measurements**
  - **Spectral Lamps**
  - **Nighttime nadir viewing**

notes:

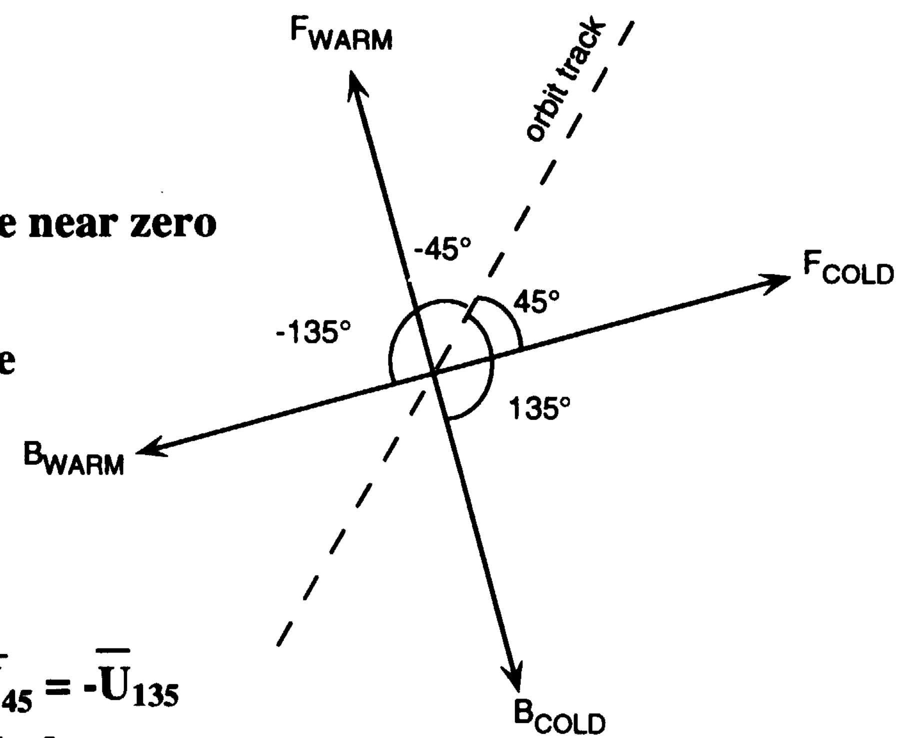
TIDI Geophysical Constraints to the Zero Position

- Assumptions
  - global mean winds sampled at a specific local time vary slowly
  - long term mean meridional winds are near zero
- Method
  - View towards the warm and cold side

    $F_{warm} = U_{-45} - v_{F0}$

    $B_{cold} = U_{135} - v_{B0}$
  - Separately average warm side and cold side data

    $\overline{F_{warm}} + \overline{B_{cold}} = -(v_{F0} + v_{B0})$, since $\overline{U_{45}} = -\overline{U_{135}}$
  - Use of long term mean meridional winds permits separating individual zero positions, v_{F0}, v_{B0}
- Yields zeros to ~10 ms^{-1}

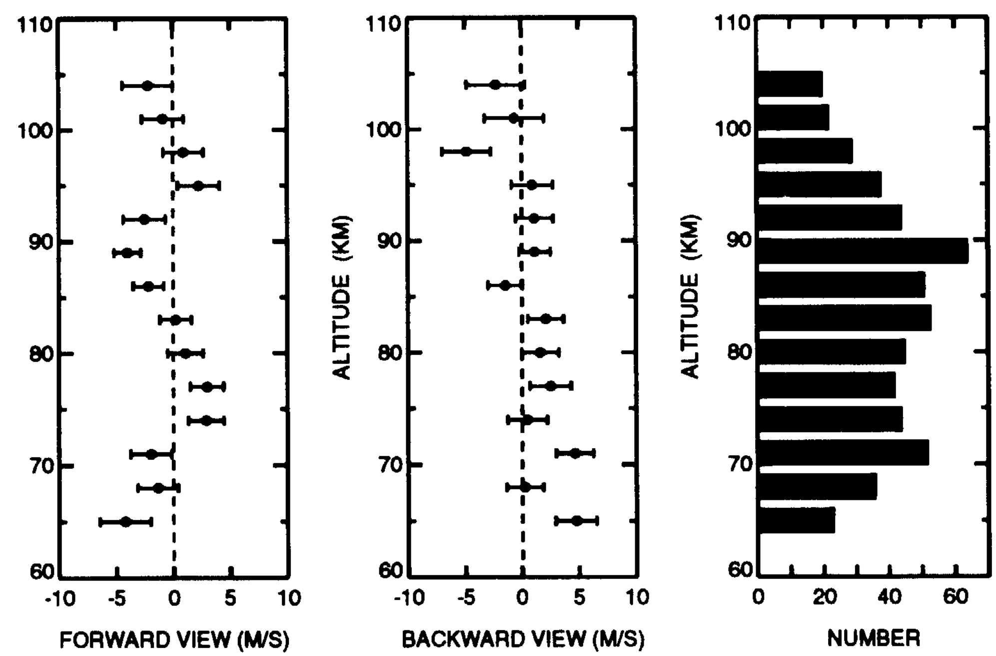


notes:

TIDI

Correlative Measurements for the Zero Position

- **Comparison of HRDI winds to MF Radar winds at Urbana, Il**
- **The figure shows the average differences between HRDI and the radar winds at each coincidence.**
- **The zero wind line location is adjusted to minimize the average difference**



notes:

TIDI

Spectral Lamps

- The position of a measured lamp line is the zero wind position of that line.
- The position of another line may be determined from the position of the lamp line. The accuracy of this measurement is limited by:
  - accuracy of the HRE gap spacing
  - illumination uniformity
  - integration period
- Lamps that provide atomic and molecular oxygen lines are available. The accuracy of the zero wind line position is limited by:
  - illumination uniformity
  - integration period

notes:

TIDI Nighttime Nadir Viewing for the Zero Position

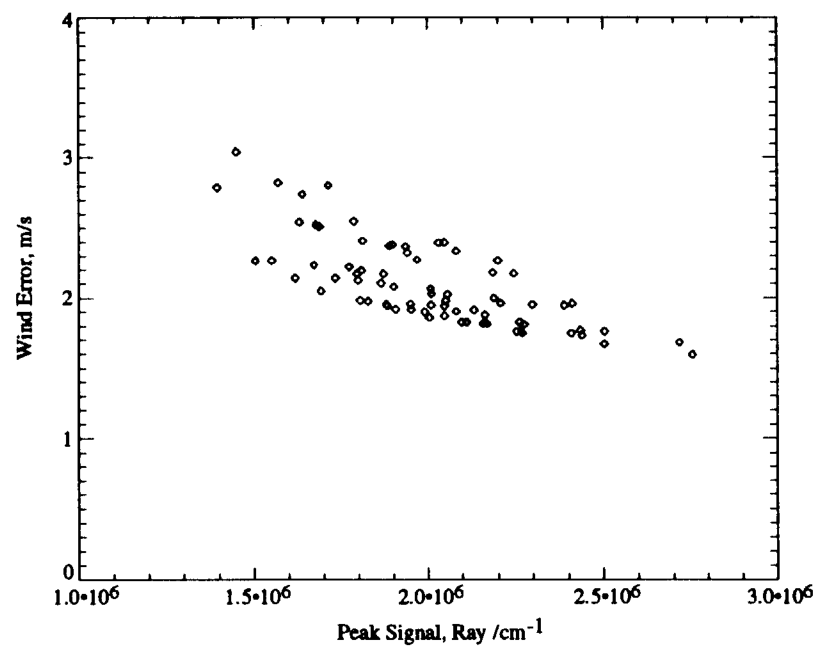
- Assumption
  - global average vertical wind is near zero
- Provides better than 1 ms^{-1} accuracy
- Method
  - View in the nadir direction
  - integrate over 1 to 3 night passes to achieve sufficient accuracy
  - read out the CCD every 10 secs and correct for attitude motion

notes:

TIDI Determining the Zero Wind Position Location

- HRDI achieves 2 ms^{-1} wind error
  - viewing A-band line on limb
  - 11.52 sec integration period
- HRDI would require 3 min. integration to achieve 0.5 ms^{-1}
- TIDI will require 54 min. to achieve 0.5 ms^{-1} error nadir viewing error
  - TIDI is 4 times more sensitive than HRDI
  - Nadir viewing reduces signal by a factor of 70
- Scaling agrees with direct estimate of 57 min.

HRDI Nighttime Wind Error
2 Jan 1995
O_2 A-band line at 761 nm (13138 cm^{-1}) on the limb

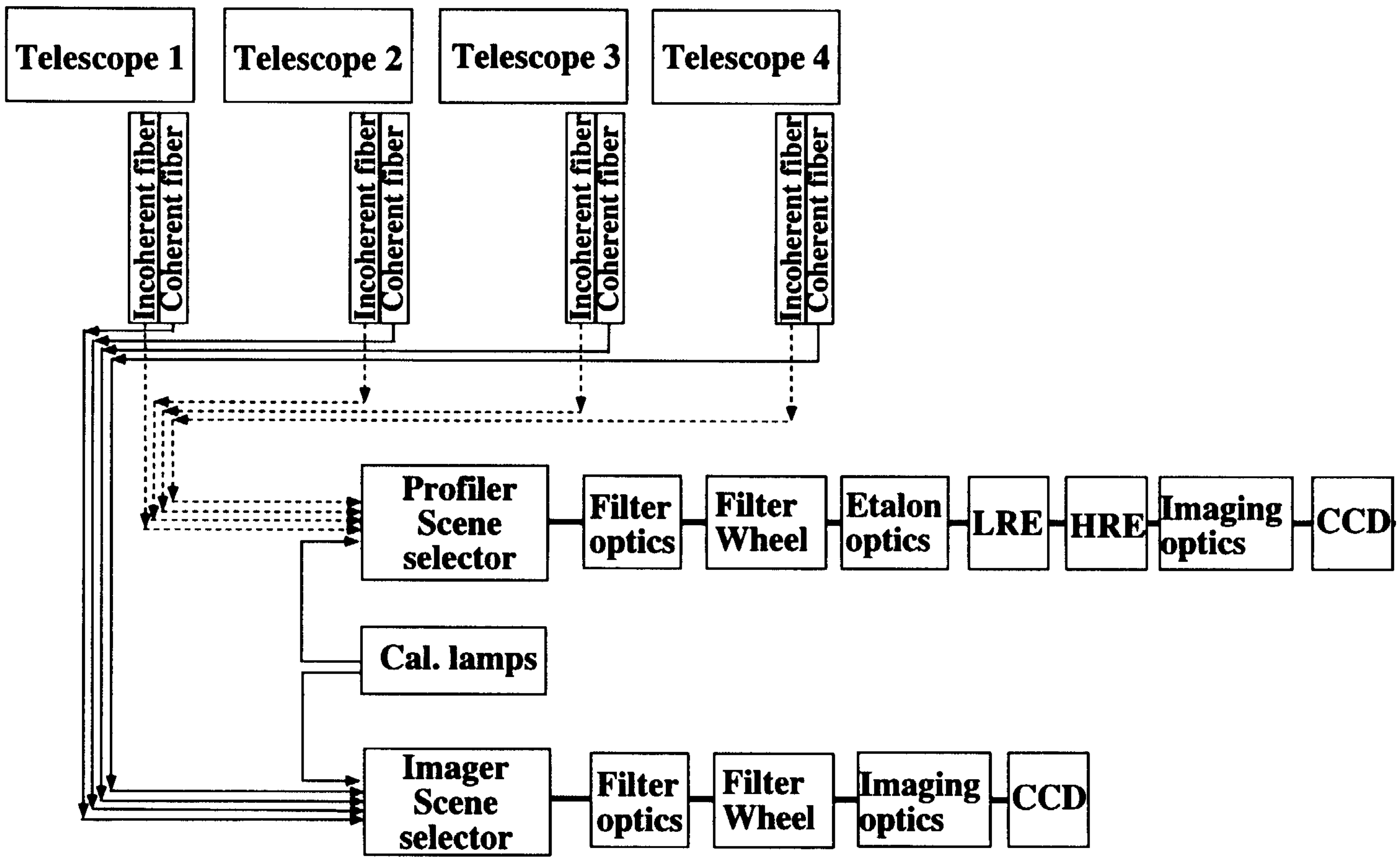


notes:

Optical Design

Heinz J. Grassl

TIDI Optical System Block Diagram



Notes:

The TIDI optical system consists of four telescopes each feeding a coherent full field sky image as well as a much smaller (vertical) incoherent image. The fibers all run to the TIDI sensor which is composed of a profiler channel and an imager channel. All coherent fibers go to the imager scene selector while all incoherent fibers go to the profiler scene selector.

The profiler and imager scene selectors are identical opto-mechanical devices that allow for the selection of any of the four telescopes, a series of calibration lamps, a "dark" port, or an outside test port.

Profiler channel:

Once the appropriate view has been selected the beam is passed through filter optics, filter wheel , etalon optics, the low resolution etalon (LRE), the high resolution etalon (HRE) the imaging optics, and finally imaged on the CCD.

Imager channel:

The front end of the imager will be identical to the profiler. The scene selector, input optics, and filter wheel will be copies of the profiler channel. Only the imaging optics and possibly the CCD will vary.

Calibration sources:

A series of calibration lamps both incandescent and spectral will be housed in the TIDI electronics section and fed via fiber optic to the two sensor channels.

"Dark" and test ports:

Since the scene selectors are eight position devices one position will be blanked off to represent a " no-light" condition and a second port will be used to inject stimuli into the sensor during ground testing.

General Optical requirements

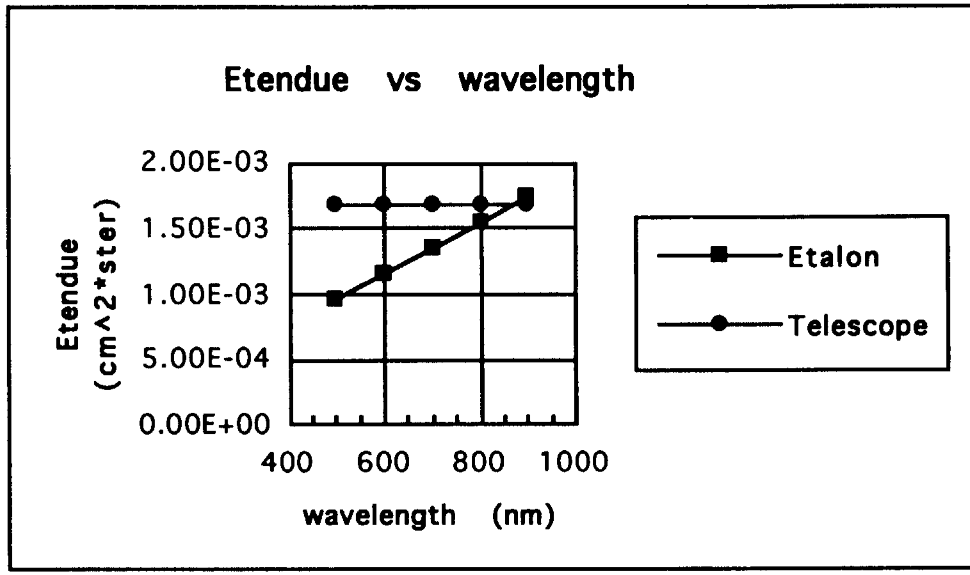
- Expected signal levels and allowable integration times determine the size of the High Resolution Etalon (HRE) needed to meet wind accuracy.
- The size of the HRE is given in terms of "etendue" (product of area and solid angle)
- Etendue is conserved through the system
- The operating wavelength for all elements is 550 - 900 nm

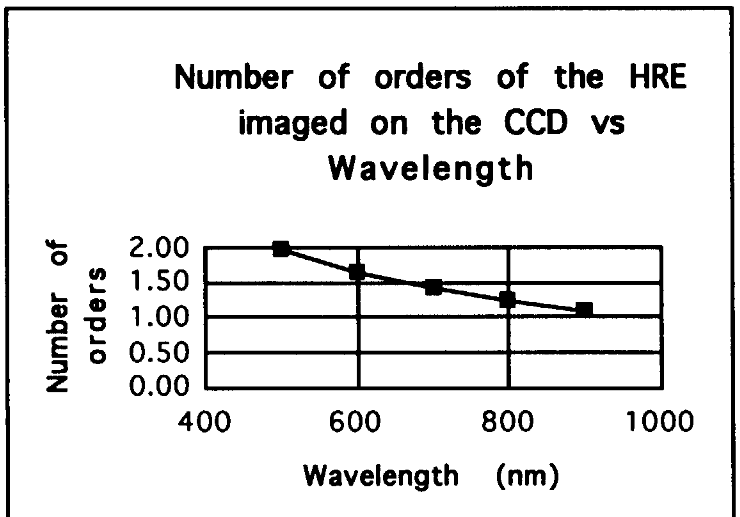
Notes:

TIDI Etalon/CCD optical requirements

Requirements:

Etalon clear aperture=3 cm dia
HRE gap = 1.26 cm
Half angle = 0.51°, 1.1 orders of the HRE @ 900 nm





CCD:
128 x 128 used for profiler fringe
Imaging optic EFL required = 337 mm

At 900 nm the 1st order image of the HRE is 3.0 mm in diameter

Notes:

Optical System Trade Studies

- Edge coatings
- Telescope clear field of view
- Telescope mirror quality
- Metal filters

Notes:

Optical system trade studies:

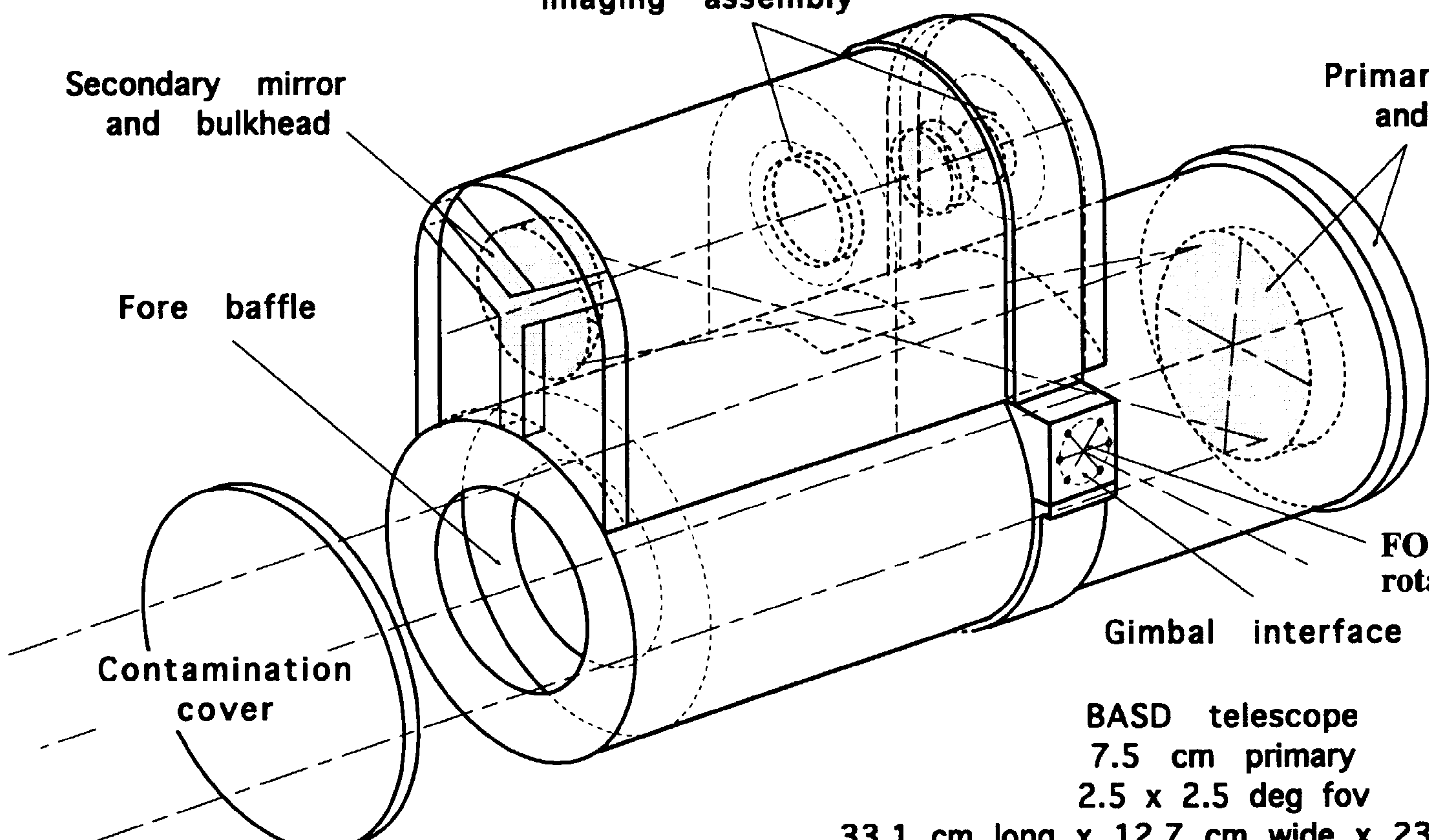
1. Early in the design process we had felt that some gains could be achieved by fully coating etalon plates to the edges rather than the standard clear central area. Five (5) cm plates only use 50% of their available area for coatings, 5% for posts, and 45% unused. Although the plate size could be dropped and fully coated to attain the same throughput the additional design and mechanical work did not warrant a change at this time.

2. Telescope clear fields of view were examined to cut down on the amount of clear real estate required on the spacecraft. The original 90 deg clear field around each telescope boresight was reduced to 35 deg.

4. Telescope mirror quality was examined by BASD to determine what amount of surface roughness could be tolerated without substantially contaminating the measured signal.

5. Metal filters provide promise for a more relaxed temperature requirement on the sensor. Typical narrow band filters have a very high temperature coefficient (0.1-0.3 A/°C), falling off peak in about 5 deg. The metal filters have a coefficient ~10 times less (0.025 A/°C) and will extend this range to about 40 deg.

Telescope



BASD telescope
7.5 cm primary
2.5 x 2.5 deg fov
33.1 cm long x 12.7 cm wide x 23.3 cm high
1.5 Kg

Notes:

TIDI telescope:

The telescope chosen for the TIDI instrument is a proven design from BASD, with HRDI heritage, incorporating off-axis parabolic optics and state of the art baffling.

The Profiler/Imager instruments will require four fixed azimuth pointing telescopes. The telescopes will be positioned ±45 and ±135 deg. azimuth from the forward looking velocity vector of the spacecraft. Each telescope will have a limb scanning capability with a range of motion of approximately 6 deg in Zenith to cover the scientific range of interest. The telescope design is an off-axis Catadioptric low scatter optical system. The primary elements of this system are a 15 deg half angle fore baffle, scanning mirror,primary and secondary parabolic mirrors and field stop. A Lyot stop is imaged at the primary mirror entrance aperture to further reduce the off axis scattered light. The off axis field and spectral image correction is accomplished with a Petzval imager design. These components are refractive elements optimized for the operational wavelength and field distortion correction. The mirrors will be coated with enhanced protected silver for maximum broadband reflectivity. The imaging optics will be coated with a broadband antireflection coating for maximum transmission. A deployable flight telescope cover as used on the DE instrument will be provided to prevent contamination of the low scatter optics.

Telescope requirements

- HRE matching etendue
- Small angle scatter< 1% signal contamination
  20 Angstrom rms mirror roughness
- Large angle scatter < 1% signal contamination
  Sun shade, 15° half angle

Telescope optical parameters:

Entrance pupil diameter	7.5 cm
Horizontal field of view	±1.25 deg
Vertical field of view	±1.25 deg
Effective focal length	13.1 cm
F-number	1.75
Image plane length	5.7 mm
Image plane width	5.7 mm
Spectral band	550 to 900 nm

Notes:

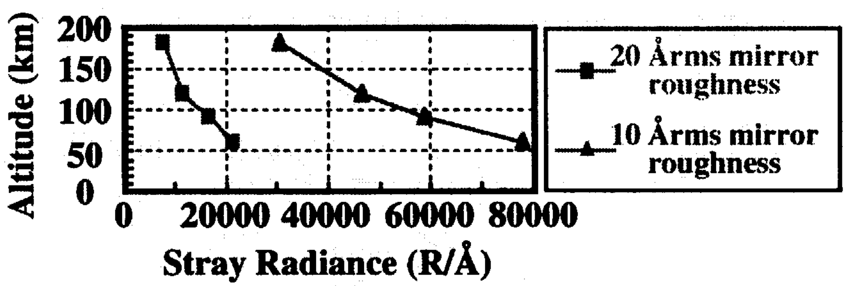
Telescope requirements:

The telescope in this application is both an imaging telescope and a collecting "light bucket", imaging to do star tracking and collecting to satisfy the photon requirements (etendue) of the HRE. In addition the telescope must be able to discriminate between photons collected from, the measurement volume of interest and those that are scattered into the field of view by surface roughness of the primary mirror (small angle scatter), and photons scattered by the telescope baffle system (large angle scatter). In each case the desired goal is to have the scattered contaminant signal be less than 1% of the expected signal. The means by which these requirements are met is through the use of quality optics and low scatter baffle processes.

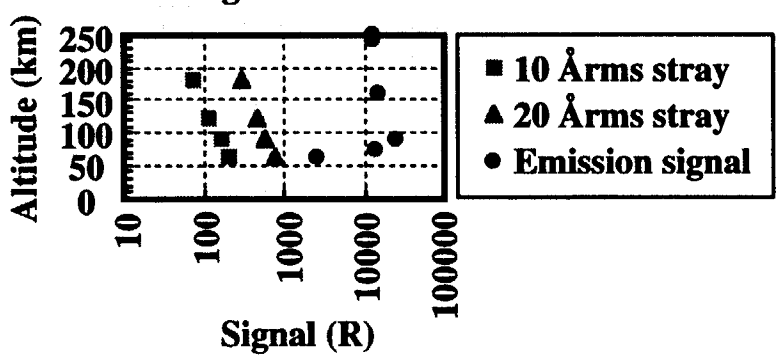
An additional requirement on this telescope is the ability to image stars for the purpose of boresight calibration. The typical spot size (80% energy) on-axis is 22.5 arcsec and off-axis is 40.2 arcsec. This corresponds to a blur circle at the focal plane of 14 microns and 26 microns respectively.

TIDI Telescope Performance

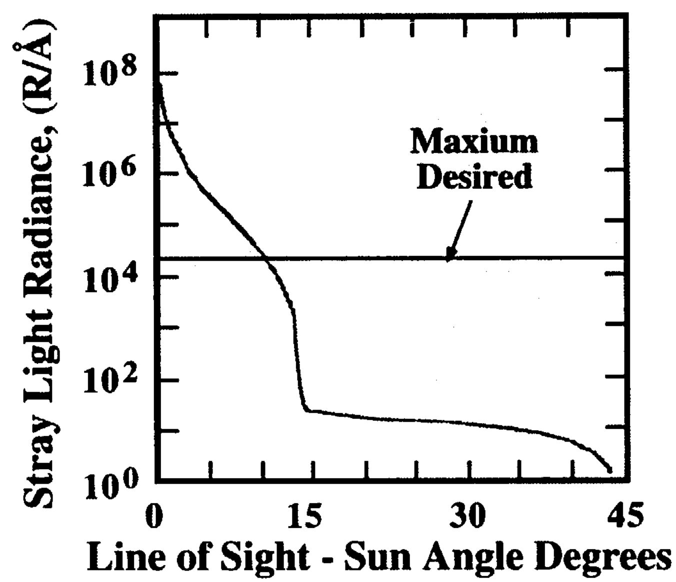
Stray radiance due to primary mirror roughness vs Altitude (600km satellite altitude)



Stray and expected signal strenght Altitude



Telescope Baffle curve



Notes:

Telescope performance:

Stray radiance vs altitude:

BASD has run two simulations of the expected stray radiance from mirrors of 10 and 20 Angstrom rms surface roughness .

radiance levels of 2-8 x 10^4 R/Å are expected at the lowest altitudes. Both levels will meet the 1% criteria over most of the scientific range of interest. A mirror surface roughness of 10 Angstroms rms is achievable but very difficult to maintain due to the extreme cleanliness imposed. By relaxing the mirror specification to 20 Angstrom rms, cost and handling ability are within reach.

Stray radiance vs sun angle:

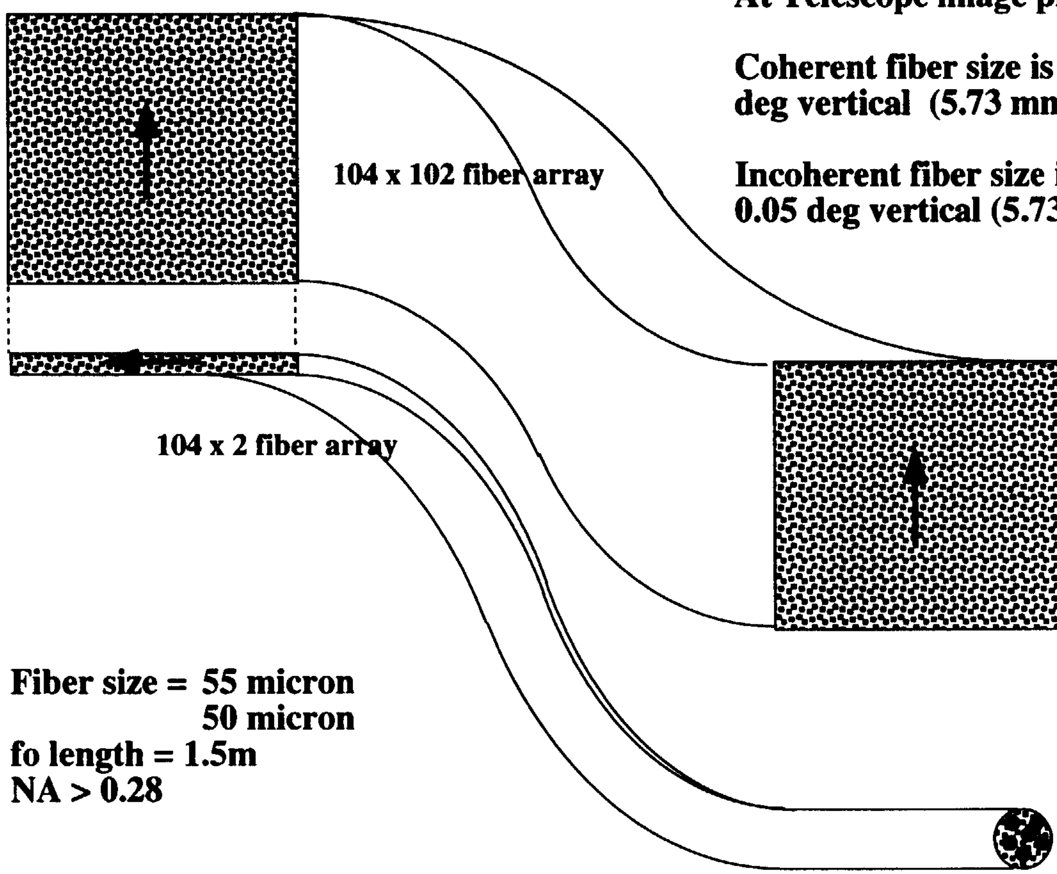
The baffle curve shown in the upper right gives the stray radiance expected from large angle scatter. This curve takes into account main baffle scatter,vane scatter,vane tip scatter, and vane and tip diffraction. Again a stray radiance of > 10^4 R/Å is acceptable with this telescope and allows measurements within approximately 10 deg of the sun.

The bottom curve compares the expected emission signal with the expected contamination signal and shows that the 1% criteria has been met.

The HRDI telescope, although larger, has identical mirror (20Å) and baffle properties and performs photon collection to the level required by the TIDI instrument.

D 8 GRASSL

TIDI Fiber Optic



At Telescope image plane:

Coherent fiber size is 2.5 deg horizontal x 2.45 deg vertical (5.73 mm x 5.62mm)

Incoherent fiber size is 2.5 deg horizontal x 0.05 deg vertical (5.73mm x 0.115mm)

At Imager input:

Coherent fiber size is 2.5 deg horizontal x 2.45 deg vertical (5.73 mm x 5.62mm)

At Profiler input:

Incoherent fiber is 0.91 mm diameter randomly scrambled

Fiber size = 55 micron
50 micron
fo length = 1.5m
NA > 0.28

Notes:

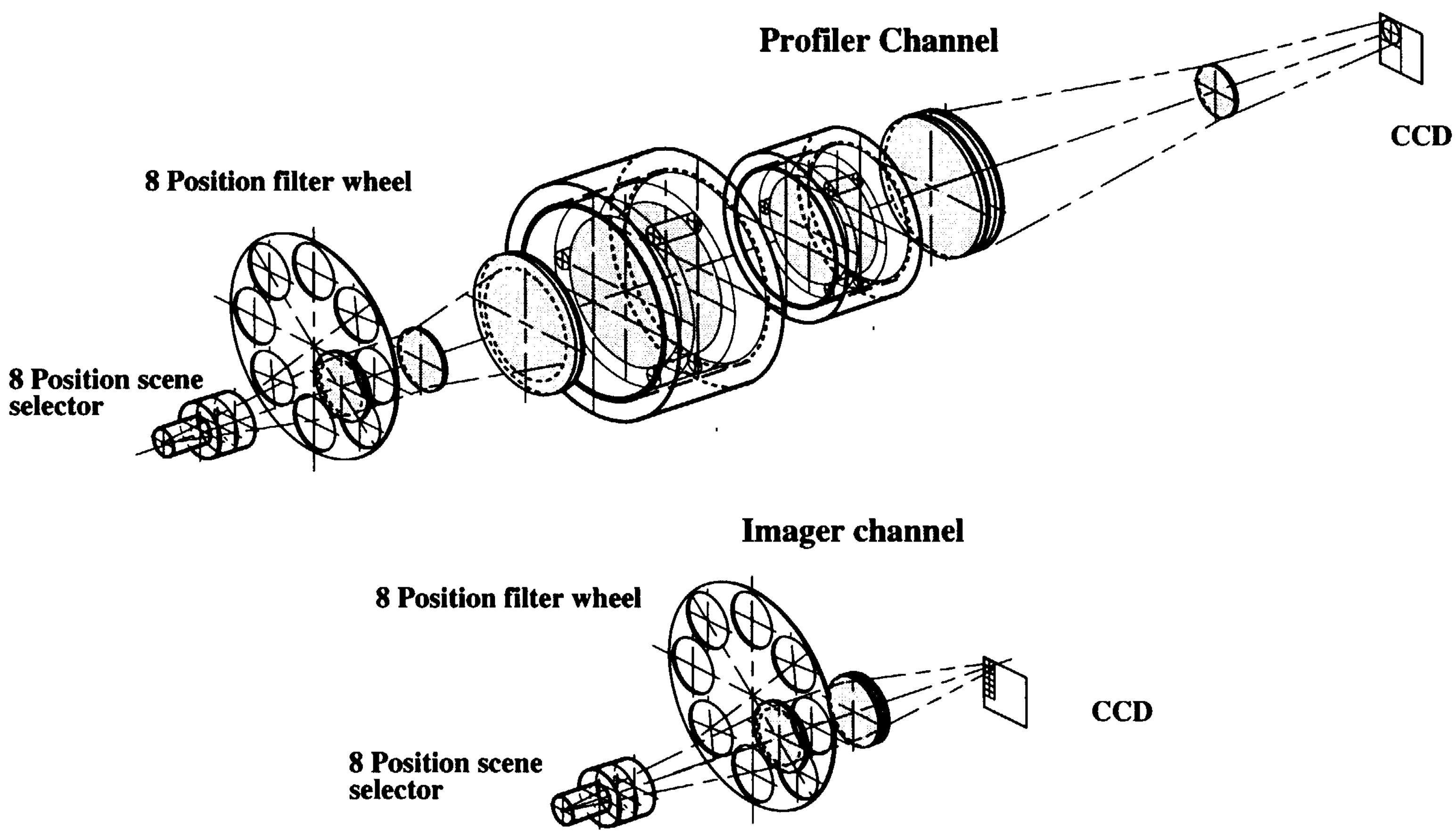
Fiber optic:

The telescopes have a large field of view, 2.5 x 2.5 deg which corresponds to an area 100 km wide x 100 km high at the horizon. 0.05 x 2.5 is required by the profiler and 2.45 x 2.5 (remainder) by the imager. These views must be moved from the telescope image plane to the inputs for the Profiler/Imager. The preferred method to accomplish this is to relay the images via fiber optics.

The Profiler, which looks at narrow slices of the atmosphere (100 km wide by 2 km high) requires a uniformly illuminated field. The fiber optic provides the ability to homogenize the horizon scene through rtandomization of the fibers. Incoherent fiber optics are now in use in the HRDI instrument.

In contrast the imager looks at the full field in a coherent fashion to determine where the boresight of the telescope is pointing. To meet this requirement the fibers are assembled with a 1 to 1 correlation between ends. These types of fiber optics are being used extensively in the medical profession by building up hexagonal arrays out of 12 micron fibers. The only change required for the TIDI application is one of size and materials used. 50 micron fibers of Silica on Silica in a 100 x 100 fiber array will meet all requirements.

TIDI Profiler&Imager channels

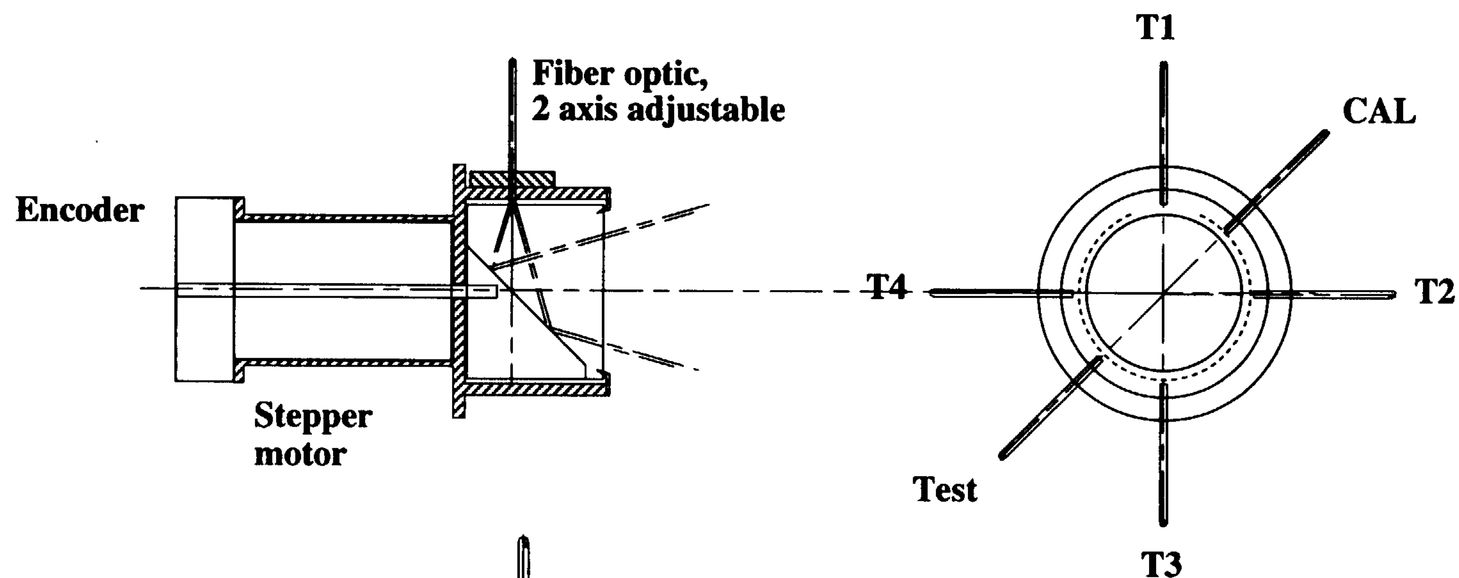


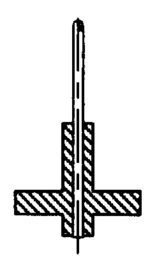
Notes:

Profiler scene selector

Requirements:

To be able to select one of 8 ports by rotating a 45° mirror to its nominal position ± 0.05°





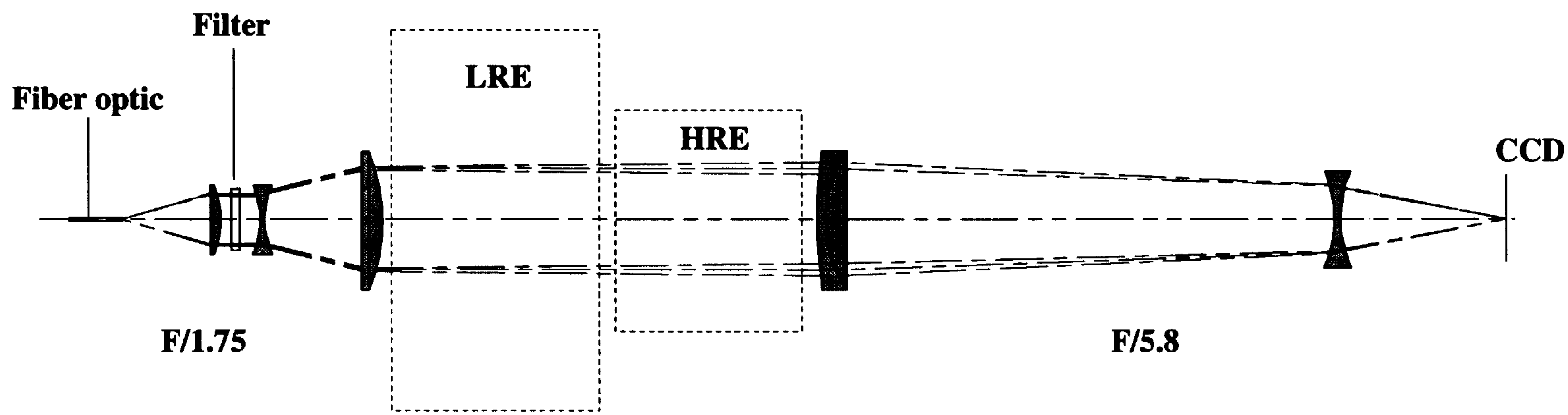
fiber optics will have flanges at both ends, permanently installed at the telescope end with mate/demate at the scene selector end.

Notes:

Profiler optics

Requirements:

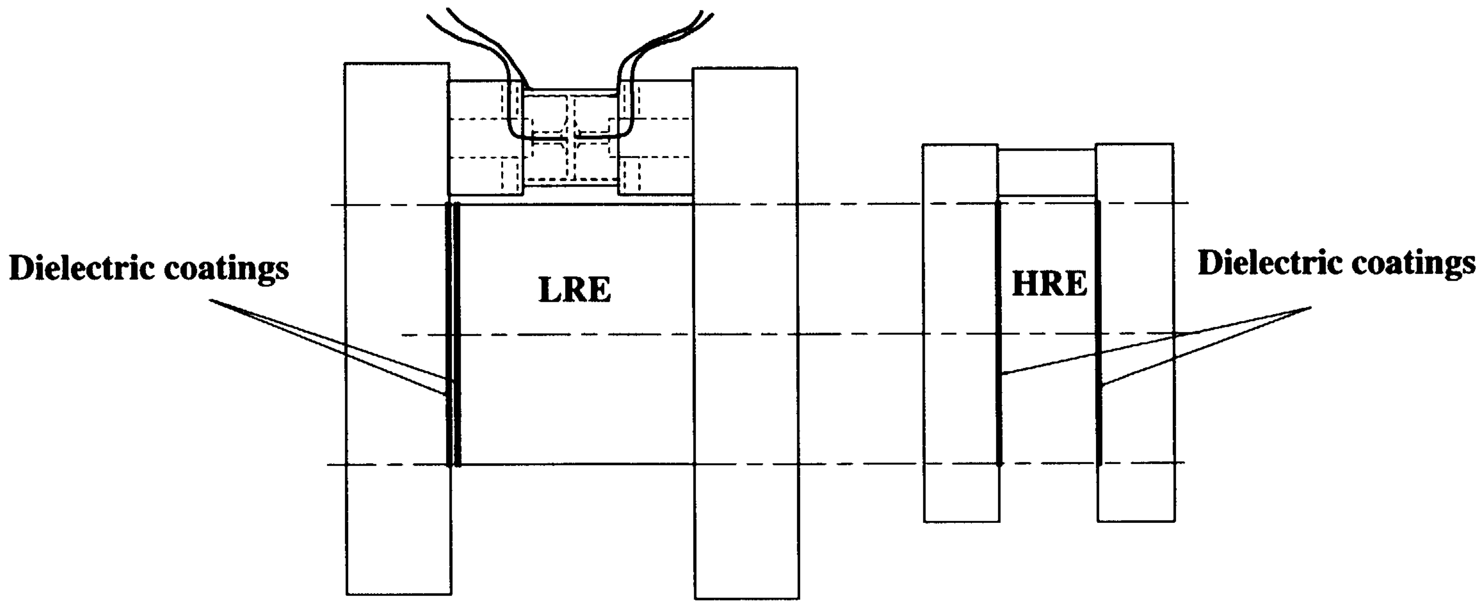
- To expand and collimate the incoming incoherent ray bundle
- To image the HRE fringe onto the CCD



Expand from 0.91mm to 14 mm, and collimate from 16 deg to 1.57 deg through filter section.
Continue to expand from 14 to 30 mm and collimate from 1.57 to 0.51 deg through etalon section.
Imaging optic will be 40mm dia x 377 mm efl

Notes:

TIDI HRE&LRE Optics

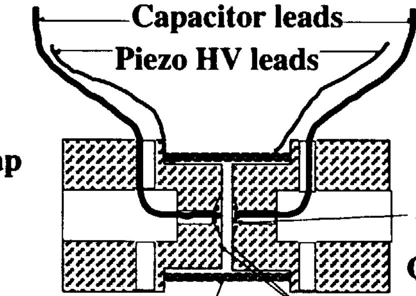


70 mm dia. x 14 mm thick Spectrosil B plates
35 mm dia. x 23 mm thick center plate,
15 mm dia x 23.072 mm long piezoelectric posts
0.072 mm gap

50 mm diameter x 10 mm thick Spectrosil B plates,
6 mm dia. x 12.6 mm long Zerodur spacer rods
12.6 mm gap

Dielectric coatings, 35 mm diameter

Notes:



Approximate size: 0.6" dia. x 1" long (15 mm x 25 mm)

HRE and LRE optics:

The HRE etalon to be used for TIDI is identical to that flown on DE. The plates are 50 mm in diameter and coated over their central 35 mm. The basic requirements on the plates is that the combination of plate flatness, reflectivity and defects total to provide us with an etalon with a finesse of 10 or greater.

The LRE is a direct copy of the design used on the HRDI instrument with only a scale change in the size of the plates. By using the HRDI piezoelectric posts we merely need to size the plates to house the 15mm posts around a 35 mm central aperture.

Again the requirements on the plates is the same as that of the HRE

Plate Physical Characteristics:

Match front surfaces to $\lambda/100$ over central 35 mm diameter, Back surface are flat to$\lambda/10$

Coating characteristics:

Reflectivity of 86-88% over the wavelength range of 550-900nm, Back surfaces are uncoated. The coating must not alter the matching plate flatness by more than $\lambda/100$.

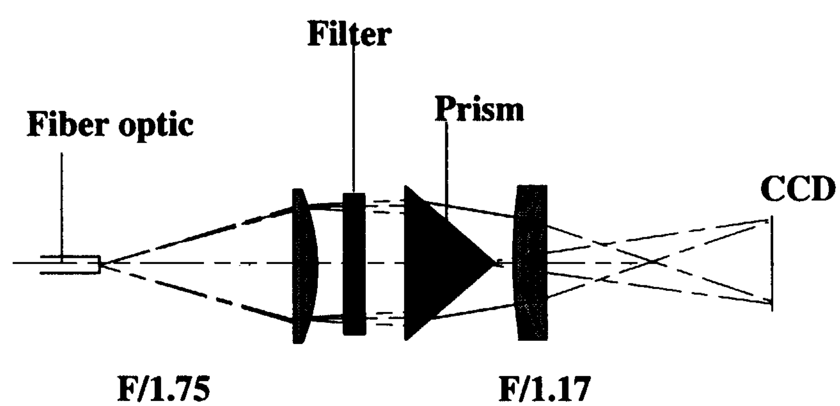
Piezoelectric posts

Piezoelectric posts were developed during the HRDI program using cylindrical piezo tubes. Quartz stepped end caps are used to form the capacitor element inside the tube that is used to control the length of the post.. All posts are precision ground for zero voltage length and for parallelism. The post have a dynamic range of 20,000 Angstroms and can be controlled to ±3 Angstroms.

TIDI — Imager optics

Requirements:

- To expand and collimate the incoming coherent ray bundle
- To image a split sky field onto the CCD



Expand from 5.7 mm to 14 mm, and collimate from 16 deg to 3.85 deg

Image onto a 128 x 128 bin array (3.8 mm x 3.8 mm)

Notes:

Optical summary status/Activities for next phase

- Telescope and sensor optics
  will meet all requirements
- Etalon designs mature

- Design lenses
- Design fiber bundles

Notes:

Mechanical Design.

Heinz J. Grassl.

Mechanical

- 4 Limb scanning telescopes
- 1 Sensor (profiler/imager)
- 1 electronics box

Connection between components by electrical harness and fiber optics

Structural Design Requirements*

Component	Weight lb(kg)	Limit load g's	Stiffness (thrust/lateral) Hz
Telescope (4)	7.9(3.6)	30	70/50
Profiler/Imager	21.4(9.7)	25	70/50
Electronics	12.6(5.7)	25	70/50

*All components to meet Safety factors, and random vibration per APL specification

Notes:

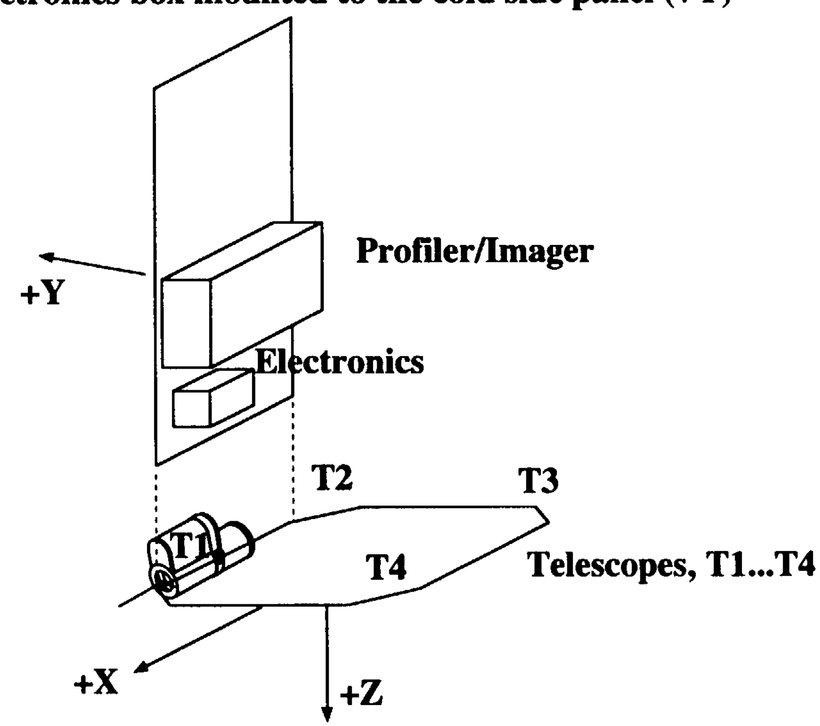
TIDI

Mechanical placement

All telescopes are on the aft deck of the Timed spacecraft (+Z) with nominal boresights @ ±45° and ±135° to the velocity vector(+X) inclined 20° to the Nadir

Profiler/Imager mounted to the cold side panel (+Y)

Electronics box mounted to the cold side panel (+Y)



Notes:

Mechanical

Design strategy strongly based on UARS/HRDI and DE/FPI instruments

Primary Assembly	Subassembly	Heritage	Change	FEM*
Telescope (4)		HRDI	Scale	Y
	Baffle/optics	HRDI		
	Telescope gimbal	Schaeffer		
Profiler/Imager				Y
	Primary structure	HRDI	Scale	
	Scene selector(2)	HRDI	Same as fw	
	Filter wheel (2)	HRDI/FPI	Scale	
	LRE	HRDI	Smaller plates	
	HRE	FPI/HRDI	Same as FPI	
	Optics	HRDI/FPI	Scale	
	CCD (2)	New	New	
Electronics				N
	Deck	Numerous	none	

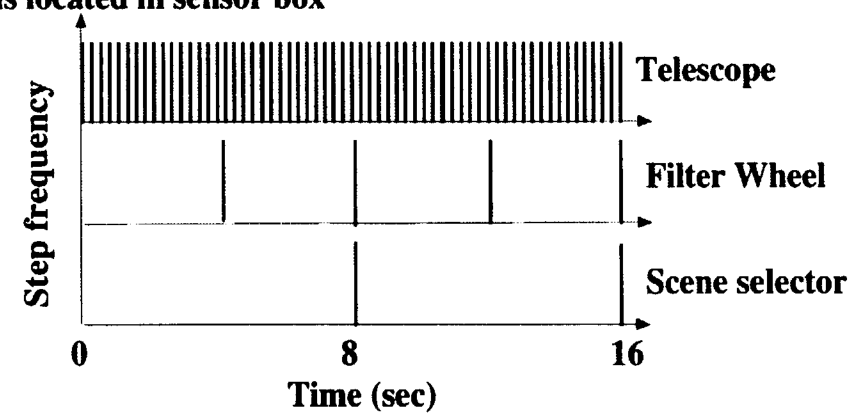
*FEM: Finite element model

Notes:

Mechanical Forcing.

Mechanism	Step rate	Step frequency	Inertia lb-in-sec^2 (gm x cm^2)	Torque lb-in (Nt-m)
Telescope Motor w/ harmonic drive	0.05 °/ 20 ms 3.75° / 20 ms	1 / 0.25 sec for 16sec 1 / 0.25 sec for 16 sec	0.147 (1.66 E5) 2E-3 (2.26E3)	1.28 (.144) 1.30 (.146)
Scene selector*	45°/ 25ms	1 / 8 sec	5E-5 (56.5)	0.26 (.03)
Filter wheel*	45°/ 50 ms	1 / 4 sec	7.8E-4 (880)	0.98 (.11)

* Direct drive mechanisms located in sensor box

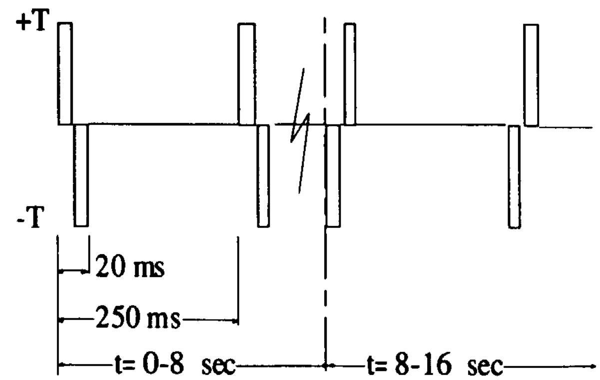


Example mechanism step sequence

Notes:

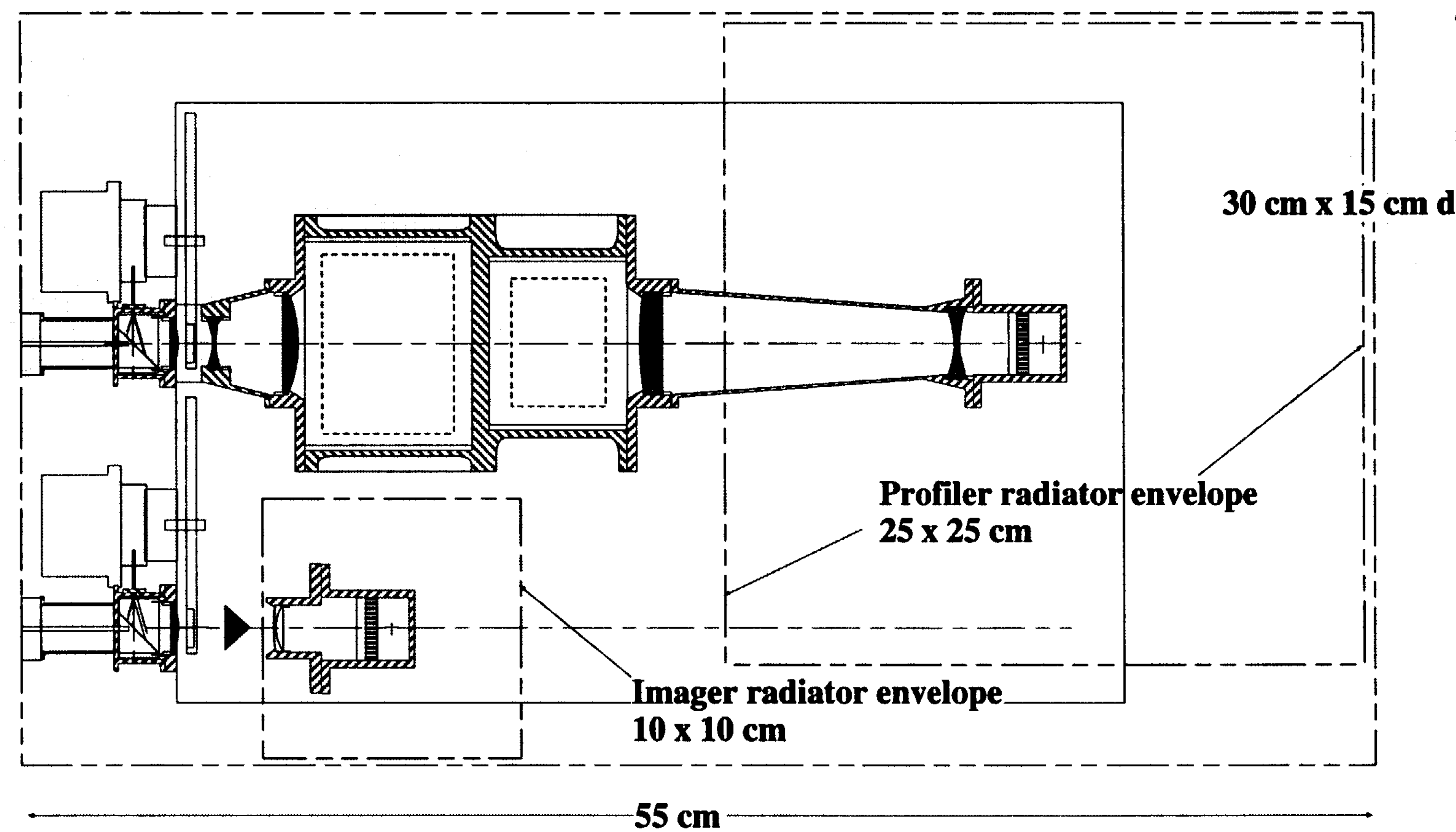
Mechanical Forcing functions:

There are three primary mechanisms employed in the TIDI instrument. A telescope Zenith drive mechanism, a scene select mechanism, and a filter wheel mechanism. There are a total of 4 telescope mechanisms, 2 scene selectors and 2 filter wheel mechanisms. The 2 scene selectors and 2 filter wheels reside in the sensor box. To achieve the 0.05 deg Zenith step size required for limb viewing the telescopes use a 3.75 deg stepper with a 75:1 harmonic drive reduction The typical actuation sequence applies a positive torque to accelerate the telescope gimbal for 10 ms and a negative torque to brake to zero for 10 ms. These torque pulses last a total of 20 ms and are repeated 4 times per sec for 8 sec running the telescope in one direction then the pulses are reversed for 8 sec returning the telescope to its original Zenith position.
The figure below shows this typical torque sequence



The scene selector and filter wheels both operate in a similar fashion however the time between pulses is very long. A scene selector change is typically made once every 8 seconds and a filter change every 4 seconds.

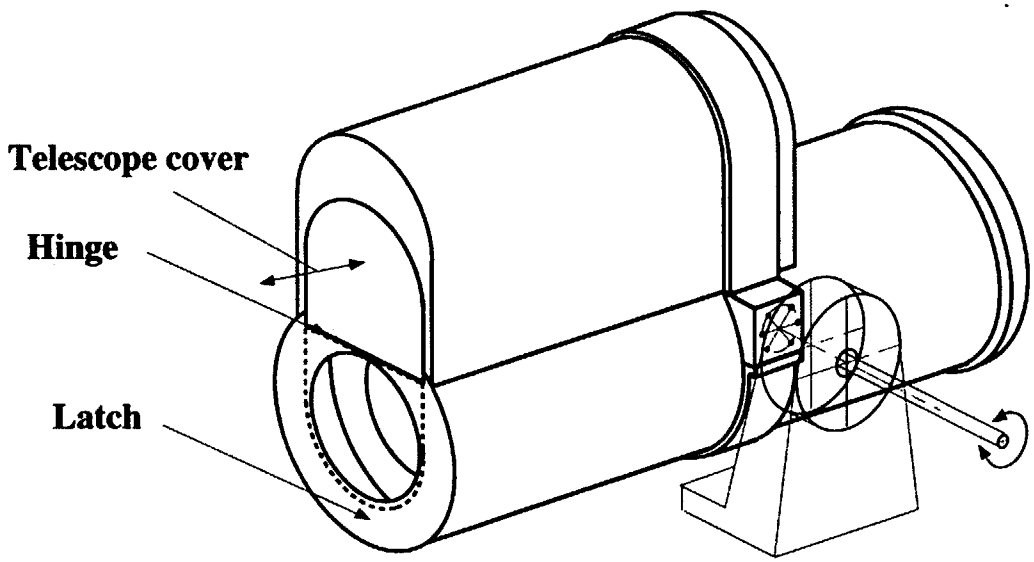
Mechanical Layout



Notes:

TIDI

Telescope Mechanical



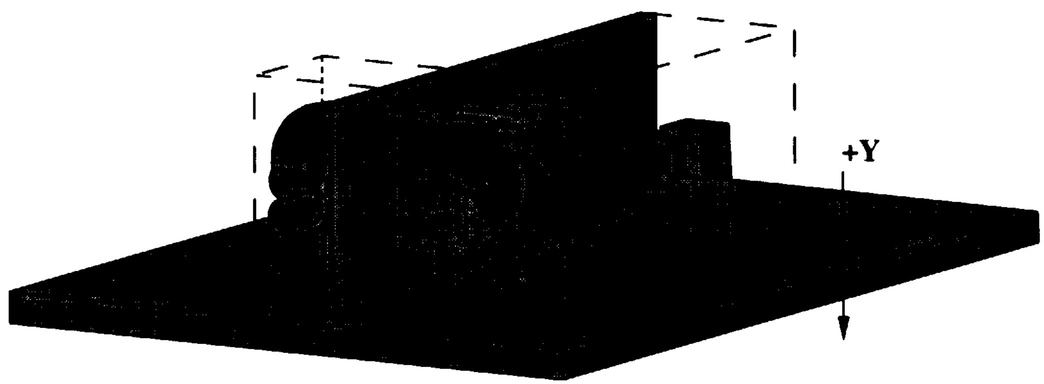
Telescope	1.5 kg
Cover	0.2 kg
Motor/encoder	1.0 kg
Structure	0.7 kg
Blanket	0.2 kg
Total assembly	3.6 kg

Assembly envelope:
33 cm x 22 cm x 27 cm

- Telescope cover spring loaded
- Latch release (DE)
- Telescope Caging: None
- Housing hermetically sealed (capped breather vents for ground testing)
- ± 3.75 deg fiber optic rotation
- 10 cm unrestrained through motor encoder housing
- Qualify by test
  2 years of operation=16 sec cycle x 4E6 cycles

Notes:

TIDI Profiler/Imager Mechanical

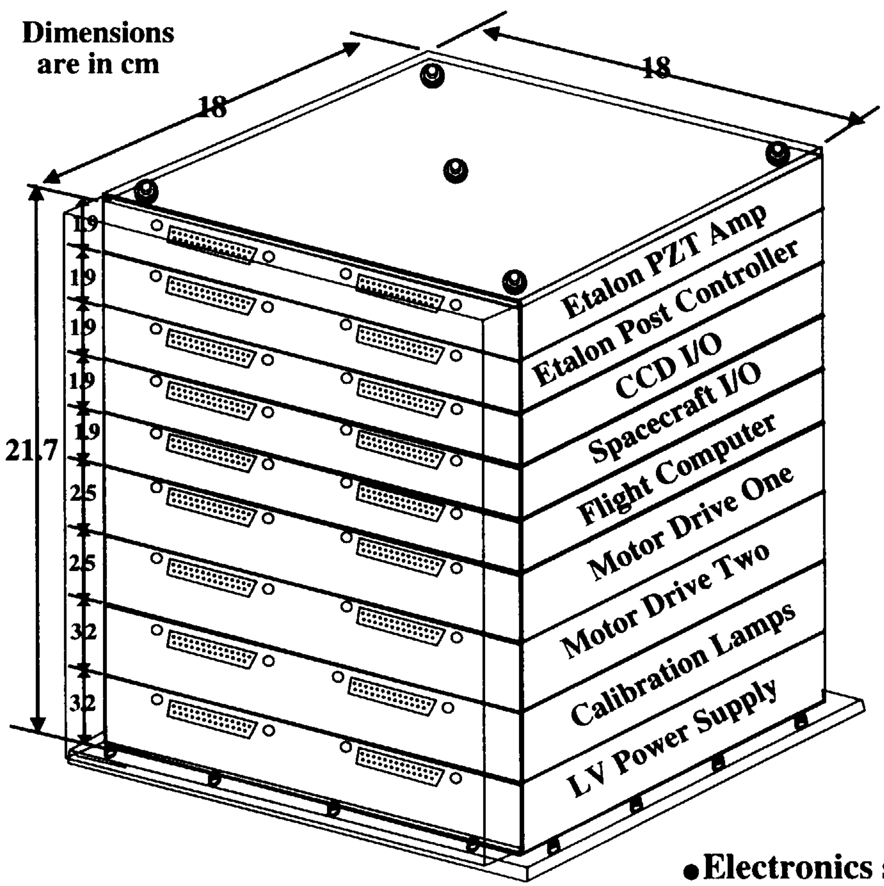


Profiler Components	Weight (kg)
5 Fiberoptic	0.13
Scene sel. 1	0.45
Filter wheel 1	0.29
HRE	0.32
LRE	0.55
Optics	0.10
Radiator	1.10
CCD	0.50
Imager Components	
5 Fiberoptic	0.6
Scene sel. 2	0.45
Filter wheel 2	0.29
Optics	0.02
Radiator	0.65
CCD	0.50
Structure	3.22
Thermal blnkt	0.57
Assembly Total	9.74

- Profiler/Imager Assembly Envelope = 55 cm x 30 cm x 15 cm
- Mechanisms, etalons,optics qualified to 0.08 g^2/hz, 8 grms
  Etalons are primary vibration sensitive element
- Housing hermetically sealed (capped breather vents for ground testing)

Notes:

TIDI | # Electronics Stack, Mechanical



Deck	Height (cm)	Weight (kg)
Etalon PZT amp	1.9	0.48
Etalon post cont.	1.9	0.47
CCD I/O	1.9	0.50
S/C I/O	1.9	0.50
Flight computer	1.9	0.50
Motor drive 1	2.5	0.50
Motor drive 2	2.5	0.50
Cal. sources	3.2	0.77
Power supply	3.2	1.00
Harness		0.50
Assembly Total		5.73

- Electronics stack Assembly Envelope = 18 cm x 18 cm x 21.7 cm
- HRDI electronics qualified at 0.08 g^2/hz, 8 grms

Notes:

Mechanical Summary

- Use existing designs for etalons filter wheels, optical mounts
- Base sensor design on HRDI

- CCD packaging
- Telescope gimbal
- Model structures
- Fiber flexure
- Spacecraft Accommodation

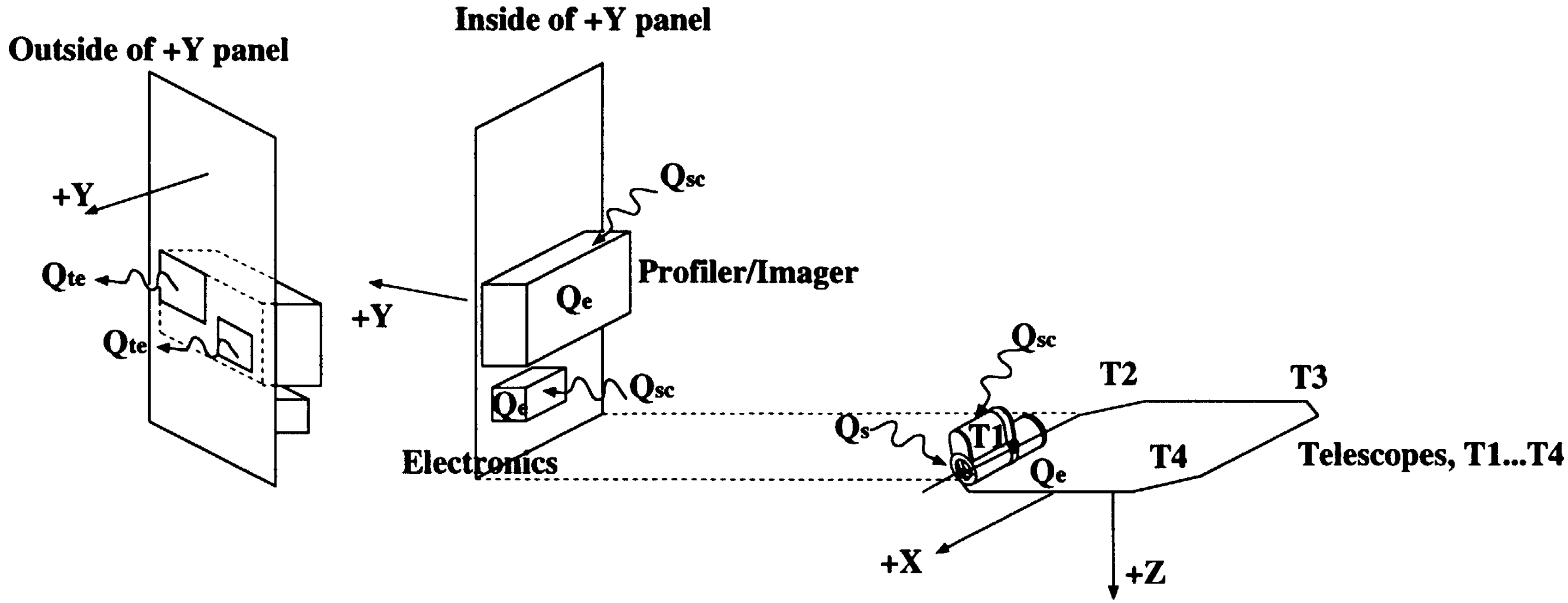
Notes:

Thermal Design

Heinz J. Grassl

Thermal

Component	Operating	Survival	Gradients
Profiler/Imager	20 ± 5°C	-40°C to +60°C	0.1°C/ orbit 1.4°C / m
Telescopes T1 to T4	-20°C to +40°C	-40°C to +50°C	
Electronics	-20°C to +40°C	-40°C to +60°C	



Notes:

Thermal

Component	Subsystem	Average internal pwr diss. (W)	Surface area m^2
Telescope 1		0.64	0.21
Telescope 2		0.64	0.21
Telescope 3		0.64	0.21
Telescope 4		0.64	0.21
Profiler/Imager		2.60	0.56
	Scene selector1	0.05	
	Scene selector2	0.05	
	Filter wheel 1	0.65	
	Filter wheel 2	0.85	
	CCD elec	0.5	
	CCD elec	0.5	
	CCD 1	0.24	0.06 @ 220°K*
	T/E 1	0.56	
	CCD 2	0.19	0.01 @ 258°K*
	T/E 2	0.32	
Electronics		7.8	0.22

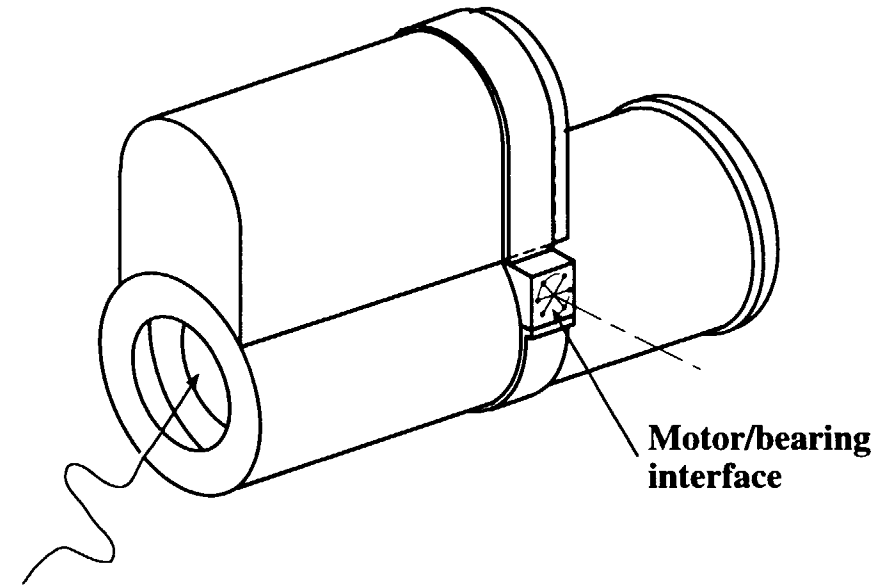
* Radiator surface area required

Notes:

TIDI Thermal, Telescope

Input area = 0.0044 m^2
$Q_s + Q_{alb} + Q_{ir} = 1800\ W/m^2$
Total power into aperture = 8 W
(2W reradiated to space)
Equilibrium temperature = 175°C
(HRDI study suggested 140 °C)

Max. allowable at bearing = 50°C
due to lubricant migration



Action:
1. Thermally isolate bearings from baffle
2. Allow baffle to float at higher temp.
3. Conduct heat from baffle to spacecraft thru flexible conductor (2.5 cm x 0.1 cm x 4 cm, baffle @ 70°C spacecraft @ 40°C)
4. No unfocused sun avoidance
5. Focused sun avoidance by Zenith placement

Thermal loads	W
motor/encoder	0.64
Cond. to S/C +Z plate	6.0*

* Per sun side telescope

Notes:

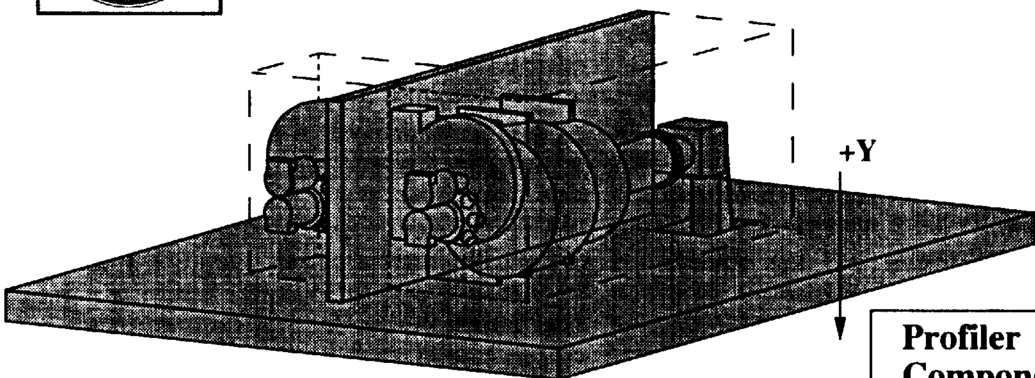
Telescopes

The 4 telescopes are believed to present the greatest challenge in thermal control. Two of the telescopes are normally shaded from the sun and will require heater power to remain within their operating limits, two will , at times, have sun shining on and in the baffle tubes. Analysis on the HRDI telescope considered unfocused sun on the baffle tube (3 to 18.5 deg off the boresight). It was found that the baffle tube temperature rose to a maximum of 140°C after about 10 orbits with a 35 deg gradient along the length of the tube,the coolest being the input end. The biggest concern with this temperature rise is not an effect on optical performance but rather a concern with lubricant migration from the drive bearings onto the optics (50°C was considered an upper limit). This condition arose a few times over the last four years with the HRDI telescope. The solution in this case was quite simple since the telescope could be moved in Azimuth and Zenith, thereby eliminating the baffle sunlight exposure condition. The TIDI telescopes do not have the luxury of moving out of the unfocused sunlight condition short of moving the entire spacecraft. Potentially this is believed to be the most serious problem for the telescopes. Calculations indicate a maximum input of 8W with 2W being re-radiated to space. The 6W balance would bring the telescope to 175°C. By isolating from the motor/bearing assembly and floating the telescope barrel at 70°C it is possible to conductively pass this heat to a 40°C spacecraft panel by the use of a conductive and flexible strap.

A second, more extreme case occurs when we get focused sun at the image plane (sun coming within 1.5 deg of the boresight).

For this case the fiber optics would reach 125°C in 15 min. and 400 °C in 1 hour. This case can be dealt with by moving the telescope in Zenith. Since the telescopes have a 2.5 deg fov and a 6 deg scan range and the sun subtends 0.5 deg it is possible to stay away from a focused sunlight condition.

TIDI Sensor (Profiler/Imager) Thermal



• Profiler/Imager Assembly footprint = 55 cm x 15 cm

Profiler Components	Power (W)
Scene sel. 1	0.05
Filter wheel 1	0.65
CCD elec	0.50
Imager Components	
Scene sel. 2	0.05
Filter wheel 2	0.85
CCD elec	0.50
Assembly Total	2.60

Profiler	Power (W)
Radiator	1.65*
Imager	
Radiator	1.35*
Total	3.00

* Power to radiator from CCD+TEC+S/C backload + conductive

Notes:

Thermal:

The thermal concept at this time hinges strongly on the HRDI experience.

Sensor (Profiler/Imager)

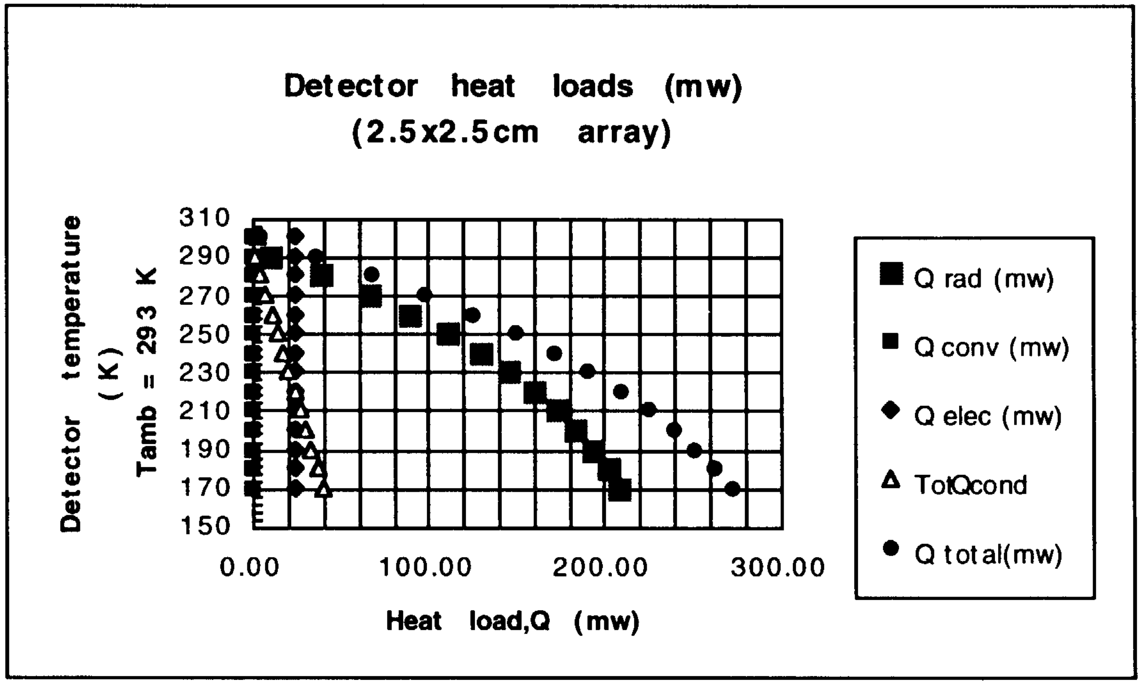
The Profiler/Imager sensor housing will be thermally isolated from the spacecraft and will be operating at a temperature setpoint, T_{set}, between 15°C and 25°C (mission variation). It is expected that this variation will be a function of the spacecraft beta cycle and the long term degradation of thermal properties. During any orbit the sensor temperature will be controlled to $T_{set} \pm 0.1$ °C. In addition a second gradient (dT/dx) along the length of the profiler optical axis must be minimized to avoid bowing of the etalon plates. For the HRDI instrument this meant a $dT < 1°C$ over the length of a 70 cm optical bench. It has been found that it is very difficult to maintain such a gradient and that typical HRDI numbers are < 0.1°C The TIDI application with its compact size and good internal conductivity should easily meet this requirement.

With the HRDI instrument a radiator dedicated to the sensor was sized to dump excess heat and was heated to provide the T_{set} required over all mission variables. In the TIDI adaptation the sensor mounting platform needs to fulfill the roll of the radiator. The sensor internal dissipation is approximately 2.6 W.

CCD Thermal

Assumptions:

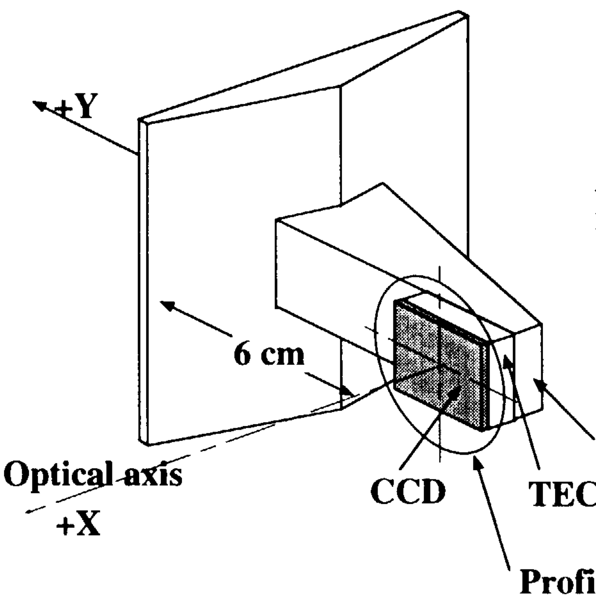
- T_{amb} = 293°K
- zero convective
- 20 Manganin and 1 Copper lead
- 2 cm lead length, 0.1mm dia.
- 0.9 emissivity



Notes:

TIDI

CCD/TEC Radiator Loads



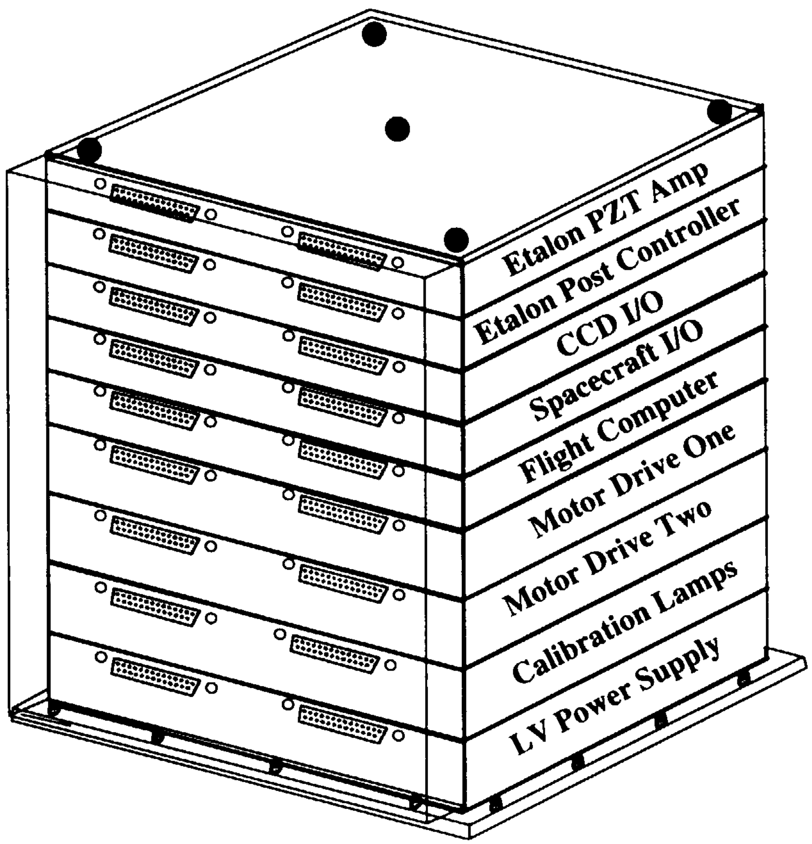
All surfaces MLI blanketed except radiator +Y and CCD +X

CCD temp °K	CCD power mW	TEC power mW	Rad Backload mW	Rad temp °K	Rad size* cm x cm
200	240	560	385	220	25 x 25
238	190	320	74	258	10 x 10

* Includes margin for CCD power to 300 mW

Notes:

TIDI Thermal, Electronics Stack Power



Deck	Avg. Power (W)
Etalon PZT amp	0.40
Etalon post cont.	0.40
CCD I/O	0.45
S/C I/O	1.00
Flight computer	3.20
Motor drive 1	0.20
Motor drive 2	0.20
Cal. sources	0.02
Power supply	@75%
Assembly Total	7.8

- Conductive Footprint 18 cm x 18 cm

Notes:

TIDI

Thermal summary status / Activities for next phase

- Thermal concept based on HRDI
- Telescope heating

- CCD thermal packaging
- CCD radiator
- Model sensor
- Model telescopes

Notes:

Mechanisms.

Walter H. Pinkus.

Mechanisms

- Filter Wheel
- Scene Selector
- Telescope Gimbal Drive
- Etalon Post Controller
- CCD Cooler
- Telescope Cover Release Heater

NOTES

TIDI Filter Wheel Derived Requirements

Number of Filter Positions	8
Filter Diameter	1.5 cm
Filter Placement Requirement	± 0.25 mm
Wheel Moment of Inertia [scaled from HRDI]	880 gm*cm^2
Motor Stall Torque [per HRDI measurement]	61.4 gm*cm
Motion Time, 45° [scaled from HRDI]	50 ms
Encoder Resolution	1024 counts/revolution
Motor Supply Voltage	28 volts
Motor Winding Impedance	60 ohms
Motor Input Power, peak	26.1 watts [two windings energized]
Average Power, Profiler	0.65 watts
Average Power, Imager	0.85 watts
Subsystem mass	0.29 kg

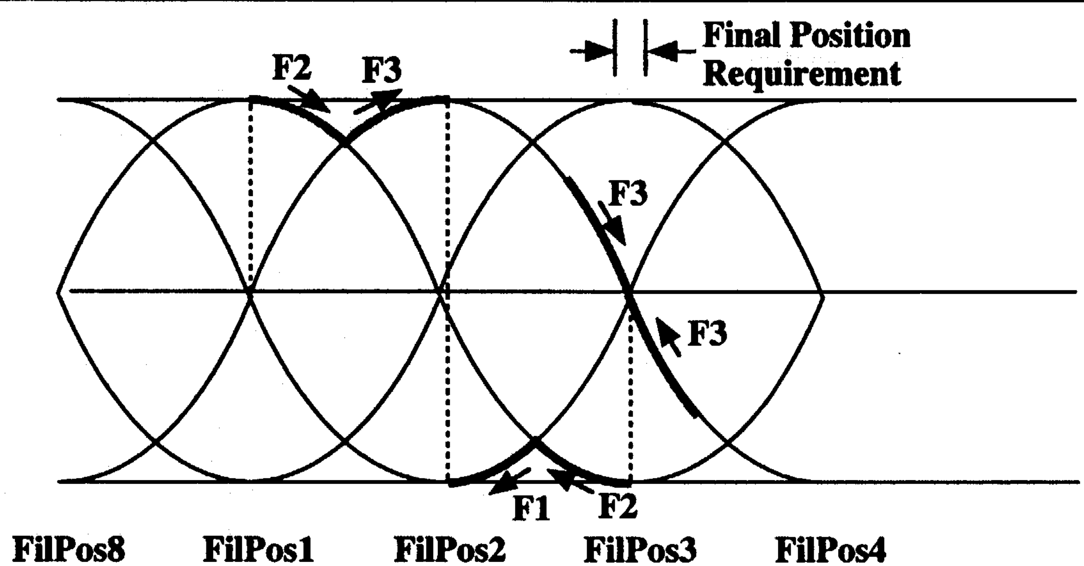
NOTE: Scaling based on HRDI's use of 2.54 cm diameter filters.

The baseline design for the Filter Wheel Drive is an eight-position device driven directly by a large-angle stepping motor. The power required is two-phase bipolar, producing a four-state sequence. The design is a direct descendant of similar systems used on DE-FPI and UARS-HRDI. The same stepping motor, a size 11, 45 degree, Samarium-Cobalt magnet, IMC Magnetics design that was used for the Filter Wheel Drive in HRDI will be used. The associated position encoder will be an evolutionary descendant of that used on HRDI, based on design studies performed after HRDI.

The HRDI design used 2.54 cm diameter filters. TIDI will use 1.5 cm diameter filters. A preliminary layout for the TIDI Filter Wheel has been performed and performance has been calculated by comparison with the measured performance of the HRDI design.

The Moment of Inertia of the Filter Wheel is large with respect to the Stall Torque of the drive motor. Thus this is a torque limited system and the Stall Torque is the Disturbance Torque for the mechanism. Because this is a torque-limited system, controlled motion is achieved using position feedback control and the Retro-Torque Braking algorithm.

TIDI Filter Wheel Retrotorque Braking



- Accelerate for half the the motion distance, plus friction offset
- Decelerate to final position
  (removes energy added to system during acceleration)
- Apply final position centering torque to ensure settling

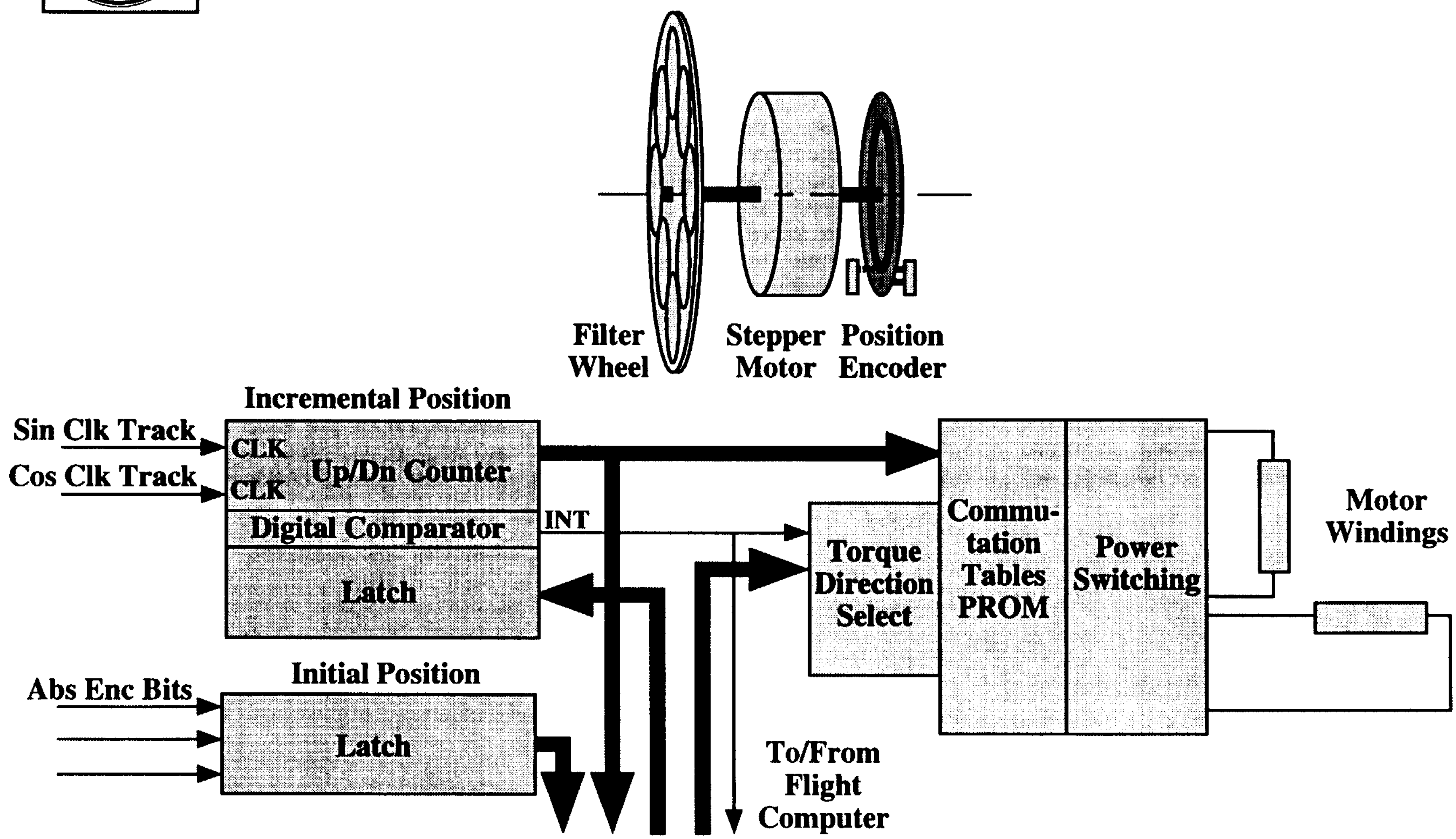
Normally, stepping motors are used with small inertial loads, such that the system response does not differ greatly from the unloaded motor response. When that is the case, these motors can easily be operated open-loop quite successfully. The usual approach is to move the motor one step at a time by applying the electrical commutation pattern for the next adjacent rest position and holding power on for sufficient time to perform the motion and then assure settling to the new position. This mode of operation is generally named Simple Stepping. Multi-step motions may shorten all but the first and last commutation hold periods in recognition that the load is already moving. This mode of operation is generally named Ramped Slewing. Motor data sheets generally provide timing information for these two modes.

The Filter Wheel design originated with the Dynamics Explorer Fabry-Perot Imager (DE-FPI) instrument. The motor selection made at the time was driven by size, weight and power restrictions. Having successfully performing the task within those limits, the basic selection has not changed. The motor for UARS-HRDI employed Samarium-Cobalt magnets which have more stable magnetic properties, instead of the Alnico V magnets of the DE motor. The same motor design used for HRDI will be used for TIMED-TIDI.

Because the Filter Wheel load inertia is very large, the mechanism cannot be successfully operated in the classic Simple Stepping mode described above. The operating algorithm that is used is called Retro-Torque Braking. As illustrated, this calls for applying torque in the direction of the desired motion for just over half the desired motion distance. Up to that point, there is no difference from the Simple Stepping mode. Beyond that point, however, torque directed in opposition to the direction of motion is applied. This removes energy from the load. The transition point is located so that the load energy is reduced to zero just as the load arrives at the desired rest position. The transition point's delay beyond the halfway point is due to the bearing friction which adds to the decelerating force but opposes the accelerating force.

Fixing the transition point with respect to motor rotational coordinates provides insensitivity to the actual magnitude of motor torque and load inertia, leaving only bearing friction and windage as potential disturbances. In recognition of potential changes in the latter, HRDI was set up to arrive at the desired final position with a small residual forward momentum. A final holding period, commutated to the final-position holding torque, was used to ensure settling. No performance degradation has been observed during the HRDI lifetime.

Filter Wheel



A feedback motion control system is used for the Filter Wheel because the mechanism is torque-limited. The mechanism's position encoder has a sin/cos clock track to display detailed incremental position. It also has a one-of-eight whole step width position track and an eight-per-revolution filter-center index signal to display absolute position.

An Up/Down counter is used to follow the motions indicated by the clock track. A latch stores the starting point of the motion indicated by the whole step track. The Flight Computer can inspect the values in either of these as needed. Motor commutation sequence tables in PROM, accessed by values from the Incremental Position tracking counter and by direction and on/off commands from the Flight Computer, control the power switches. Breakpoints for the Retro-Torque Braking motion control algorithm are stored in the Flight Computer's firmware and loaded into the comparison latch as needed.

The Retrotorque Braking mode of operation consists of applying an accelerating torque for slightly over half the desired motion angle (adjusted to account for bearing friction) and then switching to a decelerating torque for the remainder.

To operate the motor, the Flight Computer will load the expected counter value corresponding to the position for the Accelerate / Decelerate breakpoint into the comparison latch associated with the Incremental Position counter and will load motion direction and power-on commands into the Torque Direction latch. When the desired breakpoint value is reached in the Incremental Position counter, the comparator output goes TRUE. This signal is hardwired into the PROM address circuitry to reverse the direction of the torque without the delay inherent in Flight Computer intervention.

The comparator output signal is sent to the Flight Computer as an Interrupt flag. The Flight Computer responds to the Interrupt by loading a new value into the Position latch that will indicate where to change from Decelerating mode to the final filter-centering operation. The comparator again signals when that breakpoint is reached. Hardwired control again changes the the torque, this time to the final Holding commutation pattern.

Motor commutation within modes is entirely contained in the PROM and requires no intervention from the Flight Computer.

As a separate task, the Flight Computer runs a timer to place an upper bound on the time the the motor can be energized. This ensures turning the power to the mechanism off in the event of a functional failure.

Scene Selector Derived Requirements

Input Stations	6 (8 provided)
Rest Position Placement Accuracy	±0.05 degrees, maximum
Mirror Moment of Inertia	56.5 gm*cm^2, nominal
Motor Stall Torque [per HRDI measurement]	61.4 gm*cm
Motion Time, 90°	10 ms, nominal
Encoder Resolution	1024 counts/revolution
Motor Supply Voltage	28 volts
Motor Winding Impedance	60 ohms
Motor Input Power, peak	26.1 watts [two windings energized]
Average Power per Scene Selector	0.05 watts
Subsystem mass	0.45 kg

The requirement is for a means of selecting light from one of four Telescopes, one Calibration Lamps deck, and one Test Port input that its capped in Flight Configuration. The center line alignment of the selected light exiting the Scene Selector mechanism must be held to the alignment requirements for the rest of the interferometer.

The baseline design for the Scene Selector Drive is an eight-position device driven directly by a large-angle stepping motor. The power required is two-phase bipolar, producing a four-state sequence. The motor will be the same size 11, 45 degree, IMC Magnetics design that was used for the Filter Wheel Drive in HRDI and is being used for the Filter Wheel here in TIDI.

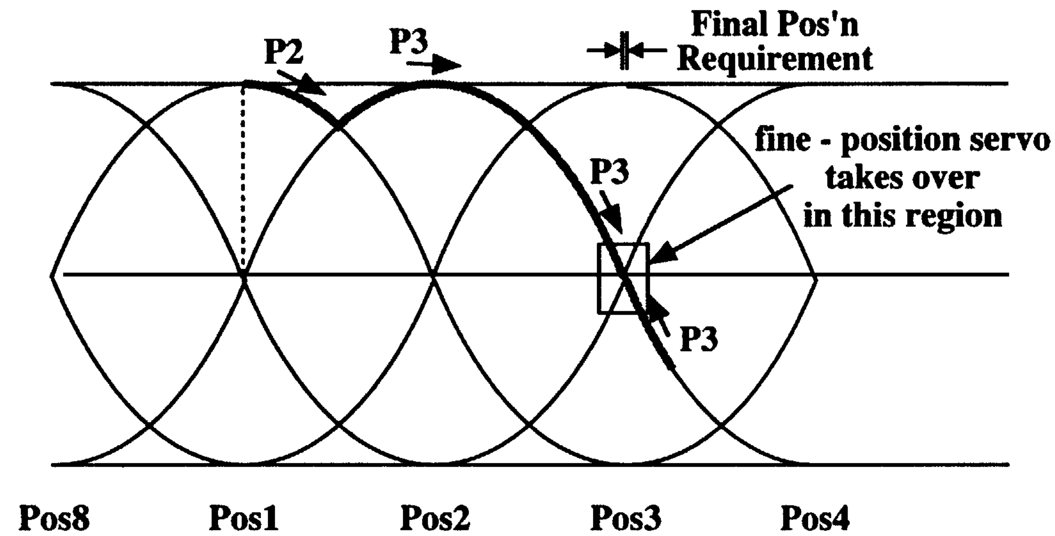
A mirror directs light from the selected input to the Interferometer input optics. Other inputs are capped to keep light from those sources from entering the instrument. Four of the eight mechanism positions select the four Telescopes; of the other four available positions, one is used for input from the Calibration Lamps Deck, and one is used to provide a built-in external input capability.

The mirror is mounted at 45 degrees to the rotational axis of the motor shaft, bending the input light through 90 degrees. The center line alignment accuracy for light entering the Interferometer is ±0.05 degrees. This requirement translates directly as a requirement on the rotational placement of the mirror.

The mirror element load inertia has been calculated and the time to complete the 90 degree motion required to transfer from one Telescope to the next has been estimated. The load moment is small enough that it is believed the task can be accomplished using Simple Stepping motor operation.

The placement accuracy requirement it very tight compared to the accuracies achievable with open-loop control of a stepping motor. For this reason, a closed-loop positioning servo, using information derivable from the same Position Encoder mechanism that will be employed for the Filter Wheel, will take control once the 90 degree step motion is completed.

Scene Selector Simple Stepping

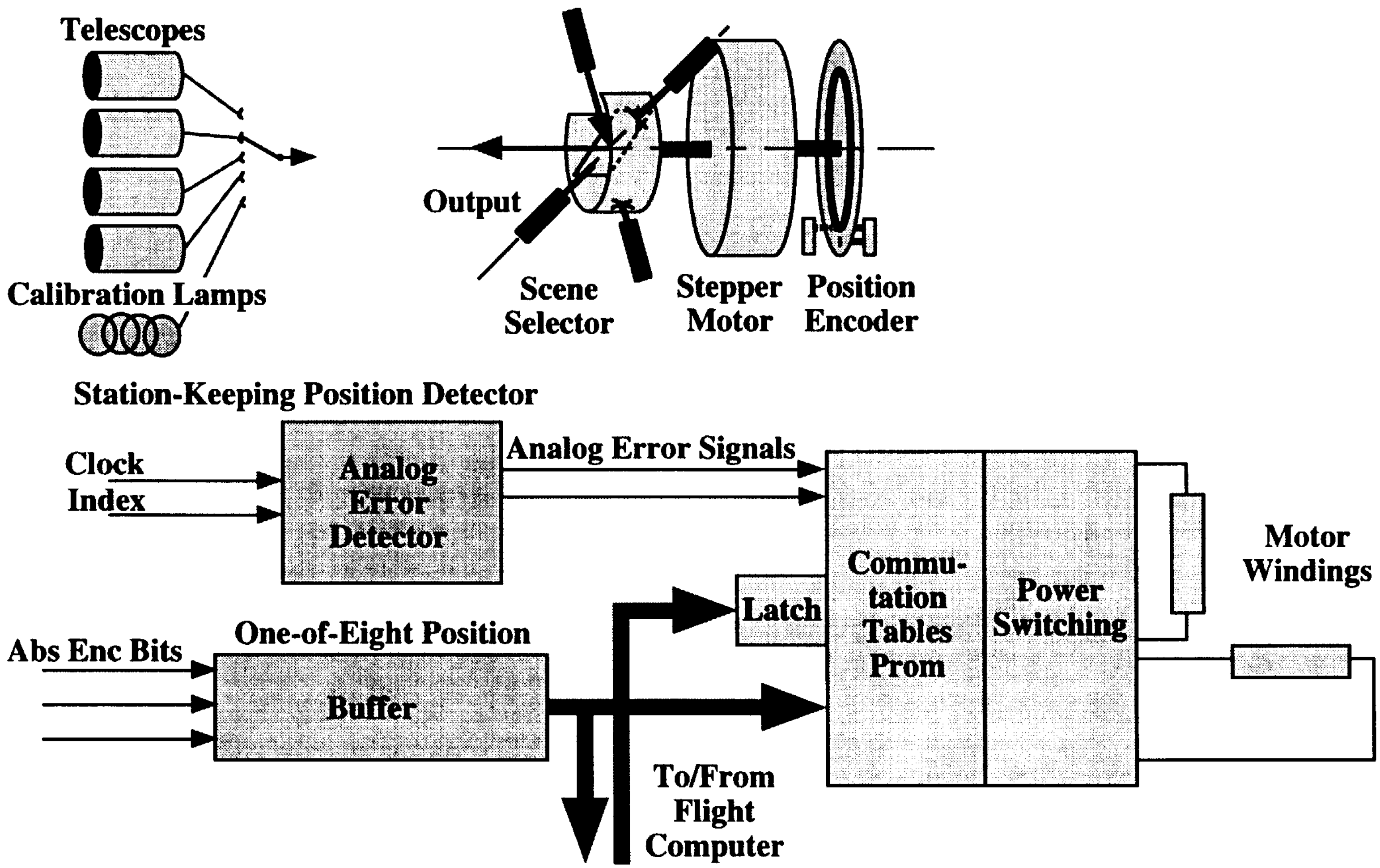


- Apply torque, with commutation, to move to final position
- After motion, change to position-based closed-loop servo mode to maintain required position accuracy

Unlike the Filter Wheel described previously, the Scene Selector mechanism is a lightly loaded case. Here the operation shown is the conventional Simple Stepping mode. Torque is applied in the direction of the desired motion and commutated along until the state for the desired final rest position is reached. Nominal settling to the desired position is achieved with little overshoot or ringing because of the light load.

The quasi-analog fine positioning control servo then completes the task of aligning the mirror. In this mode full-voltage, short-duration pulses are applied with commutation as needed to move to reduce the position error. Error sampling is clocked, placing an upper limit on the torque applied and on the power dissipated in this mode.

TIDI Scene Selector



Position selection motions are implemented with an open loop motion control system because the mechanism is very lightly loaded. The mechanism includes the same position encoder used for the Filter Wheel, which has a one-of-eight absolute position encoder to display the coarse position, as well as an eight-per-revolution position-center index signal to define absolute position for a sine/cosine clock track. Simple Stepping motion control will be used because the motor is lightly loaded. Commutation is based on whole-step feedback from the encoder and timed control by the Instrument Controller.

Since the final position of the mirror must be maintained to high accuracy to correctly center the light on the input optics, fine control of the rest position of the mechanism is performed by a quasi-analog servo loop that takes over from the digital stepping drive after the Stepping motion is completed. An analog low/middle/high detector looks at clock track transition occurring at the position-center. While low or high, it applies power to the motor to generate centering torque. While in the middle, no power is applied. Power is applied in the form of full-voltage, short-duration pulses, to reduce the torque significantly from the stall torque.

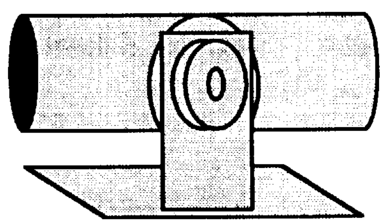
TIDI Telescope Drive Derived Requirements

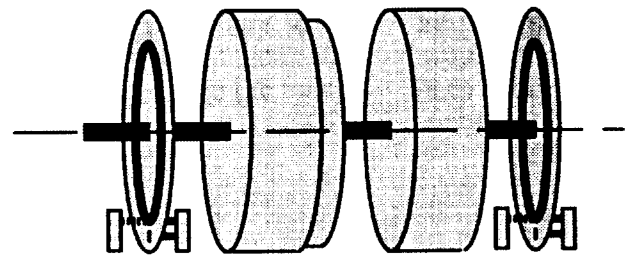
Telescope FOV Minimum Step Increment	0.05 degrees ± 0.005°
Telescope FOV Motion Range	7.5 degrees
Telescope Pointing Axis Moment of Inertia	0.0166 $kg*m^2$
Pointing Increment Step Time, max	20 ms
Pointing Increment Step Rate	4 steps/second
Required Torque [Min. Disturbance Torque]	0.144 nt*m
Motor Supply Voltage	28 volts
Motor Input Power, peak	5 watts
Average Power for 4 Telescopes	0.64 watts
Motor Stall Torque	13.0 lb*in
Subsystem Mass [motor, encoders, telescope, structure]	3.6 kg

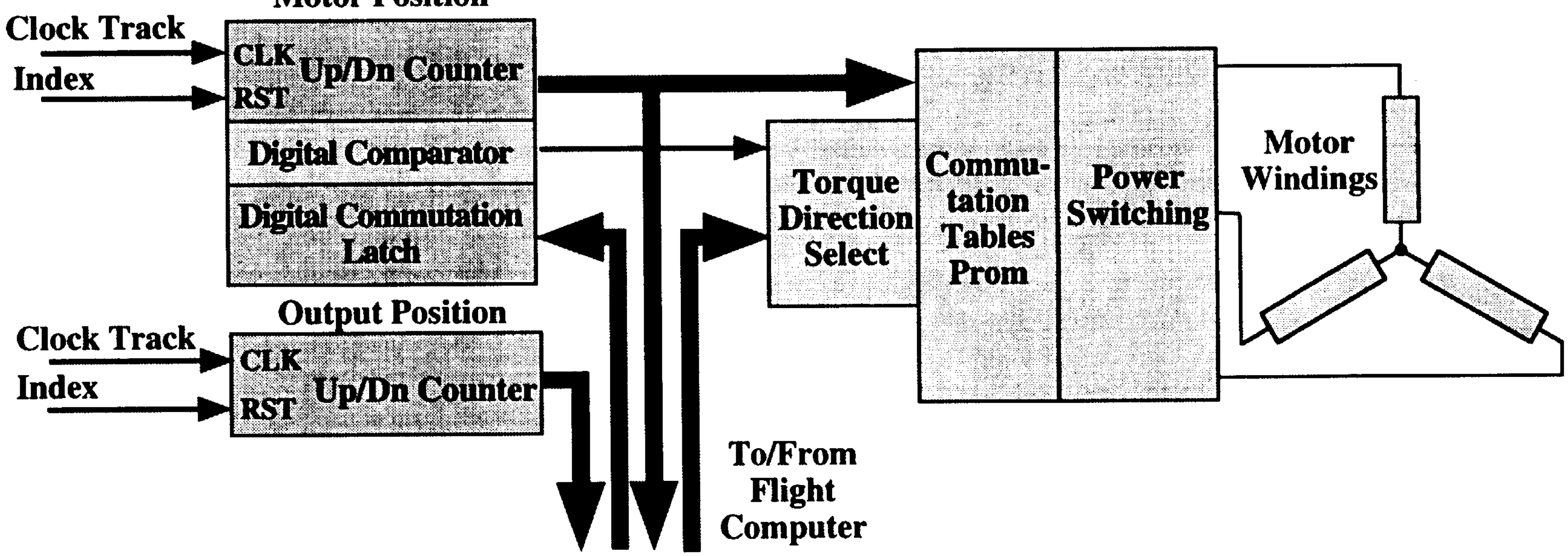
The motion requirement on the Telescope is a minimum step increment of 0.05 degrees, with a placement accuracy of ±10% of a step. The baseline design utilizes a Schaeffer Magnetics Type I Actuator as the drive element. The Schaeffer Actuator is a small-angle stepping motor geared-down by a Harmonic Drive element and provided with position encoders for both the motor and the output. The output step angle and step angle tolerance are comparable to the requirements.

The total motion range requirement includes the planned measurment scan range as well as guardbands on either end to accomodate spacecraft orientation tolerance and Earth oblateness. The desire is to make Telescope motions very short with respect to the shortest integration period for the Profiler, which is 0.25 seconds. The Baseline Operating Mode includes inter-measurement position increments of 0.05, 0.10, and 0.20 degrees, as well as a several-degree slewing motion.

TIDI — Telescope Drive Block Diagram





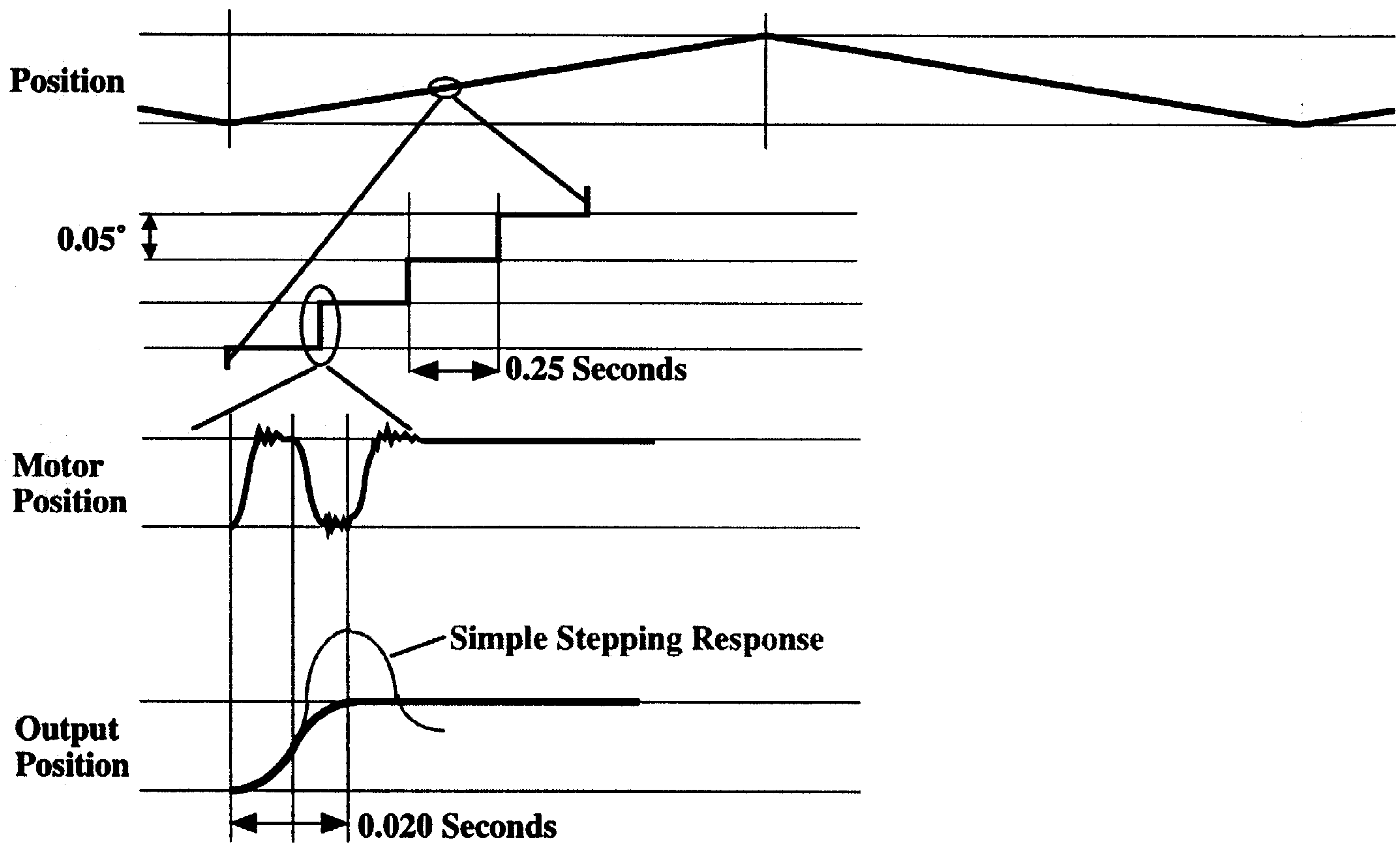


The baseline design for the Telescope Gimbal Drive utilizes a Schaeffer Magnetics Type I Actuator geared-down stepping motor. The power required is three-phase bipolar, producing a six-state sequence. The motor has incremental position encoders to display both motor position and output shaft position. Each encoder has a once per revolution index signal to define absolute position. The mechanisms will be assembled to place the Index points within the Telescopes' normal scan range to maximize the frequency of obtaining absolute position fixes.

Up/Down counters are used to track the motions indicated by the incremental encoders. The Flight Computer can inspect the values in either of these counters as needed.

The Harmonic Drive gearset in the Schaeffer Actuator can be modelled as an ideal gear ratio in series with a spring constant. When Simple Stepping operation of the motor is used, the output ringing due to the spring is of large amplitude and long duration. Retro-Torque Braking operation of the motor will be used to produce short, critically-damped output motions.

TIDI Telescope Timing Diagram



NOTES

The basic Telescope motion is an up- or down-ramp. This ramp comprises the baseline Profiler vertical measurement period. Since there are four Telescopes, successive ramp periods can be devoted to different Telescopes.

Each ramp is made up of a sequence of 0.25 second steps. The minimum step amplitude is 0.05 degrees.

The Motor Position and Output Position traces in the next level of detail illustrate the motor dynamics. The Schaeffer Motor consists of a small-angle stepping motor coupled to the load through a Harmonic Drive gearset. The Harmonic Drive can be modelled by a spring constant and an ideal gear ratio. Because of the spring, one aspect of the response on this time scale is a decoupling between motor actions and output reactions. The motor moves through its step very quickly. The output end of the spring responds to this step function according to the spring constant and the load inertia. This is a simple enough system to model that the motor can then be manipulated on the basis of timing to force a critically-damped output response.

TIDI — Etalon Control Derived Requirements

The Etalon Control & PZT Amp Decks are a Rebuild of the Design used for UARS-HRDI

	HRDI	TIDI
Measurement Dynamic Range	800 nm	same
Functional Temperature Range	-30C to +20C	+15C to +25C
Nominal Post Capacitance	11 pf	same
Nominal Post Sensitivity	0.026 pf / 100 nm	same
Nominal Piezo Voltage Coefficient	4.72 nm / Volt	same
Nominal Piezo Temperature Coefficient	100 nm / degree C	same
Nominal Piezo Dynamic Range	2,500 nm [4.72nm/V * 530 V]	same
D/A Resolution	0.081 nm / bit	same
D/A Dynamic Range	5,300 nm	same
Servo Closed Loop Repeatability	±0.3 nm	±0.15nm
Servo Closed Loop Response Time	14 msec	same
Servo Closed Loop Overshoot	1.4 %	same

NOTES

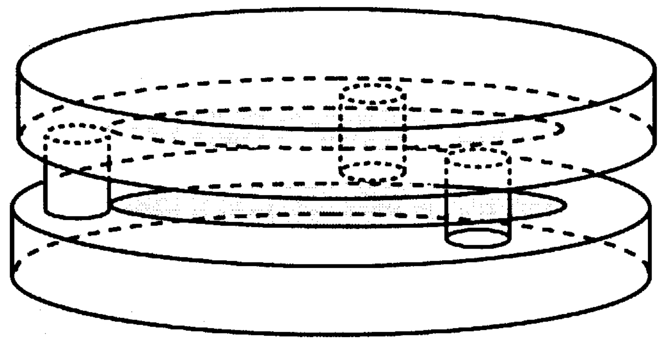
The Capacitively Controlled Etalon (CCE) electronics subsystems were designed as a part of the UARS-HRDI program. An Etalon is a tunable optical resonant cavity composed of two glass plates with reflective coatings. In this case, tuning is accomplished by varying the plate spacing.

The plates are separated by posts composed of a piezoelectric ceramic tube contained between two glass endcaps. The piezoelectric material changes length when a voltage differential is applied to two opposite surfaces. The inner faces of the two endcaps are metalized to form the plates of a capacitor. As a result, the capacitor's plate spacing changes with the Etalon plate spacing. The HRDI specifications for the piezoelectric driver and for the measuring capacitor are given.

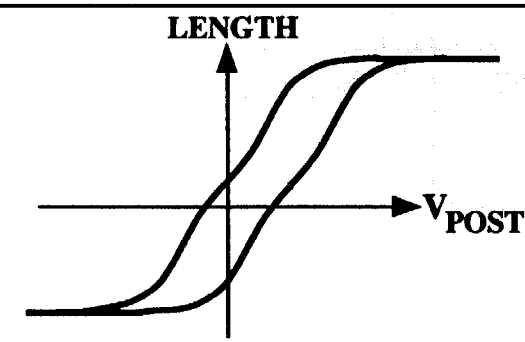
A Digital-to-Analog Converter provided the reference value for the servo loop. The D/A specifications are given. The closed-loop performance measured for the servo are given.

TIDI

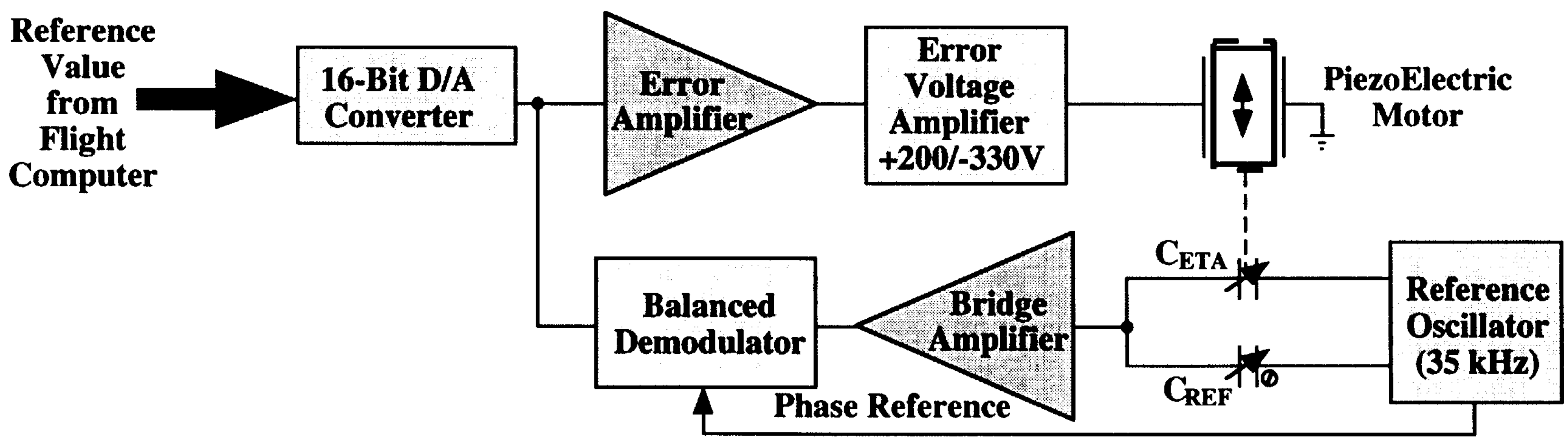
LRE Post Controller



Etalon Plates with Three Piezo Electric Posts



Piezo Electric Transfer Function



PiezoElectric Post Control Loop

NOTES

The Capacitively Controlled Etalon (CCE) electronics subsystems were designed as a part of the UARS-HRDI program. An Etalon is a tunable optical resonant cavity composed of two glass plates with reflective coatings. Tuning is accomplished by varying the plate spacing. The plates are mounted in a three-point suspension, separated by posts made of a piezoelectric ceramic material whose length changes with applied voltage. The plate spacing at each post is measured by a parallel plate capacitor. Independent servo control loops are used for each of the posts. The Flight Computer translates wavelength tuning requests into sets of reference values for the servo loops.

The Etalon Capacitor and a reference capacitor are driven by oppositely-phased high frequency ac voltages. The difference signal is amplified and detected in a balanced demodulator and lowpass filter. The Detector output is compared to a reference signal by an error amplifier. The voltage swing required by the piezoelectric is produced by a gain stage that follows the high input resolution error amplifier.

The piezoelectric transfer function actually follows a hysteresis curve. The drive voltages used are bipolar to maximize dynamic range.

Etalon Reference Value Calculation

The Etalon Reference Value applied to the Piezoelectric Post Control Loop is a function of:

- T Temperature of the plates,
- P Pressure of the atmosphere between the plates,
- λ Desired center wavelength of transmission,

and of the calibration state equivalents, T_0, P_0, and λ_0.

Then:

$$\Delta m = (\lambda - \lambda_0) / \Delta\lambda_{FSR} + \beta (T - T_0) + \gamma (P - P_0),$$

$$\Delta t = (\lambda / 2)(\Delta m - \mathrm{INT}(\Delta m)),$$

$$\Delta t = \alpha_1 \Delta V + \alpha_2 \Delta V^2$$

NOTES

The Flight Computer calculates reference signal values for the Etalon Post servo loops based on stored data from tuning calibrations performed before flight using a tunable dye laser source. The continued validity of the calibration is verified in-flight by measurements against the Calibration Lamps.

The calculation takes into account temperature and pressure changes, relative to the calibration conditions. For HRDI, separate calibration data for nominal atmospheric pressure and for vacuum were obtained, as well as for nominal room temperature and for the preferred -10C HRDI flight operating temperature.

The calculations performed in flight are shown in simplified form. The actual calculations include solving for V, the Reference Value applied to the D/A Converter.

TIDI

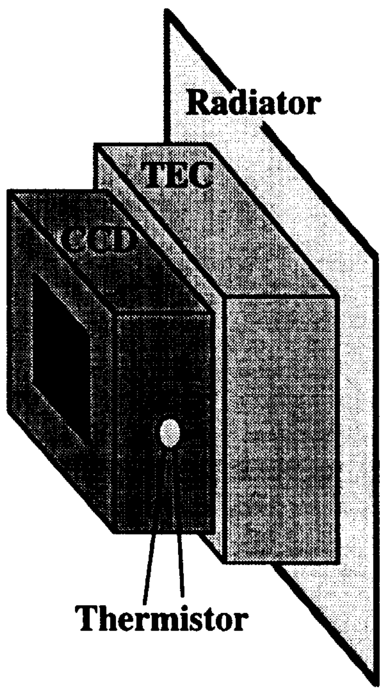
CCD Cooler Derived Requirements

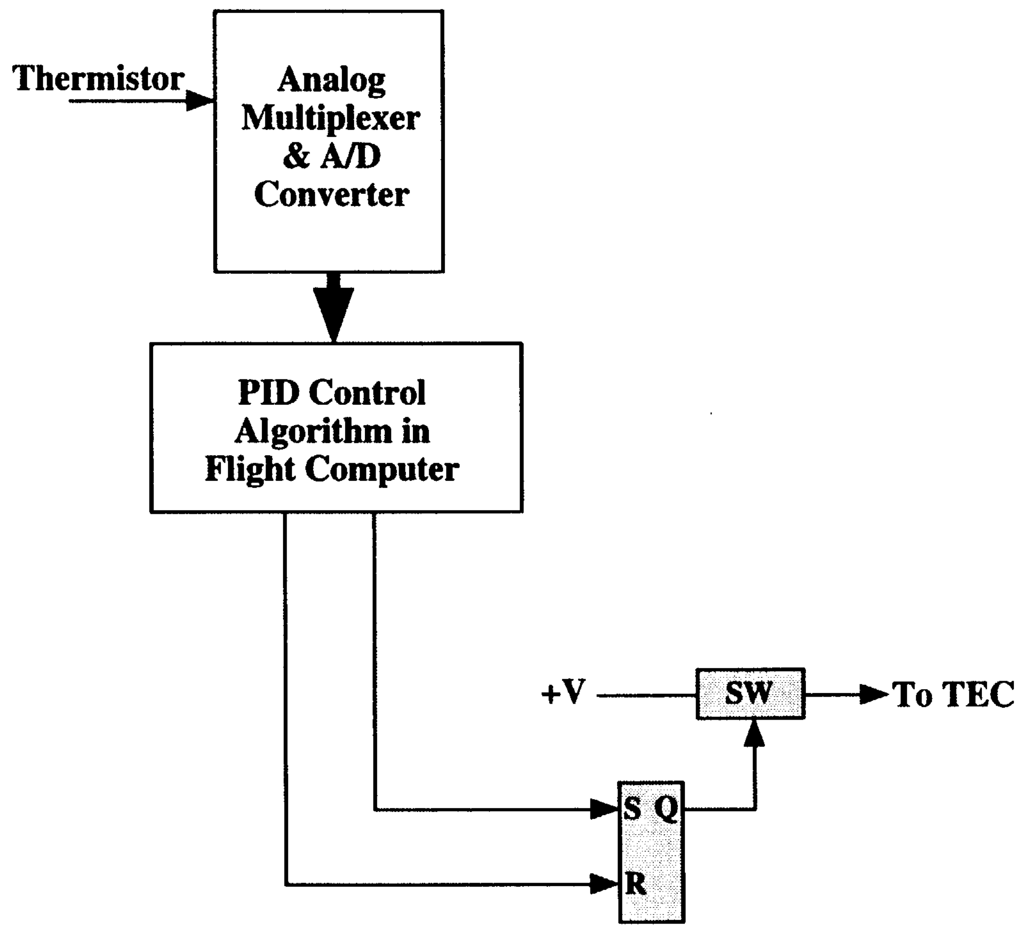
Temperature Setpoint, Profiler	200 degrees Kelvin
Temperature Setpoint, Imager	238 degrees Kelvin
Temperature Stability	±0.1 degrees Centigrade
Supply Voltage	28 Volts
Power Input, Maximum	5 Watts
Power Input, Average, Profiler	0.56 Watts
Power Input, Average, Imager	0.32 Watts

NOTES

The Charge Coupled Device (CCD) Detector has to be cooled to reduce Dark Current, increase Charge Transfer Efficiency, and reduce radiation damage effects. The CCD is mounted on the cold side of a Thermo-Electric Cooler (TEC) array. The hot side of the TEC is mounted to a Radiator that sheds the heat to space. The temperature setpoints are discussed in the Detectors presentation.

TIDI — CCD Cooler Power Control





NOTES

A Thermoelectric Cooler is an array of Peltier Effect junctions, arranged to cool the CCD Detector and shed the heat generated via a radiator to space.

The temperature of the CCD Detector is monitored via a thermistor mounted on it. The thermistor is read through the Flight Computer I/O Deck analog input hardware. The power switch for the Thermoelectric Cooler is pulse width modulated by ON/OFF signals produced by the Flight Computer according to calculations based on the thermistor measurements.

Telescope Cover Release Heater Derived Requirements

Supply Voltage	28 Volts
Power Input per Telescope	6 Watts
Total Power	24 Watts (4 on at same time)
Time	~ 10 minutes 1/mission

Each Telescope Cover is held in place by a latching mechanism that is restrained by Biphenyl wax. This material has the property of subliming away in a vacuum. When this happens, the latching mechanism releases and the cover opens. In the absence of added heat, the subliming process occurs, but very slowly: typically a week. By heating it, the process completes in under ten minutes. Exactly this approach was used for telescope covers on DE-FPI.

The heater required is an ordinary carbon composition resistor, embedded in the Biphenyl material. Power is applied and, later, removed, under control of the Flight Computer. The schematic (not shown) is a one-bit latch and a switch transistor. This is the same as that presented for the TEC Power Control, without the need for closed-loop temperature control.

Issues for Next Period – Mechanisms

- Develop retrotorque design for Telescope
- Develop design for opening telescope covers
- Develop holding servo design for Scene Selector

NOTES

Detailed development work is required to validate the motion control plan for the Telescopes. In part, this is dependent on completion of design of the telescope thermal and optical fiber bundle interfaces.

A Biphenyl wax latch design was proven on DE-FPI. The specifics of performing this task for the TIDI configuration have yet to be undertaken. Verification of the completed configuration includes both proving non-opening storage performance as well as assured opening performance.

Detailed development for the Scene Selector position-holding quasi-analog servo remains to be performed.

Detectors

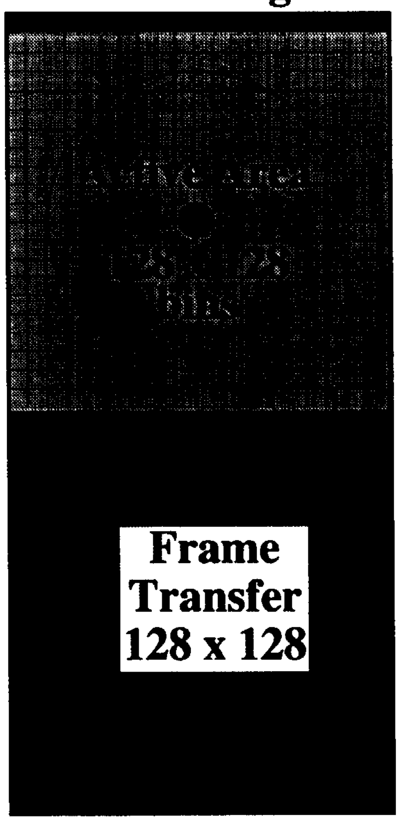
Brian C. Kennedy

TIDI

Place Holder

NOTES:

TIDI Profiler Rectangular CCD Requirements



- Spectral Range 550 - 900 nm
- Quantum Efficiency - as High as Possible
  >80% @ 550, >30% @ 900
- Aperture Finesse >30
- Bin Size ~ 20 x 20 μ –> Loral 2*(15 x 15 μ)
- Maximum Signal, 10^3 electrons/bin
- Thermal Background < 10^{-2} electrons/bin/Sec @ 200°K
  (25 pA/cm^2 @ 20°C) -> MPP
- Readout Noise < 10 electrons rms per read
- Readout Rate < 200 kbins/sec
- Vertical Line Transfer Rate < 1μSec /line
- Time Line -
- 0 to 236 ms Collect Signal in Active Area
  Readout Previous Signal Under Mask
- 236 to 236.1 ms Transfer Data from Active Area to
  Mask Area
- 236.1 to 255.9 ms Wait for Mechanisms
- 255.9 to 256.0 ms Transfer Active Area Away from
  Mask Area to Clear the Active Area
- Repeat Sequence

NOTES:

Profiler Detector Trade Studies

Three Approaches were Considered:

- Conventional Rectangular CCD as Proposed
- Circular CCD Developed by BASD
- Circle to Line Interferometer Optical (CLIO) System

- Major Effort Focused on Rectangular CCD:
  - Most Developed
  - Currently in use in Ground Based Applications
  - Results can be Applied to Other Techniques
- Current Baseline is Conventional Rectangular
  Although Other Two Methods have Significant Advantages

NOTES:

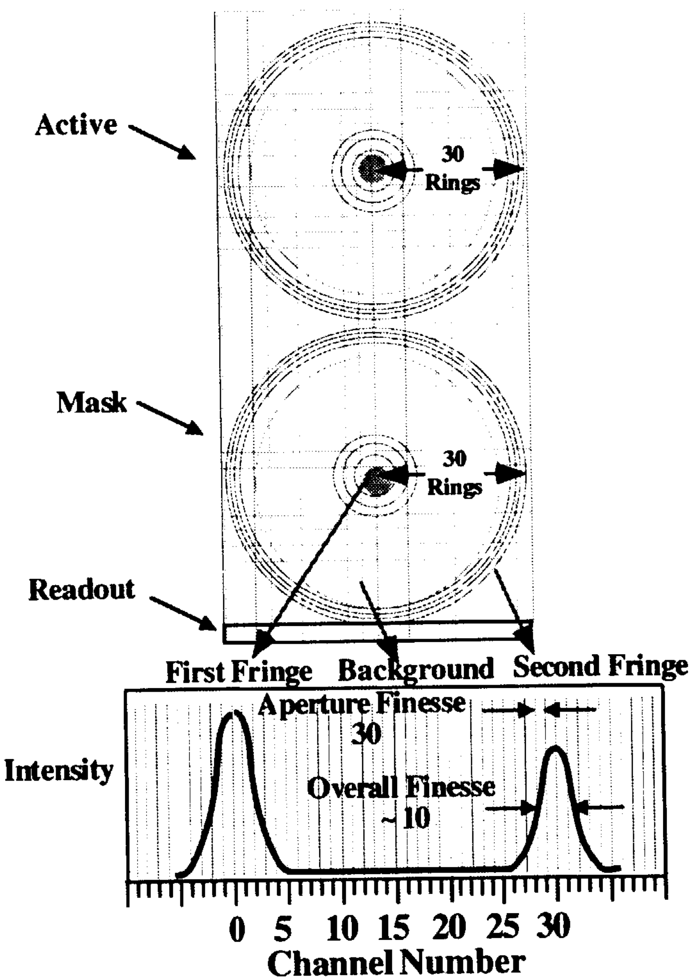
Profiler Detectors Comparison

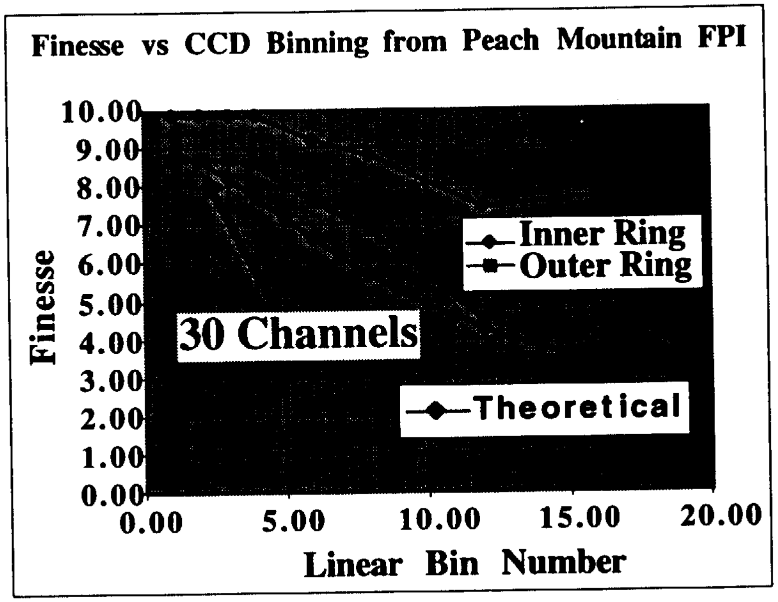
	Rectangular CCD	Concentric CCD	CLIO
Spectral Range	550-900 nm	Same	Same
Quantum Efficiency	> 80/30%	Same	Same
Thermal Background, 20°C	25 pA/cm^2	Same	Same
Detector Size (Active)	3.8 x 7.6 mm	3 x 3 mm	3 x 3 mm
Bins/Channel	400	4	1
Image Transfer Time, mS	0.128	10	0.15
Readout Time, ms, 30 Ch's	82	0.3	0.15
Charge Transfers, max	256	67	114
CTE Effects	Significant	Less significant	Significant
Imaging Optic	Normal	Normal	Special
Relative CPU Processing	1	0.01	0.01

NOTES:

TIDI Profiler Rectangular CCD Finesse

128 x 128 bins



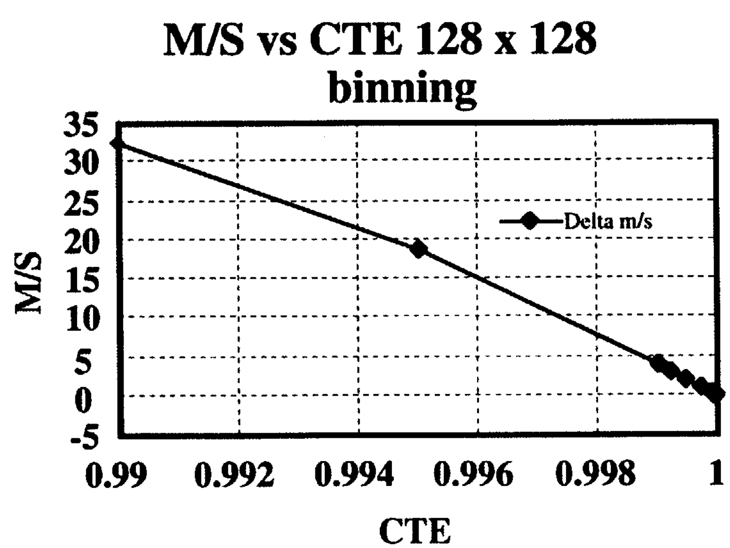


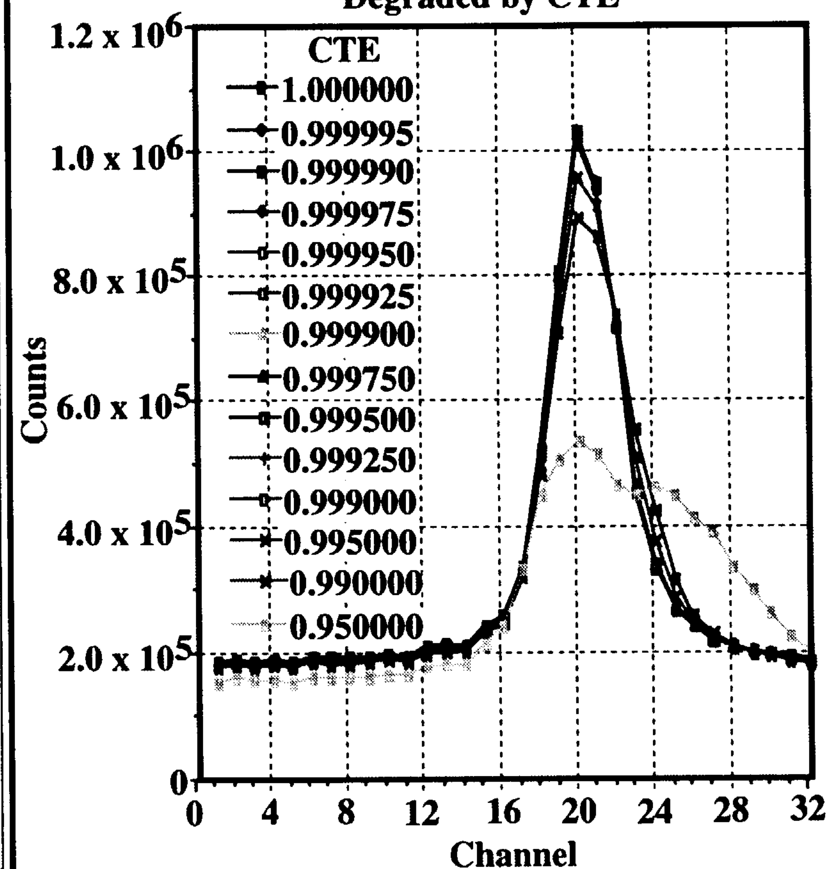
Theoretical Finesse $\frac{1}{F^2} = \sum \frac{1}{F_n^2}$

NOTES:

TIDI Rectangular CCD CTE vs FPI Peak Shape

CTE > 0.99, Further Analysis may Allow a Smaller Value
On Orbit Calibration:
Monitor Peak Shapes
Use Cal Lamps

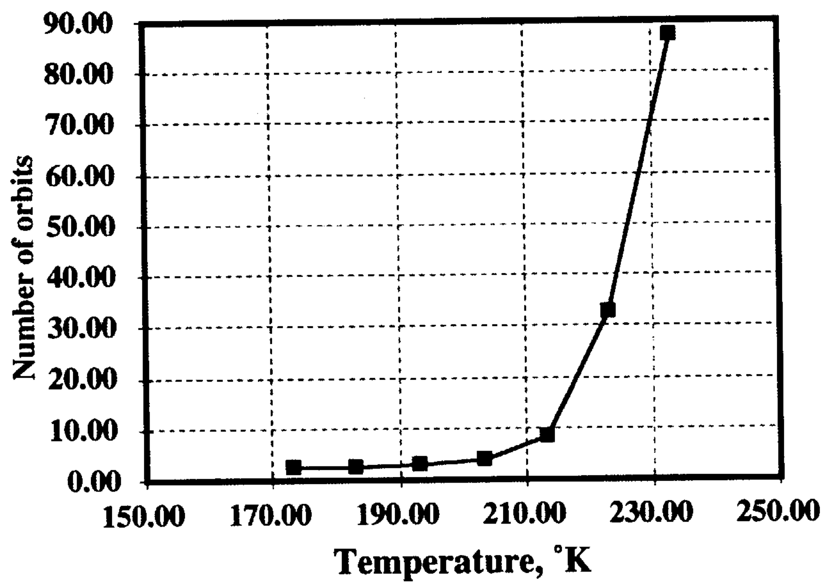




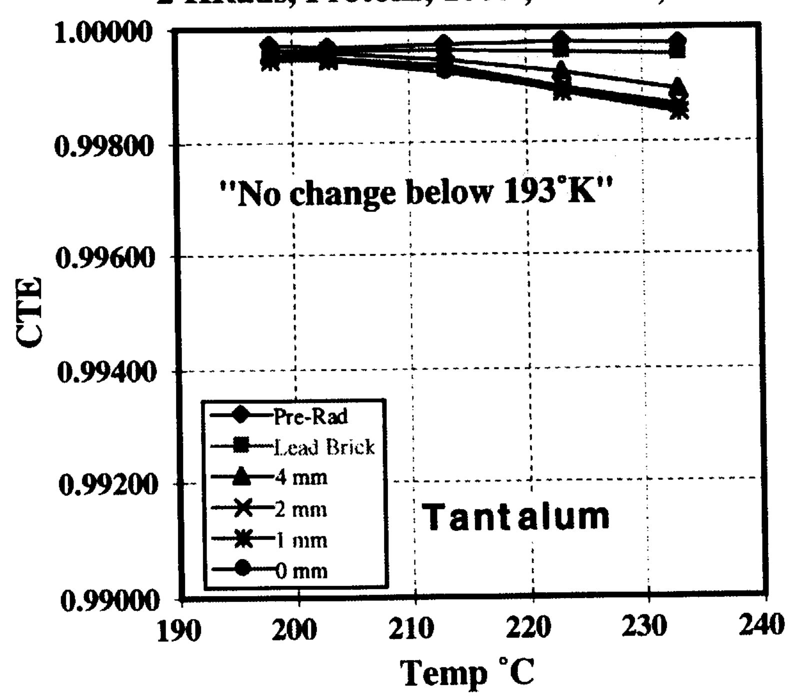
NOTES:

TIDI Rectangular CCD CTE & Temperature

557.7 nm Integration Time for 0.5 m/s Zero Wind

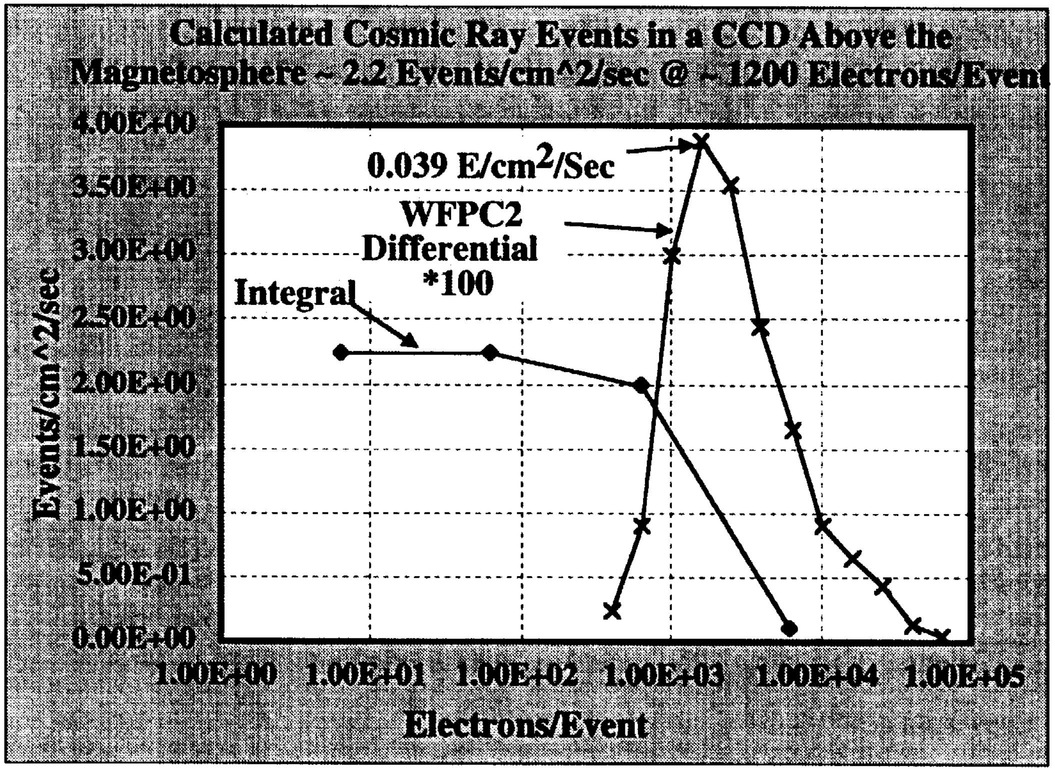


CTE vs T, Tek 1024x1024 CCD
2 KRads, Protons, 100e-, Murata, et. al.



NOTES:

Cosmic Ray Events



WFPC2 Shows 1.25 Events/cm^2/sec @ ~ 1200 e/Event

WFPC2 is at 580 km 28° Inclination

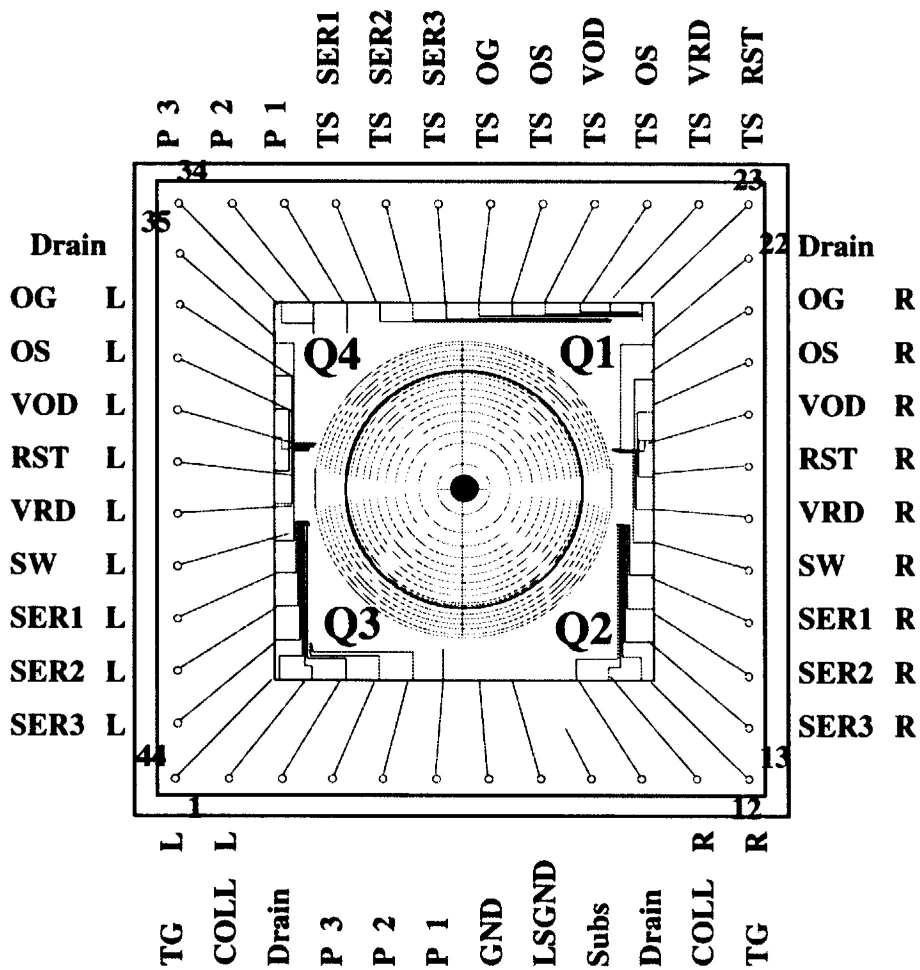
Therefore, TIDI Orbit is nearer to "Above the Magnetosphere", ~ 2 Events/cm^2/sec @ ~ 1000 Electrons/Event are used in TIDI Calculations

Cosmic Ray Events are Removed by Comparing Adjacent Data, Idenifying Unusually Large Signals, Removing and Filling in with Interpolation

NOTES:

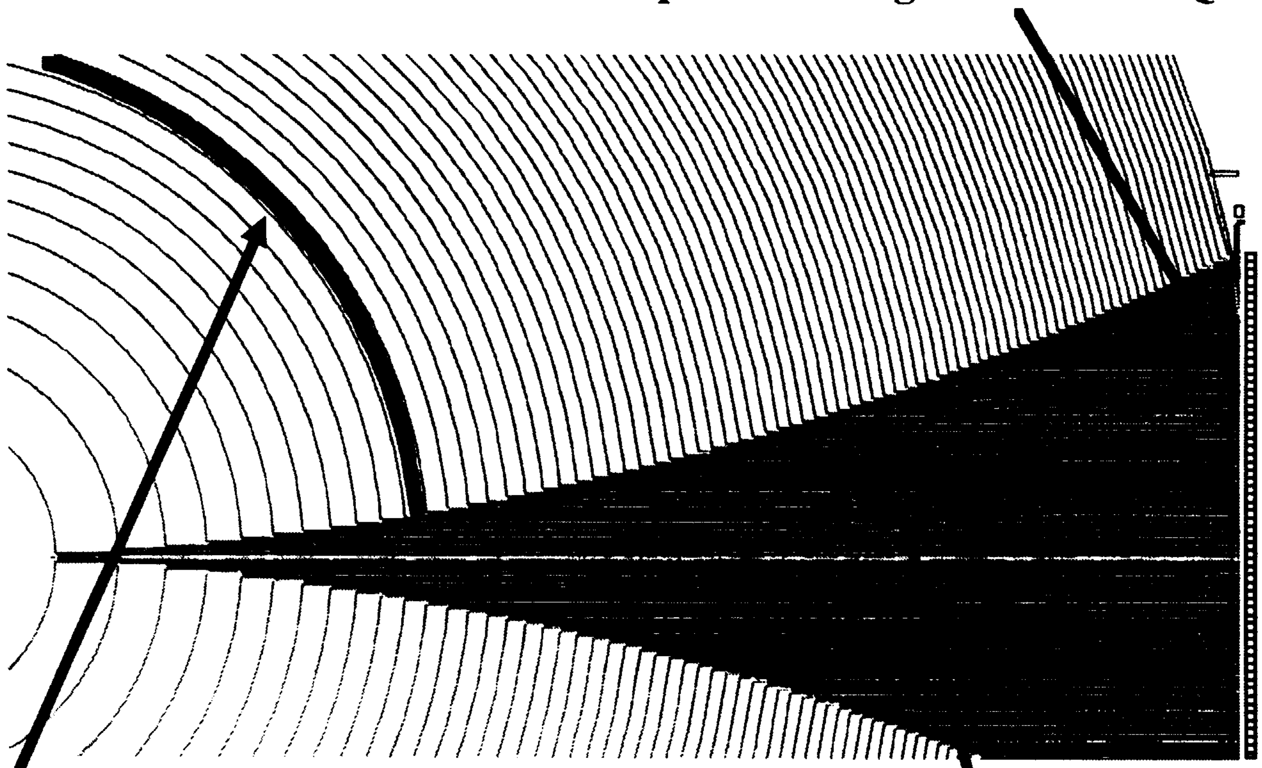
TIDI

Profiler Cirular CCD Overview



NOTES:

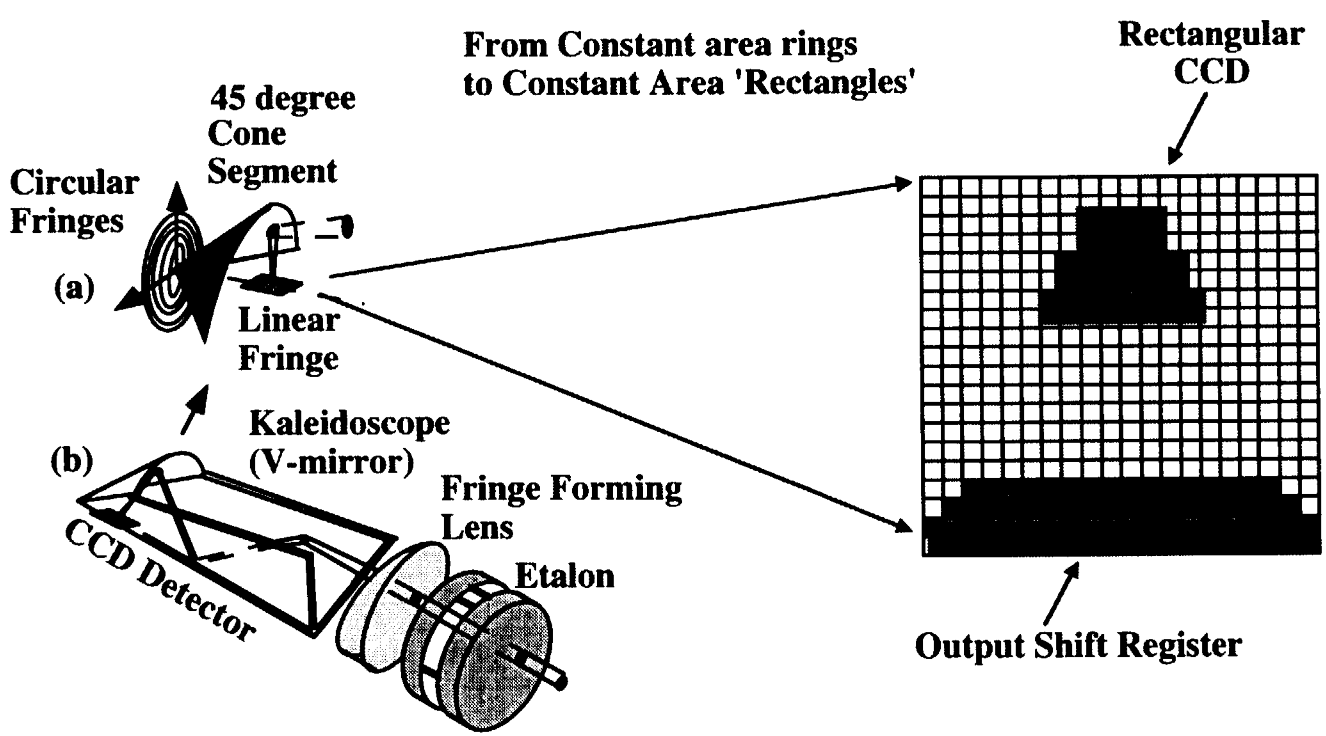
Profiler Circular CCD Operation



NOTES:

Profiler, CLIO

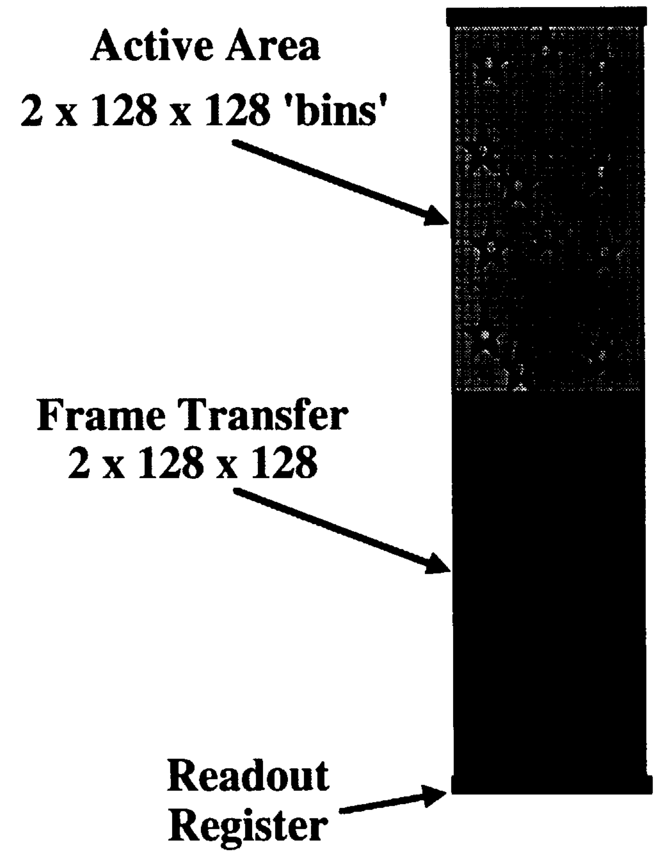
Cirle to Line Interferometer Optic, CLIO



NOTES:

TIDI Imager CCD Derived Requirements

- Spectral Range 550 - 900 nm
- Quantum Efficiency - as high as possible
  >80% @ 550, >30% @ 550
- Bin Size ~ < 30 x 30 μ (Fiber Optic 50μ)
  –> Loral 2*(15 x 15μ)
- Maximum Signal, 10^4 electrons/bin
- Thermal Background < 1 e/bin/sec @ 238°K
  (25 pA/cm^2/Sec) -> MPP
- Readout noise < 10 electrons rms per read
- Readout Rate < 200 kbins/sec
- Vertical Line Transfer Rate < 1μSec /line



NOTES:

Imager Detector Trade Studies

Three Approaches were Considered:

- Michelson as Proposed
- Remove Michelson, Retain CCD for Star Detection
- Utilize Four Separate 'Heads"

- Michelson can do both Scientific Imaging and Star Sensing. Requires Canadian Support and was not Further Considered in this Study
- Current Baseline is Conventional Rectangular CCD with Separate Filter Wheel and Scene Selector

NOTES:

Imager Detector Separate “Heads”

- Proposed: Four Separate 'Heads', each with a CCD and Simple Optics
- Pros -
  Eliminates need for Imaging FO Bundle, Potential need for Dove Prism and Mechanism, Scene Selector and Filter Wheel
- Cons -
  No Longer does Star Sensing Through Telescopes
- Conclusion -
  Retain Current Single CCD Baseline

NOTES:

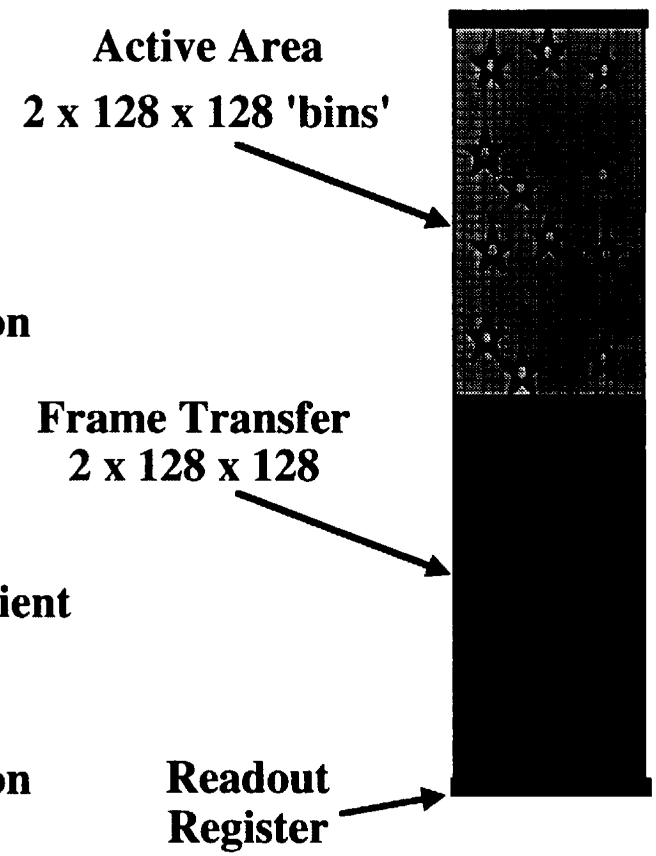
Imager CCD Operation

Star Sensing -

- Select Telescope, unused by Profiler
- Integrate 1 Sec -> 100 cnts, 4^{th} Magnitude Star
- Transfer from Active Area to Masked Area
- Readout Masked Area while Repeating Integration in Active Area
- Select 3 Brightest Stars for Data Transfer
- Repeat sequence

Wave Sensing -

- Select Fixed Telescope unused by Profiler and Orient
- Integrate for 3 Sec
- Transfer from Active Area to Masked Area
- Readout Masked Area while Repeating Integration in Active Area
- Repeat sequence



NOTES:

TIDI CCD Detector Thermal Design Derived Requirments

- Operating Temperatures -
  - Imager, 238˚K, above CTE Effect, Low Enough Thermal Background
  - Profiler, 200˚K, Below CTE Effect
- Radiator Size and Power
  - Minimize

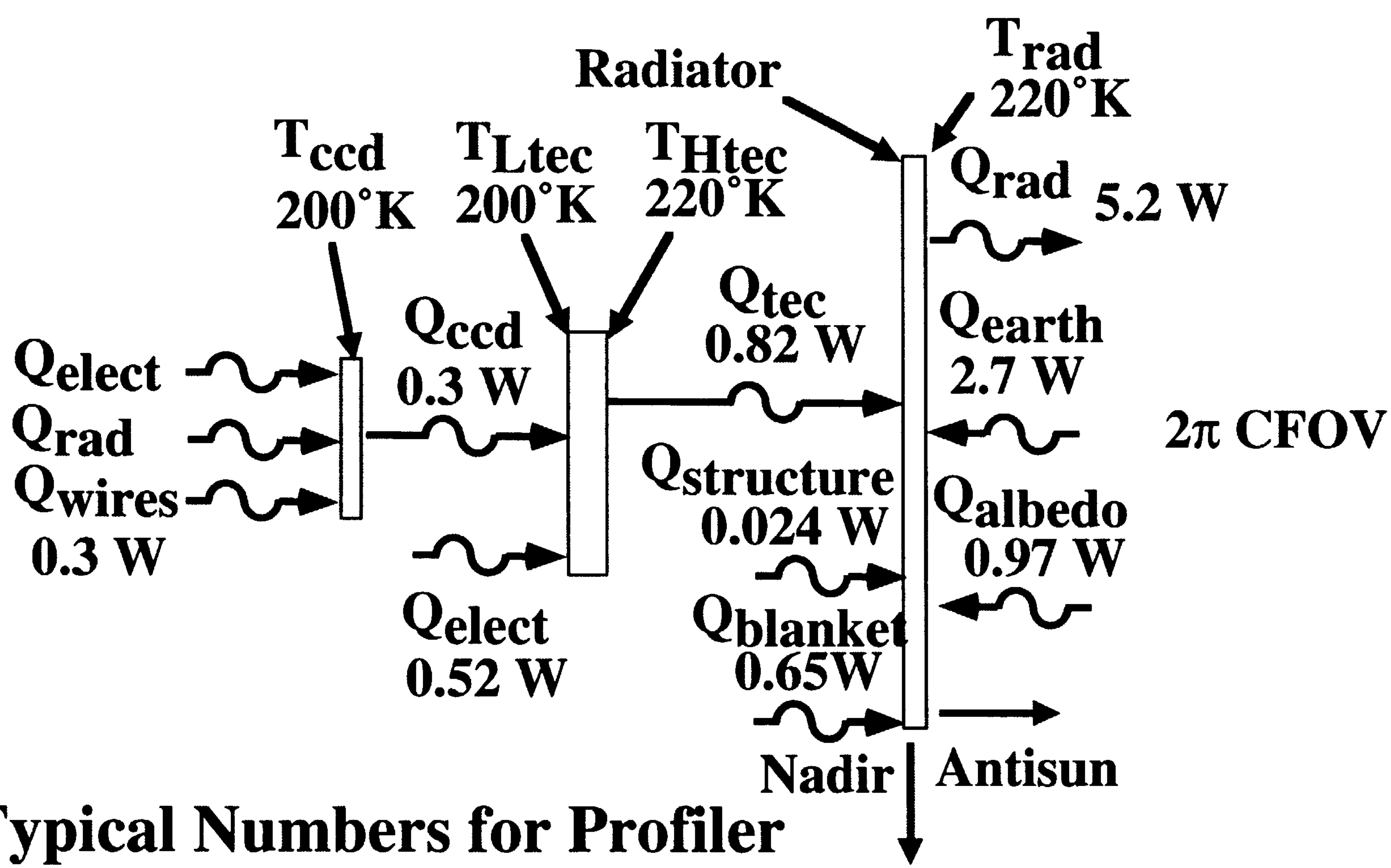
NOTES:

TIDI CCD Detector Thermal Design Approaches

- Direct TEC Couple to Spacecraft Baseplate
  Large Temperature Drop -> High TEC Power
  SC still must Provide Adequate Radiator Area
- Each Detector has it's own TEC and Radiator
  Leads to Simplest Radiator and TEC, also
  Permits Easier Testing Unless Earth Shielding
  is Required
- "Passive" Radiators
  Requires a Heater for Temperature Control, so
  more Complicated than TEC/Unshielded Radiator
  due to more Complex Radiator
- Current Study has Focused on TEC/Simple Radiator

NOTES:

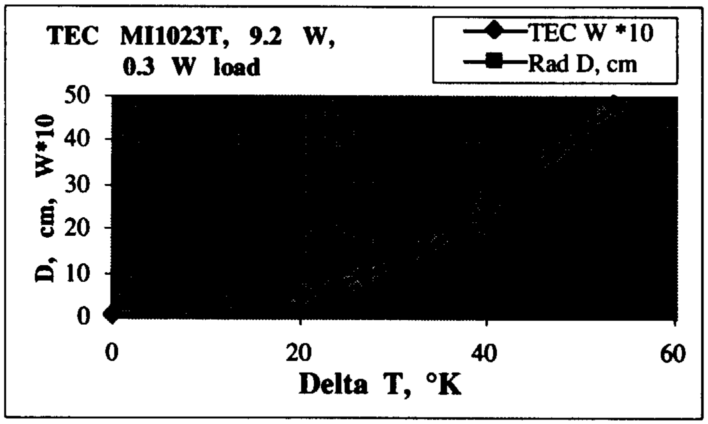
TIDI CCD Detector Thermal Design Block Diagram

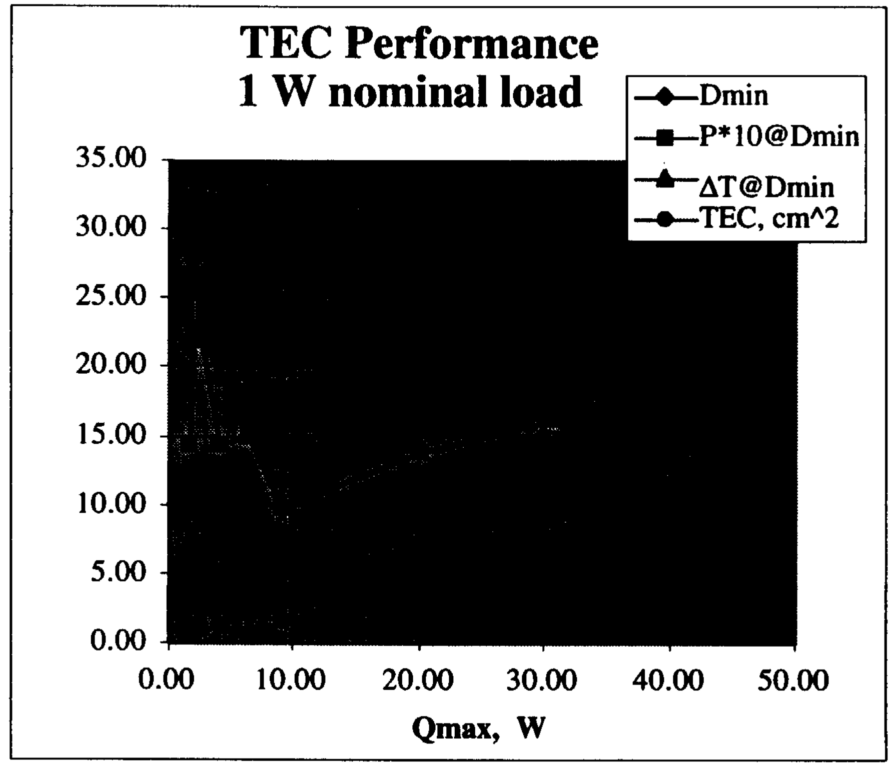


Typical Numbers for Profiler

NOTES:

Profiler Detector Thermal Analysis



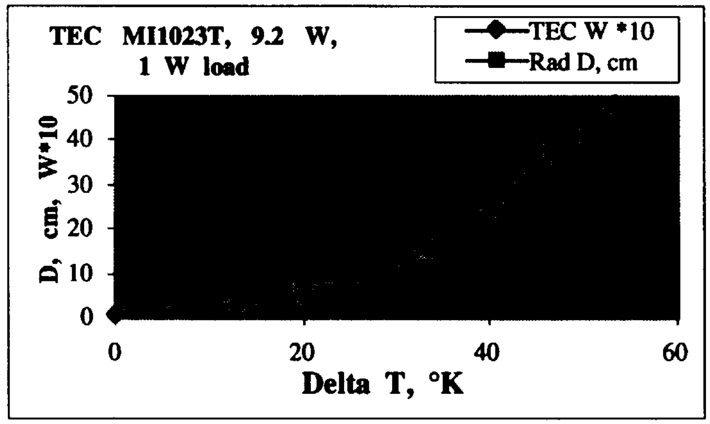


- CCD Thermal Load, 300 mW
- CCD Temperature, 200 °K
- Surrounding Temperatures, 293°K
- Thermal Blanket Emissivity, 0.002
- Changing CCD Temp to 173°K Radiator goes to ~ 80 x 80 cm

- Dmin is square radiator linear dimension, cm
- P*10@Dmin is TEC electrical input power, multiply scale by 10 to get W.
- ΔT@Dmin is Delta Temperature from CCD to Radiator
- TEC, cm^2 is TEC area

NOTES:

Imager Detector Thermal Analysis



- CCD Thermal Load, 300 mW
- CCD Temperature, 238 °K
  (Above CTE Effect)
- Surrounding Temperatures,
  293°K
- Thermal Blanket Emissivity,
  0.002
- Radiator Size Becomes
  8.2 x 8.2 cm (use 10 x 10 cm)
- TEC Power Becomes
  0.32 W

NOTES:

Detectors, Future Activities

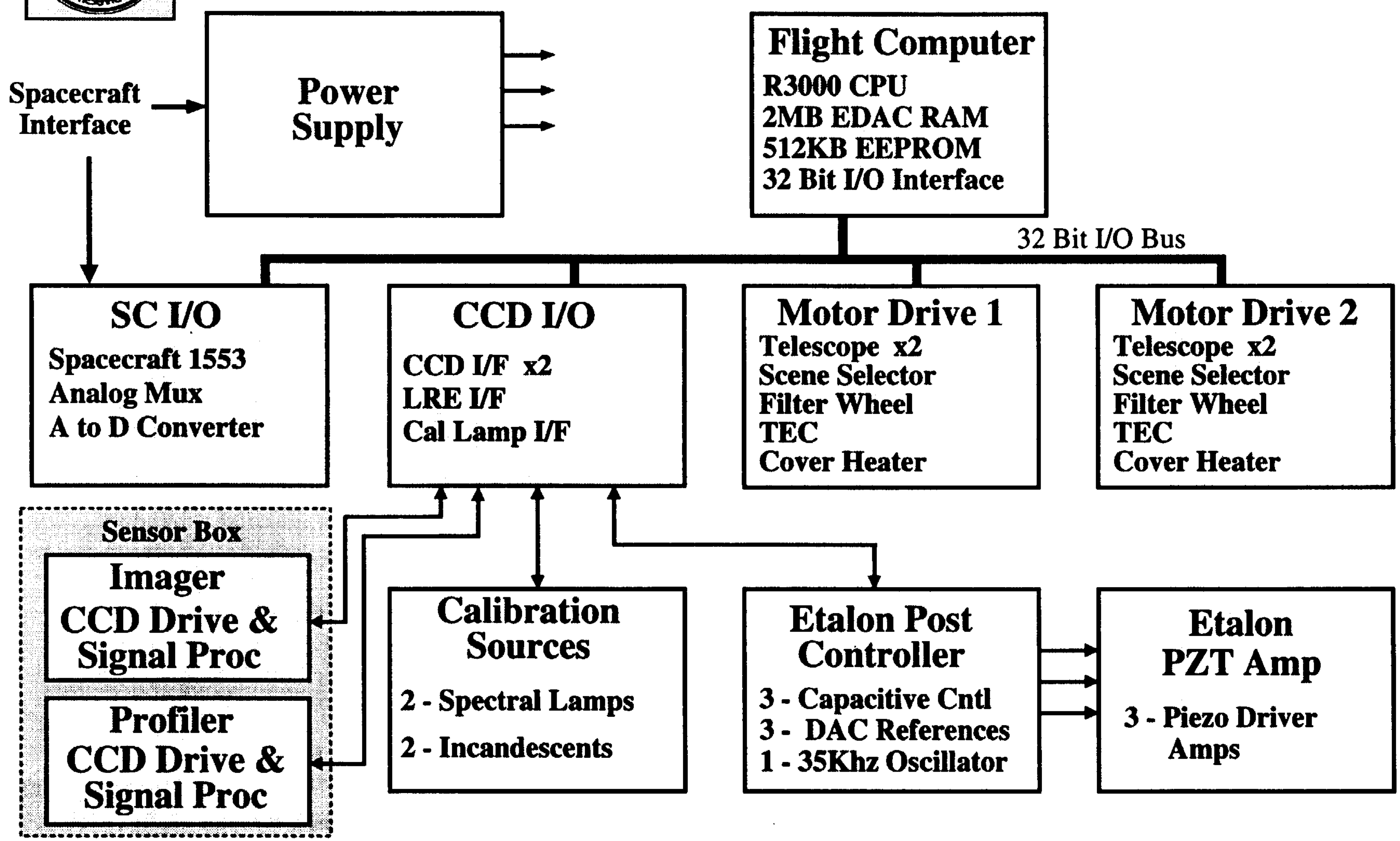
- Thermal/CTE Design for CCD's - hire Consultant for Cross Check to Verify CTE Performance
- Reexamine Zero Wind Measurement in Light of New Calibration Lamps. Can we Raise Profiler CCD Operating Temperature to 238°K?
- Examine CTE and Cosmic Ray Effects and Strategies for Circular CCE and CLIO
- Continue to Refine Mounting and Thermal Models

NOTES:

Electronics

Walter H. Pinkus

TIDI Electrical Block Diagram



NOTES:

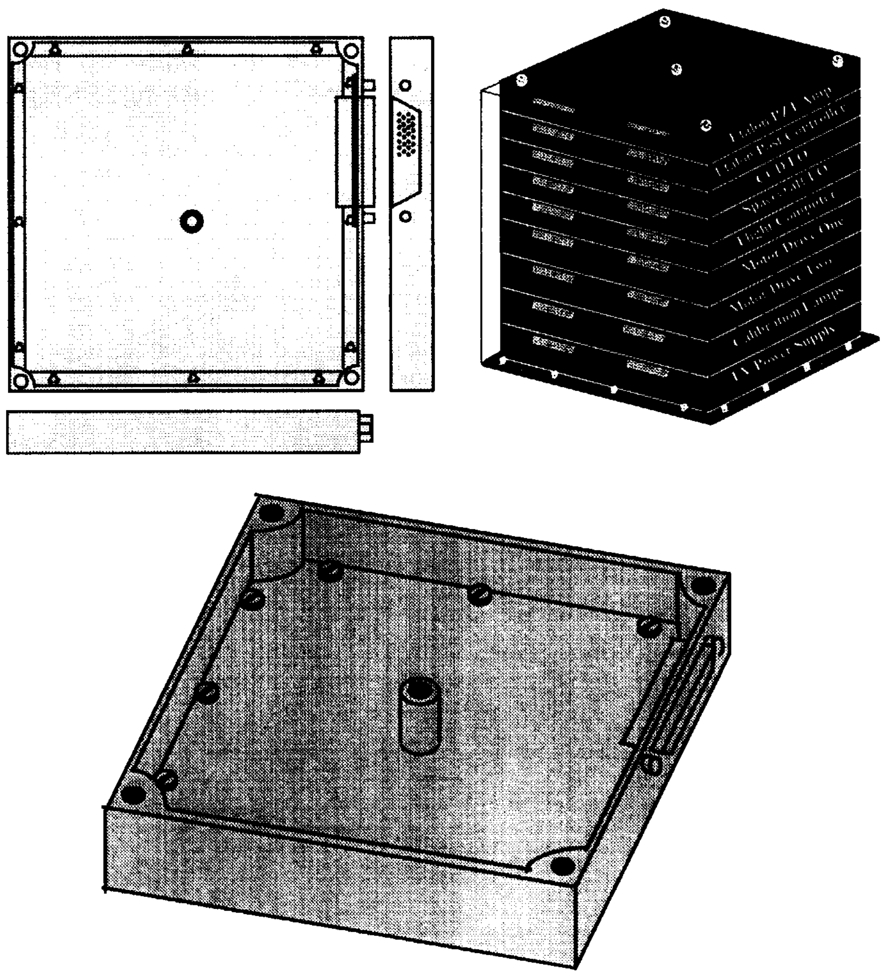
The TIDI electrical system includes shared Services, as well as Profiler-Specific, and Imager-Specific subsystems. Some of the Profiler-Specific and Imager-Specific subsystems have to be located with the optical subsystems due to temperature stability or difficult interfacing requirements. Most subsystems, however, do not have stringent requirements and will be assembled into a package that can be placed independent of the optical systems. In all, the system design has been partitioned into eleven individual circuit cards.

Each CCD Drive Electronics needs to be located close to its CCD for short wiring reasons. The Profiler and the Imager CCD Processor subsystems have somewhat different functional requirements, but will share development efforts. Each of these subsystems will occupy one circuit card.

The other nine Electronics decks will be packaged in the Electronics Stack which can be placed independent of the optical systems.

TIDI

Electronics Packaging & Harnessing



- Frame and Stacking Rod Assembly, forms rigid structural unit.
- Each Circuit Card Individually Supported and fully accessible from both faces.
- Frame supports connectors and forms thermal path to baseplate.
- Added bracket supports Interface connectors.
- Use History Includes Delta & Shuttle Launches.

NOTES:

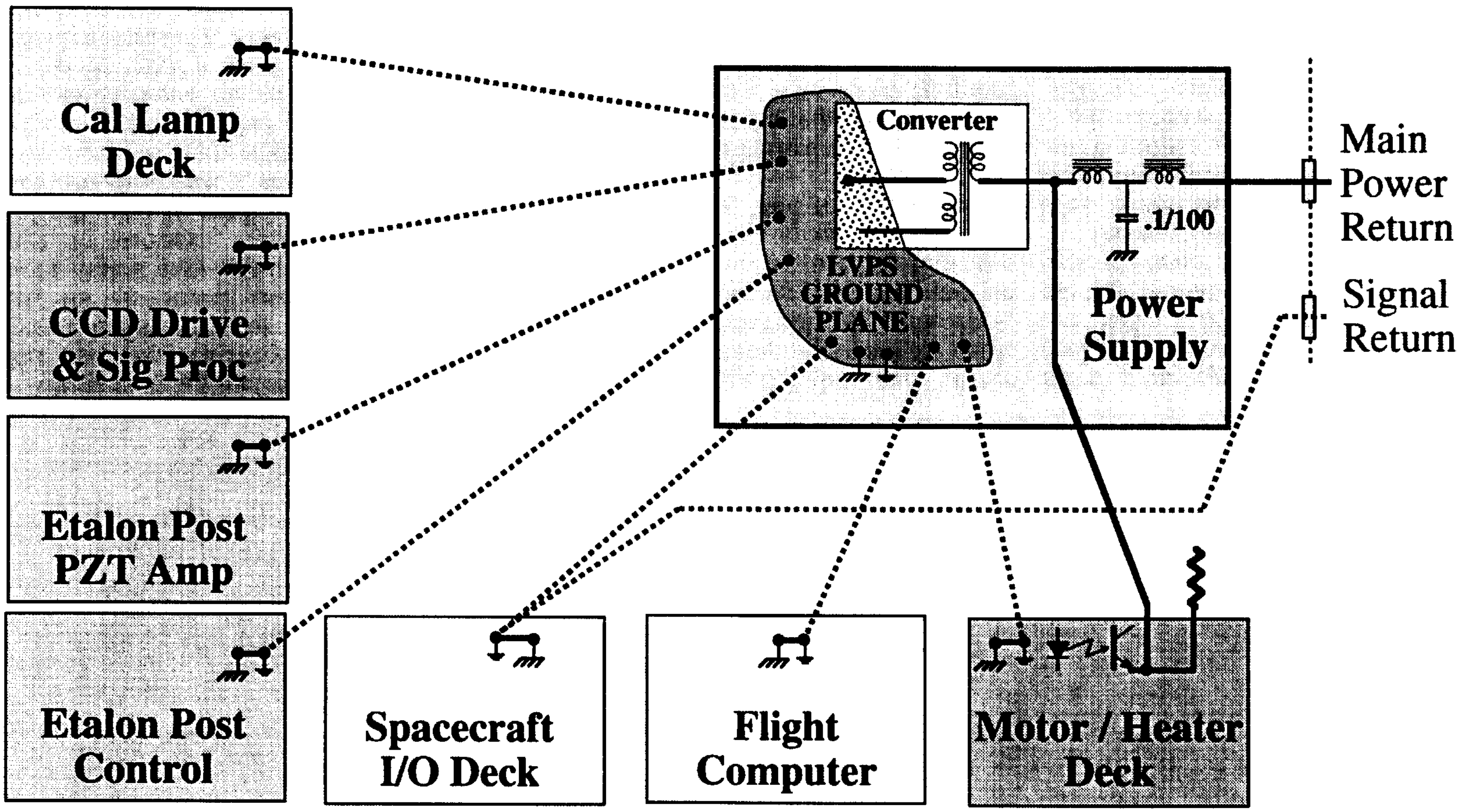
The packaging method illustrated has been used successfully by The Space Physics Laboratory for many years. In part, its continued use is due to its demonstrated easy adaptability to a wide range of situations.

Each circuit card is contained in a machined aluminum frame. All four edges of the card are supported by and screwed down to a rail at the bottom of the frame. The combination of circuit card and frame is commonly called a "deck." An assembled deck complement is called a "stack." The assembled decks are separated with flat plates that turn each deck into a fully shielded unit. Bosses with through-holes are placed in each corner of the frame. In the example shown, a center support is used to restrain the board center. The stack is turned into a rigid mass by passing rods through the corner holes and center supports and threading nuts onto the ends. Depending on the dimensions of the deck, additional side stacking rods and multiple center supports may be used to limit the dimensions of free spans. Computer modelling is now used to verify design performance.

In practice, this basic deck frame design is modified to meet the requirements of the circuits contained. The most frequent examples are adding connector cutouts to the walls and fastening heat-generating devices directly to the walls to conduct the heat away. Other examples include extending the width of mounting rails to support heavy components, making the box height greater to accomodate oversize components, and subdividing the box for shielding purposes. The stack illustrated has a mounting flange added to the bottom deck. Stacks have also been designed with the decks standing on edge, each deck having mounting ears to pull it down against a temperature-controlled plate.

The rigidity of these stacks is such that they have been employed to create mounting pedestals for associated sensors. An example of this was the Induced Environmental Contamination Monitor (IECM) Quadrupole Mass Spectrometer instrument that was flown several times on the early Engineering flights of the Space Shuttle. The Electronics Stack was used as a support for the Quadrupole Sensor and survived Shuttle Prototype vibration specifications, as well as several actual flights, and has recently been refurbished and delivered for use on an Air Force satellite.

Grounding Plan



NOTES:

The Main Power Bus Return is isolated from Secondary Signal/Power Ground and Chassis Ground. Generally, Secondary Signal/Power Ground is connected to Chassis Ground in all decks. Most of these decks contain high-frequency circuitry and past experience has indicated that this is the most effective way of reducing noise.

For reasons of power efficiency, the heavy motor and heater loads will be operated from the Main Power Bus, without the power going through the Power Converter. These loads will be returned to the Main Power Return. Isolation will be maintained by inserting opto-isolators in the control signal paths.

TIDI Motor/Heater Deck Derived Requirements

- Telescope Elevation-Axis Gimbal Motor/Encoder Interface, x2
  - **Motor & Output Position Encoders**
  - **Three-Phase, Six-State Power Switching**
- Filter Wheel Motor/Encoder Interface
  - **Motor Position Encoder**
  - **Two-Phase, Four-State Power Switching**
- Scene Selector Motor/Encoder Interface
  - **Motor Position Encoder**
  - **Analog Servo Station-Keeping**
  - **Two-Phase, Four-State Power Switching**
- Thermoelectric Cooler Power Switching
  - **PWM-Controlled On/Off Switch**
- Telescope Cover Release Heater
  - **On/Off Switch**

NOTES:

The Motor/Heater Interface Deck performs power switching to operate a number of mechanisms in the TIDI instrumentation. Since some of these functions occur independently in both the Profiler and the Imager, two identical decks will be built. The control output needed, as well as the feedback information available for each mechanism is listed. Detailed functional descriptions of each of the mechanisms and associated electronics have been provided in the Mechanisms Section of this presentation.

The Telescope Gimbal Drive is a geared-down stepping motor. The power required is three-phase bipolar, producing a six-state sequence. The motor has incremental position encoders to display both motor position and output shaft position. Each encoder has a once per revolution index signal to define absolute position. The mechanisms will be assembled to place the Index points within the Telescopes' normal scan range to maximize the frequency of obtaining absolute position fixes.

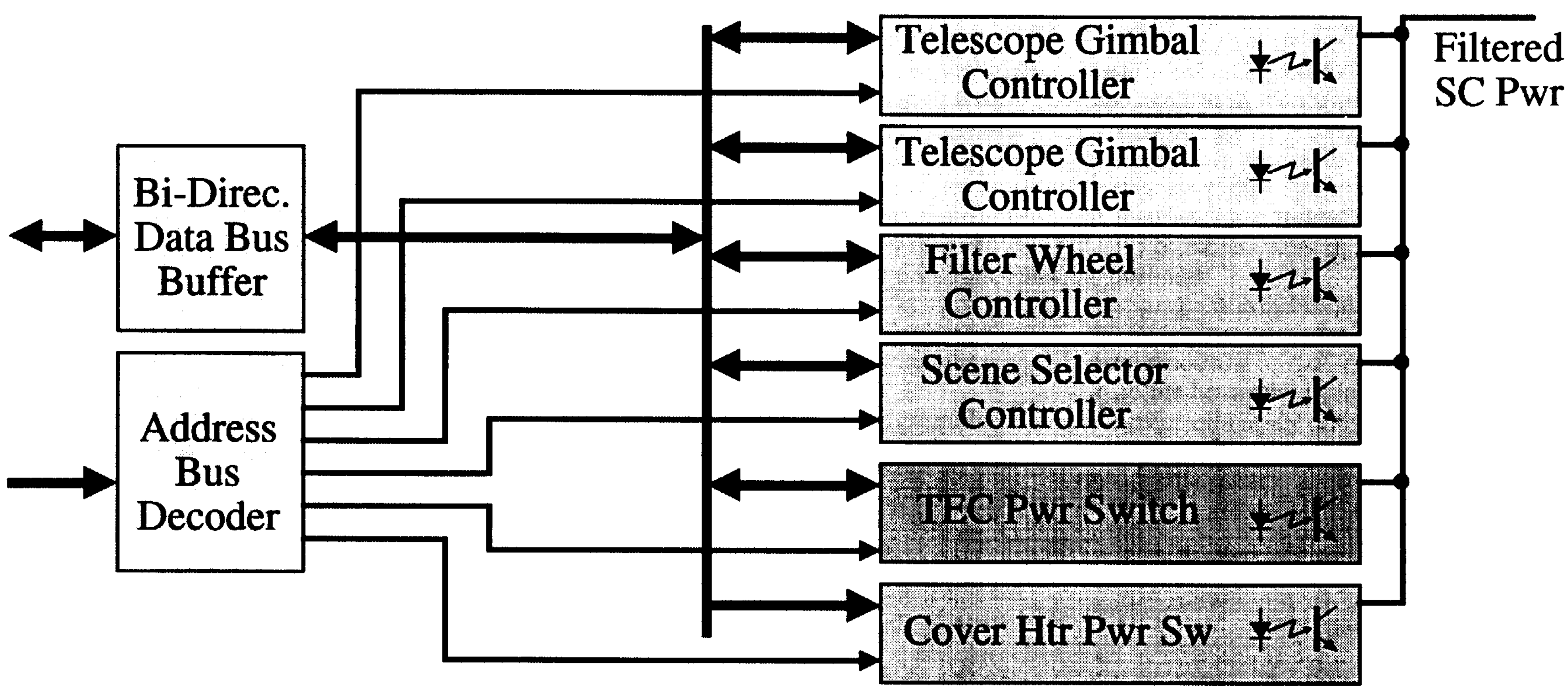
The Filter Wheel Drive is an eight-position device driven directly by a large-angle stepping motor. The power required is two-phase bipolar, producing a four-state sequence. A feedback motion control system is used because the mechanism is torque-limited. The mechanism has an incremental position encoder to display detailed position, a one-of-eight absolute position encoder to display whole step position, and an eight-per-revolution filter-center index signal to define absolute position for the clock track.

The Scene Selector Drive is an eight-position device driven directly by a large-angle stepping motor. The power required is two-phase bipolar, producing a four-state sequence. The mechanism has a one-of-eight absolute position encoder to display whole step position, as well as an eight-per-revolution position-center index signal and a sine/cosine clock track to define detailed absolute position. Motor commutation and on/off control of the power switches is derived from feedback from the encoder and from control produced by the Flight Computer.

The temperature of the CCD Detector is monitored via a thermistor mounted on it that is read through the Spacecraft I/O Deck analog input hardware. The Flight Computer directly controls pulse width modulation of the on-time of the power switch for the Thermoelectric Cooler in response to the thermistor readings. .

The telescope cover release heater is powered once after launch to allow the telescope cover to open. Each telescope cover will have redundant heaters with one heater controlled by each motor drive deck. The Flight Computer will control on/off switching of the heaters.

Motor / Heater Deck Block Diagram



NOTES:

The Motor/Heater Interface Deck performs power switching to operate a number of mechanisms in the TIDI instrumentation. Since some of these functions occur independently in both the Profiler and the Imager, two decks will be built. The deck for the Profiler will be fully populated, while that for the Imager will only include the functions it needs. The control output needed, as well as the feedback information available for each mechanism is listed. Functional descriptions of each of the mechanisms and associated electronics have been provided in the Mechanisms Section of this presentation. All of the loads receive power from the Main Power Bus Input, tapped off after the Input Filters and Soft Start Circuit in the Power Supply, and are returned to the Main Power Bus Return. Ground isolation is maintained by opto-coupling the control signals to the switches.

There are four Telescopes requiring independent drive circuits. The power required is three-phase bipolar, producing a six-state sequence. The motor has incremental position encoders to display both motor position and output shaft position.

The Filter Wheel Drive is an eight-position device driven directly by a large-angle stepping motor requiring two-phase bipolar power, producing a four-state sequence. The mechanism has an incremental position encoder, a one-of-eight absolute position encoder to display whole step position, and an eight-per-revolution filter-center index signal to define absolute position for the clock track.

The Scene Selector Drive is an eight-position device driven directly by a large-angle stepping motor requiring two-phase bipolar power, producing a four-state sequence. An analog servo is used to hold the final position to the tolerances required. The mechanism has a one-of-eight absolute position encoder, as well as an eight-per-revolution position-center index signal and a sine/cosine clock track to define absolute position.

The temperature of the CCD Detector is monitored via a thermistor mounted on it that is read through the Spacecraft I/O Deck analog input hardware. The Flight Computer directly controls pulse width modulation of the on-time of the power switch for the Thermoelectric Cooler in response to the thermistor readings. .

The telescope cover release heater is powered once after launch to allow the telescope cover to open. Each telescope cover will have redundant heaters with one heater controlled by each motor drive deck. The Flight Computer will control on/off switching of the heaters.

TIDI Calibration Sources Derived Requirements

The Calibration Sources Deck is a Rebuild of the Design used for UARS-HRDI

HRDI / TIDI Discharge Lamp specifications:

	HRDI	TIDI
Gas Composition	Neon & Helium/ Argon/Krypton (HAK)	Molecular & Atomic Oxygen
Lamp startup time	< 1 second	same
Intensity stability	±15% over 2 yrs	same

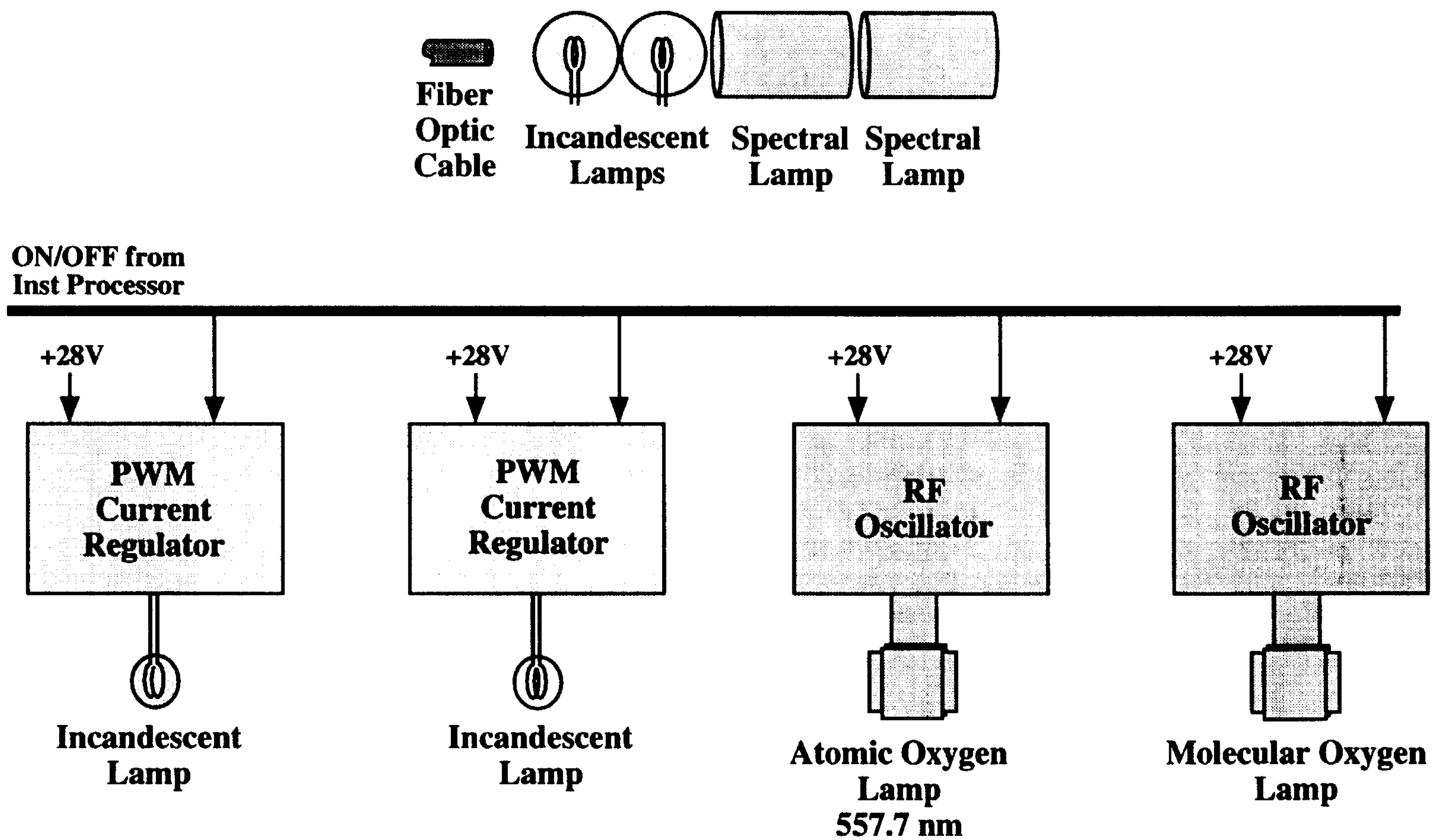
HRDI / TIDI Incandescent Lamp specifications:

	HRDI	TIDI
Lamp Intensity	> 0.1 MSCP.	same
Intensity regulation	≤ 5%	same
Lamp Lifetime	> 10% of mission lifetime	same
Color Temperature	> 2300° Kelvin.	same
Color Temp variation w/age	≤ 100° K.	same
Lamp Envelope Temperature	< 100° C.	same
Storage Temperature	-40° C to +60° C.	same
Operating Temperature	-30°C to +60° C.	-20°C to +40°C

NOTES:

The Calibration Lamps Supply Deck is a direct copy of the same assembly on the UARS-HRDI instrument. The HRDI lamps included are Helium / Argon / Krypton (HAK) and Neon low-pressure gas discharge lamps and two incandescent filament lamps. TIDI will use molecular and atomic Oxygen gas discharge lamps instead of the HAK and Neon lamps used on HRDI. The lamps are contained in the electronics deck.

TIDI Calibration Sources Block Diagram



NOTES:

The Calibration Lamps Supply Deck is a direct copy of the same assembly on the UARS-HRDI instrument. The lamps included are Molecular and Atomic Oxygen gas discharge lamps and two incandescent filament lamps. Each lamp has its own independent, switchable drive electronics.

The gas discharge lamps' excitation is rf energy produced by a simple oscillator. This circuit has a flight history including UARS and Dynamics Explorer. Operation is at 5 megahertz. Output is 800 volts peak-peak. Power consumption per circuit is 3 watts. A radioactive beta particle source was used to produce ionized atoms to start the discharge. The source used on UARS-HRDI was 1 microCurie of Europium 152.

The incandescent lamps are powered by switching regulators operating in current feedback mode. A ramped turn-on is used to extend lamp lifetime. The circuit design is the same used for UARS-HRDI. Power consumption per circuit is 2 watts.

TIDI Etalon Control Deck Derived Requirements

The Etalon Control Deck is a rebuild of the design used for UARS-HRDI.

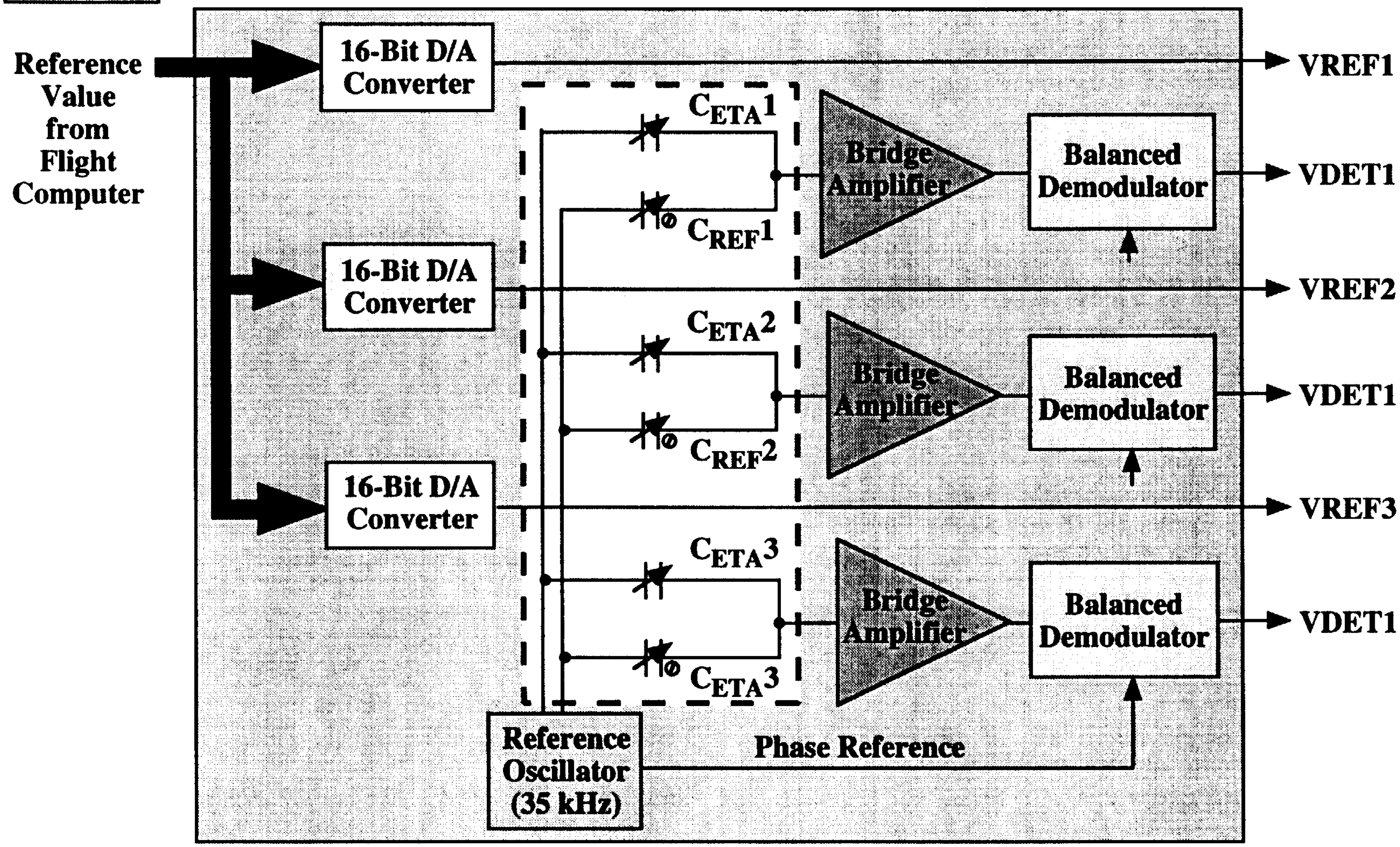
The Etalon Control Deck contains :

- **Three copies of the Capacitive Control Detector circuit,**
- **Three copies of the 16-bit DAC Reference Input circuit,**
- **One 35 kHz Oscillator drive circuit for the Capacitive Controllers.**

NOTES:

The Etalon Control Deck is the same design used on UARS-HRDI. The Deck houses three copies of the Capacitively Controlled Electronics (CCE) Detectors and Reference D/A Converters.

Etalon Control Block Diagram



NOTES:

The Etalon Control Deck is the same design used on UARS-HRDI. The Deck houses three copies of the Capacitively Controlled Electronics (CCE) Detectors and Reference D/A Converters.

TIDI Etalon PZT Deck Derived Requirements

The Etalon PZT Deck is a rebuild of the design used for UARS-HRDI.

The Etalon PZT Deck contains

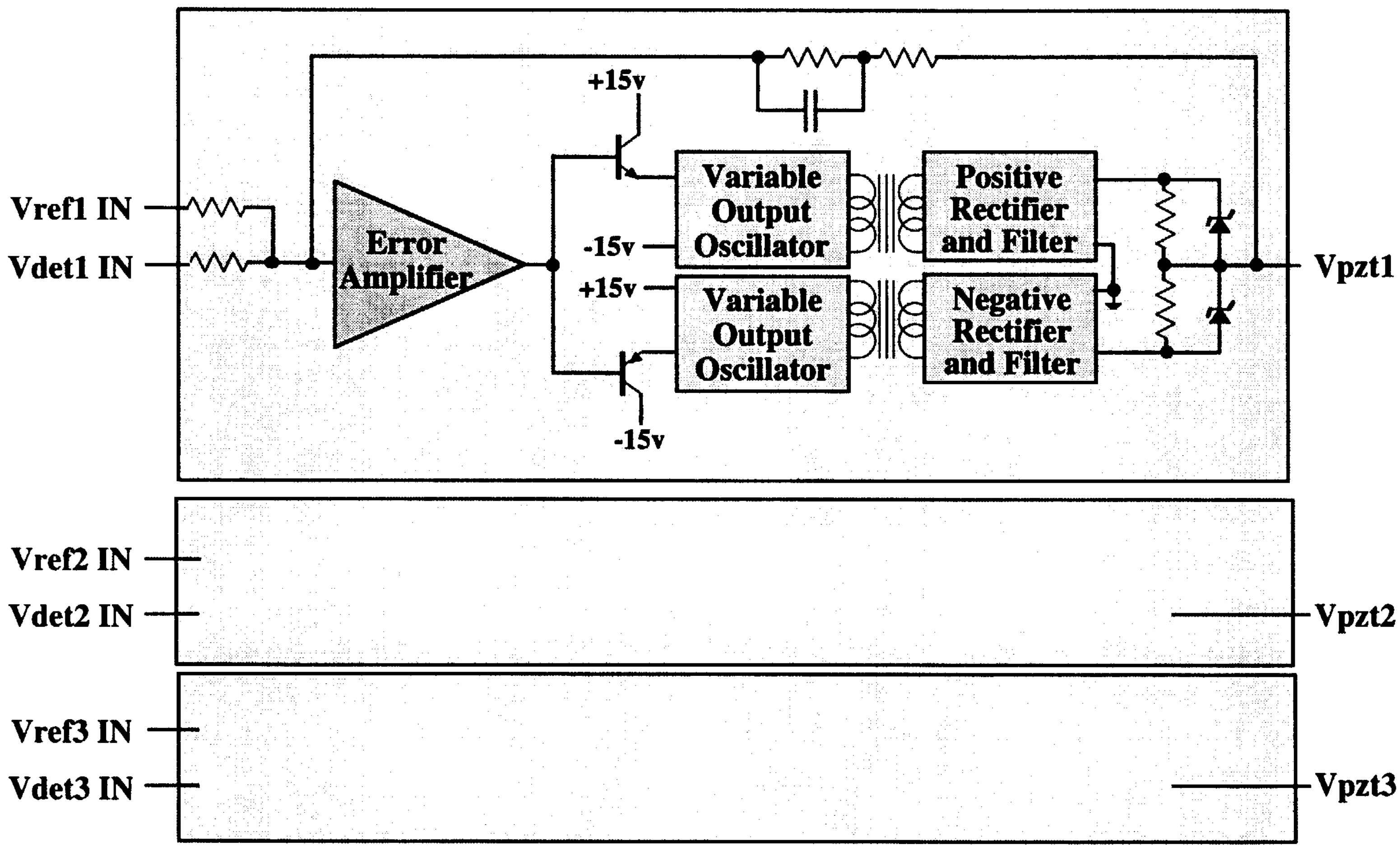
- **Three copies of the PZT Amplifier circuit.**

NOTES:

The Etalon PZT Amplifier Deck is the same design used on UARS-HRDI. The Deck houses three copies of the Piezo Drive Amplifiers used to drive the Posts.

TIDI

Etalon PZT Deck Block Diagram



NOTES:

The Etalon PZT Amplifier Deck is the same design used on UARS-HRDI. The Deck houses three copies of the Piezo Drive Amplifiers used to drive the Posts.

TIDI CCD Drive Deck Derived Requirements

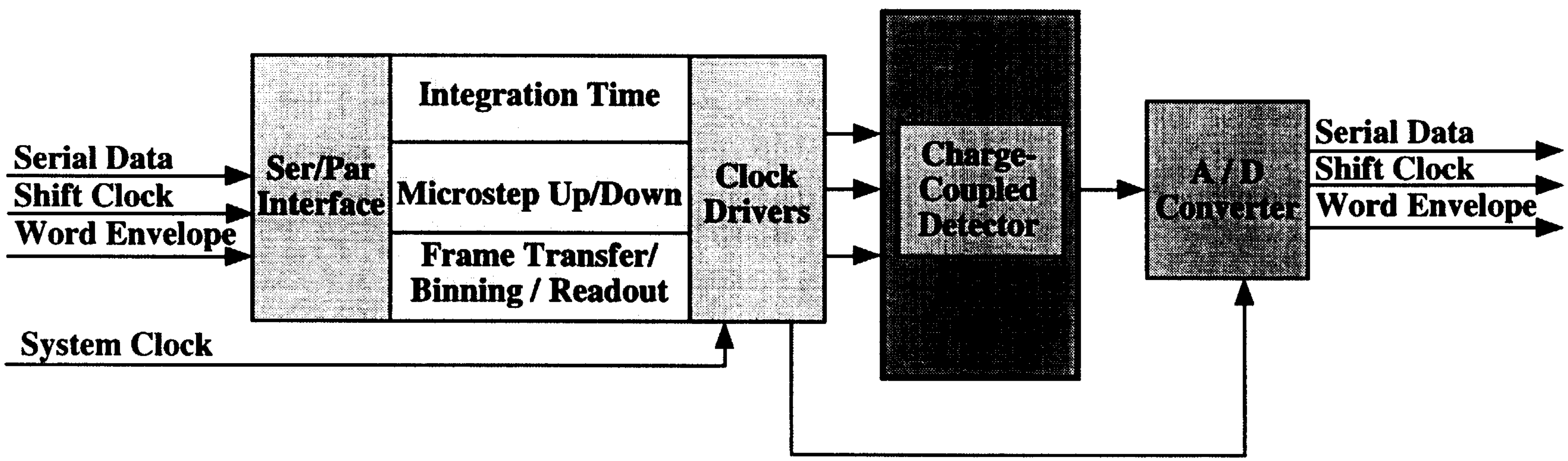
- Generate Timing Waveforms necessary to operate the CCD
  - **Accumulate Charge**
  - **Microstep Image UP/DOWN**
  - **Frame Transfer**
  - **Bin Pixels**
  - **Read Out Contents**
- Provide CCD Clock Line Drive
- Buffer CCD Output Line
- Analog / Digital Convert CCD Output
- Generate Serial Digital Data Output Stream

NOTES:

The Charge Coupled Device (CCD) Drive Deck responds to commands from the Flight Computer to perform integrations (accumulate charge), microstep the image up or down, transfer the image to the output storage area of the device, bin the pixels, read the accumulated picture out a bin at a time. Having generated the necessary clock waveforms, it then passes the signals through drive amplifiers that interface to the CCD. It buffers the output from the CCD and digitizes the signal.

Both the Control inputs and the Data outputs are serial paths to minimize the wiring interface.

CCD Drive Deck Block Diagram



NOTES:

The Charge Coupled Device (CCD) Drive Deck responds to commands from the Flight Computer to perform integrations (accumulate charge), microstep the image up or down, transfer the image to the output storage area of the device, bin the pixels, read the accumulated picture out a bin at a time. Having generated the necessary clock waveforms, it then passes the signals through drive amplifiers that interface to the CCD. It buffers the output from the CCD and digitizes the signal.

Both the Control inputs and the Data outputs are serial paths to minimize the wiring interface.

TIDI CCD Interface Deck Derived Requirements

- **Provide Control Outputs to the CCD Drive and Signal Processing Deck.**
- **Receive Serial Data Stream from CCD Drive and Signal Processing Deck and Store Data in a First-In/First-Out (FIFO) Memory for batch dumps to the Microprocessor.**
- **Provide a 16-Bit Parallel Interface for Control Outputs to the Etalon Post Controller Deck.**
- **Provide discrete ON/OFF Control signals for the Calibration Lamp Supply Deck.**

NOTES:

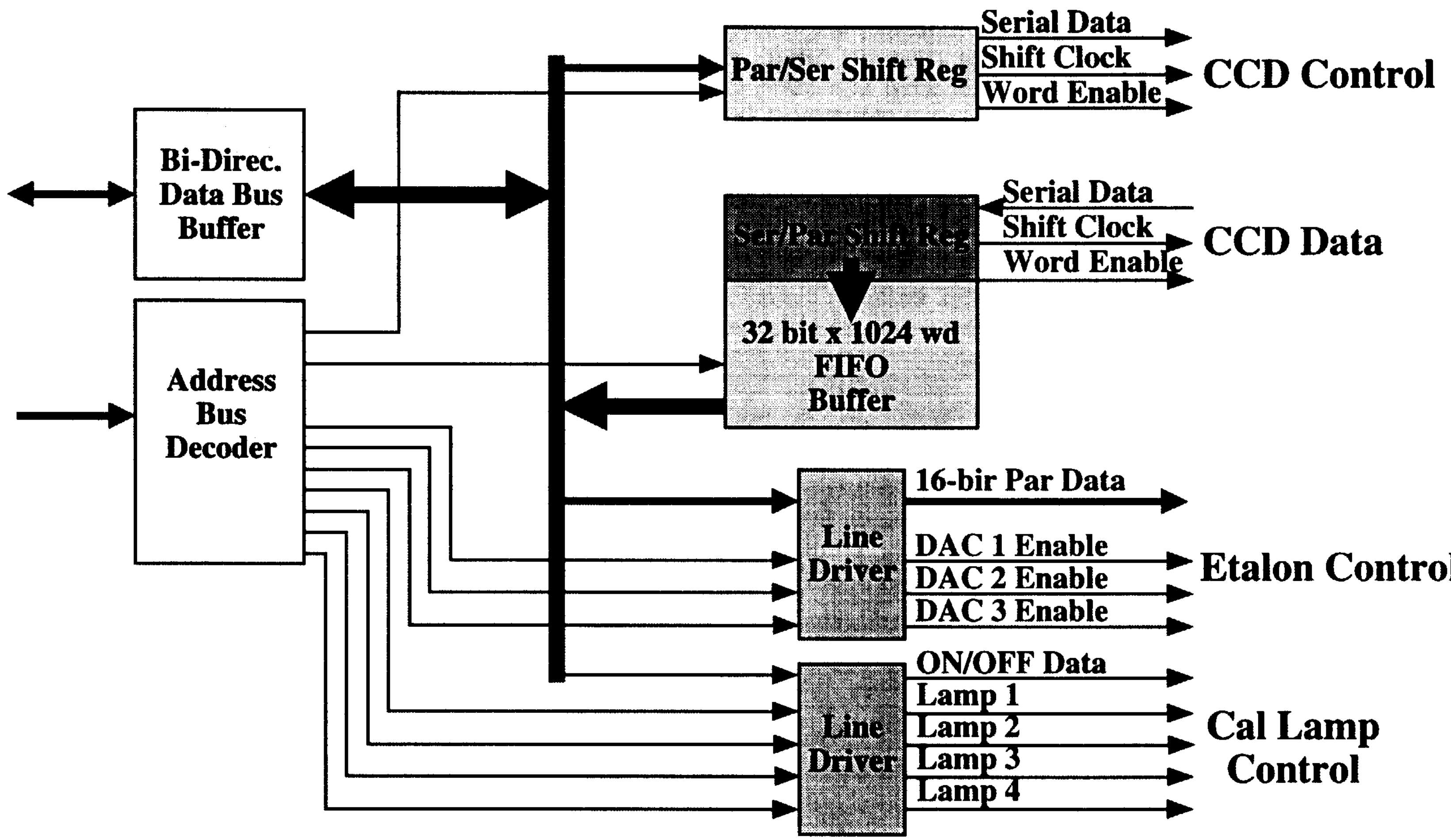
This deck provides interface format conversion between the Flight Computer parallel bus structure and several subsystems that are not compatible with that structure.

This deck has the necessary parallel to serial interfacing to operate the bit-serial contol input on the CCD Drive and Signal Processing Deck. It also has a first in / first out (FIFO) memory stack to buffer the data generated by the CCD so that the Flight Computer does not have to service the interface on a word by word basis.

The Etalon Post Controller deck is a legacy from UARS-HRDI. It does not include any address decoding hardware to allow placing it directly on the Instrument Computer's bus. This deck provides decoded address signals to access the three digital to analog converters on the Post Controller deck. It also buffers the sixteen bit parallel data bus extension to the Controller so that the Instrument Computer does not have to directly drive it.

The Calibration Lamp Supply deck is also a HRDI legacy. Its interface consists of four latched signals specifying ON/OFF control for the four lamps. This deck does address decoding to implement this interface as four writeable addresses from the Instrument Computer's point of view.

TIDI CCD Interface Deck Block Diagram



NOTES:

This deck provides interface format conversion between the Flight Computer parallel bus structure and several subsystems that are not compatible with that structure. It has a bidirectional buffer for the Data Bus and a decoder for the Address Bus from the Computer.

This deck has the necessary parallel to serial interfacing to operate the bit-serial contol input on the CCD Drive and Signal Processing Deck. It also has a serial input / parallel output first in / first out (FIFO) memory stack to buffer the data generated by the CCD so that the Flight Computer does not have to service the interface on a word by word basis.

An isolated parallel port with discrete address lines is provided for the Etalon Controller interface.

This deck does address decoding to implement the Calibration Lamps Supply Deck interface as four writeable addresses from the Flight Computer's point of view.

TIDI Spacecraft I/O Deck Derived Requirements

- **Implement a MIL-STD-1553A Remote Terminal Mode Interface to the Spacecraft for Control and Data Communications.**
- **Implement a Multiplexed 16-bit Analog-to-Digital Conversion Interface for monitoring internal Instrument voltages and temperatures.**
  - 16-Bit Analog-to-Digital Converter
  - Single-Ended Analog Multiplexer
  - Thermistor Bias Current Supply
  - Differential Analog Multiplexer and Instrumentation Amplifier with Gain for Etalon Plate Differential Temperature measurements

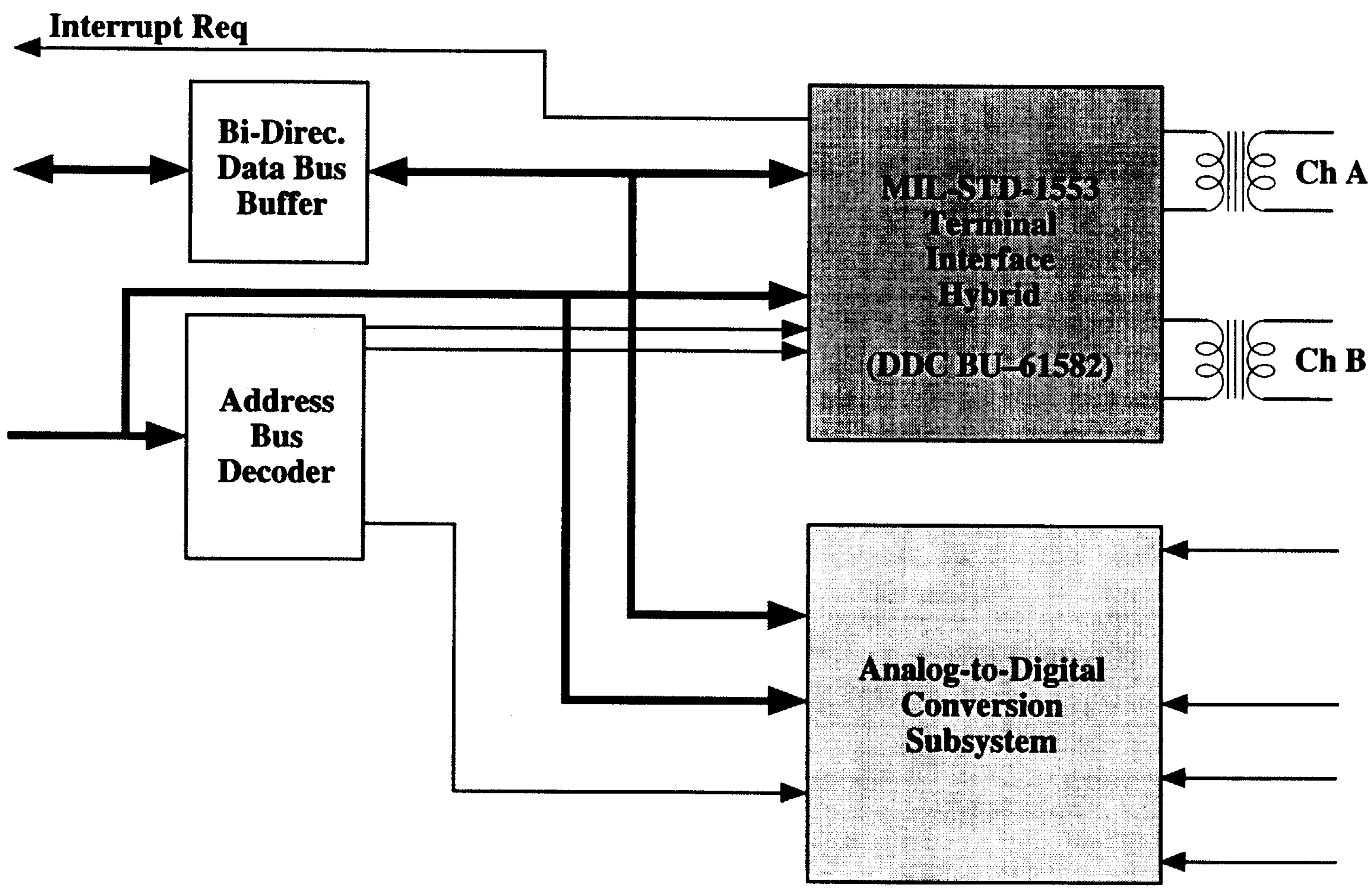
NOTES:

The Spacecraft Input / Output Deck implements the required Mil Std 1553A command and data interface to the spacecraft. It also houses the Analog-to-Digital Conversion (ADC) subsystem for the Instrument.

The hardware chosen to perform the Mil Std 1553A interface task is the ILC Data Device Corporation BU-61582 hybrid circuit.

The ADC subsystem consists of a sixteen bit analog-to-digital converter, input multiplexing, and current source resistors and a reference voltage to bias thermistors.

TIDI Spacecraft I/O Deck Block Diagram



NOTES:

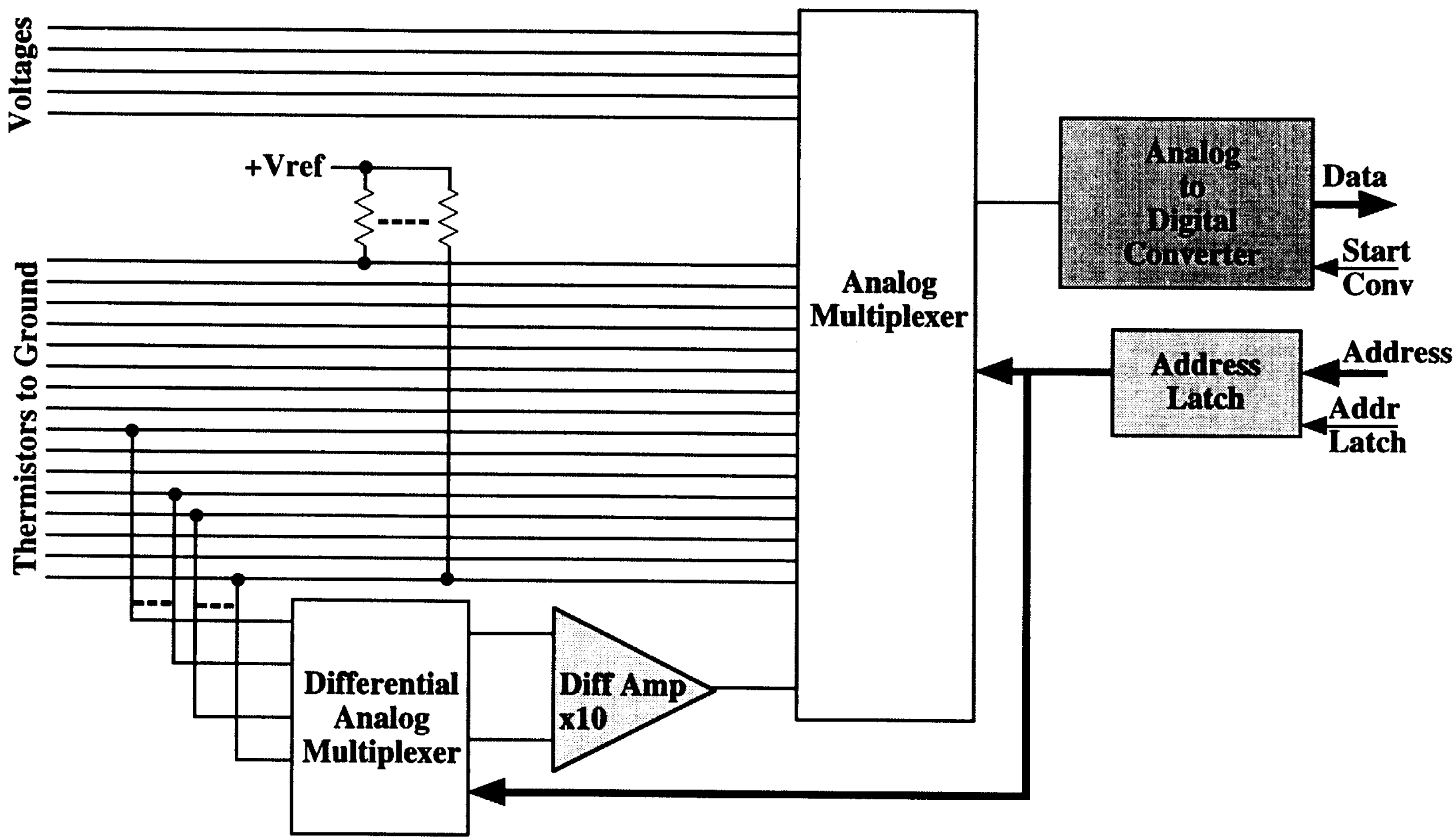
The Spacecraft Input / Output Deck implements the required Mil Std 1553A command and data interface to the spacecraft. It also houses the Analog-to-Digital Conversion (ADC) subsystem for the Instrument.

A bidirectional data bus buffer is provided, as well as a decoder for the address bus.

The hardware chosen to perform the Mil Std 1553A Remote Terminal Mode interface task is the ILC Data Device Corporation BU-61582 hybrid circuit. Isolation transformers are required in addition to the hybrid package itself. The Interrupt Request output is wired back to the Flight Computer.

The ADC subsystem consists of a sixteen bit analog-to-digital converter (A/D), input multiplexing, and current source resistors and a reference voltage to bias thermistors. Multiplexer input selection is driven directly by the Flight Computer's addressing. The Computer initiates conversions by "reading" the A/D.

TIDI SC I/O Deck ADC Block Diagram



NOTES:

The ADC subsystem consists of a sixteen bit analog-to-digital converter (A/D), input multiplexing, and current source resistors and a reference voltage to bias thermistors. Multiplexer input selection is driven directly by the Flight Computer's addressing. The Computer initiates conversions by "reading" the A/D.

A differential multiplexer is provided to sample pairs of thermistors on the Etalon to directly perform temperature difference measurements. The voltages for the selected thermistor pair are subtracted from each other and the difference is amplified. The differential amplifier output is returned to the main level multiplexer as another selectable input.

TIDI Power Supply Derived Requirements

- Input Voltage: +22 to +34 VDC
- In-Rush Current
  - Shall not exceed 25A peak for initial 20µS
  - After initial 20µS shall not exceed 2.5 times the nominal operating current or 2.5A peak, which is greater
- EMI/RFI requirements per MIL-STD-461B
- Input power lines electrically isolated by ≥1 MΩ from chassis and secondary circuits
- Turn-off voltage transients shall not exceed +60 TO -10V
- Ripple / transient currents (peak-peak) shall not exceed 0.7 times nominal operating current or 0.5A, whichever is greater
- Must survive input voltage between 0 and 40 VDC
- Must survive hard short circuit across power input
- Output Voltages
  - +/– 5
  - +/–15
  - +20
  - +15 Regulated
  - –10 Regulated
  - +28
  - +Motor (Primary Power Input)
  - –Motor (Primary Power Return)

NOTES:

The Low Voltage Power Supply (LVPS) is the interface between the spacecraft power bus and the TIDI electronics. The LVPS is designed to convert +22 to +34VDC bus voltage to levels required by the electronics, electrically isolate input power lines from chassis and secondary circuits, limit in-rush current, provide EMI filtering, and provide current limiting and primary current monitoring.

The key requirements for the LVPS are:

Input voltage of +22 to +34VDC.

Turn-on input current transients shall not exceed 25A peak for initial 20µS, after which time it shall not exceed 2.5 times the nominal operating current or 2.5A peak whichever is greater.

EMI emissions and susceptibility to conform to MIL-STD-461.

Power input electrically isolated by at least 1 megohm from chassis ground and secondary circuits.

Turn-off voltage transients not to exceed +60 to −10 volts.

Ripple or transient currents at power interface not to exceed a peak-to-peak value of 0.7 times nominal operating current or 0.5A, whichever is greater.

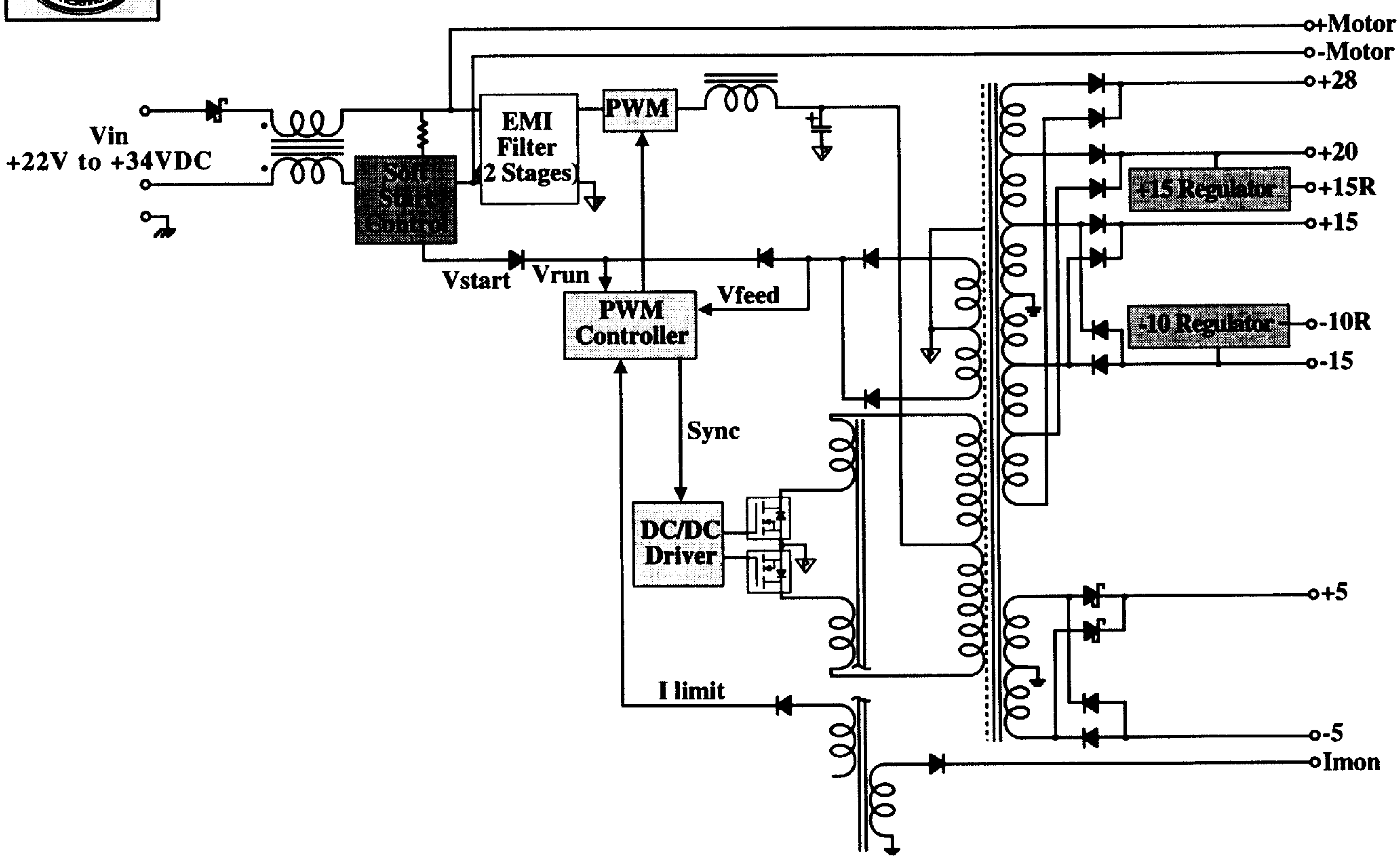
Must be able to survive input voltage between 0 and 40VDC for an indefinite time.

Withstand application of a hard short circuit across primary power input lines.

The output voltages the LVPS will provide the TIDI electronics are:

+/−5VDC,
+/−15VDC,
+15 Regulated
−10 Regulated
+20VDC
+28VDC
+/−Motor Power referenced to primary power input.

TIDI **Power Supply - Block Diagram**



NOTES:

The LVPS has an input filter consisting of a common mode choke (to decrease conducted noise) and 2 EMI filter stages. The filter also contains a soft start circuit to restrict in-rush current and to ensure that the filter is fully charged before the DC/DC converter starts.

The DC/DC converter is a Pulse Width Modulator (PWM) type consisting of a 50KHz PWM pre-regulator followed by a phase-locked 25KHz inverter which drives power MOSFETs used as chopper transistors. A constant current cascode switch drive is employed to eliminate input voltage effects on efficiency. Efficiency is about 75% over the input voltage range. A dedicated winding on the main transformer provides control power and feedback voltage to the primary circuit.

Current transformers are used to sample the primary current and to provide over-current sensing. A current limiter will safely cycle the PWM on/off until the load fault is cleared.

The output rectifiers use standard silicon or Schottky diodes and the +15R and −10R outputs contain post regulators.

TIDI

Power Supply Features

- TIDI Power Supply similar in concept to TOMS and FUSE Designs
- Input filter consists of common choke and 2 EMI filter stages
  - Common mode filter decreases conducted noise
  - Soft start circuit used to restrict in-rush current and ensure filter is fully charged prior to PWM start-up
- Pulse Width Modulator (PWM) type of DC/DC converter
  - Power stage consists of 50KHz PWM pre-regulator followed by phase-locked 25KHz driven inverter
  - Constant current cascode switch drive used to maximize speed and to eliminate input voltage effects on efficiency
  - Rad-hard Power Mosfets used as chopper transistors
  - Control power and feedback voltage provided by dedicated winding in primary circuit
  - Nearly constant efficiency (~75%) over input voltage range
  - Current transformers used to sample primary current and provide over current sensing
    - If load fault persists, current limiter continues to safely cycle on/off
- Output rectifiers use standard silicon or schottky rectifiers
- Post Regulators for +15R, –10R outputs

NOTES:

TIDI

Issues for Next Period - Electrical

Pursue Packaging of functions to improve real estate estimates

NOTES:

Flight Computer and Software

Stephen B. Musko

TIDI Operating Modes

- Standby: Not scanning, all calibration sources off

- Data Collection: Scanning, telemetering profiler data, star centroid information and compressed wave images. Operation controlled by uploaded Operation Sequence Table.

- Direct Control : Mechanisms and calibration sources directly commandable. Programmable TM rates.

- Diagnostic: Test CPU, memory and I/O

NOTES

After power up initialization, TIDI is always in one of four modes: Standby, Data Collection, Direct Control or Diagnostic.

TIDI automatically enters standby mode after initialization. In standby mode, all mechanisms are in safe positions and not moving. All calibration sources are off and only housekeeping telemetry is sent. From standby mode, TIDI can be commanded into any other mode.

Data Collection mode is the normal operating mode for collecting scientific data. The telescopes are scanning according to the Operation Sequence Table. The profiler is collecting wind profile data and the imager is collecting wave images and star position data. Profiler, wave image, star position and housekeeping data are telemetered.

Direct Control mode is used for ground calibration and testing. Each mechanism and calibration source is individually commandable. Telemetry content is programmable to allow high rate sampling of values of particular interest.

Diagnostic mode tests the processor, memory and input/output ports as much as possible without causing large or long lasting disturbances in TIDI operation. Diagnostic mode is intended as a quick test of instrument health.

Derived Processing Requirements

- Execute time-tagged commands
- Execute immediate commands
- Format & send TM
- Control mechanisms
- Control temperatures
- Process profiler CCD data
- Process imager CCD data
- Detect and recover from SEUs
- Maintain 5 msec resolution UTC
- Compensate for Earth oblateness

CCD data processing requirements drive processor and memory requirements

NOTES

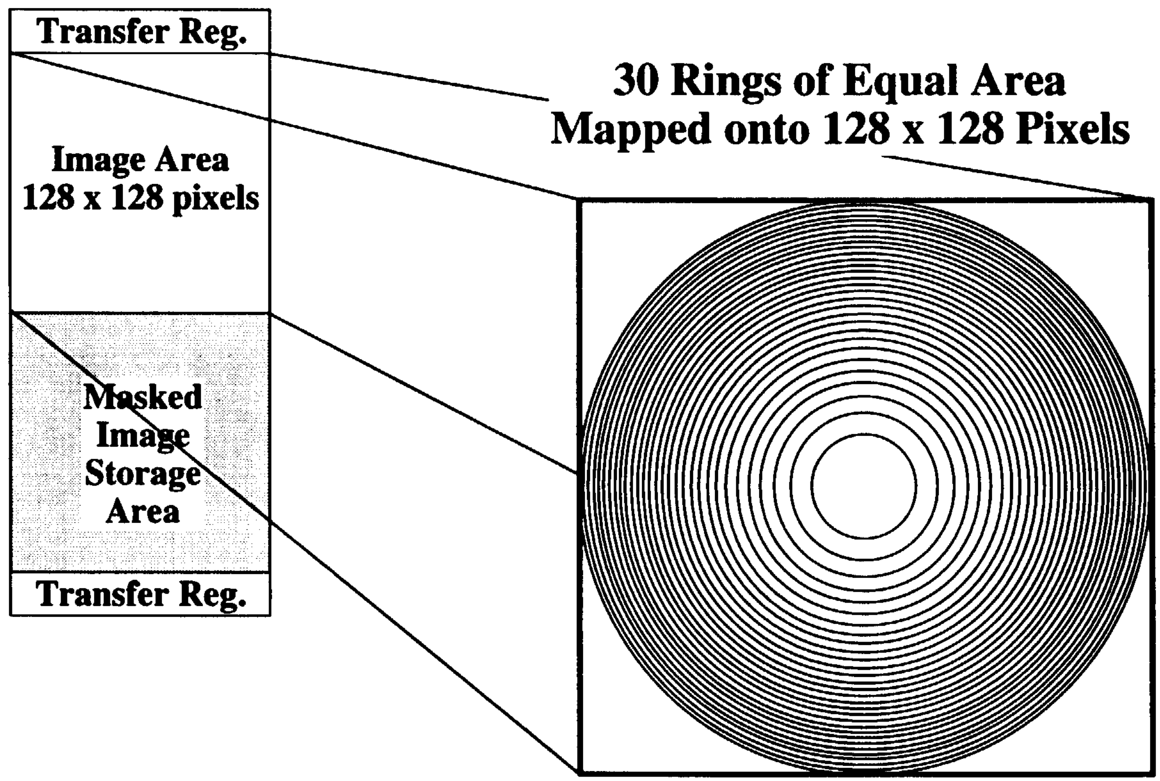
The flight processor is required to perform the following tasks:

1. Store and execute time-tagged commands autonomously since the spacecraft does not store instrument commands.
2. Execute immediate commands as they are received.
3. Control 1553 bus communication with the spacecraft.
4. Format, packetize and send telemetry to the spacecraft.
5. Control the telescope scan motors, scene selector motors, filter wheel motors andcalibration sources.
6. Control instrument operational temperatures.
7. Read and process raw profiler CCD data to determine the intensity of the light falling in each of 30 equal area concentric rings.
8. Read and compress raw imager CCD data.
9. Determine the X and Y centroids of the 3 brightest stars in the imager field of view. The imager channel is time shared for wave imaging and star imaging.
10. Continuously check for the effects of Single Event Upsets and recover from them.
11. Maintain a Universal Time clock to a resolution and accuracy of at least 5 msec.
12. Using position information received from the spacecraft, offset telescope pointing to compensate for Earth's oblateness.

CCD data processing tasks use a large majority of the total required processing power and memory .

Profiler CCD Layout

Profiler CCD



NOTES

The profiler CCD is divided into masked and unmasked areas. A 128 x 128 pixel unmasked area is exposed to the circular interference fringe image and is known as the Image Area. A 128 x 128 pixel masked area is used to store a fully integrated image while the next image is being collected.

The stored image is read off the CCD and processed while a new image is being collected.

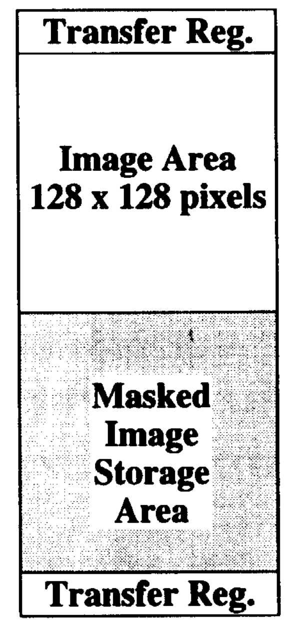
Each pixel in the image area is a member of one of 30 concentric equal-area rings. As each pixel value is read off the CCD, it is added to the running sum of the ring that contains the bin. The scaled 12-bit sum of each of the 30 rings is telemetered.

The upper transfer register is used to dispose of image data that is collected between integration periods while mechanisms are moving.

Profiler Data Processing

- 4 Samples/Sec
- 0.236 - 0.216 sec Integration Time
- Frame transfer to masked image area
- CCD Readout Rate: 200K pixels/sec
- Bins mapped to rings via lookup table
- Cosmic ray hits removed using a moving average filter
- Assuming 20 micron pixel size, image area cosmic ray hit rate is 0.2 sec^{-1}.
- Approximately 1000 electrons per hit
- Profiler data processing requires 2.0 MIPS
- Profiler TM: 1329 bits/sec (30 rings x 48 samp/scan x 8 scans/cycle x 12 bits) / (104 secs/cycle)

Profiler CCD



NOTES

The profiler is sampled at a rate of 4 Hz and the sample integration time varies between 216 and 236 msec due to variable telescope step size. Immediately after a sample integration is completed, the CCD data from the image area is shifted into the masked image storage area and another image integration begins after the next telescope step is complete. The image data that is collected while the telescope is moving is flushed to the upper transfer register immediately before the next integration period begins.

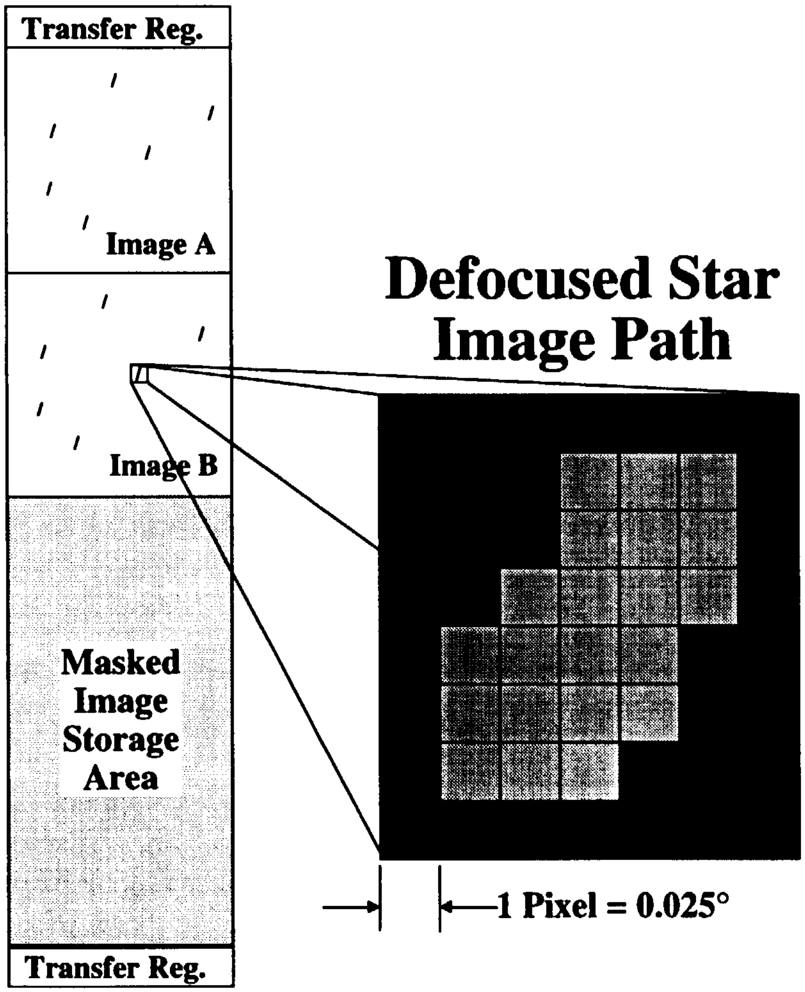
The stored image is read from the CCD and processed at an average rate of 64 Kpixels/sec. The instantaneous pixel transfer rate is limited to 200 Kpixels per second to limit read noise. The CCD interface electronics store the CCD data in a FIFO that is emptied by the processor.

At 64 Kpixels/sec, each pixel must be processed in significantly less than 15.3 usec. This processing speed is achieved by using a RAM lookup table that maps each pixel onto one of the 30 concentric rings. As each pixel value is read off the the CCD it is run through a running average filter to detect cosmic ray hits. The predicted cosmic ray hit rate for the CCD image area is 0.2 hits/sec.

The inner loops of the data processing code were written in MIPS R3000 assembly language and analyzed to determine the number of MIPS (million instructions per second) required to process the profiler data.

The loop that reads data from the CCD FIFO and stores it in a RAM table consists of 5 instructions and reads 2 pixels per iteration. The loop that removes cosmic ray contamination and converts the pixel values into 30 ring values consists of 24 instructions and processes 1 pixel per interation. Allowing for 6 possible pipeline stalls due to delayed execution of load instructions, the total number of processing instructions per pixel is 30. The total number of instructions required per second is 30 x 64K = 2.0 MIPS.

Star Imaging Data Processing



- 1.0 sec integration time
- 28 samples per 104 second cycle
- Telemeter 3 brightest star path X and Y centroids integrated magnitudes and time
- Telescope misalignment computed on the ground
- TM requirement: 28 bits/sec
  - 11 bits each for X and Y ($2^7.2^4$ pixels)
  - 4 bits for magnitude
  - 27 bits for time ($2^{17}.2^{10}$ secs of day)
- Computing requirement: 0.5 MIPS
- Cosmic ray contamination removed with image comparison

NOTES

Star imaging is used to determine telescope misalignment to a high degree of accuracy.

The star image integration time is 1.0 seconds. During this time, the star images will move and form star path images on the CCD. The flight software determines and telemeters the X and Y centroids and integrated magnitude of the 3 brightest starts in the field of view.

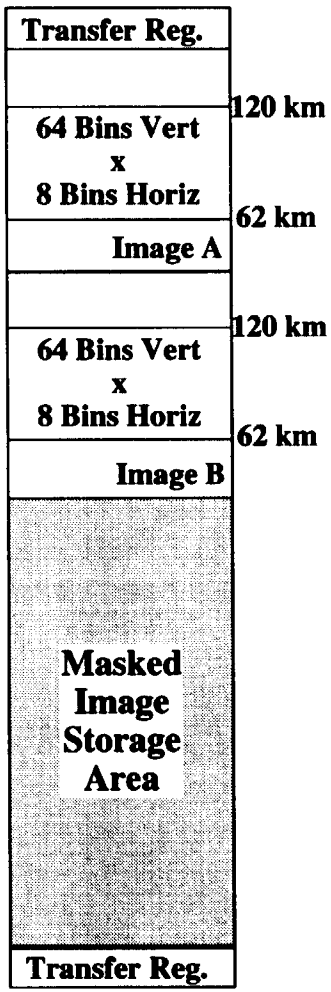
Since there are two identical star images (due to the prism required for wave imaging) the corresponding bins in each star image are added together after removing cosmic ray contamination. Cosmic ray contamination is removed by comparing star image bins before they are added together.

The telescope misalignment is derived on the ground from telemetered star centroids.

The estimated computing requirement for star image data processing is 0.5 MIPS. This estimate was derived by coding the inner filter loop that reads star image data from the CCD and selects potential star image locations for further sorting.

TIDI

Wave Image Data Processing



- Integration time: 3 seconds
- 24 images per 104 second cycle
- Telemeter Image A and ratio of of Image A and Image B
- Remove cosmic ray contamination with image comparison
- 2:1 lossless compression by sending successive bin deltas (or Huffman)
- Baseline TM Requirement: 945 bits/sec
  - (8 x 64 bins x (8 + 8 bits) x 24 images)/ (104 secs x 2 compression ratio)
- Some images may be discarded to limit TM to 945 bits/sec
- Processing requirement: 0.5 MIP

NOTES

The wave image is divided by a prism into two images that fall on the unmasked area of the imager CCD. The region of interest (corresponding to limb altitudes of 62 km to 120 km) in each image is divided into 8 horizontal bins and 64 vertical bins. The other CCD data is discarded.

Cosmic ray contamination is removed by comparing the images and removing counts due to cosmic rays.

The ratio of all corresponding Image A and Image B bins is computed and result is known as the ratio image. Each bin in the ration image is scaled to 8 bits, losslessly compressed using delta bin values or Huffman encoding and telemetered.

Image A is scaled to 8 bits/bin, losslessly compressed using delta bin values or Huffman encoding and telemetered.

The compression goal is 2 to 1. If the images have a high imformation content, lossless compression of 2:1 may not be possible. The flight software will track the long term image compresion ratio and discard images as required to maintain the long term wave image TM rate at or below 945 bits/sec.

TM Requirements by Mode (bits/sec)

	Profiler	Imager	Eng.	Total
Standby	0	0	34	34
Data Collection	1329	≤973	34	≤ 2336
Direct Control	------ Programmable ------			≤ 2336
Diagnostic	0	0	1360	1360

NOTES

TIDI

Command Summary

- Mode change commands
- Direct control commands
- Upload Scanning Sequence Table
- Select Operation Sequence Table
- Upload control parameter (temps, data format etc.)
- Upload memory
- Download memory
- UTC (1 Hz, 5 msec accuracy)
- Spacecraft position & altitude (for Earth oblateness compensation)

- 2,000 command bytes/day required for commands and Operation Sequence Tables (from UARS/HRDI experience)

NOTES

The spacecraft passes routine instrument operation commands from the ground directly to TIDI. TIDI accepts time-tagged commands for delayed and periodic execution.

TIDI expects the spacecraft to generate the following commands:

1. UTC is expected (as a 1553 message) once per second with an accuracy of ±2.5 msec.

2. Spacecraft position and altitude. This information is used to adjust telescope positions to compensate for the oblate shape of the Earth.

The details of telescope step size, scene selection, filter selection, integration periods and other aspects of scan sequencing are contained in the Operation Sequence Table. Multiple versions of the Scan Sequence Table can be stored in memory and selected with a single command.

Based on our experience with UARS/HRDI, TIDI should require less than 2000 upload command bytes per day.

TIDI Total Processing & Memory Requirements

Processing Requirement	
Profiler CCD data processing	2.0 MIPS
Imager CCD data processing	0.5
Other control functions (est.)	0.5
	3.0 MIPS
RAM Requirement	
Executable code (est.)	128 KB
2 Profiler Bin Value Tables	64
Profiler Bin to Ring Map	16
2 Imager Bin Value Tables	64
Vars, stack, TM buffers (est.)	64
	336 KB
EEPROM Requirement	
Executable code (2 copies)	256 KB
Parameters (2 copies)	16
	272 KB

NOTES

Flight Computer Selection

- Lockheed Standard 95 RH processor selected
- Loral R6000 selected as backup

Standard 95 RH Features

- IDT R3081 CPU
- 8.3 MIPS @ 10 MHz, 3.2 Watts
  176% Margin
- 20 MIPS @ 24 MHz, 5 Watts
  566% Margin
- 2 MBytes EDAC RAM
  509% Margin
- 0.5 MBytes EEPROM
  88% Margin

- 100 Krad hard
- Latchup immune
- SEU resistant (no spec yet)
- 24 bit programmable timer
- Watchdog timer
- 32 bit I/O bus interface
- Dual RS-422 serial ports
- Temp range: -40° to +85°C
- Size: 12 x 14 cm (4.7 x 5.5 in.)
- Cost: $25K per flight board
- Off the shelf, no NRE costs

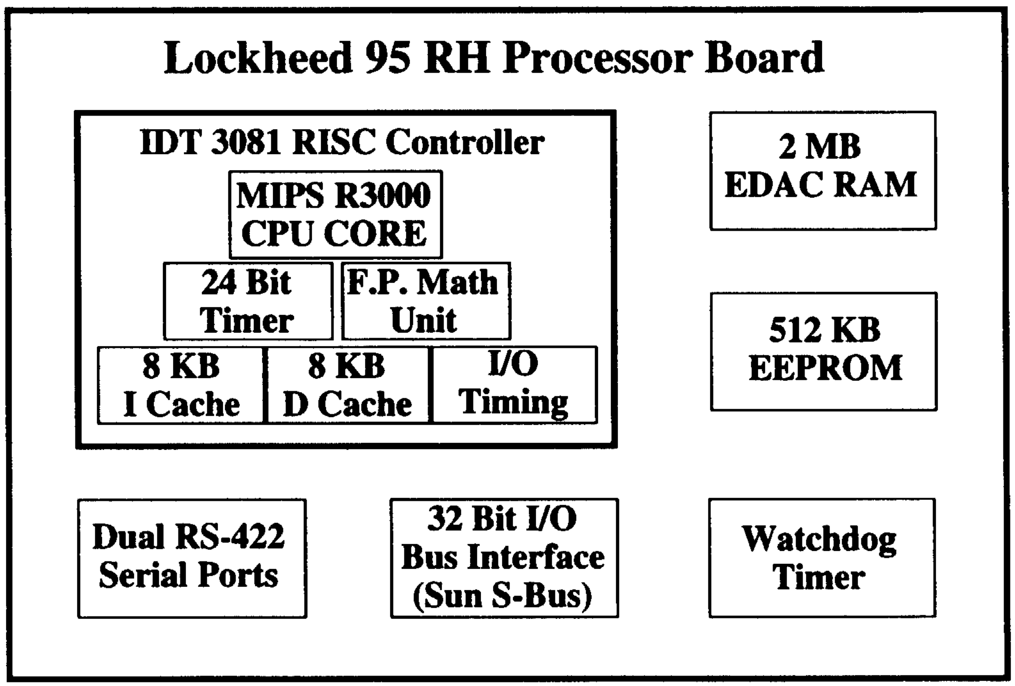
NOTES

The Lockheed 95 RH processor board was selected as the flight computer for TIDI. The Loral R6000 processor board was selected as a backup in case the the 95 RH is not available or is, for some reason, found unsuitable.

The 95 RH meets all TIDI processing and memory requirements with large margins, is relatively inexpensive and is available off the shelf directly from Lockheed.

At this point we are awaiting a formal quotation and component specifications (especially single event upset rates) from Lockheed.

Flight Computer Block Diagram

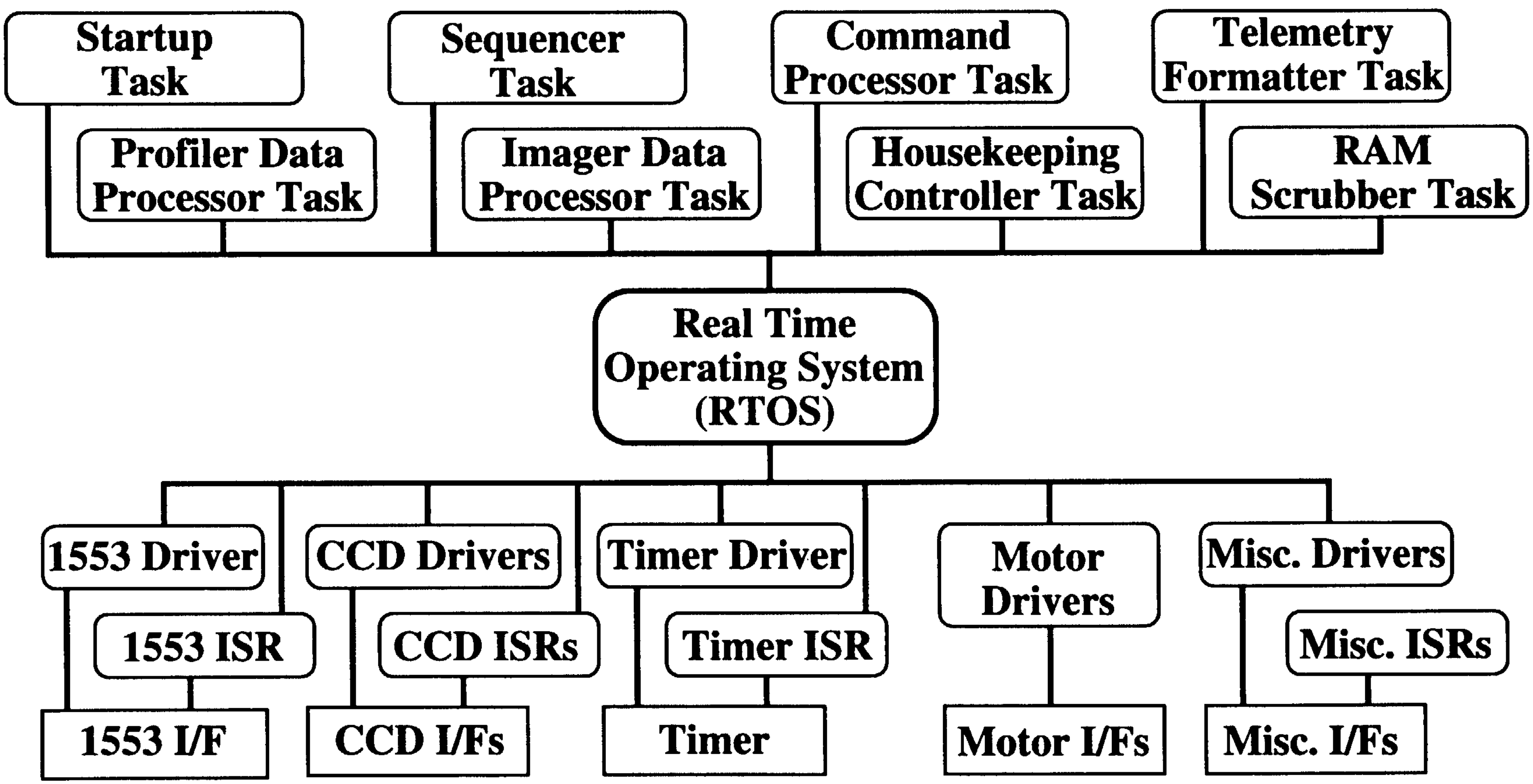


NOTES

The 95 RH processor board is based on the IDT R3081 RISC Controller. The R3081 is a monolithic device that is built around a MIPS R3000 CPU core. The R3081 also features a 24 bit counter/timer, a floating point math acceleration unit, 8 Kbytes of instruction cache, 8 Kbytes of data cache and programmable I/O device timing.

The 95 RH processor board contains 2 Mbytes of RAM, 512 Kbytes of flash EEPROM, a watchdog timer, two asynchronous RS-422 serial ports and a 32 bit I/O bus interface for controlling off board devices. RAM data is protected by Error Detection and Correction (EDAC) hardware.

Flight Software Architecture



NOTES

The flight software is built around a real time operating system (RTOS). The heart of the RTOS is a preemptive multitasking real time executive which divides processor time between competing software modules. The RTOS also provides intertask communication and memory managment.

There are three types of software modules: task, driver and interrupt service routine (ISR). Tasks handle high level processing functions that are not highly time or device dependent. Device drivers encapsulate the hardware dependent aspects of an I/O device. Tasks use device drivers to control I/O devices. Interrupt service routines are used to respond to I/O device interrupts and perform time sensitive operations.

Real Time Operating System

- RTOS Requirements
    - MIPS R3000 and IBM R6000 target support
    - IBM PC host software
    - Preemptive multitasking
    - Intertask communication
    - Memory management

- RTOS Selection
    - Wind River VxWorks
    - Existing board support packages for Lockheed 95 RH & Loral R6000 boards
    - Cost: $23,500

NOTES

The selected RTOS must be able to run on both the Lockheed 95 RH and the Loral RAD6000 to allow software portability in the case that a processor change is necessary after software development is underway.

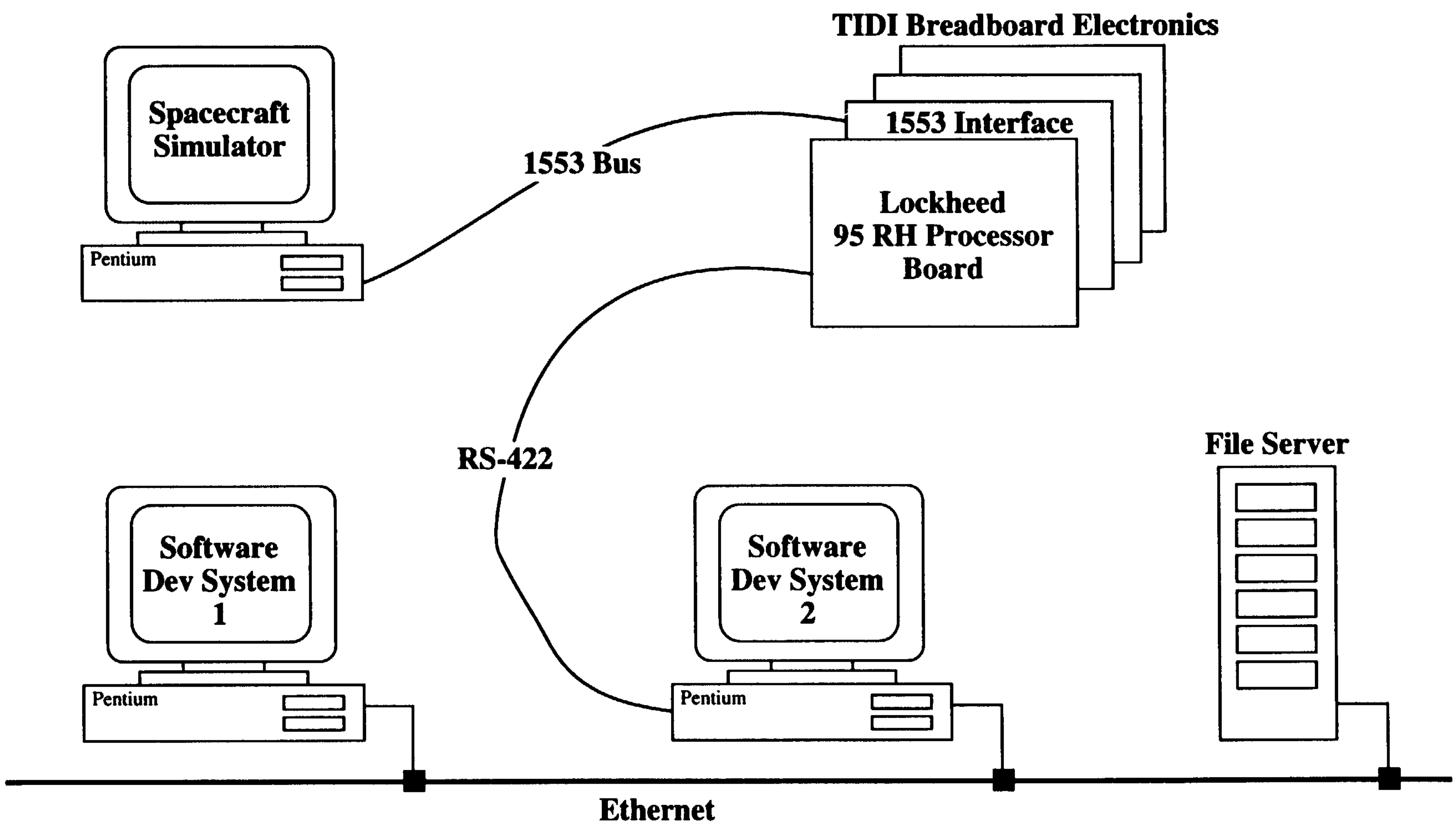
We prefer IBM PC computers for flight software development because they: are inexpensive, have sufficient computing power and storage, have a wide variety of inexpensive software tools available and are easy to administer (compared with Unix workstations).

The selected RTOS must have at least the following features: preemptive multitasking, intertask communication and memory management.

We selected the VxWorks RTOS from Wind River Systems because it meets all the requirements. and also has existing board level support software for the 95 RH and the RAD6000 processor boards.

The cost of 10 VxWorks user licenses is $23,500. We may be able to get a substatial discount because SPRL is an education institution and because we will have only 2 users.

Flight SW Development System



NOTES

The flight software development system consists of three IBM PC compatible computers and a dedicated file server. The two software development PCs and the file server are networked together on the SPRL ethernet network. The remaining PC is used as a spacecraft simulator.

Either of the software development computers may be connected via RS-422 serial link to the TIDI breadboard electronics for flight software test and debug.

The spacecraft simulator PC is connected to the TIDI electronics through an off the shelf 1553 interface board installed in the PC backplane.

The spacecraft simulator runs custom software that allows it to communicate with the TIDI electronics over the 1553 bus, send commands and, receive, display and store TIDI telemetry.

The spacecraft simulator software will be a modified version of existing spacecraft simulator software developed at SPRL.

Flight Software Development Tools

- Development Tool Requirements
  - C compiler
  - Source level target debugger
  - Program builder (make facility)
  - Source code configuration control
  - IBM PC hosted

- Development Tool Selection
  - Greenhills C Compiler and MULTI tools
  - Meets all requirements
  - Seamless integration with VxWorks
  - Cost: $13,110 for two licenses

NOTES

The flight software development tools must include a C cross compiler, a debugger that allows source level debugging of software running on the flight computer, a program builder to automate software builds and a source code configuration control program to control software module versions and built configurations. Our preferred development platform is the IBM PC or compatible.

The MULTI tools and C compiler from Greenhills Software were selected because they met all the requirements and because they offer seamless integration with the VxWorks RTOS.

The cost of the MULTI tools and C compiler for two user licenses is $13,110.

Single Event Upset Recovery

SEU Effect	Detection Method	Recovery Method
RAM bit flip	Error Detection & Correction Hardware	Periodic RAM Scrubbing
Output register bit flip	Not detectable	Rewrite output registers periodically
CPU excuting bad code	Watchdog timeout	CPU Reset
Loss of interrupts	Watchdog timeout	CPU Reset
Unexpected Interrupt	Unexpected Interrupt	CPU Reset
Transient EEPROM Data Corruption	Validate EEPROM contents with CRCs	Store and use backup copies in EEPROM

NOTES

Single Event Upsets (SEU) are caused by cosmic rays and can cause integrated circuit memory elements to change state (bit flips). The first column in this table lists the effects that can be caused by bit flips.

If a bit flip occurs in RAM, error detection and correction hardware will correct the data as it is read from RAM. Periodic RAM scrubbing is used to prevent the accumulation of error bits.

A common way to detect a bit flip in an output register is to add a read-back register which is monitored periodically. To minimize hardware, read back registers are not used in TIDI. Each output register is periodically refreshed (typically once per second). If a register bit flips, the effects will last no longer than one second. Any output registers or output devices that cannot withstand a one second upset will be hardware protected against upsets.

When the CPU is upset, the following events can occur: execution of bad code, lose of interrupts, reception of unexpected interrupts. If any of these events occur, the watchdog timer is allowed to expire, causing a CPU reset.

The EEPROM is used as a mass storage device for executable code and stored parameters, so it is accessed infrequently. Code and parameters are stored in separate, redundant, CRC protected blocks in EEPROM. After a block is transferred from EEPROM to RAM, the block CRC is computed and compared to the stored CRC. If they are not identical, the transfer process is repeated using the backup copy of the block in EEPROM.

Flight Computer Changes from Proposal

Characteristic	Proposal	Baseline
Flight Computer Type	SPRL Built, Harris HS-80C86RH Based	Lockheed 95 RH, IDT R3081 Based
Flight Computer Power	0.4 Watts	3.2 Watts
Telemetry Requirement	2520 bits/sec	2336 bits/sec

NOTES

Flight Computer Status, Next Phase Activities

- Current Status
  - Processor board selected (pending formal quotation)
  - RTOS selected
  - Software development tools selected
  - Preliminary telemetry and commands specified

- Next Phase Activities
  - Refine command and telemetry specifications
  - Refine high level flight software design
  - Evaluate and design CCD data processing algorithms.

NOTES

TIDI Ground Segment

David A. Gell

Ground Segment Concept

- Goals
  - Reduced Development Costs
  - Simplified Operations and Reliability
- Ground Segment Supports
  - Data Processing and Analysis
  - Mission Operations
  - Initial Operations
  - Spacecraft Integration
  - Instrument Test
- Integrated Ground Segment Approach
  - Eliminates Redundant Hardware and Software
  - Operating Procedures Will Be Developed Early

NOTES:

Ground Segment Requirements

- Ground Segment must support all phases of instrument lifecycle
  - Instrument Integration
  - Calibration
  - Spacecraft Integration
  - Operations
- Ground Segment must evolve with the instrument
  - Command and TM definitions required for early operations should support all subsequent phases
  - Procedures developed early must support subsequent phases without translation.

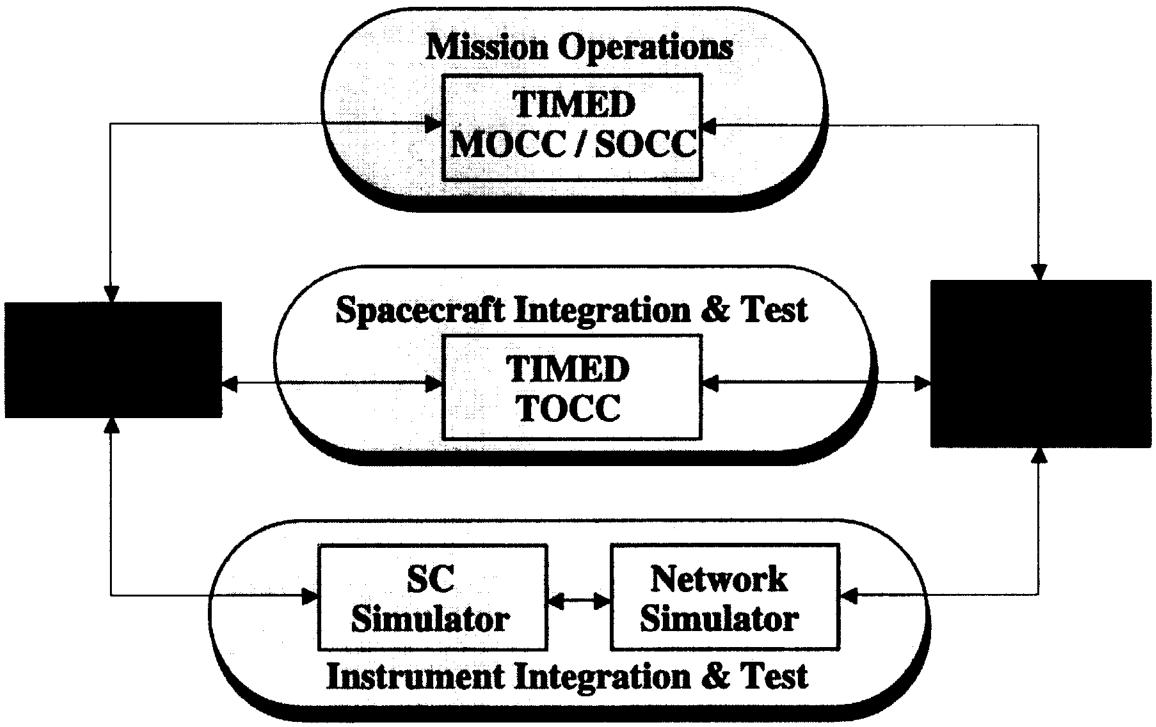
NOTES:

Ground Segment Architecture

- Spacecraft Ground Segment Provides
  - Communications with the Spacecraft
  - Command and Telemetry Processing
  - Orbit and Attitude Reconstruction
  - Data Distribution via local and wide area networks
- Instrument Ground Segment Provides
  - Instrument command planning and generation
  - Instrument health assessment
  - Instrument performance monitoring
  - Data Processing
  - Data Analysis

NOTES:

TIDI — Ground Segment Life Cycle



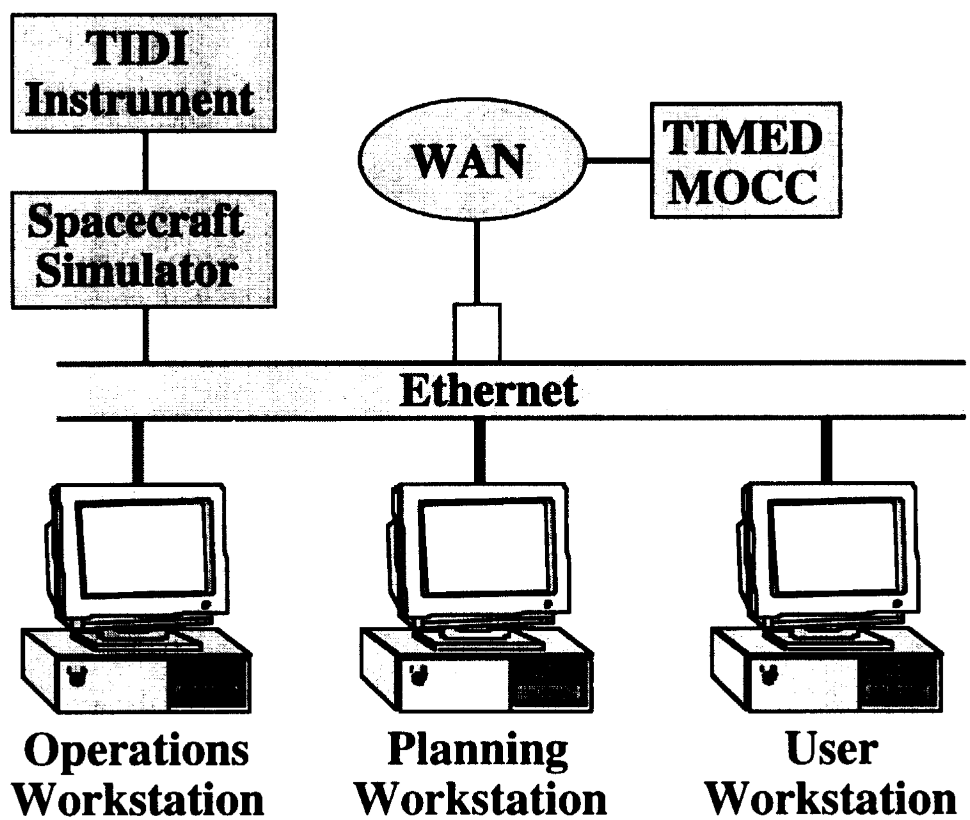
GSE HOSTS

- <u>Instrument Ops S/W</u>
  - Data Display & Logging
  - Command Transmission
  - Procs for
    - Startup
    - Shutdown
    - Functional Tests
    - Performance Tests
  - Instrument Analysis
    - Trending
    - Performance Analysis
    - Health & Safety
  - Planning
  - Command Generation
- <u>Instrument Data Processing</u>
  - Retrieval Software
  - Archive Software
  - Science Analysis

NOTES:

TIDI

GSE Hardware Block Diagram



Legend

- Instrument Integration Configuration
- Spacecraft I&T and Mission Operations Configuration

NOTES:

GSE Software

- GSE Software will make most use of Commercial, Off-the-Shelf Software (COTS)
- OASIS is baselined command and data display software
  - Performs command processing
  - Performs data display and logging
  - Developed by U. Colorado
- IDL is baselined for data analysis
  - Interactive data manipulation language

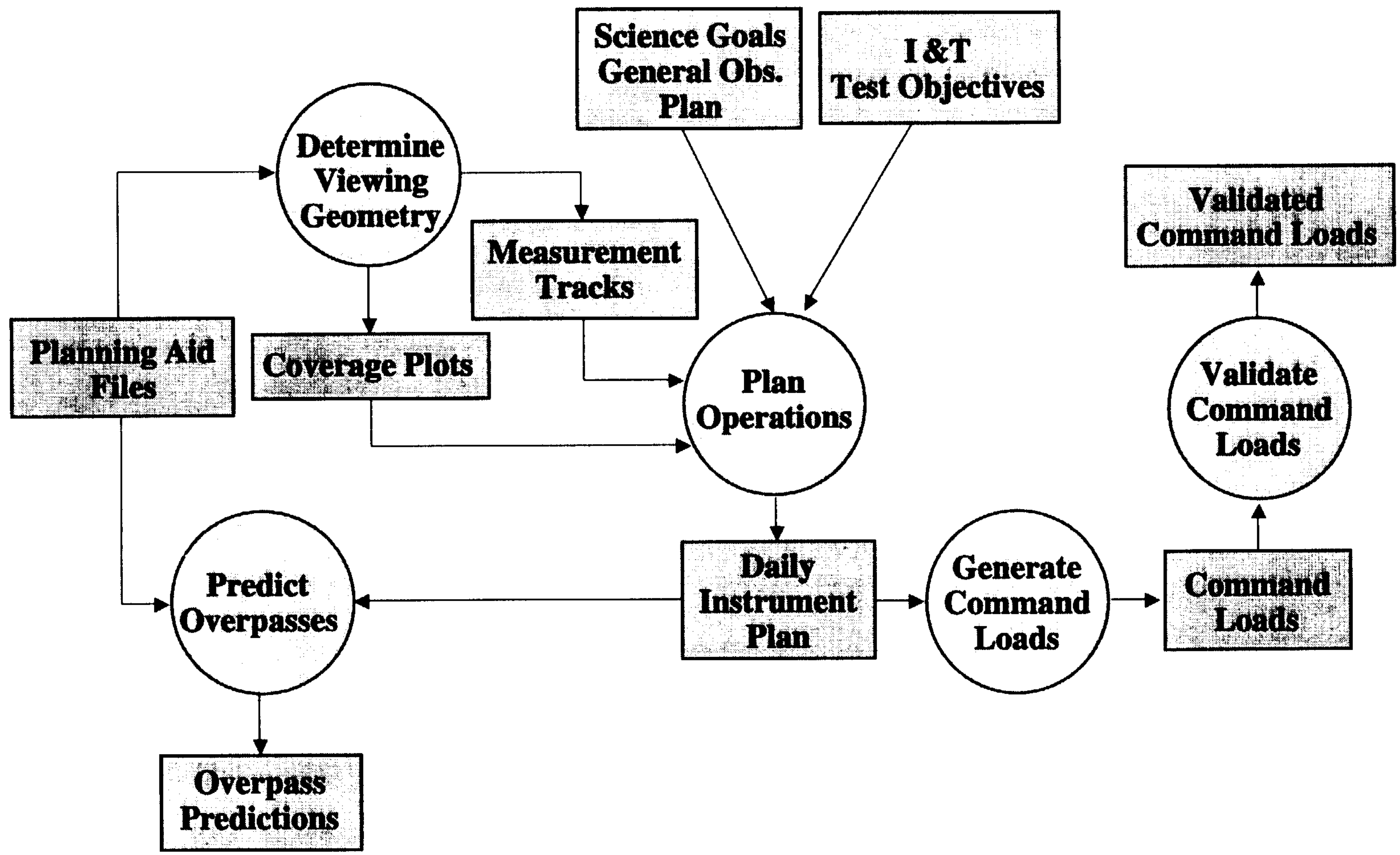
NOTES:

Instrument Operations

- Instrument Uplink Operations Include
  - Planning Observations
  - Programming the Instrument
  - Transmitting Command Loads
    - to the instrument during instrument I&T
    - to the TOCC during spacecraft I&T
    - to the MOCC during mission operations
  - Coordinating Correlative Measurements
- Instrument Downlink Operations Include
  - Monitor Instrument Health and Safety
  - Monitor Instrument Operations
  - Analyze Instrument Performance
    - Trend engineering and performance parameters
    - Determine results of tests

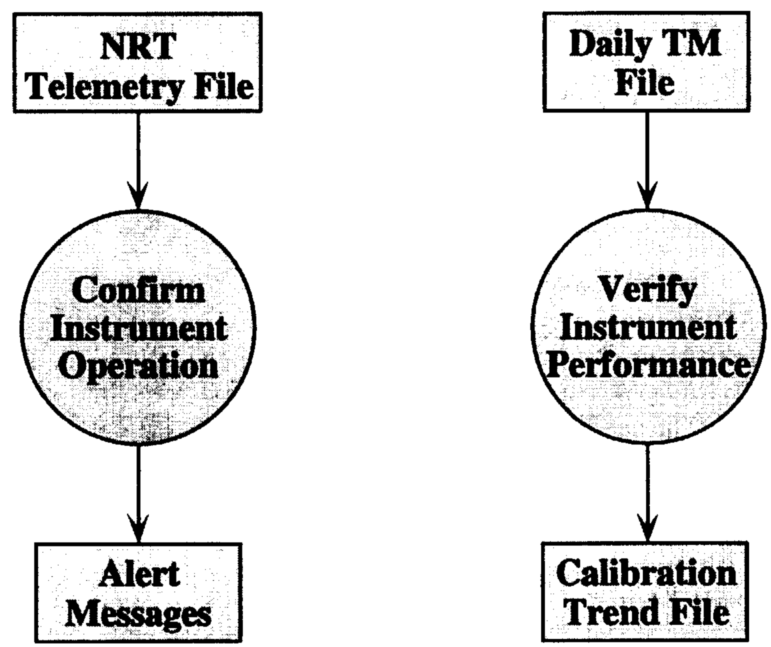
NOTES:

Uplink Operations Data Flow



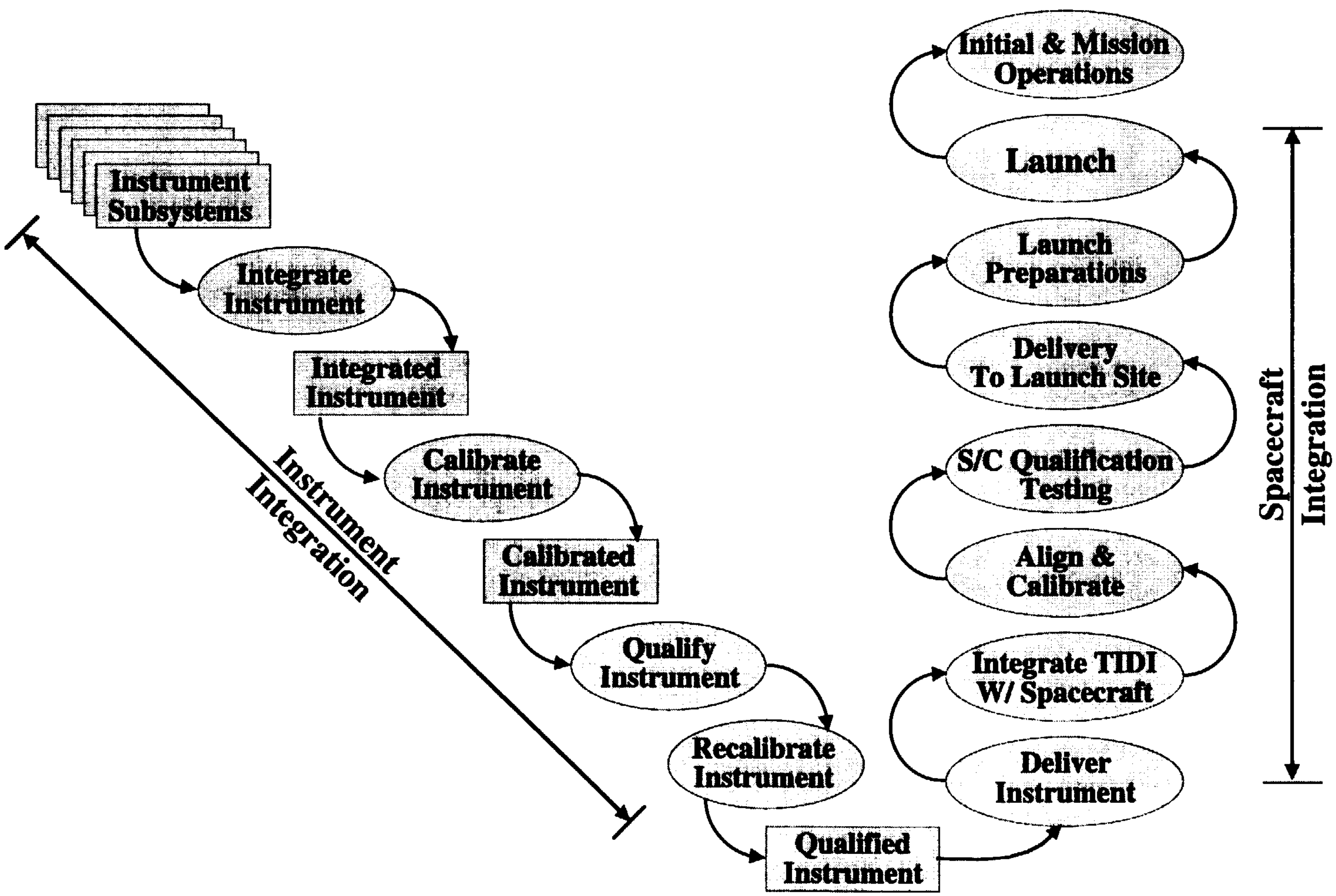
NOTES:

Downlink Operations Data Flow



NOTES:

Integration and Test Flow



NOTES:

TIDI

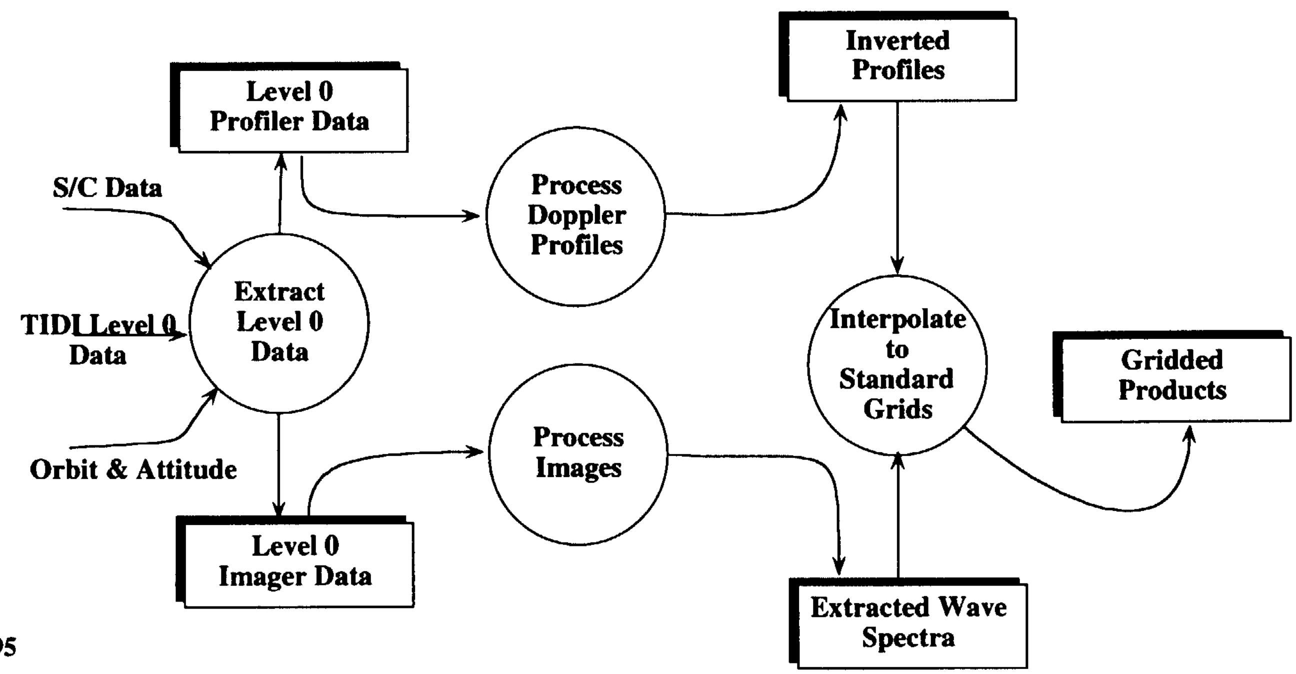
Integration and Test

- Contamination and Cleanliness
  - Bag and/or purge in uncontrolled areas
  - Handling fixtures and containers cleaned
  - Chambers monitored with cold finger or crystal thickness monitor
- Telescope Stimuli
  - External lamp required during spacecraft I&T
  - Lamp views through window in "red tag" telescope cover
- CCD cooling
  - Cold target for radiators required during thermal-vacuum testing
  - GSE cooler required during ambient pressure testing

NOTES:

TIDI — Data Processing

- Transforms Telemetry Data in Stages to Geophysically Useful Quantities
- Archives Data
- Instrument Performance Analysis (Calibration)
- Provides Input Data for Scientific Analysis

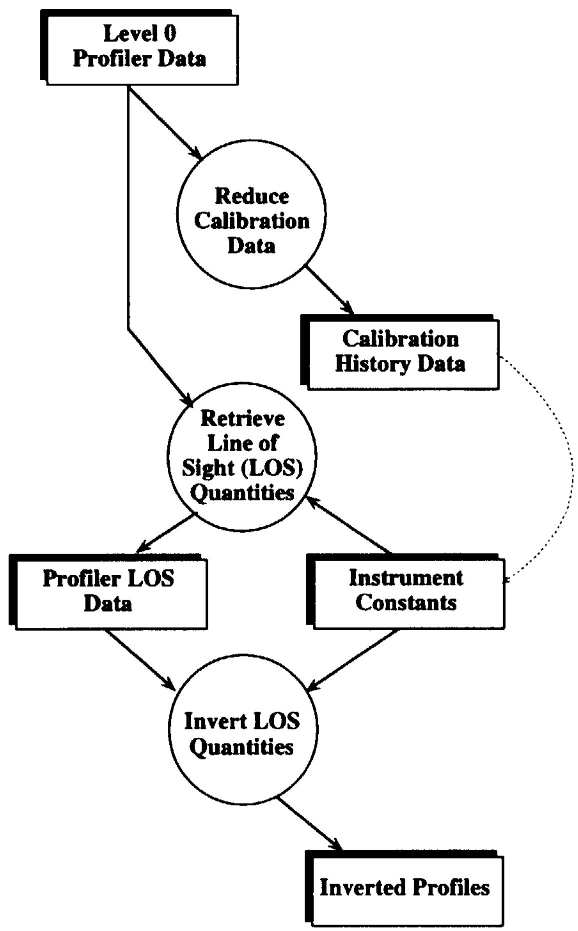


NOTES:

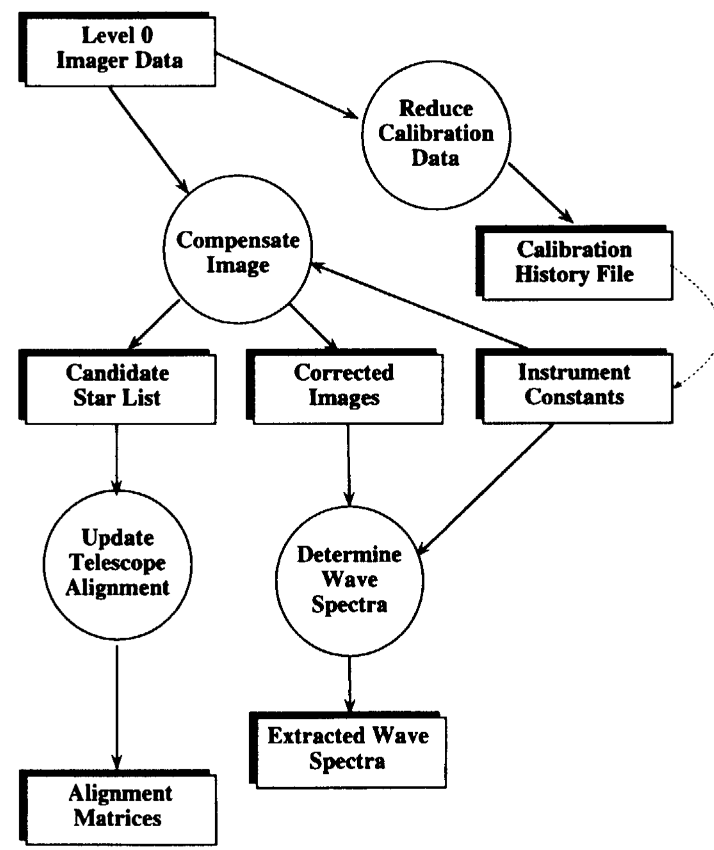
TIDI

Data Processing Data Flow

Profiler Data Processing



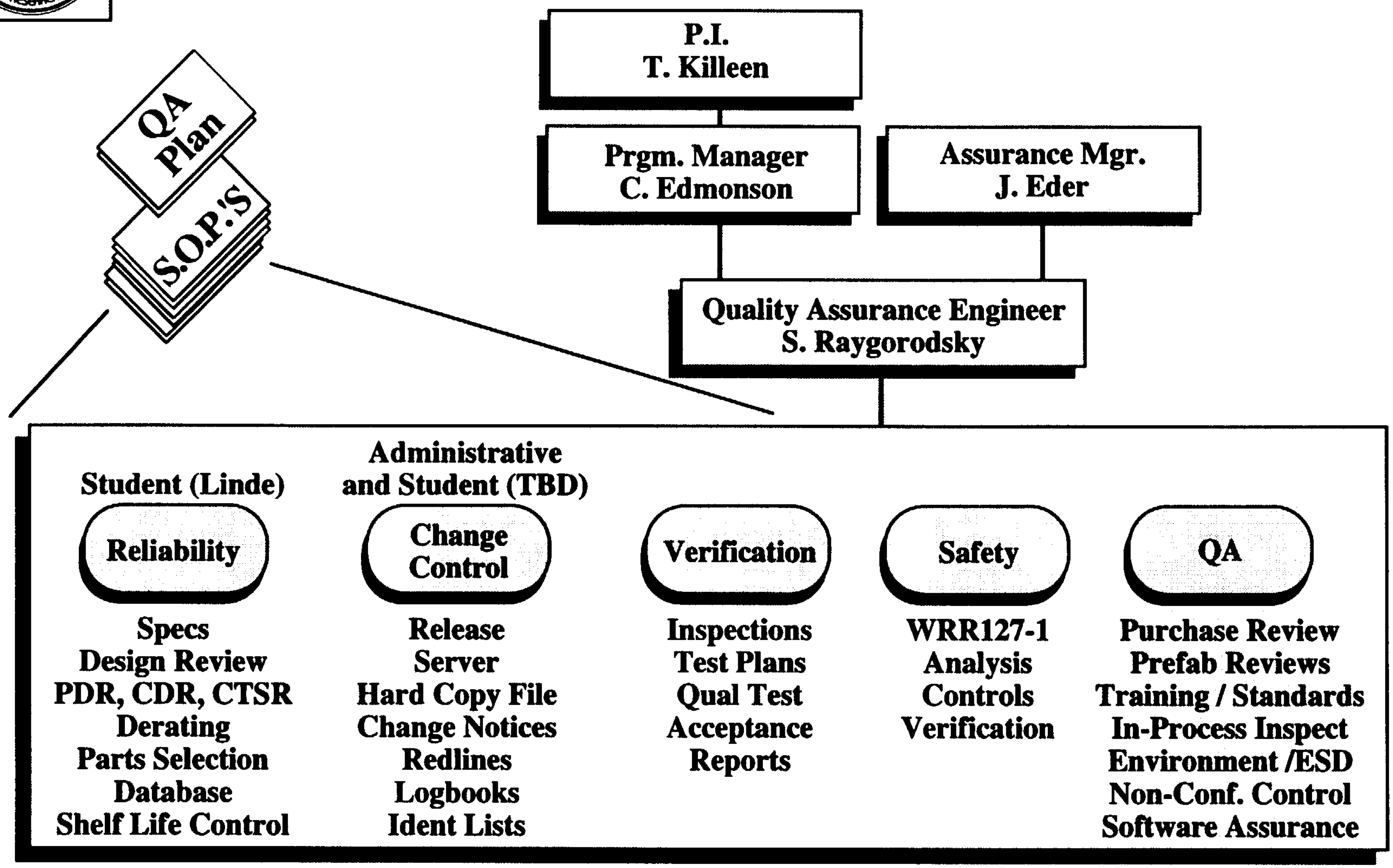
Imager Data Processing



NOTES:

Quality Assurance
John Eder

TIDI Quality Assurance Organization



Notes:

The Figure opposite is the UM SPRL QA Organization Chart. Listed at the bottom are the major tasks for the QA program. These are further described in the TIDI QA Plan (055-0160A, 8/1/95). The Plan was developed as part of the effort leading to the Conceptual Design Review. Provisions of the document will apply to Phase II/III efforts including the engineering design, production, testing, integration, and launch and flight operations of the TIMED mission. This Plan is sufficient to achieve the mission objectives as outlined in the Proposal technical section. Extensive use will be made of existing SPRL systems and procedures (SOPs) developed over four decades in the successful deployment of satellite and rocket borne instrumentation to achieve the reliability goal in a cost-effective manner.

Completion of all activities required by this document will be undertaken by Mr. John Eder, the SPRL R&QA Manager, supported by Mr. Sergei Raygorodsky, a R&QA staff Engineer I. Undergraduate students employed in Parts and Materials Control, and Configuration/Change Control areas will also be instrumental in completing various record keeping tasks. The availability of a APL and NASA experts will be treated as a potential reliability/assurance resource in addition to senior engineering resources available here.

APL or delegated Government personnel will be provided documents, records, equipment and facilities to enable them to carry out their overview activities of performance under the contract at SPRL or subcontractors/suppliers as required.

In general, the Plan and referenced procedures comply with the intent of NHB5300.4(1C) handbook, "Inspection System Provisions for Aeronautical and Space System Materials, Parts, and Components and Services".

The flowdown of requirements to subcontractor and suppliers will be accomplished by inclusion of PAG or QAIP provisions in subcontracts or by normal procurement control channels. Source inspections will be conducted by SPRL personnel whenever adequate determination of item quality cannot be made after receipt via inspection or testing.

TIDI

Safety

Preliminary Assessment

Personnel Safety:

- All mechanisms/moving parts enclosed except telescopes (envelope defined)
- No mercury, pryotechnics, pressure lines or fittings
- No exposed voltages
- Handling/lifting fixture TBD
- Radioactive source(s) for starting glow discharge calibration lamps (TBD 1μC Europium-152) would be enclosed in Cal Lamp Assembly
- Any N2 purge will be regulated/flow controlled to very low pressure
- EGSE will be transformer isolated from power line and exterior chassis grounded

Flight Safety:

- Materials selected to avoid SCC and flammables
- Stuctural analysis including fracture control will be performed
- Vents in "sealed" subsystems (Telescopes, Interferometer) to be sized for launch depressurization
- Instrument off during launch
- Short Circuit protection via packaging design, insulation & coating
- Parts derated per 975 and Spacecraft provides fusing
- Telescope covers will be captured

Notes:

The safety program is organized with QA at SPRL, and will address personnel and equipment safety and be consistent with use of an expendable launch vehicle from the Western Test Range. Assurance personnel and the SPRL Ground Segment Manager will work closely with the launch contractor to prepare a Hazard Analysis and System Safety Assessment in accordance with the Western Range Regulation 127-1. Verification of safety items will be folded into the TIDI test and inspection program.

The TIDI instrument, from a hazard analysis viewpoint, is very similar to the UARS/HRDI instrument launched on STS-48. Both are telescope and Fabry Perot interferometer plus electronics packages which have similar construction materials, mechanisms, thermal control and contamination control concerns. They are different in that TIDI is less massive and uses four smaller telescopes. Of course, the flight safety effort for TIDI is reduced because crew and landing concerns are not applicable.

Structural margins of safety will verified by modeling analysis with confirmation via the environmental qual program. It is expected that all instrument subsystem interface fasteners, the interferometer optical bench mounts, and telescope gimbal bearings will be scrutinized for fracture control.

The thermal control system will employ MLI, radiators, and heaters. Thermal blanket design will include grounding and restraint straps. Radiators will probably be passive (pending analysis work). Heaters also will be sized for operating conditions as necessary.

The use of two small (1μC) radioactive sources may be required to start the glow discharge calibration lamps. These are small beads sealed in the TIDI electronics within the interferometer. All necessary licensing and transfer/notification paperwork will be completed.

Ground safety concerns will be similar to those for HRDI except lifting and handling should be easier given the smaller size and weight. Also purging may not be necessary at WTR as it was in the humid conditions at KSC for HRDI. Also, if required, the purge panel design, assembly, testing, and certification should be simpler.

TIDI Typical SPRL Hardware Processes List

Process Type	Procedure or Specification No.	Description of Mat'l Processed
Anodizing, Sulphuric Acid	MIL-A-8625C, TYPE II, Cl 1/2	Aluminum 6061-T6
Chromate Conversion	MIL-C-5541 Class 3	Aluminum 6061-T6
Cleaning, Mechanical Pieces	060-0024	Ultasonic w/ Trichloroethylene, Acetone, and Isopropyl Alcohol
Cleaning, Soldered Assemblies	060-0092	Ethyl Alcohol
Cleaning, Vapor Degreasing	060-0018	Genesolv 2000 (HCFC 141b)
Crimping	060-0091 follows NHB5300.4(3H)	Connector Wiring
Gold Plating	MIL-G-45204C, Ty II, Gr C, Cl 2	Aluminum 6061-T6 (note 1), Brass
Printed Circuit Boards	MIL-P-55110 processing of MIL-P-13949 Laminate/Prepreg	Multilayer - PCB Type GIN / GFN
Soldering	NHB5300.4(3A-2)	Electronic components, PCB's
Staking	060-0015 follows NHB5300.4(3J) and GSFC S-313-008	Epoxy (Note 2) or Polyurethane
Spray Conformal Coating	060-0026 follows NHB5300.4(3J) and GSFC S-313-008	Uralane 5750LV A/B diluted w/ Toluene & MEK for spraying
Terminal Swaging	060-0023	Solder terminals onto PCBs

Notes:

Materials and Process Control insures that all materials used in instrument hardware and in processing are identified and examined for quality, reliability, and safety considerations.

The example table on the facing page lists typical processes applied to instrument materials and hardware All processes will be covered by a military, NASA, vendor, or SPRL specification or process procedure. It is the responsibility of the R&QA Manager to insure that processes are properly specified and procedures reviewed before implementation.

Materials will be selected on the basis of past experience and available reference data. Stress corrosion cracking susceptibility will be considered in selecting metallic materials. Materials will be from Table I of MSFC-HDBK-522B. Use of other metals will be justified. Metals used will be corrosion-resistant type or will be suitably plated/coated. Dissimilar metal contact will be avoided or protected against electrolytic corrosion.

Outgassing characteristics will be a prime consideration in utilizing organic materials. Materials with a TML>1% or VCM>.1% will not be used unless processed to mitigate their effects.

Materials with limited shelf lives are controlled by tagging with purchase order number for traceability and a "Do Not Use Beyond..." expiration date. Certain materials are refrigerated during storage. Others are enclosed and backfilled with dry nitrogen after each use. When expiration dates are reached, materials are retagged "Not for Flight Use" and are segregated or disposed according to University policy.

If use of any expired material is contemplated, it will first undergo appropriate testing to verify that essential properties are not compromised. Such materials may be retagged "Extension to ..." with a date not to exceed half the original shelf life from the date of expiration. No further extensions are allowed.

All materials used in instrument hardware which are not EEE parts will be identified on polymeric and metallic materials lists. These lists will be available to APL for their information in conjunction with the milestone reviews.

EEE Parts Program

Selection to be from Mil-Std-975 NASA Standard Parts list or other Mil ER or HR parts (883 Class B compliant microciruits, JTX semiconductors, FRL P or better passives)

Other parts are nonstandard and each will have a qualifying plan (specification, screens, DPA or other inspections or tests as deemed appropriate)

OTS or 'black box' hardware such as the Lockheed RH95 Processor will be similarily reviewed for qualifying basis. Thermal cycling in accordance with the PA Guidelines will be included

APL will be consulted

A EEE Partslist will be available at milestone reviews for APLs information

Radiation hardness and SEE immunity will be a requirement for selection

All Parts will be derated. Any exceptions will be documented via MRB

Notes:

The parts program insures that all electrical, electronic, and electro-mechanical parts and devices are selected and controlled to meet mission reliability goals

Standard parts will be used wherever possible. They will be selected from the Grade 1 or Grade 2 categories of NASA/GSFC Preferred Parts List (PPL), and NASA Standard Parts List (MIL-STD-975). Also parts available in full compliance to test requirements for Class S or B microcircuits; and JANS, JTXV or JTX semiconductors; and military HR or ER passive devices with failure rate level P or better; may be considered standard if APL concurs. The highest grade available will be obtained as long as there is no adverse programmatic impact.

Any part or device not as defined above, is considered nonstandard. Selection of nonstandard parts will be based on a rationale (similarity, manufacturer history, test data, etc.) which provides a suitable basis for the intended application.

An EEE parts list will be maintained which calls out generic part description, part number, procurement specification, manufacturer, and grade The conceptual EEE list for TIDI is one of the Appendices to this Design Review package. It is submitted to APL for information. After APL review of the EEE List, any suggestions and comments on nonstandard parts will be factored into procurement or test specifications which are generated.

Rescreening will be performed if needed to assure elimination of infant mortality failures of nonstandard parts. Test and inspection types and methods will follow selected guidelines of the PPL Appendix C as determined necessary by Engineering and R&QA, taking into account any APL comments as noted above.

DPA will be conducted on samples of selected items per criteria from S-311-M-70. The specific examinations and sample sizes will be determined on a case by case basis.

Parts will be selected or specified to meet mission radiation environment levels for total dose of 5Krads(Si) and immunity and single event upset rates as defined for TIMED.

All parts will be adequately derated in accordance with the guidelines of the PPL or MIL-STD-975.

Contamination Control Plan

Contamination Effects Potential on Hardware:

- High - Optical surfaces in Telescopes and Interferometer
  Background "noise" from scattering caused by particulates
  Throughput loss due to particulates and organic films
- Medium - Radiators and thermal blanket surfaces
  Lowered emissivity and reflectivity
- Low - Support Electronics
  Not sensitive to contamination

Design Controls:
- Materials Selection for low offgassing
- Integrated seals/covers, sintered breathing filters, purge fittings

Processing Controls:
- Cleaning, bagging, red tag covers
- Assembly in Clean Rooms
- Periodic Monitoring

Testing Controls:
- Bag/Purge in uncontrolled areas
- Handling fixtures/Shipping containers cleaned
- Monitor chambers with cold finger or crystal thickness monitor

Contamination Control Plan for TIDI

Notes:

Contamination Control is important to TIDI performance because the potential effects of contamination on optical surfaces in the telescopes and interferometer include:

1) Background "noise" from scattering caused by particulates

2) Throughput loss due to particulates and organic films

Additionally, radiators and thermal blanket surfaces need to be kept clean to avoid lowered emissivity or reflectivity. The instrument electronics is not sensitive to contamination.

Consideration will be given to the potential for transfer of contamination to, or from, other spacecraft systems. Both molecular and particulate contamination will be considered. Design controls include selecting non-metallic materials for low offgassing, and integrated seals/covers for the optical assemblies. Sintered breathing filters and purge fittings will probably be employed.

Fabrication and assembly of flight electronics hardware will occur in Class 100,000 clean areas. Assembly of optical hardware will occur in Class 10,000 or better clean areas or laminar flow clean benches. Standard measures will be taken including preassembly cleaning, bake outs, and post processing handling precautions (clean gloves, preservation packaging, and cleanliness inspections, as necessary).

Other controls include bagging in uncontrolled areas such as may be encountered during moving or test. Purging may also be used in this regard. Any handling fixtures and shipping containers will be appropriately designed and cleaned before use. The appropriate hardware specifications, special assembly procedures, and/or test procedures will outline the methods for implementing and maintaining any such special cleanliness requirements throughout instrument lifetime.

Periodic monitoring of cleanrooms via particle counter is planned. Set-up of environmental chambers with cold finger or crystal thickness monitor is necessary. Direct measurement of instrument parameters such as throughput during tests and calibrations will provide the best measure of cleanliness level.

Spacecraft Resource Summary

Brian C. Kennedy

TIDI

SC Resource Requirements 1

Heritage	DE FPI, HRDI & WINDII/UARS
Satellite Nominal Design Altitude	600 ±25 km
Satellite inclination	74.1±0.1°
Mission Lifetime	2 years
Atmospheric Region	60 - 300 km
Look directions, Azimuth	45°, 135°, 225°, & 315° (Velocity = 0°)
Look directions, Depression Angle	16° to 23° (Horiz. = 0°)
Instantaneous Field of View	2.5° V x 2.5° Imager 0.05° V x 2.5° Profiler
Placement, R, P, Y, 3σ (Inst + SC)	±0.5°
Knowledge, R,P, Y 3σ	0.03° (Inst + SC)
Jitter	0.03°/0.25sec
Stability	0.03°/10sec
Absolute Time, UTC	1 sec ±2.5 msec
Orbit; Height, Along Trk, X Trk	±1, ±1, ±1 km
Avoidance Cone, Θ1/2wrt boresight	17.5° (4 look directions)
Detector Radiator Area	25 x 25 cm Profiler CCD 10 x 10 cm Imager CCD
Detector Radiator Location	Anti-sun 2π Sr Clear Field of View

NOTES:

TIDI

SC Resource Requirements 2

Operating Temperature Range	
Electronics & Telescopes	-20 to +40°C
Sensor	20± 5°C, ±0.1°C/orbit
Survival Temperature Range	
Telescopes	-30 to +50°C
Sensor & Electronics	-40 to +60°C
Magnetic Field	Non Critical, < 5 Gauss
Electric Field	Non Critical
Mass	29.8 Kg
Power	13.3 W
Serial Commands 16Bit	2 KBytes/day
Relay Commands	1 @ 1/mission
Integration Time	0.25 Sec min
Data Rate with Housekeeping	2336 bps
Duty Cycle	100%
Contamination, particulate	Flight Covers, normal handling
Contamination, molecular	Red tag cover
Mechanical Disturbances, °/step, step time, Moment of Inertia	
Telescopes	0.05°, 20 ms, 0.0166 Kg/M^2
Filter Wheels	45°, 50 ms, $8.8x10^{-5}$ Kg/M^2
Scene Selectors	45°, 10 ms, 10^{-6} Kg/M^2

NOTES:

Potential Baseline Changes

Brian C. Kennedy

Potential Baseline Changes 1

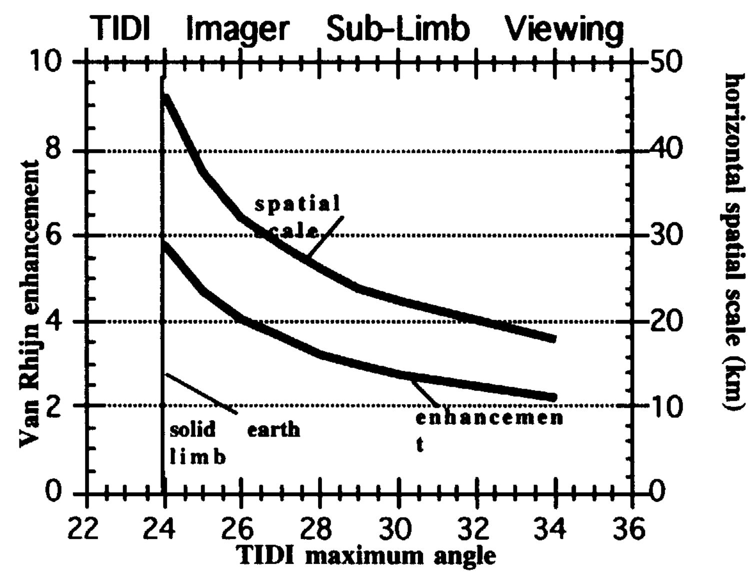
- <u>Current Baseline: 7.5-degree elevation range</u>
- Potential Change: Increase scan angle for sub-limb viewing (~32°)
- Trade-offs: +increased science (waves); -S/C accommodation change; -increased fiber-optic rotation or dove prism
- Resource Changes: Increased S/C CFOV

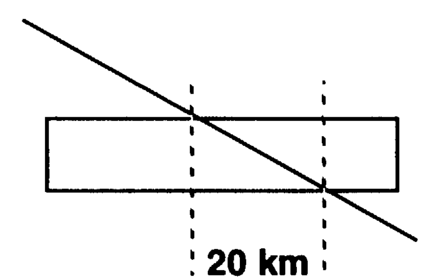
- <u>Current Baseline:Rectangular CCD in Profiler</u>
- Potential Change: Circular CCD in Profiler
- Trade-offs:+simpler image processing; +lower read noise= shorter temporal resolution/better wind accuracy, less sensitive of CTE effect, higher temperature operation-> smaller thermal radiator; -minor additional technology development
- Resource Changes: Less uP processing, less power, less mass

NOTES:

TIDI TIDI Option for Sub-Limb Viewing

- Horizontal resolution for the imager wave imaging can be improved by extending the telescope motion to view below the Earth's limb
- Sub-limb viewing reduces the signal level due to reduced Van Rhijn effect
- Option:
  - Extend telescope lower limit angle from 23.1° to 32°.
  - This would reduce horizontal resolution to about 20 km, with a factor of 2 reduction in signal to noise
  - Current baseline range is from 16.8° to 23.2° (6.4° total). New range would be from 16.8° to 32° (15.2° total)
  - Impact would include larger clear FOV requirements.





NOTES:

TIDI — Potential Baseline Changes 2

- Current Baseline: Sensor thermal control provided by SC
- Potential Change: Sensor thermal control provided by TIDI, similar to UARS/HRDI approach
- Trade-offs: +Mounts electronics with sensor for shorter and simpler cabling, +simpler interface to SC, +tighter temperature control, +possible bottom line mass savings
- Resource Changes: Less mass, less cost

- Current Baseline: TIDI subsystems distributed on nadir and +Y panels, fiber-optic cables and electrical harnesses cross through S/C
- Potential Change: Mount entire TIDI instrument on a single S/C baseplate
- Trade-offs: +simpler fiber-optic cable and harness routing; +simpler instrument integration
- Resource Changes: Less mass, less cost

NOTES:

Potential Baseline Changes 3

- Current Baseline: 3 m/s wind accuracy
- Potential Change:1 m/sec accuracy
- Trade-offs: +higher quality science (meridional residual circulation); -more complex and frequent on-orbit calibrations; -increased cost; -tighter S/C & instrument attitude knowledge requirement
- Resource Changes: S/C maneuvers for nadir viewing, possibly addition of Dove prism, or FO to 90°
- Current Baseline: ±0.5° 3σ Placement
- Potential Change:±0.1°3σ Placement (or smaller)
- Trade-offs: +Science data goes from 61 to 83%; -If SC Utilizes star sensor data in control, perhaps small impact

NOTES:

Appendix

Parameter Summary
Brian C. Kennedy

	A	B	C	D	E	F	G
1	file: 3131.B.ParamSum.TIDI			TIDI File #	055-3131		
2	latest line RevDate:	10/28/95					NOTE: Please enter new date & your initials when
3							making a change. ALL CALCULATED ENTRIES
4	**TIMED-TIDI INSTRUMENT PARAMETER SUMMARY**						should say "calculated" INSTEAD of having a date,
5							since all the basic VALUE lines already have dates.
6	**Item**	**Value**	**Units**	**Reference**	**RevDate**	**By**	**Comments**
7							
8	**INSTRUMENTATION REQUIREMENTS**						
9							
10	Atmospheric Region Observed	60-300	km		11/16/94	wp	
11	Look directions, Azimuth Angles	45, 135, 225, 315	deg		11/16/94	wp	wrt Velocity Vector = 0 degrees
12	Look Directions, Depression Angles, Typical	22.69, 21.38, 19.98, 16.86	deg		11/16/94	wp	@ 60, 120, 180, & 300 km tangent height, wrt local horizontal = 0, spacecraft altitude = 600 km.
13	Instrument Heritage	DE-FPI, UARS-HRDI & WINDII			11/16/94	wp	
14	Mission Lifetime	2	years		11/16/94	wp	
15	Total Radiation Dose	5	krads		10/24/95	bck	
16							
17	**Profiler:**						
18	Vertical Resolution, maximum	2.5	km		10/24/95	bck	
19	Wind Accuracy maximum, 1s	3	m/S		07/27/95	wp	hg/10/5/95
20	Temperature Accuracy maximum	2	K		07/27/95	wp	
21	Wavelength Range, maximum	900	nm		10/08/95	bck	
22	Wavelength Range, minimum	550	nm		11/10/93	wp	
23	Spectral Resolution, maximum	tbd	nm		07/27/95	wp	
24	Sensitivity, minimum	tbd	cnts/R/int.		07/31/95	wp	
25	Signal/Background, minimum	tbd			07/31/95	wp	
26							
27							
28							
29							
30							

	A	B	C	D	E	F	G
31	**Imager:**						
32	Spatial Resolution, maximum	10	km		07/27/95	wp	
33	Wind Resolution, maximum	7	m/S		07/27/95	wp	
34	Wavelength Range, maximum	900	nm		11/10/93	wp	
35	Wavelength Range, minimum	550	nm		11/10/93	wp	
36	Spectral Resolution, maximum	tbd	nm		07/27/95	wp	
37	Sensitivity, minimum	tbd	cnts/R/int.		07/31/95	wp	
38	Signal/Background, minimum	tbd			07/31/95	wp	
39							
40	**Spacecraft Platform:**						
41	Orbit Altitude, nominal	600±25	km		10/24/95	bck	
42	Orbit Inclination	74.1±0.01	deg		10/28/95	bck	SC CoDR says 74±.1°??
43	Precession Rate	tbd					
44	Nodal Regression Rate	-1.971	deg/day		11/16/94	wp	720 deg/yr
45	Apsidal Rotation Rate	-2.302	deg/day		11/16/94	wp	
46	Altitude (Radius) Knowledge, 3s	±1	km		10/08/95	bck	
47	Position Knowledge, Along-Trk, 3s	±1	km		10/08/95	bck	
48	Position Knowledge, Cross-Trk, 3s	±1	km		10/08/95	bck	
49	Velocity Knowledge, 3sigma	±.25	m/S		10/08/95	bck	Easily achieved by GPS, could be relieved if necessary.
50	SC Coordinates Pointing Placement: R,P,Y; 3sigma	1	deg		11/16/94	wp	1 deg provided by Spacecraft
51	SC Coordinates Pointing Knowledge, R,P,Y; 3sigma	0.03	deg		10/22/95	bck	1 deg provided by Spacecraft
52	Instrument Coordinates Pointing Knowledge, R,P,Y; 3sigma	0.0015	deg		10/08/95	bck	0.03 deg provided by TIDI
53	Jitter, max; 3sigma	0.0015	deg/ 0.25 S		10/08/95	bck	Profiler Integ Time = 0.25 S
54	Stability, max; 3sigma	0.0015	deg / 10 S		10/08/95	bck	Vertical Profile Time = 10 S
55	FOV Avoidance Cone, half-angle	17.5	deg		10/05/95	hjg	wrt boresight, each look direction,hg/10/5/95
56	Telescope Survival Temp Limits	-40 to 50	C		11/14/94	wp	
57	Sensor Survival Temp Limits	-40 to 60	C		11/14/94	wp	
58	Electronics Survival Temp Limits	-40 to 60	C		11/14/94	wp	
59	Magnetic Field Susceptability	<5	Gauss		11/16/94	wp	
60	Electric Field Susceptability	Non-Crit			11/16/94	wp	

	A	B	C	D	E	F	G
61							
62	**INSTRUMENTATION PARAMETERS**						
63							
64	**Power:**						
65	Worst-Case @ 28 v nom bus	142.7	W		calculated	wp	All mechanisms energized simultaneously
66	Average @ 28 v nom bus	13.31	W		calculated	wp	Normal operation, orbit average,hg/10/5/95
67	Standby @ 28 v nom bus	10.33	W		calculated	wp	Safe Stow, minimal activity, TEC's on.
68	Survival, max @ 28 v nom bus	10	W		01/15/95	wp	Thermostatted heaters, This is a heater max power, actual average power is determined from thermal design and should be much less.
69	**Power & Mass Subsytem Sum.**	**W**	**Kg**				
70	Telescope subass'y, 1	0.64	3.60				
71	Scene selectors (2)	0.10	0.90				
72	FW, Profiler	0.65	0.29				
73	FW, Imager	0.84	0.29				
74	Profiler CCD Elect	0.50	0.15				
75	Profiler TEC	0.56	0.35				
76	Profiler CCD Radiator		1.10				
77	Imager CCD Elect	0.50	0.15				
78	Imager TEC	0.32	0.35				
79	Imager CCD Radiator		0.65				
80	LRE PZT Amp	0.4	0.48				
81	LRE PZT Control	0.4	0.47				
82	CCD I/O	0.45	0.50				
83	SC I/O	1.00	0.50				
84	uP	3.2	0.50				
85	Motor Drive 1	0.2	0.50				
86	Motor Drive 2	0.2	0.50				
87	Calibration Lamps	0.02	0.77				
88	Low Voltage Power Supply Efficiency	75%	1.00				
89	Harnesses		0.50				
90	Fiber Optics, Profiler		0.13				
91	Fiber Optics, Imager		0.60				
92	Profiler, etalon, optics, etc		0.97				

	A	B	C	D	E	F	G
93	Imager, optics		0.02				
94	Sensor Structure		3.22				
95	Sensor Thermal Blanket		0.57				
96							
97	**Mass:**						
98	TIDI Total	29.86	kg		calculated	wp	
99	Electronics Total	5.72	kg		calculated	wp	
100	Telescopes Total	14.40	kg		calculated	wp	
101	Sensor Total	9.73	kg		calculated	wp	
102							
103	**Operating Temperature Limits:**						
104	Telescope	-20 to 40	C		10/23/95	bck	
105	Sensor	20±5	C		10/23/95	bck	
106	Electronics	-20 to 40	C		10/23/95	bck	
107							
108	**Operating Temperature Gradients:**						
109	Telescope	20	°K/orbit		10/23/95	bck	
110	Sensor	0.1°K	°K/orbit		10/23/95	bck	
111	Electronics	5	°K/orbit		10/23/95	bck	
112							
113	**Command & Data:**						
114	Relay Command Channels	1			11/10/93	wp	
115	Relay Command Frequency	1	per Mission		11/10/93	wp	Flight/Test Mode; Telescope cover removal enable
116	C&D Interface Method	MilStd1553			11/09/94	wp	
117	1553 Cmd Input Addresses	1			11/09/94	wp	
118	1553 Cmd Rate, max	2,000	bytes/Day		11/09/94	wp	
119	CCSDS Packet Output Addresses	3			11/09/94	wp	Profiler, Imager, Housekeeping
120	CCSDS Packet Size	256	bytes		11/09/94	wp	
121	Profiler Data Rate	1329	bits/S		10/23/95	sm	not including CCSDS packet overhead
122	Imager Data Rate	973	bits/S		10/23/95	sm	not including CCSDS packet overhead
123	Housekeeping Data Rate	34	bits/S		10/23/95	sm	not including CCSDS packet overhead
124	Total Data Rate	2336	bits/S		10/23/95	sm	not including CCSDS packet overhead
125	Absolute Time , UTC	±1.0	S		11/10/93	wp	knowledge on-board ±2.5 ms
126							

	A	B	C	D	E	F	G
127	**Telescopes:**			055-166			
128	Number of Telescopes	4			11/08/94	wp	
129	Telescope Aperture Diameter	7.5	cm		06/29/95	hg	baseline BASD design
130	Instantaneous Field of View	2.5x2.5	deg		11/10/93	wp	0.05 deg vertical for Profiler
131	Image spot size, center of FOV	20	u		10/08/95	bck	Need to check
132	Image spot size, edge of FOV	25	u		10/08/95	bck	
133	Pointing Motion	1	axis		11/10/93	wp	
134	FOV Motion Range	5.83	deg		11/16/94	wp	
135	FOV Step Increment, minimum	0.05	deg		11/08/94	wp	
136	Small-Angle Scattered Light @ 90 km	24	kR/Å		07/27/95	wp	effect of bright Earth with FOV 90 km above
137	Small-Angle Scattered Light @ 60 km	30	kR/Å		07/27/95	wp	effect of bright Earth with FOV 60 km above
138	Pointing Increment Step Rate	4	steps/S		calculated	wp	1 Step per Profiler Minimum Integ Time
139	Pointing Increment Step Time, max	20	mS		11/08/94	wp	10 mS accelerating, 10 mS decelerating, move during Detector readout times
140	Unidirectional Motion Duration	10	S		calculated	wp	1 Motion per Profiler Vertical Profile
141	Operational duty cycle, max	continuous			07/27/95	wp	
142	Moment of Inertia	166	kg*cm2		11/08/94	wp	
143	Required Torque, min	0.105	nt*m		11/08/94	wp	Equivalent to Minimum Disturbance Torque
144	Required Torque, min	0.009	oz*in		11/08/94	wp	Equivalent to Minimum Disturbance Torque
145	Motor	Schaeffer Type I			11/10/93	wp	
146	Motor Supply Voltage	28	V		11/16/94	wp	direct from sc power bus
147	Motor Input Power, peak	5	W		11/08/94	wp	
148	Motor Energization Time per Step	20	mS		11/08/94	wp	
149	Energy per step	0.1	W*S		calculated	wp	Peak Power * Energization Time
150	Motor Power, Average	0.4	W		calculated	wp	Energy per Step * Step Rate
151	Position Encoder Power	0.06	W		12/07/94	wp	LEDS strobed
152	Power, 1 Telescope, Peak	5.06	W		calculated	wp	Motor + Encoder
153	Power, All Telescopes, Peak	20.24	W		calculated	wp	All energized at same time
154	Power, 1 Telescope, Profile Average	0.64	W		calculated	wp	Motor + 4 Encoders
155	Power, 1 Telescope,w/ LVS eff	0.85					
156	Dimensions, each Telescope	25 dia x 30	cm		06/29/95	hg	
157	Mass, 1 Telescope	1.50	kg		06/29/95	hg	telescope only
158	Mass, 1 cover	0.10	kg		110/22/95	bck	
159	Mass, 1 Thermal blanket	0.20	kg		110/22/95	bck	

	A	B	C	D	E	F	G
160	Mass, 1 Motor/Encoder	1.00	kg		110/22/95	bck	From Jim Hammond, Shaeffer Type 2 w/encoder
161	Mass. 1 structure	0.80	kg		06/29/95	hg	est
162	Mass, 1 telescope subassembly	3.60	kg				
163	Total telescope assy (4 units)	14.40	kg		calculated	wp	est
164							
165	**Sensor (Includes Scene Selectors, Fiber Optics, Filter Wheels, Radiator, Imager, and Profiler):**						
166	Dimensions	15x20x60	cm		11/10/93	wp	
167	CCD elect both	1.00	W		calculated	wp	
168	CCD elect both w/LVs eff	1.33	W		calculated	wp	
169	Mech & TECs	2.47	W		calculated	wp	
170	Mech & TECs w/LVS eff	3.29					
171	Total average power	4.63	W				From SC
172	Power dissipated in sensor	3.47					For thermal design
173	Total Mass	9.733	kg		calculated	wp	
174							
175	**Scene Selector:**			HRDI data	12/14/93	wp	
176	Number of Scene Selectors	2			11/08/94	wp	hg/10/5/95
177	Step Increment	45	deg		11/10/93	wp	hg/10/5/95
178	Step Range	Cont Rot			11/10/93	wp	
179	Step Rate, average, Profiler	0.077	steps/Sec		10/24/95	wp	1 chng's per vertical profile 8 in 104 secs
180	Step Rate, average, Imager	0.125	steps/Sec		10/24/95	wp	13 chng's in 104 secs
181	Motion Time, 90 deg	10	mS		12/14/93	wp	
182	Moment of Inertia	56.5	gm*cm2		10/22/95	wp	
183	Required Torque, min	7.3	gm*cm		10/22/95	wp	Equivalent to Minimum Disturbance Torque
184	Required Torque, min	0.65	oz*in		10/22/95	wp	Equivalent to Minimum Disturbance Torque
185	Motor	IMC 011-889-1			10/22/95	wp	
186	Motor Supply Voltage	28	V		11/16/94	wp	direct from sc power bus
187	Motor Winding Impedance	60	ohms		10/22/95	wp	
188	Motor Input Power, peak	26.1	W		calculated	wp	two windings energized
189	Motor Energization Time	10	mS		10/24/95	wp	motion time
190	Energy per step	0.26	W*S		calculated	wp	Peak Power * Motor Energization Time

	A	B	C	D	E	F	G
191	Motor Power, average, Profiler	0.02	W		calculated	wp	Energy per step * Average Step Rate
192	Motor Power, average, Imager	0.03	W		calculated	wp	Energy per step * Average Step Rate
193	Holding/Peak Torque ratio	0.0005			10/24/95	wp	
194	Motor Power, Holding Torque	0.013	W		calculated	wp	
195	Position Encoder Power	0.01	W		10/24/95	wp	LEDS strobed
196	Power, Peak, 1 SS	26.14	W		calculated	wp	Motor + Encoder
197	Power, Peak, All SS's	52.29	W		calculated	wp	
198	Power, Average, Scene Selectors	0.10	W		calculated	wp	2 Motors + 2 Encoders
199	Mass, 1 SS	0.45	kg		10/24/95	wp	
200	Total Mass, All SS's	0.90	kg		calculated	wp	
201							
202	**Fiber Optics Profiler:**						
203	Number of FO's	5			10/22/95	bck	
204	Mass	0.13	kg		10/22/95	bck	Heinz' #
205	Number of fibers	100 x 2			10/22/95	bck	
206	Diameter of Fiber w/cladding	50.00	u		10/08/95	bck	Heinz needs to check
207	Diameter of Fiber w/o cladding	40.00	u		10/08/95	bck	Heinz needs to check
208							
209	**Fiber Optics, Imager:**						
210	Number of FO's	5			10/22/95	bck	
211	Mass	0.60	kg		10/22/95	bck	
212	Number of fibers	100 x 100			10/08/95	bck	
213	Diameter of Fiber w/cladding	50.00	u		10/22/95	bck	Heinz needs to check
214	Diameter of Fiber w/o cladding	40.00	u		10/22/95	bck	Heinz needs to check
215							
216	**Filter Wheel(s):**			055-134	12/14/93	wp	
217	Number of Filter Wheels	2			11/08/94	wp	
218	Filter Positions per Wheel	8			07/27/95	wp	
219	Step Increment	45	deg		11/10/93	wp	
220	Step Range	Cont Rot			11/10/93	wp	
221	Step Rate , Profiler	0.250	steps/S		10/08/95	bck	Three changes per Vertical Profile of 12 sec
222	Step Rate, Imager	0.333	steps/S		10/08/95	bck	Four changes per Vertical Profile of 12 sec
223	Filter Diameter	1.5	cm		12/14/93	wp	
224	Motion Time, 45°	50	mS		12/14/93	wp	

	A	B	C	D	E	F	G
225	Moment of Inertia	880	gm*cm2		12/14/93	wp	
226	Required Torque, min	61.4	gm*cm		12/14/93	wp	Equivalent to Minimum Disturbance Torque
227	Required Torque, min	5.5	oz*in		12/14/93	wp	Equivalent to Minimum Disturbance Torque
228	Motor	IMC 011-889-1			12/14/93	wp	
229	Motor Supply Voltage	28	V		11/16/94	wp	direct from sc power bus
230	Motor Winding Impedance	60	ohms		12/14/93	wp	
231	Motor Input Power, peak	26.1	W		12/14/93	wp	two windings energized
232	Motor Energization Time, 45° motion	90	mS		10/22/95	wp	
233	Energy per 45° motion	2.4	W*S		calculated	wp	Peak Power * Motor Energization Time
234	Motor Power, average, Profiler	0.59	W		10/08/95	bck	Energy per step * Average Step Rate
235	Motor Power, average, Imager	0.78	W		10/08/95	bck	Energy per step * Average Step Rate
236	Position Encoder Power	0.06	W		12/07/94	wp	LEDS strobed
237	Power, Peak, 1 FW	26.19	W		calculated	wp	Motor + Encoder
238	Power, Peak, All FW's	52.39	W		calculated	wp	
239	Power, Average, All FW's	1.49	W		calculated	wp	2 Filter Wheels + 2 Encoders
240	Mass, 1 FW	0.29	kg		12/14/93	wp	
241	Total Mass, All FW's	0.57	kg		calculated	wp	
242							
243	**Profiler:**						
244	Field of View, Horizontal	2.5	deg		11/15/93	wp	
245	Field of View, Vertical	0.05	deg		11/15/93	wp	
246	Sensor Aperture (circular)	3	cm		11/10/93	wp	
247	Filter #1	763.6	nm		07/27/95	wp	
248	Filter #2	764.5	nm		07/27/95	wp	
249	Filter #3	765.9	nm		07/27/95	wp	
250	Filter #4	557.7	nm		07/27/95	wp	
251	Filter #5	630.0	nm		07/27/95	wp	
252	Filter #6	732.0	nm		07/27/95	wp	
253	Filter #7	844.6	nm		07/27/95	wp	
254	Filter #8	892.0	nm		07/27/95	wp	
255	HRE Gap	1.26	cm		11/10/93	wp	
256	HRE mass	0.32	kg		10/22/95	bck	from HJG
257	LRE Gap	0.072	cm		11/10/93	wp	
258	LRE mass	0.55	kg		10/22/95	bck	from HJG

	A	B	C	D	E	F	G
259	Etalon Finesse	10			11/10/93	wp	hg/10/5/95
260	Optical Transmission, overall	0.11			11/10/93	wp	
261	Parasitic Light Transmission, max	tbd			07/27/95	wp	
262	Detector Resolution	30	rings		07/27/95	wp	equal-area rings
263	Ring Sensitivity	tbd	cnts/R		07/27/95	wp	
264	Ring Value Quantization	12	bits		10/08/95	bck	
265	Ring Value S/N Ratio, max	tbd			07/27/95	wp	Not relevant, we're more interested in m/s, °K
266	Detector Type	CCD			11/10/93	wp	
267	CCD Format	TBD	pixels		11/15/93	wp	
268	CCD Binning	128x128	bins		11/15/93	wp	
269	CCD Bin Sampling Depth	12	bits		12/14/93	wp	
270	Dark Current	<.01	e/S/bin		10/22/95	bck	25 pA/cm^2/sec
271	Readout Noise	<10	electrons		11/10/93	wp	
272	Saturation Level	150,000	e/bin		11/10/93	wp	
273	Quantum Eff @550 nm	> 80%?			10/08/95	bck	
274	Quantum Eff @900 nm	>35%?			10/08/95	bck	
275	Vertical Profile Time	10	S		11/10/93	wp	
276	Vertical Step Integration Time, min	0.25	S		07/27/95	wp	
277	Vertical Step Integration Time, max	unlimited	S		07/27/95	wp	
278	Data Rate	1,440	bits/S		10/22/95	bck	30 ch's 12 bits, .25 sec
279	CCD Elect Mass	0.15	kg		10/20/95	cc	
280	CCD Elect Size	10x10x1.25	cm		10/20/95	cc	
281	CCD Elect Input power, avg	0.50	W		10/24/95	cc	carried to LVS output total power
282	TEC Temperature Setpoint	-73	C		11/10/93	wp	200°K
283	TEC Supply Voltage	28	V		11/16/94	wp	direct from sc power bus
284	TEC Power Input, max	5	W		11/16/94	wp	heat loads calculation value
285	TEC Power Input, average	0.56	W		10/24/95	wp	carried to sensor total Power
286	CCD/TEC subassembly, mass	0.35	kg		10/22/95	bck	
287	Profiler Optics, mass	0.10	kg		10/22/95	bck	
288	Profiler CCD, TEC, Optics, mass	1.47	kg				
289							
290	**Imager:**						
291	Field of View, Horizontal	2.5	deg		11/15/93	wp	
292	Field of View, Vertical	2.5	deg		11/15/93	wp	

	A	B	C	D	E	F	G
293	Sensor Aperture (square)	3x3	cm		11/10/93	wp	
294	Filter #1	844.6	nm		07/27/95	wp	
295	Filter #2	866.0	nm		07/27/95	wp	
296	Filter #3	892.0	nm		07/27/95	wp	
297	Filter #4	open	nm		07/27/95	wp	
298	Filter #5	766.0	nm		07/27/95	wp	
299	Filter #6	732.0	nm		07/27/95	wp	
300	Filter #7	tbd	nm		07/27/95	wp	
301	Filter #8	tbd	nm		07/27/95	wp	
302	Path Differential	7.3	cm		11/10/93	wp	
303	Optical Transmission, overall	0.07			11/10/93	wp	
304	Image Resolution	128x128	pixels		10/08/95	bck	
305	Pixel Sensitivity	tbd	cnts/R		07/27/95	wp	
306	Pixel Value S/N Ratio, max	tbd			07/27/95	wp	
307	Detector	CCD			11/10/93	wp	
308	CCD Format	TBD	pixels		10/08/95	bck	Could be as small aas 512 x 512
309	CCD Binning	128x128	bins		11/15/93	wp	
310	CCD Bin Sampling Depth	12	bits		12/14/93	wp	
311	Dark Current	<1	e/S/pixel		10/08/95	bck	
312	Readout Noise	10	electrons		11/10/93	wp	
313	Saturation Level	150000	e/bin		11/10/93	wp	
314	Quantum Eff @550 nm	>85%?			10/08/95	bck	
315	Quantum Eff @900 nm	>35%?			10/08/95	bck	
316	Integration Time, stars	~ 2 sec	S		calculated	wp	Int Time synchronized to Vertical Profile Time
317	Data Rate	1,464	bits/S		11/10/93	wp	305 bins*12 bits*4 images/10 sec
318	CCD Elect, mass	0.15	kg		10/22/95	bck	
319	CCD Elect Size	10x10x1.25	cm		10/20/95	cc	
320	CCD Elect Input power, avg	0.50	W		10/24/95	wp	carried to LVS output total power
321	TEC Temperature Setpoint	-35	C		10/08/95	bck	238°K
322	TEC Supply Voltage	28	V		11/16/94	wp	direct from sc power bus
323	TEC Power Input, max	5	W		11/16/94	wp	heat loads calculation value
324	TEC Power Input, average	0.32	W		10/24/95	wp	carried to sensor total Power
325	CCD/TEC subassembly, mass	0.35	kg		10/22/95	bck	
326	Imager Optics Mass	0.02	kg		10/22/95	bck	

	A	B	C	D	E	F	G
327	Imager CCD, TEC, Optics, mass	0.52	kg		10/22/95	bck	
328							
329	**TEC Radiator: Profiler**						
330	Radiator Dimensions	25x25	cm	HJG	10/08/95	bck	for one CCD
331	Radiator Mass	1.1	kg		10/22/95	bck	for one CCD
332							
333	**TEC Radiator:Imager**						
334	Radiator Dimensions	10x10	cm	HJG	10/08/95	bck	for one CCD
335	Radiator Mass	0.65	kg		10/22/95	bck	for one CCD
336							
337	**Sensor Structure**						
338	Mass	3.22	kg		10/22/95	.	
339							
340	**Sensor Thermal Blanket**						
341	Mass	0.57					
342							
343	**Electronics (summary):**						
344	Subsystem Dimensions	18x18x21	cm		11/10/93	wp	
345	Subsystem Power, average	5.87	W		calculated	wp	Power Supply output. Heat loads tabulated in appropriate sections
346	Subsystem Input Power, average	7.83	W		calculated	wp	Power Supply Efficiency applied.
347	Subsystem Mass	5.72	kg		calculated	wp	
348							
349	**LRE PZT Amp:**						
350	Dynamic Range	tbd			11/10/93	wp	
351	Resolution	tbd			11/10/93	wp	
352	Size	18x18x1.9	cm		10/22/95	bck	
353	Power	0.4	W		11/10/93	wp	
354	Mass	0.48	kg		11/10/93	wp	
355							
356	**LRE PZT Control:**						
357	Dynamic Range	tbd			11/10/93	wp	
358	Resolution	tbd			11/10/93	wp	

	A	B	C	D	E	F	G
359	Size	18x18x1.9	cm		10/22/95	bck	
360	Power	0.4	W		11/10/93	wp	
361	Mass	0.47	kg		11/10/93	wp	
362							
363	**CCD I/O:**						
364	Size	18x18x1.9	cm		10/22/95	bck	
365	Power	0.45	W		11/10/93	wp	
366	Mass	0.50	kg		11/10/93	wp	
367							
368	**SC I/O**						
369	Size	18x18x1.9	cm		10/22/95	bck	
370	Power	1.00	W		11/15/94	wp	
371	Mass	0.50	kg		11/10/93	wp	
372							
373	**Flight Computer, uP:**						
374	Orbit Clock Maximum Count	2^32			11/10/93	wp	
375	Orbit Clock Resolution	0.01	S		11/10/93	wp	
376	Size	18x18x1.9	cm		10/22/95	bck	
377	Power	3.2	W		11/10/93	wp	
378	Mass	0.50	kg		11/10/93	wp	
379							
380	**Motor & TEC Controller 1, MD1:**						
381	Size	18x18x2.5	cm		10/22/95	bck	
382	TEC Design Setpoint, operating	200 & 238	°K		10/08/95	bck	
383	TEC Stability	±0.1	°K		10/08/95	bck	
384	Subsystem Power	0.2	W		11/16/94	wp	
385	Mass	0.50	kg		11/10/93	wp	
386							
387	**Motor & TEC Controller 2:**						
388	Size	18x18x2.5	cm		10/22/95	bck	
389	TEC Design Setpoint, operating	200 & 238	°K		10/08/95	bck	
390	TEC Stability	±0.1	°K		10/08/95	bck	
391	Subsystem Power	0.2	W		11/16/94	wp	
392	Mass	0.50	kg		11/10/93	wp	

	A	B	C	D	E	F	G
393							
394	**Calibration Lamps:**						
395	Size	18x18x3.2	cm		10/22/95	bck	
396	Power	0.02	W		11/10/93	wp	
397	Mass	0.77	kg		11/10/93	wp	
398							
399	**Power Supply:**						
400	Size	18x18x3.2	cm		10/22/95	bck	
401	Conversion Efficiency	0.75			11/10/93	wp	
402	Mass	1.00	kg		11/10/93	wp	
403							
404	**Wiring Harnesses & Structure:**						
405	Mass	0.50	kg		11/10/93	wp	
406	**UNITS ABBREVIATIONS:**						
407	meters		m				
408	kilometers		km				
409	centimeters		cm				
410	centimeters squared		cm2				
411	nanometers		nm				
412	seconds		S				
413	milliseconds		mS				
414	degrees		deg				
415	degrees Kelvin		K				
416	degrees Centigrade		C				
417	watts		W				
418	kilograms		kg				
419	newtons		nt				
420	ounces		oz				
421	volts		V				
422	electrons		e				
423	counts		cnts				
424	Rayleighs		R				
425	kiloRayleighs		kR				
426	Angstroms		Å				

	A	B	C	D	E	F	G
427							