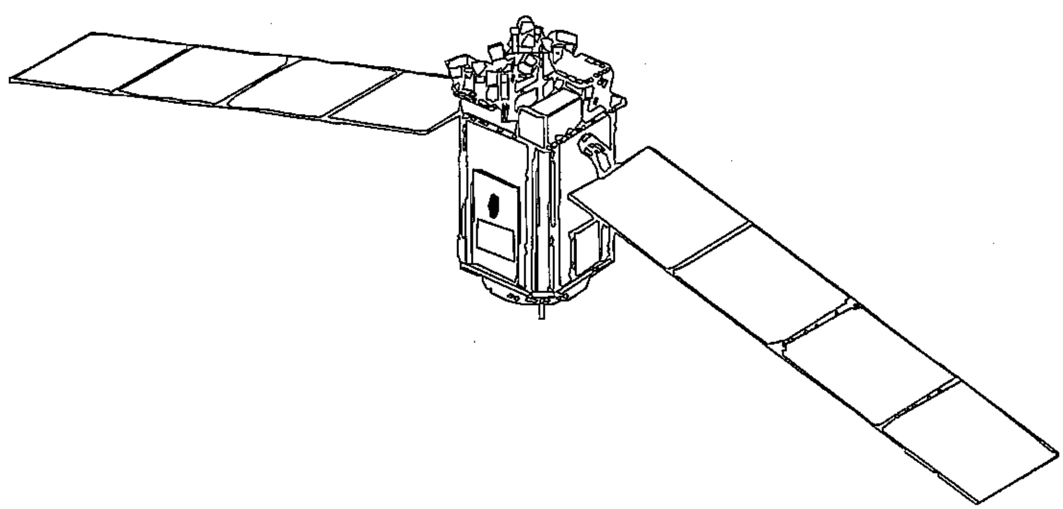
SDL/97-076

SABER
CRITICAL DESIGN REVIEW

20-22 October 1997



Space Dynamics Laboratory
Utah State University

Contract No. NAS1-20467

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Table of Contents

SABER CRITICAL DESIGN REVIEW

Acronyms and Abbreviations

BB	Blackbody
BRDF	Bidirectional reflectance distribution function
C&DH	Control and data handling
CC&S	Chopper control and synchronization
ECO	Engineering change order
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
FEM	Finite element model
FiST	Fiber support technology
FPA	Focal plane array
FWHM	Full width half maximum
GSE	Ground support equipment
IEB	Interface electronics box
IFC	In-flight calibrator
IFOV	Instantaneous field of view
MLI	Multilayer insulation
MRB	Material review board
MSDS	Material safety data sheet
MTF	Modulation transfer function
POC	Payload operation center
RFE	Refrigerator electronics
RSR	Relative spectral response
SABER	Sounding of the Atmosphere using Broadband Emission Radiometry
S/C	Spacecraft
STP	Standard temperature and pressure
SNR	Signal-to-noise ratio
TIMED	Thermosphere Ionosphere Mesosphere Energetics and Dynamics

SABER CDR Agenda, Day One
Monday, 20 October 1997
Building 2 Conference Room (127 & 128)

Time	Topic	Presenter
8:00	Welcome	James Ulwick
	Agenda and Logistics	Lorin Zollinger
	Opening Remarks	Lenny McMaster
8:15	Project Status, Milestones, and Funding	Jim Miller
8:20	PDR Action Item Status	Jim Miller
8:30	Science Overview	Jim Russell
9:00	Requirements, Baseline Changes, Instrument Overview, and Risk Management	Steven Brown
10:00	Break	
10:15	Radiometric and Optical Subsystem Overview	Roy Esplin
11:00	Scanner Subsystem Overview	Steven Brown
11:15	Thermal Overview	Scott Jensen
11:45	Mechanical/Structural Subsystem Overview	Mehrdad Roosta/Steve Folkman
12:15	Lunch	
1:15	Electronics Overview	Mark Jensen
1:45	Calibration Plan and GSE Overview	Joe Tansock
2:30	Electrical GSE, GSE, and Calibration Software	Keith Paskett / Guy Beaver
3:15	Break	
3:30	Fabrication, Integration, Test, and Calibration Plans	Steven Brown
4:30	Contamination Control	Jim Dyer
4:45	Action Item Review	

SABER CDR Agenda, Day Two
Tuesday, 21 October 1997

Building 2 Conference Room (127 & 128)			Building 4 Room A151	
Time	**Topic**	**Chairman/Presenter**	**Topic**	**Chairman/Presenter**
8:00	Optics and Radiometrics Subsystem Review	Tony Jalink (Chairman) Roy Esplin (SDL Lead)	Thermal Subsystem Review	Bob Sherrill (Chairman) Scott Jensen (SDL Lead)
9:30			Mechanical / Structural Subsystem Review	Bob Sherrill (Chairman) Mehrdad Roosta (SDL Lead)
11:00	Break			
11:30	Report - Radiometric and Optical Subsystem Review	Tony Jalink		
11:45	Report - Mechanical, Structural, and Thermal Subsystem Review	Bob Sherrill		
12:00	Lunch			
1:00	Calibration Subsystem Reviews	Tony Jalink (Chairman) Joe Tansock (SDL Lead)	Electronics Subsystem Reviews	Tom Shull (Chairman) Mark Jensen (SDL Lead)
4:30	Report - Electronics Subsystem Review	Tom Shull		
4:45	Report - Calibration Subsystem Review	Tony Jalink		
5:00	Action Item Review			

SABER CDR Agenda, Day Three
Wednesday, 22 October 1997
Building 2 Conference Room (127 & 128)

Time	Topic	Presenter
8:00	Software Development Plan Software Quality Assurance Flight Data Processing Approach (overview)	Larry Gordley
8:15	Mission Operations and POC Software Development Flight Data Processing Approach	Jim Craft
8:45	Data Retrieval Algorithm Development	Marty Mlynczak
9:15	Product Assurance Safety Parts Management Configuration Management	Richard Austin
10:15	Break	
10.30	Cost Schedule Descope Options	Jim Miller/ Lorin Zollinger
11:15	Plant Tour	
12:15	Lunch	
1:15	Action Item Review and Committee Feedback	
2:30	Adjourn	

Optical and Radiometric Splinter Topics

- **Radiometry**
  - Noise equivalent radiance
  - Dynamic range
  - Jones sources
- **Instrument Full Width Half Maximum and Modulation Transfer Function**
- **Telescope Assembly**
  - Prescription
  - Tolerance budget
- **Mirror Design & Fabrication**
  - Finite element analysis
- **Stray Light**
  - Diffraction from apertures and secondary mirror spider
  - Mirror BRDF
  - Nonrejected radiance from earth and atmosphere
- **Chopper**
  - Prototype will be available for inspection
  - Chopping efficiency and operation
- **Detector/Filter Assembly**
- **Detector Assembly**
  - EG&G Judson, detector subcontractor, attending
  - Prototype status
  - D*
  - Responsivity
  - Temperature effects
- **Filter Assembly**
  - Prototype status
  - In-band performance
  - Out-of-band performance

Mechanical and Structural Splinter Topics

- **Top Level Assembly**
- **Interfaces**
- **Telescope Assembly**
  - Baffle
  - Scanner
  - Caging
  - Foreoptics
  - Reimaging optics
  - Detector mount
- **Structure Assembly**
- **Cover**
- **IEB Structure**

Thermal Splinter Topics

- **Instrument Thermal Design**
  - Thermal environment (boundary conditions)
  - Spacecraft interface
  - Discussion of thermal modeling and results
- **Refrigerator Performance**
  - Test data
  - Performance curves
- **FPA Mount Requirements**
  - Optical
  - Thermal
  - Structural
- **Concentric G-10 Tube Mount**
  - Analysis and results
  - Prototype test plans and schedule
  - Flight unit schedule
- **Discussion of FiST Test Data and Backup Plans**

Calibration Splinter Topics

- **Calibration**
  - Data collection details
  - Low and high temperature blackbodies
  - Full field collimator
  - Test chamber
  - IFC blackbody

Electrical Splinter Topics

- **General**
  - Power, electronics box, grounding, etc.
- **Signal Processing**
  - Schematics, parts, layouts
  - Modeling, analysis, test results
- **C&DH**
  - Schematics, parts, layouts
  - System description
  - Timing, state diagrams, VHDL implementation, sequences
  - Modeling, analysis, test results
- **Scan Mirror Controller**
  - Schematics, parts, layouts
  - State diagrams, VHDL implementation
  - Modeling and analysis results
- **Analog Controllers**
  - Schematics, parts, layouts
  - State diagrams, VHDL implementation
  - Modeling and analysis results
- **Power Converters**
  - Schematics, parts, layouts
  - Modeling, analysis, test results
- **TRW Electronics**
  - Description, interface, function, status, etc.
- **Interconnect**
  - Motherboard: schematics, parts, layouts
  - Harness: block diagram, parts, wiring diagrams

SABER Project Management Overview

James Miller

October 20, 1997

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E-Mail: j.b.miller@larc.nasa.gov

TIMED Mission

Thermosphere Ionosphere Mesosphere Energetics and Dynamics

- TIMED is the first mission in the Office of Space Science's Solar Connections Program
- TIMED is a "Survey" mission to measure fundamental properties that influence the energy balance of the study region
- Mission Managed by Johns Hopkins University Applied Physics Laboratory (APL)
- "Build-to-Cost" mission
  - $100M (FY 94) hard cost cap on Phase C/D
    - Instruments, Spacecraft, Ground Segment, & Data Processing Software
- Shared launch on Delta II with Jason (French/MTPE) May 2000*

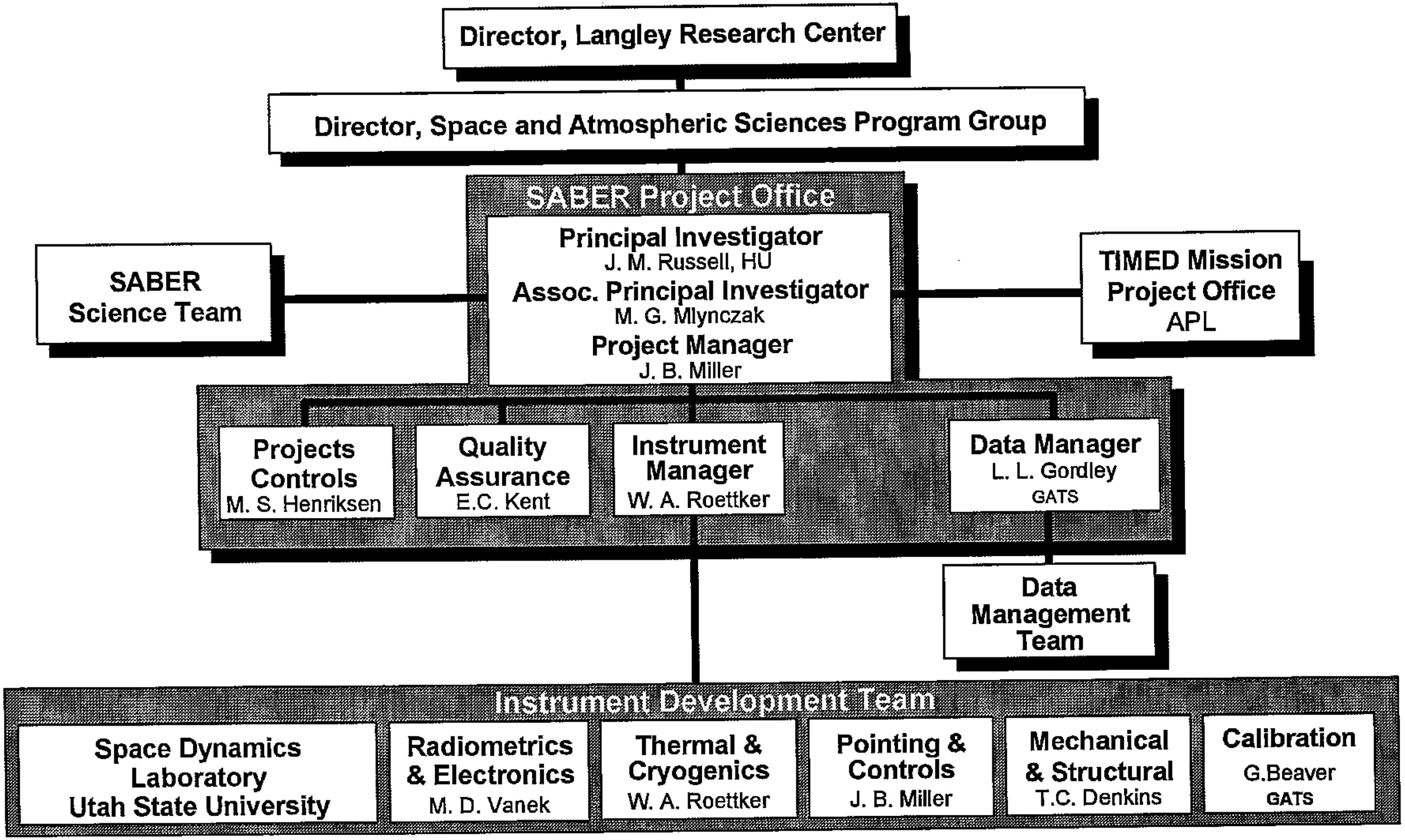
* Awaiting written confirmation of launch vehicle and date change from Jan to May.

SABER Project

Sounding of the Atmosphere using Broadband Emission Radiometry

- **SABER provides key measurements for the TIMED mission**
  - Temperature, Density, Pressure
- **The SABER Team includes the combined expertise and experience of:**
  - Langley Research Center
  - Hampton University
  - Space Dynamics Laboratory / Utah State University
  - GATS
- **Original baseline $12.8 Phase C/D cost cap in FY 94 dollars**
  - Rebaselined at $14.03M in FY 95 dollars
  - Rebaseline included descope and a real $732K increase in science funding
- **Phase C/D Funding**
  - $3.15M authorized in FY 1997
  - Includes a late year shift of $250K from FY 1998 to FY 1997
  - Guidelines indicate $8.54M in FY 1998 (adjusted for $250K shift)

SABER Project Organization

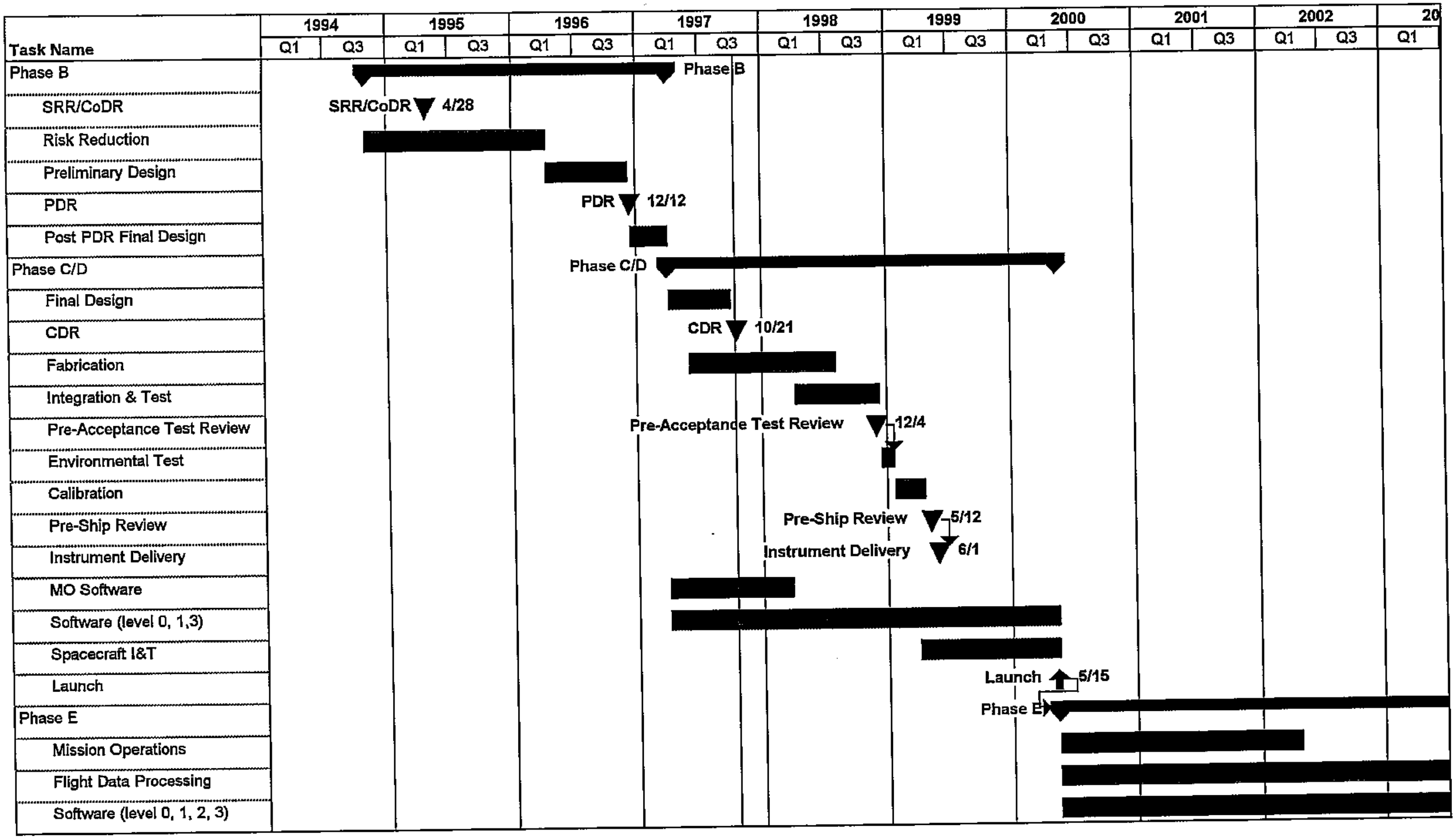


Major Project Milestones

- November 1995 - "Slow start" Phase B
- April 1995 - System Requirement Review & Conceptual Design Review
- December 1996 - Preliminary Design Review
- February 1997 - TIMED Non-Advocate Review
- June 1997 - Phase C/D "Authorization" (Delayed from planned April 1997)
- October 1997 - Critical Design Review
- December 1998 - Pre-Environmental Test Review
- May 1999 - Pre-Ship Review
- June 1, 1999 - Deliver Instrument to APL
- May 2000 - Delta II Launch with Jason / Begin Mission Operations*
- May 2002 - Mission Operations Terminated*
- May 2002 - Delivery of Data Processing Software*
- May 2004 - Deliver Final Report, Archived Data & Final Software*

* Awaiting written confirmation of launch vehicle and date change from Jan to May.

SABER/TIMED Major Milestone Schedule



SABER Critical Design Review

NASA LANGLEY RESEARCH CENTER & SPACE DYNAMICS LABORATORY/USU

JBM 6

Impact of Project Constraints

- **Fixed cost and short development cycle results taking some calculated risks**
- **Schedule is exceedingly tight**
  - Success oriented schedule
  - < 4 weeks total slack
  - Multiple essentially equal critical paths
- **Start-up delay exacerbated schedule problems**
  - Start delayed 2 months (April to June)
  - No change in delivery date
  - Early funding for FPA development provided
- **Transfer of FY-98 funds to FY-97 allowed timely long lead procurement**
  - Cryo-Cooler & Mirrors
- **Schedule dictated early fabrication of significant elements of flight hardware**
  - Cryo-cooler, Mirrors, Motor-Encoder, Chopper, Focal-Plane-Array
  - All on or near the critical path
- **Budget has only small management reserve**

Project Status at CDR

- **Major elements of the design have reached maturity, are fully ready for flight fabrication, and need to start immediately**
  - Telescope (except for scanner & baffle assembly)
  - Primary Structure
  - Electronics (almost all components)
  - Focal-Plane-Array
- **Prototypes of key components delivered or in progress**
  - Motor-Encoder Assembly (BEI) - Delivered
  - Chopper (TFR) - Delivered
  - Focal-Plane-Array (EG&G and OCLI) - Scheduled delivery Dec 97
  - Complete prototype main electronic partially complete
- **Fabrication of major subcontract flight components started**
  - Mirrors (SSG) - Scheduled delivery Jan - Feb 98
  - Pulse Tube Cryogenic Refrigerator (TRW) - Scheduled delivery July 98
  - Motor-Encoder Assembly (BEI) -Scheduled delivery April 98
  - Chopper (TFR) - Scheduled delivery Jan 98
  - Focal-Plane-Array (EG&G and OCLI) - Scheduled delivery July 98

Project Status at CDR (continued)

- **In a few areas we have not reached the level of maturity associated with a traditional CDR design.**
  - **Interface Documents not fully singed-off**
    - GIIS in signature cycle, most section signed, no significant issues
    - SIIS draft completed, few open issues
    - Risk of significant design perturbation is small
  - **Mechanical**
    - Scanner and baffle assembly design complete, shop drawings not complete
    - Main electronics box design complete, shop drawings not complete
    - Purge system design complete, shop drawings not complete
  - **Electronics**
    - 5 boards - complete and under configuration control
    - 4 boards - schematic and layouts complete, ready for final review
    - 3 boards - schematic complete, layouts in progress (analog controller & 2 power)
  - **Thermal**
    - FPA suspension design not tested
  - **Calibration GSE**
    - Design complete, shop drawings for some mechanisms not complete

Issues & Resolution Plans

- **Little or no margin in worst case thermal design**
  - Revised suspension design prototype built and tested by end of year
  - Continued work to resolve fiber suspension in background as back-up
- **Death of owner and principal designer at TFR (chopper)**
  - Complete testing of prototype by December
- **Extended wavelength InGaAs detectors are not realizable within schedule**
  - Baseline change of OH channels (#8 & #9) to InSb
  - Improve filter blocking (#8) & attempt early out-of-band testing
- **New agency priority Hyper-spectral Recovery Mission may claim residual SSTI controller electronics**
  - Negotiations with SSTI continuing
  - Build-to-print fabrication plan would be significant impact (+9 mo., $500K)
- **Potentially serious straylight path identified late in detailed design development**
  - Consulting with leading expert on straylight (Brault)
  - Early testing to confirm straylight performance

Summary

- Overall SABER design is mature and ready to go into proto-flight instrument build
- TIMED/SABER development schedule dictates that we begin fabrication of major subsystems immediately
- Most subsystems have been designed conservatively, have adequate margin, and present low risk
- A few areas are not fully mature, but most deficiencies present little technical or schedule risk
- Prototypes of key components completed or in progress
  - Focal-Plane-Array
  - FPA suspension & cold strap
  - Scanner Assembly
  - Electronics
  - Optical Chopper
- A few key risks exist, plans are in place to resolve them, and they should not cause significant perturbation of the overall system design

SABER Science Overview

Presented at the Critical Design Review Meeting

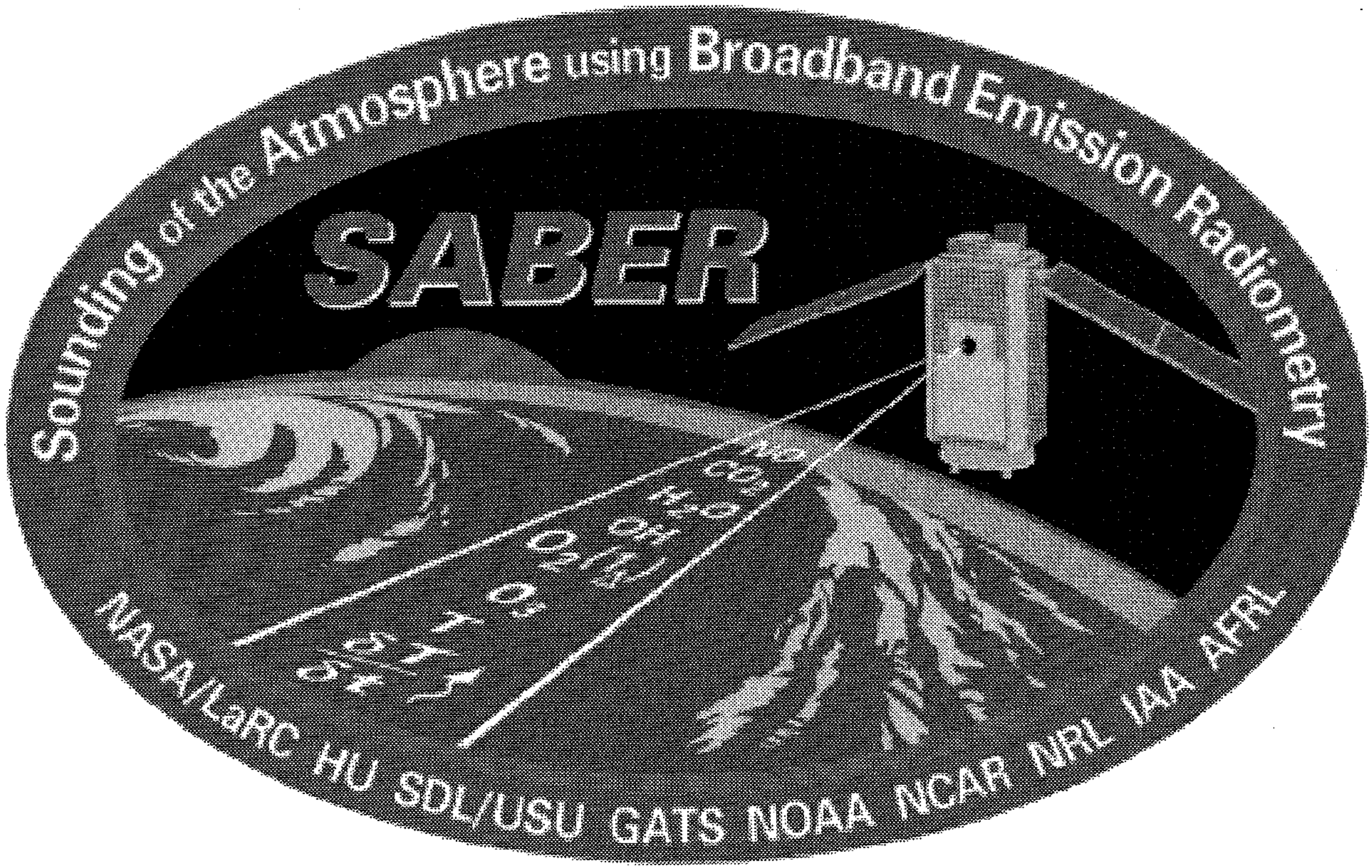
by

James M. Russell III
Principal Investigator

and

Martin G. Mlynczak
Associate Principal Investigator

October 20, 1997


Sounding of the Atmosphere using Broadband Emission Radiometry
SABER
CO_2
H_2O
OH
O_3
T
NASA/LaRC HU SDL/USU GATS NOAA NCAR NRL IAA AFRL

SABER Scientific Goal and Objectives

- Scientific Goal

  - To explore the mesosphere and lower thermosphere globally and achieve a major improvement in our understanding of the fundamental processes governing the energetics, chemistry, dynamics, and transport

- Scientific Objectives

  - Study the M/LT thermal structure and its variations

  - Implement studies of energetics and radiatively active species in the non-LTE environment

  - Analyze Oy and HOy chemistry

  - Conduct dynamics and transport studies

SABER SCIENCE TEAM

Principal Investigator

James M. Russell III	Hampton University

Associate Principal Investigator

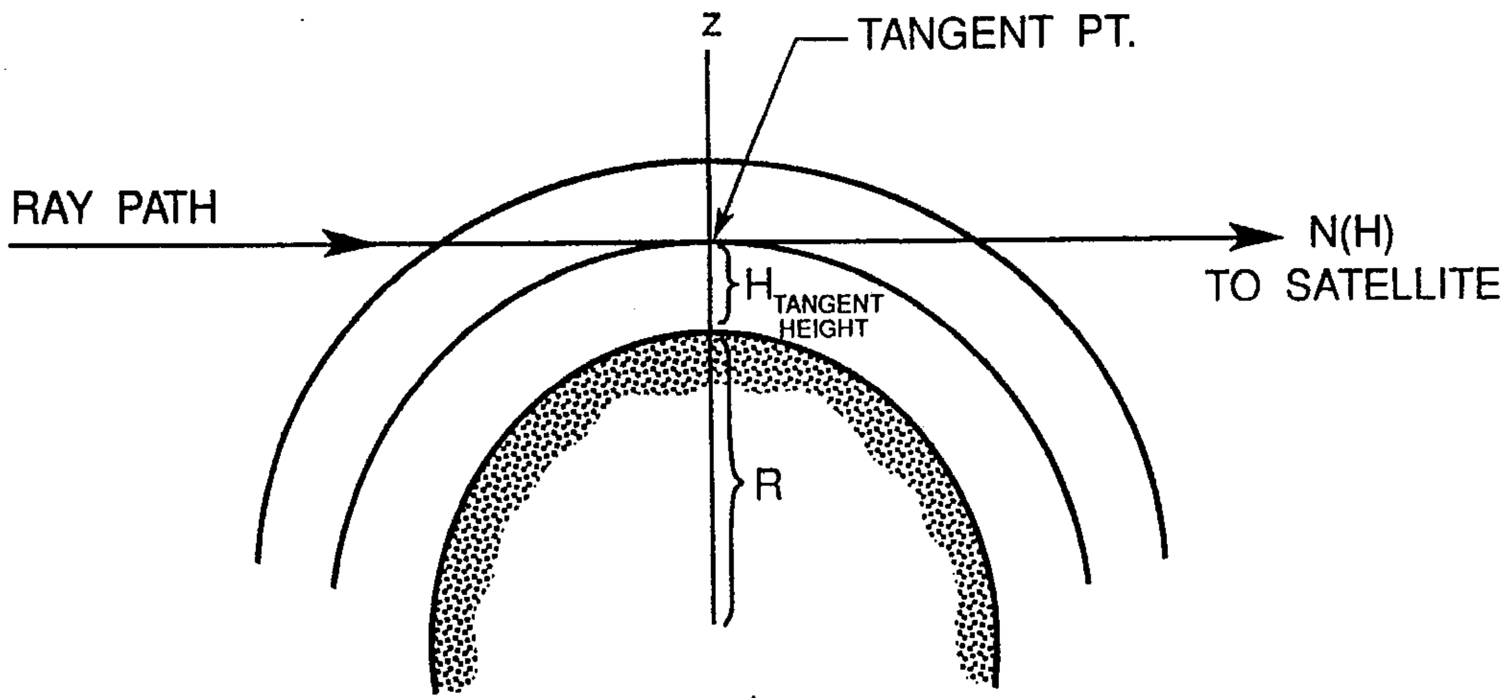
Martin G. Mlynczak	NASA Langley Research Center

Co-Investigators

Ellis E. Remsberg	NASA Langley Research Center
Susan Solomon	NOAA Aeronomy Laboratory
Doran J. Baker	Utah State University
Patrick J. Espy	Utah State University
James C. Ulwick	Stewart Radiance Laboratory
Rolando R. Garcia	NCAR
Raymond G. Roble	NCAR
David E. Siskind	Naval Research Laboratory
Larry L. Gordley	G & A Technical Software
Manuel Lopez-Puertas	IAA, Spain
Richard H. Picard	Phillips Laboratory

SABER Experiment Approach

- Measurement of earth limb emission in the near and mid-infrared (1.27 - 16 μm)
- Employs state-of-the-art mechanical cooling of the focal plane in order to achieve high sensitivity and long experiment life with reduced mass and power
- Provides autonomous pressure registration using CO_2 channels at 15 μm
- Continuous sounding both day and night, permitting diurnal change and polar night studies to be conducted
- Draws on significant spaceflight heritage:
  LIMS, SAMS, HALOE, CIRRIS, ATMOS, CLAES, ISAMS, SME



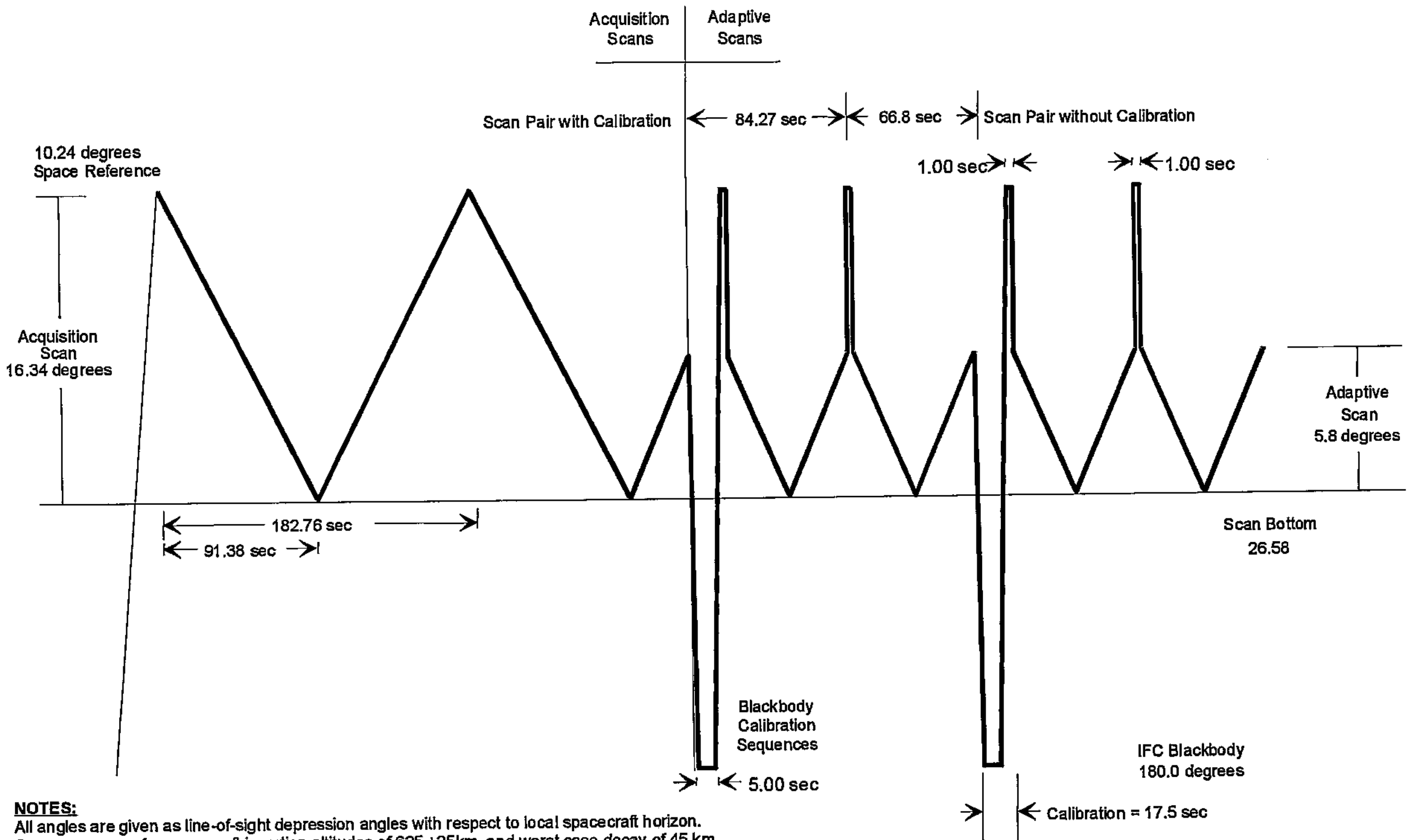
$$N(H) = \int_{\tau}^{1} J(\nu, T)\, d\tau(\nu, q, T, P)$$

q known (e.g. CO_2) $\longrightarrow$ T

T known $\longrightarrow$ q (e.g. O_3, CO_2 H_2O . . .)

SABER EMISSION EXPERIMENT GEOMETRY AND INVERSION APPROACH

SABER Limb Scan Sequence (10/14/97 Baseline)



NOTES:
All angles are given as line-of-sight depression angles with respect to local spacecraft horizon.
Scan sequences for spacecraft insertion altitudes of 625 ±25km, and worst case decay of 45 km.
Acquisition scan accommodates worst case spacecraft altitude and attitude variations over mission.
Adaptive scan angle accommodates the worst case spacecraft altitude.
Adaptive scan location is varied based on location of CO_2 horizon derived from instrument data.
All times are given at baseline scan and slew rates and worst case altitude and oblateness.
2:1 ratio of non-calibration to calibration scans is baseline, and can be increased in flight
Acquisitions scans are commanded only when the scanner is transitioned from the safe-hold position to scanning.

Not to Scale

SABER Focal Plane Array Channel Locations

#4 O_3 9.3 µm	
#5 H_2O 6.8 µm	#6 NO 5.4 µm
#1 CO_2 - N 15.2 µm	#2 CO_2-W 14.9 µm
#3 CO_2-W 14.9 µm	#7 CO_2 4.24 µm
#8 OH(A) 2.06 µm	#9 OH(B) 1.64 µm
#10 $O_2(^1\Delta)$ 1.27 µm	

SABER Measurement Objectives

- Conduct global-scale, simultaneous, vertical profile measurements of temperature, key chemical constituents, and key emission features, including the following:

  - Kinetic Temperature
  - O_3, H_2O, NO, CO_2
  - $O_2(^1\Delta)$, $OH(\upsilon)$, $NO(\upsilon)$, $O_3(\nu 3)$, $CO_2(\nu 2)$
  - Atomic Species O and H (O inferred 4 different ways)

- Conduct measurements (e.g., T, O_3, H_2O, CO_2) that can be used to derive and study dynamical quantities such as geopotential height and potential vorticity

- Conduct measurements of key radiative emissions to study true cooling, e.g., $CO_2(\nu 2)$, $NO(\upsilon)$, $O_3(\nu 3)$, $H_2O(\nu 2)$

SABER Inferral of Atomic Species

- Atomic oxygen and hydrogen are crucial to the energetics and chemistry of the mesosphere and lower thermosphere

- SABER will infer atomic species several different ways between 60 and 135 km, day and night:

  - [O] and [H] from combination of OH(υ = 7,8,9) at 2.0 μm and O_3 at 9.6 μm (night and day, 80-100 km)

  - [O] from ozone day/night differences using photochemical balance (60-80 km, day)

  - [O] from $O_2(^1\Delta)$ nightglow (80 - 100 km, night)

  - [O] from CO_2 density and CO_2(15 μm) emission (100-135 km, day)

SABER Measurement Objectives (Concluded)

- **Conduct measurements to derive chemical heating [O_3, O_2, OH(υ)]**

- **Conduct measurements to derive solar heating [O_3, O_2, CO_2(υ3)]**

- **Conduct measurements of key emissions that result in the reduction of the solar and chemical heating efficiencies, e.g., $O_2(^1\Delta)$, OH(υ), O_3(ν3), CO_2(ν3)**

- **Conduct most detailed study to date of ozone photochemistry in this region [O_3, H_2O, OH(υ), O, H]**

TIMED Scientific Objectives Directly Addressed by SABER

- Objective 1: Determine T, p, wind structure and seasonal latitudinal variations

  - SABER measures T, ρ, and derives geostrophic wind both night and day

- Objective 2: Relative importance of various sources and sinks of energy

  - SABER measures true cooling emissions [$CO_2(\nu 2)$, $O_3(\nu 3)$, $NO(\nu)$] and emissions which reduce solar and chemical heating efficiency [$OH(\nu)$, $O_2(^1\Delta)$, $O_3(\nu 3)$, $CO_2(\nu 3)$]

  - SABER determines virtually all of the key measurable diabatic terms in the thermodynamic equation (except solar input provided by SEE, and particle input) and provides information to infer the net dynamical heating

  - Measurements are made night and day

TIMED Scientific Objectives Directly Addressed by SABER (Continued)

- **Objective 6: Relative importance of radiative minor species and role of [O]**

  - **Measures seven key radiative emission features:**

    CO_2(15 μm), O_3(9.6 μm), NO(5.3 μm), OH(2.0 μm), OH(I.6 μm), $O_2(^1\Delta)$ [1.27 μm], and CO_2(4.3 μm)

  - **Provides measurements to infer [O] 4 different ways, covering the range 60-135 km**

  - **Measurements Of CO_2 (15 μm) emission, CO_2 concentrations, and inferred [O] will allow the role of [O] in enhancing cooling to be inferred**

TIMED Scientific Objectives Directly Addressed by SABER (Continued)

- **Objective 8: Spatial and temporal variations of O_x, HO_x, and NO_y species**

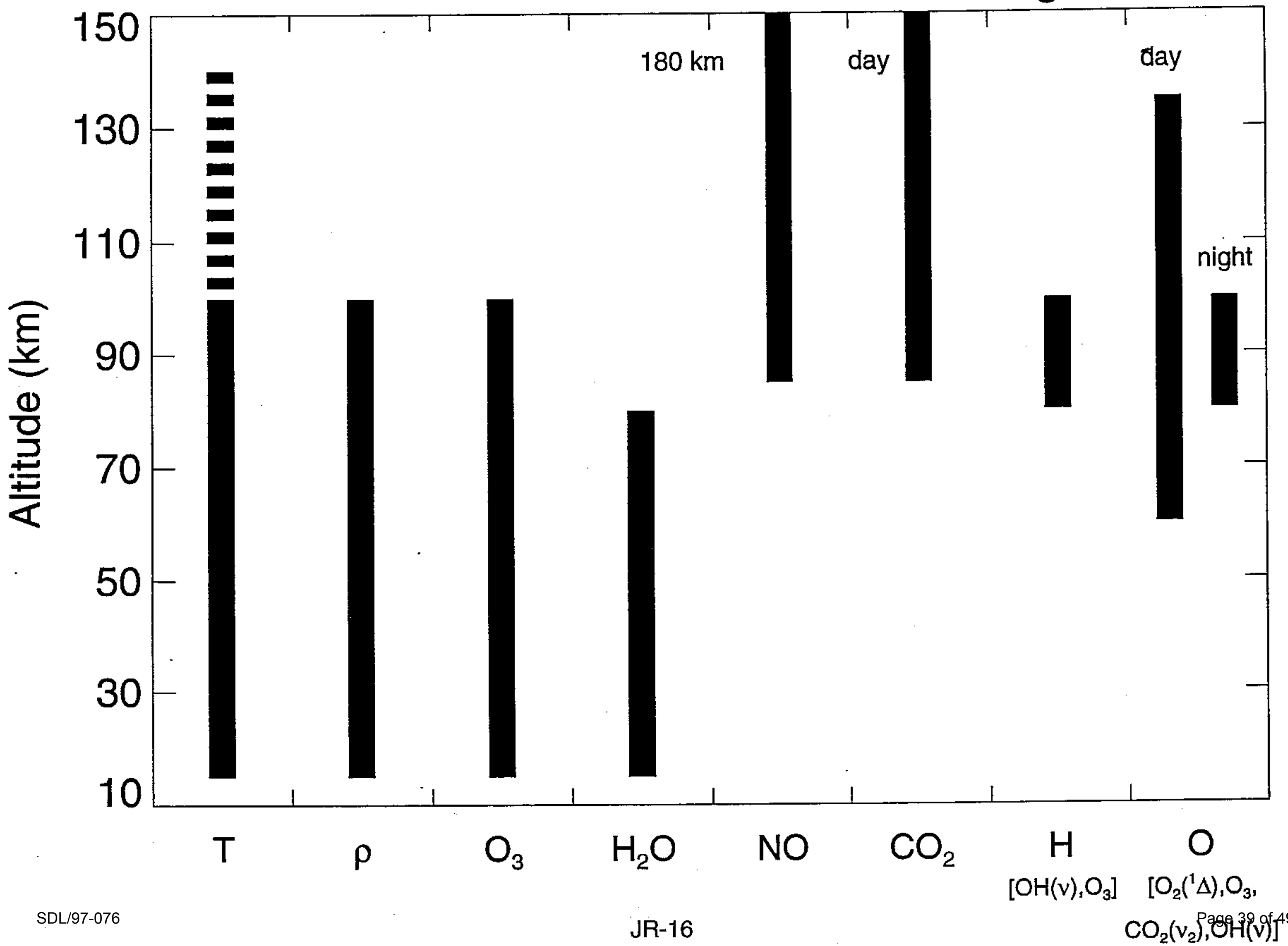
  - **Makes measurements globally, night and day of key members in each chemical family (O_3, H_2O, NO) and the main carbon budget molecule CO_2**

SABER Measurements and Applications*

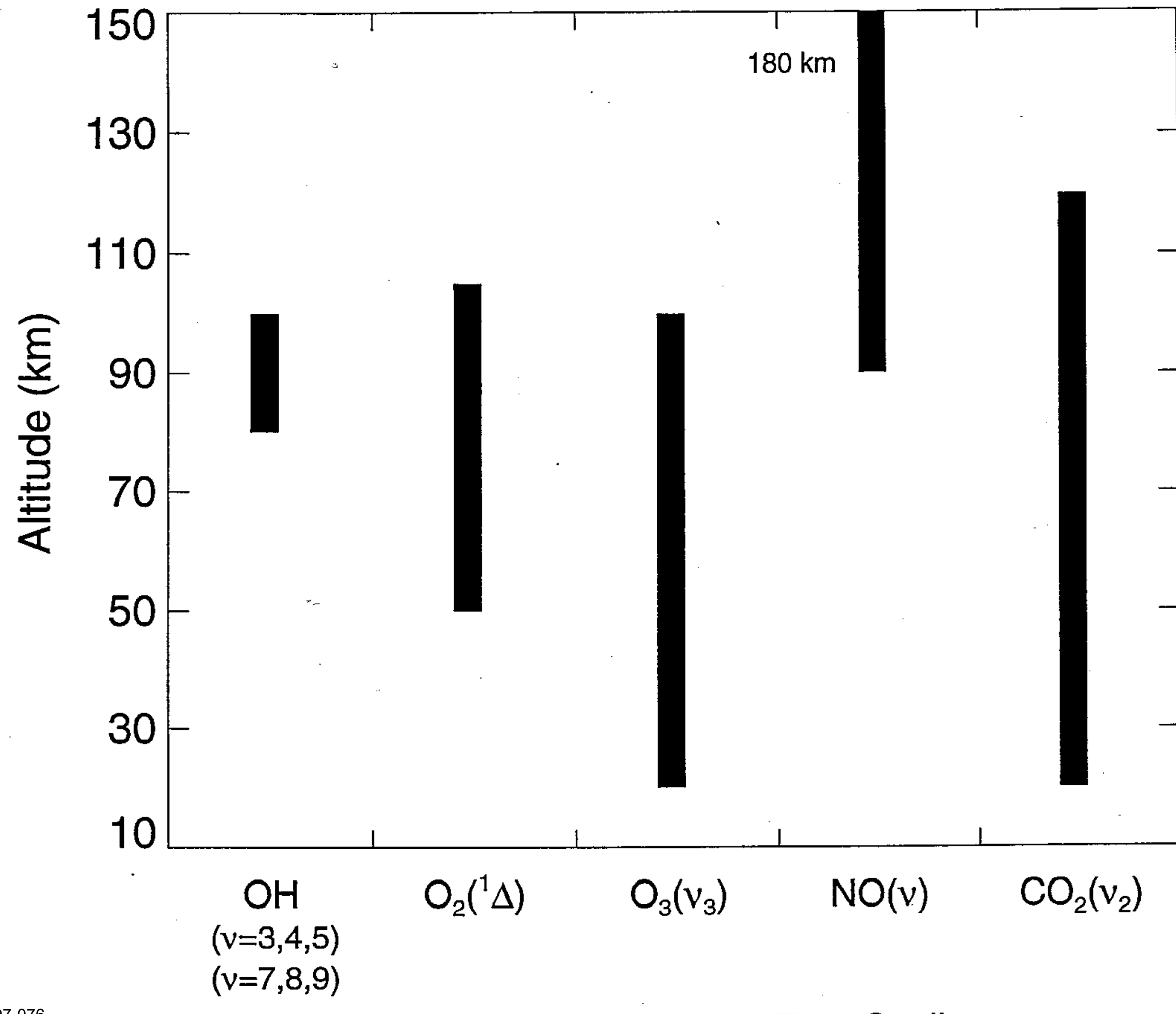
Parameter	Wavelength (μm)	Geophysical Information/Application	Altitude Range (km)
CO_2	15	Kinetic temperature and density; infrared cooling rates; altitude/pressure registration, non-LTE/LTE nature of CO_2. T uncertainty due to non-LTE is large for Z >100 km	10-130
O_3	9.6	Ozone concentration; cooling rates; solar heating rates; fundamental chemistry and dynamics studies	15-100
$O2(^1\Delta)$	1.27	O_3 concentration (daytime); energy loss for solar heating efficiency; inferred [O] at night	50-105
CO_2	4.3	CO_2 concentration ; upper mesospheric solar heating; dynamical tracer above $\approx$ 90 km	85-150
OH(ν)	2.0 1.6	Fundamental chemistry/chemical heat source emission used to infer [H], [O] Chemiluminescent energy loss; dynamics/ wave studies; polar mesospheric cloud studies	80-100
NO	5.3	Thermospheric cooling; NO_x chemistry	90-180
H_2O	6.9	Odd-hydrogen source gas; dynamical tracer	15-80

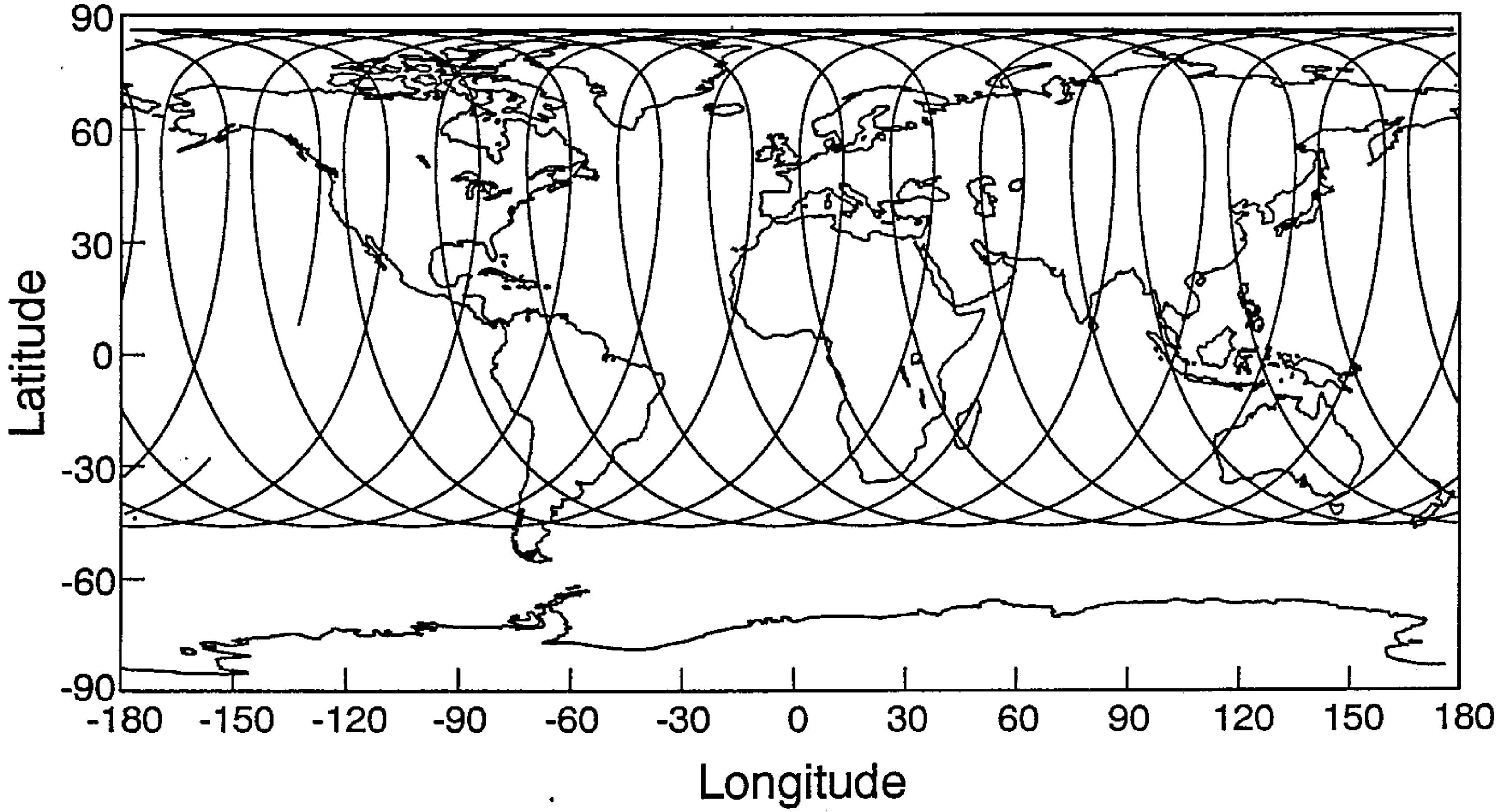
*2.2 km IFOV at the limb and ~ 300 km horizontal resolution along the limb track

Saber Single Profile Day/Night Temperature and Constituent Measurement Ranges

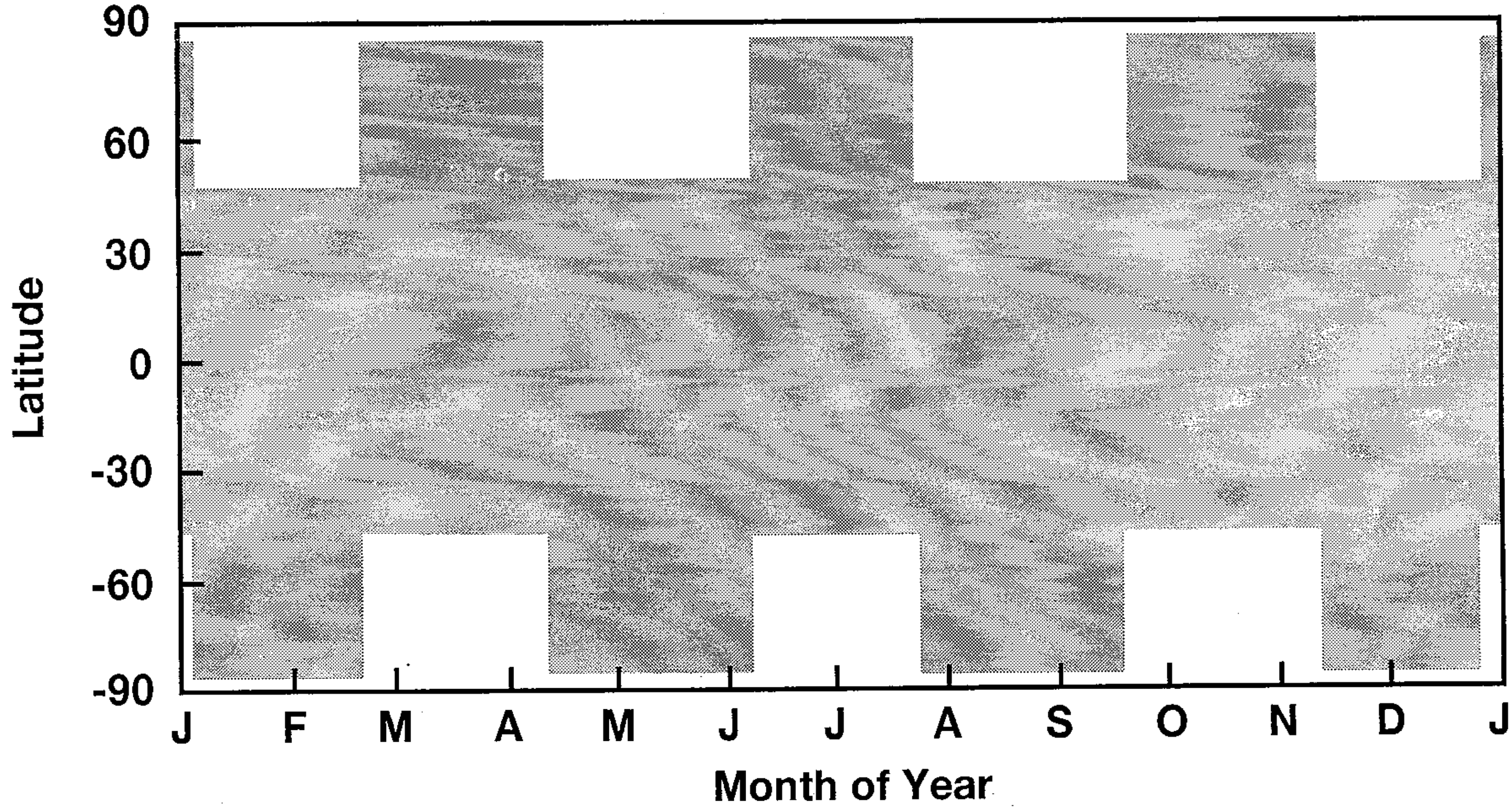


Saber Single Profile Energetics Measurement Ranges



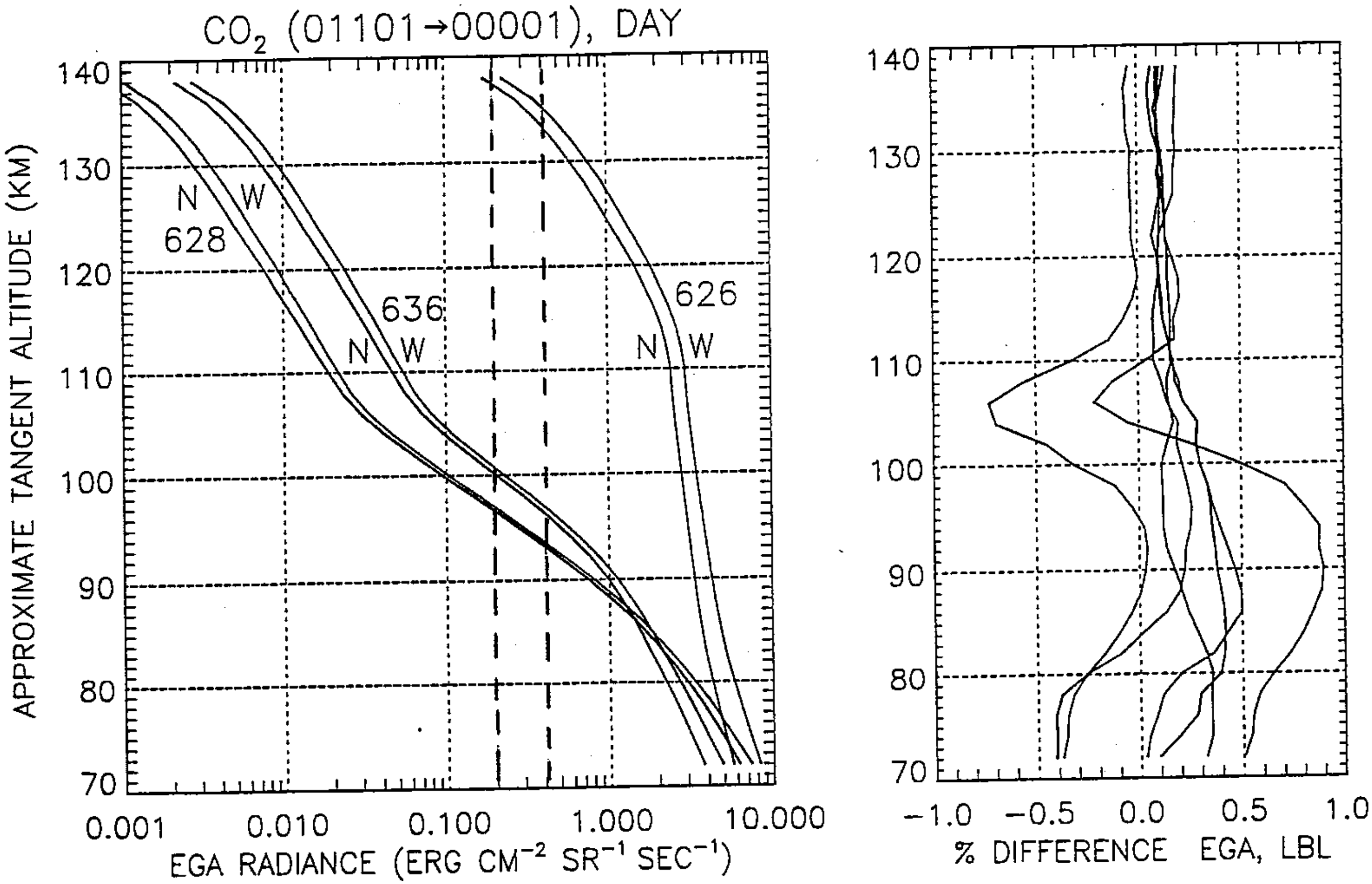


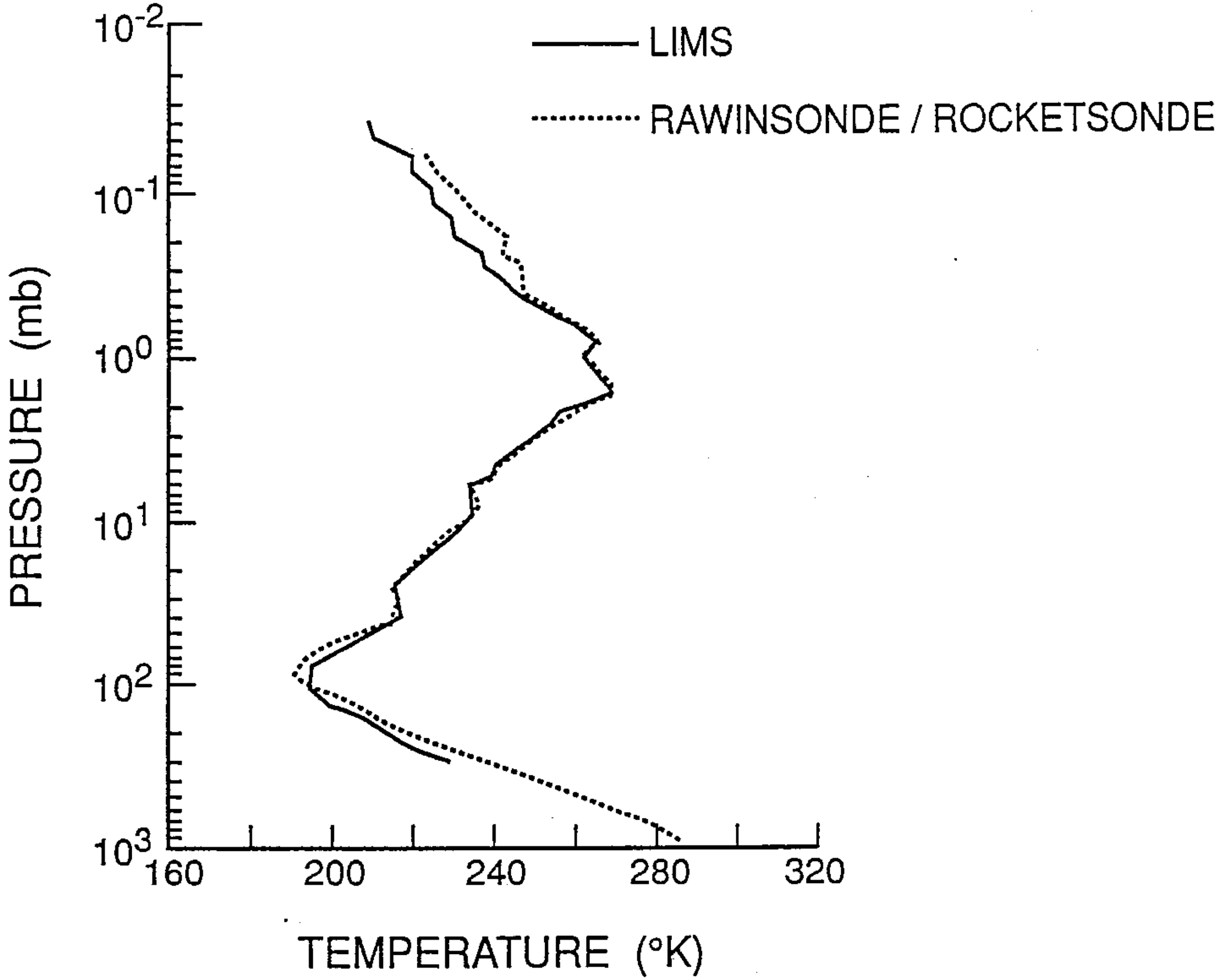
SABER daily latitude versus longitude coverage viewing North for a 70°, 600 km orbit.



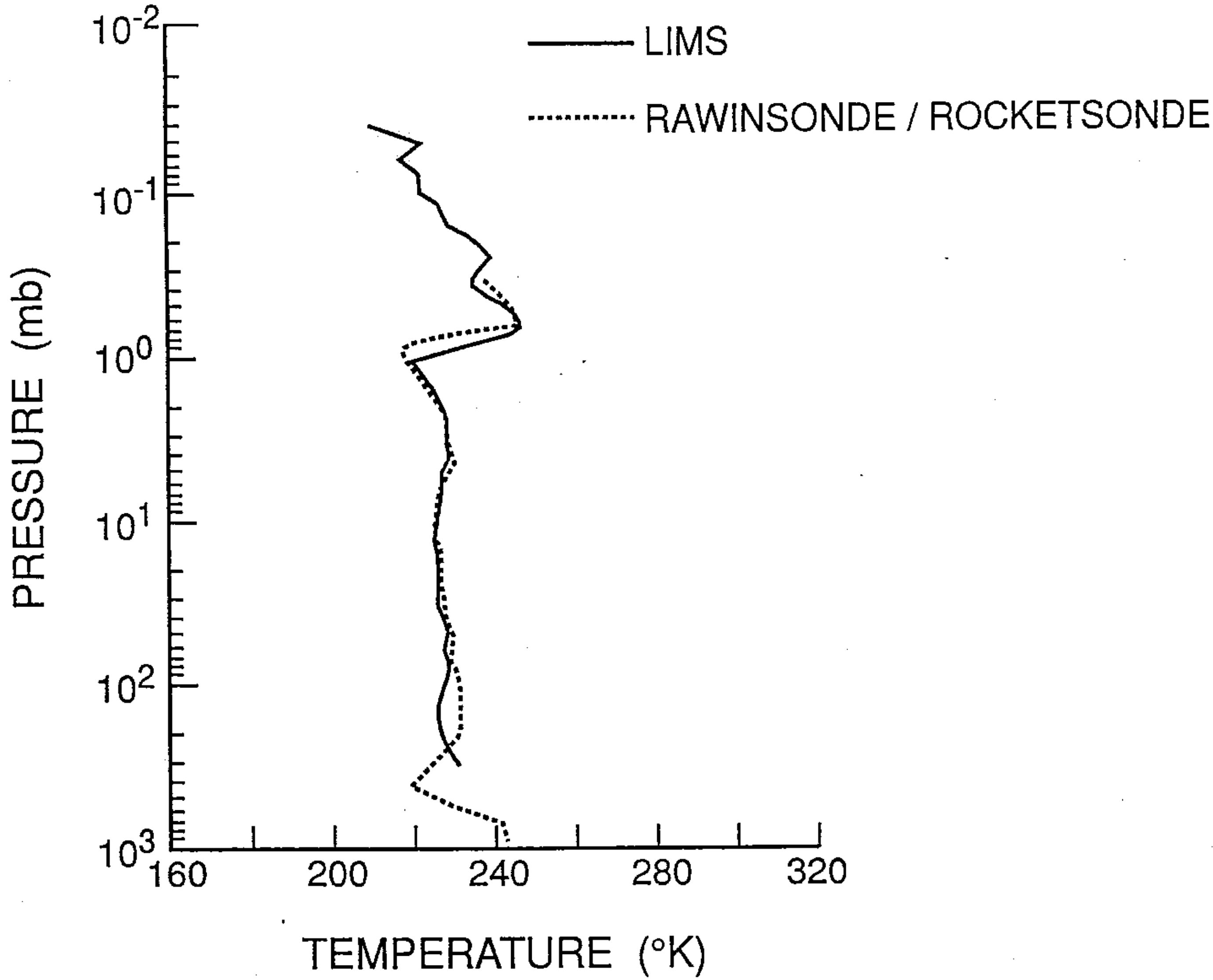
SABER latitude coverage versus time for a 70^{o}, 600 km orbit

SABER CO2 15μm Wide and Narrow Channel Radiances for the Fundamental and Isotopic Bands



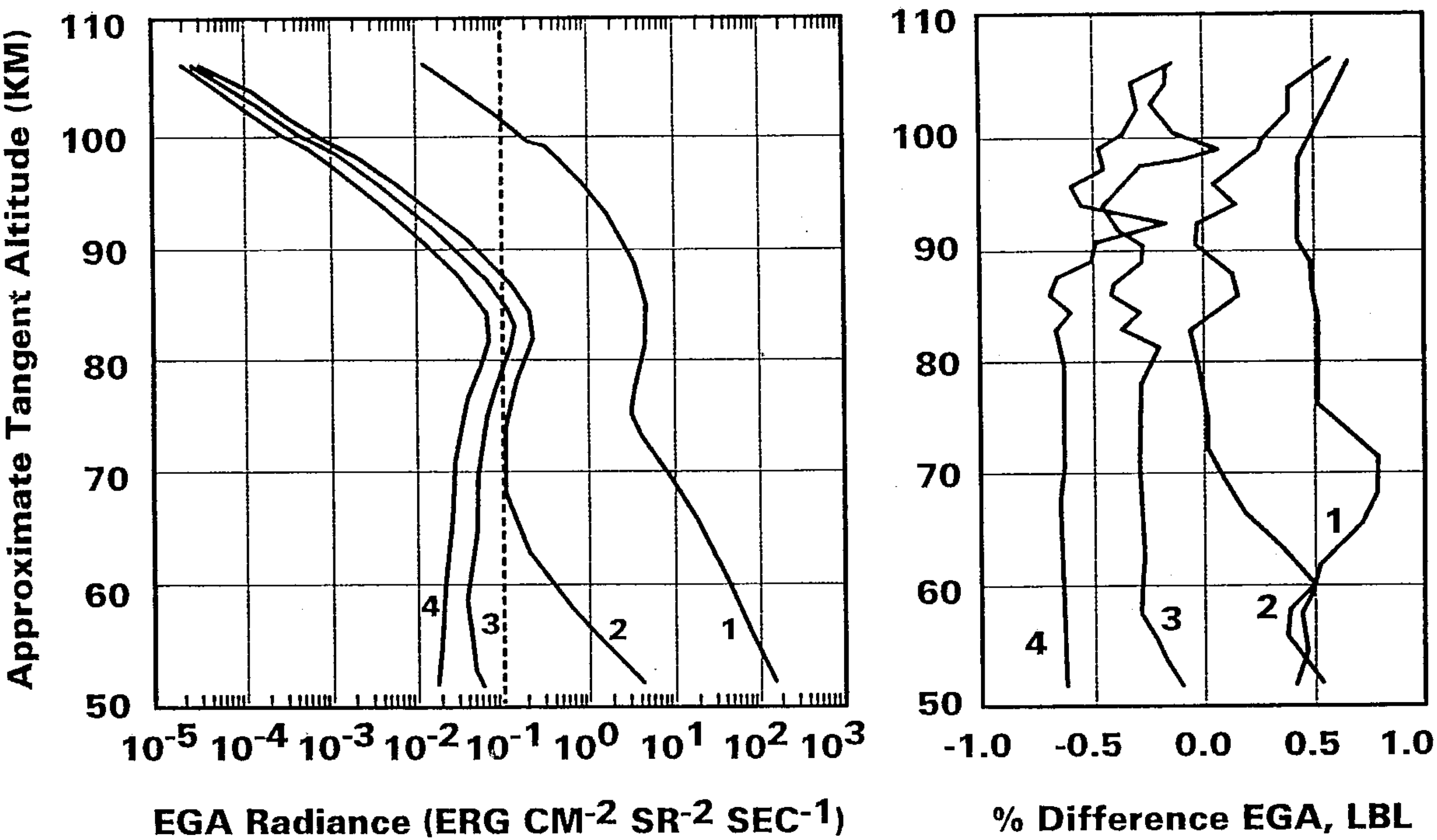


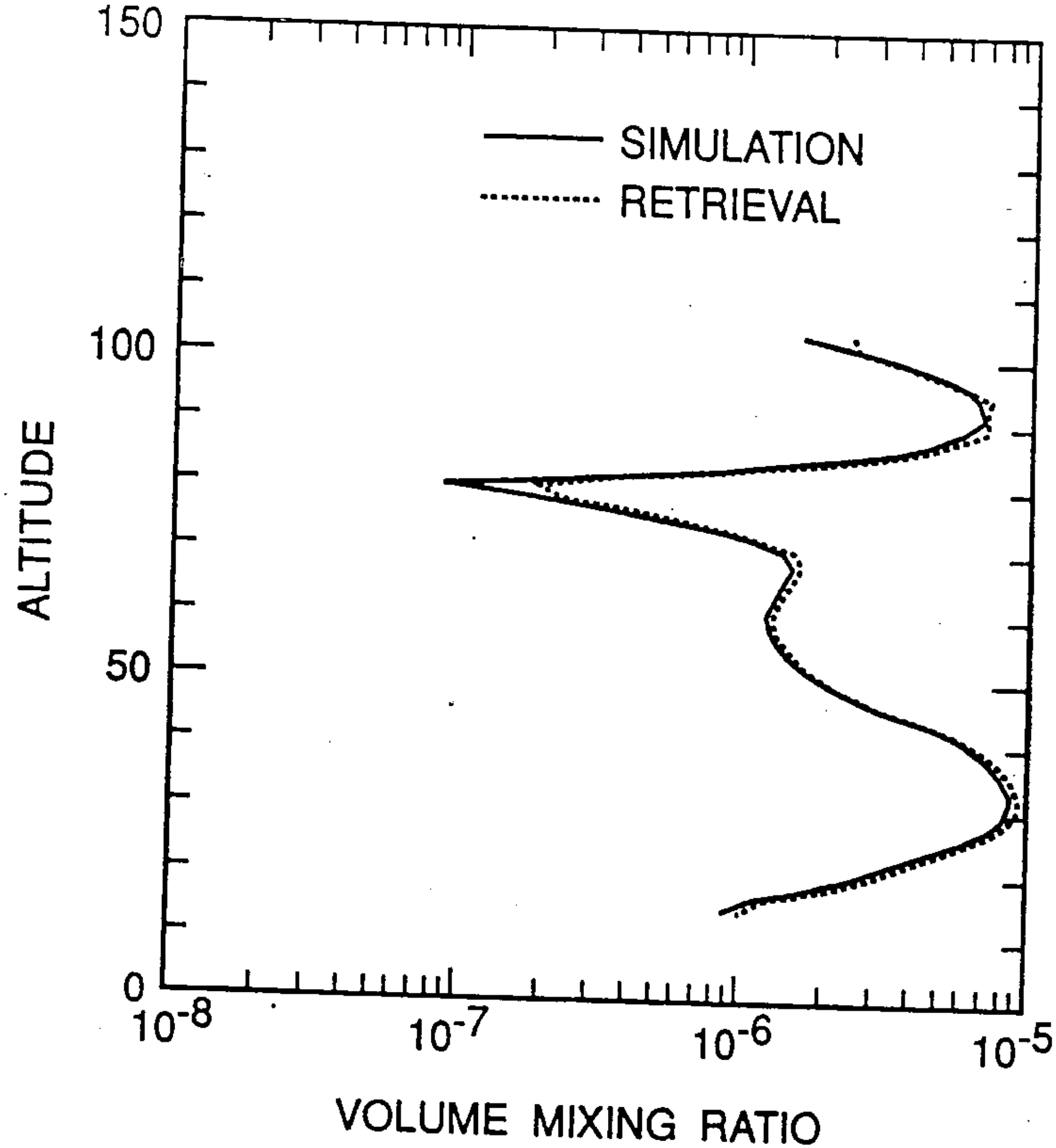
LIMS DAYTIME TEMPERATURE RETRIEVAL COMPARED TO RAWINSONDE / ROCKETSONDE RESULTS AT 18°N, 300°E ON JANUARY 10, 1979



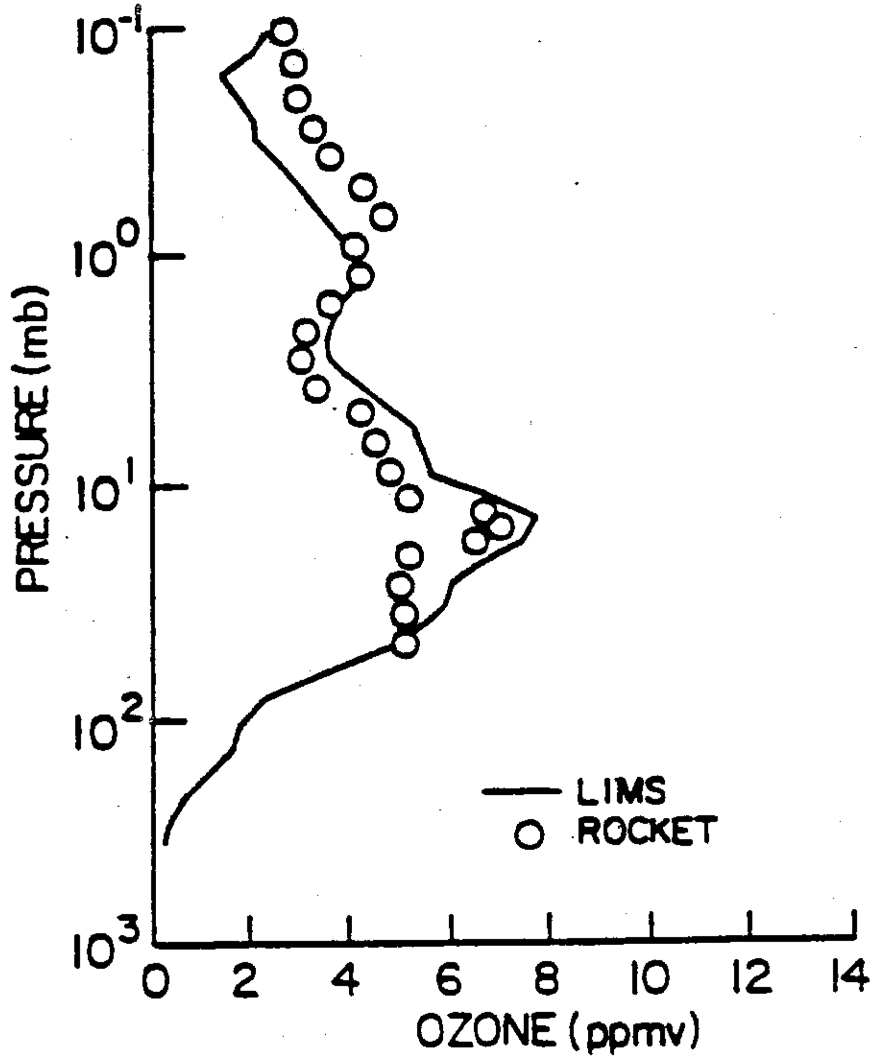
LIMS DAYTIME TEMPERATURE RETRIEVAL COMPARED TO RAWINSONDE / ROCKETSONDE RESULTS AT 59°N, 273°E ON FEBRUARY 2, 1979

Ozone Night, 925-1141 CM^{-1}



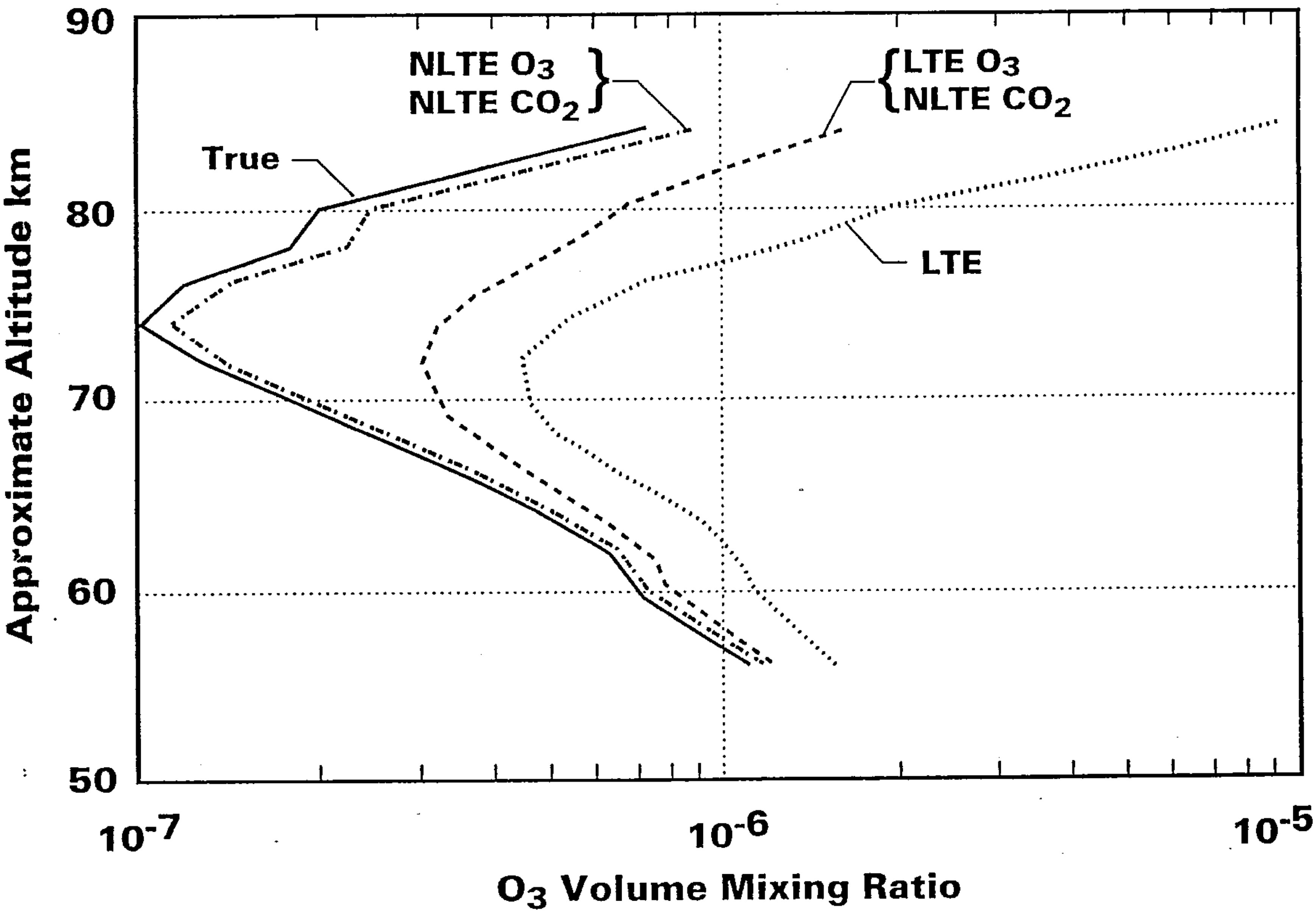


SABER SIMULATED O_3 (9.6) μm) RETRIEVAL



LIMS OZONE SOUNDING OVER POKER FLAT, ALASKA, ON JANUARY 28, 1979, COMPARED TO ROCKET CHEMILUMINESCENT RESULTS.

Impact of Non-LTE on Ozone Retrievals, 9-11μm



SABER Temperature and Constituent Estimated Accuracies and Precisions

Parameter	Measurement Range	Accuracy	Precision
Temperature	10-130 km	1.5K, 15-80 km 4.0K, 80-100km	0.5K, 15-70 km 1.0K, 70-80 km 2.0K, 80-100 km
O_3 (9.6μm)*	15-100 km	20%, 15-90 km 30%, 90-100 km	≤5%, 15-70 km 20%, 70-90 km
O3 [from O2($^1\Delta$)]**	50-105 km	20%, 50-105 km	10%, 50-85 km 15%, 85-105 km
H_2O	15-80 km	20%, 15-70 km 30%, 70-80 km	10%, 20-70 km 25%, 70-80 km
NO^+	90-180 km	30%, 90-150 km	10%, 90-150 km
CO_2^{++}	85-150 km	30%, 95-140 km	10%, 95-140 km

* Nightime accuracy estimates. Daytime accuracy degrades due to Non-LTE

** Daytime measurement only. Under twilight conditions accuracy degrades due to difference in chemical lifetime of O_3 and radiative lifetime of $O_2(^1\Delta)$

\+ Assumes [O] is known to 25% accuracy

++ Daytime measurement only

SABER Energy Loss Rate Per Unit Volume Estimated Accuracy and Precision*

Parameter	Measurement Range	Accuracy	Precision
OH (ν)	80-100 km	3%, 80-90 km 5%, 90-100km	0.1%, 80-90 km 5%, 90-100 km
$O_2(^1\Delta)$	50-105 km	3%, 50-90 km	0.05%, 50-70 km 0.2%, 70-80 km 1.0%, 80-90 km
$O_3(\nu_3)$	15-100 km	3%, 50-90 km	0.05%, 50-70 km 0.1%, 70-90 km
$CO_2(\nu_2)$	15-120 km	3%, 90-120 km	1%, 80-120 km
NO(ν)	90-180 km	5%, 100-170 km	3%, 100-150 km 5%, 150-170 km

* Applies to daytime, nightime, and twilight

SABER Experiment Summary

- Provides measurements of the temperature and density of the core region globally including seasonal and latitudinal changes

- Measures all radiative emission features important in the energy budget including the true cooling emissions [$CO_2(\nu_2)$, $NO(\nu)$, $O_3(\nu_3)$] and key emissions which reduce efficiency of solar and chemical heating [$O_2(^1\Delta)$, $OH(\nu)$, $CO_2(\nu_3)$, $O_3(\nu_3)$]

- The primary chemical constituents in the lower portion of the core region will be observed globally including O_3, H_2O, CO_2, and NO (requires [O]). [O] will be inferred four different ways and [H] one way

- The measurement set includes tracer molecules H_2O and CO_2 which will provide important data on horizontal and vertical motion for study of coupling between atmospheric regions

SABER Experiment Summary (Concluded)

- Continuous day and night observations will be made of temperature, constituents, and energetics

- Observations will cover a broad altitude range which includes the gravity wave source region in the stratosphere, the altitude range where gravity wave energy is deposited, and the lower thermosphere

- Experiment directly address 4 of the 9 highest priority TIMED science objectives (1, 2, 6, 8) and provides supporting data for study of 3 others (3, 4, 5)

- T(P) and all other profiles are measured with high vertical resolution (2.2 km IFOV) and independently of spacecraft attitude and attitude rate information

SABER Science Measurement Requirements

Parameter	Measurement Requirements
Spectral Resolution	Broadband Rad., 45 to 700 cm^{-1}; depending on channel
Spectral Characteristics	See Table
System Noise-Equivalent-Radiance (NEN)	See Table
Instrument Calibration: • Radiometric Accuracy • Long-term Radiometric Precision • Radiance Bias Drift • Residual Scale Error	Errors shall not exceed the following after all calibration corrections are applied: 5.0% Absolute Radiance; 3% Goal* 2.0% Radiance Precision; 1% Goal* ≤ 1 NEN change between space looks ≤ 1% Linearity over the dynamic range*
IFOV @ 60 km Earth limb tangent height	2 km FWHM
Limb Scan Mirror Jitter	3 arcsec (1σ)
Limb vertical sampling interval	0.4 km
Along-Track Latitude Resolution	$< 5°$
Focal Plane Channel Locations	See Figure
Limb Vertical Scan Depression Angle Range	Φ_{max} = Angle required to place the top edge of the FPA at a tangent altitude 3 km below the horizon Φ_{min} = Angle required to place the bottom edge of the FPA at a tangent altitude of 400 km
Measurement Altitude Range	10 km to 180 km

* For SNR > 100, % is defined as a percentage of the signal. For SNR ≤ 100, % is defined as a percent of the signal that produces a SNR = 100.

SABER Channel Spectral Response and Noise-Equivalent-Radiance (NEN) Specifications

Channel No.	Atmospheric gases	Center Wavenumber/ Wavelength cm^{-1} (μm)	5% Cut-on Point (cm^{-1})	Cut-on Slope (%)	5% Cut-Off Point (cm^{-1})	Cut-on /Cut-off Tolerance (%)	Cut-off Slope (%)	Average Out-of-band Transmission (%)	Long Wave Block Limit (cm^{-1})	System NEN x 10^9 ($W\text{-}cm^{-2}\text{-}sr^{-1}$)
1	CO_2 N	658 (15.2)	680	≤ 3.0	635	± 0.5	≤ 2.9	≤ 0.01	446	17.5
2	CO_2 W	670 (14.9)	760	≤ 2.4	580	± 0.5	≤ 2.9	≤ 0.1	410	28.0
3	CO_2 W	670 (14.9)	760	≤ 2.4	580	± 0.5	≤ 2.9	≤ 0.1	410	28.0
4	O_3	1075 (9.3)	1140	≤ 2.4	1010	± 1.0	≤ 2.9	≤ 0.05	645	11.2
5	H_2O	1470 (6.8)	1560	≤ 2.6	1380	± 1.0	≤ 2.9	≤ 0.01	800	3.73
6	NO	1850 (5.4)	1925	≤ 2.0	1775	± 1.0	≤ 2.0	≤ 0.01	1000	2.49
7	CO_2	2360 (4.24)	2400	≤ 2.0	2320	± 1.0	≤ 2.0	≤ 0.01	1000	1.32
8	OH(A)	4850 (2.06)	5200	≤ 2.5	4500	± 1.0	≤ 2.5	≤ 0.01	1667	0.47
9	OH (B)	6088 (1.64)	6435	≤ 2.5	5740	± 1.0	≤ 2.5	≤ 0.01	1667	0.70
10	O_2	7850 (1.27)	7970	≤ 2.5	7730	± 0.2	≤ 2.5	≤ 0.01	2000	0.70

SABER Focal Plane Array Channel Locations

#4 O_3 9.3 µm

#5 H_2O 6.8 µm

#6 NO 5.4 µm

#1 CO_2 - N 15.2 µm

#2 CO_2-W 14.9 µm

#3 CO_2-W 14.9 µm

#7 CO_2 4.24 µm

#8 OH(A) 2.06 µm

#9 OH(B) 1.64 µm

#10 $O_2(^1\Delta)$ 1.27 µm

SABER INSTRUMENT OVERVIEW

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20 October 1997

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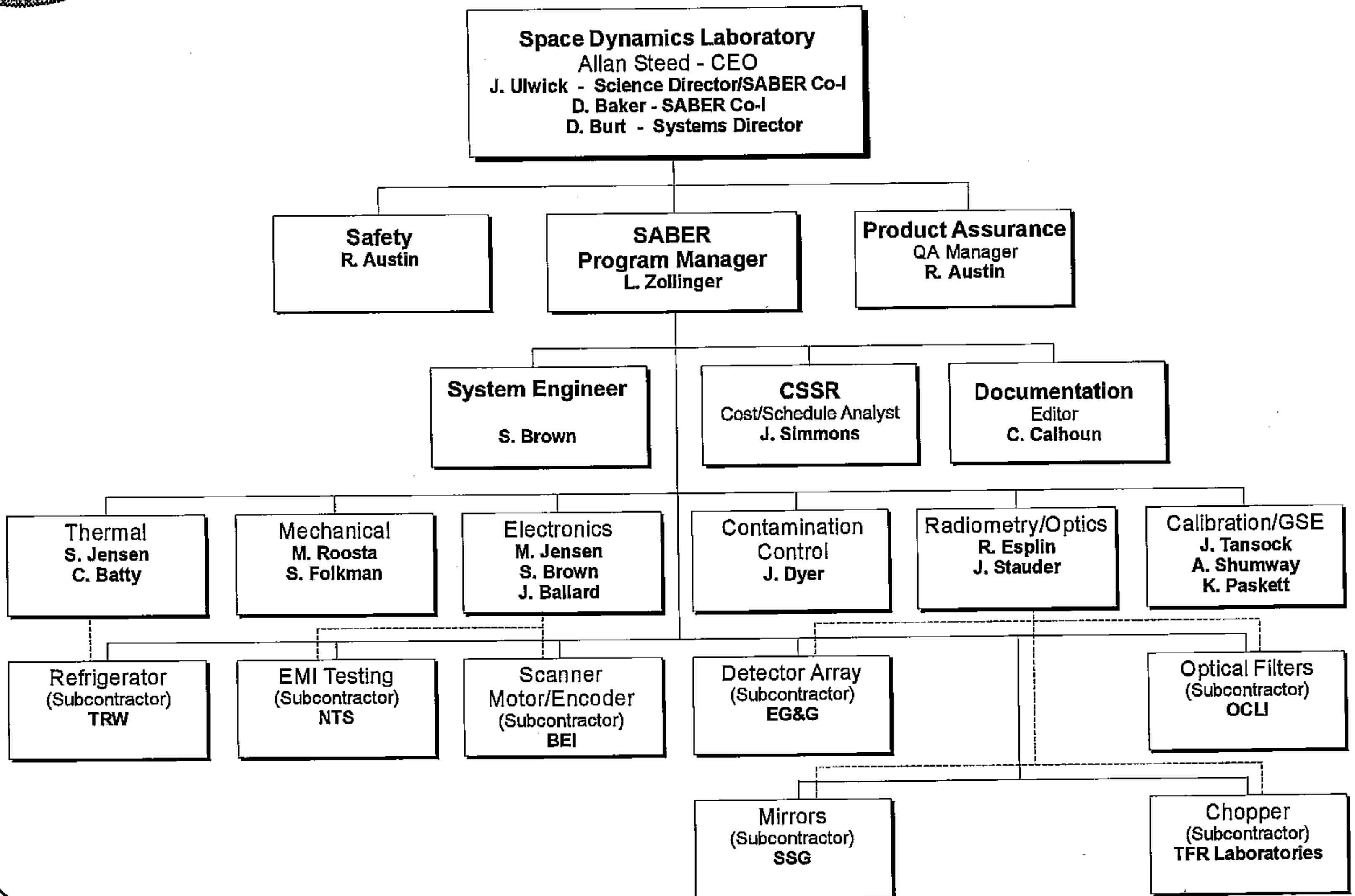
INSTRUMENT OVERVIEW OUTLINE

- SDL SABER Organization
- Instrument Requirements
- Baseline Changes
- Instrument Overview
- Risk Management

SDL/USU SABER ORGANIZATION CHART



INSTRUMENT REQUIREMENTS

REQUIREMENTS PREFACE

- Some minor changes to the instrument requirements have been made since PDR, which are highlighted in the following three charts
- Instrument/spacecraft interface specifications shown in the last four charts include specifications that flow from the instrument to the spacecraft and from the spacecraft to the instrument

INSTRUMENT REQUIREMENTS

Parameter	Measurement Requirement
Spectral Resolution	Broadband radiometer, 45, 80, 110, 150, 180, 240, 695 and 700 cm^{-1}, depending on channel
Instrument Calibration:	Systematic errors shall not exceed the following after all calibration corrections are applied:
Radiometric Accuracy	5.0% absolute radiance; 3% goal*
Long Term Radiometric Precision	2.0% radiance precision; 1% goal*
Radiance Bias Drift	≤1 NEN between space looks
Residual Scale Error	≤1% linearity over dynamic range*
IFOV @ 60 km Earth Limb Tangent Height	2 km FWHM
Limb Scan Mirror Jitter	3 arcsec (1σ)
Limb Vertical Sampling Interval	0.4 km
Along-Measurement-Track Latitude Resolution	≤5°
Measurement Altitude Range	10 km to 180 km

*For SNR >100, % is defined as a percentage of the signal.
For SNR ≤100, % is defined as a percent of the signal that produces a SNR=100.

INSTRUMENT REQUIREMENTS
SABER Channel Parameters

Channel	Species	Center Wavenumber /Wavelength (cm^{-1}) (μm)	Spectral Bandpass (cm^{-1})	Filter 5% Rel.Trans Limits (cm^{-1})	Filter Out-of-Band Rejection Ratio	System NEN + W cm^{-2} sr^{-1}	Dynamic Range
1	CO_2 (N)	658 (15.2)	45	680 - 635	$< 10^{-4}$	17.5×10^{-9}	1.5×10^4
2	CO_2 (W)	670 (14.9)	80	760 - 580	$< 10^{-3}$	28.0×10^{-9}	3.6×10^4
3	CO_2 (W)	670 (14.9)	80	760 - 580	$< 10^{-3}$	28.0×10^{-9}	3.6×10^4
4	O_3	1075 (9.3)	110	1140 - 1010	$< 5 \times 10^{-4}$	11.2×10^{-9}	5.1×10^4
5	H_2O	1470 (6.8)	180	1560 - 1380	$< 10^{-4}$	3.73×10^{-9}	1.3×10^4
6	NO	1850 (5.4)	150	1925 - 1775	$< 10^{-4}$	2.49×10^{-9}	8.2×10^4
7	CO_2	2360 (4.24)	80	2400 - 2320	$< 10^{-4}$	1.32×10^{-9}	1.2×10^3
8	OH (A)	4850 (2.06)	700	5200 - 4500	$< 10^{-4}$	0.47×10^{-9}	5.3×10^5
9	OH (B)	6088 (1.64)	695	6435 - 5740	$< 10^{-4}$	0.70×10^{-9}	6.7×10^5
10	O_2	7850 (1.27)	240	7970 - 7730	$< 10^{-4}$	0.70×10^{-9}	3.1×10^5

+ For 0.110 second integration time.

Note: Highlighted values indicate changes made since PDR (3/12/97).

INSTRUMENT REQUIREMENTS

Scan Angle Requirements

Scan Angle	Scan Range
Maximum Depression Angle	Angle required to place the top edge of the FPA at a tangent altitude 3 km below the horizon
Minimum Depression Angle	Angle required to place the bottom edge of the FPA at a tangent altitude of 400 km

Focal Plane Array Channel Locations

#4 O_3 9.3μm

#5 H_2O 6.8μm | #6 NO 5.40μm

#1 CO_2-N 15.2μm | #2 CO_2-W 14.9μm

#3 CO_2-W 14.9μm | #7 CO_2 4.24μm

#8 OH (A) 2.06μm | #9 OH (B) 1.64μm

#10 O_2 ($^1\Delta$) 1.27μm

INSTRUMENT/SPACECRAFT INTERFACE SPECIFICATIONS

Parameter	Value	Units
Mechanical Requirements:		
Envelope Dimensions	77.47 W x 104.24 H x 62.56 D	cm
Baseplate/Ref & Elec Radiator Footprint	77.47 W x 62.89 H	cm
Optics Radiator Dimensions	49.61 W x 37.34 H	cm
Total Weight	65.63 kg	
Center of Gravity	1.10(x), 17.00(y), 37.20(z)	cm
Pointing Direction	90° off-ram, on-limb, anti-sun	
Boresight Alignment Knowledge	<0.10	deg
Boresight to Instrument interface		
Optical Clear Fields of View	±30 horizontal, 25 vertical top, 55 vertical bottom	deg
Thermal Clear Fields of View	Full hemisphere (small TIDI intrusion)	
Limit Loads	16	g
Minimum Frequency	35 thrust axis, 20 lateral axis	Hz
Thermal Requirements:		
Interface Resistance	> 5	deg C/w
Cleanliness Requirements:		
Cleanliness Levels for Spacecraft Integration	Class 100,000	
Pre-spacecraft Integration Test	Class 100 clean tent	
Spacecraft Surface Cleanliness	Level 750	
Purge Gas	N_2 boil off gas from liquid LN_2	
Purge Rate	0.5 at 4 psi delivery pressure	scfm

INSTRUMENT/SPACECRAFT INTERFACE SPECIFICATIONS

Parameter	Value	Units
Attitude and Navigational Requirements:		
Orbit Insertion Altitude	625 ±25	km
Worst Case Orbit Decay	43	km
Orbit Inclination	74.4	deg
Pointing Accuracy (at s/c interface)	0.6	deg
Pointing Knowledge	0.1	deg
Instrument to s/c alignment	0.1 (scan plane)	deg
	0.25 (other axes)	deg
Alignment knowledge	0.05	deg
Jitter (includes mirror jitter)	f < 0.5 Hz, jitter increases as 1/f	
	0.5 Hz < f < 10 Hz, jitter = 0.005 (goal of 0.001)	deg
	f > 10 Hz, jitter = 0.028	deg
Stability (peak attitude rates):		
In Scan Plane	0.0075	deg/sec
In Planes Orthogonal to Scan	0.025	deg/sec
Position Knowledge:		
Altitude	300	m
Along Track and Cross Track	1000	m
Perturbing Mechanisms:		
Scan Mirror	1.0 x 10-4 (TBR)	N-m-sec
Refrigerator Compressor	0.02	lbf
Optical Chopper	0.002	lbf

INSTRUMENT/SPACECRAFT INTERFACE SPECIFICATIONS

Parameter	Value	Units
Command & Data Handling Requirements:		
Modes of Operation	Off, Power-up, Safe, Standby, Stabilize, Calibration, Data Collection, Diagnostic	
Peak Data Rate for each Mode of Operation:		
Off	0	kbits/sec
Power-up	0.063	kbits/sec
Safe	0.063	kbits/sec
Standby	0.063 or 3.97 (depends on previous mode)	kbits/sec
Stabilize	0.063	kbits/sec
Calibration	3.97	kbits/sec
Data Collection	3.97	kbits/sec
Diagnostic	3.97	kbits/sec
Command Uplink Rate	2	kbytes/day
Duty Cycle	100	%
Time Knowledge	0.1	sec
Special Data Needs	None	
Spacecraft Data Interface	MIL-STD-1553	

Note: Two MIL-STD-1553 connections: one for the instrument and one for the refrigerator

INSTRUMENT/SPACECRAFT INTERFACE SPECIFICATIONS

Parameter	Value		Units
Power Requirements:			
Average & Peak Power for each Mode of Operation:	Avg	Peak	
Off	28.5	62.5 (survival)	W
Power-up	74.5	74.5	W
Safe	74.5	74.5	W
Standby	69.7	69.7	W
Stabilize	69.7	69.7	W
Calibration	72.6	92.7	W
Data Collection	72.6	92.7	W
Diagnostic	72.6	92.7	W
Voltage Range	28 +7, -6		V
Special Requirements for:			
Integration and Test	Full functional test requires vacuum test chamber with LN_2 for cooling chamber		
Keep-Out Zones	Keep sun from clear fields of view, avoid long-term exposure of aperture to ram		
Mission Operations	Door release attitude		
Safety	None		
EMC	None		

BASELINE CHANGES

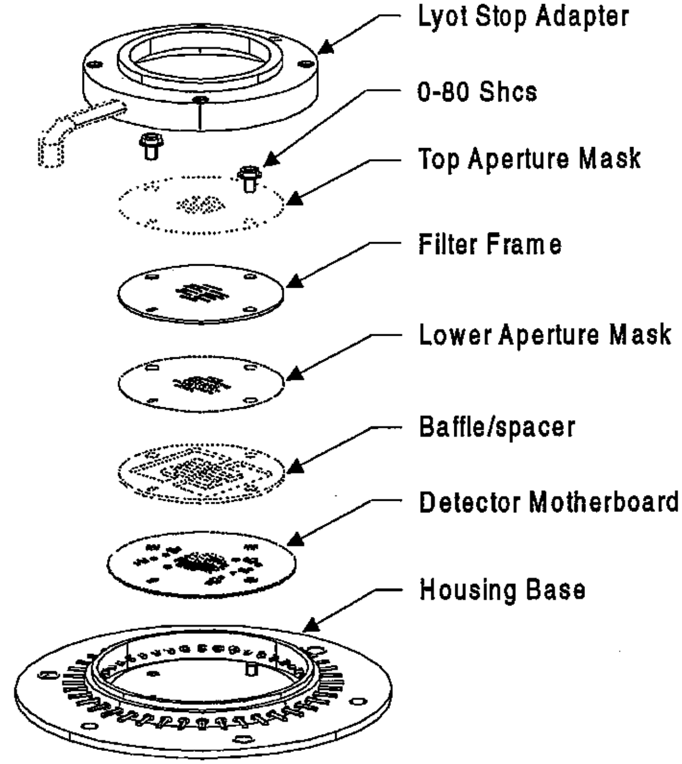
BASELINE CHANGE
FPA Window Eliminated

Change Driven By:

- Internal reflections from window and filters cause significant cross-talk
- EG&G test data showed HgCdTe detector response change when exposed to humidity returns to its pre-exposure level after 1 week in vacuum
- Efforts to achieve a KBr window seal design that survives repeated thermal cycles were unsuccessful

Change Resulted In:

- Eliminated KBr window seal problem
- Eliminated filter/window reflection cross-talk risk
- Eliminated sealed package leak risk
- Provision to directly purge FPA detector assembly



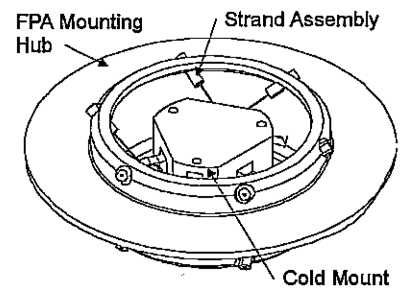
BASELINE CHANGE
FPA Support Design

Change Driven By:

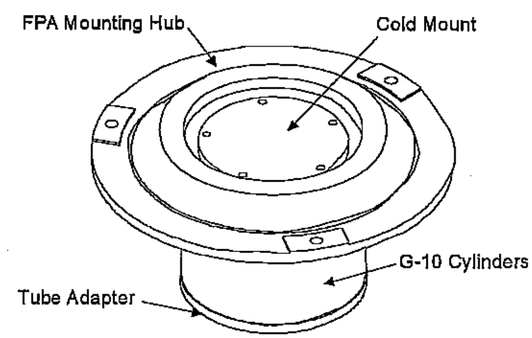
- SDL unable to demonstrate by test that the Kevlar strand support system was sufficiently stable (30 arcsec) when subjected to thermal cycling

Change Resulted In:

- More conventional design based on a folded thin-wall G-10 cylinder approach
- Design is easier to blanket
- Higher heat load to refrigerator



FPA Kevlar Strand Suspension Design



FPA Folded G-10 Tube Design

BASELINE CHANGE
Filter Refinements and Channel Locations

Channel Location Change Driven By:

- Realization that reflected solar radiation in short wavelength channels was much greater than previously anticipated
- Detectors at the bottom of the FPA are best protected from reflected solar radiation

Change Resulted In:

- Scattered solar radiation impact was reduced

Filter Refinements Driven By:

- Limitation of state of the art in filter fabrication
- Desire to improve scientific measurements (CO_2 & OH channels 7 & 9)

Change Resulted In:

- Reduced filter fabrication risks
- Improvement in science capability of SABER

	#6 NO 5.40µm	
#7 CO_2 (4.3) 4.27µm		#8 OH (A) 2.06µm
#9 OH (B) 1.62µm		#10 O_2 1.27µm
#4 O_3 9.39µm		#3 CO_2-W 14.9µm
#2 CO_2-W 14.9µm		#1 CO_2-N 15.2µm
	#5 H_2O 6.80µm	

FPA Channel Locations at PDR

	#4 O_3 9.3µm	
#5 H_2O 6.8µm		#6 NO 5.40µm
#1 CO_2-N 15.2µm		#2 CO_2-W 14.9µm
#3 CO_2-W 14.9µm		#7 CO_2 4.24µm
#8 OH (A) 2.06µm		#9 OH (B) 1.64µm
	#10 O_2 ($^1\Delta$) 1.27µm	

Current FPA Channel Locations

BASELINE CHANGE
Detector Change for OH Channels

Change Driven By:

- EG&G has not been able to meet the required detector sensitivity for the OH channels (8 & 9) using extended InGaAs detectors

Change Resulted In:

- Change to InSb detectors that meet the sensitivity requirements for OH channels
- Need for additional filter long wavelength blocking for channel 8
  - OCLI has designed a filter that meets the additional blocking requirements

BASELINE CHANGE
Refrigerator Electronics

Change Driven By:

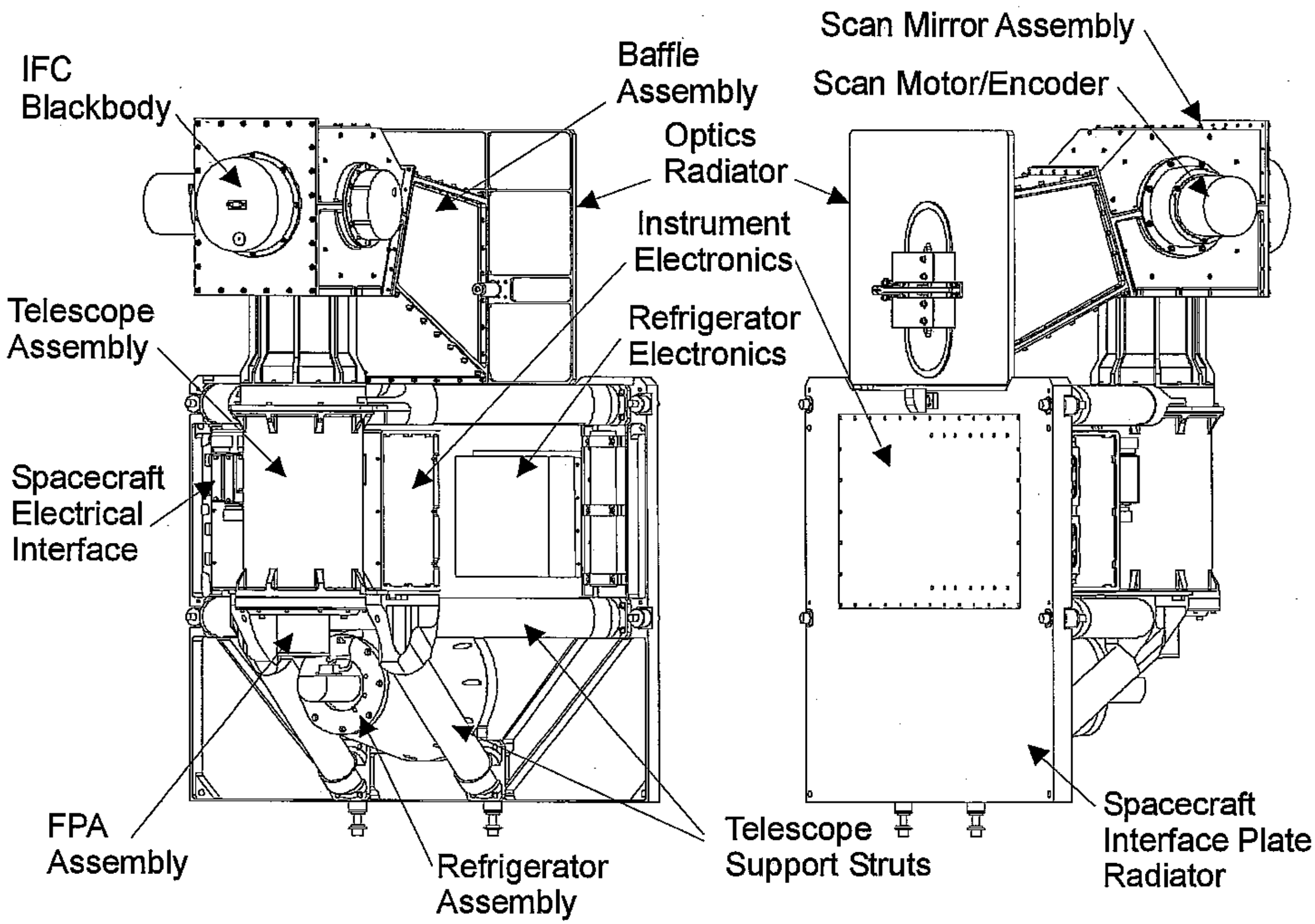
- Cost

Change Resulted In:

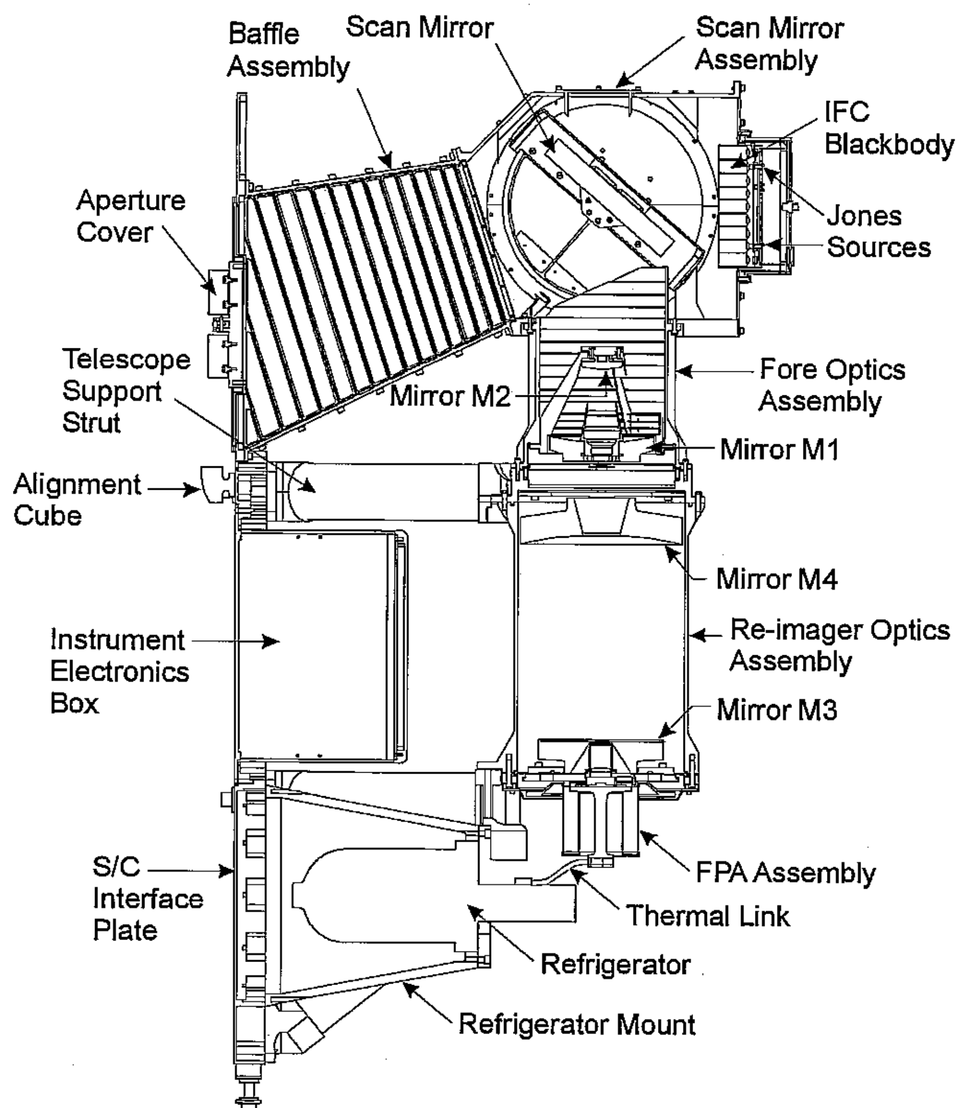
- Larger electronics box
- Added refrigerator MIL-STD-1553 interface to spacecraft
- Relocated refrigerator electronics box
- Weight and power increased

INSTRUMENT OVERVIEW

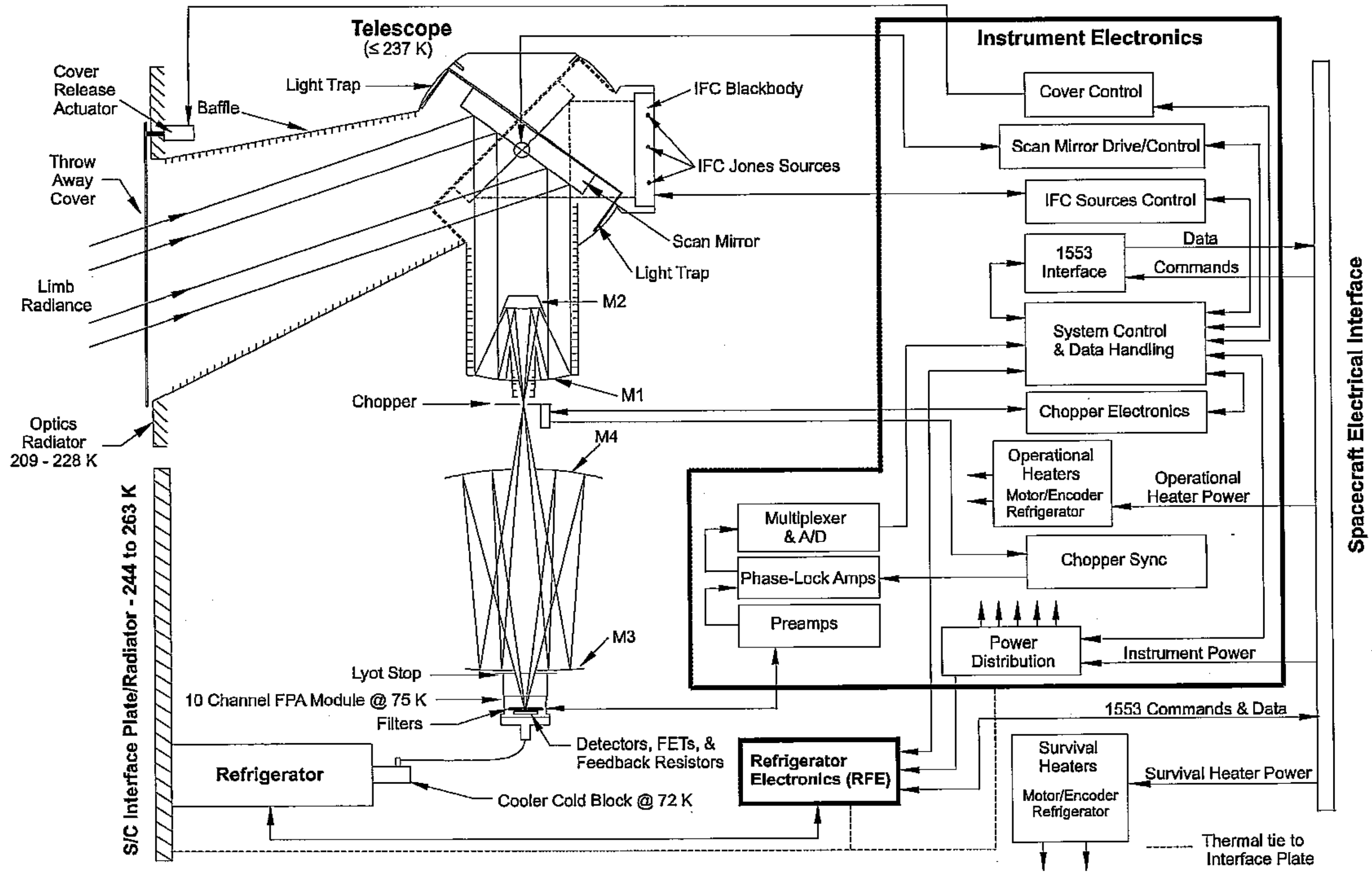
SABER INSTRUMENT CONFIGURATION



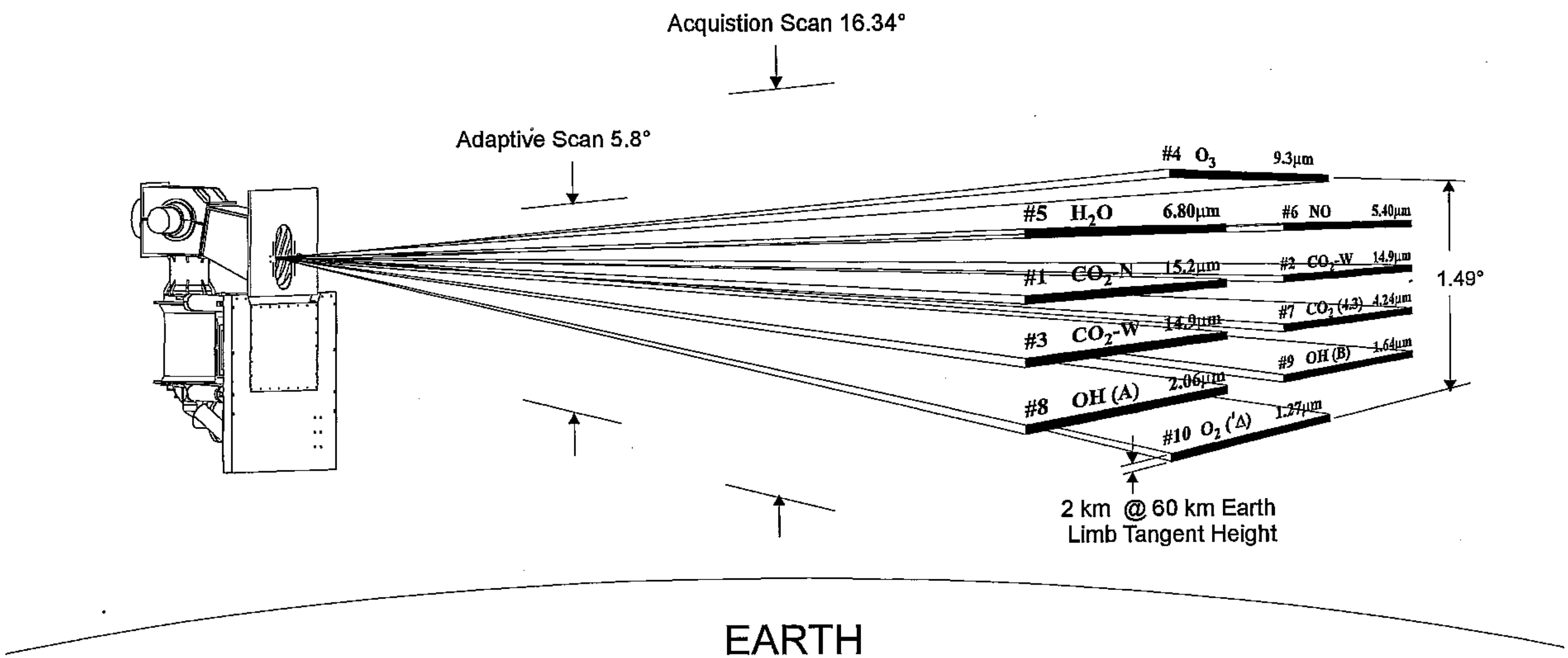
SABER INSTRUMENT CUT-AWAY VIEW



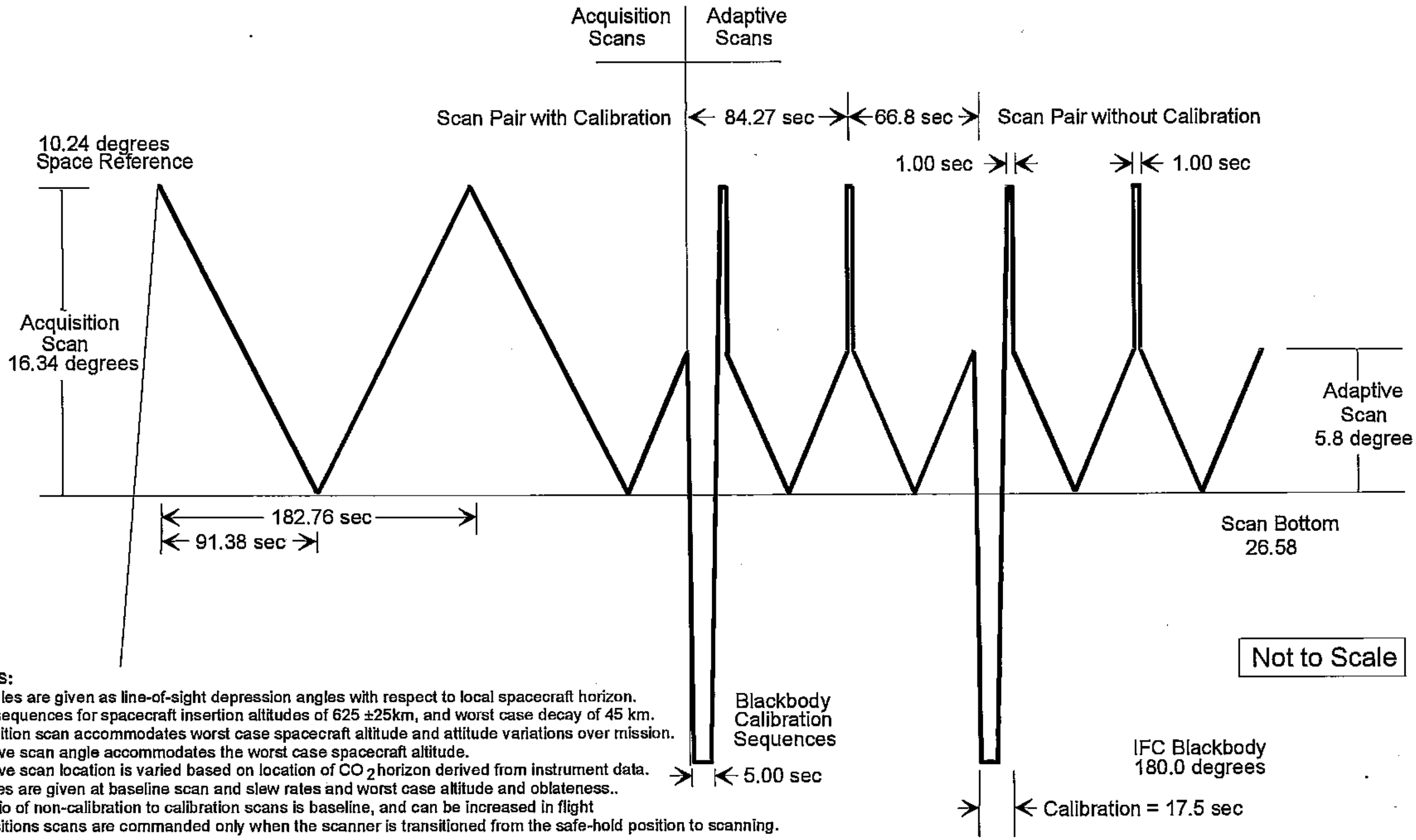
SABER FUNCTIONAL BLOCK DIAGRAM



SABER FIELD OF VIEW



SABER LIMB SCAN SEQUENCE



NOTES:
All angles are given as line-of-sight depression angles with respect to local spacecraft horizon.
Scan sequences for spacecraft insertion altitudes of 625 ±25km, and worst case decay of 45 km.
Acquisition scan accommodates worst case spacecraft altitude and attitude variations over mission.
Adaptive scan angle accommodates the worst case spacecraft altitude.
Adaptive scan location is varied based on location of CO_2 horizon derived from instrument data.
All times are given at baseline scan and slew rates and worst case altitude and oblateness..
2:1 ratio of non-calibration to calibration scans is baseline, and can be increased in flight
Acquisitions scans are commanded only when the scanner is transitioned from the safe-hold position to scanning.

RISK MANAGEMENT

IDENTIFIED RISKS

Risks identified and in work for the past 2 years:

- **Refrigerator Launch Survivability Risk**
- **Refrigerator Thermal Performance Risk**
- **Refrigerator Electronics Risk**
- **Thermal Link Development Risk**
- **Focal Plane Assembly Mount Risk**
- **Detector Assembly Risks**
- **Focal Plane Array Packaging Risk**
- **Chopper Development Risk**
- **Calibration Blackbody Development Risk**

REFRIGERATOR LAUNCH SURVIVABILITY RISK

- **Risk Description:**
  - Baselined TRW refrigerator has not been qualified to the original structural levels required by the TIMED mission, and qualification may be cost and schedule prohibitive

- **Risk Mitigation:**
  - SDL has conducted searches for alternate suppliers of a refrigerator that meets SABER requirements, but to date TRW still comes closest to meeting all requirements
  - An interface to the spacecraft has been agreed to which provides SABER with a rigid mounting configuration and minimizes amplification of launch vibrations to the refrigerator mount
  - Decision to launch the TIMED spacecraft on a Delta II launch vehicle rather than a Taurus has resulted in sufficient reduction of the launch and test load requirements that the qualification levels of the TRW refrigerator fall within these new requirements
  - Risk closed

REFRIGERATOR THERMAL PERFORMANCE RISK

- **Risk Description:**
  - Expected thermal performance of the refrigerator is based on projections of TRW's data to SABER's operating conditions; thermal performance test data at SABER's operating conditions are needed to verify performance

- **Risk Mitigation:**
  - SDL conducted searches for alternate suppliers of a refrigerator that meets SABER requirements, but to date TRW still comes closest to meeting all requirements
  - Performed in-house testing with TRW refrigerator on loan from USAF Phillips Lab; one of two refrigerators that successfully completed 17,000 hours of life testing
  - Refrigerator test results and analysis of new FPA mount indicate that when operated at 273 K, there is sufficient capacity to cool the FPA to its operational temperature of 75 K, although no margin exists in the extreme hot case. Conservative assumptions were used to establish the hot case, which will only exist near the end of TIMED's 2 year mission
  - TRW has provided data indicating that the pulse tube refrigerator meets the minimum requirements. The TRW pulse tube refrigerator is on order and no further risk reduction actions are planned

REFRIGERATOR ELECTRONICS RISK

- **Risk Description:**
  - To keep refrigerator costs within the scope of the TIMED mission, SDL has requested quotations on existing designs for both the refrigerator and its electronics
  - Quotations received are based on using an existing design developed for the SSTI Lewis mission and include no modifications to satisfy TIMED mission requirements
  - New hyper-spectral mission may claim the SSTI residual electronics

- **Risk Mitigation:**
  - SDL has conducted searches for alternate suppliers of a refrigerator that meets SABER requirements, but to date TRW still comes closest to meeting all requirements
  - SDL will provide a power converter to condition the power and compensate for the shortcomings of the TRW electronics
  - Remaining technical issues have been negotiated with TRW
  - TRW is on contract to gain approval for and the transfer of the residual SSTI electronics to the SABER project
  - Closure of risk pending approval and transfer of the SSTI electronics by GSFC

THERMAL LINK DEVELOPMENT RISK

- **Risk Description:**
  - The thermal link must have good thermal conduction and yet be sufficiently flexible and low in mass to prevent transmitting refrigerator vibrations to the focal plane and to prevent applying too large a load to the refrigerator thermal link attach point

- **Risk Mitigation:**
  - Thermal link has been prototyped and tested
  - Link exceeds the thermal conductivity, vibration isolation, and mass requirements
  - Risk closed

FOCAL PLANE ASSEMBLY MOUNT RISK

- **Risk Description:**
  - Kevlar FPA support system is a relatively new technology
  - Alignment stability and thermal performance of the Kevlar FPA support system is unproven

- **Risk Mitigation:**
  - Prototypes were fabricated to prove the Kevlar FPA support system
    - Tests showed that the system met structural and thermal requirements
    - Thermal cycle alignment stability tests however failed
      - Stability requirements were not met due to failure of a glue bond joint in 1 of the 12 fasteners
  - As documented in the risk management plan, the more conventional concentric cylinder support system is the new baseline design
  - Analysis indicates that the concentric G-10 cylinder FPA mount will meet requirements for parasitic heat loads, although no margin exists in the extreme hot case. Conservative assumptions were used to establish the hot case, which will only exist near the end of TIMED's 2 year mission

FOCAL PLANE ASSEMBLY MOUNT RISK (continued)

- **Risk Mitigation (continued):**
  - A prototype will be fabricated and tested to verify that it meets requirements prior to building the flight unit
  - SDL will continue development of the Kevlar strand design in the background as a risk mitigation effort

DETECTOR ASSEMBLY RISKS

- **Risk Description:**
  - SABER instrument detector sensitivity requirements are at or above the standard commercial product levels
  - Original plan was to use two channels using a new technology, long wavelength, InGaAs detector
  - Limited data available for these detectors

- **Risk Mitigation:**
  - EG&G performed space application environment testing of 2.6 μm cut-off wavelength InGaAs detectors (this testing was successful)
  - EG&G fabricated and tested several runs of extended InGaAs detectors but have not been able to meet the required detector sensitivity
  - Based on data presented at EG&G's CDR, filter design data from OCLI, and a review of the impact on science, the decision has been made to baseline low-risk InSb detectors for the OH channels (8 & 9)

FOCAL PLANE ARRAY PACKAGING RISK

- **Risk Description:**
  - Mechanical interface between the detector assembly and the filter frame assembly is complex and requires close tolerances
  - This assembly consists of two expensive, long-lead items; if a problem occurs with the integration of these assemblies, it could have a major impact to cost and schedule
  - The detectors need to be protected from moisture in the environment, requiring a sealed package, strict environmental control through launch, or a protective encapsulation

- **Risk Mitigation:**
  - EG&G and OCLI are prototyping the detector and filter frame assemblies
    - Sufficient parts were made for the prototype and flight
  - EG&G is integrating the assembly and will complete testing early December 97
  - Detector assembly window has been eliminated
  - Detector environment will be controlled - dry nitrogen purge

CHOPPER DEVELOPMENT RISK

- **Risk Description:**
  - Subcontractor for SABER chopper is TFR, the only known chopper supplier with flight history
  - Company expertise resides with owner who is beyond retirement age
- **Risk Mitigation:**
  - Design has been completed and a prototype chopper fabricated and assembled
  - Prototype testing will be completed by 4 November
  - Closure of risk pending successful completion of the chopper prototype tests

CALIBRATION BLACKBODY DEVELOPMENT RISK

- **Risk Description:**
  - New, complicated, large (8 inch), high temperature (620 K) blackbody development
- **Risk Mitigation:**
  - A thorough review of the Calibration Plan and calibration GSE was held and resulted in a simplified approach with less risk
  - A cavity enhanced radiator plate design is acceptable and was adopted for the low temperature blackbody and a small aperture design for the high temperature blackbody
    - New designs reduce risk with lower power requirements and less temperature control zones
    - Outgassing risk is diminished with the size reduction
    - Smaller size enables simpler construction and testing
  - The high temperature blackbody will be subcontracted to Mikron, an experienced blackbody manufacturer, who will verify by test that it meets both the outgassing and performance requirements
  - Risk closed

RISK SUMMARY

Risk	Status
Refrigerator Launch Survivability	Closed
Refrigerator Thermal Performance	No further action
Refrigerator Electronics	Pending transfer of SSTI electronics
Thermal Link Development	Closed
FPA Mount	New baseline to concentric cylinder design Prototype testing Background development of suspension design
Detector Assembly	InSb detectors for OH channels (8 & 9)
FPA Packaging	Prototype testing
Chopper Development	Prototype testing
Calibration Blackbodies	Closed

RADIOMETRIC AND OPTICAL SUBSYSTEM

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OUTLINE

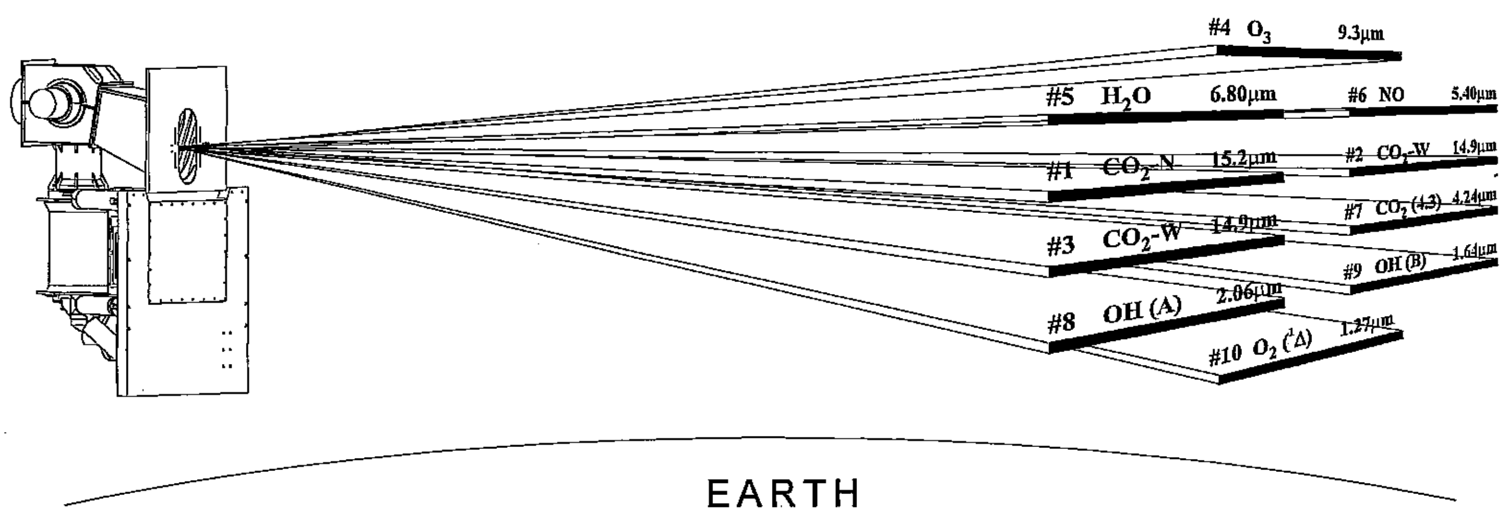
- Requirements and Design Performance
- Telescope
- Chopper
- Detector Assembly
- Detectors
- Filters
- Conclusions

OCAL PLANE ARRANGEMENT REQUIREMENT AND DESIGN

- **Requirement**

#4 O_3 9.3μm	
#5 H_2O 6.8μm	#6 NO 5.40μm
#1 CO_2-N 15.2μm	#2 CO_2-W 14.9μm
#3 CO_2-W 14.9μm	#7 CO_2 4.24μm
#8 OH (A) 2.06μm	#9 OH (B) 1.64μm
#10 O_2 ($^1\Delta$) 1.27μm	

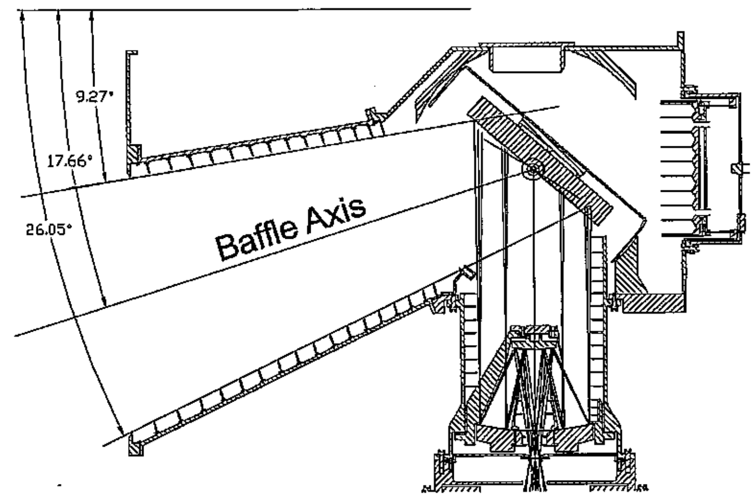
- **Design**



SCAN ANGLE REQUIREMENTS AND PERFORMANCE

Scan Angle Requirements

Scan Angle	Scan Range
Maximum Depression Angle	Angle required to place the top edge of the FPA at a tangent altitude 3 km below the horizon
Minimum Depression Angle	Angle required to place the bottom edge of the FPA at a tangent altitude of 400 km



- **Baffle angles meet the scan angle requirements**
- **Orbit altitude 625 ± 25 km**
- **Maximum orbit decay 45 km**
- **Pointing error**
  - 0.6 ° Spacecraft
  - 0.3 ° Saber instrument
  - 0.9 ° Total

IFOV REQUIREMENT AND DESIGN PERFORMANCE

- **Requirement: IFOV (instantaneous field of view) at 60 km earth tangent height ≤ 2 km FWHM (full width at half maximum)**
- **Design performance:**

Channel Number	Species	Design FWHM (km)
1	CO_2 (N)	1.783
2	CO_2 (W)	1.776
3	CO_2 (W)	1.778
4	O_3	1.914
5	H_2O	1.884
6	NO	1.871
7	CO_2 (B)	1.858
8	OH (A)	1.837
9	OH (B)	1.835
10	O_2	1.833

NOISE EQUIVALENT RADIANCE (NEN) REQUIREMENTS AND DESIGN PERFORMANCE

Channel	Species	NEN Requirement ($Wcm^{-2}sr^{-1}$)	NEN Design ($Wcm^{-2}sr^{-1}$)	NEN_{Req}/NEN_{Design}
1	CO_2 (N)	1.75E-8	1.04E-8	1.68
2	CO_2 (W)	2.80E-8	1.40E-8	2.00
3	CO_2 (W)	2.80E-8	1.40E-8	2.01
4	O_3	1.12E-8	3.38E-9	3.31
5	H_2O	3.73E-9	2.76E-9	1.35
6	NO	2.49E-9	1.83E-10	13.59
7	CO2 (B)	1.32E-9	1.21E-10	10.94
8	OH (A)	4.70E-10	2.42E-10	1.94
9	OH (B)	7.00E-10	3.48E-10	2.01
10	O_2	7.00E-10	3.55E-10	1.97

For 0.110 integration time T (noise equivalent electrical bandwidth = 1/2T =4.545 Hz)

DYNAMIC RANGE REQUIREMENT AND DESIGN PERFORMANCE

Ch	Species	N_{MEAR} ($Wcm^{-2}sr^{-1}$)	$\frac{N_{IFCBB}}{NEN_{Req}}$	$\frac{N_{300K}}{NEN_{Req}}$	Required Dynamic Range $\frac{N_{MEAR}}{NEN_{Req}}$	Design Dynamic Range $\frac{N_{Max\ Signal}}{NEN_{Req}}$
1	CO_2 (N)	2.70E-4	1.64E4	3.21E4	1.54E4	3.25E4
2	CO_2 (W)	9.98E-4	4.29E4	8.44E4	3.56E4	8.57E4
3	CO_2 (W)	9.98E-4	4.29E4	8.44E4	3.56E4	8.57E4
4	O_3	5.67E-4	2.80E4	8.22E4	5.06E4	8.28E4
5	H_2O	4.96E-5	3.26E4	1.42E5	1.33E4	1.44E5
6	NO	2.03E-4	1.05E4	6.73E4	8.16E4	1.02E5
7	CO_2 (B)	1.56E-6	1.65E3	1.78E4	1.18E3	1.79E4
8	OH (A)	2.48E-4	0	16	5.27E5	6.61E5
9	OH (B)	4.69E-4	0	0	6.69E5	8.42E5
10	O_2	2.15E-4	0	0	3.08E5	3.83E5

N_{MEAR} is maximum earth and atmospheric radiance
N_{IFCBB} is IFC blackbody radiance with T=247 K
N_{300K} is radiance from 300 K source with emissivity of 0.97

RADIANCE BIAS DRIFT REQUIREMENT AND DESIGN PERFORMANCE

- **Requirement: ≤ 1 NEN between space looks**
  - Interpreted as dark offset drift
- **Design performance:**

Channel	Species	Optics Temperature Component (NEN)	FPA Temperature Component NEN	Total (NEN)
1	CO_2 (N)	0.002	0.4	0.4
2 & 3	CO_2 (W)	0.006	0.9	0.9
4	O_3	0.006	0.5	0.5
5	H_2O	0.008	0.5	0.5

- **Key parameters used in performance calculation**
  - Detector responsivity variation -5.7%/K (measured value for CO_2 (N) prototype detector)
  - FPA temperature drift: 0.008 K/min
  - Optics temperature drift: 1E-4/min
  - Time between space looks: 66 sec

FILTER SPECTRAL BANDWIDTH REQUIREMENTS AND DESIGN

Ch	Species	5% Transmission Cut-on Point (cm^{-1})			5% Transmission Cut-off Point (cm^{-1})		
		Requirement	Spec.	Design	Requirement	Spec.	Design
1	CO_2 (N)	680 (14.71 μm)	680 ± 3	681.7	635 (15.75 μm)	635 ± 3	632.9
2	CO_2 (W)	760 (13.16 μm)	760 ± 4	758.5	580 (17.24 μm)	580 ± 3	581.2
3	CO_2 (W)	760 (13.16 μm)	760 ± 4	758.5	580 (17.24 μm)	580 ± 3	581.2
4	O_3	1140 (8.77 μm)	1140 ± 11	1138.5	1010 (9.90 μm)	1010 ± 10	1011.1
5	H_2O	1560 (6.41 μm)	1560 ± 16	1564.0	1380 (7.25 μm)	1380 ± 14	1376.7
6	NO	1925 (5.19 μm)	1925 ± 19	1941.9	1775 (5.63 μm)	1775 ± 18	1761.6
7	CO_2 (B)	2400 (4.17 μm)	2400 ± 24	In Spec	2320 (4.41 μm)	2320 ± 23	In Spec
8	OH (A)	5200 (1.92 μm)	5200 ± 52	In Spec	4500 (2.22 μm)	4500 ± 45	In Spec
9	OH (B)	6435 (1.55 μm)	6435 ± 64	In Spec	5740 (1.74 μm)	5740 ± 58	In Spec
10	O_2	7970 (1.25 μm)	7970 ± 16	7973.8	7730 (1.29 μm)	7730 ± 15	7728.6

FILTER SLOPE REQUIREMENTS

Channel Number	Cut-on Slope (%) *		Cut-off Slope (%) *	
	Spec.	Design	Spec.	Design
1	≤ 3.0	1.09	≤ 2.9	1.19
2 & 3	≤ 2.4	1.50	≤ 2.9	1.39
4	≤ 2.4	1.05	≤ 2.9	1.21
5	≤ 2.6	1.02	≤ 2.9	1.07
6	≤ 2.0	1.24	≤ 2.0	1.37
7	≤ 2.0	In Spec	≤ 2.0	In Spec
8	≤ 2.5	In Spec	≤ 2.5	In Spec
9	≤ 2.5	In Spec	≤ 2.5	In Spec
10	≤ 2.5	0.78	≤ 2.5	0.81

* % Slope $\equiv$ ((λ 80% of peak - λ 5% absolute)/λ 5% absolute) x 100

FILTER OUT-OF-BAND REJECTION REQUIREMENTS*

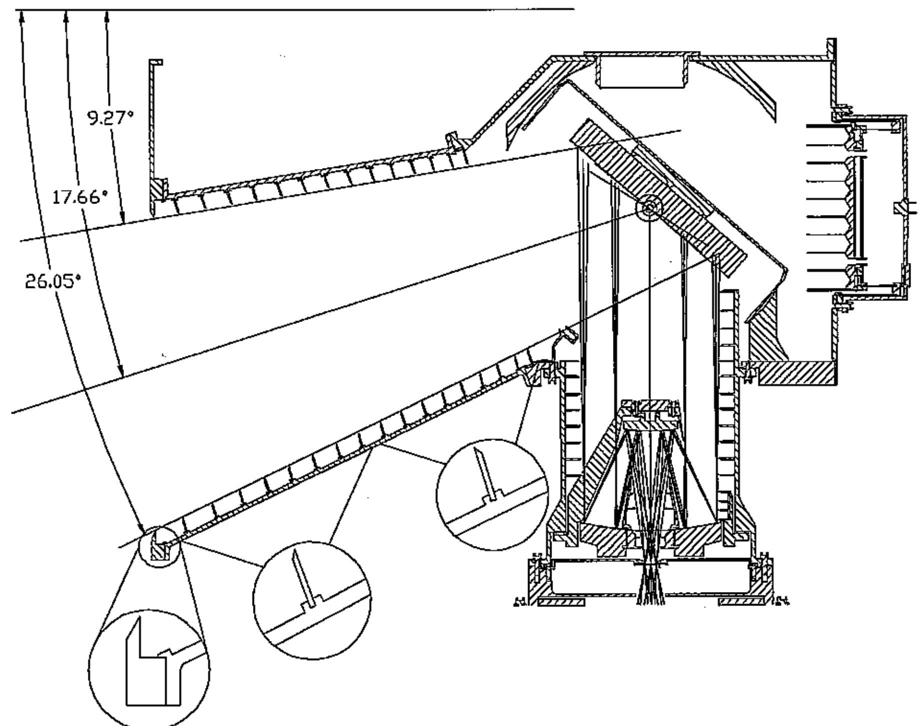
Channel Number	Average Out-of-Band Transmittance (%)		Long Wavelength Blocking Limit (μm)	
	Req.	Design **	Req.	Design
1	≤ 0.01	0.00051 below band 0.022 above band	22.4	22.4
2 & 3	≤ 0.1	< 0.05	24.4	24.4
4	≤ 0.05	< 0.001	15.5	15.5
5	≤ 0.01	< 0.001	12.5	12.5
6	≤ 0.01	< 0.001	10.0	10.0
7	≤ 0.01	< 0.001	10.0	10.0
8	≤ 0.01	< 0.001	6.0	6.0
9	≤ 0.01	< 0.001	6.0	6.0
10	≤ 0.01	< 0.001	5.0	5.0

* Given a well-behaved detector roll-off on the long wavelength side

** Design does not include Stierwalt effect, which degrades out-of-band blocking when filters close to detectors. OCLI experience has shown margins on filter numbers 2 to 10 adequate to compensate for Stierwalt effect.

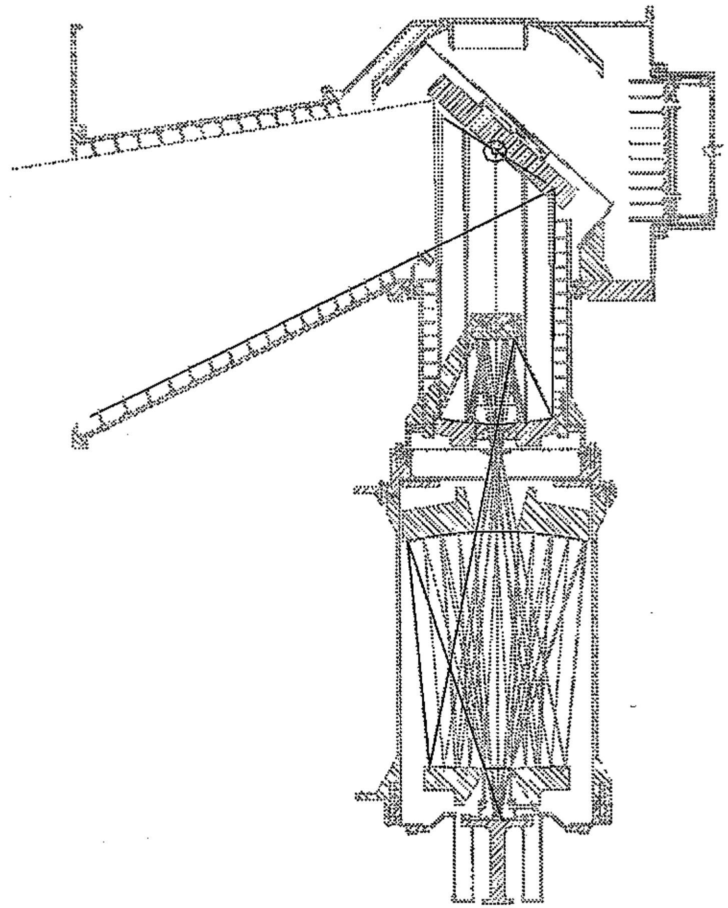
TELESCOPE BAFFLES

- **Telescope baffles**
  - Main baffle
  - Fore-optics baffle
  - Secondary conical baffle
  - Inner primary conical baffle
- **Main baffle depression angles**
  - Axis: 17.66°
  - Top of scan: 9.27°
  - Bottom of scan: 26.05°
- **Off-axis illumination limits**
  - Scan mirror: 23°
  - Primary mirror: 15°
  - Secondary mirror: 13°
- **Baffle paint: Aeroglaze Z 306**
- **Baffle vane tips NOT painted**
- **Vane tip edge radius: 0.1 mm**
- **Baffle vanes spaced to meet two bounce criteria with 0.4 mm tolerance**
- **Baffle bevels oriented so they are either hidden from the mirror or are not illuminated**
- **Vane tips have a 1 mm tolerance with respect to marginal rays**
- **Scattered light from baffles negligible**

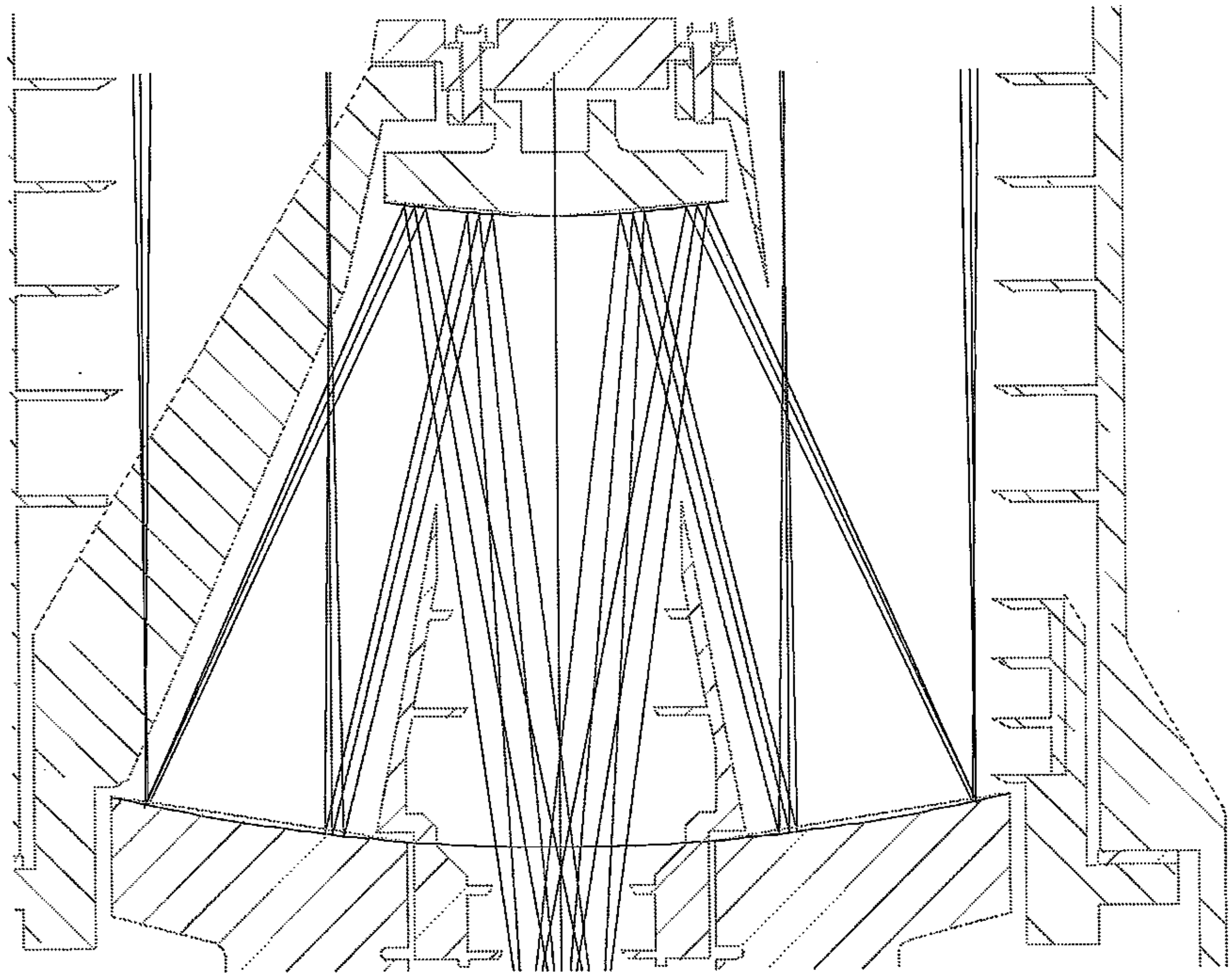


TELESCOPE

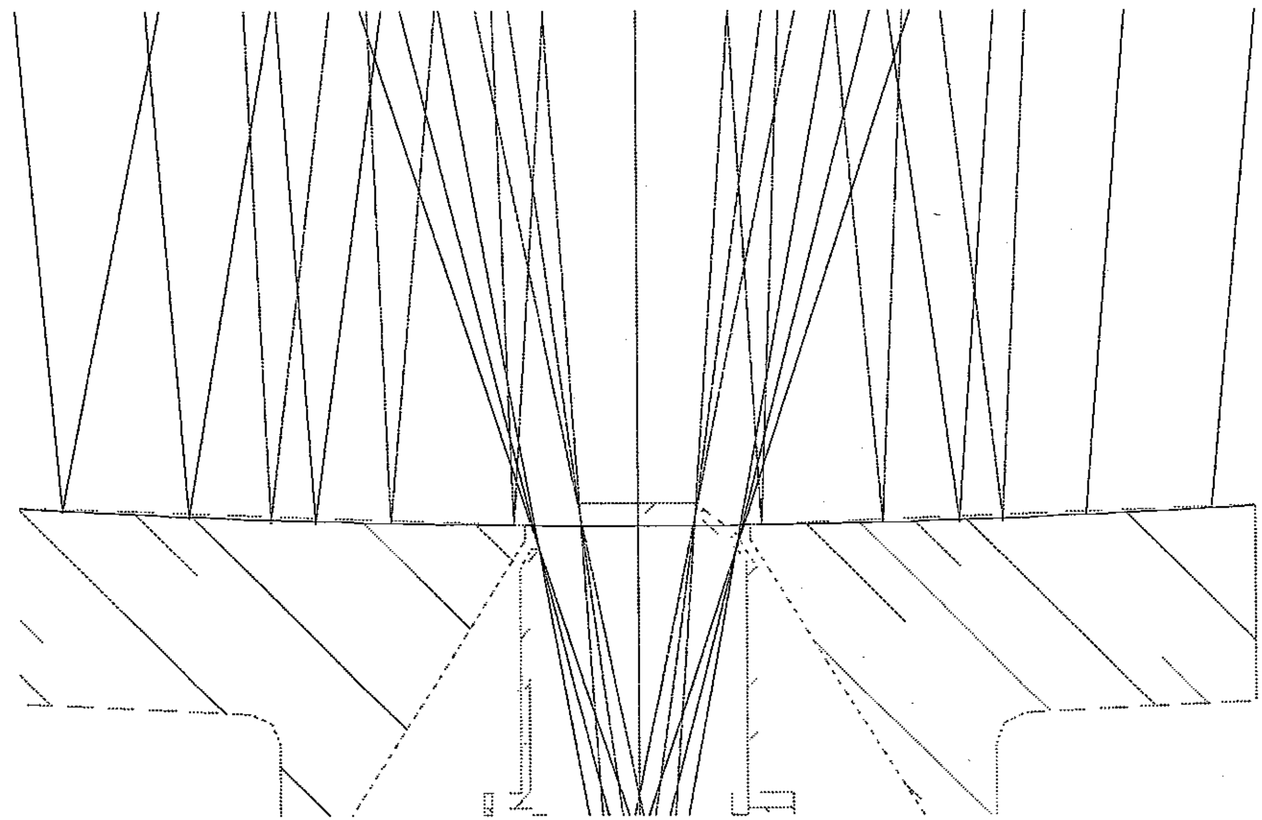
- On-axis Cassegrain followed by clam shell reimager
- Off-axis scatter dominated by mirror BRDF of scan, primary and secondary mirrors
- Cold Lyot stop blocks scatter from entrance aperture, central obscuration and secondary mirror spider
- F/2
- Focal length: 200 mm
- Entrance pupil diameter: 98 mm
- Entrance pupil inner diameter: 27 mm
- Fraction of entrance pupil annulus obscured by spider: 6%
- Focal length at chopper: 300 mm
- Detector magnification at chopper: 1.5
- Demagnification at Lyot stop: 0.2



MARGINAL RAYS IN FORE OPTICS

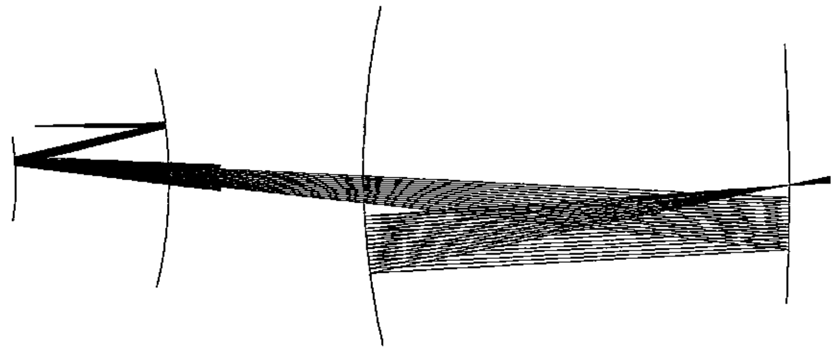


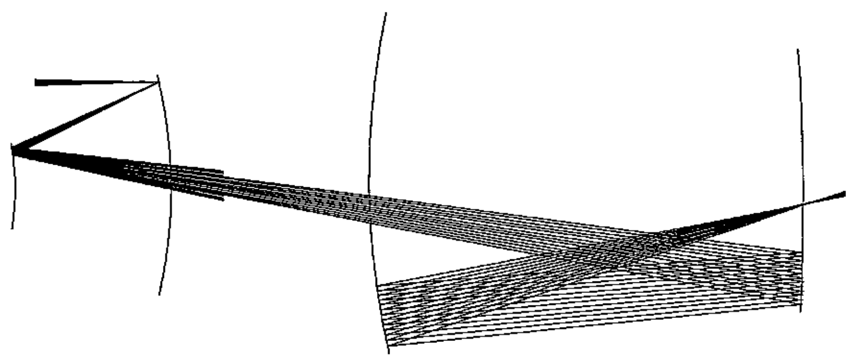
MARGINAL RAYS AT LYOT STOP AND M4



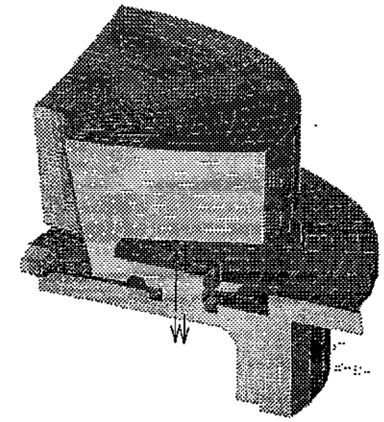
IMAGES OF APERTURES AND SPIDER

- Lyot stop 3-dimensional to match images of inner and outer Lyot stops and spider struts supporting secondary mirror
- Maximum spot size: ≤ 0.110 mm (diffraction limit for channel 1)
- Spot size is small because chopper holes limit range of angles to ±0.85°
- Spot is diffraction limited
- Only spider strut edges nearest mirror can be seen At Lyot stop because struts are beveled 0.89° in direction of rays (2.0° perpendicular to strut edges)
- Light scattered from strut edges is blocked By the chopper because strut bevel in direction of rays is greater than 0.85°





MIRROR DESIGN



M4

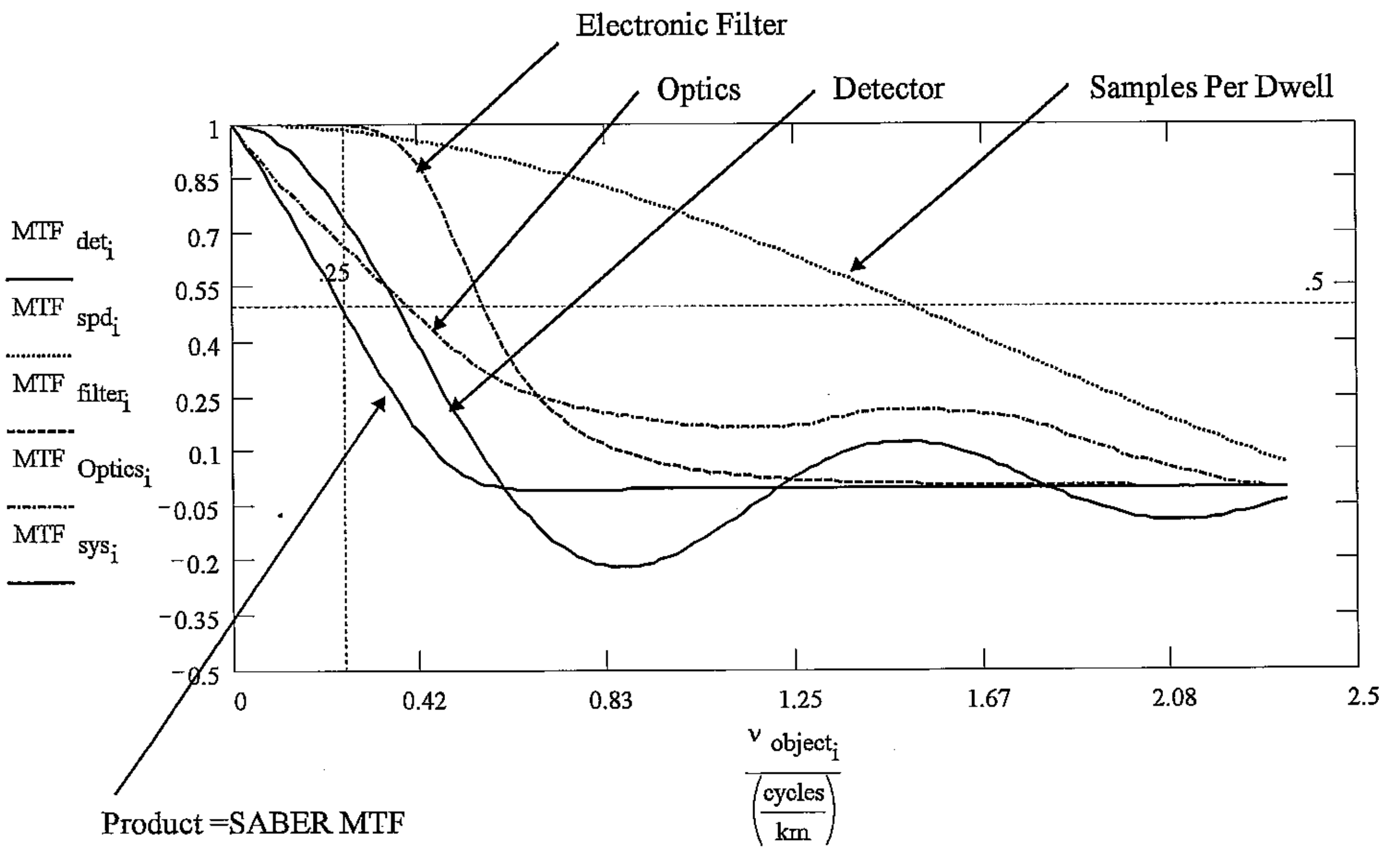
- **Design Principles**
  - Thickness of nickel coating minimized to reduce bimetallic effect
  - Mounts as compliant as 1 g sag and launch loads allow
    - Stress relief
    - Separate feet
    - Pin two feet
    - Mount bend rather than joints slip during cooling
  - Balance thickness of nickel on front and back surfaces of mirrors
  - Mirrors mount to interface plates lapped pad to lapped surface with no shim
  - Adjustment shims between interface plate and optical bench
- **Finite element analysis used to analyze bimetallic, bolting, and g loading effects**
- **Scan, primary and secondary mirrors are super polished mirrors**
  - Gold plated super polished nickel
- **Tertiary and quaternary mirrors are post polished diamond turned mirrors**
  - BRDF an order of magnitude greater than super polished mirrors
  - Larger BRDF does not significantly affect stray light
  - Nickel plated mirrors impractical because of small margin for edge bending around center

SABER IFOV AND MTF IN OBJECT SPACE

Channel	Species	FWHM (km)	MTF @ 0.25 cycles/km
1	CO_2 (N)	1.783	0.485
2	CO_2 (W)	1.776	0.489
3	CO_2 (W)	1.778	0.488
4	O_3	1.904	0.479
5	H_2O	1.884	0.535
6	NO	1.871	0.556
7	CO_2	1.858	0.576
8	OH (A)	1.837	0.604
9	OH (B)	1.835	0.602
10	O_2	1.833	0.615

Note: Includes diffraction from spider

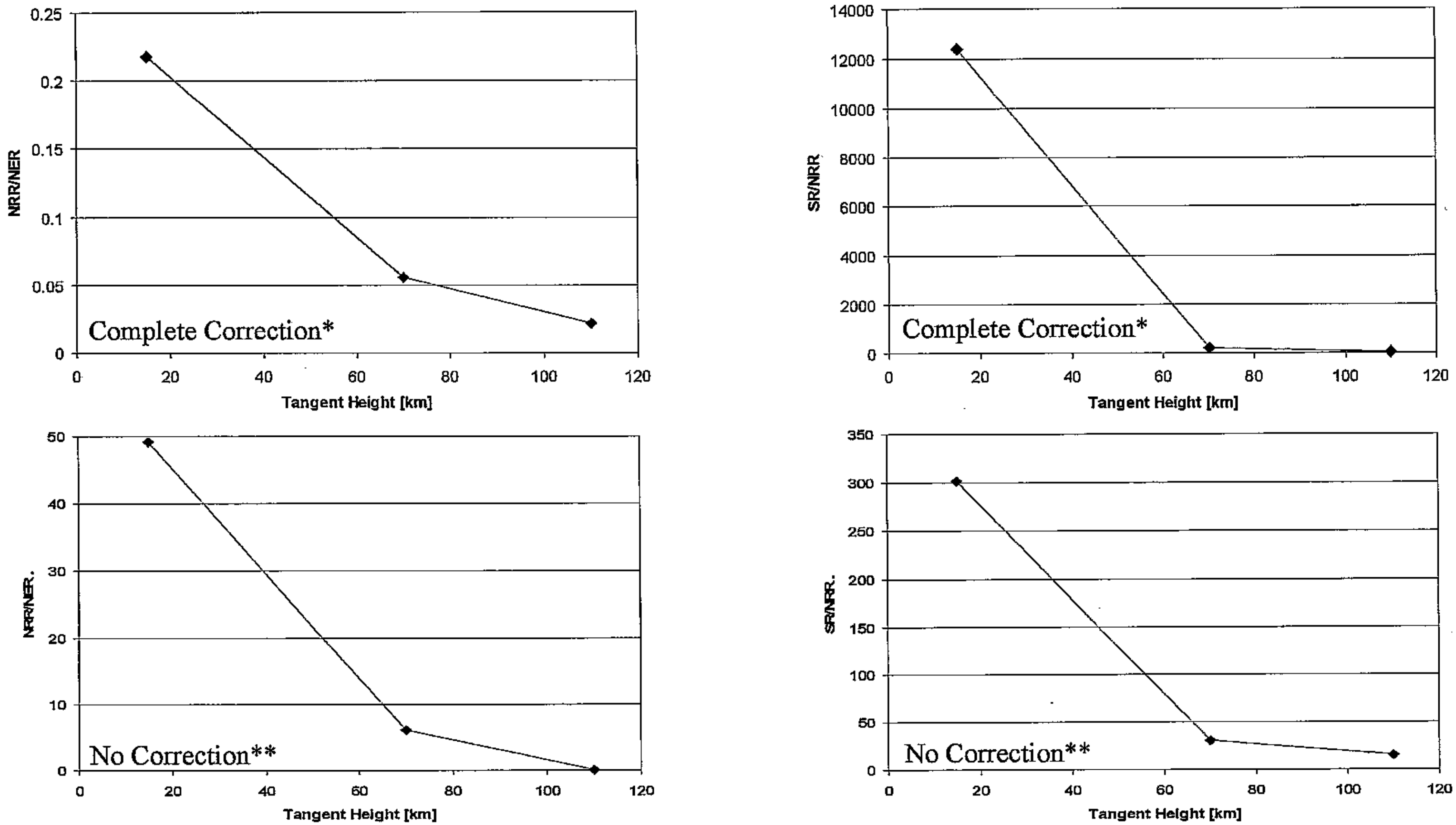
SABER CHANNEL 1 MODULATION TRANSFER FUNCTION



STRAY LIGHT PERFORMANCE OF CHANNEL 1 (CO_2 (N))

Normalized NRR

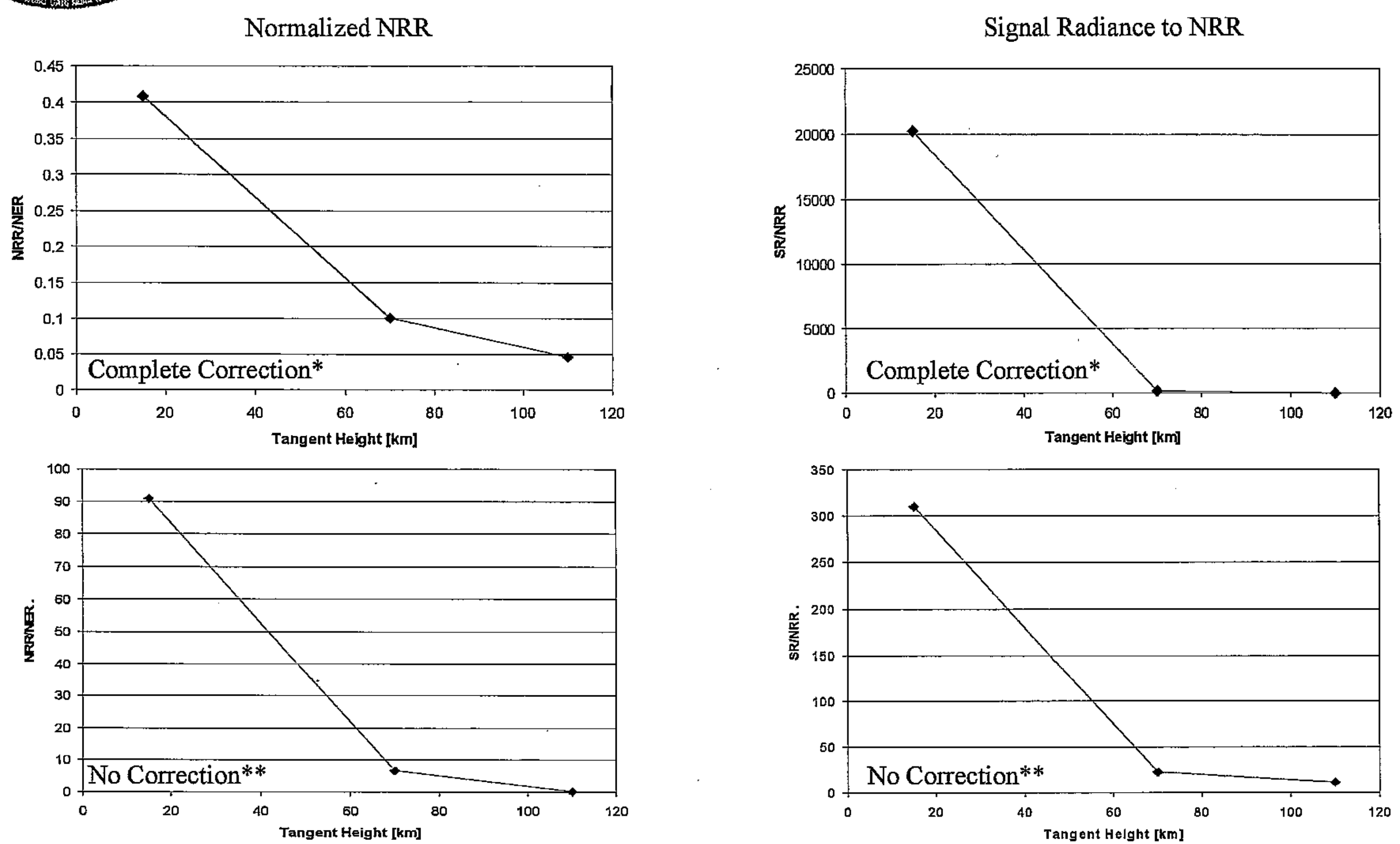
Signal Radiance to NRR



*Assumes data processing can totally correct for stray light from non-signal chopper holes

** Assumes no data processing correction for non-signal chopper holes

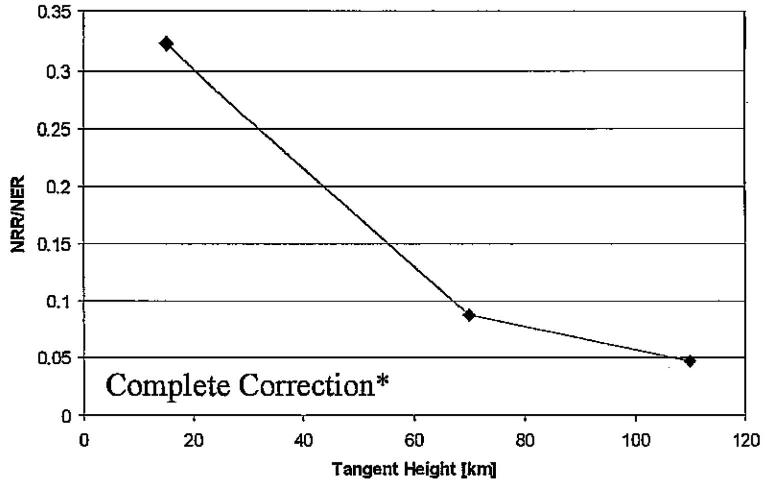
STRAY LIGHT PERFORMANCE OF CHANNEL 2 (CO_2 (W))



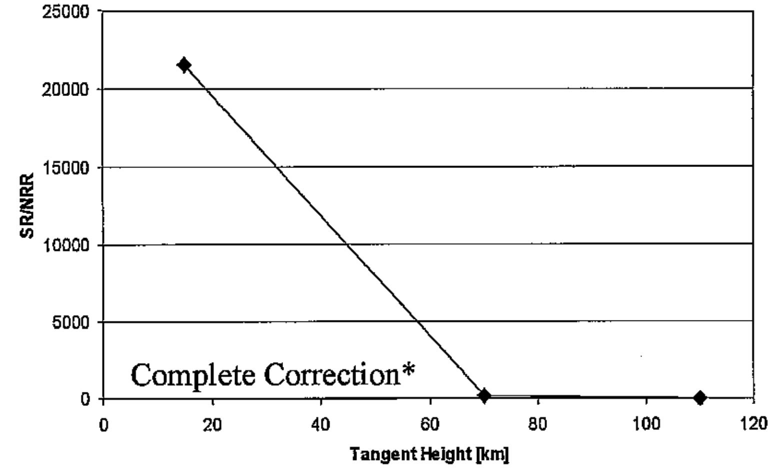
*Assumes data processing can totally correct for stray light from non-signal chopper holes
** Assumes no data processing correction for non-signal chopper holes

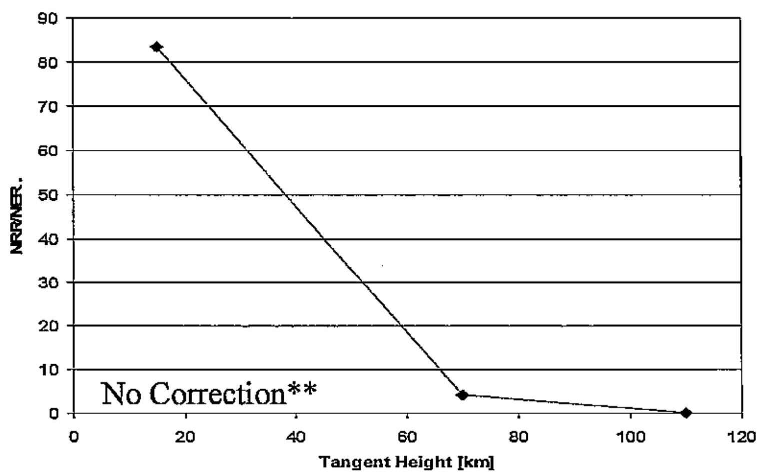
STRAY LIGHT PERFORMANCE OF CHANNEL 3 (CO_2 (W))

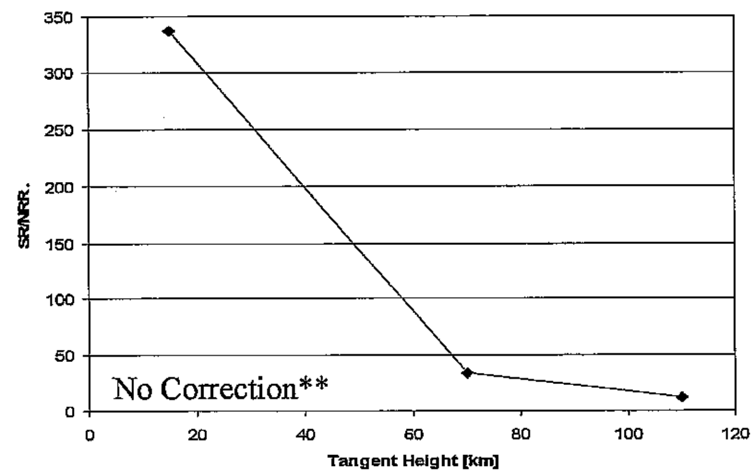
Normalized NRR



Signal Radiance to NRR





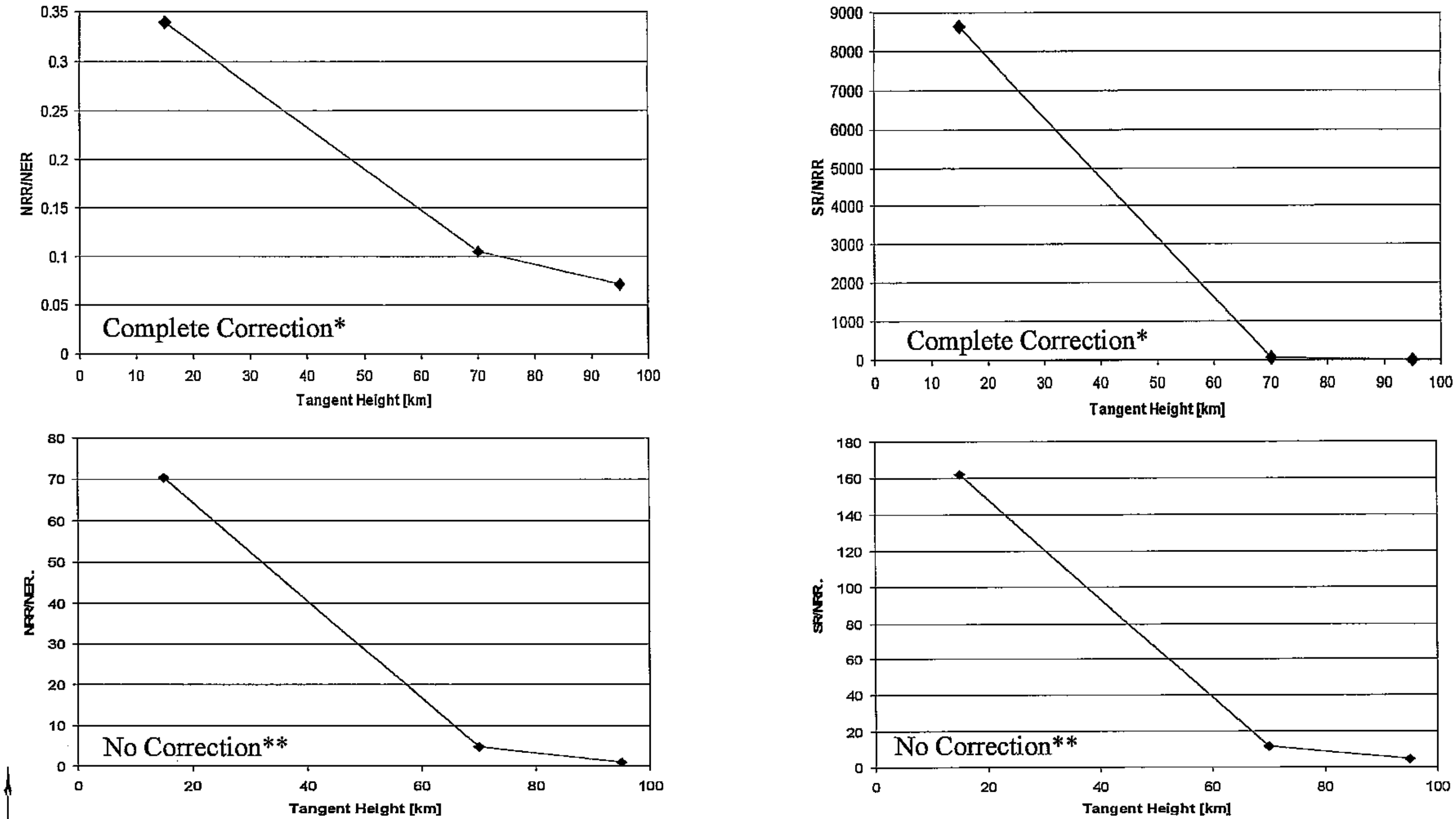


*Assumes data processing can totally correct for stray light from non-signal chopper holes
** Assumes no data processing correction for non-signal chopper holes

STRAY LIGHT PERFORMANCE OF CHANNEL 4 (O_3)

Normalized NRR

Signal Radiance to NRR

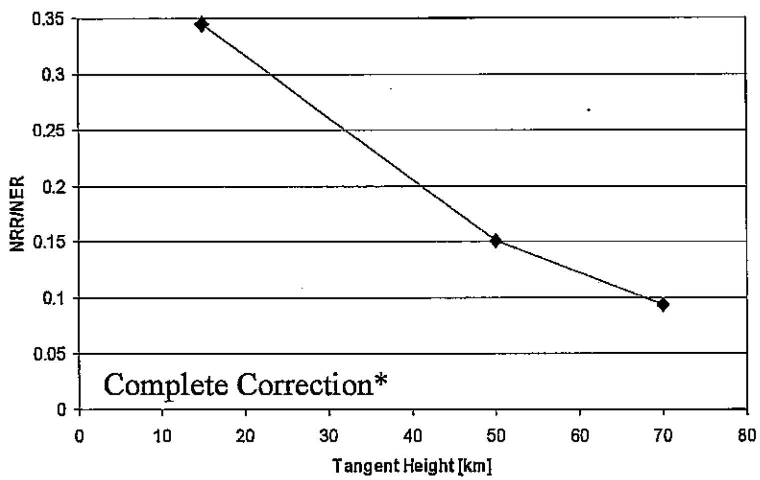


*Assumes data processing can totally correct for stray light from non-signal chopper holes

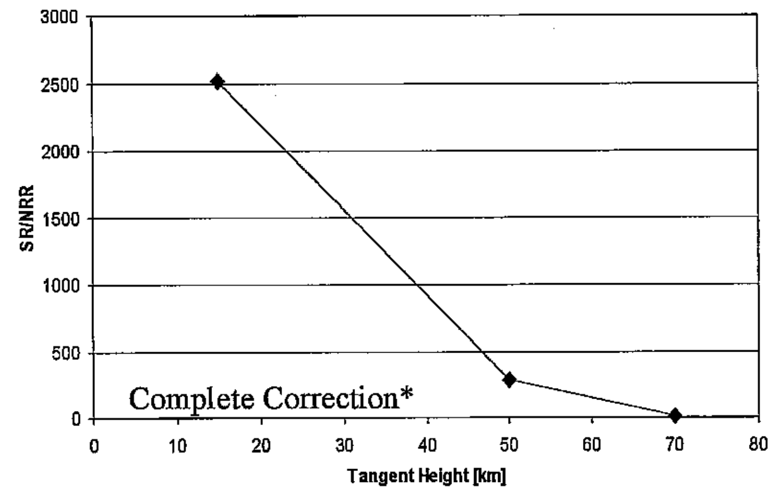
** Assumes no data processing correction for non-signal chopper holes

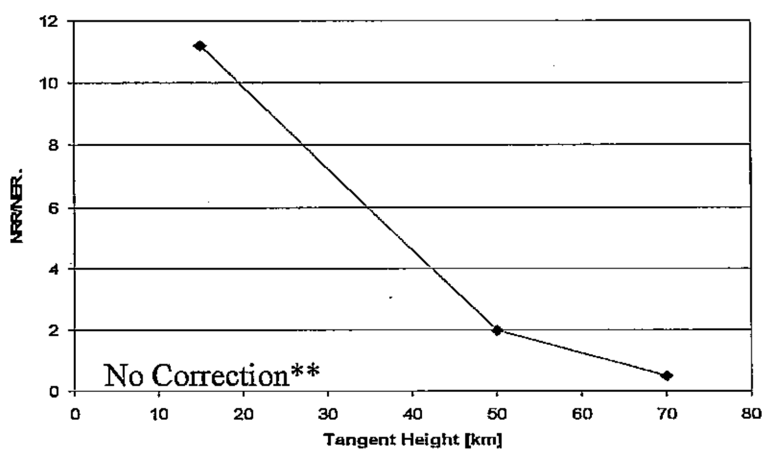
STRAY LIGHT PERFORMANCE OF CHANNEL 5 (H_2O)

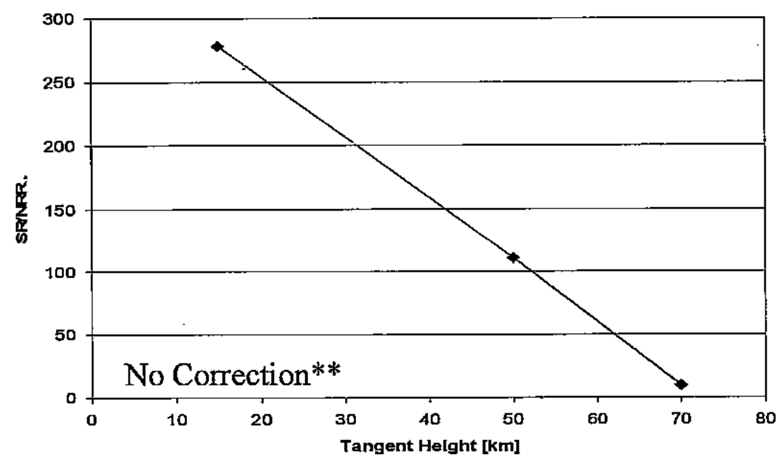
Normalized NRR



Signal Radiance to NRR



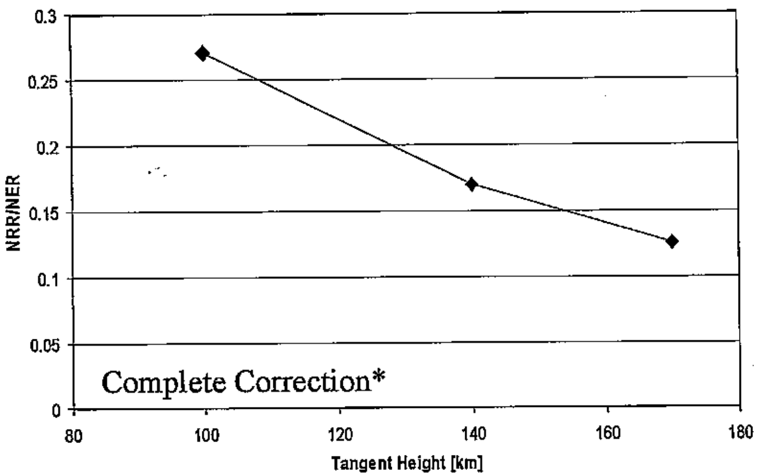




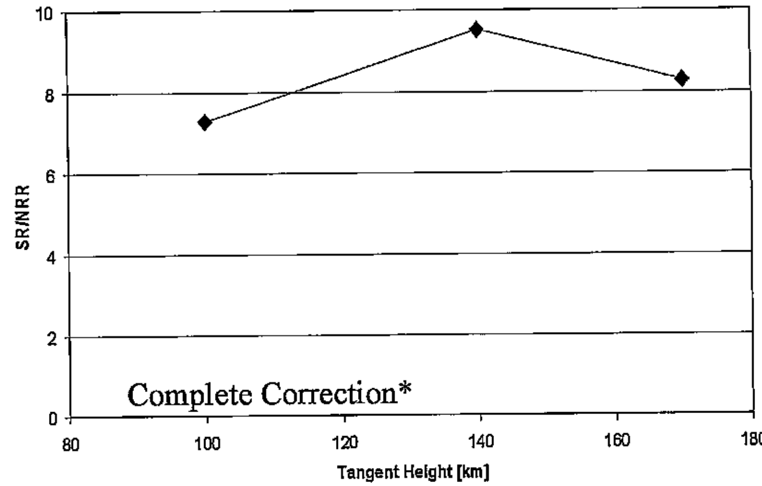
*Assumes data processing can totally correct for stray light from non-signal chopper holes
** Assumes no data processing correction for non-signal chopper holes

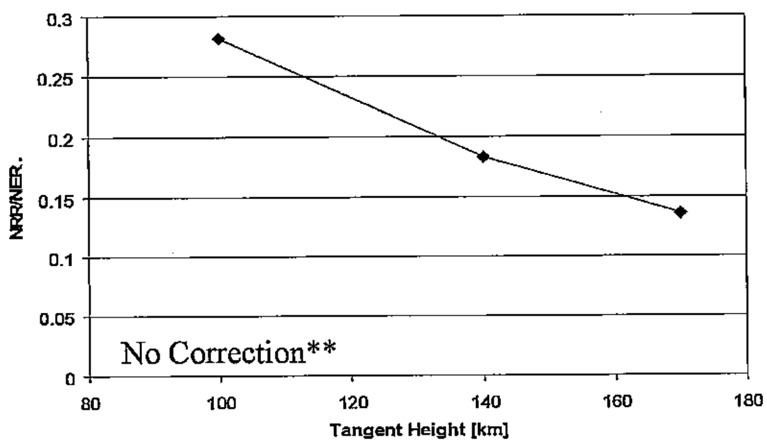
STRAY LIGHT PERFORMANCE OF CHANNEL 6 (NO)

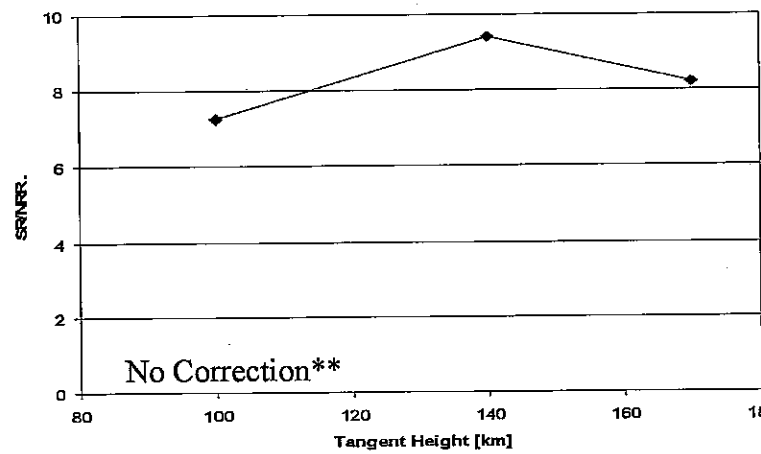
Normalized NRR



Signal Radiance to NRR



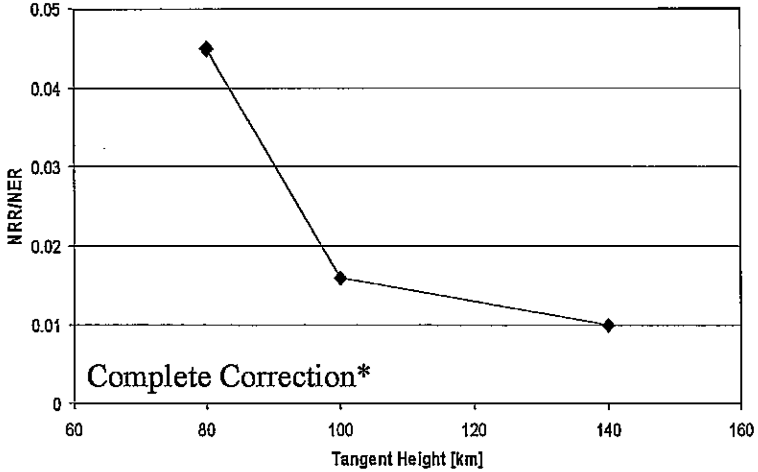


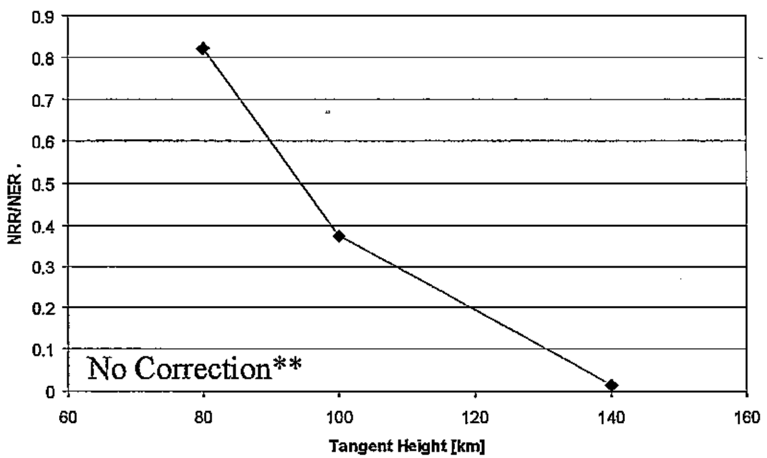


*Assumes data processing can totally correct for stray light from non-signal chopper holes
** Assumes no data processing correction for non-signal chopper holes

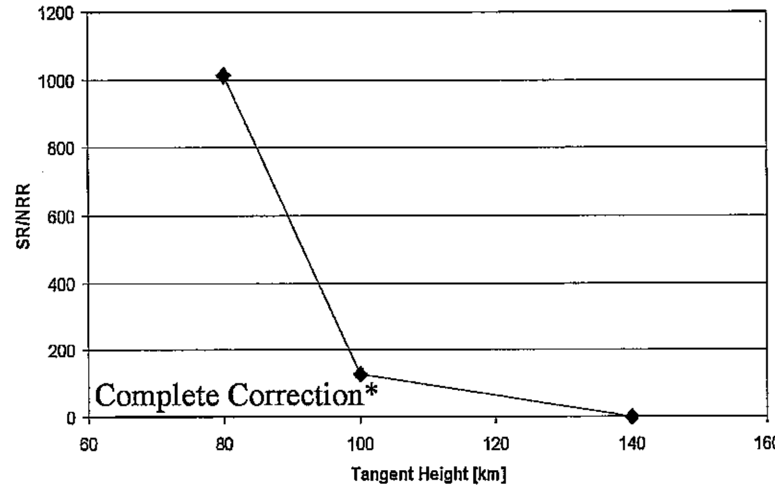
STRAY LIGHT PERFORMANCE OF CHANNEL 7 (CO_2-4.3) Day

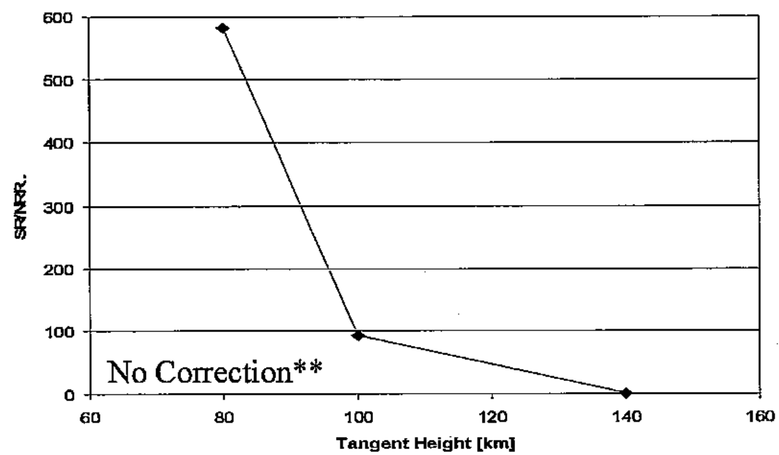
Normalized NRR





Signal Radiance to NRR





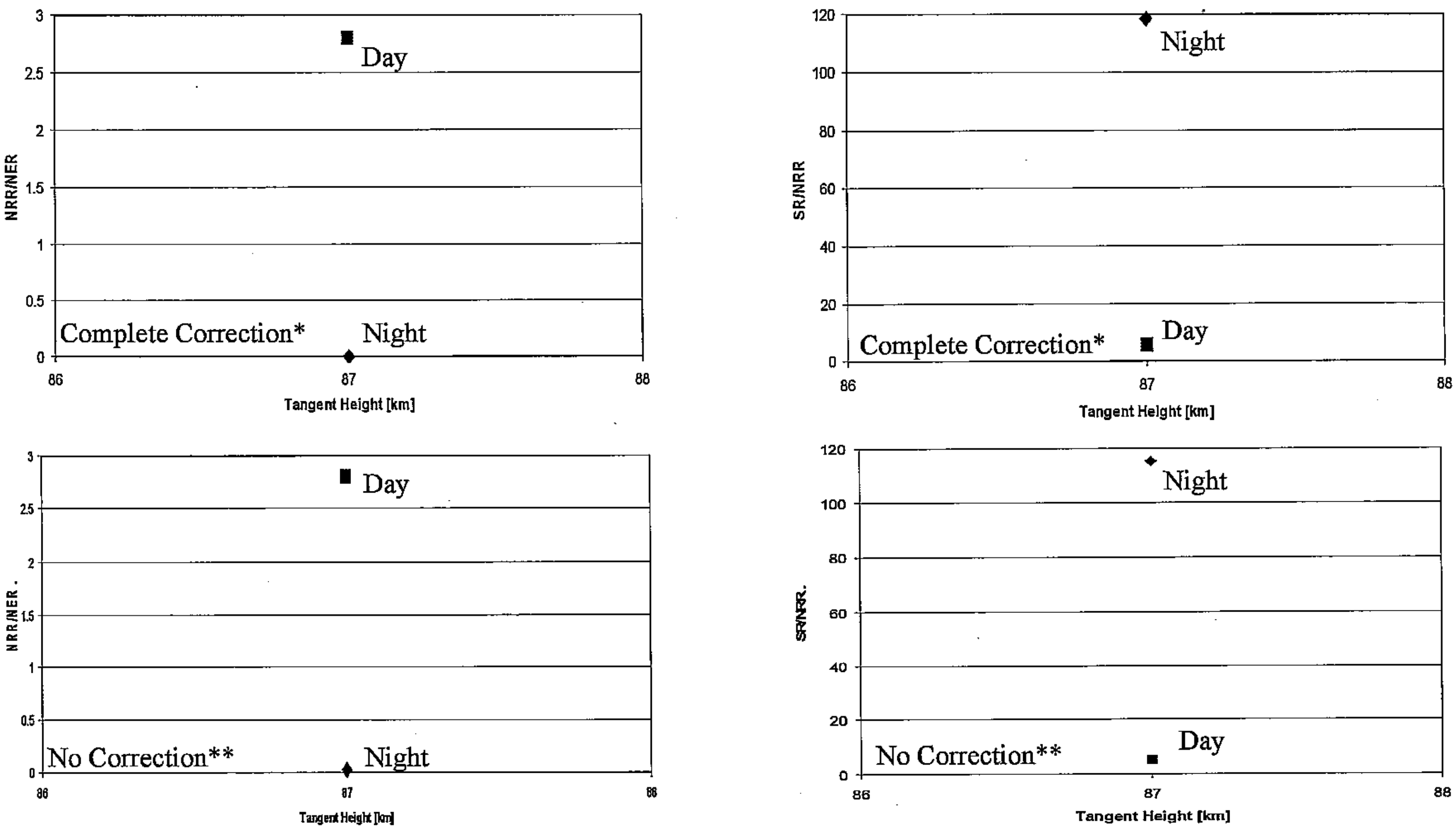
*Assumes data processing can totally correct for stray light from non-signal chopper holes

** Assumes no data processing correction for non-signal chopper holes

STRAY LIGHT PERFORMANCE OF CHANNEL 8 (OH (A))

Normalized NRR

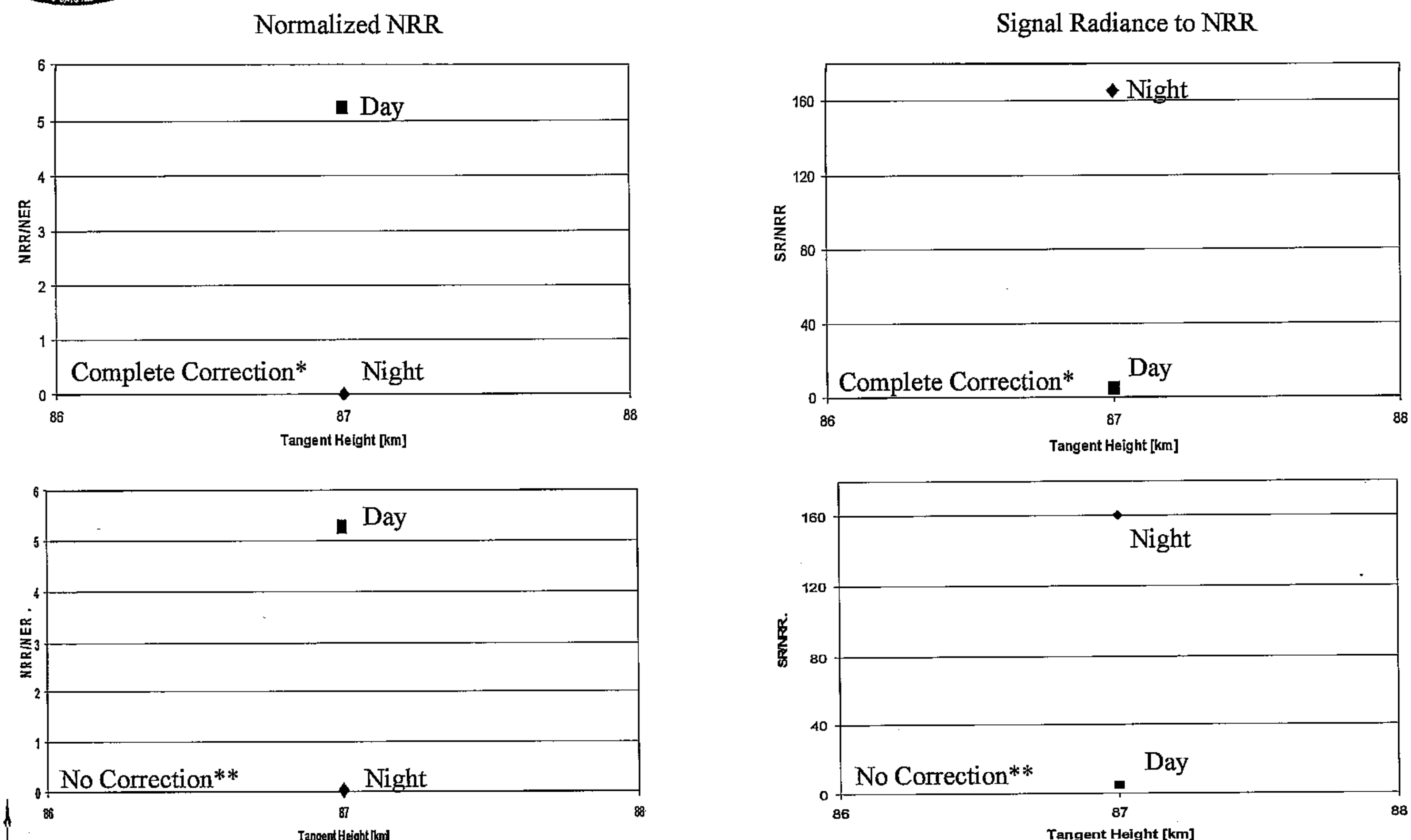
Signal Radiance to NRR



*Assumes data processing can totally correct for stray light from non-signal chopper holes

** Assumes no data processing correction for non-signal chopper holes

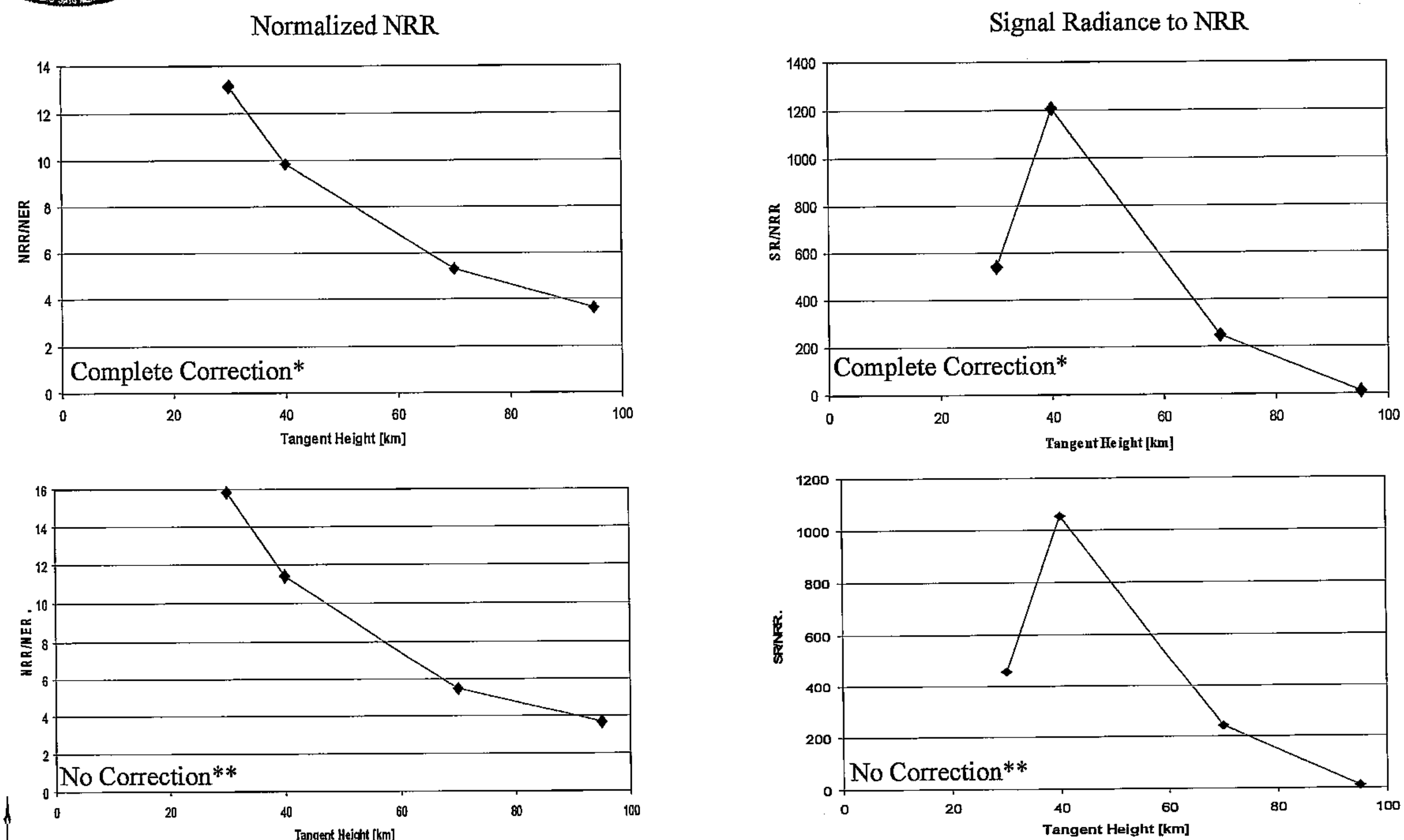
STRAY LIGHT PERFORMANCE OF CHANNEL 9 (OH(B))



*Assumes data processing can totally correct for stray light from non-signal chopper holes

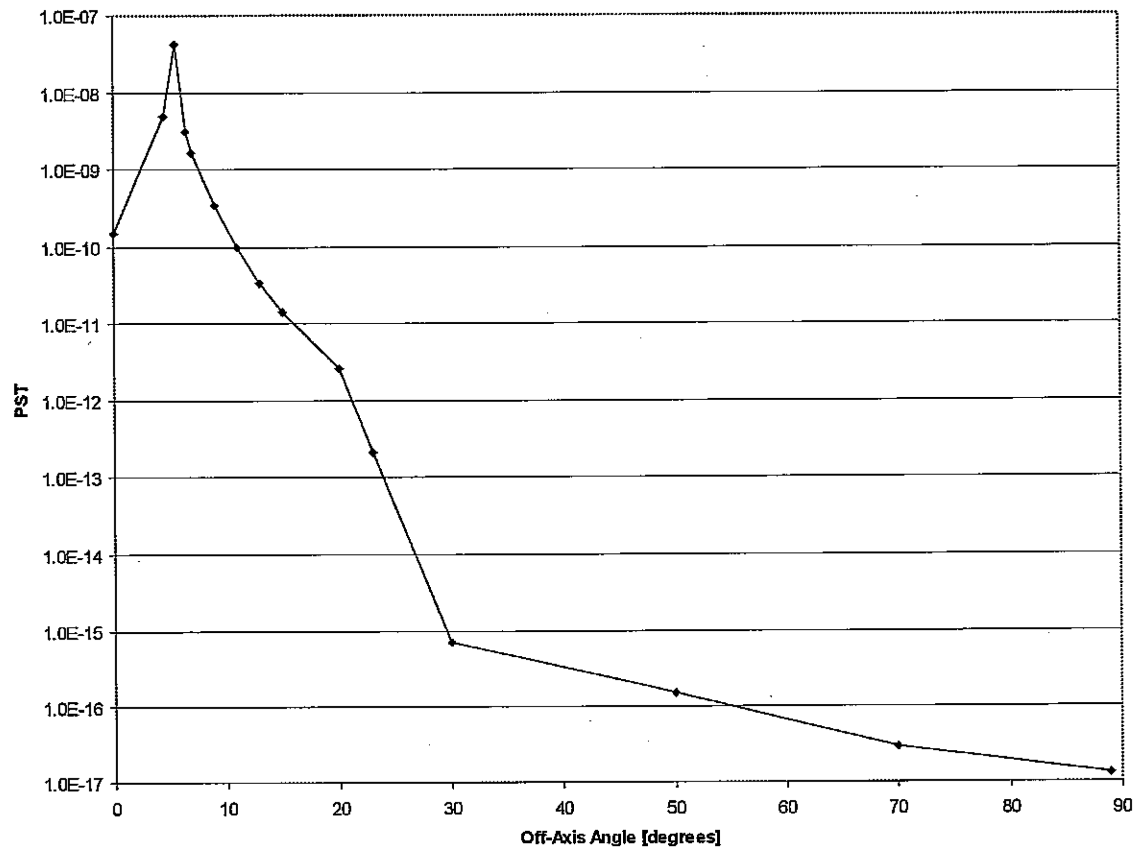
** Assumes no data processing correction for non-signal chopper holes

STRAY LIGHT PERFORMANCE OF CHANNEL 10 (O_2) Day

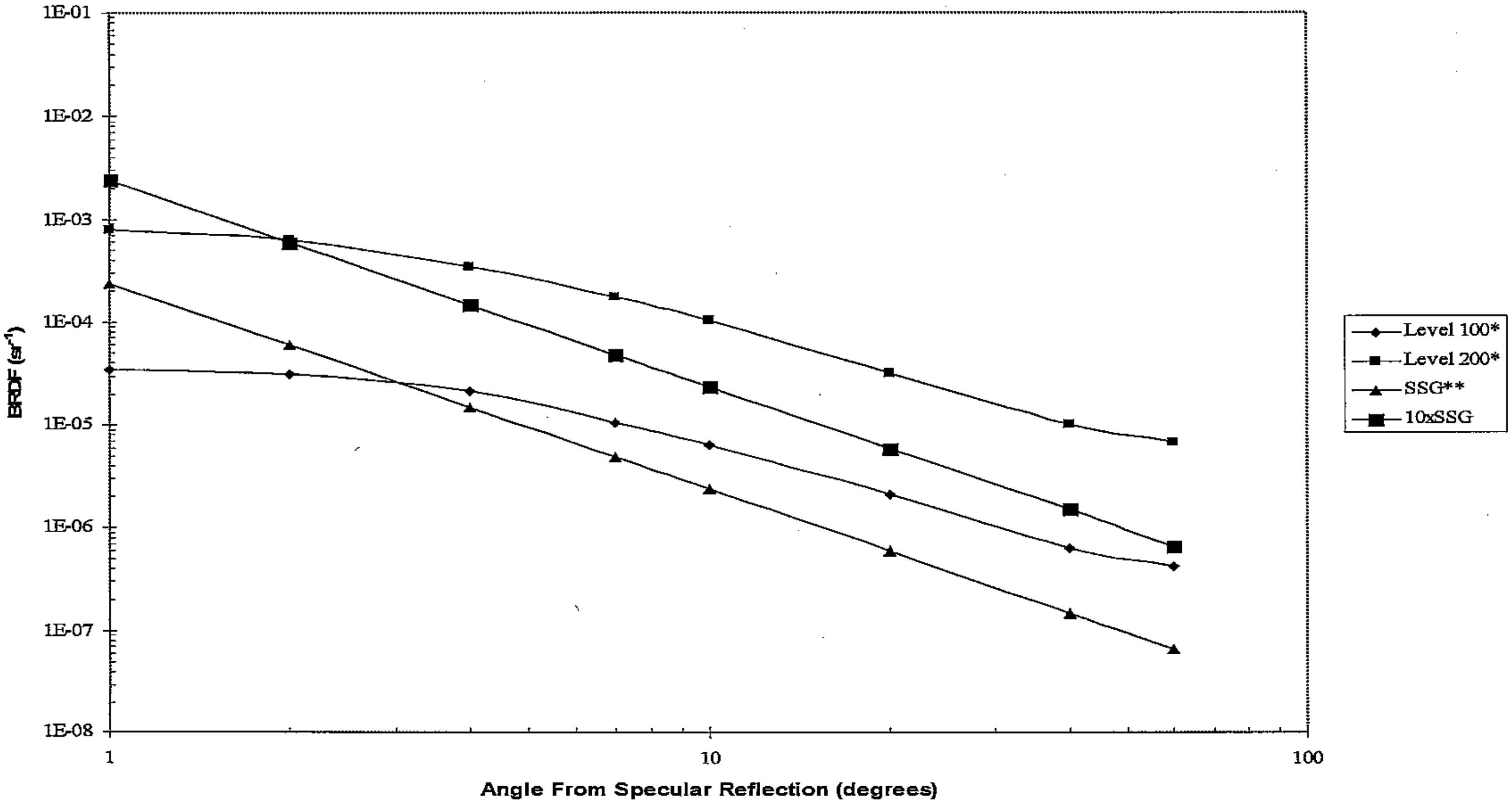


*Assumes data processing can totally correct for stray light from non-signal chopper holes
** Assumes no data processing correction for non-signal chopper holes

POINT SOURCE TRANSMISSION (PST) CURVE
CHANNEL 1 (CO_2 (N)), TANGENT HEIGHT 70 km, 625 km ORBIT

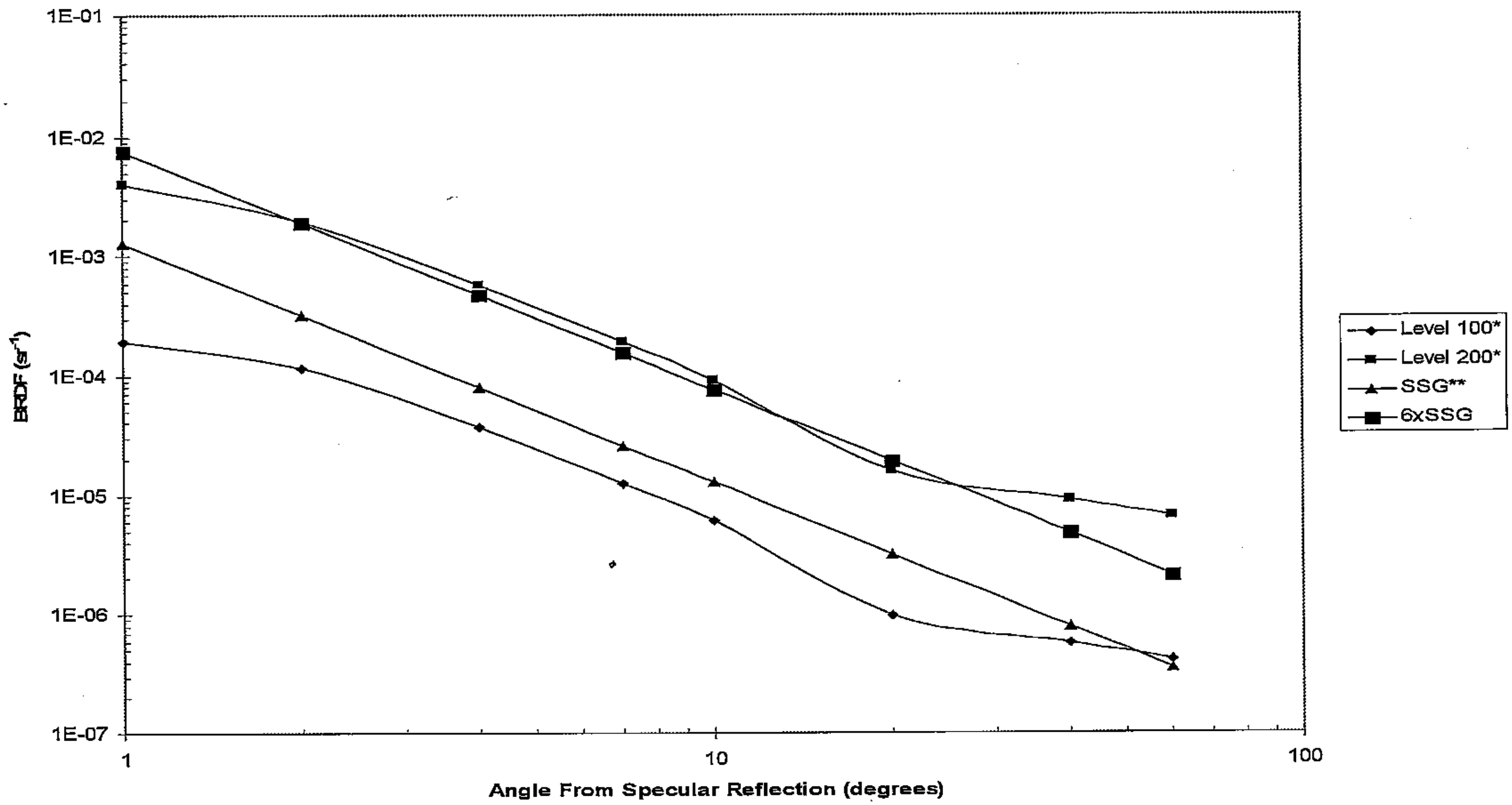


MIRROR BRDF AT 10.6 mm



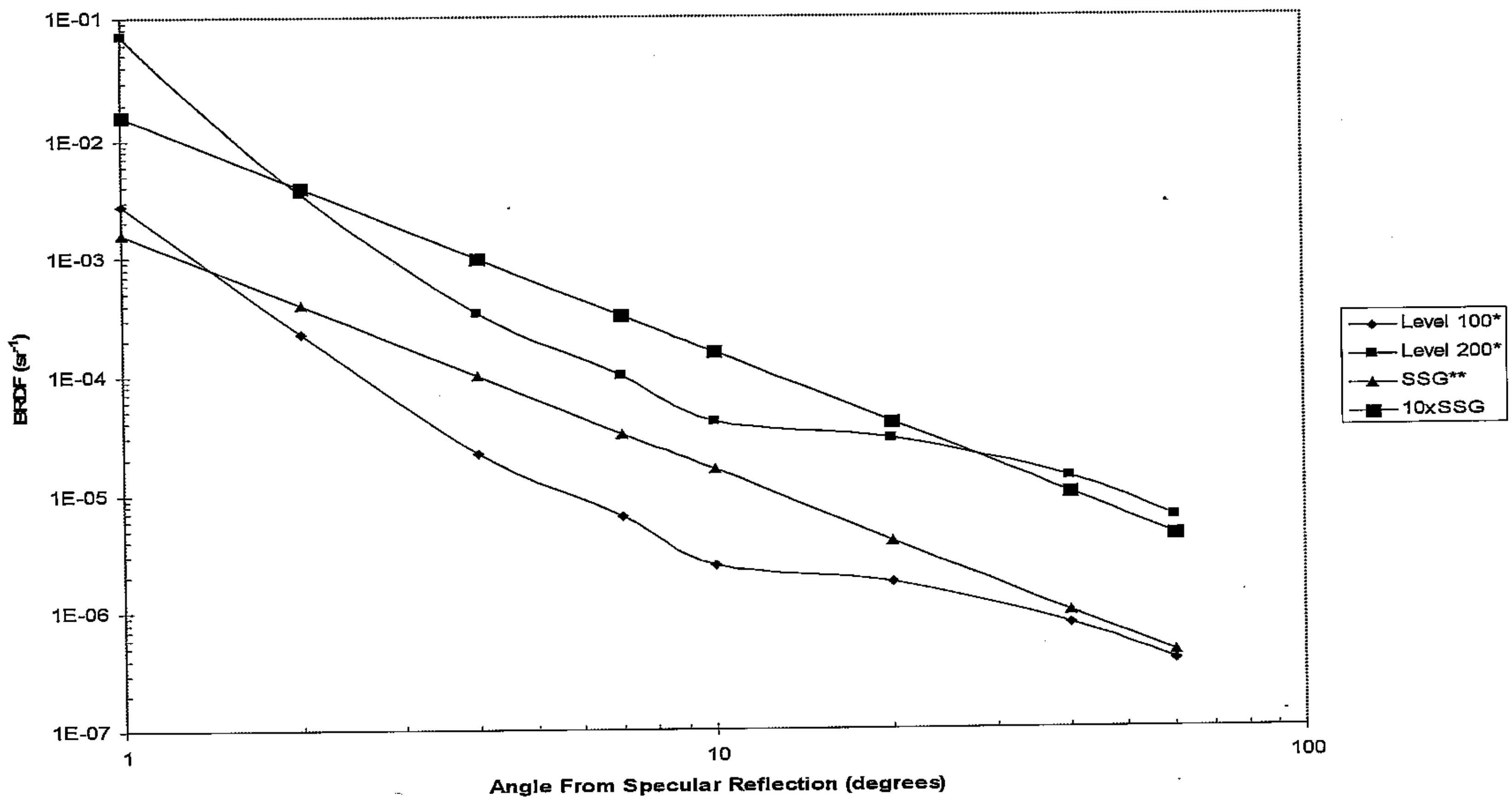
*Spyak and Wolf, Optical Engineering Vol. 31, p 1746 - 1784, (1992)
**SSG measured data of pristine mirror

MIRROR BRDF AT 3.39 μm



*Spyak and Wolf, Optical Engineering Vol. 31, p 1746 - 1784, (1992)
**SSG measured data of pristine mirror

MIRROR BRDF AT 0.633 μm



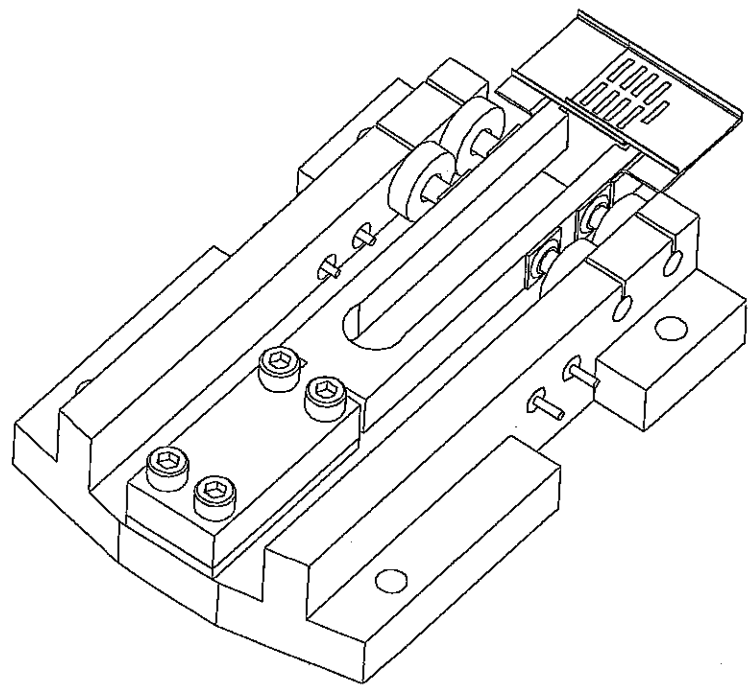
*Spyak and Wolf, Optical Engineering Vol. 31, p 1746 - 1784, (1992)
**SSG measured data of pristine mirror

TRIPLE DIFFRACTION STRAY LIGHT PATH

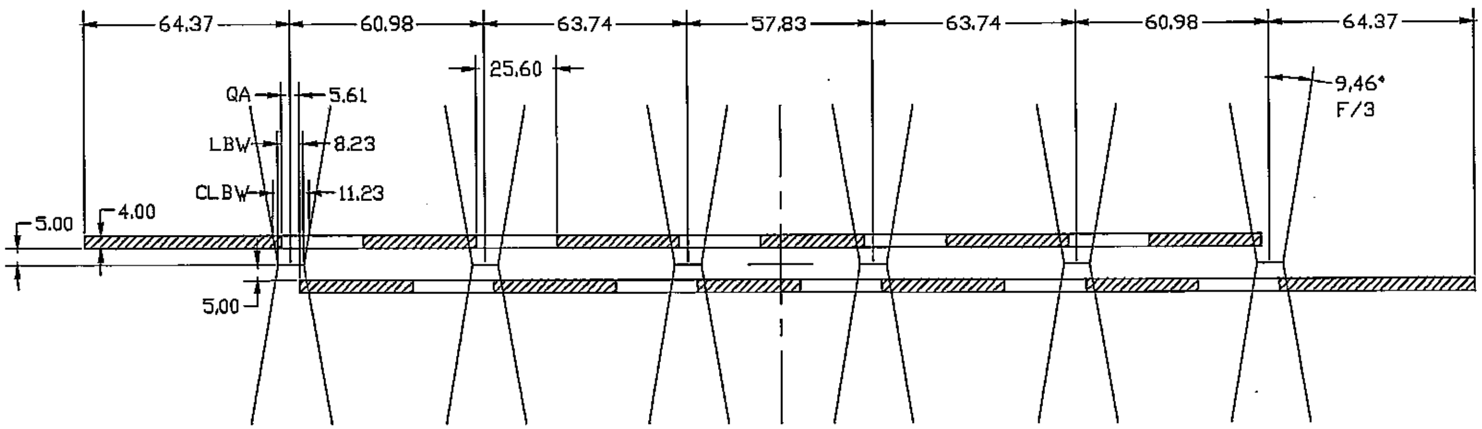
- **Stray light modeling results do not include triple diffraction path because analysis results to date have been inconsistent**
- **Triple diffraction path consists of three segments**
  - 1) Light is diffracted at aperture stop in front of primary mirror
  - 2) Light is diffracted again by chopper holes
  - 3) Light is diffracted a second time at Lyot stop and spread across focal plane
- **This path not unique to on-axis designs**
- **Effect largest for long wavelength channels**
- **Because modeled double diffraction was insignificant, SDL did not attempt to analyze triple diffraction until recently**
  - Triple diffraction modeling results inconsistent
  - Modeling results discussed with stray light experts at SSG and Breault Research Organization (BRO)
  - BRO is checking SDL's model and APART program
  - SDL will continue efforts to get trustworthy analysis of this path
  - Stray light testing of telescope with 10.6 μm laser recommended

CHOPPER

- Tuning fork chopper
- 10-aperture shutter design
- Moving magnet electrodynamic balanced drive and pickup
- Hi Q NiSpan C tuning fork
- 6061 aluminum base
- Shutters half hard stainless
- Shutters gold plated both sides
- Shutters spot welded to brackets
- Bracket spot welded to tines
- Shutters and brackets formed and optimized for low mass and high rigidity
- Frequency
  - Nominal: 1000 ± 0.5 Hz
  - Temperature Variation: ≤ ± 0.2 Hz
  - Long Term Variation: ≤ ± 0.2 Hz
- Peak motion of each shutter
  - Nominal: 0.012 inches
  - Maximum: 0.015 inches

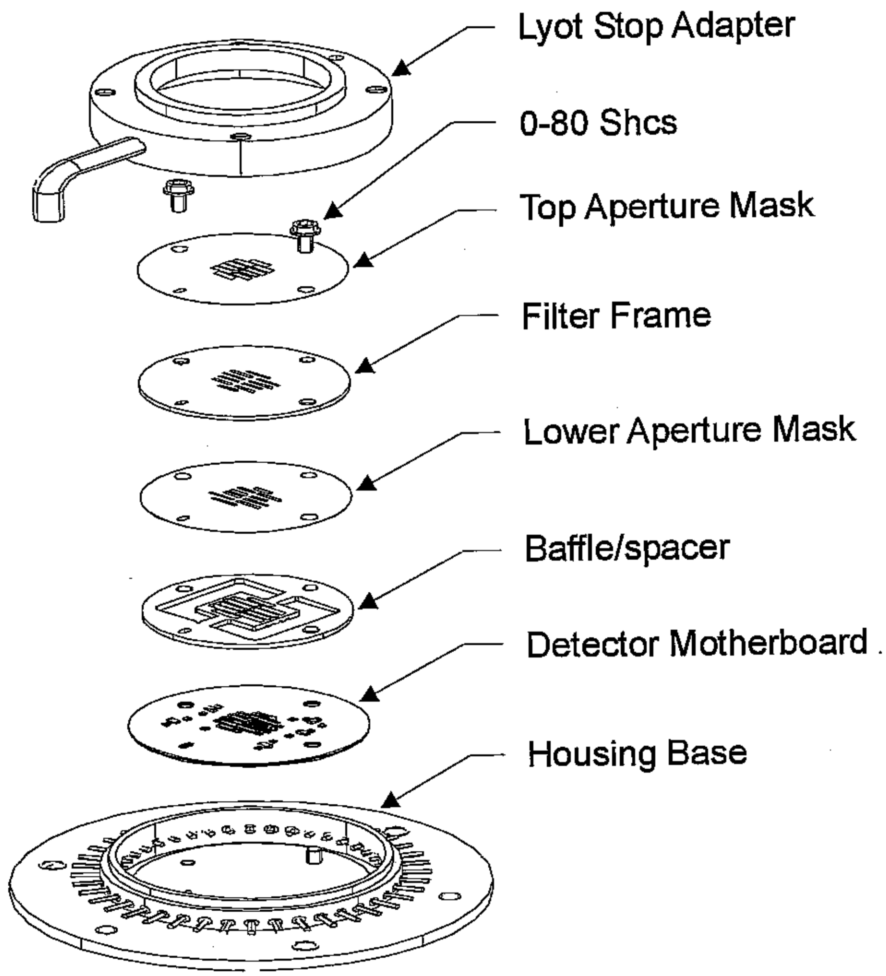


CHOPPER SHUTTERS DIMENSIONS

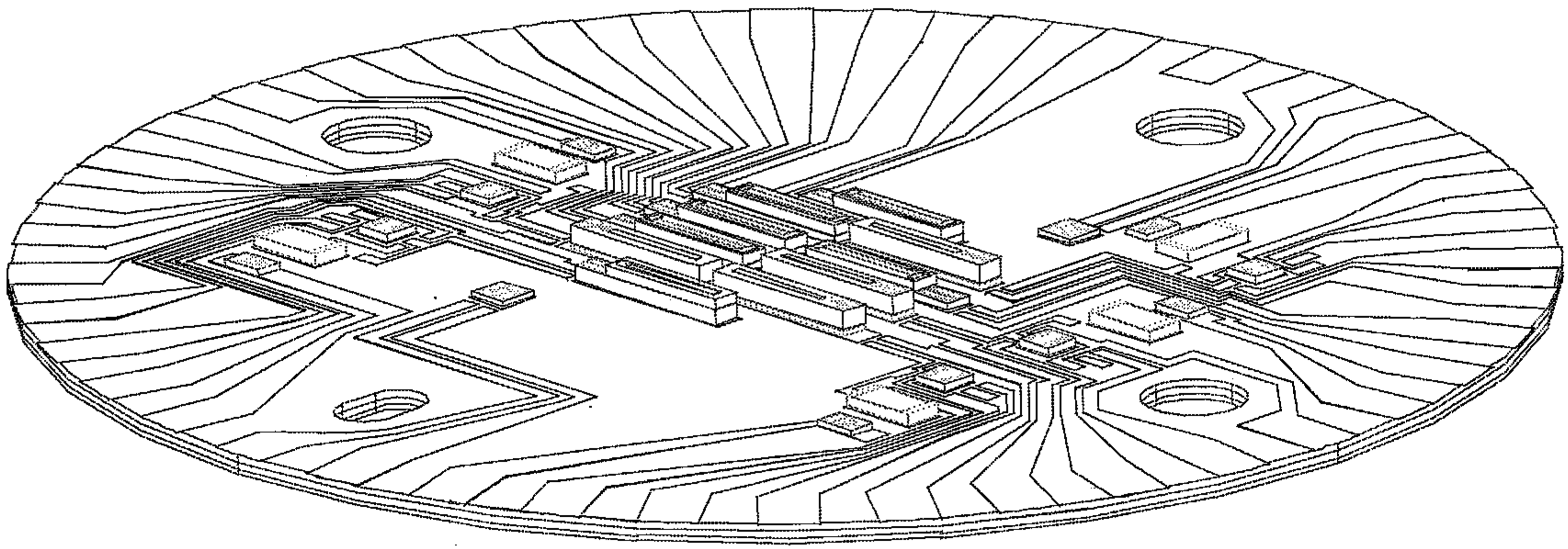


Dimensions in mills

DETECTOR/FILTER ASSEMBLY



DETECTOR MOTHERBOARD

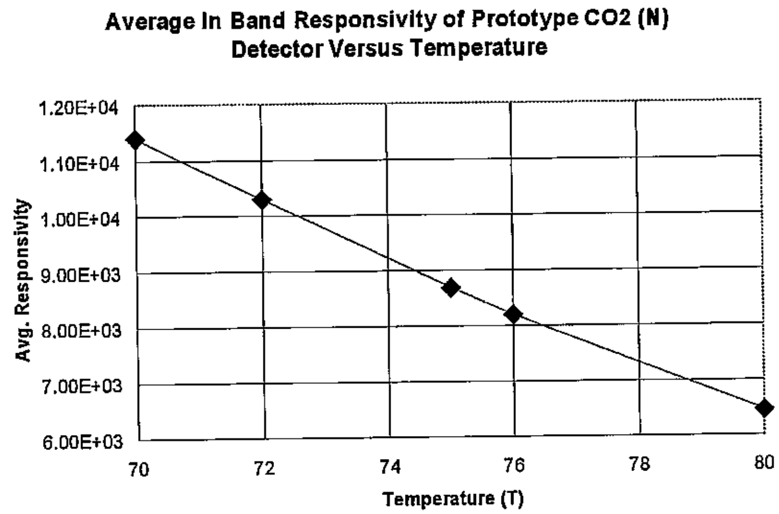


DETECTOR PARAMETER SUMMARY

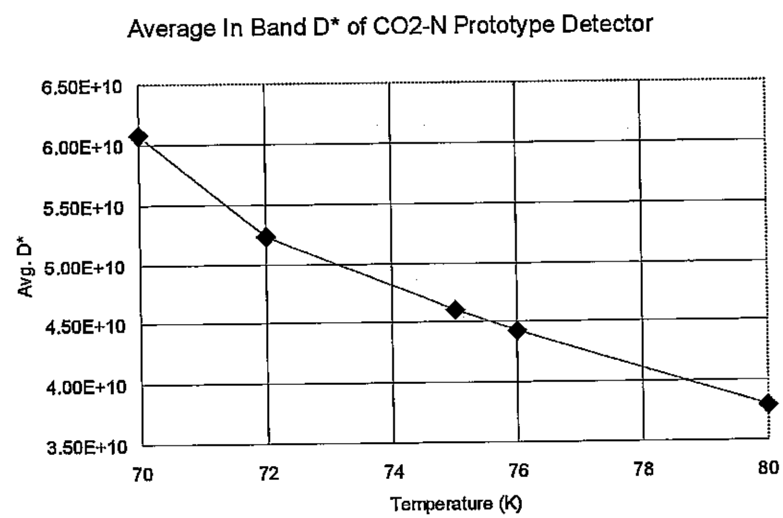
Ch	Species	Type	Material	Width (mm)	FPA Dissipation (mW)	D* ($cmHz^{1/2}W^{-1}$)	Responsivity
1	CO_2 (N)	PC	HgCdTe	0.120	3	9.52E10	1.04E4 V/W
2	CO_2 (W)	PC	HgCdTe	0.120	3	7.28E10	1.16E4 V/W
3	CO_2 (W)	PC	HgCdTe	0.120	3	7.28E10	1.16E4 V/W
4	O_3	PC	HgCdTe	0.140	10	3.84E11	1.79E4 V/W
5	H_2O	PC	HgCdTe	0.140	10	6.02E11	3.75E4 V/W
6	NO	PV	InSb	0.140	3	7.70E12	3.47 A/W
7	CO_2 (B)	PV	InSb	0.140	3	9.08E12	2.75 A/W
8	OH (A)	PV	InSb	0.140	3	4.04E12	1.24 A/W
9	OH (A)	PV	InSb	0.140	3	3.09E12	0.98 A/W
10	O_2	PV	InGaAs	0.140	3	3.35E12	0.82 A/W

HgCdTe DETECTOR RESPONSIVITY AND D* VARIATION WITH FOCAL PLANE TEMPERATURE

- **Responsivity variation with FPA temperature**
  - Responsivity variation of prototype CO_2 (N) detector at 2 mA bias measured -5.7%/K
  - Responsivity variation between space looks is 0.05% using
    - 0.008 K/min detector temperature variation
    - 66 seconds between space looks



- **D* variation with FPA temperature**
  - SABER signal-to-noise ratio (SNR) is directly proportional to D*
  - NER is inversely proportional to detector D*
  - D* of prototype CO_2 (N) detector D* variation measured -30%/K

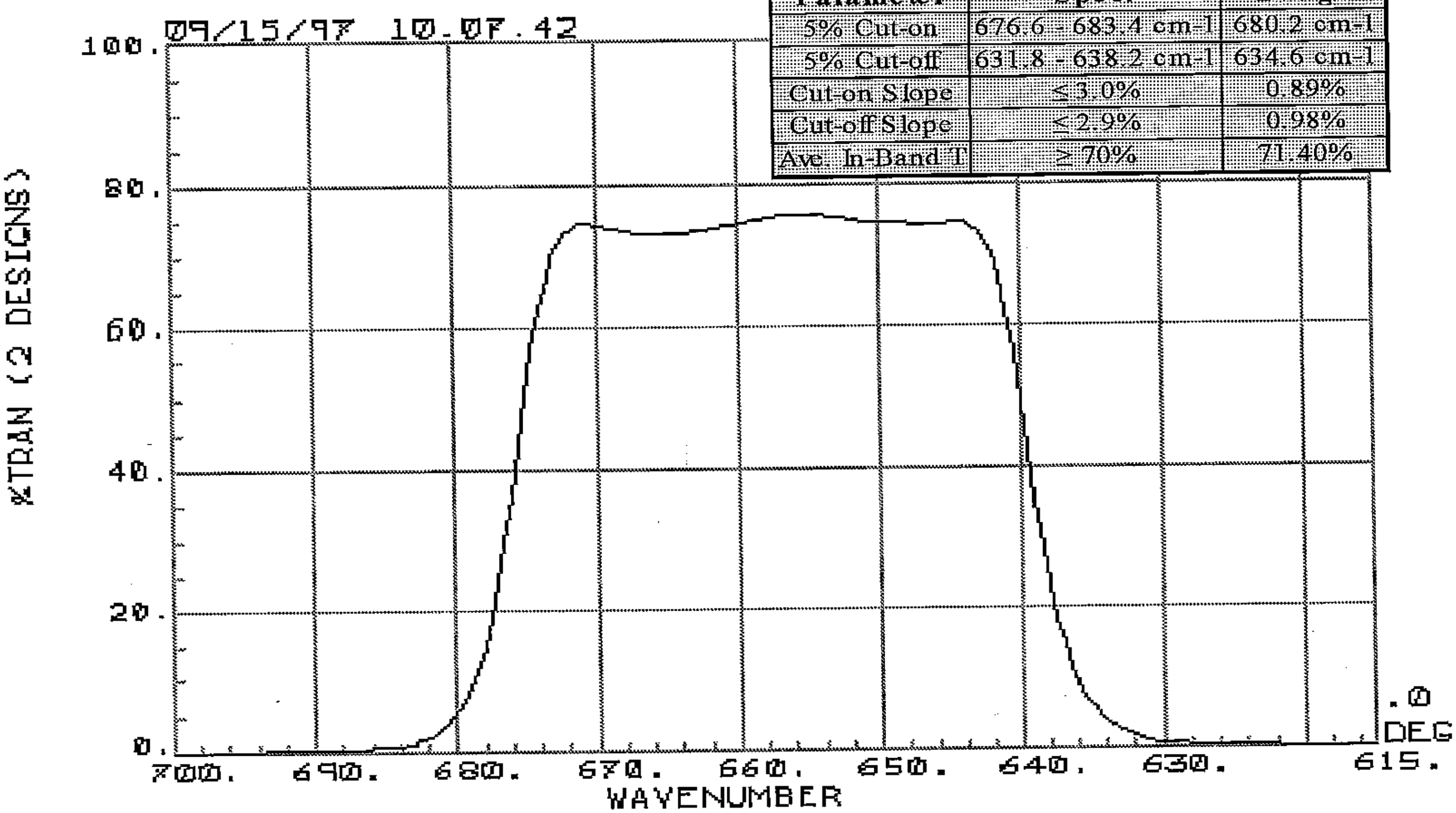


FILTER AVERAGE IN-BAND TRANSMISSION USED IN RADIOMETRIC MODEL

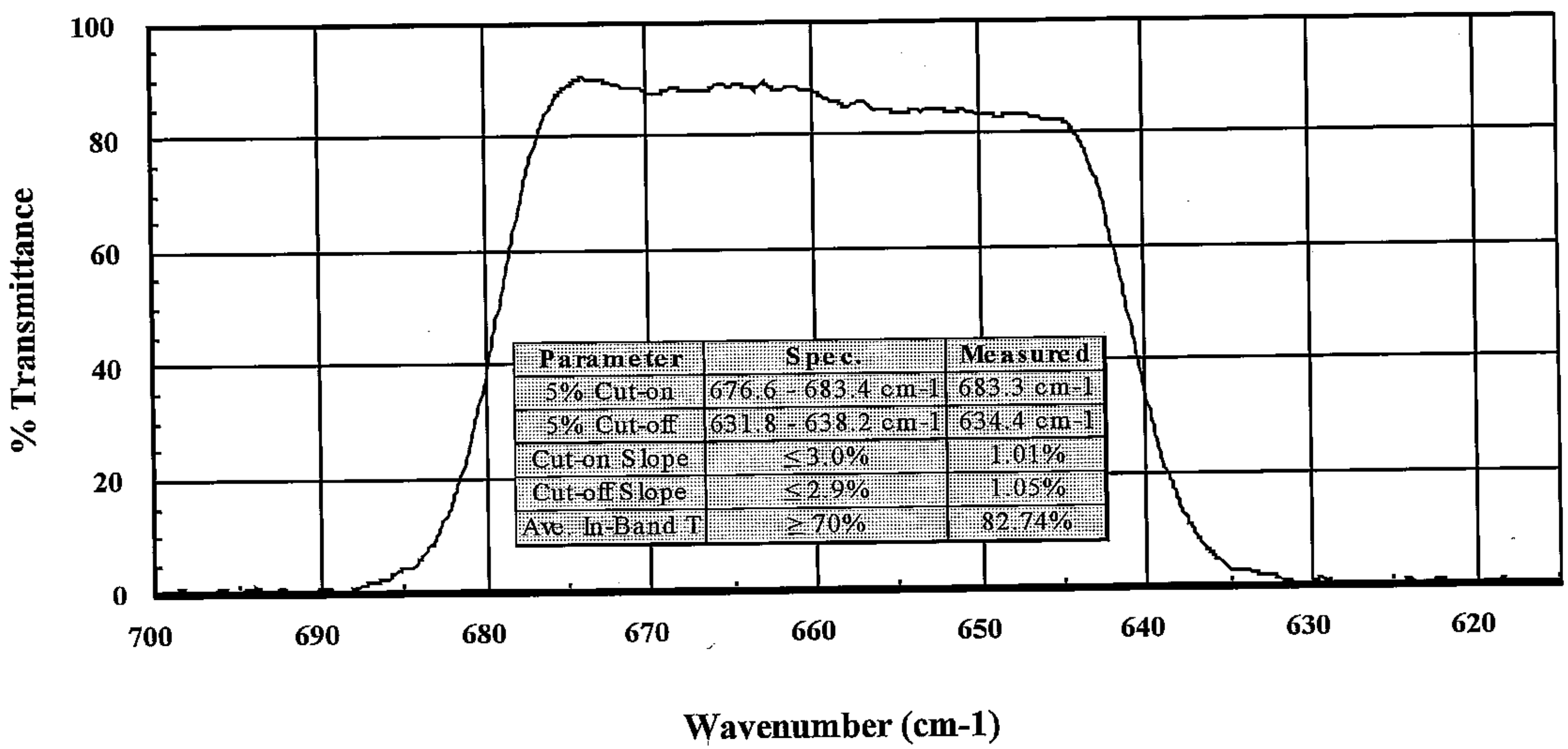
Channel	Transmission (%)	Basis For Use
1	82.7	Measured
2	83.4	Design
3	83.4	Design
4	78.5	Design
5	75.9	Design
6	78.3	Design
7	82.8	Design
8	80.0	Measured 83.7% but redesign that has more blocking for use with InSb detector has 79.5%
9	80.4	Design
10	70.4	Design

THEORETICAL IN-BAND TRANSMISSION OF ORIGINAL CHANNEL 1 FILTER f/2 AT NORMAL INCIDENCE

Parameter	Spec.	Design
5% Cut-on	676.6 - 683.4 cm-1	680.2 cm-1
5% Cut-off	631.8 - 638.2 cm-1	634.6 cm-1
Cut-on Slope	≤ 3.0%	0.89%
Cut-off Slope	≤ 2.9%	0.98%
Ave. In-Band T	≥ 70%	71.40%

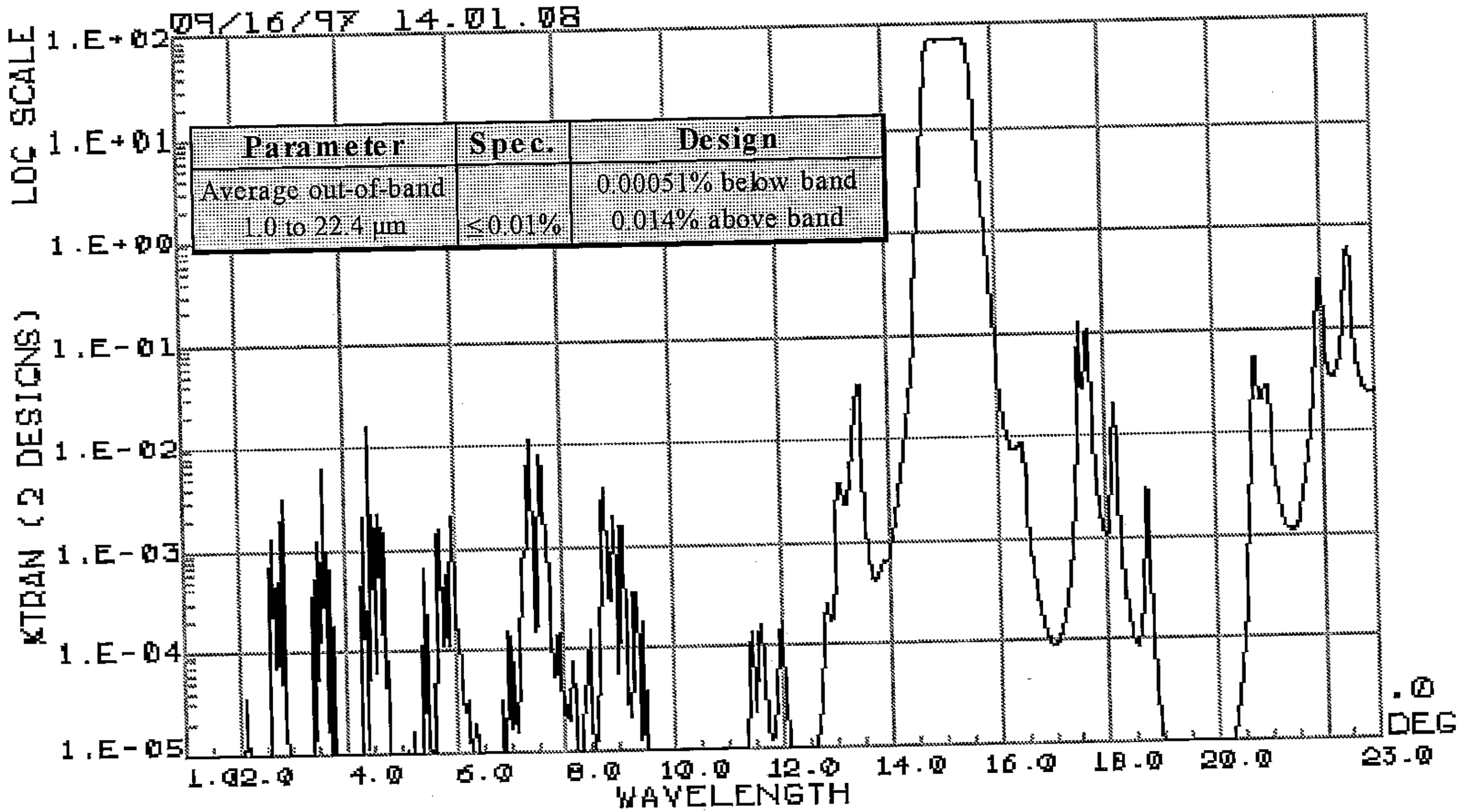


MEASURED IN-BAND TRANSMISSION OF ORIGINAL CHANNEL 1 FILTER f/2 AT NORMAL INCIDENCE, 75K



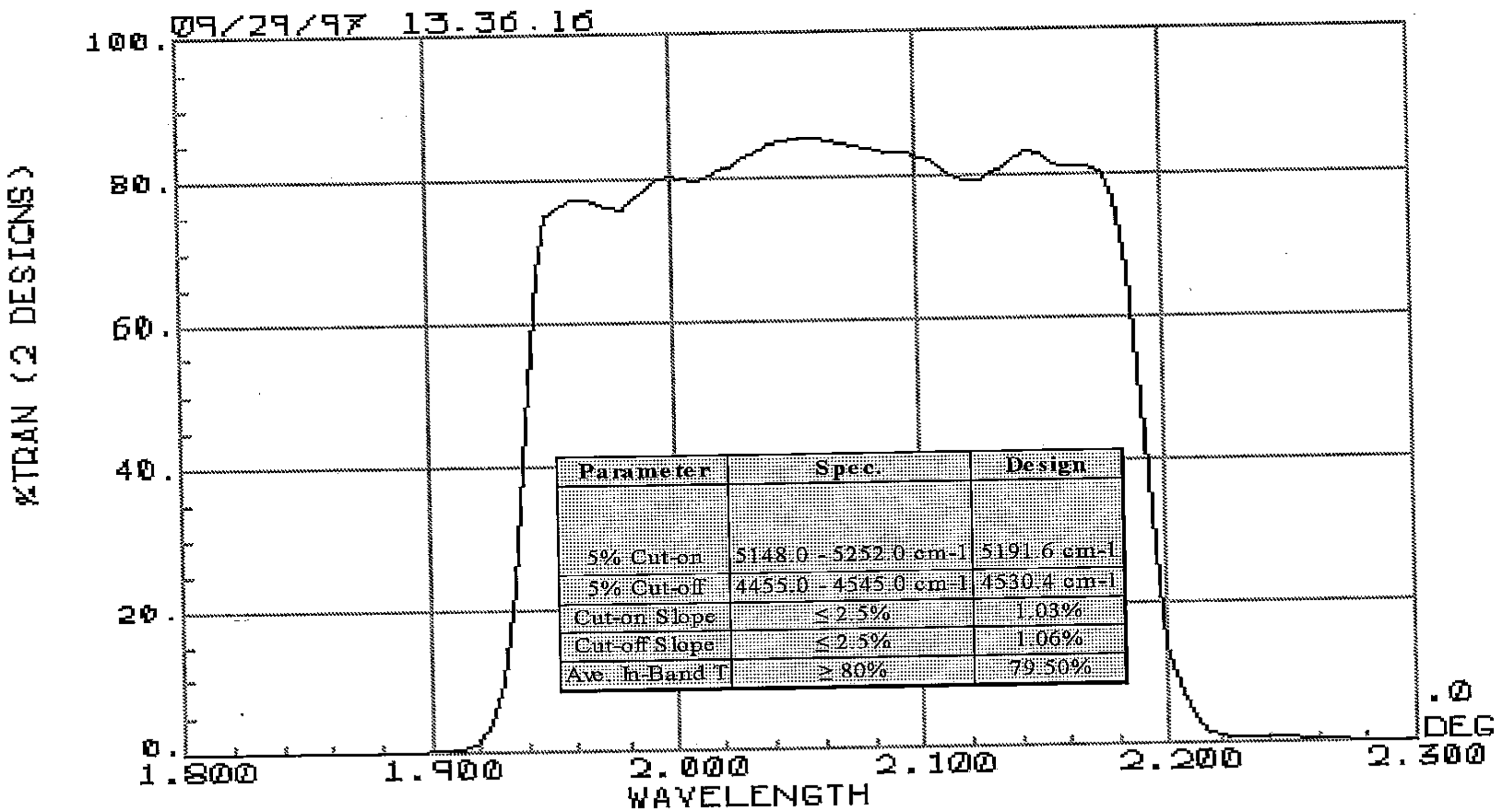
Parameter	Spec.	Measured
5% Cut-on	676.6 - 683.4 cm-1	683.3 cm-1
5% Cut-off	631.8 - 638.2 cm-1	634.4 cm-1
Cut-on Slope	≤ 3.0%	1.01%
Cut-off Slope	≤ 2.9%	1.05%
Ave. In-Band T	≥ 70%	82.74%

THEORETICAL OUT-OF-BAND TRANSMISSION OF ORIGINAL CHANNEL 1 FILTER f/2 AT NORMAL INCIDENCE



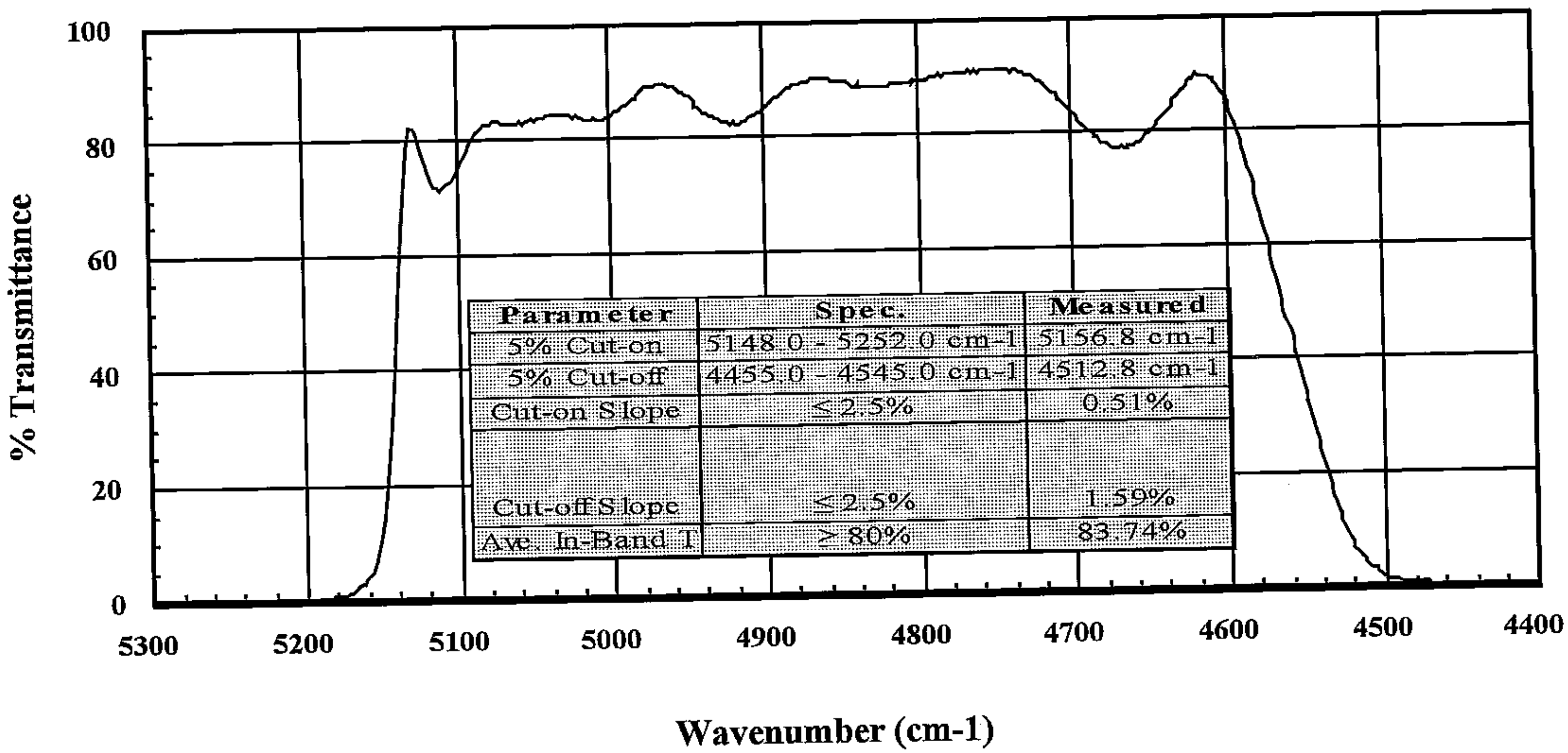
Parameter	Spec.	Design
Average out-of-band 1.0 to 22.4 μm	≤0.01%	0.00051% below band 0.014% above band

THEORETICAL IN-BAND TRANSMISSION OF NEW CHANNEL 8 FILTER f/2 AT NORMAL INCIDENCE



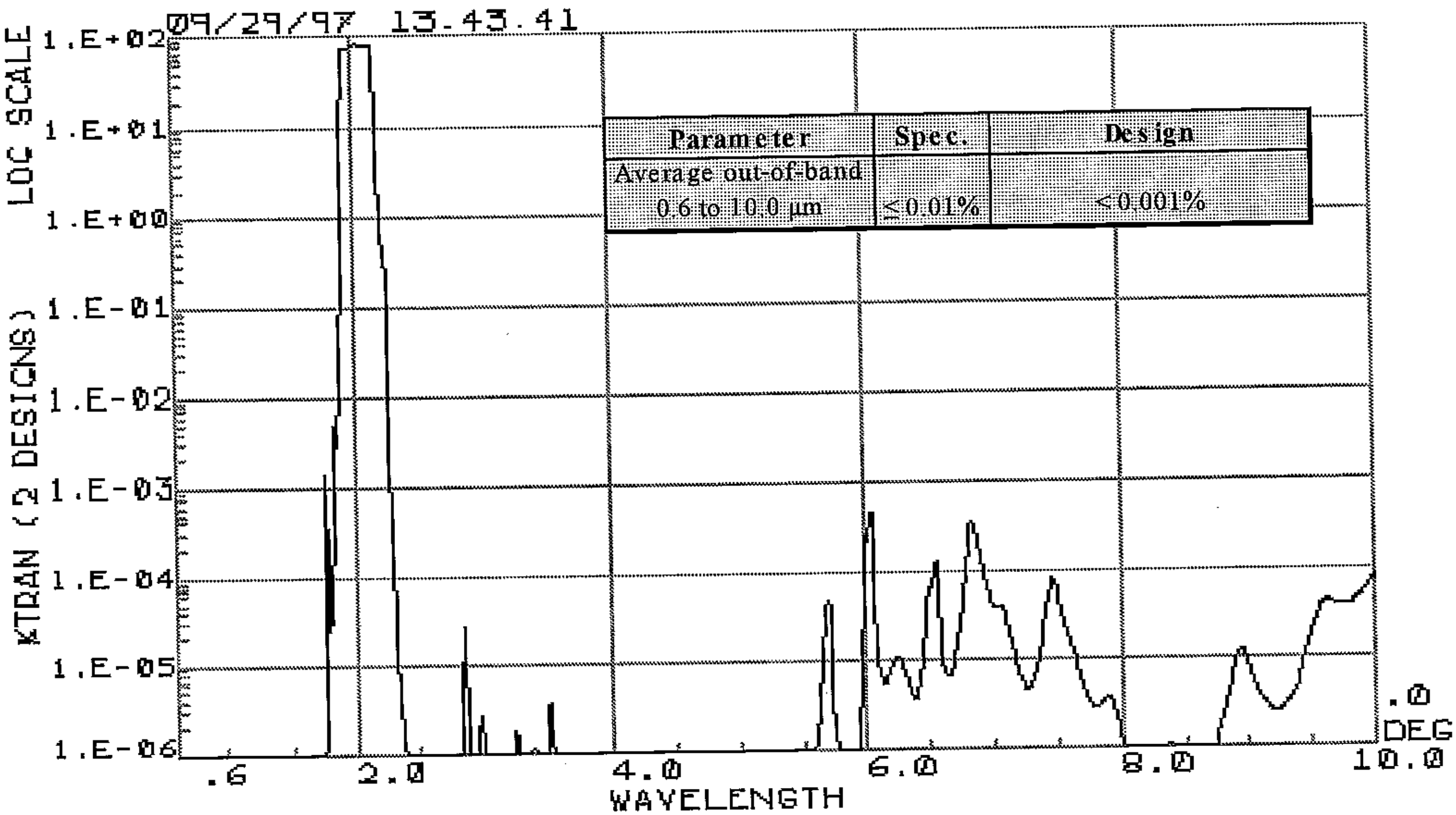
Parameter	Spec.	Design
5% Cut-on	5148.0 - 5252.0 cm-1	5191.6 cm-1
5% Cut-off	4455.0 - 4545.0 cm-1	4530.4 cm-1
Cut-on Slope	≤ 2.5%	1.03%
Cut-off Slope	≤ 2.5%	1.06%
Ave. In-Band T	≥ 80%	79.50%

MEASURED IN-BAND TRANSMISSION OF CHANNEL 8 FILTER f/2 AT NORMAL INCIDENCE, 75K



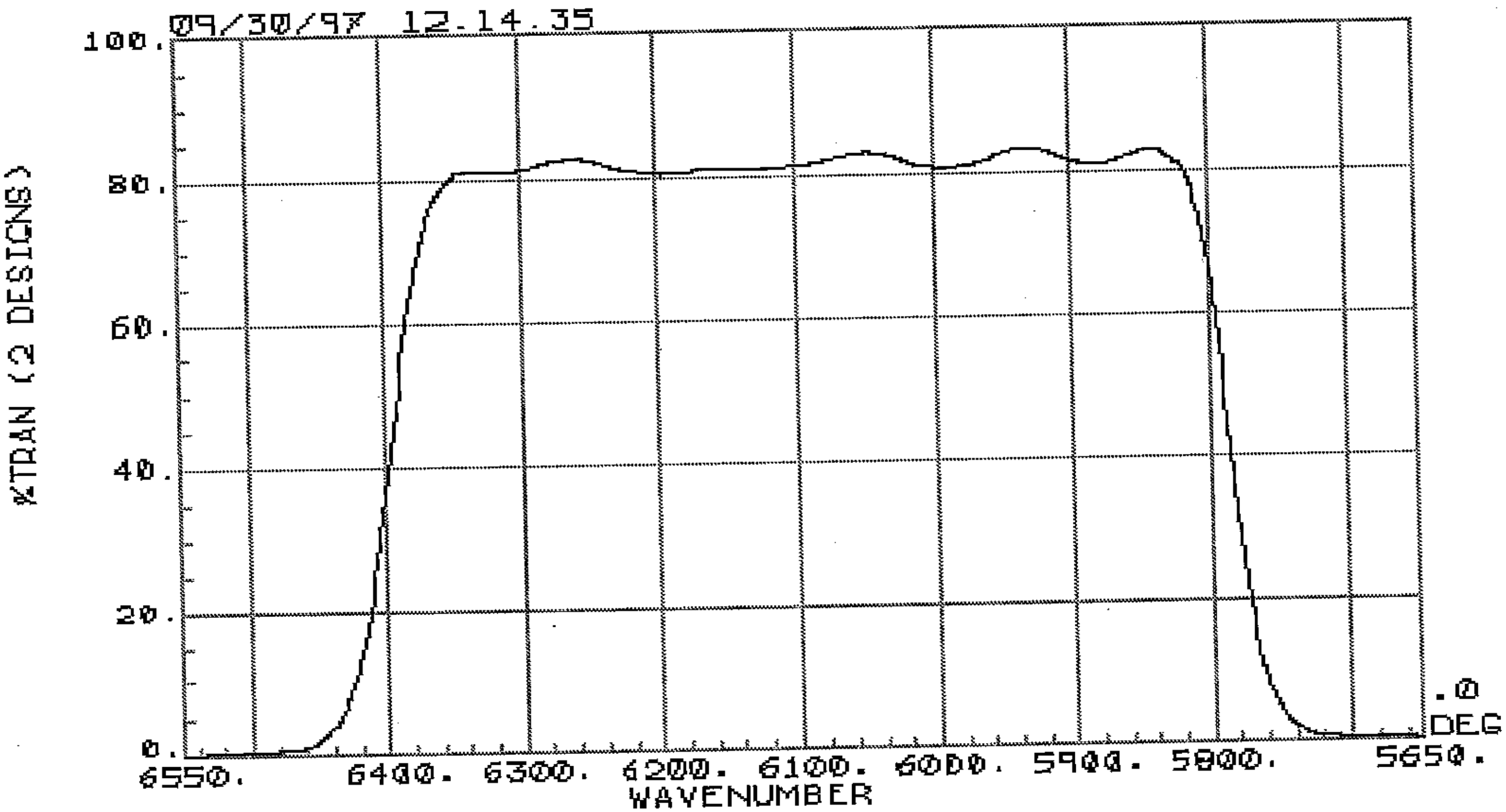
Parameter	Spec.	Measured
5% Cut-on	5148.0 - 5252.0 cm-1	5156.8 cm-1
5% Cut-off	4455.0 - 4545.0 cm-1	4512.8 cm-1
Cut-on Slope	≤ 2.5%	0.51%
Cut-off Slope	≤ 2.5%	1.59%
Ave. In-Band T	≥ 80%	83.74%

THEORETICAL OUT-OF-BAND TRANSMISSION OF NEW CHANNEL 8 FILTER f/2 AT NORMAL INCIDENCE

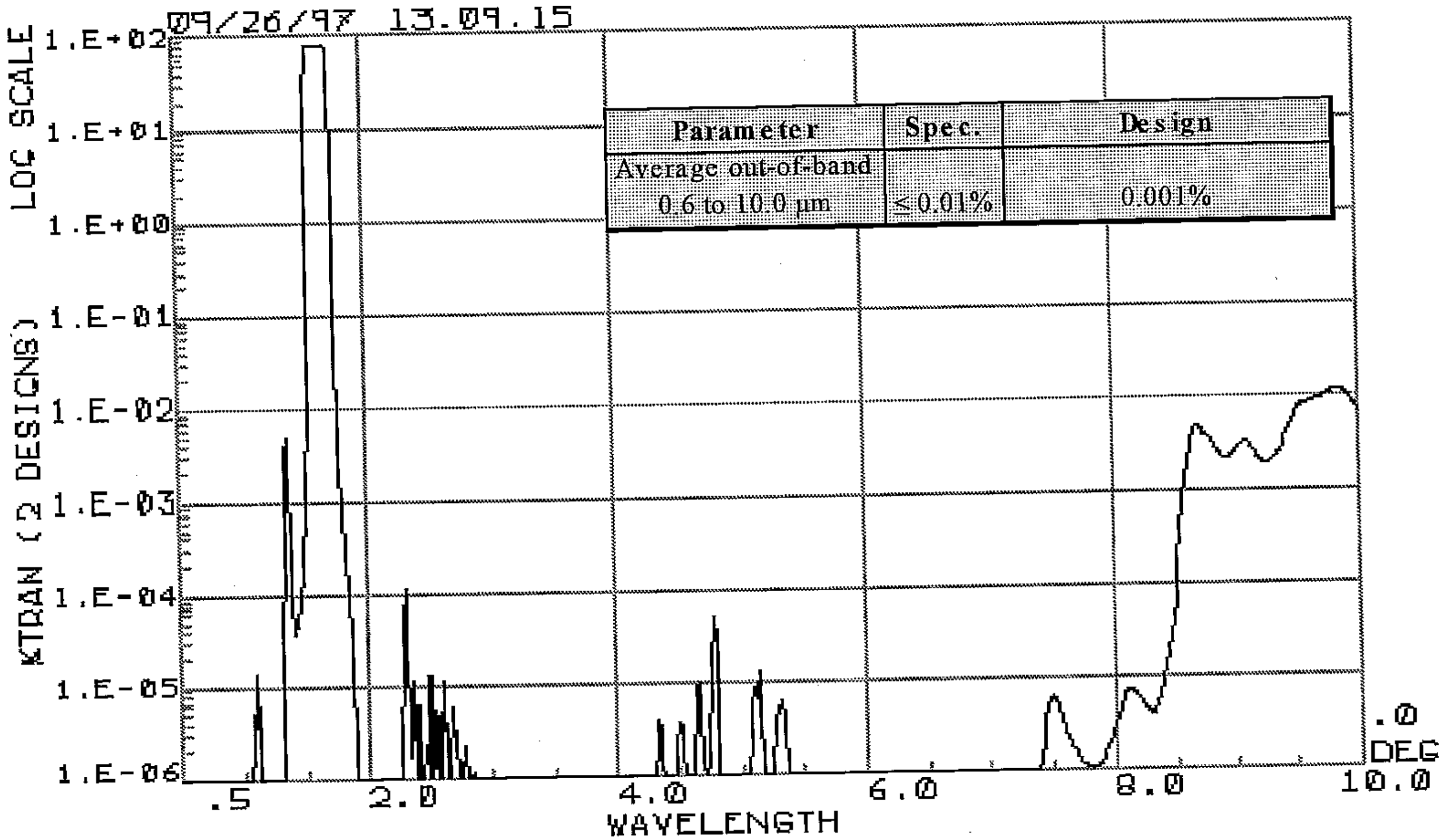


Parameter	Spec.	Design
Average out-of-band 0.6 to 10.0 µm	≤ 0.01%	< 0.001%

THEORETICAL IN-BAND TRANSMISSION OF CHANNEL 9 FILTER f/2 AT NORMAL INCIDENCE



THEORETICAL OUT-OF-BAND TRANSMISSION OF CHANNEL 9 FILTER f/2 AT NORMAL INCIDENCE



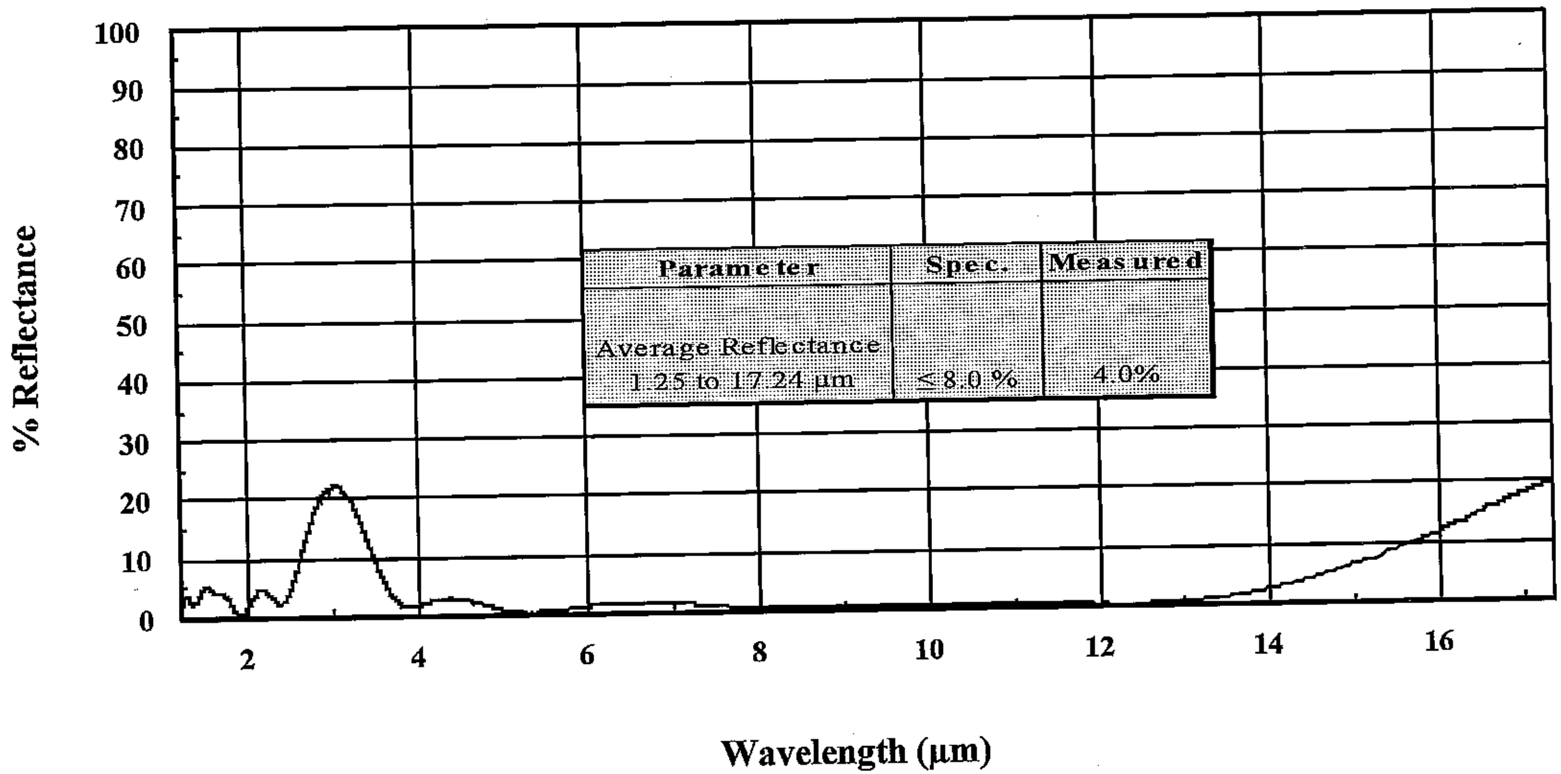
Parameter	Spec.	Design
Average out-of-band 0.6 to 10.0 µm	≤ 0.01%	0.001%

SABER Critical Design Review

SPACE DYNAMICS LABORATORY / UTAH STATE UNIVERSITY

RE-49

MEASURED REFLECTANCE OF THE DARK MIRROR COATING 10° INCIDENCE AT ROOM TEMPERATURE



CONCLUSIONS

- Further analysis of triple diffraction effect on stray light required
- Telescope stray light performance should be checked at long wavelength
- Sizing difficulties with channel 1 filter preclude obtaining long wavelength blocking better than 0.02% above band
- Successful sizing of channel 1 a major priority
- Temperature stability of FPA critical to attaining radiometric accuracy
- The detector temperature must be very close to the nominal 75 K to meet SABER sensitivity requirements. A temperature rise of 1 K wipes out sensitivity margins of channel 1.
- Early fabrication and testing of optical system critical to maintaining schedule
- The Radiometric/Optical Subsystem meets requirements and is ready to proceed to fabrication phase

SCANNER SUBSYSTEM OVERVIEW

Steven Brown

October 20, 1997

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OVERVIEW

- Scan Requirements
- Scan Profile
- Scanner Mechanism
- Controller Design Method and Features
- Control System Block Diagram
- Scanner Controller Analysis
- Electrical Block Diagram
- Scanner Motor / Encoder
- Scanner Prototype Plan

SCAN REQUIREMENTS

- **Scan Range**
  - Maximum depression angle places top of FPA at -3 km
  - Minimum depression angle places bottom of FPA at 400 km
  - In-flight calibration sources at 180° line of sight (los)

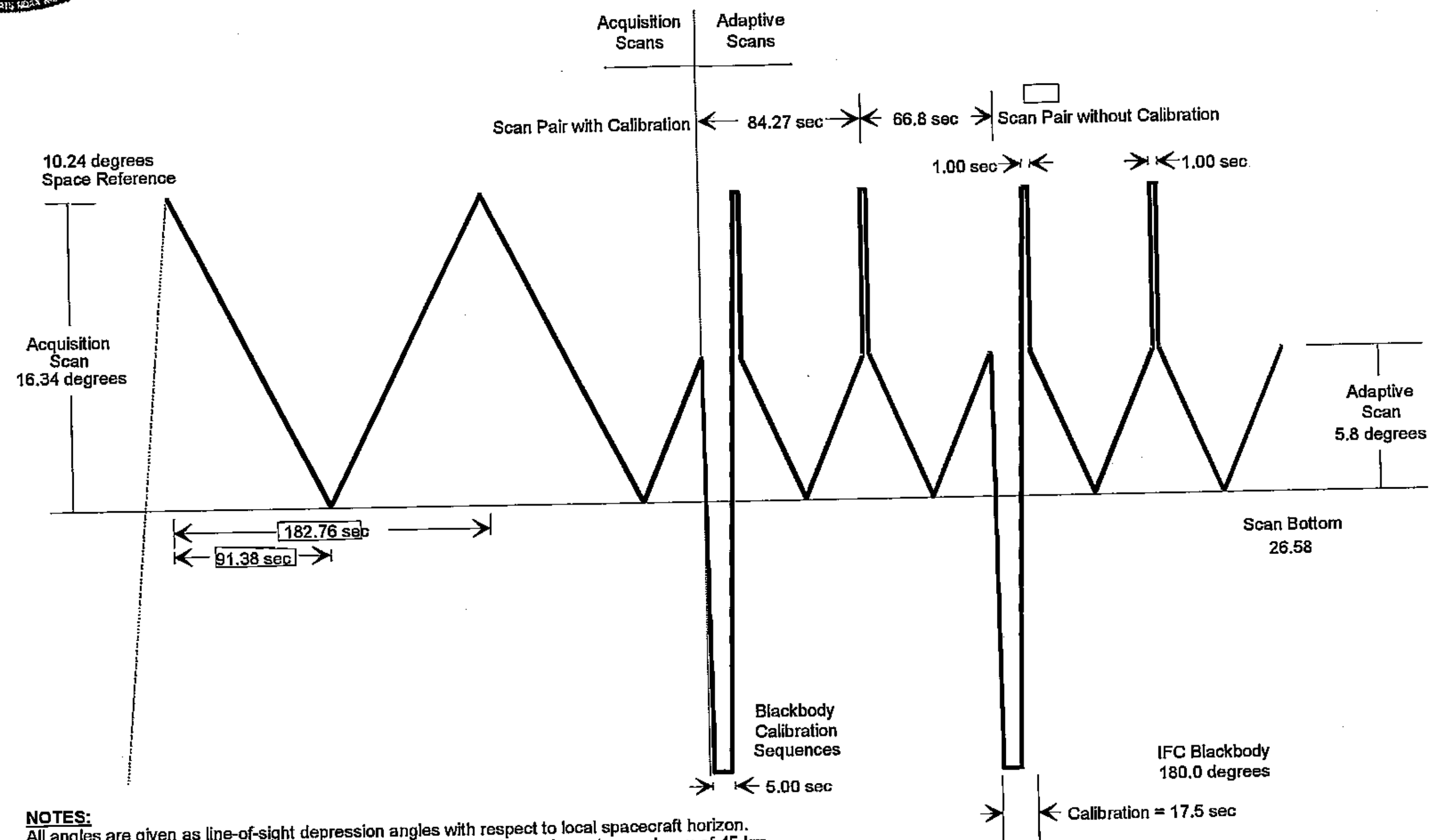
- **Scan Velocity**
  - Five samples at the instrument sample rate in each 2 km vertical interval, referenced at a 60 km tangent altitude
    - Maximum rate = 0.187 °/sec
  - Two scans within a 5° latitude cell
    - Minimum rate = 0.161 °/sec (profile dependent)

- **In-Flight Calibration Requirements**
  - Dwell at space and blackbody reference positions to acquire radiometrically stable data
    - Dwell at space reference once for each scan pair
    - Dwell at blackbody and Jones sources once for each two scan pairs

SCAN REQUIREMENTS (continued)

- **Sample-to-Sample Vertical Spacing Knowledge**
  - ±1% of the distance between samples for samples separated by 3 km or more
  - ±30 m for samples separated by 3 km or less
  - Corresponds to ±2.27 arc-sec los (±1.14 arc-sec mechanical) angular knowledge at a 60 km tangent height
- **Controller Performance**
  - Stable Operation
  - Negligible scan rate jitter in 0.5 to 8 Hz frequency range
  - Scan linearity < ±1%
  - Position mode transient settling time < 100 ms (± 2 counts with respect rest position)
- **Thermal**
  - Motor Encoder Operating Range: -55°C to +60°C
  - Motor Encoder Survival Range: -65°C to +60°C
  - T between Motor Stator and Rotor: ≤ 5°C

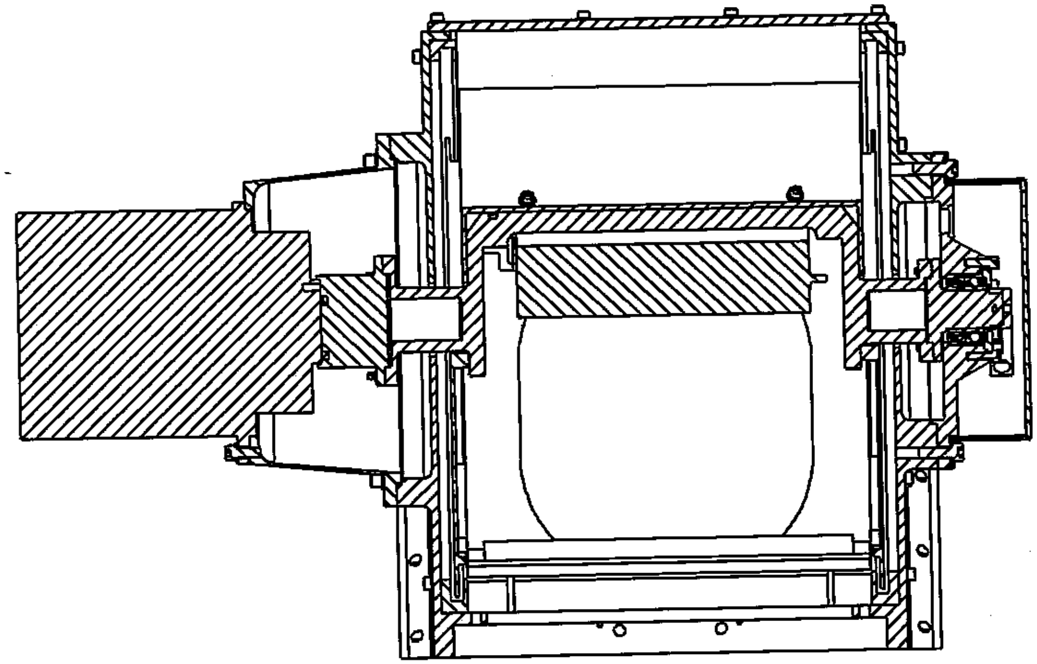
SCAN PROFILE



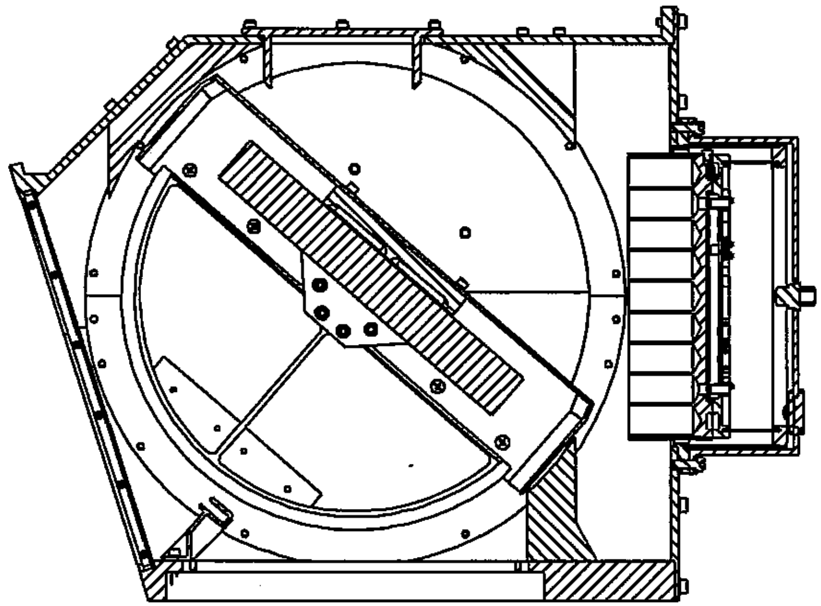
NOTES:
All angles are given as line-of-sight depression angles with respect to local spacecraft horizon.
Scan sequences for spacecraft insertion altitudes of 625 ±25Km, and worst case decay of 45 km.
Acquisition scan accommodates worst case spacecraft altitude and attitude variations over mission.
Adaptive scan angle accommodates the worst case spacecraft altitude.
Adaptive scan location is varied based on location of CO_2 horizon derived from instrument data.
All times are given at baseline scan and slew rates and worst case altitude and oblateness.
2:1 ratio of non-calibration to calibration scans is baseline, and can be increased in flight
Acquisitions scans are commanded only when the scanner is transitioned from the safe-hold position to scanning.

Not to Scale

SCANNER MECHANISM



SCANNER MECHANISM

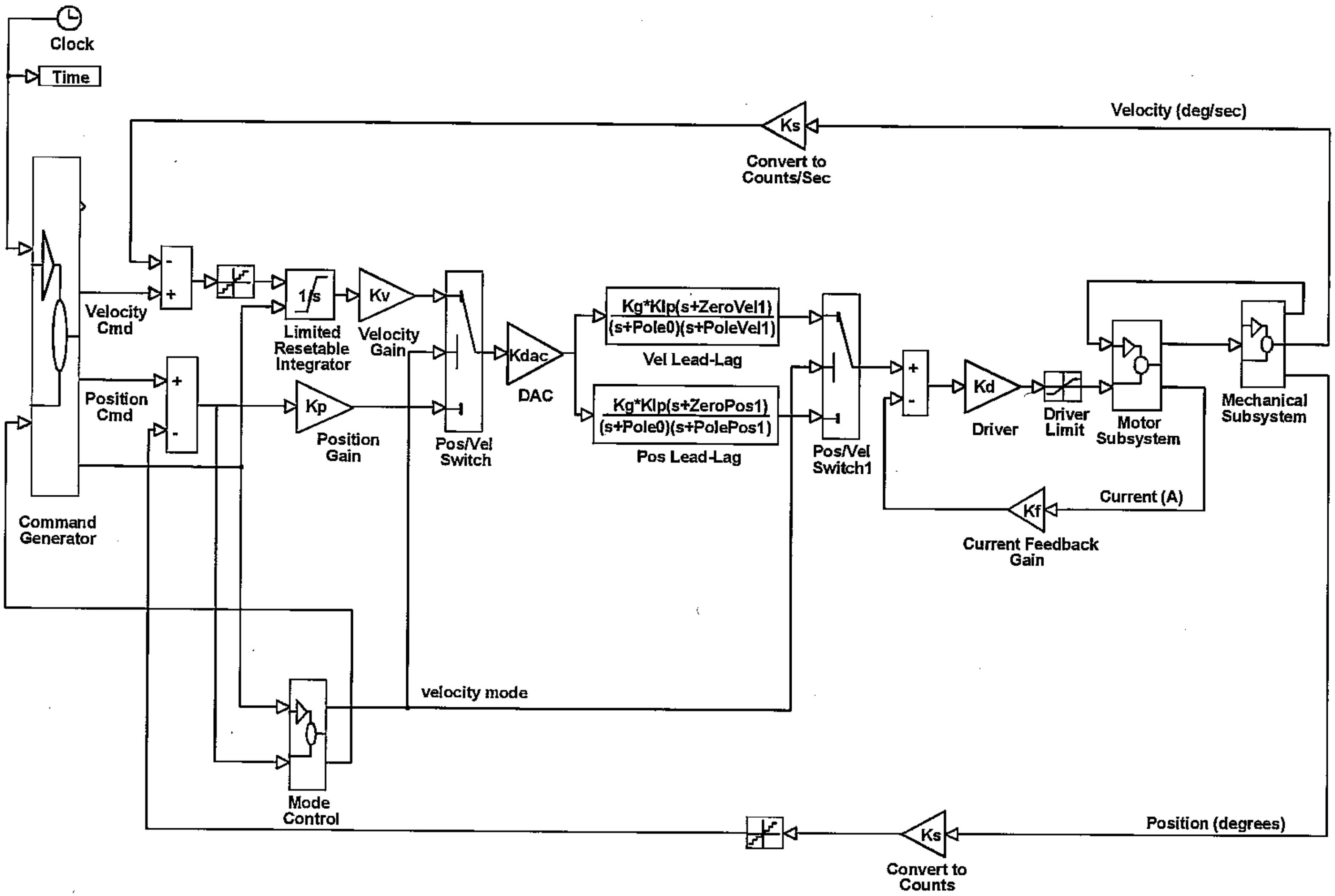


CONTROLLER DESIGN METHOD AND FEATURES

- **Method**
  - Closed-loop control of mirror using conventional analog and digital circuitry
  - Digital interface to instrument controller
  - Velocity and position feedback control
  - Pulse-width modulation (PWM) drive
  - Motor commutation derived from hall-effect sensors

- **Features**
  - Scan control independent of instrument control
  - Command format:
    - Position (12 bit)
    - Velocity (2 bit)
      - Scan
      - Calibration: 1/4 scan velocity
      - Slew
      - Fast Slew: 2 * Slew velocity

SIMPLIFIED CONTROL SYSTEM BLOCK DIAGRAM



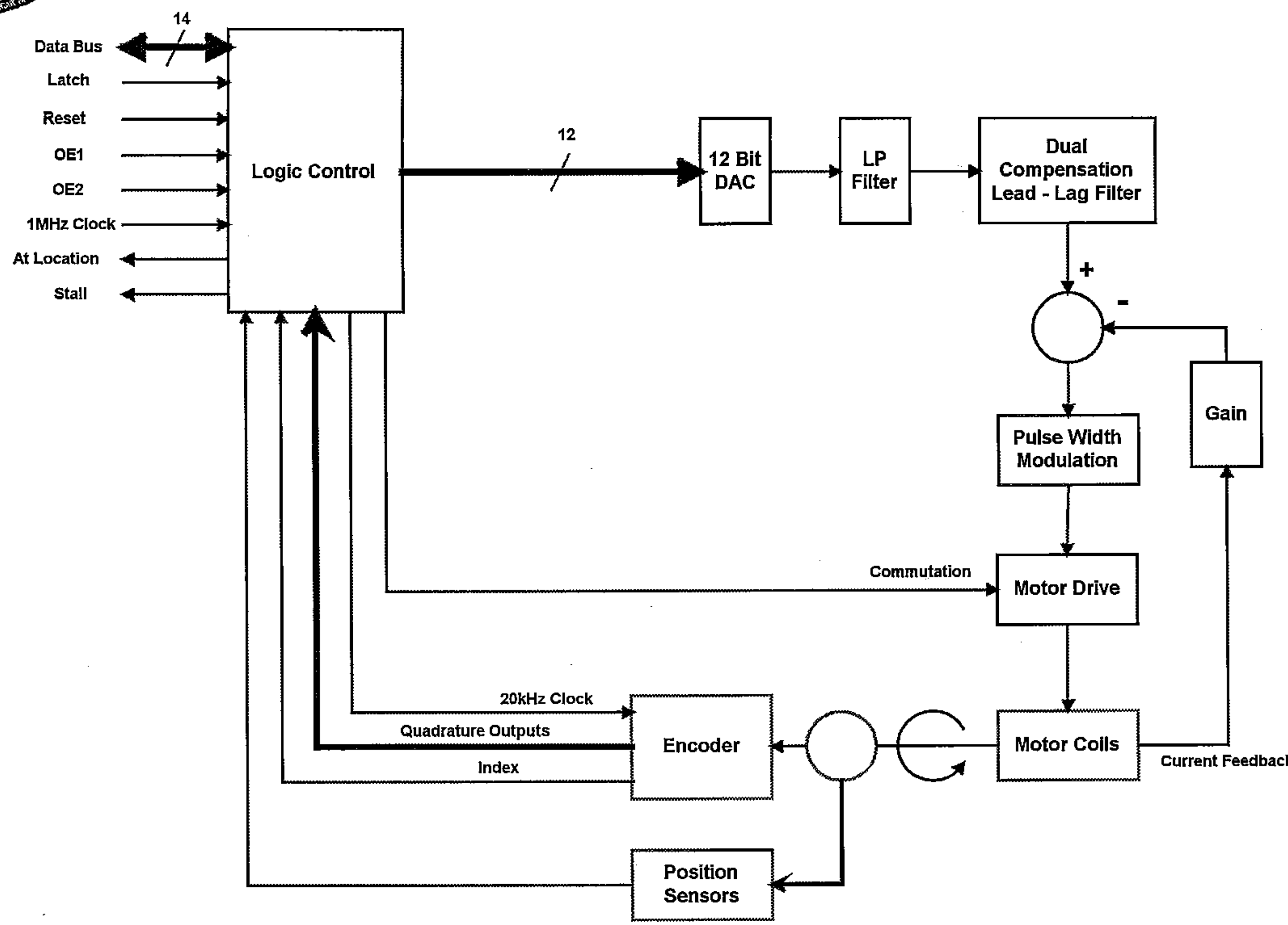
SCANNER CONTROLLER ANALYSIS

- **Frequency Domain Models & Analysis**
  - Linearized control loop model
  - Bode, Nyquist and root locus analysis of controller designs
  - Controller loops have good stability margins
    - Velocity loop: phase margin 46.6°, gain margin 19.7 dB
    - Position loop: phase margin 25.7°, gain margin 15.5 dB
      (Most of position gain is "digital" not subject to change)
  - Controller closed-loop bandwidth
    - Velocity Loop: 35 Hz
      - Negligible jitter in the 0.5 to 8 Hz range
    - Position Loop: 100 Hz
  - Settling times < 50 ms (linear prediction from model)

SCANNER CONTROLLER ANALYSIS (continued)

- **Time Domain Models & Analysis**
  - Two models
    - Continuous
    - Mixed discrete-continuous
  - Models include nonlinear effects:
    - Flight-like commanding including velocity-position transitions
    - Limits (voltage & discrete device)
    - Quantization
    - Back-emf and motor cogging
    - Friction & drag
    - Discrete controller (mixed discrete-continuous model only)
  - Mixed discrete-continuous model includes a discrete controller implementation
  - Simulation results consistent with linear response prediction, accounting for nonlinearities
    - Transient response within specification
    - Scan Linearity << ±1%

ELECTRICAL BLOCK DIAGRAM



SABER Critical Design Review

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SB-12

SCANNER MOTOR / ENCODER

- **Motor**
  - 3-phase, 12-pole brushless DC motor manufactured by Inland Motor
  - Hall-effect sensors included for commutation

- **Encoder**
  - BEI design
  - Code disk has four channels of 4096 lines plus an index line
  - Encoder electronics interpolate the 4 channels into two signals providing 2^{18} quadrature cycles per revolution
  - SDL electronics translate these signals into a direction signal and a 2^{20} transition per revolution signal
  - 20-bit encoder results in angular resolution of 1.24 arc-second
  - BEI calibration test accuracy to 2^{24} bits per 360°
    - Accuracy requirement: 5.1 arc seconds peak-to-peak rms error per channel
    - Prototype measured accuracy: 3.16 arc-sec peak-to-peak rms error (worse channel)
    - Expected performance over < 6° scan range at or better than resolution

- **BEI to integrate motor and encoder and provide bearing assemblies and interface flange to SDL scan mirror/baffle assembly**

SCANNER PROTOTYPE PLAN

- **Motor Encoder Prototype**
  - Uses Inland motor from Flight build
  - Mechanically identical to flight unit except for bearing material
    - Flight: 440C stainless steel (flight approved material)
    - Prototype: 52100 stainless steel (non flight, industrial material)
  - Electrical
    - Flight: IC specifications as per product assurance plan
    - Prototype: Commercial IC's

- **Scan Controller Prototype**
  - Circuit board fabricated to flight specifications
  - Commercial IC's
  - Some potentiometers used for tuning
    - Potentiometers will be replace with fixed resistors on flight board
  - Accommodations made for adjusting some parameters internal to the Actel controller IC

SCANNER PROTOTYPE PLAN (continued)

- **Mechanical Fixture**
  - Dummy mass used to approximate the moving mirror mass and inertia
  - Built to flight dimensions to allow for:
    - Testing of assembly and alignment procedures
    - Testing of controller operation
    - Vibration testing on prototype test bearings

- **Tests**
  - Prototype motor / encoder received
    - Initial prototype tests completed by end of year
  - Bearing survivability to vibration
  - Bearing assembly and alignment
  - Scan controller interface to motor / encoder
  - Controller function
  - Power consumption
  - Main controller interface to scan controller

ELECTRONICS OVERVIEW

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20 October 1997

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ELECTRICAL ASSEMBLY SPECIFICATIONS (1 of 7)

Parameter	Source	Requirement	Specification	Comply	Units	Comments
GENERAL						
Operation Modes	IRD	Off Power-up Safe Stabilization Standby Calibrate Data Collection Diagnostic/ Reprogram	Off Power-up Safe Stabilization Standby Calibrate Data Collection Diagnostic/ Reprogram	✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓		
Power	GIIS	69.8	72.6		Watts	average orbital power
Voltage range	GIIS	28 +7/-6	28 +22/-12	✓	Volts	
Power source transients	GIIS	+56, -2	+80, -150	✓	Volts	
EMI	GIIS	MIL-STD-461B	MIL-STD-461B	✓		
Isolation	GIIS	1MΩ @50 V	>1MΩ @500 V	✓		primary to secondary
Bonding	GIIS	0.0025	< 0.0025	✓	ohms	
S/C Data Interface	GIIS	MIL-STD-1553	MIL-STD-1553	✓		configuration described in GIIS
Data Packet Length	GIIS	2096	2096	✓	bits	
Data Transfer Rate	SIIS	3.97	3.97	✓	kbits/sec	
Command Packet Length	GIIS	4000 maximum	1968	✓	bits	
Command Transfer Rate	SIIS	2kBytes	2kBytes	✓	/day	maximum
Status Link	GIIS	64	64	✓	bits	

ELECTRICAL ASSEMBLY SPECIFICATIONS (2 of 7)

Parameter	Source	Requirement	Specification	Comply	Units	Comments
GENERAL (cont.)						
Communication Format						
downlink	GIIS	CCSDS	CCSDS	✓		
uplink	GIIS	CCSDS	CCSDS	✓		
Reliability	IRD	2	2	✓	years	mission life
Radiation hardness	GIIS					
Latch-up		no latch-up	no latch-up	✓		
SEU		non fatal	non fatal	✓		
Total Dose		5	5	✓	krad	75 mil Al

ELECTRICAL ASSEMBLY SPECIFICATIONS (3 of 7)

Parameter	Source	Requirement	Specification	Comply	Units	Comments
SIGNAL PROCESSING						
Radiometric accuracy and precision	IRD	NEN = 3 LSB	NEN = 3 LSB	✓		in highest gain range
Electronic Stability	IRD	< 1 NEN		✓		between space looks
Dynamic Range (required NEN to Max Sig)	IRD					
Channel 1		15,429	32,494	✓		
Channel 2		35,629	85,695	✓		
Channel 3		35,629	85,716	✓		
Channel 4		50,607	82,802	✓		
Channel 5		13,298	144,342	✓		
Channel 6		81,606	102,102	✓		
Channel 7		1,182	17,856	✓		
Channel 8		526,596	661,475	✓		
Channel 9		669,286	841,746	✓		
Channel 10		307,714	383,239	✓		
Preamp Type	SYS	PC Ch. 1-5 PV Ch. 6-10	PC Ch. 1-5 PV Ch. 6-10	✓ ✓		driven by electro /optical detector choice
Integration time	IRD	0.110	0.110	✓	sec	4.545 Noise Equivalent BW
Sample Rate	IRD	5	5 22.73	✓	/IFOV /sec	
Chopper frequency	SYS	1000	1000	✓	Hz	radiometric requirement
Dark offset cancel range	SYS	±11.5 0.05-0.1	±16.5 0.05-0.1	✓ ✓	K	optical temperature range chopper emissivity

ELECTRICAL ASSEMBLY SPECIFICATIONS (4 of 7)

Parameter	Source	Requirement	Specification	Comply	Units	Comments
SYSTEM CONTROL AND DATA HANDLING **Data Formatter**	IRD	format data	3 op. modes	✓		
Data Collection Data sample rate Housekeeping sample rate Bit rate	 IRD SYS SIIS	 5 <3.97	 5 (22.73 s/s) 0.063 3.97	 ✓ ✓ ✓	 /IFOV /sec kbits/sec	normal mode for Data Collection, Calibrate, Diagnositc/Reprogram modes
Housekeeping Data sample rate Housekeeping sample rate Bit rate	SYS SYS SYS SIIS	 <3.97	 0 0.063 0.13	 ✓ ✓ ✓	 /sec /sec kbits/sec	normal mode for Power-up, Safe, Stabilization, Standby
Memory Dump Data sample rate Housekeeping sample rate Bit rate	SYS SYS SYS SIIS	 <3.97	 0 0 3.97	 ✓ ✓ ✓	 /sec /sec kbits/sec	controlled by uplink command
Command echo	SYS	log sys control cmds in TM	FIFO buffer 341 cmds	✓		assess system controller performance
System Controller						
Commands	IRD IRD	stored uplink	16,383 cmds 511 cmds	✓ ✓		automated routines RAM buffer
Interrupts	SYS SYS IRD SYS	1. Power down 2. S/C Yaw 3. Uplink cmd 4. Timer	1. Power down 2. S/C Yaw 3. Uplink cmd 4. Timer	✓ ✓ ✓ ✓		
C&DH Reset	SYS	uplink reset	uplink reset	✓		3 continuous uplink words

ELECTRICAL ASSEMBLY SPECIFICATIONS (5 of 7)

Parameter	Source	Requirement	Specification	Comply	Units	Comments
System Controller (cont.)						
Uplink packet verification	SYS	CRC	CRC	✓		
Limit scan mirror stalls	SYS	halt if ≥7 stalls reset if time-out	halt if ≥7 stalls reset if time-out	✓ ✓		uplink disable adjustable time-out
Limit TRW refrigerator overstrokes	SYS	halt if ≥7 overstrokes	halt if ≥7 overstrokes	✓		uplink disable
Adaptive Scan Reference Function	SYS SYS SYS	ON/OFF Update/scan up and down Set @ % of peak radiance of Channel #1 CO2 narrow	ON/OFF Update/scan up and down Set @ 50% of peak radiance of Channel #1 CO2 narrow	✓ ✓ ✓		System Controller function
Timer	SYS	Interrupt System Controller @ preset UT	Interrupt System Controller @ preset UT	✓		max time 2.13 years with 17.1 minute resolution
Cover release enable	SYS	2 steps to release cover	enable and fire	✓		fire—time-out or wait for temperature
Temperature wait	SYS	halt operation until temp	halt operation until temp	✓		

ELECTRICAL ASSEMBLY SPECIFICATIONS (6 of 7)

Parameter	Source	Requirement	Specification	Comply	Units	Comments
Scan Mirror Controller						
Scan velocity	SYS	0.194 max	0.179	✓	°/sec	
Slew velocity	SYS	29.62	30.0	✓	°/sec	
¼ Scan velocity	SYS	0.049 max	0.045	✓	°/sec	
Fast Scan velocity	SYS	59.24	60.0	✓	°/sec	
Scan mirror jitter	IRD	< 3	2.5	✓	arcsec	
Encoder resolution	IRD	1.236	1.236	✓	arcsec	
Command resolution	SYS	0.088	0.044	✓	°	
ANALOG CONTROLLERS **Blackbody Controller**						
Temperature Set Range	SYS	228-305	225-315	✓	K	uplink adjustable
Stability	SYS	0.1	0.028	✓	K	IRD 1% residual scale error
Temperature set step	SYS	22	22	✓	mK	12 bit DAC
Jones Source Controller						
Number of Jones Sources	SYS	3	3	✓		
Temperature Set Range	SYS	1800	<2100	✓	K	in flight adjustable
Current set step	SYS	32.7	32.7	✓	μA	12 bit DAC
Stability	SYS	<1.0	<1.0	✓	K	worse case
Operational Heater Cntl.						
Temperature set point (Refrigerator)	SYS	260	260	✓	K	
Temperature set point (encoder)	SYS	225	225	✓	K	
Power (Refrigerator)	SYS	35	54.1 available	✓	Watts	cold power-up @28V
Power (Encoder)	SYS	8	12.4 available	✓	Watts	cold power-up @28V

ELECTRICAL ASSEMBLY SPECIFICATIONS (7 of 7)

Parameter	Source	Requirement	Specification	Comply	Units	Comments
CHOPPER CONTROL AND SYNC						
Chopper Control						
Operating frequency	SYS	1000±0.5	1000±0.5	✓	Hz	free running
Long term variation	SYS	±0.02	±0.02	✓	Hz	
Chopper Sync						
Delay per channel	SYS	adjustable	0-360, 0.35 steps	✓	degrees	manually adjusted
POWER CONVERTERS						
Isolation	GIIS	50 1	500 1	✓ ✓	Volts MΩ	
Input Range	GIIS	28 +7/-6	28 +22/-12	✓	Volts	
Input transients	GIIS	+56, -2	+80, -150	✓	Volts	
turn on	SYS	separate groups	3 groups	✓		
COVER DEPLOYMENT						
Method	SYS	one time throw away	one time throw away	✓		Commanded by operator with 4 commands
REFRIGERATOR ELECTRONICS						
Low operating limit	SYS	72	70	✓	K	
Control	SYS	vibration cancellation	vibration cancellation	✓		automatic, on/off operator controlled
Temperature set	SYS	70 - 100	70 - 100	✓	K	uplink command
Command/TM interface	SIIS	MIL-STD-1553	MIL-STD-1553	✓		

CHANGES SINCE PDR
Subsystems

Signal processing
- Extended dynamic range ch 8-10
- 8 to 12 bit DAC on offset adj. (-2.2 W)

Control and data handling (C&DH)
- Upgrade from ACTEL A1020 to A1280
- GIIS definition and autonomy issues
  - Memory dump data format mode
  - Uplink CRC capability
  - Uplink C&DH system reset
  - Scan mirror stall limit at 7 (override)
  - Refrigerator overstroke at 7 (override)
- Jump loops increased from 2 to 4
- Eliminated AD620 amplifiers from housekeeping temp. Monitors (-3.4 W)
- Memory devices — different parts

Refrigerator electronics (RFE) (TRW)
- RFE DC/DC isolated (+5.8 W)
- 1553 interface/driver inefficiency (+5.1 W)

Analog controllers
- New Jones source lamp
  - Drive voltage +28 to +15 V
- Added 3rd Jones source lamp
- 8 to 12 bit DAC on JS and BB set (-1.1 W)
- Operational heater controllers moved to primary side of DC/DC converters (-3.0 W)
- Operational heater power transistor mounted with heating element (-6.1 W)

Power converters
- Using single supplies instead of duals
- In-rush circuit to eliminate turn-on transients

Scan mirror control
- Changed to dual velocity-position loop
- 1/4 scan and fast slew speeds added

Electronics box
- Spare card used for RFE DC/DC converter

CHANGES SINCE PDR
Power Changes Due to Electronics

PDR (Main + Operational Heaters)

- Data collection mode — cold case
- 82.4 W

Increases since PDR

+5.8 W RFE DC/DC isolation
+4.6 W RFE 1553 interface
+0.5 W RFE driver inefficiencies
+1.5 W scan motor/encoder
+12.4 W Total increase

Savings since PDR

-6.1 W op htr drive transistor mount w/ htr
-3.0 W op htr control moved to primary pwr
-2.2 W 8 to 12 bit DAC in signal processing
-1.1 W 8 to 12 bit DAC in analog controllers
-3.4 W eliminate AD620 in temp. monitors
-0.4 W misc. electronics
-5.2 W refrigerator power (20 W not needed)
-21.4 W Total savings

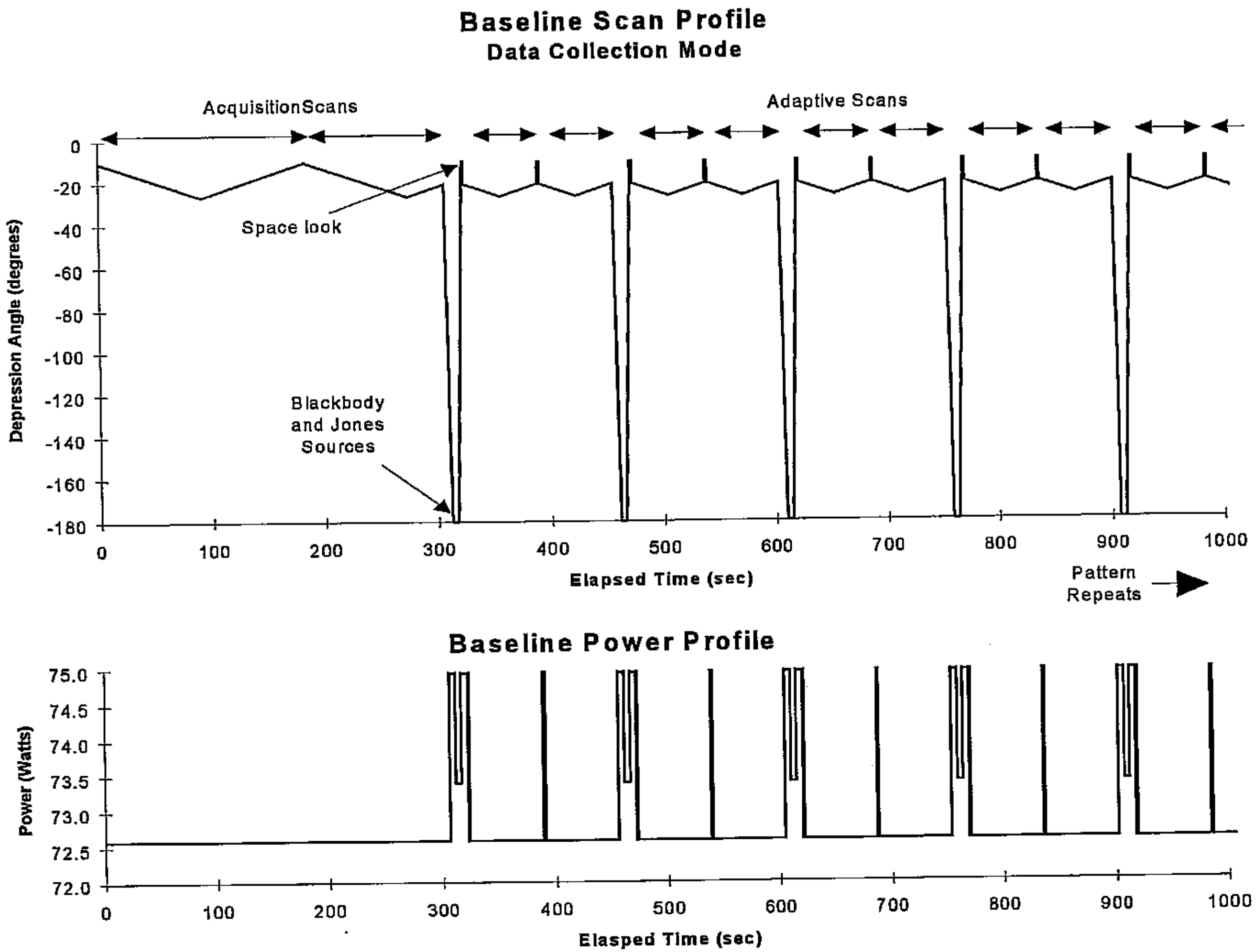
Balance

82.4 W PDR value
+12.4 W increase
-21.4 W savings
73.4 W (thermal analysis--72.6W CDR)

SPACECRAFT INTERFACE
Power Requirements

Box Assignment	Board #	Name	System	Calibration, Data Collection, Diagnostic Average (Watts)	Calibration, Data Collection, Diagnostic Peak (Watts)	Standby, Stabilizaton Average (Watts)	Standby, Stabilizaton Peak (Watts)	Power-up, Safe Average (Watts)	Power-up, Safe Peak (Watts)
1	210	PC Channels (1-5)	Signal Processing	2.9	2.9	2.9	2.9	0.0	0.0
2	211	PV Channels (6-10)	Signal Processing	2.9	2.9	2.9	2.9	0.0	0.0
3	212	Mux--A/D Converter	Signal Processing	1.3	1.3	1.3	1.3	0.0	0.0
shield									
4	213	DC/DC Converters (3) (Signal Processing)	Power	3.0	3.0	3.0	3.0	0.0	0.0
5	214	DC/DC Converters (4) (RFE and Cooler)	Power	5.8	7.7	5.8	5.8	0.0	0.0
6	215	DC/DC Converters (1 and 2) (C&DH, Scan, Analog)	Power	6.9	9.1	6.5	6.5	2.0	2.0
shield									
7	216	BB/JS/Heaters/Chop C&Sync	Analog Controllers/Chopper	1.3	2.1	1.3	1.3	0.0	0.0
8	217	Sys. Cnt/Formatter/1553	Sys. Control & Data Handling	4.2	4.2	4.2	4.2	4.2	4.2
9	218	Scan MirrorControl/Driver	Scan Mirror Controller	1.5	3.2	1.5	1.5	0.0	0.0
10	219	Housekeeping (2)	Sys. Control & Data Handling	1.7	1.7	1.7	1.7	1.7	1.7
11	220	Housekeeping (1)	Sys. Control & Data Handling	0.1	0.1	0.1	0.1	0.1	0.1
		TOTAL Box Power Dissapated		31.6	38.2	31.2	31.2	8.0	8.0
		External Components							
			Focal plan components	0.0	0.0	0.0	0.0	0.0	0.0
			Scan motor, encoder	4.1	6.5	1.6	1.6	0.0	0.0
			Chopper	0.1	0.1	0.1	0.1	0.0	0.0
			Calibration sources	1.5	2.3	1.5	1.5	0.0	0.0
			Refrigerator (RFE)	11.6	12.7	11.6	11.6	0.0	0.0
			Refrigerator (Compressor)	14.8	24.0	14.8	14.8	0.0	0.0
			SubTOTAL	63.7	83.8	60.8	60.8	8.0	8.0
			Encoder Operational Heater	2.6	2.6	2.6	2.6	12.4	12.4
			Refrigerator Operational Htr.	6.3	6.3	6.3	6.3	54.1	54.1
		TOTAL Power Required	TOTAL	72.6	92.7	69.7	69.7	74.5	74.5

SPACECRAFT INTERFACE
Power Profile



SPACECRAFT INTERFACE
Connectors

Connector No.	Connector Type	Description
A500-J1	DEMM9P	Instrument Power
A500-J2	DEMM9S	Main 1553 bus A
A500-J3	DEMM9S	Main 1553 bus B
A500-J4	DAMM15P	Operational & Survival Heater Power
A500-J5	DBMM25S	Temperature Monitors
A500-J6	DEMM9S	Refrigerator 1553 bus A
A500-J7	DEMM9S	Refrigerator 1553 bus B
A500-PG1	SWAGELOK SS-400-XX OR PFA-400-XX	Purge Intake

SPACECRAFT INTERFACE
Command Uplink Format

Packet Primary Header							
Version Number	Packet Identification			Packet Sequence Control		Packet Data Length	
	Type Indicator	Packet Secondary Header Flag	Application Process Identifier	Sequence Flags	Source Sequence Count		Tot. Bits
3	1	1	11	2	14	16	48
0	1	0	1408	BB	0-16383	255	

Instruction word #1	Data #1 word 1	Data #1 word 2	Uplink format word #1	64
Instruction word #2	Data #2 word 1	Data #2 word 2	Uplink format word #2	64
Instruction word #3	Data #3 word 1	Data #3 word 2	Uplink format word #3	64
Instruction word #4	Data #4 word 1	Data #4 word 2	Uplink format word #4	64
Instruction word #5	Data #5 word 1	Data #5 word 2	Uplink format word #5	64
Instruction word #6	Data #6 word 1	Data #6 word 2	Uplink format word #6	64
Instruction word #7	Data #7 word 1	Data #7 word 2	Uplink format word #7	64
Instruction word #8	Data #8 word 1	Data #8 word 2	Uplink format word #8	64
Instruction word #9	Data #9 word 1	Data #9 word 2	Uplink format word #9	64
Instruction word #10	Data #10 word 1	Data #10 word 2	Uplink format word #10	64
Instruction word #11	Data #11 word 1	Data #11 word 2	Uplink format word #11	64
Instruction word #12	Data #12 word 1	Data #12 word 2	Uplink format word #12	64
Instruction word #13	Data #13 word 1	Data #13 word 2	Uplink format word #13	64
Instruction word #14	Data #14 word 1	Data #14 word 2	Uplink format word #14	64
Instruction word #15	Data #15 word 1	Data #15 word 2	Uplink format word #15	64
Instruction word #16	Data #16 word 1	Data #16 word 2	Uplink format word #16	64
Instruction word #17	Data #17 word 1	Data #17 word 2	Uplink format word #17	64
Instruction word #18	Data #18 word 1	Data #18 word 2	Uplink format word #18	64
Instruction word #19	Data #19 word 1	Data #19 word 2	Uplink format word #19	64
Instruction word #20	Data #20 word 1	Data #20 word 2	Uplink format word #20	64
Instruction word #21	Data #21 word 1	Data #21 word 2	Uplink format word #21	64
Instruction word #22	Data #22 word 1	Data #22 word 2	Uplink format word #22	64
Instruction word #23	Data #23 word 1	Data #23 word 2	Uplink format word #23	64
Instruction word #24	Data #24 word 1	Data #24 word 2	Uplink format word #24	64
Instruction word #25	Data #25 word 1	Data #25 word 2	Uplink format word #25	64
Instruction word #26	Data #26 word 1	Data #26 word 2	Uplink format word #26	64
Instruction word #27	Data #27 word 1	Data #27 word 2	Uplink format word #27	64
Instruction word #28	Data #28 word 1	Data #28 word 2	Uplink format word #28	64

TOTAL BITS 1968

When a new command uplink sequence is transmitted, the first three uplink format words send information about the command packet as follows:

#	Description
1	Bit 15 (MSB) set indicates start of new message
2	Number of words in this message
3	CRC count in this message

SPACECRAFT INTERFACE

Data Formatter Modes — Data Collection

Modes supported:	Data Collection, Calibration, Diagnostic*, Standby **
Radiometric sample rate:	22.73 samples/sec (5.0 samples/IFOV)
Housekeeping sample rate:	0.063 samples/sec (worst case)
Packet length:	2096 bits
Packet transfer rate:	1.894 packets/sec (125/66)
Bit rate:	3969.7 bits/sec

*Diagnostic mode remains at previous mode data rate unless changed by uplink command.

**Standby mode data rates depend on the previous mode data rate.

	Packet Primary Header								Packet Secondary Header				
	Version Number	Packet Identification			Packet Sequence Control			Packet Data Length	S/C Time (to 1sec)	S/C Time (to 1ms)	Not used		
		Type Indicator	Packet Sec. Header Flag	Appl. Process Identif.	Grouping Flags	Source Sequence Count							Tot. Bits
bits	3	1	1	11	2	14		16	32	10	6		96
value	0	0	1	see note 1	2	0-16383		255	MET	MET	0		
bits	Scan Location 20	Gain 20	CH#1 12	CH#2 12	CH#3 12	CH#4 12	CH#5 12	CH#6 12	CH#7 12	CH#8 12	CH#9 12	CH#10 12	160
bits	Scan Location 20	Gain 20	CH#1 12	CH#2 12	CH#3 12	CH#4 12	CH#5 12	CH#6 12	CH#7 12	CH#8 12	CH#9 12	CH#10 12	160
bits	Scan Location 20	Gain 20	CH#1 12	CH#2 12	CH#3 12	CH#4 12	CH#5 12	CH#6 12	CH#7 12	CH#8 12	CH#9 12	CH#10 12	160
bits	Scan Location 20	Gain 20	CH#1 12	CH#2 12	CH#3 12	CH#4 12	CH#5 12	CH#6 12	CH#7 12	CH#8 12	CH#9 12	CH#10 12	160
bits	Scan Location 20	Gain 20	CH#1 12	CH#2 12	CH#3 12	CH#4 12	CH#5 12	CH#6 12	CH#7 12	CH#8 12	CH#9 12	CH#10 12	160
bits	Scan Location 20	Gain 20	CH#1 12	CH#2 12	CH#3 12	CH#4 12	CH#5 12	CH#6 12	CH#7 12	CH#8 12	CH#9 12	CH#10 12	160
bits	Scan Location 20	Gain 20	CH#1 12	CH#2 12	CH#3 12	CH#4 12	CH#5 12	CH#6 12	CH#7 12	CH#8 12	CH#9 12	CH#10 12	160
bits	Scan Location 20	Gain 20	CH#1 12	CH#2 12	CH#3 12	CH#4 12	CH#5 12	CH#6 12	CH#7 12	CH#8 12	CH#9 12	CH#10 12	160
bits	Scan Location 20	Gain 20	CH#1 12	CH#2 12	CH#3 12	CH#4 12	CH#5 12	CH#6 12	CH#7 12	CH#8 12	CH#9 12	CH#10 12	160
bits	Scan Location 20	Gain 20	CH#1 12	CH#2 12	CH#3 12	CH#4 12	CH#5 12	CH#6 12	CH#7 12	CH#8 12	CH#9 12	CH#10 12	160
bits	Scan Location 20	Gain 20	CH#1 12	CH#2 12	CH#3 12	CH#4 12	CH#5 12	CH#6 12	CH#7 12	CH#8 12	CH#9 12	CH#10 12	160
bits	Scan Location 20	Gain 20	CH#1 12	CH#2 12	CH#3 12	CH#4 12	CH#5 12	CH#6 12	CH#7 12	CH#8 12	CH#9 12	CH#10 12	160
bits	Command Echo 27					Housekeeping (1 of 30) format see table below						not used 5	80

TOTAL BITS 2096

SPACECRAFT INTERFACE
Data Formatter Modes — Housekeeping

Modes supported: Power-up, Diagnostic *, Standby**, Stabilize, Safe
Radiometric sample rate: 0.0 samples/sec
Housekeeping sample rate: 0.063 samples/sec (worst case)
Packet length: 2096 bits
Packet transfer rate: 0.063 packets/sec (25/396)
Bit rate: 132.3 bits/sec
*Diagnostic mode remains at previous mode data rate unless changed by uplink command.
**Standby mode data rates depend on the previous mode data rate.

	Packet Primary Header							Packet Secondary Header			
	Version Number	Packet Identification			Packet Sequence Control		Packet Data Length	S/C Time (to 1sec)	S/C Time (to 1ms)	Not Used	
		Type Indicator	Packet Sec. Header Flag	Appl. Process Identif.	Grouping Flags	Source Sequence Count					Tot. Bits
bits	3	1	1	11	2	14	16	32	10	6	96
value	0	0	1	see note 1	2	0-16383	255	MET	MET	0	
bits	Housekeeping format see table below 1440										1440
bits	Command Echo 558									not used 2	560

TOTAL BITS 2096

SPACECRAFT INTERFACE

Data Formatter Modes — Memory Dump

Modes supported: Diagnostic
Radiometric sample rate: 0.0 samples/sec
Housekeeping sample rate: 0.0 samples/sec
Packet length: 2096 bits
Packet transfer rate: 1.894 packets/sec (125/66)
Bit rate: 3969.7 bits/sec

	Packet Primary Header							Packet Secondary Header			
	Version Number	Packet Identification			Packet Sequence Control		Packet Data Length	S/C Time (to 1sec)	S/C Time (to 1ms)	Not used	
		Type Indicator	Packet Sec. Header Flag	Appl. Process Identif.	Grouping Flags	Source Sequence Count					Tot. Bits
bits	3	1	1	11	2	14	16	32	10	6	
value	000	0	1	see note 1	2	0-16383	255	MET	MET	0	96
bits	120, 16 bit PROM and EEPROM words or 40 instruction sets (1st word will be PROM word at start address followed associated 2 EEPROM words, next address will follow)										1920
bits	Command Echo 72									not used 8	80

TOTAL BITS 2096

SPACECRAFT INTERFACE

Instrument Status Words — Telemetry Subaddress T12

BIT	Description
T12-0	
15	Heart Beat
14	Zero
13 – 11	Command Packet Receive Count
10 – 8	Command Packet Reject Count
7 – 5	Mirror Stall Count
4 – 3	Mirror Reset Count
2 – 0	Refrigerator Overstroke Count
T12-1	
15	Uplink OK
14	Uplink Incoming Message
13	Incorrect Number of Words
12	CRC Error
11 – 10	Zeros
9 – 0	Word Count in Current Session

BIT	Description
T12-2	
15	Relay 7 – refrigerator cage/uncage
14	Relay 6 – RFE primary/secondary
13	Relay 5 – wax actuator sec. on/off
12	Relay 4 – wax actuator primary on/off
11	Relay 3 – power group #3 on/off
10	Relay 2 – power group #2 on/off
9	Relay 1 – refrigerator on/off
8	Jones source #1 on/off
7	Jones source #2 on/off
6	Jones source #3 on/off
5 – 4	Zeros
3 – 0	Instrument Mode
T12-3	
15 – 4	Refrigerator cold sting temperature
3 – 0	Zeros

SYSTEM DESIGN
Design Considerations

Minimize Noise

- Control ground currents
  - Opto-isolate digital signals in and out of signal processing unit and calibration controllers
  - Separate DC/DC converters for signal processing unit
  - Star power, ground, and box at DC/DC converter boards
  - Differential digitization of data channels
  - Pseudo-differential digitization of housekeeping signals powered by supplies other than the housekeeping supplies
- Low noise power supplies
  - Signal processing DC/DC converters are synchronized with system clock which controls signal processing A/D converter ⇒ controls when switching spikes occur
- Multilayer boards consisting of ground and power planes
- Slow system clock — 1 MHz
- Use slow digital logic if feasible
- Package noise sensitive circuits away from noisy circuits
  - Signal processing boards in shielded compartment
  - DC/DC converters in shielded compartment
- Shielded cables
  - Shield individual channels to and from focal plane

SYSTEM DESIGN
Design Considerations (continued)

Minimize power consumption

- Low power analog circuitry for signal processing
  - Use low-bandwidth, low-power LT1078 op amps
- Simple state machine controllers
- Efficient DC/DC converters
- Simplicity in design

Minimize cost

- Simple state machine controllers
- Analog circuitry for signal processing
- Simplicity in design

Maximize reliability

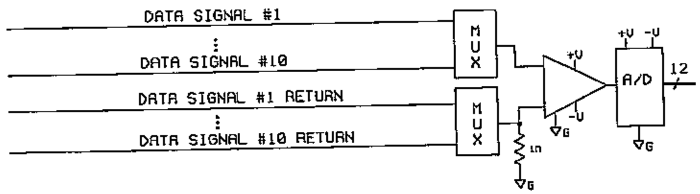
- Design
  - Use flight heritage
  - Simplicity in design such as state machine controllers $\Rightarrow$ predicted operation, not reconfigurable
- Parts
  - Where can, use preferred parts or parts with past flight heritage
  - Ensure radiation performance

SYSTEM DESIGN
Power, Ground, and Signal Interconnects

ANALOG SIGNALS

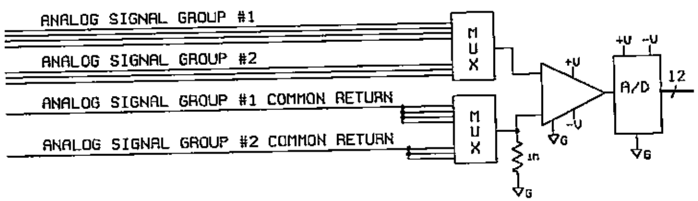
DATA SIGNALS
(SIGNAL PROCESSING)

FULL DIFFERENTIAL

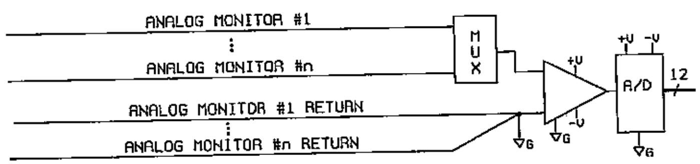


MONITORS

ISOLATED (PSEUDO DIFFERENTIAL)

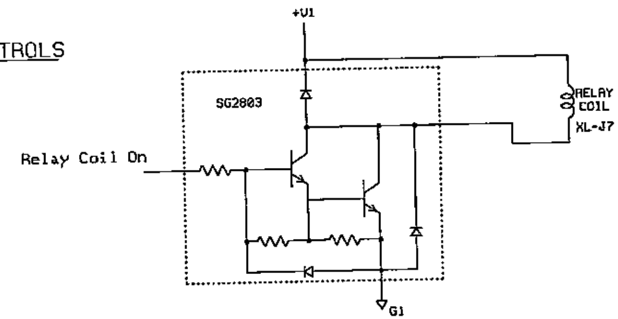


NON ISOLATED (SINGLE ENDED)

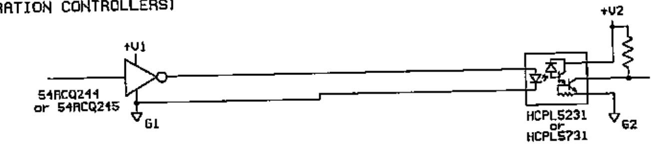


DIGITAL SIGNALS

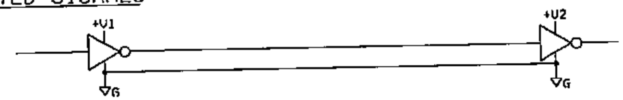
RELAY CONTROLS



ISOLATED SIGNALS
(SIGNAL PROCESSING)
(CALIBRATION CONTROLLERS)

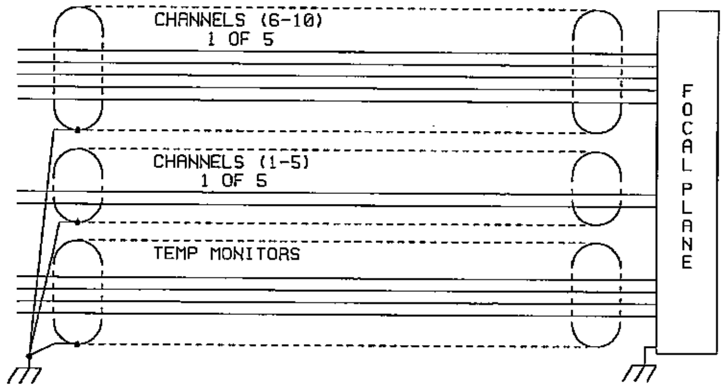


NON ISOLATED SIGNALS

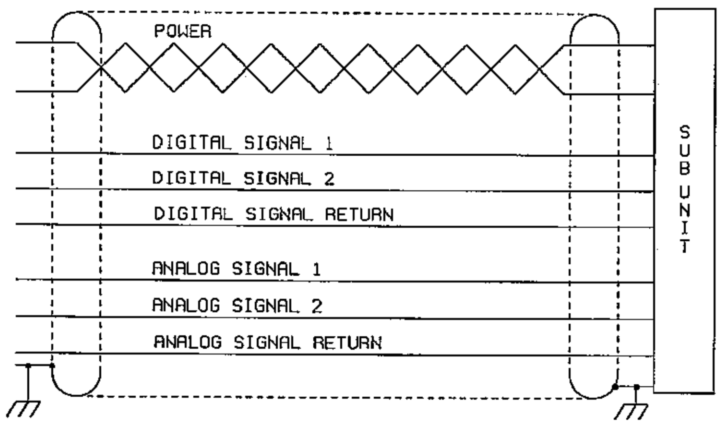


SYSTEM DESIGN
Power, Ground, and Signal Interconnects (continued)

INTERFACE TO FOCAL PLANE

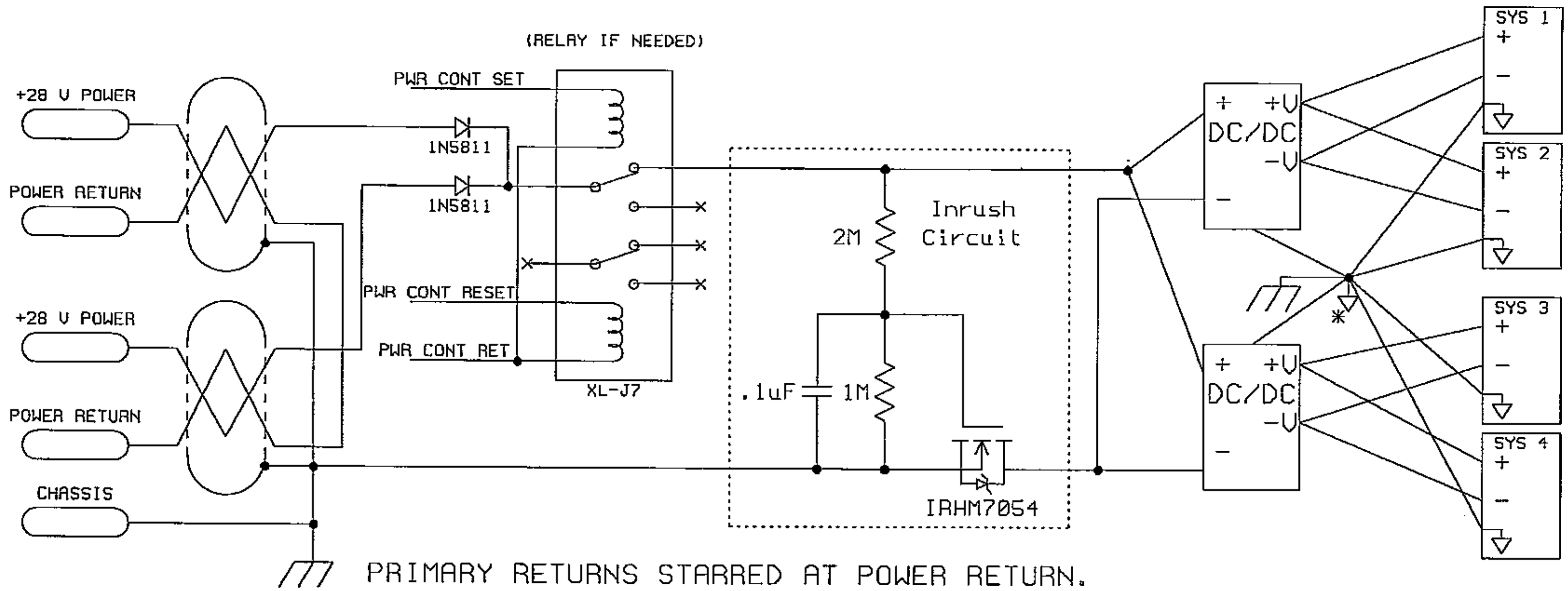


INTERFACE TO SUBUNIT / MONITORS



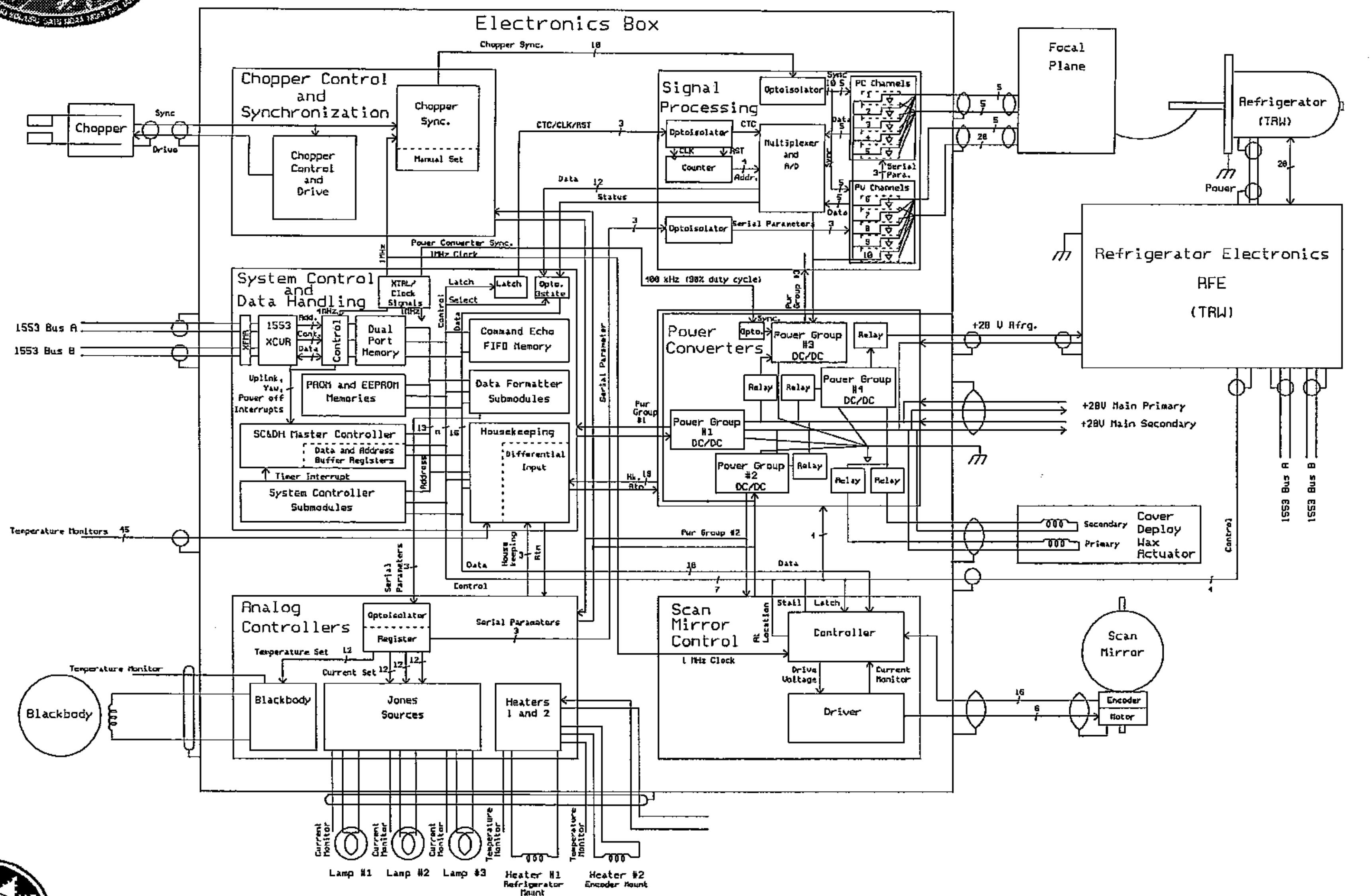
SYSTEM DESIGN
Power, Ground, and Signal Interconnects (continued)

TYPICAL POWER CONFIGURATION



PRIMARY RETURNS STARRED AT POWER RETURN.
SYSTEM RETURNS STARRED AT DC/DC RETURN.
* SEC DC/DC RETURNS STARRED AT GOUND PLANE.

SYSTEM BLOCK DIAGRAM



SYSTEM DESIGN
Subsystems

Signal Processing
- PC data channels (1-5)
- PV data channels (6-10)
- Multiplexer and A/D converter

System Control and Data Handling (SC&DH)
- System controller
- Data formatter
- 1553 interface
- Housekeeping and monitors

Analog Controllers
- Calibration controllers
  - Blackbody controller
  - Jones source controllers (1, 2, 3)
- Operational heater controllers (1 and 2)

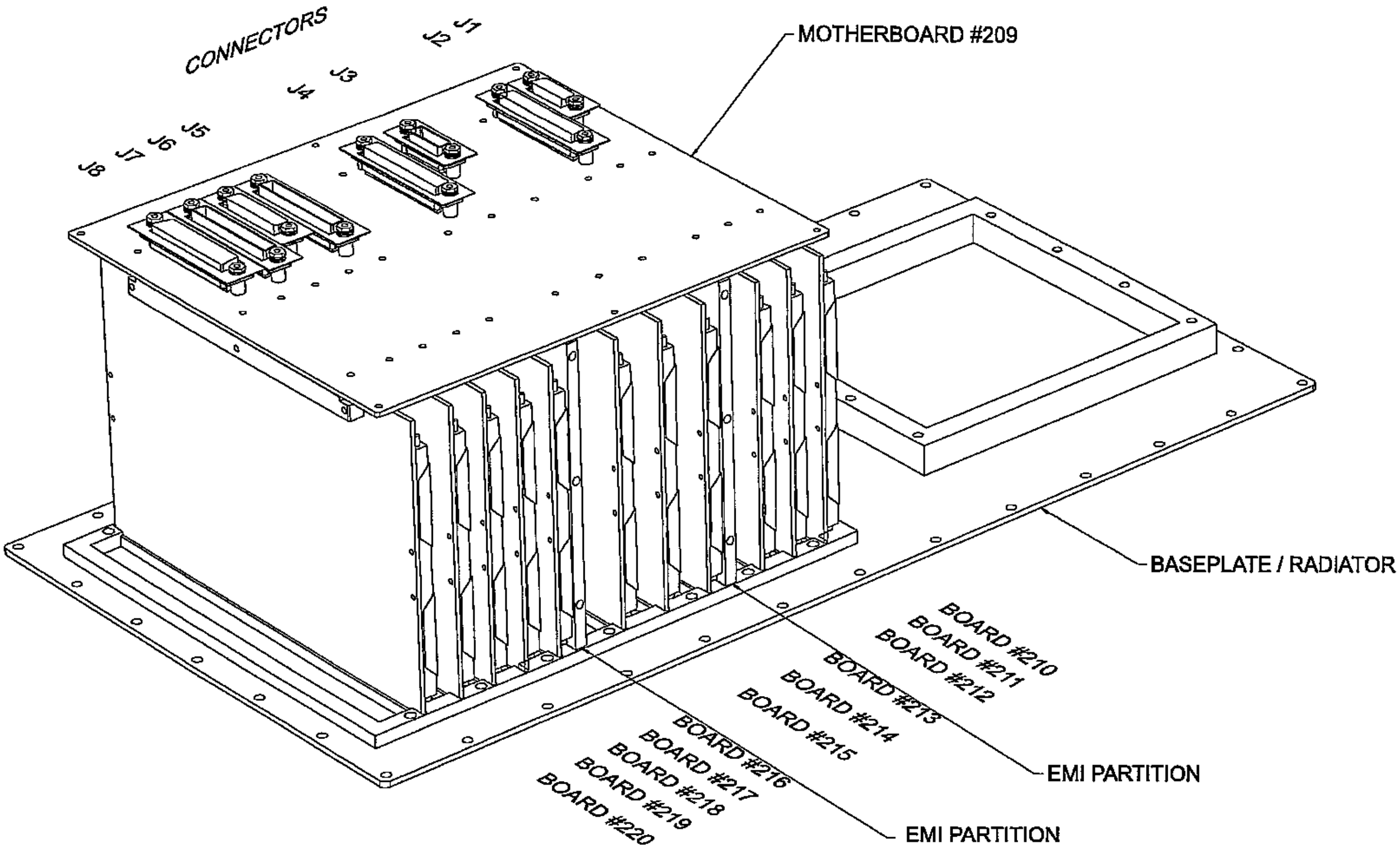
Chopper Control and Synchronization (CC&S)
- Chopper control and drive
- Chopper synchronization, delay adjustment for 10 data channels coherent rectification

Scan Mirror Control
- Scan mirror control and monitoring
- Scan mirror driver

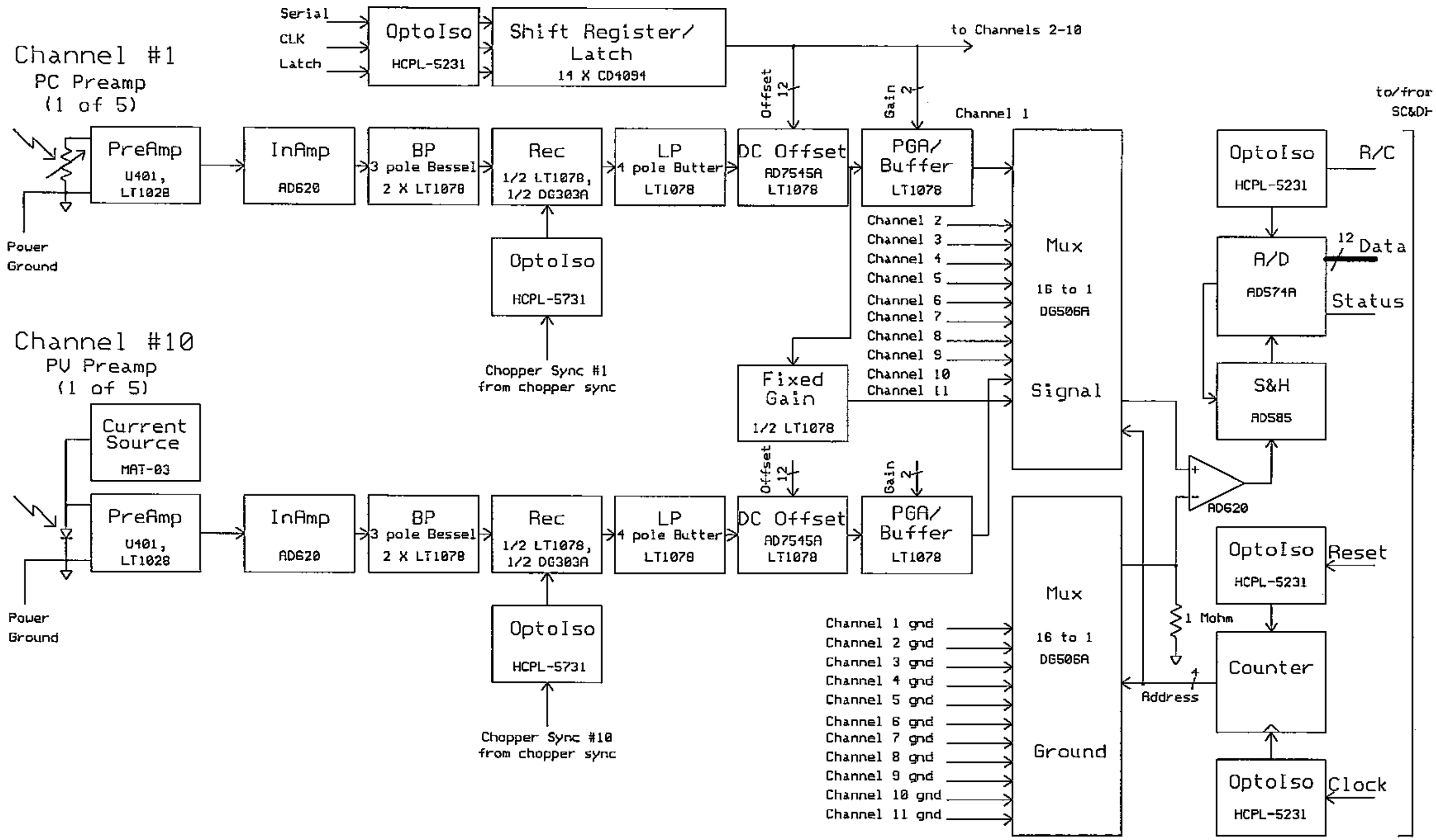
Power Converters
- DC/DC converters
- Power switching

Refrigerator Electronics (RFE) (TRW)
- Pulse tube refrigerator control and monitoring

SYSTEM DESIGN
Electronics Box Layout



SIGNAL PROCESSING BLOCK DIAGRAM



SIGNAL PROCESSING
Design Description

Method

- Analog signal processing utilizing coherent rectification (synchronize with chopper)
- Photoconductive (PC) preamplifiers for channels 1-5
- Photovoltaic (PV) preamplifiers for channels 6-10
- Differential multiplexed data channels into single A/D converter

Features

- Isolated preamplifiers
- 3-pole bessel bandpass filter prior to coherent rectification ⇒ removal of unwanted chopper modulation products
- 4-pole butterworth final low-pass filter ⇒ removal of 2nd harmonic created by coherent rectification
- Uplink programmable DC offset adjust ⇒ nulling of dark offset created by warm optics
- Programmable gain amplifier (PGA) ⇒ increase dynamic range of electronics
  - Intermediate gain ranges used to maintain SNR > 100
  - Automatic or manual gain changes
- Fixed gain channel 1 output used for adaptive scan reference computation (channel 11)
- Differential input multiplexer ⇒ data channel isolation

Heritage

Warm Infrared radiometer (WIRR)

SIGNAL PROCESSING
Status

Design: complete

Schematic: complete

Parts List: active and passive

Prototype Boards: 2 of 3 boards built, assembly and testing proceeding

Analysis:

- Preamp noise sources
- System noise
- DC drift
- PGA linearity
- Power requirements

Studies:

- Signal processing methods and modeling (coherent rectification)--document written in support of MathCAD system model

Breadboarding:

- 2 complete channels with digitizer (PC and PV)
  - Noise measured at 67% required NEN

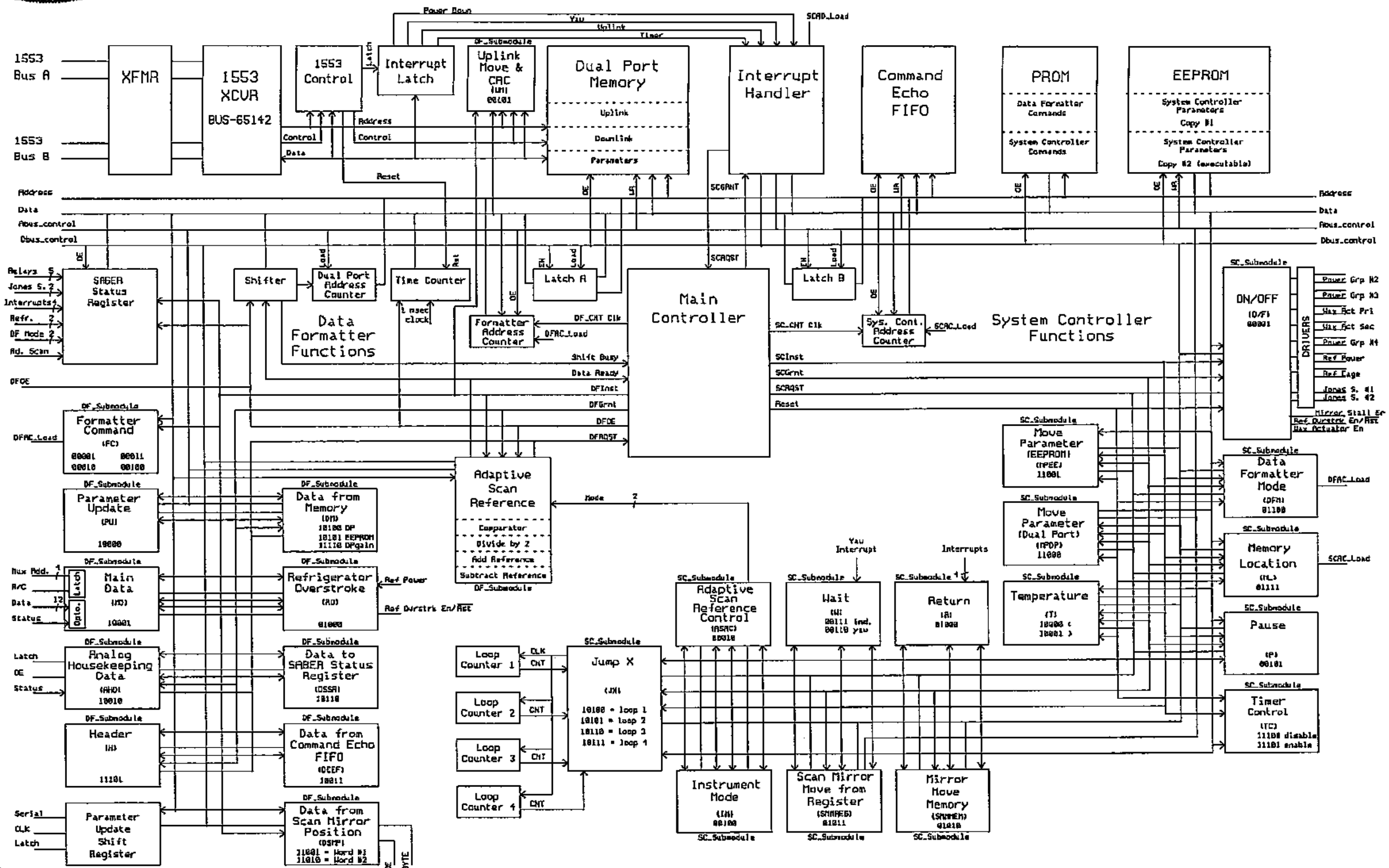
MCT detector test with PC channel breadboard:

- Noise measured at 2.67 counts
- signal response verified

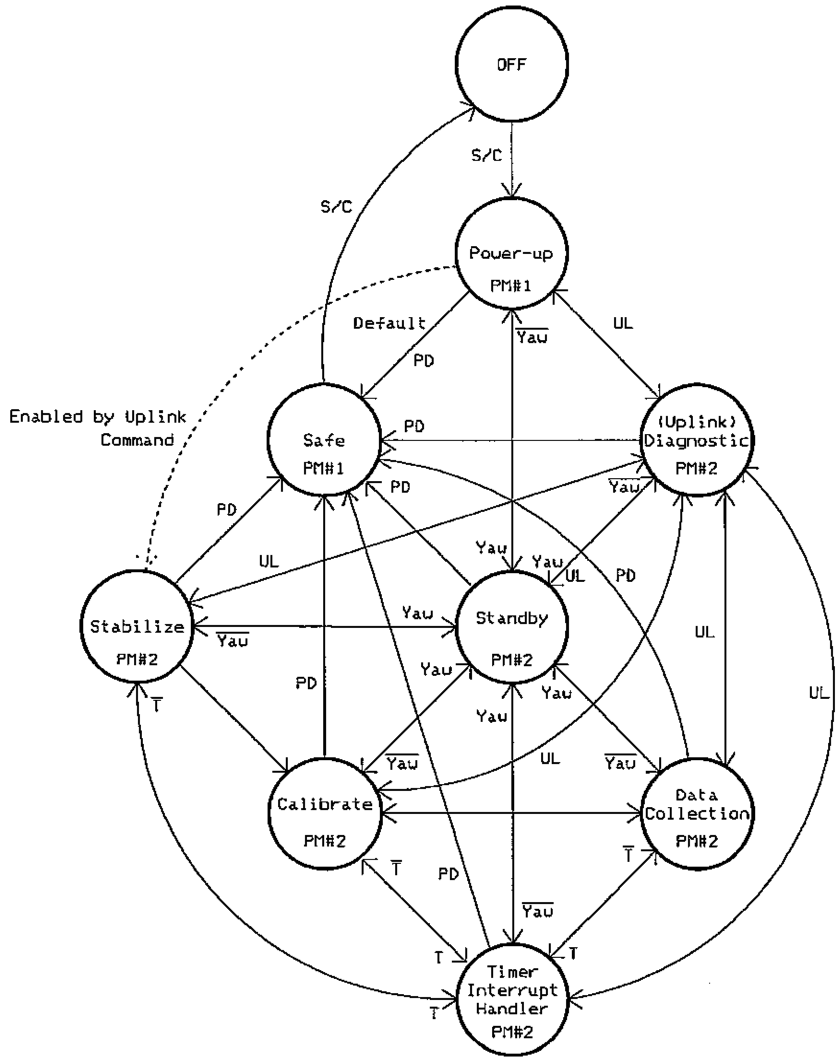
Simulation and Modeling:

- MathCAD system noise model
  - Signal response
  - System noise
  - Signal to noise ratio (SNR)
- MathCAD preamp noise model
  - noise components vs. frequency
- PSPICE
  - AC (frequency response)
    - Preamps, bandpass, coherent rectification, low-pass, PGA
  - DC
    - Offset, PGA
  - Transient (step response)
    - Preamp, bandpass, coherent rectification, low-pass, PGA, system
  - Temperature
    - PGA

SYSTEM CONTROL & DATA HANDLING BLOCK DIAGRAM



SYSTEM CONTROLLER & DATA HANDLING
System Controller Function



Interrupts (in order of priority):
- PD = power down
- Yaw = S/C yaw maneuver
- UL = uplink
- T = timer

Power Modes:
- PM#1--SC&DH, Operational Heaters
- PM#2--SC&DH, Operational Heaters, Analog Controllers, Scan Mirror, Chopper Control and Sync, AFE

SYSTEM CONTROLLER & DATA HANDLING
Design Description

Method

- 1553 isolated by dual-port RAM
- Integrated system control, and data formatter sharing common bus and memory
- Time multiplexed control ⇒ system controller bus activity during data formatter dead time
  - All modules run synchronous with each other
- 1553 controller, main controller, and submodules are state machine implemented in firmware (ACTEL A1280)

  ⇒ Predicted operation—limited number of states, all states defined, recoverable from upset

  ⇒ Not reconfigurable, insures reliability
- Commands identifying order of submodule execution, stored in PROM
- Parameters needed by submodules stored in EEPROM and RAM
- Uplink commands stored in ram — not permanently retained
- Parameters of permanently stored commands can be altered by uplink command

Heritage

- Skipper, CADO, Bowshock I,II, METEORS

SYSTEM CONTROLLER & DATA HANDLING
System Controller Features

- Interrupts handled (in order of priority):
  - Power down ⇒ safe mirror, turn off subsystems in an orderly manner
  - Spacecraft yaw maneuver ⇒ safe mirror
  - Uplink commands ⇒ halt operation and execute new commands
  - Timer ⇒ when timer trips, execute timer handler commands
- After interrupts, return to where interrupted
- Uplink control
  - Single commands or blocks of commands
  - Change command parameters (permanent)
  - Change parameters associated with subunits such as refrigerator temperature, blackbody temperature, Jones source current, dark offsets on each channel (permanent)
  - Return to command where interrupted or new command location
  - Remain in uplink mode until return is sent
  - CRC check
- Switch subunits on/off
- Refrigerator — cage/uncage, vibration cancellation on/off, shut-down if overstroke (override)
- Deploy cover, control time wax actuators are on
- Change data formatter mode to data collection, housekeeping, or memory dump
- Move scan mirror to any location
- Reset scan mirror if command is not executed determined by changeable time-out or stall
- Scan mirror shut-down if continue to stall (override)
- Loop back in command blocks (# is changeable)
- Set programmable gains or allow automated operation
- Change which command blocks are executed
- Halt operation until a parameter comes within range such as refrigerator, blackbody, or heater temperature
- Halt operation up to 1.82 hours
- Halt operation until an uplink command is issued
- Halt operation until a yaw maneuver is done
- Interrupt operation within 17 minutes of a certain UT
- Control operation of the adaptive scan reference
- Executed commands and parameters echoed in downlink data stream

SYSTEM CONTROLLER & DATA HANDLING
System Controller Limitations

- Cannot overwrite existing commands
- Cannot uplink permanent commands
- Cannot overwrite subunit control (firmware)
- No loop back capability in uplink command list (illegal)
- Cannot exit from power down interrupt — only exit is for spacecraft to follow through and remove power
- An uplink cannot cause an exit from yaw maneuver interrupt--only exit is yaw interrupt flag reset by spacecraft or power down interrupt
- Cannot have multiple time tagged events (only one at a time)

SYSTEM CONTROLLER & DATA HANDLING
Data Formatter Features

- Three formats — data collection, housekeeping, and memory dump
- Sample data channels at every 44 ms (22.73 samples per second)
- Complete sample of housekeeping every 15.8 seconds
- Implement user determined telemetry matrix stored in PROM — format can be altered on ground only by burning a new PROM
- Update parameters needed by other systems — rate determined by frequency of command in PROM telemetry matrix
- Insert CCSDS header
- Insert time to 1 ms resolution
- Monitor SABER status — relays, Jones sources on/off, adaptive scan reference on/off, refrigerator cage/uncage, refrigerator vibration on/off, data formatter mode, active interrupts, scan mirror status, system controller submodule active
- Echo commands and data parameters executed by the system controller
- Scan mirror location

Data Formatter Limitations

- Cannot be turned off
- Cannot overwrite existing telemetry matrix formats stored in PROM
- Cannot change sampling rate of data or housekeeping
- Cannot change the rate parameters are updated to other systems

SYSTEM CONTROLLER & DATA HANDLING
Design Description (continued)

1553 Features:

- ILC DDC BUS-65142 remote terminal hybrid
- Dual redundant bus capability
- Supports all 13 mode codes
- Mode code/command word illegalization
- DMA-type transfers
- Built-in-test word register
- Continuous self-test

SYSTEM CONTROLLER & DATA HANDLING
Status

Design:
- State diagrams: complete
- VHDL code: complete, compiled
- FPGAs defined, code compiled, fit checks
- Commands defined
- Command blocks defined

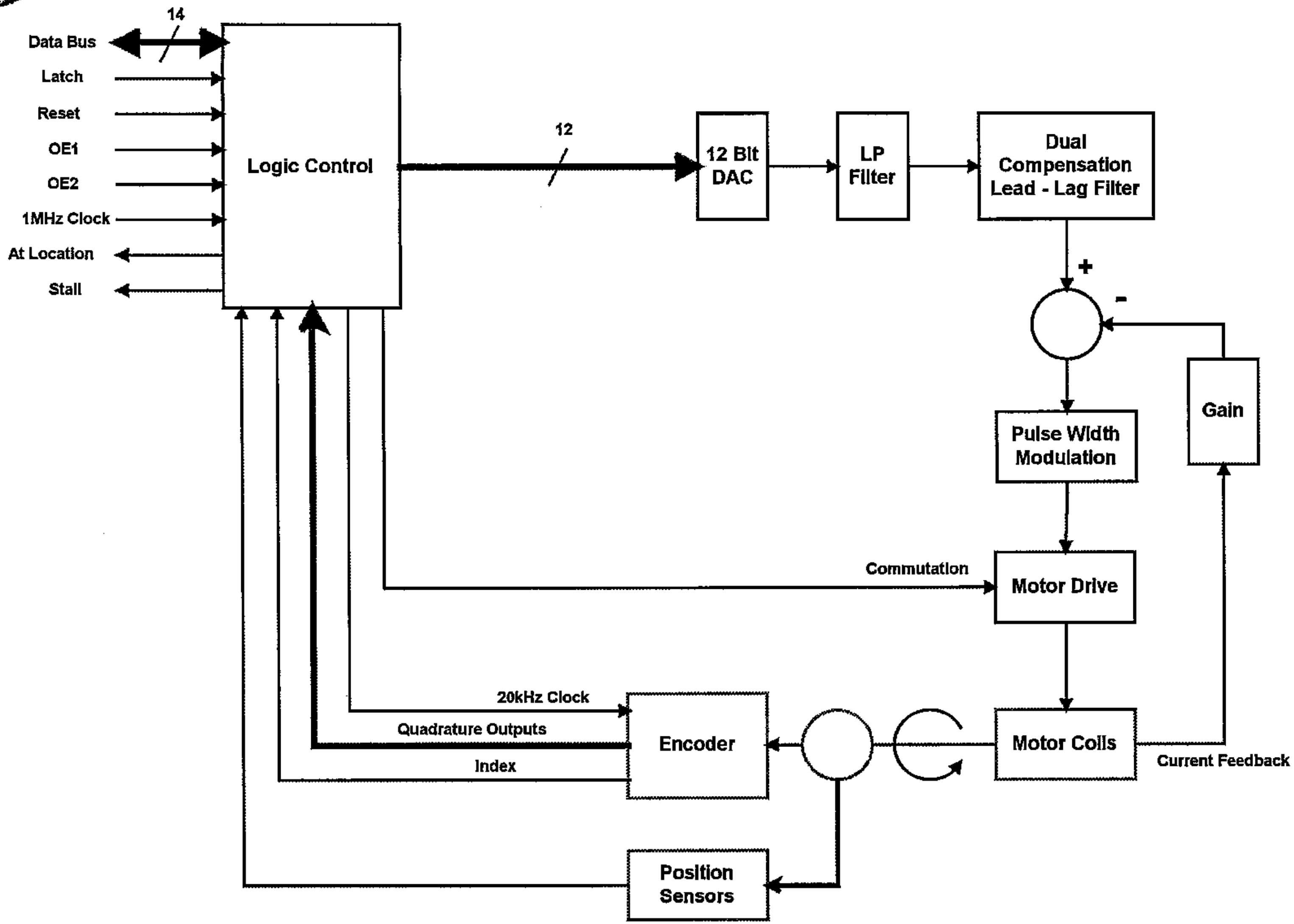
Schematic: complete

Parts List: active and passive

Prototype Board:
- Assembled
- Testing has begun

Simulation:
- Viewlogic simulations
  - Main controller
  - Submodules
  - Supporting logic

SCAN MIRROR CONTROLLER BLOCK DIAGRAM



SCAN MIRROR CONTROLLER
Design Description

Method

- Closed-loop control of mirror using conventional analog and digital circuitry
- Digital interface to instrument controller
- Velocity and position feedback control
- Pulse-width modulation (PWM) drive
- Motor commutation derived from hall-effect sensors

Features

- Scan control independent of instrument control
- Command format:
  - Position (12-bit)
  - Rate (2-bit) — scan, calibration (1/4 scan velocity), slew, fast slew (2 * slew velocity)
- Brushless DC servo motor for scan mirror positioning
  - Direct drive, pancake configuration allows integration into mirror mechanism
- 20 bit BEI relative optical encoder
  - Quadrature output with single index

Heritage

- BEI heritage: numerous programs such as SEAWIFS, UARS, HUBBLE

SCAN MIRROR CONTROLLER
Status

Design: complete

Schematic: complete

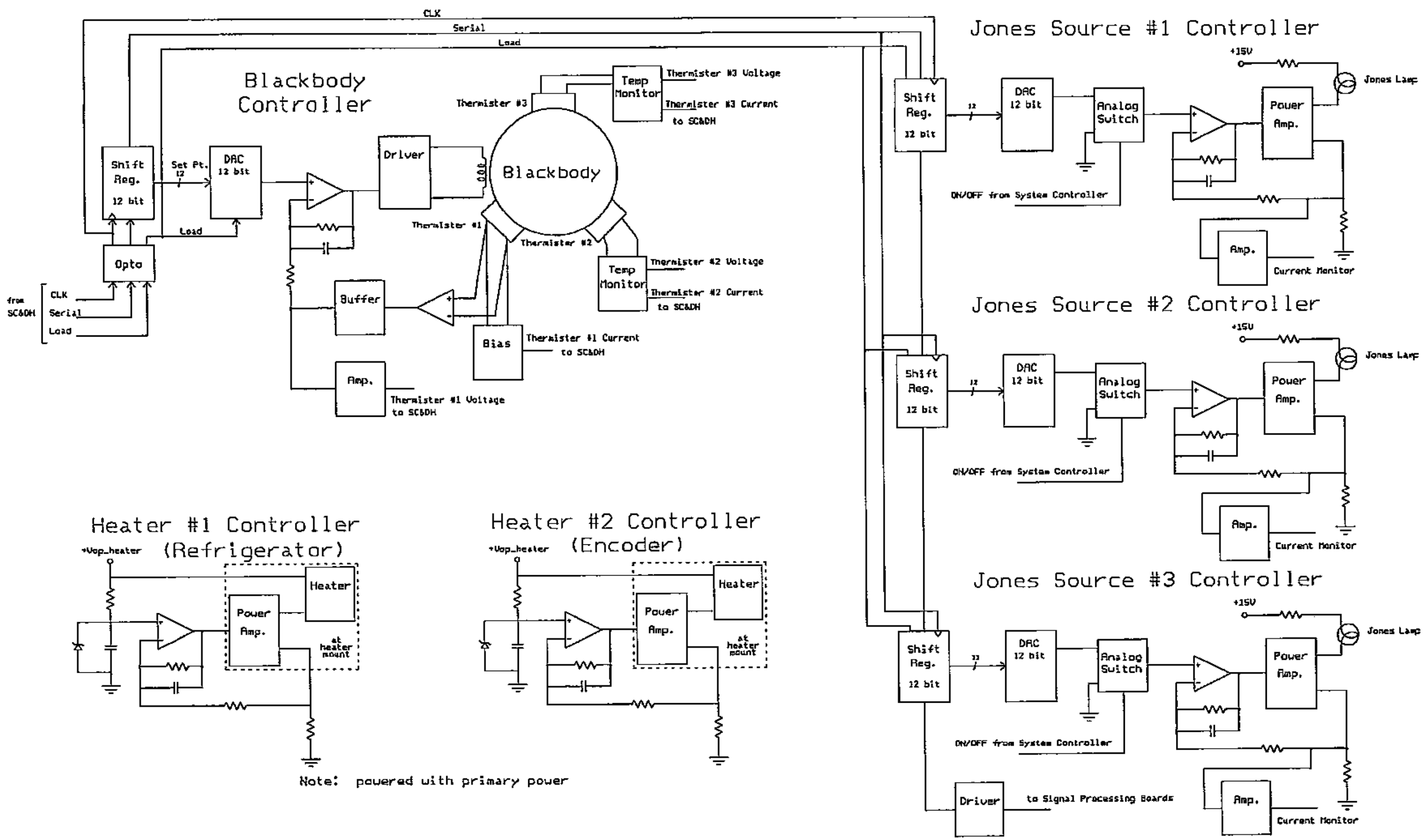
Parts List: active and passive

Prototype Board: layout complete, under review

Analysis:
- Gain calculations
- Power requirements

Simulation:
- MatLab control law model (LaRC)
- PSPICE
  - AC (frequency response)
    - Filters
  - Transient
    - Filters, pulse width modulation, drive circuitry

ANALOG CONTROLLERS BLOCK DIAGRAM



ANALOG CONTROLLERS
Design Description

Blackbody Controller

Method
- Phase-lag analog linear controller

Features
- Adjustable temperature set point changed by uplink command
- Temperature range: 218 to 280 K
- Nominal temperature: 250 K

Heritage
- SPAS

Heater Controllers

Method
- Phase-lag analog linear controller

Features
- Fixed temperature set point
- Nominal temperature: 255 K
- Heater power range
  - Refrigerator: 0 to 54.1 W @ 28 V
  - Encoder: 0 to 12.4 W @ 28 V

Jones Source Controllers

Method
- Phase-lag analog linear controller

Features
- Adjustable lamp current set point changed by uplink command
- Current set range: 0 to 134 ma (0 to 2192 K bulb temperature)
- Nominal setting: 115 mA

Heritage
- SPIRIT III

ANALOG CONTROLLERS
Status

Design: complete

Schematic: complete

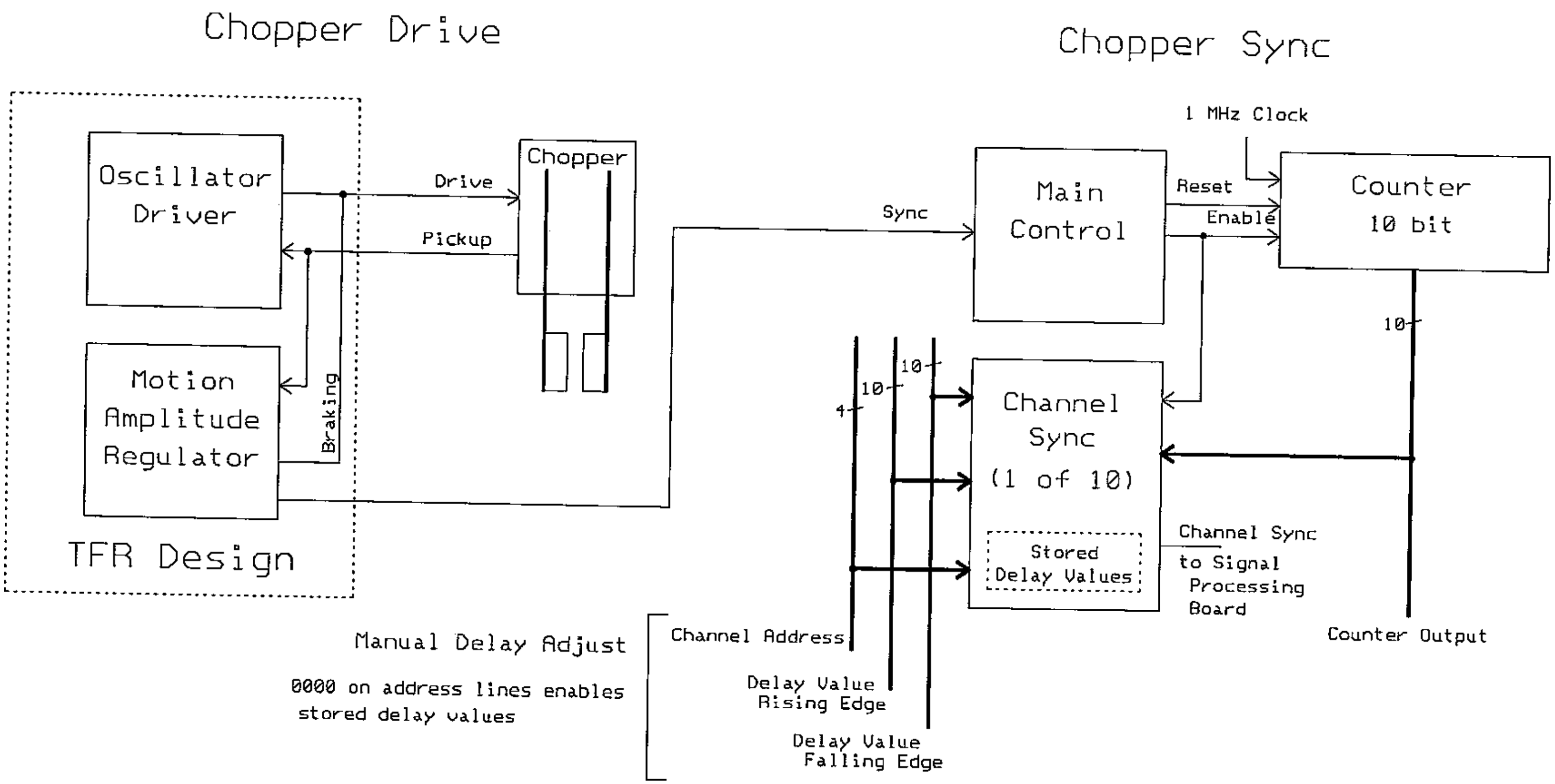
Layout: in progress

Parts List: active and passive

Analysis:
- Power requirements
- Blackbody controller
  - Stability vs. temperature and time
- Jones source controllers
  - SPIRIT III analysis

Simulation:
- Blackbody controller
  - MatLab control law model
    - Stability
    - Turn-on transient
- Jones source controllers
  - PSPICE
    - Transient (step response)

CHOPPER CONTROL AND SYNC BLOCK DIAGRAM



CHOPPER CONTROL AND SYNC
Design Description

Chopper Control and Drive (TFR design)

Method

- Free running oscillator drive, operates at chopper mechanical resonant frequency

Features

- Motion amplitude regulator
- Chopper sync output

Heritage

- CIRRIS 1A

Chopper Synchronization

Method

- Digital delay set for each channel

Features

- Delay set in 1 μsec steps
- Delay adjustment for both rising and falling edge $\Rightarrow$ adjustable duty cycle
- Manual adjustment for each channel with final values stored in firmware

Heritage

- CIRRIS 1A

CHOPPER CONTROL AND SYNC
Status

Design:

- Chopper controller — TFR design complete
- Chopper synchronization
  - Analog design complete
  - Logic design — state diagrams and VHDL code complete

Schematic: complete

Layout: in progress

Parts List: active and passive

Analysis:

- Power requirements

REFRIGERATOR ELECTRONICS (TRW)
Description

- SSTI Pulse Tube Cryocooler Control Electronics (PTCCE) built by TRW
  - Three 4.0" x 6.0" PC boards
    - Control board
    - Analog board
    - Power filter and DC/DC converter board
  - Motherboard with 1553 interface
- Drives motor of refrigerator
- Monitors temperature, position, and acceleration sensors of refrigerator
- Provides temperature control and vibration control (adaptive vibration cancellation)
- Interfaces for command, housekeeping, and 28 V primary power
- Commands for temperature setpoint override default setpoint
- Provides tripout if an overstroke condition occurs, resets and resumes operation
- Motor frequency between 32 to 127 Hz set with eight on board jumpers
- Cycling power will reset PTCCE to its normal operating mode and default temperature setting
- Primary and secondary DC/DC converters (can switch between units)

REFRIGERATOR ELECTRONICS (TRW)
Refrigerator Interface

1553 commands
- Temperature set (10 bit)
- Reset
- Vibration cancellation on/off

Discrete commands
- Motor cage (relay)
- Motor uncage (relay)
- Primary DC/DC converter enable
- Secondary DC/DC converter enable
- Switch to primary DC/DC converter (relay)
- Switch to secondary DC/DC converter (relay)

Power inputs
- $+28 \pm 6$ V
- 10.0 W

1553 housekeeping data
- Accelerometer (0-5 V AC)
- Cold finger temperature (0-5 V DC)
- Compressor position (0-5 V avg)
- Compressor motor current (0-5 V avg)
- Balancer position (0-5 V avg)
- Balancer motor current (0-5 V avg)

SSTI PEA ELECTRONICS

- **Developed from a Brilliant Pebbles prototype design**
- **Designed for low cost with class B parts in benign environments**
- **Engineering and flight model cards and unit developed and qualified for SSTI**
  - HSI experiment; (1) refrigerator system
  - LEISA (GFE) experiment; (1) refrigerator system
- **Engineering model card set (baseline for SABER) was last (3rd) set built; used extensively for functional flight testing of the HSI payload**

SSTI PEA QUALIFICATION

- **PEA Component / Board Level**
  - Random vibration, proto-flight level
    - 14.14 grms
    - Knee points, g^2/Hz
      - 20 Hz, 0.26
      - 50 Hz, 0.16
      - 800 Hz, 0.16
      - 2000 Hz, 0.26
      - 1 minute each of 3 axes
  - 8 thermal cycles (powered but not operating a refrigerator)
    - -20 C to +60 C
  - EMI (box aliveness only, no refrigerator loads)
    - MIL-STD-461C tailored
- **HSI Payload Level**
  - Refrigerator functional operation only
    - PEA operating at ambient conditions

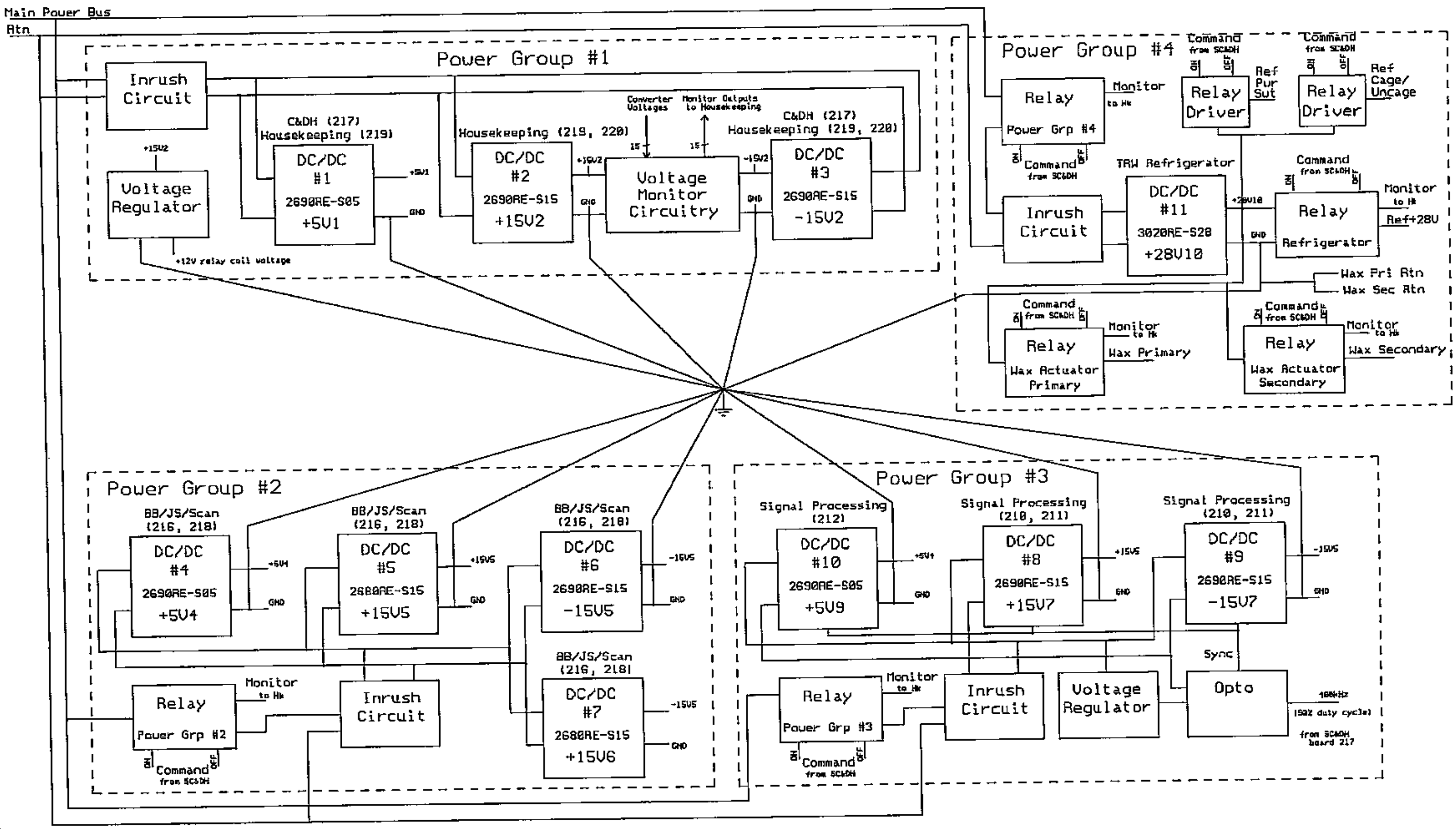
SSTI PEA QUALIFICATION (continued)

- **SSTI Spacecraft Level**
  - Thermal vac (unpowered PEA)
    - 4 cycles @ -20 C to +60 C
  - Random vibration (unpowered PEA)
    - 5.5 grms
    - 3 axis, 1 minute each
  - Spacecraft separation pyroshock test (2 x)
    - 100 Hz, 25 g; 2000 Hz, 1500 g
  - PEA functional test
    - aliveness only in ambient air

EM CARDS

- **Built to same level as SSTI cards**
  - Same solder flow process (vapor phase re-flow)
  - Same qualified assembler
- **Some subsequent SIT parts added by engineer during acceptance testing will be replaced by qualified assemblers for SABER**
- **Microprocessor will be replaced for SABER because pins were cut too short to meet TRW workmanship criteria**

POWER CONVERTERS
Block Diagram



POWER CONVERTERS
Design Description

Method

- Use dense, high efficient DC/DC converters, Modular Devices Inc.
  - 2690RE (6.5 W), 2680RE (30 W), 3031RE (70 W)

Features

- Isolated design
- Power on soft start
- 200 kHz operation for low ripple and fast response time
- Built-in EMI input filter meets MIL-STD-461C requirements CE01, CE03, CE07, CS01, and CS02
- Built-in output spike and EMI filter
- Short circuit and overvoltage protection
- Capable of externally synchronizing switching frequencies

Heritage

- DC/DC converters — Skipper, Mars Pathfinder, used by major military and aerospace firms and US government agencies

POWER CONVERTERS
Status

Design: complete

Schematic: complete

Layouts: in progress

Parts List: active and passive

Testing:

- DC/DC converters
  - Noise
  - Isolation
  - Turn-on transients
  - Efficiency
  - Output capacitive loading
- In-rush circuit
  - Breadboard tested with DC/DC converters

INTERCONNECT
Design Description

Method

- Box — motherboard supporting 11, 6 × 9 inch cards
- Shielded subminiature D connectors used where possible
- Cabling shielded

Features

- Box — connectors to outside world located on backside of motherboard
- Box — signals not routed through entire motherboard; only localized
- External signals enter and leave motherboard near board of origin or destination
- Multilayer motherboard incorporating ground planes

Status

Design: complete

Wiring Diagrams: complete

Parts List: passive

Prototype Motherboard: assembled and tested

SUMMARY

- Specifications meet requirements
- Design complete
- Analysis, modeling, simulation, and test results available

THERMAL DESIGN AND ANALYSIS

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20 October 1997

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OUTLINE

- Flow down requirements
- Design changes to thermal design since PDR
- Overview of instrument thermal design
- Performance charts
- Summary

FLOW DOWN REQUIREMENTS

- **Requirement 1 — 2 Year Mission Life**
  - Implications
    - Eliminates use of cryogen (550 kg or 540 liters)
- **Requirement 2 — 75 K Focal Plane Temperature**
  - Implications
    - Eliminates use of a passive radiator to cool the focal plane
    - Implies cooling by a mechanical refrigerator
- **Requirement 3 — Mass, Power, and Volume Constraints**
  - Implications
    - Eliminates high capacity refrigerators (too power hungry)
- **Requirement 4 — Spacecraft to SABER Conducted Resistance > 5.0 K/W**
  - Implications
    - Minimizes thermal interaction between spacecraft and instrument
    - Mechanical interface less stiff than direct mount
- **END RESULT**
  - TRW's miniature long life pulse tube refrigerator selected to cool the focal plane
  - Optics radiator to cool telescope, reduce parasitic heat loads, and background noise
  - Refrigerator/electronics radiator to reject instrument electronics heat

CHANGES TO THERMAL DESIGN SINCE PDR

- Focal plane assembly support method changed from FiST (fiber support technology) approach to a folded G-10 tube design
- Radiator surface coating changed from 5 mil FEP Silverized Teflon to 10 mil FEP Silverized Teflon
- Standoff scheme to the spacecraft shortened slightly to enhance mechanical stiffness
- Supported slightly in front of spacecraft (no longer flush mount)
- TIDI has crept into thermal field of view (minimal)
- Power increase on TRW electronics of ~5.1 W from 6.5 W to 11.6 W
- Power increase from DC/DC converters of ~ 5.8 W
- Power increase of ~ 1.5 W on scan motor/encoder assembly from 2.6 W to 4.1 W
- Power savings in SABER electronics of ~ 7.1 W from 32.8 W to 25.7 W
- Moved transistors to mount with heating elements (avoid running through DC/DC converters), saving ~ 9.1 W

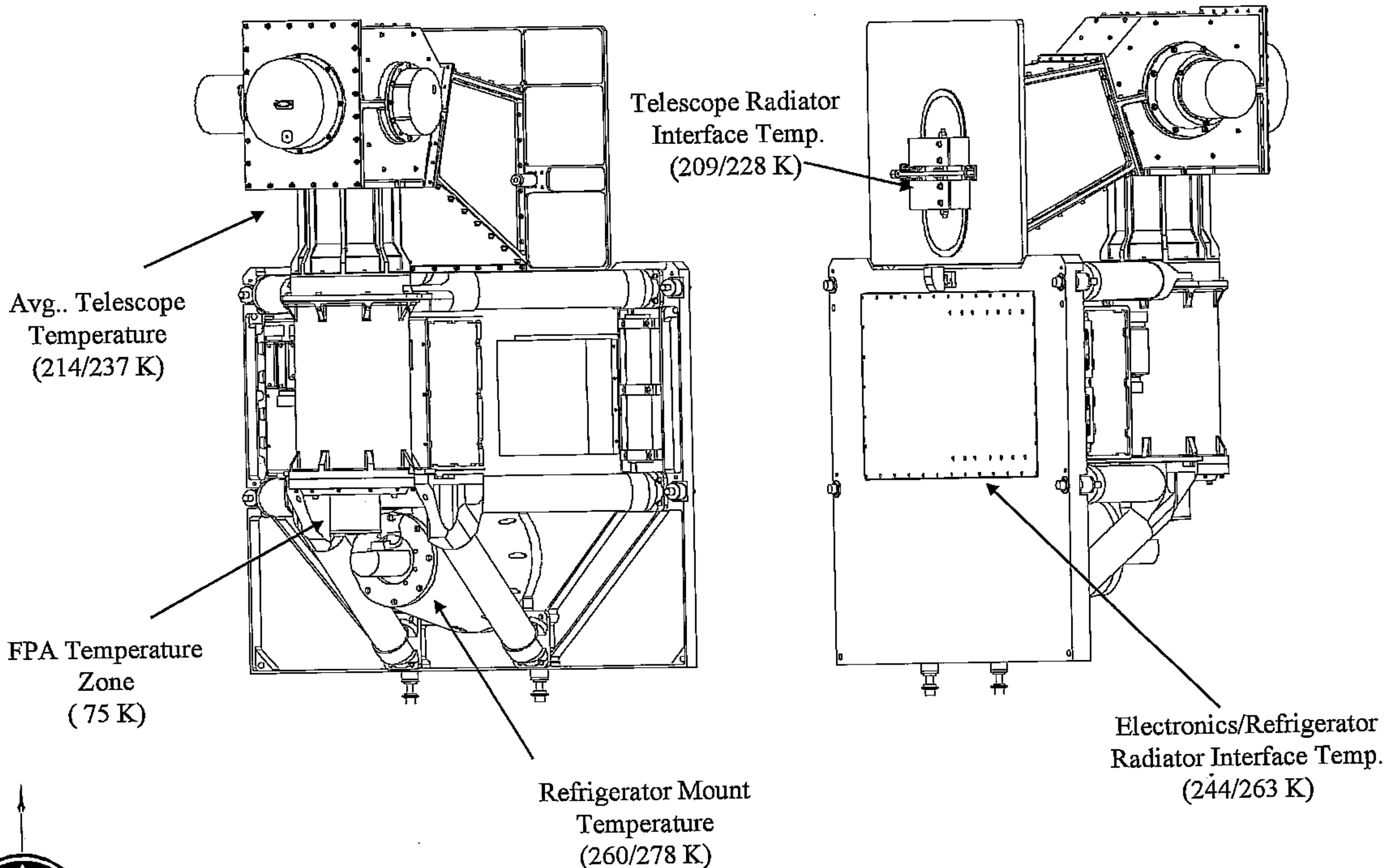
THERMAL DESIGN PARAMETERS

- **Extreme Hot Case**
  - Absorbtivity =.21
  - Emissivity =.85
  - Solar Flux = 1419 W/m^2
  - Albedo = 568 W/m^2
  - Earthshine = 268 W/m^2
  - Beta Angle = 0
  - Orbit Altitude = 555 km
    - Circular
  - Inclination = 74.5 degrees
  - Spacecraft Temperatures
    - Operating
      - +Y Panel = 303 K
      - Interior = 323 K
    - Survival
      - +Y Panel = 333 K
      - Interior = 333 K

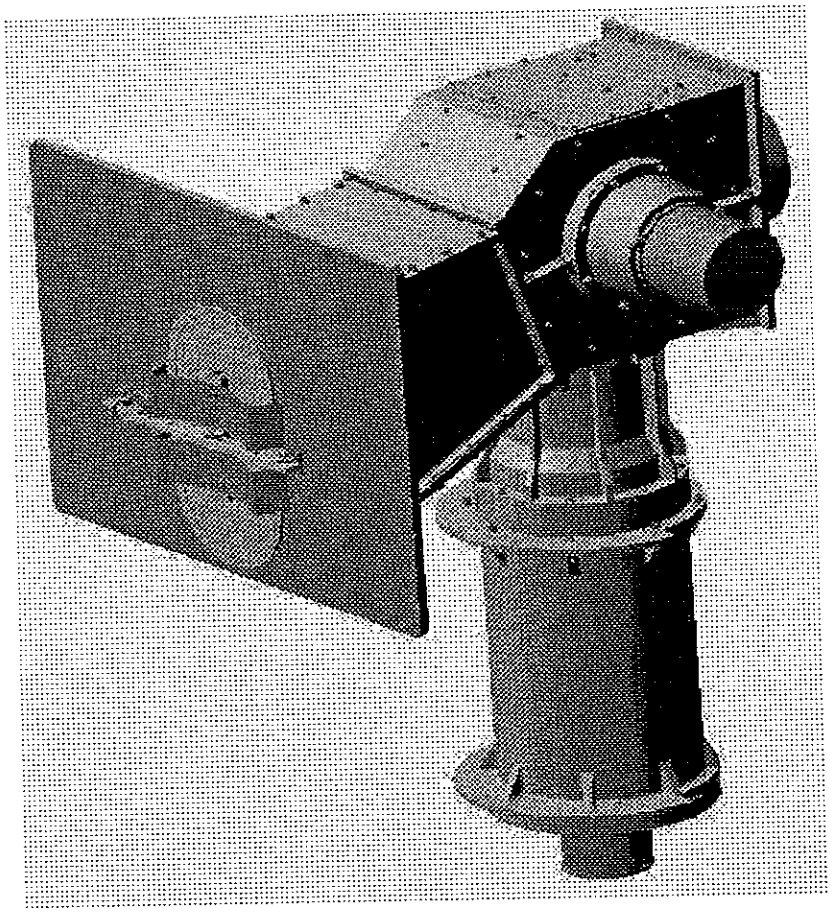
- **Extreme Cold Case**
  - Absorbtivity =.09
  - Emissivity =.88
  - Solar Flux = 1286 W/m^2
  - Albedo = 267 W/m^2
  - Earthshine = 189 W/m^2
  - Beta Angle = 90
  - Orbit Altitude = 650 km
    - Circular
  - Inclination = 74.5 degrees
  - Spacecraft Temperatures
    - Operating
      - +Y Panel = 244 K
      - Interior = 253 K
    - Survival
      - +Y Panel = 239 K
      - Interior = 239 K

* These numbers are agreed upon by the thermal engineers from APL, Langley, and SDL.
These numbers represent a compilation of data from various sources.

TEMPERATURE ZONE OVERVIEW
Extreme Cold Case/Extreme Hot Case



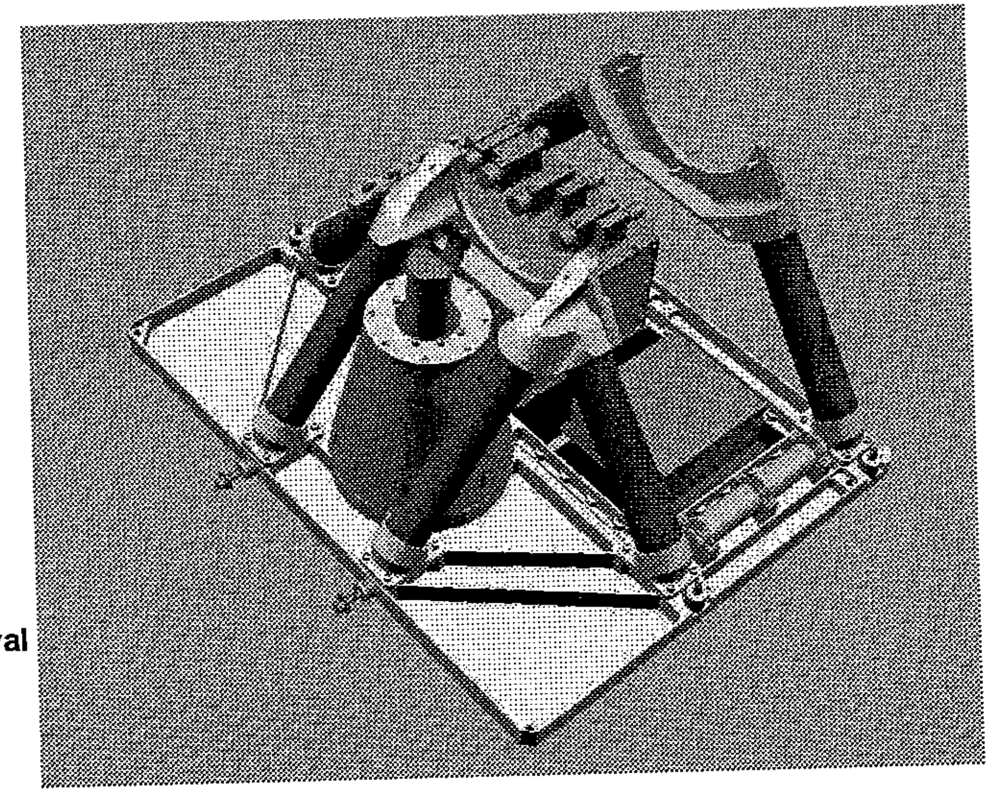
TELESCOPE TEMPERATURE ZONE



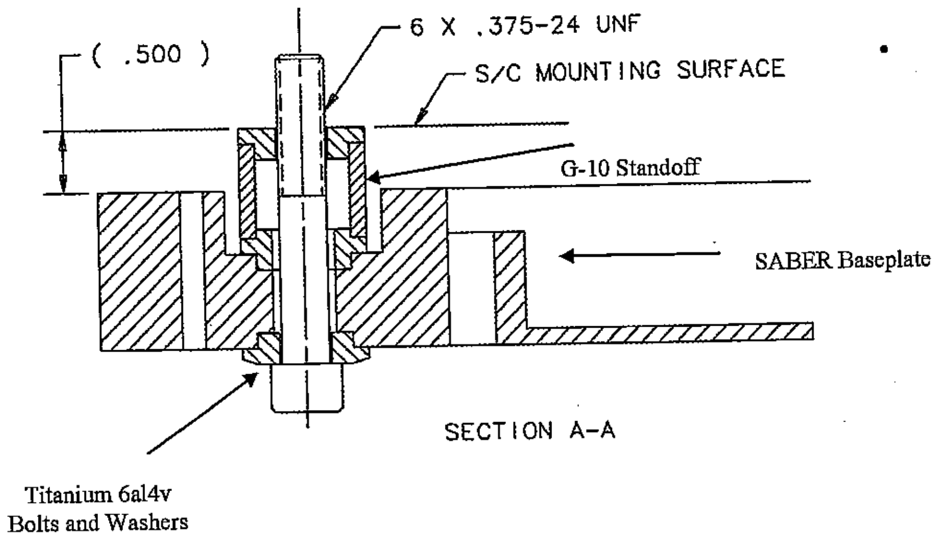
- **Cooled by optics radiator (+Y panel)**
  - Radiator interface temp. 209/228 K
- **Radiator area = .185 m^2**
- **Temperature gradients**
  - Radiator interface to FPA interface
    - ~ 11 K
  - Radiator interface to encoder/motor
    - ~ 12 K
- **Thermally isolated from spacecraft by G-10 struts and MLI blanketing**
- **Proportional heaters used in the cold case to maintain a minimum operational encoder temperature of 223 K**
- **Heaters used to maintain encoder/motor assembly above 208 K in survival mode**

REFRIGERATOR/ELECTRONICS TEMPERATURE ZONE

- Cooled by refrigerator/electronics radiator (+Y panel)
  - Radiator interface temp. 244/263 K
- Radiator area = .46 m^2
- Thermally isolated from spacecraft by G-10 washers and MLI
- Minimum refrigerator reject temperature set to 260 K
- Delta T across refrigerator mount ~ 10 K
- Proportional heaters used to maintain refrigerator mount at a minimum operational temperature of 260 K in cold case
- Survival heaters used to maintain refrigerator mount temperature at or above 235 K in survival mode



SPACECRAFT THERMAL STANDOFF

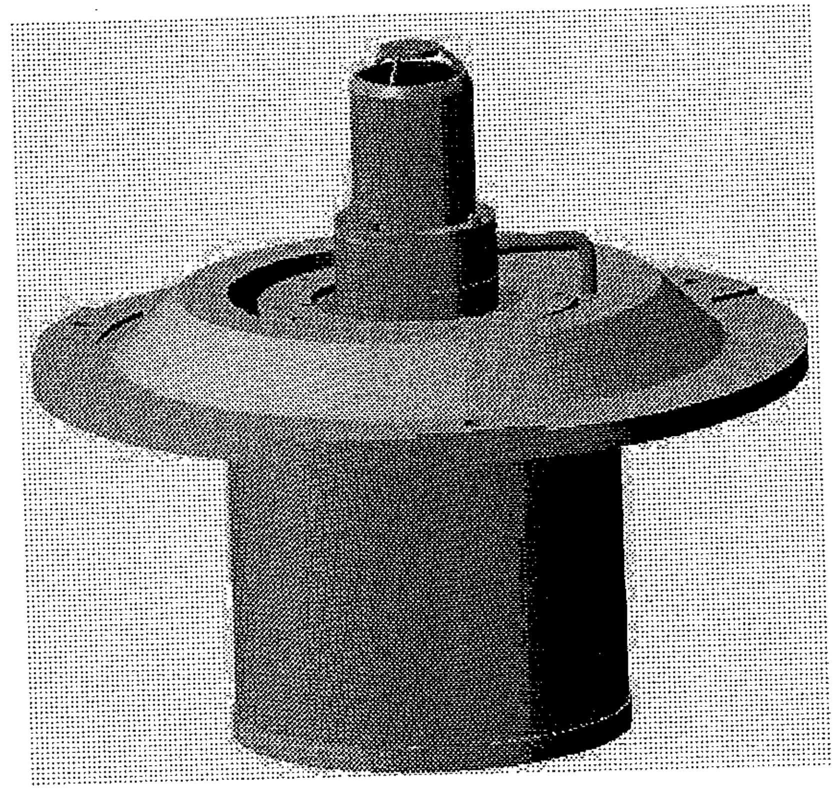


- **Number of bolts = 6**
- **Spacecraft interface resistance 5.5 K/W**
- **Hot case — Beta=0 heat leak (operational)**
  - 7.26 W received from spacecraft
- **Cold case — Beta=90 heat leak (operational)**
  - Refrigerator mount set point of 260 K
    - .045 W received from spacecraft

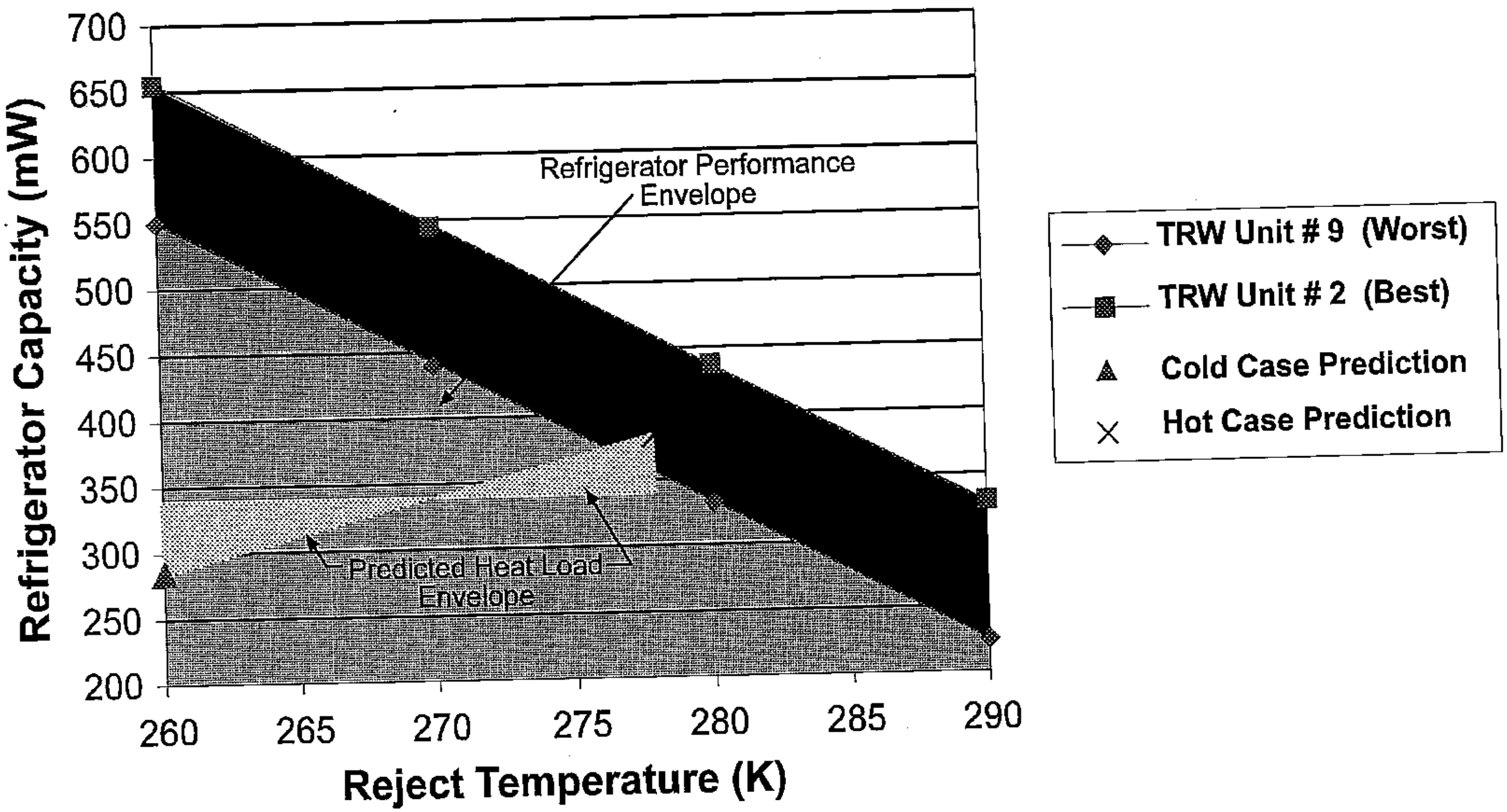
FPA TEMPERATURE ZONE

- Cooled by TRW miniature pulse tube refrigerator
- Detector operating temperature 75 K
- Folded G-10 tube support approach
- Predicted 1st natural resonant frequency of ~256 Hz
- Predicted heat load breakdown

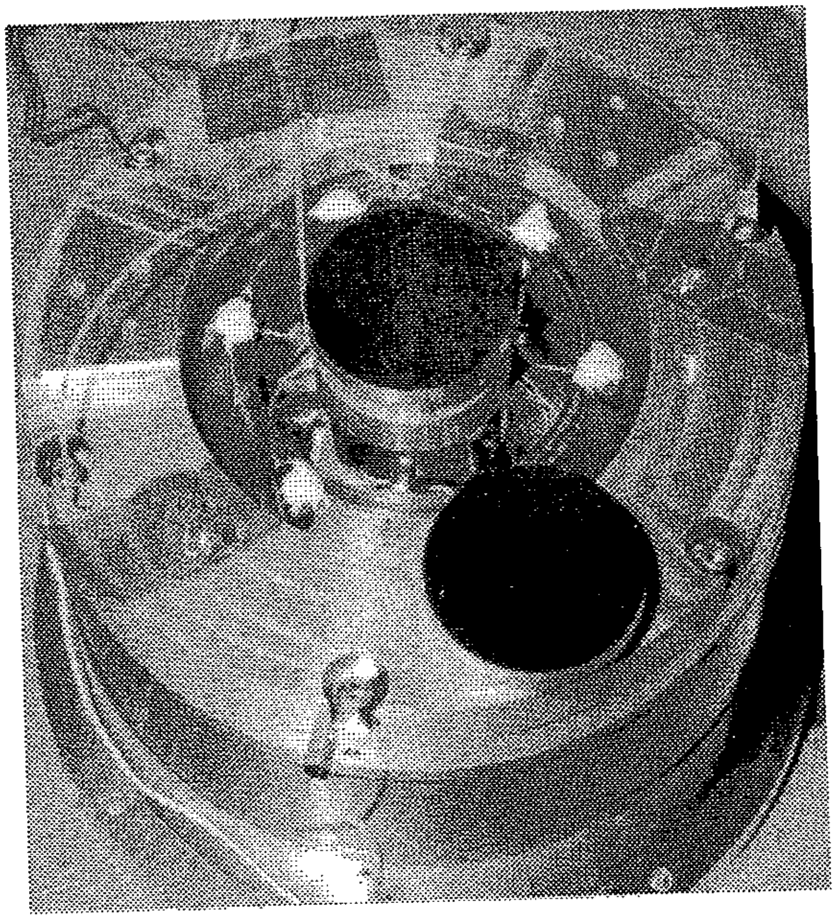
Description	Hot Case	Cold Case
G-10	65.0	62.0
Wiring	54.0	48.0
Detectors	44.0	44.0
Aperture	60.0	45.0
Radiation	161.0	85.0
TOTAL	**384.0**	**284.0**



MARGIN ON REFRIGERATOR CAPACITY



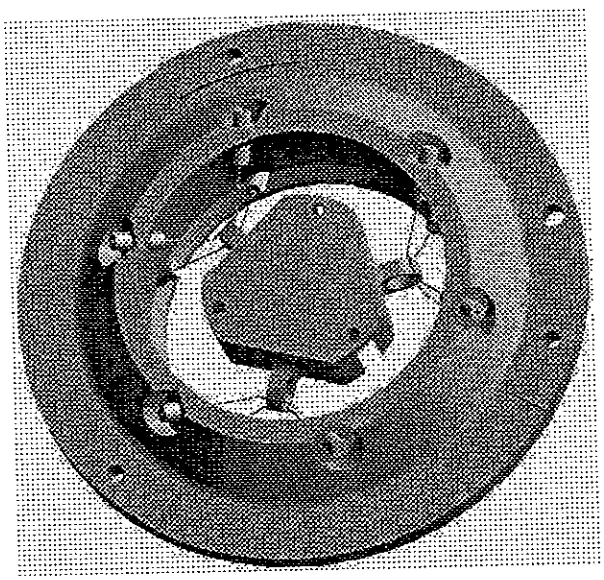
FiST OPTICAL STABILITY TESTS



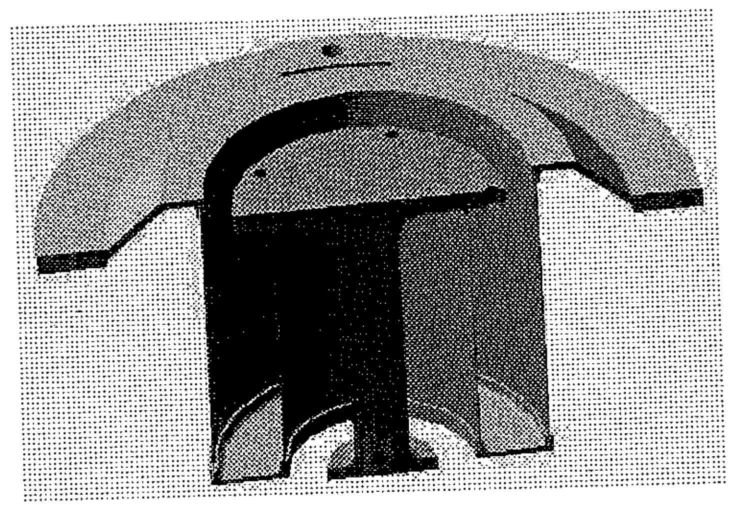
- Shake tests performed and optical measurements made before and after shake to verify repeatability — Results were promising
- Thermal cycle tests were performed to determine if thermal cycling affected optical stability — After approximately 5 cycles, a "crawling" trend in the relative angle between the two mirrors was noticed
- Concern over schedule led to a decision to baseline traditional folded tube support system

FPA SUPPORT APPROACH COMPARISON

- **FiST (Fiber Support Technology)**
  - Heat loads predicted and correlated to test breadboard (Hot Case = 285 mW)
  - Measured 1st natural resonant frequency ~ 700 Hz
  - Optical stability tested—Repeatability problems due to assembly quality control
  - Experimental prototype (concept never flown)



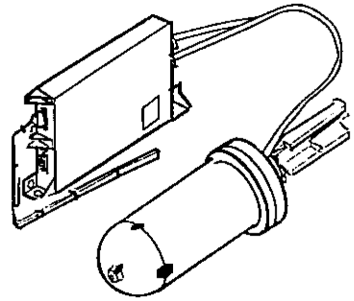
- **Folded G-10 Tube**
  - Heat loads predicted (Hot Case = 384 mW)
  - Predicted resonance based on IDEAS model ~ 256 Hz
  - Optical stability predicted to be repeatable
  - Similar concepts flown in the past with success



Miniature Pulse Tube Space Cooler

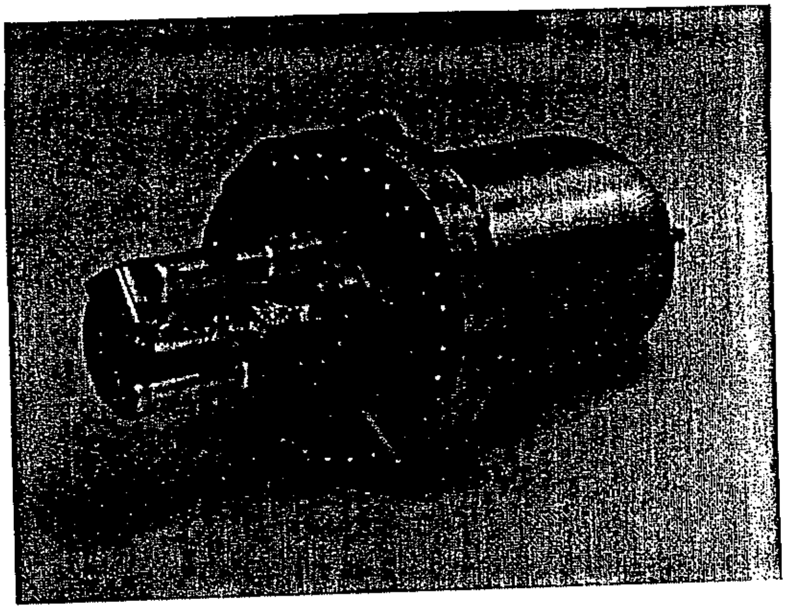
TRW

A. INTERNALLY BALANCED COOLER



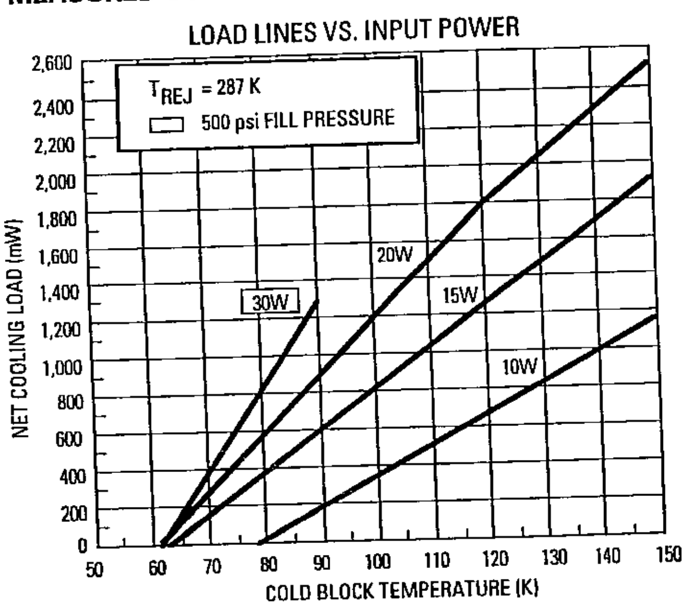
B. SPECIFICATIONS

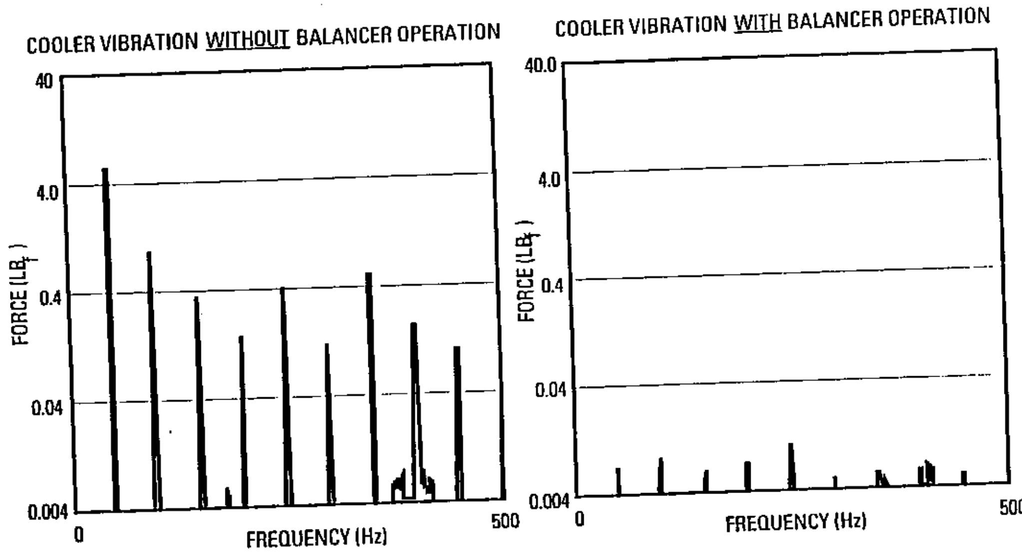
WEIGHT (Kg)		VIBRATION	<0.02 Lbf rms
COOLER	2.0		
ELECTRONICS	3.0	LIFE/RELIABILITY (INCLUDES 883 ELECTRONICS)	5 YEARS/ 0.96
	5 .0		
RATED POWER (WATTS)			
COOLER	20		
ELECTRONICS	6		
	26		
FOOTPRINT (IN.^{2})			
COOLER	50		
ELECTRONICS	55		



TRW's MINIATURE PULSE TUBE COOLER

C. MEASURED COOLER PERFORMANCE

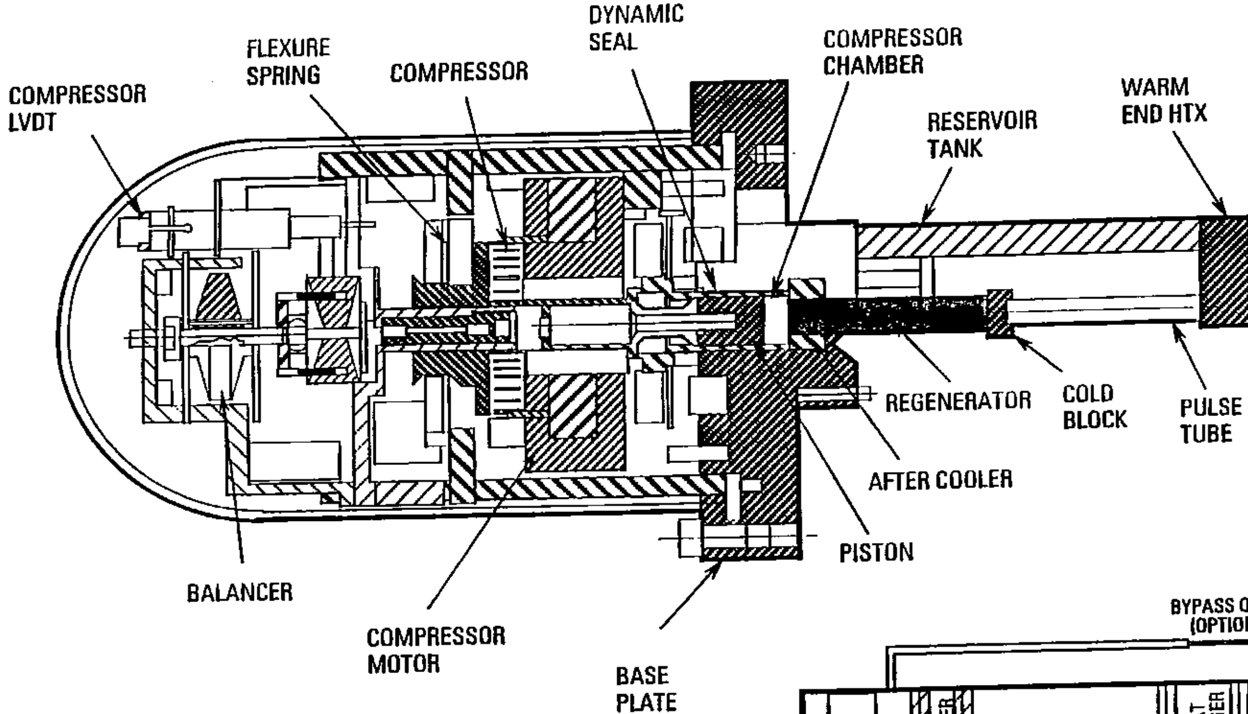




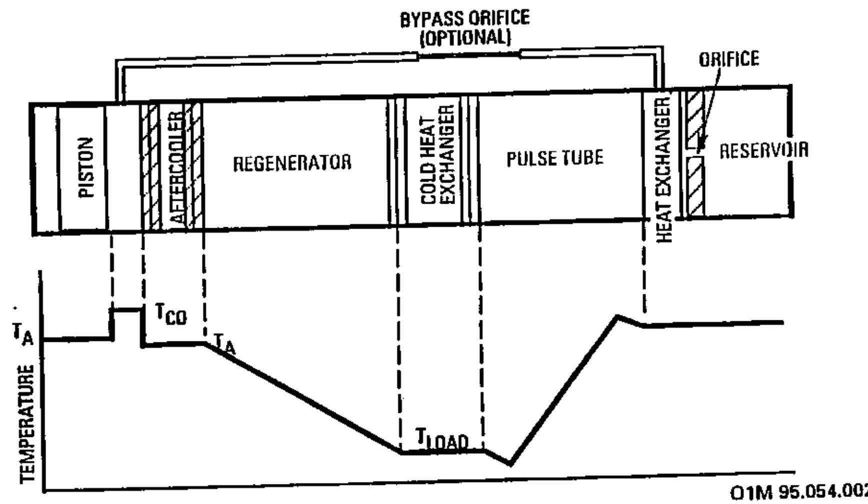
SJ-15

R1M 94.0109.06a

Cross-Section of the TRW Miniature Pulse Tube Cooler



Orifice Pulse Tube Cooler Operation



SABER Critical Design Review

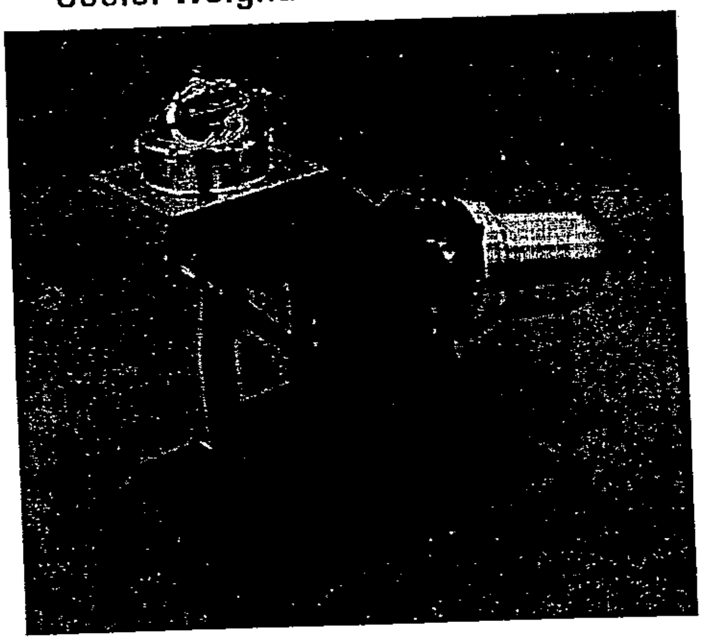
SPACE DYNAMICS LABORATORY / UTAH STATE UNIVERSITY

SJ-16

Off-the Shelf Cooler Design

Heritage

- Result of seven years of development using Oxford cooler technology
- Developed for Brilliant Pebbles against a reliability-driven, non-redundant cooler mission need
- Designed for 10-year life with 95% reliability
- Designed for weight-constrained spacecraft
  - Cooler weight: 4.4 lb



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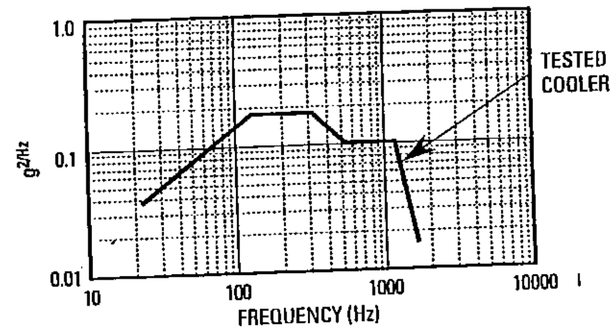
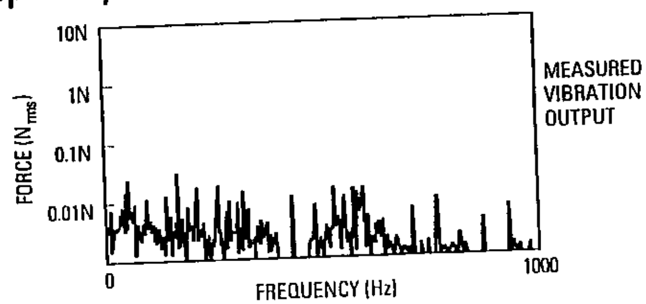
Performance

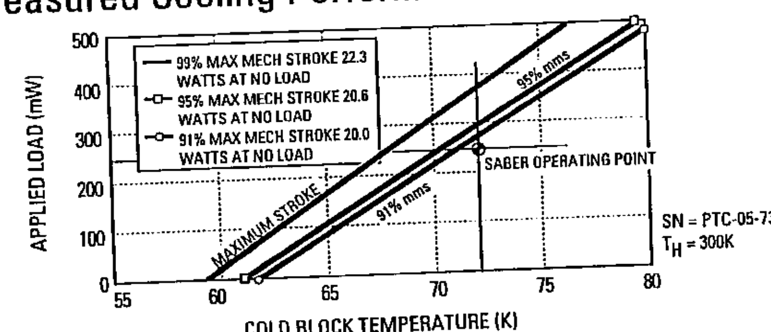
- Qualified for space launch unit vibrated to 14 gms



- Adaptively balanced for low-jitter operation



- Measured Cooling Performance

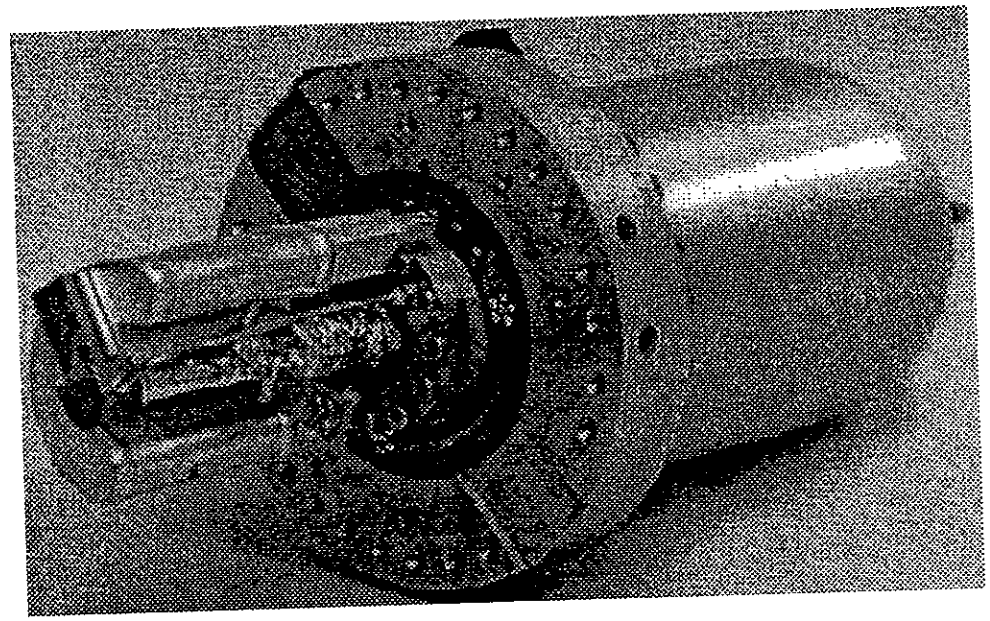


SJ-17

O1M 95.054.005

TRW REFRIGERATOR HERITAGE

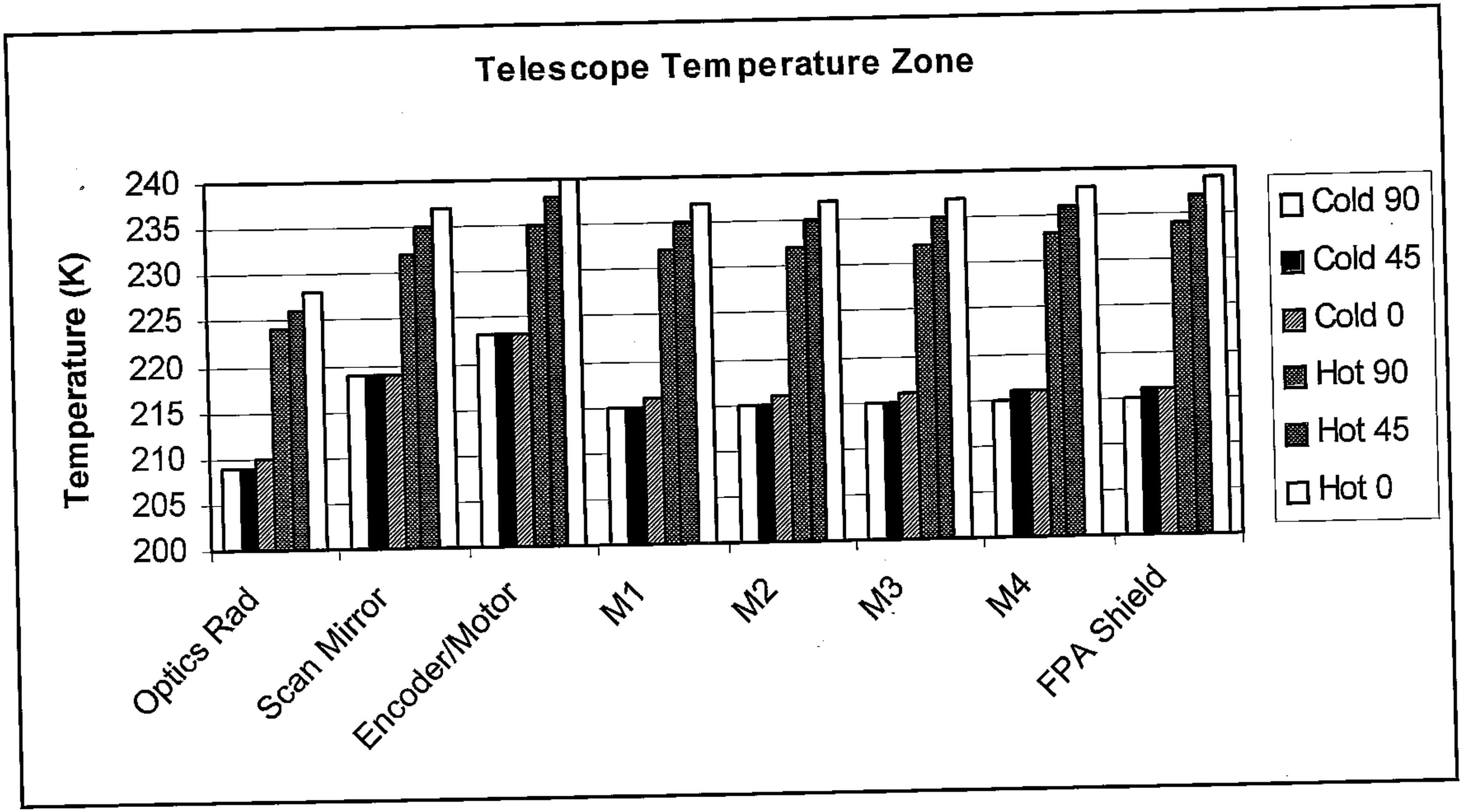
- To date, 10 units have been built to our knowledge
- To date, no units have failed
- 2 units have survived extensive life testing ~ 17000 hours
- A 3rd unit is currently being life tested at Hughes by the Air Force
- 2 units have been through the complete spacecraft integration process
- Pulse tube refrigerator #5 was tested extensively at SDL and met all test requirements



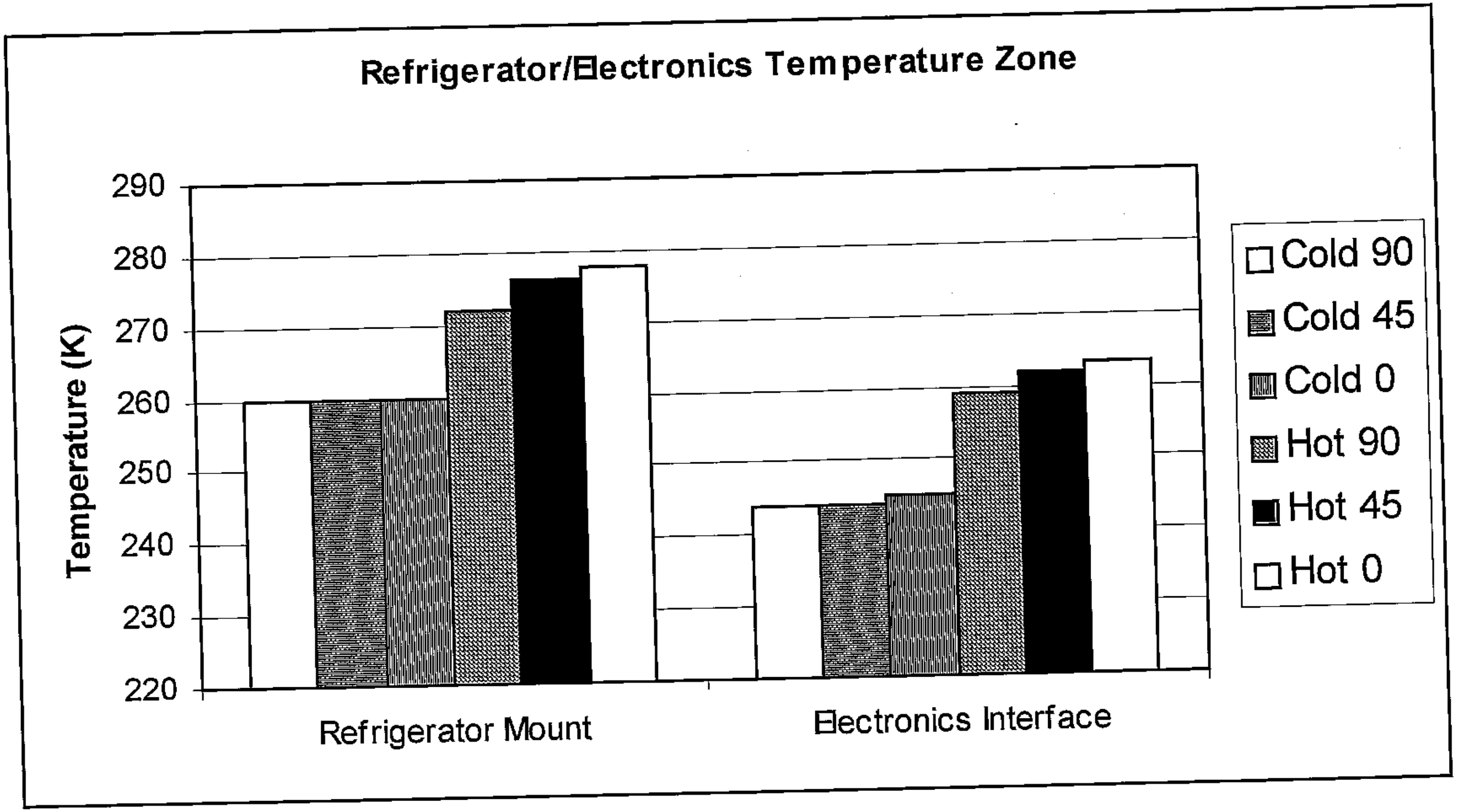
SABER POWER SUMMARY

Description	Predicted Operational Power (average)					
	Beta=0		Beta=45		Beta=90	
	Cold Case (W)	Hot Case (W)	Cold Case (W)	Hot Case (W)	Cold Case (W)	Hot Case (W)
Encoder/Motor Assembly	4.1	4.1	4.1	4.1	4.1	4.1
Encoder/Motor Assembly Heater	2.1	0.0	2.3	0.0	2.6	0.0
IFC Blackbody	1.5	0.8	1.5	0.9	1.5	1.0
Chopper	0.1	0.1	0.1	0.1	0.1	0.1
Refrigerator	14.9	19.1	14.9	18.6	14.8	17.8
Refrigerator Mount Heater	5.3	0.0	5.6	0.0	6.3	0.0
Refrigerator Electronics	11.7	12.1	11.7	12.1	11.6	12.0
SABER Electronics	31.8	32.4	31.7	32.3	31.6	32.1
TOTALS	**71.5**	**68.6**	**71.9**	**68.1**	**72.6**	**67.1**
FPA Heat Load	0.291	0.384	0.29	0.371	0.284	0.355

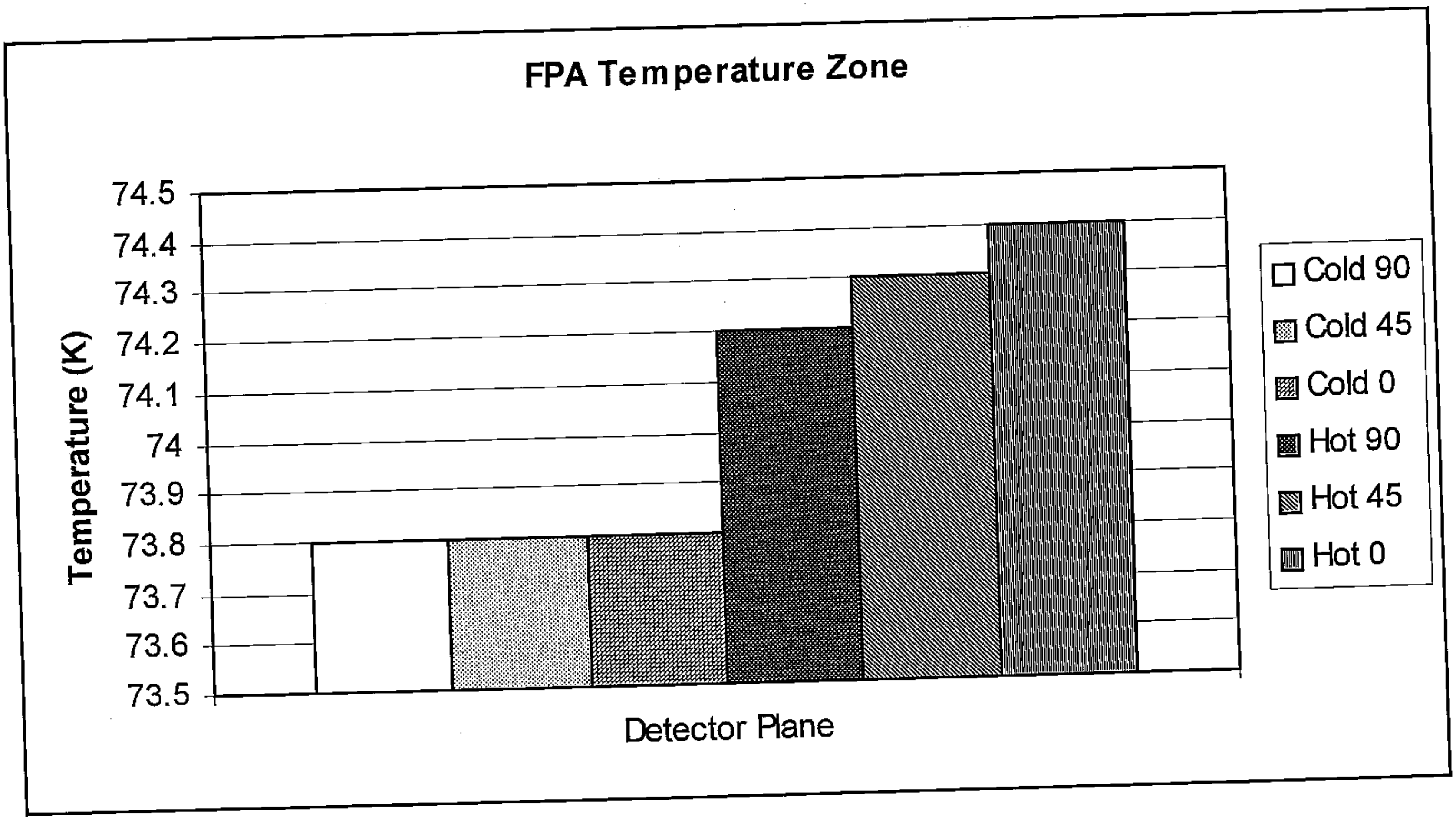
SABER TEMPERATURE PROFILE



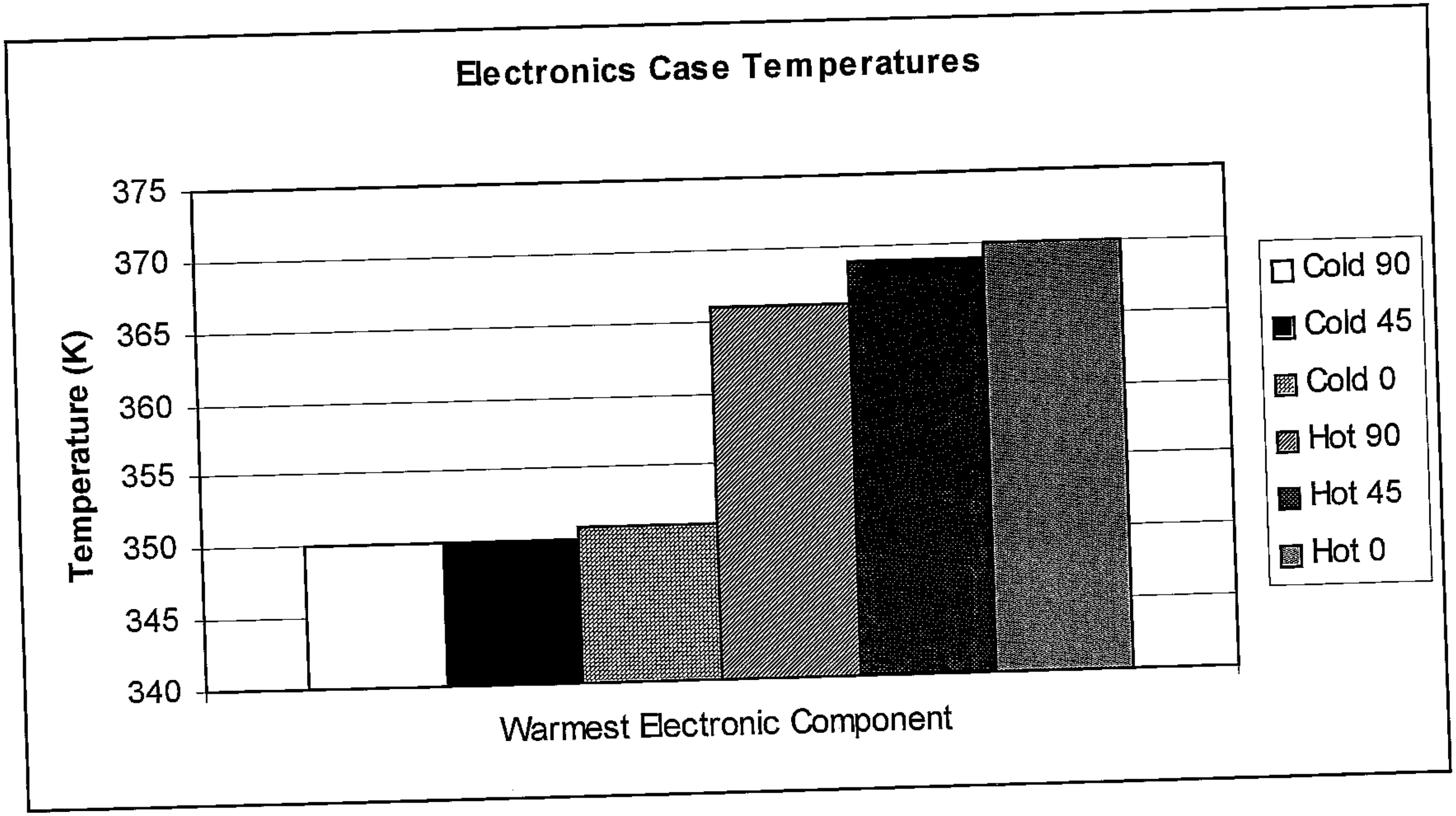
SABER TEMPERATURE PROFILES



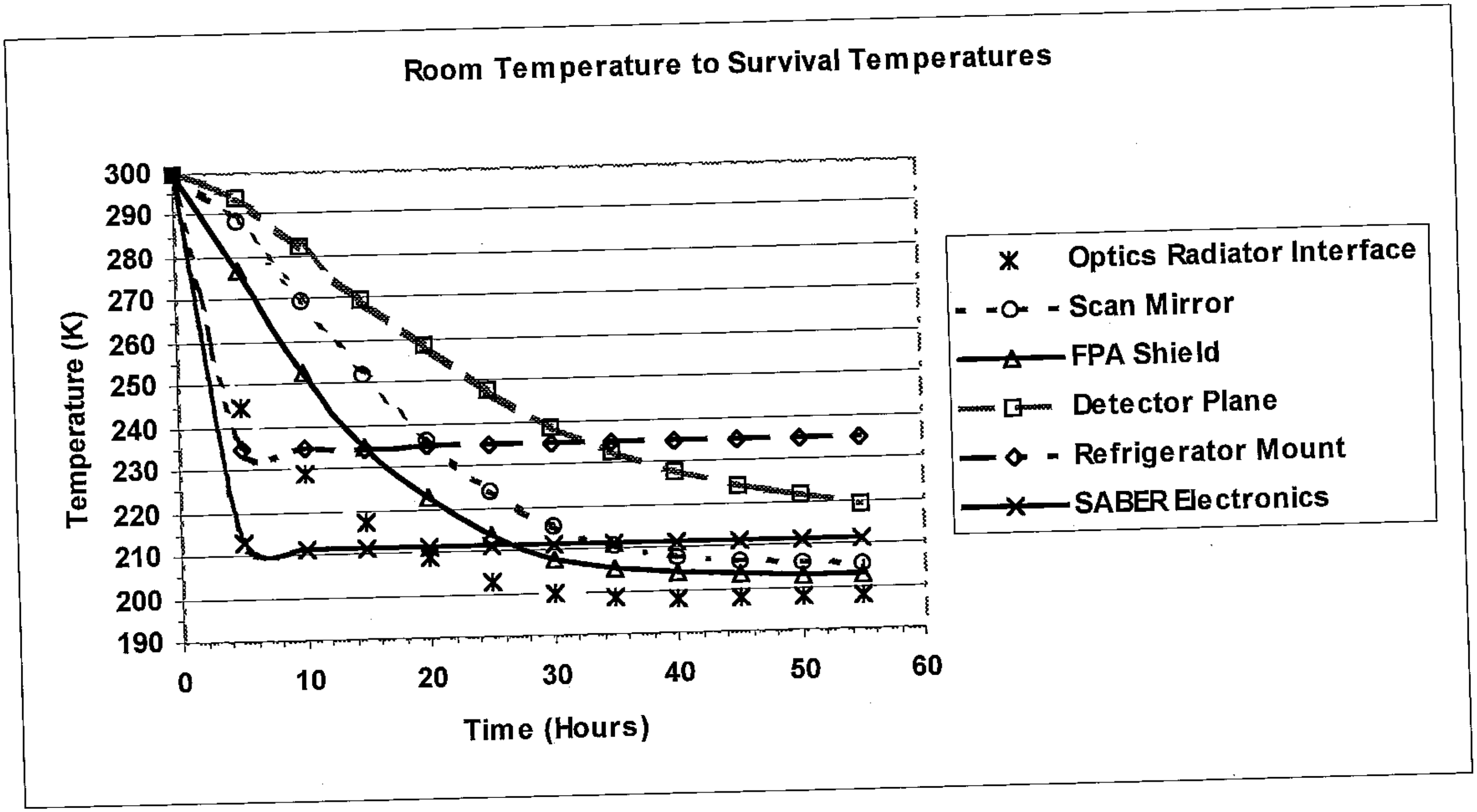
SABER TEMPERATURE PROFILES



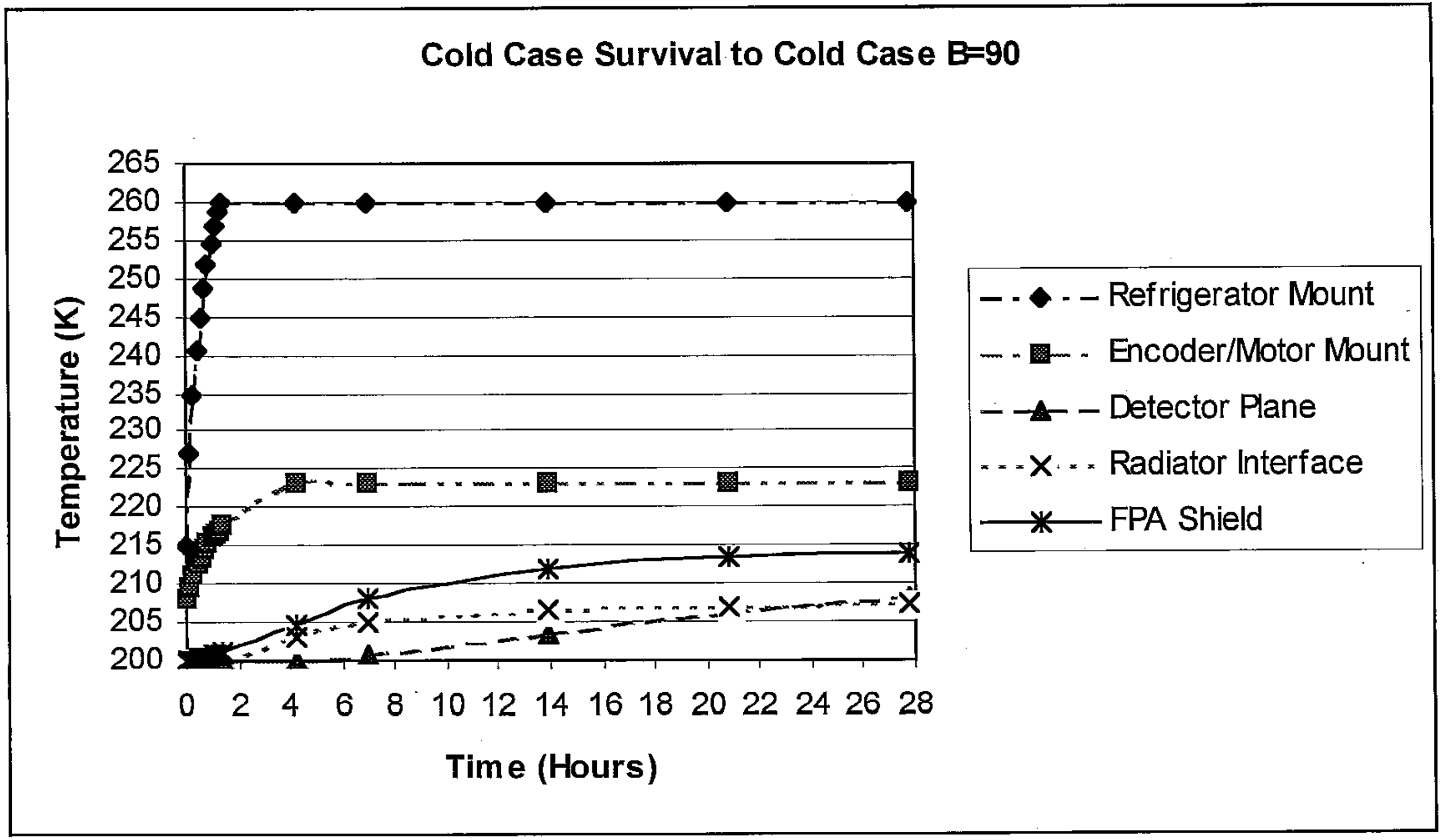
SABER TEMPERATURE PROFILE



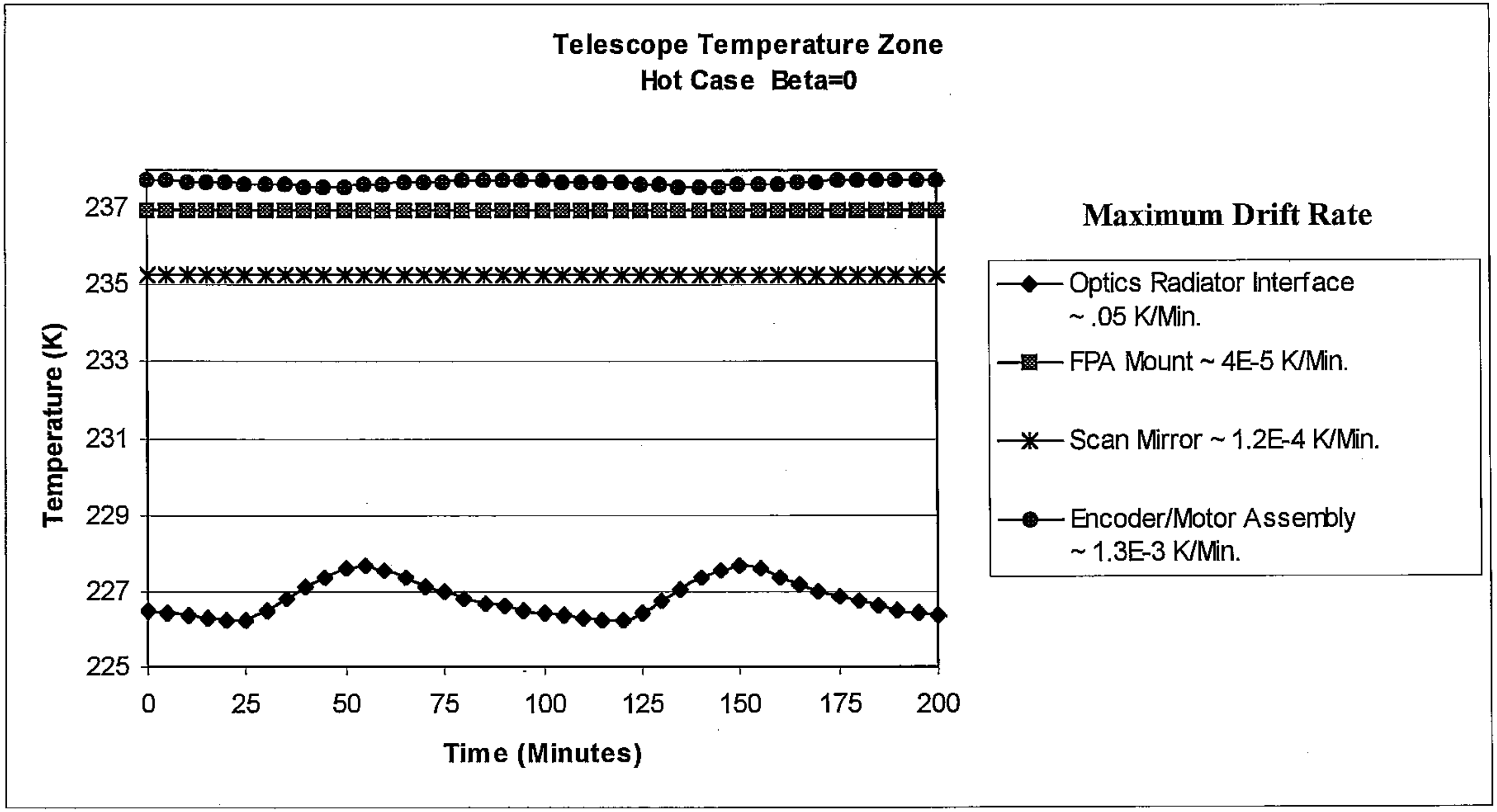
INITIAL COOL DOWN PROFILE



WARMUP PROFILE FROM SURVIVAL CONDITIONS



ON-ORBIT FLUCTUATIONS



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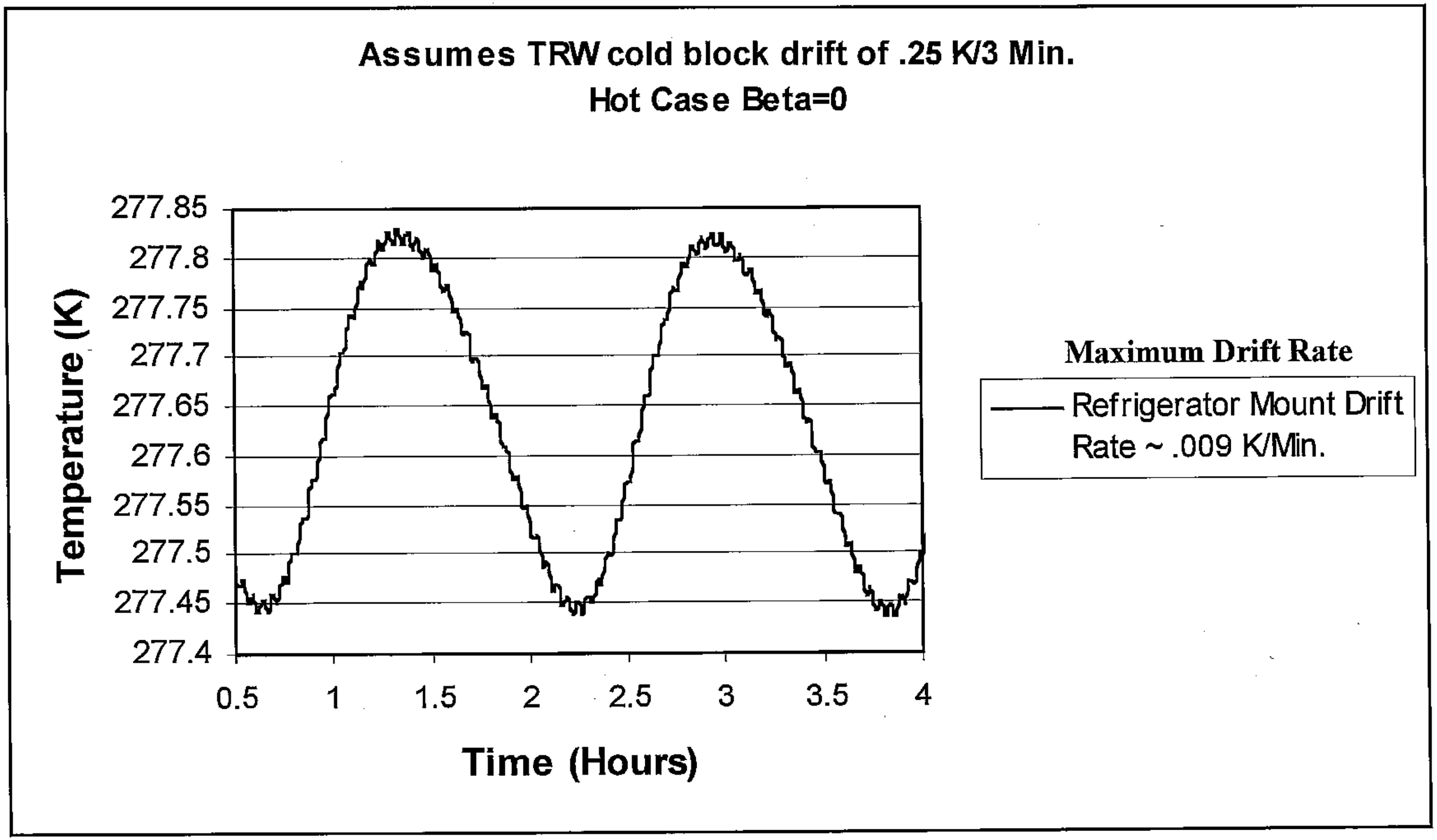
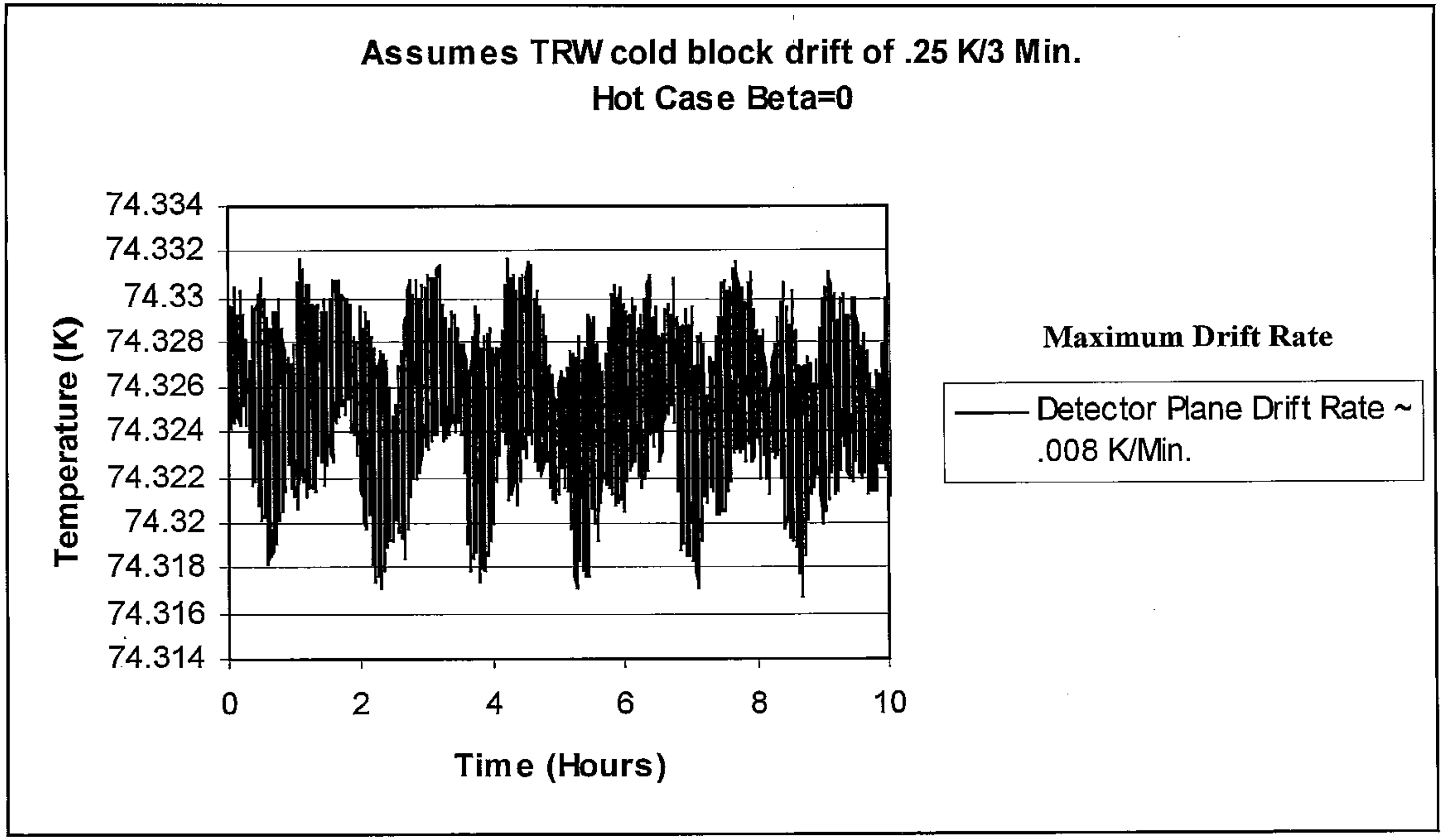
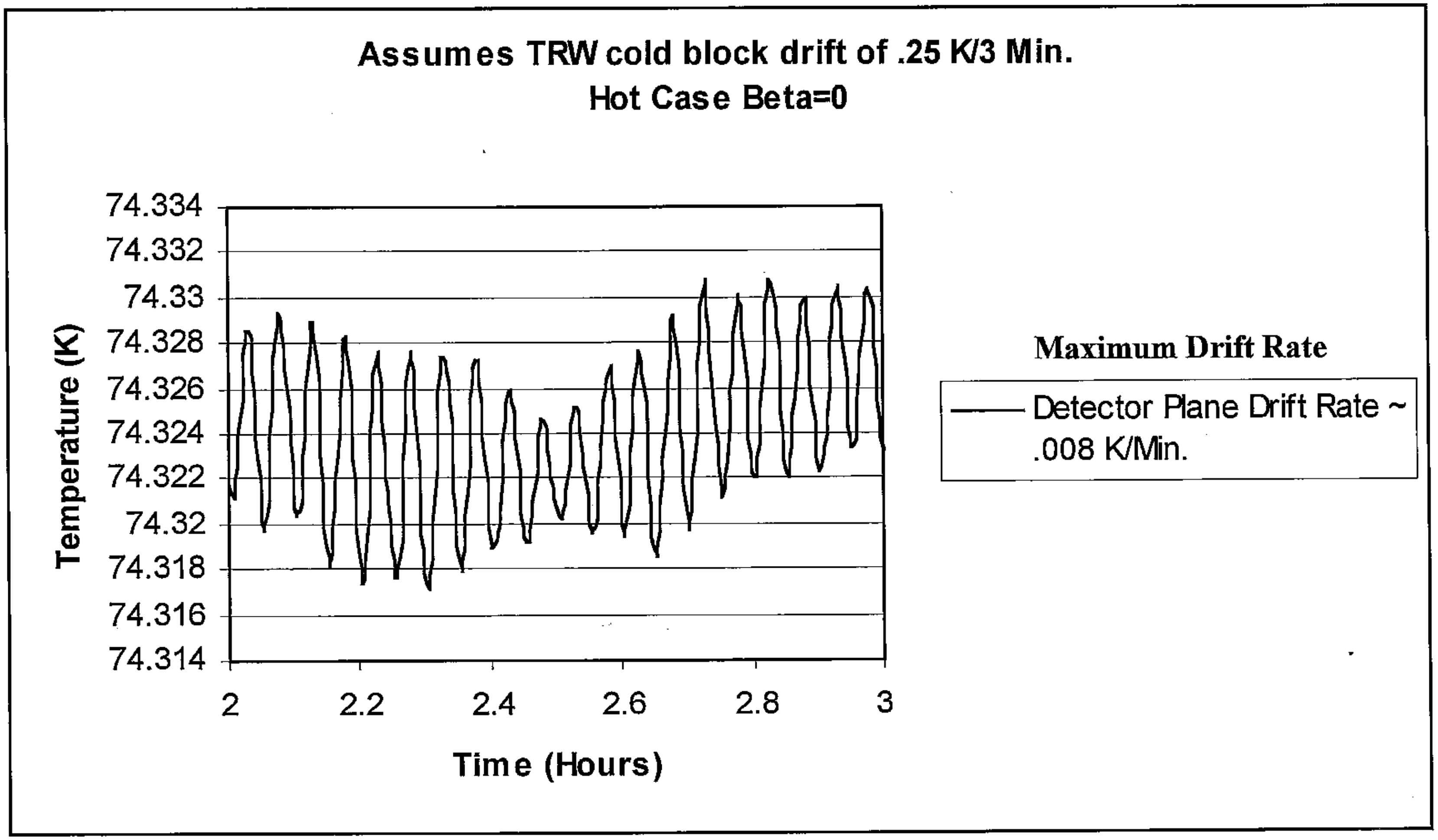


ON-ORBIT FLUCTUATIONS



ON-ORBIT FLUCTUATIONS



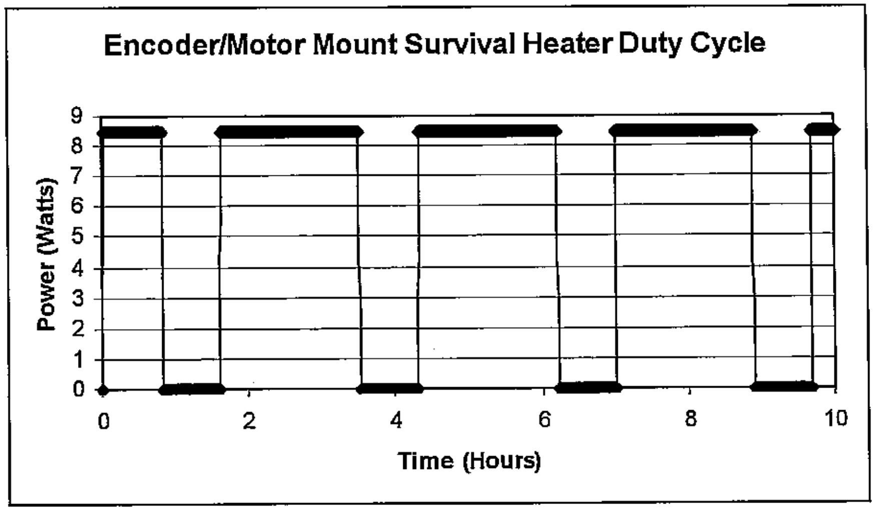
SURVIVAL MODE SUMMARY

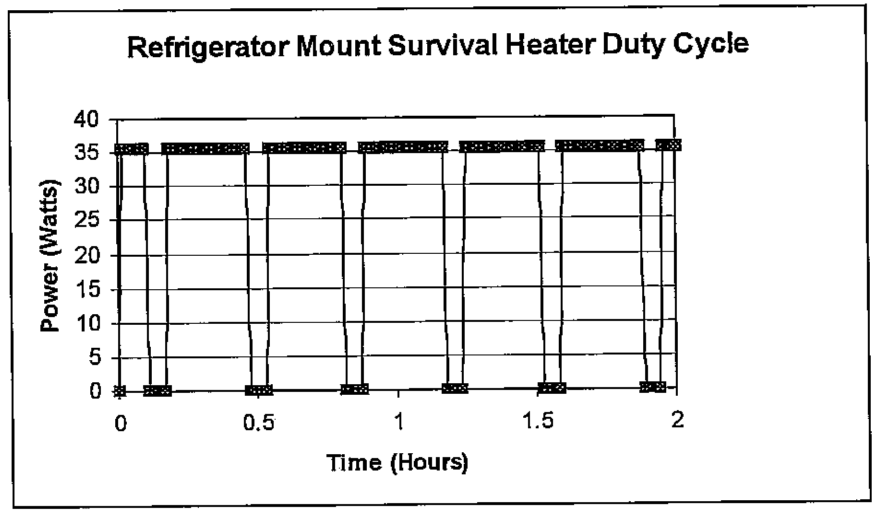
- **Hot Case**
  - Assumptions
    - Beta Angle= -90
    - Extreme hot case conditions
  - Results
    - No heater power required
    - Temperatures (predicted/rated)
      - Refrigerator (304/333 K)
      - Encoder/Motor (327/333 K)
      - Detectors (323/350 K)
- **Cold Case**
  - Assumptions
    - Extreme cold case conditions
  - Results
    - Heater power (average)
      - Refrigerator 23.0 W
      - Encoder/Motor 5.5 W
    - Temperatures (predicted/rated)
      - Refrigerator (235/235 K)
      - Encoder/Motor (208/208 K)
      - Detectors (210/NA K)

SURVIVAL HEATER DUTY CYCLE

- **Encoder/Motor Mount**
  - Dead Band = 8 K
    - Low set point = 208 K
    - High set point = 216 K
  - Duty Cycle = 71 %

- **Refrigerator Mount**
  - Dead Band = 15 K
    - Low set point = 235 K
    - High set point = 250 K
  - Duty Cycle = 84 %





THERMAL RISK REDUCTION

- **Fabricate and test folded G-10 tube FPA breadboard**
  - Prototype unit assembled by 2nd week in November
  - Preliminary test results by 3rd week in December
- **Continue background work on FiST to fix fastening problems**
  - Re-work of current design by 3rd week of January
  - Test results of re-worked unit by 2nd week in February

SUMMARY

	Comfortable Margin	Attention to Detail	No Margin
• **2 year mission life**			
– Radiator size and surface coatings	X		
– Refrigerator reliability	X		
– Heater sizing and reliability	X		
• **75 K focal plane array temperature**			
– Delta T from refrigerator cold block to detectors	X		
– FPA heat loads		X	
– Refrigerator capacity (extreme hot case/worst unit)			X
• **Mass, power, and volume constraints**			
– Power in extreme cold case to maintain temperatures	X		
• **Spacecraft to SABER conducted resistance > 5.0 K/W**			
– Current resistance of 5.5 K/W	X		
– Mechanical stiffness of mount	X		

SABER INSTRUMENT
MECHANICAL SYSTEMS OVERVIEW

Mehrdad Roosta

20 October 1997

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Dean Shaffer	Design, Chopper	435-797-4578	dean.shaffer@sdl.usu.edu
Andrew Shumway	Calibration Systems	435-797-4383	andrew.shumway@sdl.usu.edu

MECHANICAL SYSTEMS OVERVIEW

- SABER instrument will be packaged and delivered as a single integrated protoflight unit
  - SABER will be mounted and aligned to spacecraft frame on +Y side
  - SABER structure thermally insulates the telescope from the spacecraft
- SABER envelope, mass properties, and interfaces meet spacecraft requirements
  - Mechanical interfaces are in place as described by APL GIIS and SIIS documents
- Mechanical design meets structural and thermo-mechanical requirements
  - SABER instrument design is mature and ready for fabrication phase
  - Instrument fundamental frequency > 35 Hz (Rigid mount using thermal washers)
  - Positive margins of safety against limit loads and test factors
  - Extensive stability analyses have been performed on components and systems
- SABER instrument will undergo proto-flight level environmental tests at SDL
- SABER will be shipped to spacecraft integration site mounted inside the calibration chamber

Mehrdad Roosta
October 20-22, 1997

SUMMARY STATUS

- Instrument design is frozen and is mostly under configuration control
  - Primary system wide analyses are complete
  - Analysis iterations will continue past CDR
  - Stability and sensitivity analyses will continue in support of instrument tests
- Folded G-10 tube detector mount design is in detailed analysis phase
  - Structural and thermal performance meets goals
  - Design optimization is continuing
  - Prototypes are being fabricated for testing
- An instrument fabrication plan has been established by SDL
  - Most of the critical items already have completed shop drawings
  - Remaining items will be completed according to the plan timeline
- SABER WWW site at SDL is established to hold the most updated drawings and related information

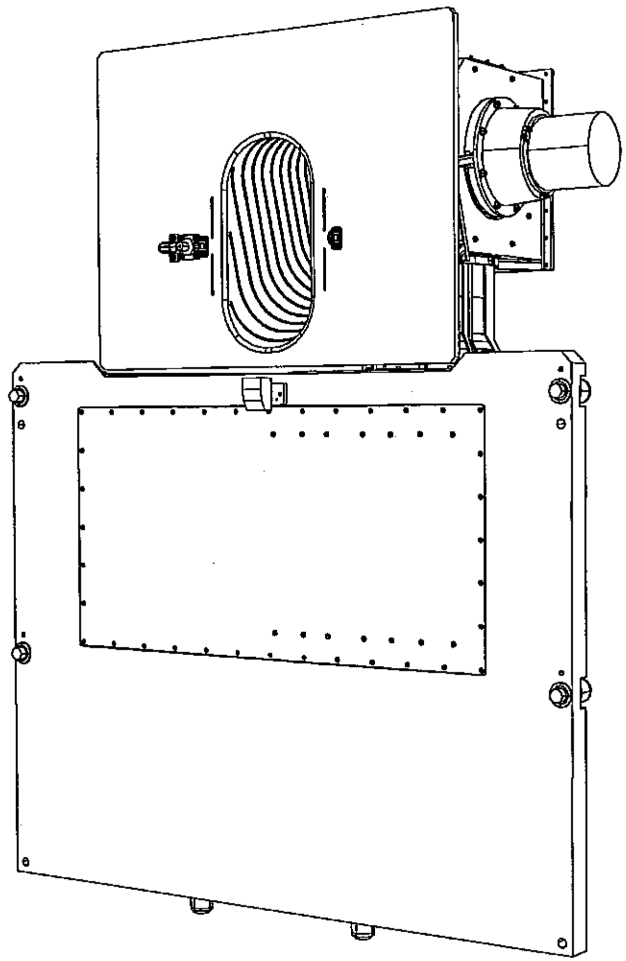
SABER INSTRUMENT

- Mass: 65.63 kg
- Weight: 144.38 lb
- Envelope: 30.5” x 24.63” x 41.04”

- Temperature limits:
  - 323 K - 200 K for structures
  - 315 K - 70 K for detectors

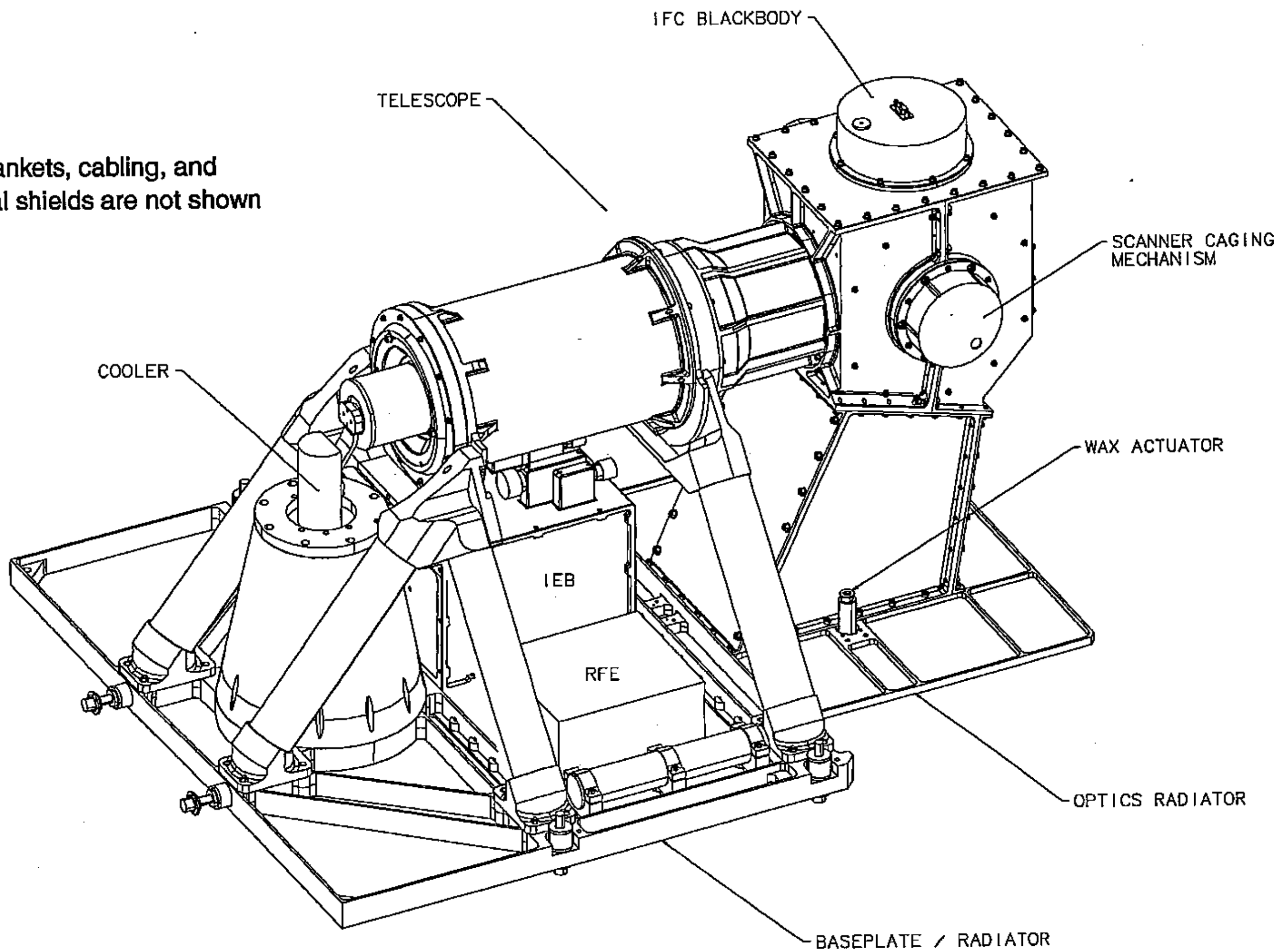
- Fundamental frequency: 50 Hz

- Positive margins of safety against:
  - 16 g’s quasi-static limit loads
  - 10.5 grms random loads



SABER INSTRUMENT

MLI blankets, cabling, and thermal shields are not shown



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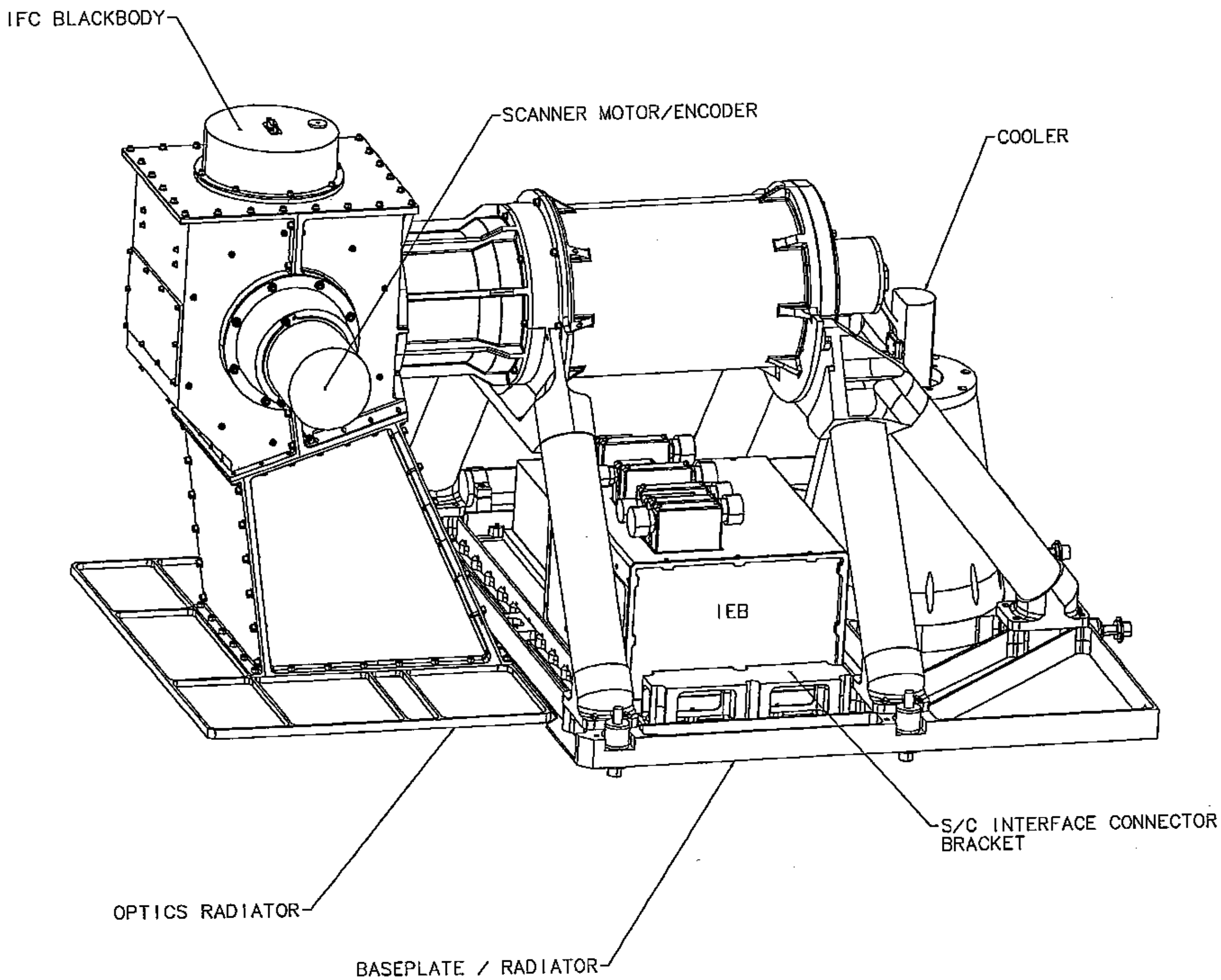
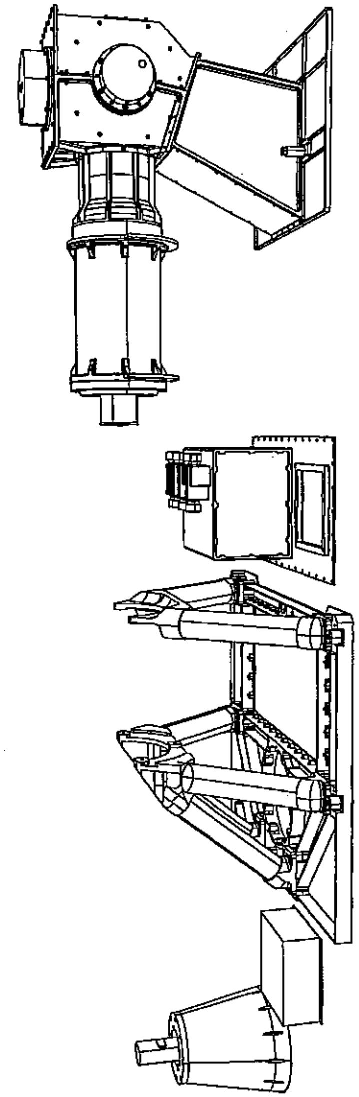
SABER INSTRUMENT

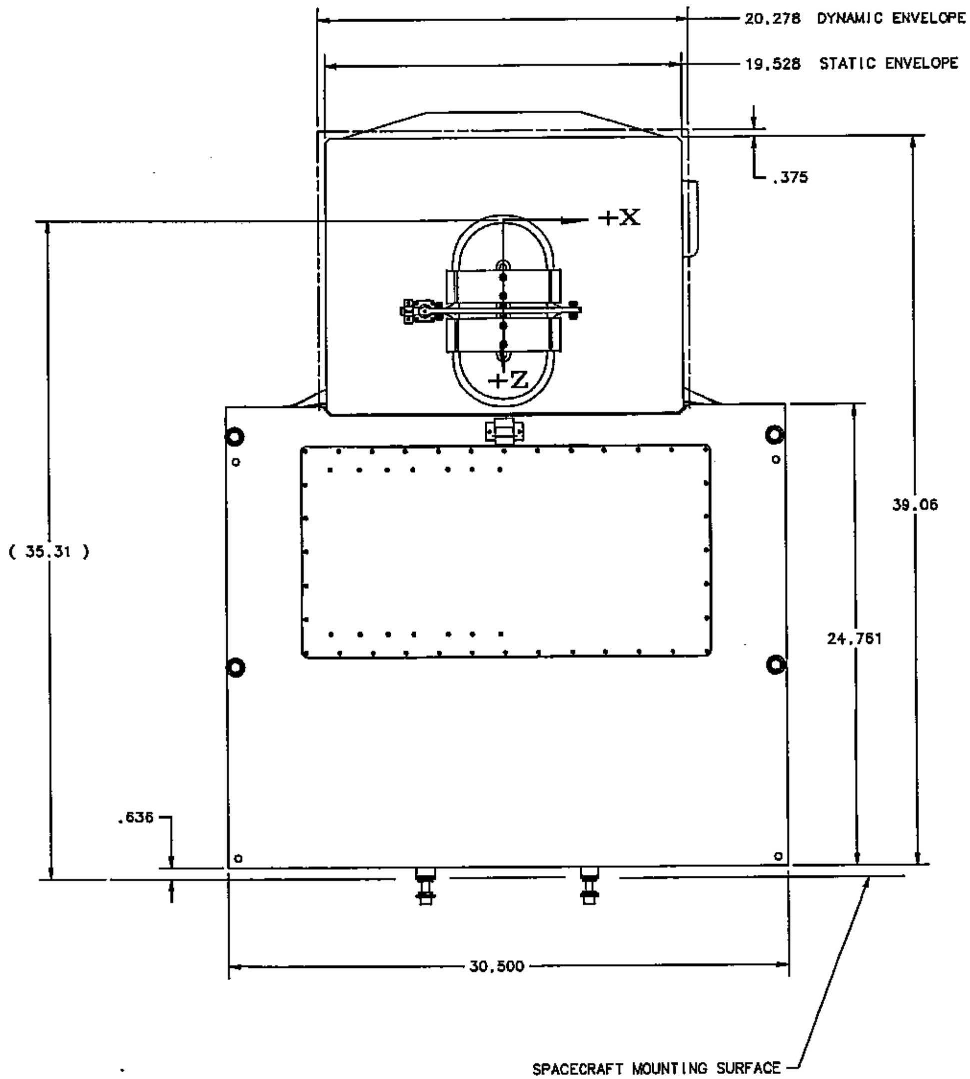


SABER INSTRUMENT MECHANICAL SUBSYSTEMS

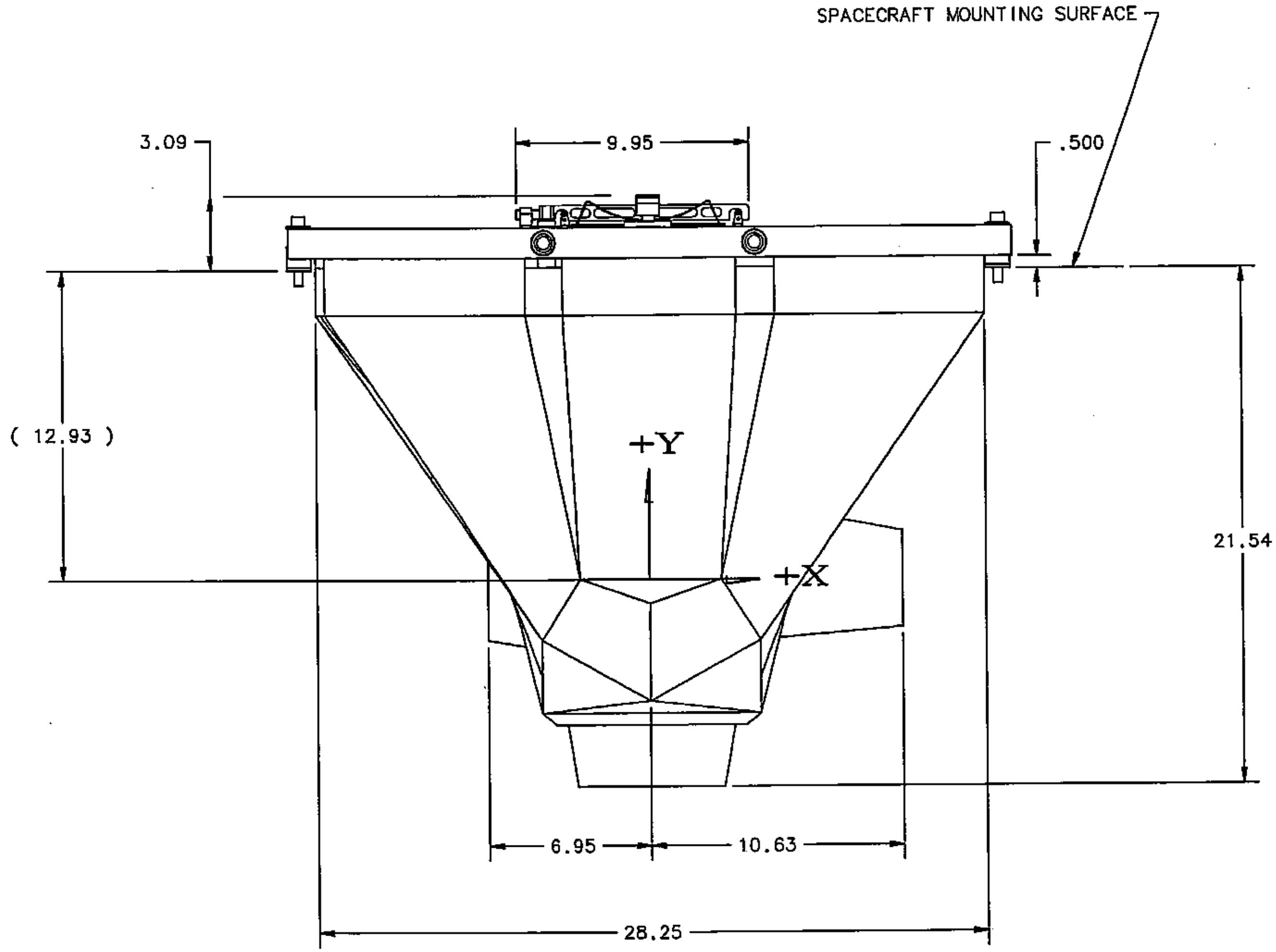
- Telescope
  - Baffle
  - Scanner
  - Foreoptics
  - Reimaging optics
- Interface electronics box (IEB)
- Structure
- Mechanical refrigerator
  - Pulse tube refrigerator
  - Refrigerator electronics (RFE)
- Purge system



SABER INSTRUMENT XZ ENVELOPE



SABER XY ENVELOPE



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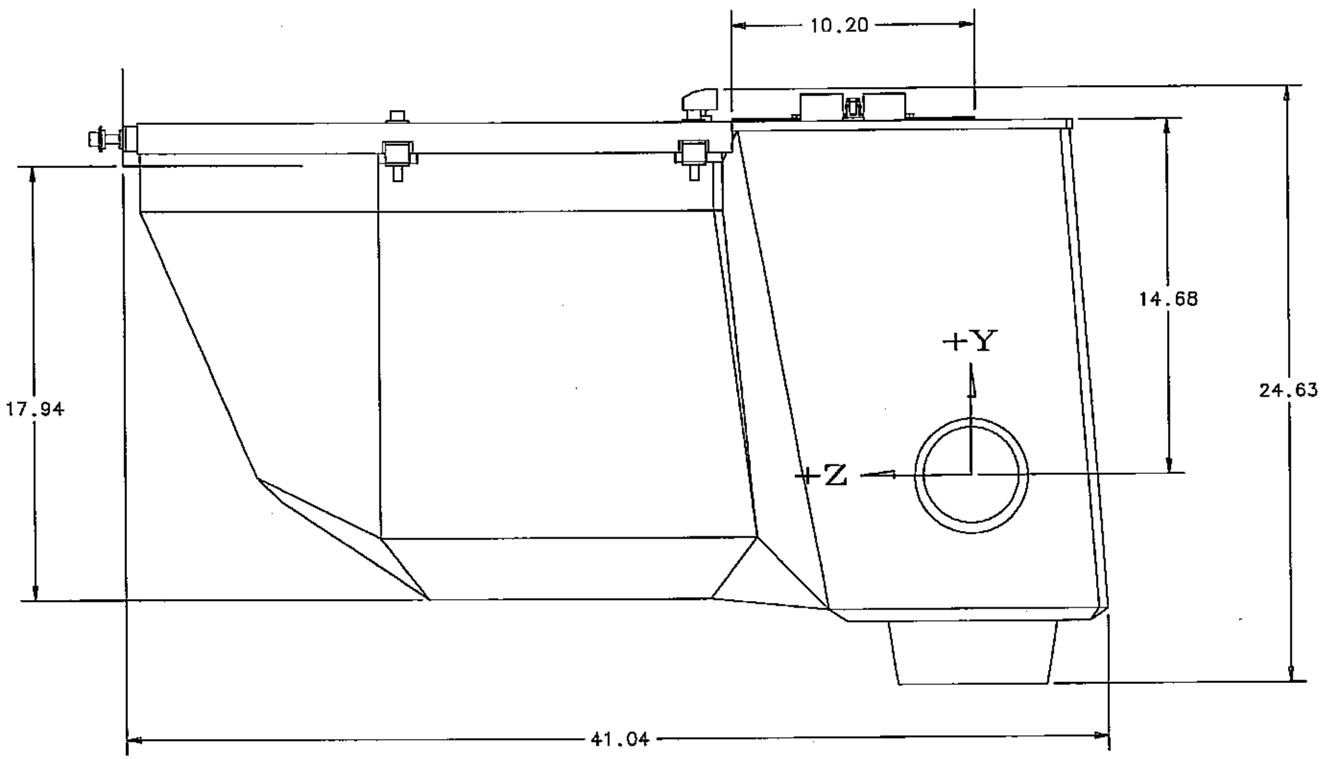
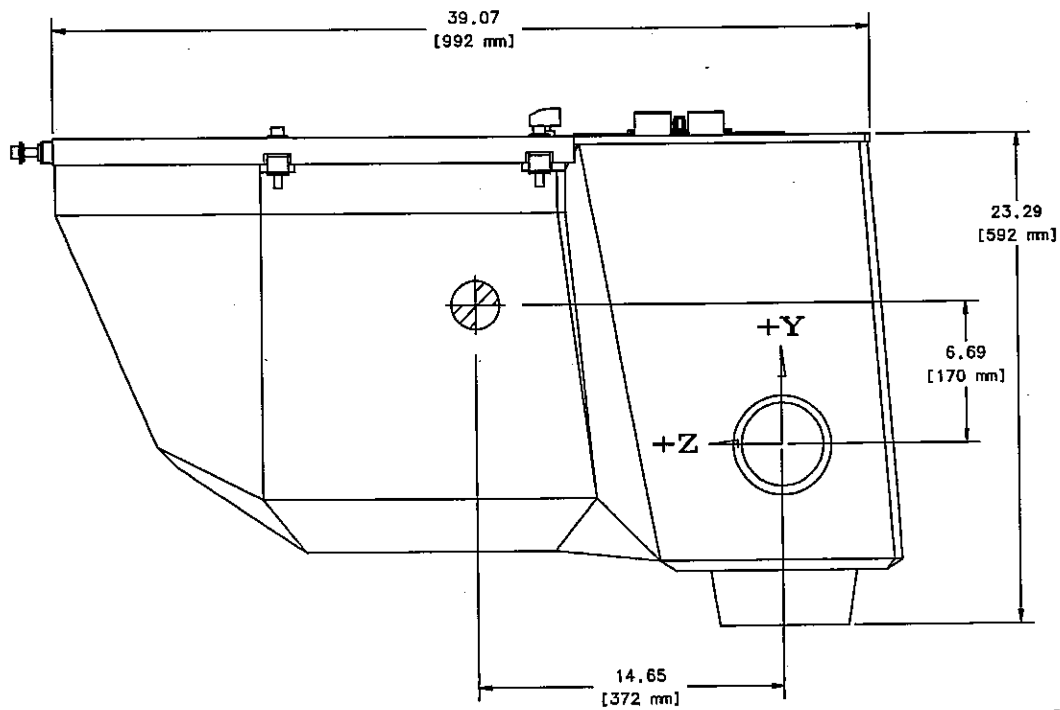
SABER YZ ENVELOPE



SABER MASS PROPERTIES SUMMARY

	MASS	Ixx	Iyy	Izz	Ixy	Iyz	Ixz	
		MOMENTS OF INERTIA ABOUT SABER COORDINATE SYSTEM						
	kg	kg.m^2	kg.m^2	kg.m^2	kg.m^2	kg.m^2	kg.m^2	
SABER INSTRUMENT	65.63	16.262626	14.379022	4.795706	0.021101	5.004947	0.123024	LAUNCH CONFIGURATION
	65.18	16.189400	14.370000	4.729630	0.0213490	4.983800	0.123103	COVER DEPLOYED



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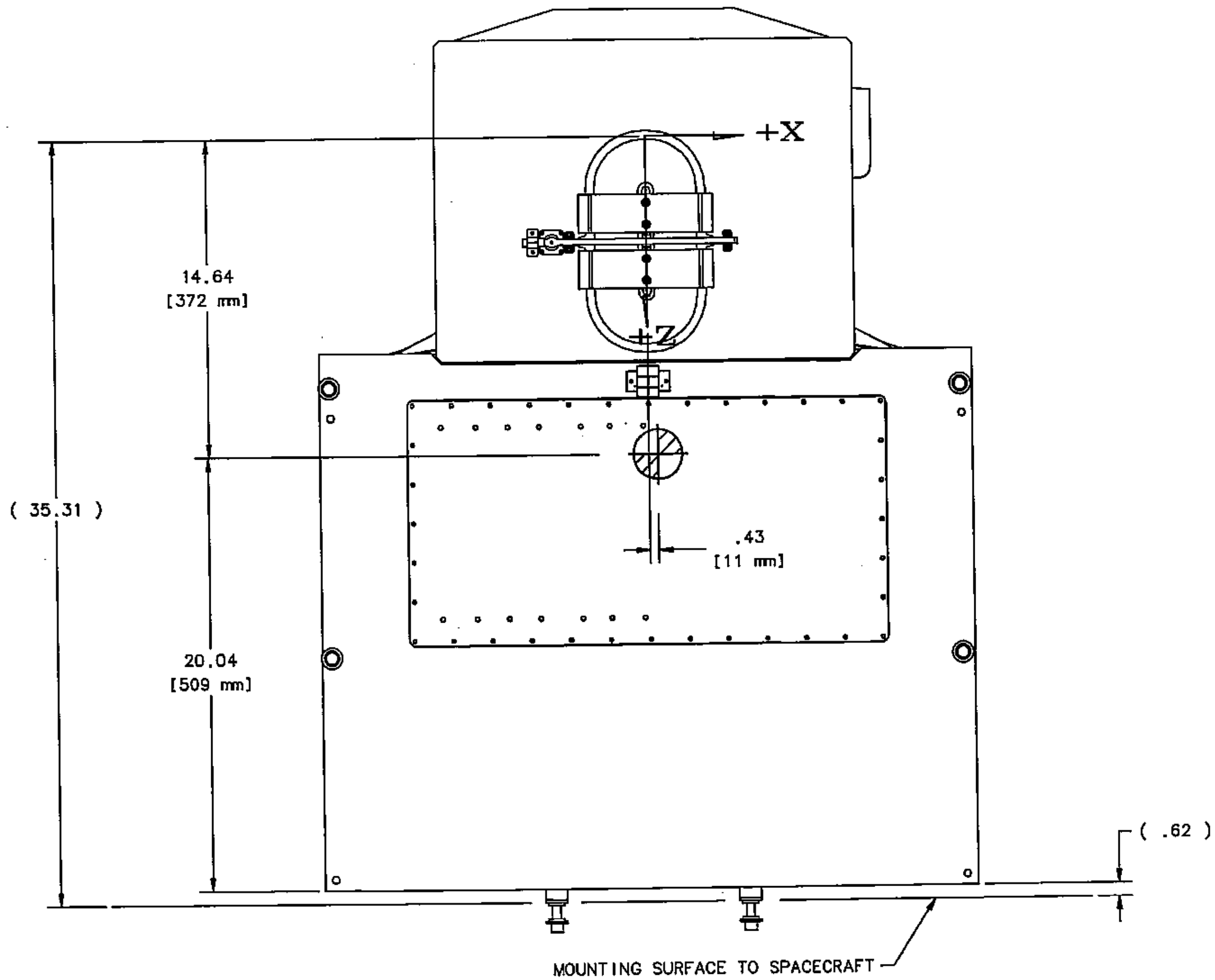
October 20-22, 1997

INSTRUMENT XZ CG LOCATION



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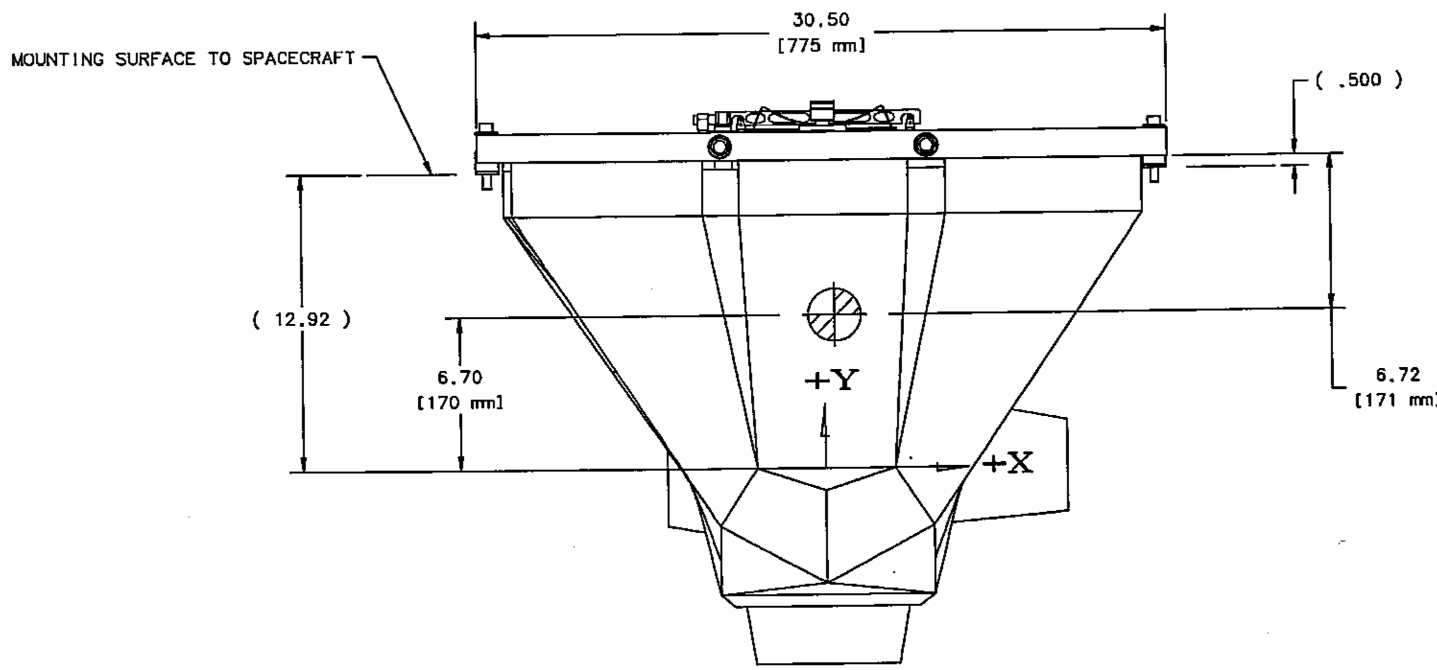
INSTRUMENT XY CG LOCATION



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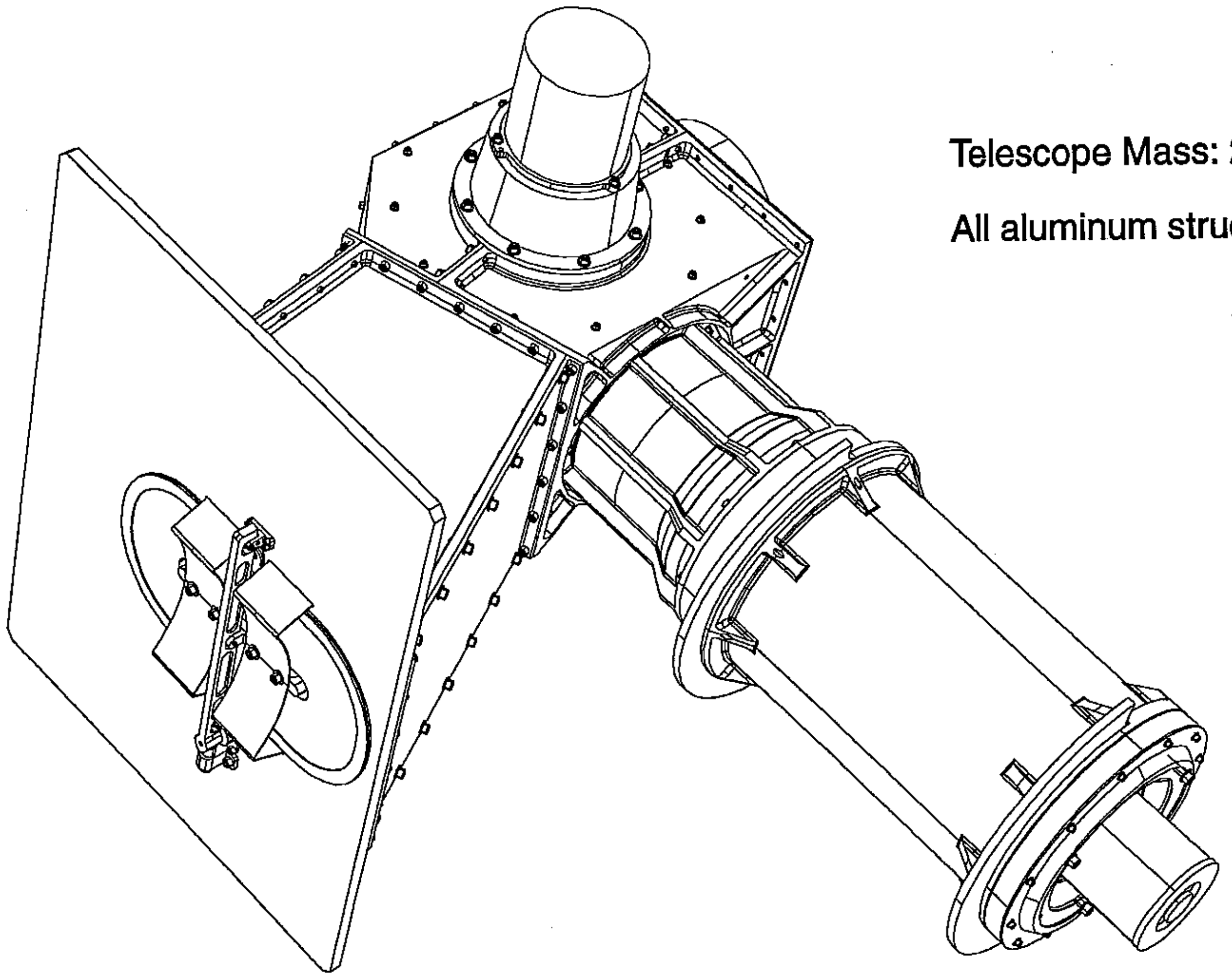
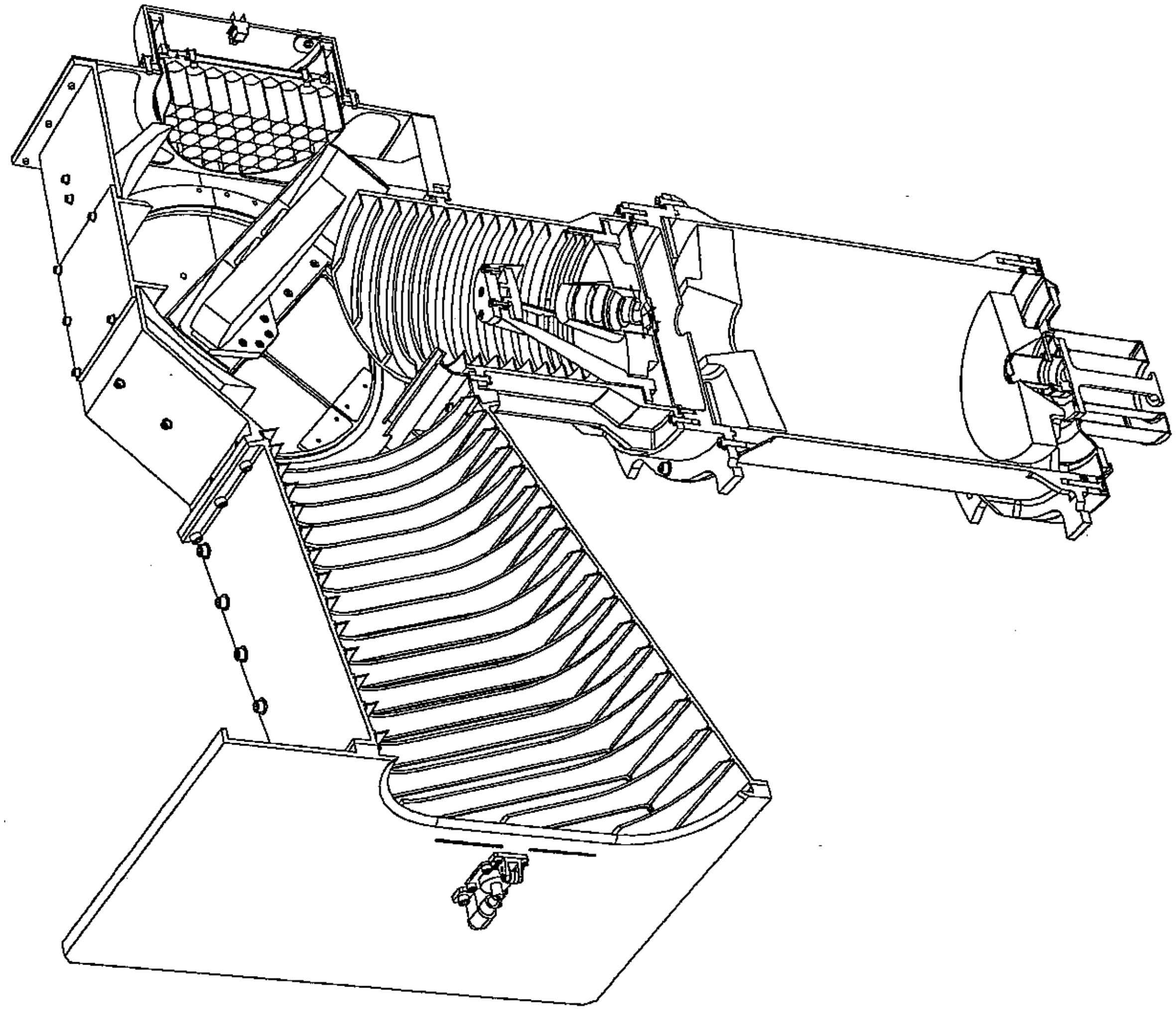
SABER TELESCOPE



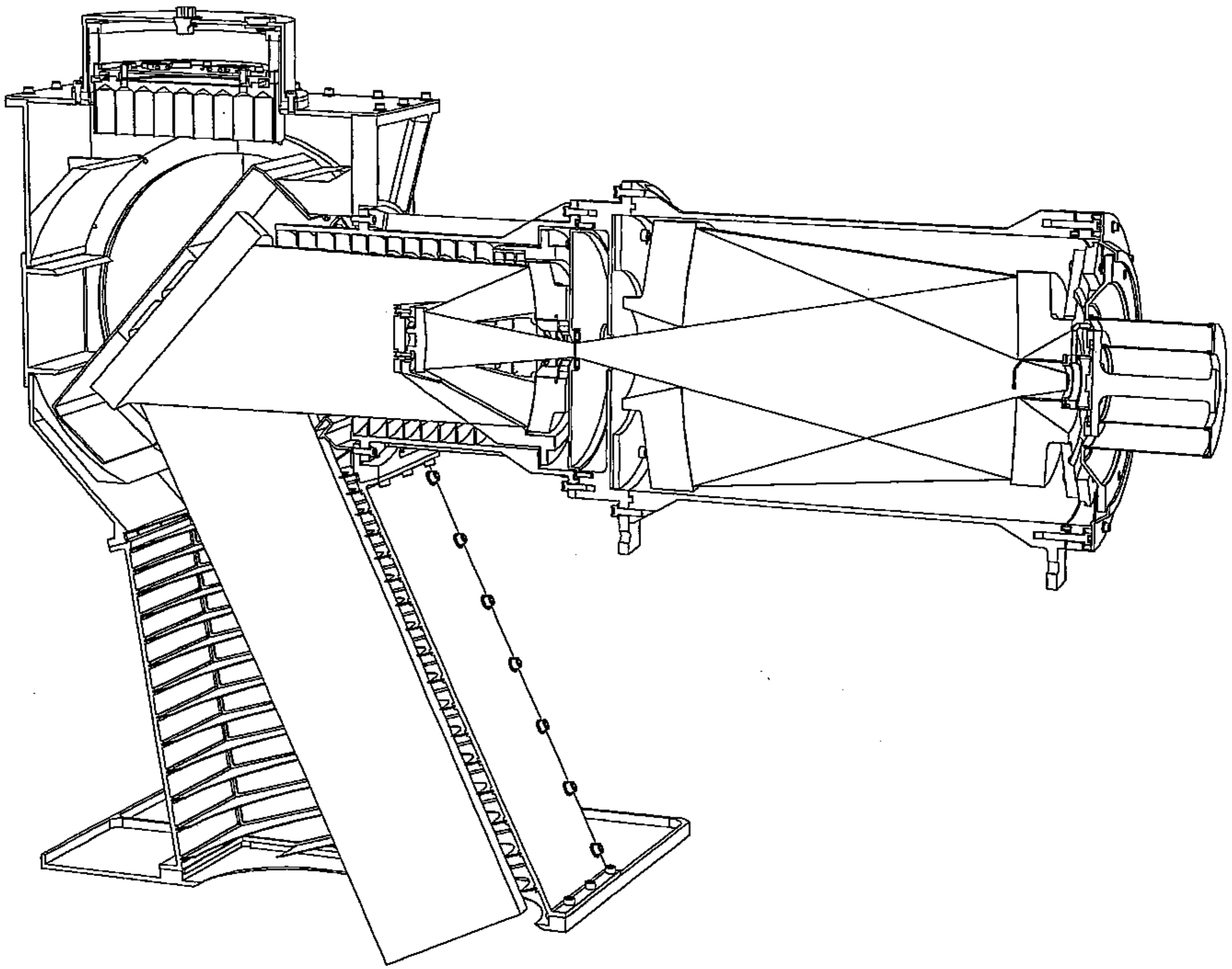
Telescope Mass: 26.62 kg

All aluminum structure & Optics

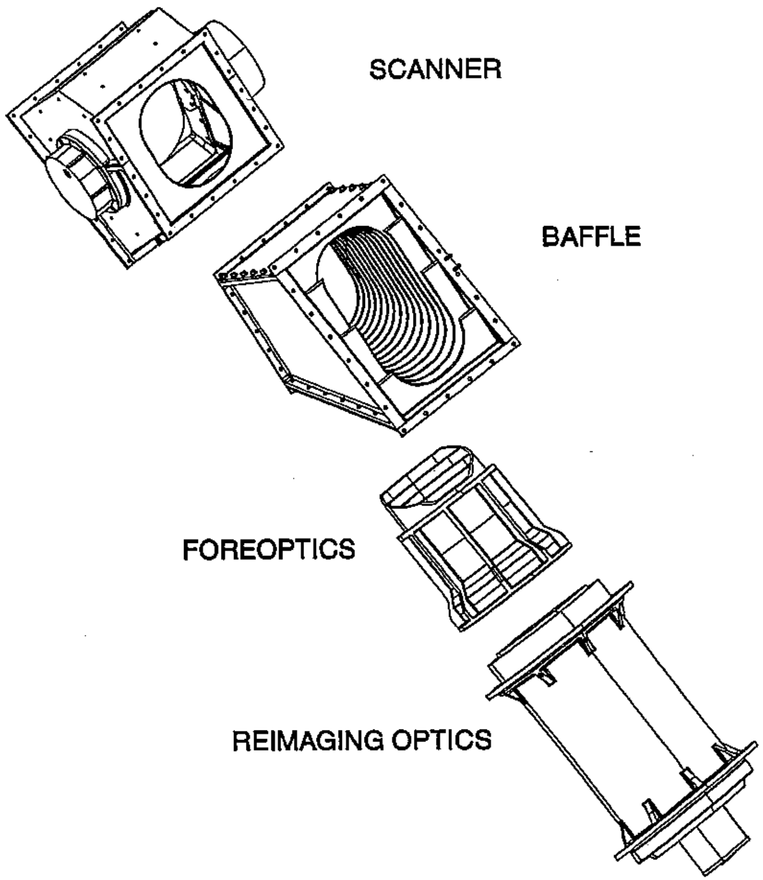
SABER TELESCOPE SECTION VIEW

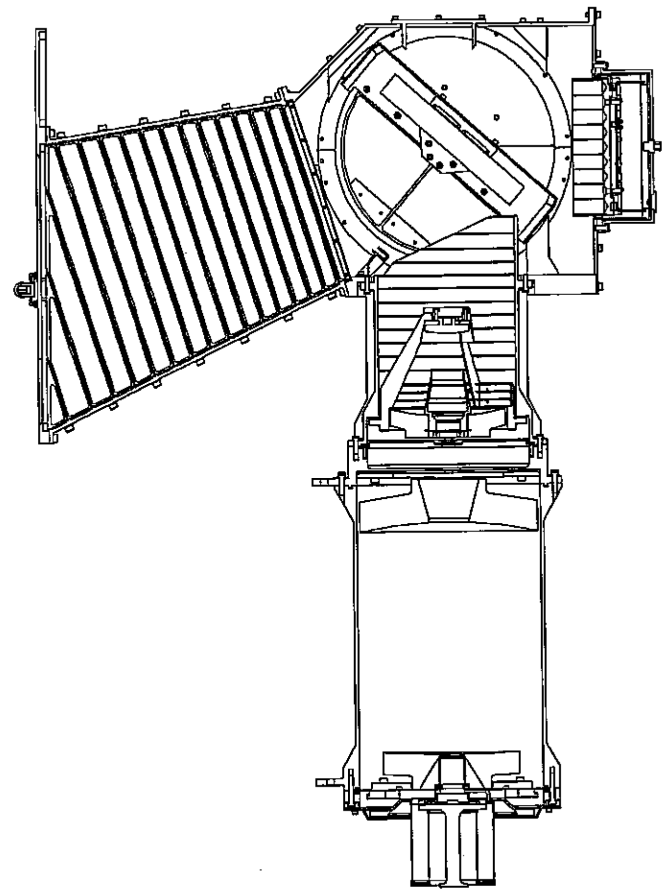


SABER TELESCOPE RAY PATH



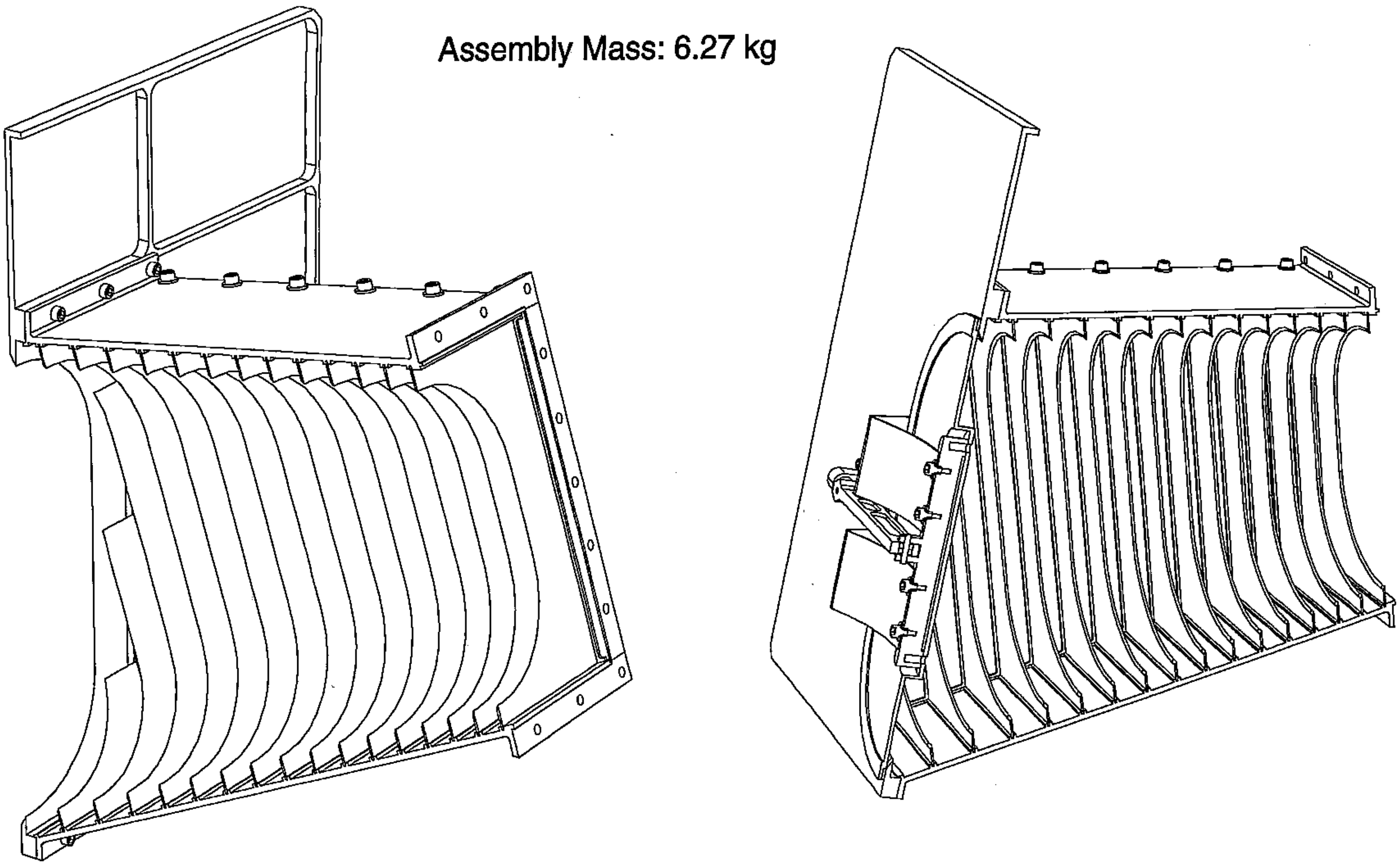
SABER TELESCOPE SUBSYSTEMS





TELESCOPE BAFFLE SECTION VIEW

Assembly Mass: 6.27 kg



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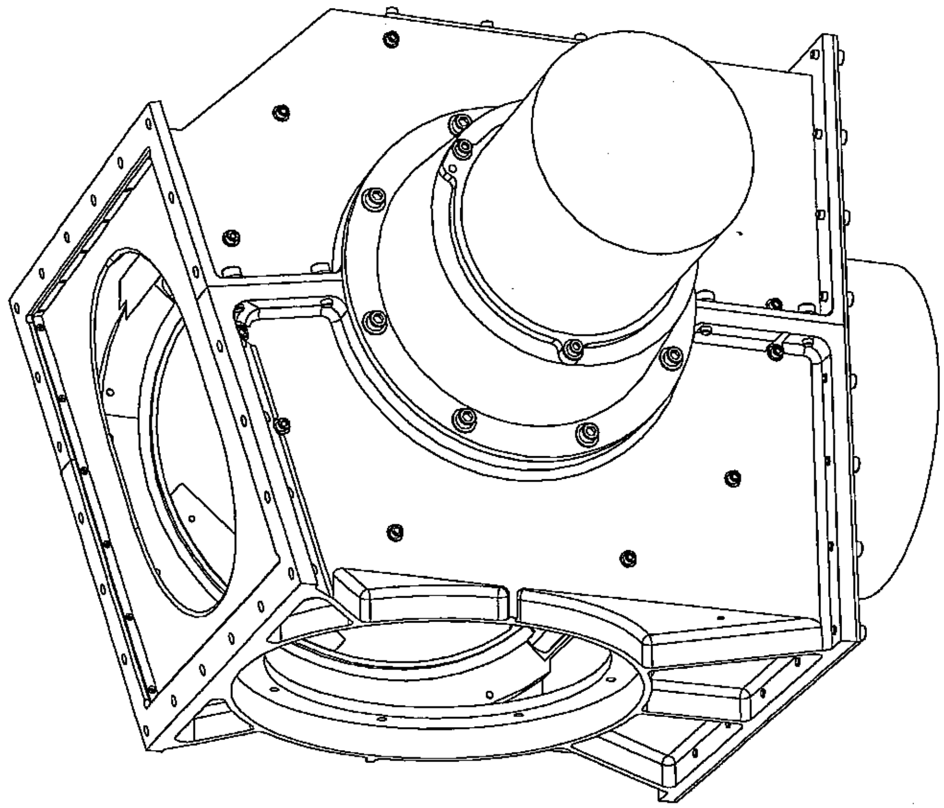
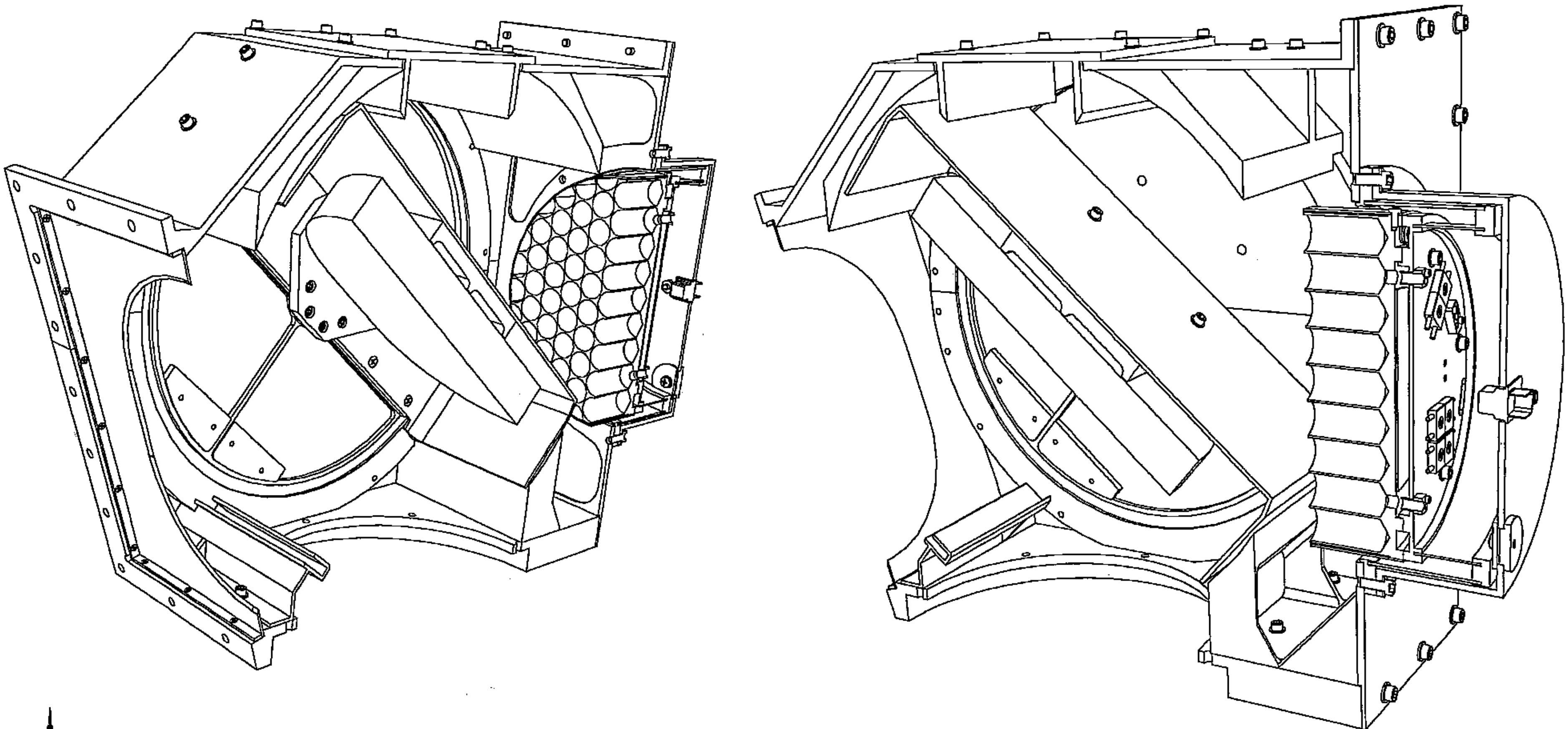
TELESCOPE SCANNER MODULE

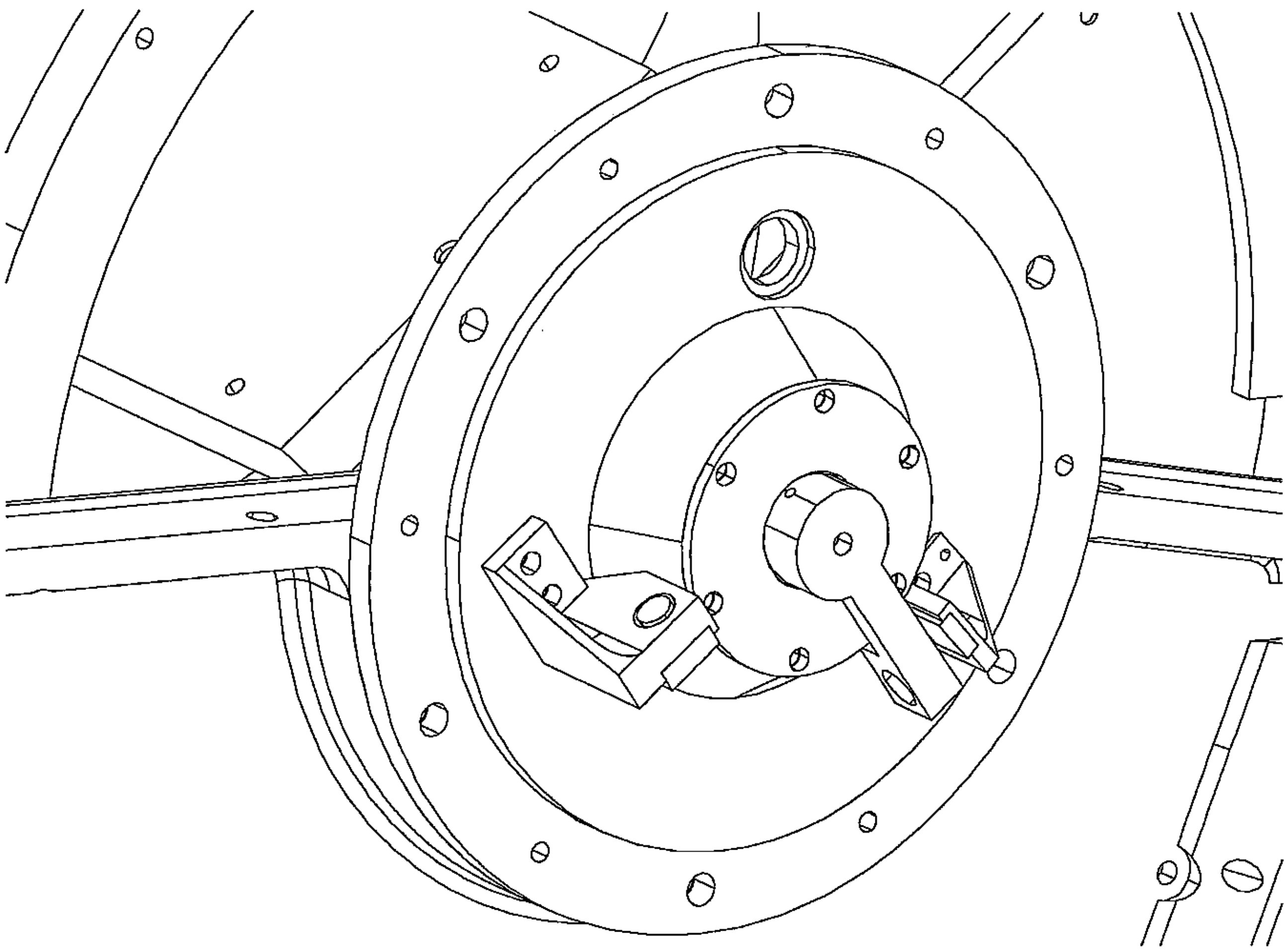
Assembly Mass: 10.68 kg



SCANNER MODULE SECTION VIEWS



SCANNER MODULE PASSIVE CAGING MECHANISM



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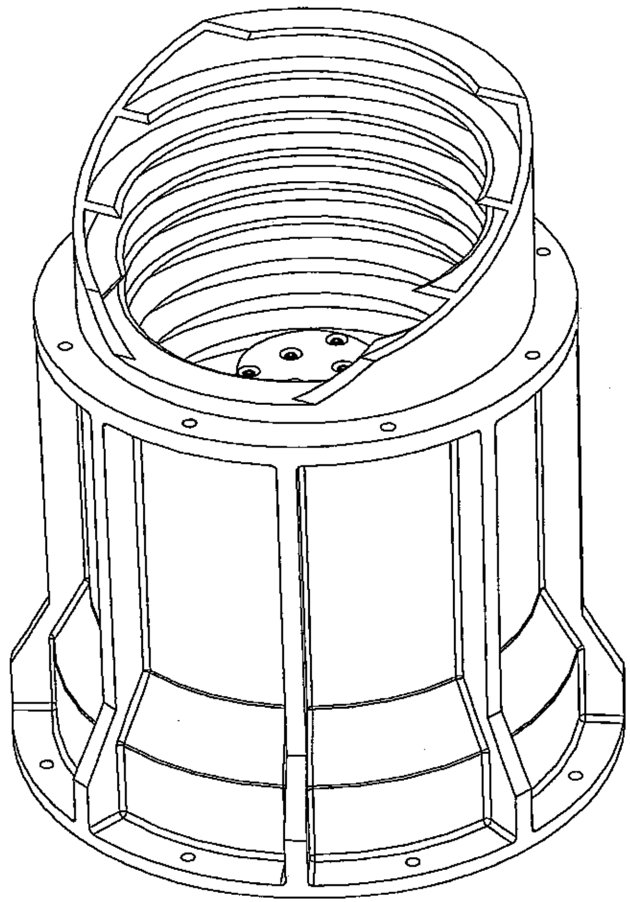
TELESCOPE FOREOPTICS ASSEMBLY

Assembly Mass: 2.26 kg



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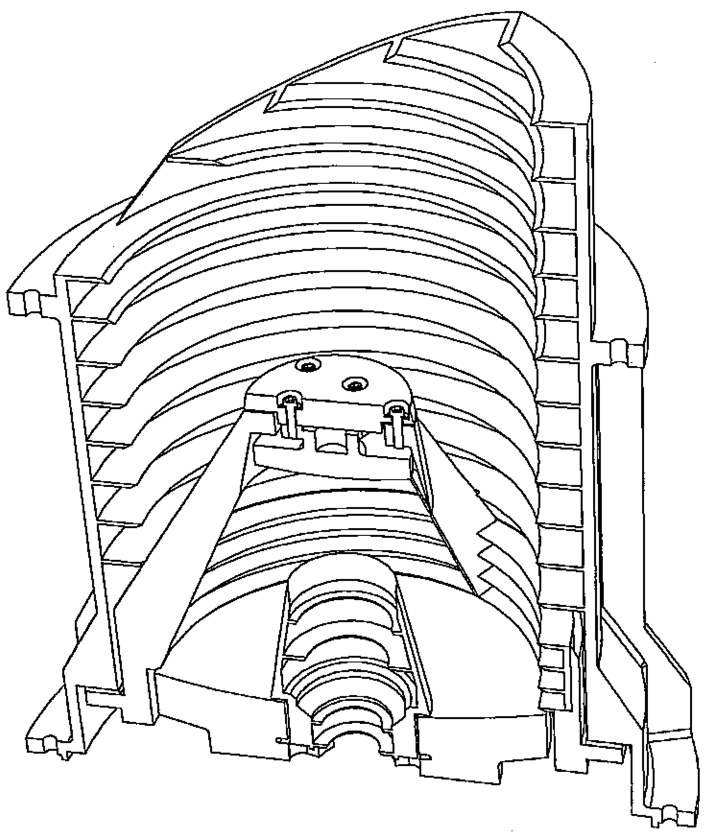
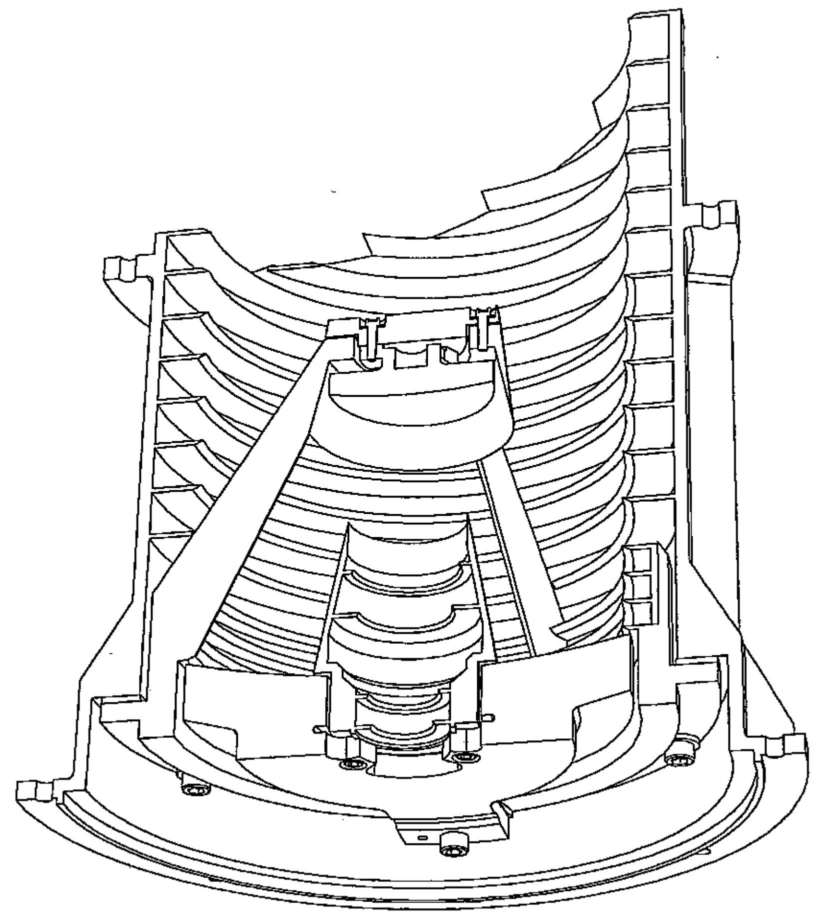
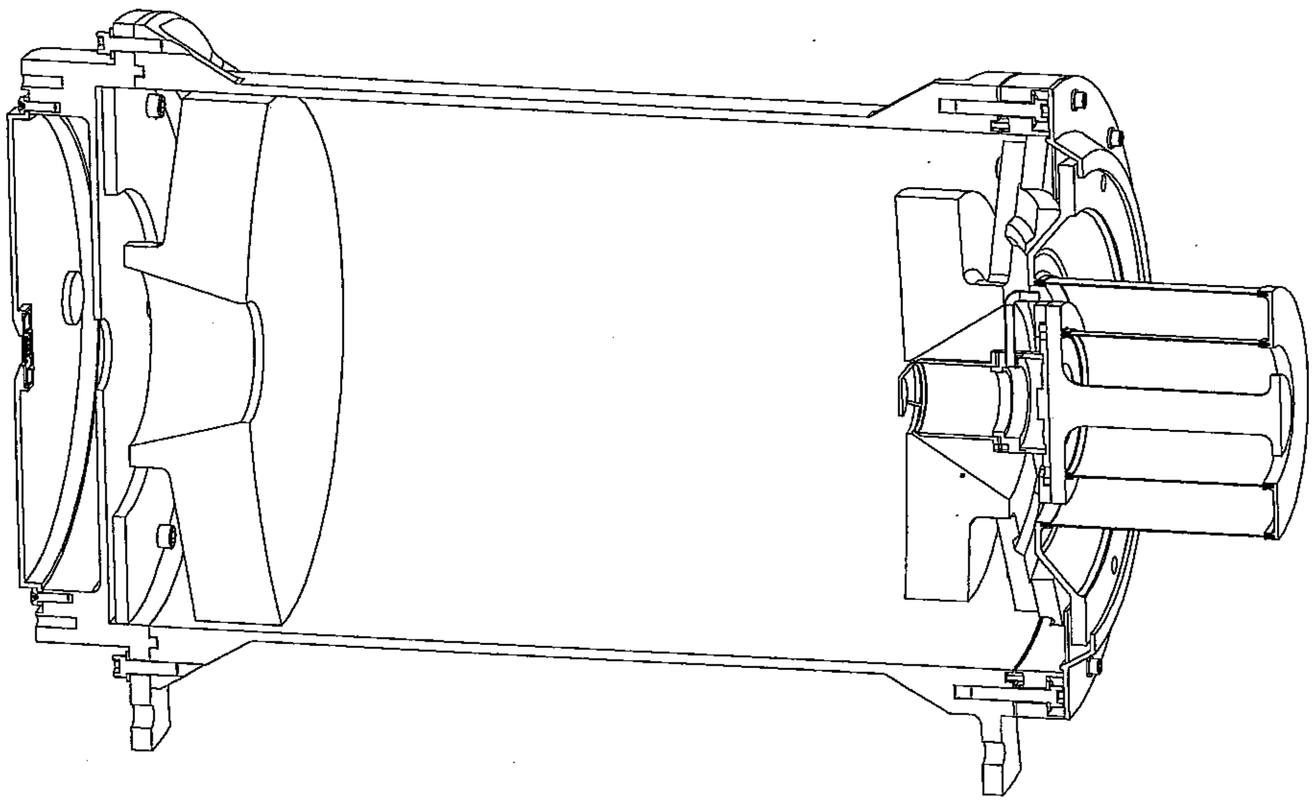
FOREOPTICS ASSEMBLY SECTION VIEWS



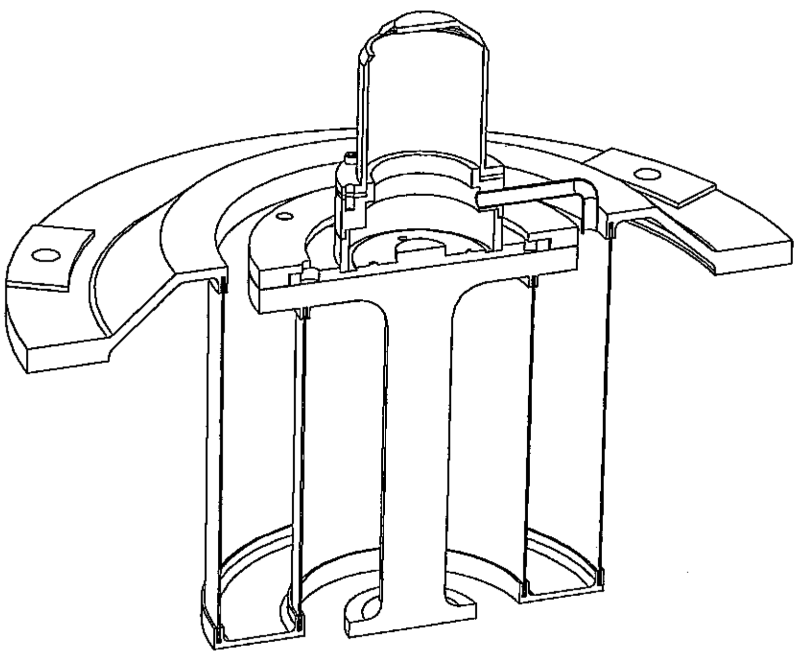


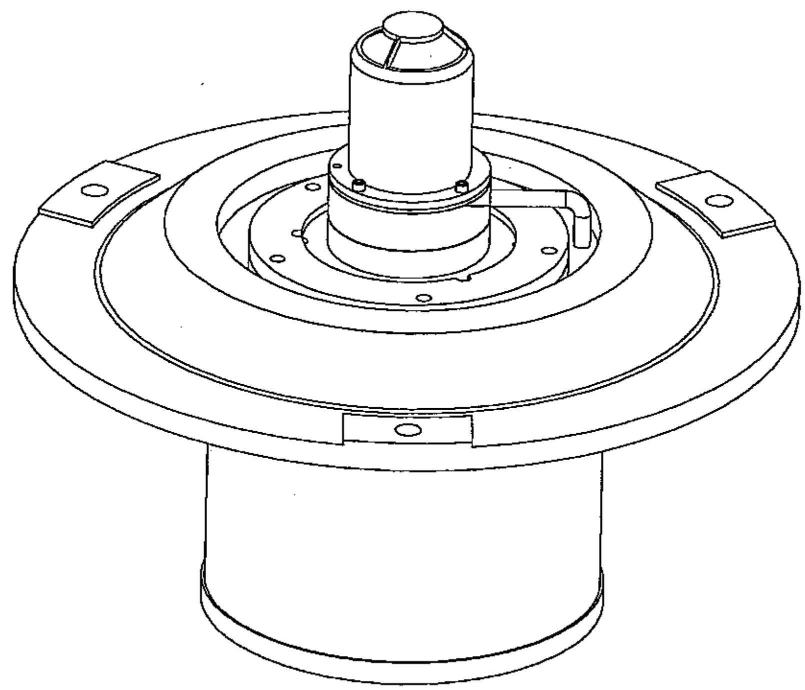
TELESCOPE REIMAGING OPTICS

Assembly Mass: 6.53 kg



DETECTOR MOUNT ASSEMBLY





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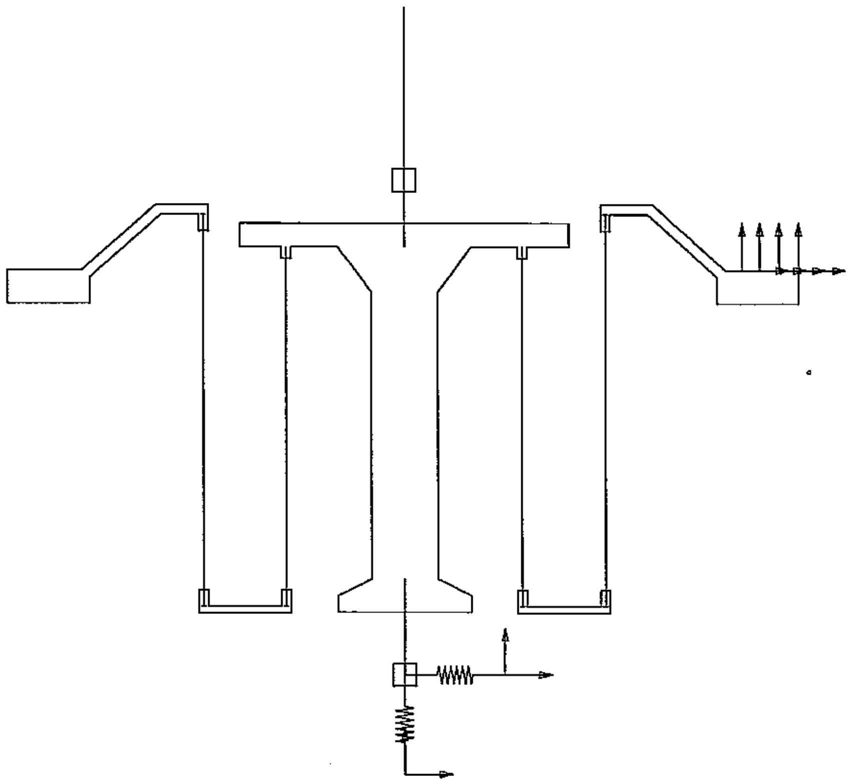
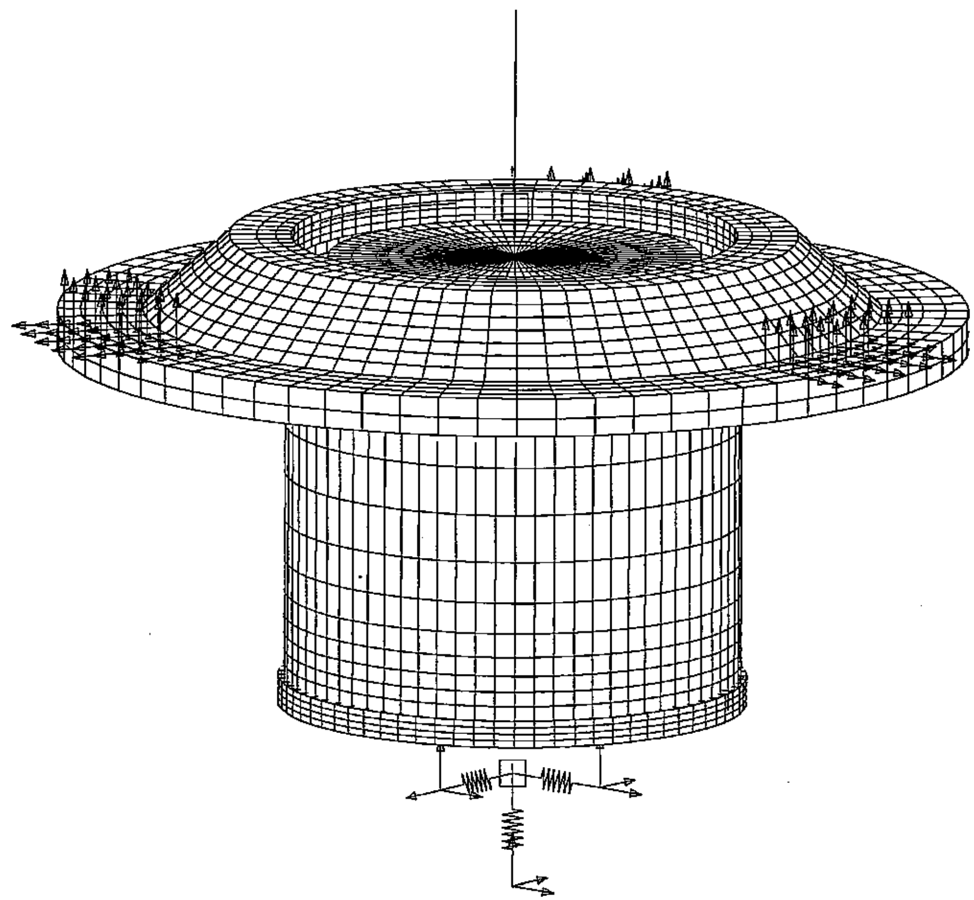
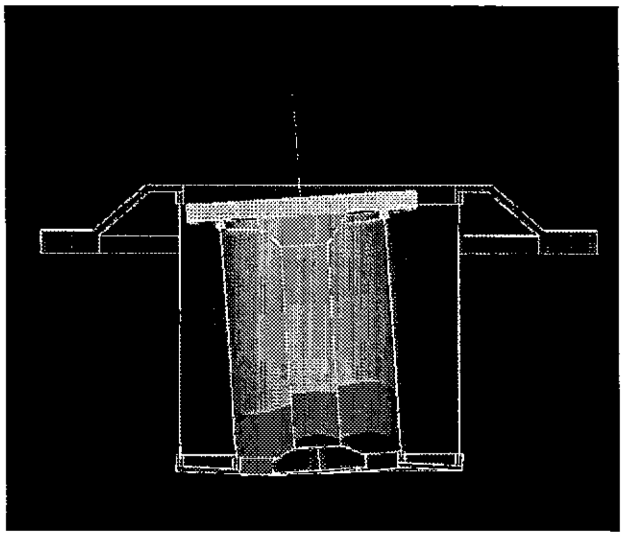
DETECTOR MOUNT ASSEMBLY FEM

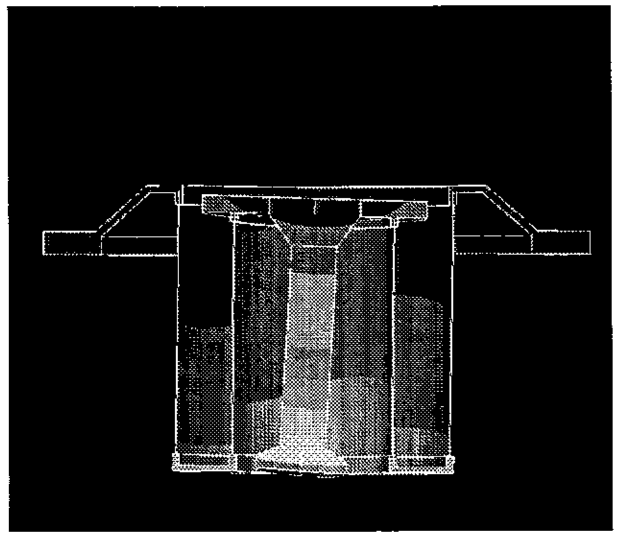




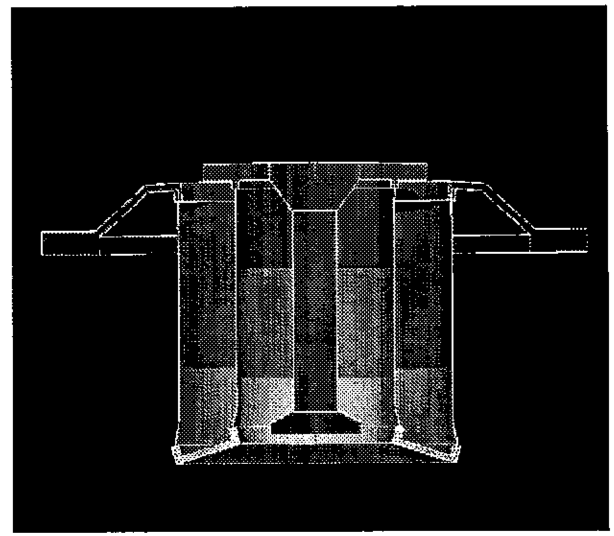
DETECTOR MOUNT ASSEMBLY NORMAL MODES



256 Hz



372 Hz



608 Hz

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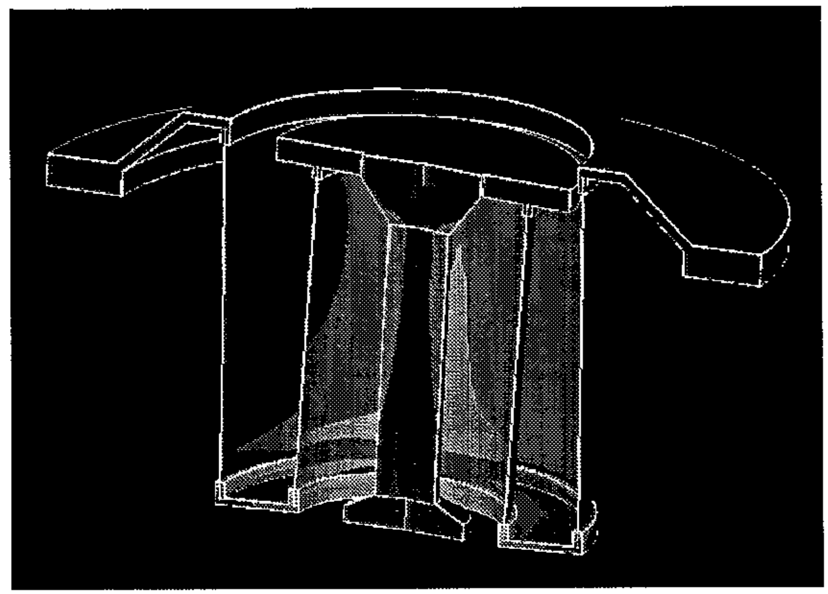
DETECTOR MOUNT ASSEMBLY

1 g loading

- At the center of detector plane:
    - Translation: 0.00014"
    - Tilt: 37 μrad



SABER STRUCTURE

- Structure design meets the following criteria:
  - Low strain support of telescope assembly
  - Stiff attachment to the spacecraft (System $f_n > 35$ Hz)
  - Thermal insulation between spacecraft and different parts of SABER
  - Minimizes transfer of spacecraft distortions to the telescope
- Structure is all 6061-T651 aluminum with six G-10 struts
  - SDL has extensive experience with aluminum / G-10 structures
  - Cost effective approach
  - Critical members will be fully tested and qualified before proto-flight unit is made
- Structural baseplate also functions as a radiator
- Structure will be used as the alignment jig for the telescope

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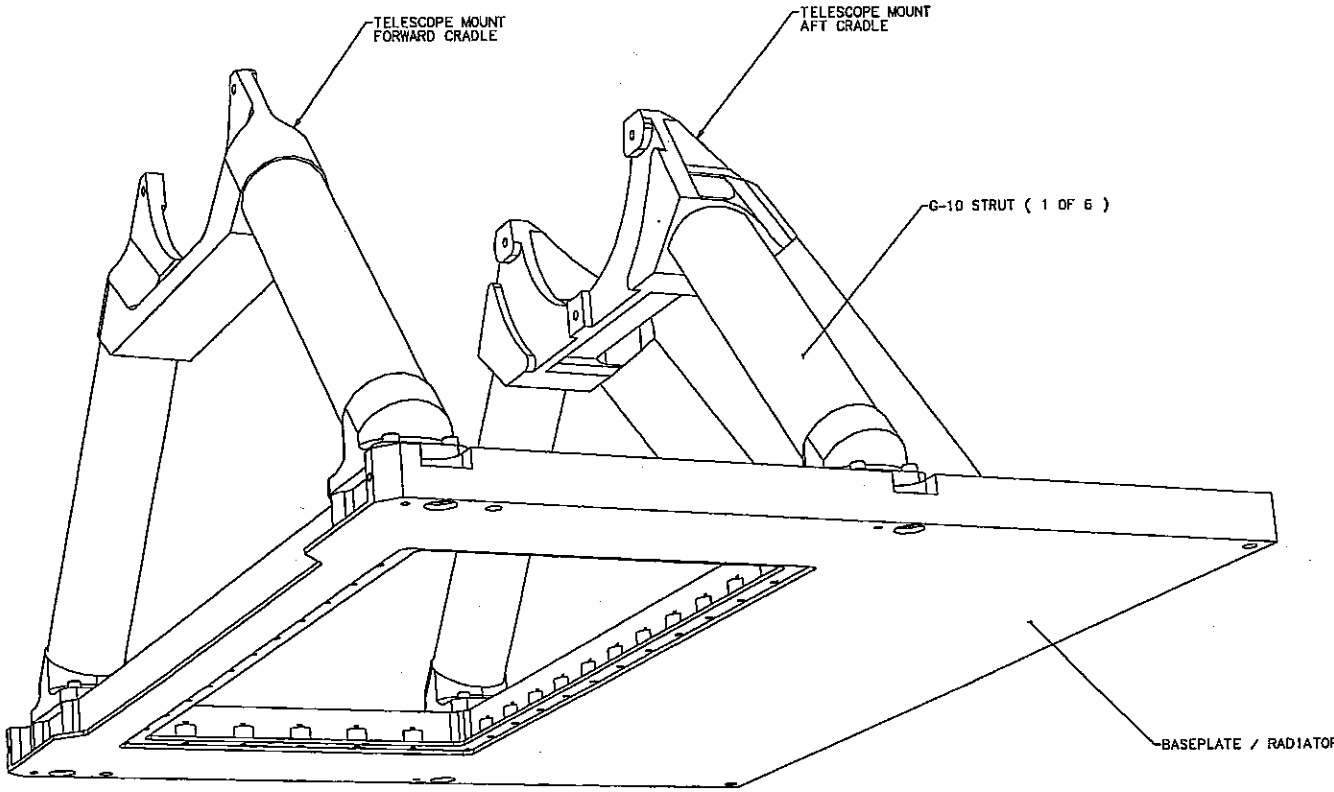
SABER STRUCTURE



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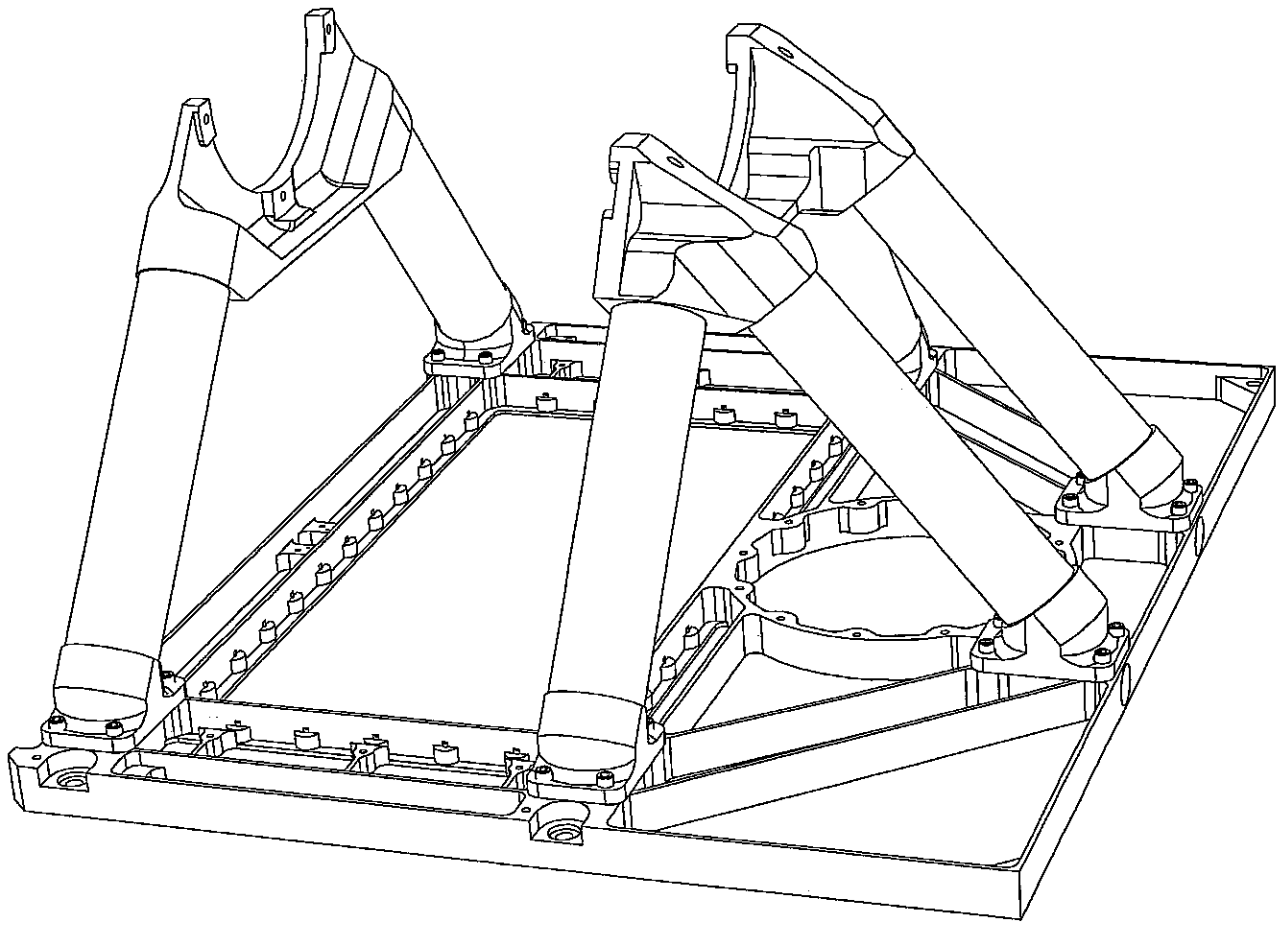
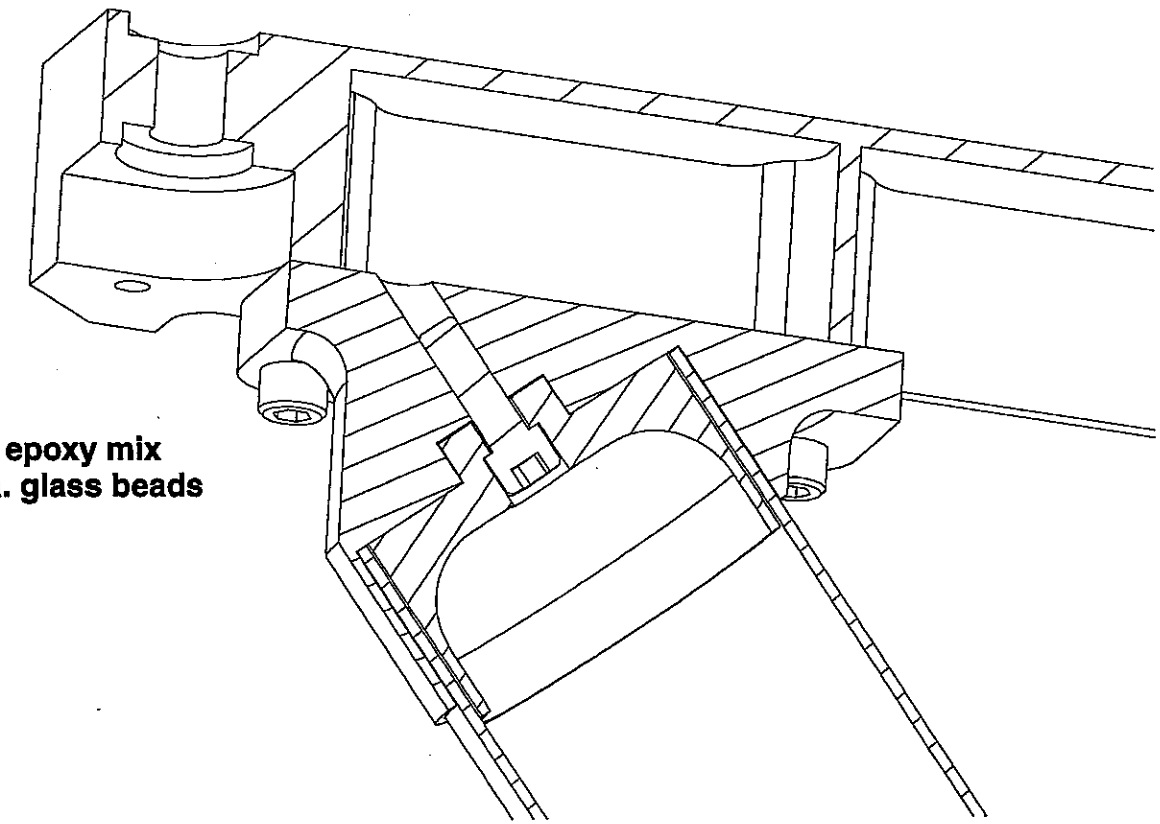
SABER STRUCTURE

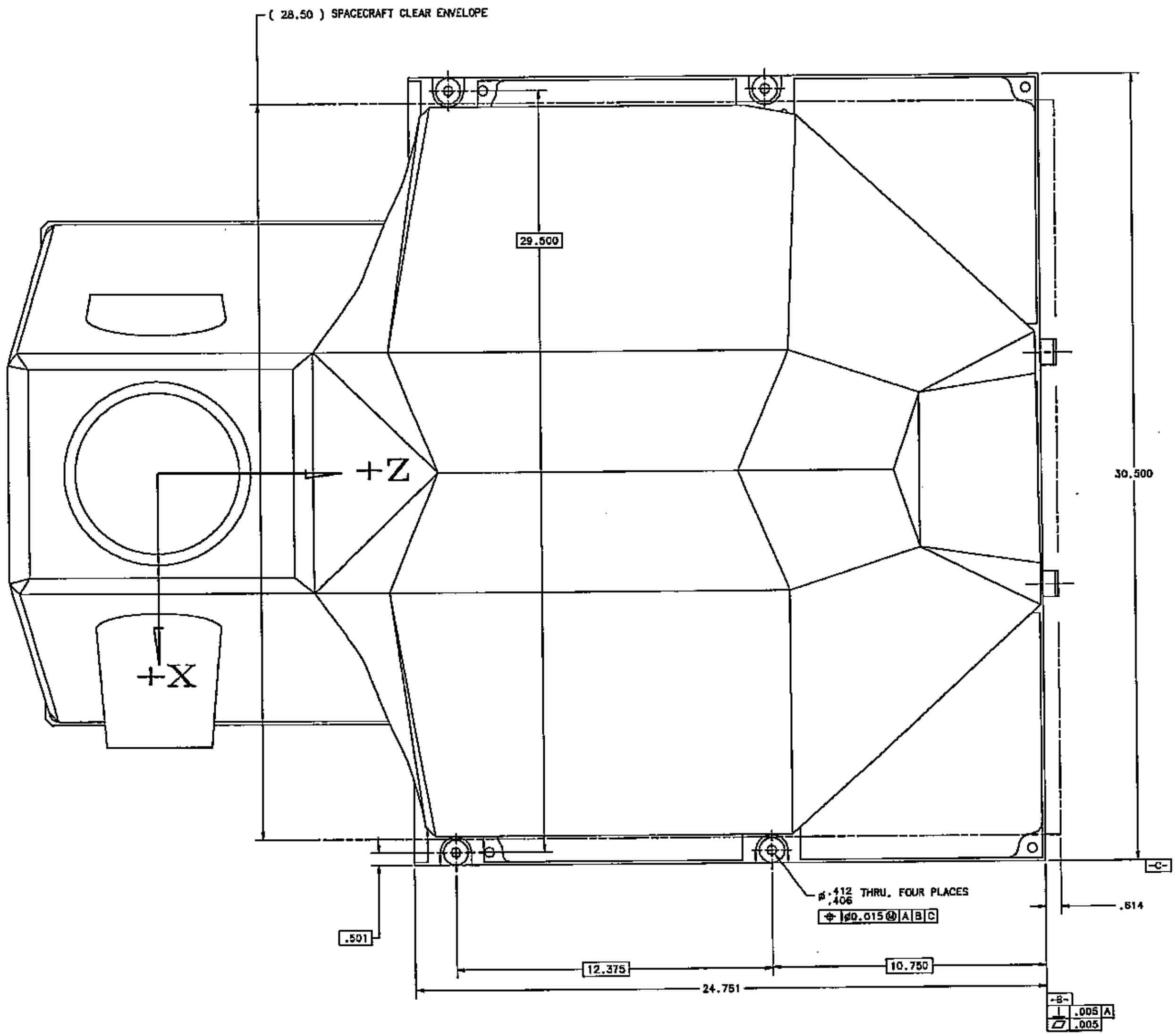


STRUCTURE STRUT DETAIL

Double Lap Joint
Aluminum to G-10
Epibond 1210A 2:1 epoxy mix
with 0.005" dia. glass beads



SABER MECHANICAL INTERFACES (1 of 4)



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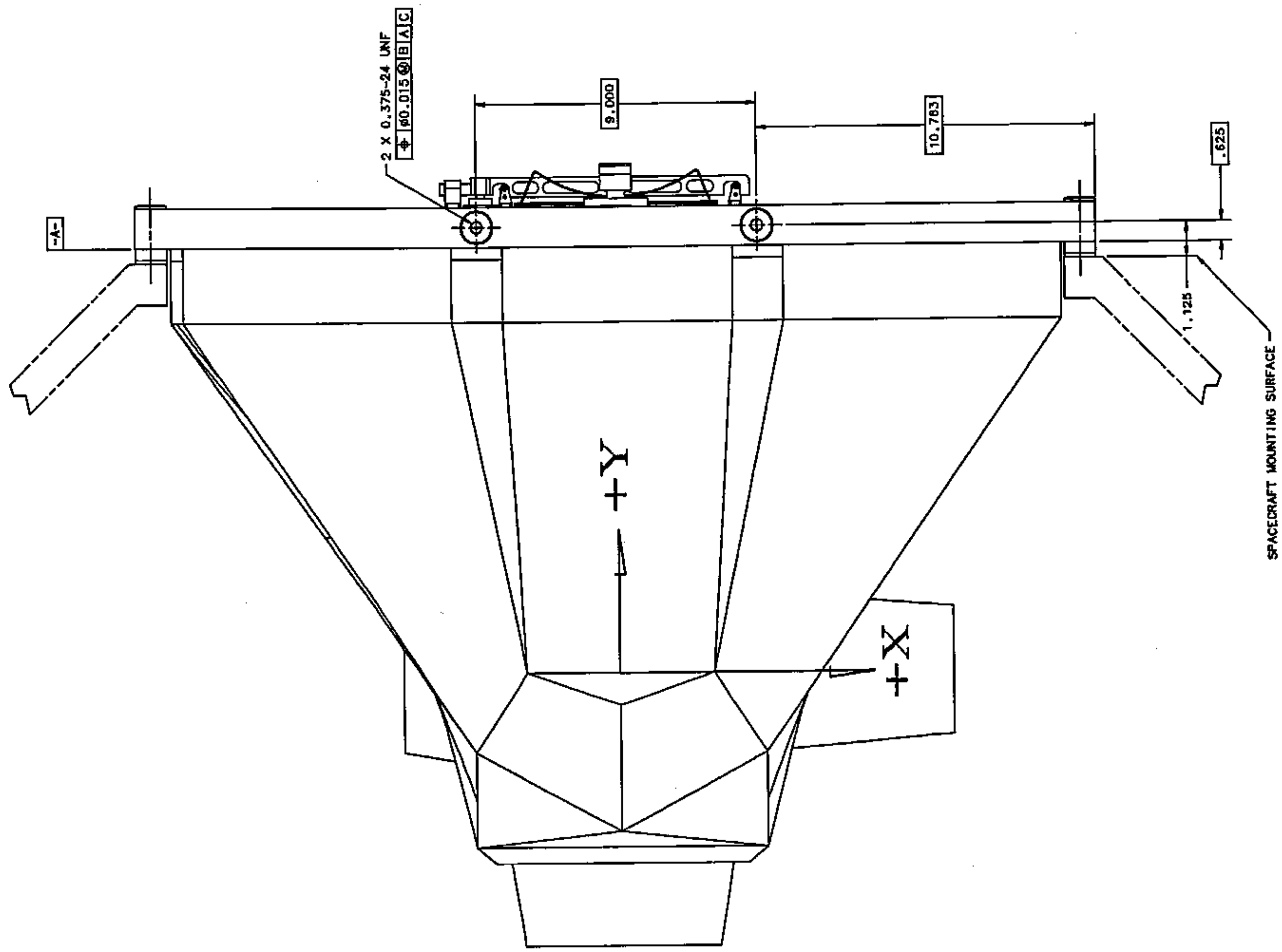
SABER MECHANICAL INTERFACES (2 of 4)



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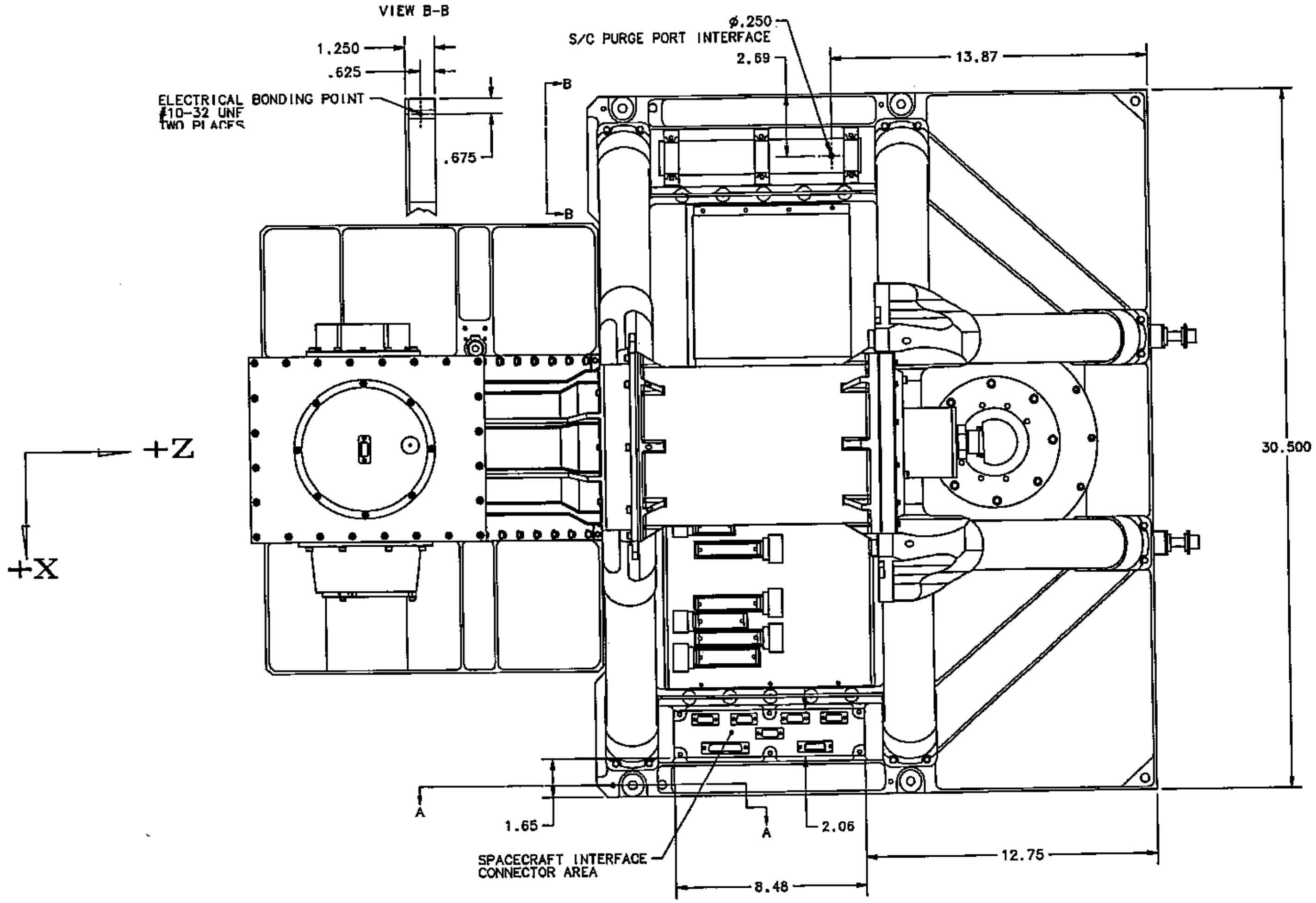
SABER MECHANICAL INTERFACES (3 of 4)



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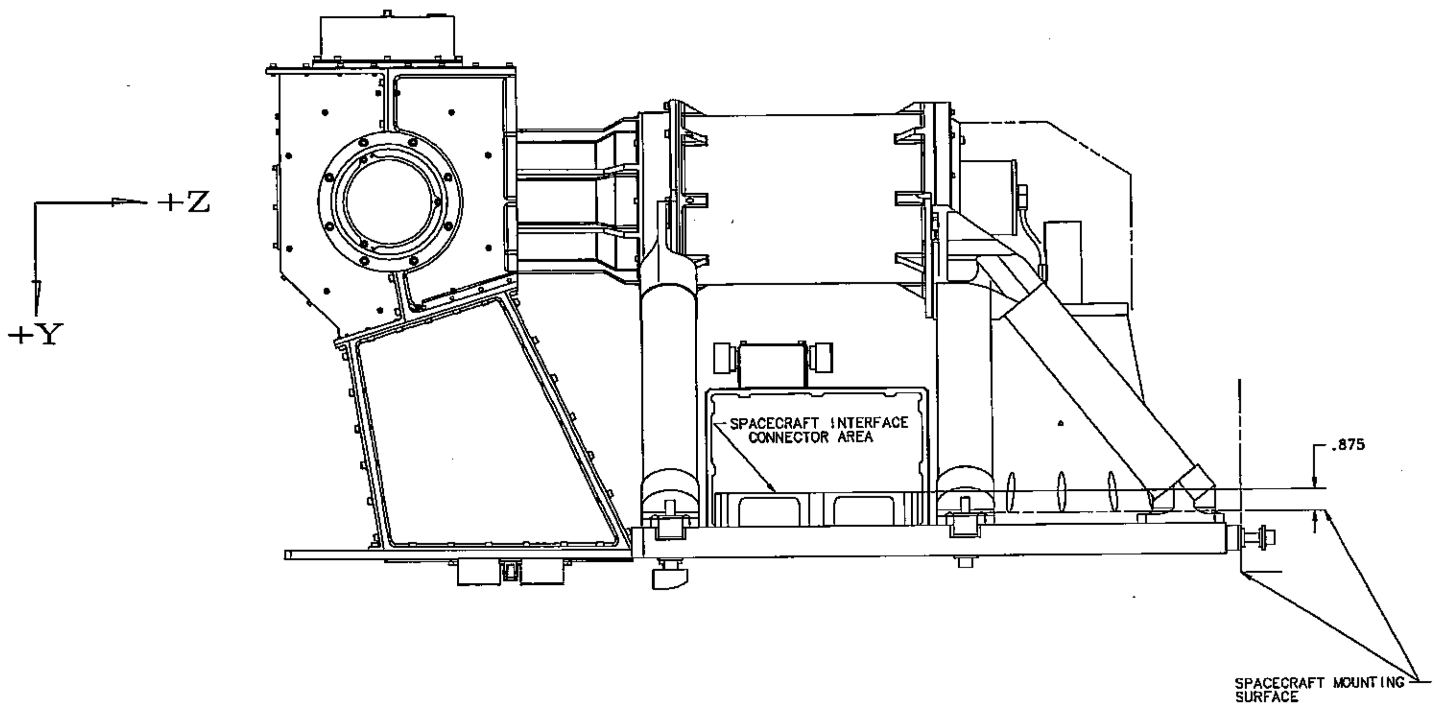
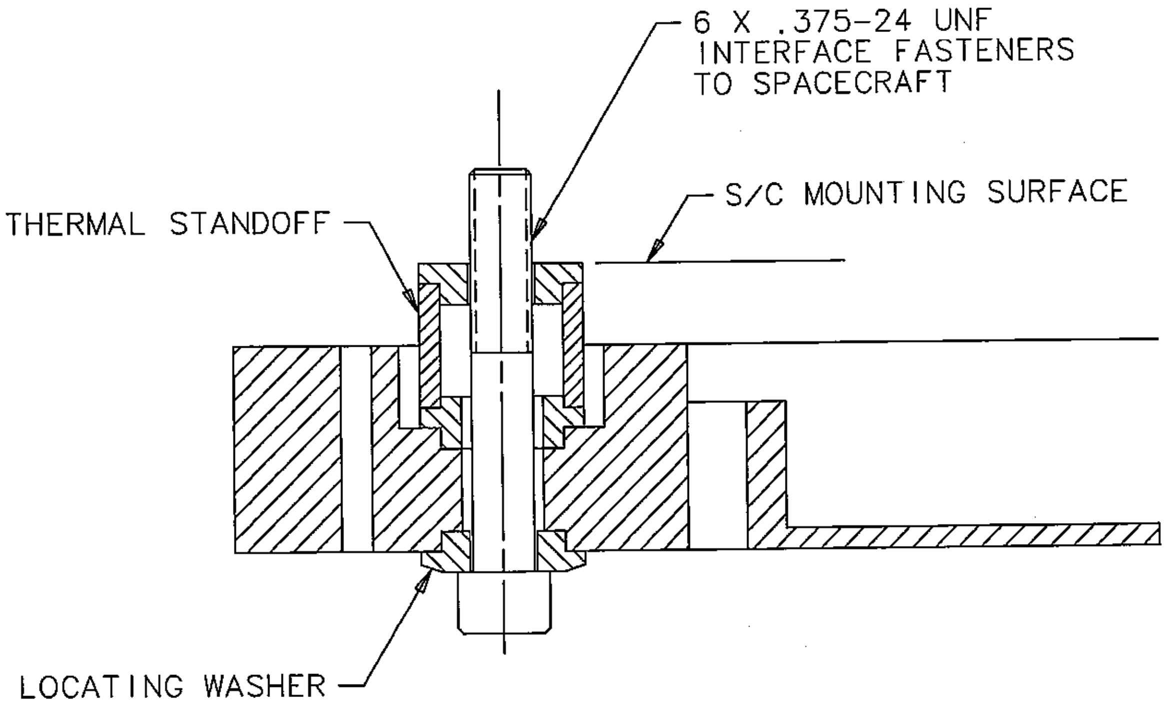
SABER MECHANICAL INTERFACES (4 of 4)



SABER MECHANICAL INTERFACE DETAILS



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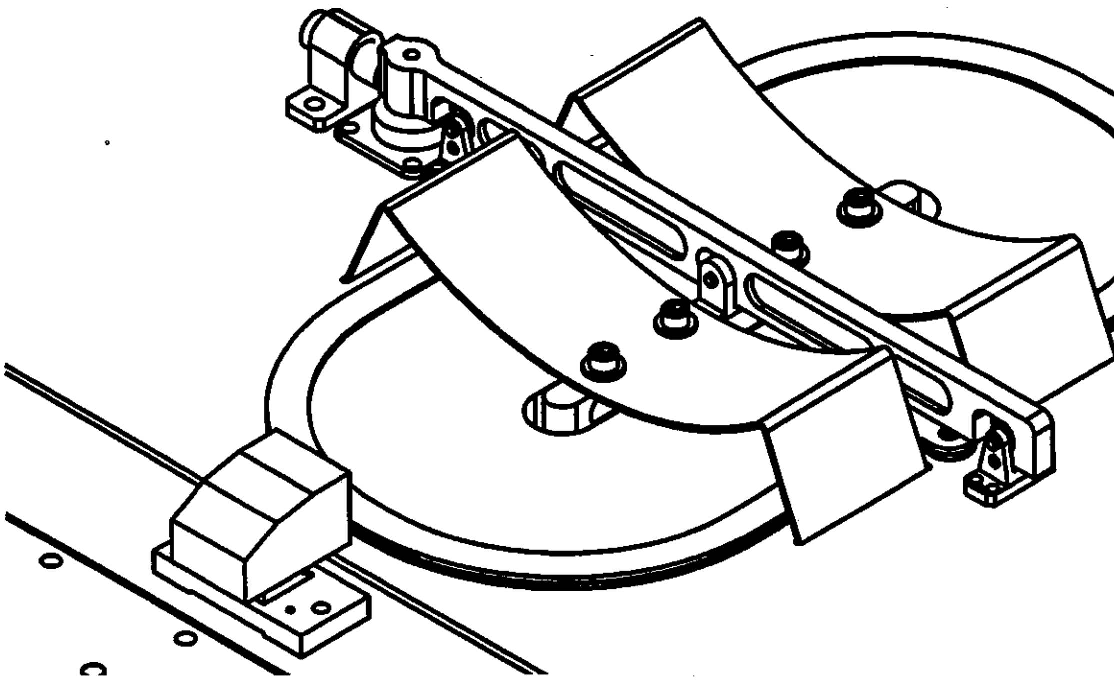
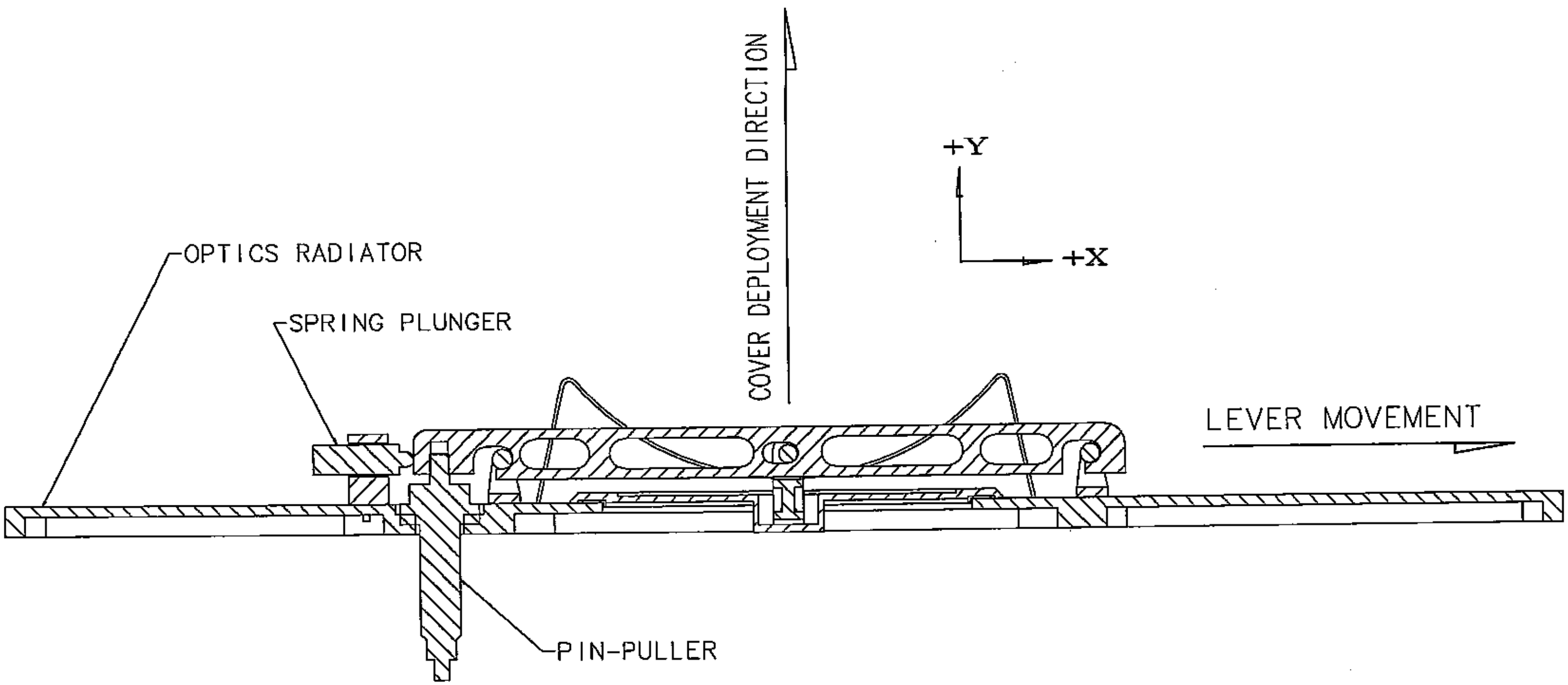
SABER DEPLOYABLE COVER

Assembly Mass: 0.53 kg



COVER DEPLOYMENT



- Mass of deployed portion of the cover is 450 grams
- Initial escape velocity is 98 in/sec or 2.48 m/sec

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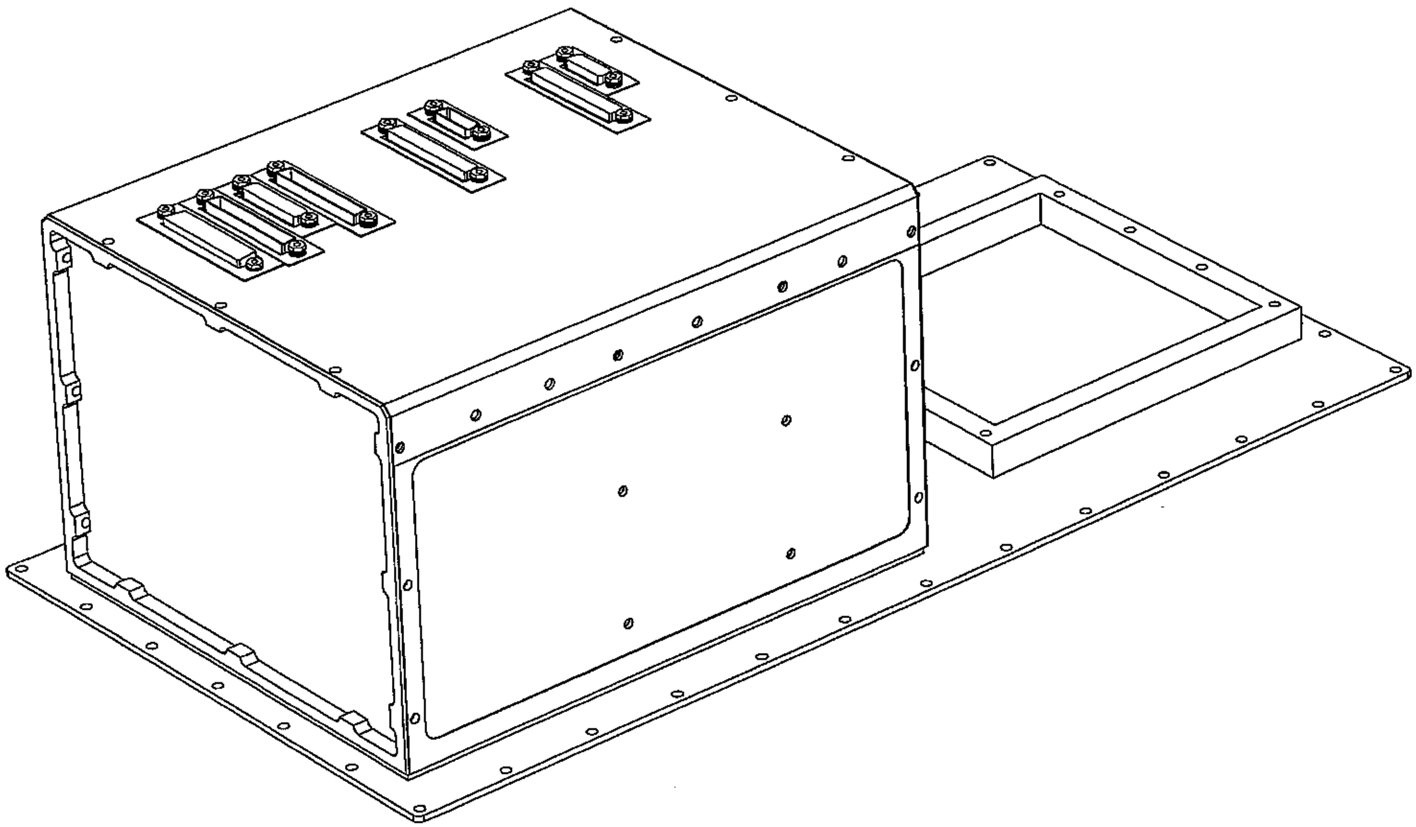
IEB ENCLOSURE

Assembly Mass: 9.27 kg



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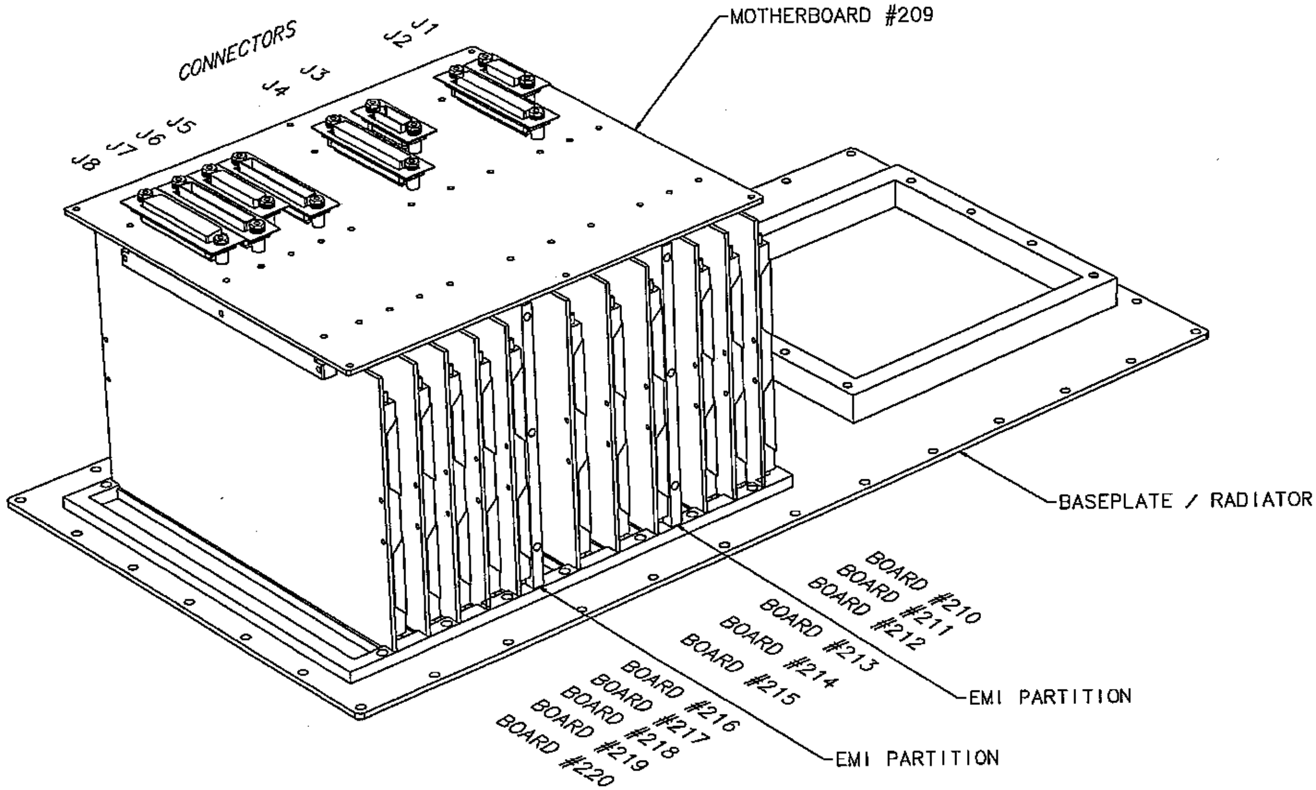
IEB DETAILS



STRUCTURAL ANALYSIS

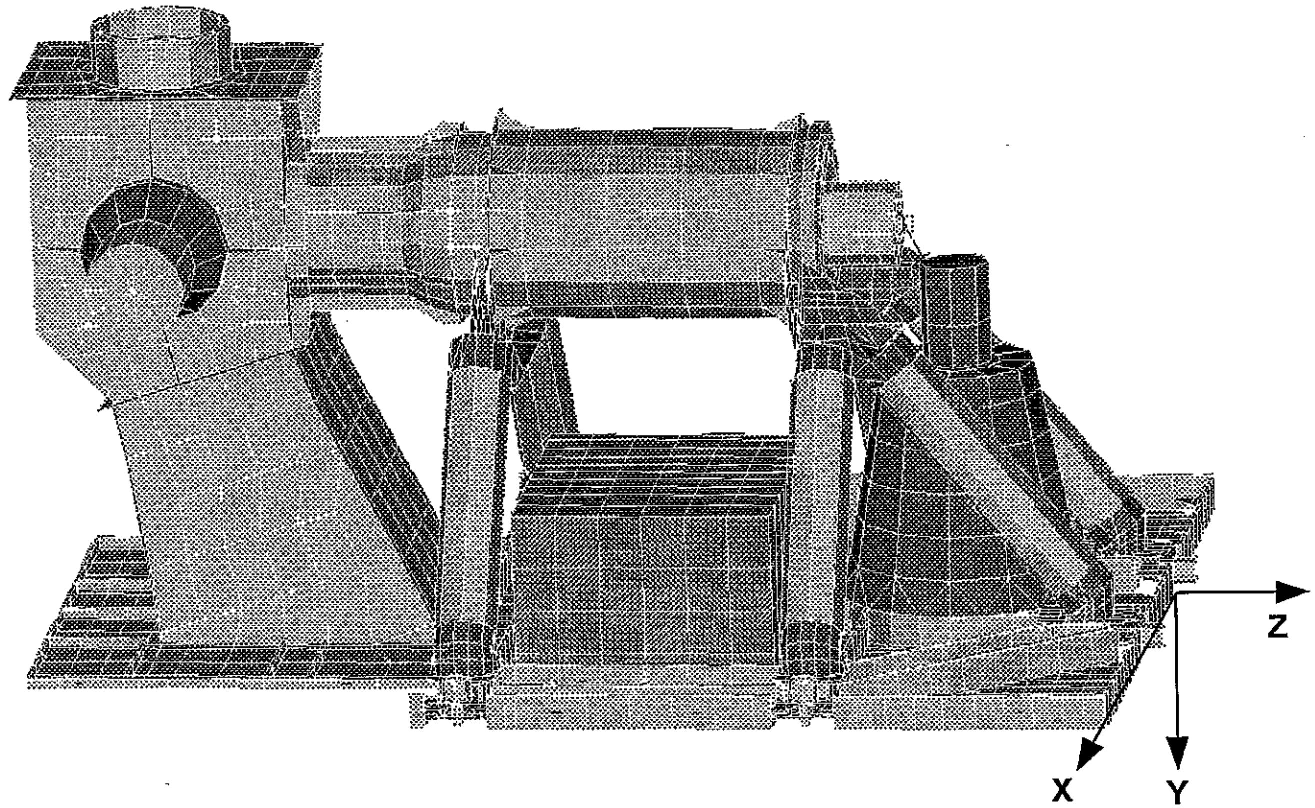
Steven Folkman

20 October 1997

Phone: (435) 797-2879
Fax: (435) 797-2417
E-mail: stevef@mae.usu.edu

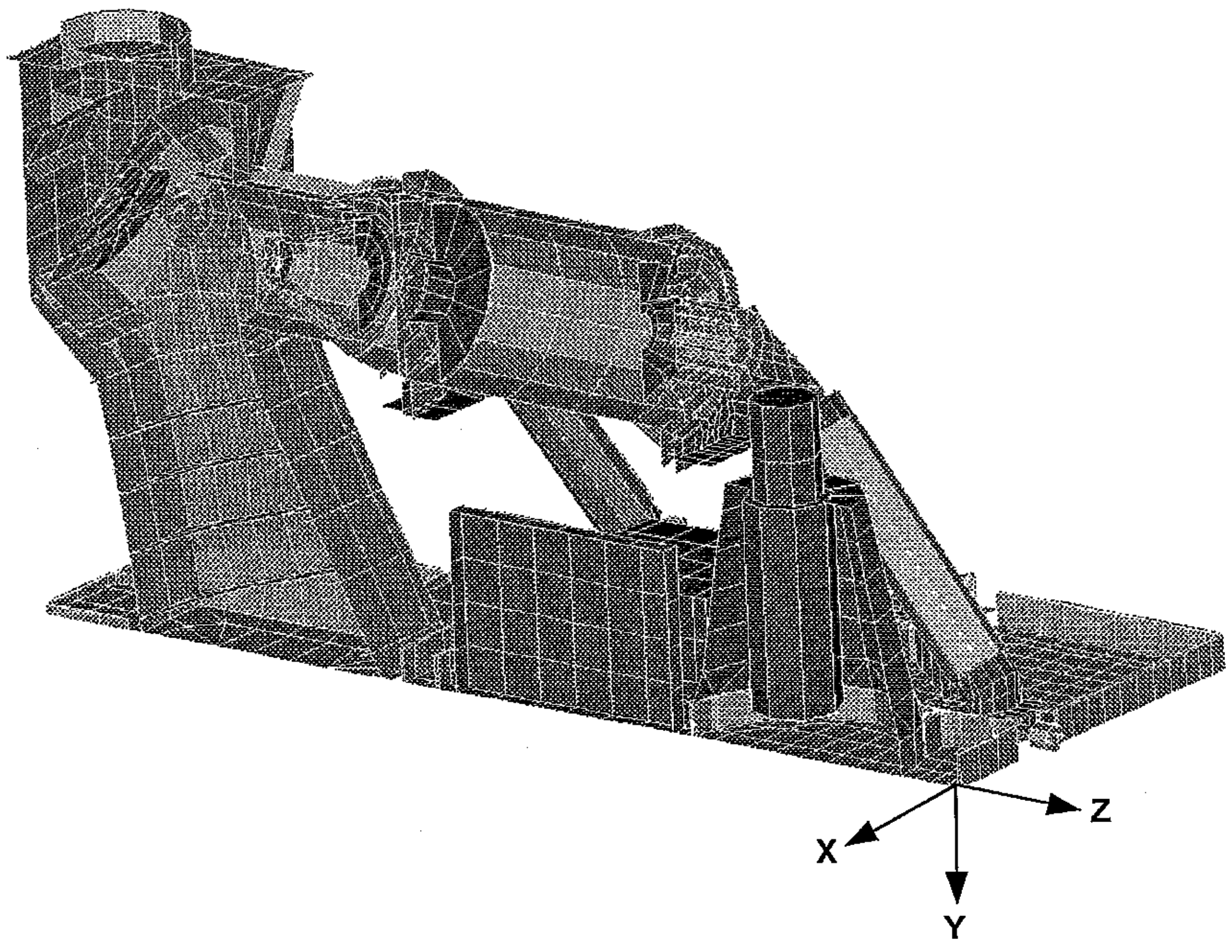
FINITE ELEMENT MODEL DESCRIPTION
Detailed Finite Element Model Constructed

- 5505 elements
- 4768 nodes
- Model mass 65.63 kg
- G-10 struts modeled with beam elements
- G-10 mount washers modeled with beam elements
- Refrigerator model by a stiff beam
- Coordinate system used shown in sketch



FINITE ELEMENT MODEL DESCRIPTION
Model Components

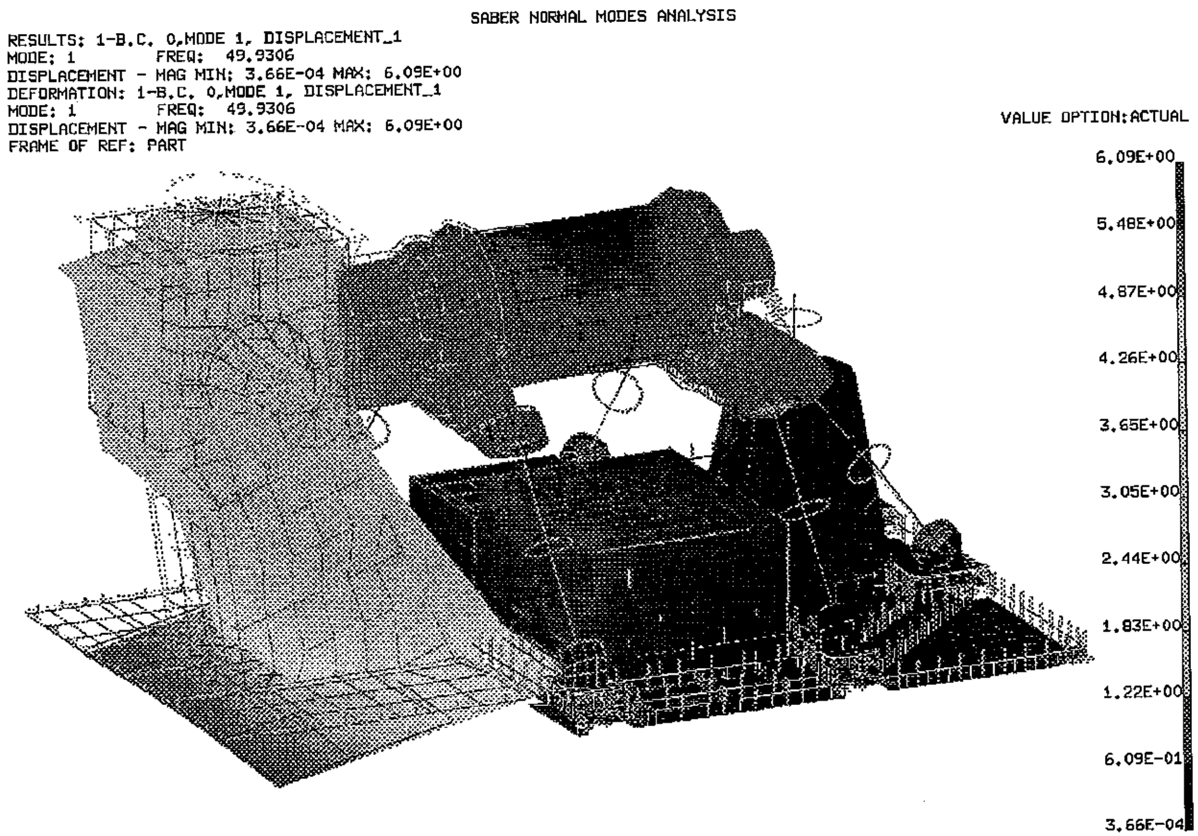
- **Pointing mirror**
- **Four fixed mirrors**
- **Optical bench**
  - G-10 tube support
  - Springs connected to refrigerator
- **About 1/3 of baffles included in the model at 3 times the thickness**
- **Inside view displayed**



PREDICTED VIBRATION MODES
Normal Modes Analysis

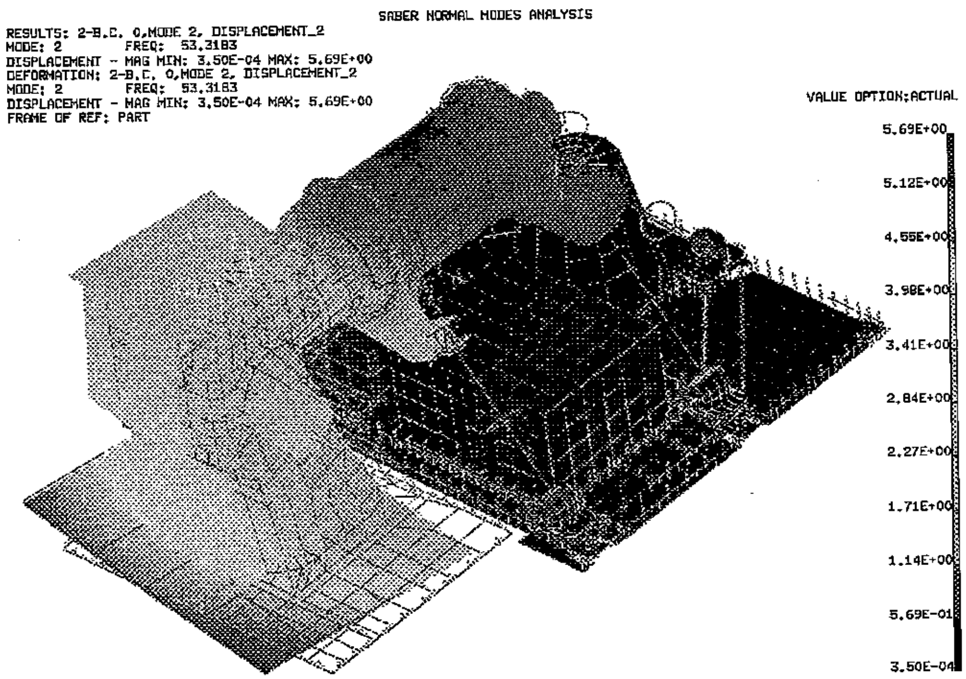
Assumptions and results

- **Model is restrained by clamped nodes at the spacecraft attach points**
- **First 5 modes**
  - 49.9 Hz
  - 53.3 Hz
  - 76.9 Hz
  - 86.6 Hz
  - 104.3 Hz
- **First mode shape displayed (color view shows the deformed geometry)**

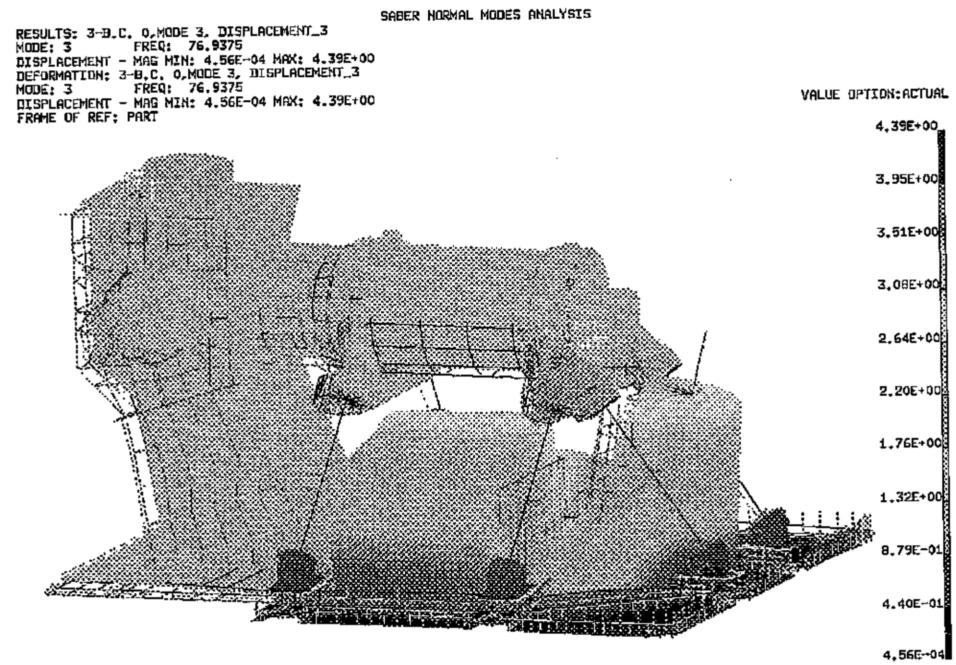


PREDICTED VIBRATION MODES
Normal Modes Analysis

2nd Mode



3rd Mode



STRESS ANALYSIS
16 g Loads in Each Axis

Stress analysis

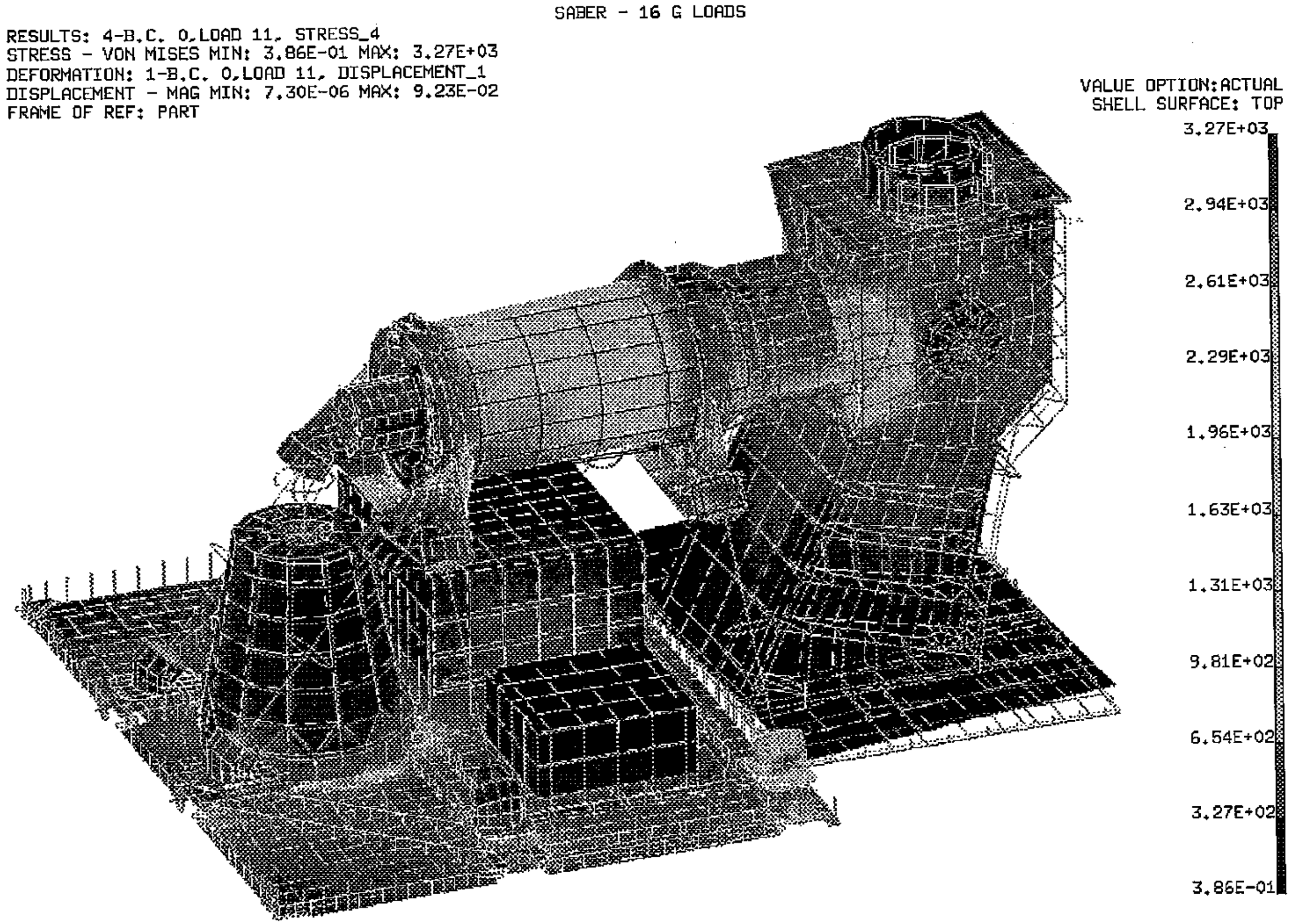
- **Nodes at spacecraft interface were fixed**
- **16 g loads applied individually in X, Y, and Z axes**
- **Predicted stresses increased by a factor of 3.0 in thin shell elements (not beams) to account for stress risers and/or a course mesh**
- **Factor of safety applied: 1.4 used on yield, 1.875 on ultimate, 2.0 on composites**
- **Predicted stresses are low and positive margins obtained**

	Maximum Stress (ksi)	Stress Concent. Factor	Safety Factor for Yield	Yield Strength (ksi)	Margin of Safety for Yield	Safety Factor for Ult.	Ultimate Strength (ksi)	Margin of Safety for Ultimate
Telescope	3.8	3	1.4	35	1.2	1.875	42	1.0
Scan Assembly	3.6	3	1.4	35	1.3	1.875	42	1.1
Baffle	1.4	3	1.4	35	5.0	1.875	42	4.3
Optics Radiator	2.1	3	1.4	35	3.0	1.875	42	2.6
Mounting Plate	4.7	3	1.4	35	0.8	1.875	42	0.6
Cradles	3.5	3	1.4	35	1.4	1.875	42	1.1
Brackets for G10 Tubes	4.1	3	1.4	35	1.0	1.875	42	0.8
Elec. Box and Radiator	6.7	3	1.4	35	0.2	1.875	42	0.1
G10 Tubes for Telescope	6.3	1	2			2	24	0.9
G10 Tubes for FPA	0.4	1	2			2	24	29.0

STRESS ANALYSIS
16 g Loads in Each Axis

Maximum displacements

- **0.092 inch at a 16 g load in X direction**
- **Stresses and displacements shown for this load case**
- **Dynamic envelope around telescope is 0.375 inch**

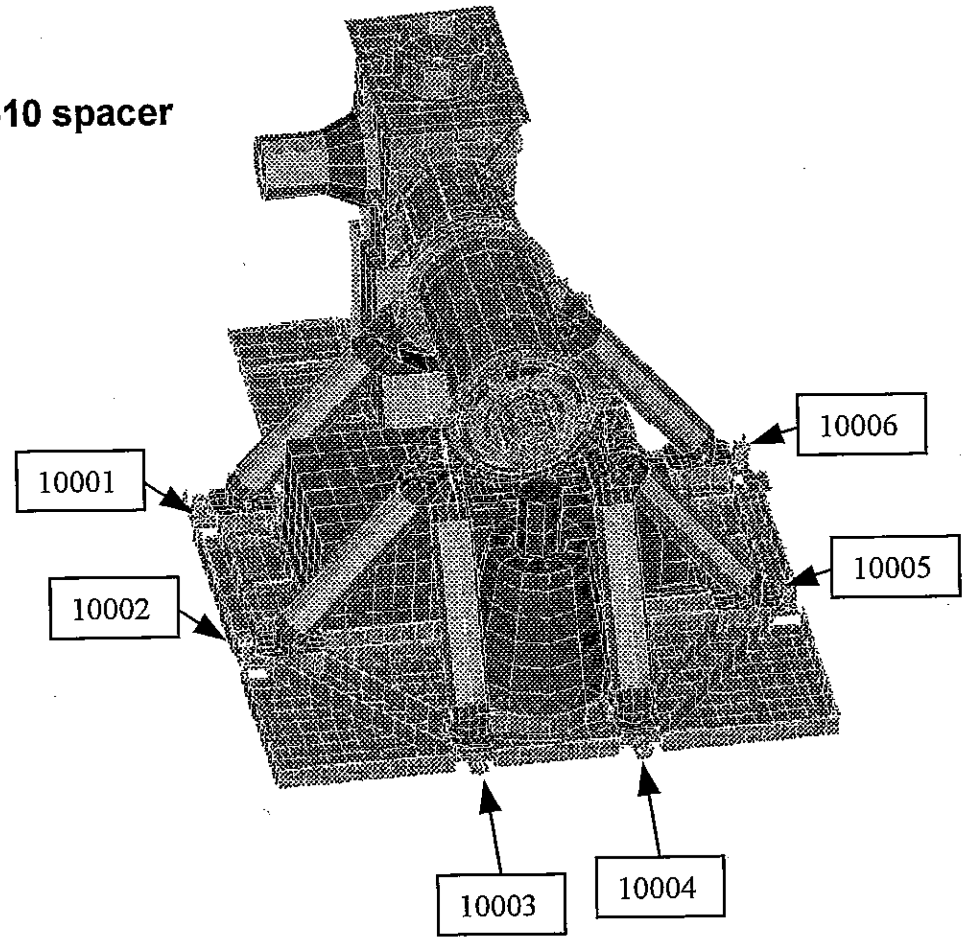


STRESS ANALYSIS
16 g Loads in Each Axis

Predicted bolt loads from 16 g load cases

- **Maximum axial force is 654 lb**
- **Last column is shear load carried by the G-10 spacer**
- **Figure shows bolt locations**

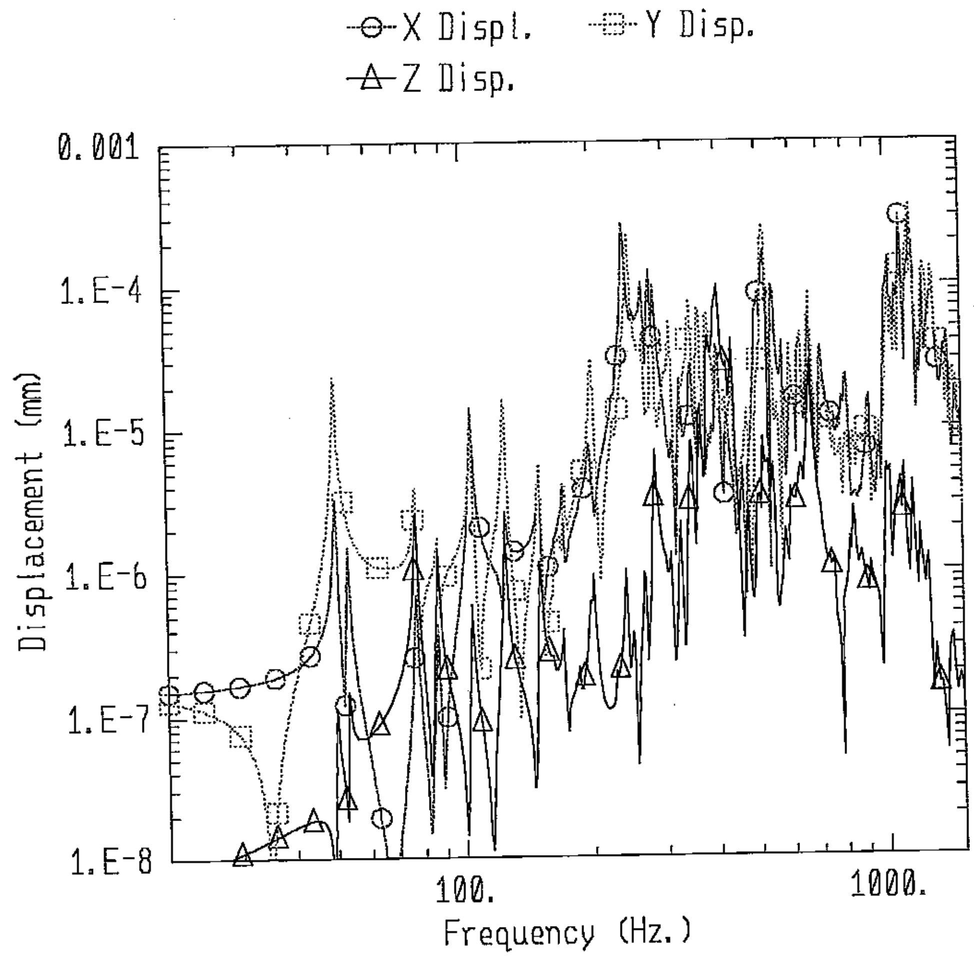
16 G Load Direction	Element ID	Axial Force (lbs)	Bolt Shear Force (lbs)	G10 Spacer Shear Forc (lbs)
X	10001	349.8	127.6	524.3
	10002	-97.6	72.6	279.3
	10003	-40.5	197.6	106.4
	10004	10.6	166.3	89.5
	10005	102.0	70.0	253.5
	10006	-351.6	124.1	498.2
Y	10001	494.7	34.6	291.4
	10002	135.9	34.2	255.4
	10003	145.8	39.5	21.3
	10004	209.1	52.9	28.5
	10005	106.2	35.7	262.8
	10006	472.6	34.2	275.7
Z	10001	-82.9	23.5	166.5
	10002	-191.6	25.5	131.8
	10003	-632.5	329.8	177.6
	10004	-654.6	305.8	164.7
	10005	-171.4	22.4	131.0
	10006	-97.0	19.2	132.4



REFRIGERATOR DISTURBANCES
Steady State Response

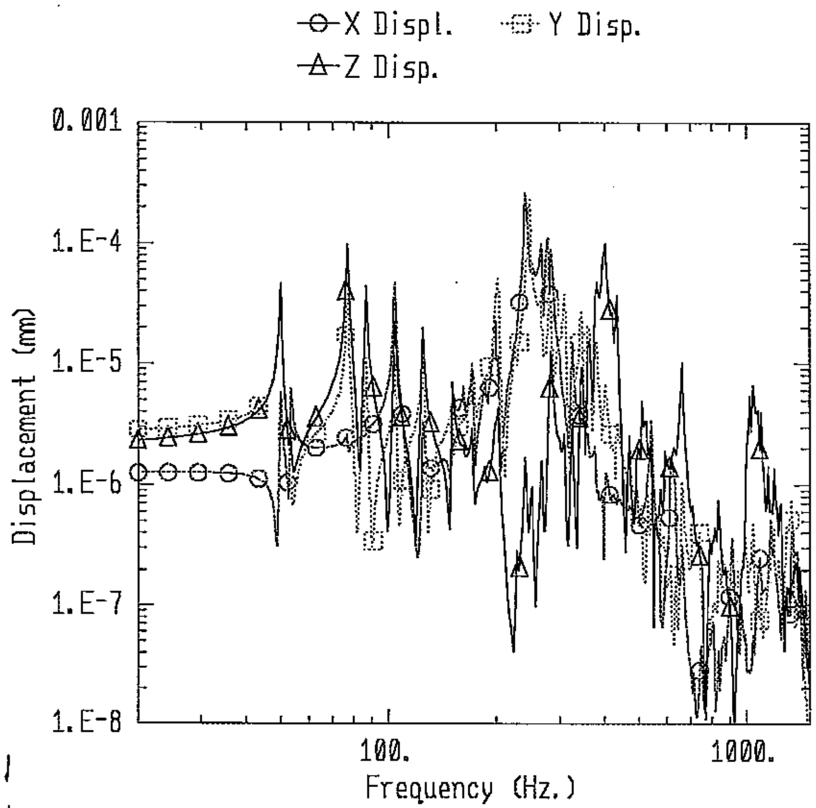
Analysis assumptions and results

- **0.02 lb load applied in Y direction at refrigerator mount node**
- **Model clamped at spacecraft mount nodes**
- **Damping set at Q=100**
- **All modes between 0-1500 Hz included in analysis**
- **Relative displacements between the scan mirror and various points on mirrors and focal plane predicted**
- **Figure shows relative displacements between focal plane and the center of mirror 2**

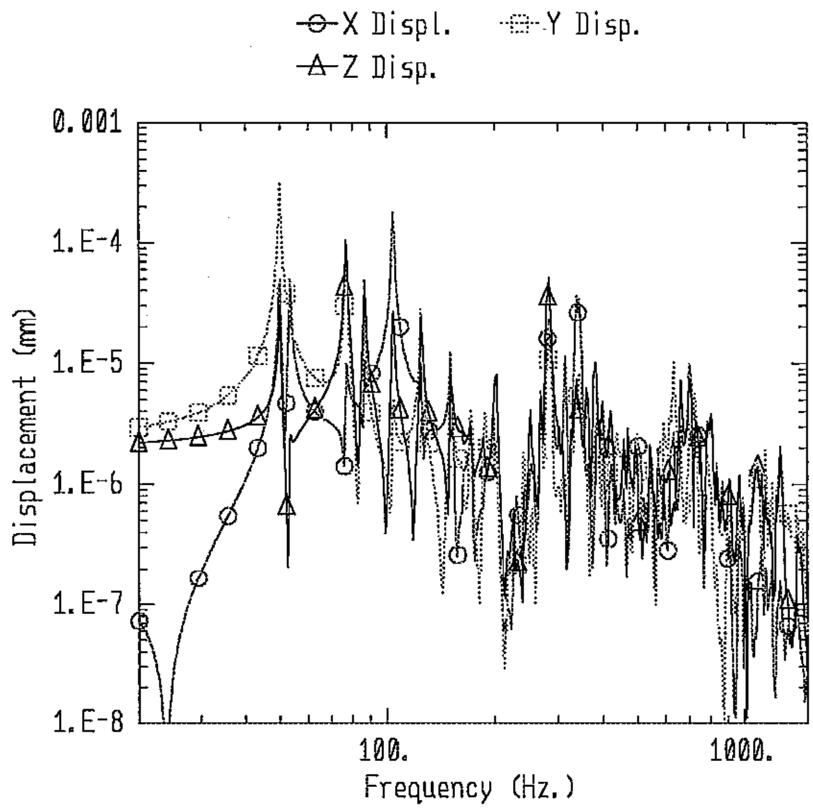


REFRIGERATOR DISTURBANCES
Steady State Response

Predicted displacement at the focal plane

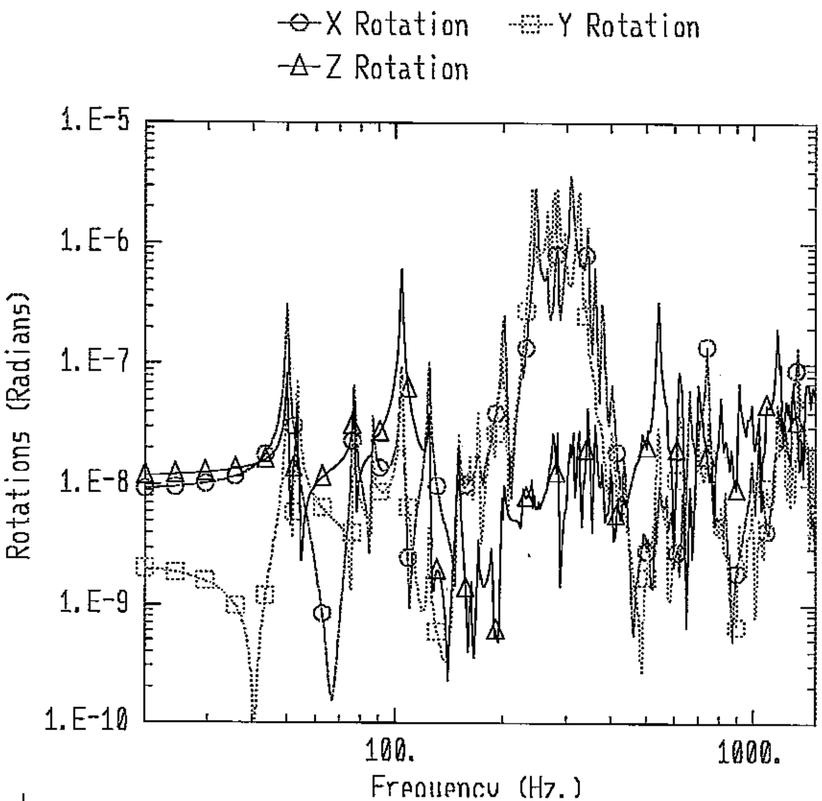


Predicted displacement at the center of the scan mirror

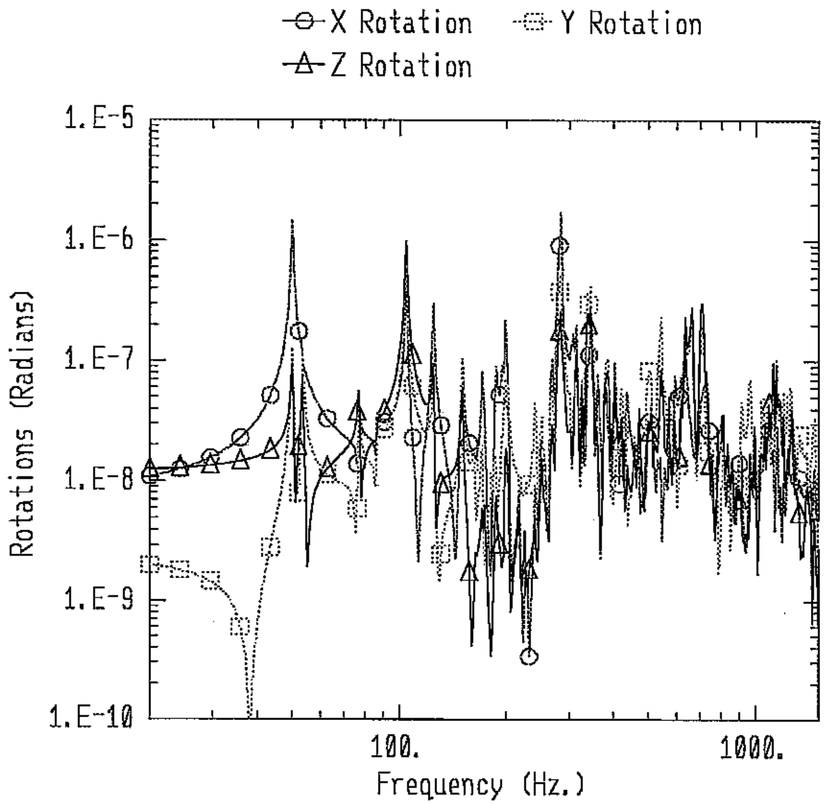


REFRIGERATOR DISTURBANCES
Steady State Response

Predicted rotation at the focal plane



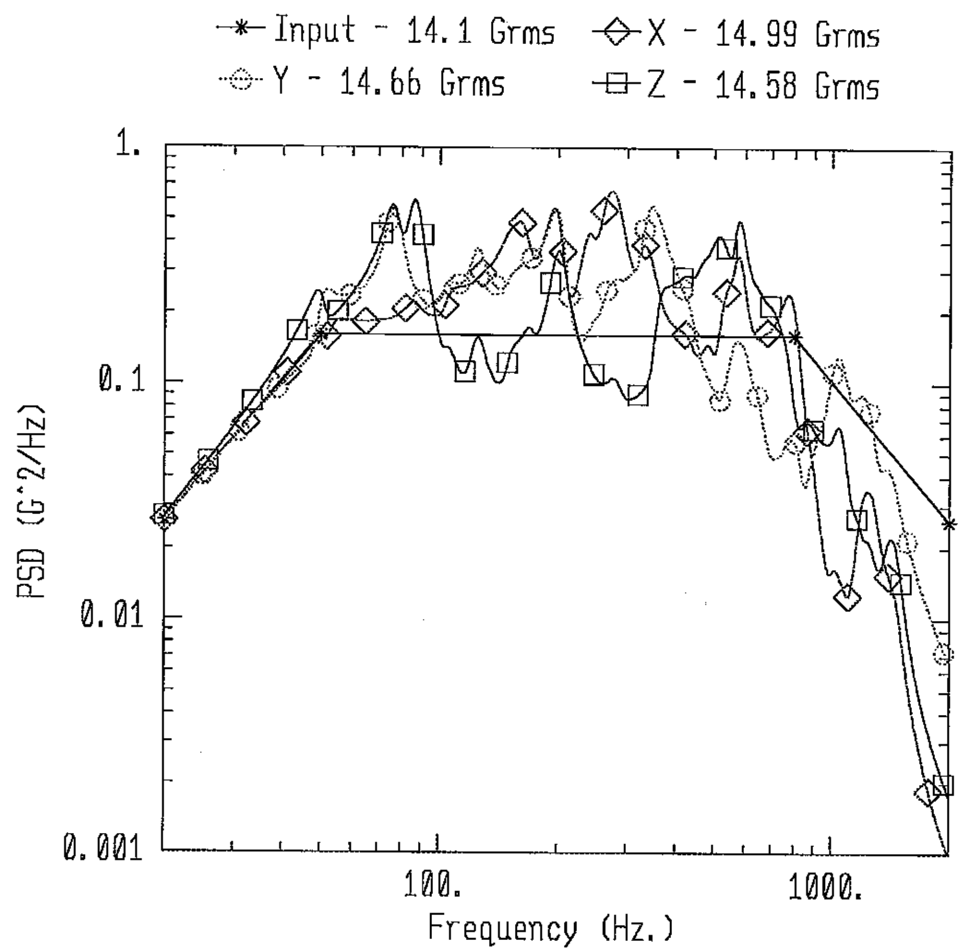
Predicted rotation at the center of the scan mirror



RANDOM VIBRATION
Frequency Response at Refrigerator Mount

Analysis assumptions and results

- A 1.0 g enforced motion applied at spacecraft mount points
- Damping set at Q=10
- All modes between 0-1500 Hz included in analysis
- Frequency response function at the refrigerator mount determined
- Accelerations computed for inputs in X, Y, and Z directions
- Figure shows the input PSD and the PSD's measured at the refrigerator mount



TEMPERATURE GRADIENTS EFFECTS
Simulation of Hot Case Conditions

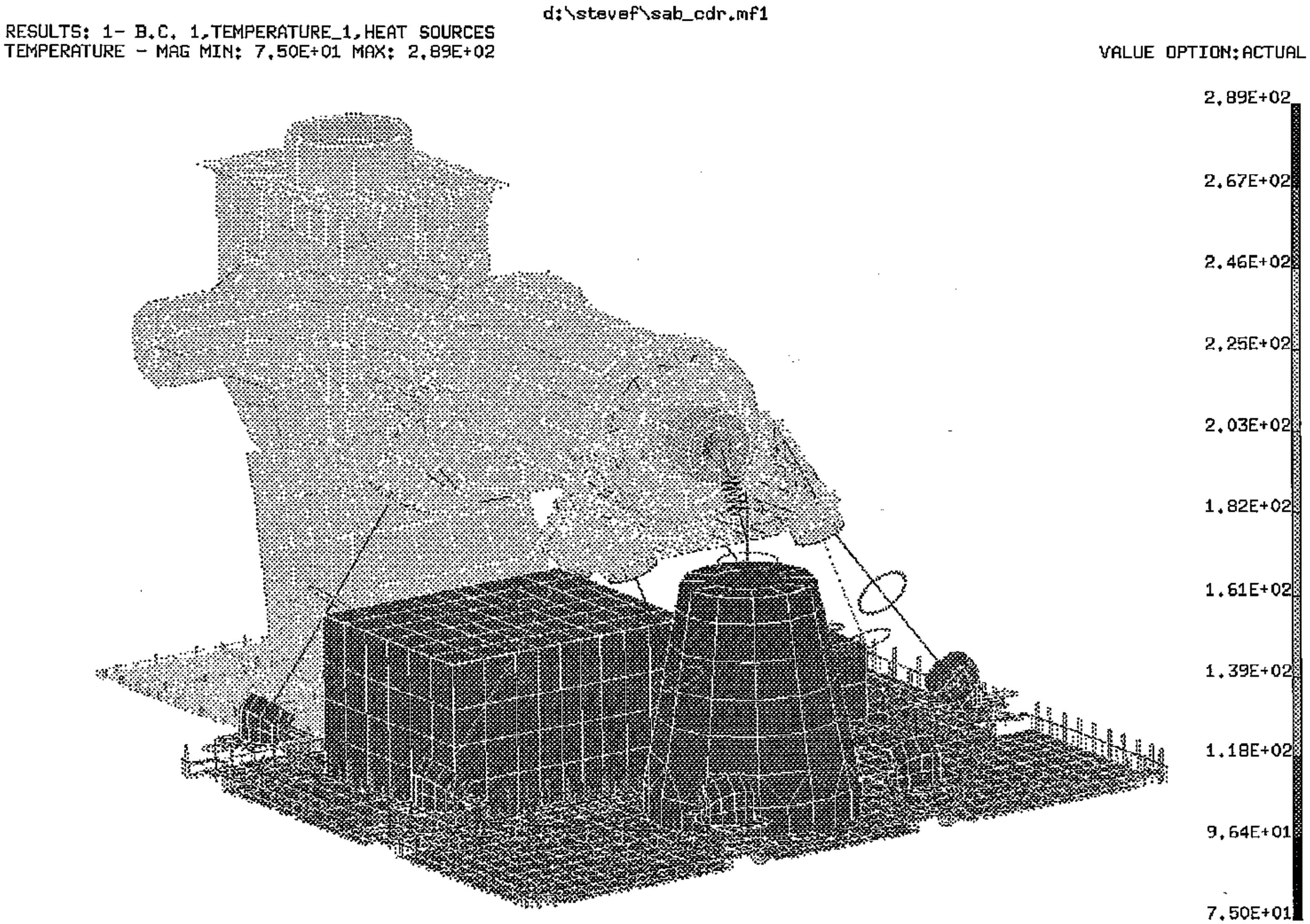
Assumptions

- **Hot case thermal loads considered**
- **Restrained temperatures:**
  - Optics radiator - 228 K
  - Electronics box - 275 K
  - Mount plate - 272 K with a +/- 5 K gradient
  - Blackbody - 250 K
  - Focal plane - 75 K
- **Heat loads applied:**
  - Scan mirror motor - 4.1 W
  - Chopper - 0.1 W
  - Radiation load uniformly applied inside telescope - 5.0 W
  - Refrigerator mount - 20 W
- **Only conduction heat transfer considered**
- **Steady state temperature predicted**

TEMPERATURE GRADIENTS EFFECTS
Simulation of Hot Case Conditions

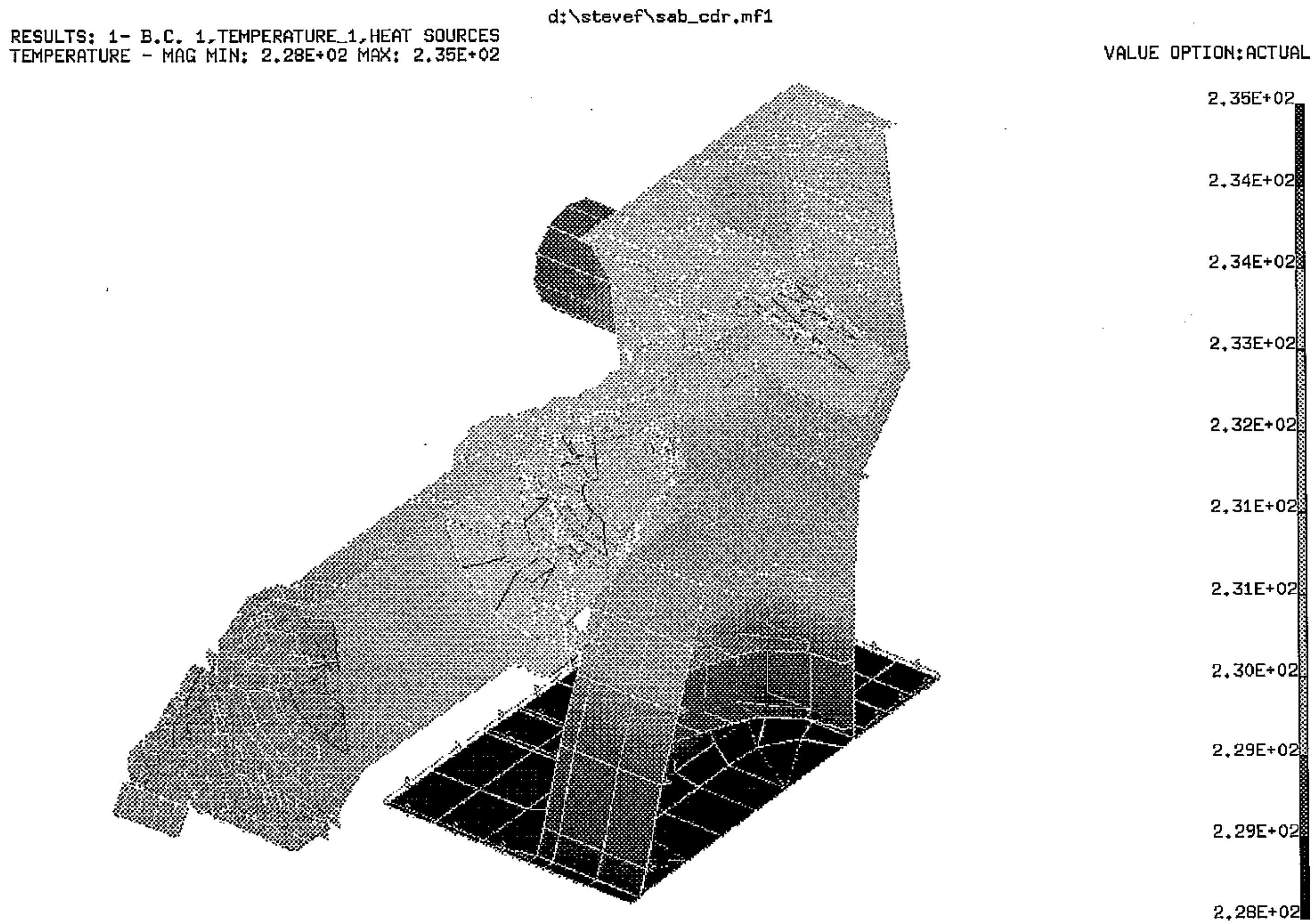
Results:

Full model temperature in Kelvin



TEMPERATURE GRADIENTS EFFECTS
Simulation of Hot Case Conditions

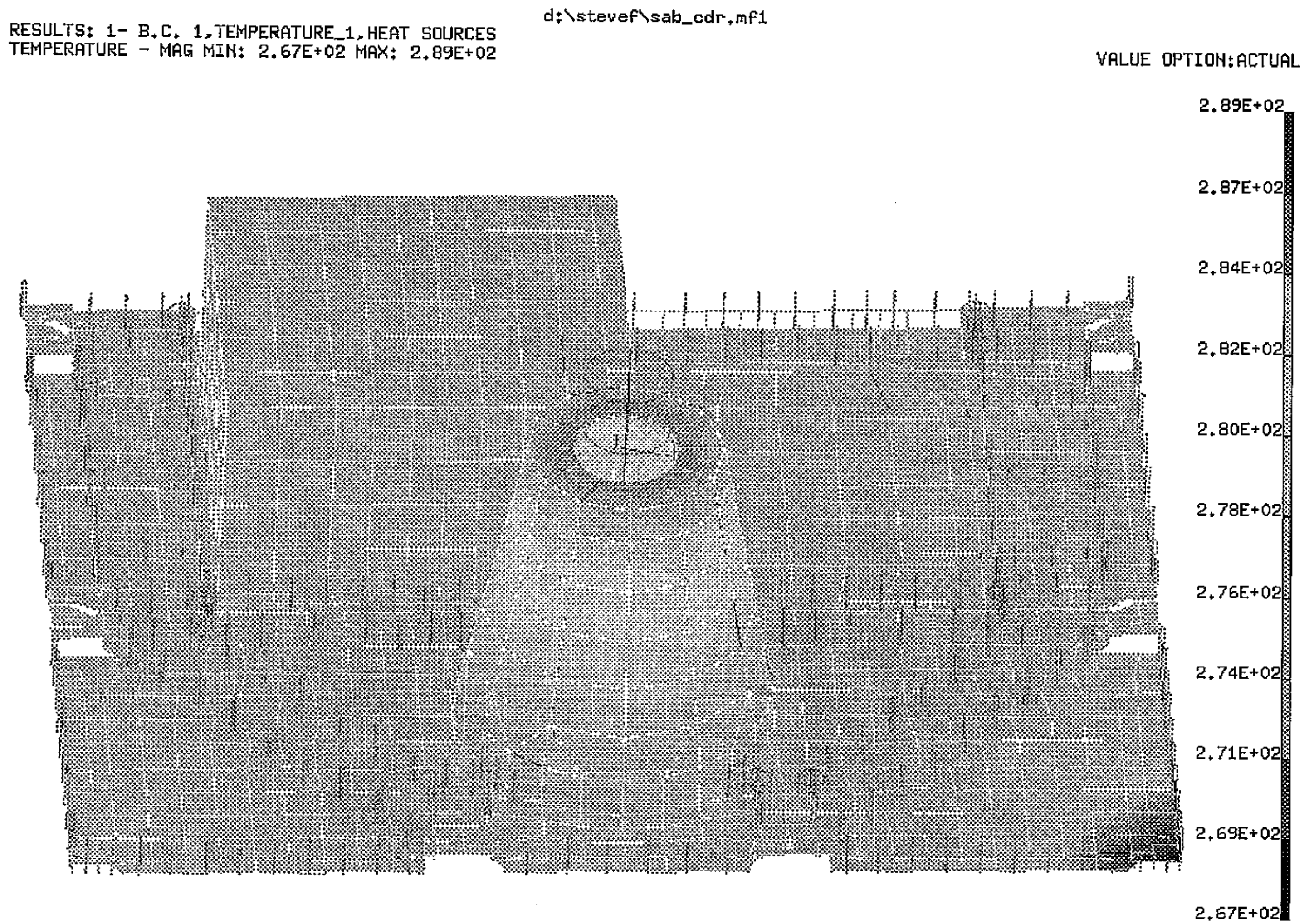
Results:
Inside telescope temperature in Kelvin



TEMPERATURE GRADIENTS EFFECTS
Simulation of Hot Case Conditions

Results:

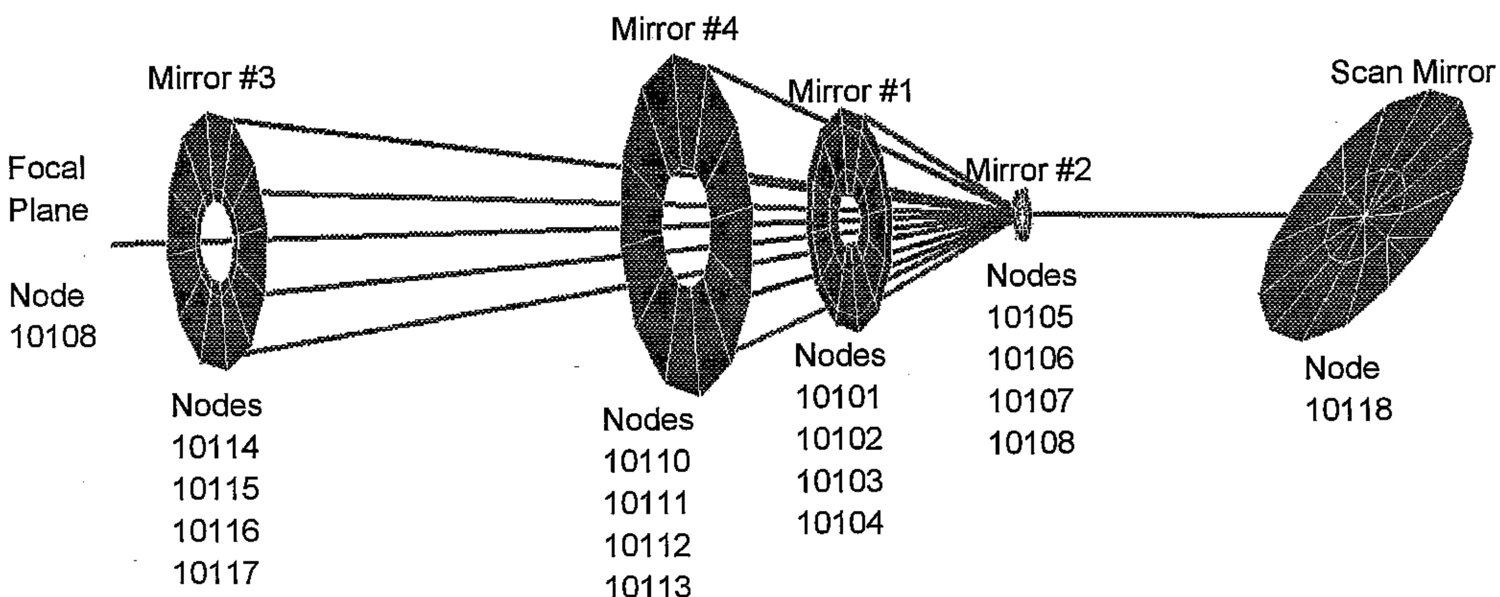
Mounting plate and refrigerator mount temperature in Kelvin



TEMPERATURE GRADIENTS EFFECTS
Simulation of Hot Case Conditions

Assumptions of static analysis model:

- **Coincident nodes created on mirrors but not attached to them**
- **Stiff aluminum beams attach the coincident nodes to the center of mirror 2**
- **The stiff beams will shrink as cooled and move and rotate with the mirror 2**
- **Relative displacements and rotations between coincident nodes were measured**
- **Nodal temperatures from heat transfer results input and displacements computed**
- **Experiment spacecraft mounts allowed to move with temperature changes**



TEMPERATURE GRADIENTS EFFECTS
Simulation of Hot Case Conditions

Predicted mirror displacements relative to mirror 2 for the hot case temperatures

Node	Location	X Disp. (mm)	Y Disp. (mm)	Z Disp. (mm)	X Rot. (radians)	Y Rot. (radians)	Z Rot. (radians)
10101	Mirror 1	6.85E-05	-8.08E-04	-3.77E-05	8.18E-07	-5.24E-07	7.46E-07
10102	Mirror 1	1.05E-04	-7.68E-04	-4.62E-05	7.59E-07	-7.31E-07	7.66E-07
10103	Mirror 1	2.61E-05	-7.68E-04	4.03E-05	8.69E-07	-7.28E-07	7.27E-07
10104	Mirror 1	6.41E-05	-7.30E-04	4.25E-05	8.16E-07	-9.79E-07	7.27E-07
10105	Mirror 2	-2.53E-10	-3.47E-09	1.62E-09	-6.89E-11	4.96E-11	2.43E-10
10106	Mirror 2	-1.29E-09	1.09E-08	-1.77E-08	1.85E-09	4.68E-11	1.52E-10
10107	Mirror 2	-3.63E-09	-1.31E-09	-1.36E-08	-4.96E-10	-3.71E-10	1.28E-10
10108	Focal Plane	7.98E-04	1.31E-03	-7.52E-02	-1.46E-05	-1.71E-06	7.26E-06
10109	Mirror 2	-4.60E-09	-7.76E-10	7.30E-09	3.91E-10	-3.55E-10	-2.17E-10
10110	Mirror 4	1.21E-04	-1.16E-03	-2.68E-05	-8.39E-07	2.19E-06	3.51E-06
10111	Mirror 4	1.70E-04	-6.51E-04	-1.65E-04	-4.16E-07	2.19E-06	3.85E-06
10112	Mirror 4	-4.09E-04	-1.10E-03	-3.02E-04	-1.25E-06	2.18E-06	3.17E-06
10113	Mirror 4	-3.53E-04	-5.84E-04	-4.11E-04	-8.29E-07	2.42E-06	3.51E-06
10114	Mirror 3	3.79E-03	9.76E-04	-4.94E-03	-1.26E-05	-2.79E-05	5.85E-07
10115	Mirror 3	2.83E-03	1.99E-03	-2.30E-03	-1.34E-05	-2.89E-05	7.07E-07
10116	Mirror 3	2.75E-03	3.95E-05	-3.96E-03	-1.29E-05	-2.79E-05	7.12E-07
10117	Mirror 3	1.80E-03	1.06E-03	-1.37E-03	-1.36E-05	-2.74E-05	5.78E-07
10118	Scan Mirror	3.07E-05	-3.25E-03	-1.17E-03	-2.59E-05	-1.86E-05	7.09E-06

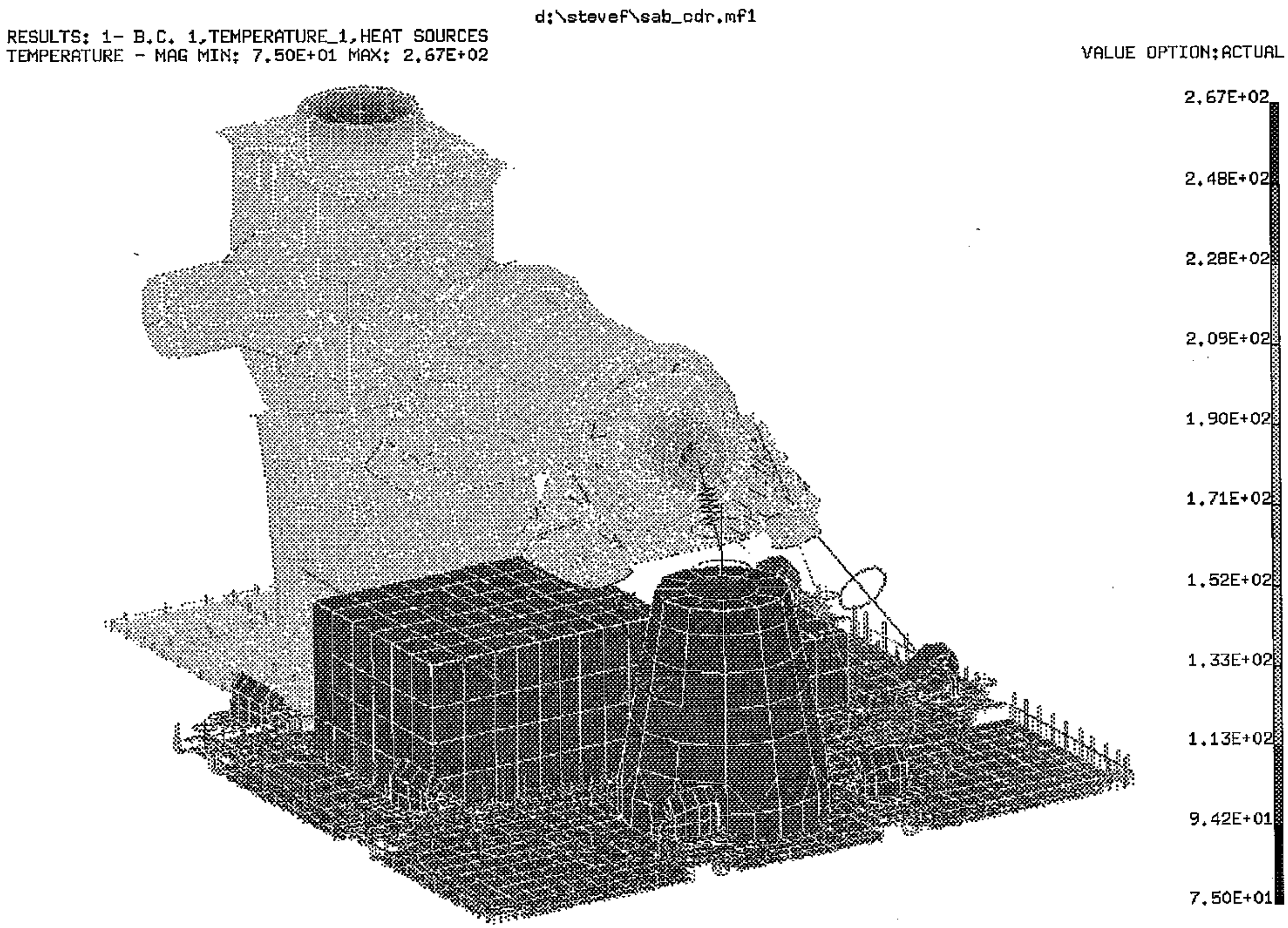
TEMPERATURE GRADIENTS EFFECTS
Simulation of Cold Case Conditions

Assumptions

- **Cold case thermal loads considered**
- **Restrained temperatures:**
  - Optics radiator - 209 K
  - Electronics box - 255 K
  - Mount plate - 244 K with a +/- 5 K gradient
  - Blackbody - 250 K
  - Focal plane - 75 K
- **Heat loads applied:**
  - Scan mirror motor - 4.1 W
  - Chopper - 0.1 W
  - Radiation load uniformly applied inside telescope - 1.5 W
  - Refrigerator mount - 20 W
- **Only conduction heat transfer considered**
- **Steady state temperature predicted**

TEMPERATURE GRADIENTS EFFECTS
Simulation of Cold Case Conditions

Results:
full model temperature in Kelvin



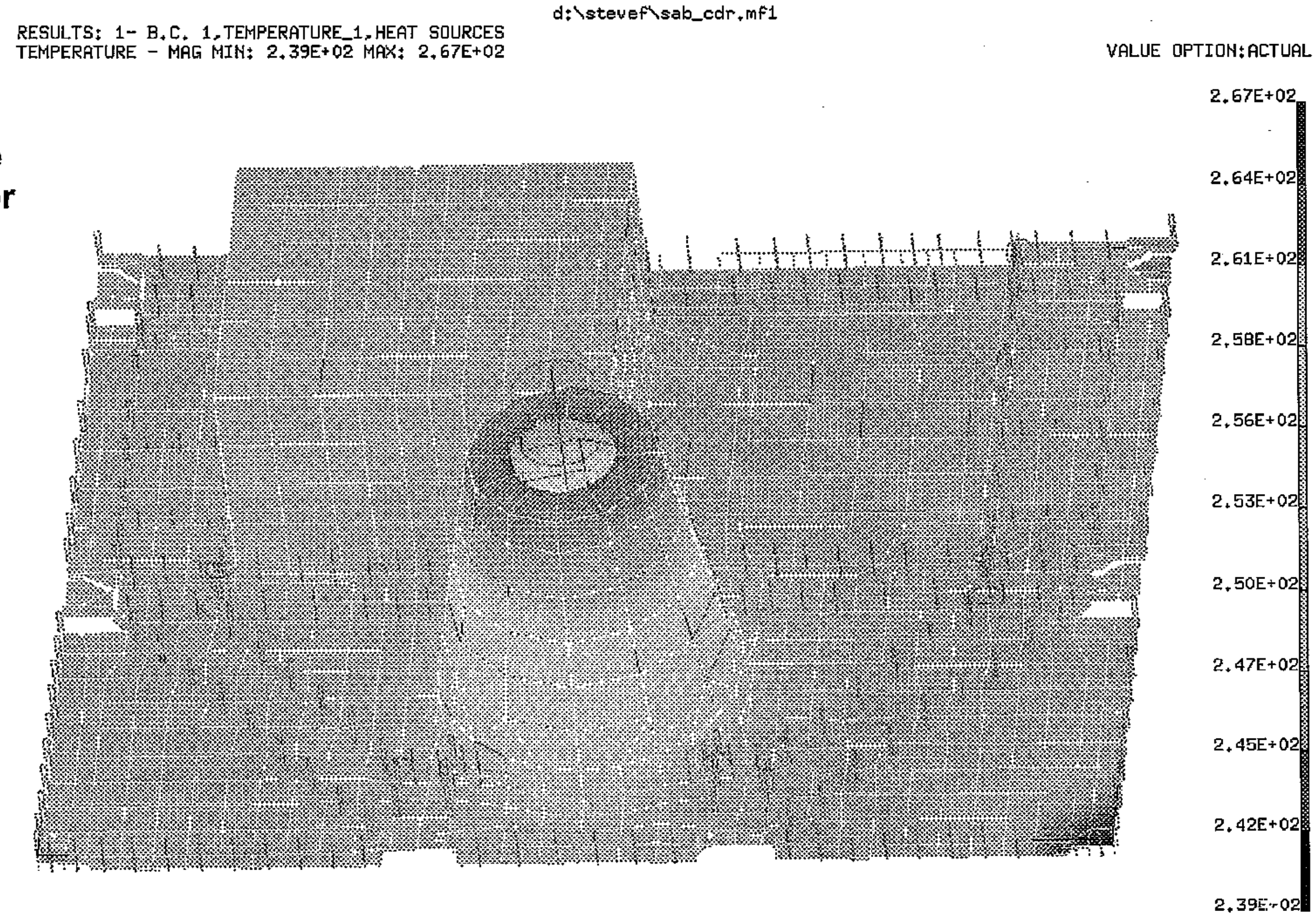
TEMPERATURE GRADIENTS EFFECTS
Simulation of Cold Case Conditions

Results:
Inside telescope temperature in Kelvin

TEMPERATURE GRADIENTS EFFECTS
Simulation of Cold Case Conditions

Results:

Mounting plate and refrigerator mount temperature in Kelvin



TEMPERATURE GRADIENTS EFFECTS
Simulation of Cold Case Conditions

Predicted mirror displacements relative to mirror 2 for the cold case temperatures

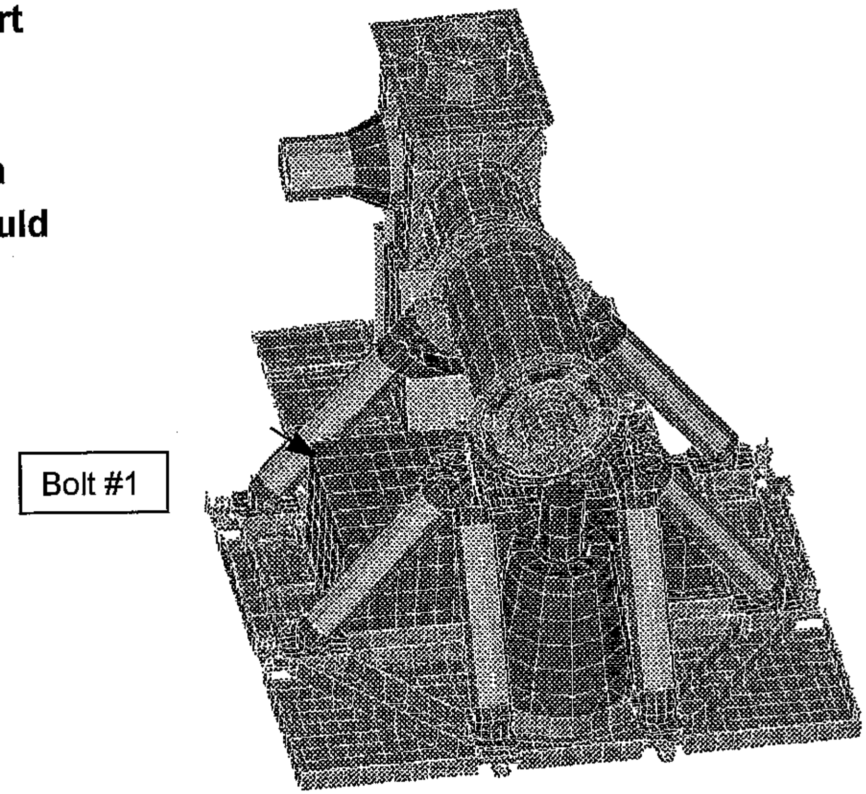
Node	Location	X Disp. (mm)	Y Disp. (mm)	Z Disp. (mm)	X Rot. (radians)	Y Rot. (radians)	Z Rot. (radians)
10101	Mirror 1	6.50E-05	-6.64E-04	-2.34E-05	6.16E-07	-3.18E-07	6.69E-07
10102	Mirror 1	9.76E-05	-6.29E-04	-3.25E-05	5.61E-07	-5.18E-07	6.86E-07
10103	Mirror 1	2.71E-05	-6.29E-04	3.26E-05	6.66E-07	-5.15E-07	6.46E-07
10104	Mirror 1	6.10E-05	-5.95E-04	3.29E-05	6.14E-07	-7.28E-07	6.48E-07
10105	Mirror 2	-2.08E-11	-4.37E-09	1.57E-09	-2.82E-11	7.52E-11	3.22E-10
10106	Mirror 2	-1.61E-09	1.50E-08	-2.29E-08	2.42E-09	5.70E-12	1.99E-10
10107	Mirror 2	-4.38E-09	-1.61E-09	-1.62E-08	-5.71E-10	-4.58E-10	1.68E-10
10108	Focal Plane	7.38E-04	1.16E-03	-6.57E-02	-1.13E-05	-1.97E-07	5.02E-06
10109	Mirror 2	-5.93E-09	-1.18E-09	9.64E-09	4.83E-10	-4.91E-10	-3.22E-10
10110	Mirror 4	4.38E-05	-9.18E-04	3.33E-06	-1.03E-06	1.31E-06	2.89E-06
10111	Mirror 4	1.67E-04	-5.88E-04	-5.36E-05	-5.36E-07	1.41E-06	3.35E-06
10112	Mirror 4	-3.09E-04	-7.72E-04	-2.23E-04	-1.51E-06	1.40E-06	2.43E-06
10113	Mirror 4	-1.77E-04	-4.42E-04	-2.58E-04	-1.02E-06	1.75E-06	2.89E-06
10114	Mirror 3	2.61E-03	8.53E-04	-2.85E-03	-9.97E-06	-2.12E-05	7.57E-07
10115	Mirror 3	2.25E-03	1.31E-03	-8.20E-04	-1.05E-05	-2.19E-05	8.45E-07
10116	Mirror 3	2.14E-03	5.02E-04	-2.13E-03	-1.01E-05	-2.11E-05	8.48E-07
10117	Mirror 3	1.78E-03	9.55E-04	-1.42E-04	-1.07E-05	-2.08E-05	7.52E-07
10118	Scan Mirror	1.07E-04	-2.02E-03	1.19E-04	-1.72E-05	-1.94E-05	7.28E-06

SPACECRAFT DISTORTION EFFECTS
Displacement at Bolt #1

It was desired to examine how displacements at the spacecraft interface would distort the telescope

Assumptions

- **Expected motions/forces are uncertain**
- **Examined a bolt displacement that would put the SABER mounting plate at a stress near 50% of yield**
- **Displacements relative to mirror 2 examined**



SPACECRAFT DISTORTION EFFECTS
Displacement at Bolt #1

Units for results displayed on right:

Displacements in mm

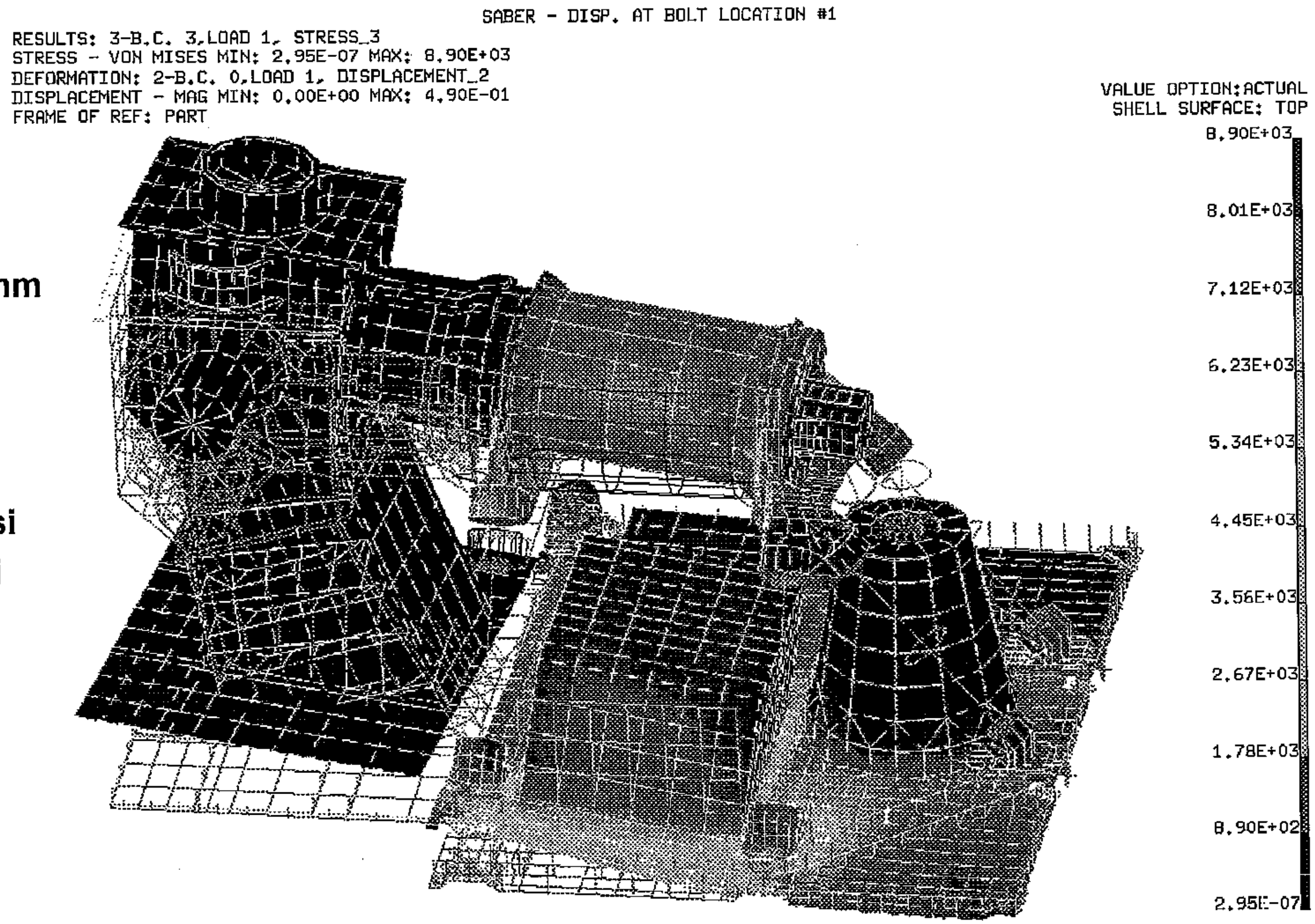
Stresses in Kpa

Predicted stress values:

Mount plate 17.4 ksi

G-10 tubes 11.5 ksi

Mirror tabs 4.8 ksi



SABER Critical Design Review

SPACE DYNAMICS LABORATORY / UTAH STATE UNIVERSITY

SF-25

SPACECRAFT DISTORTION EFFECTS
Displacement at Bolt #1

Predicted mirror displacements relative to mirror 2

Node	Location	X Disp. (mm)	Y Disp. (mm)	Z Disp. (mm)	X Rot. (radians)	Y Rot. (radians)	Z Rot. (radians)
10101	Mirror 1	1.86E-04	3.04E-04	1.70E-05	-9.40E-08	2.13E-07	-4.13E-07
10102	Mirror 1	1.64E-04	2.82E-04	1.04E-05	-1.58E-07	2.46E-07	-4.11E-07
10103	Mirror 1	2.10E-04	2.81E-04	-4.55E-06	-1.98E-07	3.50E-07	-4.01E-07
10104	Mirror 1	1.87E-04	2.58E-04	-1.55E-05	-1.20E-07	3.93E-07	-4.55E-07
10105	Mirror 2	1.09E-10	2.94E-10	1.07E-10	4.39E-11	2.91E-11	-1.54E-11
10106	Mirror 2	-2.14E-11	9.33E-11	5.00E-10	-3.67E-11	-2.70E-11	-1.40E-11
10107	Mirror 2	3.56E-10	1.13E-10	-4.30E-10	-1.54E-11	1.03E-10	-8.68E-12
10108	Focal Plane	-1.37E-03	-1.09E-03	9.54E-05	4.27E-06	4.47E-06	-5.36E-05
10109	Mirror 2	9.91E-11	-1.69E-10	-1.04E-09	-9.99E-11	1.90E-11	-1.42E-11
10110	Mirror 4	2.79E-04	4.35E-04	-5.30E-05	9.43E-07	-1.20E-06	-1.48E-06
10111	Mirror 4	1.56E-04	3.12E-04	-3.70E-05	1.02E-06	-1.19E-06	-1.49E-06
10112	Mirror 4	4.01E-04	3.13E-04	1.26E-04	9.54E-07	-1.26E-06	-1.49E-06
10113	Mirror 4	2.78E-04	1.90E-04	1.49E-04	1.02E-06	-1.23E-06	-1.48E-06
10114	Mirror 3	-2.67E-03	5.22E-03	-1.34E-03	4.21E-05	-1.25E-05	-7.06E-05
10115	Mirror 3	-7.15E-03	7.47E-04	-3.25E-03	4.23E-05	-1.20E-05	-7.05E-05
10116	Mirror 3	1.81E-03	7.38E-04	2.20E-03	4.30E-05	-1.39E-05	-7.05E-05
10117	Mirror 3	-2.66E-03	-3.74E-03	3.55E-04	4.40E-05	-1.45E-05	-7.06E-05
10118	Scan Mirror	5.80E-04	-1.35E-04	-5.33E-05	-1.68E-06	-1.11E-06	-8.86E-07

SUMMARY OF STRUCTURAL ANALYSIS

SABER meets design goals

- Minimum frequency > 35 Hz
- High margins of safety
- Refrigerator disturbances are small
- Thermally induced displacements of the telescope are acceptable
- Telescope mirror alignment appears good even when mounting plate is highly stressed

Normal modes analysis of SABER mounted to the spacecraft not yet completed

- Current spacecraft model was recently received and analysis will be completed soon

CALIBRATION PLAN AND GSE OVERVIEW

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20 October 1997

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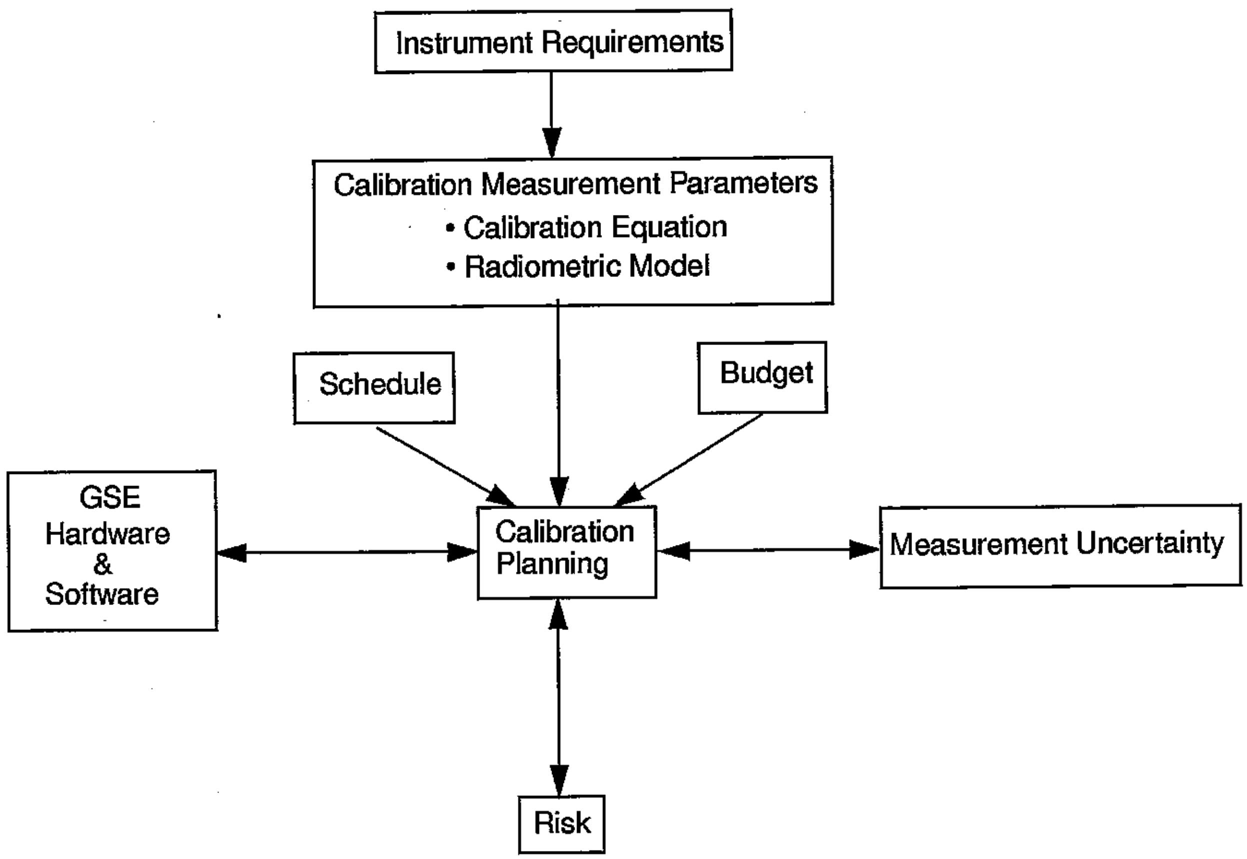
OUTLINE

- Calibration Planning Philosophy
- Instrument Requirements Driving Calibration
- Instrument Requirement and Calibration Measurement Matrix
- Calibration Measurement Parameters
    - Calibration Equation
    - In-Flight Calibrator (IFC) Sources
    - Radiometric Model
- SABER Operated in LN_2 Cooled Test Chamber
- Calibration Measurement Configurations
    - Full Field Collimator
    - Low Temperature GSE Blackbody
    - High Temperature GSE Blackbody
    - Large Area Knife Edge
    - Boresight Collimator
- Calibration Uncertainty Budget

CALIBRATION PLANNING PHILOSOPHY



INSTRUMENT REQUIREMENTS DRIVING CALIBRATION

Parameter	Measurement Requirement
System Noise Equivalent Radiance (NER)	Refer to SABER Instrument Requirements Document, SDL/95-006
Radiometric Accuracy[a]	5.0% absolute radiance; 3.0% goal
Long-Term Radiometric Precision[a]	2.0% radiance precision; 1% goal
Radiance Bias Drift	≤ 1 NEN between space looks
Residual Scale Error	≤ 1% linearity over dynamic range
Limb Scan Mirror Jitter (1 σ)	≤ 3 arc seconds
Spectral Response	Refer to SABER Instrument Requirements Document, SDL/95-006
IFOV @ 60 km Earth Limb Tangent Height	2 km FWHM
Limb Vertical Scan Range	Maximum and minimum depression angle Refer to SABER Instrument Requirements Document, SDL/95-006
Measurement Altitude Range	10 km to 180 km
Focal Plane Channel Location	Refer to SABER Instrument Requirements Document, SDL/95-006
Boresight Alignment Knowledge	0.1 deg
Limb Vertical Sampling Interval	0.4 km

a. For SNR > 100, % is defined as a percentage of the signal. For SNR ≤ 100, % is defined as a percent of the signal that produces SNR = 100

INSTRUMENT REQUIREMENT AND CALIBRATION MATRIX

Calibration Measurement Parameter	Measurement Requirement												
	NER	Radiometric Accuracy	Long-Term Radiometric Precision	Radiance Bias Drift	Residual Scale Error	Limb Scan Mirror Jitter (1 σ)	Spectral Response	IFOV @ 60 km	Limb Vertical Scan Range	Measurement Altitude Range	Focal Plane Channel Location	Boresight Alignment Knowledge	Limb Vertical Sampling Interval
Radiance Responsivity	X	X											
IFC Radiance		X											
Off-Axis Extended Source Throughput Correction		X											
Linearity		X			X								
Gain Mode Normalization		X											
IFC Measurement Long-Term Repeatability			X										
Noise Equivalent Radiance (NER)	X												
Medium-Term Repeatability of Sensor Offset				X									
Relative Spectral Responsivity (RSR)		X					X						
Sensor Boresight												X	
Instantaneous Field of View (IFOV)								X			X		X
Scatter from Non-Signal Chop-per Holes		X											
Scan Mirror Transfer Function						X			X	X			
Knife Edge Response		X											
Temporal Frequency Response													X

CALIBRATION MEASUREMENT PARAMETERS

Calibration Equation

- Relates sensor output (counts) to measured flux (radiance)

$$L_m = \frac{1}{\Re_{ch}} r_{c,ch} = \frac{1}{\Re_{ch}} [\Upsilon_{ch,i}(Scn) L_{ch,i}(G_{ch,i}(r_{ch,i}) - O_{ch,i})]$$

where

where	L_m	=	measured radiance (W cm^{-2} sr^{-1})
	$\Re_{ch}$	=	peak radiance responsivity (counts/W cm^{-2} sr^{-1})
	$\Upsilon_{ch,i}(\ )$	=	off-axis extended source throughput correction (unitless)
	Scn	=	scan mirror pointing position (counts)
	$r_{c,ch}$	=	corrected scene response (counts)
	$G_{ch,i}$	=	gain-mode normalization (unitless)
	$L_{ch,i}(\ )$	=	linearity correction (unitless)
	$r_{ch,i}$	=	detector response (counts)
	$O_{ch,i}$	=	sensor offset (counts)
	ch	=	channel number (1 to 10)
	i	=	gain mode (unitless)

CALIBRATION MEASUREMENT PARAMETERS

Calibration Equation Parameters

Parameter	Symbol	Permutations[a]	Measurement Requirement	Test Configuration
Sensor Offset (Space Look)	$O_{ch,i}$	(10 det), 3 optics temp, 3 baseplate temp, 2 focal plane temp	Radiometric Accuracy	Low Temperature Blackbody
Sensor Offset Measurement Uncertainty	σ_O	(10 det), 3 optics temp, 3 baseplate temp, 2 focal plane temp	Radiometric Accuracy	Low Temperature Blackbody
Linearity Correction Function	$L_{ch,i}(\ )$	(7 det), 3 optics temp, 3 baseplate temp, 2 focal plane temp (3 det), 3 baseplate temp, 2 focal plane temp	Radiometric Accuracy Residual Scale Error	Low Temperature Blackbody & Full Field Collimator
Linearity Correction Uncertainty	σ_L	(7 det), 3 optics temp, 3 baseplate temp, 2 focal plane temp (3 det), 3 baseplate temp, 2 focal plane temp	Radiometric Accuracy Residual Scale Error	Low Temperature Blackbody & Full Field Collimator
Gain Mode Normalization	$G_{ch,i}$	(9 det), 3 gains (1 det), 2 gains	Radiometric Accuracy	Electronics Subassembly
Gain Mode Normalization Uncertainty	σ_G	(9 det), 3 gains (1 det), 2 gains	Radiometric Accuracy	Electronics Subassembly
Peak Radiance Responsivity	$\Re_{ch}$	(10 det), 3 optics temp, 3 baseplate temp, 2 focal plane temp	Radiometric Accuracy	GSE Full-Aperture Blackbody
Peak Radiance Responsivity Uncertainty	$\sigma_{\Re}$	(10 det), 3 optics temp, 3 baseplate temp, 2 focal plane temp	Radiometric Accuracy	GSE Full-Aperture Blackbody
Off-Axis Extended Source Throughput Correction as a Function of Scan Mirror Position	$\Upsilon_{ch,i}(scn)$	(7 det), 3 optics temp (3 det), 1 optics temp	Radiometric Accuracy	GSE Full-Aperture Blackbody
Off-Axis Extended Source Throughput Correction Uncertainty	σ_{Υ}	(7 det), 3 optics temp (3 det), 1 optics temp	Radiometric Accuracy	GSE Full-Aperture Blackbody

a. If optics temp, baseplate temp, and/or focal plane temp permutations are not specified, assume nominal temperature setting

CALIBRATION MEASUREMENT PARAMETERS

In-Flight Calibrator (IFC) Sources

- Transfer ground based blackbody radiance to IFCs during ground calibration
  - Full-aperture blackbody (CO_2, O_3, H_2O, and NO channels 1 to 7)
  - Calibration lamps (OH and O_2 channels 8 to 10): three Jones source calibration lamps
- Use IFC response to update responsivity on-orbit

$$\Re_{ch} = \frac{r_{c,IFC}}{\cdot N_{IFC}}$$

where $\Re_{ch}$ = updated peak radiance responsivity (counts/W cm^{-2} sr^{-1})

$r_{c,IFC}$ = corrected IFC response (counts)

N_{IFC} = IFC radiant flux (W cm^{-2} sr^{-1})

ch = channel number (1 to 10)

CALIBRATION MEASUREMENT PARAMETERS

In-Flight Calibrator (IFC) Parameters For Each IFC Configuration

Parameter	Symbol	Permutations[a]	Measurement Requirement	Test Configuration
IFC Radiance	N_{IFC}	(7 det), 3 source settings, 3 optics temp (3 det), 3 source settings, 1 optics temp	Radiometric Accuracy	Low & High Temperature Blackbodies
IFC Radiance Uncertainty	$\sigma_{N_{IFC}}$	(7 det), 3 source settings, 3 optics temp (3 det), 3 source settings, 1 optics temp	Radiometric Accuracy	Low & High Temperature Blackbodies
IFC Radiance Long-Term Repeatability	$\sigma_{IFC, repeat}$	(10 det)	Long-Term Radiometric Precision	Design & Analysis

a. If optics temp, baseplate temp, and/or focal plane temp permutations are not specified, assume nominal temperature setting

CALIBRATION MEASUREMENT PARAMETERS

Radiometric Model

- Characterizes spatial, spectral, and temporal responsivity domains
- Calibration parameters

Parameter	Symbol	Permutations[a]	Measurement Requirement	Test Configuration
Noise Equivalent Radiance	NER	(7 det), 3 optics temp, 3 baseplate temp, 2 focal plane temp (3 det), 3 baseplate temp, 2 focal plane temp	System Noise Equivalent Radiance (NER)	Low & High Temperature Blackbody
Medium-Term Repeatability of Sensor Offset (i.e., time between space looks)	$\sigma_{O,\,med}$	(10 det), 3 optics temp, 3 baseplate temp, 2 focal plane temp	Radiance Bias Drift	Low Temperature Blackbody
Relative Spectral Responsivity	$RSR(\lambda)$	(10 det), 2 focal plane temp	Spectral Response	Full Field Collimator & External Interferometer
Relative Spectral Responsivity Uncertainty	$\sigma_{RSR}(\lambda)$	(10 det), 2 focal plane temp	Spectral Response	Full Field Collimator & External Interferometer
Sensor Boresight	$P_{bor}(in, cr)$	1	Boresight Alignment Knowledge	GSE Test Chamber & TBD Collimator
Uncertainty of Sensor Boresight	σ_{bor}	1	Boresight Alignment Knowledge	GSE Test Chamber & TBD Collimator
IFOV	$IFOV(in, cr)$	(10 det)	IFOV @ 60 km Earth-limb Tangent Height	Full Field Collimator

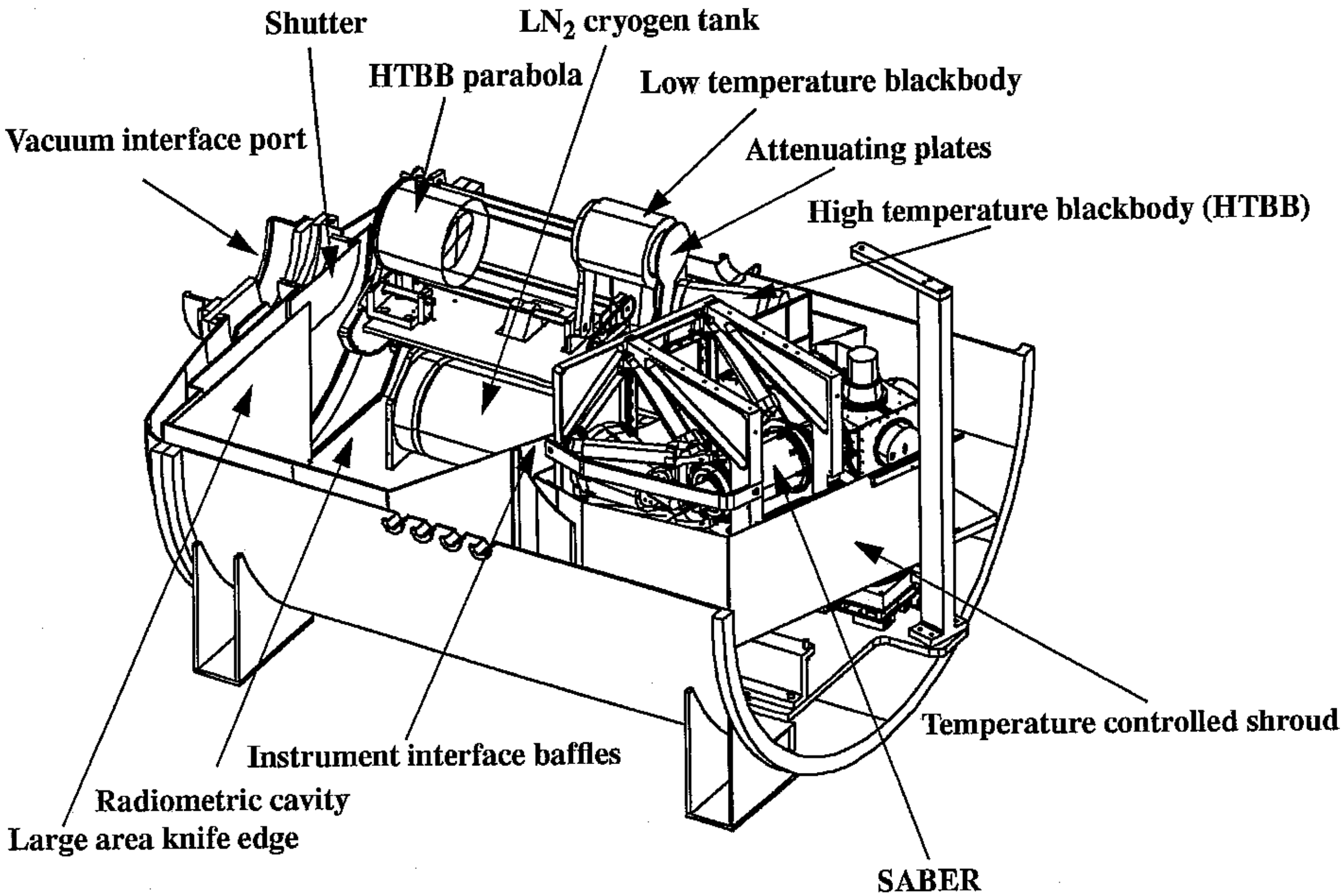
a. If optics temp, baseplate temp, and/or focal plane temp permutations are not specified, assume nominal temperature setting

CALIBRATION MEASUREMENT PARAMETERS (continued)

Parameter	Symbol	Permutations[a]	Measurement Requirement	Test Configuration
Scatter from Non-Signal Chopper Holes	$Scat_{chop}$	(10 det)	Radiometric Accuracy	Full Field Collimator
Object Space Detector Positions	$P(in, cr)$	(10 det)	Focal Plane Channel Location	Full Field Collimator
Modulation Transfer Function	MTF	(10 det)	Limb Vertical Sampling Interval	Full Field Collimator
Scan Mirror Transfer Function (encoder to angle)	$F_{scan}(\ )$	1	Limb Vertical Scan Range Measurement Altitude Range	Encoder Manufacture Acceptance Test
Scan Mirror Transfer Function Uncertainty	σ_{scan}	(10 det)	Limb Vertical Scan Range Measurement Altitude Range	Encoder Manufacture Acceptance Test
Knife Edge Response (off-axis response far from IFOV)	S_{Knife}	(10 det)	Radiometric Accuracy	GSE Test Chamber
Temporal Frequency Response (amplitude versus frequency)	$A_{mp}(f)$	1	Limb Vertical Sampling Interval	Theoretical LPF Response
Temporal Frequency Response (phase versus frequency)	$P_{hase}(f)$	1	Limb Vertical Sampling Interval	Theoretical LPF Response

a. If optics temp, baseplate temp, and/or focal plane temp permutations are not specified, assume nominal temperature setting

SABER OPERATED IN LN_2 COOLED TEST CHAMBER



SABER OPERATED IN LN_2 COOLED TEST CHAMBER (continued)

- Instrument views light resistant radiometric cavity cooled with LN_2 to approximately 90 K
  - Reduces off-axis radiation (thermal and reflected) to levels that do not stress the off-axis performance of the instrument
- SABER thermal control
  - Optics cavity and baseplate radiators cooled with 90 K radiative heat exchanger
  - Radiators warmed to expected on-orbit temperatures with trim heaters
    - Trim heaters mounted on back of optics and baseplate radiators
  - Temperature controlled shroud to simulate internal spacecraft environment (thermal balance test)
- SABER rotates in test chamber about rotation axis of SABER scan mirror
  - Views a fixed blackbody equivalent to the full range of on-orbit scan mirror angles
  - Simplifies the design of the full field collimator
  - View a fixed knife edge at multiple sensor rotation angles
- Low temperature GSE blackbody rotates into SABER field of view
- Off-axis parabola rotates into SABER field of view for high temperature blackbody measurements
- Large area knife edge is integrated into radiometric cavity
- Shutter at end of radiometric cavity provides capability to shutter full field collimator

CALIBRATION MEASUREMENT CONFIGURATIONS

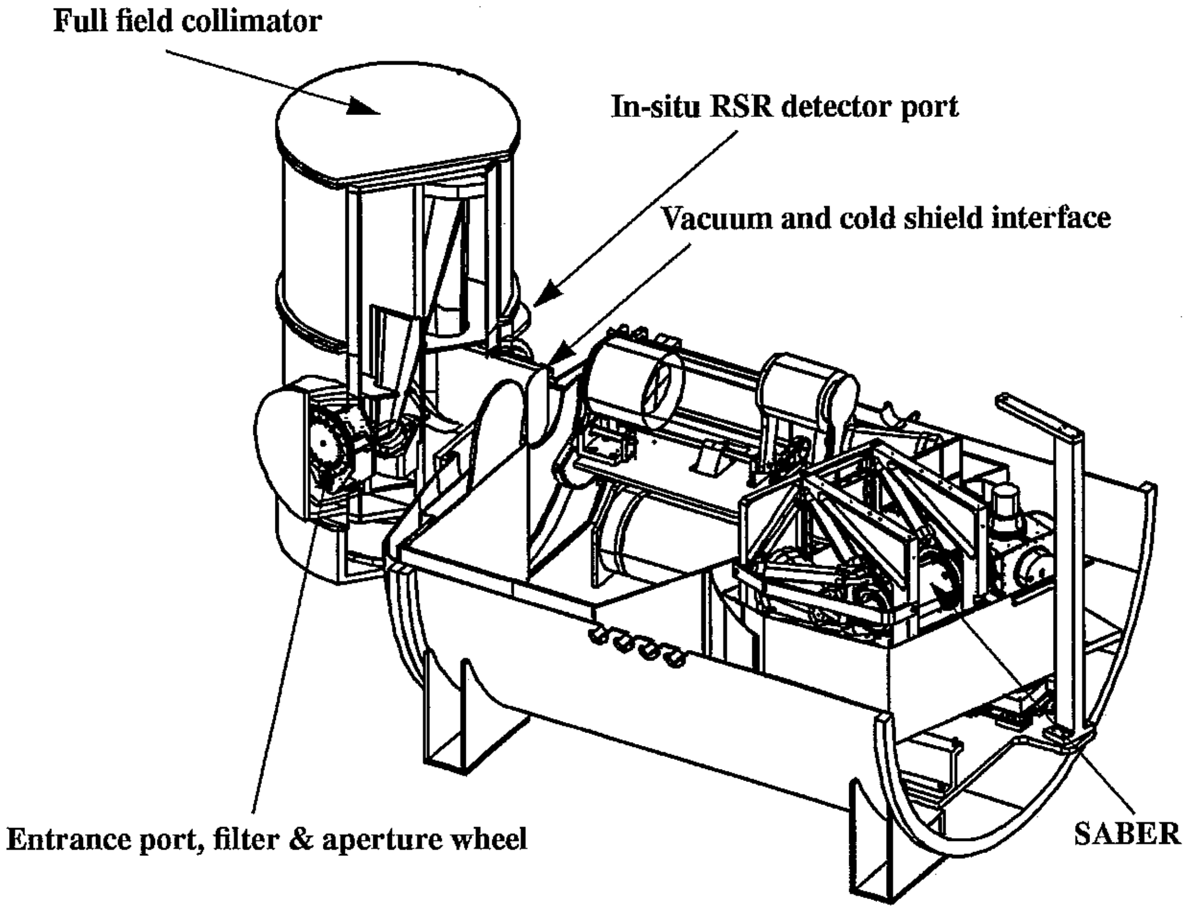
Full Field Collimator

- Calibration parameters

Parameter	Symbol
Instantaneous Field of View (IFOV)	$IFOV(in, cr)$
Object Space Detector Positions	$P(in, cr)$
Modulation Transfer Function	MTF
Scatter from Non-Signal Chopper Holes	$Scat_{chop}$
Temporal Frequency Response (verify only)	$A_{mp}(f), P_{hase}(f)$
Scan Mirror Transfer Function (verify only)	$F_{scan}(\ )$
Linearity Correction Function (OH and O_2 channels 8-10)	$L_{ch,\,i}(\ )$
Relative Spectral Response (RSR)	$RSR(\lambda)$

CALIBRATION MEASUREMENT CONFIGURATIONS

Full Field Collimator (continued)



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CALIBRATION MEASUREMENT CONFIGURATIONS

Full Field Collimator (continued)

- Passively cooled with LN_2 holding tank for low background operation
- Presents collimated source that will overfill filter and detector IFOV for linearity and relative spectral response measurements
  - Accounts for filter and detector nonuniformities
  - Accounts for Stierwalt effect
- Measures IFOV response
  - Design image quality sufficient to characterize FWHM
    - 4% error (CO_2 channels 1 to 3)
    - 3% error (O_3, H_2O, NO, OH, and O_2 channels 4 to 10)
- Measures scatter from non-signal chopper holes
  - Requires source that overfills chopper hole with chopper in open position
- Simple optical design reduces risk and cost
  - Single axis pointing mirror (±1.6°)
  - Off-axis parabola with focal length of 1055 mm
  - Fold mirror, aperture, and filter slide
  - In-situ RSR detector

CALIBRATION MEASUREMENT CONFIGURATIONS

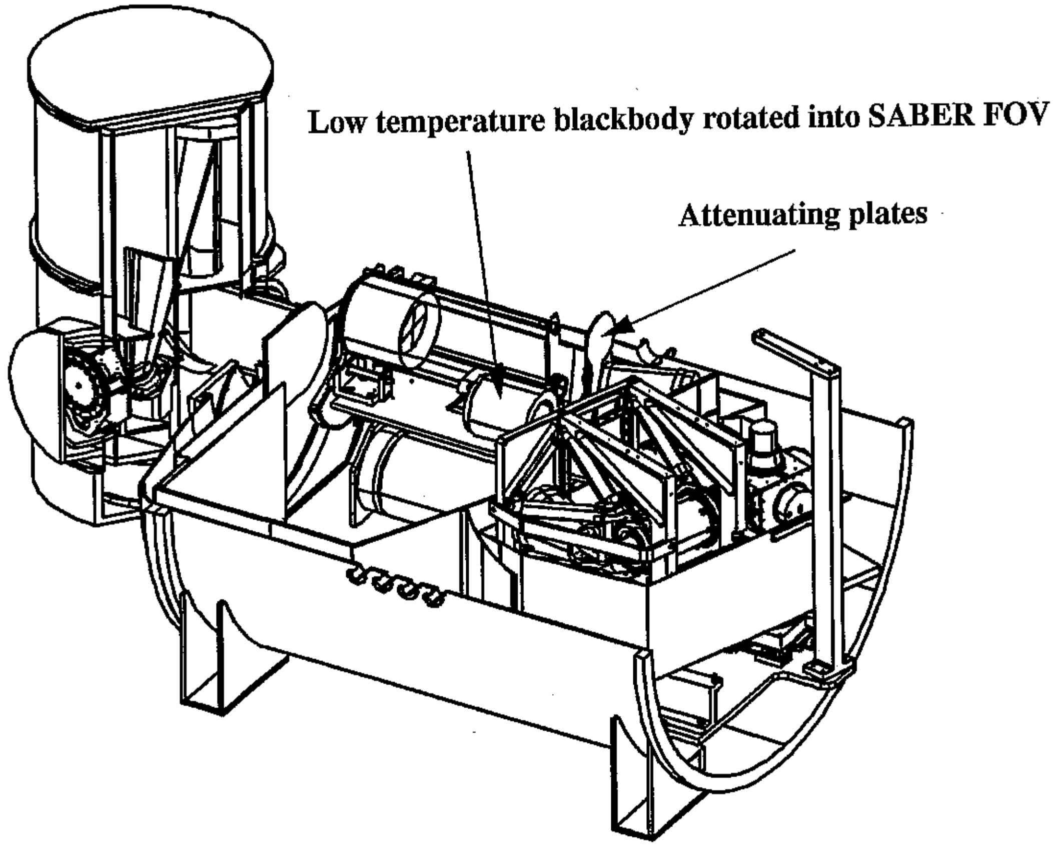
Low Temperature GSE Blackbody

- Calibration parameters

Parameter	Symbol
IFC Radiance (CO_2, O_3, H_2O, and NO channels 1-7)	N_{IFC}
IFC Radiance Uncertainty (channels 1-7)	$\sigma_{N_{IFC}}$
IFC Radiance Long-Term Repeatability (channels 1-7)	$\sigma_{IFC, repeat}$
Off-Axis Extended Source Throughput Correction as a Function of Scan Mirror Position (channels 1-7)	$\Upsilon_{ch, i}(scn)$
Off-Axis Extended Source Throughput Correction Uncertainty (channels 1-7)	σ_{Υ}
Sensor Offset (all channels)	$O_{ch, i}$
Sensor Offset Uncertainty (all channels)	$\sigma_{O_{ch, i}}$
Noise Equivalent Radiance (all channels)	NER
Sensor Offset Medium-Term Repeatability (i.e., time between on-orbit space look, duration of approximately 2.3 min) (all channels)	$\sigma_{O, med}$
Linearity Correction Function (channels 1-7)	$L_{ch, i}(\ )$
Gain Mode Normalization (channels 1-7) (verify only)	$G_{ch, i}$

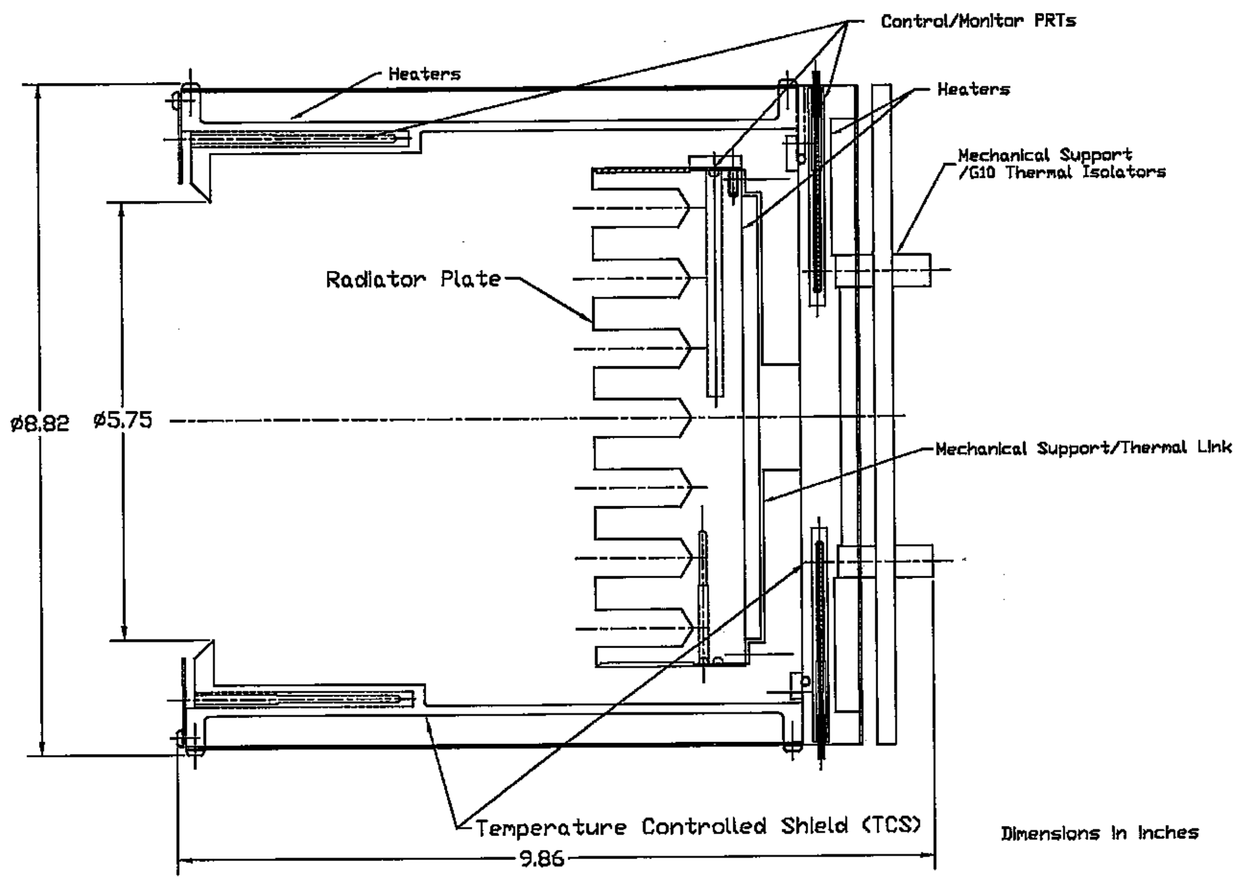
CALIBRATION MEASUREMENT CONFIGURATIONS

Low Temperature GSE Blackbody (continued)



CALIBRATION MEASUREMENT CONFIGURATIONS

Low Temperature GSE Blackbody (continued)



CALIBRATION MEASUREMENT CONFIGURATIONS

Low Temperature GSE Blackbody (continued)

- Blackbody radiator plate
  - Painted with Aeroglaze Z306
  - Cavity enhancement
    - 0.5 inch diameter holes
    - 1.25 inch deep holes
  - Three monitor PRTs
  - Kapton heater and control PRT
- Temperature controlled shield (TCS)
  - Operated at same temperature as blackbody radiator plate
  - Minimizes temperature gradients on surface of blackbody
  - Independent temperature control
  - Two monitor PRTs
  - Two Kapton heaters and two control PRTs
- Cooling foot
  - Rapid cooling
  - Contact made with LN_2 cooled cold finger when blackbody is in retracted position

CALIBRATION MEASUREMENT CONFIGURATIONS

Low Temperature GSE Blackbody - Specifications Overview

- Mechanical
  - Assembly length: 9.9 inch (251 mm)
  - Assembly outer diameter: 8.8 inch (224 mm)
  - Clear aperture: 5.75 inch (146 mm)
  - Mass: ~15 lbm (7 kg)
- Thermal performance
  - Temperature range: 100 K to 350 K
  - Temperature uncertainty (1 σ): 0.09 K at 100 K, 0.33 K at 350 K
  - Steady-state power dissipated: ~25 W at 350 K
  - Full range transient rates
    - 350 K to 100 K (clamped): < 8 hr
    - 100 K to 350 K: < 1 hr
- Control stabilization time (transient change of 10 K)
  - Near 350 K: < 10 minutes
  - Near 100 K: < 15 minutes

CALIBRATION MEASUREMENT CONFIGURATIONS

Low Temperature GSE Blackbody - Specifications Overview

- Emissivity
  - Normal emissivity: > 0.994
  - Uncertainty (1σ): 0.006
- Directional reflectance
  - Channels 1 through 7: < 0.07
- Absolute radiance uncertainty

Channel	Absolute Radiance Uncertainty (1σ)[a]	Absolute Radiance Uncertainty at 250 K Blackbody Temperature (1σ)
1 (CO_2)	1.0%	0.6%
2 (CO_2)	1.2%	0.6%
3 (CO_2)	1.2%	0.6%
4 (O_3)	1.2%	0.6%
5 (H_2O)	1.1%	0.7%
6 (NO)	1.3%	0.8%
7 (CO_2)	1.1%	0.9%
8 (OH)	1.9%	N/A

a. Using SNR =100 with achievable NER

CALIBRATION MEASUREMENT CONFIGURATIONS

Low Temperature GSE Blackbody - NIST Traceability

- PRT temperature calibration traceable to International Temperature Scale - 90 (ITS-90)
  - Standard scale adopted by NIST
  - Test and analyses have been performed to ensure traceability
- In-situ uniformity temperature verification
  - Temperature soak blackbody in vacuum to achieve isothermal temperature
  - Monitor PRTs and identify discrepancies among PRT readings
- NIST radiometric verification
  - View blackbody with NIST Transfer Radiometer (TXR)
  - TXR used as verification and not calibration
    - TXR can calibrate blackbody for limited operating temperature range
    - TXR does not provide spectral calibration

CALIBRATION MEASUREMENT CONFIGURATIONS

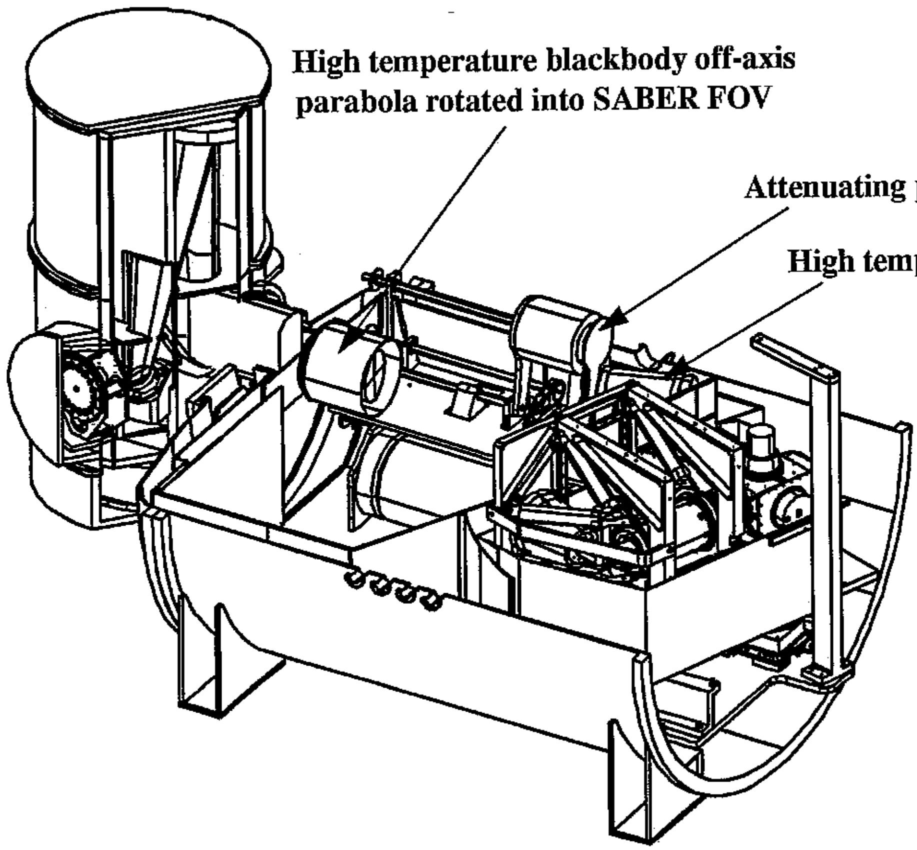
High Temperature GSE Blackbody

- Calibration parameters

Parameter	Symbol
IFC Radiance (OH and O_2 channels 8-10)	N_{IFC}
IFC Radiance Uncertainty (channels 8-10)	$\sigma_{N_{IFC}}$
IFC Radiance Long-Term Repeatability (channels 8-10)	$\sigma_{IFC,\,repeat}$
Off-Axis Extended Source Throughput Correction as a Function of Scan Mirror Position (channels 8-10)	$\Upsilon_{ch,\,i}(scn)$
Off-Axis Extended Source Throughput Correction Uncertainty (channels 8-10)	σ_{Υ}
Noise Equivalent Radiance (channels 8-10)	NER
Linearity Correction Function (verify OH channels 8 and 9)	$L_{ch,\,i}(\ )$

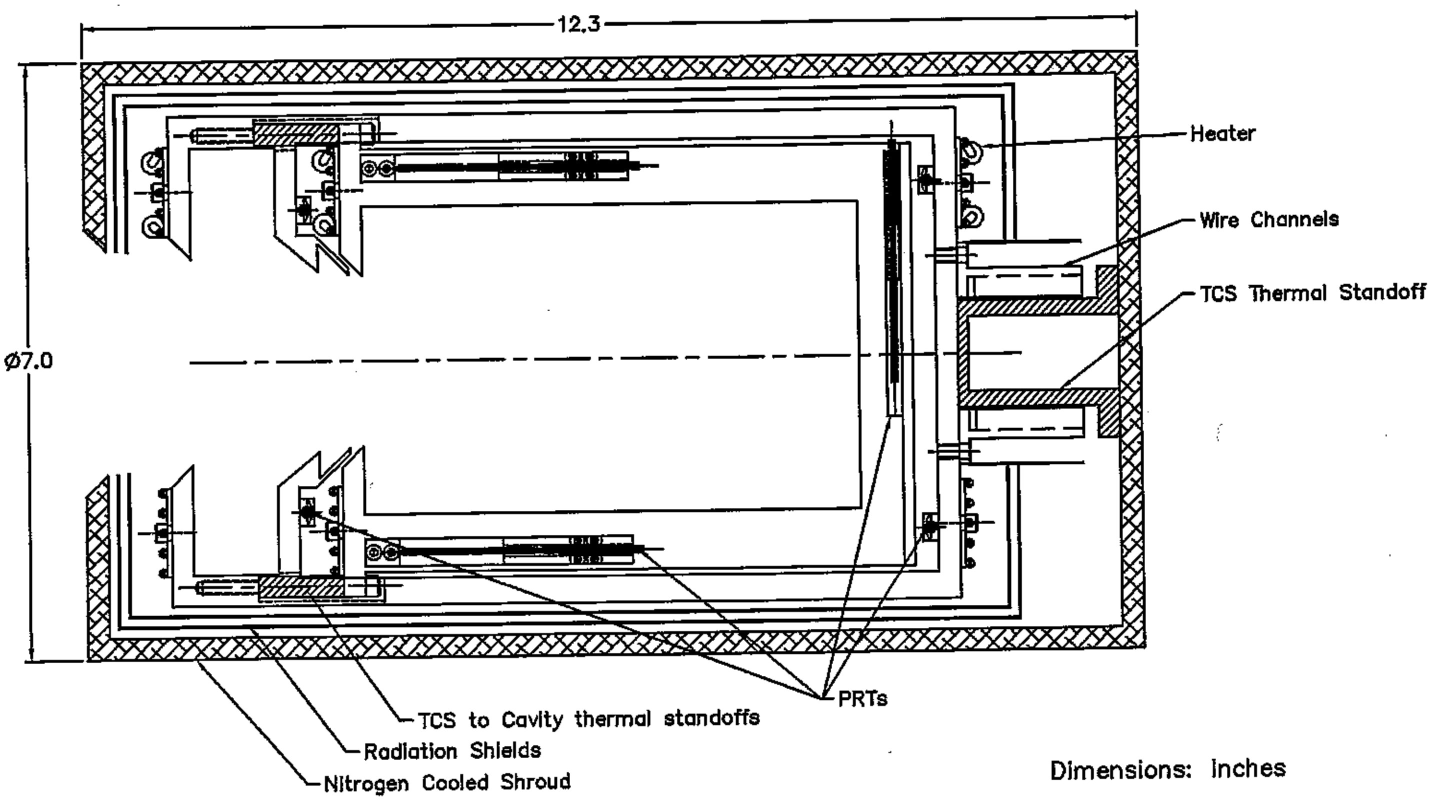
CALIBRATION MEASUREMENT CONFIGURATIONS

High Temperature GSE Blackbody (continued)



CALIBRATION MEASUREMENT CONFIGURATIONS

High Temperature GSE Blackbody (continued)



Dimensions: inches

CALIBRATION MEASUREMENT CONFIGURATIONS

High Temperature GSE Blackbody (continued)

- Mikron will build high temperature blackbody
- Vacuum blackbody design
  - Minimize radiometric uncertainty
- Small aperture blackbody design
  - Requires imaging optic to overfill SABER focal plane
  - Reduces complexity when compared to large aperture high temperature blackbody
  - Includes 2 inch limiting aperture
  - Meets volume constraints for being integrated into test chamber
  - Cavity design minimizes temperature gradients (especially for temperatures above 400 K)
  - Cavity design maximizes emissivity
- Cooled with LN_2 for rapid cooling

CALIBRATION MEASUREMENT CONFIGURATIONS

High Temperature GSE Blackbody - Specifications Overview

- Mechanical
  - Assembly length: 12.3 inch (305 mm)
  - Assembly outer diameter: 7.0 inch (216 mm)
  - Clear aperture: 2.0 inch (50.8 mm)
  - Mass: ~88 lbm (40 kg)
- Thermal performance
  - Temperature range: 300 K to 710 K
  - Temperature uncertainty (1σ): 0.3 K at 350 K, 0.7 K at 710 K
  - Steady-state power dissipated: <600 W @ 710 K
  - Full range transient rates
    - 710 K to 250 K: <10 hours
    - 100 K to 710 K: <2 hours
- Control stabilization time: < 20 minutes (transient change of 10 K)

CALIBRATION MEASUREMENT CONFIGURATIONS

High Temperature GSE Blackbody - Specifications Overview (continued)

- Emissivity
  - Normal emissivity: >0.993
- Parabola specifications
  - Focal length: 34 inch (863.6 mm)
  - Off axis: 11 inch (279.4 mm)
  - Diameter: 6.8 inch (172.7 mm)
  - Reflectance uncertainty (1σ): < 0.01
- Absolute radiance uncertainty (includes parabola reflectance uncertainty)

Channel	Absolute Radiance Uncertainty (1σ)
8 (OH)	1.6%[a]
9 (OH)	1.4%[b]
10 (O_2)	1.7%[c]

a. $T_{BB} = 430$ K
b. $T_{BB} = 480$ K
c. $T_{BB} = 582$ K

CALIBRATION MEASUREMENT CONFIGURATIONS

GSE High Temperature Blackbody - NIST Traceability

- Radiometric calibration
  - Transfer radiometer
  - Freezing point blackbodies (3)
- NIST radiometric verification
  - View blackbody with NIST Transfer Radiometer (TXR)
  - TXR used as verification and not calibration
    - TXR can calibrate blackbody for limited operating temperature range
    - TXR does not provide spectral calibration

CALIBRATION MEASUREMENT CONFIGURATIONS

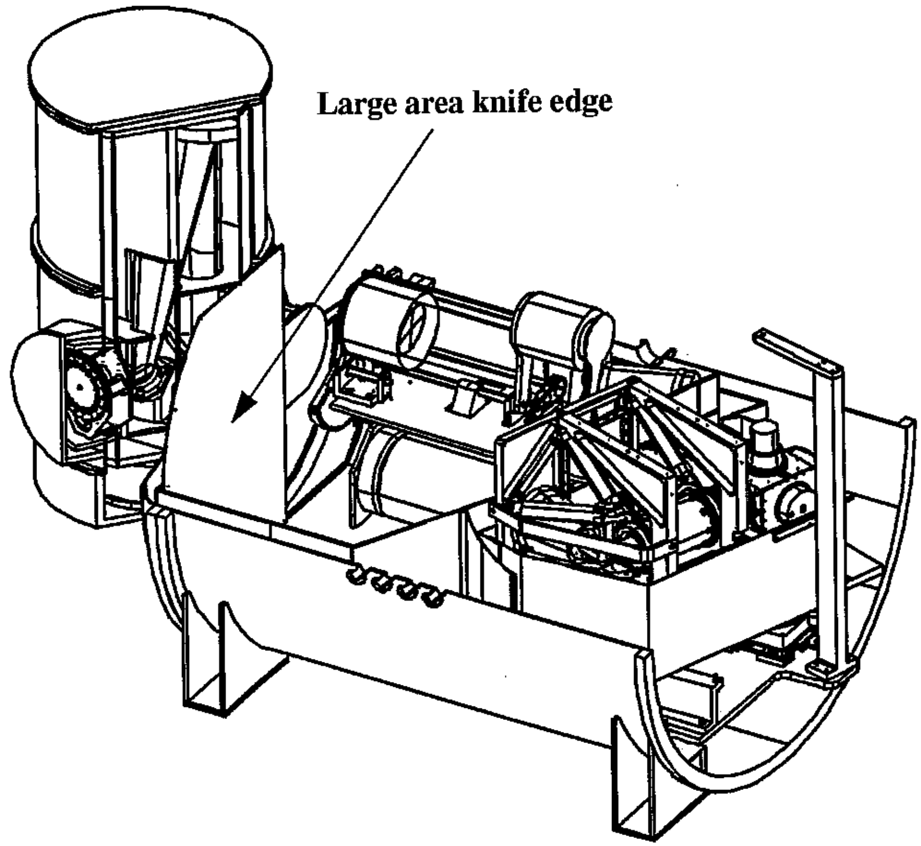
Large Area Knife Edge

- Calibration parameters

Parameter	Symbol
Knife edge test	S_{Knife}

CALIBRATION MEASUREMENT CONFIGURATIONS

Large Area Knife Edge (continued)



CALIBRATION MEASUREMENT CONFIGURATIONS

Large Area Knife Edge

- Verifies off-axis scatter response for angular dimensions larger than focal plane array
  - Sources of scatter include BRDF of mirrors and off-axis rejection performance of baffles
- Large area knife edge integrated into test chamber
  - Located at the end of the radiometric cavity inside test chamber
  - No need to break vacuum to reconfigure for knife edge test
  - Knife edge angular dimensions are 24° in-scan by 34° cross-scan (sufficient to overfill SABER scan mirror with off-axis flux)
  - Knife edge heated to 300 K during test
  - Knife edge temperature is approximately 90 K when not being operated
- Design features improve quality of measurement
  - Radiometric cavity cooled to 90 K and painted with Aeroglaze Z306
  - Shutter is cavity enhanced and painted with Aeroglaze Z302 to reduce reflected energy from reaching SABER FOV
  - Shutter cooled with neon to bring shutter temperature below radiometric noise floor of instrument (< 60 K)

CALIBRATION MEASUREMENT CONFIGURATIONS

Large Area Knife Edge (continued)

- Expected measurement performance for CO_2 channel 3
  - Based on APART, RENO, and MathCad models
  - Design off-axis response is expected to be approximately 32 times smaller than knife edge measurement uncertainty
  - Knife edge measurement uncertainty is only 2.3 times larger than the noise floor given by required NER
- Limitations of measurement
  - Verify no light leaks or unexpected sources of scatter

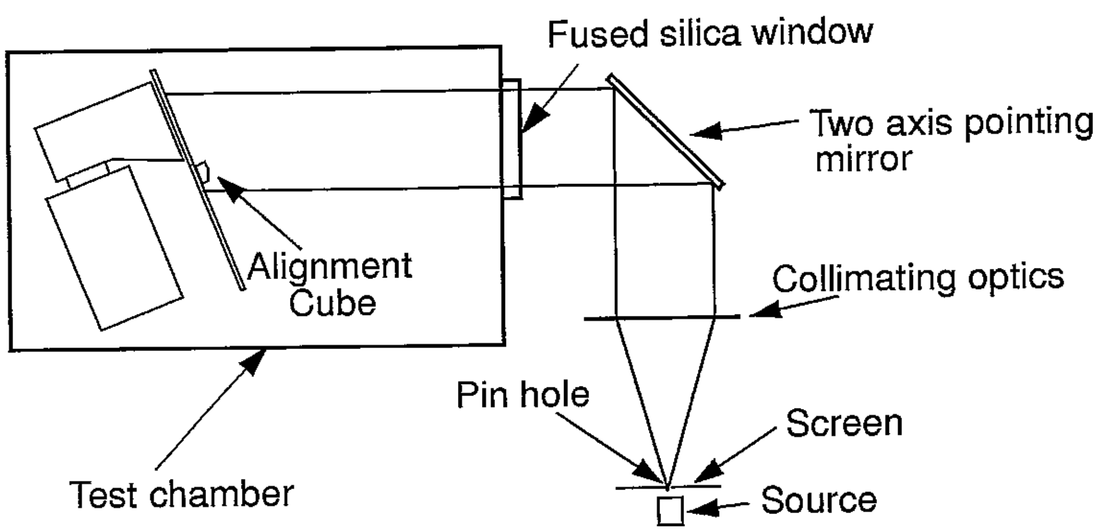
CALIBRATION MEASUREMENT CONFIGURATIONS

Boresight Collimator

- Calibration parameters

Parameter	Symbol
Sensor boresight	$P_{bor}(in, cr)$
Sensor boresight uncertainty	σ_{bor}

- Measure angular alignment between O_2 channel 10 FOV and sensor boresight defined by an optical alignment cube mounted on SABER's mounting plate
- Measurement configuration



- Measurement performed at two instrument rotation angles to quantify scan plane orientation relative to optical cube

CALIBRATION UNCERTAINTY BUDGET

- Used as a tool to identify dominant sources of uncertainty
- Will evolve as sensor and calibrator performance information is updated
- Organized into three sources of uncertainty for on-orbit calibration
  - Uncertainty of SABER response to external source
  - Uncertainty of SABER response to IFC
  - Uncertainty of IFC radiance
- Uncertainty estimates assume:
  - Science measurement with SNR = 100
  - Sensor performance (requirements)
  - Estimated calibration source uncertainties

CALIBRATION UNCERTAINTY BUDGET (continued)

- Radiance uncertainty for CO_2 channel 1

Term	Description	Uncertainty Error Budget (%)	Combined RSS Uncertainty (%)	Total RSS Uncertainty (%) 3% Goal 5% Requirement
$\sigma_{r_{c,sig}}$ - Uncertainty of Signal Corrected Response				
σ_O	Sensor offset measurement uncertainty (average 10 samples)	0.32	1.8	3.1
$\sigma_{o,med}$	Medium-term uncertainty of sensor offset (i.e., time between space looks)	1.0		
σ_N	Signal noise uncertainty (SNR = 100)	1.0		
σ_L	Linearity correction uncertainty	1.0		
σ_G	Gain mode normalization uncertainty	0.1		
$\sigma_{\Upsilon_{ext}}$	Uncertainty of off-axis extended source throughput correction (i.e., throughput correction as function of scan angle)	0.5		
$\sigma_{r_{c,IFC}}$ - Uncertainty of IFC Corrected Response				
σ_O	Sensor offset measurement uncertainty (average 10 samples)	0.0	1.0	
σ_N	IFC signal noise uncertainty	0.02		
σ_L	Linearity correction uncertainty	1.0		
σ_G	Gain mode normalization uncertainty	0.1		
σ_{IFC} - Uncertainty of IFC Radiance				
$\sigma_{\Re,BB}$	Radiance uncertainty of full-aperture blackbody	0.6	2.2	
σ_{RSR}	Uncertainty of IFC channel radiance due to uncertainty of instrument relative spectral response	1.8		
$\sigma_{N_{IFC}}$	Uncertainty of IFC radiance (calibration transfer to IFC)	1.0		
$\sigma_{IFC,repeat}$	Uncertainty due to IFC radiance long-term repeatability	0.7		

CALIBRATION UNCERTAINTY BUDGET (continued)

- Total RSS uncertainty for each SABER channel

Channel	Total RSS Uncertainty (%) 3% Goal 5% Requirement
1 (CO_2)	3.1
2 (CO_2)	3.3
3 (CO_2)	3.3
4 (O_3)	2.9
5 (H_2O)	3.1
6 (NO)	3.2
7 (CO_2)	3.4
8 (OH)	3.5
9 (OH)	3.8
10 (O_2)	3.4

ELECTRICAL GSE and GSE SOFTWARE

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20 October 1997

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OUTLINE

- Fixed Requirements
- Derived Requirements
- Milestone Schedule
- SABER Electrical GSE
- GSE Software Design
  - Development Environment
  - Data Flow
  - Graphical User Interface
  - Functionality
- Software Testing / Revision Control / Documentation
- Risk Assessment / Mitigation
- Acronyms

FIXED REQUIREMENTS

- Command SABER instrument via TIMED spacecraft emulator
  - Prepare and deliver CCSDS packets as required by the spacecraft emulator
- Receive, monitor, and store SABER housekeeping and science data
  - Receive SABER CCSDS packet data from TIMED spacecraft emulator
  - Store all CCSDS packets received from SABER instrument
  - Unpack and decode data packets
  - Pass data packets on to the POC software via tcp socket for quick-look analysis
- Control power to SABER instrument prior to integration onto the spacecraft
- Control and monitor GSE test chamber
  - Control rotary table position (instrument rotation) via stepper motor controller
  - Monitor vacuum level
  - Monitor temperatures (thermocouples)
  - Control cryogen flow through solenoid-operated valves
  - Monitor and control shutter position
  - Control knife edge plate heater
  - Monitor flip-in source position switches over IEEE 488
  - Control high and low temperature blackbodies over ethernet

FIXED REQUIREMENTS (continued)

- Provide strobe pulse to operate source shutter
- Monitor sync pulse from Bio-Rad step-scan interferometer and synchronize test events
- Monitor external blackbody temperature via Keithley DMM
- Control and monitor full field collimator
  - Monitor temperatures via LakeShore 820 thermometer and 8085 scanner
  - Control and monitor pointing mirror position via NEAT stepper controller
  - Command aperture and filter position via NEAT stepper controller
  - Monitor aperture position via resolver readout
  - Monitor filter position switches

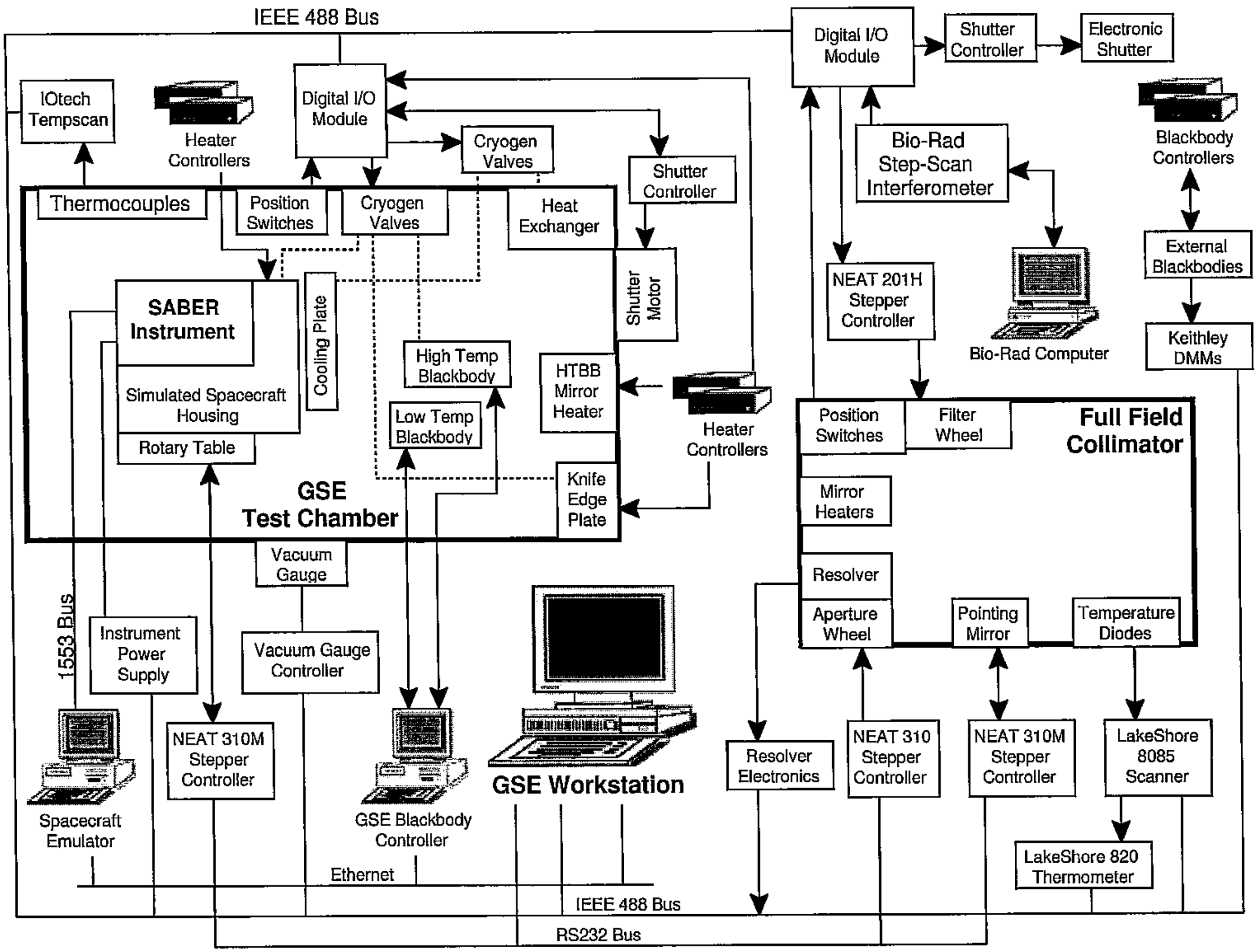
DERIVED SOFTWARE REQUIREMENTS

- Validate commands for current conditions prior to execution
- Log all commands executed by the SABER GSE software
- Provide operator with real-time feedback of command execution
- Execute built-in test sequences
  - Source scan (instrument rotation, instrument scan mirror, and FFC pointing mirror)
  - Interferometer scan (Bio-Rad)
- Execute commands from a script file
- Log and archive GSE status information
- Provide real-time display of SABER science data
- Create test event database

MILESTONE SCHEDULE

- 15 July 97 — Initial GUI and RDBMS (completed)
- 15 August 97 — Draft of GSE software users manual (completed)
- 20 October 97 — SABER CDR
- 5 January 98 — Receive electrical GSE
- 27 January 98 — Begin test and debug of individual software modules
- February 98 — Spacecraft emulator interface tests
- 1 June 98 — Begin test and debug of integrated software (Release 1.0)
- 7 August 98 — Software testing complete to support integration and testing (I&T) of instrument and GSE hardware (Release 2.0)
- 11 August - 1 October 98 — Exercise software during I&T cold tests
- 15 October 98 — Final release (3.0) of software to support engineering calibration

SABER ELECTRICAL GSE



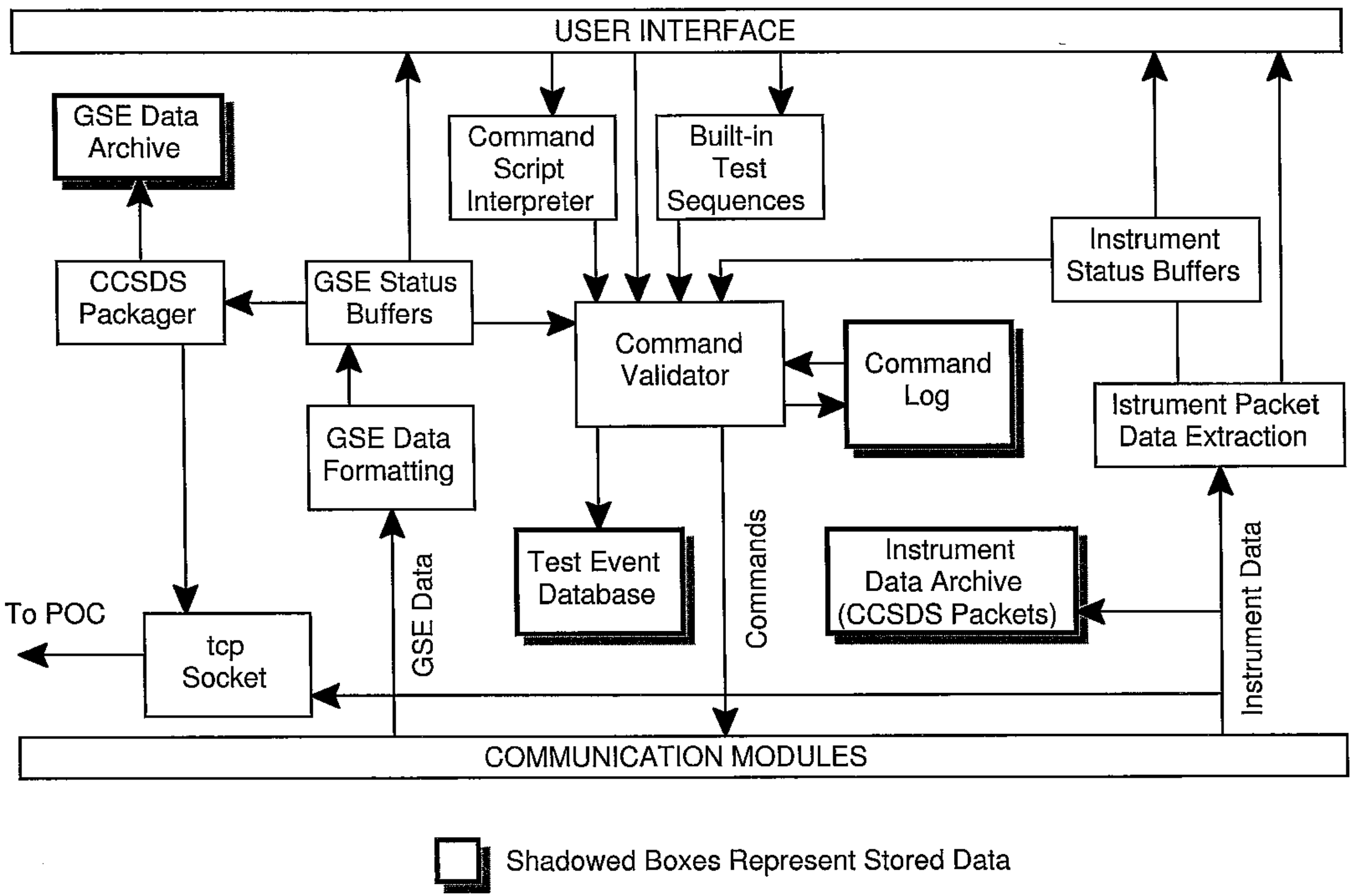
GSE SOFTWARE DESIGN

Development Environment

- Sun Sparcstation with Solaris 2.6 (UNIX) operating system
  - Platform chosen to take advantage of SDL's existing control software, programming expertise, and data analysis environment
- 4 Gbytes of on-line storage for instrument data and GSE data logs
- 4 mm tape drive for system and data backups
- CD-ROM writer for data archival
  - Provides more convenient access than tape storage
- Printer
- C, C++, and Fortran Compilers
- XRT® GUI components from KL group
- PostgreSQL relational database
- RS/1, PV~Wave, and BBN Cornerstone data analysis software

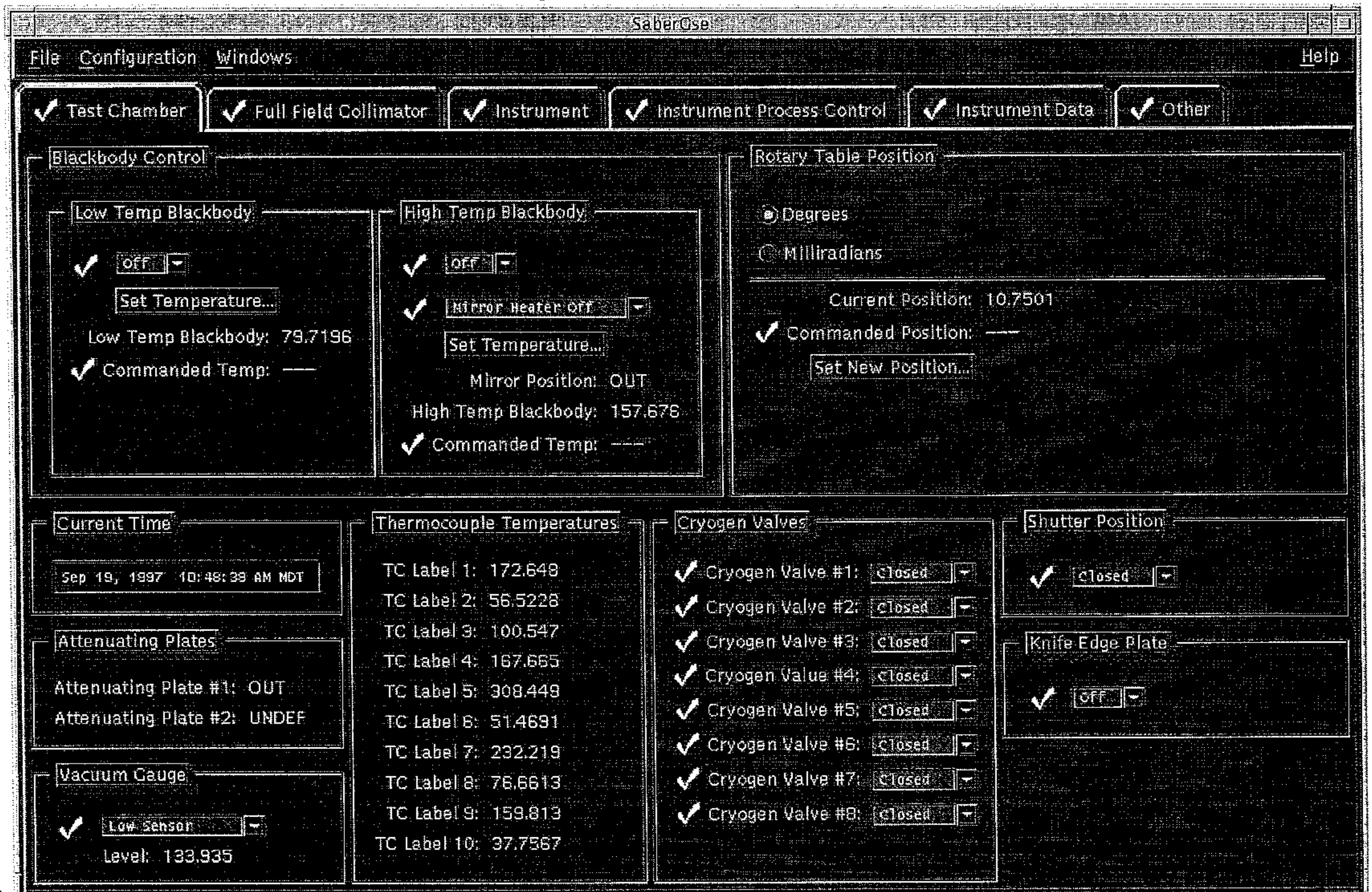
GSE SOFTWARE DESIGN

Data Flow



GSE SOFTWARE DESIGN

Graphical User Interface



GSE SOFTWARE DESIGN

Functionality

- Command and data handling
  - All commands are validated in the current system context before being executed
  - All instrument data are recorded and archived
  - Each instrument power-on command starts a new instrument data file and corresponding GSE data files
  - Instrument data file name is displayed on the GUI
  - Instrument status is extracted from the telemetry data and displayed on the GUI
  - Science data can be extracted and displayed in real time in a pop up window
  - All GSE and instrument data packets are written to disk and a tcp socket
- Test events will be logged with an entry in a test event database that will include:
  - A unique test identifier
  - Instrument data location (file name and position) of first sample
  - Number of samples for test
  - Sensor and GSE status information
  - Representative statistics (mean and standard deviation) of science data
    - Gives ready access to data frequently used for data analysis
    - Allows data analyst to search for test events with specific data characteristics

GSE SOFTWARE DESIGN

Functionality (continued)

- Automation
  - Built in test sequences allow predetermined and repetitive command sequences to be performed more quickly and reliably
  - GSE software also reads and executes commands from command scripts
  - Execution of built-in sequences and scripts can be paused and restarted or aborted
- Preprocessor
  - Checks validity of instrument data
  - Populates test-event database with representative statistics of instrument data
  - Extracts instrument data to RS/1 tables or ASCII files for further analysis
  - Converts instrument housekeeping to engineering units

GSE SOFTWARE TESTING / REVISION CONTROL / DOCUMENTATION

- Control and monitor functions associated with the test chamber, SABER instrument, GSE blackbodies, and full field collimator will be tested as the components for those systems become available
- All software functions will be exercised during I&T cold tests
- Further operational testing will be performed during the engineering calibration
- All GSE software will be developed under revision control using Sunsoft's TeamWare software
    - Tracks version number for each file with comments for each version
    - Allows multiple developers to work on the same software modules
- After initial testing and debug of the complete GSE software package (after Release 2.0), an internal (SDL) review will be required of all software changes
- Technical software users manual will be the software design document
    - Will be under revision control with the software
    - Assumes user is familiar with SABER instrument and its GSE
- Bugs, feature requests, and software issues will be entered and tracked using a WWW-based project tracking software

RISK ASSESSMENT / MITIGATION

- The GSE hardware and electrical GSE have been designed so that software commands will not damage hardware
  - At worst, a misconfigured or inappropriate command would result in lost or unusable data
- GSE software is only used to control the SABER instrument prior to spacecraft integration
  - Instrument data integrity will be checked within a few hours of collection
    - Unusable data can be recollected before the GSE hardware or instrument configurations are changed
- Commands that would result in an interruption of data from the instrument will require operator confirmation prior to being executed

ACRONYMS

- DMM - Digital Multi-Meter
- SABER - Sounding of the Atmosphere using Broadband Emission Radiometry
- GSE - Ground Support Equipment
- TIMED - Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics
- CCSDS - Consultative Committee for Space Data Systems
- IEEE - Institute of Electrical and Electronic Engineers
- NEAT - New England Affiliated Technologies
- FFC - Full Field Collimator
- RDBMS - Relational Database Management System

SABER Calibration Software Development Plan

Guy Beaver
Larry Gordley

Calibration Objective

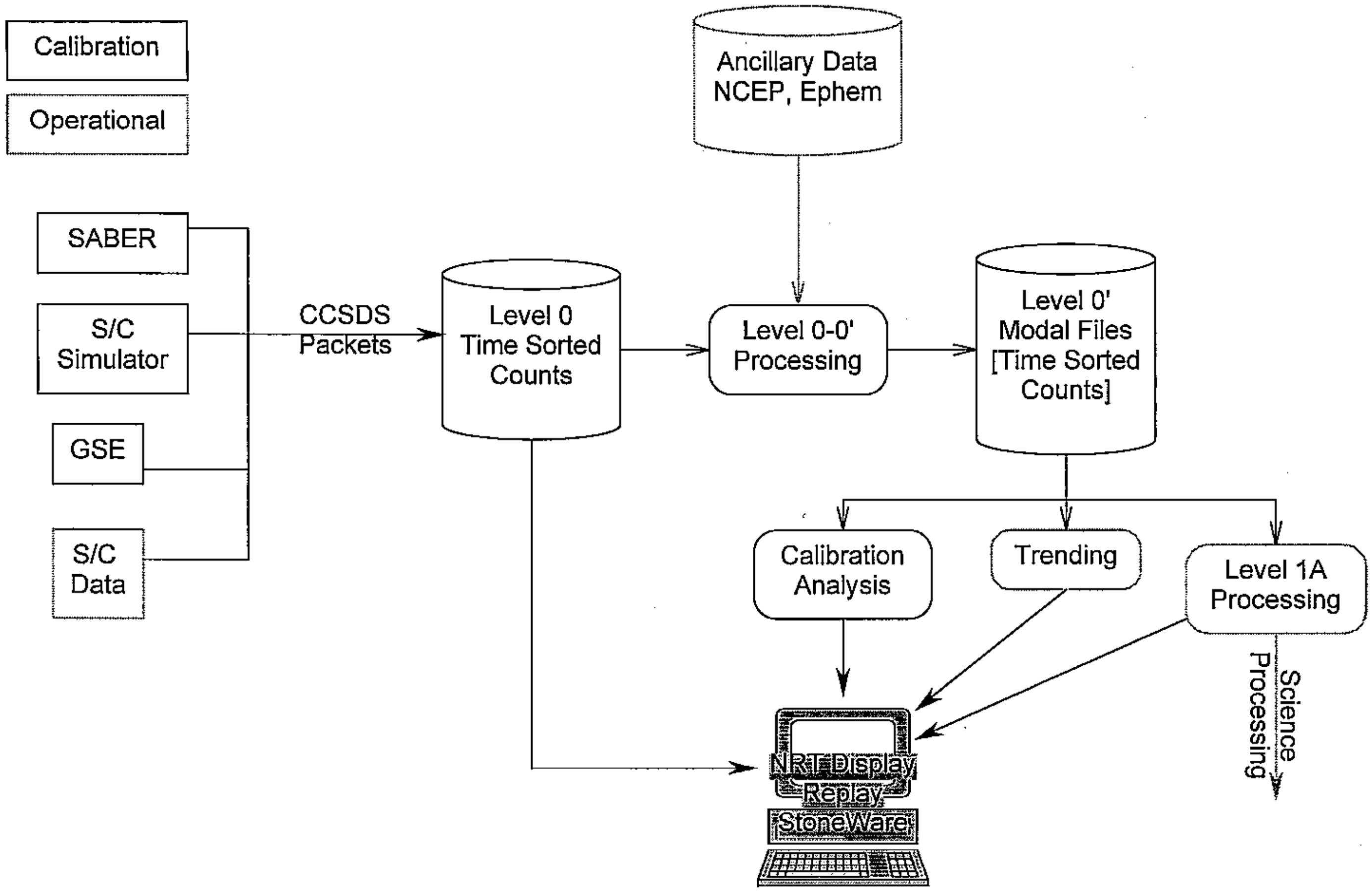
- Characterize Instrument Response Components:
  - –Spectral (RSR)
  - –Spatial (1-D IFOV)
  - –Temporal (Impulse Response of Electronic Filter)
  - –Thermal (Dependence on Instrument Temperature)
- Level 1 Processing Requires Accurate Instrument Characterization to Correct Data for Instrument Effects
- Science Processing Requires Accurate Instrument Characterization for Retrieval Forward Model

- Pentium-based PC's with Major Peripherals
- MS Windows NT Operating System

    May use LINUX and Windows 95 for Minor Tasks

- C / C++ / IDL / FORTRAN /
- GATS Replay System
- Custom Analysis Software

Calibration/Operational Data Flow



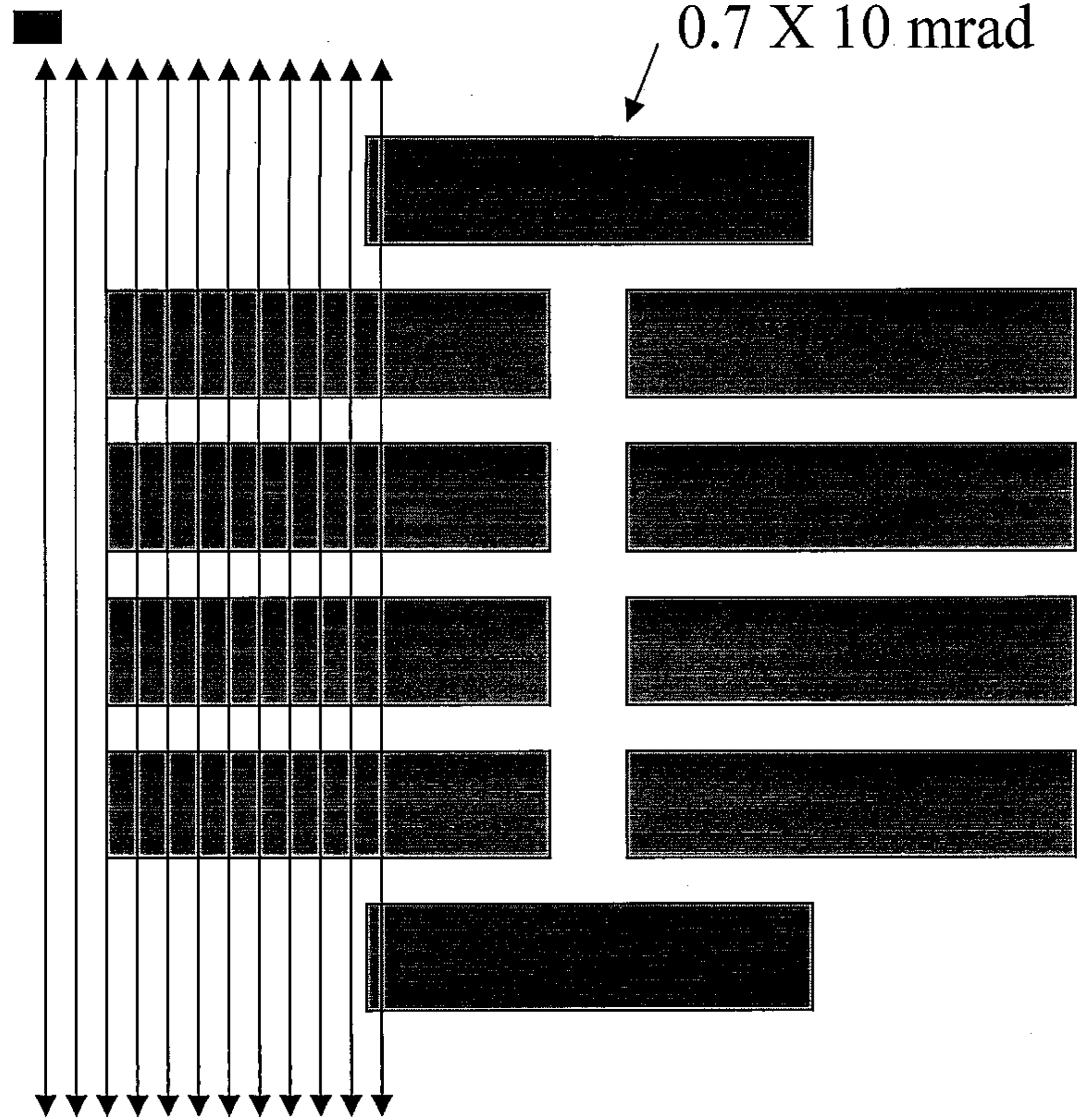
CSCI Breakdown

CSCI	Calibration Product	Responsibility (Primary/Secondary)
CSCI 6.1	IFOV	GATS / SDL
CSCI 6.2	MTF	GATS /SDL
CSCI 6.3	RSR	SDL / GATS
CSCI 6.4	Linearity	GATS / SDL
CSCI 6.5	Absolute Radiance	GATS / SDL
CSCI 6.6	Off-Axis Response	GATS / SDL

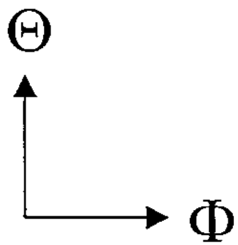
FPA

Point Source
(0.14 X 1 mrad)

Detector
0.7 X 10 mrad

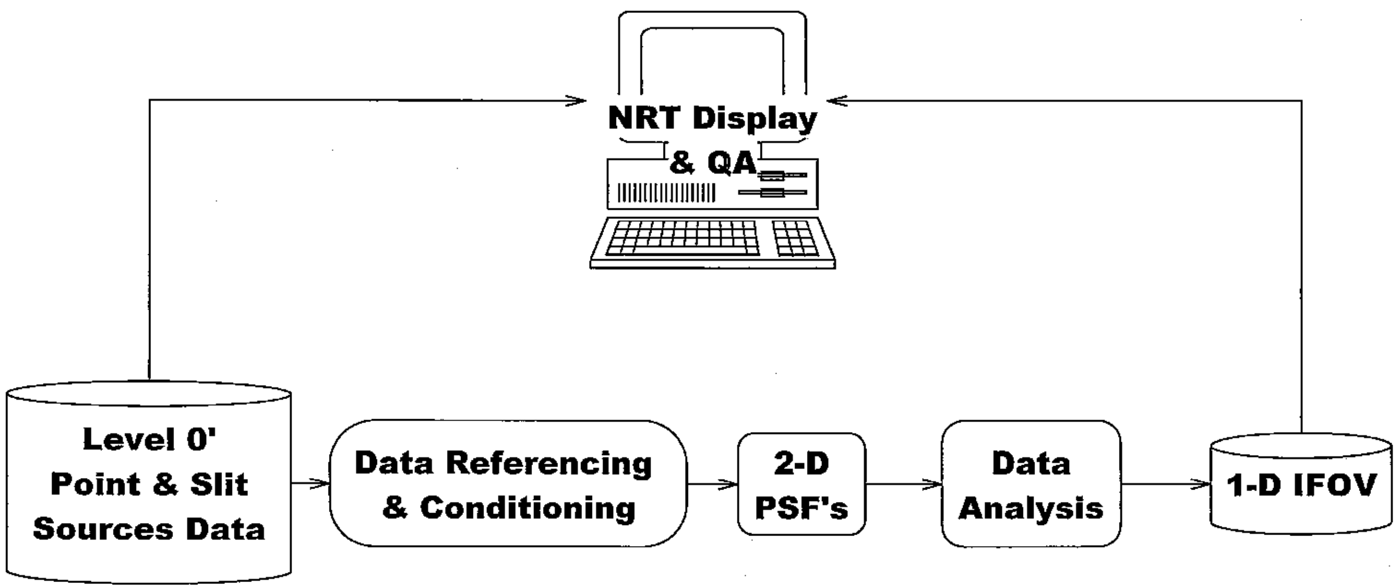


Measure:
$V_N(\Theta,\Phi)$ =
voltage output for
detector N.



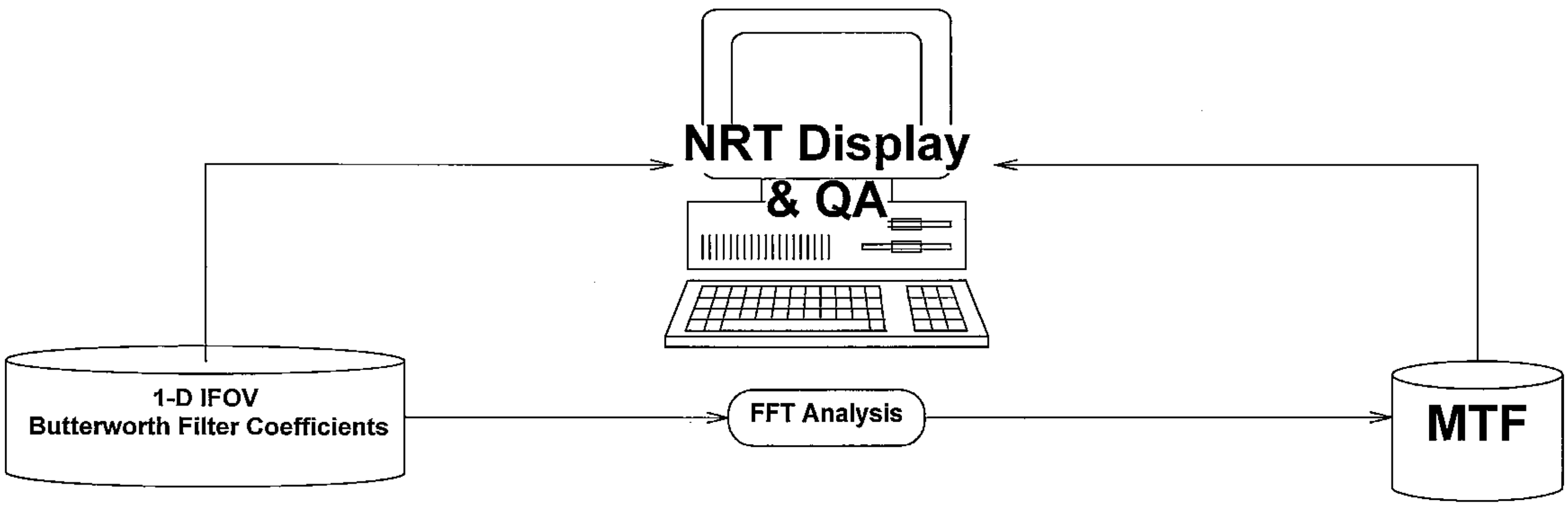
CSCI 6.1: IFOV

- Requirements
  * 2-D Mapping of the Point Spread Function (PSF) to Estimate the Effective 1-D IFOV
  * Measure & Characterize any Cross-Channel Response.



CSCI 6.2: MTF

- Requirements
  * FFT Analysis of the IFOV for Spatial Component.
  * Validate Butterworth Filter by Step Response Data.
  * Total MTF: 50% +/- 3% @ 0.25 [cycles/km]

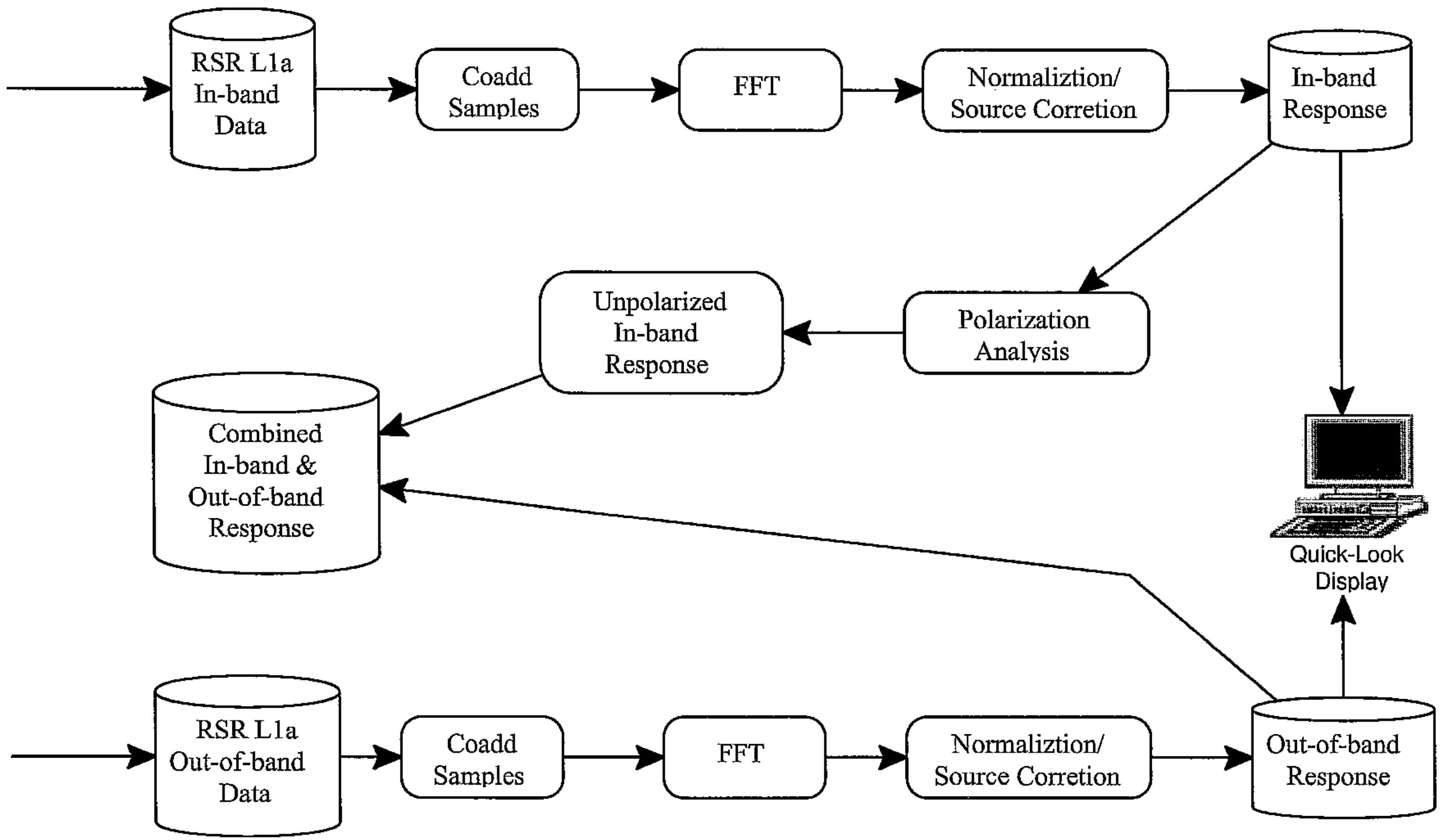


CSCI 6.3 Requirements

In-band: FTI Measurements at 4-8 cm^{-1}

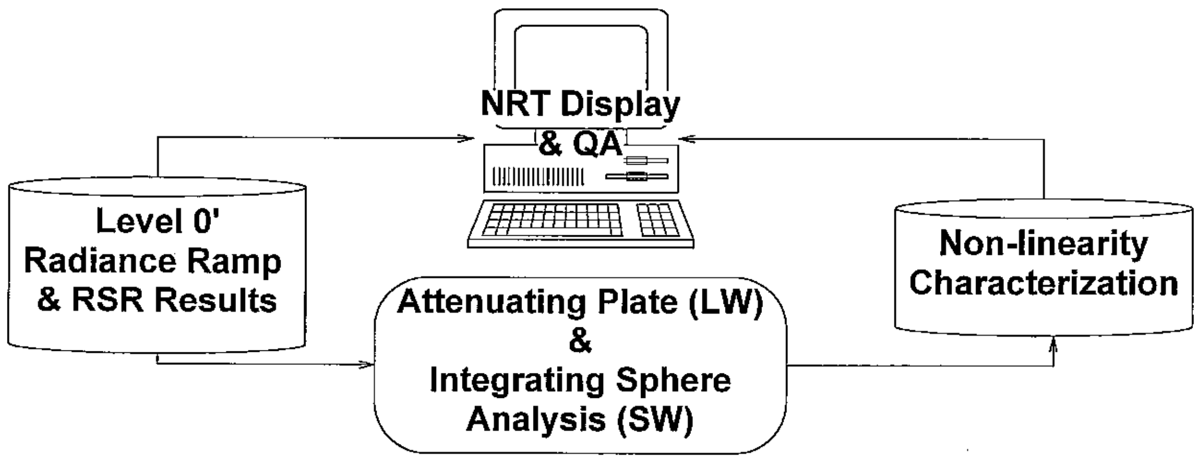
Polarization Analysis at 3 Angles

Out-of-band: FTI Measurements at 4-8 cm^{-1}



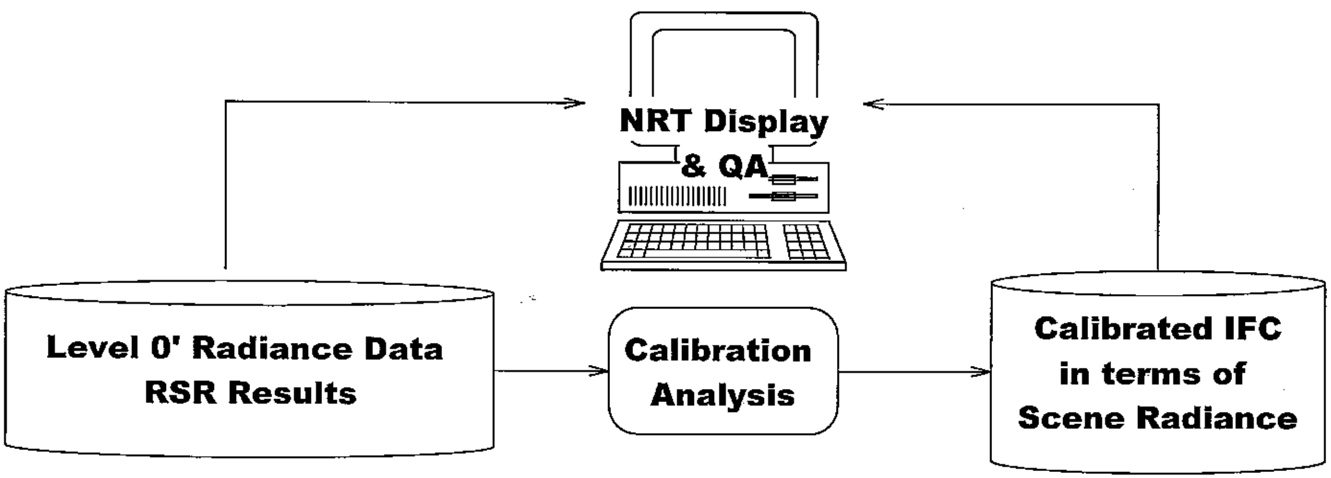
CSCI 6.4: Linearity

- Requirements
  - * Non-Linearity Characterization of Calibration Coefficient
  - * Attenuating Plate Analysis (LW)
  - * Integrating Sphere Analysis (SW)



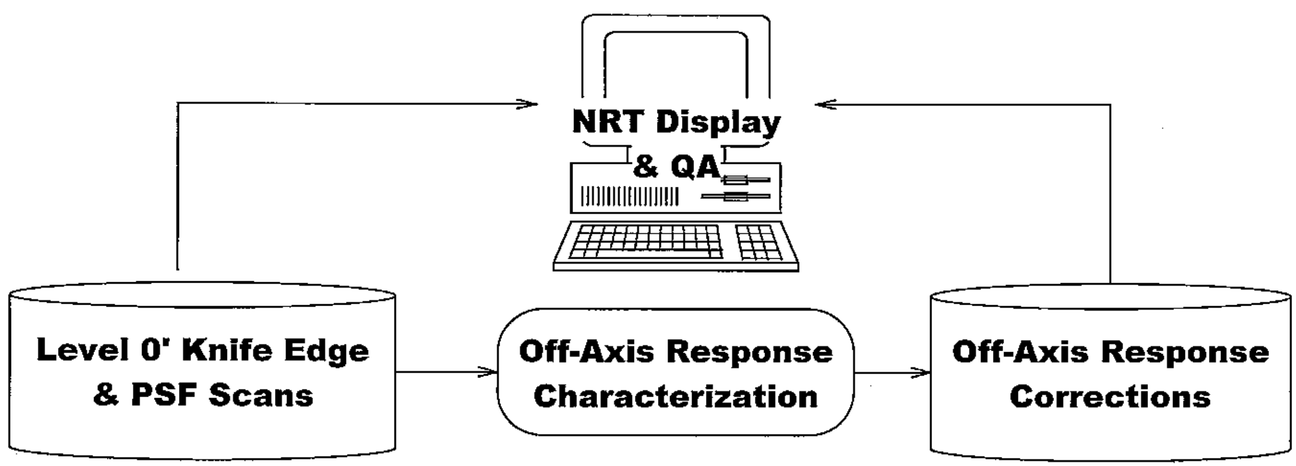
CSCI 6.5: Absolute Radiance

- Requirements
  - * Determine Calibration for IFC Blackbody and Jones Source using GSE Blackbody and RSR Results.
  - * Infer Zero Offset (Regression Analysis of Temperature Ramp Data)
    - - Validate On-orbit by looking at Cold Space.
  - * 5% Absolute Radiance, 2% Long Term Precision



CSCI 6.6: Off-Axis Response

- Requirements
  * Measure Off-Axis Response from Knife Edge and PSF Scans in "Black Hole Facility".
  * Verify Off-Axis Performance On-orbit
    - Roll Up & Roll Down Looks
    - Scan into Baffle



Existing S/W

- Templates from Previous Missions:
  LIMS, HALOE…
- Display/Analysis/Comparison:
  REPLAY, STONEWARE

- Preliminary Testing:

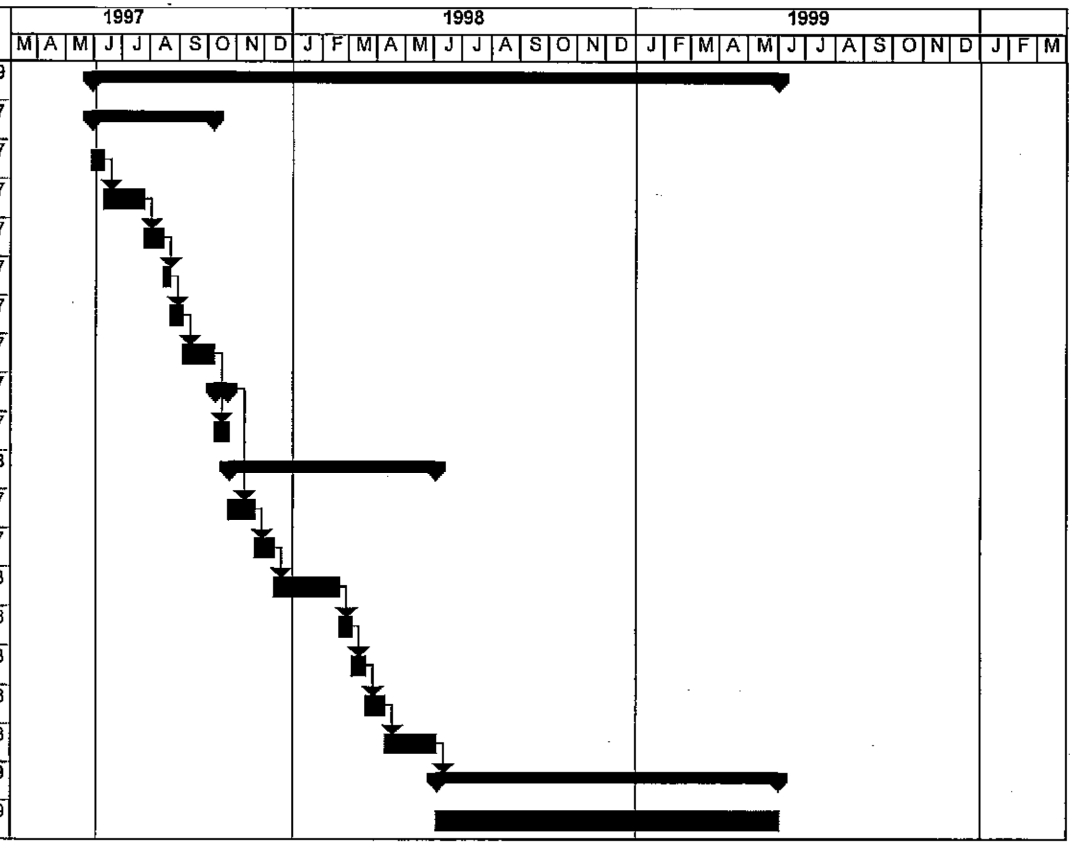
Debugging, Syntax, Modularity:

  * Test Modules Individually
  * Test Integrated CSCI with Simulated Data

- Testing Readiness by Pre-Calibration

Calibration Software Schedule

ID	Task Name	Duration	Finish
56	1.3 Calibration Analysis Software	525d	6/1/99
57	1.3.1 Design Calibration Software	95d	10/7/97
58	Linearity	2w	6/10/97
59	Relative Spectral Response	6w	7/22/97
60	IFOV	3w	8/12/97
61	MTF	1w	8/19/97
62	Radiance	2w	9/2/97
63	Off Axis Rejection	5w	10/7/97
64	1.3.2 Prepare for CDR	10d	10/21/97
65	Prepare for SABER CDR	2w	10/21/97
66	1.3.3 Write Calibration Software	160d	6/2/98
67	Develop Simulated Data	4w	11/18/97
68	Linearity	3w	12/9/97
69	Relative Spectral Response	10w	2/17/98
70	IFOV	2w	3/3/98
71	MTF	2w	3/17/98
72	Radiance	3w	4/7/98
73	Off Axis Rejection	8w	6/2/98
74	1.3.4 Test / Maintain calibration Soft	260d	6/1/99
75	Maintain software support calibrati	52w	6/1/99



SABER Software Critical Design Review

Risk Assessment/Mitigation

Primary Calibration Challenge:

Verify that all Needed Calibration Data is Valid and on Schedule

Mitigation:

- Perform Near Real-Time Analysis
- Pre-calibration (October '98) provides Opportunity to Refine Test/Analysis Methods
- Close Involvement with Science Team and Engineers in Instrument Requirements, Design and Testing During Pre-Calibration
- Preliminary Calibration Report after 10 Days
- Compare Independent Analyses by GATS & SDL

SABER INSTRUMENT FABRICATION, INTEGRATION, TEST, AND CALIBRATION

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20 October 1997

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OVERVIEW

Fabrication Plans

- **Mechanical / Structural**
- **Electrical**

Integration, Test, and Calibration

- **Engineering and Development Tests**
- **Proto-Flight Tests**
- **Test Plans and Procedures**
- **Test Reports**
- **Specifications and Requirements for Verification**
- **Test Flow**
  - Development and Engineering Tests
  - Proto-Flight Acceptance Tests
  - Calibration
  - Spacecraft Integration and Test
  - Launch Support
- **Test Matrix**
- **Test Organization Chart**

MECHANICAL / STRUCTURAL FABRICATION

- **Parts will be fabricated using both in-house and out-of-house shops**
  - Mechanical parts list was reviewed to identify parts that exceed in-house capacity or require special processing not available in-house
  - Parts that require special processing have been identified
    - Baseplate (large mill)
    - Telescope cradle (5 axis mill)
    - Secondary support for M2 (EDM)
    - Lyot stop (EDM)
    - Upper telescope housing (NC lathe)
  - Bids are being procured for special processing parts
- **Parts manufacturing schedule has been developed for instrument, GSE, and handling fixtures**
  - Scheduling delineates the parts to be fabricated in-house and out-of-house
  - Schedules are being coordinated with out-of-house shops
- **Assembly procedures are being developed for critical optical parts**
- **Product Assurance and Logbook System was used during prototype and test assembly fabrication to verify the process**

ELECTRICAL FABRICATION

- **All prototype circuit boards are receiving full Product Assurance overview to verify fabrication and logbook processes**
  - Prototype circuit boards are being manufactured to flight specifications
  - These boards may be populated with flight components and used for flight if no changes are necessary
- **Long lead items were identified and ordered early**
- **Technicians are trained and certified to NASA soldering standards, NHB 5300.4(3A-2)**
- **ESD precautions are observed**
  - Equipment upgrades have been made where necessary

ENGINEERING AND DEVELOPMENT TESTS

- **Engineering and development tests are conducted during design phase and early in integration phase**
- **Design and manufacturing processes have been verified**
- **Logbooks and travelers will follow flight assemblies**
- **Summary reports will include**
  - Summary of significant data
  - Location of test data including file names
  - Test conclusions

PROTO-FLIGHT TESTS

- **Proto-flight tests are performed at the integrated instrument level**
  - Two electronics tests will be performed at the subsystem level
- **Includes functional, performance, environmental, and calibration testing**
- **Formal test plans and procedures are required**
- **Test levels**
  - Exceed expected lifetime environments
  - Low enough to maintain flight integrity of equipment
- **Tests will be conducted under direction of system engineer**

TEST PLANS AND PROCEDURES

- **Development by engineering team is under direction of the system engineer**
  - Procedure development will occur during engineering development testing
- **Test procedure due to LaRC 10 days prior to test**
- **Test procedure requirements**
  - Test item description, level of assembly, and configuration
  - Test objectives and outline
  - Test environments, duration, cycles, and methods
  - Performance requirements
  - Test facility, equipment, and instrument needs
  - Test equipment and instrument certification policies
  - Test personnel responsibilities
  - Test quality and safety activities
  - Test photographic coverage required

TEST REPORTS

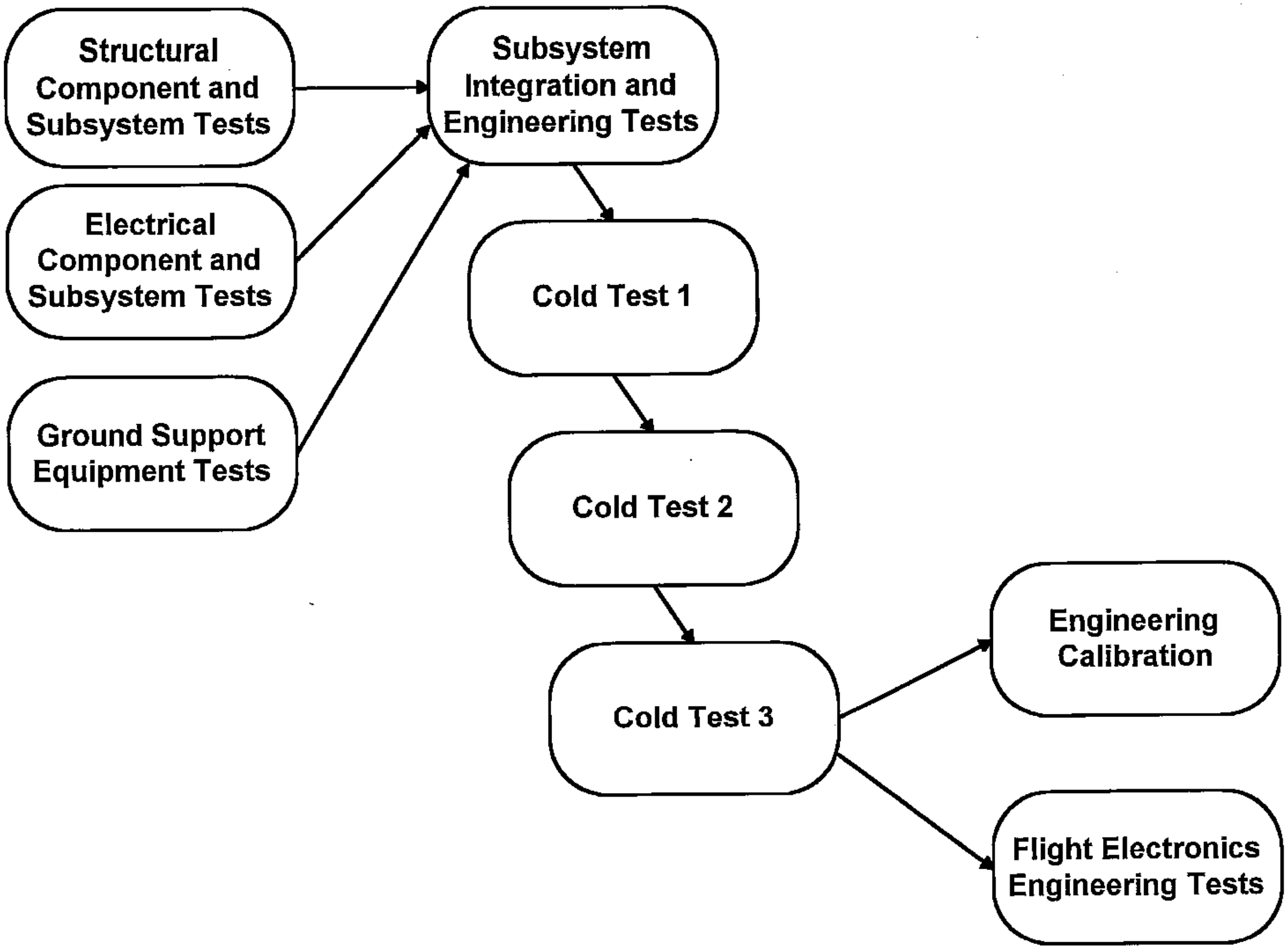
- **Preliminary report of initial results**
  - Due 10 days following the test
  - By either fax or e-mail
- **Final report**
  - Due 6 months after test completion
  - Final reports will include
    - Completed test procedure or test documentation as an attachment
    - List of changes in procedures, hardware, or software made from the original
    - Reports of all nonconformance and failures occurring during the test
    - Summary of all significant test results, test data, and conclusions
    - Photographs if available
    - Location of raw test data
    - Certification from Quality Assurance and Project Manager

SPECIFICATIONS AND REQUIREMENTS FOR VERIFICATION

The SABER instrument tests will provide verification of the following specifications and requirements

- Total mass
- Total power
- Structural integrity
- Structural workmanship
- Minimum frequency
- EMC / EMI
- Thermal vacuum cycle
- External dimensions
- Mounting configuration (footprint)
- Signal measurement dynamic range
- Mechanical alignment error
- Temperature range
- Temperature stability
- Residual scale error
- Cleanliness requirements
- Noise equivalent radiance
- Radiometric accuracy
- Radiance bias drift
- Long-term radiometric precision
- Command and data handling requirements
- Limb scan mirror jitter
- Spectral response
- IFOV @ 60 km tangent height
- Limb vertical scan range
- Measurement altitude range
- Focal plane channel location
- Electronic temporal response
- Center of mass
- Limb vertical sampling interval
- Boresight alignment knowledge

DEVELOPMENT AND ENGINEERING TEST FLOW



DEVELOPMENT AND ENGINEERING TESTS

Component and subsystem tests

- **Structural component and subsystem tests**
  - Focal plane support system tests
  - Scan mirror bearing tests
  - Optical component and subsystem tests
  - Thermal control components and subsystem tests
- **Electrical component and subsystem tests**
  - Scan mirror control system tests
  - Command and data handling electronics tests
  - Housekeeping electronics tests
  - Signal processing electronics tests
  - Analog controller electronics tests
    - Analog prototype board IFC control tests
    - IFC blackbody operation in vacuum chamber
  - Power converter electronics tests
  - Refrigerator electronics tests
  - Prototype electronics functional and EMC/EMI tests

DEVELOPMENT AND ENGINEERING TESTS (continued)

Ground support equipment tests

- Electrical GSE tests
- GSE software tests
- Blackbody tests
- Full field collimator tests
- GSE test chamber tests

Subsystem integration and engineering tests

- Telescope integration and alignment
- Initial GSE and instrument checkout
- Initial telescope structural integrity tests
- IFC thermistor calibration and stabilization
- Stray light tests
- Warm focus and boresight test (OH and O_2 channels - 8, 9, 10)
- Cover deployment system tests

DEVELOPMENT AND ENGINEERING TESTS (continued)

Engineering and precalibration tests

- **Cold test 1 (electronics prototype box mounted outside chamber)**
  - Warm boresight and focus
  - Electronics warm functional test
  - Thermal checkout
  - Housekeeping checkout
  - Refrigerator temperature setup
  - Scanner checkout
  - Cold boresight and focus test
  - Amplifier gain setup and test
  - IFC source checkout
  - Thermal extremes test

DEVELOPMENT AND ENGINEERING TESTS (continued)

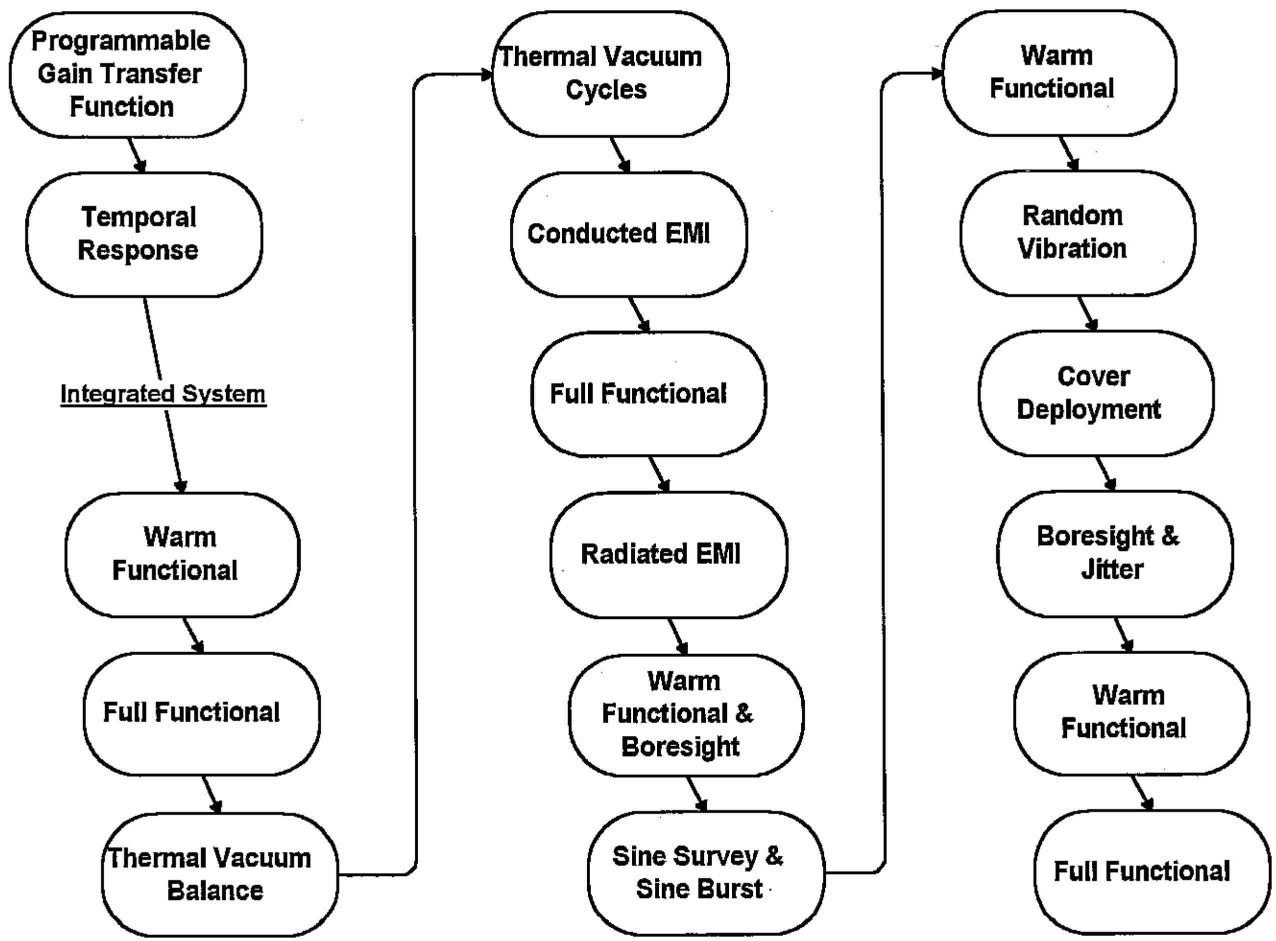
Engineering and precalibration tests (continued)

- **Cold test 2 (prototype electronics box mounted on SABER inside chamber)**
  - Electronics warm functional test
  - Cold boresight and focus test
  - Electronics cold functional test
- **Cold test 3 (flight electronics box mounted on SABER inside chamber)**
  - Electronics warm functional test
  - Cold boresight and focus test
  - Electronics cold functional test
- **Engineering calibration (using prototype electronics box)**
  - Electronics warm functional test
  - Data collection checkout
  - Engineering calibration measurements (subset of full calibration test sequence)
- **Flight electronics engineering tests**
  - Electronics box thermal cycle tests
  - Electronics box vibration tests

PROTO-FLIGHT ACCEPTANCE TEST FLOW

Signal Processing Circuit Tests

Integrated System Tests



SUBSYSTEM PROTO-FLIGHT ACCEPTANCE TESTS

Signal processing circuit tests

- Temporal response test
- Programmable gain transfer function test

INTEGRATED SYSTEM PROTO-FLIGHT ACCEPTANCE TESTS

Warm functional test

- **Developed during the integration and cold tests**
- **Checks function of all systems that may be operated warm**
  - IFC operation
  - Scan controller operation
    - Scan mirror cage
  - Refrigerator checkout
    - Short duration: cold finger temperature maintained above dew point
    - Refrigerator cage
  - Operate cover release mechanism
  - Verify OH and O_2 channels (8, 9, 10) operation
    - Verify response to Jones sources
  - Verify housekeeping telemetry
  - Verify communications for command and data
    - Verify uplink commands
    - Verify limited set of stored commands
    - Exercise limited set of refrigerator commands

INTEGRATED SYSTEM
PROTO-FLIGHT ACCEPTANCE TESTS (continued)

Full functional test

- **Developed during the integration and cold tests**
- **Test conducted only while instrument is at operational temperature in a vacuum**
- **Full functional check of all systems and commands**
- **Includes all warm functional test operations**
- **In addition:**
  - Survival and operational heater checkout
  - Full refrigerator operational checkout
  - Verify all detector channels
    - Verify detector response to IFCs
    - Verify detector response to GSE sources
  - Exercise all operational modes
  - Exercise spacecraft interrupts
  - Exercise timed command sequence
  - Exercise comprehensive list of commands
    - Combination of uplink and stored commands

INTEGRATED SYSTEM PROTO-FLIGHT ACCEPTANCE TESTS (continued)

Thermal vacuum balance

Thermal vacuum cycle

- **Test conditions**

Test parameter	Parameter value
– Pressure	< 10^{-4} torr
– Survival temperature limit	-34° C to +60° C
– Operational temperature limit	-29° C to +50° C
– Stability	< 3° C / hr
– Soak time	4 hr minimum
– Cycles	1 survival and a minimum of 6 operational

Emi-conducted tests

- **Contracted to NTS**

Emi-radiated tests

- **Contracted to NTS**

Warm functional test and boresight measurement

INTEGRATED SYSTEM PROTO-FLIGHT ACCEPTANCE TESTS (continued)

Sine survey and sine vibration or sine burst

- **Sine survey test conditions**
  - Frequency range 10 - 500 Hz
  - Level 0.25 g
  - Duration 10 oct / min
  - Test in 3 orthogonal axes
- **Sine vibration test levels**

Frequency (Hz)	Acceleration
Thrust Axis	
5 – 12.5	0.50 in (double amplitude)
12.5 – 35	4.0 g
35 – 100	2.0 g
Lateral Axes	
5 – 11.0	0.50 in (double amplitude)
11.0 – 20	3.0 g
20 – 100	1.5 g

INTEGRATED SYSTEM PROTO-FLIGHT ACCEPTANCE TESTS (continued)

- **Sine burst test levels (may replace sine vibration test)**
  - <u>**Direction**</u> <u>**Test load**</u>
  - Thrust axis 15.5 g
  - Lateral axis 8.5 g

  (per discussions with APL)

Random vibration test

- **Random vibration test levels**

	Frequency (Hz)	Acceleration (g^2/Hz)
3 axes Test Duration 1.0 min / axis Overall Level 10.0 g rms	20	0.013
	20 – 50	+6.0 dB / oct
	50 – 800	0.080
	800 – 2000	-6.0 dB / oct
	2000	0.013

INTEGRATED SYSTEM
PROTO-FLIGHT ACCEPTANCE TESTS (continued)

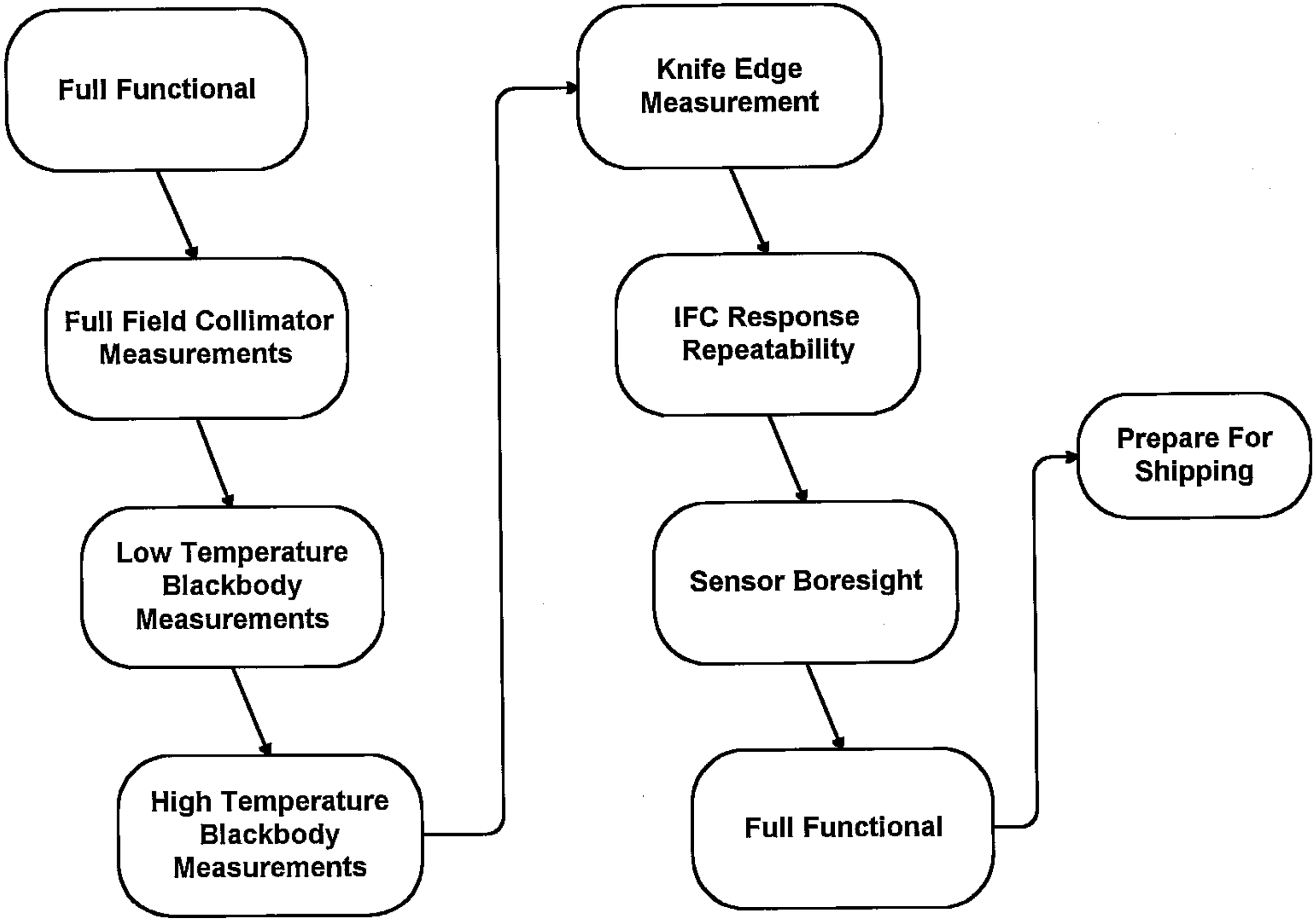
Cover deployment test

- Verify actual deployment of cover

Warm functional test, boresight measurement, and jitter test

- Repeat warm functional test
- Repeat boresight measurement
- Measure pointing jitter

CALIBRATION TEST FLOW



CALIBRATION

- **Precalibration full functional test**
- **Full field collimator measurements**
  - IFOV
  - Object space detector positions
  - Modulation transfer function (MTF)
  - Scatter from non-signal chopper holes
  - Temporal frequency response
  - Relative spectral response (RSR)
    - In-band RSR
    - Out-of-band RSR
  - Linearity (OH and O_2 channels - 8, 9, 10)

CALIBRATION (continued)

- **Low temperature blackbody measurements**
  - Linearity (CO_2, O_3, H_2O, and NO channels - 1-7)
  - IFC blackbody radiance
  - Off-axis extended source throughput correction
  - Noise equivalent radiance
  - Medium-term repeatability of sensor offset
  - Measurement of dynamic range (channels 1 - 7)
  - Verify gain mode normalization (channels 1 - 7)

CALIBRATION (continued)

- **High temperature blackbody measurements**
  - Determine radiance of Jones sources
  - Noise equivalent radiance (OH and O_2 channels - 8, 9, 10)
  - Verify linearity (OH channels - 8, 9)
  - Calibrate IFC Jones sources

- **Knife edge measurement**
  - Verify off-axis performance

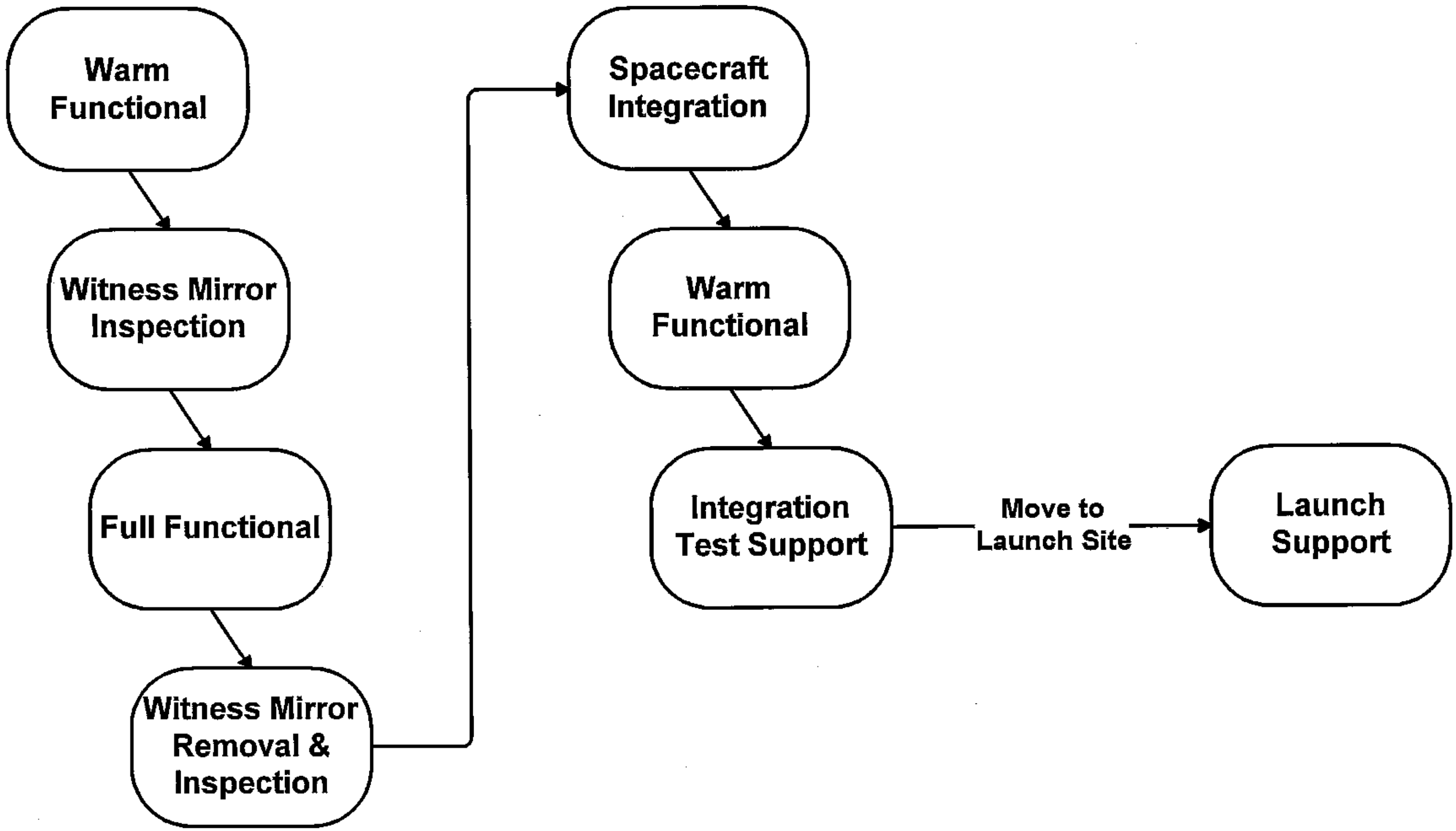
- **IFC response repeatability**

- **Sensor boresight**

- **Post-calibration full functional test**

- **Shipping preparation**
  - Install SABER instrument in chamber with shipping fixtures

SPACECRAFT INTEGRATION AND TEST FLOW



SPACECRAFT INTEGRATION AND TEST
LAUNCH SUPPORT

- **Spacecraft integration and test**
  - Warm functional test
  - Witness mirror inspection
  - Pre-spacecraft integration full functional test
  - Witness mirror removal and inspection
  - Post-spacecraft integration warm functional test
  - Post-spacecraft integration test support
    - Spacecraft tests as per APL's test schedule
    - A modified full functional test will be performed during the spacecraft thermal vacuum chamber test

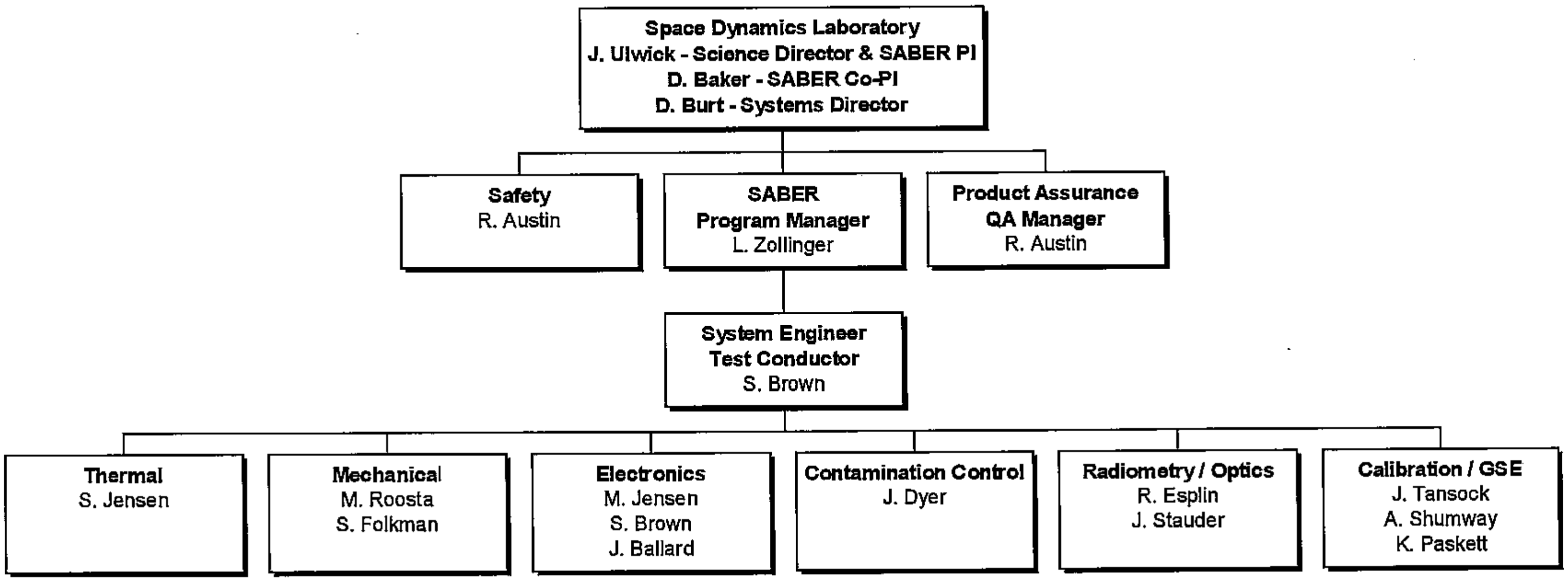
- **Launch support**
  - Tests as per APL's test schedule

TEST MATRIX

Legend:
X = Test Performed
A = Analysis
S = Subcontractor Performed Test
Bold = Proto-Flight Tests

Hardware Description	Test Program Description																																																					
	Functional Tests	Push/Pull Stress Tests	Load Carrying Ability tests	Vacuum Bakeout	Thermal Vacuum Cycle	Wave Front Tests	BRDF	Mass	Moments of Inertia	Center of Mass	Fit Check	Random Vibration	Sine Survey	Sine Burst or Spin Table	Kevlar Fiber Tests	Tension Measurement Calibration	Heat Load Test	Simulated Spacecraft housing Checkout	Spectral Reference Detector Test	Rotational Table Functional Test	Vacuum and/or Cryo Leak Check	Radiometric Cavity Cooling Test	Axis of Rotation Adjustment	Thermister calibration & drift tests	Outgas Tests	Mechanical / Optical Stability	PRT stabilization and calibration	Witness sample reflectance tests	In-situ verification	NIST Calibration Verification	Image quality / focus tests	Boresight / Alignment Tests	Jitter Tests	Stray Light Test	Thermal Checkout	Housekeeping Checkout	Refrigerator Temperature Setup	Scanner Checkout	Aperture Cover Deployment Tests	Thermal Vacuum Balance Test	IFC Source Checkout	Thermal Extremes Test	EMC/EMI Tests	Data Collection Checkout	Relative Spectral Response	Instrument Field of View Tests	Slit Source Response Test	Temporal Response Test	Linearity calibration	IFC Radiance Calibration and Tests	Knife Edge Test	Electrical Systems Checks	Electronic Gain Tests	Scan Motor / Encoder Transfer Function
Prototype Assemblies																																																						
Support Struts		X																																																					
Instrument Electronics	X							X	A	X	X																																					X				X	X	
Scan Motor/Encoder w/ electronics	X				S			S	A	A	X	S																					X			X					X		X	X								X		S
Scan Bearings			X					X					X	X																																								
Detector Assembly	S				S																																															X		
Focal Plane Support System (FIST)	X				X							X	X	X	X	X	X									X																												
Pulse Tube Refrigerator	X				X			X			X						X																																					
Focal Plane Assembly	X																																																			X		
Black Body Heater																									X																													
Chopper (TFR)	S							X			X																																									X		
Flight Components																																																						
Baseplate & Struts				X				X	A	A																																												
Mirrors						S	S	X	A	A																																												
Reimaging & Fore Optics subassemblies				X				X	A	A	X																				X	X																						
Chopper (TFR)	S			S				X	A	A	X																																									X		
Instrument Electronics	X			X	X			X	A	X	X	X	X	X																						X					X			X				X				X	X	
Integrated Telescope	X							X	A	A	X	X	X	X																	X	X	X	X																				
IFC Blackbody	X							X	A	A	X													X				X																								X		
Jones Sources	X							X			X																																									X		
Detector Subassembly	S			S	S			S				S	S	S																																								
Filter Subassembly	S			S	S			S				S	S	S																																								
Pulse Tube Refrigerator / RFE	S			S	S			S	A	A	X	S	S	S																																						X		
Scan Motor/Encoder	S			S	S			S	A	A	X	S	S	S																																						X		S
Cable Assemblies	X			X				X																																														
Fully Integrated Instrument	X				X																										X	X			X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X		
GSE																																																						
Test Chamber	X			X														X		X	X	X	X									X																				X		
GSE Software	X																																																					
High Temperature Blackbody	X			X																					X		X	X	X	X																						X		
Low Temperature Blackbody	X			X																							X																											
Full Field Collimator	X			X															X		X										X	X																				X		
GSE Electronics	X																																																			X		
Flip-in Parabolic Mirror																												X																										
Acceptance Testing and Calibration																																																						
Signal Processing Electronics																																																X					X	
Fully Integrated Instrument	X				X			X	A	X		X	X	X																		X	X						X	X			X	X	X	X	X	X	X	X	X	X		
Space Craft Integration and Test	X																																						X					X								X		
Launch Site	X																																																						

TEST ORGANIZATIONAL CHART



SABER INSTRUMENT CONTAMINATION CONTROL

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CONTAMINATION CONTROL
Optics Cleanliness Requirements

Updated Mirror Cleanliness Requirements:

- **Detailed stray light analyses indicate Level 100 requirement (on-orbit) for scan mirror, primary mirror, and secondary mirror**
- **Level 100 mirrors have been maintained during long-term development and ground testing at SDL/USU**
- **Maintaining Level 100 mirror cleanliness through launch will be a challenge**
- **Orientation of sensor relative to launch acceleration vector is somewhat favorable**
  - Scan mirror and secondary mirror are least susceptible to fallout
  - Primary and tertiary mirrors will be susceptible to fallout
  - Potential particulate generation in bearing assemblies will be entrained in directed vent out of bearing housings during launch depressurization
  - Molecular film deposition must be $\leq$ 100 nm per optic or < 500 nm total
  - Water cryodeposition on optics is not a concern at >200 K operating temperatures
  - Cryodeposition of organics on optics is not expected to be significant
    - Outgassing of Z306/9929 optical black will be reduced by vacuum bakeout process
    - Outgassing of GSE and IFC blackbodies has been quantitatively assessed
    - Return flux of organics from spacecraft at 625 km orbit is expected to be low

SABER CONTAMINATION CONTROL
Materials and Processes used in Optical Compartments

- **Nonmetallic materials satisfy NASA RP 1124: < 1% TML, < 0.1% CVCM**
- **Principal nonmetallic materials within optical compartments:**
  - Aeroglaze Z306 black polyurethane on 9929 epoxy primer
    - Painting, curing, vacuum-bakeout, and cleaning are process controlled
    - CO_2 jet spray effective in removal of loose paint overspray
  - Epibond 1210 A epoxy with Epibond 9615-10 hardener
    - Can be baked to 65 C to reduce outgassing
  - G-10 fiberglass support tubes (vacuum-baked after bonding)
  - Kapton and aluminized mylar tapes with Y-966 acrylic adhesive
  - FEP Teflon purge line (to FPA)
  - Double aluminized mylar
  - Dacron net
  - Tefzel-insulated wire with optional Halar cable sleeve and fluorocarbon ties or Dacron lacing (internal wiring materials will be vacuum-baked prior to installation)

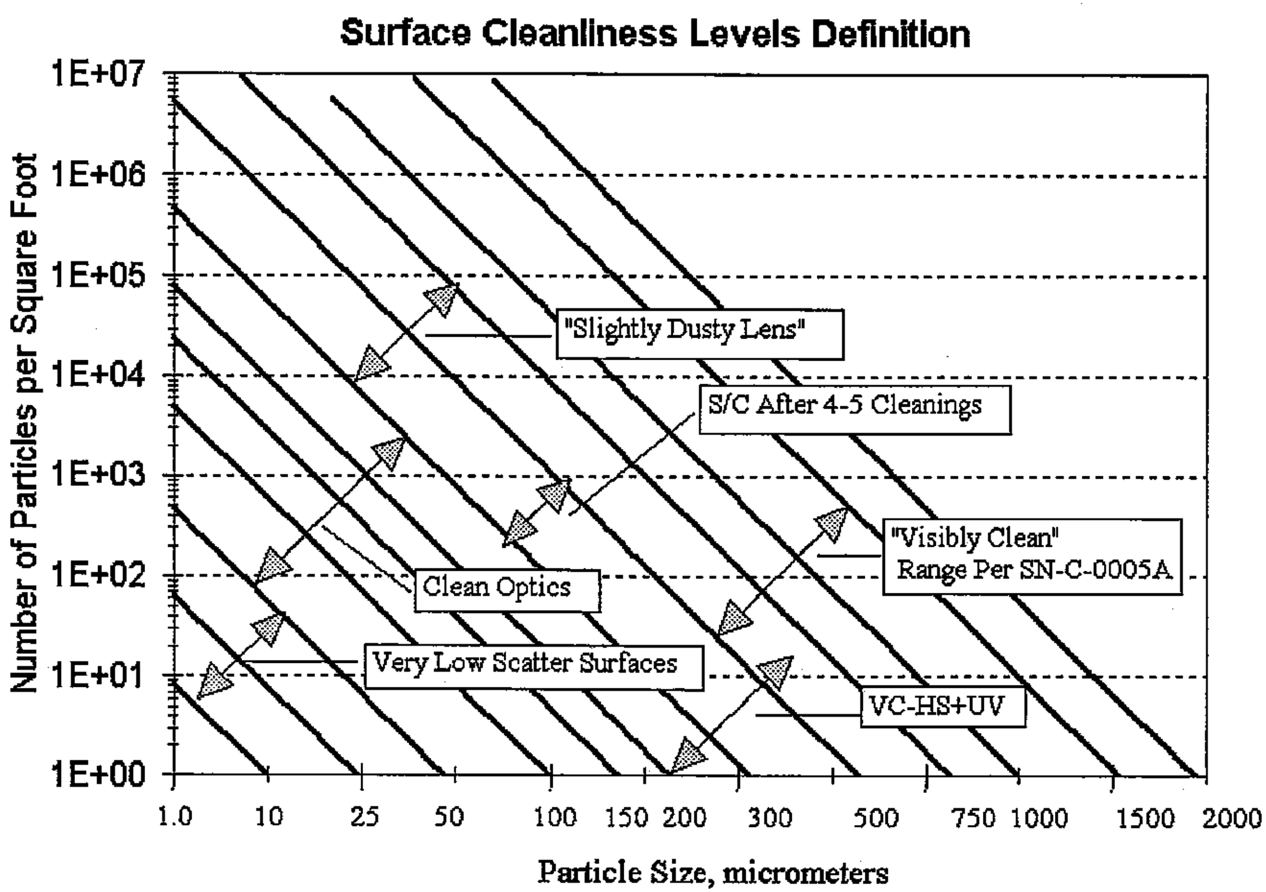
CONTAMINATION CONTROL
During Assembly and Alignment of Optics

- **Each optical assembly (reimager, foreoptics, scanner, detector) is assembled and aligned individually, then integrated and aligned with other optical subassemblies**
- **After initial alignment, subassemblies will be cleaned to flight standards and strict contamination control protocol employed**
- **Cleaning methods include wet cleaning, CO_2 jet spray, vacuum nozzle**
- **Cleanliness level verification methods:**
  - Witness mirrors and plates
    - BRDF
    - Particle counts
    - IR absorption
  - Tape lifts per MIL-STD-1246
  - NASA SN-C-0005 methods
    - White light inspection: Visibly Clean - Highly Sensitive "VC-HS"
    - White and black light inspection: "VC-HS+UV"
- **Filtered N_2 purge of assembled optics effective in maintaining clean optics and reducing absorption of atmospheric moisture or contaminant vapors**

SABER CONTAMINATION CONTROL
Plan for Assembly and Alignment of Optics

Operation	Machine Shop or Fabrication Area	Generally Clean Lab	Clean Tent or Clean Bench in Lab	Class 100 Cleanroom or Large Class 100 Tent
Rough machining	✔			
Stress relieve	✔			
Final machining, lapping, fit checks	✔			
Clean and paint	✔	✔		
Vacuum bake painted parts		✔		
Precision clean and CO_2 jet spray			✔	
Assemble w/ optics and/or alignment fixtures			✔	
Align using theodolites and coordinate mapping machine			✔	
Reclean optical components for flight			✔	✔
Final alignment of subassembly				✔
Integrate with other optical subassemblies				✔
Optical tests on system (e.g., image quality, boresight)				✔
Install or remove from GSE test chamber				✔

SABER CONTAMINATION CONTROL
MIL-STD-1246



SABER CONTAMINATION CONTROL
Final SDL/USU Surface Cleanliness Requirements

Instrument/ Subsystem	Location	Cleanliness Requirement MIL-STD-1246, NASA SN-C-0005	Final Verification Time and Method
Optics	Mirrors	Level 100 VC-HS+UV	Mirror BRDF prior to telescope assembly; witness mirror BRDF after integration and test; visible inspections
Optical compartments	Baffles, field stops, optically black surfaces	Level 200 VC-HS+UV	Preceding sensor assembly: tape lifts, visible inspection; solvent rinses with particle count Preceding integration onto spacecraft: visible inspection of baffle assembly
Focal plane assembly	Inside sealed detector assembly	Level 100 No particles > 20 μm	During assembly, prior to sealing: cleaning and verification performed under microscope

SABER CONTAMINATION CONTROL
Final SDL/USU Surface Cleanliness Requirements (continued)

Instrument/ Subsystem	Location	Cleanliness Requirement MIL-STD-1246, NASA SN-C-0005	Final Verification Time and Method
Refrigerator assembly	External surfaces	Level 300 VC-HS+UV	Preceding blanketing: particle counts by tape lift and visible inspection
Multilayer insulation	External to sensor optics	VC-HS	Visible inspection prior to installation
External support structure	External to sensor optics	Level 500 VC-HS+UV	Prior to integration with spacecraft: particle counts by tape lift, visible inspection
Aperture cover	Internal surface	Level 200 VC-HS+UV	At last opportunity to open cover in controlled environment: particle counts by tape lift, witness mirror inspections

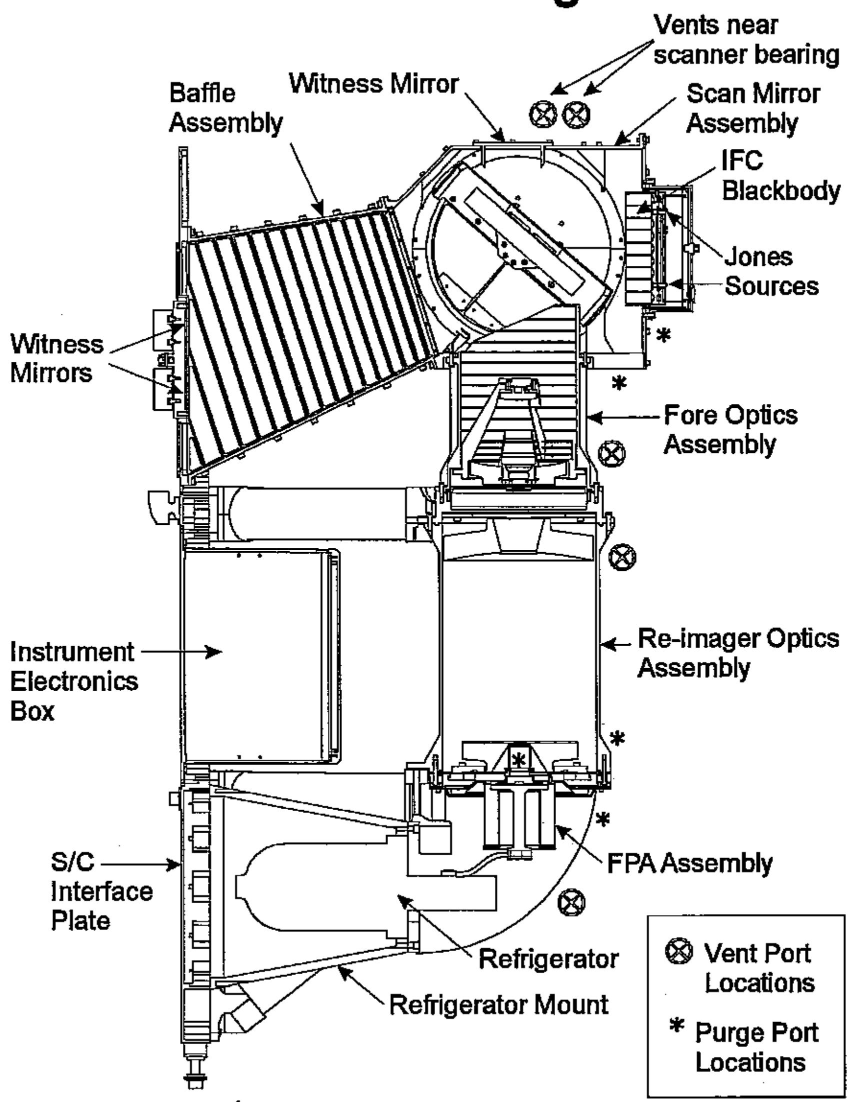
SABER CONTAMINATION CONTROL
Final SDL/USU Surface Cleanliness Requirements (continued)

Instrument/ Subsystem	Location	Cleanliness Requirement MIL-STD-1246, NASA SN-C-0005	Final Verification Time and Method
Aperture cover	Door release mechanism and external surfaces surrounding seal	Level 300 VC-HS+UV	At last opportunity to inspect/clean cover by SABER personnel prior to launch. Probable prelaunch degradation toward generic spacecraft Level 750 is tolerable but should be minimized
Radiators	Telescope and mounting plate radiators (SABER's external spacecraft panels)	VC-HS+UV	At last opportunity to inspect/clean by SABER personnel prior to launch
Electronics	Exterior surfaces within SABER compartment (outside optics)	Level 500 VC-HS+UV	Prior to integration with spacecraft: particle counts by tape lift, visible inspection

SABER CONTAMINATION CONTROL
Purge System

- **Nearly uninterrupted flow of LN_2 boil-off purge gas necessary**
  - Maintain detector stability
    - Detector no longer has a window that isolates it from sensor
    - Detector housing has dedicated 1/8" purge connection
    - Passivation studies indicate detector responsivity and stability are mostly restored after a week in high vacuum
  - Minimize moisture absorption and dust migration into optical compartments and MLI
- **Purge design changes since PDR**
  - Purged volume limited to optics and cold post compartments that are well-isolated from external MLI, electronics, and structure
  - Purge distributed into each compartment via 5 low-flow ports
  - Estimated gas exchange rate will be $\leq$ 4 min
- **Purge requirement**
  - 0.5 scfm 99.999% pure N_2 filtered to 0.5 μm
  - 4 psi delivery pressure at SABER connection to spacecraft
  - Minimum downtime (exact tolerance cannot be determined)

SABER CONTAMINATION CONTROL
Locations of Purge and Vent Ports



SABER CONTAMINATION CONTROL
Vent Design

- **New design has refrigerator/cold post compartment sealed to allow controlled venting**
  - Flexible “boot” made of *cepac 143* moisture barrier attaches to refrigerator mount and telescope extension
    - Puncture and tear-resistant 8 mil aluminized polyester and polyethylene film
    - Heat-sealed seam will not open during depressurization
    - Satisfies NASA outgassing requirement
  - Use of film reduces thermal short from refrigerator to telescope
- **Compartments connected to a single vent manifold via 3/8” OD tubulation**
  - Vent rate will adequately follow launch depressurization
  - Vent locations will control particulate redistribution during launch
    - Each bearing housing will have a vent port
    - Vent ports located on each side of chopper to minimize pressure differentials
    - Cold post compartment will vent separately from optics
- **Pressure relief valve implements APL-validated design used on MSX UVISI and Contamination Experiment instruments**

SABER CONTAMINATION CONTROL
Integration and Facility Requirements

- **Class 100 tent needed for removal of sensor from GSE test chamber, cover deployment tests, and final witness mirror removal**
- **External surfaces of aperture cover will be cleaned to Level 300 prior to integration with spacecraft**
  - Concerns related to accumulation of dust near cover seal that may redistribute during cover deployment
  - SABER cover and cold radiator should be protected by local bagging whenever possible during integration, test, and tower operations
  - Spacecraft integration in Class 10,000 operational environment should allow maintenance of general Level 750 spacecraft ground cleanliness requirement
- **Lessons learned from MSX**
  - ESD control using spacecraft air ionizers should be used as much as possible to minimize cling of particulates to spacecraft
  - Strong interaction with launch team and launch facility necessary to avoid pitfalls
    - Overhead cranes and fairing installation can be a significant contamination source
    - Contamination control procedures necessary to maintain clean white room, and HEPA-filtered air into fairing should be identified

Data Processing Software Development Plan

Larry Gordley

SABER Software Critical Design Review, Logan, Utah 10/97

SABER Software Development Overview

Organization

Software Reuse

Support Staff & Experience

Communication

Responsibilities

	Primary	Secondary
Instrument Build	SDL	LaRC
Test/Calibration	SDL	LaRC
GSE Software	SDL	
I & T	SDL	LaRC/GATS
Calibration Data Analysis	GATS	SDL
Operational Data Processing (Level 0 - 3)	GATS	Science Tea
Payload Operation Control (POC)	GATS	Science Tea
Inversion Algorithm Development	Science team	GATS

GATS ORGANIZATION

SABER
PI - HU - James M. Russell III
Associate PI - LaRC - Martin G. Mlynczak
Project Manager - LaRC - James B. Miller

GATS, Inc.

SABER Software Project Manager
Larry Gordley

Chief Engineer
Mike Cisewski

Software QA Manager
Earl Thompson
0.1 FTE

Software System Engineer
Jim Craft 1.0 FTE

Levels 0 to 1A
POC development
Mission Operations
System Management
Validation

Data Manager
TBD* 1.0 FTE

Web Set-up
Data Base Management
Rendering and Statistical Tools
Correlative Data Management System

Science Data Analyst
Chris Mertens 1.0 FTE

Levels 1A to 3
Forward Models
Retrieval System
Validation
Gridding

Instrument Performance Engineer
Guy Beaver 1.0 FTE

Test Support
Calibration
Level 1b Software
Validation

Software QA / Testing
Configuration Management

* Will be matrixed.
FTE Full Time Equivalent

SABER Software Critical Design Review, Logan, Utah 10/97

SABER / SDL Team Organization

- **Space Dynamics Laboratory**
  J. Ulwick - Science Director & SABER PI
  D. Baker - SABER Co-I
  D. Burt - SABER Co-I
  - **SABER Program Manager**
    L. Zollinger
    - **Safety**
      R. Austin
    - **Product Assurance**
      QA Manager
      R. Austin
    - **System Engineer**
      S. Brown
    - **CSSR**
      Cost Schedule Analyst
      J. Sites
    - **Thermal Design & Analysis**
      C.Batty
      S. Jensen
      - **Refrigerator** (Subcontractor) TRW
    - **Mechanical Design & Analysis**
      S. Folkman
      M. Roosta
      - **EMI Testing** (Subcontractor) NTS
    - **Electronics**
      M. Jensen
      S. Brown
      J. Ballard
      - **Scanner Motor/Encoder** (Subcontractor) BEI
    - **Mechanical Design**
      D.McLain
      P.Brunson
      - **Detector Array** (Subcontractor) EG&G
      - **Mirrors** (Subcontractor) SSG
    - **Radiometry/Optics**
      B. Esplin
      J. Stauder
    - **Calibration/GSE**
      J. Tansock
      A. Shumway
      K. Pickett
      - **Optical Filters** (Subcontractor) OCLI
      - **Chopper** (Subcontractor) TFR Laboratories

SABER Software Critical Design Review, Logan, Utah 10/97

Software Reuse

- **Major systems ready for reuse**
  - POC (software)
  - Level 1a-Level 2a
  - Graphical analysis
  - Science data manager
  - Web systems
  - Correlative data manager

- **Experts (outside the SABER project) on all systems are available for consulting and porting**

Software Systems for Reuse

LIMS level 0 to level 2 processing

- From current LIMS reprocessing effort - operational
- Nearly identical to SABER 1a to level 2a.
- Major tasks will be changing rates, calibration files, channel details, forward model tables and spacecraft motion correction

SAGE III & HALOE Mission Ops Software

- Trending
- Playback
- Level 0 to Level la tool kit
- Packet ingest and decom

Software Systems for Reuse Cont'd

HALOE Web Site System

- Data Management
  - Instrument and Correlative
- Document Management
- Code Access
- Project information
- Image generation and management

Quality Management Tools

- CVS and extraction tools

Software Systems for Reuse Cont'd

Data Analysis and Rendering Tools

- STONEWARE
  - Profiler Graphics and Statistics
- Correlative Data Manager
  - Correlative data ingest, statistical comparison and rendering
- Data browse and selection

Forward Model Packages - GATS proprietary

- LINEPAK & BANDPAK - JQSRT 1994
  - Licensed in 6 countries
  - Used on LIMS, HALOE, CLAES, ISAMS (Table generation), CRISTA
  - Used for SABER filter specifications and scene radiance simulation
  - Rigorous and robust
    - Detailed ray trace over oblate earth in inhomogeneous asymmetric atmospheres

Key Staff Available for Consulting

Mike Cisewski

SAGE III and HALOE Mission Ops lead (POC software)

Earl Thompson

QA lead, former HALOE level 2 lead and now LIMS reprocessing lead (Level 1 & code)

Ken Stone

HALOE data analysis tool kit development (STONEWARE)

Orbital Mechanics

Tom Marshall

Forward Model and Retrieval specialist (LINEPAK & BANDPAK)

John Burton

PhD In Computer Science and GATS internet systems specialist (Web Site)

Risk / Mitigation

Risk

- Small Staff And Loss Of Staff (already experienced)
- Coordination/Communication (i.e. APL, LaRC, SDL, Science Team, GATS, SAIC)

Mitigation

- Reuse Software
- Solid Matrix Of Support
- Close Interaction With Developer
- Lost staff replaced with more experienced proven performers
- Online Information For Project Management (web sites)
- QA Designed To Be By-Product Of MO, Not Additional Tasks

Quality Assurance

Earl Thompson
Larry Gordley

SABER Quality Assurance

SABER Software Quality Assurance will be managed by:

- NASA LaRC OSEMA / Hernandez Engineering under guidelines specified in the:

- Quality Assurance Plan for the SABER Project, NAS1-20469

GATS will support Software Quality Assurance activities using a subset of the above plan:

- GATS Quality Assurance Plan for SABER Payload Operations, Ground Support and Science Data Processing

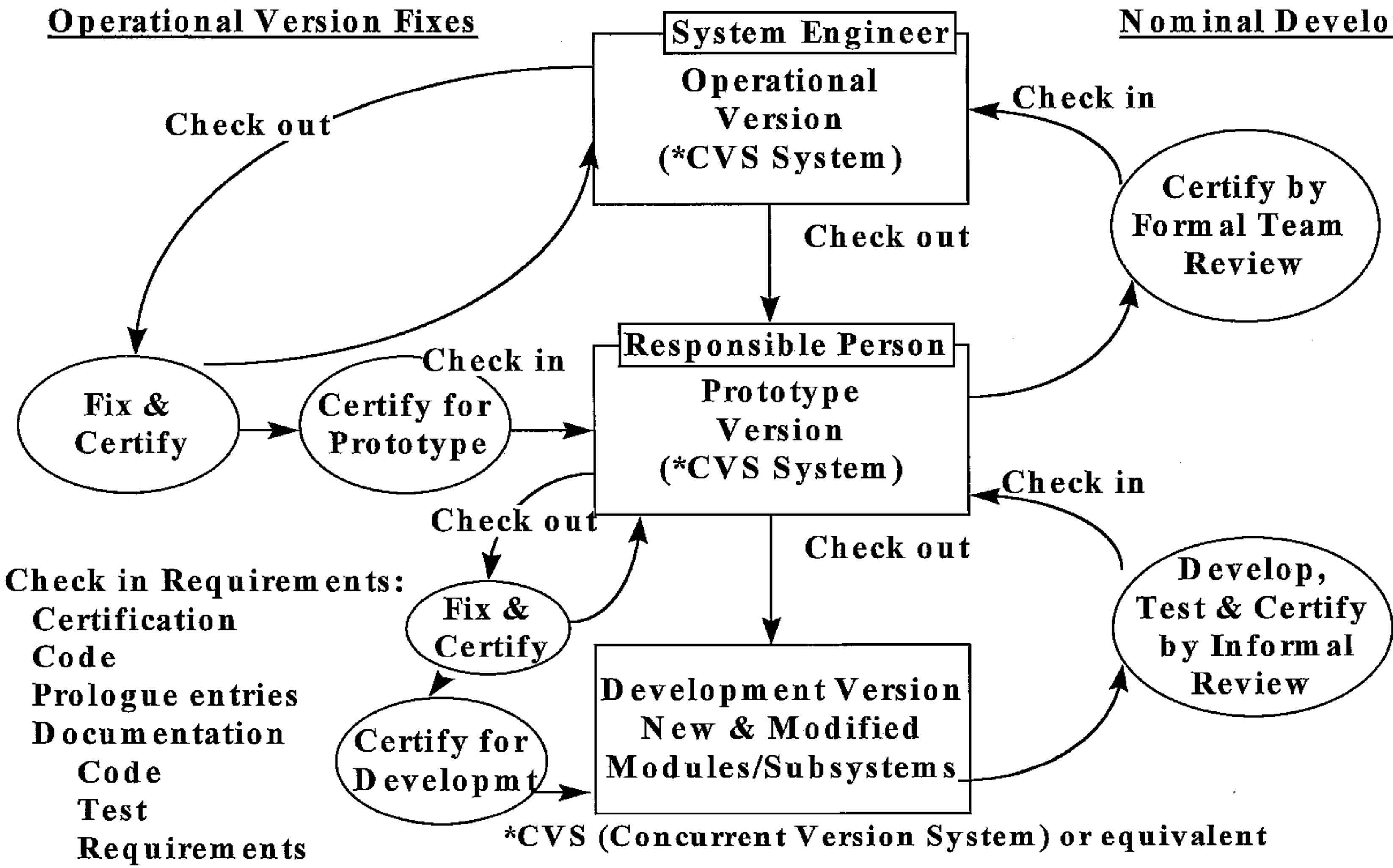
DOCUMENT STATUS

Software Development Plan
Second Draft

Software Quality Assurance Plan
updated and finished

SABER Quality Assurance

GATS Software Configuration Management Plan



SABER Software Critical Design Review, Logan, Utah 10/97

SOFTWARE PRACTICES

- GATS Prologue Extractor used for reports and traceability
- Requirements Reviews, Tests and Mods Documented in Prologue
  - forced at check-in by version control tools.
- Code and Documents under Configuration Management
- Coding Standard
  - modular
  - extensive comments
  - object oriented at system level
- Testing
  - documented
  - traceable

SOFTWARE PRACTICES CONT'D

- Documentation
  - online links to all pertinent information
- Everything on web site

CVS Software Header Example

```
C Modification History:
C
C $Log: main.f,v $
C  Revision 2.2  1994/07/08  17:52:23  jcburt
C   TEST,REVIEW - Completed final code testing & acceptance review
C          BTM & LLG Reviewing
C          Test procedure available in /home/jcburt/doc/codetest.doc
C          Results available in /home/jcburt/doc/results.doc
C
C  Revision 2.1.1.2  1994/07/01  18:48:27  jcburt
C   PROGRESS - Completed construction of final test suite. Debugging of
C            the test suite code is currently in progress
C
C  Revision 2.1.1.2  1994/06/28  18:48:27  jcburt
C   BUG FIX - Off by one error in array indexing for RAD1
C
C  Revision 2.1.1.1  1994/05/18  11:45:17  jcburt
C   CHANGE - Revised the algorithm for radiance matching to use the
C          slope of the log of the radiance
C
C  Revision 2.1.0.1  1994/04/08  08:08:00  jcburt
C   CERTIFICATION - PDR accepted design - BTM & LLG reviewing
C
C  Revision 2.1.0.1  1994/04/07  09:00:00  jcburt
C   REVIEW - PDR - BTM & LLG reviewing
C
C  Revision 2.1.0.1  1994/04/05  16:00:00  jcburt
C   REQUIREMENTS - This module required to serve as a CVS example
C
C-----------------------------------------------------------------
C
        SUBROUTINE Dummy(x,y,z)
C-----------------------------------------------------------------
```

SOFTWARE MANAGEMENT PRACTICES

- Risk Analysis
- Requirements Specified And Documented
- Monthly Status/Schedule Updates
- Code/Document Reviews at prototype and operational levels
- Test Result Reviews at prototype and operational levels
- Audits at prototype level

Payload Operations Center (POC) Software Development

Jim Craft
GATS, Inc

POC Introduction

What are the SABER POC's responsibilities? The POC is responsible for issuing the commands required to move the SABER instrument between operational states, and for extracting telemetry needed for both scientific results of the experiment and the instruments health and performance.

The SABER POC software is planned to be developed and operated from the following platform, peripherals and S/W utilities:

- **Intel 200 MHz Pentium Pro microprocessor**
  - **128 MB RAM**
  - **2GB hard drive storage**
- **21" monitor**
- **10/100 baseT, PCI, UTP, Ethernet Card**
- **Windows NT operating system**
- **Microsoft Visual C++ V5.0 or higher compiler**
- **IDL V5.0 or higher data analysis and visualization S/W**
- **Winsock network communication routines**
- **PGP Encryption Software**

POC Introduction and Overview

A Day in the Life of the SABER POC

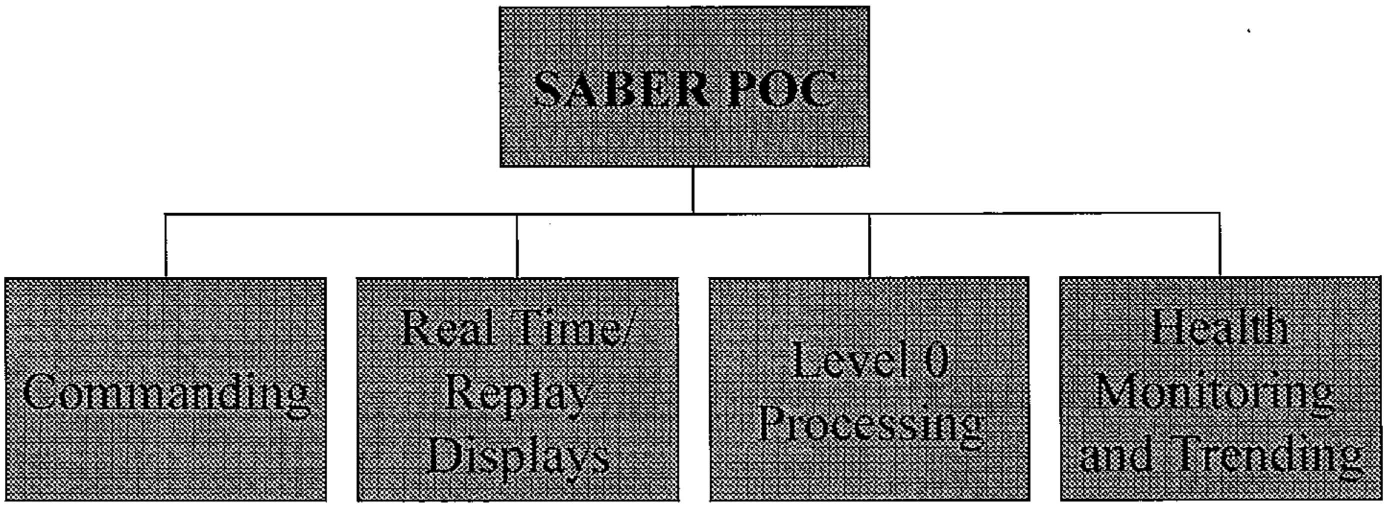
- **Review TIMED Contact Plans (Monthly/Weekly)**
- **Review TIMED Predicted Orbits (8 weeks advanced)**
- **Review SABER Planned Timeline (8 weeks advanced)**
- **Generate Commanding based on above Plans**
- **FTP Encrypted CMF to TIMED MOC (min. 4 hours before contact)**
- **Receive and process Authentication Return Receipt**
- **Monitor telemetry during contact**
- **Receive and process Command Return Receipt**
- **Ingest new SABER events into Planned Timeline**
- **FTP Planned Timeline to TIMED MOC**

A Day in the Life of the SABER POC

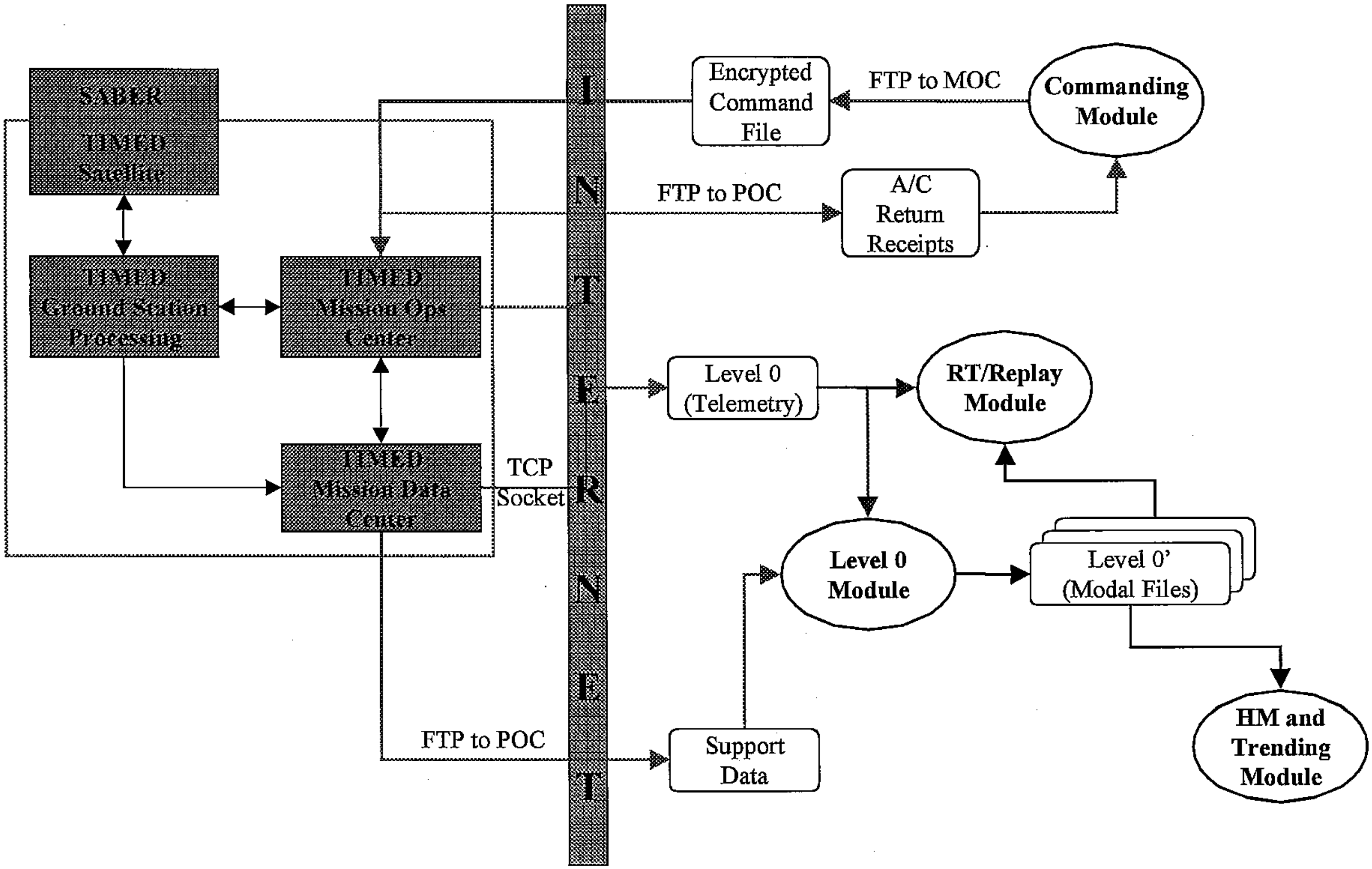
- Download the following previous day's file:
  - Dump Telemetry
  - Orbit Number File
  - NMC Support Data File
  - S/C Ephemeris Data File
  - Current Good Telemetry File
  - Current Bad Telemetry File
  - Actual Daily Contact File
- Process previous day's Level 0 and 0' modal data
- Process Health Monitoring and Trending for previous day
- Generate and FTP As-Flown Timeline to TIMED MOC

POC Overview

The POC consists of 4 basic modules: Commanding, Real Time/Replay Telemetry Displays, Level 0 Processing, and Health Monitoring and Trending.



POC Overview



Major File Types Operated on or Generated by the POC

- **Level 0** This is the telemetry provided in either stream or file format from the Mission Data Center. Only AP Id's that pertain to SABER will be provided by the MDC. The telemetry will be in either CCSDS Packets or Supplemented CCSDS Packets.

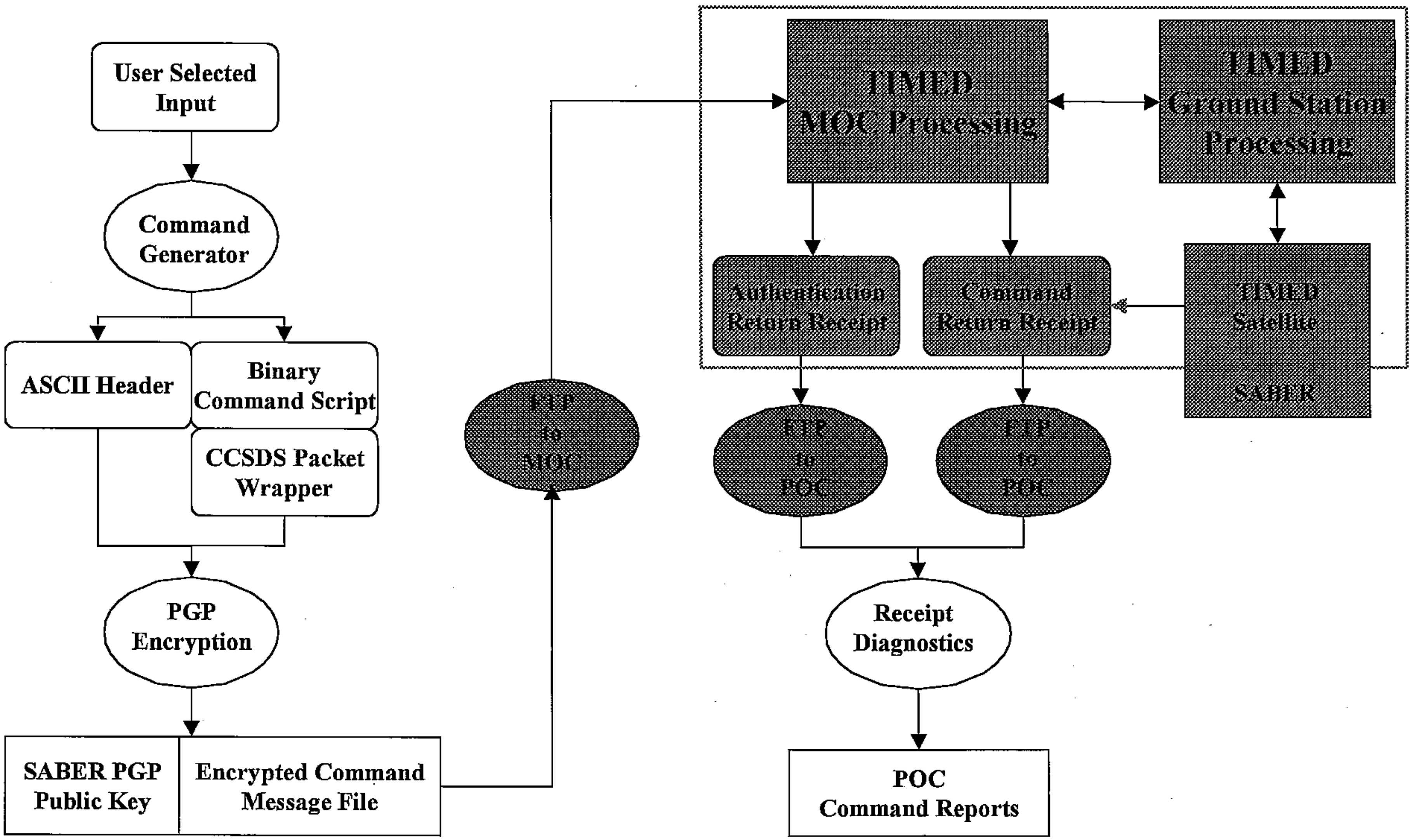
- **Level 0'** This data format is Level 0 data that has been sorted by AP Id's and ordered in time. The CCSDS header has been removed. The data is still in counts at this level. In generating this level a status file containing time gap annotations and data quality is created for later use in higher level processing. Other files generated at this level are called MODAL files pertaining to the instruments MODE. There will be one modal file created for each AP Id. Each modal file contains one days telemetry.

POC Command Module Requirements

SABER POC Command Module will have the following requirements:

- **Generate CCSDS Telecommand Packet**
- **Generate ASCII Command Header**
- **PGP Encryption**
- **Delivery of Encrypted CMF to TIMED MOC via FTP**
- **Receive and Verify Authentication Return Receipt**
- **Receive and Verify Command Return Receipt**

POC Commanding Module

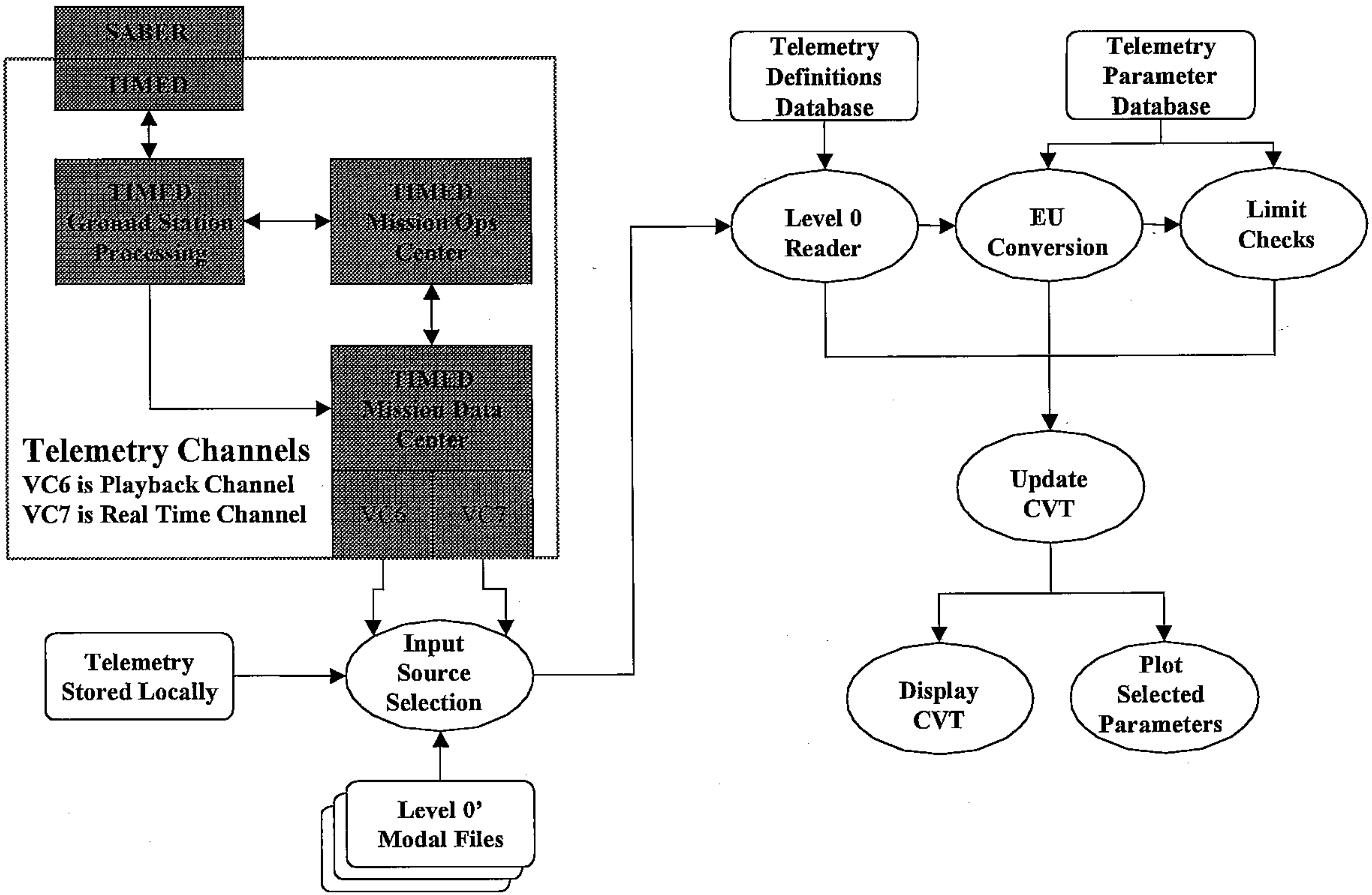


POC Replay/Real Time Module Requirements

SABER POC real time and replay data monitoring displays will have the following requirements:

- **Receive Real Time Telemetry via TCP/IP Sockets**
- **Receive Playback Dump Telemetry via TCP/IP Sockets**
- **Open and Read Local Telemetry File**
- **CCSDS Packet Format Read and Unpack**
  - **Packet number or time seeking capability**
  - **Single step or continuous play modes**
  - **Setting of step size and direction**
  - **Marking of start and end packets**
- **Current Value Table Display**
- **Time history plotting capabilities**

POC Replay/Real Time Module

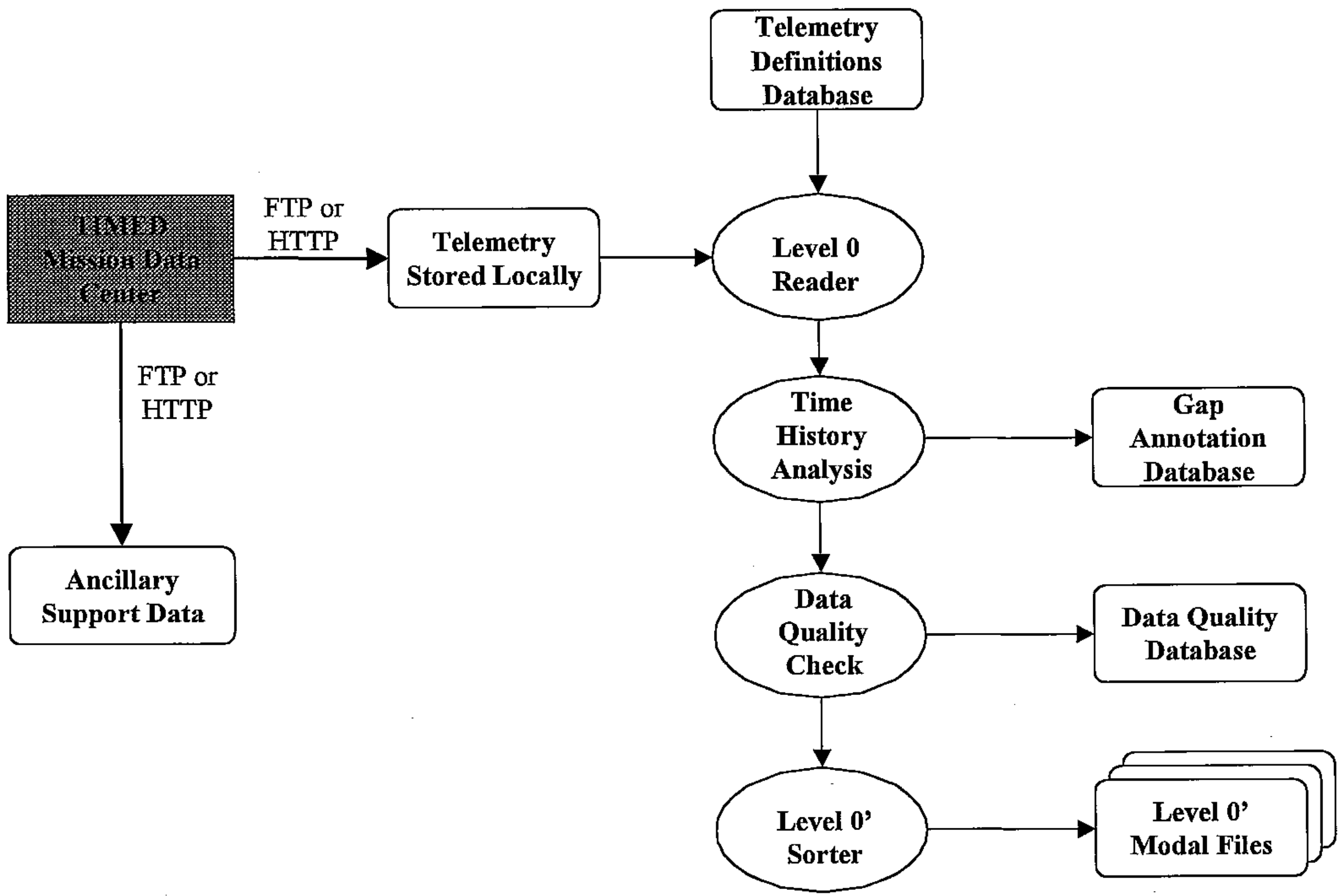


POC Level 0 Module Requirements

SABER POC level 0 processing software will have the following requirements:

- **HTTP/FTP File Transfer Capabilities**
- **CCSDS Packet Format Read and Unpack**
- **Level 0' Data and 0' Modal File Generation and Storage**
- **Data Quality Check**
- **Gap Annotation**

POC Level 0 Module



POC Level 0 Module

Level 0' Modal Files are telemetry separated by AP Id and packet type. The following are expected:

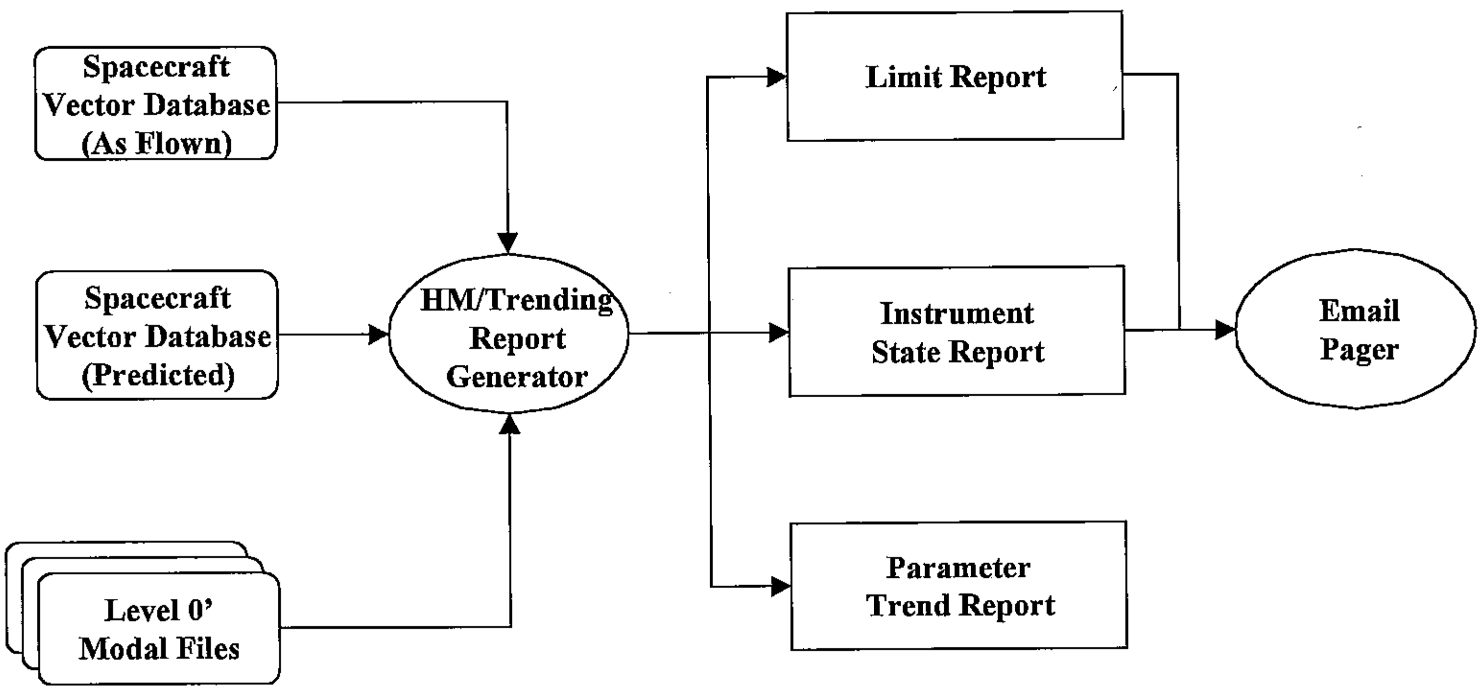
- **Scan Data**
- **Calibration Data**
- **Housekeeping Data**
- **S/C Data**
- **Data Quality and Gap Annotations**
- **GSE Data (which can be further subdivided)**
  - **Test Chamber**
  - **Full Field Collimator**
  - **Blackbody**
  - **Other GSE**
- **Special Scans or Calibrations**

POC Health Monitoring/Trending Module Requirements

SABER POC instrument health monitoring and trending software will have the following requirements:

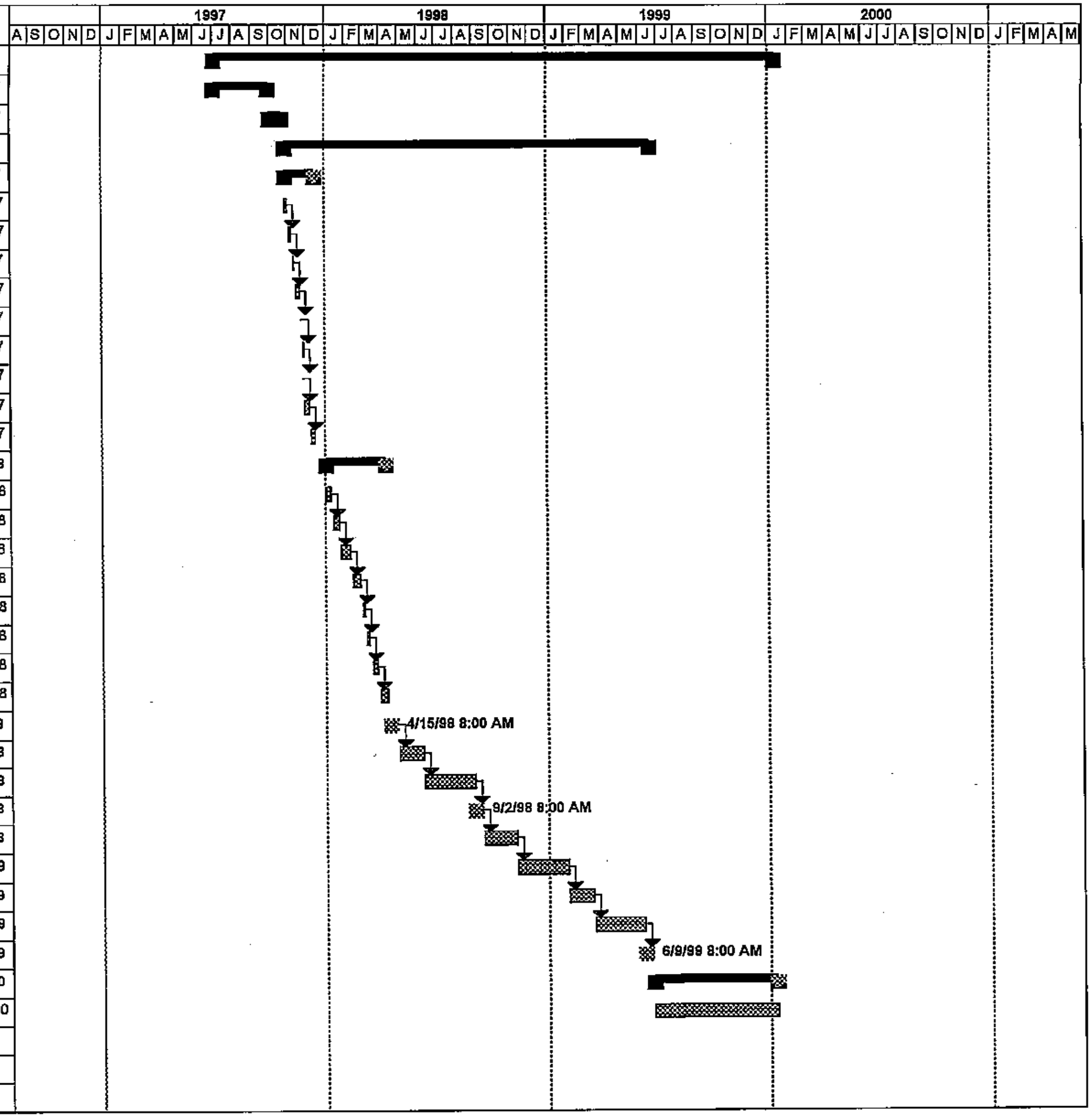
- **Read Level 0' Modal Files**
- **Variable sorting and plotting capabilities**
- **Instrument parameter trending identification**
- **Data anomaly identification**
- **Multivariable analysis capabilities**

POC Health Monitoring/Trending Module



POC Software Development Schedule

ID	Task Name	Start	Finish
1	**1.2 POC Software Development**	Tue 7/1/97	Tue 1/11/00
2	**1.2.1 Software Design**	Tue 7/1/97	Wed 10/1/97
7	**1.2.2 Critical Design Review**	Thu 10/2/97	Thu 10/23/97
10	**1.2.3 Write Software**	Mon 10/27/97	Tue 6/22/99
11	**1.2.3.1 Phase I - POC Commanding Module**	Mon 10/27/97	Mon 12/15/97
12	Macro Command Database	Mon 10/27/97	Fri 10/31/97
13	Binary Command Group	Mon 11/3/97	Fri 11/7/97
14	ASCII Command Description	Mon 11/10/97	Wed 11/12/97
15	CCSDS Telecommand Packet	Thu 11/13/97	Fri 11/21/97
16	Command Message File	Mon 11/24/97	Tue 11/25/97
17	PGP Encryption of CMF	Wed 11/26/97	Wed 11/26/97
18	FTP Delivery of Command Packet	Thu 11/27/97	Thu 11/27/97
19	ARR Verification/Reporting	Fri 11/28/97	Fri 12/5/97
20	CRR Verification/Reporting	Mon 12/8/97	Mon 12/15/97
21	**1.2.3.2 Phase I - POC RT/Replay**	Thu 1/1/98	Fri 4/10/98
22	Develop Telemetry Definitions Database	Thu 1/1/98	Fri 1/9/98
23	Develop Telemetry Parameter Database	Mon 1/12/98	Fri 1/23/98
24	Develop Simulated Data	Mon 1/26/98	Wed 2/11/98
25	Level 0 Reader	Thu 2/12/98	Fri 2/27/98
26	Engineering Unit Conversion	Mon 3/2/98	Fri 3/6/98
27	Limit Checks	Mon 3/9/98	Fri 3/13/98
28	Update CVT	Mon 3/16/98	Fri 3/27/98
29	CVT Display	Mon 3/30/98	Fri 4/10/98
30	**1.2.3.3 Initial POC Interface Test**	Wed 4/15/98	Tue 4/28/98
31	**1.2.3.4 Phase I - POC HM and Trending**	Wed 4/29/98	Tue 6/9/98
32	**1.2.3.5 Phase I - Level 0 Module**	Wed 6/10/98	Tue 9/1/98
33	**1.2.3.6 Phase I - POC Test**	Wed 9/2/98	Tue 9/15/98
34	**1.2.3.7 Phase II - POC Commanding Module**	Wed 9/16/98	Tue 11/10/98
35	**1.2.3.8 Phase II - POC RT/Replay Module**	Wed 11/11/98	Tue 2/2/99
36	**1.2.3.9 Phase II - HM and Trending**	Wed 2/3/99	Tue 3/16/99
37	**1.2.3.10 Phase II - Level 0 Module**	Wed 3/17/99	Tue 6/8/99
38	**1.2.3.11 Phase II - POC Test**	Wed 6/9/99	Tue 6/22/99
39	**1.2.4 Test / Maintain Software**	Wed 6/23/99	Tue 1/11/00
40	Maintain Software	Wed 6/23/99	Tue 1/11/00
41			
42			
43			



ALGORITHM DEVELOPMENT AND DATA PRODUCTS FOR THE *SABER* EXPERIMENT

MARTY MLYNCZAK
NASA LANGLEY RESEARCH CENTER

JIM RUSSELL
HAMPTON UNIVERSITY

&

The SABER Science Team

SABER CRITICAL DESIGN REVIEW

October 20-22, 1997
LOGAN, UTAH

OUTLINE

Review SABER data products

Algorithm development since PDR (12/96)

- Brief review of radiative transfer calculation in non-LTE environment
- Summarize Algorithm Meeting in Granada, Spain 9/97
- Summarize studies of kinetics/spectroscopy requirements

Algorithm Status

Summary

SABER ALGORITHM STATUS

Significant progress since SABER PDR (12/96)

Majority of Routine data products have prototype algorithms in place
Several Analysis products have prototype algorithms in place

- Developed and Tested Prototype Retrieval Algorithms for:
  Ozone 9.6 μm
  Atomic hydrogen [H]
  Solar heating (Hartley Band, Schumann-Runge Continuum)[1]
  Chemical Heating due to reaction of [H] and [O_3]

[1] Fundamentally new approach -- more accurate than conventional approaches

- Developed Conceptual Approaches for
  Kinetic Temperature Retrieval (T_K)
  Water Vapor Retrieval (H_2O)

- Conducted METEORS Rocket Flight, August 1997, from White Sands
  METEORS made several measurements which SABER/TIMED will make
  O_3 (9.6 μm), $O_2(^1\Delta)$, $O_2(^1\Sigma)$ for evaluating ozone abundance from non-LTE radiation
  Data analysis presently underway

SABER ALGORITHM STATUS

Kinetics and Spectroscopy

- Defined Kinetics and Spectroscopy Needs:
  - Ozone (9.6 μm retrieval)
  - Chemical Heating
  - Study underway for H2O non-LTE

Conducted special session of AGU (12/96) on kinetics/spectroscopy needs
    Several SABER-related papers presented

Considering a second special AGU session on mesospheric chemical kinetics for
    Spring AGU 1998 or perhaps Fall AGU 1998.

At least 3 kinetics proposals submitted to NSF or NASA since PDR

Submitted 2 publications on SABER needs to GRL, 3rd in preparation

Thus, the "plan" is working --
- State our needs through formal publication in refereed literature
- Tie them to an upcoming spaceflight program
- Lab community senses funding opportunity and proposes

SABER ALGORITHM STATUS

Routine Products:

Product	Conceptual Approach	Prototype Software	Operational Software	Kinetics Needs/ Error Analysis
T_K	yes	no	no	underway soon
O_3 (9.6 μm)	yes	yes[a]	no	yes (*GRL*)
O_3(1.27 μm)	yes	yes	no	yes (*GRL*)
H_2O	yes	no	no	underway
Vol. Em. Rates				
NO	yes	yes	no	yes (Laboratory)
OH(1.6 μm)	yes	yes	no	yes (*GRL*)
OH(2.0 μm)	yes	yes	no	yes (*GRL*)
$O_2(^1\Delta)$	yes	yes	no	yes (*GRL*)

Notes:

a) Prototype software for weak-line radiative transfer regime, z > 70 km only

(*GRL*) means publication in Geophysical Research Letters of requirements

(Laboratory) implies new laboratory measurements recently reported

SABER ALGORITHM STATUS

Analysis Products:

Product	Conceptual Approach	Prototype Software	Operational Software	Kinetics Needs/ Error Analysis
Minor species				
CO_2	yes	yes	no	underway
O	yes	no	no	no
H	yes	yes	no	yes
Cooling rates				
CO_2 (15 μm)	yes	yes	no	underway
O_3(9.6 μm)	yes	yes	no	underway
NO (5.3 μm)	yes	no	no	(Laboratory)
H_2O(6.7, far-ir)	yes	yes	no	underway
Solar Heating				
O_3	yes	yes	no	yes
O_2	yes	yes	no	yes
CO_2	yes	yes	no	yes

SABER ALGORITHM STATUS

Analysis Products:

Product	Conceptual Approach	Prototype Software	Operational Software	Kinetics Needs/ Error Analysis
Chemical Heating				
$H + O_3$	yes	yes	no	yes
$O + O + M$	yes	no	no	no
$O + O_2 + M$	yes	no	no	yes
$O + OH$	yes	no	no	yes
$H + O_2$	yes	no	no	N.A.
$O + O_3$	yes	no	no	N.A.
$OH + O_2$	yes	no	no	N.A.

Note:
Prototype software for some chemical heating reactions is only a few lines of code once the reactants are known -- e.g., once [H] is derived then heating due to reaction of H and O_2 is very simple to calculate.

SABER ALGORITHM STATUS

SABER-Related Bibliography since PDR (12/96)

<u>Science:</u>

Mlynczak, M.G., Energetics of the mesosphere and lower thermosphere and the SABER Experiment, *Adv. Space. Res.*, in press, 1997

Mlynczak, M. G., C. Mertens, R. R. Garcia, S. Solomon, and R. Portmann, A detailed evaluation of radiative heating, cooling, and diabatic circulations in the stratosphere, *J. Geophys. Res.,* in preparation, 1997.

<u>Kinetics needs:</u>

Mlynczak, M. G., and D.K. Zhou, Kinetic and spectroscopic requirements for the measurement of ozone at 9.6 μm under non-LTE conditions, *Geophys. Res. Lett.*, submitted, 1997.

Mlynczak, M.G., D.K. Zhou, and S.M. Adler-Golden, Kinetic and spectroscopic requirements for the inference of chemical heating rates and atomic hydrogen densities from OH Meinel band measurements, *Geophys. Res. Lett.*, submitted, 1997.

SABER ALGORITHM STATUS

SABER-Related Bibliography since PDR (12/96)

Algorithms/Radiative Transfer Calculation

Zhou, D. K., M. G. Mlynczak, G.E. Bingham, J. O. Wise, and R. M. Nadile, CIRRIS-1A limb spectral measurements of mesospheric 9.6 μm airglow and ozone, *Geophys. Res. Lett.*, submitted, 1997.

Mertens, C., M. G. Mlynczak, B. T. Marshall, and L. Gordley, Application of the emissivity growth approximation to radiative heating and cooling rate computation, *JQSRT*, in preparation, 1997.

Mlynczak, M. G., Retrieval of mesospheric solar and chemical heating rates from airglow measurements, *JQSRT*, in preparation, 1997.

SABER ALGORITHM SUMMARY

Prototype algorithms developed for all but temperature and water vapor

Kinetics and spectroscopy requirements studies to be completed by 12/97

Operational software development now underway

Goals:

Prototype algorithms for all routine products by ~ June, 1998

Operational algorithms in place as soon as possible

Remaining Concerns:

Temperature and water vapor:

Highly non-LTE emissions, in strong-line radiative transfer regime for limb viewing

No prototype algorithms as of yet -- Good conceptual approaches developed

Kinetic/spectroscopic sensitivity studies underway

Temperature and water vapor are now the focus of algorithm development

SABER INSTRUMENT PRODUCT ASSURANCE

Richard Austin

22 October 1997

Phone: (435) 797-4183
Fax: (435) 797-4475
E-Mail: richard.austin@sdl.usu.edu

PRODUCT ASSURANCE

- **Scope**

  SDL's product assurance activities are defined in the SABER Product Assurance Plan (SDL/94-088) which was developed in compliance to the requirements of DRD 12, Assurance Management Plan, and DRD 14, Configuration Management Plan

- **Overview**

  This presentation will show a summary and status of the product assurance activities that have been and will be performed by SDL

SABER PRODUCT ASSURANCE AUDIT AT SDL

- **LaRC and APL performed an audit at SDL on 17 April 1997**

- **Recommendations resulting from audit**
  - Commendation for receiving clerk
  - Separate flight and non-flight hardware storage
  - Ad hoc inspection personnel to be issued different QA stamp
  - Failure-type nonconformances are to be noted on DR. Failure analysis to be performed on failures
  - Publish list of SABER MRB members in MRB log book
  - Establish independent SDL internet connection to GIDEP
  - ECOs to be incorporated and revised drawings to be released prior to inspection (as opposed to using redline drawings)
  - Complete calibration procedure for flagging overdue test equipment

- **All recommendations have been addressed and corrected; LaRC verified the completion of these recommendations in a follow-up audit on 29 July 1997**

SUBCONTRACTOR CONTROL

- Subcontractor product assurance activities are summarized in the SABER Product Assurance Matrix for SDL Subcontractors
- Periodic audits of subcontractors will be performed by LaRC (or its government quality assurance representative) and SDL
- LaRC (or its government quality assurance representative) will perform source inspection at subcontractors

SABER Product Assurance Matrix for SDL Subcontractors

August 26, 1997

Subcontractor	Product	Method of Product Assurance Requirements Flow down	Product Assurance Section/Requirement (from SDL PA Plan)																									
			1.7 Monthly Status Report	1.8.1 Acceptance Data Pkg	2.2 System Reviews (PDR, CDR, & PSR)	3.0 Test Plan	4.3.d Electrostatic Discharge (ESD)	5.0 (7.3) Approved EEE Parts List	6.0 (7.3) Approved Materials List	7.2 Critical Fastener List	7.4 Limited Life Items List	8.1 (7.1.2) Configuration Control	8.2 Lot Traceability for Parts & Material	8.3 Procurement Control	8.4 Receiving Inspection	8.5 Controlled Stockroom	8.6 Mfg Control (Shop Traveler Pkg)	8.7 Training and Certification	8.8 Nonconformance Control	8.9 GIDEP Alerts	8.10 Inspection Stamps	8.11 In-Process Inspection	8.11.1 Pre-Lid Inspection	8.11.2 PWB Fabricated to Mil-P-55110	8.14 Metrology	8.15 Shipping Control (Document)	8.16 Final Inspection	9.0 Contamination Control
TRW[1]	Refrigerator	SOW	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X[2]	X	X[3]	X	X	X	X	X	X	X	X
BEI	Scanner Motor/Encoder	SOW		X		X	X	X	X	NA	X	X	X	X	X	X	X	X[2]	X	X[3]	X	X	X	X	X	X	X	X
EG&G	Detector Array	SDL PA Plan	X	X	X[4]	X	X	X	X	NA	NA	X	X	X	X	X	X	X	X	X[3]	X	X	X	NA	X	X	X	X
OCLI	Optical Filters	SDL PA Plan	X	X	X[4]	X	NA	NA	X	NA	NA	X	X	X	X	X	X	NA	X	NA	X	X	NA	NA	X	X	X	X
SSG[5]	Mirrors	SDL PA Plan		X		X	NA	NA	X	NA	NA	X	X	X	X	X	X	NA	X	NA	X	X	NA	NA	X	X	X	X
TFR[5]	Chopper	SOW		X		X	NA	NA	X	NA	NA	X	X	X	X		X			NA		X[6]	NA	NA	X	X	X	

[1] These product assurance requirements shall apply to new hardware only. Pre-existing hardware shall comply on a best effort basis.

[2] In-house training to subcontractor's specifications.

[3] Alert checks shall be performed by SDL to parts lists submitted by subcontractors.

[4] CDR only.

[5] Product assurance requirements for SSG and TFR have not been negotiated as of this date. Matrix shows best estimate.

[6] LaRC or Government Representative will perform source inspection.

DELIVERABLE DATA REQUIREMENTS

- **Product Assurance Plan**
  - Final published 19 August 1997
- **Parts and Materials Lists**
  - Updates included in CDR package
- **Safety Checklist**
  - Included in safety section
- **Acceptance Data Package**
  - To be presented at PSR

SAFETY CHECKLIST

- **The SABER instrument and associated GSE were evaluated against the following hazard categories; responses were submitted to APL on 24 January 1997**

Hazard	Response
Ionizing Radiation Sources	No ionizing radiation sources will be used in the SABER instrument. An ESD ionizer will be used that contains ^{241}Po.
EMI/EMC	No transmitters will be used in the SABER instrument.
Laser	Four GSE lasers will be used: 1. HeNe laser will be used in MIC1 LUPI for SDL boresight measurements. This laser will not be used at APL. Operating instructions to include: Do not allow undiffused, direct, or reflected laser beam to enter eye. 2. HeNe laser internal to and sealed within Bio-Rad interferometer will be used during SABER calibration. This laser will not be used at APL. 3. Particle counter containing an internal sealed HeNe or diode laser will be used. 4. CO_2 continuous wave laser will be used for component level BRDF testing. This laser will not be used at APL. Operating instructions to include: Only authorized personnel may be in the area when laser i in use. When laser is in use, personnel in the area must wear protective eyewear appropriate for the CO_2 laser.

SAFETY CHECKLIST (continued)

Hazard	Response
Hazardous/Toxic Material	Concerning flammable materials, Isopropyl Alcohol will be used for cleaning. Concerning toxic substances, irritants, and carcinogens, the following materials will be used: Molybdenum disulfide (lubricant), paint (Z306), epoxies, and conformal coating (5750-LV Uralane). An MSDS sheet is available for each material.
Purge Systems	A dry nitrogen purge will be performed at APL in the High Bay. The flow rate will be approximately .5 cubic feet per minute.
Pyro Systems	Pyro devices will not be used in the SABER instrument. The instrument cover will be actuated by a spring loaded mechanism. The spring forces are low energy.
Pressure Systems	SABER cooler uses He refrigerant and operates at a nominal pressure of 400 psig. Approximately 1 liter of He at STP is contained within the sealed pressure vessel.
Cryogenics	GSE test chamber uses liquid nitrogen and will have a maximum pressure of 30 psi. Relief devices include burst discs and series 500 Circle Seal pressure relief valves.

SAFETY CHECKLIST (continued)

Hazard	Response
Hydraulics	No hydraulics will be used in the SABER instrument.
Flight or Ground Batteries	No batteries are used in or with the SABER instrument.
Handling Fixtures	Handling fixtures will be used and proof tested. They will be designed to 5 times the rated load and tested to 2 times the rated load. Steel cables will be used in the sling construction.
Explosive Atmospheres	No explosive materials will be used in the SABER instrument or GSE.
High Voltage	No high voltage will be used in the SABER instrument.
Electrical GSE (EGSE)	EGSE will be used to support the SABER instrument. This equipment will be mounted in a rack with casters that are capable of being locked.

EEE PARTS SELECTION CRITERIA

- **Grade 1 parts (per NASA PPL 21)**
  - MIL-M-38510 class S microcircuits
  - MIL-S-19500 JANS semiconductors
  - S failure rate level, established reliability, passive and electromechanical parts
- **Grade 2 parts (per NASA PPL 21)**
  - MIL-M-38510 class B microcircuits
  - MIL-S-19500 JANTXV and JANTX semiconductors
  - Minimum P FRL, established reliability, passive and electromechanical parts
- **Grade 3 parts**
  - MIL-STD-883 class B microcircuits
  - Standard Military Drawing (SMD) microcircuits
  - MIL-S-19500 JAN semiconductors
  - Minimum P FRL, ER and Non-ER, passive and electromechanical parts
- **Grade 4 parts**
  - Commercial parts

PARTS SELECTION PROCESS

- **Grade 1 or 2 parts will be used when:**
  - Available with no impact on cost and schedule
- **Grade 3 parts will be used when:**
  - Grade 1 and 2 parts are not available
  - Cost and/or schedule of grade 1 and 2 parts are prohibitive
- **Grade 4 parts (commercial) will be used when:**
  - Grade 1, 2, and 3 parts not available
  - Required circuit function cannot be achieved using higher grades
  - Approved by LaRC on a Nonstandard Parts Approval Request (NSPAR)
- **Printed Wiring Boards**
  - Manufactured to MIL-P-55110

MATERIALS CONTROL

- **Metallic materials will be selected from Table 1 of MSFC-SPEC-522, Design Criteria for Controlling Stress Corrosion Cracking. Materials from Tables 2 and 3 require justification and approval**
- **Nonmetallic materials shall meet the following outgassing requirements in accordance with NASA Reference Publication 1124, Outgassing Data for Selecting Spacecraft Materials**
  - 1.0% maximum Total Mass Loss (TML)
  - 0.1% maximum Collected Volatile Condensable Material (CVCM)
- **Purchased parts and critical materials shall be maintained in a controlled stockroom**
- **Lot traceability of parts and materials shall be maintained from procurement through all phases of assembly**

CONFIGURATION MANAGEMENT AND CONTROL

- **Flight hardware shall be fabricated, assembled, and tested to controlled engineering drawings and specifications with subsequent redlines and authorized updates**
- **Engineering drawings and specifications shall be maintained under configuration control:**
  - Drawings and specifications shall be governed by the following procedures:
    - SDL/90-011, Drawing Procedure
    - SDL/90-010, Drawing Change Control Procedure
  - Drawing changes shall be reviewed and approved by:
    - Cognizant Engineer
    - System Engineer
    - Quality Assurance
    - Documentation control group (release, filing, and distribution)
- **System requirements, management plans, and other contract documents shall also be maintained under configuration control**
  - Configuration changes to these documents shall be approved by:
    - SDL Program Manager
    - SDL System Engineer
    - SDL Quality Assurance
    - LaRC Representative
    - SDL Documentation control group

QUALITY ASSURANCE

- **Traceability**
  - Purchasing and receiving records are maintained for all parts and materials
    - Certificate of conformance including lot control
  - Computer records for all as-built flight hardware are maintained
  - Parts and materials are tracked for each detail part and assembly
  - Forward and backward traceability capability
- **Controlled stockroom**
  - Computer records of all controlled parts are maintained
  - All controlled flight parts are stored in locked storage cabinets
  - ESD protection is provided for static sensitive parts (storage and handling)
  - Limited access

QUALITY ASSURANCE (continued)

- **Manufacturing control**
  - Log books and documentation packages shall contain essential information for assemblies and detail parts and shall be composed of at least the following elements:
    - Engineering drawing
    - Traceability information (kitting lists and/or traceability records)
    - Shop traveler
    - Test requirements and test data
  - Shop travelers shall be used to document history of manufacturing operations, tests, inspections, reworks, and repairs
    - Discrepancy reports, purchase orders, engineering change orders, entries in engineering log books, and other applicable information shall be referenced on the shop traveler

QUALITY ASSURANCE (continued)

- **Training and certification**
  - Soldering personnel to be used on the SABER project have been trained and certified
  - All personnel that will be involved with ESD sensitive components or equipment have had ESD training
  - Records of trained and certified personnel are on file and maintained by quality assurance
- **Testing**
  - Testing will be performed as specified in the SABER Instrument Integration and Test Plan, SDL/97-020, and the SABER Test and Calibration Plan, SDL/97-069
  - Engineering-level testing will be recorded in laboratory notebooks
    - Log books and travelers will follow flight assemblies
    - Summary level reports will be written and include location of test data (file names, etc.)
  - Functional and environmental test results will be recorded and maintained by the cognizant engineer on test data sheets
  - Records of formal acceptance testing will be maintained by quality assurance

QUALITY ASSURANCE (continued)

- **QA inspections**
  - Receiving inspection
  - In-process inspection
  - Final inspection
- **Nonconformance control**
  - All nonconformances shall be documented:
    - In laboratory notebooks during prototype and engineering development
    - On discrepancy reports for flight hardware
  - Waivers will be submitted to LaRC for approval of any deviation from safety, performance, reliability, weight, interface, or basic contract requirements
  - Material Review Board
    - Members - quality assurance, project engineering, and program management
    - Shall make all dispositions except those warranted by a waiver
    - Discrepancy reports shall be maintained by quality assurance