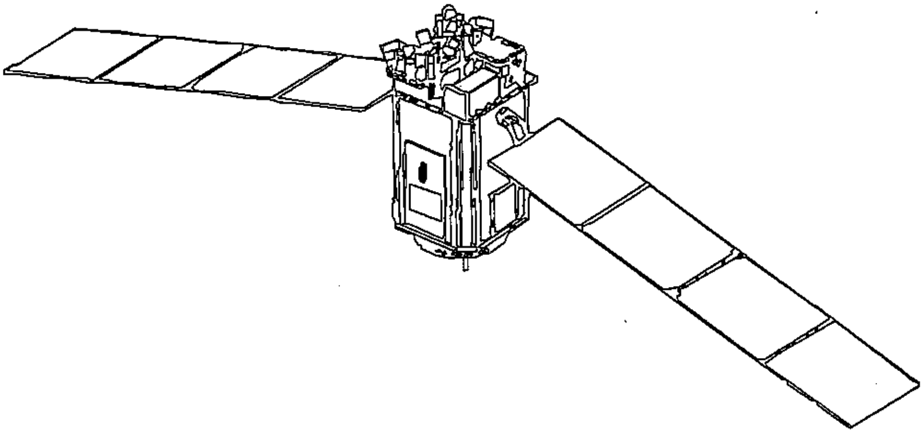
SDL/96-067

SABER
Preliminary Design Review

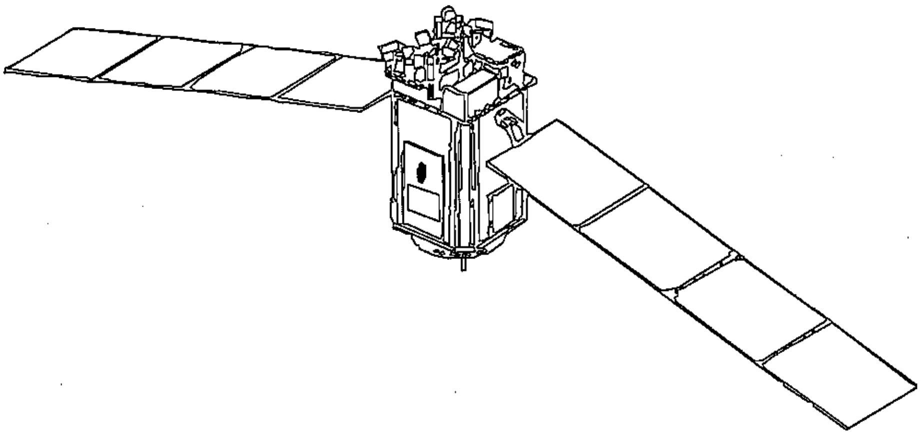


Contract No. NAS1-20467
December 10,11 & 12, 1996

SPACE DYNAMICS LABORATORY
UTAH STATE UNIVERSITY LOGAN, UTAH 84321-1942

SDL/96-067

SABER
Preliminary Design Review



Contract No. NAS1-20467
December 10,11 & 12, 1996

SABER PDR Agenda, Day One
Tuesday, December 10, 1996

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

SABER PDR Agenda, Day Two
Wednesday, December 11, 1996

Building 2 Conference Rooms 127& 128			Building 4 Conference Room A151	
Time	Topic	Chairman/Presenter	Topic	Chairman/Presenter
8:00	Optics & Radiomemetrics Subsystem Review	Tony Jalink (Chairman) Roy Esplin (SDL Lead)	Mechanical, Structural & Thermal Subsystem Review	Bob Sherrill (Chairman) Clair Batty (SDL Lead)
11:30	Report - Radiometric & Optical Subsystem Review	Tony Jalink		
11:45	Report - Mechanical, Structural & 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	Review Action Review			

SABER PDR Agenda, Day Three
Thursday, December 12, 1996

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

SABER Project Management Overview

James B. Miller

December 10, 1996

Phone: (757) 864-7101
Fax: (757) 864-8818
E-Mail: j.b.miller@larc.nasa.gov

TIMED Mission

Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics

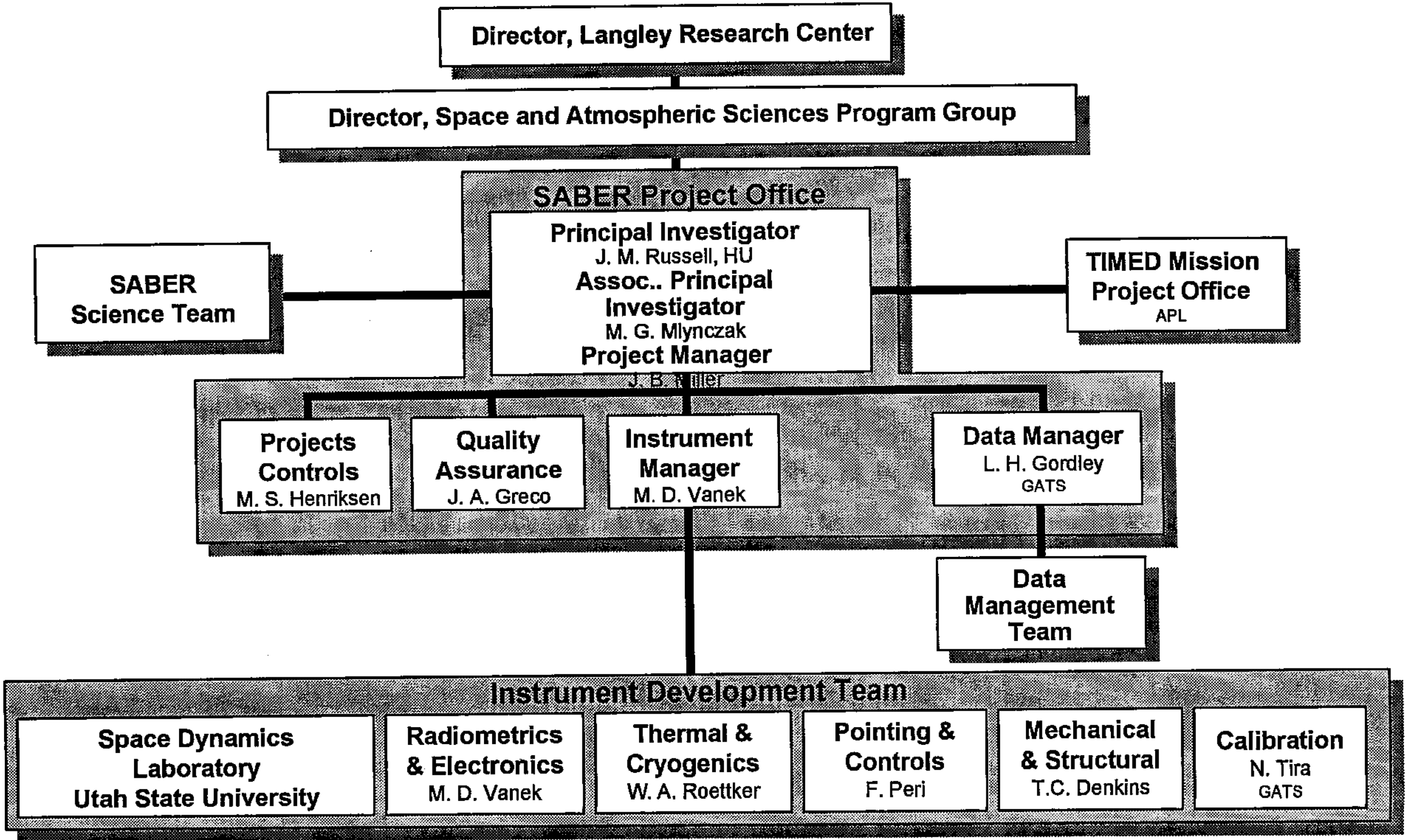
- **TIMED is the first mission in the Office of Space Science's Solar Connections Program**
- **TIMED is a "survey" mission to measure fundamental properties which influence the energy balance of this unexplored region**
- **Mission Managed by Johns Hopkins University Applied Physics Laboratory (APL)**
- **"Build-to-Cost" mission**
  - $100M (FY 94) hard cost cap on Phase C/D
    - Instruments, Spacecraft, Ground Segment, & Data Processing Software
- **Baseline funding:**
  - $25M authorized in FY 1997
  - FY 1998 funding uncertain

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
- **SABER Project $12.8 Phase C/D cost cap in FY 94 dollars**
  - $13.3M in FY95 dollars
- **Baseline funding:**
  - $3.6M authorized in FY 1997
  - FY 1998 funding uncertain

SABER Project Organization



Director, Langley Research Center

Director, Space and Atmospheric Sciences Program Group

SABER Project Office

Principal Investigator
J. M. Russell, HU
Assoc.. Principal Investigator
M. G. Mlynczak
Project Manager
J. B. Miller

SABER Science Team

TIMED Mission Project Office
APL

Projects Controls
M. S. Henriksen

Quality Assurance
J. A. Greco

Instrument Manager
M. D. Vanek

Data Manager
L. H. Gordley
GATS

Data Management Team

Instrument Development Team

Space Dynamics Laboratory Utah State University

Radiometrics & Electronics
M. D. Vanek

Thermal & Cryogenics
W. A. Roettker

Pointing & Controls
F. Peri

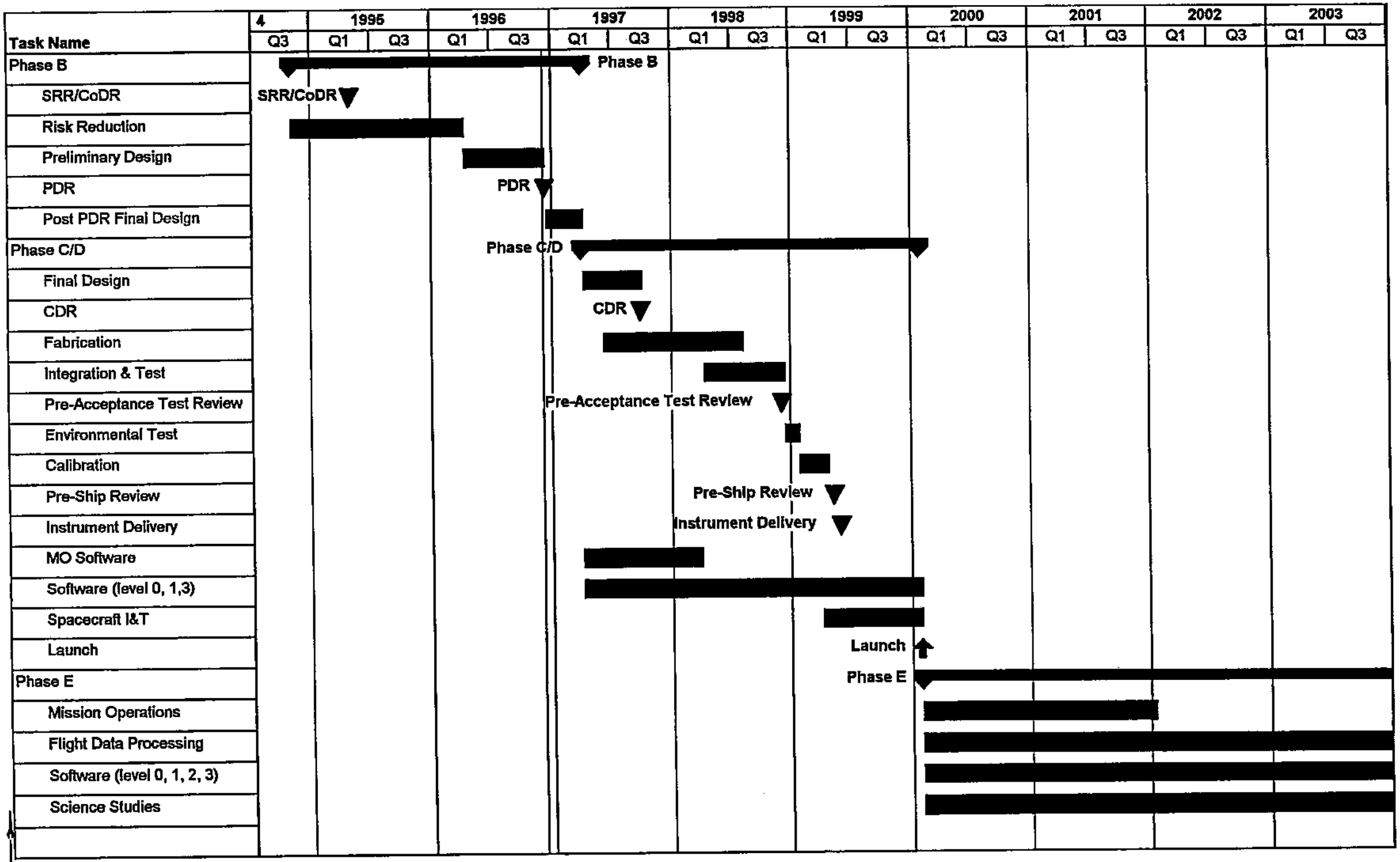
Mechanical & Structural
T.C. Denkins

Calibration
N. Tira
GATS

Major Project Milestones

- November 1995 - “Slow start” Phase B
- April 1995 - Systems Requirements & Conceptual Design Review
- December 1996 - Preliminary Design Review
- February 1997 - TIMED Non-Advocate Review (tentative)
- April 1997 - Phase C/D Authorization
- September/October 1997 - Critical Design Review
- December 1998 - Pre-Environmental Test Review
- May 1999 - Pre-Ship Review
- June 1, 1999 - Deliver Instrument to APL
- January 2000 - Launch / Begin Mission Operations
- January 2002 - Mission Operations Terminated
- January 2002 - Delivery of Data Processing Software
- January 2004 - Deliver Final Report, Archive Data & Final Software

SABER/TIMED Major Milestone Schedule



SABER Science Overview

Presented at the Preliminary Design Review Meeting

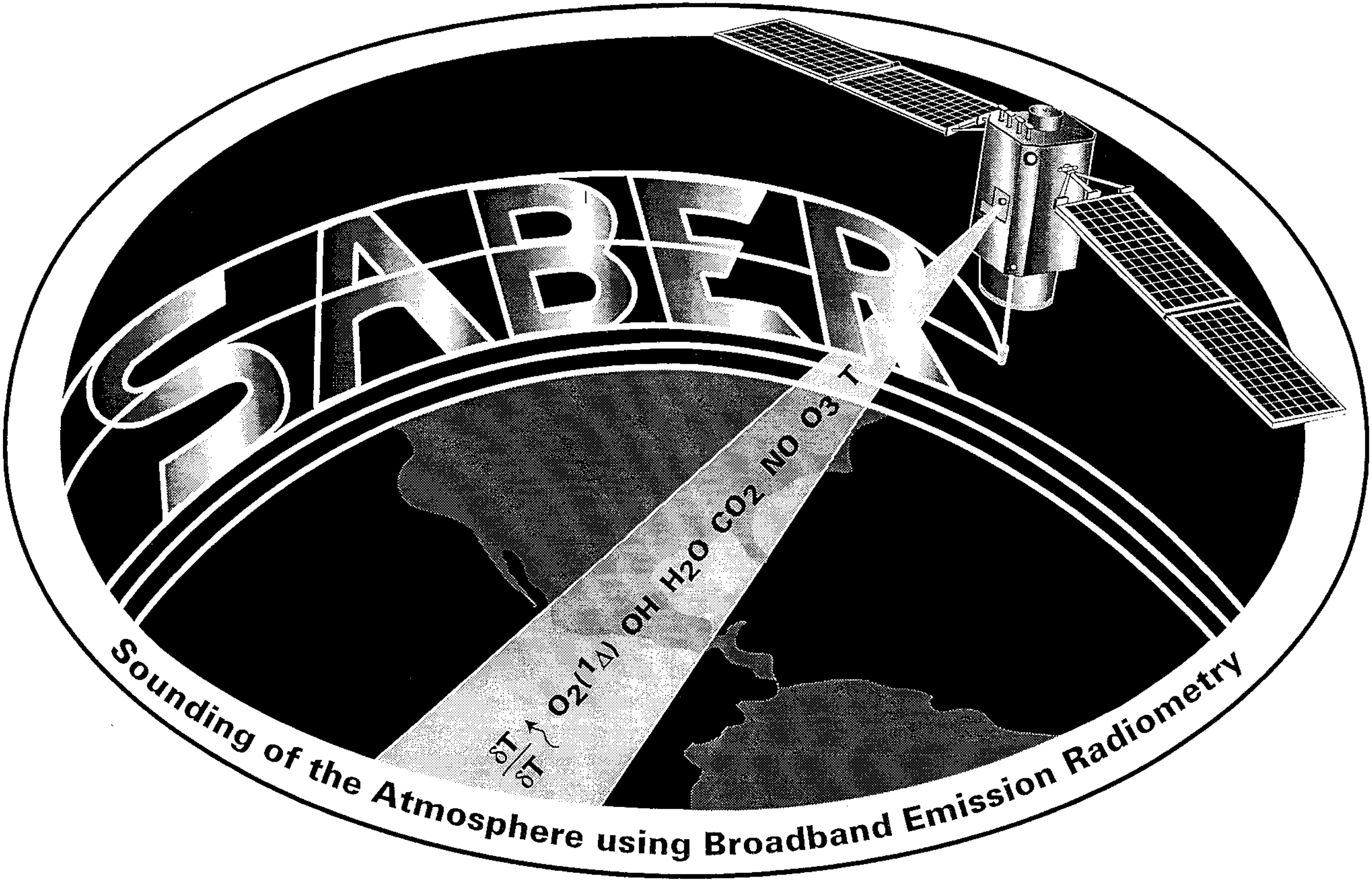
by

James M. Russell III
Principal Investigator

and

Martin G. Mlynczak
Associate Principal Investigator

December 10, 1996


SABER
$\frac{\delta T}{\delta T}$ ~ $O_2(^1\Delta)$ OH H_2O CO_2 NO O_3 T
Sounding of the Atmosphere using Broadband Emission Radiometry

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 Picard	Phillips Laboratory

SABER Experiment Approach

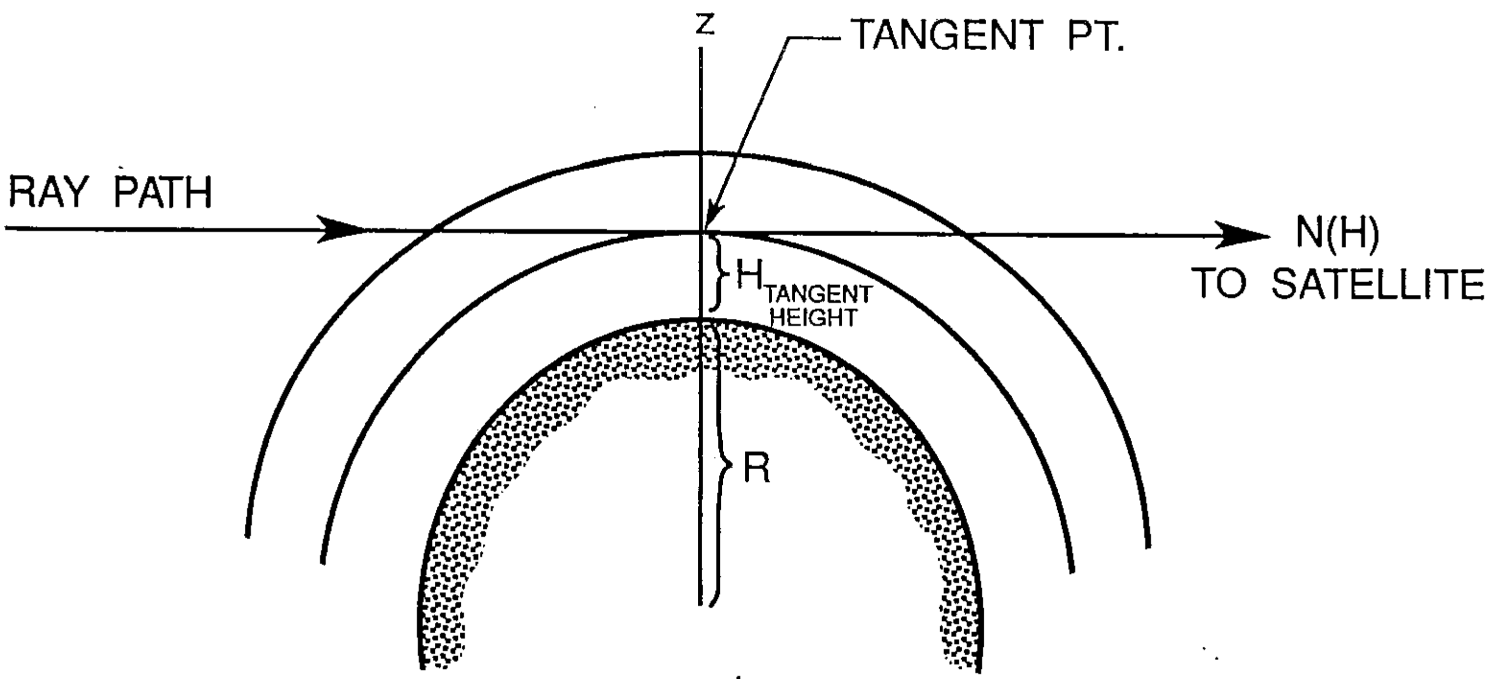
- Measurement of earth limb emission in the near and mid-infrared (1.27 - 16 μm)

- 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



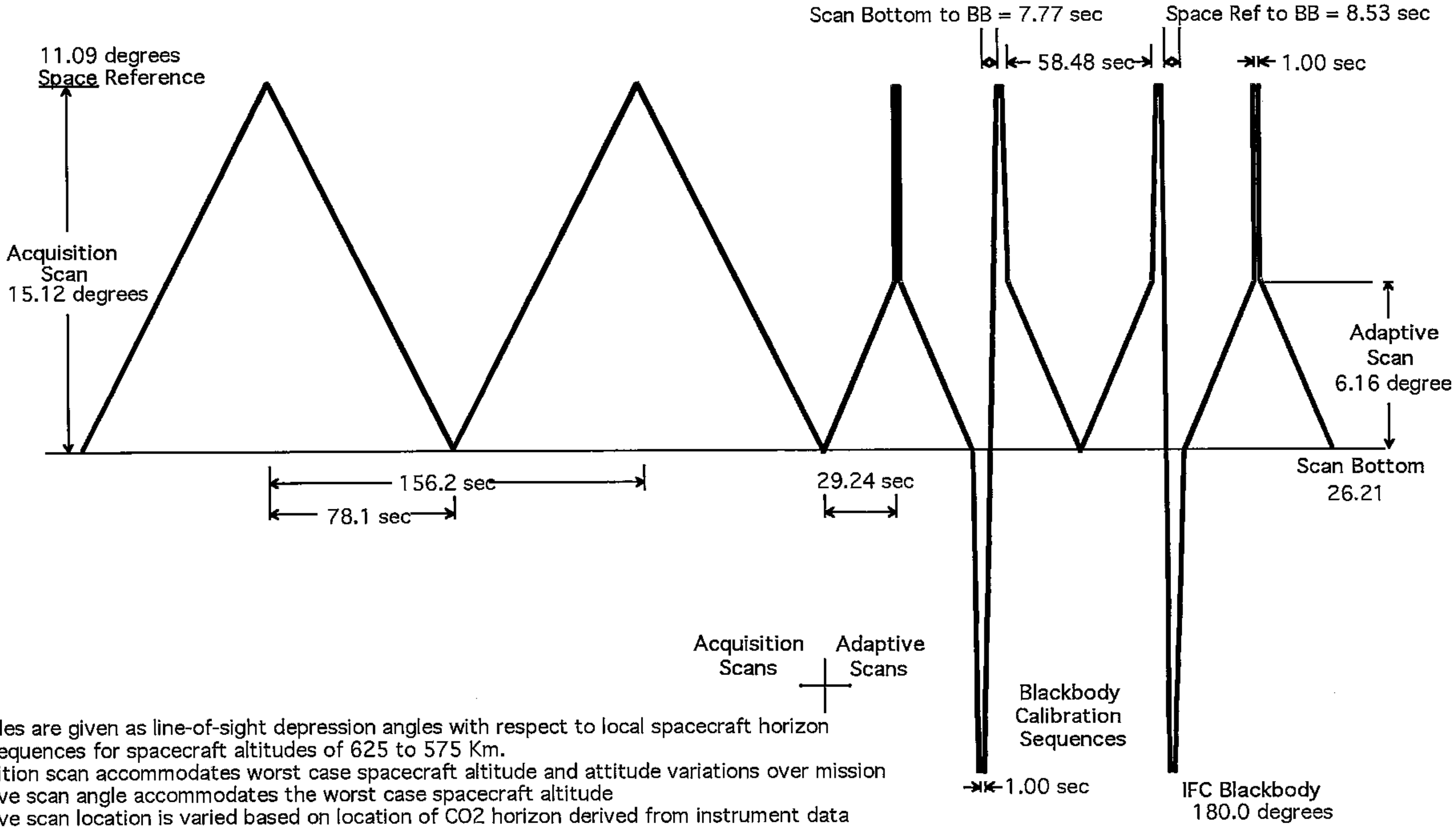
$$N(H) = \int_{\tau}^{1} J(\nu,T)\, d\tau(\nu, q, T, P)$$

q known (e.g. CO_2) → T

T known → q (e.g. O_3, CO_2 H_2O . . .)

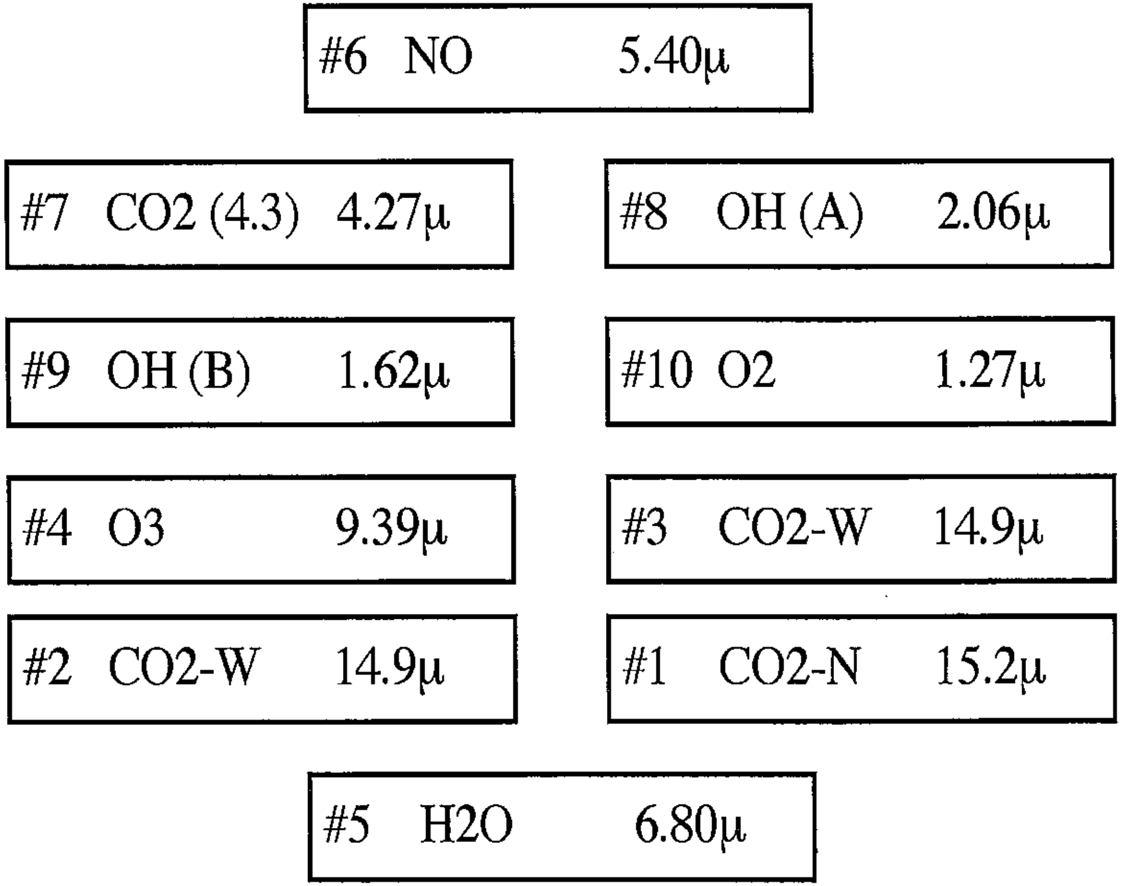
SABER EMISSION EXPERIMENT GEOMETRY AND INVERSION APPROACH

SABER Limb Scan Sequence (11/25/96 Baseline)



All angles are given as line-of-sight depression angles with respect to local spacecraft horizon
Scan sequences for spacecraft altitudes of 625 to 575 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 CO2 horizon derived from instrument data

SABER Focal Plane Array Channel Locations



#6 NO 5.40μ

#7 CO2 (4.3) 4.27μ

#8 OH (A) 2.06μ

#9 OH (B) 1.62μ

#10 O2 1.27μ

#4 O3 9.39μ

#3 CO2-W 14.9μ

#2 CO2-W 14.9μ

#1 CO2-N 15.2μ

#5 H2O 6.80μ

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(υ), NO(υ), $O_3(\nu 3)$, $CO_2(\nu 2)$
  - 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(υ), $O_3(\nu 3)$, $H_2O(\nu 2)$

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($\upsilon = 7,8,9$) 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, $OH(\upsilon)$]
- Conduct measurements to derive solar heating [O_3, O_2, $CO_2(\upsilon 3)$]
- Conduct measurements of key emissions that result in the reduction of the solar and chemical heating efficiencies, e.g., $O_2(^1\Delta)$, $OH(\upsilon)$, $O_3(\nu 3)$, $CO_2(\nu 3)$
- Conduct most detailed study to date of ozone photochemistry in this region (O_3, H_2O), $OH(\upsilon)$, O, H)

TIMED Scientific Objectives Directly Addressed by SABER

- Objective 1: Determine T, ρ, 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(1.6 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, 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

TIMED Scientific Objectives Supported by SABER Observations

- Objectives 3, 4, and 5: Related to sources and variability of gravity and planetary waves; global mean tidal structure; interactions among tidal, gravity, and planetary waves

  - The one spacecraft SABER mission, supports these objectives by:

    - Providing temperature and constituent observations over the full altitude range from the gravity wave source to energy deposition regions

    - Making tracer observations (H_2O, CO_2) to allow study of vertical transport

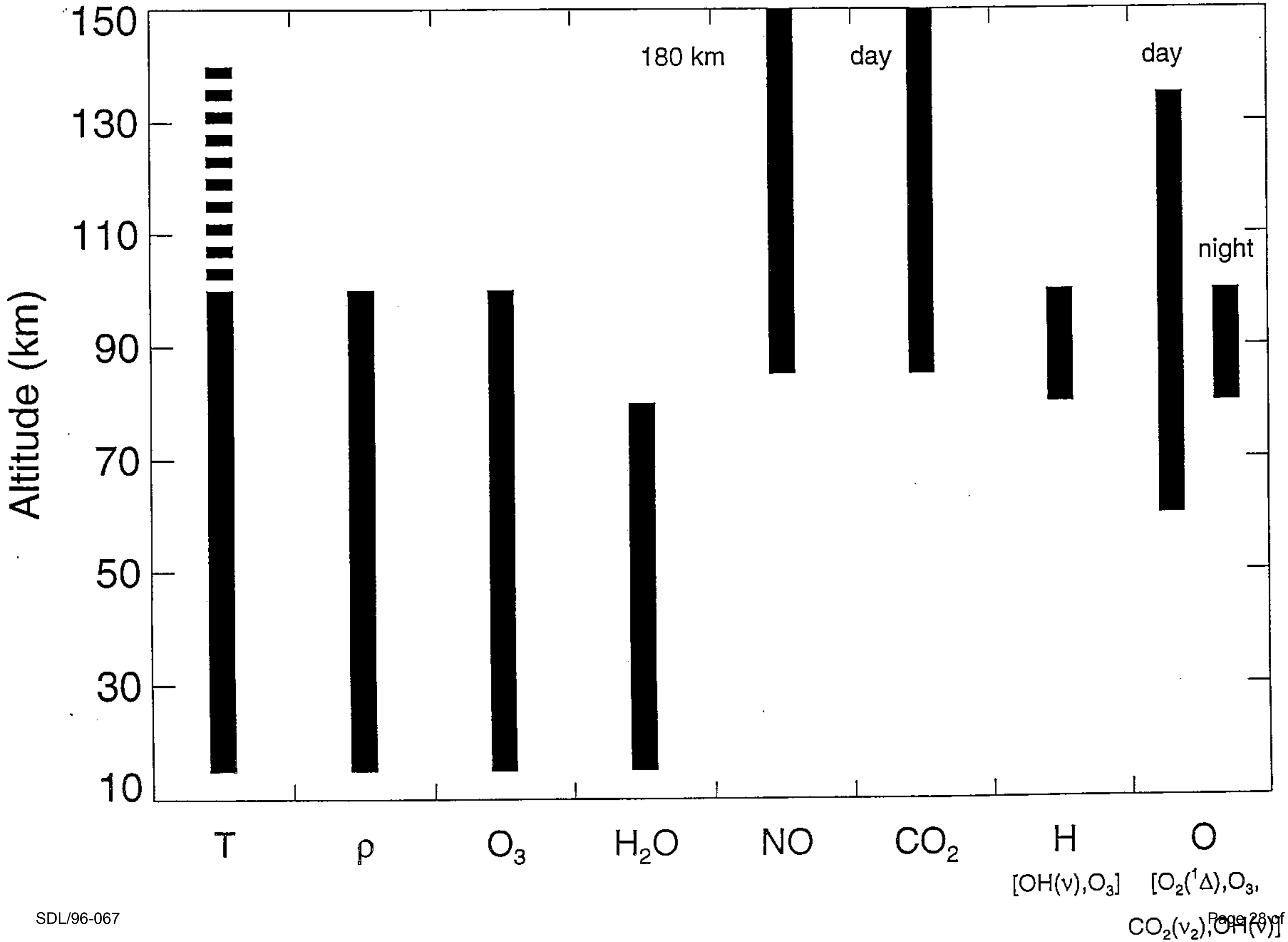
    - Making day and night observations which provides sampling of all local times twice per season

SABER Measurements and Applications*

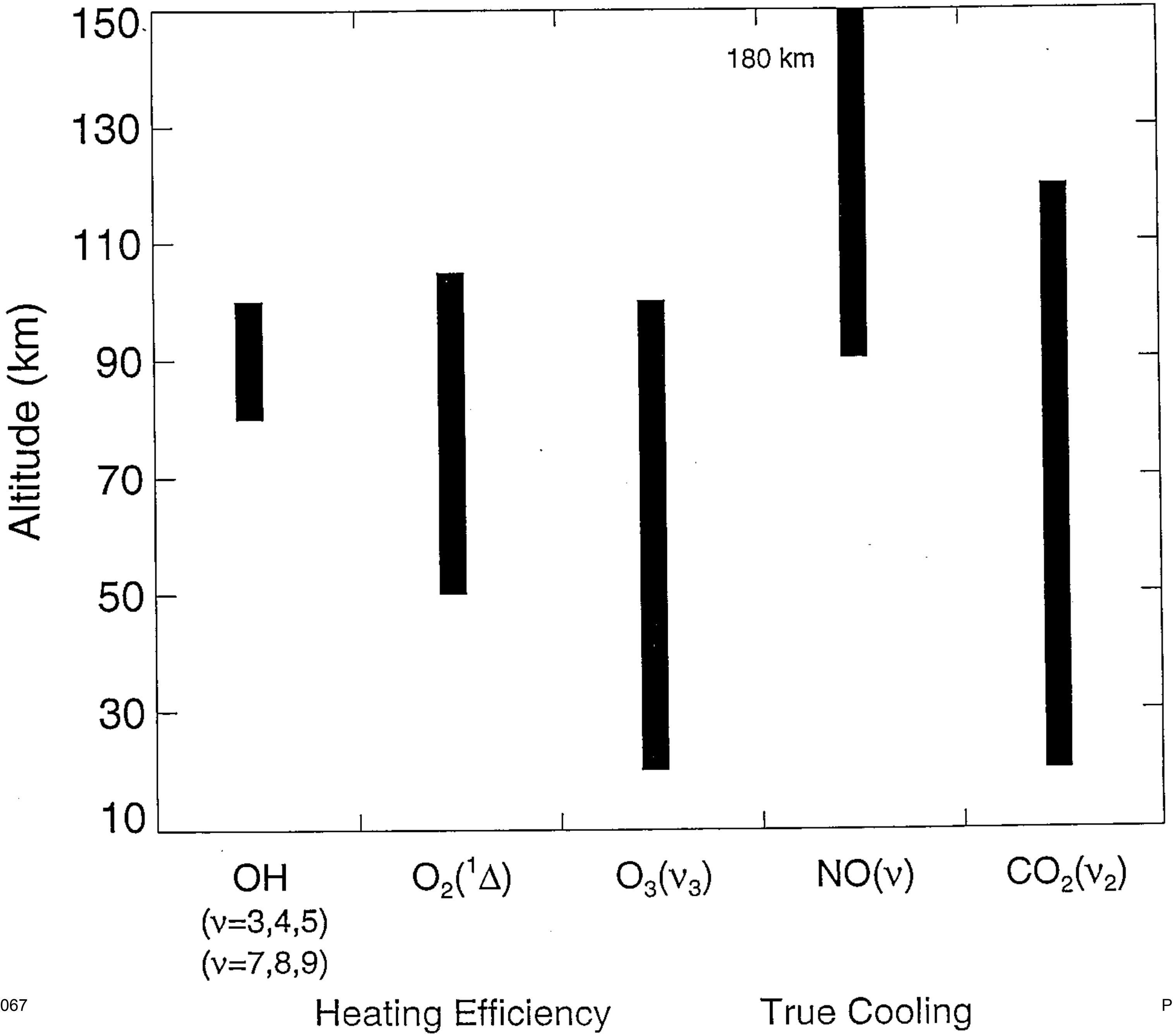
Parameter	Wavelength (μm)	Geophysical Information/Application	Altitude Range (km)
CO_2	15	Kinetic temperature and density; infrared cooling rates; altitude/pressure registration, non-LTE/LTE nature of CO_2. T uncertainty due to non-LTE is large for Z >100 km	10-130
O_3	9.6	Ozone concentration; cooling rates; solar heating rates; fundamental chemistry and dynamics studies	15-100
$O_2(^1\Delta)$	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 ≈ 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; dynamical tracer; NO_x chemistry	90-180
H_2O	6.9	Odd-hydrogen source gas; dynamical tracer	15-80

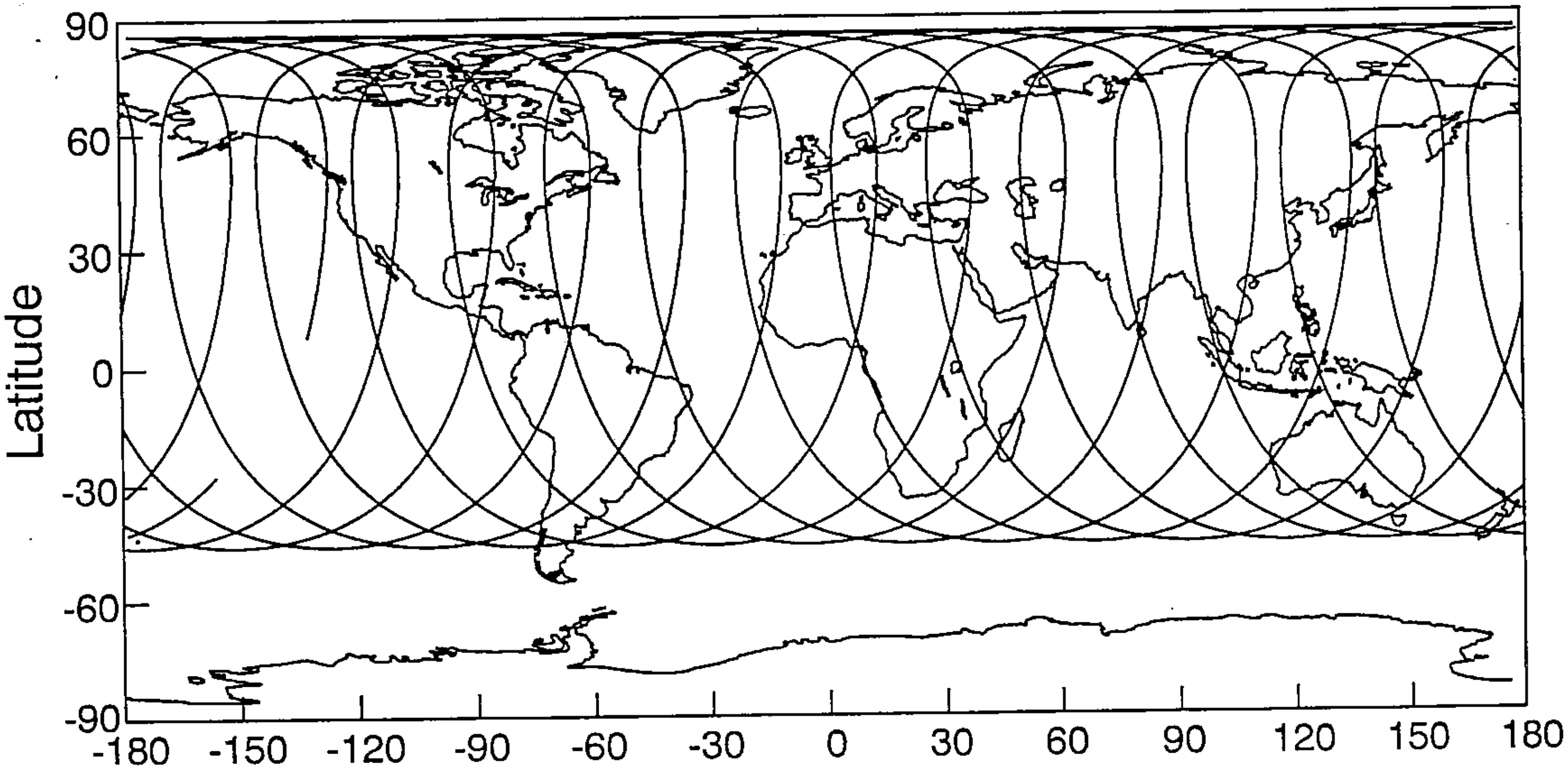
*2.2 km IFOV at the limb and ~ 300 km horizontal resolution along the limb track

Saber Single Profile Day/Night Temperature and Constituent Measurement Ranges

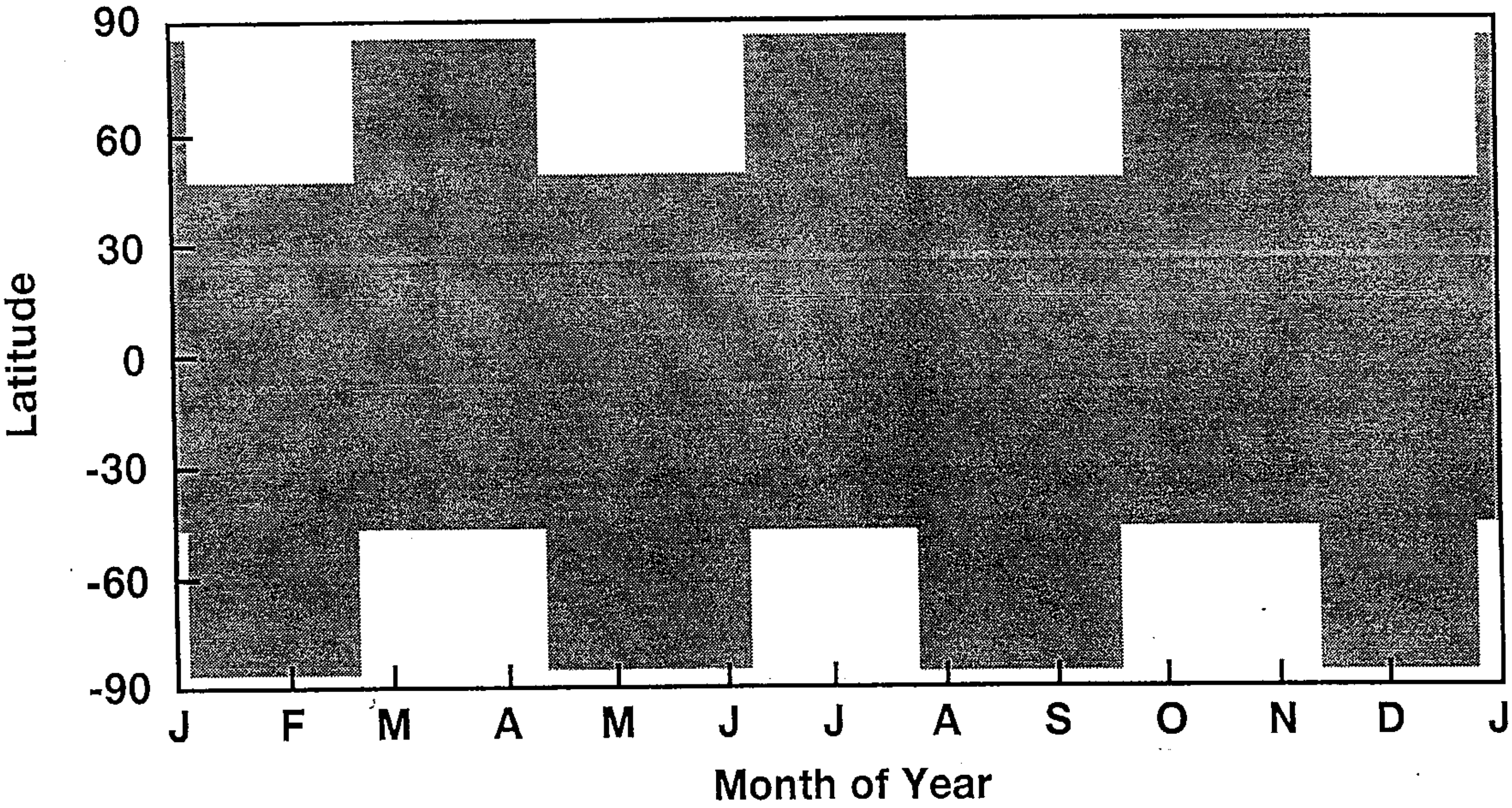


Saber Single Profile Energetics Measurement Ranges



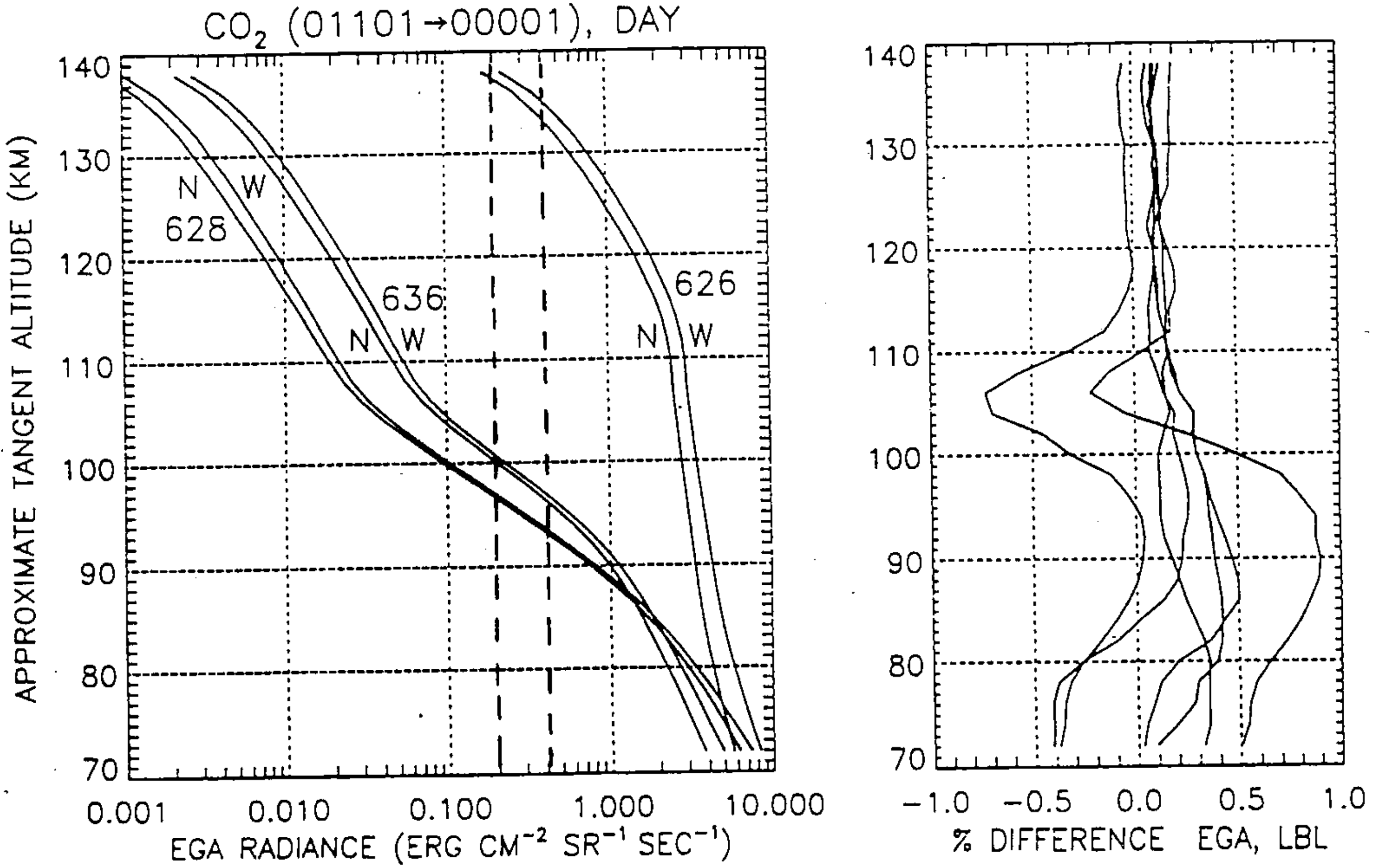


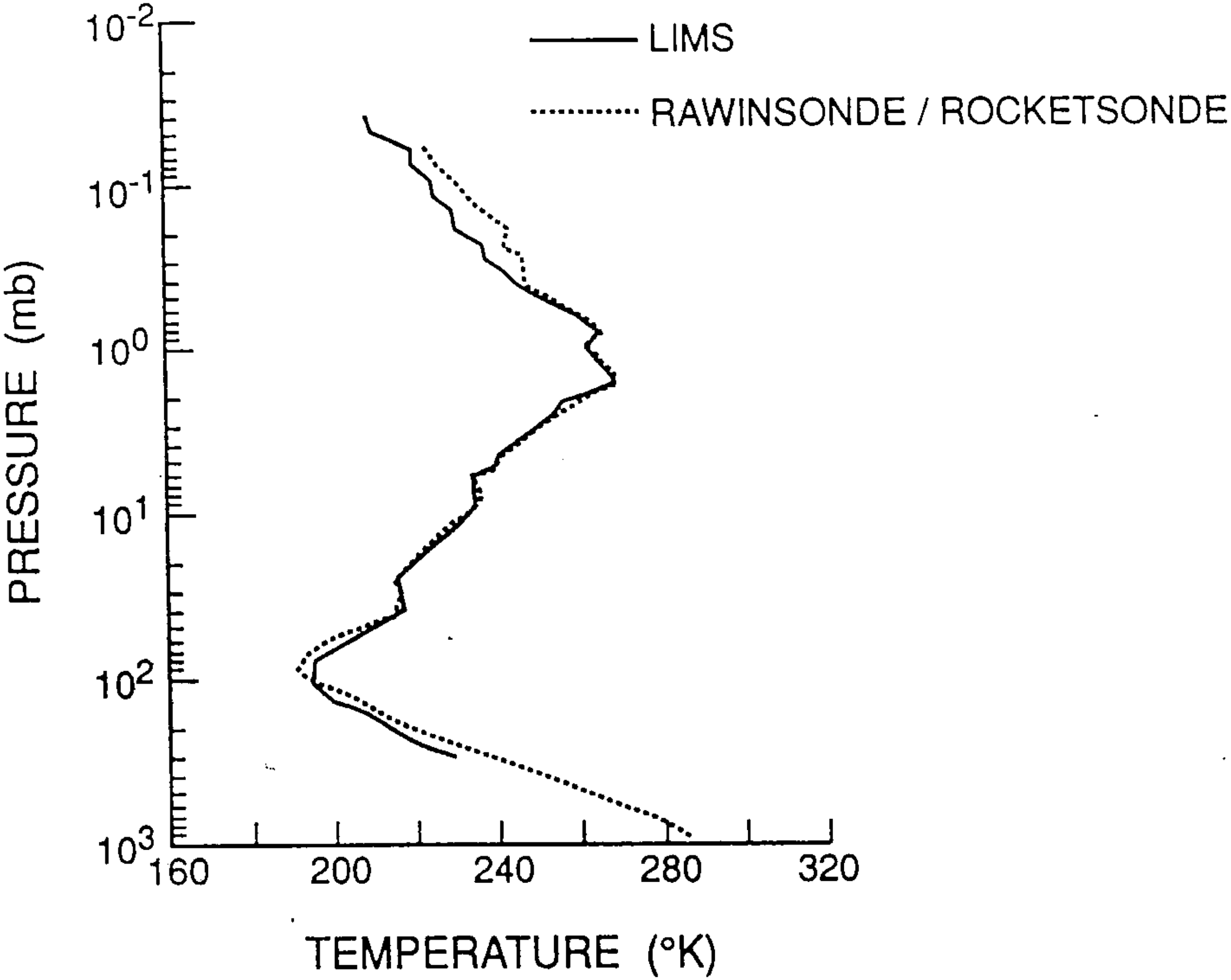
SABER daily latitude versus longitude coverage viewing North for a 70°, 600 km orbit.



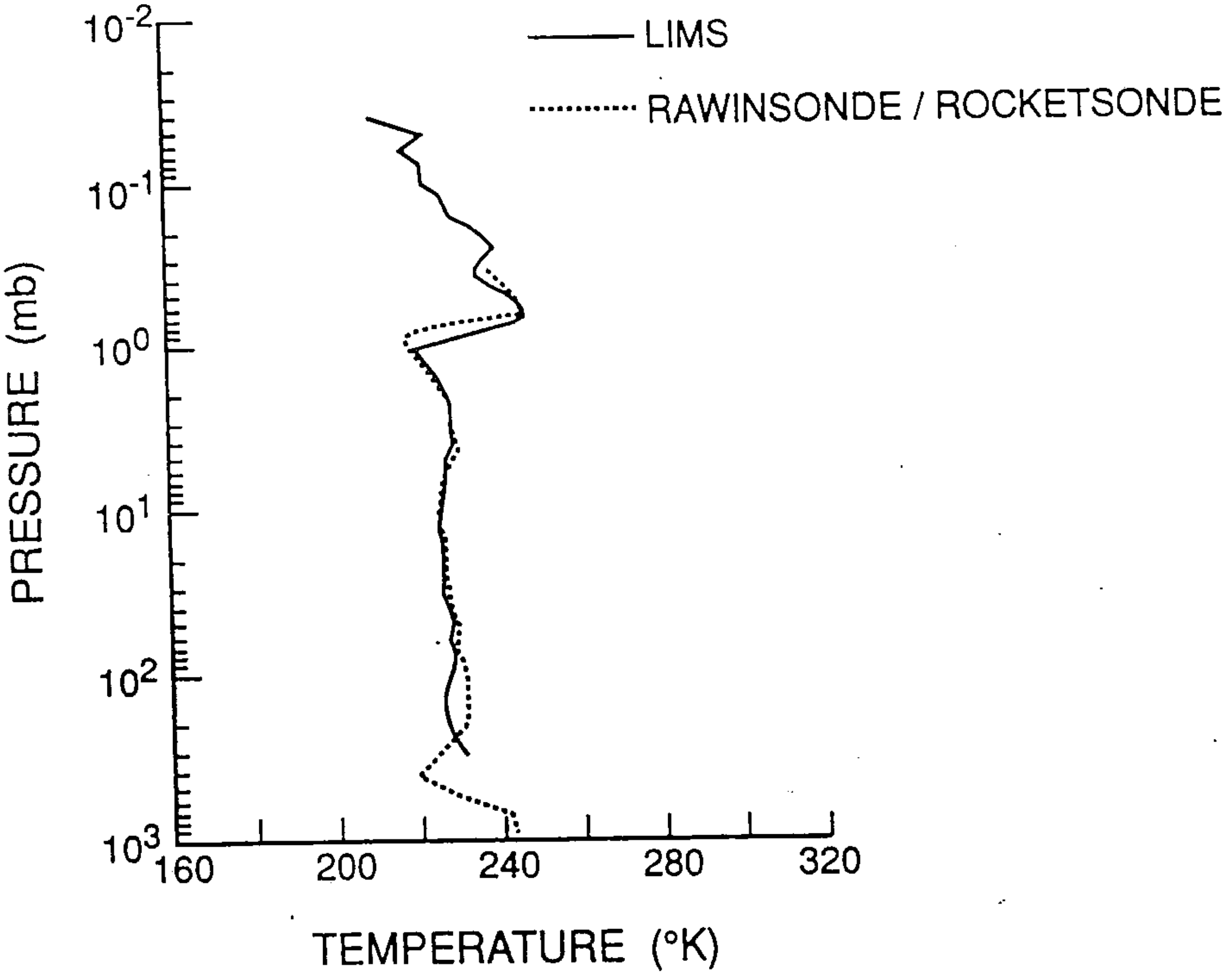
SABER latitude coverage versus time for a 70^o, 600 km orbit

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



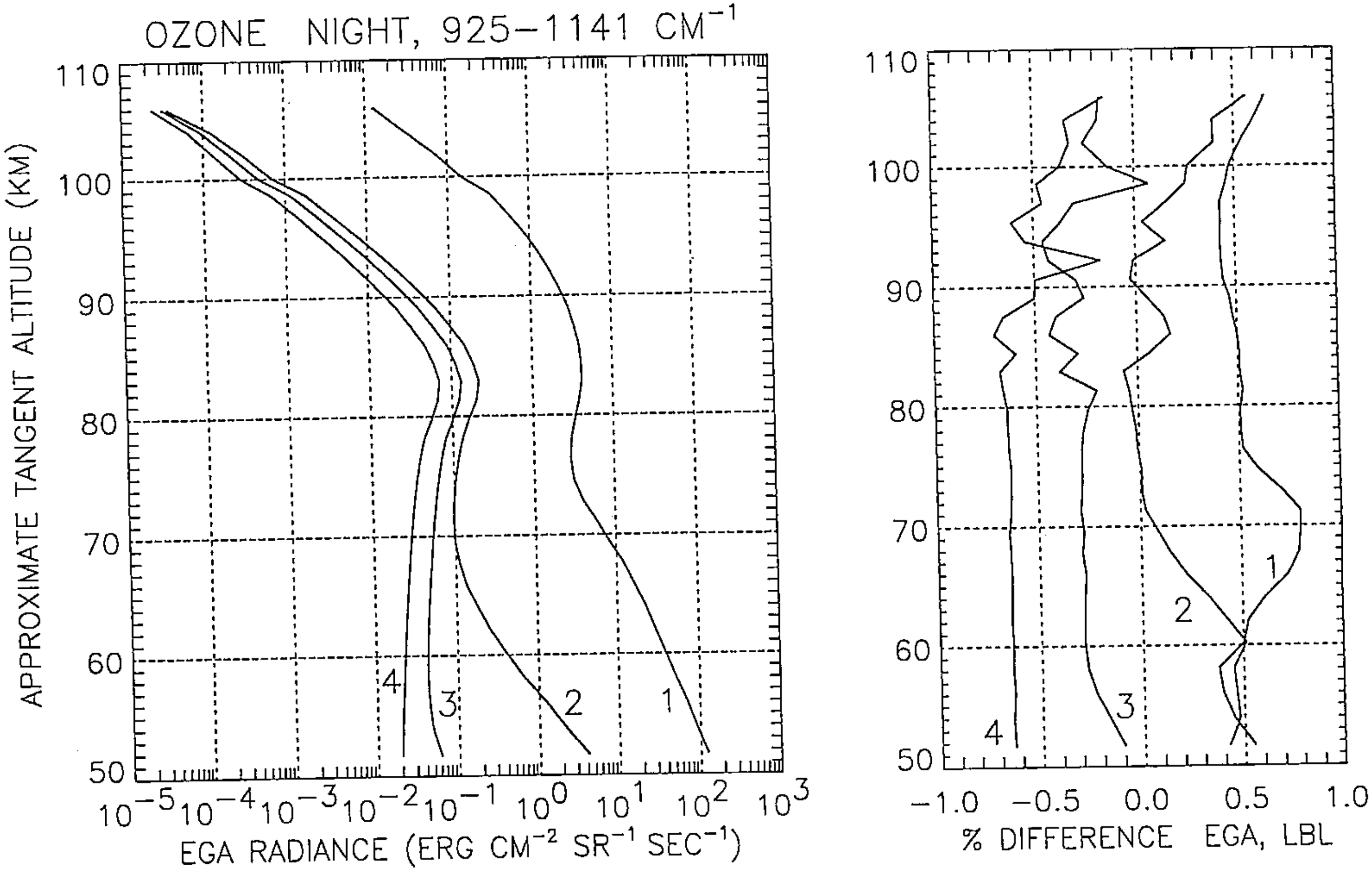


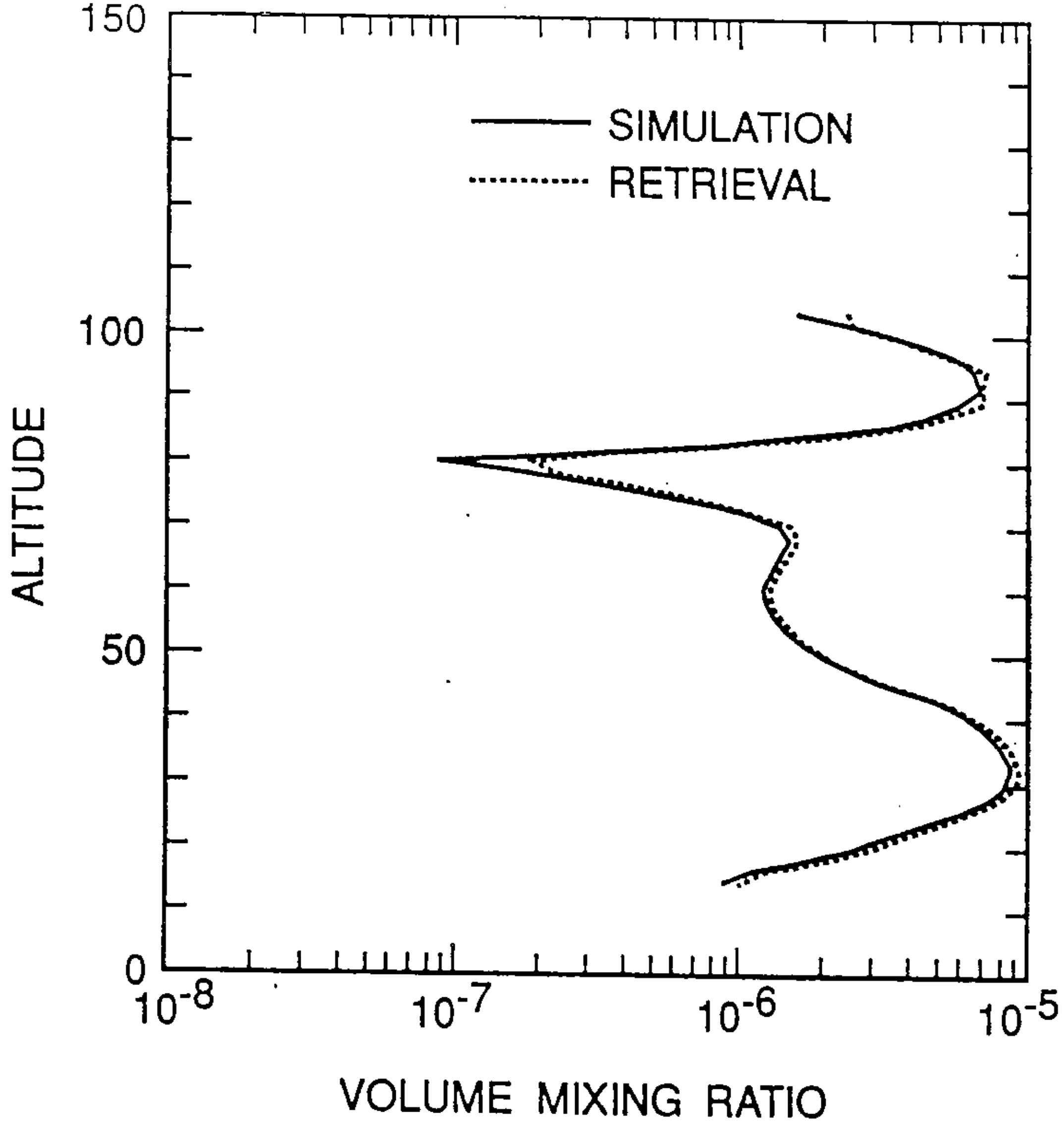
LIMS DAYTIME TEMPERATURE RETRIEVAL COMPARED TO RAWINSONDE / ROCKETSONDE RESULTS AT 18°N, 300°E ON JANUARY 10, 1979



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

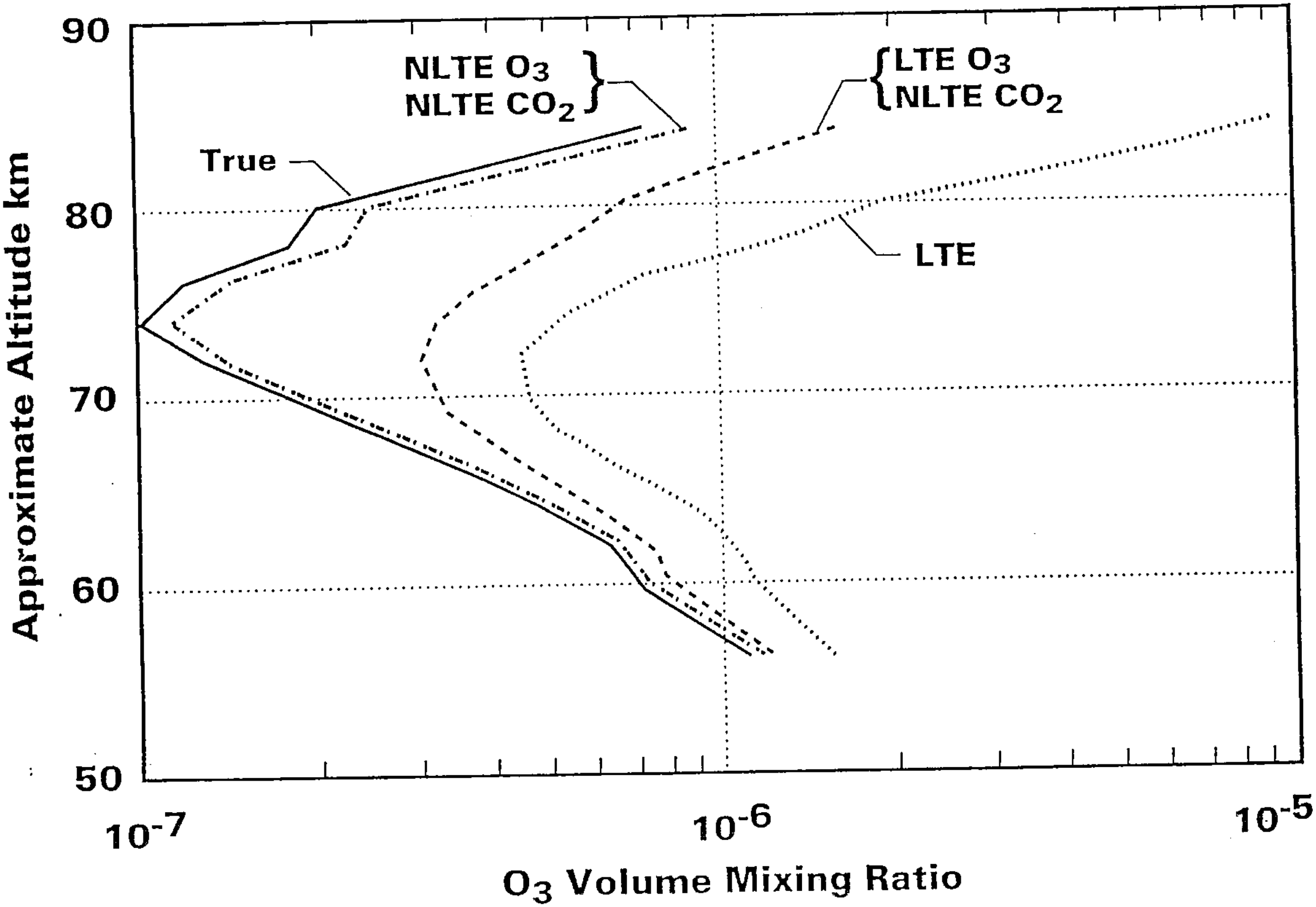
Ozone (9.6 μm) Radiance, Night, Fundamental and Hot Bands





SABER SIMULATED O_3 (9.6) µm) RETRIEVAL

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
$O_3(\nu 3)$	20-100 km	3%, 50-90 km	0.05%, 50-70 km 0.1%, 70-90 km
$CO_2(\nu 2)$	20-120 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 radiometer, 45 to 700 cm-1, depending upon channel
Filter Characteristics	See Table
System Noise Equivalent Radiance (NEN)	See Table
Flight Data 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°
Focal Plane Channel Location	See Figure
Limb Vertical Scan Angle Range	See Table
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 Spectral Response

Channel	Species	Center Wavelength (cm^{-1})	Spectral Bandpass (cm^{-1})	Filter 5% Rel.Trans Limits (cm^{-1})	Filter Out of Band Rejection Ratio	System NEN $^{+}$ $w\text{-}cm^{-2}\text{-}sr^{-1}$	Dynamic Range
1	CO_2 (N)	650	45	635 - 680	10^{-4}	17.5×10^{-9}	≥18985
2	CO_2 (W)	670	80	580 - 760	10^{-4}	28.0×10^{-9}	≥71749
3	CO_2 (W)	670	80	580 - 760	10^{-4}	28.0×10^{-9}	≥71749
4	O_3	1065	110	1010 - 1140	10^{-4}	11.2×10^{-9}	≥46908
5	H_2O	1470	180	1380 - 1560	10^{-4}	3.73×10^{-9}	≥85234
6	NO	1850	150	1775 - 1925	10^{-4}	2.49×10^{-9}	≥30745
7	CO_2 (B)	2360	80	2320 - 2400	10^{-4}	1.32×10^{-9}	≥7632
8	OH (A)	4850	700	4500 - 5200	10^{-4}	0.47×10^{-9}	≥850
9	OH (B)	6088	695	5740 - 6435	10^{-4}	0.70×10^{-9}	≥360
10	O_2	7850	240	7730 - 7970	10^{-4}	0.70×10^{-9}	≥14300

$^{+}$ For 0.110 second integration time.

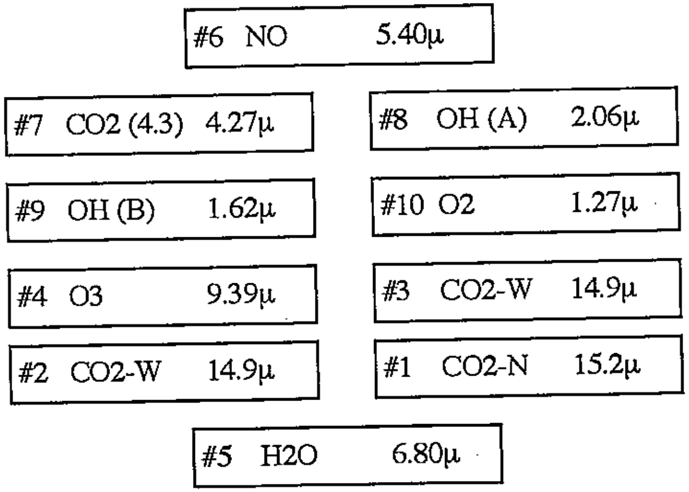
Note: Hi-lited values indicate changes made since PDR (12/19/96).

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


#6 NO 5.40μ
#7 CO2 (4.3) 4.27μ
#8 OH (A) 2.06μ
#9 OH (B) 1.62μ
#10 O2 1.27μ
#4 O3 9.39μ
#3 CO2-W 14.9μ
#2 CO2-W 14.9μ
#1 CO2-N 15.2μ
#5 H2O 6.80μ

SABER INSTRUMENT OVERVIEW

Lorin Zollinger

December 10, 1996

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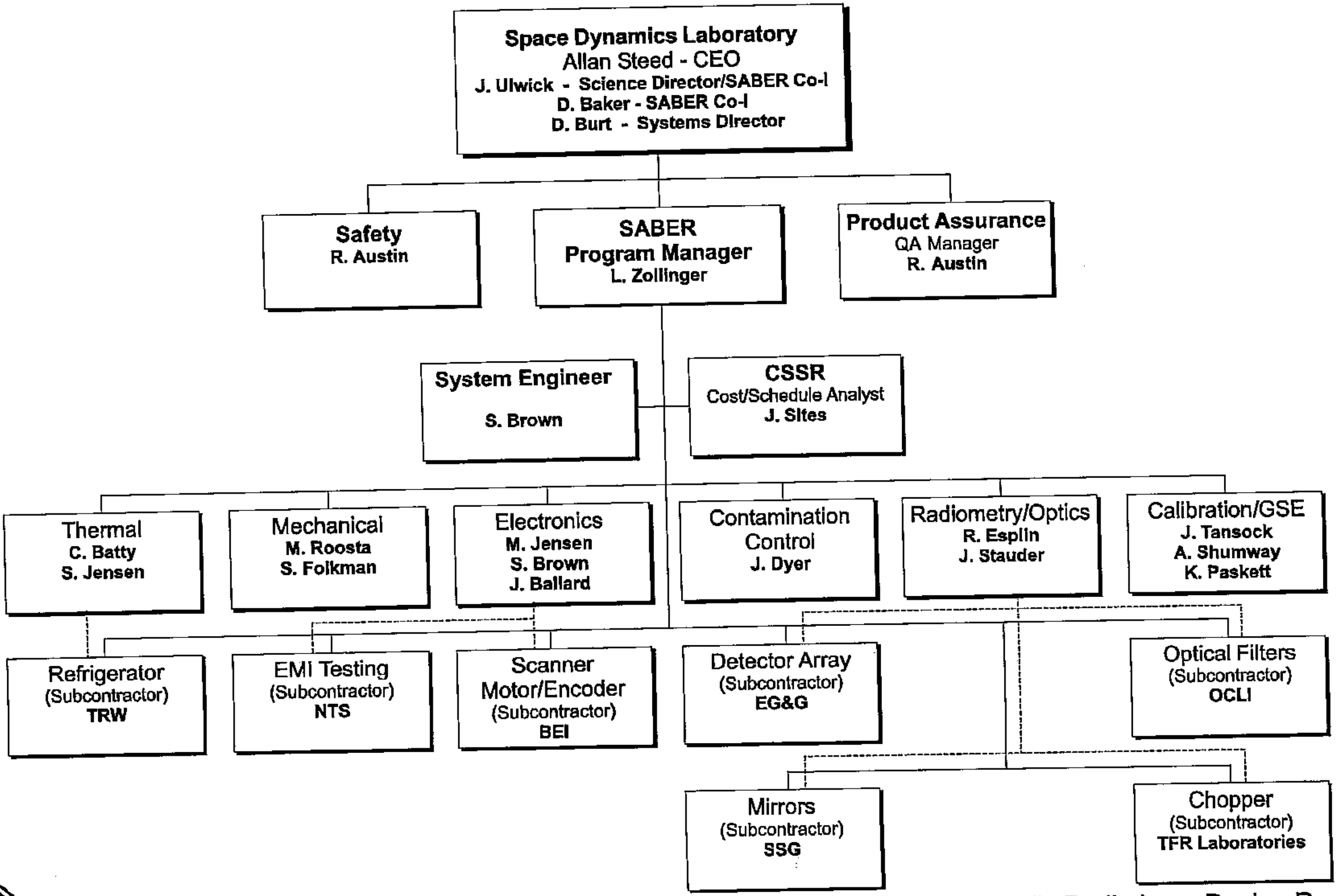
Instrument Overview Outline

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

SDL/USU SABER Organization Chart



Space Dynamics Laboratory
Allan Steed - CEO
J. Ulwick - Science Director/SABER Co-I
D. Baker - SABER Co-I
D. Burt - Systems Director

Safety
R. Austin

SABER
Program Manager
L. Zollinger

Product Assurance
QA Manager
R. Austin

System Engineer
S. Brown

CSSR
Cost/Schedule Analyst
J. Sites

Thermal
C. Batty
S. Jensen

Mechanical
M. Roosta
S. Folkman

Electronics
M. Jensen
S. Brown
J. Ballard

Contamination Control
J. Dyer

Radiometry/Optics
R. Esplin
J. Stauder

Calibration/GSE
J. Tansock
A. Shumway
K. Paskett

Refrigerator
(Subcontractor)
TRW

EMI Testing
(Subcontractor)
NTS

Scanner Motor/Encoder
(Subcontractor)
BEI

Detector Array
(Subcontractor)
EG&G

Optical Filters
(Subcontractor)
OCLI

Mirrors
(Subcontractor)
SSG

Chopper
(Subcontractor)
TFR Laboratories

INSTRUMENT REQUIREMENTS

Requirements Preface

- **Instrument requirements shown in the next 3 charts remain unchanged from the SRR/CoDR with the exception that minor spectral changes to two channels is in work**
- **Instrument/spacecraft requirement shown in the last 4 charts include requirements which flow from the instrument to the spacecraft and from the spacecraft to the instrument**
- **Instrument/spacecraft interface has evolved since the SRR/CoDR**
  - Thermal inteface is simpler and thermal control independent of the spacecraft
  - Mechanical interface has evolved and provides simpler and stiffer mount
  - Interfaces are defined in the draft interface documents which are evolving
  - Last 4 slides represent a snap shot of the present configuration of the instrument and its interface with the spacecraft

Instrument Requirements

Parameter	Measurement Requirement
Spectral Resolution	Broadband radiometer, 45, 80, 110, 140, 150, 180, 240, and 700 cm^{-1}, depending upon channel
Flight Data 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 Spectral Response

Channel	Species	Center Wavelength (cm^{-1})	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)	650	45	635 - 680	10^{-4}	17.5×10^{-9}	≥18985
2	CO_2 (W)	670	80	580 - 760	10^{-4}	28.0×10^{-9}	≥71749
3	CO_2 (W)	670	80	580 - 760	10^{-4}	28.0×10^{-9}	≥71749
4	O_3	1065	110	1010 - 1140	10^{-4}	11.2×10^{-9}	≥46908
5	H_2O	1470	180	1380 - 1560	10^{-4}	3.73×10^{-9}	≥85234
6	NO	1850	150	1775 - 1925	10^{-4}	2.49×10^{-9}	≥30745
7	CO_2 (B)	2360	80	2320 - 2400	10^{-4}	1.32×10^{-9}	≥7632
8	OH (A)	4850	700	4500 - 5200	10^{-4}	0.47×10^{-9}	≥850
9	OH (B)	6088	695	5740 - 6435	10^{-4}	0.70×10^{-9}	≥360
10	O_2	7850	240	7730 - 7970	10^{-4}	0.70×10^{-9}	≥14300

[+] For 0.110 second integration time.

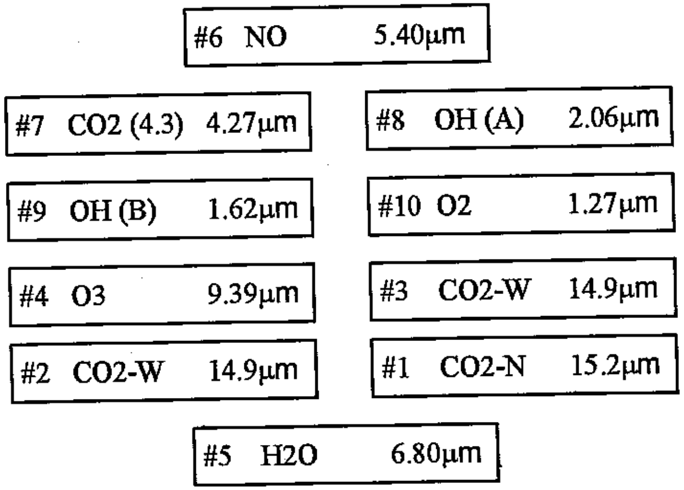
Note: Hi-lited values indicate changes made since PDR (12/19/96).

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



#6 NO 5.40μm

#7 CO2 (4.3) 4.27μm

#8 OH (A) 2.06μm

#9 OH (B) 1.62μm

#10 O2 1.27μm

#4 O3 9.39μm

#3 CO2-W 14.9μm

#2 CO2-W 14.9μm

#1 CO2-N 15.2μm

#5 H2O 6.80μm

Instrument/Spacecraft Requirements

1 of 4

Parameter	Value	Units
Mechanical Requirements:		
Envelope Dimensions	77.47 W x 103.13 H x 60.45D	cm
Baseplate/Ref & Elec Radiator Footprint	77.47 W x 61.91 H	cm
Optics Radiator Dimensions	49.61 W x 37.34 H	cm
Total Weight	61.7	kg
Center of Gravity	1.81(x), 18.08(y), 39.99(z)	cm
Pointing Direction	90° Off-Ram, On-Limb, Anti-Sun	
Boresight Alignment Knowledge	0.02	deg
Optical Clear Fields of View	29 horizontal, 23 vertical top, 54 vertical bottom	deg
Thermal Clear Fields of View	Full Hemisphere	
Limit Loads	16	G's
Minimum Frequency	> 80 Thrust Axis, > 50 Lateral Axis	Hz
Thermal Requirements:		
Interface Conductance	20	deg C/w
Cleanliness Requirements:		
Cleanliness Levels for S/C Integration	Class 100,000	
S/C Surface Cleanliness	Level 750	
Purge Gas	N2 boil off gas from liquid LN2	
Purge Rate	0.4	SCFM

Instrument/Spacecraft Requirements

2 of 4

Parameter	Value	Units
Attitude and Navigational Requirements:		
Orbit Altitude	600	km
Orbit Inclination	74.4	deg
Pointing Control	1.0	deg
Pointing Knowledge	0.1	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:		
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
Velocity Knowledge	3	m/s
Keep out Zones	Keep sun from clear fields of view, avoid long-term exposure of aperture to ram.	
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 Requirements

3 of 4

Parameter	Value	Units
Command & Data Handling Requirements:		
Modes of Operation	Off, Power-up, Safe, Stand-by, Stabilize, Calibration, Data Collection, Diagnostic	
Peak Data Rate for each Mode of Operation:		
off	0	kbits/sec
Power-up	0.08	kbits/sec
Safe	0.08	kbits/sec
Stand-by	0.08	kbits/sec
Stabilize	0.08	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	sun angle knowledge	
S/C data interface	MIL-STD-1553	

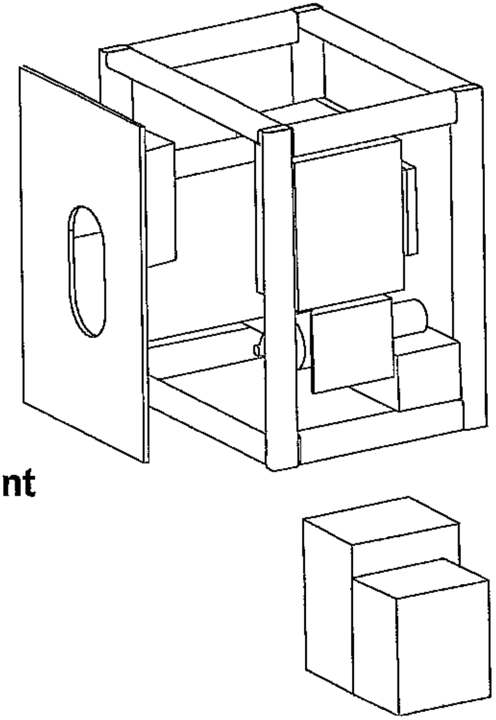
Instrument/Spacecraft Requirements

4 of 4

Parameter	Value		Units
Power Requirements:			
Average & Peak Power for each Mode of Operation	Ave.	Peak	
off	0	0	watts
Power-up	36.9	36.9	watts
Safe	36.9	36.9	watts
Stand-by	60.5	60.5	watts
Stabilize	60.5	60.5	watts
Calibration	64.0	74.0	watts
Data Collection	64.0	74.0	watts
Diagnostic	64.0	74.0	watts
Voltage Range	28 ±6	volts	
Special Requirements For:			
Integration and Test	Full functional test requires vacuum test chamber with LN2 for cooling chamber.		
Mission Operations	door release attitude		
Safety	none		
EMC	none		

BASELINE CHANGES

Baseline Configuration at SRR/CoDR



- **Baseline configuration at SRR/CoDR as shown at right**
- **Telescope was an unobscured high off axis rejection design**
  - All reflective front end with a lens reimager
  - Cold Lyot stop
  - Each channel focused by adjusting filter thickness
  - 2 IFC Blackbodies and flip-in mirror
- **Frame/baseplate mounted to +X spacecraft panel**
- **Telescope view through +Y panel**
- **2 of 4 electronics boxes mounted remotely from instrument**

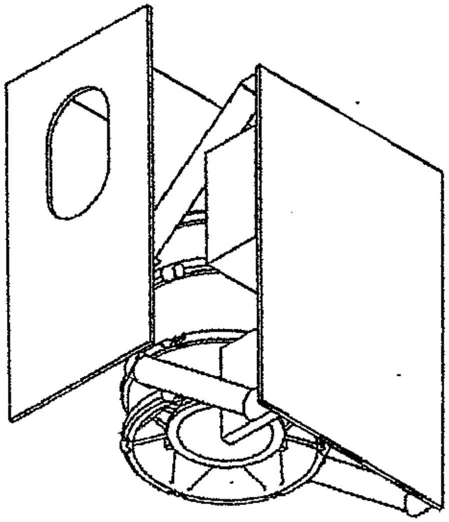
Rebaselined Telescope Design

Change Driven By:

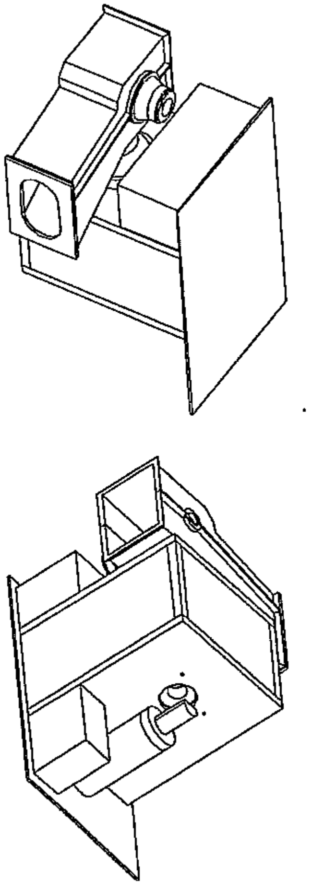
- Achieving focus by adjusting filter thickness was impractical because of the wide spectral range required

Change Resulted In:

- Telescope design consisting of a Cassegrain front end followed by a clam shell reimager
- This design eliminated the lens which:
  - Solved the focus problem
  - Increased transmission - no broadband lens coating
  - lowered thermal background - less emmision from mirrors than lens
- Simpler more rugged telescope design - cylindrical tube design
- improved filter frame assembly - filters the same thickness
- Eliminated flip in mirror & one IFC blackbody



Telescope Temperature Increased to 240 K



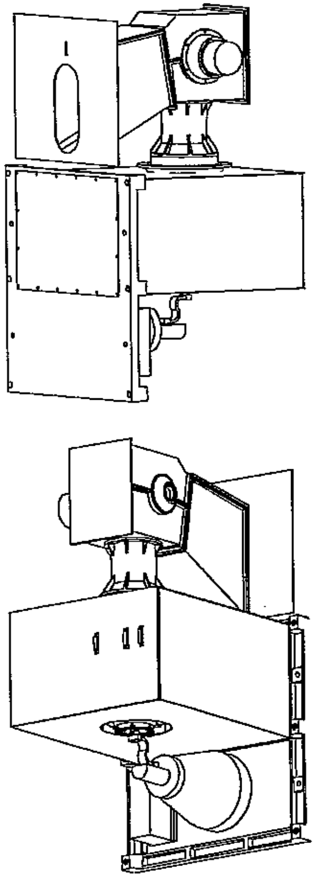
Change Driven By:

- Complex scan mirror design driven by thermal considerations
  - 180-210 K telescope temperature, 233 K encoder minimum
  - Bearing/Lube design/Friction/Preload/Life/Thermal conduction
- Concern over Kevlar tension support of telescope

Change Resulted In:

- Reduced risk/concern about motor/encoder lubricant and thermal gradients
- Reduced size, weight and complexity of optics radiator
- Allowed a composite "box" support system which provided stiffer design and eliminated tension supports on telescope

Baselined Y Panel Mount & Single Instrument Electronics Box



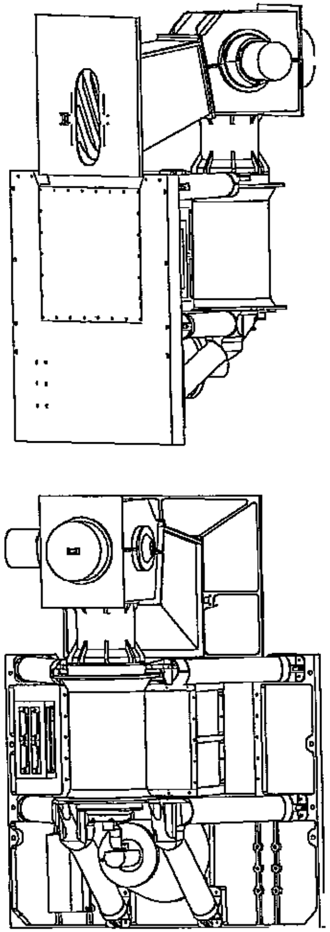
Change Driven By:

- Need to provide greater thermal capacity for the cooler
- Need to provide a workable thermal/mechanical S/C interface
- Provide a stiff cooler mount

Change Resulted In:

- Significantly simpler thermal and mechanical S/C interface
- Ability to compensate for thermal uncertainties
- Provided stiffer cooler mount
- Provided better packaging of electronics - Reduced volume and provided easier access

Telescope Support Structure Change



Change Driven By:

- Spacecraft increase in first mode structural resonance requirement from 70 Hz to 80 Hz for instruments and spacecraft subsystems
- Increased baseplate width about 6" to "pick-up" spacecraft structure

Change Resulted In:

- Adding tubular G-10 struts from baseplate to the composite box and telescope to stiffen the baseline composite box design and meet the new 80 Hz requirement
- A trade study which determined that the struts were doing the most of the "work," would provide sufficient thermal isolation of the telescope and that the expensive composite box was not required structurally

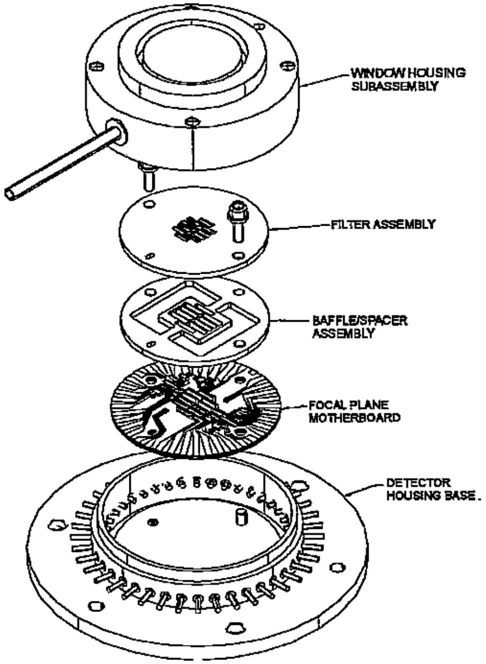
Baselined a Sealed FPA Package Backfilled with Inert Gas

Change Driven By:

- HgCdTe detector characteristics change when exposed to humidity

Change Resulted In:

- consideration of four options
  - Sealed package with baked-out detectors then back-filled with inert gas
  - Sealed evacuated package with baked-out detectors
  - Vented package with baked-out detectors, controlled handling and environment
  - Use of detectors which are not enhanced by bake-out process
- Baselined option 1 which was felt to have the lowest overall risk/uncertainty
- Option 1 is EG&G Judson's recommendation - similar packaging has flight history
- Option 1 has significant technical issue - KBr window to package seal



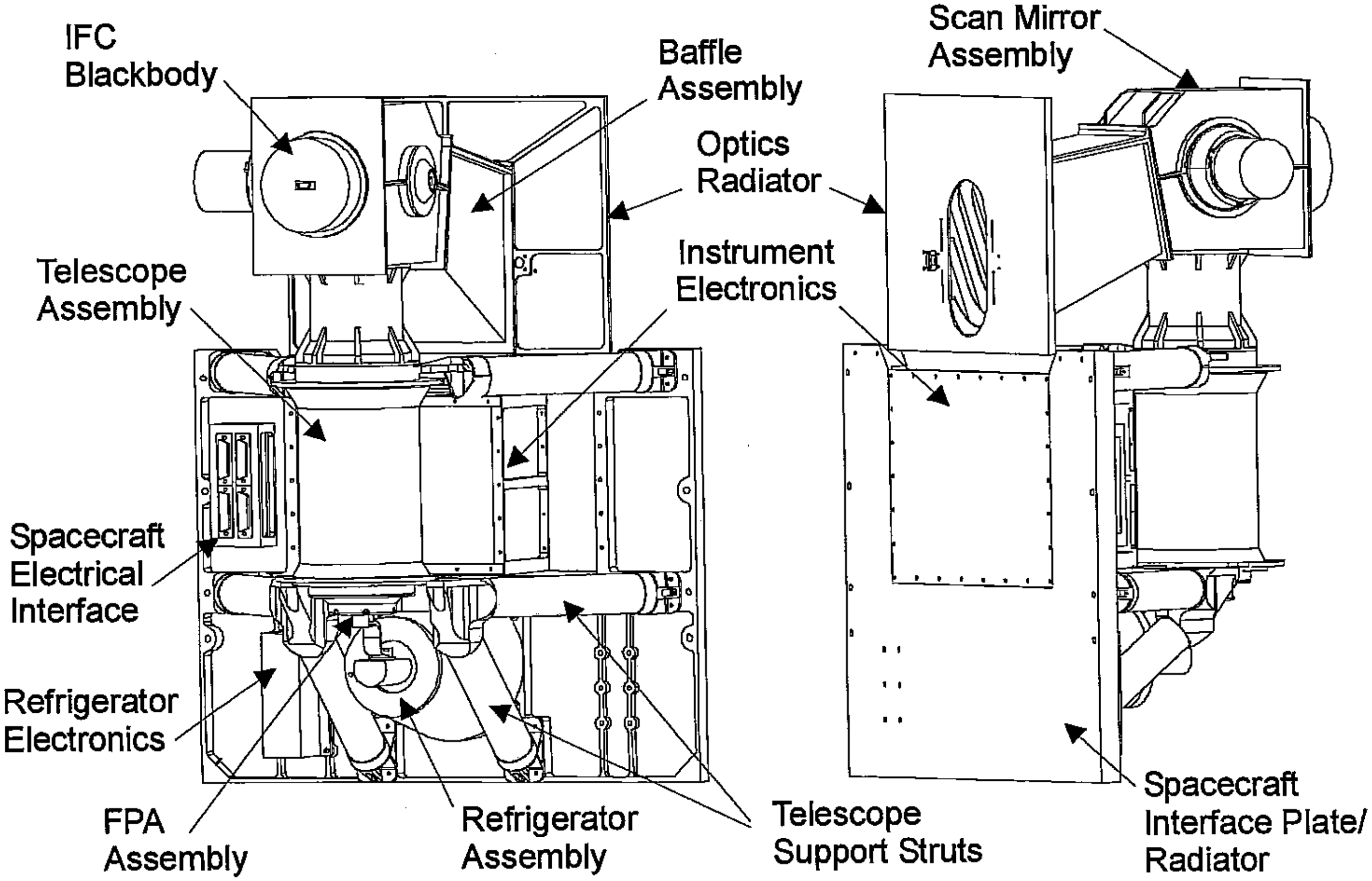
Other Baseline Changes since SRR/CoDR

- **Requirement to View Hard Earth Added**
  - Requirement clarification resulted in dynamic range design change for 7 channels

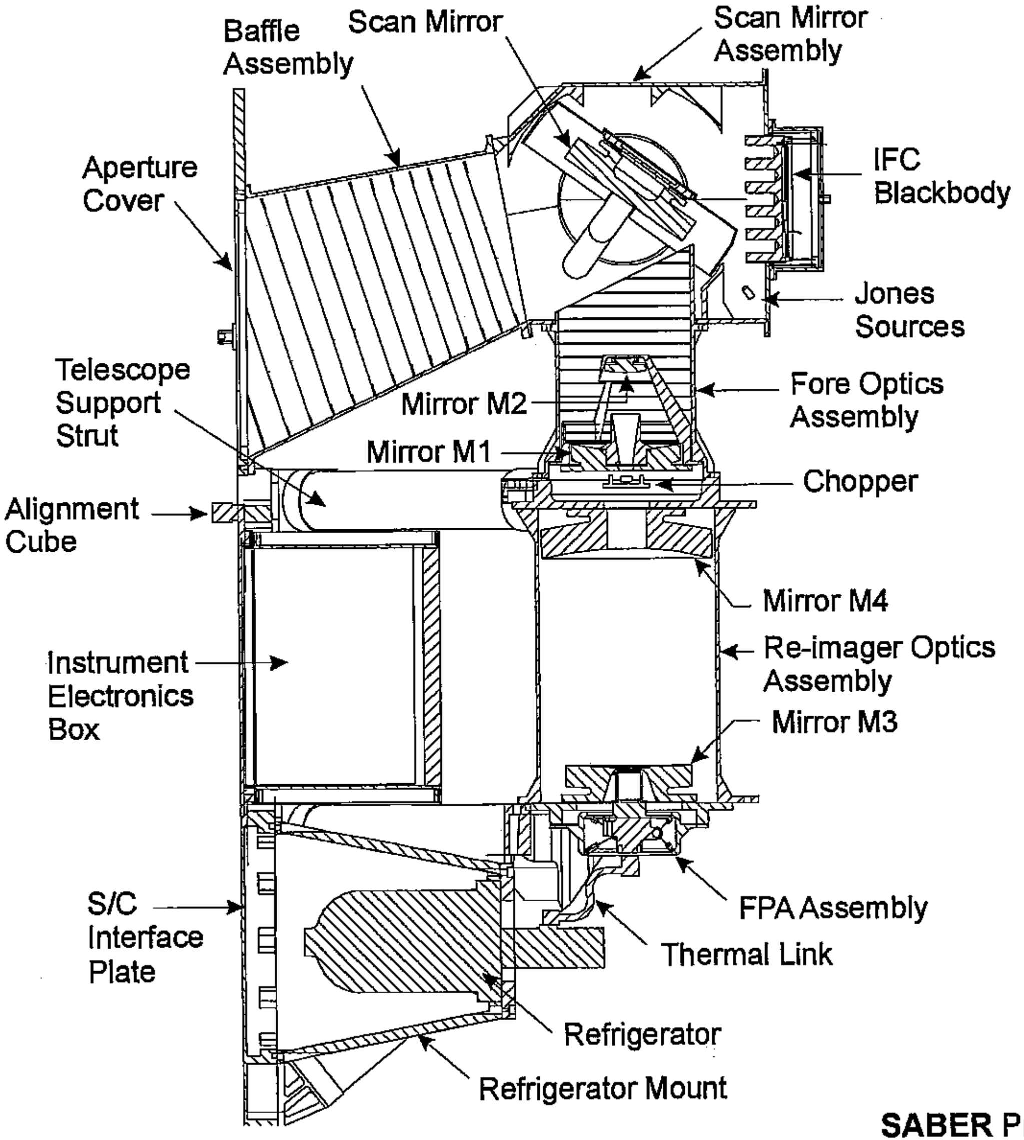
- **Compression**
  - Data compression eliminated, APL agreed to support the higher 4K bit/sec data rate

INSTRUMENT OVERVIEW

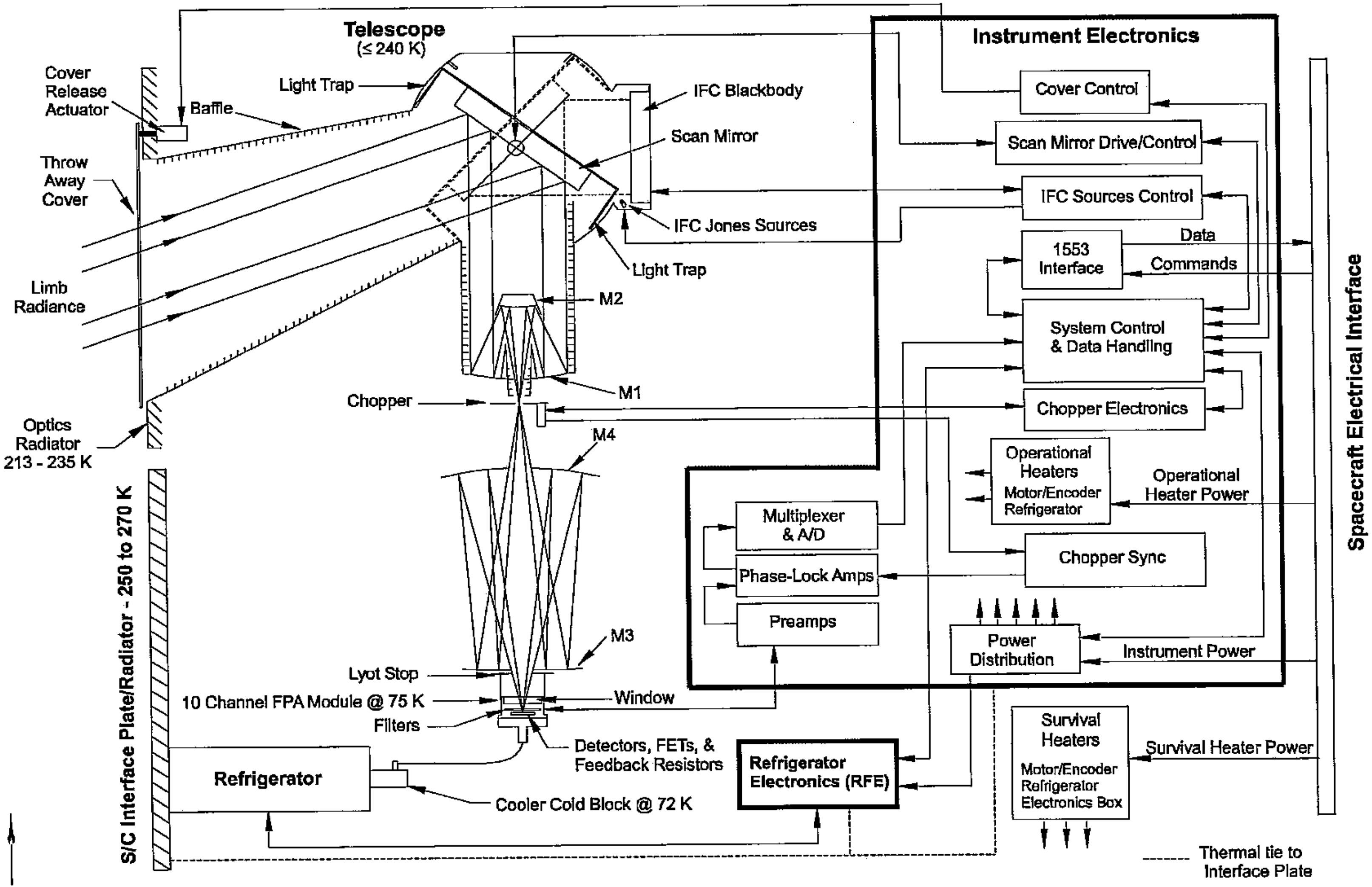
SABER Instrument Configuration



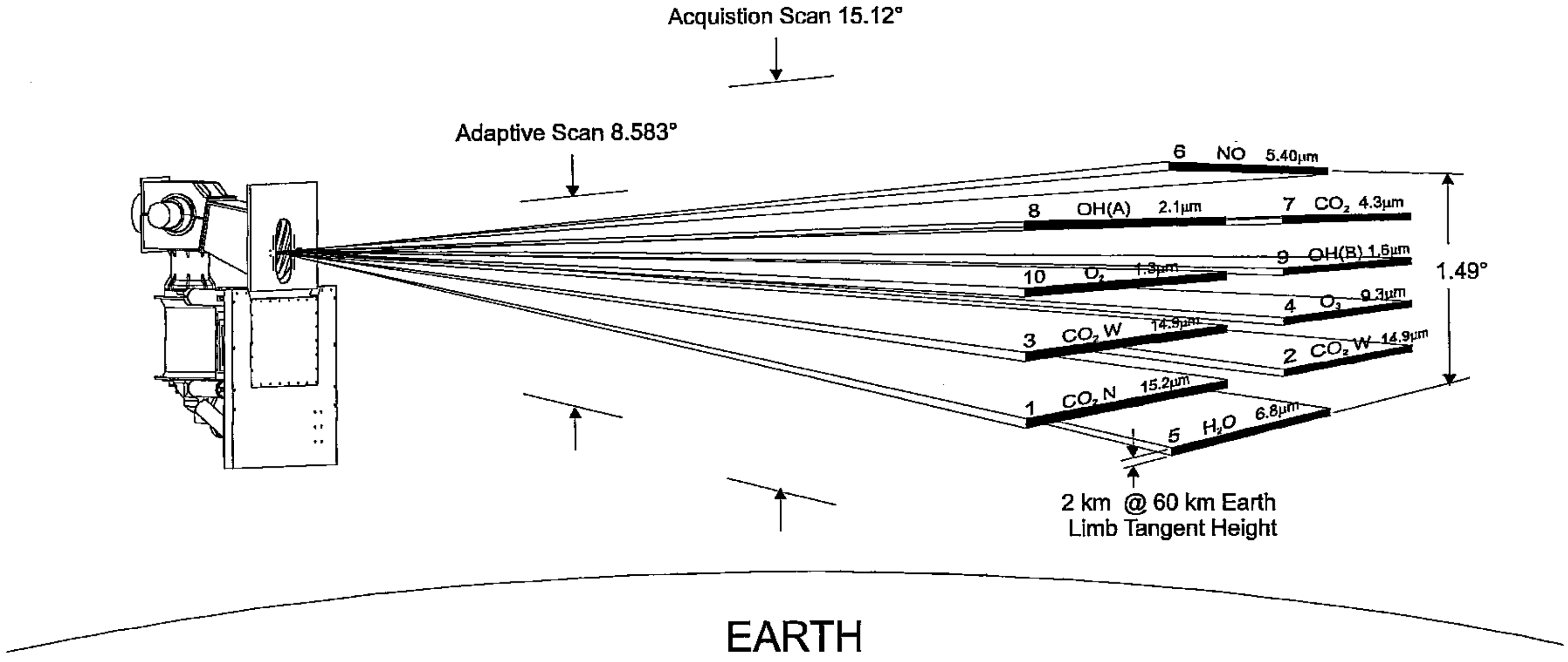
SABER Instrument Cut-Away View



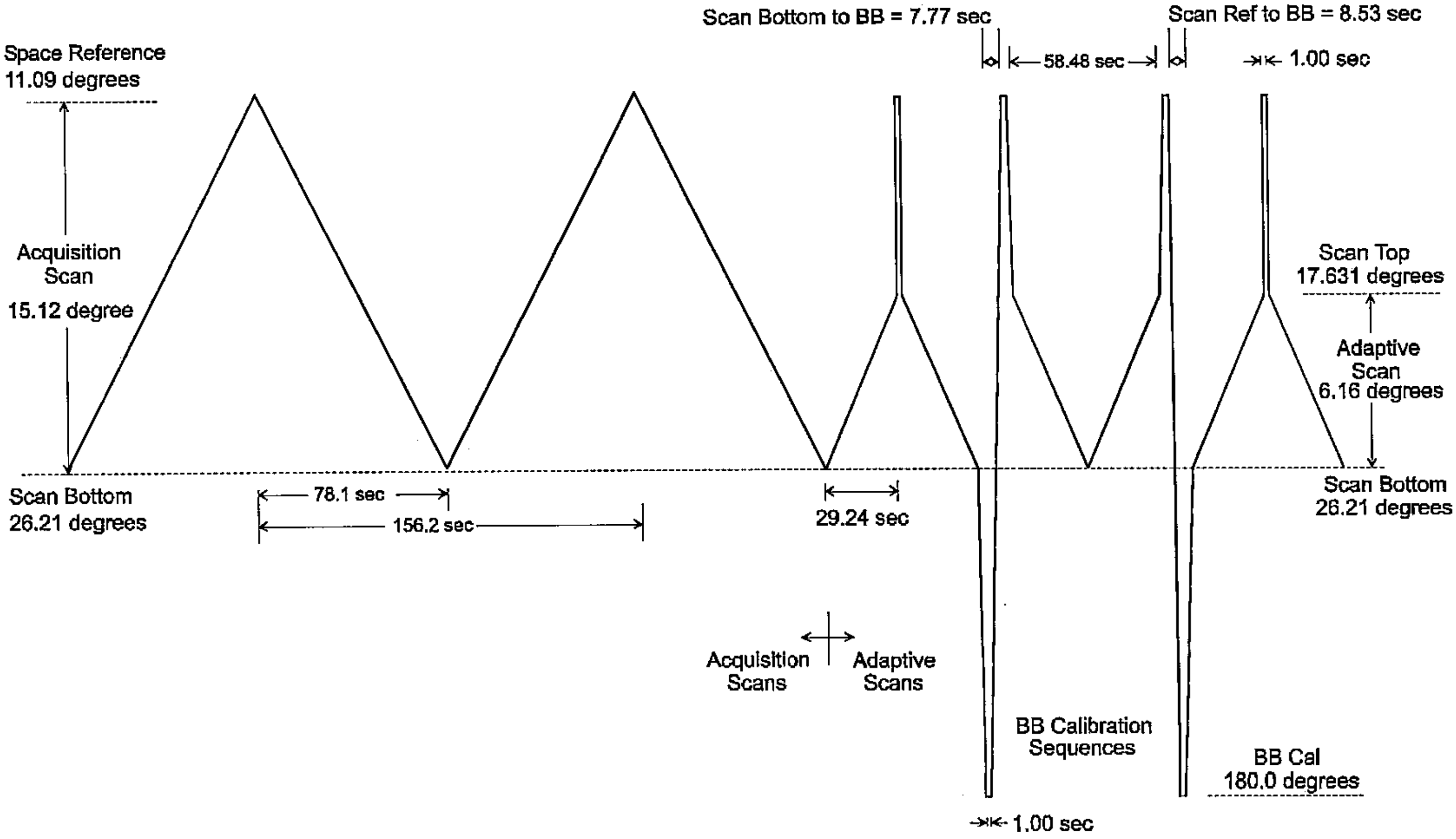
SABER Functional Block Diagram



SABER Field of View



SABER Limb Scan Sequence



RISK MANAGEMENT

Identified Risks

- Microminiature Detector/Filter Assembly Risks
- InGaAs Detector Risk
- Chopper Development Risk
- FPA Support Assembly Risks
- Refrigerator Risks
- Refrigerator to FPA Thermal Link Risks
- Calibration GSE Blackbody
- Funding Profile

Detector / Filter Assembly Risk Reduction

- **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 and a problem with the integration of these assemblies could have a major impact to the cost & schedule
  - Performance of HgCdTe detectors degrade when exposed to atmospheric water
- **Risk Mitigation:**
  - EG&G and OCLI will prototype the detector and filter frame assemblies
  - EG&G will integrate and test the completed package
  - EG&G is currently performing a KBr window seal evaluation
  - EG&G is also performing a HgCdTe detector passivation study to evaluate the effectiveness of a deposited CdTe film to protect the detectors from atmospheric water

InGaAs Detector Risk Reduction

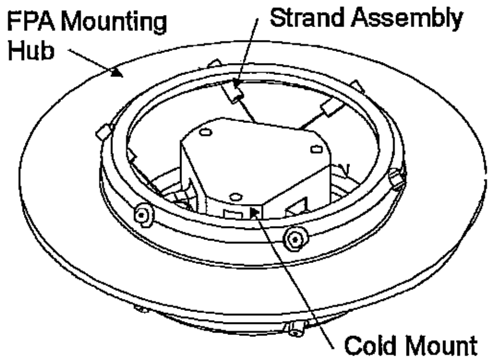
- **Risk Description:**
  - Two channels will use a new technology, long wavelength, InGaAs detector
  - Limited data is available for these detectors
- **Risk Mitigation:**
  - EG&G is currently performing space application environment testing of 2.6 micron cut-off wavelength InGaAs detectors to determine if performance issues exist
  - EG&G will fabricate and test as part of the detector assembly prototype the InGaAs detector for channel 8

Chopper Risk Reduction

- **Risk Description:**
  - SABER subcontract for chopper is with TFR - only known supplier with flight history
  - Company expertise resides with owner who is beyond retirement age
- **Risk Mitigation:**
  - Preliminary Design is complete and chopper breadboard near completion
  - TFR has agreed to share with SDL the critical design and fabrication techniques needed to fabricate the chopper if TFR could not build the prototype or flight units
  - TFR contract options will be exercised to perform final design, prototype fabrication and fabrication of up to 3 flight units as soon as funding is available

FPA Support Assembly Risk Reduction

- **Risk Description:**
  - Alignment stability and thermal performance of the kevlar FPA support system is unproven
  - Kevlar support system is a relatively new technology
- **Risk Mitigation:**
  - Two breadboards of the kevlar support system have been built and tested
  - First breadboard tests showed support system will meet the structural and thermal requirements
  - First breadboard testing also verified kevlar manufactures material properties data
    - Creep and ultimate strength characteristics verified
    - Same lot of Kevlar material tested will be used for flight support system
  - Second higher fidelity breadboard tested with and without a TRW refrigerator
    - Results show that the support system meets SABER's thermal requirements
  - Testing in progress to verify alignment stability



Refrigerator Risk Reduction

- **Risk Description:**
  - Baselined TRW refrigerator has not been qualified to the structural levels required by the TIMED mission and qualification may be cost prohibitive
  - Refrigerator performance at the SABER operating conditions is uncertain
  - Vibration caused by the refrigerator could cause the FPA or telescope to vibrate
- **Risk Mitigation:**
  - SDL has conducted searches for alternate suppliers of a refrigerator which would meet the SABER requirements but to date TRW still comes closest to meeting all the 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 cooler mount
  - Continuing to monitor the expected launch loads and will consider vibration isolation if the loads exceed the refrigerators capacity
  - Performed inhouse testing with TRW refrigerator on loan from USAF Phillips Lab - one of two coollers that successfully completed 17,000 Hr. of life testing
  - Test results shows the refrigerator when operated at 273 K has sufficient capacity at to cool the FPA to its operational temperature of 75 K
  - USAF Phillips Lab has agreed to conduct performance tests at SABER operational conditions on early TRW production units

FPA Thermal Link Risk Reduction

- **Risk Description:**
  - thermal link must have good thermal conduction and yet be sufficiently flexible to prevent transmitting refrigerator vibrations to the FPA
- **Risk Mitigation:**
  - Thermal link has been prototyped and tested
  - Link exceeds both thermal conductivity and vibration isolation requirements

Calibration Blackbody Risk Reduction

- **Risk Description:**
  - New, complicated, large (8 inch), high temperature (620 K) blackbody development
- **Risk Mitigation:**
  - **Mica Heaters Breadboard :** Heaters have been operated in a vacuum above anticipated watt densities and temperatures without failure
  - **Optical Black Surfaces:** Tested Enhanced Martin Black under the blackbody operating conditions.
  - **Outgassing:** Outgassing of mica heaters is under investigation. Past operation has shown an initial high outgassing rate which diminishes greatly during bakeout.
  - **High Temperature wire:** High temperature wire has been proven to operate in a vacuum at high temperatures without trouble. Wire heat sink potting methods have also been tested.
  - **PRTs:** Have identified designs for the two required styles of PRTs, are building and testing these PRT designs for self-heating in a vacuum, hysteresis and resistance drift. This is a major factor in the success of the blackbody
  - **Segment control system breadboard:** Plan to breadboard the blackbody control system. Control software and electrical hardware will operate a single segment heater assembly in a vacuum.
  - **Will conduct study following PDR to look at alternatives to this blackbody**

Funding Profile Risk Reduction

- **Risk Description:**
  - Most recent FY 1997 funding profile still only adequate when prorated for 3/4 year
  - FY 1998 funding uncertain
  - Limited funding level delays cooler, flight FPA, and mirror contracts until FY 1998
  - Subcontract procurements are on critical path
  - Subcontract costs potentially higher due to stringing out funding/work
- **Risk Mitigation:**
  - Contracts to be tailored to expected funding profile
  - Contracts will have a series of costed options which can be executed when funds are available
  - Identify subcontractor long lead items which could be procured early to reduce subcontractors schedule

RADIOMETRIC & OPTICAL SUBSYSTEM OVERVIEW

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December 10, 1996

OUTLINE

- **Requirements and Design Performance of Radiometric Subsystem**
- **Top-Level Design Description**
- **Telescope**
  - Ray Trace and key optical parameters
  - System MTF and Telescope Tolerance Budget
  - Straylight Performance
- **Detector Assembly**
  - Mechanical Configuration
  - Detector Performance
  - Filter Performance
- **Conclusion**

NOISE EQUIVALENT RADIANCE (NER) & DYNAMIC RANGE REQUIREMENTS

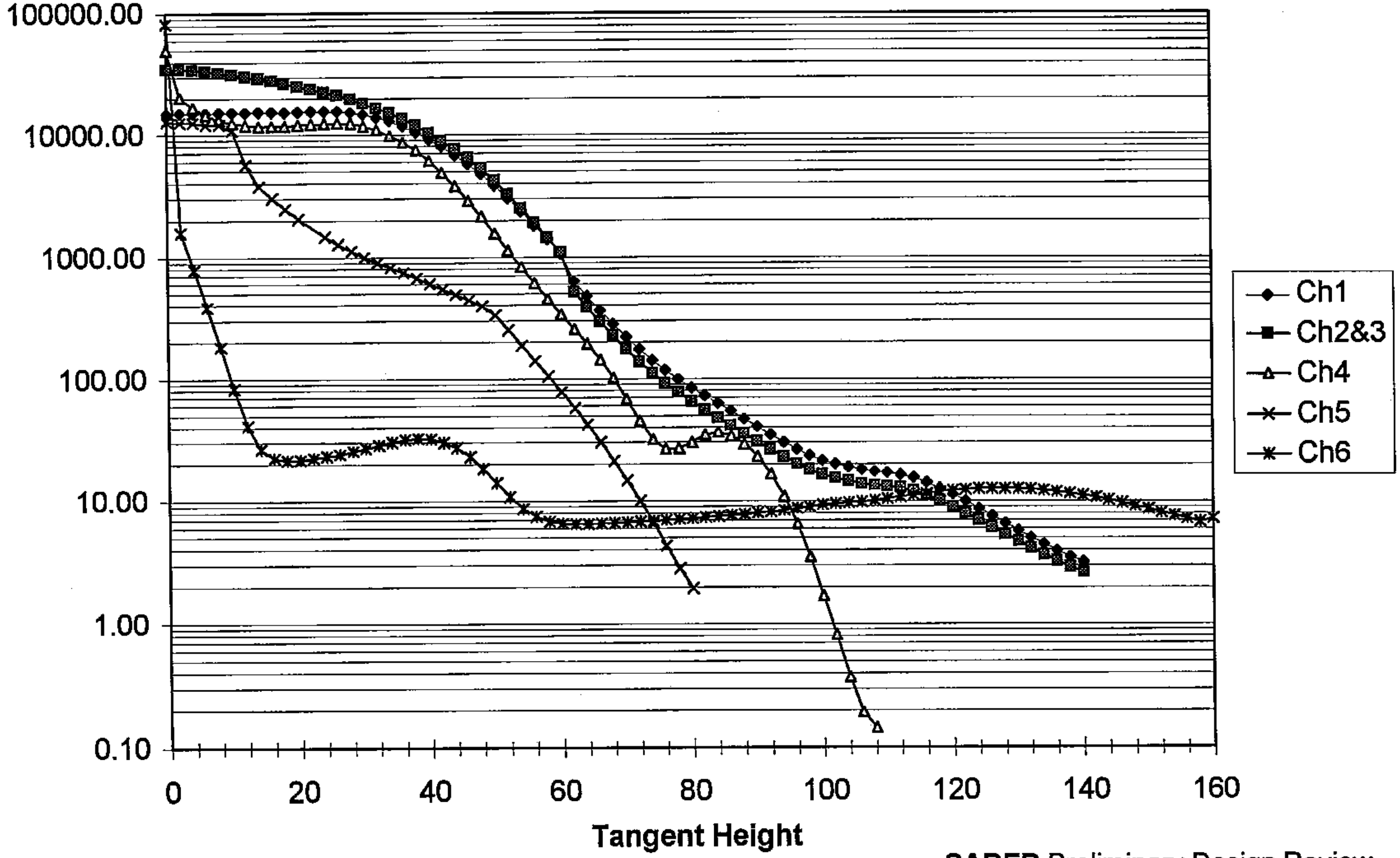
Channel Number	Noise Eq. Radiance (NER) * ** $(Wcm^{-2}sr^{-1})$			Dynamic Range		
	Requirement	Design	Req./Design.	Science Req.	Earth View Req.	Design
1	1.75E-8	1.29E-8	1.36	5700	19572	> 19572
2 & 3	2.80E-8	1.56E-8	1.79	21400	73968	> 73968
4	1.12E-8	3.13E-9	3.58	13400	59401	> 59401
5	3.73E-9	2.12E-9	1.76	2150	87419	> 87419
6	2.49E-9	1.49E-10	16.74	10	31372	> 31372
7	1.32E-9	1.24E-10	10.62	1000	7868	> 7868
8	4.70E-10	2.54E-10	1.85	850	6	> 850
9	7.00E-10	3.23E-10	2.17	360	0	> 360
10	7.00E-10	3.72E-10	1.88	14300	0	> 14300

*For 0.110 integration time T (Noise Equivalent Electrical Bandwidth = 1/2T =4.545 Hz)

**Assuming minimum values for filter transmission, detector D* and responsivity

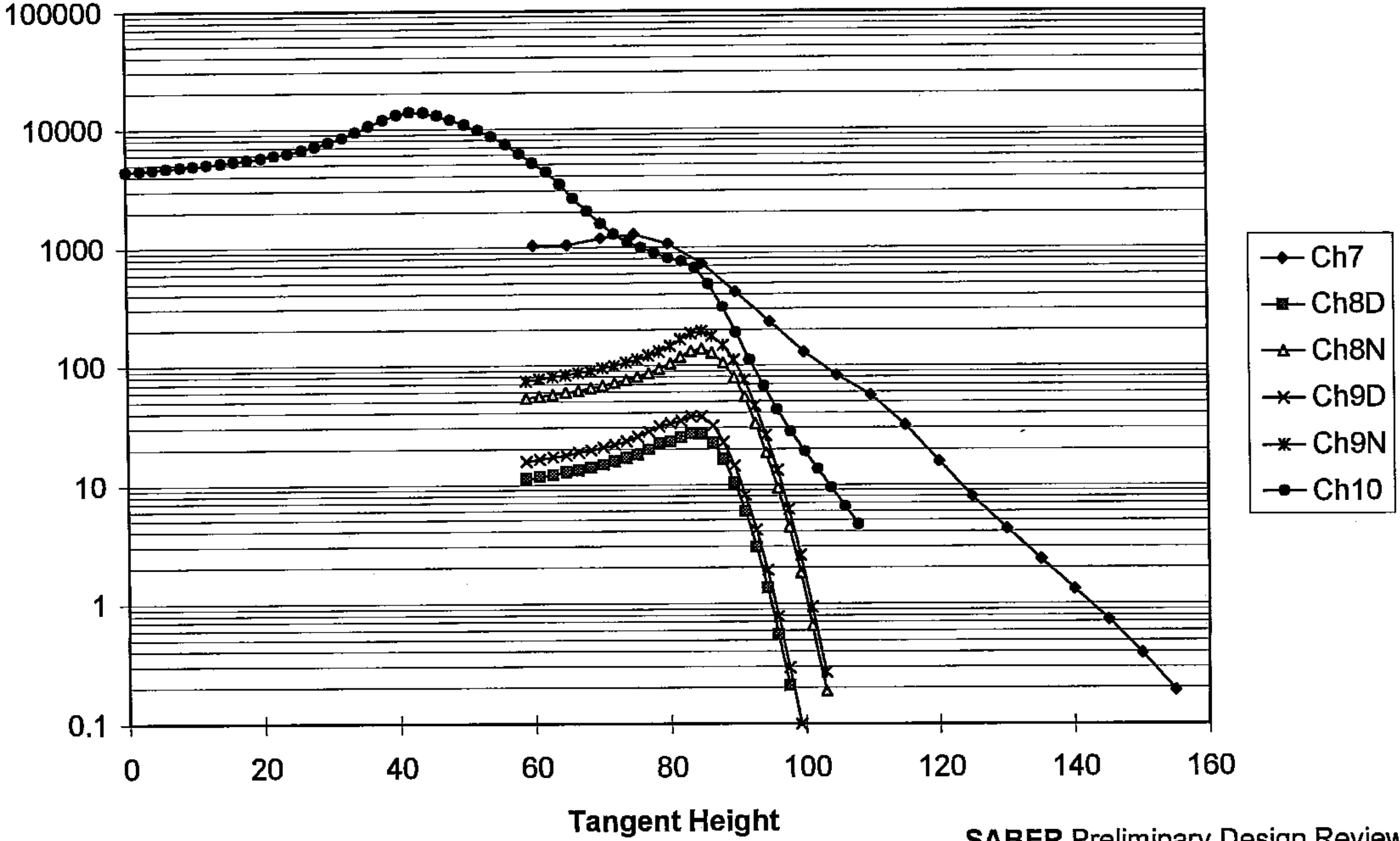
(LIMB RADIANCE) / (REQUIRED NER)

Chart 1 of 2



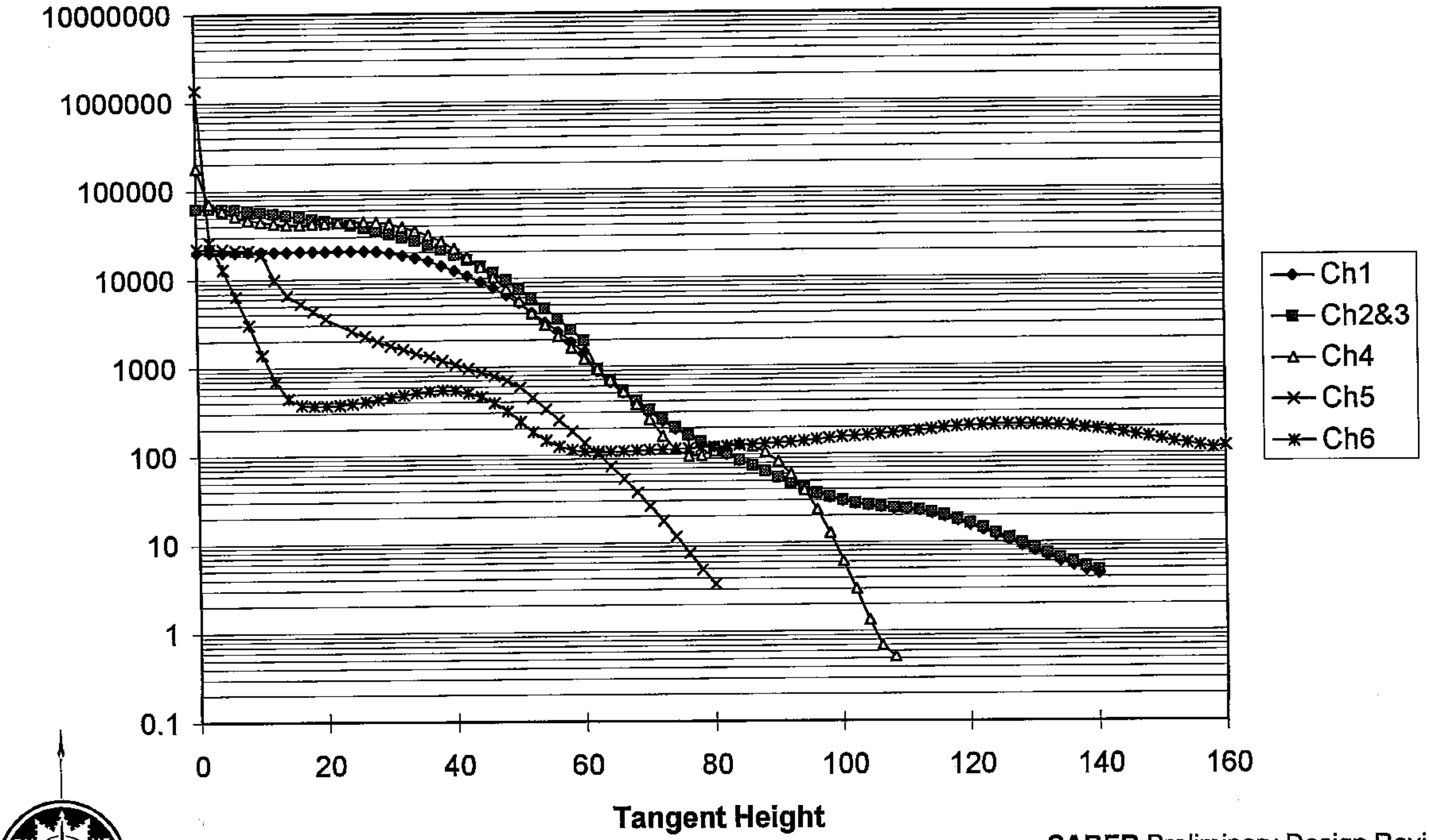
(LIMB RADIANCE) / (REQUIRED NER)

Chart 2 of 2



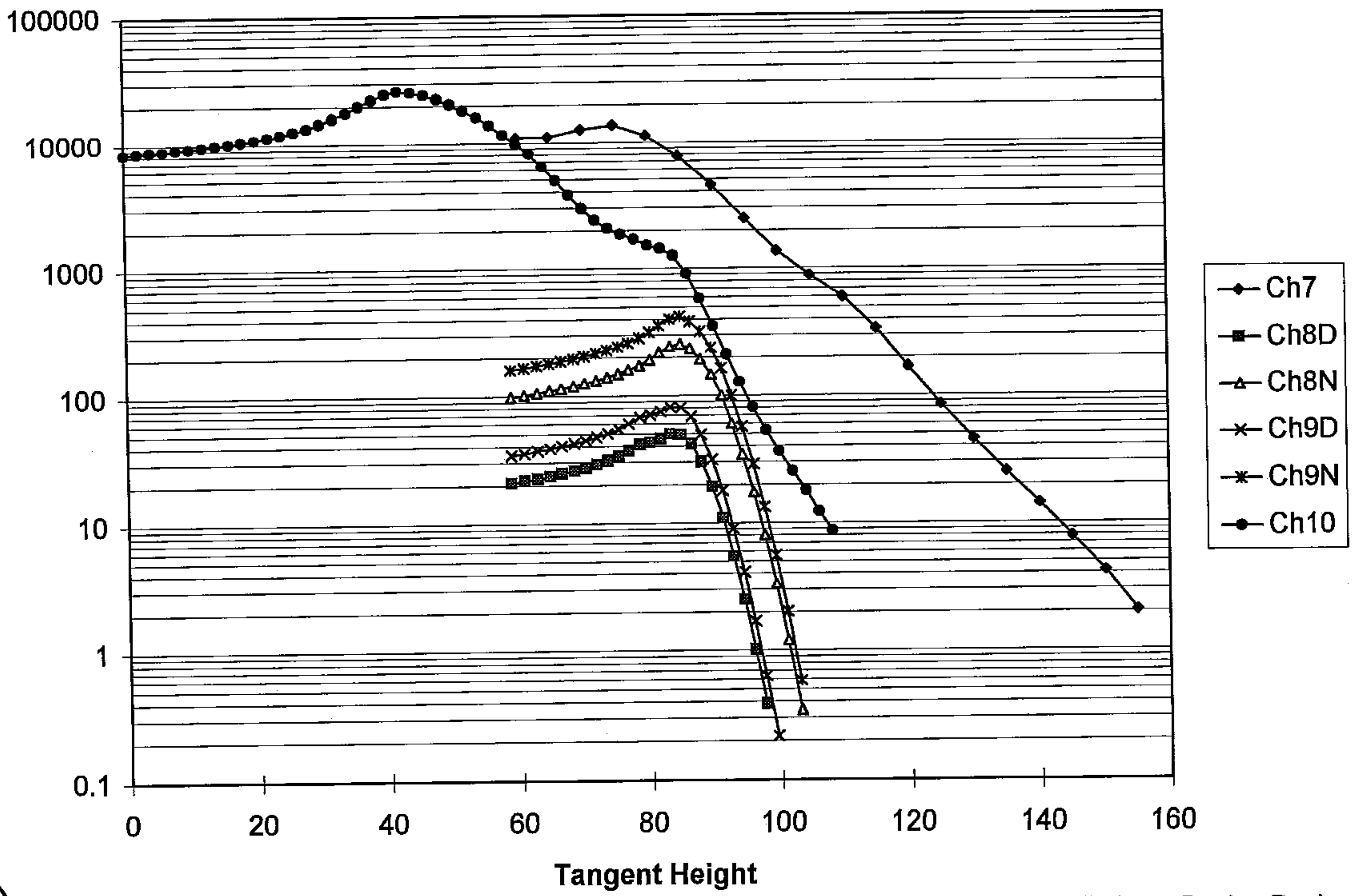
(LIMB RADIANCE) / (DESIGN NER)

Chart 1 of 2



(LIMB RADIANCE) / (DESIGN NER)

Chart 2 of 2



FILTER SPECTRAL BANDWIDTH REQUIREMENTS

Channel	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$_2$O	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)	2410 (4.15 μm)	2410 ± 24	2413.9	2270 (4.41 μm)	2270 ± 23	2271.9
8	OH (A)	5200 (1.92 μm)	5200 ± 52	5184.8	4500 (2.22 μm)	4500 ± 45	4516.5
9	OH (B)	6500 (1.54 μm)	6500 ± 65	6495.2	5800 (1.72 μm)	5800 ± 58	5813.3
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	0.68	≤ 2.0	0.72
8	≤ 2.5	0.86	≤ 2.5	1.45
9	≤ 2.5	0.84	≤ 2.5	0.84
10	≤ 2.5	0.78	≤ 2.5	0.81

* % Slope ≡ ((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

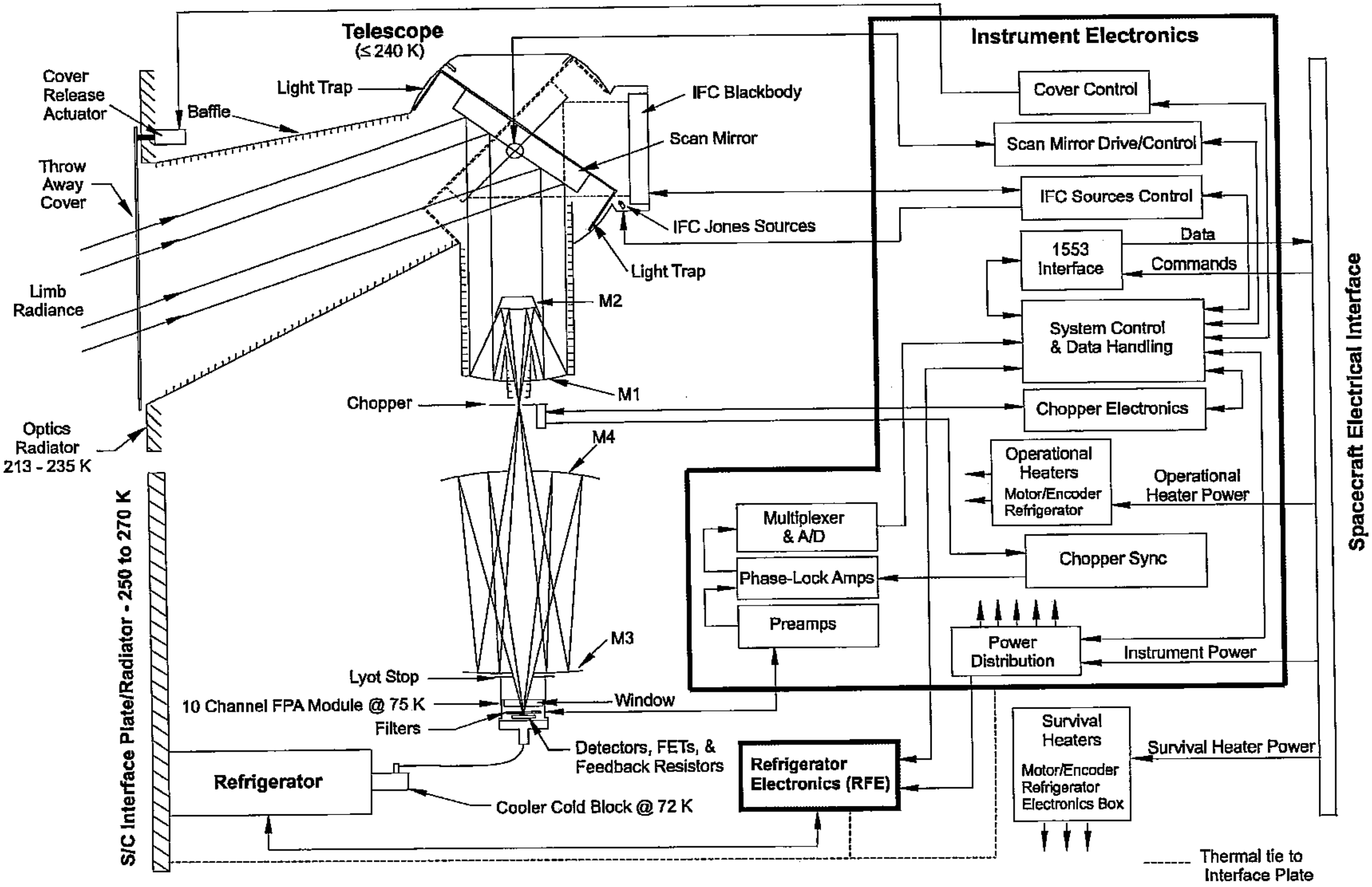
** Average In-Band Transmittance calculated between half power points

*** 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.

MISCELLANEOUS REQUIREMENTS

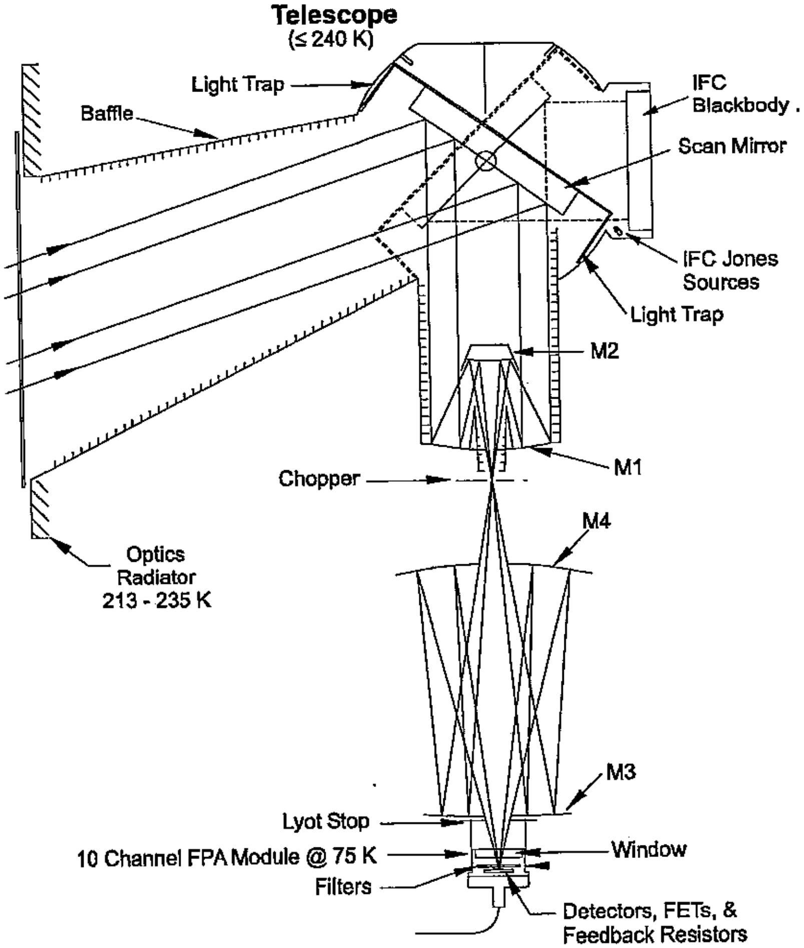
Parameter	Requirement	Design
Focal plane channel locations	IRD Figure 3	IRD Figure 3
Instantaneous Field of View (IFOV) at 60 km tangent height	2 km Full Width at Half Maximum (FWHM)	1.88 FWHM
System Modulation Transfer Fuction (MTF) at 0.25 cyles/km	≥ 0.5 channels 4 through 10	Design ≥ 0.546 Design+(Static and Dynamic Error Budgets) ≥ 0.528
Maximum Depression Angle	Angle required to place top edge of FPA at a tangent altitude 3 km below the horizon. (Scanner line of sight (LOS) depression angle 26.214°)	Top edge of the top detector (detector 6) has a clear view through the baffle when the scanner LOS depression angle is 26.214°
Minimum Depression Angle	Angle required to place bottom edge of FPA at a tangent altitude of 400 km (Scanner LOS depression angle equals 11.097°)	Bottom edge of bottom detector has a clear view through the baffle when the scanner LOS depression angle is 11.097°
Radiance Bias Drift	≤ 1 NER betweeen space looks	≤ 1 NER betweeen space looks

SABER FUNCTIONAL DIAGRAM

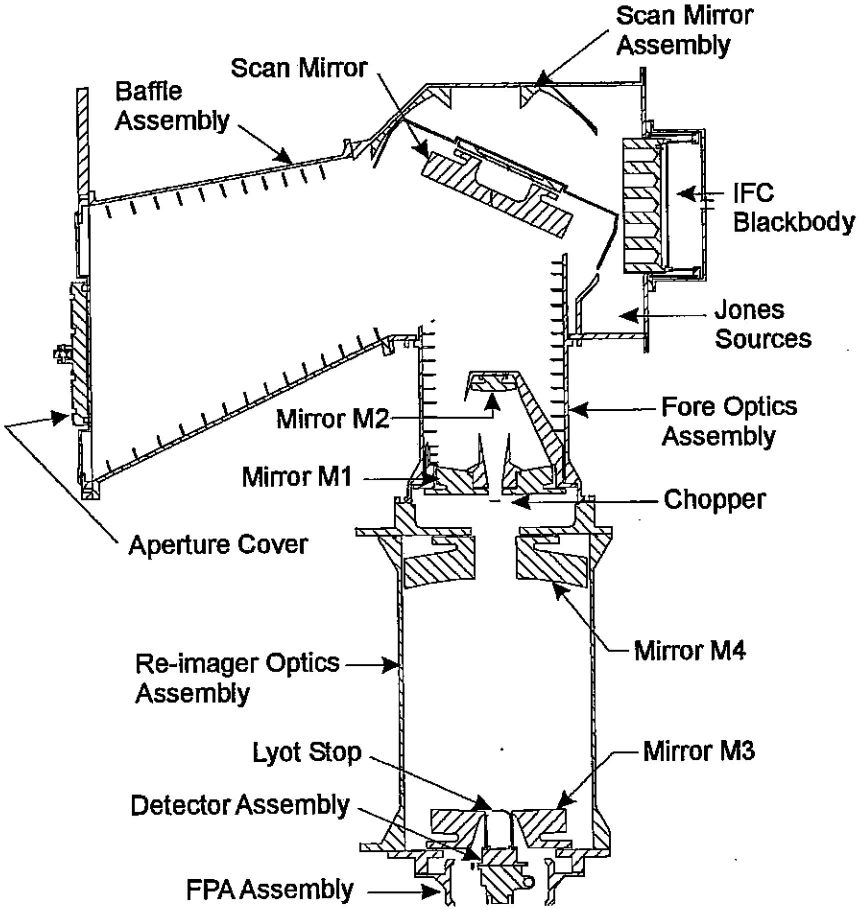


RADIOMETRIC SUBSYSTEM

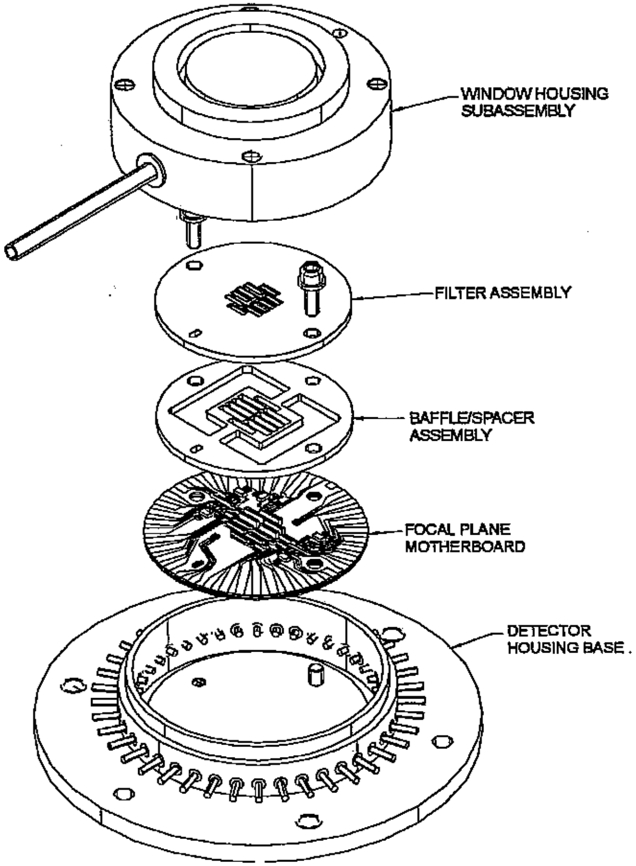
- **Telescope**
  - On-Axis Cassegrain with clamshell reimager
  - Cold Lyot stop
  - Low scatter super polished mirrors by SSG
- **Detector Assembly**
  - Filters
    - 10 miniature filters in a common frame
    - Subcontractor: OCLI
  - Detectors
    - 5 HgCdTe, 2 InSb, 3 InGaAs
    - Subcontractor: EG&G, Judson
- **In Flight Calibration (IFC) Sources**
  - Described in calibration presentation
  - Full aperture black body
  - Two Tungsten Lamp Jones Sources
- **Chopper**
  - 1000 Hz tuning fork
  - 10 hole "picket fence" shutters
  - Efficiency 0.446
  - Subcontractor: TFR



RADIOMETRIC SUBSYSTEM IMPLEMENTATION



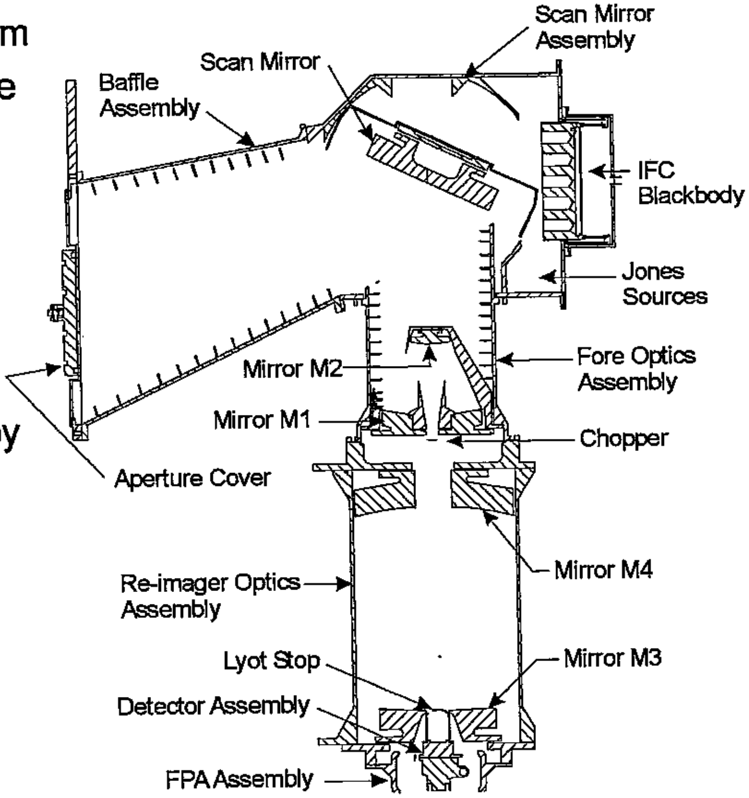
Radiometric Subsystem



Detector Assembly

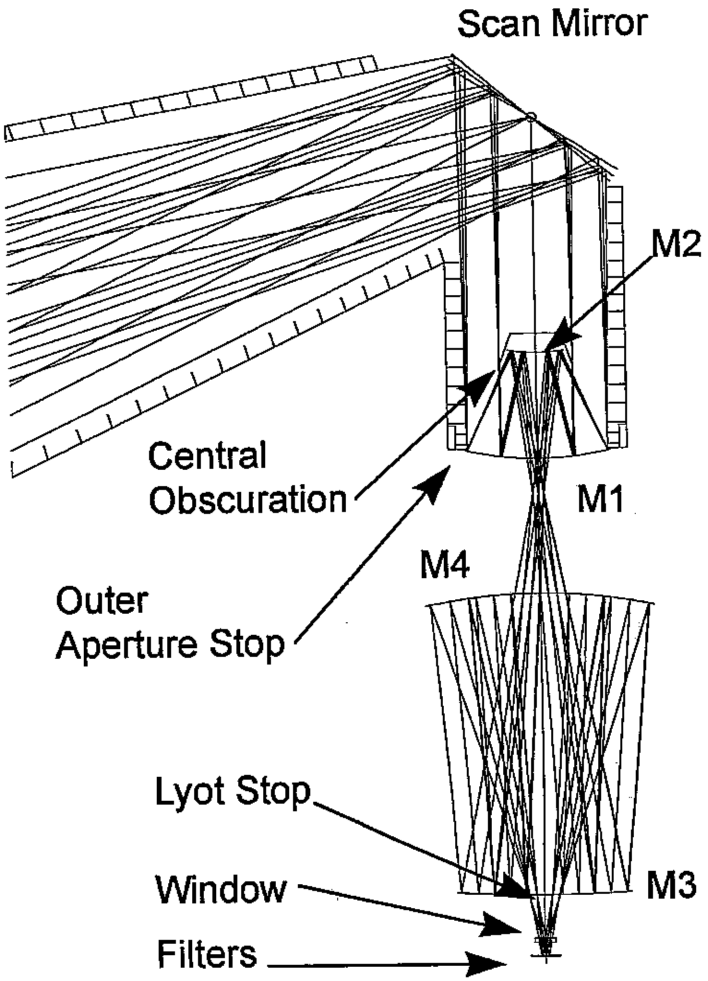
TELESCOPE

- Mirrors thermally cycled 6061 aluminum plated with nickel for super polishing then plated with gold
- Telescope structure thermally cycled 6061 aluminum
- Telescope nearly insensitive to uniform temperature changes
  - Reflective optical system all made from the same materially simply scale with uniform temperature changes
  - Everything aluminum except
    - Nickel plating on mirrors
      - Very thin bimetalic stress balanced by coating front and back
    - Detector assembly
      - Temperature controlled by cooler
    - Kevlar FPA support
      - Length short
  - Residual errors compensated by focusing SABER at nominal operating temperature
- High thermal conductance and symmetry of mirrors and spacers minimize thermal gradient errors

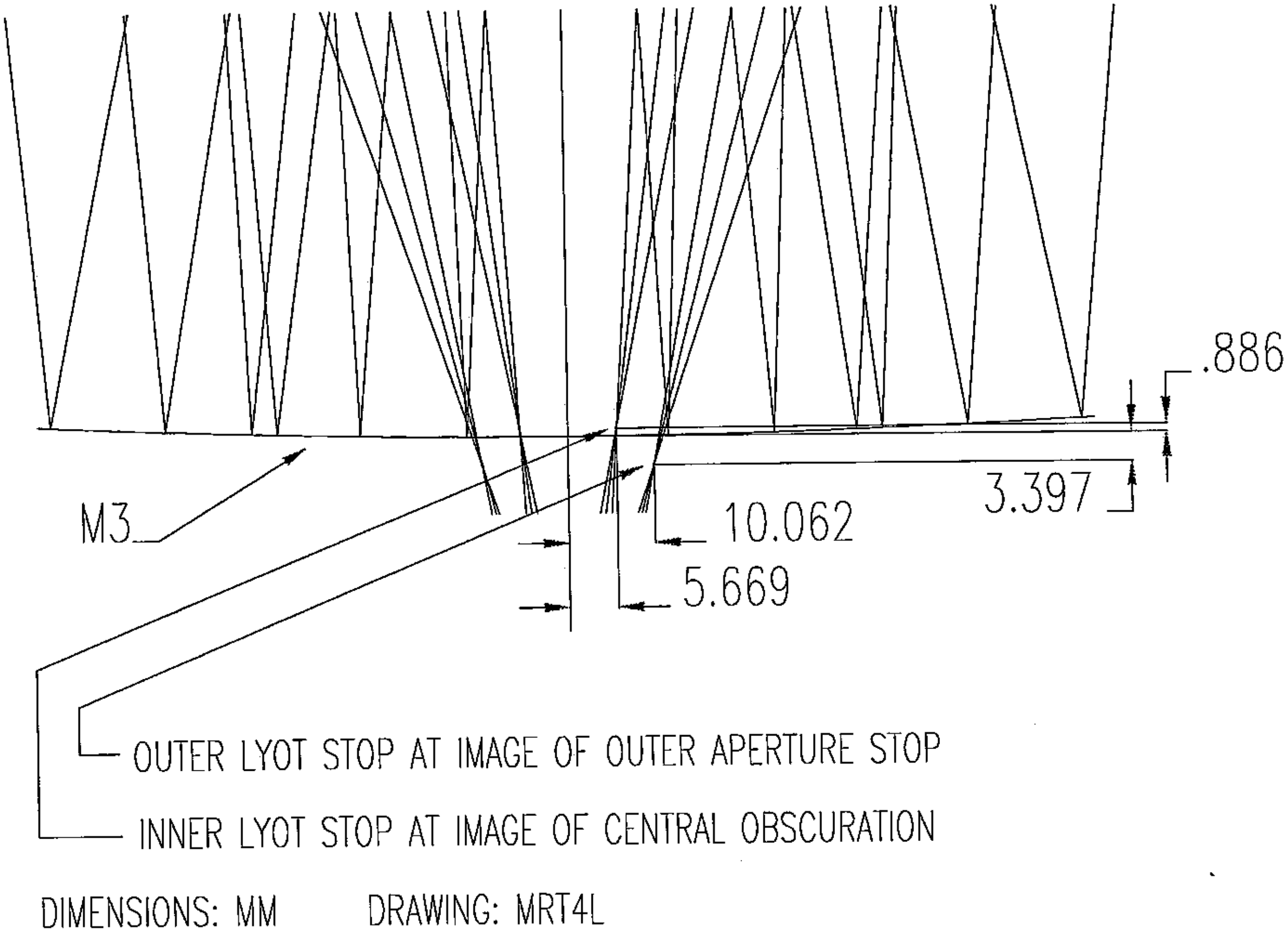


TELESCOPE RAY TRACE AND OPTICAL PARAMETERS

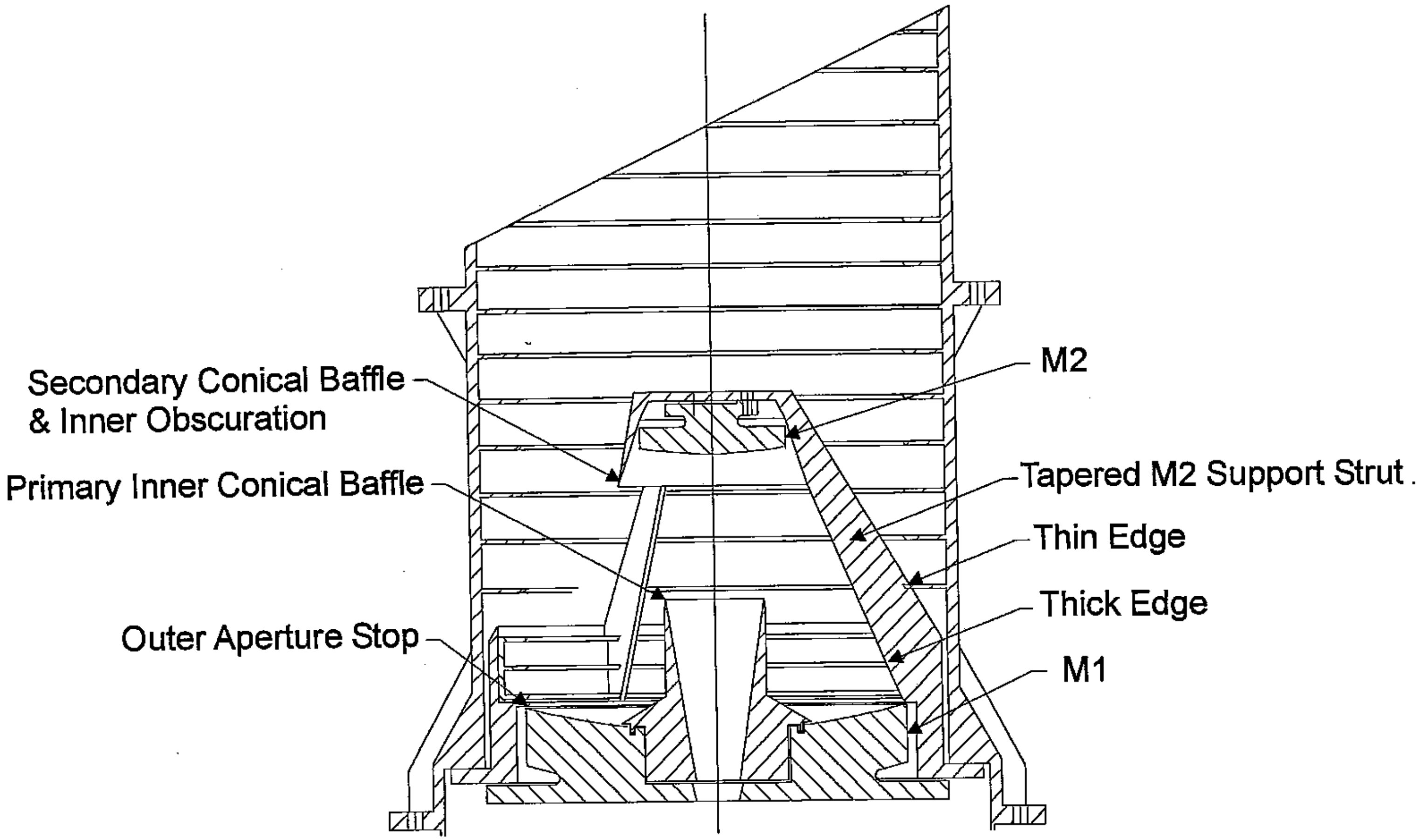
- Focal Length: 200 mm
- F-Number: 2
- Entrance Pupil Diameter: 100 mm
- Central Obscuration Diameter: 52 mm (27% area)
- Primary Mirror M3
  - Radius: 225.00 mm concave
  - Conic constant: -1.15149 (Hyperbola)
- **Secondary Mirror M4**
  - Radius: 120 mm convex
  - Conic constant -6.62063 (Hyperbola)
- **Tertiary Mirror M3**
  - Radius: 1050 mm concave
  - Conic constant -60.08293 (Hyperbola)
- **Quaternary Mirror M4**
  - Radius: 384.41 mm
  - Conic constant : .39100 (Oblate ellipse)
- **Spacings**
  - Scan Mirror to M1: 241.402 mm
  - M1 to M2: 75.00 0 mm
  - M2 to M3: 380.000 mm
  - M3 to M4: 210.000 mm
  - M4 to Window: 240.337 mm
  - KBr Window thickness: 3mm



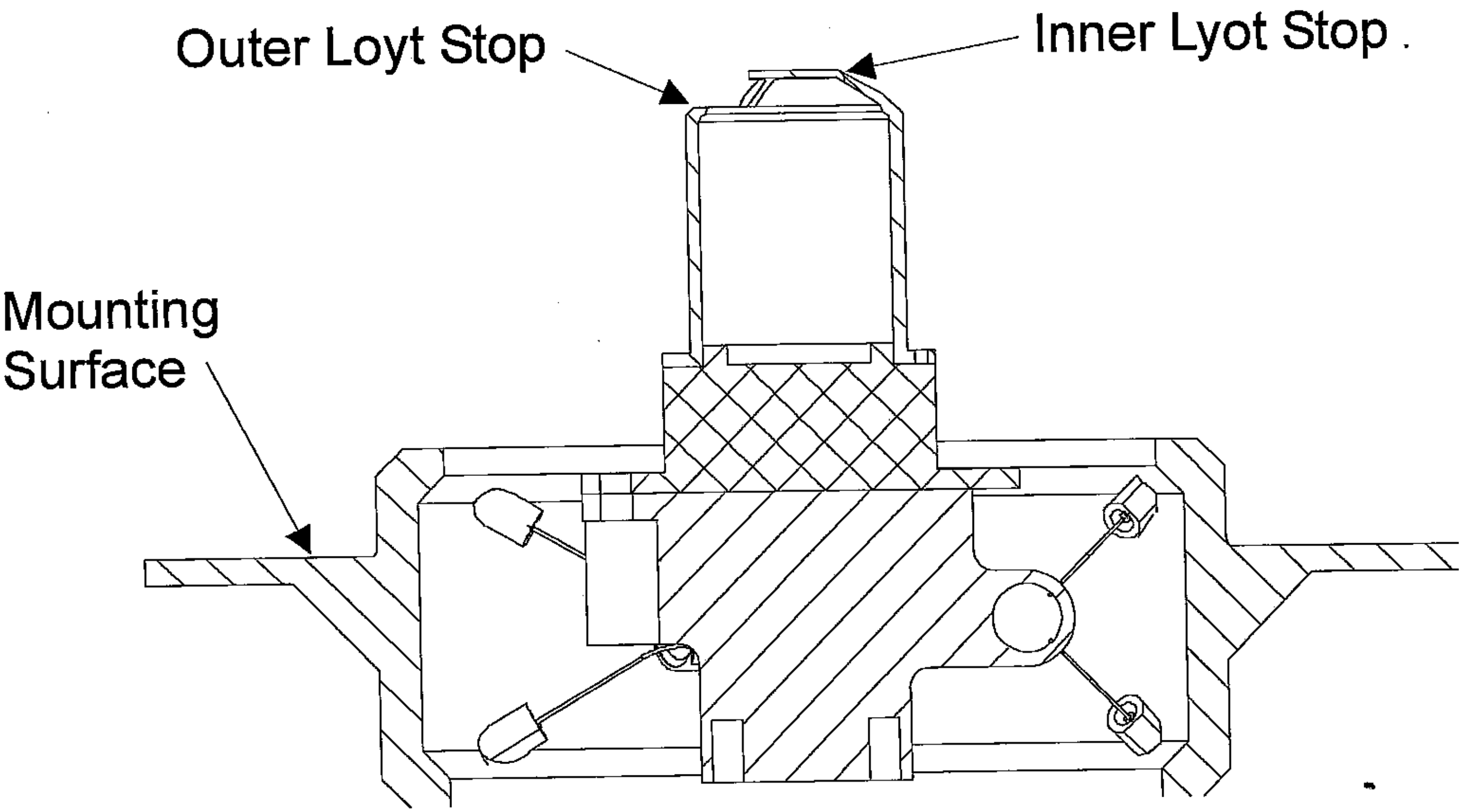
LYOT STOP LOCATION



FORE OPTICS ASSEMBLY



FPA ASSEMBLY



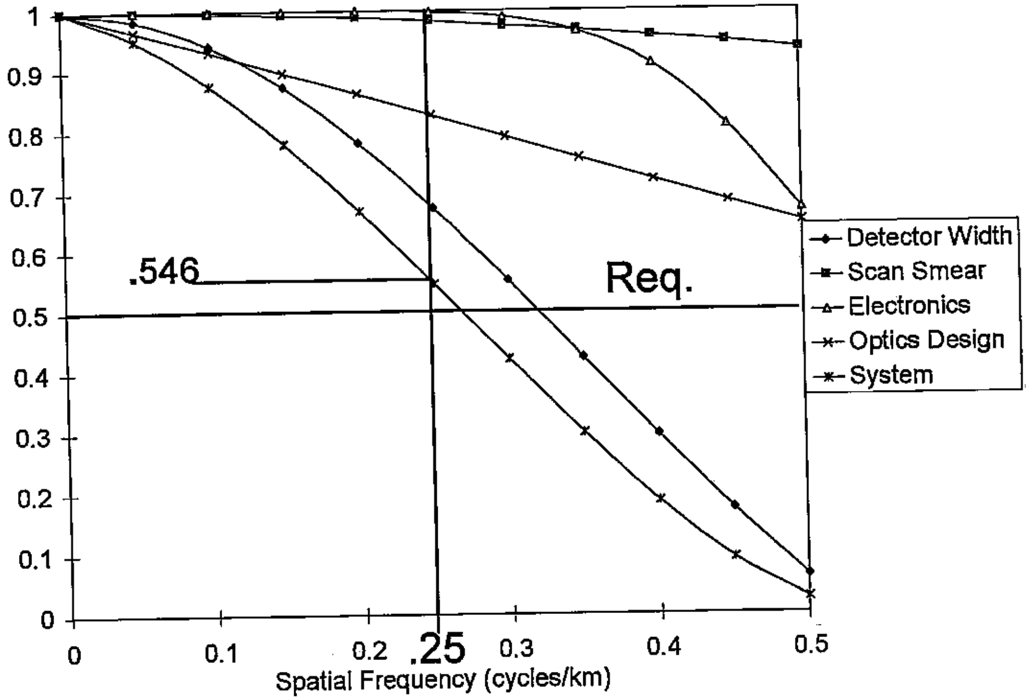
Outer Loyt Stop

Inner Lyot Stop

Mounting Surface

CHANNEL 4 SYSTEM MTF AND OPTICAL TOLERANCE BUDGET

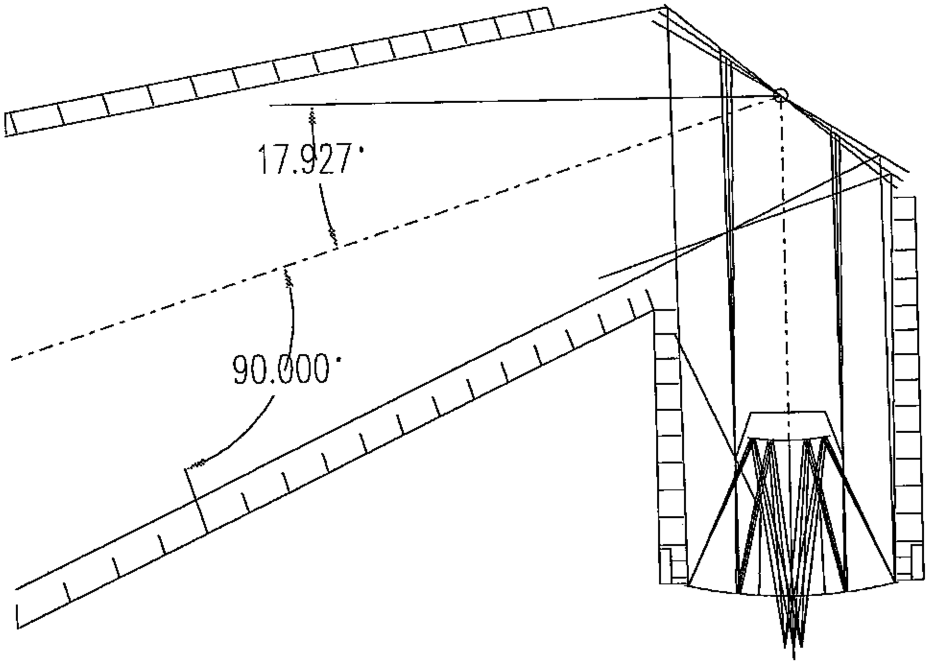
- System MTF = .546 with optics as designed. (RMS wavefront error =0.036 waves)
- System MTF =.500 when RMS wavefront error =.160 waves
- System MTF = 0.528 at budgeted RMS wavefront error.
- Static Errors
  - Focus adjustment can compensate for many of these errors
  - Budgeted error = .053 waves
- Dynamic Errors
  - Focus adjustment can not be used
  - Budgeted error = 0.033 waves
- RSS design, static and dynamic error budgets = 0.0985 waves



STRAY LIGHT DESIGN FEATURES

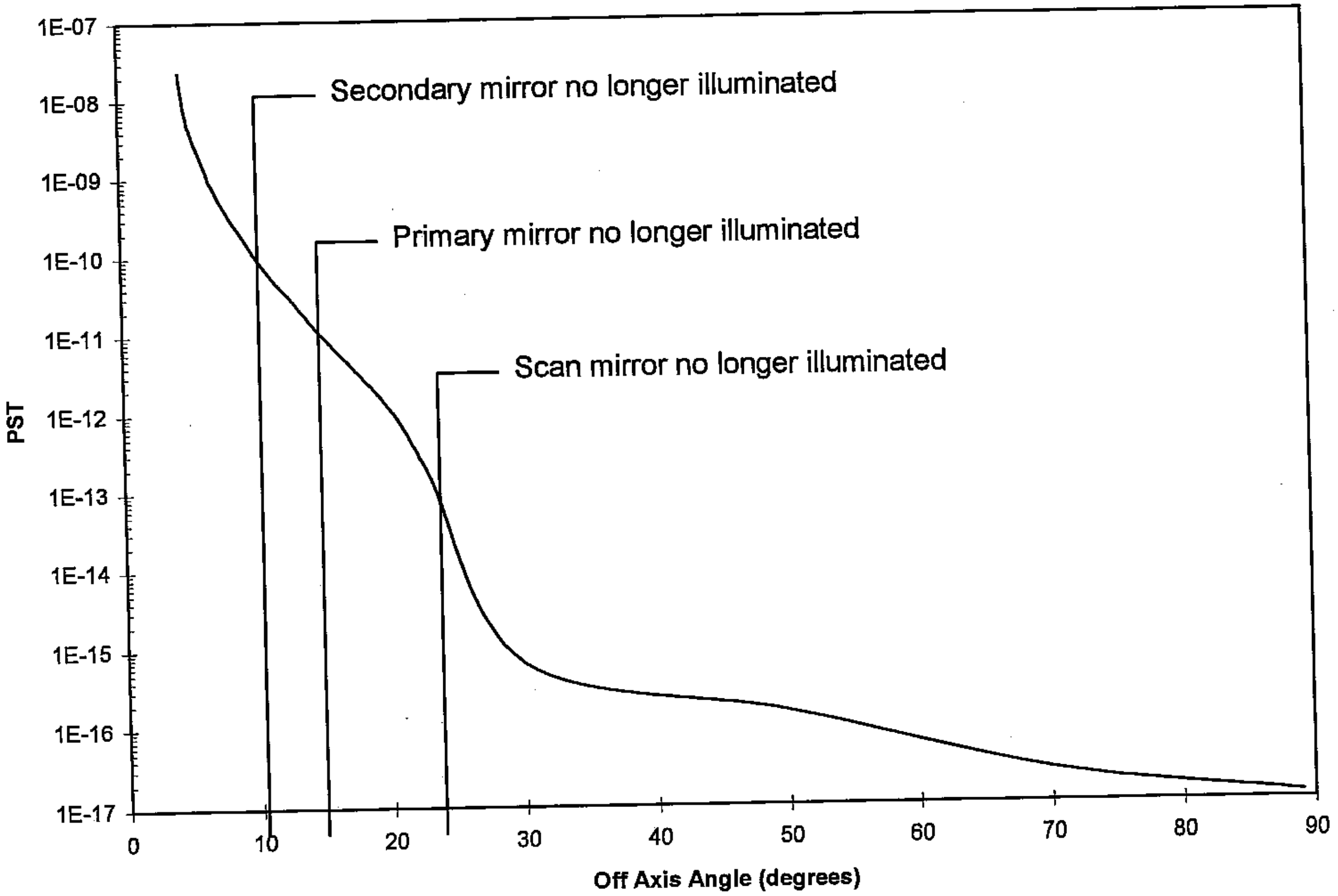
- **Reimaging optics allow for the use of two key features**
  - Intermediate field stop
    - Only scattered light from the mirrors and baffles located prior to stop are allowed to enter the reimaging part of the system
  - Cold Lyot stop
    - Removes diffracted light from aperture stop and direct scatter from baffle
    - Blocks scatter from inner primary baffle
    - Lyot stop supports totally block diffraction secondary supports
    - Limits the background radiation from within telescope
- **Mirrors are superpolished**
- **Main baffle limits the angles that the mirrors can be illuminated by off axis sources**
- **Baffle vanes and non-optical elements are coated with a highly absorptive paint**

BAFFLE DESIGN



- **Baffle limits off axis illumination of mirrors**
- **Scattered light from baffle is negligible**
- **Baffle vanes are perpendicular to baffle axis**
- **Vane tips have 2 mm tolerance w.r.t. marginal rays**
- **Baffle vane layout meets two bounce criteria**
- **Vane depth and spacing**
  - Main Baffle
    - Vane depth: 10 mm
    - Vane Spacing: 21 mm
  - Fore-optics Baffle
    - Vane depth: 10 mn
    - Vane Spacing: 12 mm
- **Aeroglaze 306 paint is modeled as a diffuse surface having 7.0 to 8.5 % reflectivity**
- **Baffle axis depression angle: 17.927 degrees**

POINT SOURCE TRANSMISSION (PST) CURVE*



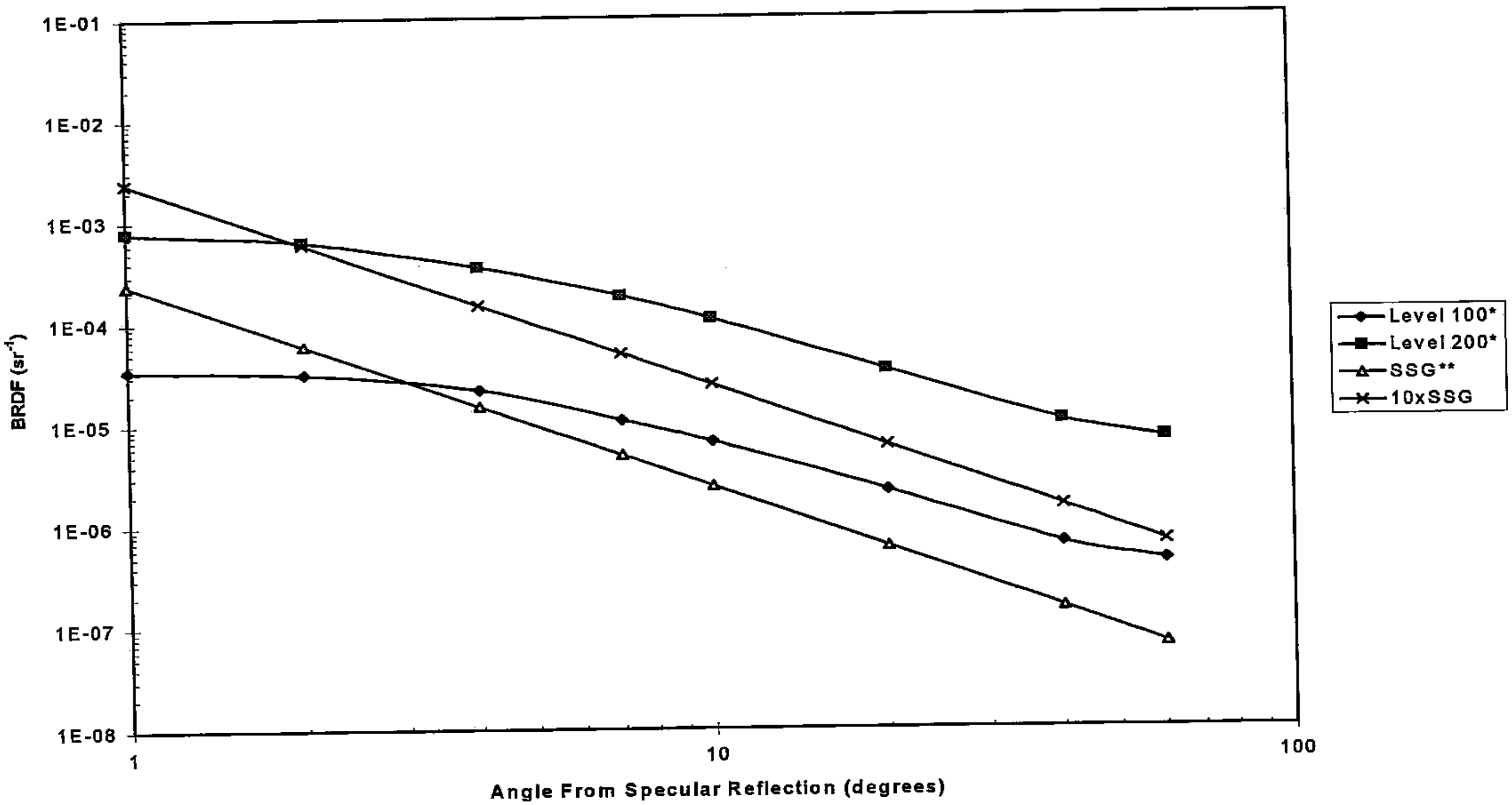
*Channel 3 for 80 km tangent height. Other channels and tangent heights are similar.

NON-REJECTED RADIANCE (NRR) FROM EARTH & ATMOSPHERE

Channel Number	Day or Night	NRR (W/cm^2/sr)	$\frac{\text{NRR}}{\text{NER}}$	$\frac{\text{Signal Radiance}}{\text{NER}}$	$\frac{\text{Signal Radiance}}{\text{NER + NRR}}$
1	-	8.96E-9	0.04	84.30	81.06
2	-	1.26E-8	0.09	64.99	59.84
3	-	2.83E-8	0.07	64.98	60.87
4	-	3.70E-9	0.07	30.23	28.27
5	-	2.33E-10	0.06	1.95	1.83
6	-	1.20E-9	0.47	7.22	4.91
7	-	2.26E-9	0.01	1061	1048
8	Day	7.81E-12	9.9E-5	23.06	23.06
8	Night	3.6E-11	4.8E-4	102.6	102.6
9	Day	1.14E-11	1.8E-4	32.28	32.28
9	Night	5.39E-11	8.7E-4	143.7	143.6
10	-	5.97e-10	0.11	809.4	732.7

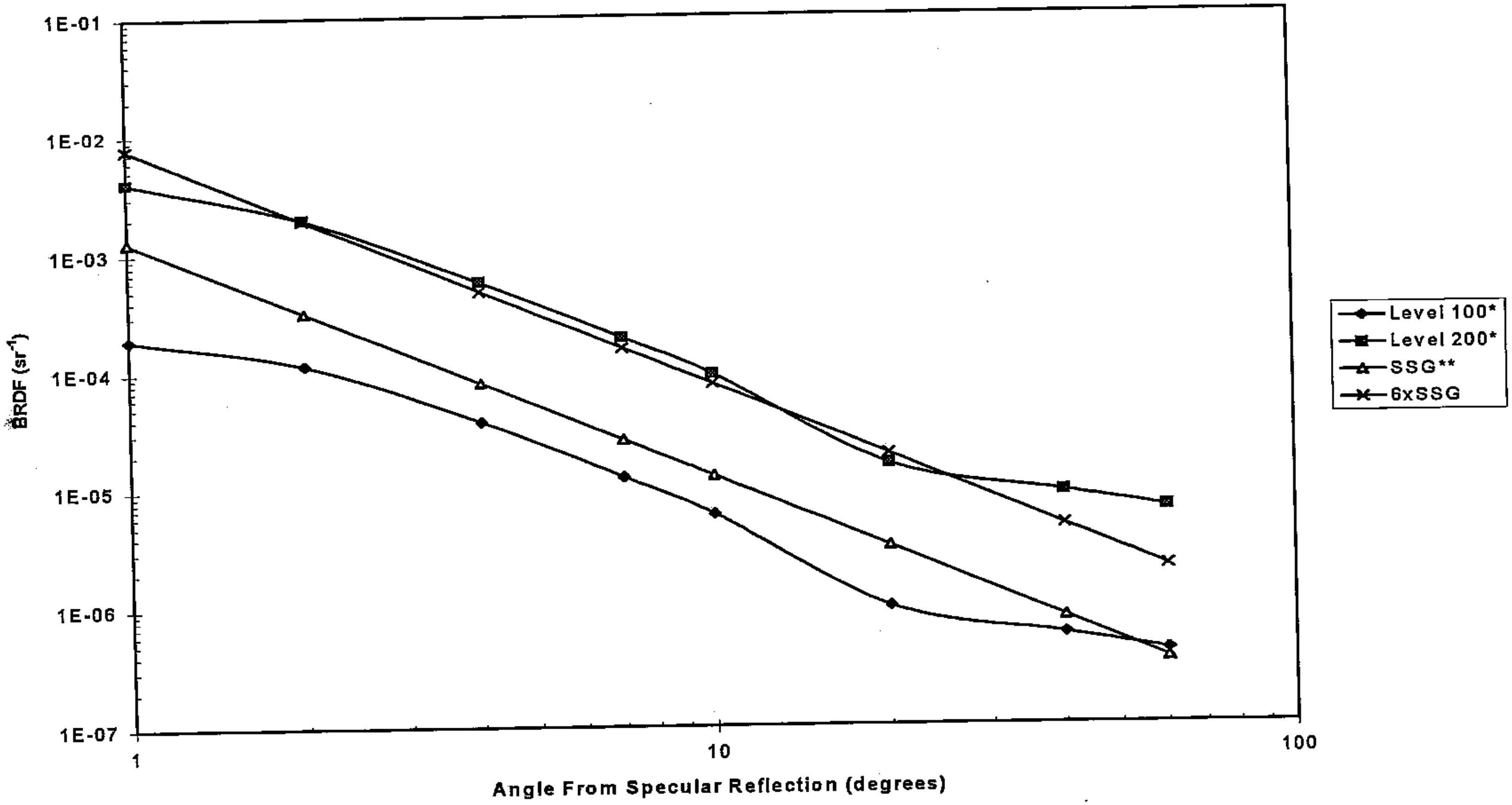
1) NER is IRD Required Noise Equivalent Radiance
2) BRDF: Chs. 1 thru 4, 2.39E-4 at 1° with 1.84 slope; Chs. 5 thru 8, 1.28E-3 at 1° with 2.15 slope; Chs. 9 thru 10,1.58E-3 at 1° with 2.00 slope. (SSG pristine clean mirror data for 10.6μm, 3.39μm and 0.63μm wavelengths respectively)
3) Reflected sunlight not included
4) Off-axis paths through chopper holes not yet included (Analysis still in progress)

MIRROR BRDF at 10.6 μm



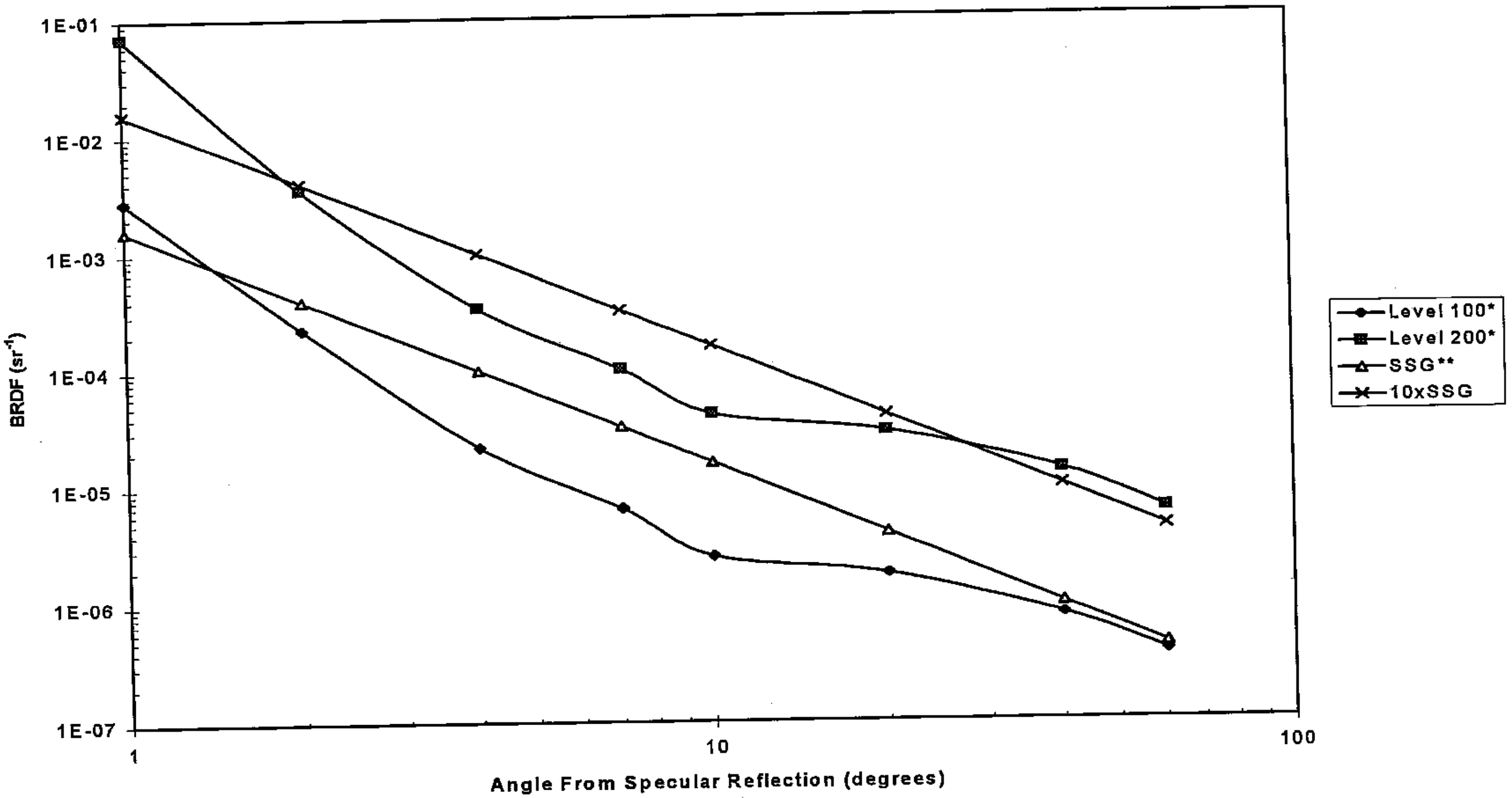
*Spyak and Wolf, Optical Engineering Vol. 31, p 1746 - 1784, (1992)
**SSG measured data of pristine mirror

MIRROR BRDF at 3.39 μm



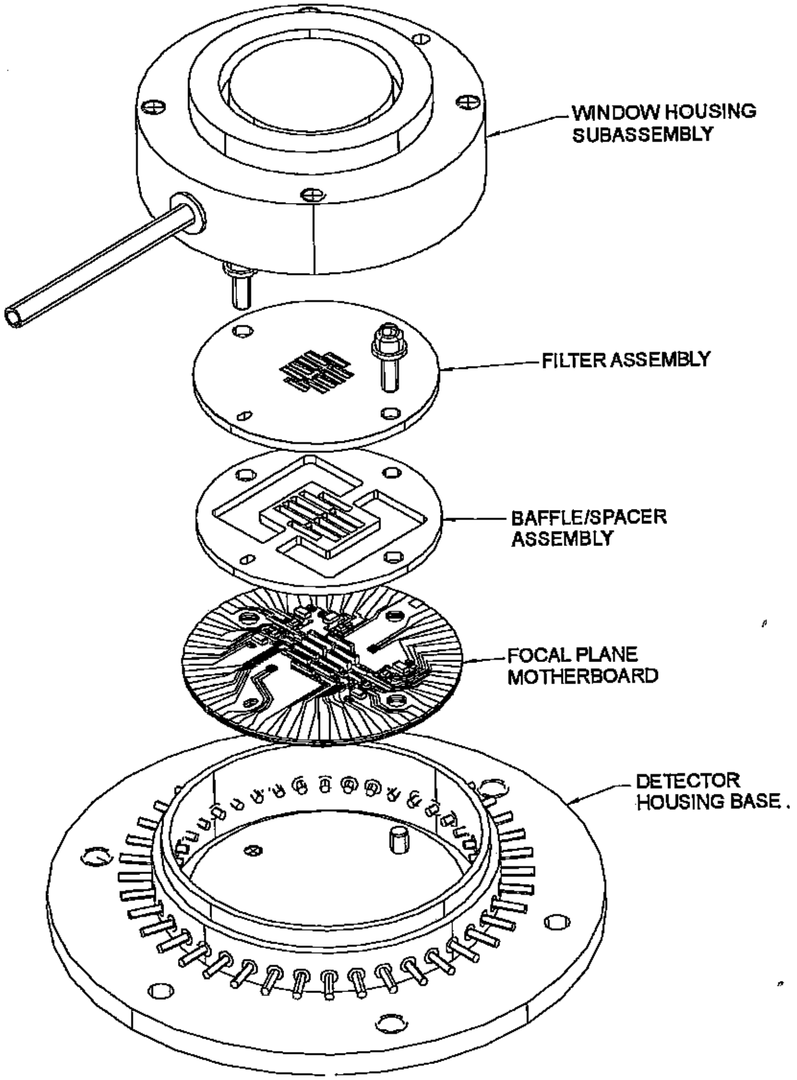
*Spyak and Wolf, Optical Engineering Vol. 31, p 1746 - 1784, (1992)
**SSG measured data of pristine mirror

MIRROR BRDF at 0.633 μm

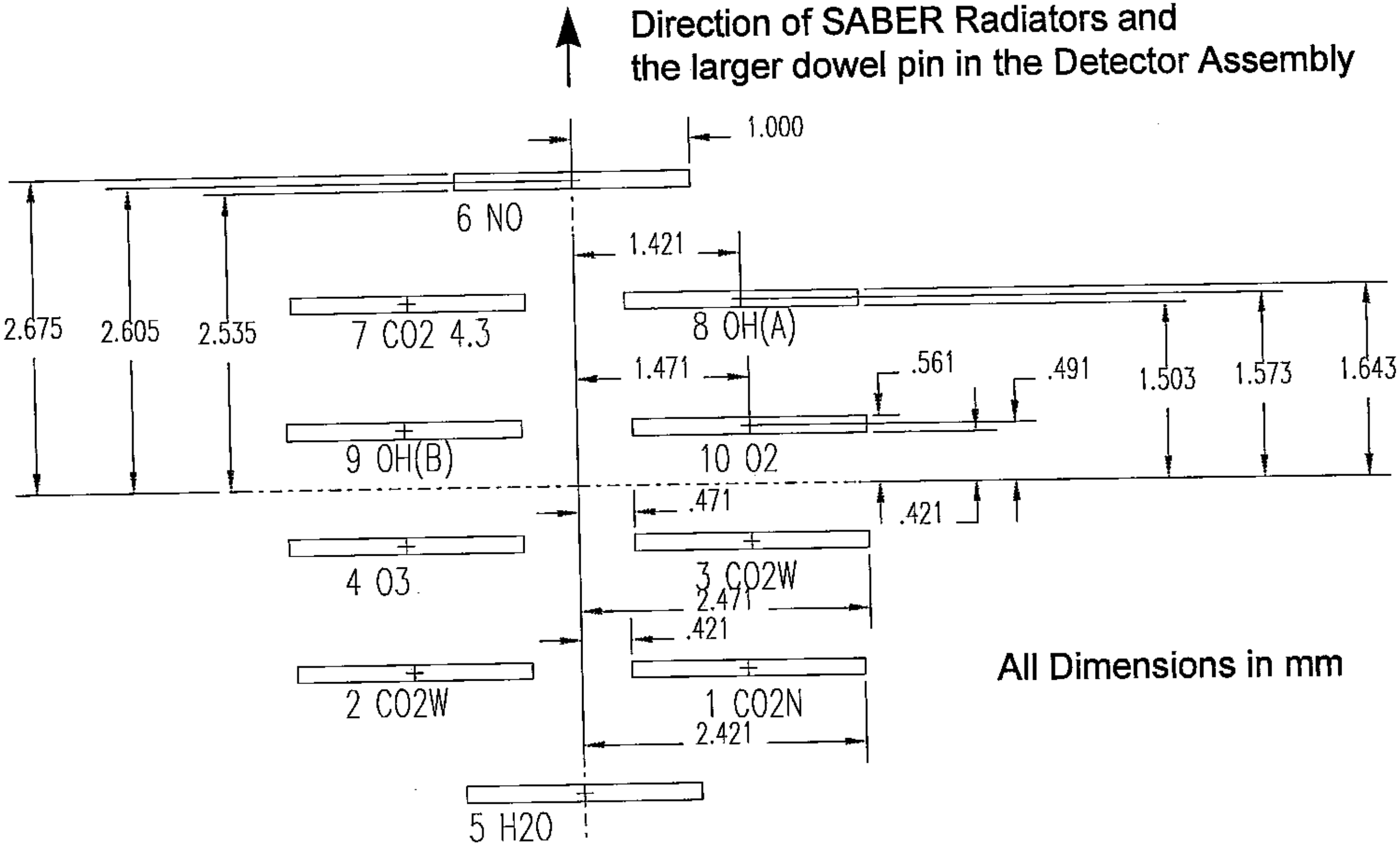


*Spyak and Wolf, Optical Engineering Vol. 31, p 1746 - 1784, (1992)
**SSG measured data of pristine mirror

DETECTOR ASSEMBLY



DETECTOR LOCATIONS

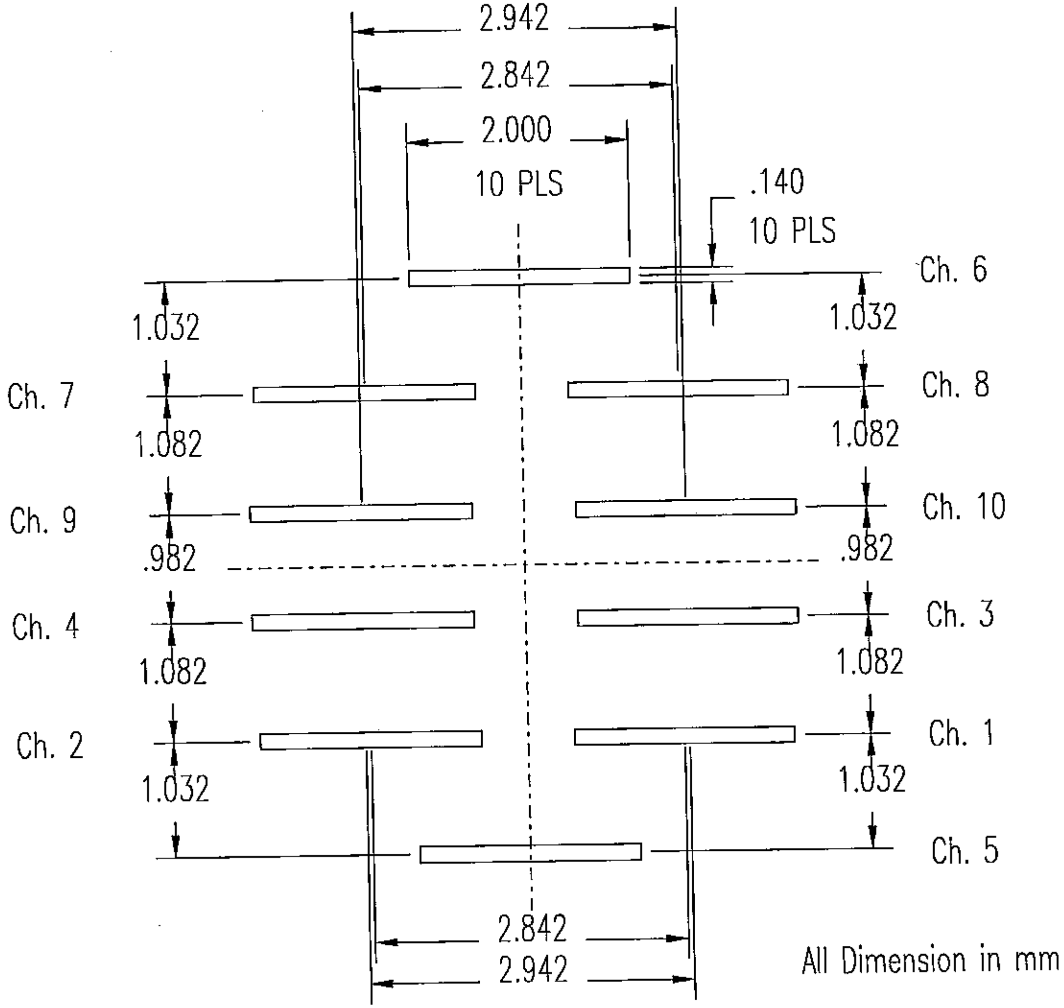


Direction of SABER Radiators and
the larger dowel pin in the Detector Assembly

All Dimensions in mm

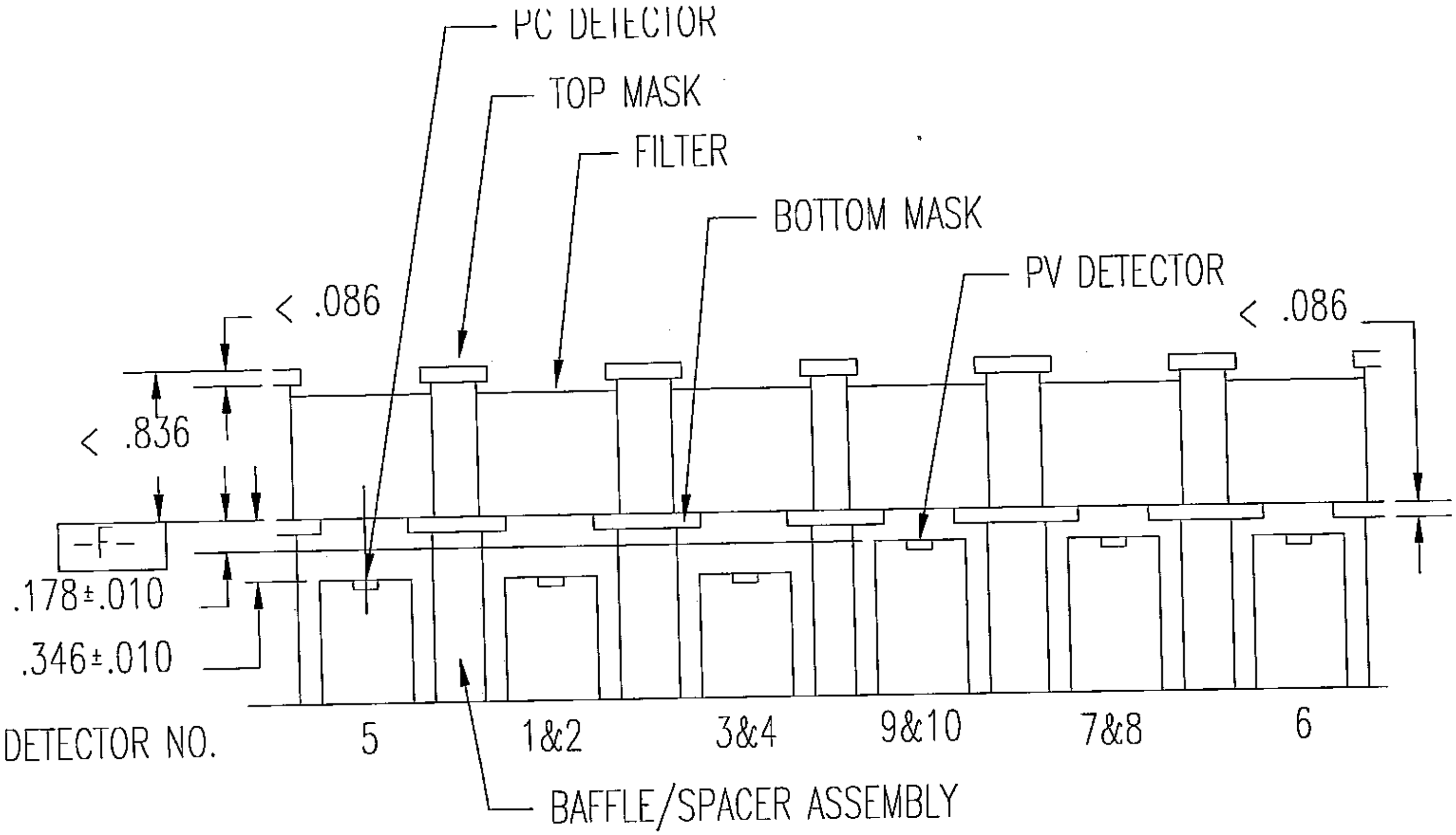
VIEW LOOKING AT TOP SURFACES OF DETECTORS

DETECTOR ARRAY DIMENSIONS



TOP VIEW

FILTER ASSEMBLY, BAFFLE/SPACER & DETECTORS



All Dimensions in mm

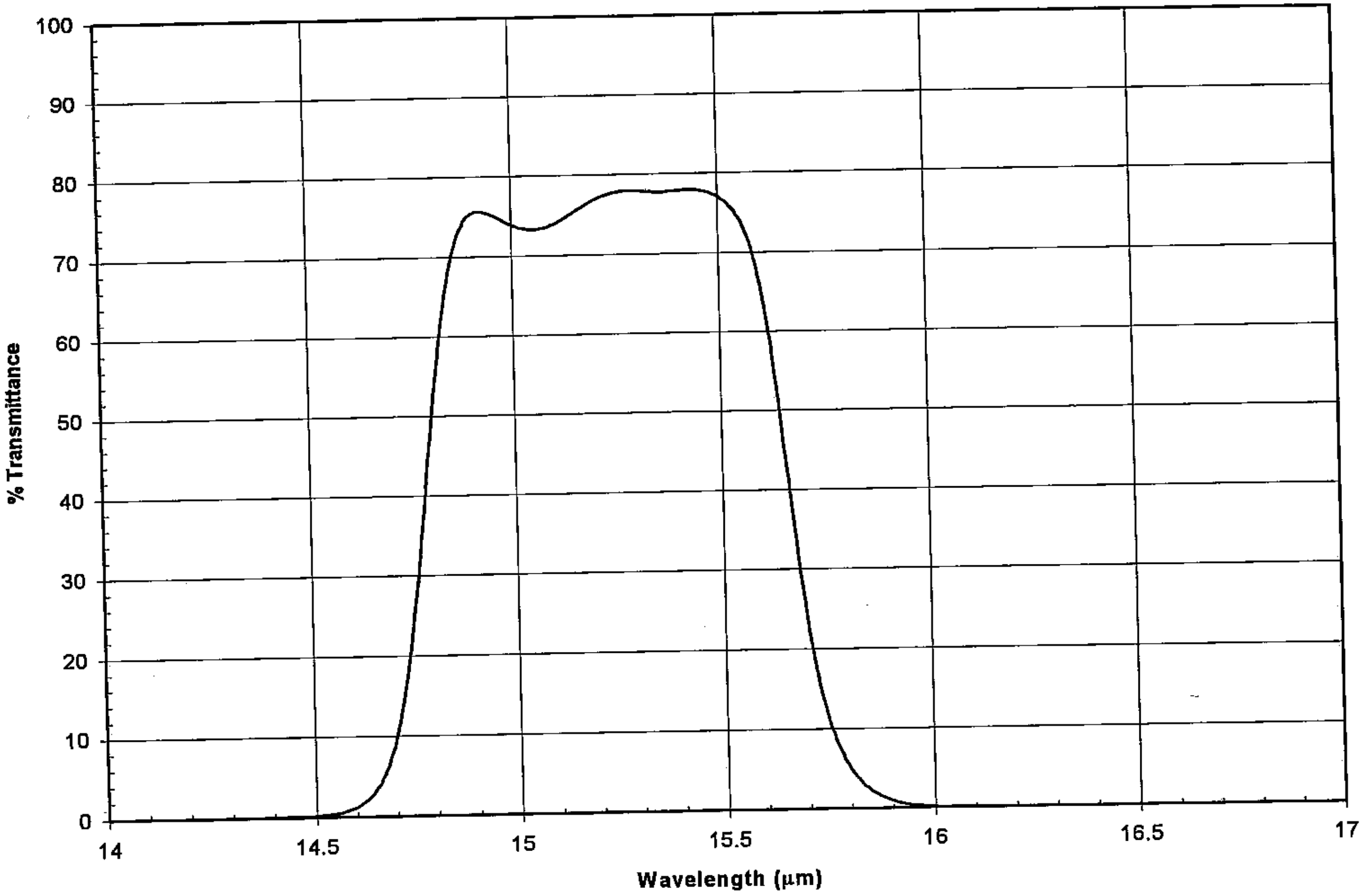
DETECTOR PERFORMANCE SUMMARY

Ch. No.	Material	Type	Bias Power * (mW)	*Background Photon Irradiance (ph/sec/cm^2)	Minimum D (cmHz$^{1/2}$/W)	Minimum Responsivity	Dominate Noise Sources
1	HgCdTe	PC	3	1.88E14	9.5E10	8.6E3 V/W	Thermal GR
2	HgCdTe	PC	3	1.20E15	7.3E10	9.6E3 V/W	Thermal GR
3	HgCdTe	PC	3	1.20E15	7.3E10	9.6E3 V/W	Thermal GR
4	HgCdTe	PC	10	1.18E14	3.8E11	1.8E4 V/W	Detector. Resistance
5	HgCdTe	PC	10	2.20E13	6.0E11	3.7E4 V/W	Detector. Resistance
6	InSb	PV	3	2.32E12	8.0E12	3.5 A/W	Background Photons Detector Resistance JFET Current Noise
7	InSb	PV	3	1.16E11	8.8E12	2.8 A/W	Detector Resistance JFET Current Noise
8	InGaAs	PV	3	2.13E8	4.4E12	1.2 A/W	Detector Resistance JFET Current Noise
9	InGaAs	PV	3	2.45E8	3.5E12	1.0 A/W	Detector Resistance JFET Current Noise
10	InGaAs	PV	3	1.68E8	3.9E12	0.8 A/W	JFET Current Noise

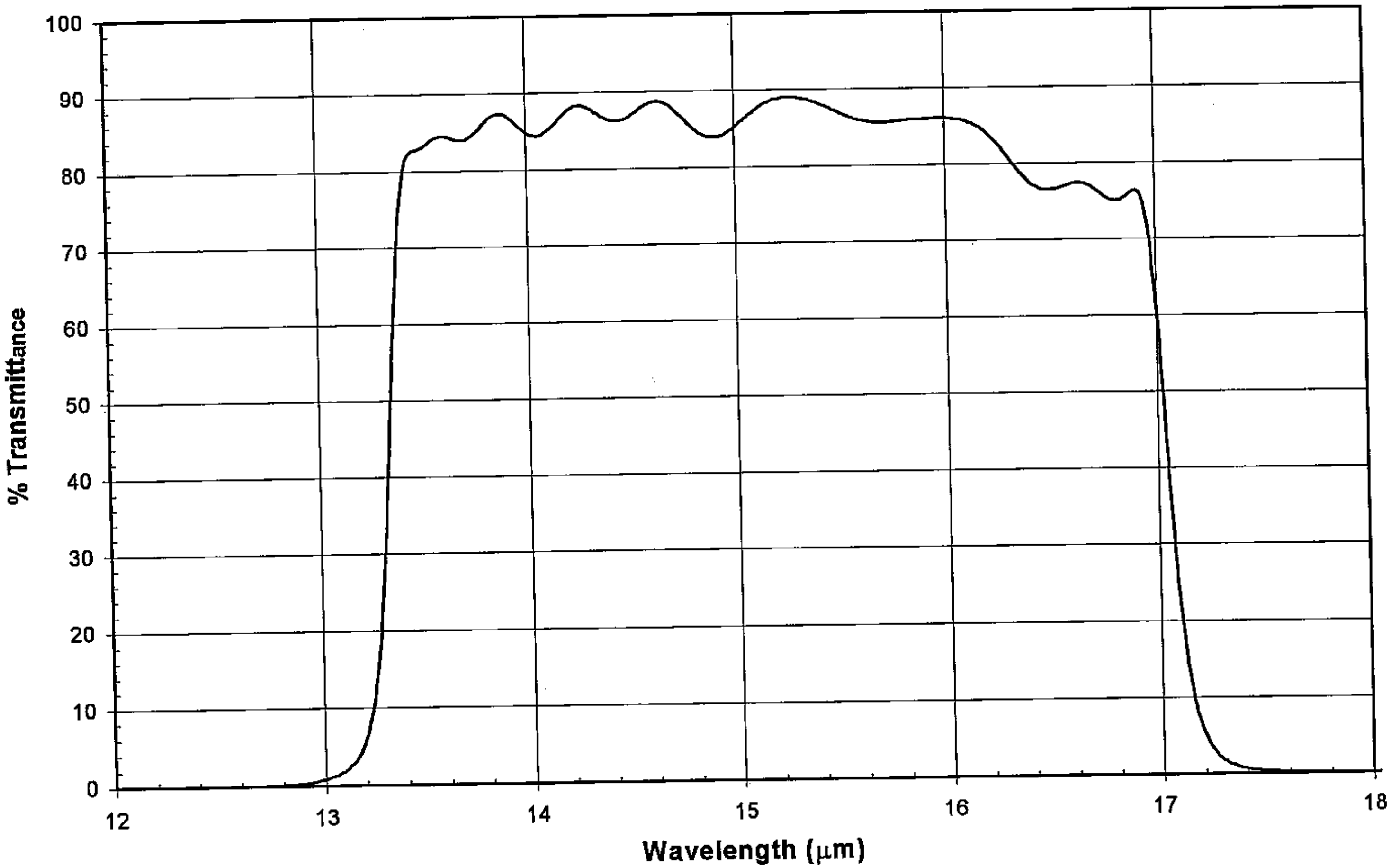
*Power is dissipated in detectors and FPA JFETS for PC and PV detectors, respectively

Chopping frequency is 1000 Hz

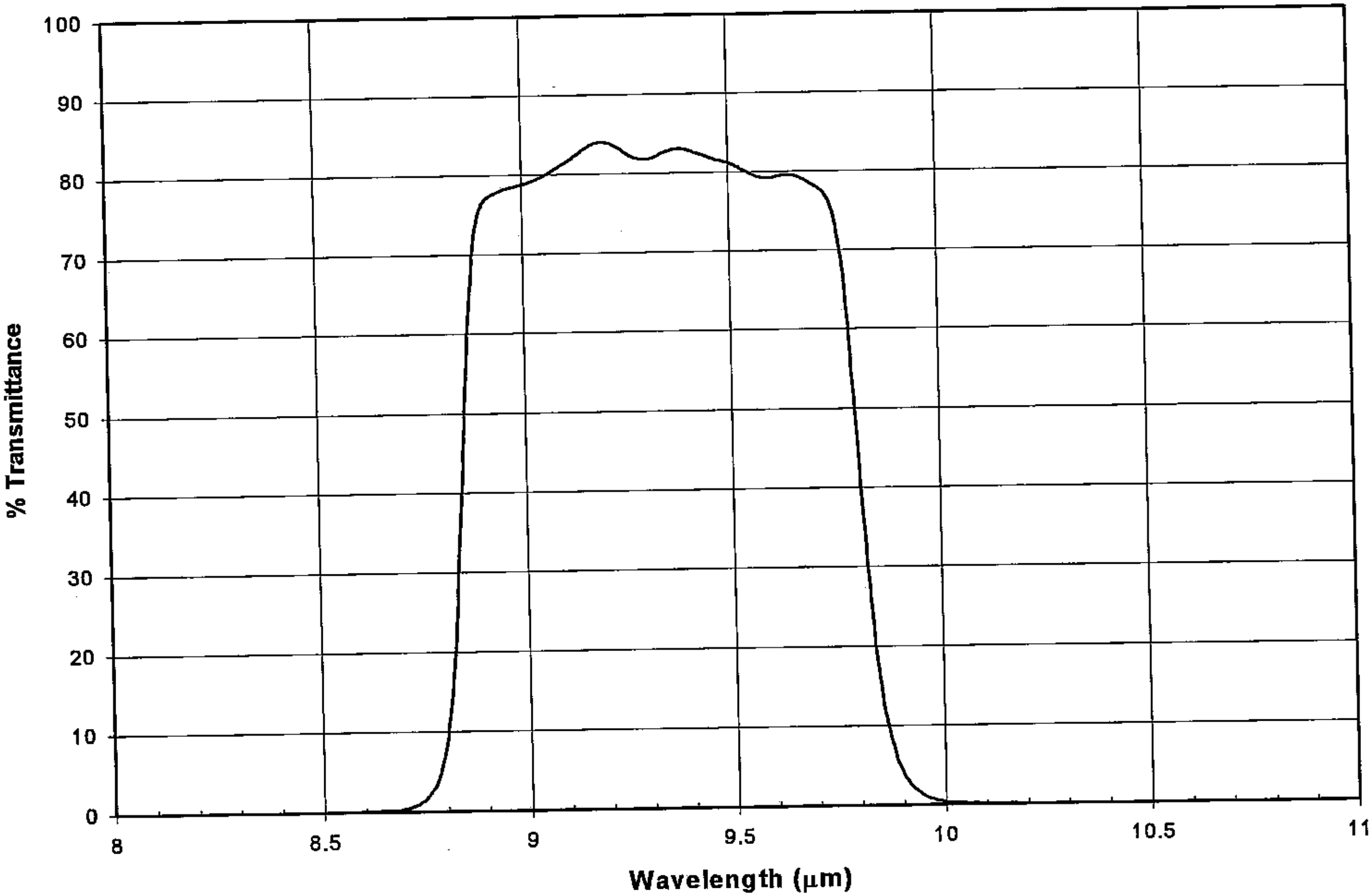
CHANNEL 1 FILTER DESIGN TRANSMITTANCE



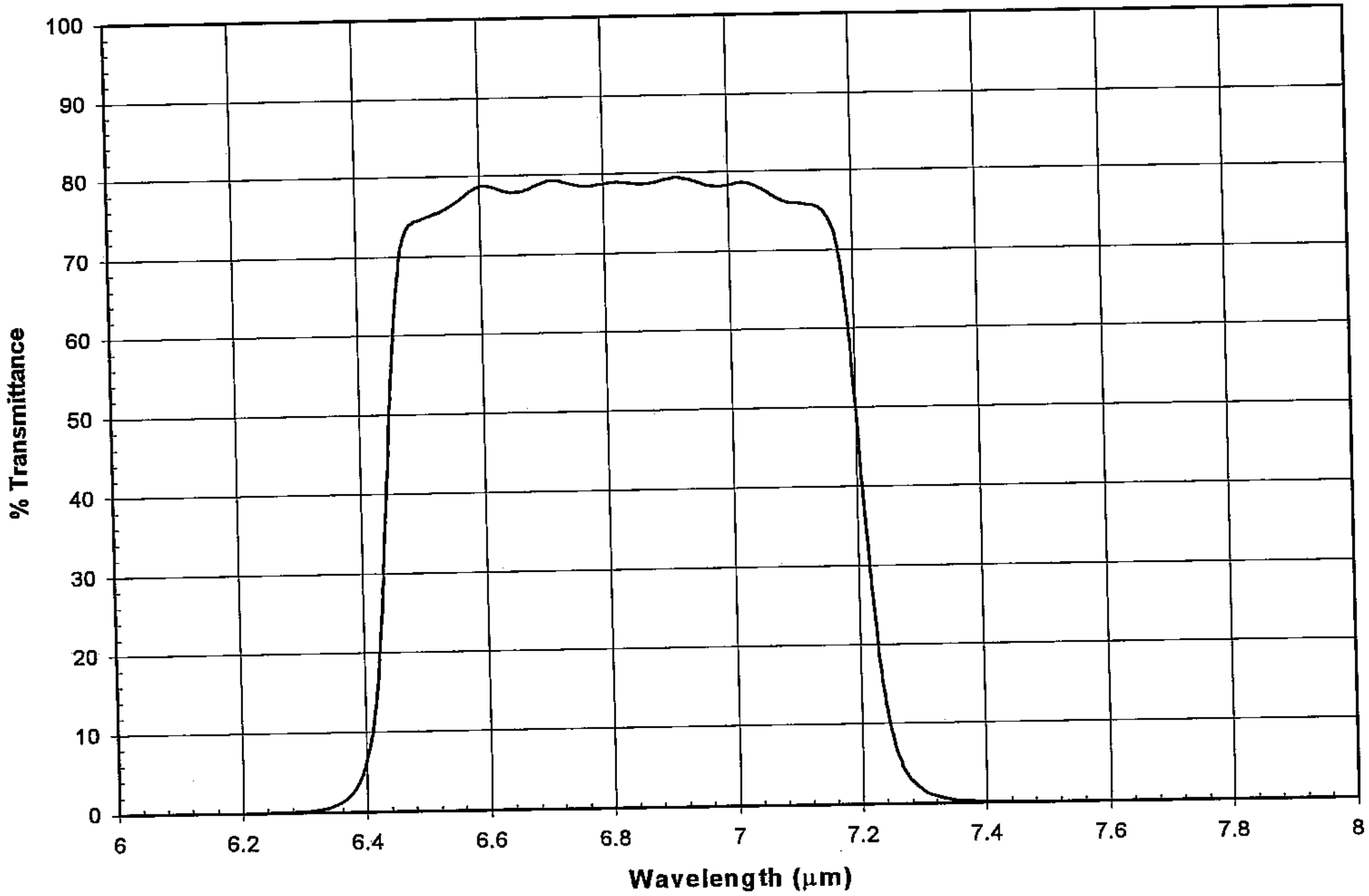
CHANNELS 2 & 3 FILTER DESIGN TRANSMITTANCE



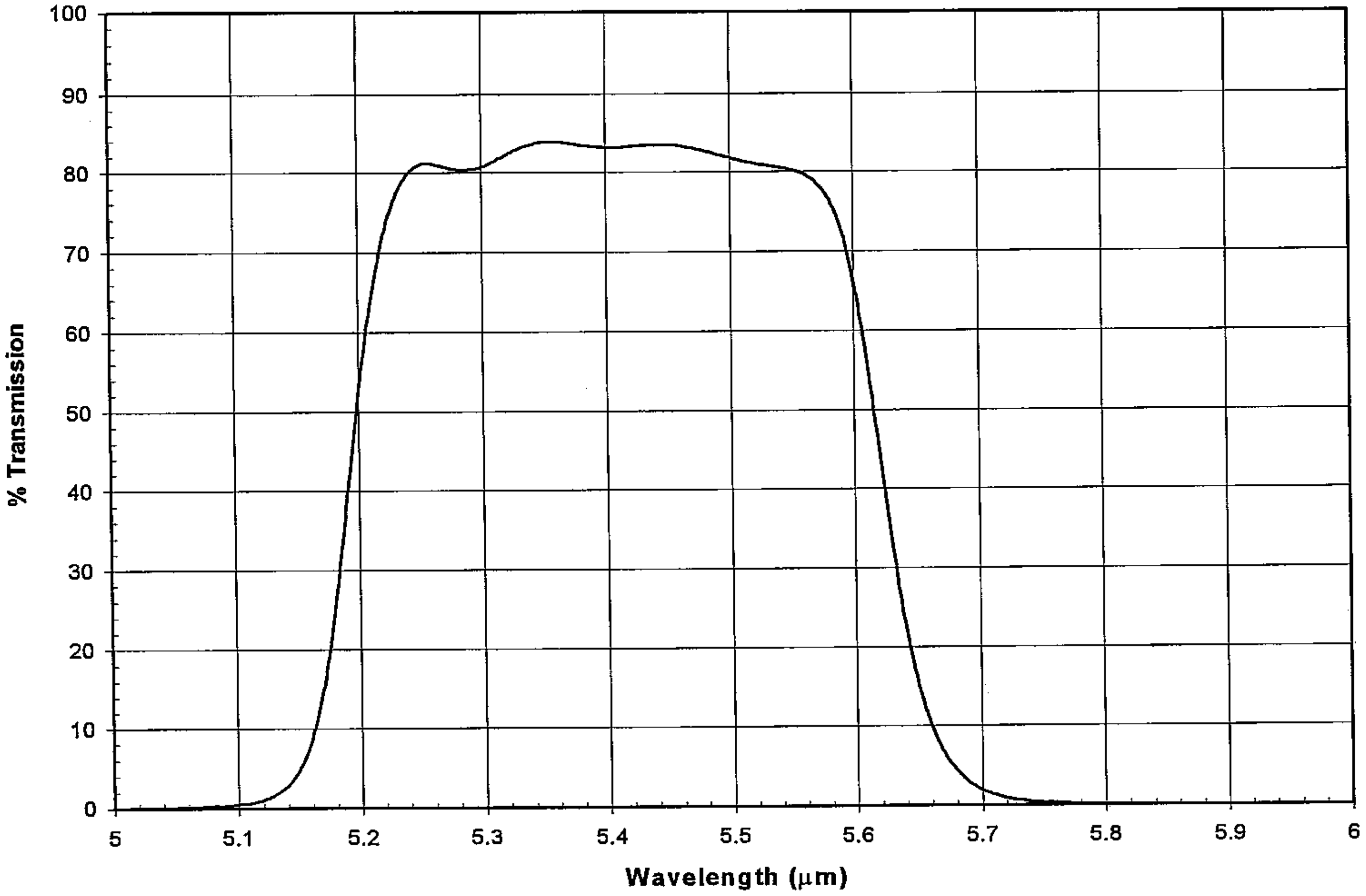
CHANNEL 4 FILTER DESIGN TRANSMITTANCE



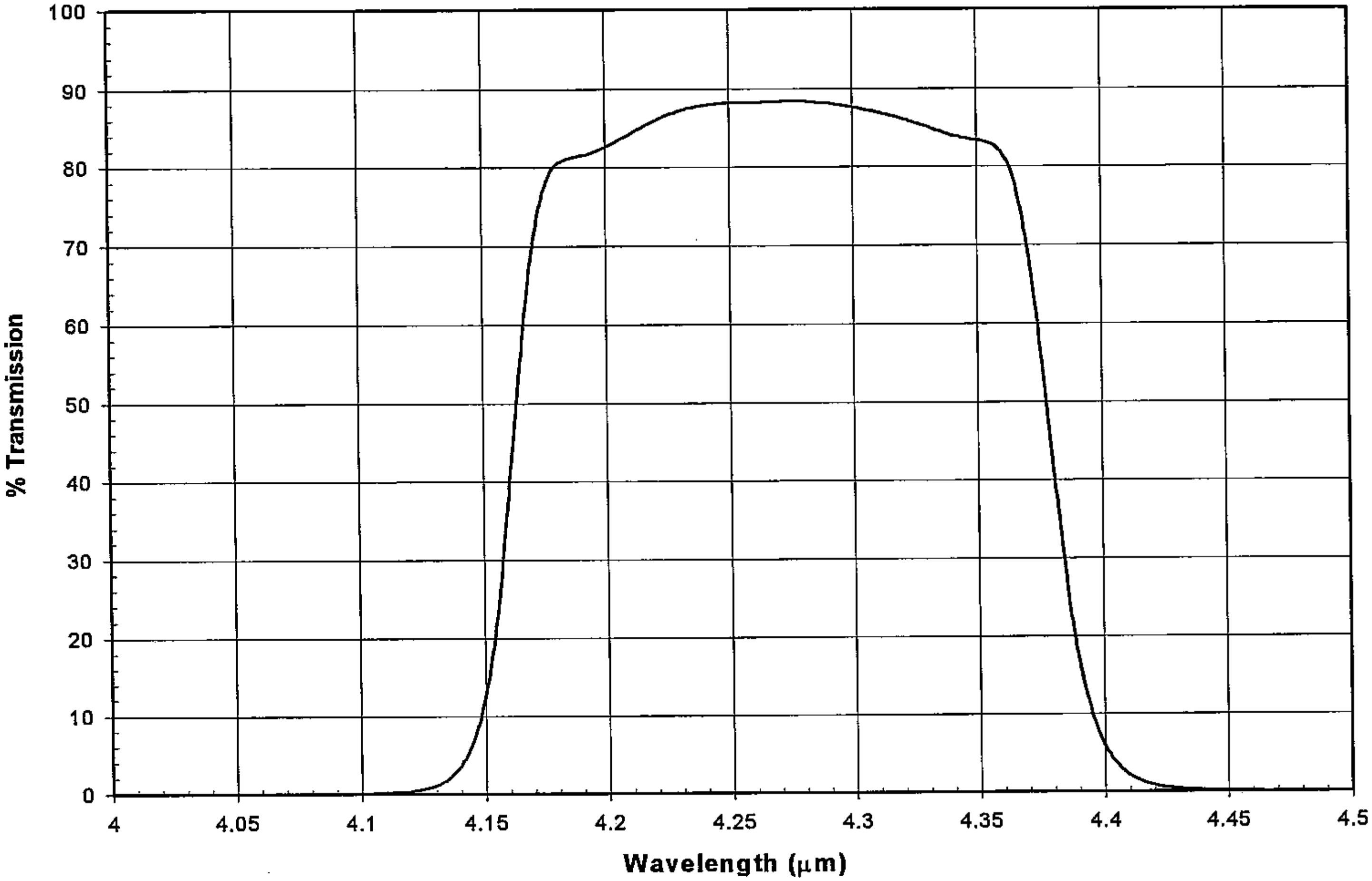
CHANNEL 5 FILTER DESIGN TRANSMITTANCE



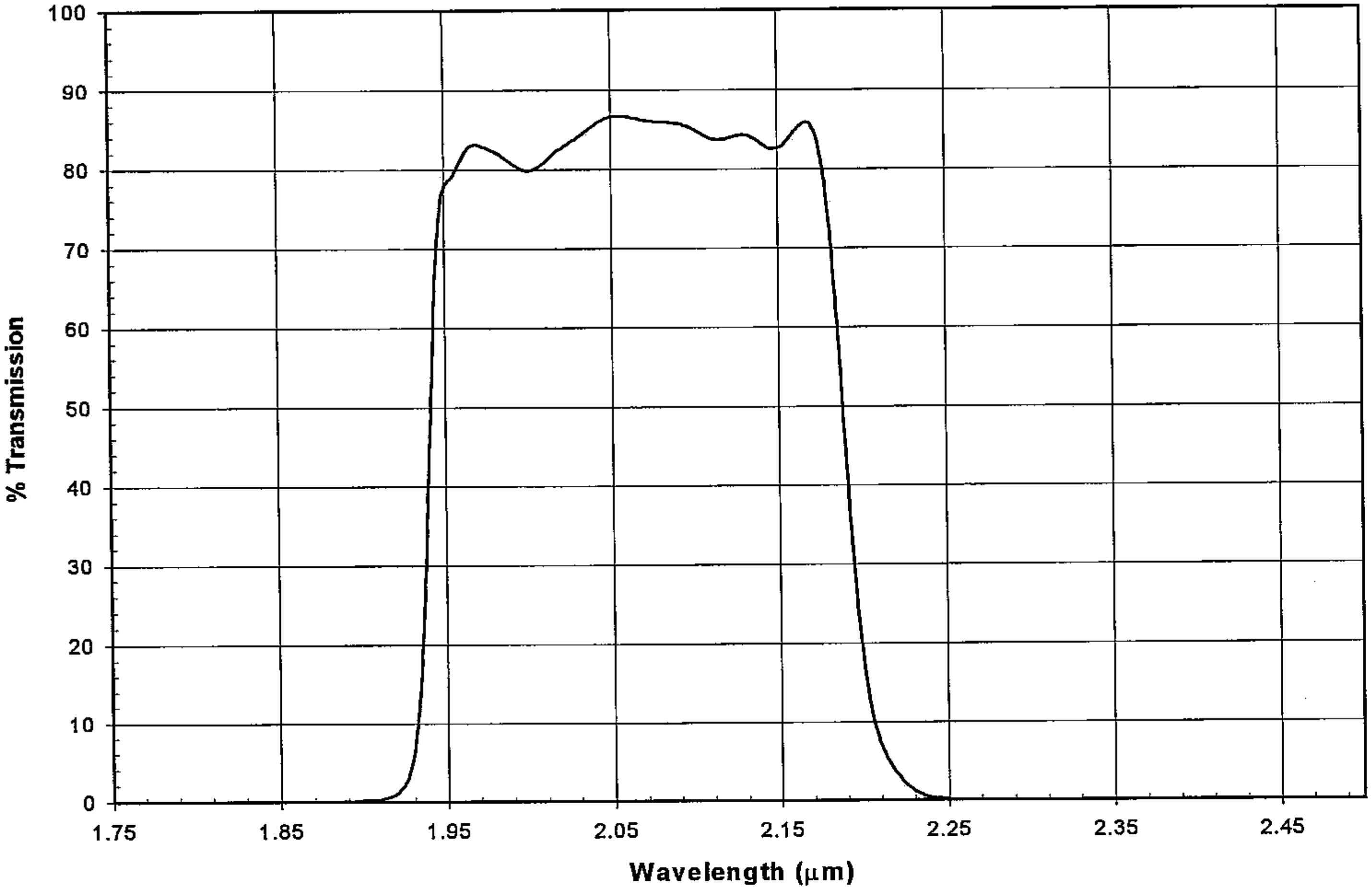
CHANNEL 6 FILTER DESIGN TRANSMITTANCE



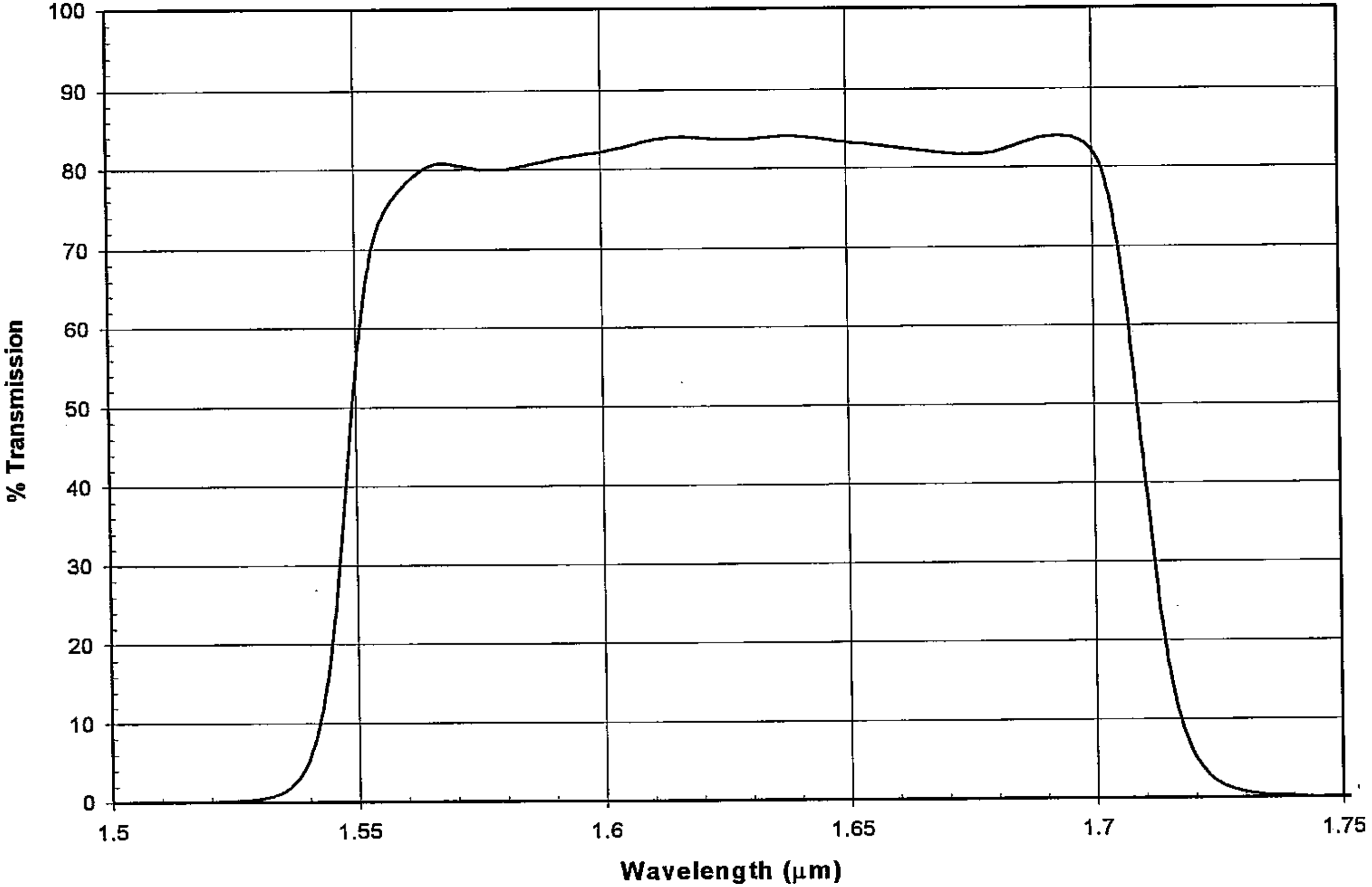
CHANNEL 7 FILTER DESIGN TRANSMITTANCE



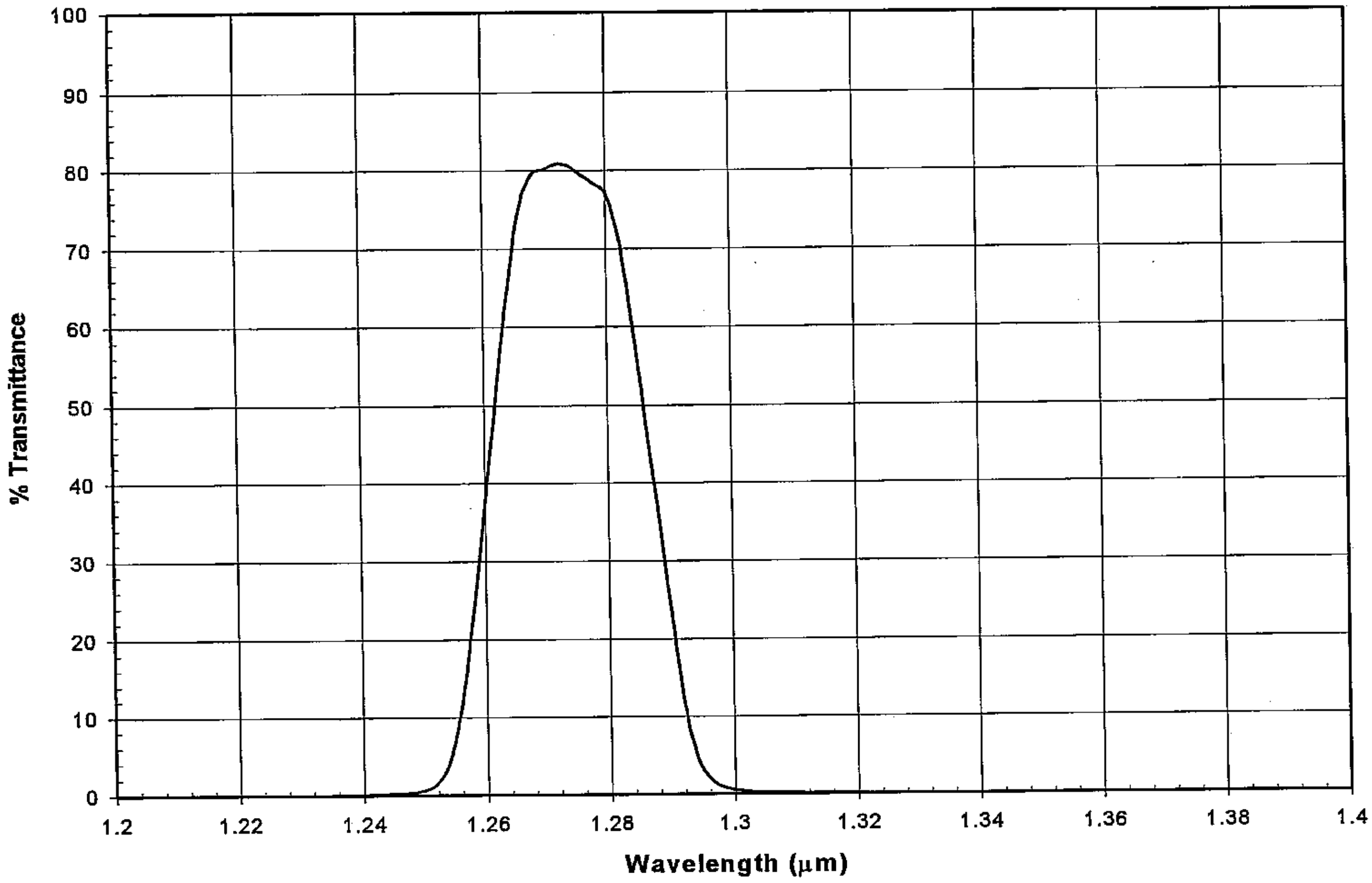
CHANNEL 8 FILTER DESIGN TRANSMITTANCE



CHANNEL 9 FILTER DESIGN TRANSMITTANCE



CHANNEL 10 FILTER DESIGN TRANSMITTANCE



CONCLUSION

- The Radiometric subsystem design meets all design requirements with margin except the long wavelength blocking for channel 1 is a factor of 2 too small.

SCANNER SUBSYSTEM OVERVIEW

Frank Peri

December 10, 1996

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E-Mail: f.peri@larc.nasa.gov

SCAN REQUIREMENTS

Scan Range

- Minimum depression angle places top of FPA at -3km
- Maximum depression angle places bottom of FPA at 400km

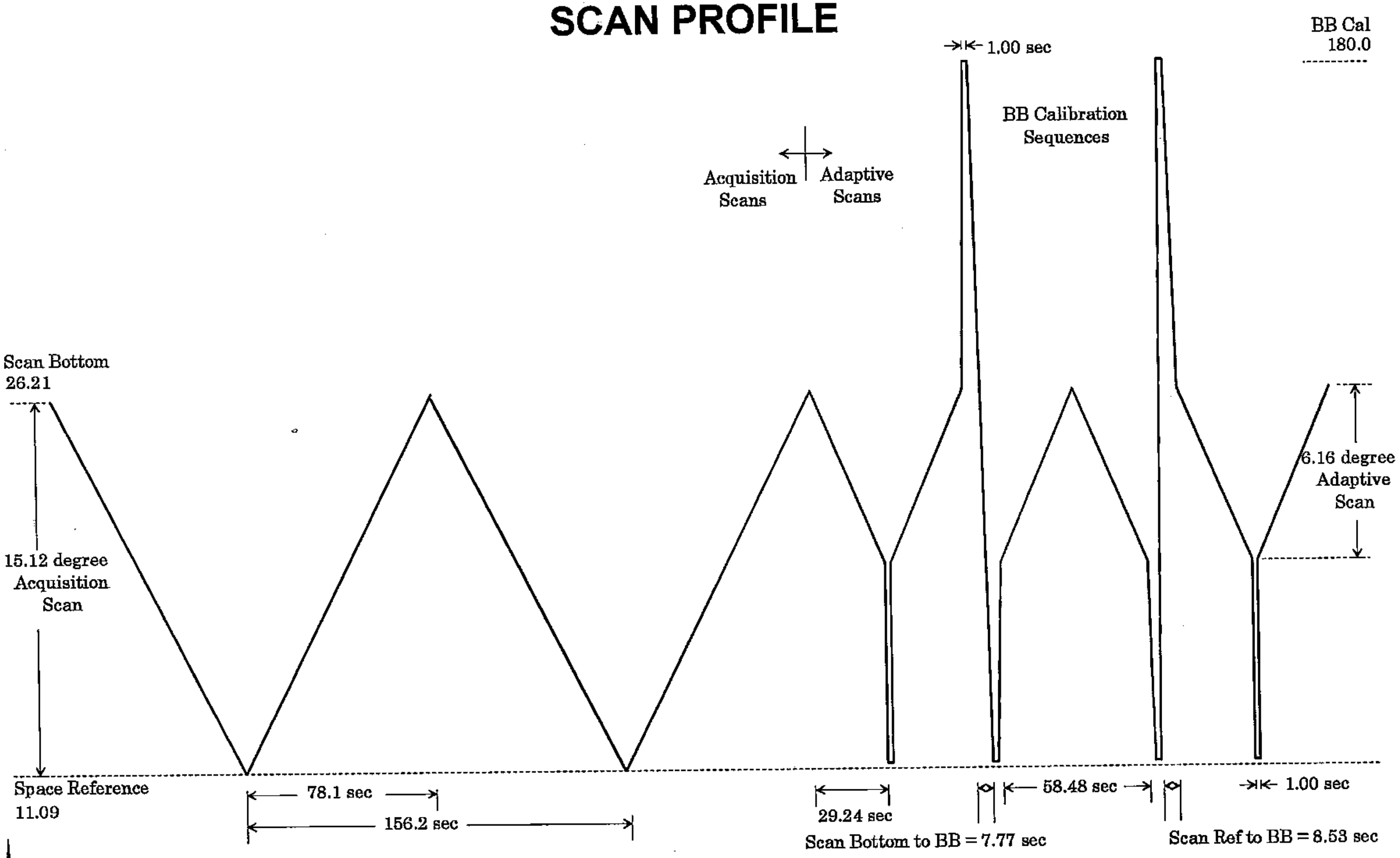
Scan Velocity

- Five samples at the instrument sample rate (22.5 Hz) in each 2km of vertical interval, referenced at a 60km tangent altitude.
- Corresponds to 0.19357 degrees per second

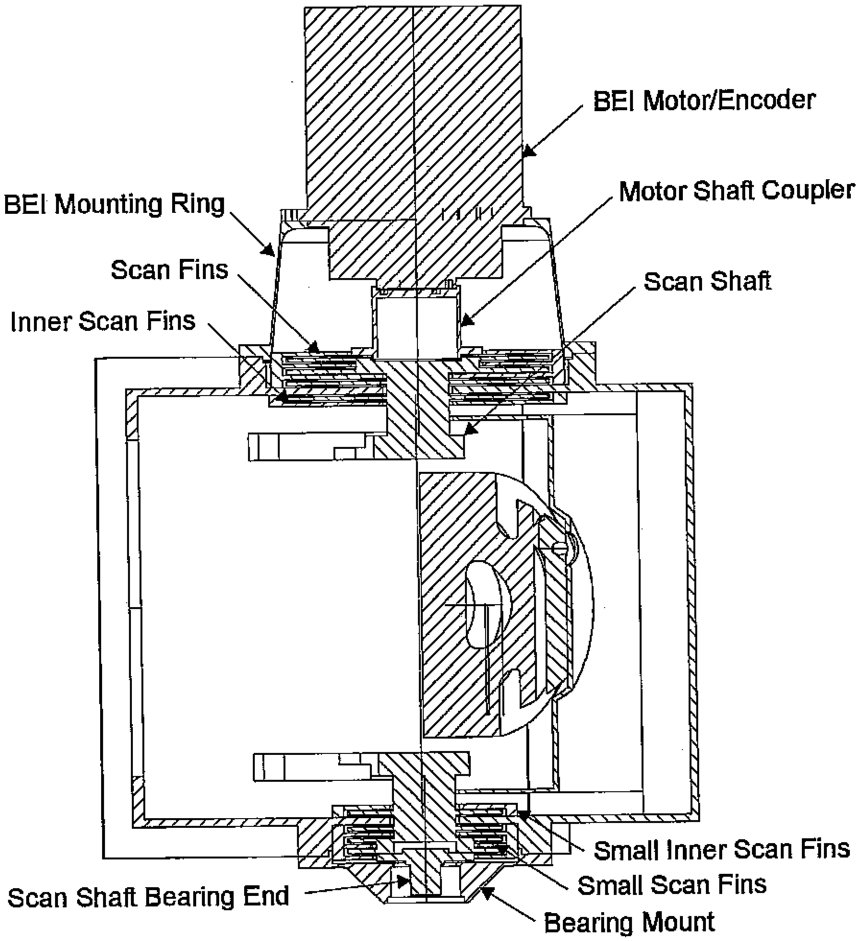
Vertical Sample Spacing Knowledge

- Samples spaced within 3km
  - Knowledge of error between samples is 30 meters
- Samples spaced farther than 3 km apart
  - Knowledge of error between samples to within 1% of the distance between the samples
  - Corresponds to 2.2 arc-sec angular knowledge

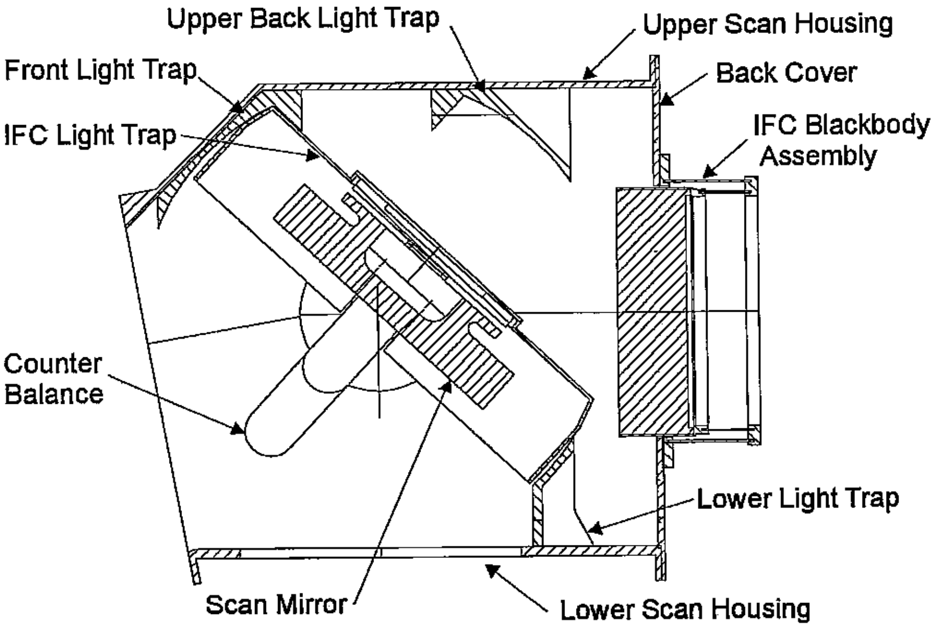
SCAN PROFILE



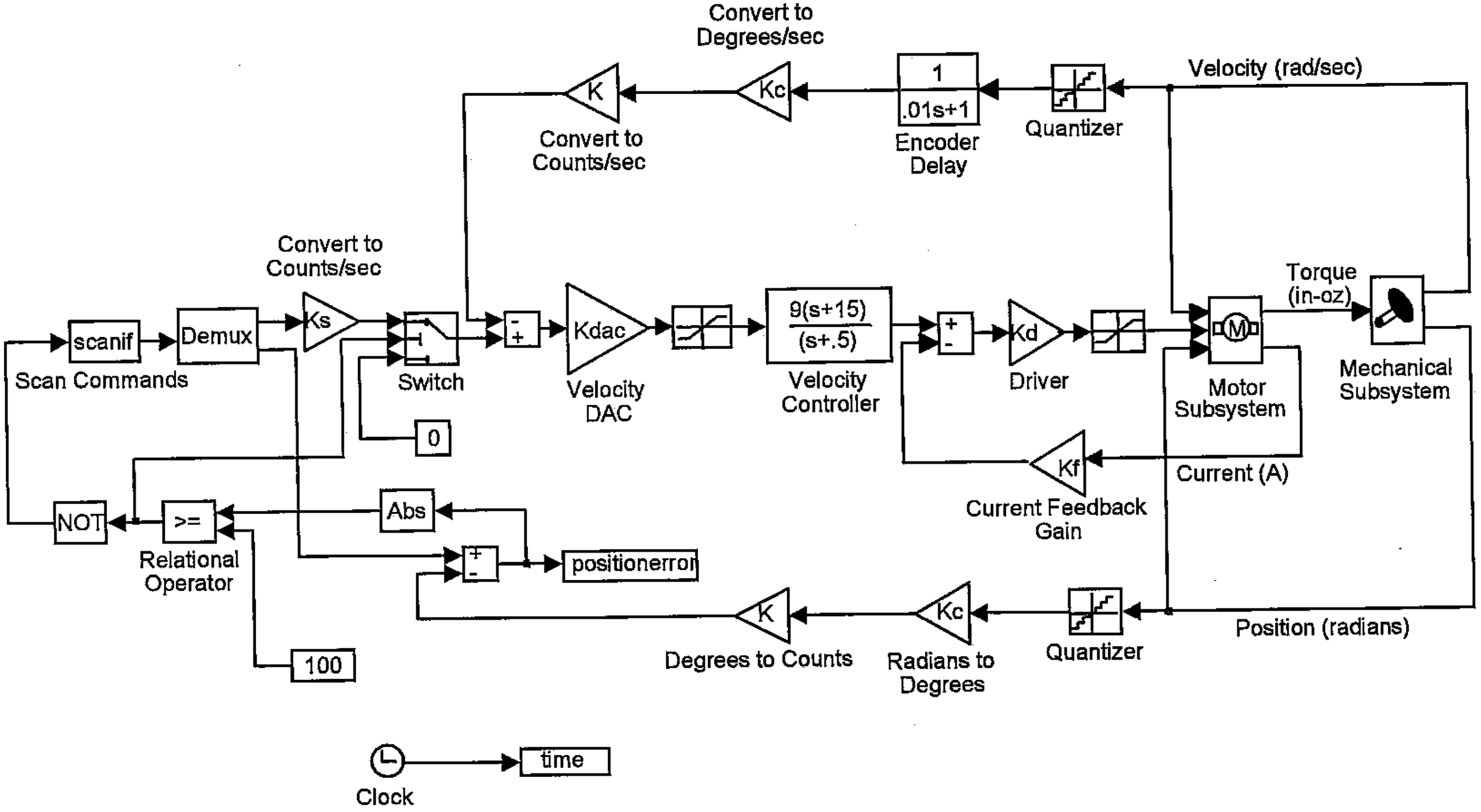
SCANNER MECHANISM



SCANNER MECHANISM



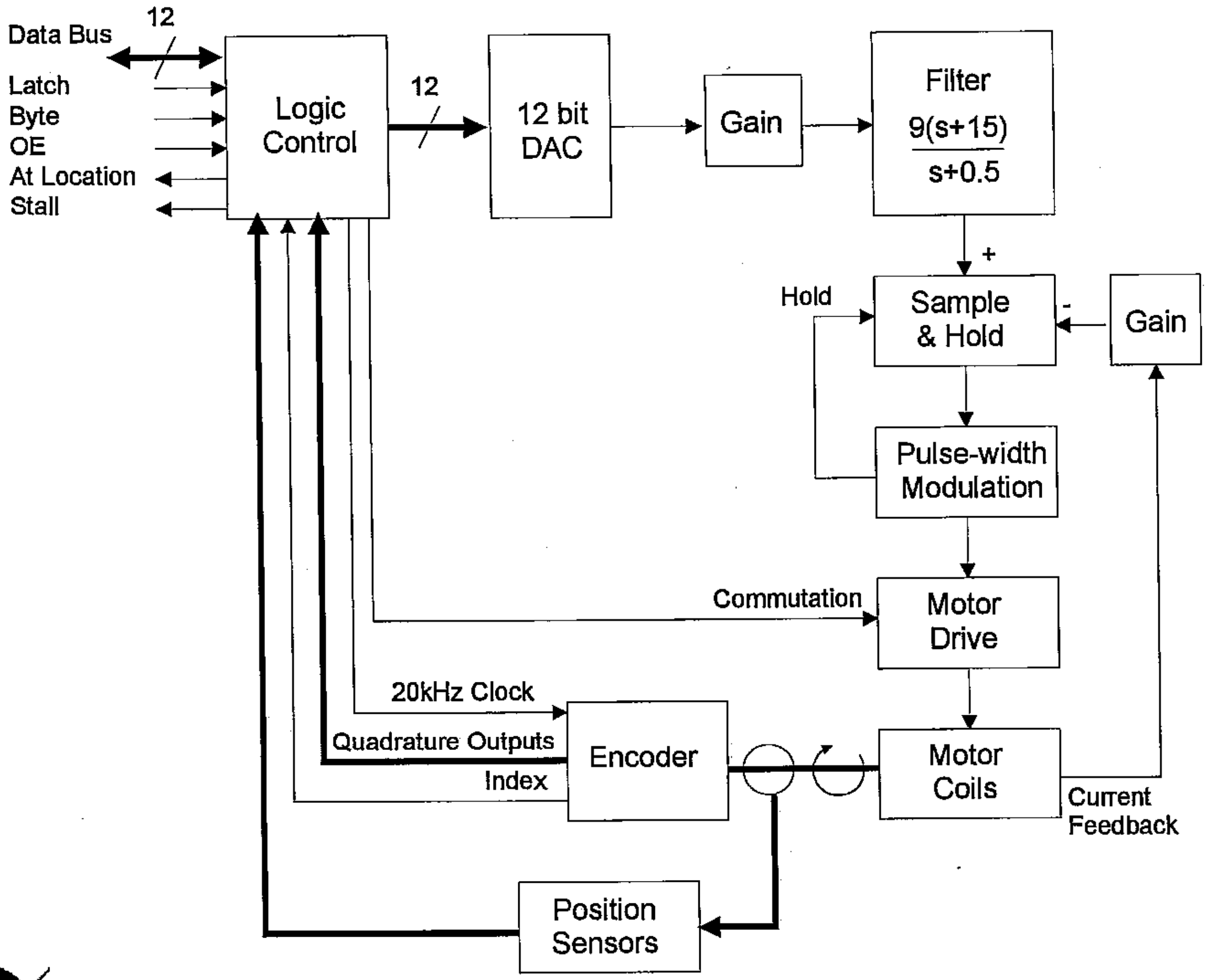
CONTROL SYSTEM BLOCK DIAGRAM



SABER Preliminary Design Review

NASA Langley Research Center/SDL-USU

ELECTRICAL BLOCK DIAGRAM



SCANNER CONTROLLER DESIGN

Method

- Closed-Loop control of mirror using conventional analog circuitry with digital interface to instrument controller.
- Velocity 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 (scan or slew) (1-bit)

SCANNER MOTOR/ENCODER

- **Motor**
  - 3-phase, 24-pole brushless DC motor manufactured by Inland Motor.
  - Hall Effect sensors included for commutation.

- **Encoder**
  - BEI design
  - Provides four sinusoidal quadrature count output signals on code disk: +cos(4096), -cos(4096), +sin(4096) and -sin(4096).
  - Encoder electronics interpolates these signals into two signals providing 2^{18} quadrature cycles per revolution.
  - SDL electronics translates these signals into a direction signal and a 2^{20} pulse per revolution signal.
  - 20-bit encoder results in angular position knowledge of 1.24 arc-sec.

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

SCANNER SUBSYSTEM SUMMARY

- **Requirements achieved**:
  - Motor/Encoder allows free range of motion, limited by mechanical stops that prescribe scan range.
  - Position knowledge requirement exceeded by use of 20-bit encoder.
  - Constant velocity adaptive scans achieved by use of velocity feedback controller.

- **Scan mirror motion does not require continuous instrument control.**
- **Encoder manufacturer providing motor/encoder integration and interface to SABER scan mirror assembly.**

SABER MECHANICAL SYSTEMS

OVERVIEW

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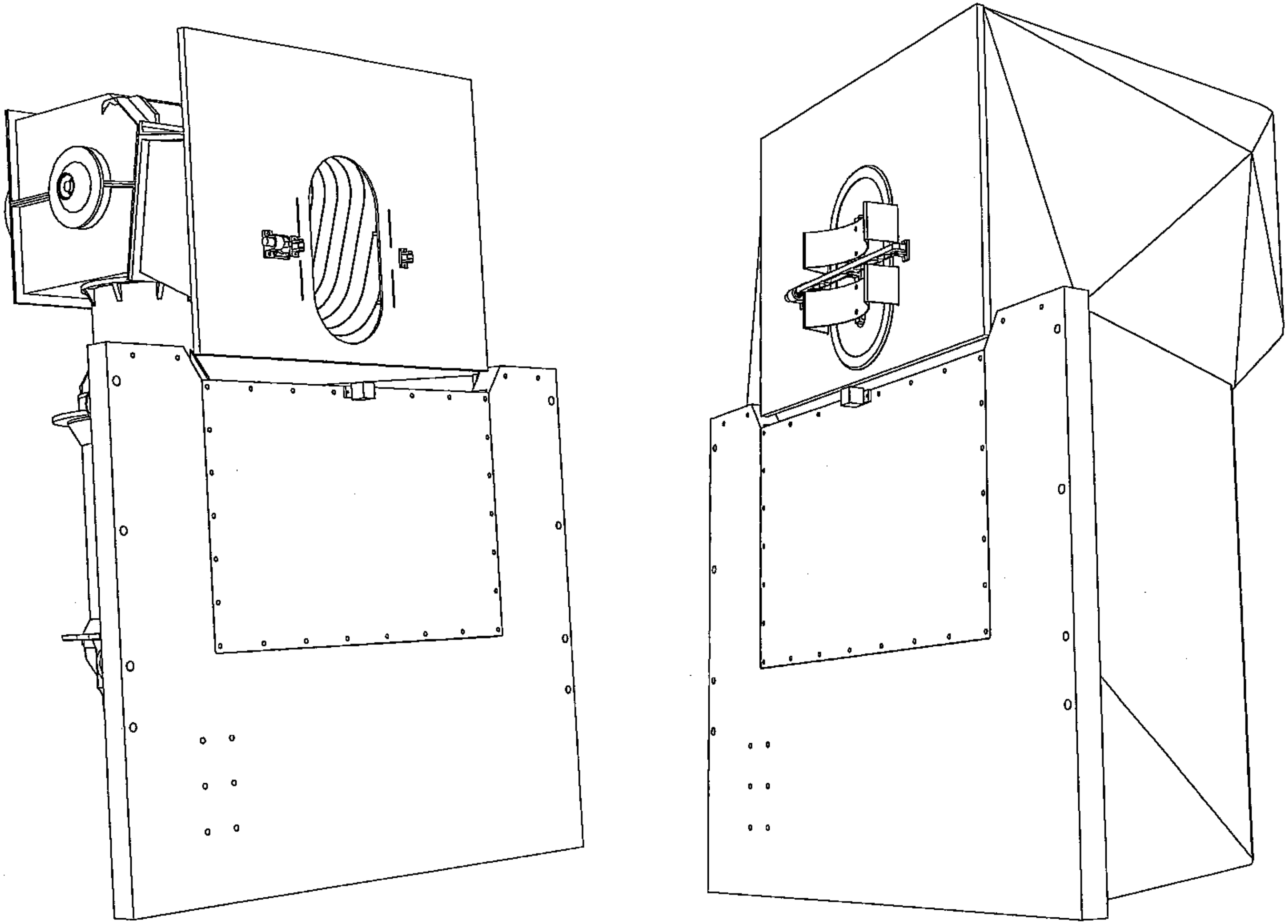
DECEMBER 10, 1996

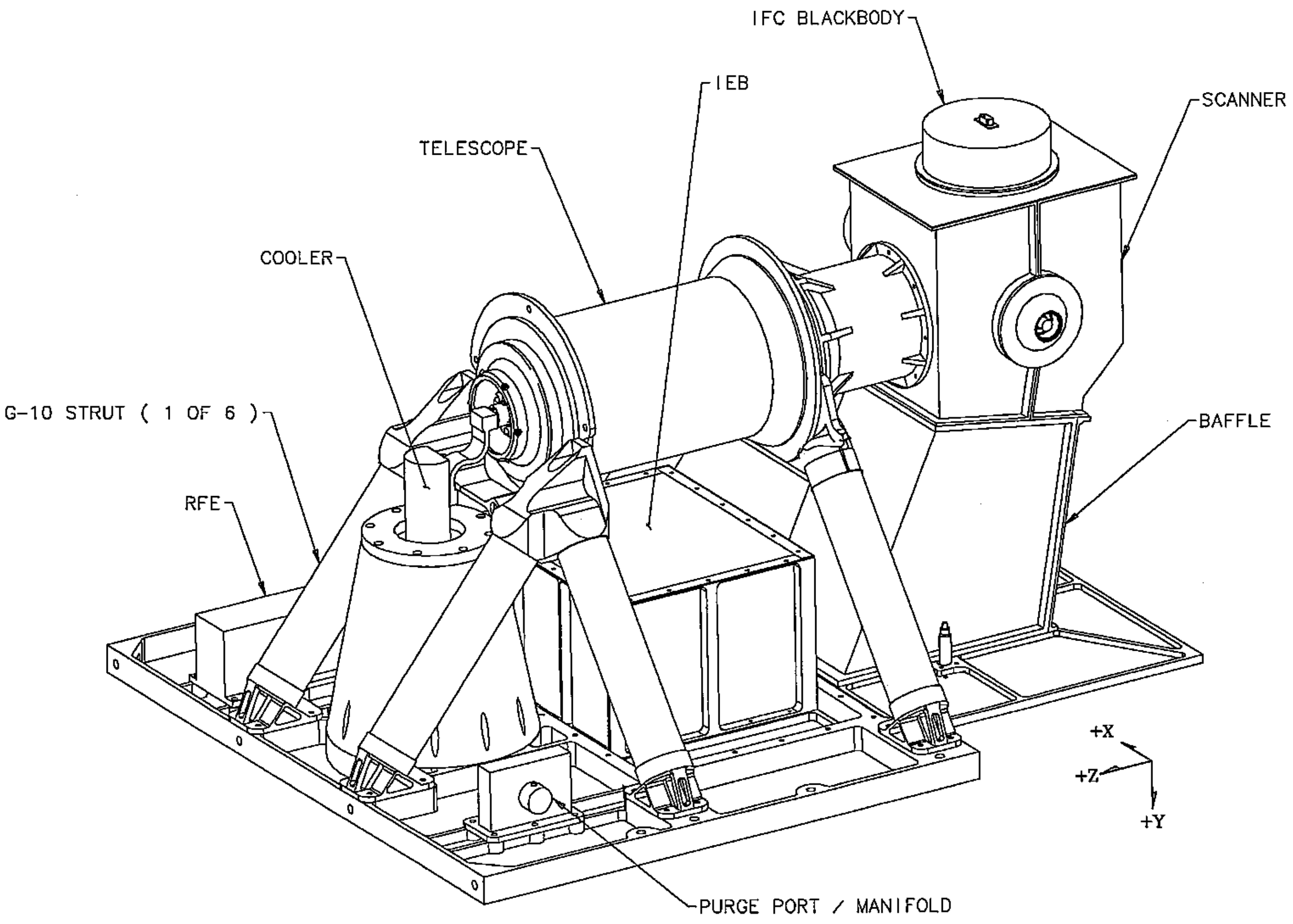
SABER MECHANICAL SYSTEMS OVERVIEW

- SABER instrument is packaged and delivered as a single integrated protoflight unit.
  - SABER will be mounted and aligned to Spacecraft +Y face.
  - SABER Structure thermally insulates the Telescope from the S/C frame.
- SABER Volume, Mass Properties, and interfaces meet S/C requirements.
  - Payload mass is 61.7 Kg
  - Mechanical Interfaces are in place and are maturing as S/C design develops.
- Mechanical design meets structural and thermo-mechanical requirements.
  - Fundamental Frequency > 80Hz (Including the Thermal Washers)
  - Positive Margins of Safety against limit loads and test factors.
  - Ongoing stability analysis against S/C and Structure thermal gradients.
- SABER instrument will undergo protoflight level environmental tests at SDL.
- SABER will be shipped to S/C integration site mounted inside the calibration chamber.

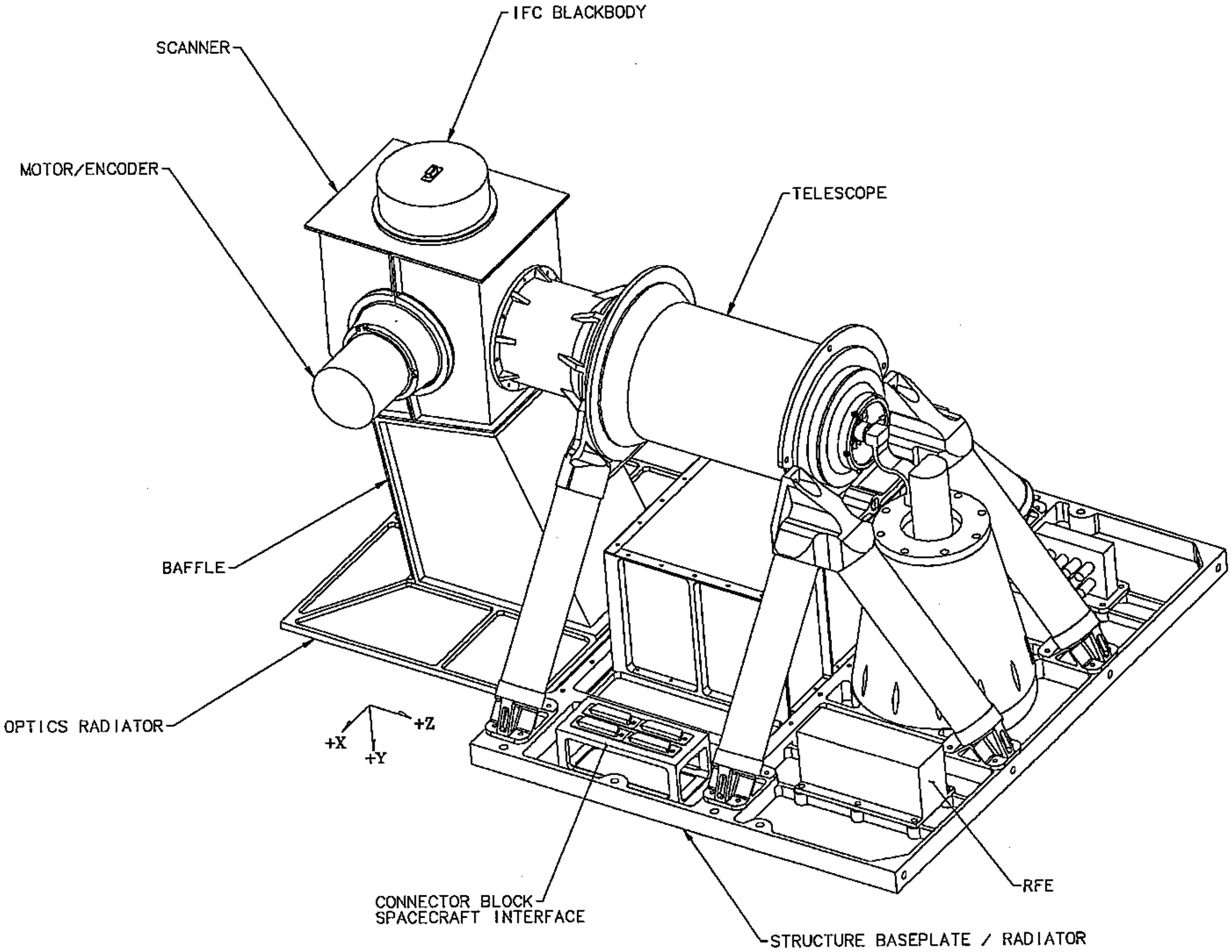
SABER INSTRUMENT



SABER INSTRUMENT



SABER INSTRUMENT

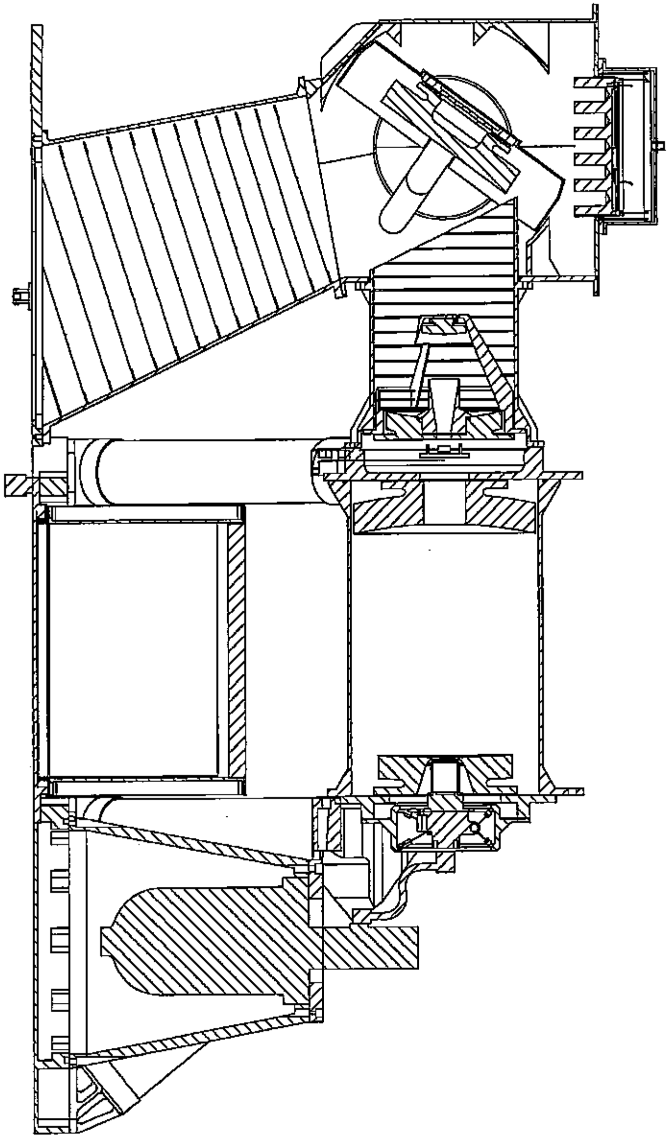


Mehrdad Roosta

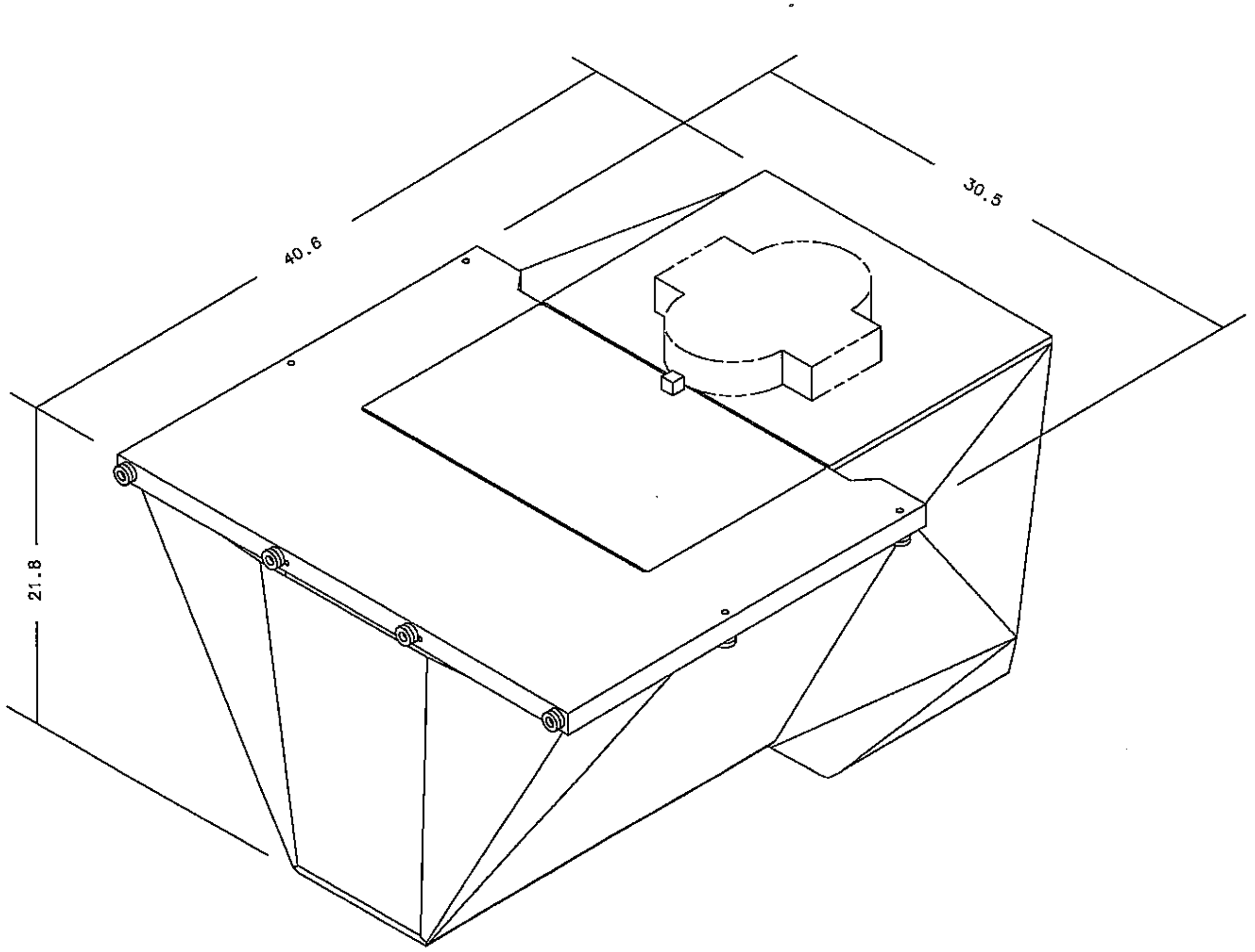
December 10, 1996

SABER Instrument Mechanical Subsystems

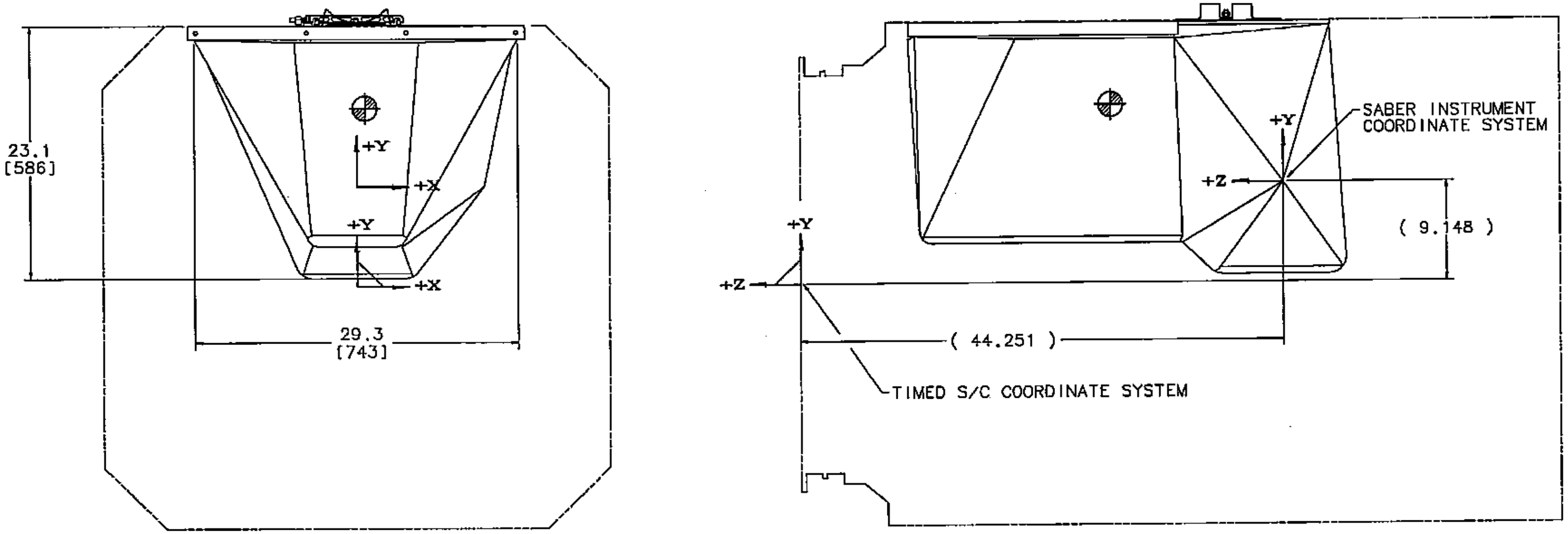
- Telescope
  - Baffle
  - Scanner
  - Optics Radiator
- Cooler
- Structure
- Deployable Cover
- Electronic Enclosure
- Purge System
- Mechanical GSE



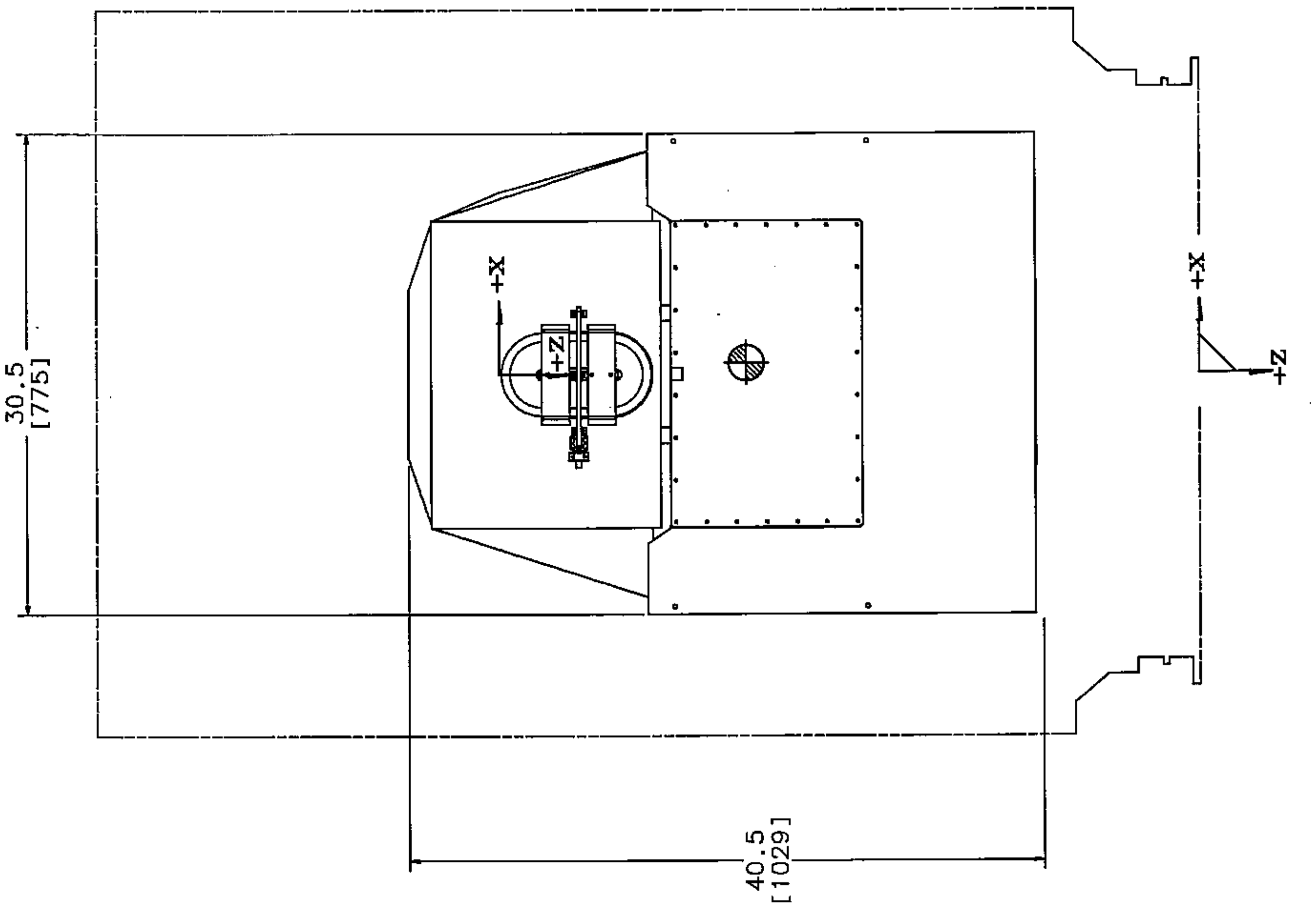
SABER Instrument Envelope



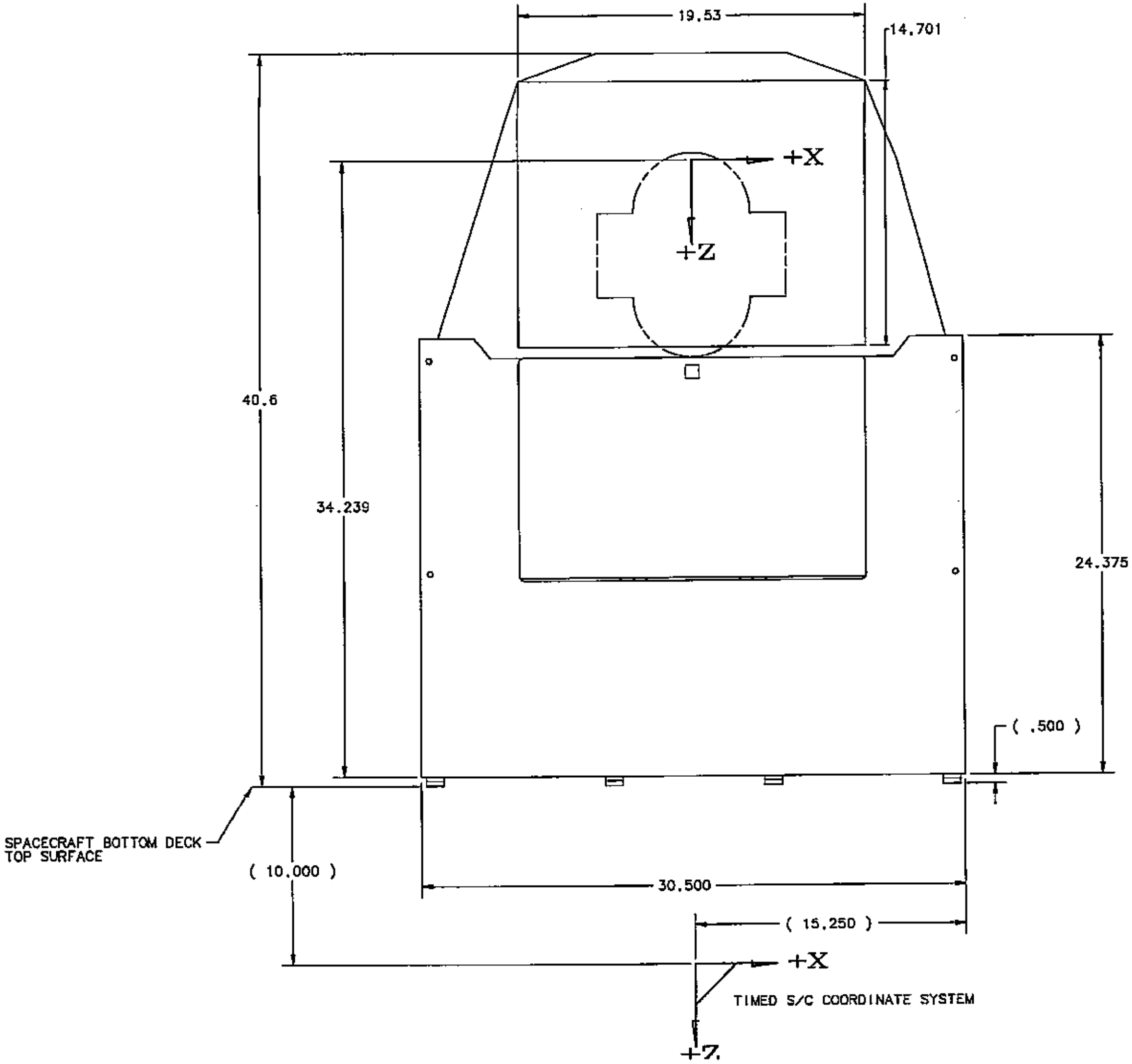
SABER Instrument & Spacecraft Envelopes



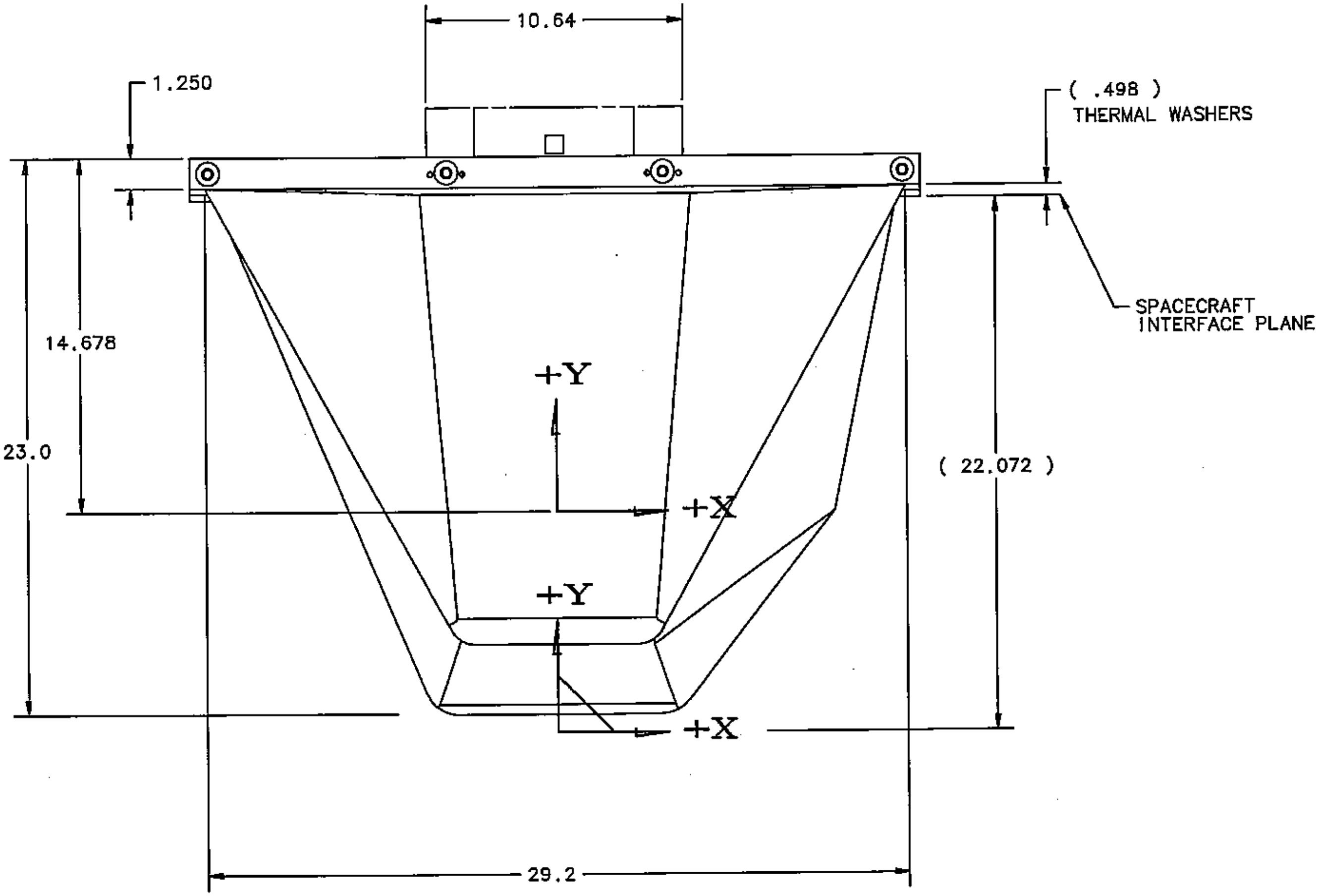
SABER Instrument & Spacecraft Envelopes



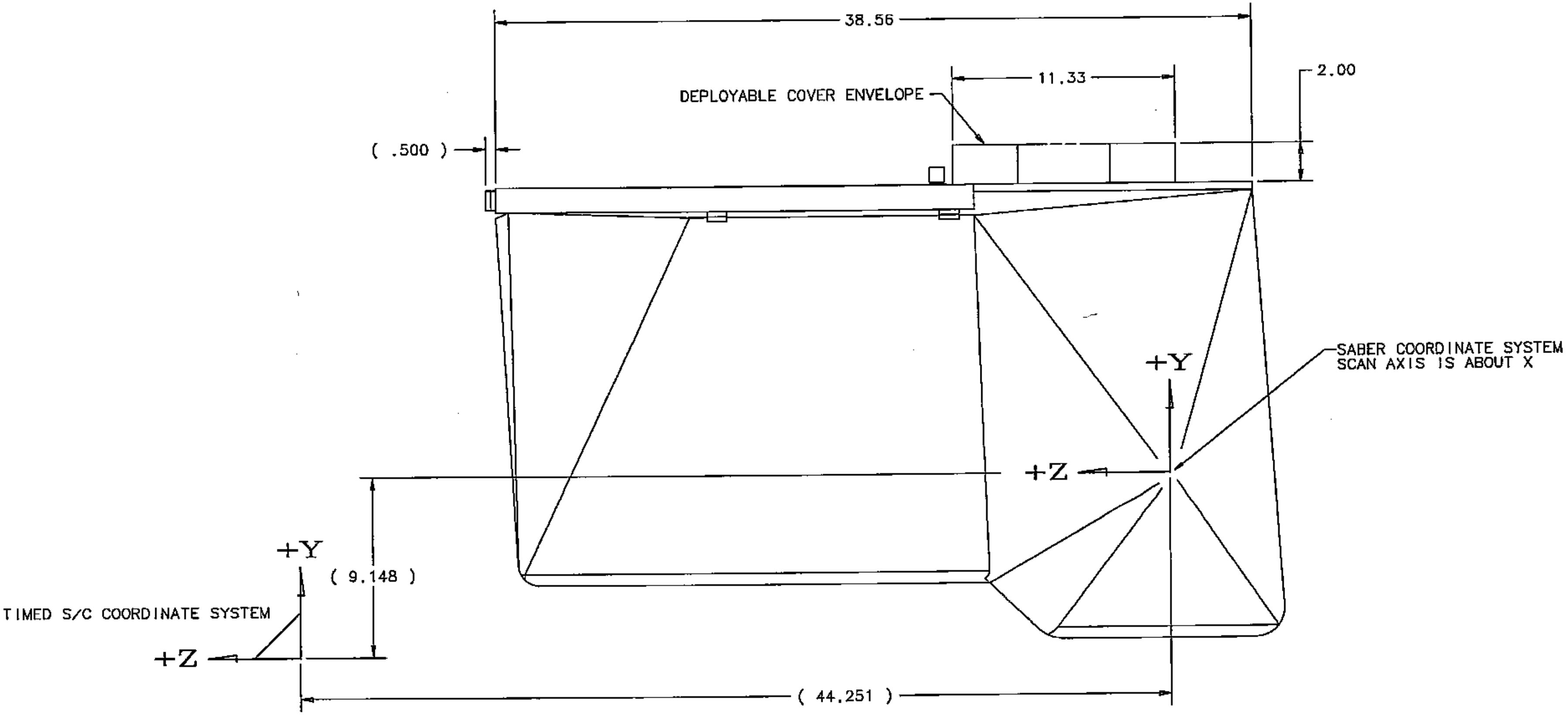
SABER Instrument XZ Envelope



SABER Instrument XY Envelope



SABER Instrument YZ Envelope



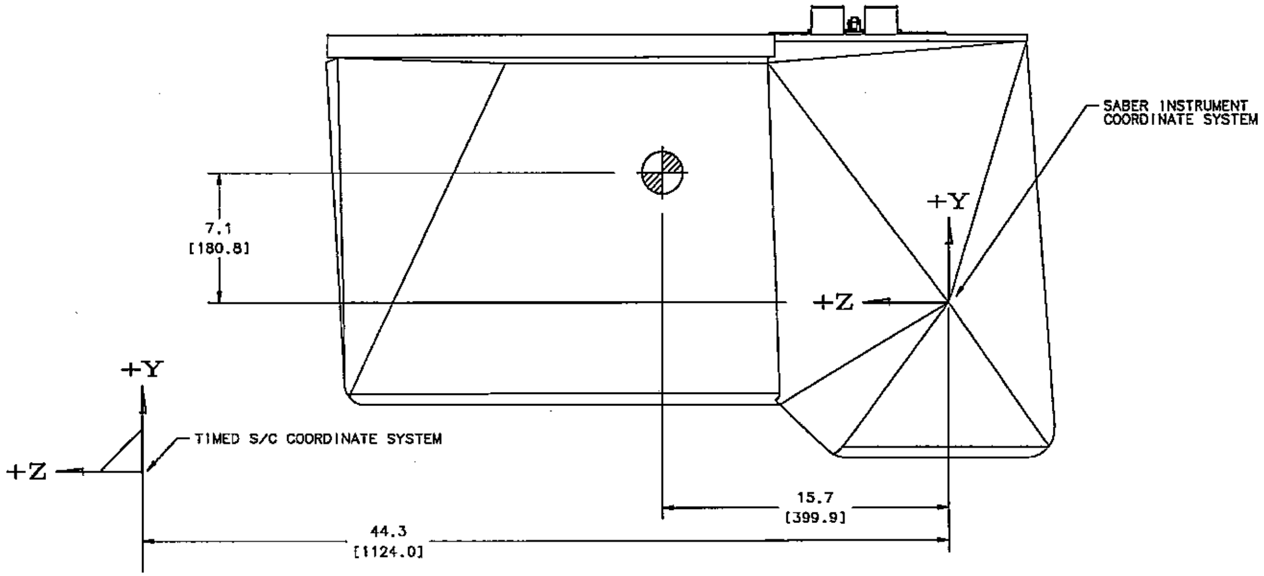
SABER Preliminary Design Review

SPACE DYNAMICS LABORATORY / UTAH STATE UNIVERSITY

SABER Mass Properties

	MASS	Ixx	Iyy	Izz	Ixy	Iyz	Ixz	
	Kg	Kg.mm^2	Kg.mm^2	Kg.mm^2	Kg.mm^2	Kg.mm^2	Kg.mm^2	
SABER INSTRUMENT	61.71	1.790E+7	1.530E+7	5.068E+6	1.813E+5	5.711E+6	4.290E+5	MOMENTS OF INERTIA ABOUT SABER COORDINATE SYSTEM
		6.117E+6	5.918E+6	3.049E+6	-1.863E+4	1.286E+6	-1.337E+4	MOMENTS OF INERTIA ABOUT SABER CG

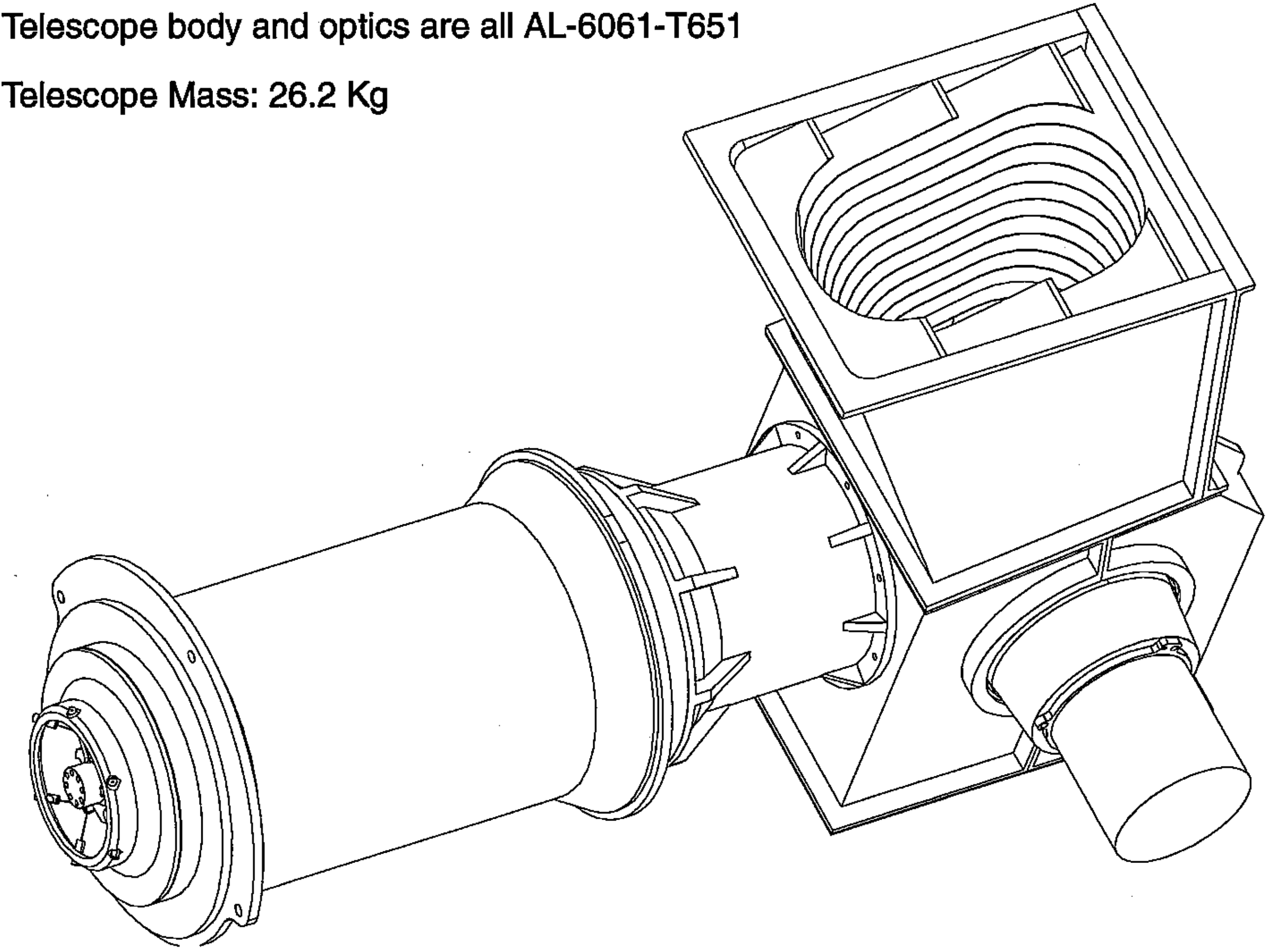
Instrument CG is at (18.1, 180.8, 399.9) mm, or (0.7, 7.1, 15.7) in.



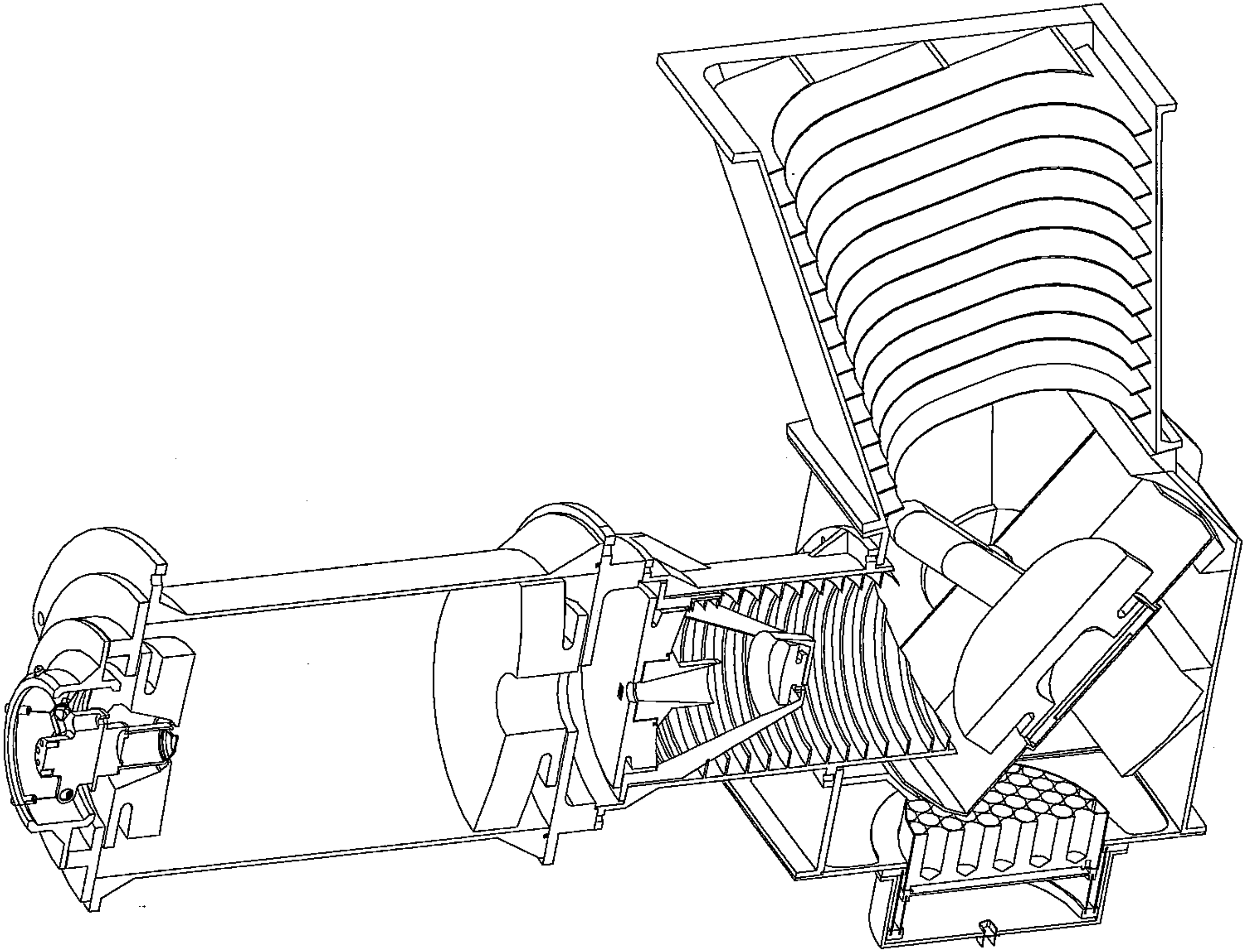
SABER Telescope

Telescope body and optics are all AL-6061-T651

Telescope Mass: 26.2 Kg



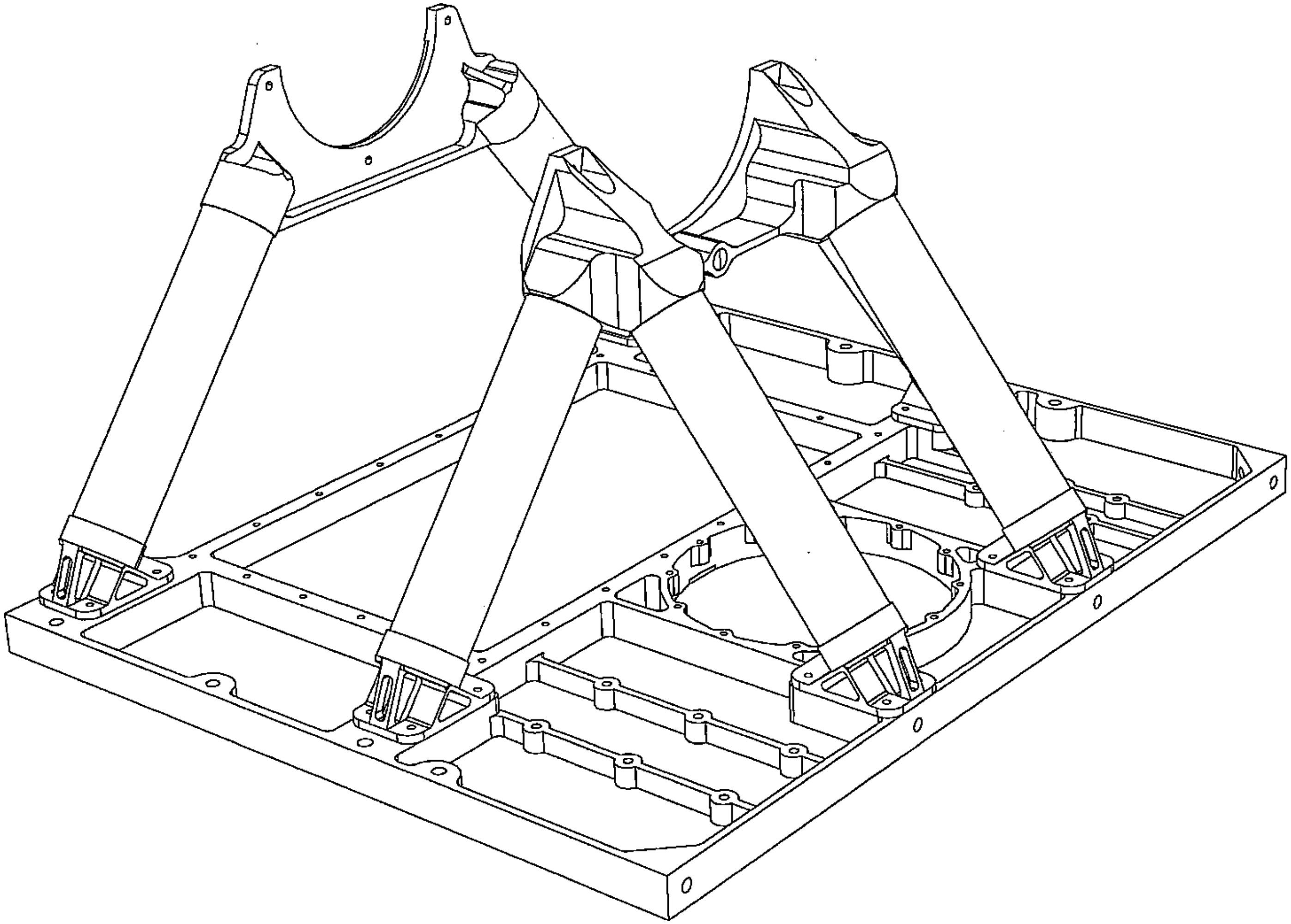
SABER Telescope YZ Section View



SABER Structure

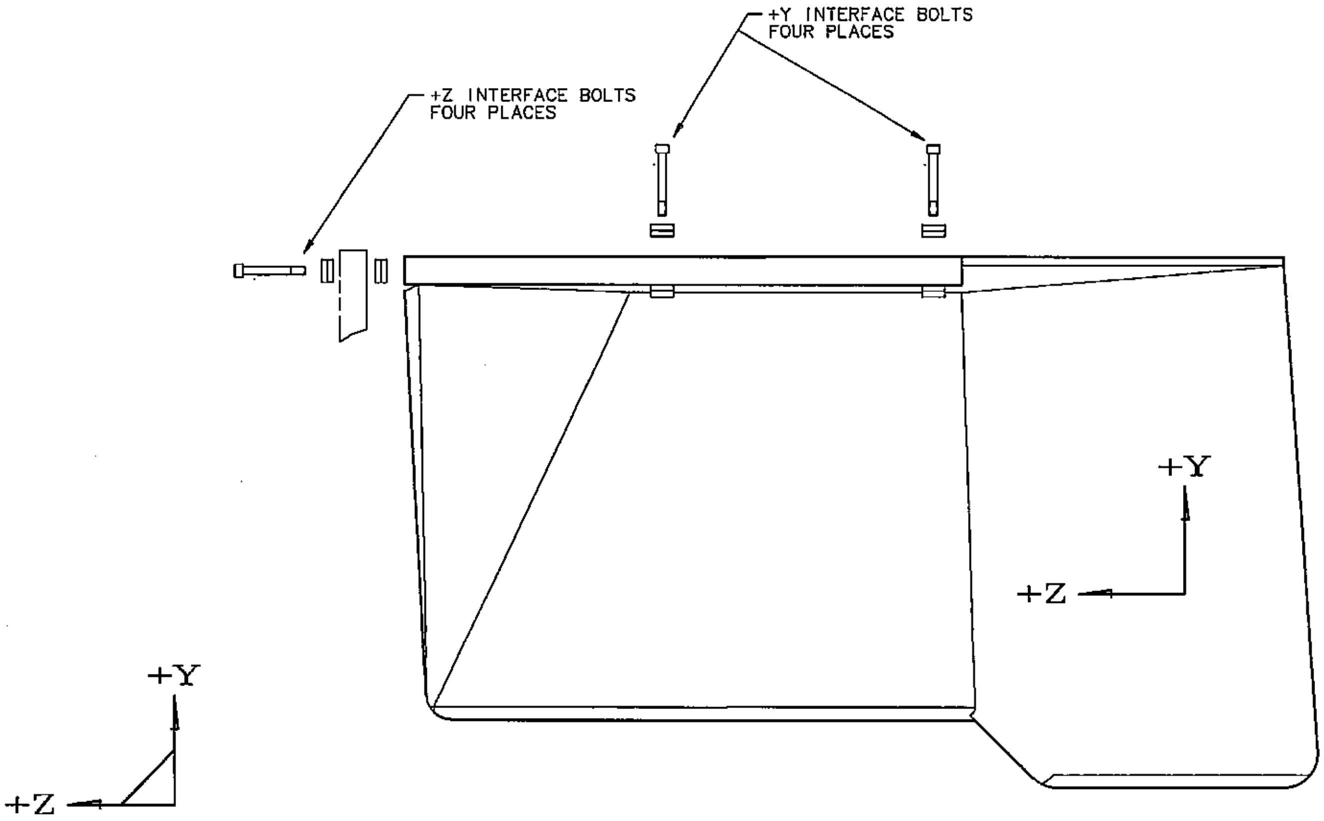
- Structure Design meets the following Criteria:
  - Strain Free support of Telescope Assembly.
  - Provide Stiff attachment to the Spacecraft (System $f_n > 80$ Hz)
  - Provide thermal insulation between S/C and different parts of SABER.
- Structure is all 6061-T651 Aluminum with eight G-10 Struts.
  - SDL has extensive experience with AL / G-10 structures.
  - Cost effective approach.
  - Critical members will be fully tested and qualified before protoflight unit is made.
- Structural Baseplate also functions as a radiator.
- Structure will be used as the alignment jig for the telescope.

SABER Structure



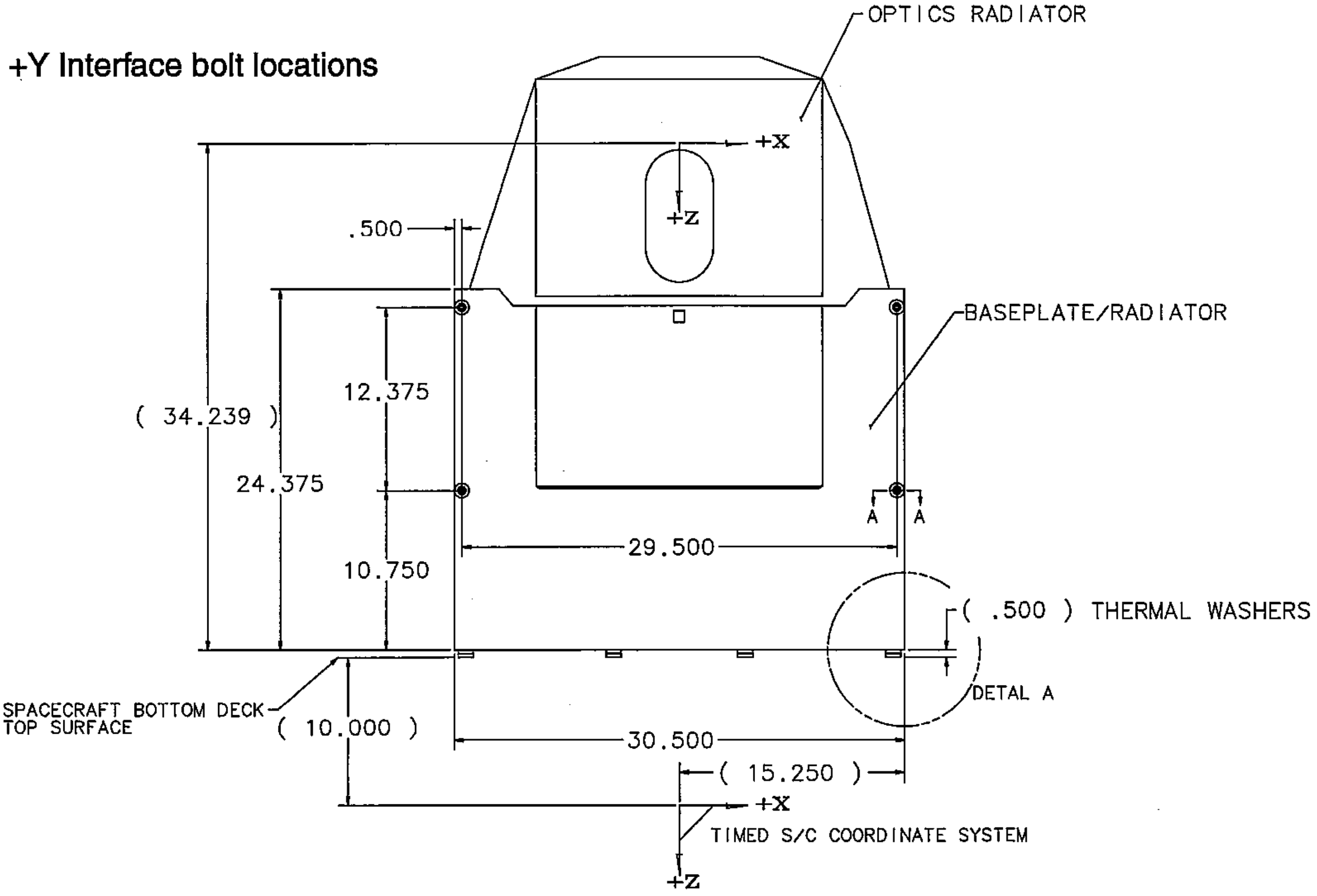
SABER Mechanical Interfaces

- SABER is mounted to the spacecraft by eight sets of bolts and thermal washers.



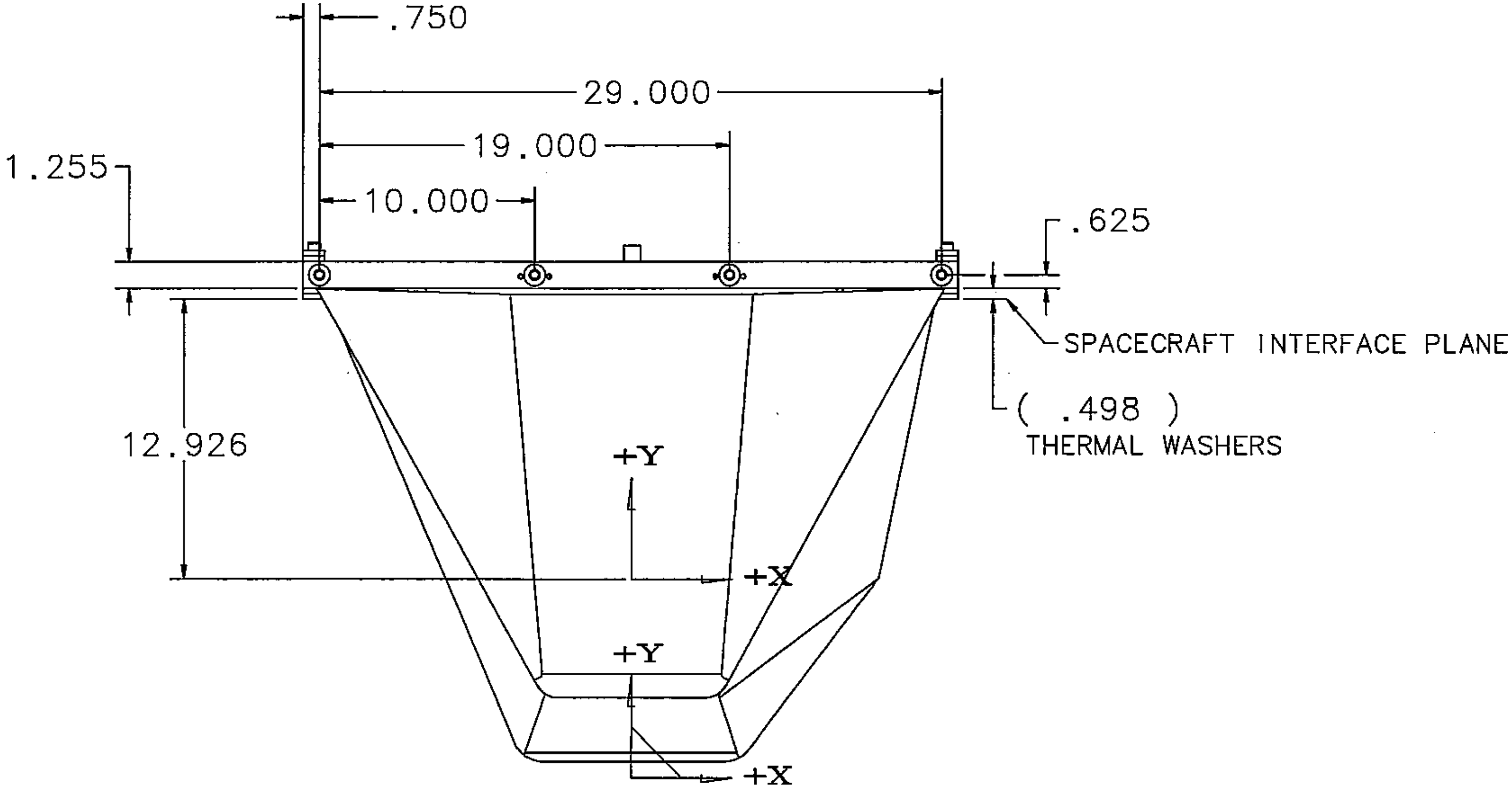
SABER Mechanical Interfaces

+Y Interface bolt locations

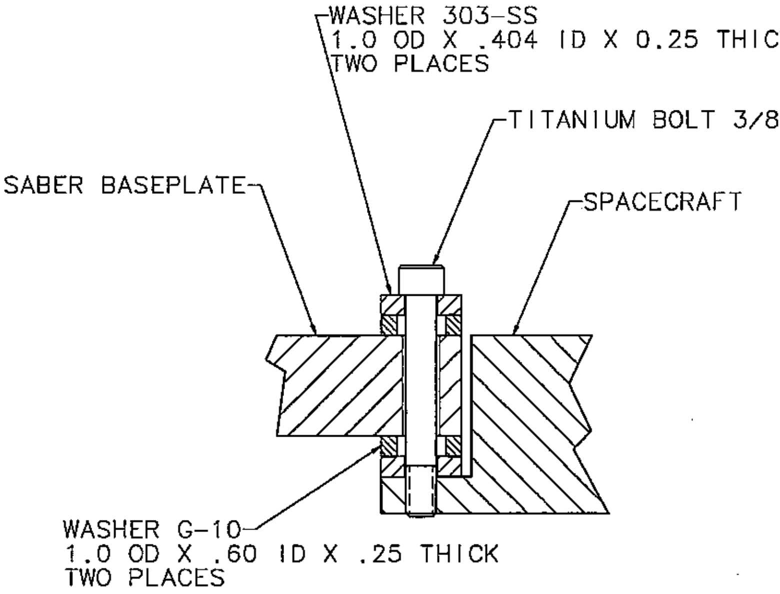


SABER Mechanical Interfaces

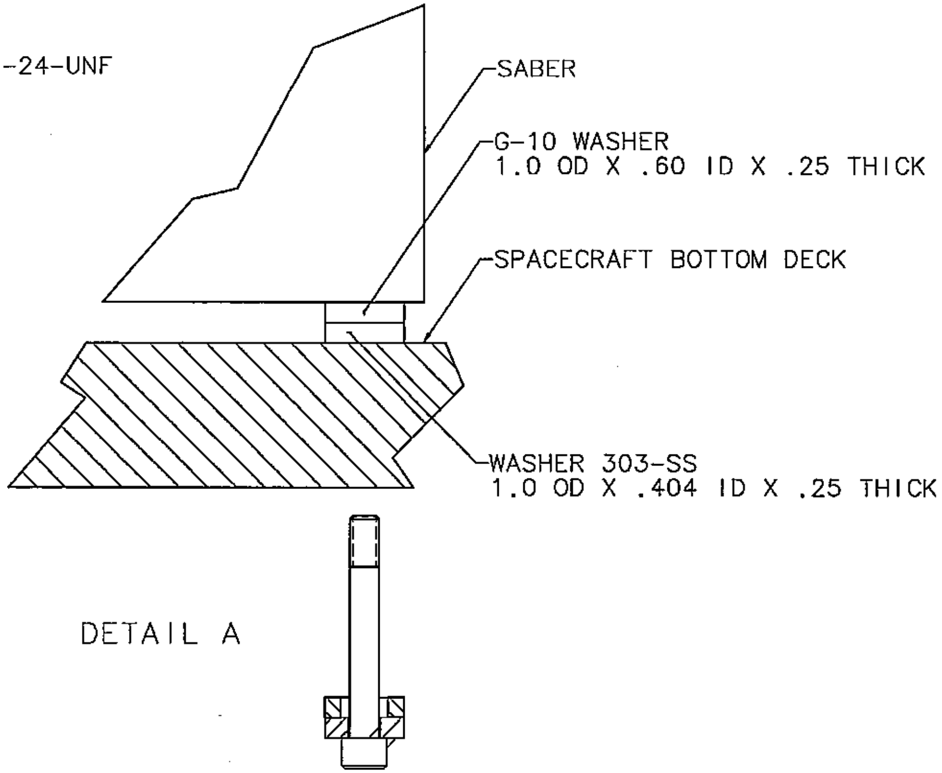
+Z Interface bolt locations



SABER Mechanical Interface Details

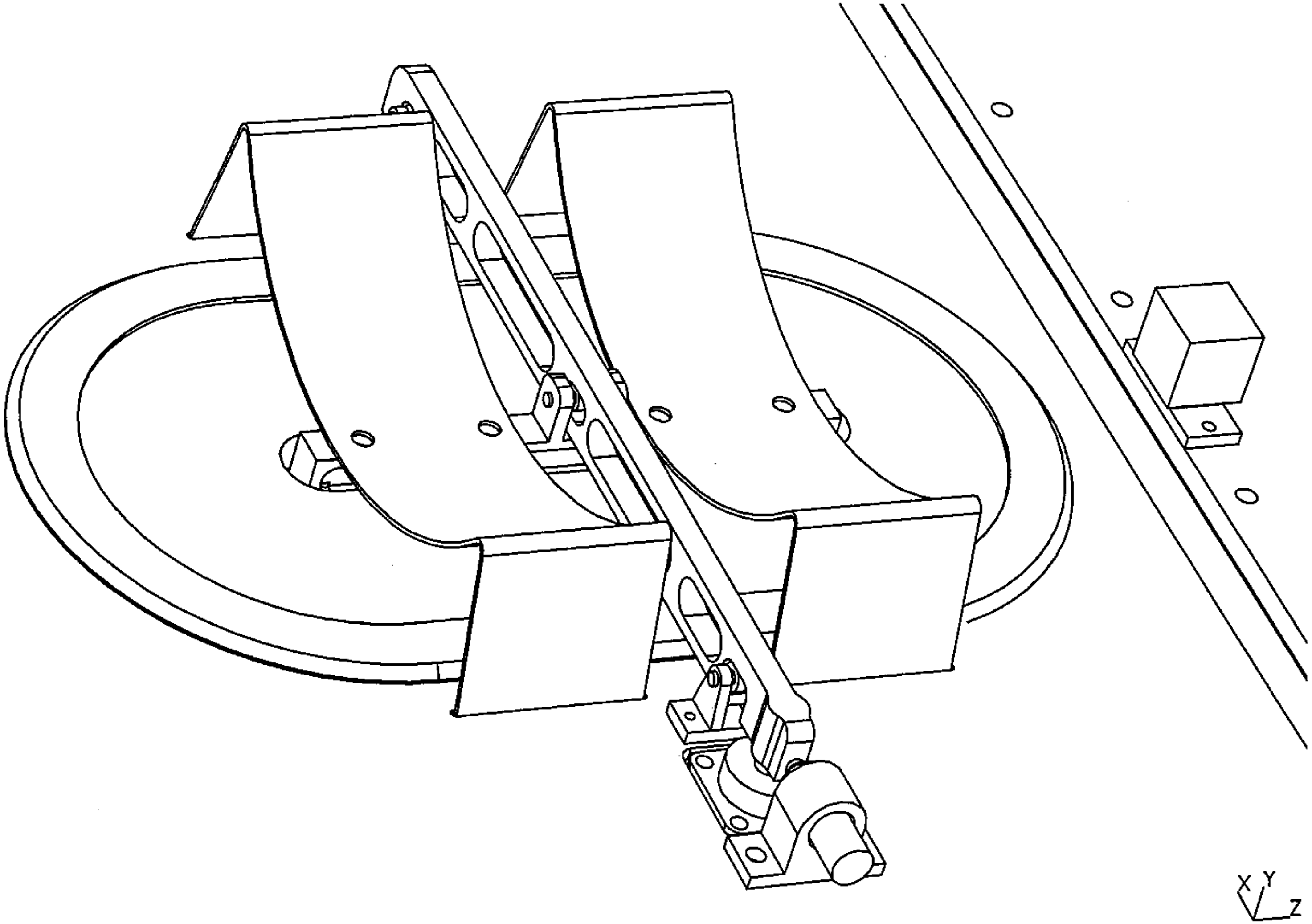


SECTION A-A

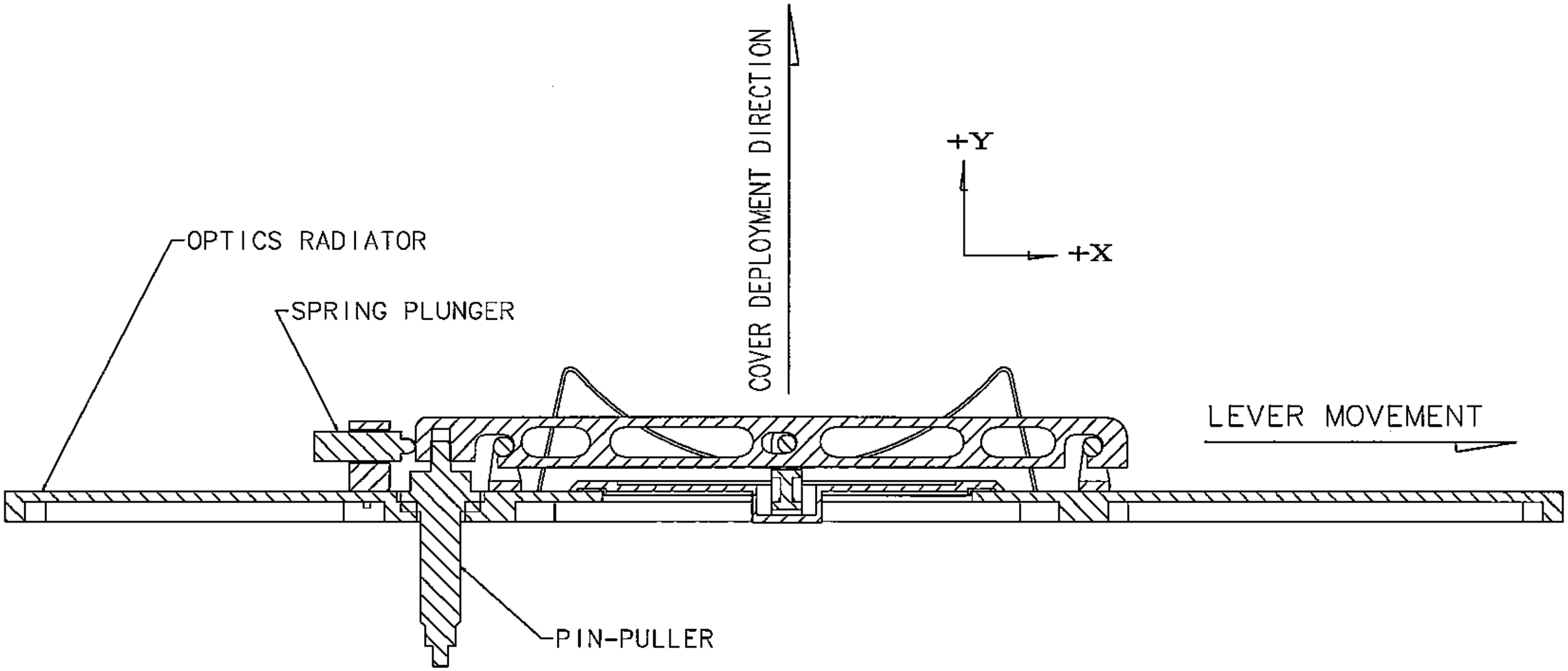


DETAIL A

SABER Deployable Cover

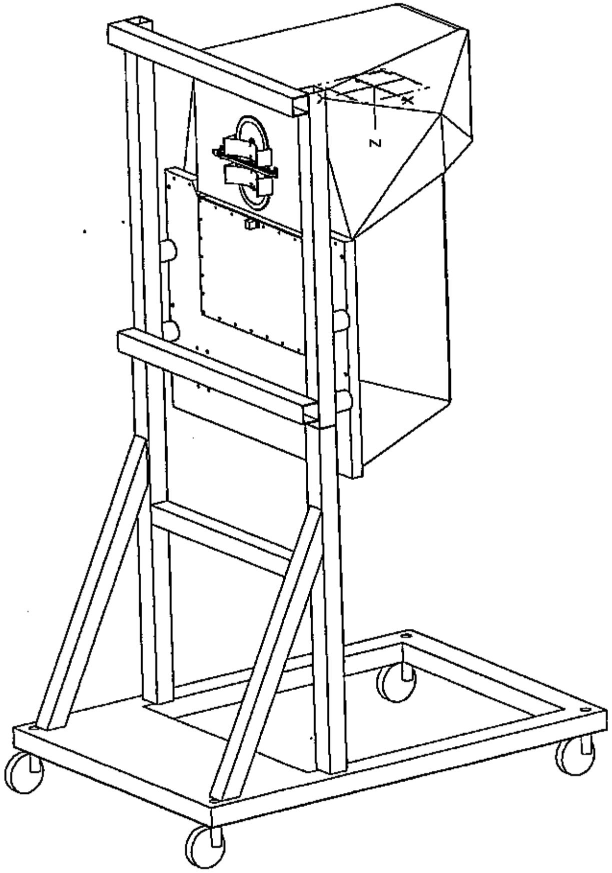


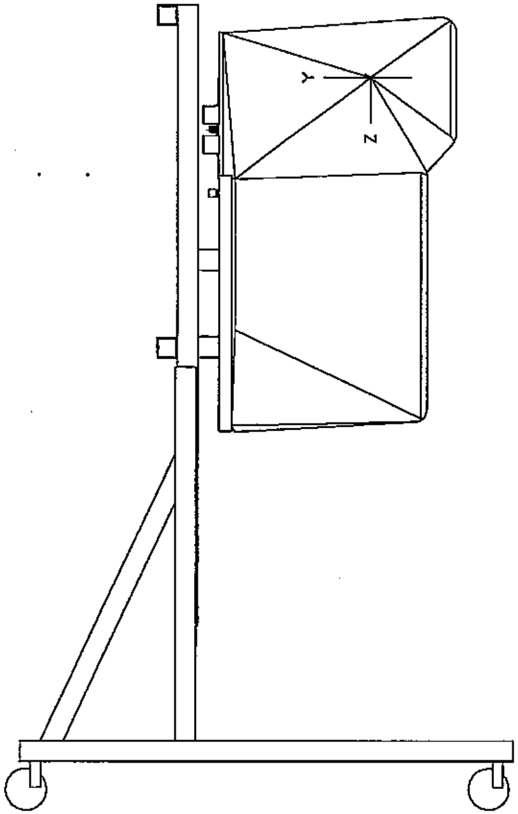
SABER Deployable Cover



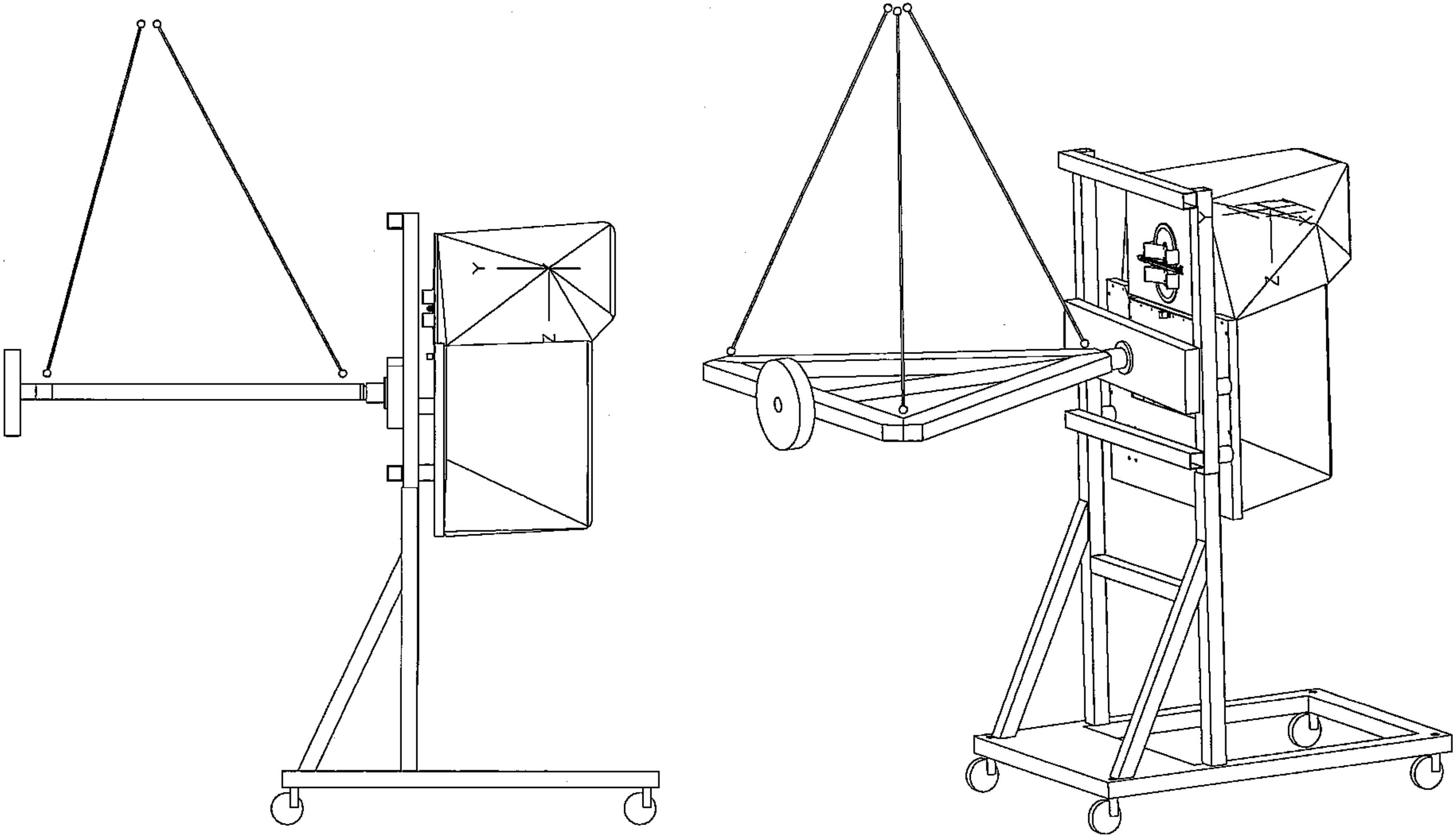
The mass of deployed portion of cover is less than 300 grams.

SABER Mechanical GSE / Handling Cart



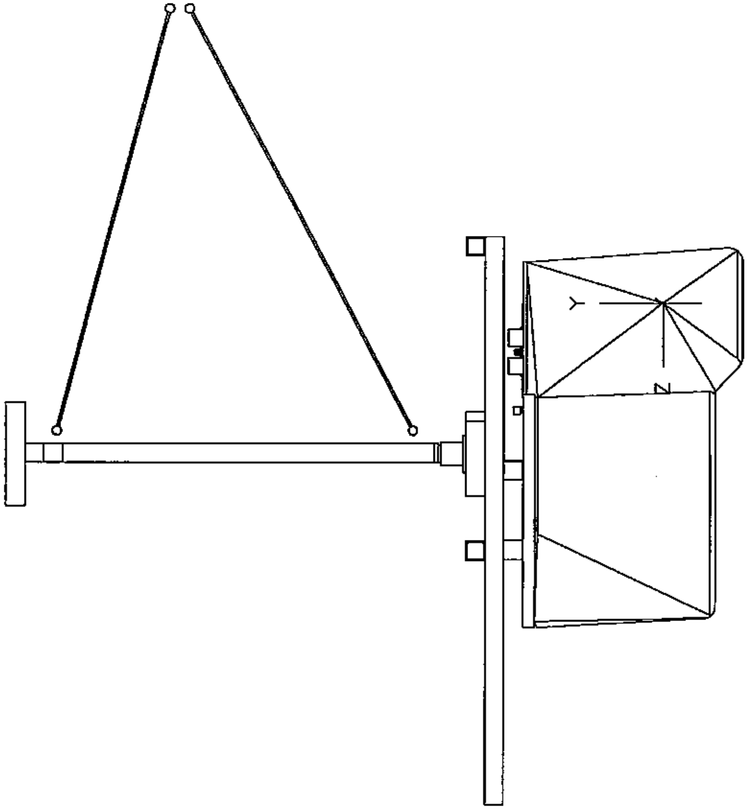


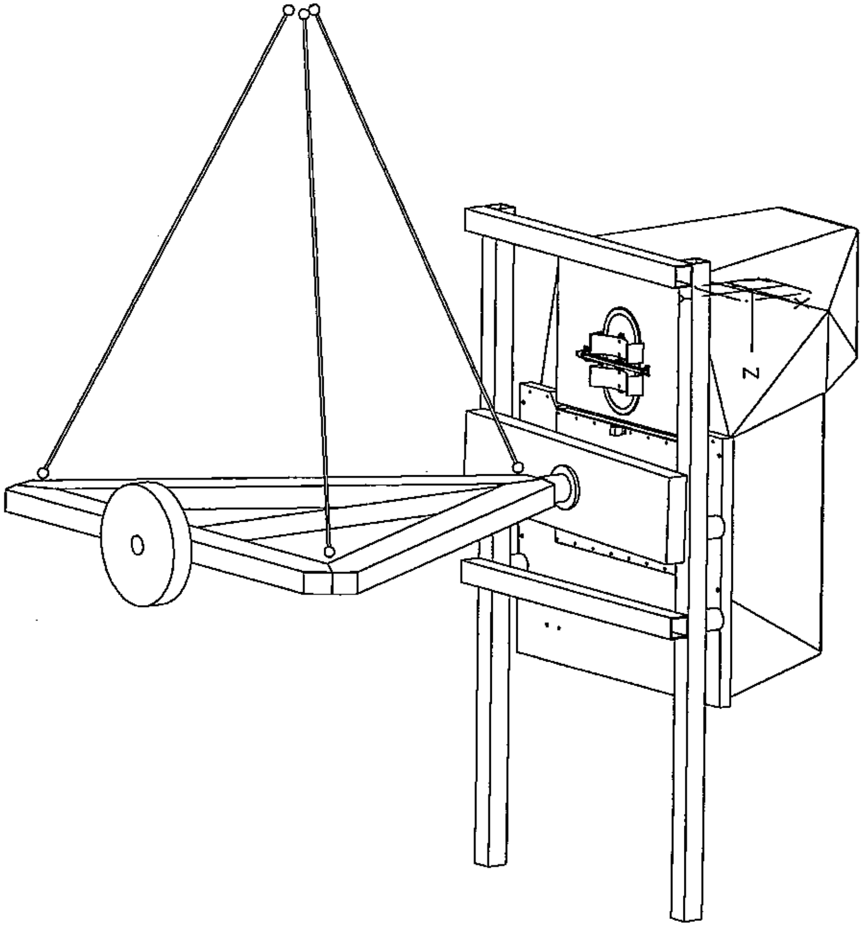
SABER Mechanical GSE / Lifting Sling



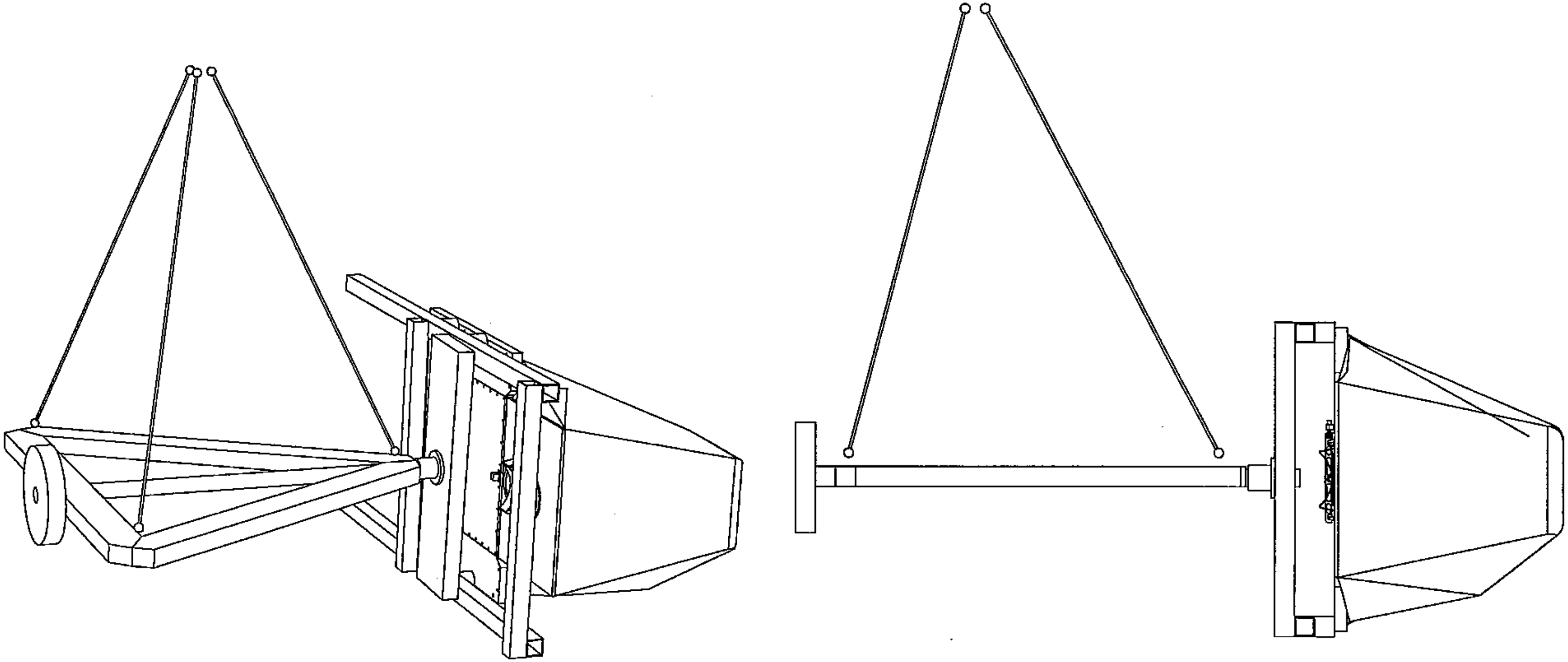
Hand-off to lifting sling from handling cart

SABER Mechanical GSE / Lifting Sling





SABER Mechanical GSE / Lifting Sling



SABER is rotated for horizontal handling

STRUCTURAL ANALYSIS

Steven L. Folkman

December 10, 1996

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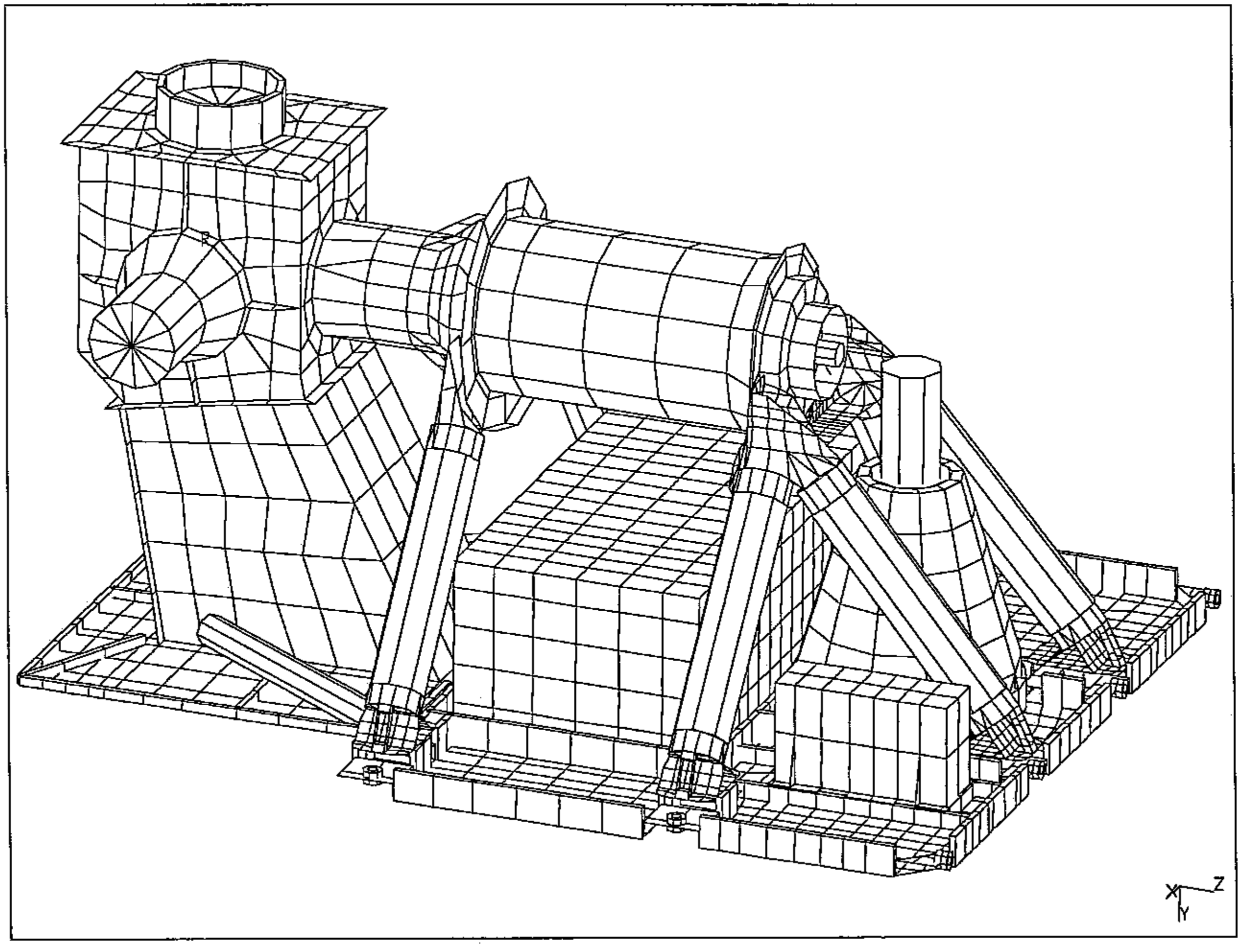
E-Mail: stevef@mae.usu.edu

FINITE ELEMENT MODEL
Description

Detailed Finite Element Model Constructed

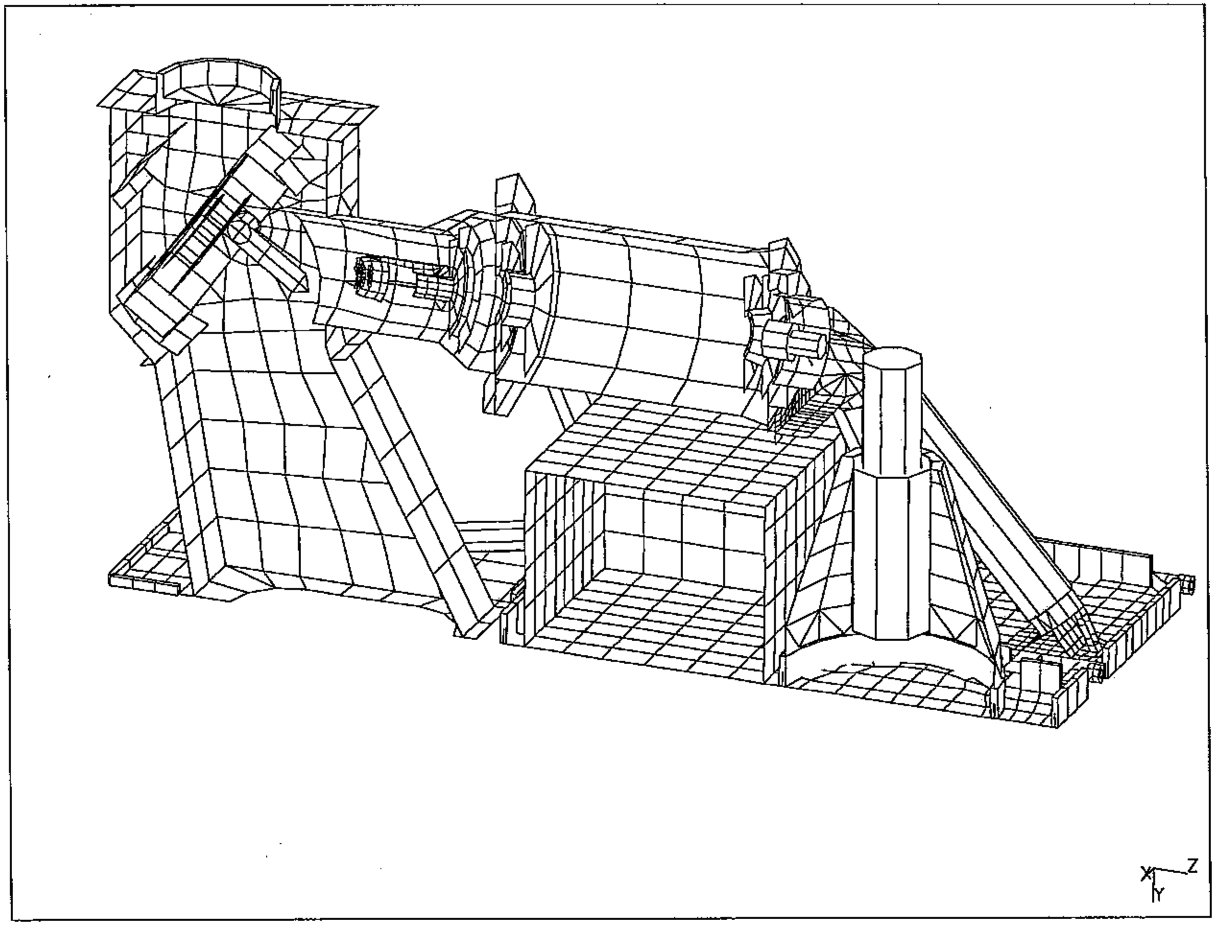
- 4543 Elements
- 4244 Nodes
- Model Mass 59.0 kg
- G10 struts modeled with beam elements
- G10 mount washers modeled with beam elements
- Refrigerator model by a stiff beam



FINITE ELEMENT MODEL
Description

Components in the Finite Element Model

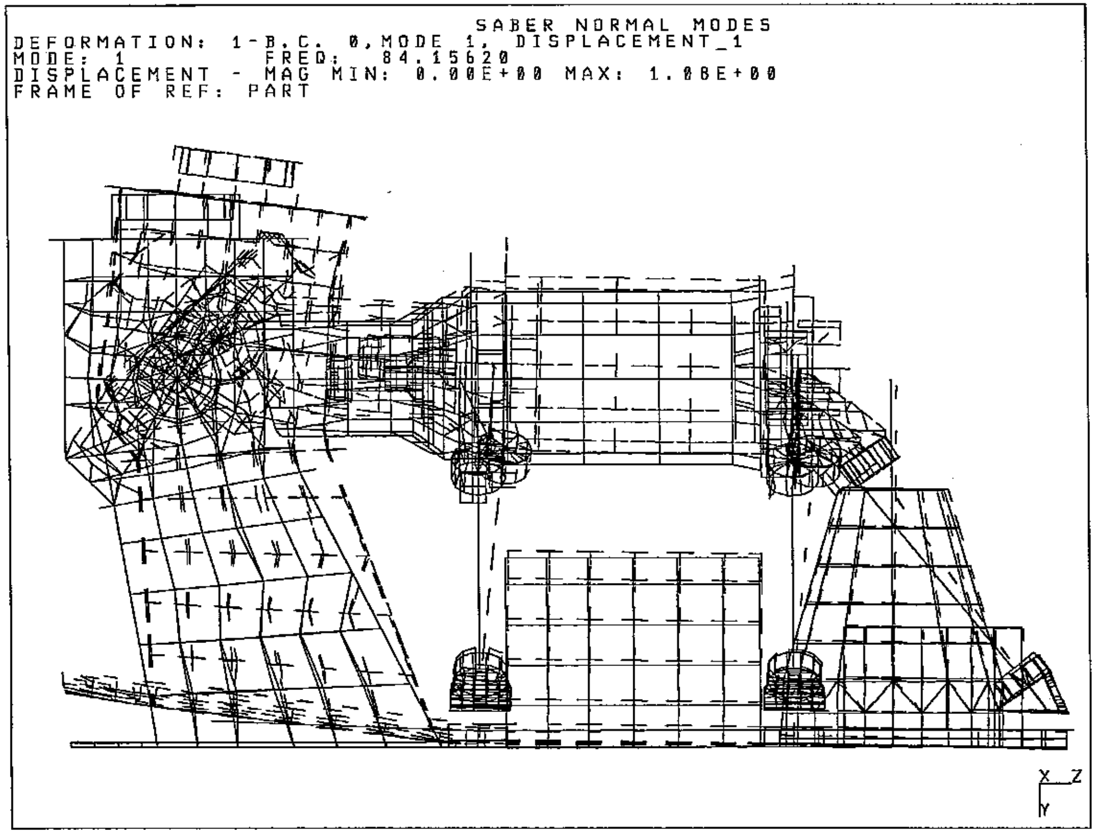
- Pointing Mirror
- Four fixed mirrors
- Optical bench
  - Kevlar fiber support
  - no linkage to cooler
- Inside view displayed on the right



PREDICTED VIBRATION MODES
Normal Modes Analysis

Results

- Analysis Assumptions
  - Model is restrained by clamped nodes at the Spacecraft attach points
- First 5 Modes
  - 84.2 Hz.
  - 97.8 Hz.
  - 115.3 Hz.
  - 119.6 Hz.
  - 128.6 Hz.
- The first mode shape displayed on the right (the dashed lines are the deformed geometry)

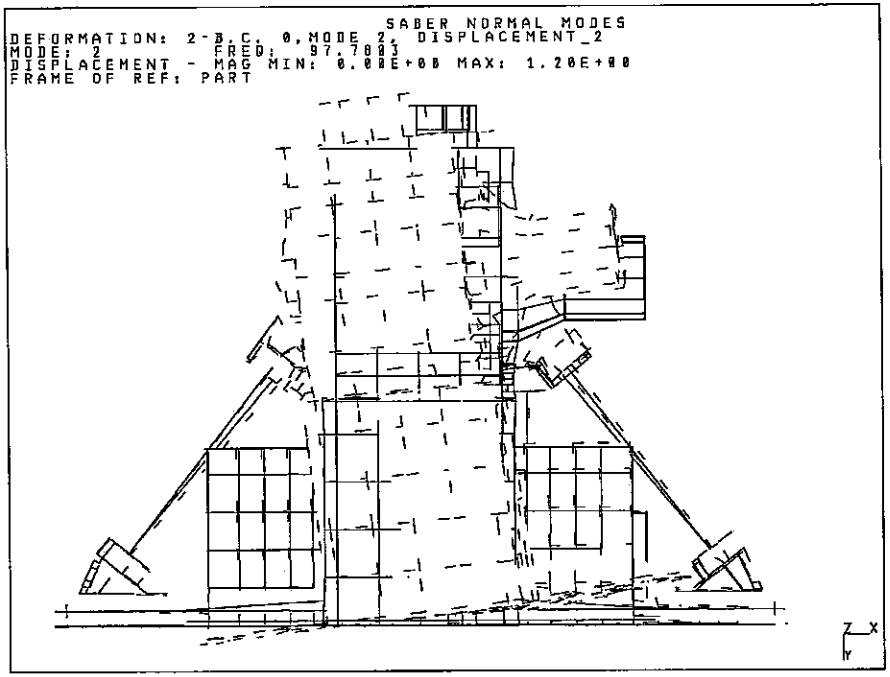


```
                                   SABER NORMAL MODES
DEFORMATION: 1-B.C. 0,MODE 1, DISPLACEMENT_1
MODE: 1         FREQ:   84.15620
DISPLACEMENT - MAG MIN: 0.00E+00 MAX: 1.08E+00
FRAME OF REF: PART
```

PREDICTED VIBRATION MODES

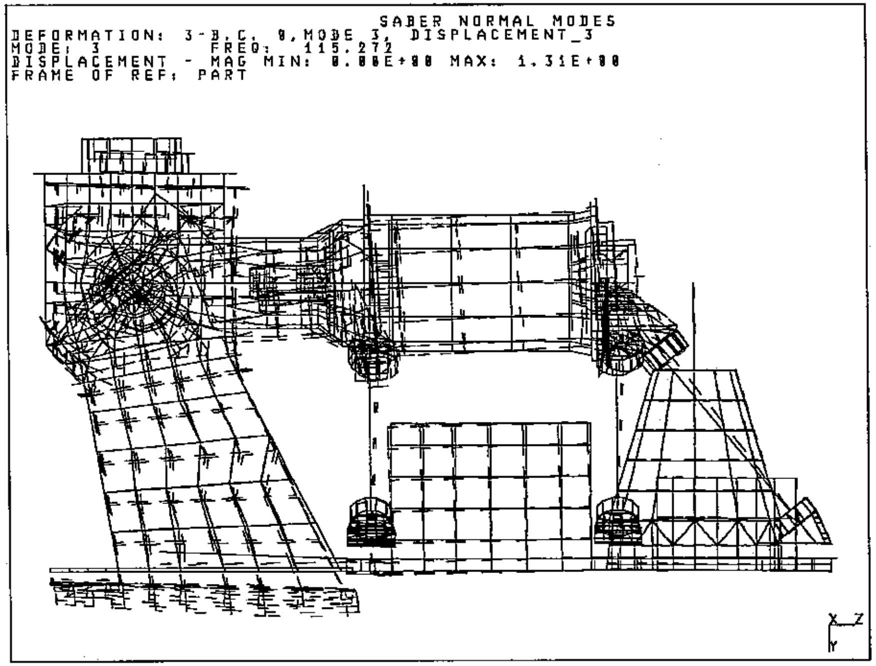
Normal Modes Analysis

2nd Mode



```
                                   SABER NORMAL MODES
DEFORMATION: 2-B.C. 0,MODE 2, DISPLACEMENT_2
MODE: 2          FREQ:   97.7803
DISPLACEMENT - MAG MIN: 0.00E+00 MAX: 1.20E+00
FRAME OF REF: PART
```

3rd Mode



```
                                   SABER NORMAL MODES
DEFORMATION: 3-B.C. 0,MODE 3, DISPLACEMENT_3
MODE: 3          FREQ:   115.272
DISPLACEMENT - MAG MIN: 0.00E+00 MAX: 1.31E+00
FRAME OF REF: PART
```

STRESS ANALYSIS
16G Loads In Each Axis

Stress Analysis

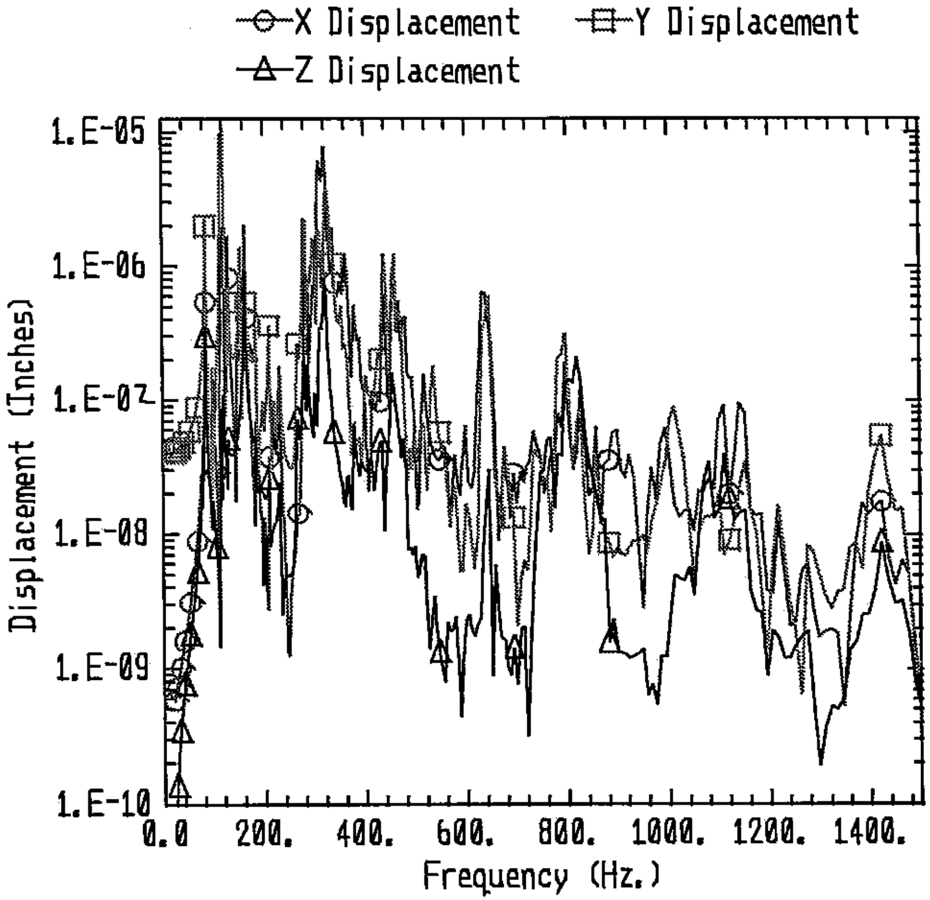
- Nodes at spacecraft interface were fixed
- 16 G loads applied individually in X, Y, and Z axes
- Predicted stresses increased by a factor of 3.0 to account for stress risers or a course mesh
- Factor of Safety applied: 1.4 used on yield, 1.875 on ultimate, 2.0 on composites
- Predicted stresses are low and positive margins obtained
- Max forces at spacecraft bolts: 322 lbs axial, 78 lbs shear, 66 in-lbs moment

Location	Maximum Stress (ksi)	Yield Margin of Safety	Ultmate Strength Margin of Safety
Telescope	2.8 ksi	2.0	1.7
Baffle	2.3 ksi	2.6	2.2
Optics Radiator	2.0 ksi	3.2	2.7
Mounting Plate	3.4 ksi	1.5	1.2
Telescope Mounting Brackets	5.1 ksi	0.6	0.5
Kevlar Fibers	2.5 ksi	-	8.5
G10 Tubes	1.6 ksi	-	1.5

REFRIGERATOR DISTURBANCES
Steady State Response

Analysis Assumptions and Results

- Analysis Assumptions
  - 0.02 pound load applied in the Y direction at the 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 the mirrors and the focal plane predicted
- The figure on the right shows the relative displacements between focal plane and the scan mirror

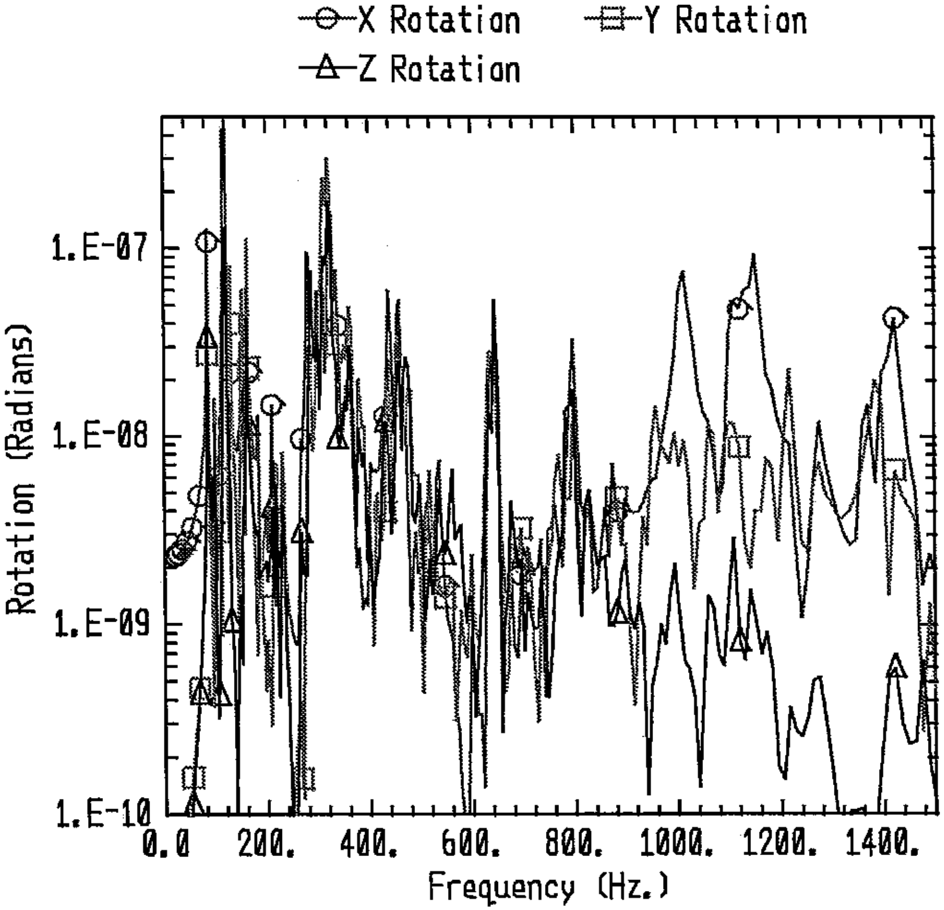


REFRIGERATOR DISTURBANCES

Steady State Response

Analysis Results

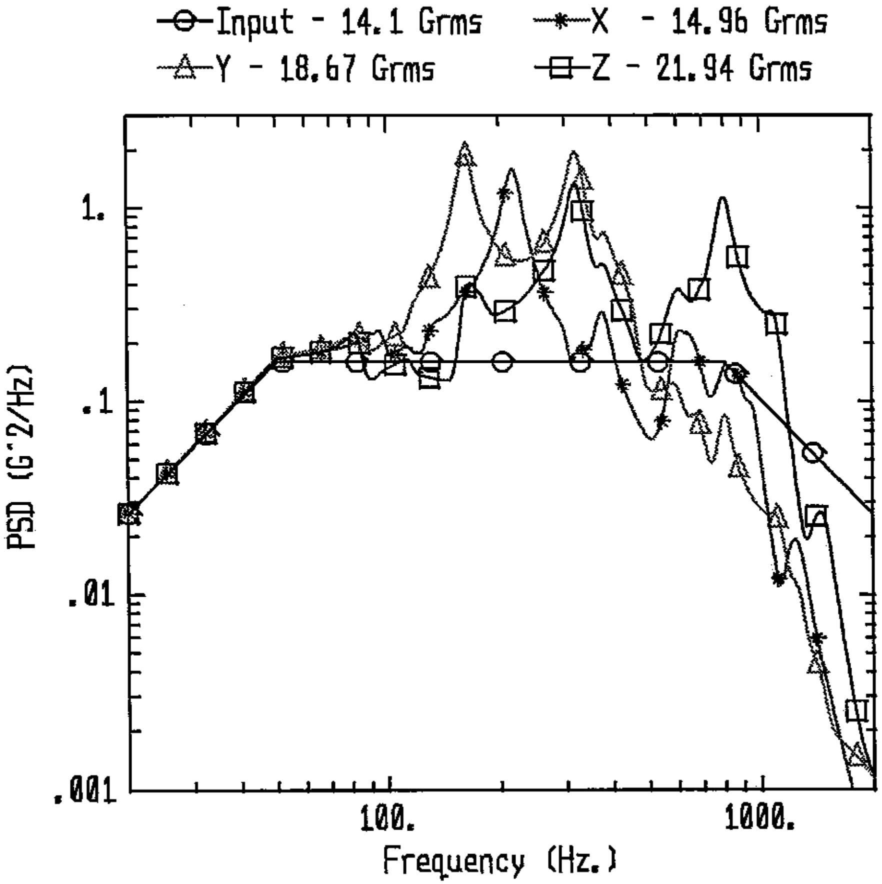
- The figure on the right shows the relative rotations between the focal plane and the scan mirror



RANDOM VIBRATION
Frequency Response at the Refrigerator Mount

Analysis Assumptions and Results

- Analysis Assumptions
  - 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 the X, Y, and Z directions
- The figure on the right shows the input PSD and the PSD's measured at the refrigerator mount



EFFECT OF TEMPERATURE GRADIENTS ON THE TELESCOPE

Simulation of Hot Case Conditions

Assumptions

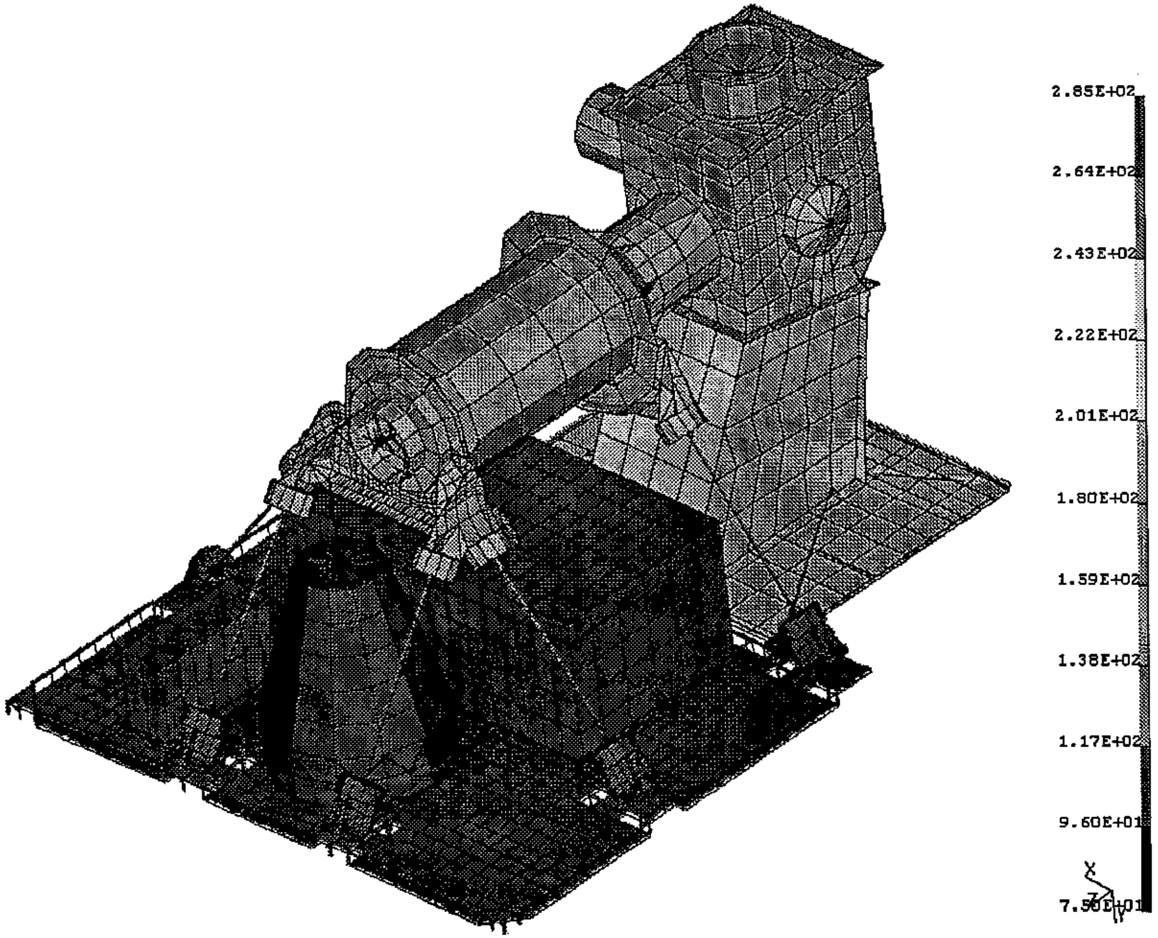
- Hot case thermal loads considered
- Restrained temperatures:
  - optics radiator - 235 K
  - electronics box - 272 K
  - mount plate - 272 K with a +/- 5 K gradient
  - blackbody - 250 K
  - focal plane - 75 K
- Heat loads applied:
  - Scan mirror motor - 3.5 W
  - Chopper - 0.1 W
  - Radiation load uniformly applied inside telescope 2.5 W
  - Refrigerator mount - 20 W
- Only conduction heat transfer considered
- Steady state temperature predicted

EFFECT OF TEMPERATURE GRADIENTS ON THE TELESCOPE

Simulation of Hot Case Conditions

Results

- Full Model

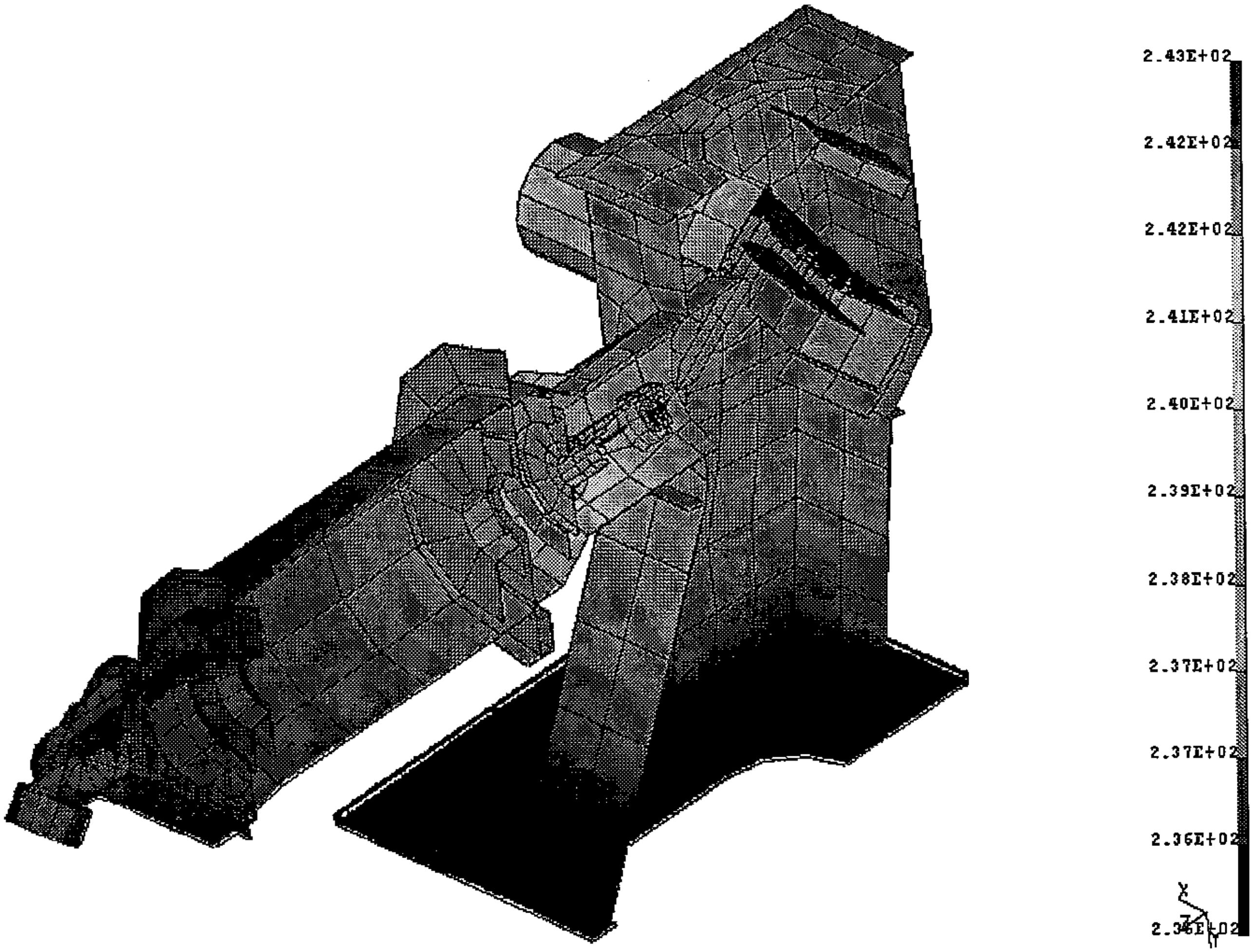


EFFECT OF TEMPERATURE GRADIENTS ON THE TELESCOPE

Simulation of Hot Case Conditions

Results

- Inside of Telescope

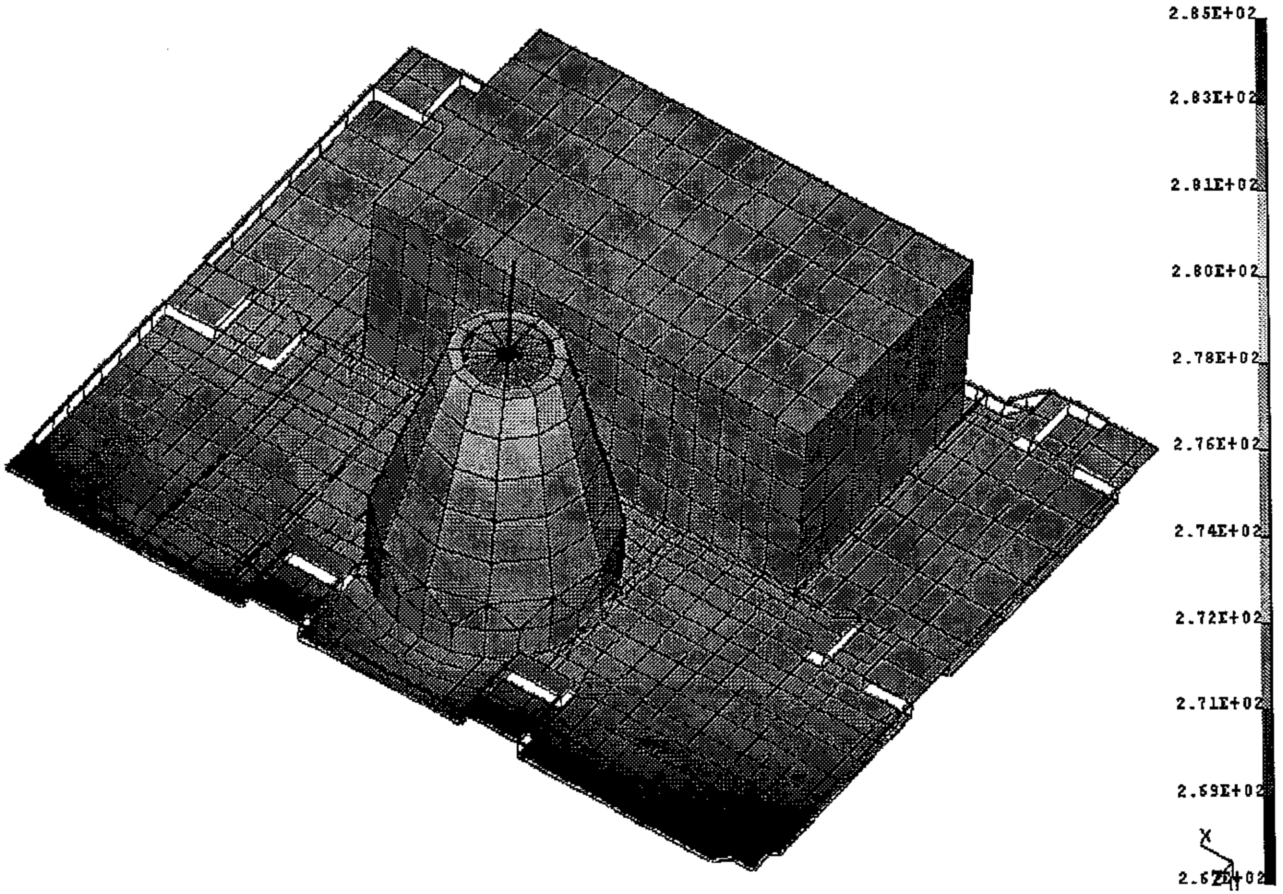


EFFECT OF TEMPERATURE GRADIENTS ON THE TELESCOPE

Simulation of Hot Case Conditions

Results

- Mounting plate and Refrigerator mount

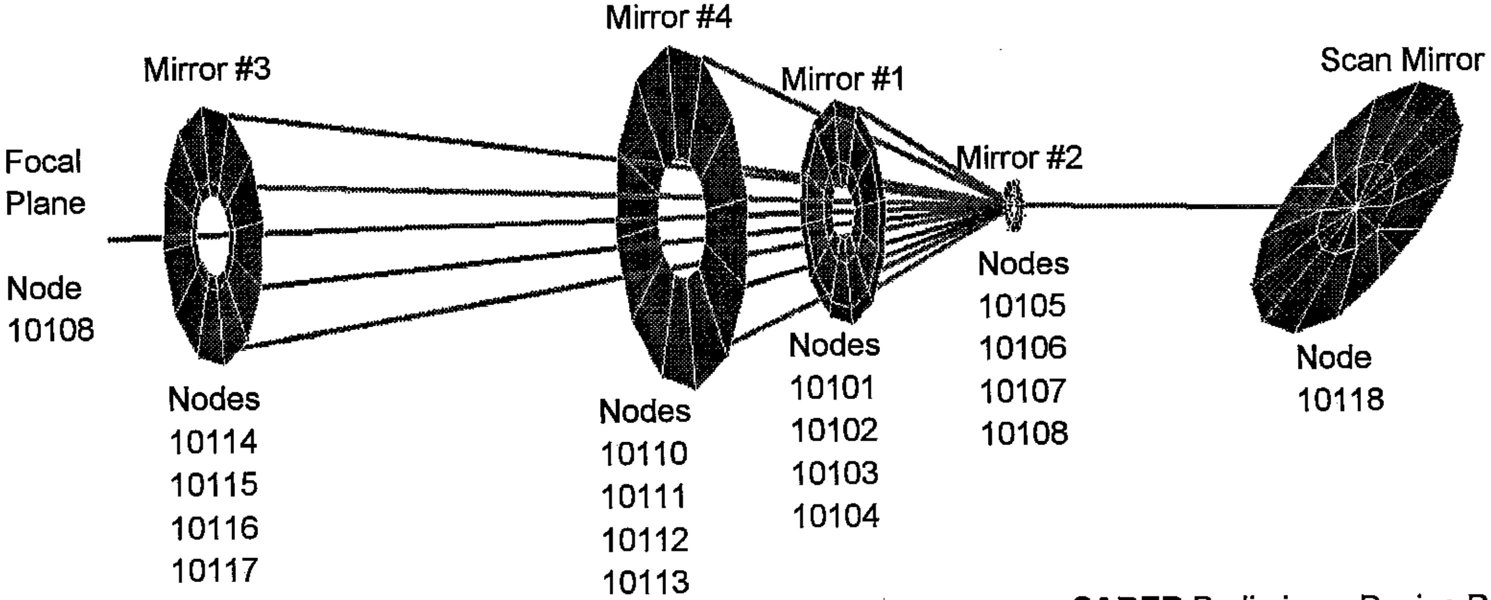


EFFECT OF TEMPERATURE GRADIENTS ON THE TELESCOPE

Telescope Relative Displacements

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



EFFECT OF TEMPERATURE GRADIENTS ON THE TELESCOPE

Telescope Relative Displacements

Results

- Predicted Mirror Displacements relative to Mirror 2 for the Hot Case temperatures

Node	Location	X Disp. (Inch)	Y Disp. (Inch)	Z Disp. (Inch)	X Rot. (Radians)	Y Rot. (Radians)	Z Rot. (Radians)
10101	Mirror 1	-9.336E-08	-1.709E-07	-6.985E-08	4.263E-07	3.349E-08	-2.621E-08
10102	Mirror 1	-5.383E-09	4.997E-07	1.598E-06	-2.022E-06	9.301E-08	-3.598E-10
10103	Mirror 1	1.128E-08	-6.529E-08	6.725E-07	4.335E-07	1.076E-08	-1.654E-08
10104	Mirror 1	5.645E-08	-1.806E-07	-4.177E-08	4.975E-07	-9.366E-08	4.309E-08
10105	Mirror 2	1.451E-10	-1.200E-08	1.068E-07	1.973E-13	-4.788E-13	-5.333E-14
10106	Mirror 2	1.447E-10	-1.200E-08	1.068E-07	3.708E-12	1.909E-13	1.102E-12
10107	Mirror 2	1.439E-10	-1.200E-08	1.068E-07	1.863E-12	4.405E-13	1.196E-12
10108	Focal Plane	-1.159E-05	4.628E-04	-2.315E-04	-3.874E-05	-6.351E-07	-7.464E-07
10109	Mirror 2	1.436E-10	-1.200E-08	1.068E-07	-2.688E-14	1.206E-12	9.845E-13
10110	Mirror 4	4.463E-06	5.284E-05	-1.226E-05	-1.773E-05	-1.826E-06	-1.508E-07
10111	Mirror 4	-9.545E-06	6.606E-05	4.876E-05	-1.732E-05	-2.239E-06	-1.471E-07
10112	Mirror 4	-8.614E-06	3.866E-05	-6.314E-05	-1.814E-05	-2.142E-06	-1.417E-07
10113	Mirror 4	-2.265E-05	5.191E-05	1.581E-06	-1.783E-05	-2.530E-06	-1.506E-07
10114	Mirror 3	5.895E-05	4.059E-04	-1.693E-04	-2.542E-05	-2.088E-06	-7.949E-07
10115	Mirror 3	-1.236E-05	4.741E-04	-1.023E-04	-2.662E-05	-5.389E-07	-7.830E-07
10116	Mirror 3	-8.629E-06	3.341E-04	-2.237E-04	-2.435E-05	-5.505E-07	-7.830E-07
10117	Mirror 3	-7.994E-05	4.022E-04	-1.667E-04	-2.541E-05	9.970E-07	-7.690E-07
10118	Scan M.	-2.018E-05	3.340E-03	-4.938E-04	6.413E-04	-1.095E-05	3.234E-06

SUMMARY OF STRUCTURAL ANALYSIS

SABER Meets Design Goals

- Minimum Frequency > 80 Hz.
- High Margins of Safety
- Refrigerator Disturbances are small
- There is concern about how to qualify the refrigerator
- Thermally induced displacements of the telescope are acceptable

Thermal Design and Analysis

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Scott Jensen
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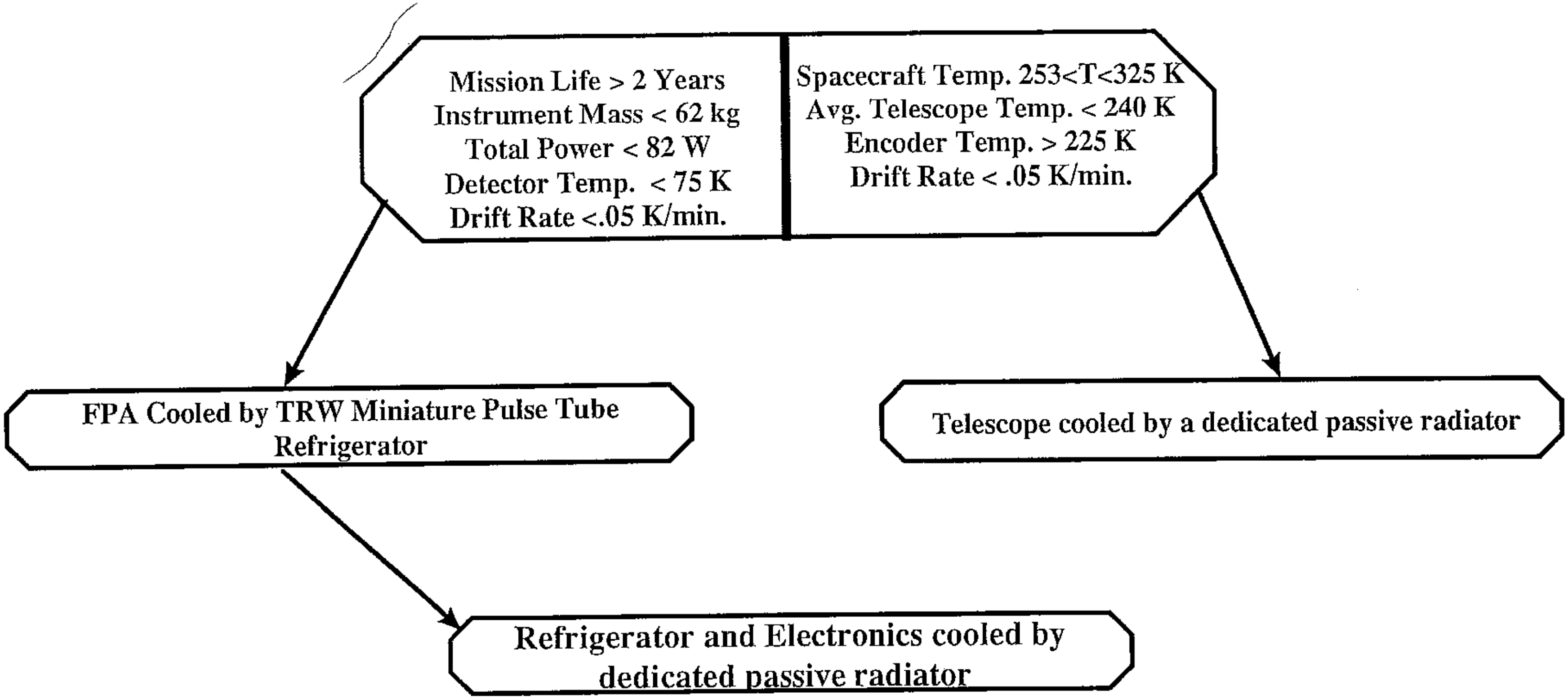
Fax:(801)-755-4299
email:scott.jensen@sdl.usu.edu

December 10-12, 1996

Thermal Flow Down Requirements



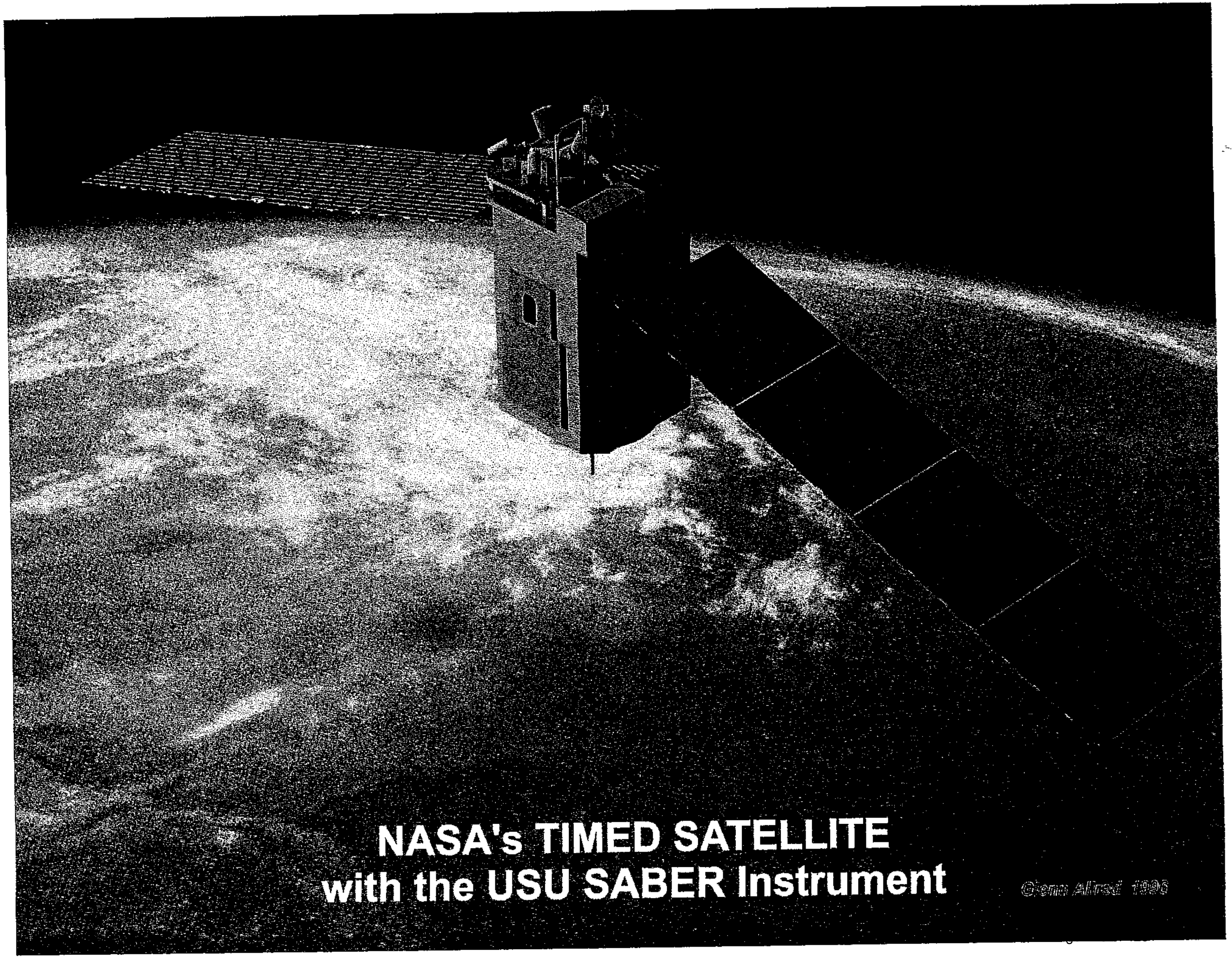
Mission Life > 2 Years
Instrument Mass < 62 kg
Total Power < 82 W
Detector Temp. < 75 K
Drift Rate <.05 K/min.

Spacecraft Temp. 253<T<325 K
Avg. Telescope Temp. < 240 K
Encoder Temp. > 225 K
Drift Rate < .05 K/min.

FPA Cooled by TRW Miniature Pulse Tube Refrigerator

Telescope cooled by a dedicated passive radiator

Refrigerator and Electronics cooled by dedicated passive radiator



NASA's TIMED SATELLITE
with the USU SABER Instrument

Glenn Allred 1996

Thermal Design Assumptions

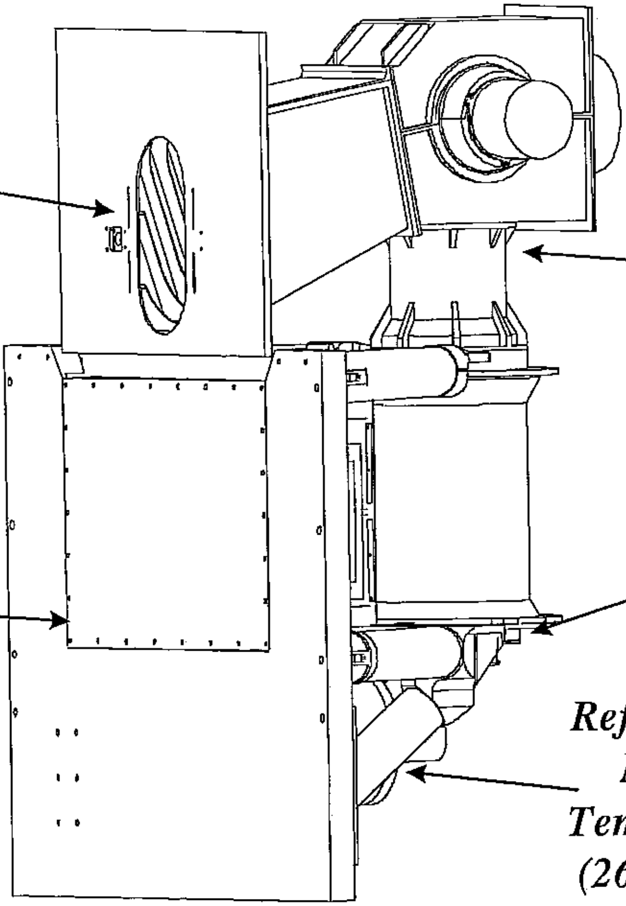
- **Hot Case**
  - Absorbtivity* =.25
  - Emissivity* =.75
  - Solar Flux^ = 1419 W/m^2
  - Albedo^ = 568 W/m^2
  - Earthshine^ = 268 W/m^2
  - Beta Angle = 0
  - Orbit Altitude = 600 km
    - Circular
  - Inclination = 74.5 degrees
  - Spacecraft Temperatures^
    - +Y Panel = 303 K
    - Interior = 323 K

- **Cold Case**
  - Absorbtivity* =.08
  - Emissivity* =.78
  - Solar Flux^ = 1286 W/m^2
  - Albedo^ = 257 W/m^2
  - Earthshine^ = 189 W/m^2
  - Beta Angle = 90
  - Orbit Altitude = 600 km
    - Circular
  - Inclination = 74.5 degrees
  - Spacecraft Temperatures^
    - +Y Panel = 253 K
    - Interior = 253 K

* Numbers recommended by NASA

^ Provided by APL

Overview



Telescope Radiator Interface Temp. (213/235 K)

Avg. Telescope Temperature (215/240 K)

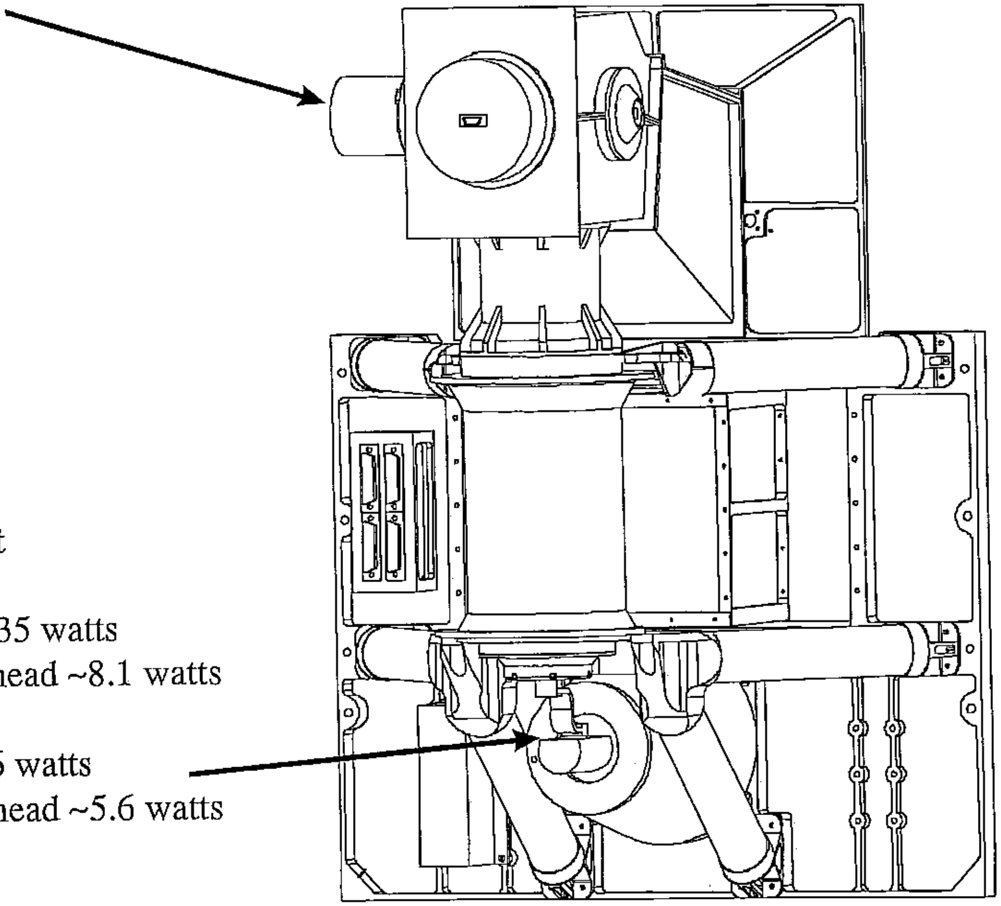
FPA Temperature Zone (75 K)

Electronics/Refrigerator Radiator Interface Temp. (250/270 K)

Refrigerator Mount Temperature (260/280 K)

Operational Heaters

(Cold Case)

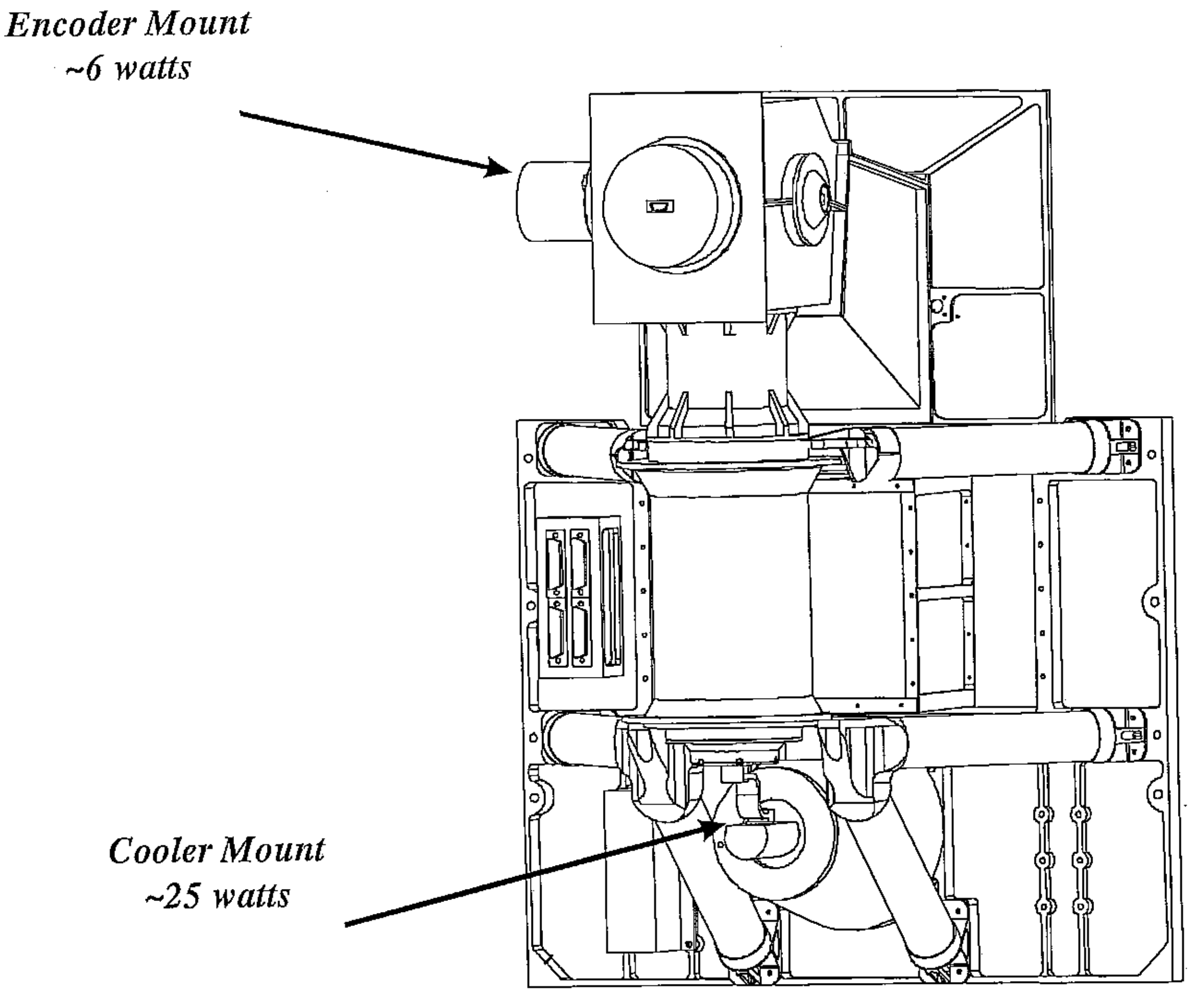


Encoder Mount
Heater~ 1.4 watts
Elec. Overhead~ 1.0 watts

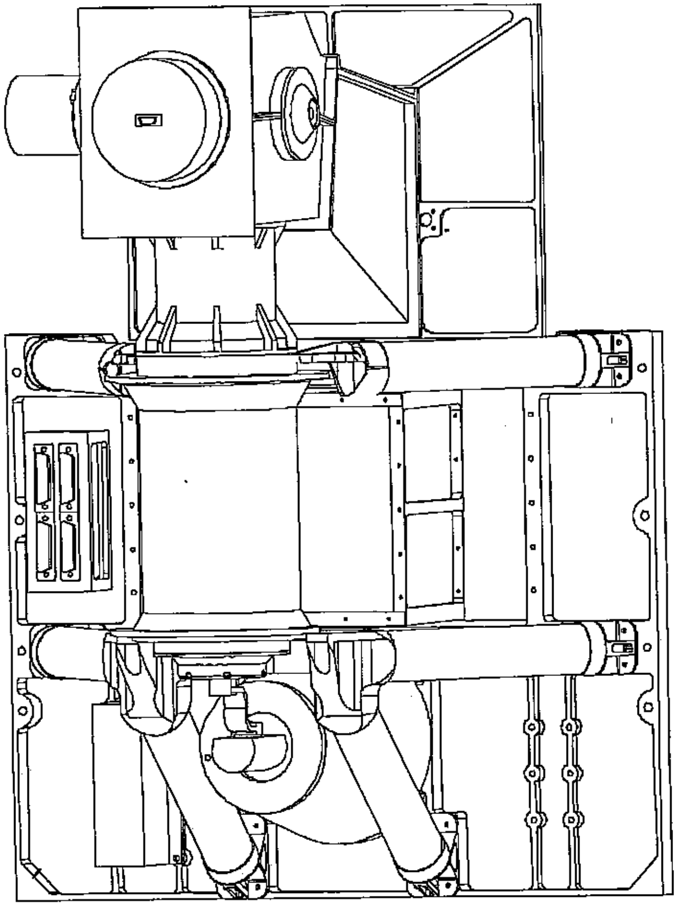
Cooler Mount
270 K min.
Heater ~ 6.35 watts
Elec. Overhead ~8.1 watts
260 K min.
Heater ~1.6 watts
Elec. Overhead ~5.6 watts

Survival Heaters

(Cold case non-operating)



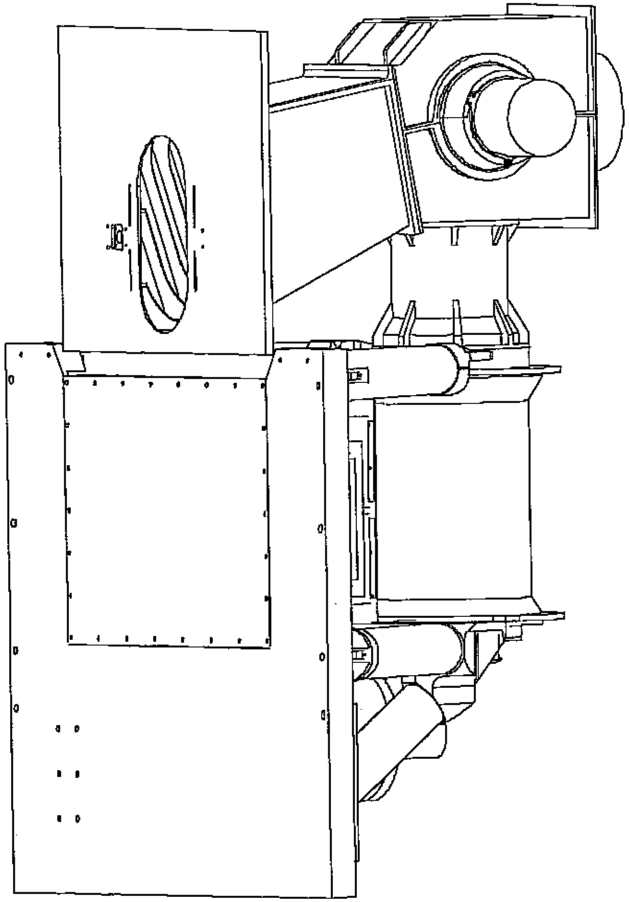
Telescope Temperature Zone



- Cooled by passive radiator (+Y Panel)
  - Radiator Interface Temp. 213/235 K
- Radiator Area = .185 m^2
- Temperature difference across telescope
  - Less than 12 K
- Thermally isolated from spacecraft by G-10 struts and MLI blanketing

Telescope Radiator

(Baseline Area = .185 m^2)



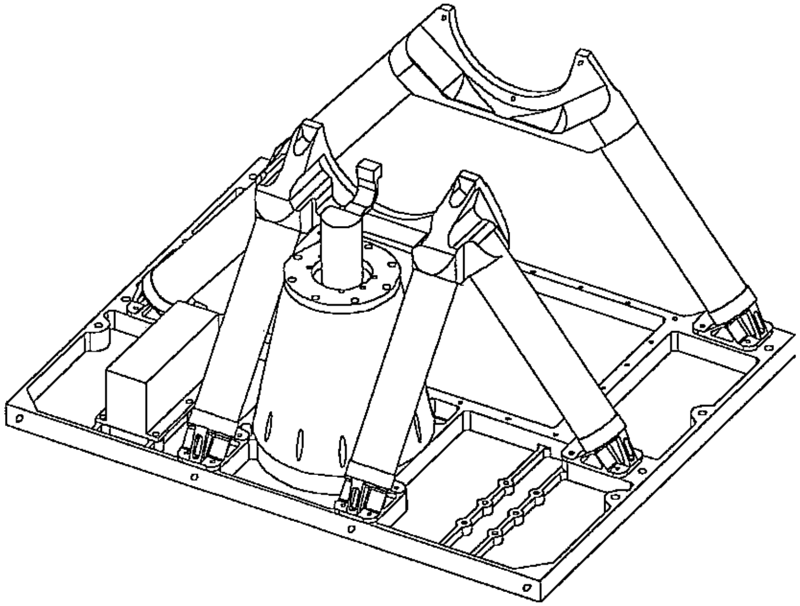
- **Balances**
  - Hot Case
    - Maximum average temperature in telescope approximately 240 K
  - Cold Case
    - Heater power required to keep encoder temperature at least 225 K is reasonable (~2.4 Watts)
- **Increasing radiator area to maximum available**
  - Reduces maximum average temperature in telescope
  - Increases encoder heater power
  - Increases mass of instruments

Telescope Radiator Power Summary

Description	Operational (Hot Case)	Operational (Cold Case)	Survival
Scan Motor	2.5	2.5	0
Encoder Assembly	1.0	1.0	0
IFC Blackbody	0.3	1.5	0
Chopper	0.1	0.1	0
Encoder Mount Heater	0.0	1.4	6.0
Conduction Parasitics	0.7	0.8	0.0
Radiation Parasitics	6.9	1.7	0.0
TOTAL	***11.5***	***9.0***	***6.0***

Refrigerator/Electronics Temperature Zone

- Cooled by passive radiator (+Y panel)
  - Radiator Interface Temp. 250/270 K
- Radiator Size = .46 m^2
- Thermally isolated from spacecraft by G-10 washers and MLI
- Minimum cooler reject temperature set to 260 K
- Delta T across cooler mount ~ 10 K

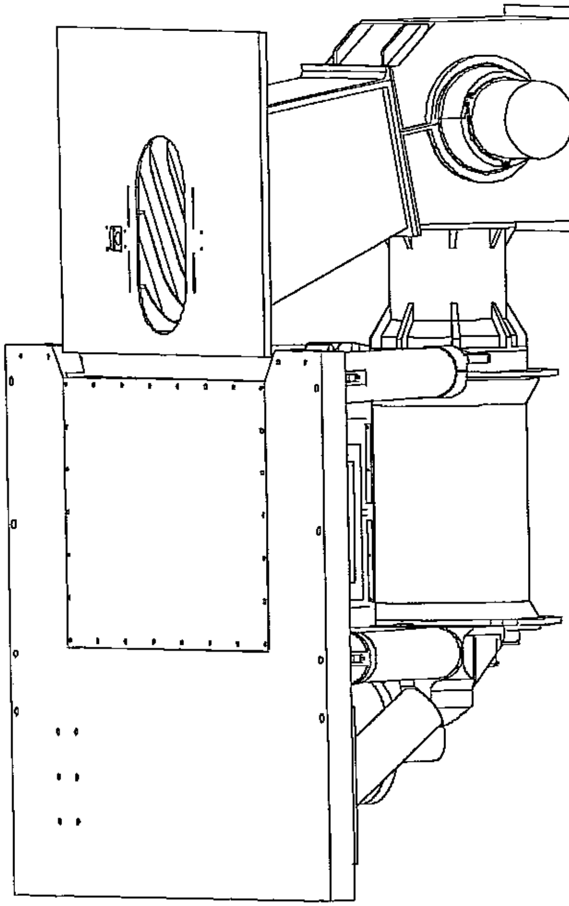


Refrigerator Electronics Radiator

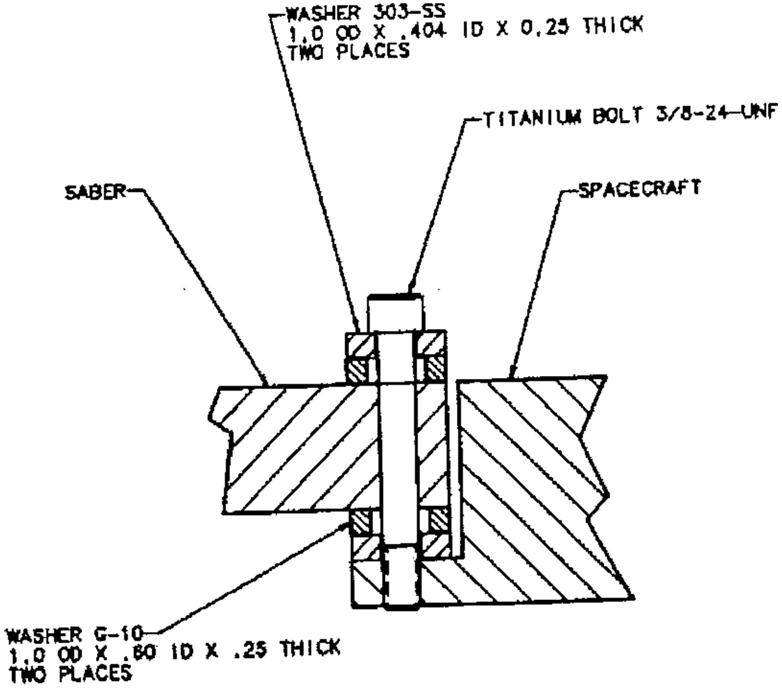
(Baseline Area =.46 m^2)

- **Balances**
    - Hot Case
        - For refrigerator heat reject temperature of 280 K refrigerator capacity is 380 mW
    - Cold Case
        - Compressor+Heater+Elec. Overhead:
          at 270 K =31.5 W
          at 260 K =22.5 W

- **Using total area currently available**
- **Reducing area would**
    - Increase refrigerator hot case reject temperature (reduces margin)
    - Decrease power required to keep refrigerator mount at specified temperature



S/C Thermal Standoff



SECTION A-A

SCALE: 1.0

- Number of bolts = 8
- S/C interface resistance 2.0 K/W
- Hot case heat leak
  - 17.5 watts received from s/c
- Cold case heat leak
  - Set Point of 260 K
    - 1.5 watts received from S/C
  - Set Point of 270 K
    - 1.5 watts delivered to S/C

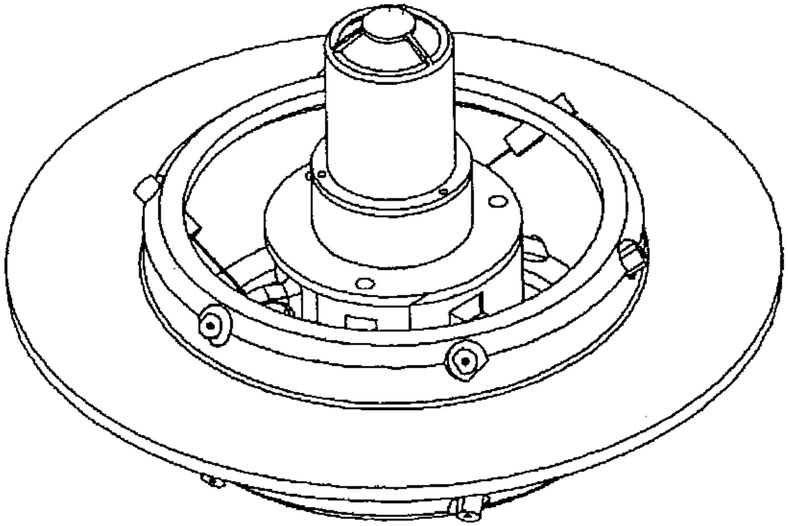
Electronics Radiator Power Summary

Description	Operational (Hot Case)	Operational (Cold Case) Cooler @ 270 K	Operational (Cold Case) Cooler @ 260 K	Survival Cooler @ 250 K
Refrigerator	18.6	16.0	14.3	0.0
Cooler Mount Heater	0.0	6.4	1.6	25.0
Electronics	32.8	41.9	39.4	0.0
Cooler Electronics	7.0	7.0	7.0	0.0
Conduction Parasitics	17.5	1.5	-1.5	0.0
Radiation Parasitics	1.5	0.0	0.0	0.0
Total Heat To Radiator	***77.4***	***72.8***	***60.8***	***25.0***
Total Instrument Power	***62.3***	***77.8***	***68.8***	

FPA Temperature Zone

- **Cooled by TRW miniature pulse tube refrigerator**
  - Operating temperature 75 K
- **Utilizes Fiber Support Technology (FiST) to support FPA**
- **FPA POWER SUMMARY**
  (Test Adjusted SINDA Model)
- **Description**

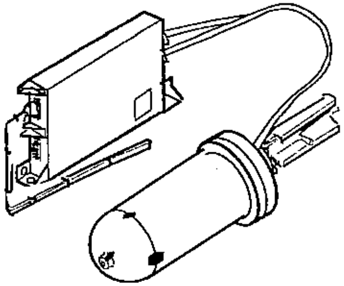
Description	Hot Case	Cold Case
– Supports	4.0	4.0
– Wiring	54	48.0
– Detectors	35	35.0
– Aperture	60	45.0
– Radiation	172	125.0
– ***TOTAL***	***325***	***253.0***



Miniature Pulse Tube Space Cooler

TRW

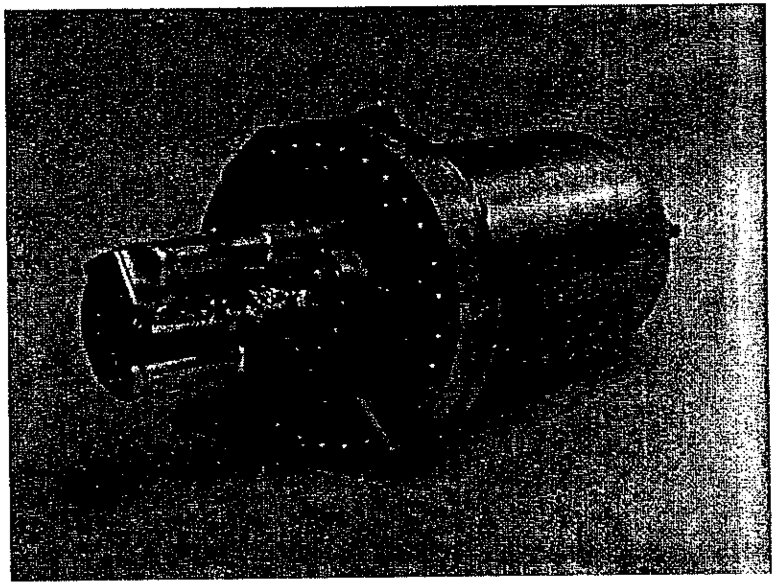
A. INTERNALLY BALANCED COOLER



B. SPECIFICATIONS

WEIGHT (Kg)	
COOLER	2.0
ELECTRONICS	3.0
	5 .0
RATED POWER (WATTS)	
COOLER	20
ELECTRONICS	6
	26
FOOTPRINT (IN.^{2})	
COOLER	50
ELECTRONICS	55

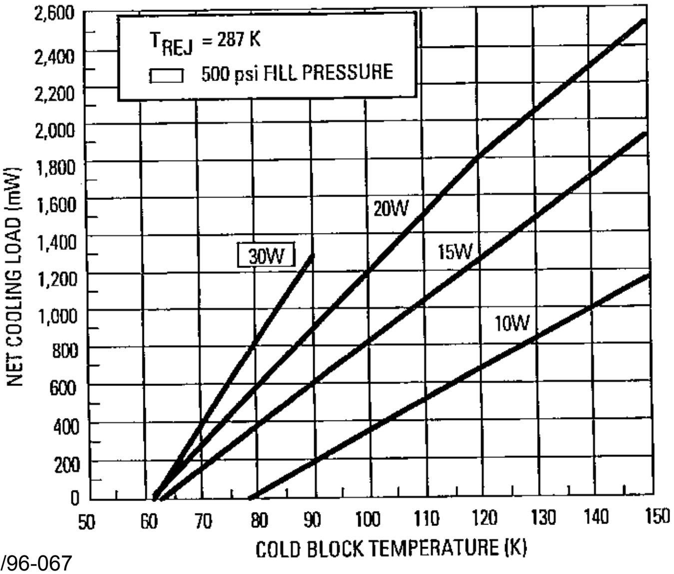
VIBRATION	<0.02 Lbf rms
LIFE/RELIABILITY (INCLUDES 883 ELECTRONICS)	5 YEARS/ 0.96



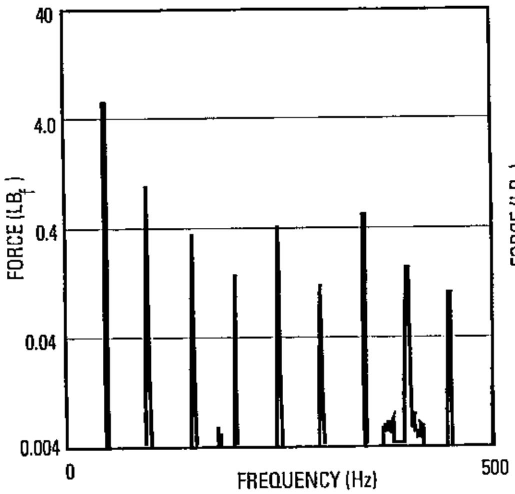
TRW's MINIATURE PULSE TUBE COOLER

C. MEASURED COOLER PERFORMANCE

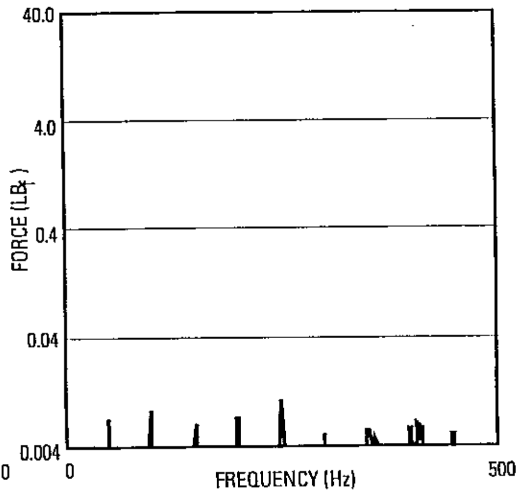
LOAD LINES VS. INPUT POWER



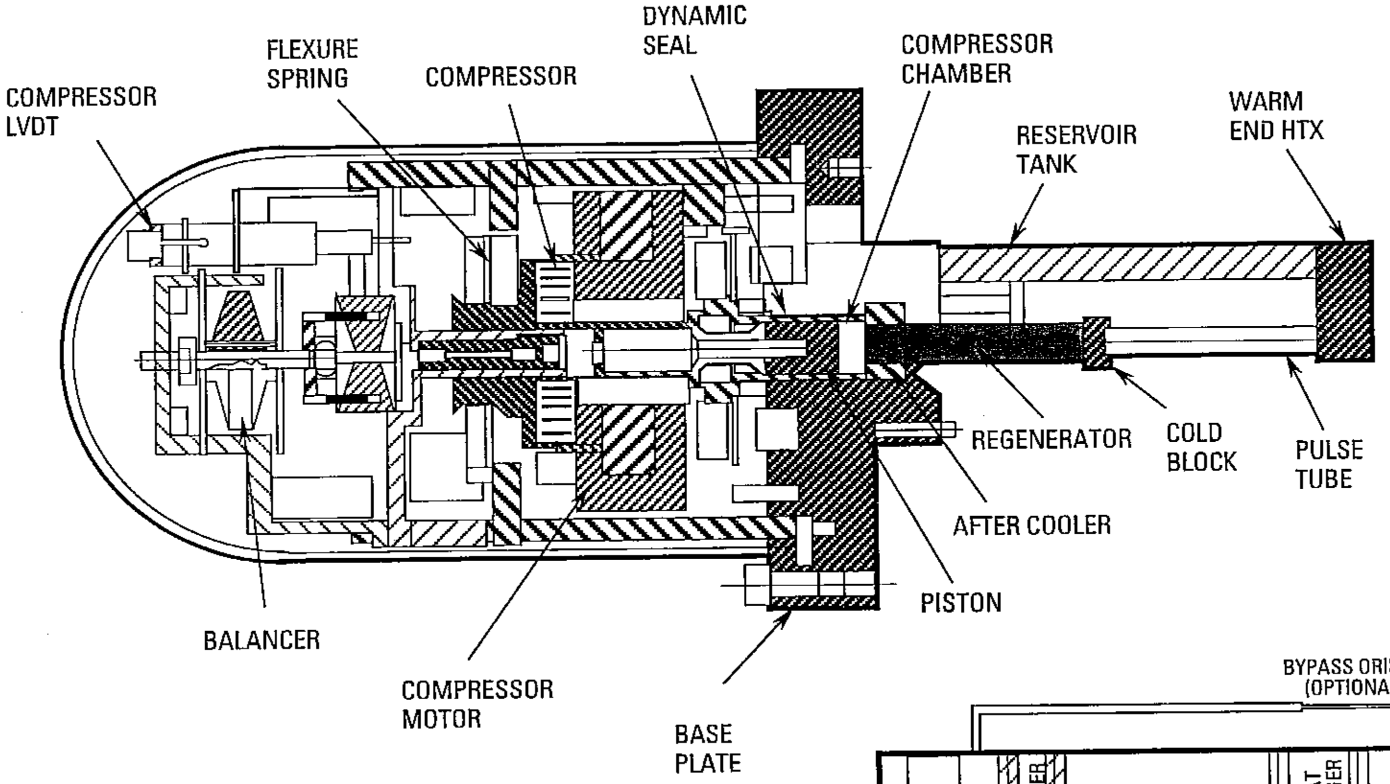
COOLER VIBRATION WITHOUT BALANCER OPERATION



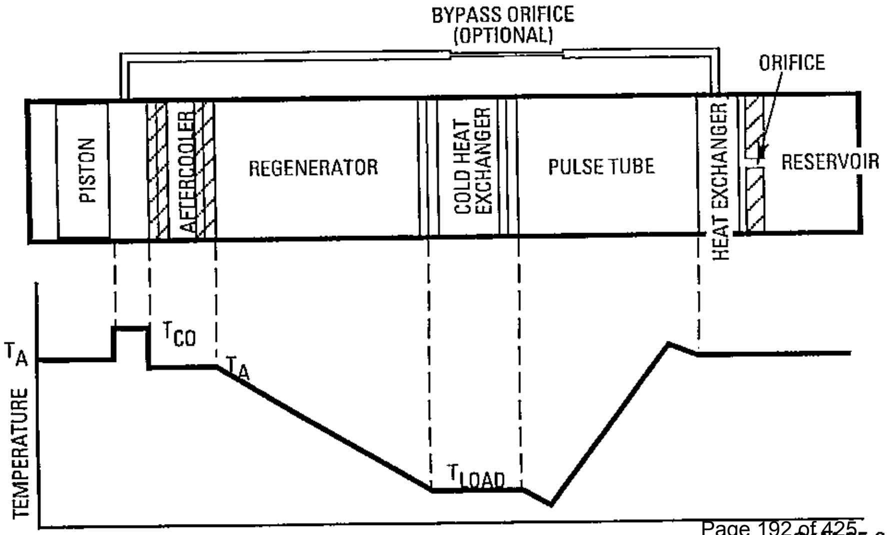
COOLER VIBRATION WITH BALANCER OPERATION



Cross-Section of the TRW Miniature Pulse Tube Cooler



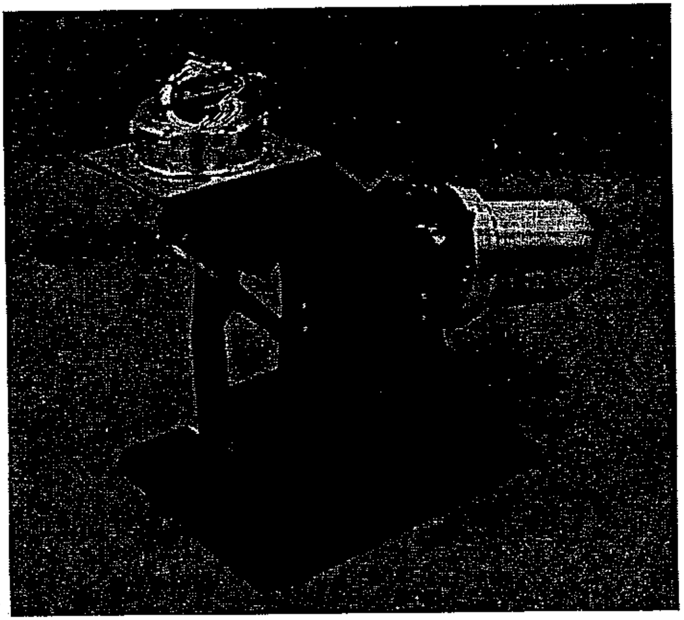
Orifice Pulse Tube Cooler Operation



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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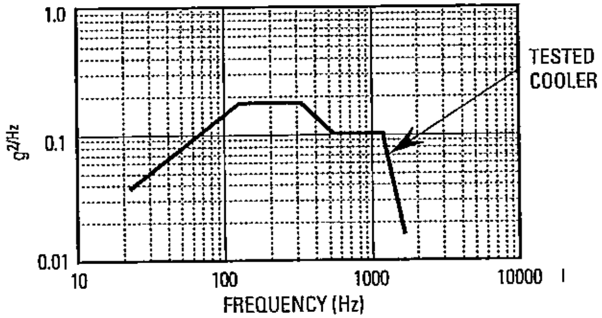
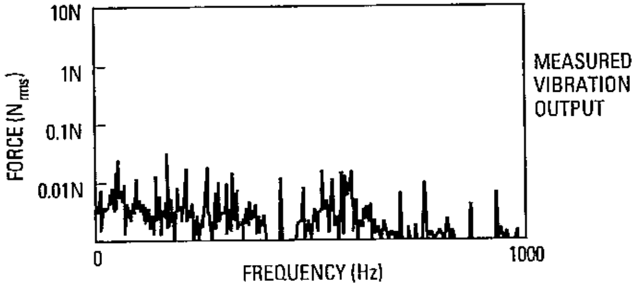
Performance

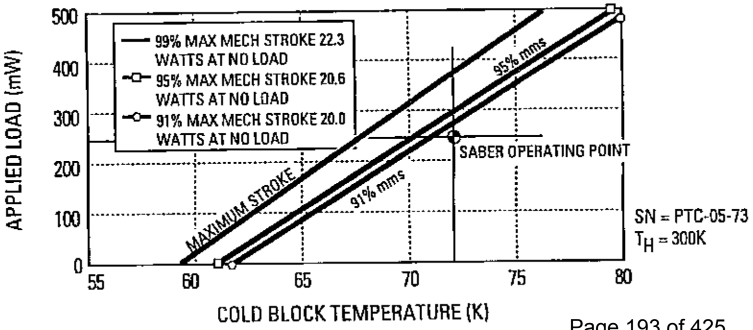
- Qualified for space launch unit vibrated to 14 gms



- Adaptively balanced for low-jitter operation



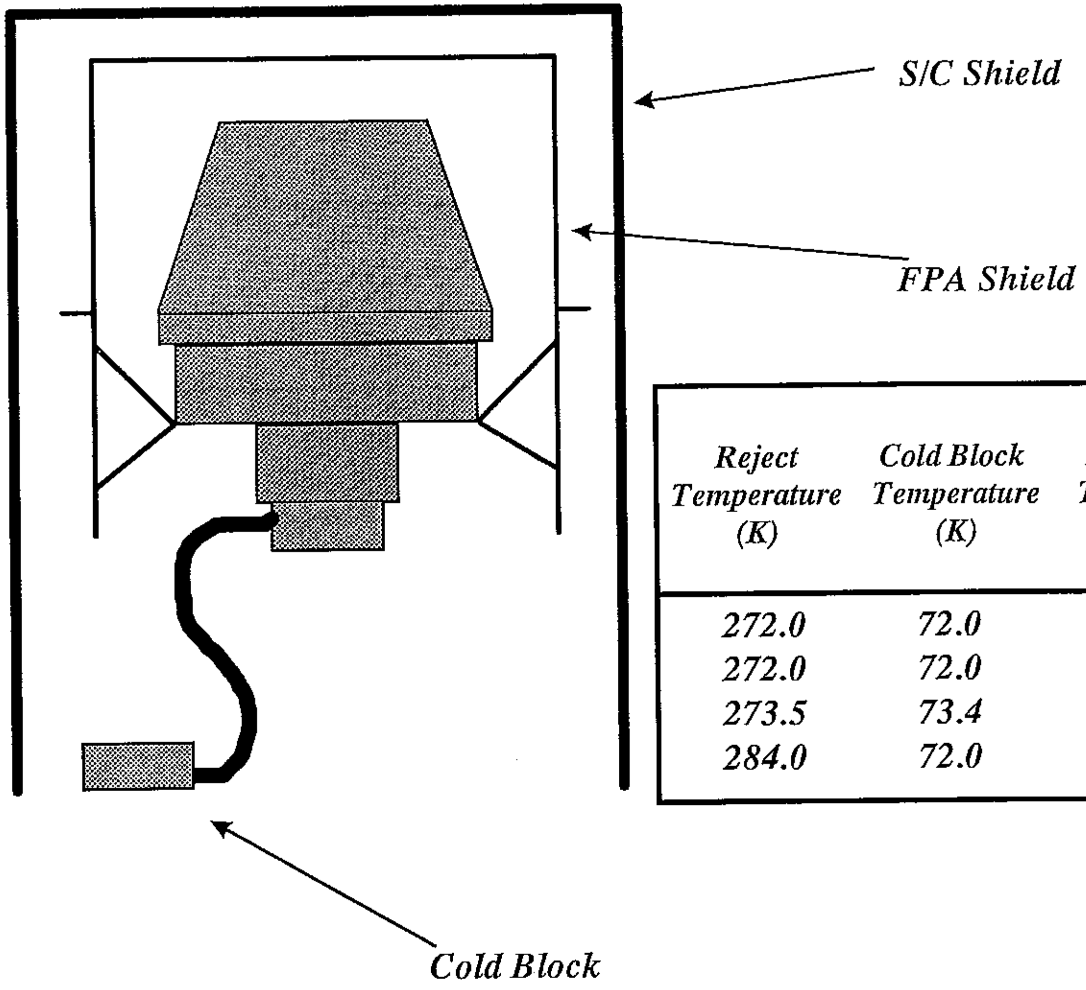
- Measured Cooling Performance



Refrigerator Capacity

Baseplate Temperature (K)	*Cold Block Temperature (K)*	*Compressor Power (W)*	*Cooling Capacity (mW)*
290	72	20	270
290	72	22.4	330
290	73.5	20	315
280	72	20	380
280	72	18	320
280	73.5	20	425
270	72	20	500
270	72	16.5	260
270	73.5	20	545
260	72	20	620
260	72	14.5	250
260	73.5	20	665

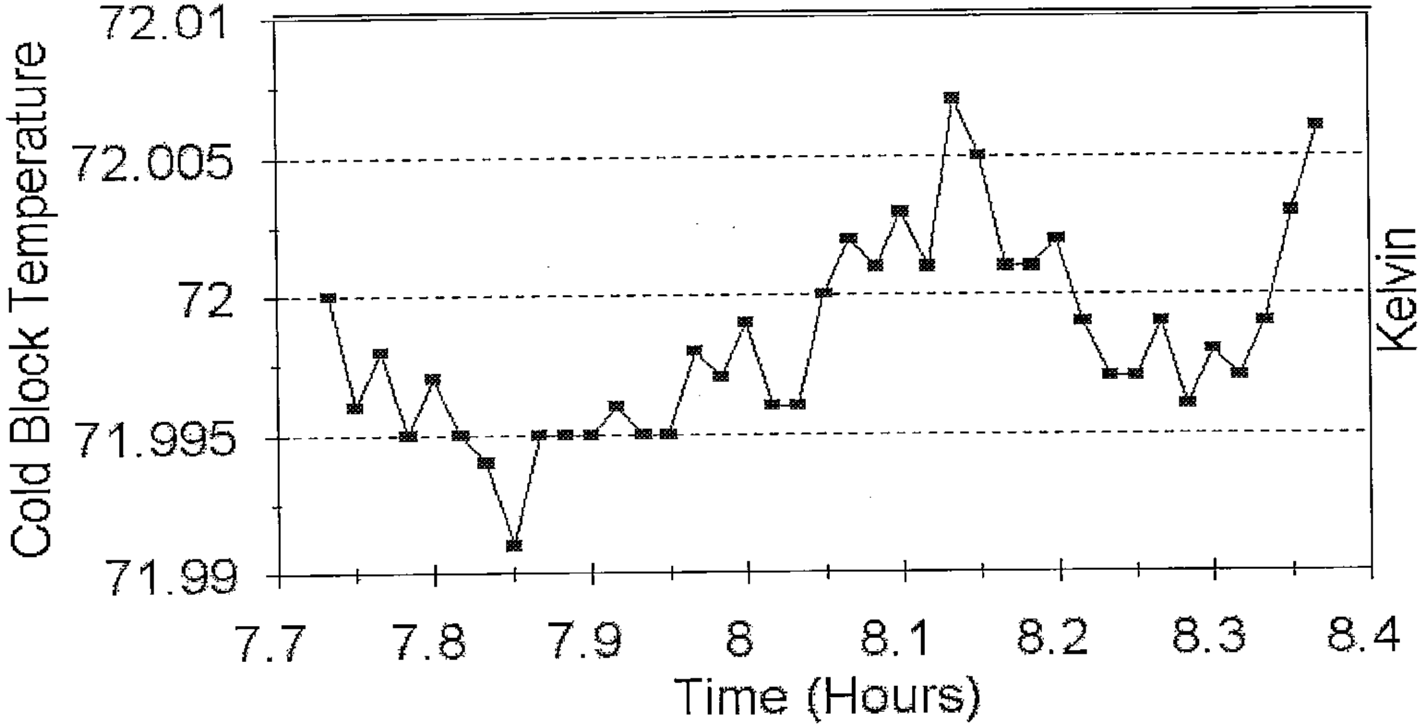
FPA Breadboard Test Results

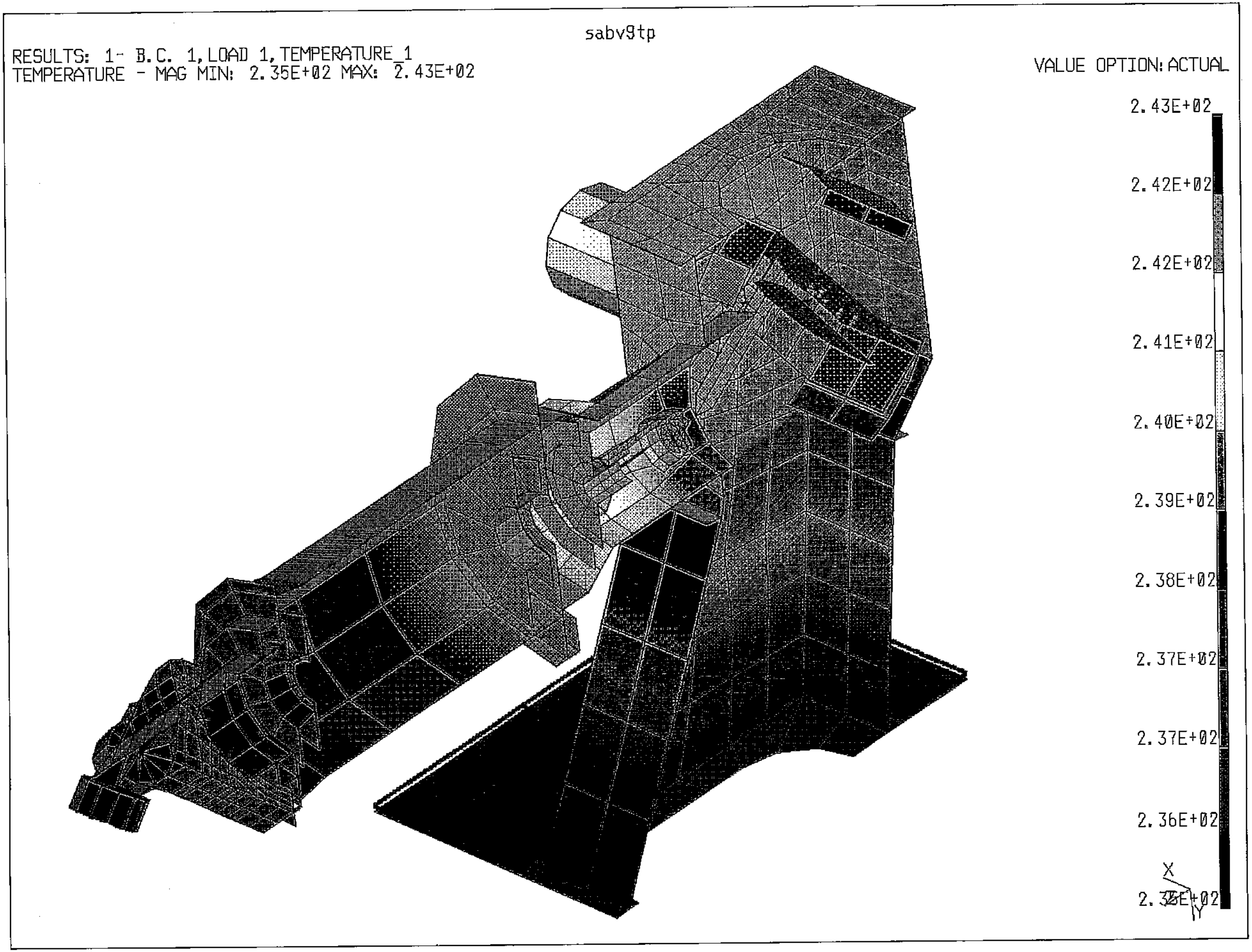


Reject Temperature (K)	Cold Block Temperature (K)	FPA Shield Temperature (K)	S/C Shield Temperature (K)	Compressor Power (W)	Calculated Heat Load (mW)
272.0	72.0	218.0	258.0	16.34	238.0
272.0	72.0	240.0	260.0	17.15	299.0
273.5	73.4	225.0	293.0	16.85	260.0
284.0	72.0	240.0	323.0	20.68	425.0

COLD BLOCK STEADY STATE TEMPERATURE DRIFT

(TEST #9)




sabv9tp
RESULTS: 1- B.C. 1, LOAD 1, TEMPERATURE_1
TEMPERATURE - MAG MIN: 2.35E+02 MAX: 2.43E+02
VALUE OPTION: ACTUAL
2.43E+02
2.42E+02
2.42E+02
2.41E+02
2.40E+02
2.39E+02
2.38E+02
2.37E+02
2.37E+02
2.36E+02
2.35E+02
X
Z
Y

SUMMARY OF TEMPERATURES
(SINDA Model)

Description	Operational (Hot Case) (K)	Operational (Cold Case 260) (K)
Telescope Rad. Interface	235.0	213.0
Elec./Ref. Rad. Interface	270.0	250.0
Motor/Encoder Assemby	247.5	225.0
Scan Mirror	245.5	222.0
Chopper Base	242.0	218.0
FPA Mounting Ring	243.0	219.0
Detector Plane	73.6	73.3
Refrigerator Cold Block	72.0	72.0
Electronics Radiator	270.0	250.0
Cooler Mounting Flange	280.0	260.0
Electronics Junction	<320.0	<320.0

Thermal Risk Reduction

- Fabricate focal plane assembly breadboard (FiST)
- Developed low impedance-flexible thermal links
- Conducted tests with TRW pulse tube refrigerator-FPA Mount
- Improved radiation isolation from S/C

Summary

This thermal design provides

- Ample margin in refrigerator capacity even in extreme hot case
- Adequate telescope radiator area to operate in extreme hot case
- Ample heater power to operate in extreme cold case
- Sufficiently stable temperatures

AND THUS...

Meets all flowdown requirements

ELECTRONICS OVERVIEW

Mark D. Jensen

December 10, 1996

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Fax: (801 755-4299
E-Mail: Mark.Jensen@sdl.usu.edu

Electrical Assembly Specifications (1 of 7)

Parameter	Source	Requirement	Specification	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	~60.8 ~66.8	64.0 74.0	Watts Watts	average peak
Voltage range	GIIS	28 +6/-6	28 +6/-6	Volts	
S/C Data Interface	GIIS	MIL1553	MIL1553		configuration described in GIIS
Data Packet Length	GIIS	2096	2096	bits	
Data Transfer Rate	GIIS	1.894 (125/66)	1.894 (125/66)	pkt/sec	
Command Packet Length	GIIS	2048	2048	bits	
Command Transfer Rate	GIIS	2kBytes	2kBytes	/day	maximum
Status Link	GIIS	16	16	bits/sec	
Communication Format					
downlink	GIIS	CCSDS	CCSDS		
uplink	GIIS				

Electrical Assembly Specifications (2 of 7)

Parameter	Source	Requirement	Specification	Units	Comments
GENERAL (cont.)					
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	

Electrical Assembly Specifications (3 of 7)

Parameter	Source	Requirement	Specification	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		18,985	48,976		
Channel 2		71,749	204,134		
Channel 3		71,749	204,134		
Channel 4		57,738	436,606		
Channel 5		85,234	213,823		
Channel 6		30,745	741,367		
Channel 7		7,632	84,996		
Channel 8		850	3,226		
Channel 9		360	1,513		
Channel 10		14,300	56,229		
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 bandwidth
Sample Rate	IRD	5	5 22.73	/IFOV /sec	
Chopper frequency	SYS	1000	1000	Hz	radiometric require.

Electrical Assembly Specifications (4 of 7)

Parameter	Source	Requirement	Specification	Units	Comments
SYSTEM CONTROL AND DATA HANDLING					
Data Formatter	IRD	format data	2 op. modes		
Data Collection					normal mode for Data Collection, Calibrate, Diagnositc/Reprogram modes
Data sample rate	IRD	5	5 (22.73 s/s)	/IFOV	
Control	SYS	on/off	on/off		
Housekeeping sample rate	SYS		0.0902	/sec	
Packet rate	GIIS	1.894	1.894 (125/66)	/sec	
Bit rate	GIIS	3969.7	3969.7	/sec	
Housekeeping	SYS				normal mode for Power-up, Safe, Stabilization, Standby
Data sample rate	SYS		0	/sec	
Housekeeping sample rate	SYS		0.0902	/sec	
Packet rate	GIIS	0.0395	0.0451	/sec	
			(125/2772)	/sec	
Bit rate	GIIS	82.7	94.5	/sec	
System Controller					
Commands	IRD	stored	512 cmds		automated routines
	IRD	uplink	512 cmds		RAM buffer
Interrupts	SYS	1. Power down	1. Power dwn		
	SYS	2. S/C Yaw	2. S/C Yaw		
	IRD	3. Uplink cmd	3. Uplink cmd		
	SYS	4. Timer	4. Timer		

Electrical Assembly Specifications (5 of 7)

Parameter	Source	Requirement	Specification	Units	Comments
System Controller (cont.)					
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		

Electrical Assembly Specifications (6 of 7)

Parameter	Source	Requirement	Specification	Units	Comments
Scan Mirror Controller					
Scan velocity	SYS	0.194	0.194	°/sec	
Slew velocity	SYS	29.62	29.62	°/sec	
Scan mirror jitter	IRD	≤ 3	≤ 3	arcsec	
Encoder resolution	IRD	1.236	1.236	arcsec	
Command resolution	SYS	0.088	0.088	°	
ANALOG CONTROLLERS **Blackbody Controller**					
Temperature Set Range	SYS	218-280	215-280	K	in flight adjustable
Stability	SYS	0.1	0.028	K	IRD 1% residual scale error
Jones Source Controller					
Temperature Set Range	SYS	1800	<2100	K	in flight adjustable
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	8	18	Watts	
Power (Encoder)	SYS	1	2.25	Watts	

Electrical Assembly Specifications (7 of 7)

Parameter	Source	Requirement	Specification	Units	Comments
CHOPPER CONTROL AND SYNC					
Chopper Control					
Operating frequency	SYS	1.0	1.0	kHz	free running
Chopper Sync					
Delay per channel	SYS	adjustable	0-360, 0.36 steps	degrees	manually adjusted
POWER CONVERTERS					
Isolation	GIIS	100 1	100 1	Volts Mohm	
Input Range	GIIS	28±6	28-12,+22	Volts	
Input transients	GIIS	-6 to 62	80	Volts	
turn on	SYS	separate groups	3 groups		
COVER DEPLOYMENT					
Method	SYS	one time throw away	one time throw away		Commanded by operator with 3 commands
Refrigerator Electronics					
Low operating limit	SYS	72	70	K	
Control	SYS	vibration cancellation	vibration cancellation		automatic, on/off operator controlled

Spacecraft Interface

Connectors

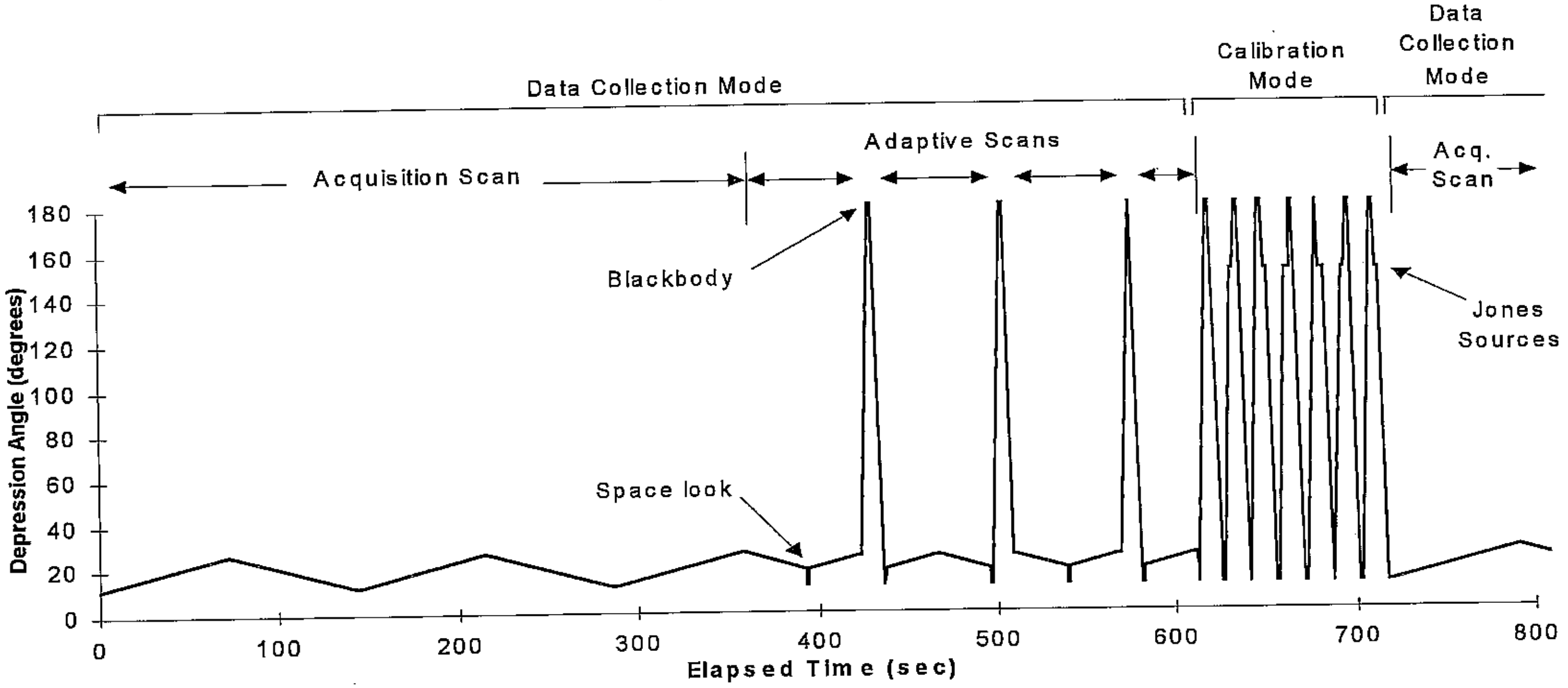
Pin #	Name: A500 P1 Function: Power Type: DAMM15PE	Name: A500 J2 Function: 1553 Type: DEMM9SE	Name: A500 P3 Function: Temperature Sensor Type: DEMM9PE
1	+28V Main Primary	1553 Bus A	Temp Sensor 1
2	+28V Main Secondary		Temp Sensor 2
3			Temp Sensor 3
4	+28V Survival Heater		Temp Sensor 4
5		1553 Bus B	
6		1553 Bus A Return	Temp Sensor 1 Return
7			Temp Sensor 2 Return
8			Temp Sensor 3 Return
9	Main Primary Return	1553 Bus B Return	Temp Sensor 4 Return
10	Main Secondary Return		
11	Operational Heater Return		
12	Survival Heater Return		
13			
14			
15			

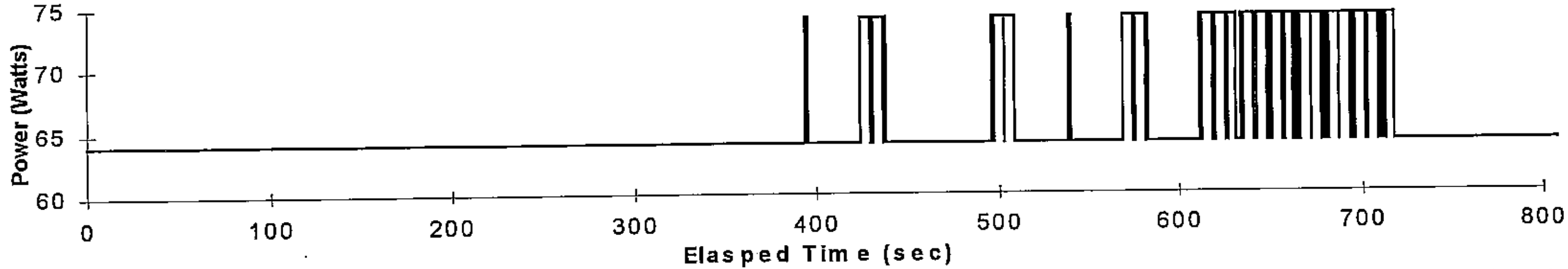
Spacecraft Interface

Power Requirements

Assembly	AVERAGE POWER			PEAK POWER			
	Power-up Safe	Standby Stabilize	Data Col. /Calibrate /Diagnostic	Power-up Safe	Standby Stabilize	Data Col. /Calibrate /Diagnostic	Power Uncertainty
Optics							
Scan Mirror (Motor & Encoder)	0.0	0.0	2.6	0.0	0.0	6.5	
Chopper	0.0	0.1	0.1	0.0	0.1	0.1	
Full Aperture BB and Jones Sources	0.0	1.5	1.5	0.0	1.5	1.5	
Cryogenic (Focal Plane)	0.00	0.04	0.04	0.00	0.04	0.04	
Refrigerator	17.2	20.0	20.0	17.2	20.0	20.0	
Refrigerator Electronics (RFE)	7.0	7.0	7.0	7.0	7.0	7.0	
Instrument Electronics							
Signal Processing	0.0	9.3	9.3	0.0	9.3	9.3	
System Control and Data Handling	9.4	9.4	9.4	9.4	9.4	9.4	
Analog Controllers	0.0	1.9	1.9	0.0	1.9	3.9	
Scan Mirror Controller	0.0	2.3	2.3	0.0	2.3	3.7	
Chopper Control and Sync.	0.0	0.5	0.5	0.0	0.5	0.5	
Power	3.3	8.6	9.5	3.3	8.6	12.0	
TOTAL Main Power	36.9	60.5	64.0	36.9	60.5	74.0	
Operational Heaters	18.4	18.4	18.4	18.4	18.4	18.4	
TOTAL BUS POWER	55.3	78.9	82.4	55.3	78.9	92.3	

Spacecraft Interface
Power Profile


Scan Profile


Power Profile

Spacecraft Interface

Data Formatter Modes--Data Collection

Modes supported:	Data Collection, Calibration, Diagnostic
Radiometric sample rate:	22.73 samples/sec (5.0 samples/IFOV)
Housekeeping sample rate:	0.090 samples/ sec (worst case)
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)	Format Mode	Packet Identifier	
		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	1	5	96
value	000	0	1	11	2	0-16383		255	MET	MET	0	0-23	
bits	Scan Location 20	Gain 16	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	156
bits	Scan Location 20	Gain 16	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	156
bits	Scan Location 20	Gain 16	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	156
bits	Scan Location 20	Gain 16	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	156
bits	Scan Location 20	Gain 16	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	156
bits	Scan Location 20	Gain 16	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	156
bits	Scan Location 20	Gain 16	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	156
bits	Scan Location 20	Gain 16	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	156
bits	Scan Location 20	Gain 16	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	156
bits	Scan Location 20	Gain 16	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	156
bits	Scan Location 20	Gain 16	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	156
bits	Scan Location 20	Gain 16	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	156
bits	Command Echo 81						Housekeeping (1 of 21) format 40					not used 7	128
									TOTAL BITS				2096

SABER Preliminary Design Review

SPACE DYNAMICS LABORATORY / UTAH STATE UNIVERSITY

Spacecraft Interface

Data Formatter Modes--Housekeeping

Modes supported:	Power-up, Standby, Stabilize, Safe
Radiometric sample rate:	0.0 samples/sec
Housekeeping sample rate:	0.090 samples/ sec (worst case)
Packet length:	2096 bits
Packet transfer rate:	0.045 packets/sec (125/2772)
Bit rate:	94.5 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)	Format Mode	Packet Identifier	
		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	1	5	96
value	000	0	1	11	2	0-16383	255	MET	MET	1	0	
bits	Housekeeping Sample 1 840											840
bits	Housekeeping Sample 2 840											840
bits	Command Echo 315										not used 5	320
								TOTAL BITS				2096

Spacecraft Interface

Instrument Status Words--Telemetry Subaddress T12

Word 1

Bit#	Description
0 LSB	Relay 1–power group #2
1	Relay 2–power group #3
2	Relay 3--power group #4
3	Relay 4--wax acuator primary
4	Relay 5–wax acuator secondary
5	Jones Source #1 on/off
6	Jones Source #2 on/off
7	adaptive scan reference on/off
8	power down interrupt
9	yaw maneuver interrupt
10	uplink interrupt
11	timer interrupt
12	
13	
14	
15 MSB	

Word 2

Bit#	Description
0 LSB	refrigerator inhibit
1	refrigerator vibration on/off
2	data formatter mode
3	scan mirror at location flag
4	scan mirror stall flag
5	system controller submodule active bit 0
6	system controller submodule active bit 1
7	system controller submodule active bit 2
8	system controller submodule active bit 3
9	
10	
11	
12	
13	
14	
15 MSB	

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
  - differental 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
- utilize slow digital logic
- package nose 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 (cont.)

Minimize power consumption

- low power analog circuitry for signal processing
  - utilize low-bandwidth, low-power LT1078 op amps
- simple state machine controllers
- efficient DC/DC converters
- simplicity in design

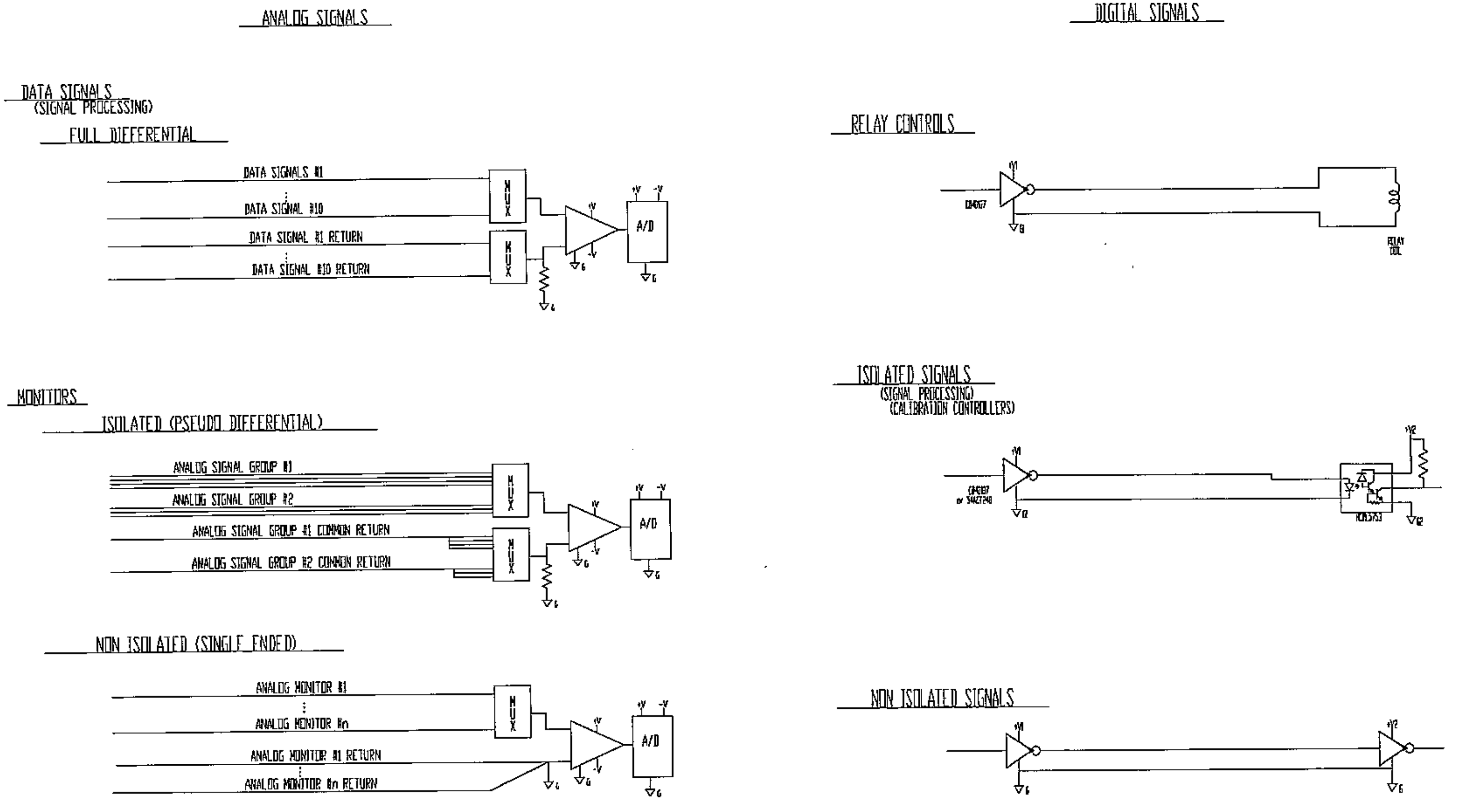
Minimize cost

- simple state machine controllers
- analog circuitry for signal processing
- simplicity in design

Maximize reliability

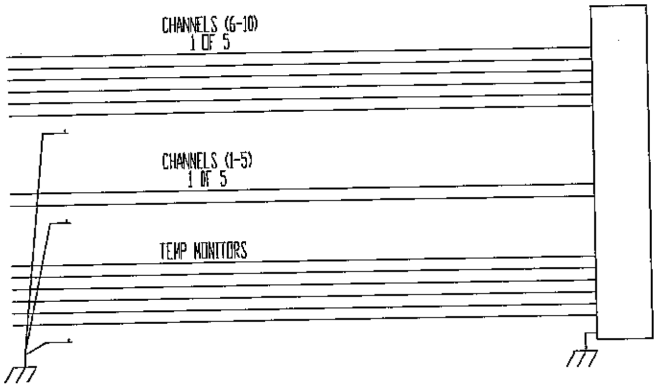
- design
  - utilize flight heritage
  - simplicity in design such as state machine controllers ⇒ predicted operation, not reconfigurable
- parts
  - where can use preferred parts or parts with past flight heritage
  - ensure radiation performance

System Design
Power, Ground, and Signal Interconnnects

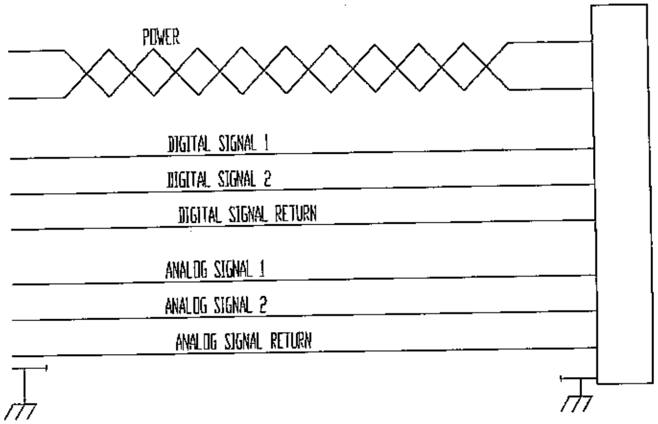


System Design
Power, Ground, and Signal Interconnnects (cont.)

INTERFACE TO FOCAL PLANE



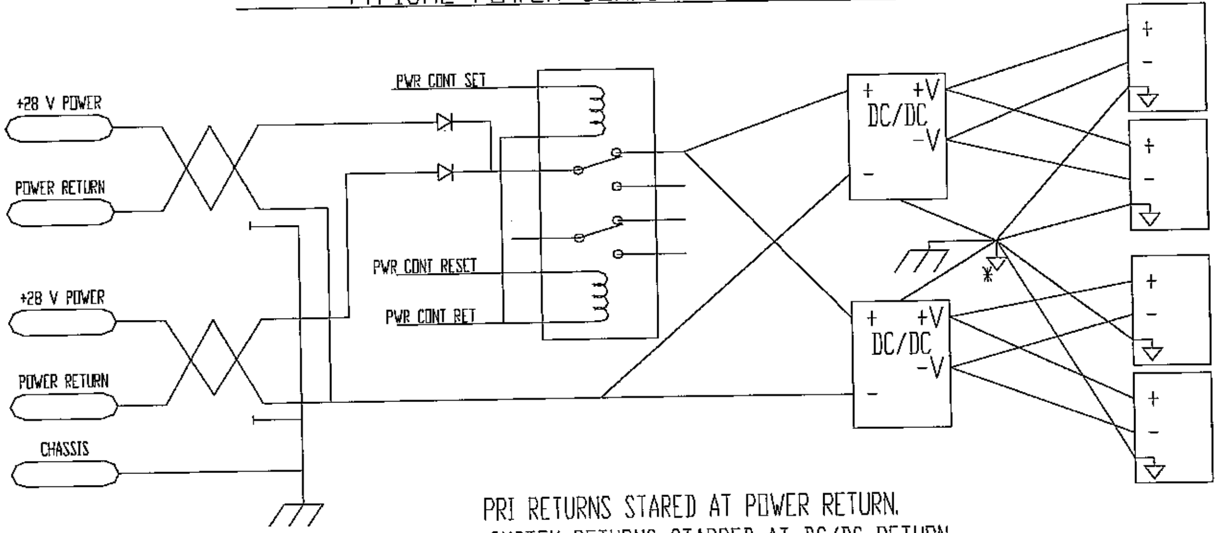
INTERFACE TO SUBUNIT / MONITORS



System Design

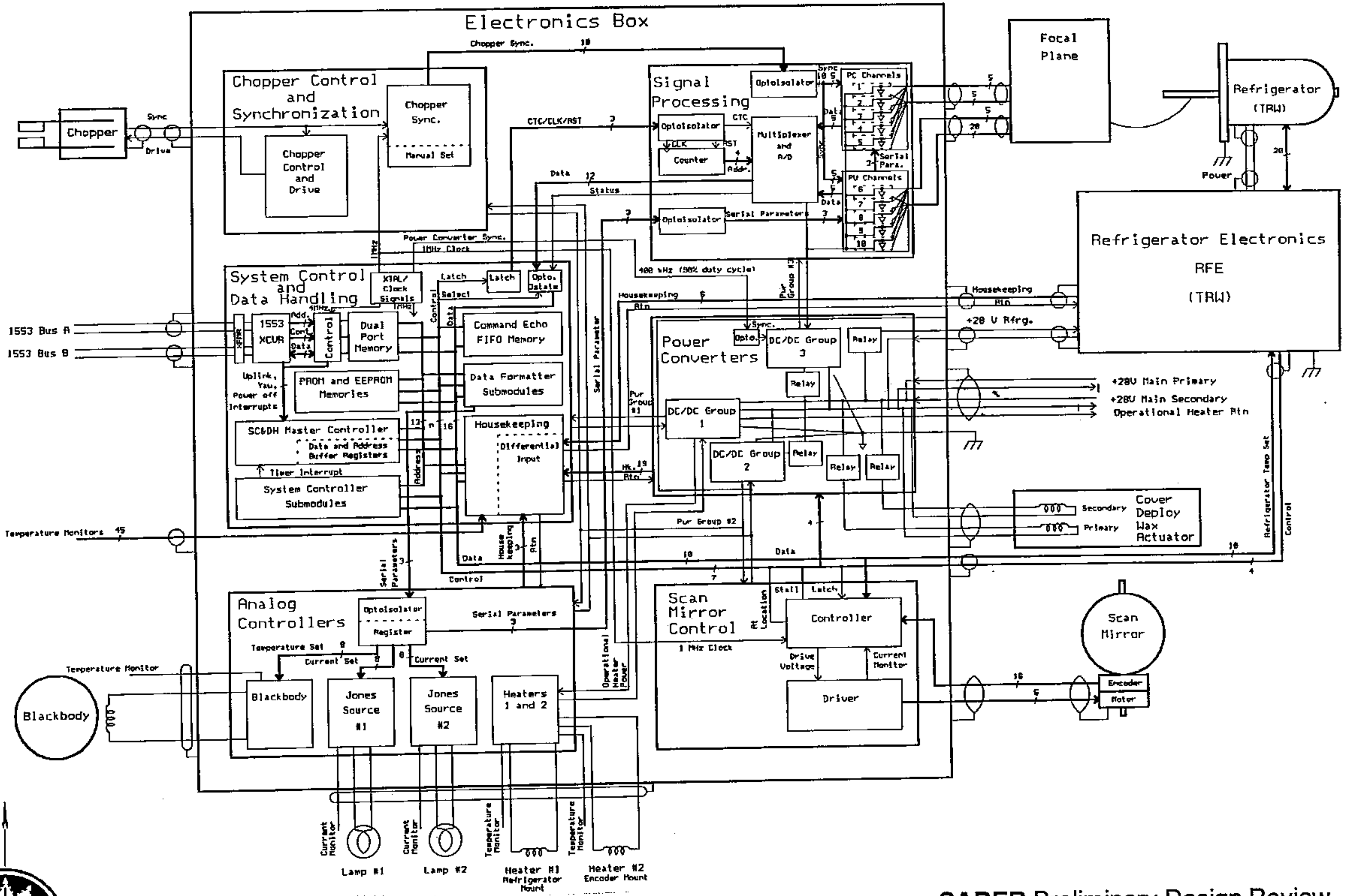
Power, Ground, and Signal Interconnnects (cont.)

TYPICAL POWER CONFIGURATION



PRI RETURNS STARED 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 and 2)
- 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

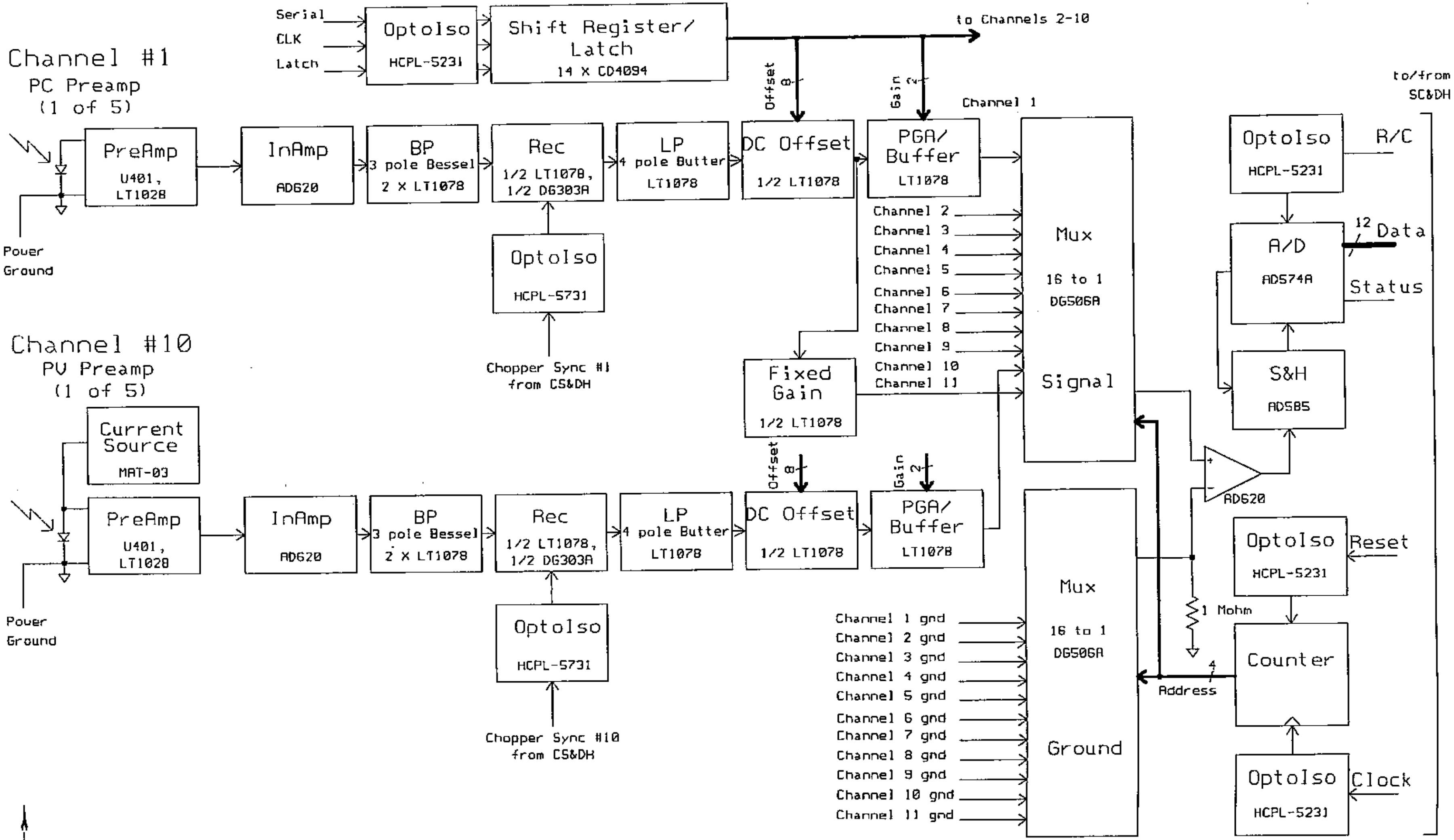
Refrigerator Electronics (RFE) (TRW)
- pulse tube cryocooler control and monitoring

System Design

Electronics Box Assignments and Power Dissapation

Box Assignment	Name	System	Data Collection, Calibration, Diagn.		Standby Stabilize		Power-up Safe	
			Average (Watts)	Peak (Watts)	Average (Watts)	Peak (Watts)	Average (Watts)	Peak (Watts)
1	PC Channels (1-5)	Signal Processing	3.4	3.4	3.4	3.4	0.0	0.0
2	PV Channels (6-10)	Signal Processing	3.4	3.4	3.4	3.4	0.0	0.0
3	Mux–A/D Converter	Signal Processing	2.4	2.4	2.4	2.4	0.0	0.0
shield								
4	DC/DC Converters (3)	Power	3.3	3.3	3.3	3.3	0.0	0.0
5	DC/DC Converters (1 and 2)	Power	10.9	13.5	10.0	10.0	8.1	8.1
shield								
6	BB/JS/Heaters/Chop C&Sync	Analog Controllers/Chopper	7.0	9.0	7.0	7.0	4.6	4.6
7	Sys. Cnt/Formatter/1553	Sys. Control & Data Handling	4.8	4.8	4.8	4.8	4.8	4.8
8	Spare							
9	Scan MirrorControl/Driver	Scan Mirror Controller	2.3	3.7	2.3	2.3	0.0	0.0
10	Housekeeping (2)	Sys. Control & Data Handling	3.7	3.7	3.7	3.7	3.7	3.7
11	Housekeeping (1)	Sys. Control & Data Handling	0.9	0.9	0.9	0.9	0.9	0.9
	TOTAL Box Main Power Dissapated		42.1	48.1	41.3	41.3	22.1	22.1

Signal Processing Block Diagram



Signal Processing
Design Description

Method

- analog signal processing utilizing coherent rectification (synchronize with chopper)
- photo-conductive (PC) preamplifiers for channels 1-5
- photo-voltaic (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 lowpass 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 S/N > 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

Preliminary Design: complete

Preliminary Schematic: complete

Parts List: active and passive

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

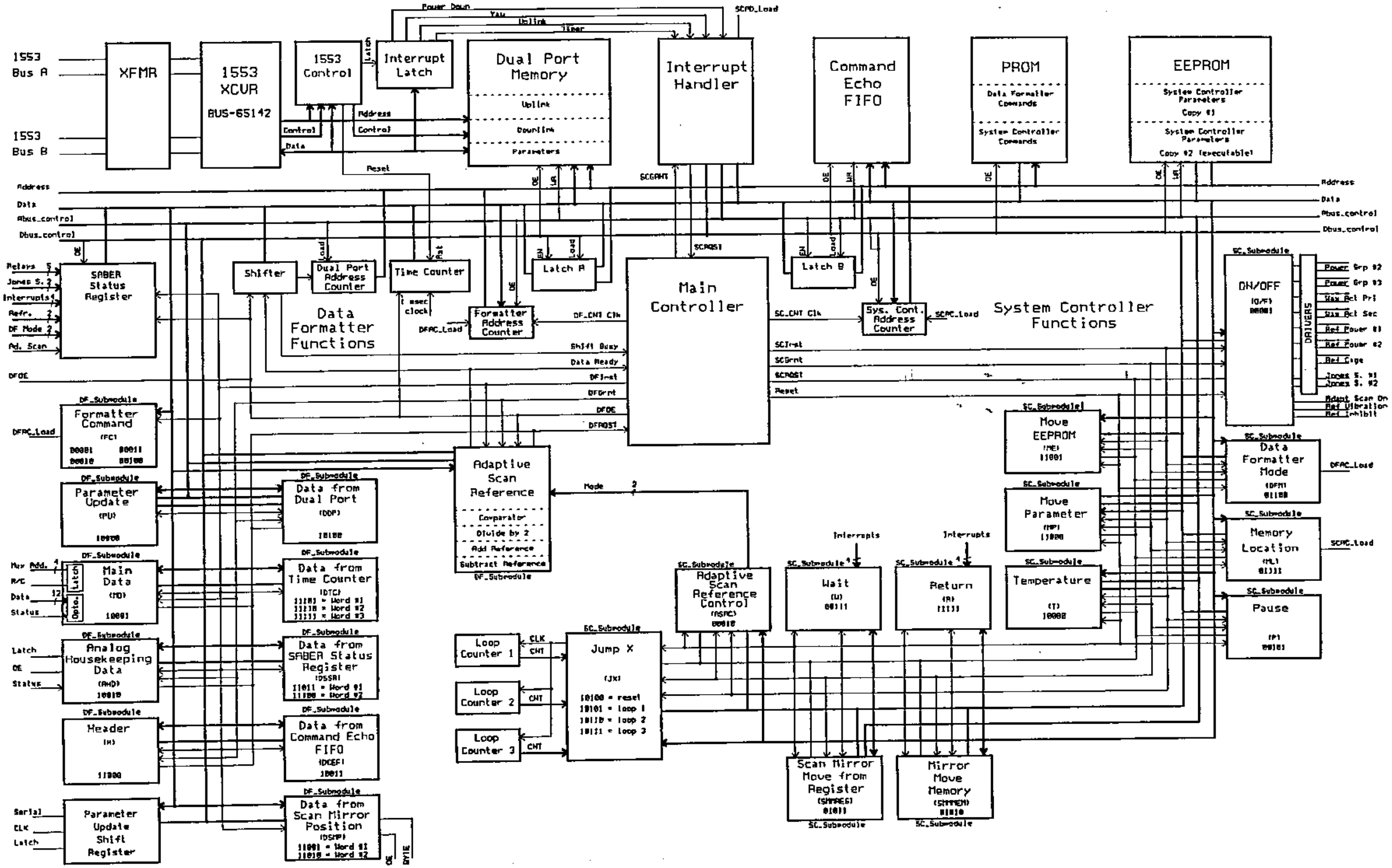
Breadboarding:

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

Simulation and Modeling:

- MathCAD system noise model
  - signal response
  - system noise
  - Signal to Noise ratio (S/N)
- MathCAD Preamp noise model
  - noise components vs frequency
- PSPICE
  - AC (frequency response)
    - preamps, bandpass, coherent rectification, lowpass, PGA
  - DC
    - offset, PGA
  - Transient (step response)
    - preamp, bandpass, coherent rectification, lowpass, PGA, system
  - Temperature
    - PGA

System Control & Data Handling Block Diagram



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 implementated in firmware (ACTEL A1020 2.0 μ)

  ⇒ predicted operation--limited number of states, all states defined, recoverable from upset

  ⇒ not reconfigurable, issures 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

System Controller & Data Handling
Design Description (cont.)

System Controller Features:

Can

- take appropriate action for the following interrupts (in order of priority):
  - power down ⇒ safe mirror, turn off subsystems in an orderly manner
  - s/c 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 in each uplink packet
  - 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
  - will remain in uplink mode until return is sent
- switch subunits on/off
- cage/uncage, vibration cancellation on/off for refrigerator
- deploy cover, control time wax actuators are on
- change data formatter mode to data collection, or housekeeping
- move scan mirror to any location
- reset scan mirror if command is not executed
- loop back in command blocks (# of times is changeable)
- set any or all 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 a certain UT within 16 min.
- halt operation until an uplink command
- control operation of the adaptive scan reference calculation in conjunction with the data formatter
- executed commands with associated data parameters are echoed in downlink data stream

System Controller & Data Handling
Design Description (cont.)

System Controller Features: (cont.)

Cannot

- cannot overwrite existing commands
- cannot uplink permenant commands
- cannot overwrite sub-unit control (firmware)
- no loop back capability in uplink command list (illegal)
- cannot exit from power down interrupt--only exit is for the s/c to follow through and remove power
- an uplink cannot cause an exit from yaw maneuver interrupt--only exit is yaw interrupt flag is reset by s/c or power down interrupt

Data Formatter Features:

Can

- two formats--data collection and housekeeping
- sample data channels at every 44 ms (22.73 samples per second)
- complete sample of housekeeping every 25.3 seconds
- implement user determined telemetry matrix stored in PROM--format can be altered on ground only by burning a new PROM

Data Formatter Features:

Can (cont.)

- 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

Cannot

- 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

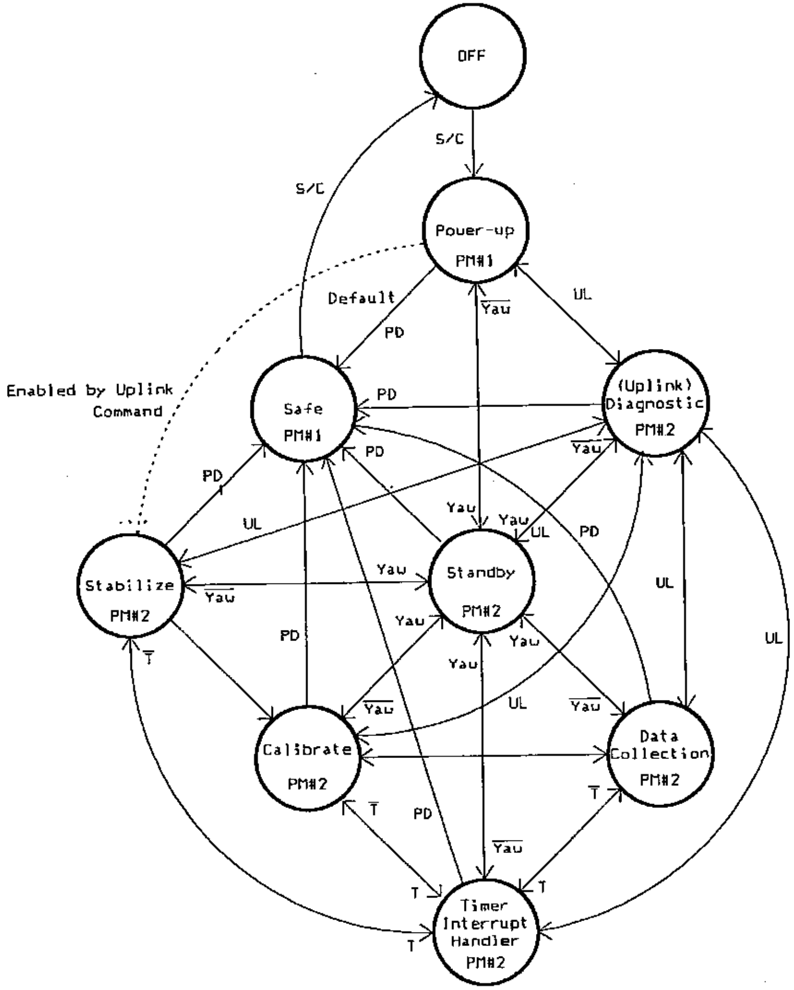
System Controller & Data Handling
Design Description (cont.)

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

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, RFE

System Controller & Data Handling
Status

Preliminary Design:

- state diagrams: complete
- VHDL code: complete, compiled
- FPGAs defined, code compiled, fit checks, preliminary pin assignments
- commands defined
- command blocks defined

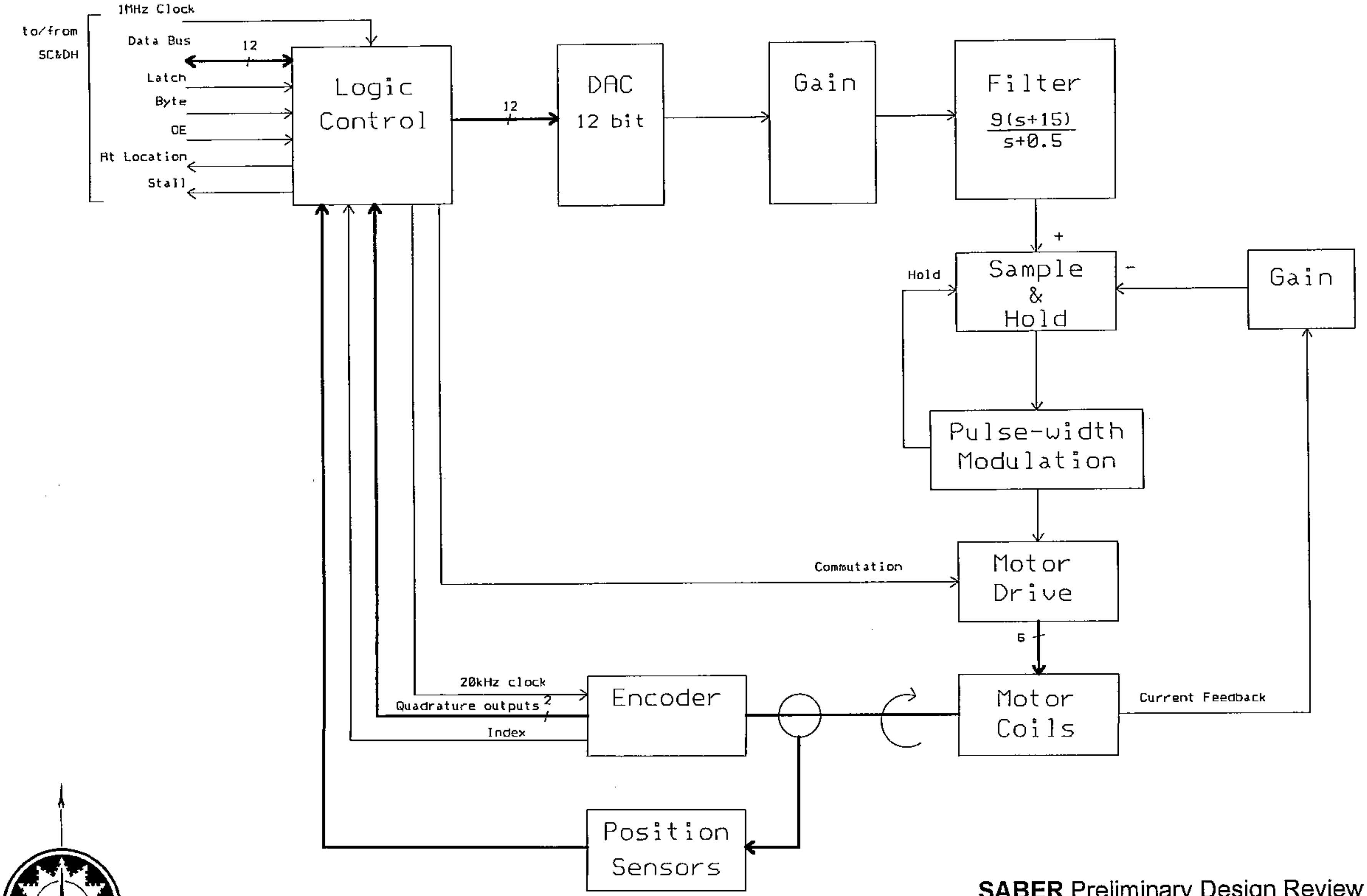
Preliminary Schematic: complete

Parts List: active and passive

Simulation:

- Viewlogic simulations
  - main controller
  - submodules
  - supporting logic

Scan Mirror Controller Block Diagram



SABER Preliminary Design Review

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Scan Mirror Controller
Design Description

Method
- closed-loop control of mirror using conventional analog circuitry with digital interface
- velocity 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 (scan or slew) (1-bit)
- 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 heratage: numerous programs such as SEAWIFS, UARS, HUBBLE

Scan Mirror Controller
Status

Preliminary Design: complete

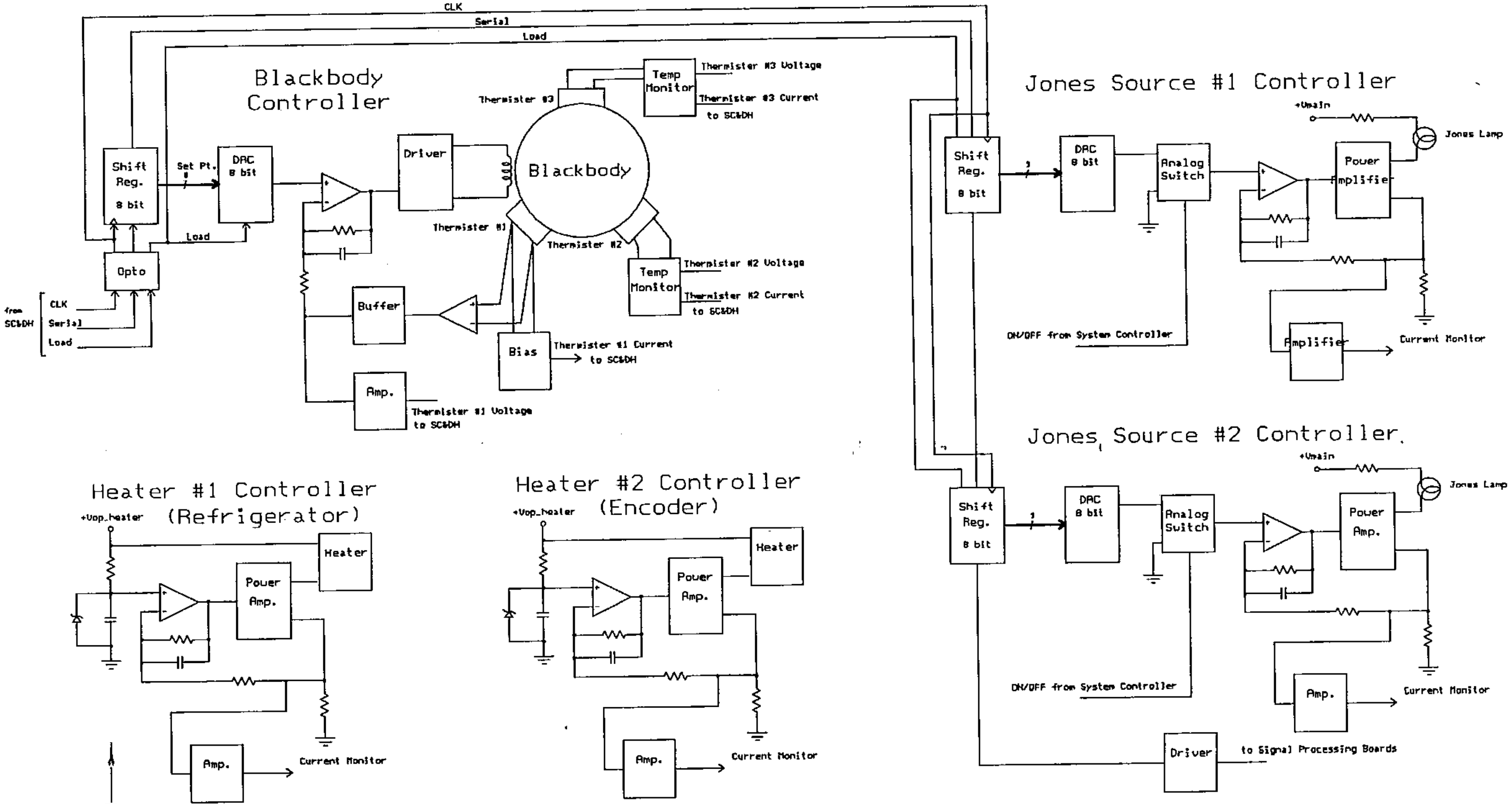
Preliminary Schematic: complete

Parts List: active and passive

Analysis:
- gain calculations
- power requirements

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

Analog Controllers Block Diagram



SABER Preliminary Design Review

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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 18 W, 8 W nominal
  - encoder--0 to 2.25 W, 1 W nominal

Jones Source Controllers

Method

- phase-lag analog linear controller

Features

- adjustable lamp current set point changed by uplink command
- current set range 0 to 35.7 mA (0 to 2172 K bulb temperature)
- nominal setting--23.4 mA (1578 K bulb temperature)

Heritage

- SPIRIT III

Analog Controllers
Status

Preliminary Design: complete

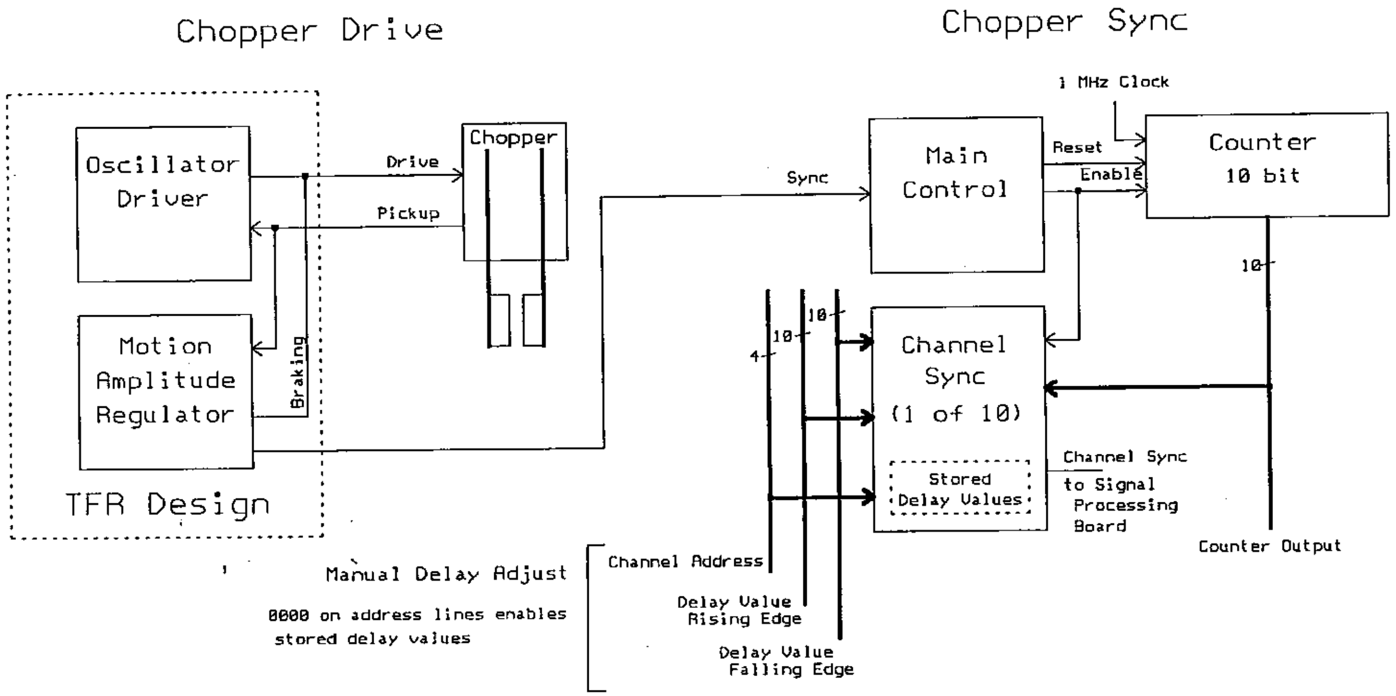
Preliminary Schematic: complete

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 ⇒ adjustable duty cycle
- manual adjustment for each channel with final values stored in firmware

Heritage

- CIRRIS 1A

Chopper Control and Sync
Status

Preliminary Design:
- chopper controller--TFR design
- chopper synchronization
  - analog design complete
  - logic design--state diagrams complete
  -

Analysis:
- power requirements

Preliminary Schematic: complete

Parts List: active and passive

Refrigerator Electronics (TRW)

Description

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 & DC/DC converter board
- drives motor of the cryocooler
- monitors temperature, position, and acceleration sensors of the cryocooler
- provides temperature control and vibration control (Adaptive Vibration Cancellation)
- interfaces for command, housekeeping, and 28 V primary power
- commands for temperature setpoint overide 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 the PTCCE to its normal operating mode and default temperature setting
- primary and secondary DC/DC converters, (can switch between units)

Refrigerator Electronics (TRW)

Interface

Cryocooler interface

Temperature command

- 10 bit bus with command word
- temperature command write--latches in temperature command word

Discrete commands

- Vibration on/off
- 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)

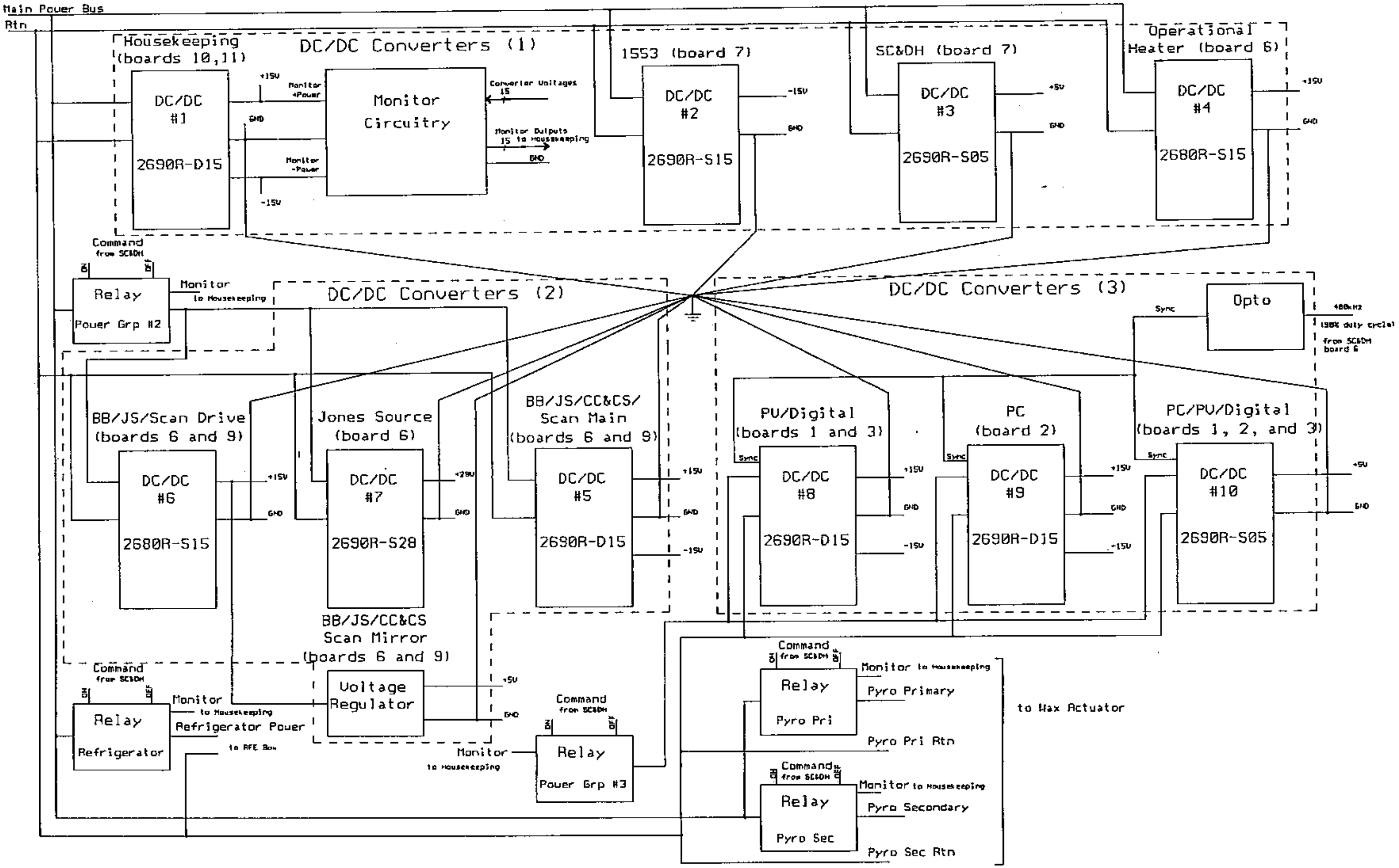
Power inputs

- +28 ± 6 Volts
- 5.5 Watts

Housekeeping Analog Channels

- accelerometer (0-5V ac)
- cold finger temperature (0-5V dc)
- compressor position (0-5V ave.)
- compressor motor current (0-5Vave.)
- balancer position (0-5V ave.)
- balancer motor current (0-5V ave.)

Power Converters Block Diagram



Power Converters
Design Description

Method

- utilize dense, high efficient DC/DC converters, Modular Devices Inc.
  - 2690R (6.5 W), 2680R (30W)

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, used by major military and aerospace firms and agencies of the US government

Power Converters
Status

Preliminary Design: complete

Preliminary Schematic: complete

Parts List: active and passive

Testing:

- DC/DC converters (similar MDI units)
  - noise
  - isolation
  - turn-on transients

Interconnect
Design Description

Method
- box--motherboard supporting 11, 6 × 9 inch cards
- shielded subminiature D connectors used where possble
- 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

Preliminary Design: complete

Preliminary Wiring Diagrams: complete

Parts List: passive

Summary

- specifications meet requirements
- preliminary design completed
- analysis, modeling, simulation, testing results available

System/Board	Design	Schematic	Analysis	Simulation	Parts List	Documentation
System			Power EXCEL	System Mod. MathCAD	EXCEL	ISD
Signal Processing			Noise, DC drift, PGA linearity	PSPICE AC, DC, Transient, Temp.		System Model
1—PC Channels (1-5)	done	preliminary			Act&Pas	
2—PV Channels (6-10)	done	preliminary			Act&Pas	
3—Mux, A/D Converter	done	preliminary			Act&Pas	
System Control & Data Handling						
7—SC&DH	VHDL done	preliminary		logic	Act&Pas	commands, formats, progs.
10—Housekeeping (2)	done	preliminary			Act&Pas	
11—Housekeeping (1)	done	preliminary			Act&Pas	
Analog Controllers						
6—Blackbody/Jones Sources Op. Heater Controllers	done	preliminary	Noise, Stability	MatLab PSPICE	Act&Pas	
Scan Mirror Controller				MatLab, PSPICE		scan profile, power require.
9—Scan Mirror Control	done	preliminary			Act&Pas	
Chopper Control & Sync.						
6—Chopper Control & Sync	done	preliminary			Act&Pas	
Power			noise, inrush, isolation			
5—DC/DC Converters (1 & 2)	done	preliminary			Act&Pas	
4—DC/DC Converters (3)	done	preliminary			Act&Pas	
Interconnect						
motherboard	done	preliminary			Passive	wiring diagram

Calibration Plan & GSE Overview

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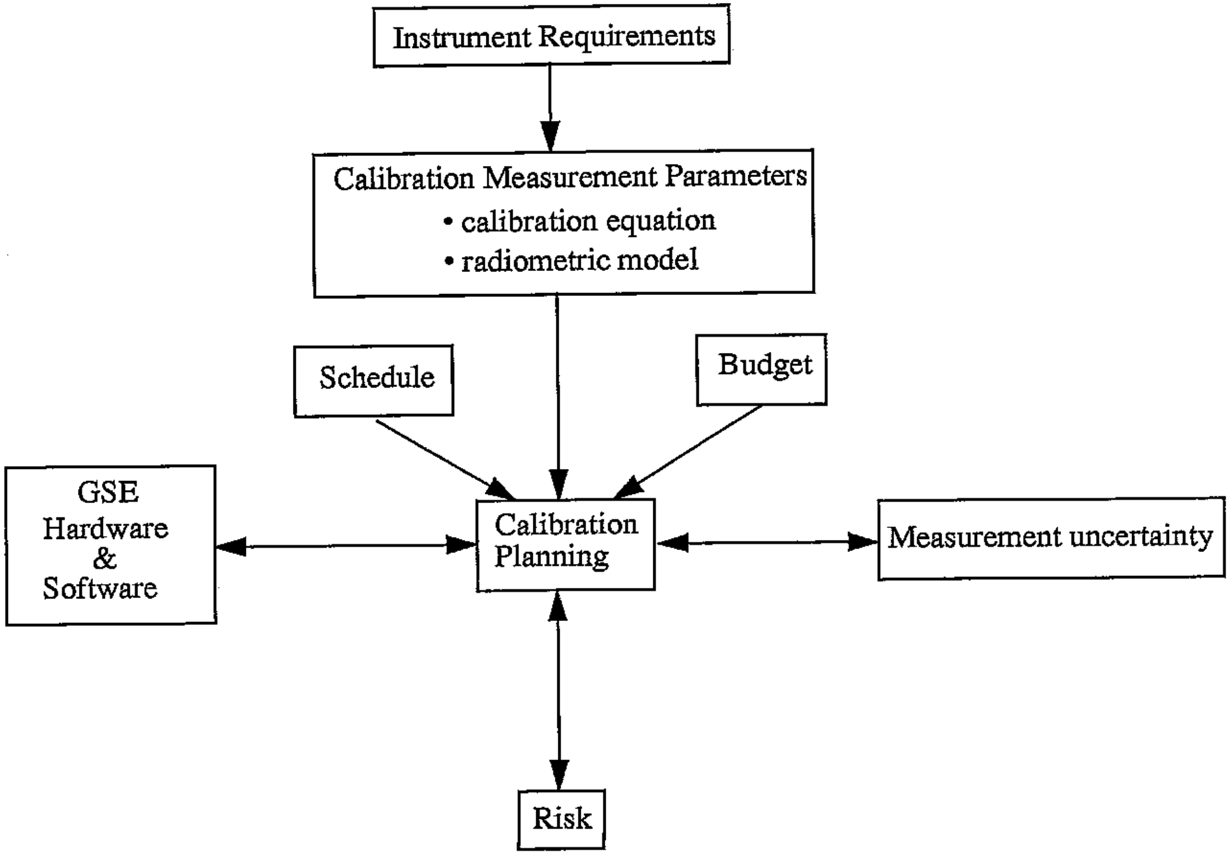
Outline

- 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 Test Configurations
  - Full Field Collimator
  - Low and High Temperature GSE Blackbodies
  - Boresight Collimator
  - Knife Edge Test
- Calibration Uncertainty Budget

Calibration Planning Philosophy



Instrument Requirements

Calibration Measurement Parameters
- calibration equation
- radiometric model

Schedule

Budget

GSE
Hardware
&
Software

Calibration
Planning

Measurement uncertainty

Risk

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	0.02 deg
Signal measurement dynamic range	Refer to SABER Instrument Requirements Document (SDL/95-006)
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 Measurement Matrix

Calibration Measurement Parameter	Instrument 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	Signal Measurement Dynamic Range	Limb Vertical Sampling Interval
Radiance Responsivity	✓	✓												
IFC Radiance		✓												
Off-Axis Extended Source Throughput Correction		✓												
Linearity		✓			✓									
Gain Mode Normalization		✓												
IFC Measurement Long- Term Repeatability			✓											
Noise Equivalent Radiance (NER)	✓													
Medium-Term Repeatability Of Sensor Offset				✓										
Saturation Equivalent Radiance (SER)													✓	
Relative Spectral Responsivity (RSR)		✓					✓							
Sensor Boresight												✓		
Instantaneous Field of View (IFOV)								✓			✓			✓
Scan Mirror Transfer Function						✓			✓	✓				
Slit Source Response		✓												
Knife Edge Response		✓												
Temporal Frequency Response														✓

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 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	Measurement Requirement	Test Configuration
Sensor Offset (Space Look)	$O_{ch,i}$	(10 det)	Radiometric Accuracy	All
Sensor Offset Measurement Uncertainty	σ_O	(10 det)	Radiometric Accuracy	All
Linearity Correction Function	$L_{ch,i}(\ )$	(10 det)	Radiometric Accuracy Residual Scale Error	Full-Field Collimator
Linearity Correction Uncertainty	σ_L	(10 det)	Radiometric Accuracy Residual Scale Error	Full-Field Collimator
Gain Mode Normalization	$G_{ch,i}$	(7 det) X (3 gains) (3 det) X (2 gains)	Radiometric Accuracy	Electronics subassembly
Gain Mode Normalization Uncertainty	σ_G	(7 det) X (3 gains) (3 det) X (2 gains)	Radiometric Accuracy	Electronics subassembly
Peak Radiance Responsivity	$\Re_{ch}$	(10 det)	Radiometric Accuracy	GSE Full-Aperture Blackbody
Peak Radiance Responsivity Uncertainty	$\sigma_{\Re}$	(10 det)	Radiometric Accuracy	GSE Full-Aperture Blackbody
Off-Axis Extended Source Throughput Correction as a Function of Scan Mirror Position	$\Upsilon_{ch,i}(scn)$	(10 det)	Radiometric Accuracy	GSE Full-Aperture Blackbody
Off-Axis Extended Source Throughput Correction Uncertainty	σ_{Υ}	(10 det)	Radiometric Accuracy	GSE Full-Aperture Blackbody

Calibration Measurement Parameters

In Flight Calibrator (IFC) Sources

- Transfer ground based blackbody radiance to IFCs during ground calibration
  - Full-aperture blackbody (channels 1 to 7)
  - Calibration lamps (channels 8 to 10)
    - Two Jones source calibration lamps
- Use IFC response to update responsivity on-orbit

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

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	Measurement Requirement	Test Configuration
IFC Radiance	N_{IFC}	(10 det.) X 3 source settings	Radiometric Accuracy	GSE Full-Aperture Blackbody
IFC Radiance Uncertainty	$\sigma_{N_{IFC}}$	(10 det.) X 3 source settings	Radiometric Accuracy	GSE Full-Aperture Blackbody
IFC Radiance Long- Term Repeatability	$\sigma_{IFC, repeat}$	(10 det)	Long Term Radiometric Precision	All

Calibration Measurement Parameters

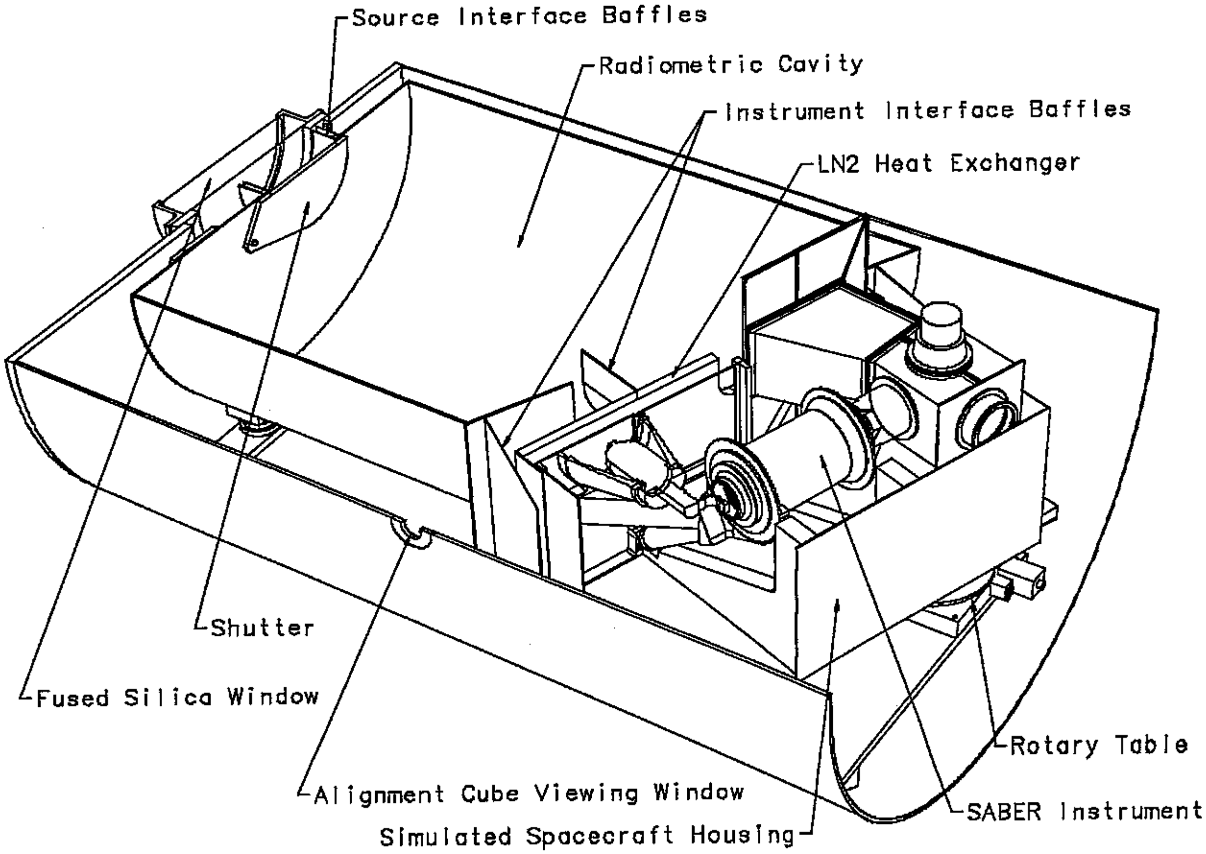
Radiometric Model

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

Parameter	Symbol	Permutations	Measurement Requirement	Test Configuration
Noise Equivalent Radiance	NER	(10 det)	System Noise Equivalent Radiance (NER)	GSE Test Chamber and GSE Full-Aperture Blackbody
Medium-Term Repeatability of Sensor Offset. (i.e., time between space looks)	$\sigma_{O,\,med}$	(10 det)	Radiance Bias Drift	Full-Field Collimator
Saturation Equivalent Radiance	SER	(10 det)	Signal Measurement Dynamic Range	Full-Field Collimator and GSE Full-Aperture Blackbody
Relative Spectral Responsivity	$RSR(\lambda)$	(10 det)	Spectral Response	Full-Field Collimator & External Interferometer
Relative Spectral Responsivity Uncertainty	$\sigma_{RSR}(\lambda)$	(10 det)	Spectral Response	Full-Field Collimator & External Interferometer
Sensor Boresite	$P_{bor}(in, cr)$	1	Boresight Alignment Knowledge	GSE Test Chamber and TBD collimator
Uncertainty of Sensor Boresight	σ_{bor}	1	Boresight Alignment Knowledge	GSE Test Chamber and TBD collimator
IFOV	$IFOV(in, cr)$	(10 det.)	IFOV @ 60 km Earthlimb Tangent Height	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

Parameter	Symbol	Permutations	Measurement Requirement	Test Configuration
Slit Source Response (off-axis response near IFOV)	S_{Slit}	(10 det)	Radiometric Accuracy	Full-Field Collimator
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
Focal Plane Temperature Effects				
1. NER		(10 det) X (2 temperatures)	System Noise Equivalent Radiance	GSE Test Chamber
2. Linearity Correction		(10 det) X (2 temperatures)	Radiometric Accuracy	Full-Field Collimator
3. Radiance Responsivity		(10 det) X (2 temperatures)	Radiometric Accuracy	Full-Aperture Blackbody
Optical Cavity Temperature				
1. NER		(10 det) X (3 temperatures)	System Noise Equivalent Radiance	GSE Test Chamber
2. Linearity Correction		(7 det) X (3 temperatures)	Radiometric Accuracy	Full-Field Collimator
3. IFC radiance		(7 det) X (3 temperatures)	Radiometric Accuracy	Full-Aperture Blackbody
Baseplate Temperature				
1. Linearity Correction		(10 det) X (3 temperatures)	Radiometric Accuracy	Full-Field Collimator
2. Radiance Responsivity		(10 det) X (3 temperatures)	Radiometric Accuracy	Full-Aperture Blackbody

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 90K
    - Reduces off-axis radiation (thermal and reflected) to levels that do not stress the off-axis performance of the instrument
- Instrument Thermal Control
    - Optics cavity and baseplate radiators cooled with 90K radiative heat exchanger
    - Radiators warmed to expected on-orbit temperatures with trim heaters
    - Temperature controlled shroud to simulate internal spacecraft environment (thermal balance test)
- Instrument rotates in test chamber about rotation axis of SABER scan mirror
    - view a fixed blackbody between 0 km and 400 km equivalent on-orbit scan mirror look angles
    - simplifies the design of the full field collimator
    - view a fixed knife edge at multiple sensor rotation angles
- Shutter at end of radiometric cavity provides capability to shutter calibration sources

Calibration Test Configurations

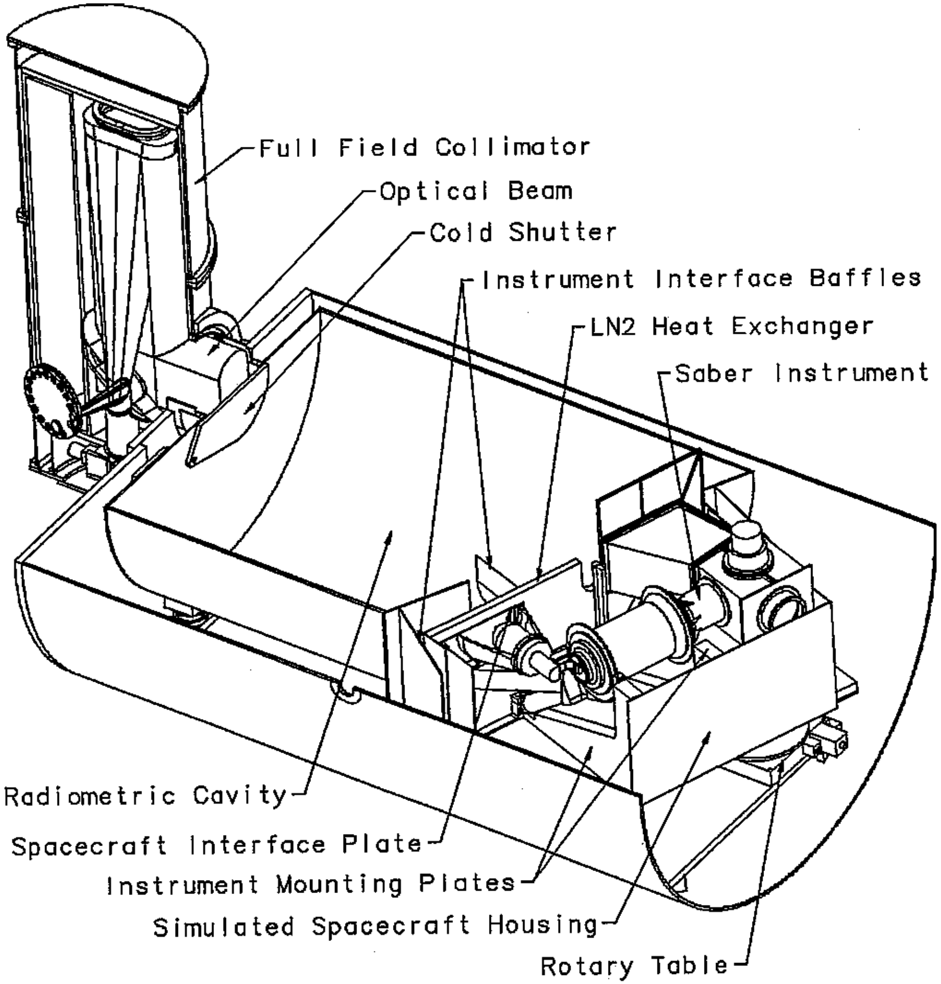
Full Field Collimator

- Calibration Parameters

Parameter	Symbol
IFOV	$IFOV(in, cr)$
Object space detector positions	$P(in, cr)$
Modulation transfer function	MTF
Temporal Frequency Response (verify only)	$A_{mp}(f), P_{hase}(f)$
Scan mirror transfer function (verify only)	$F_{scan}(\ )$
Linearity correction function (channels 8 to 10)	$L_{ch,\, i}(\ )$
Relative Spectral Response (RSR)	$RSR(\lambda)$
Slit source response	S_{Slit}

Calibration Test Configurations

Full Field Collimator (continued)



Calibration Test Configurations

Full Field Collimator (continued)

- Passively cooled with LN_2 holding tank for low background operation
- Will be used to present collimated source that will overfill filter and detector IFOV for linearity and relative spectral response measurements
  - Account for filter and detector non-uniformities
  - Account for Stierwalt effect
- Will be used to measure slit source response
  - Characterizes scatter for angular dimensions smaller than focal plane array
  - Slit source longer than angular length of detector
  - Design image quality sufficient to characterize FWHM with less than 3% error
- Simple optical design to reduce risk and cost
  - Single axis pointing mirror (±1.6°)
  - Off-axis parabola with focal length of 1035mm
  - Fold mirror, aperture, and filter slide

Calibration Test Configurations

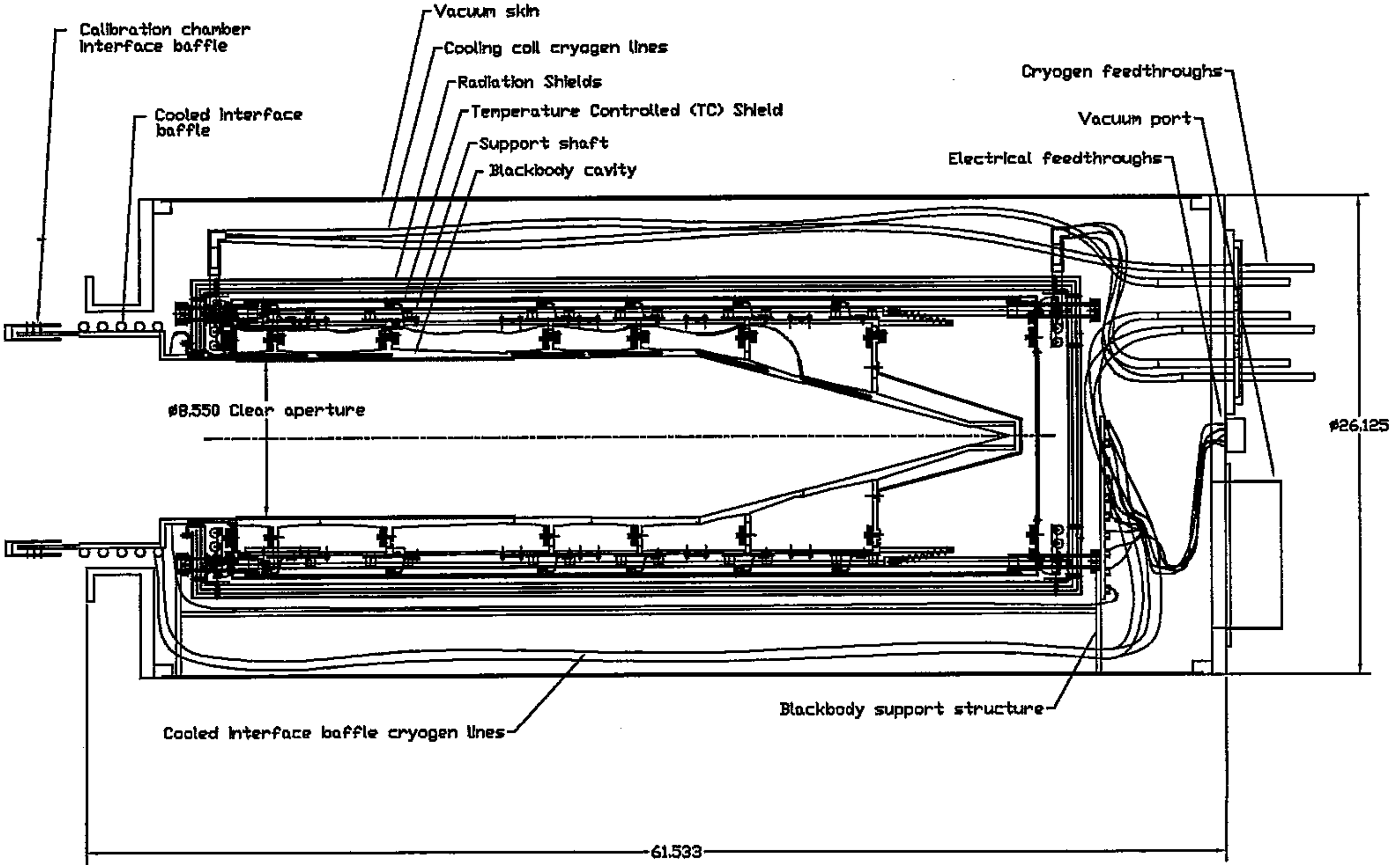
Low and High Temperature GSE Blackbodies

- Calibration Parameters

Parameter	Symbol
IFC radiance	N_{IFC}
IFC radiance uncertainty	$\sigma_{N_{IFC}}$
Off-axis extended-source throughput correction as a function of scan mirror position	$\Upsilon_{ch,\,i}(scn)$
Off-axis extended-source throughput correction uncertainty	σ_{Υ}
Sensor offset	$O_{ch,\,i}$
Sensor offset uncertainty	$\sigma_{O_{ch,\,i}}$
Noise equivalent radiance	NER
Sensor offset medium term repeatability (time between on-orbit space look, duration of approximately 2.3 min.)	$\sigma_{O,\,med}$
Linearity correction function (channels 1 to 7)	$L_{ch,\,i}(\ )$
Gain mode normalization (verify only)	$G_{ch,\,i}$

Calibration Test Configurations

Low and High Temperature GSE Blackbodies (continued)



Calibration Test Configurations

Low and High Temperature GSE Blackbodies (continued)

- SABER views rear conical portion of blackbody
- Blackbody size:
  - 8.5 inch clear aperture
  - 43 inch cavity length
  - L/D ~ 5
- Blackbody composed of 6 segments
  - Each segment has MICA heater, control PRT, and monitor PRTs
  - Front two segments comprise aperture extension
    - Minimizes thermal gradients on four rear segments
    - Brings wires up to temperature before reaching PRT
- Blackbody is surrounded with a temperature controlled shield
  - Operated near temperature of blackbody
    - Cooled with LN2
    - Heated with MICA heaters
  - Minimizes blackbody thermal gradients
  - Required for blackbody temperature control

Calibration Test Configurations

Low and High Temperature GSE Blackbodies (continued)

- Blackbody radiance uncertainty specified at 1.5% for SABER SNR $\geq$ 100
  - Temperature uncertainty
  - Emittance uncertainty
  - Reflectance uncertainty (channels 1 to 7 only)
- Single design for the low and high temperature blackbodies to reduce cost of design and manufacturing
- Low Temperature blackbody operating range of 90 K to 350 K (channels 1 to 7)
- High Temperature blackbody operating range of 300 K to 620 K (channels 8 to 10)

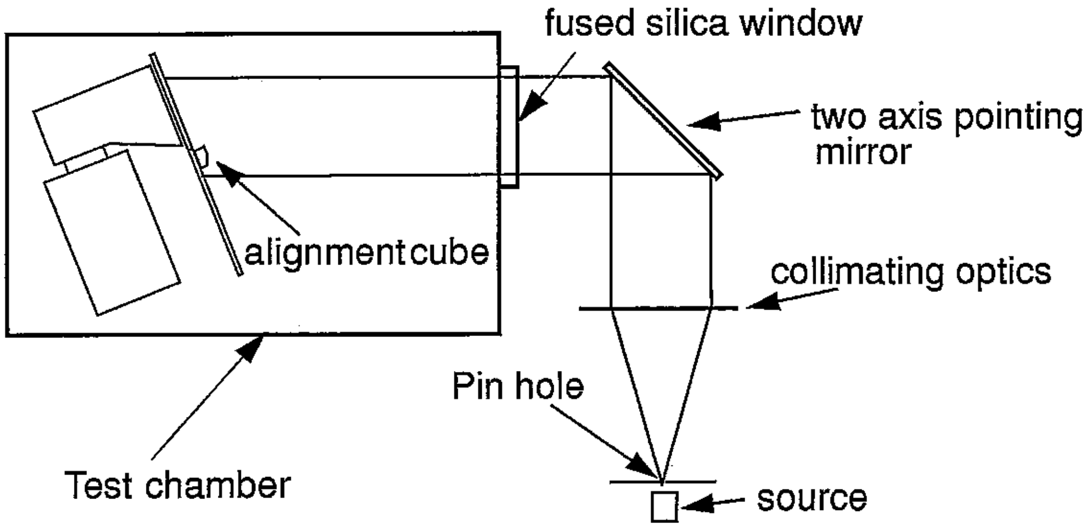
Calibration Test Configurations

Boresight Collimator

- Calibration parameters

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

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



Calibration Test Configurations

Large Area Knife Edge

- Calibration parameters

Parameter	Symbol
Knife edge test	S_{Knife}

- Verify off-axis scatter response for angular dimension larger than focal plane array
    - Sources of scatter include BRDF of mirrors and off-axis rejection performance of baffles
- Use SABER scan mirror to scan the detectors field of view toward a heated knife edge baffle (300K) located at the end of the of the radiometric cavity inside the test chamber
    - Test chamber provides 90K background
    - Knife edge 56 inches away from instrument to give blur radius of 1.4°
    - Knife edge angular dimensions of 24° in-scan by 34° cross-scan (sufficient to overfill SABER scan mirror with off-axis flux)

Calibration Uncertainty Budget

- Used as a tool to identify dominant sources of uncertainty
- Budget will evolve as sensor and calibrator performance information becomes available
- 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 channel 1

Term	Description	Relative Uncertainty Error Budget (%)	Combined RSS Uncertainty (%)	Total RSS Uncertainty (%) 3% Goal 5% Requirement
$\sigma_{r_{c,sig}}$ - Uncertainty of SABER Response to External Source				
σ_O	Sensor offset measurement uncertainty (average 10 samples)	0.32	1.8	4.2
$\sigma_{O,med}$	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 SABER Response to IFC				
σ_O	Sensor offset measurement uncertainty (average 10 samples)	0.0	1.0	
σ_N	IFC signal noise uncertainty	0.05		
σ_L	Linearity correction uncertainty	1.0		
σ_G	Gain mode normalization uncertainty	0.1		
σ_{IFC} - Uncertainty of IFC Radiance				
$\sigma_{\mathfrak{R},BB}$	Radiance uncertainty of full aperture blackbody	1.5	3.6	
σ_{RSR}	Uncertainty of IFC channel radiance due to uncertainty of instrument relative spectral response	3.1		
$\sigma_{N_{IFC}}$	Uncertainty of IFC radiance (calibration transfer to IFC)	1.0		
$\sigma_{IFC,repeat}$	Uncertainty due to IFC radiance long-term repeatability	0.5		

Calibration Uncertainty Budget (continued)

- Dominant sources of uncertainty
  - Uncertainty of IFC channel radiance due to uncertainty of instrument relative spectral response (3.1%)
  - Radiance uncertainty of GSE blackbody (1.5%)

SABER Electrical GSE & GSE Software Overview

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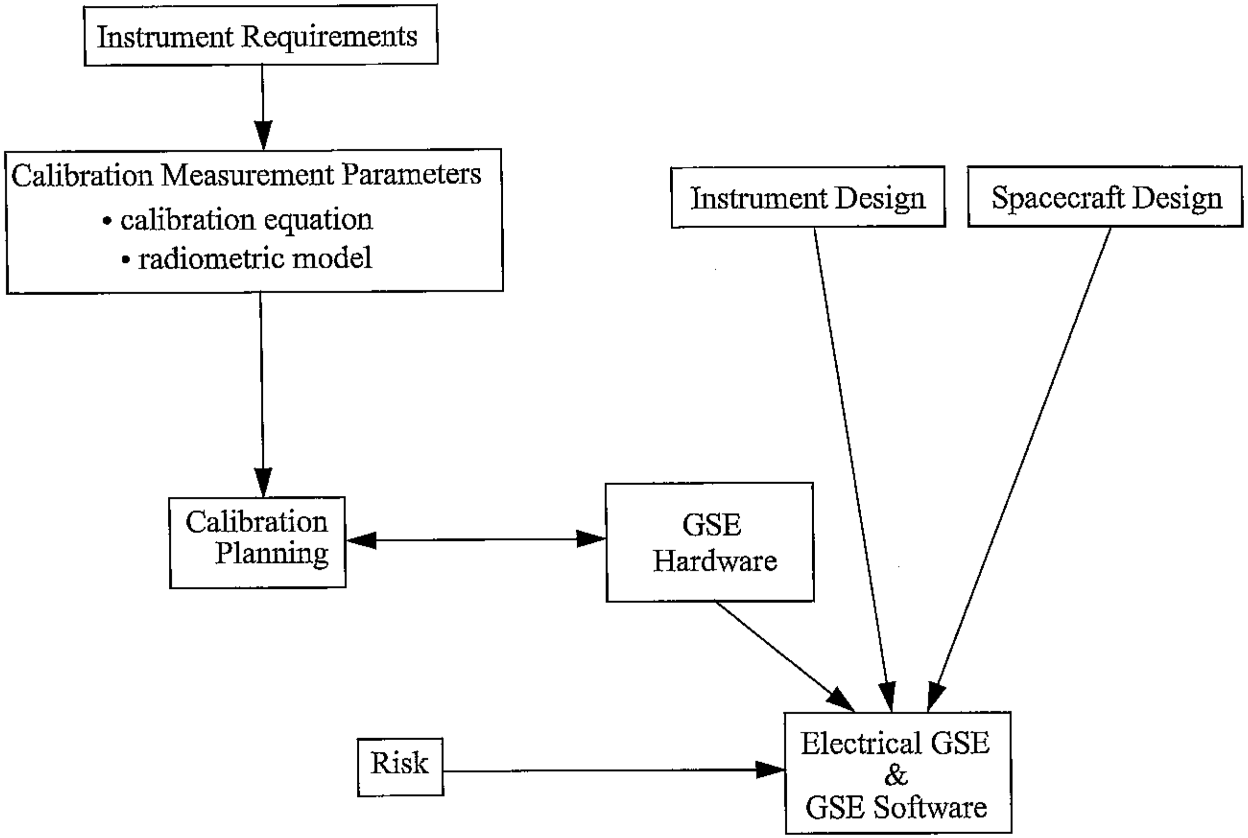
Outline

- Electrical & Software Requirements Flow Down
- Electrical GSE
    - GSE Workstation
    - GSE Electrical Interfaces
- GSE Software

Electrical & Software Requirements Flow Down



Instrument Requirements

Calibration Measurement Parameters
- calibration equation
- radiometric model

Instrument Design

Spacecraft Design

Calibration Planning

GSE Hardware

Risk

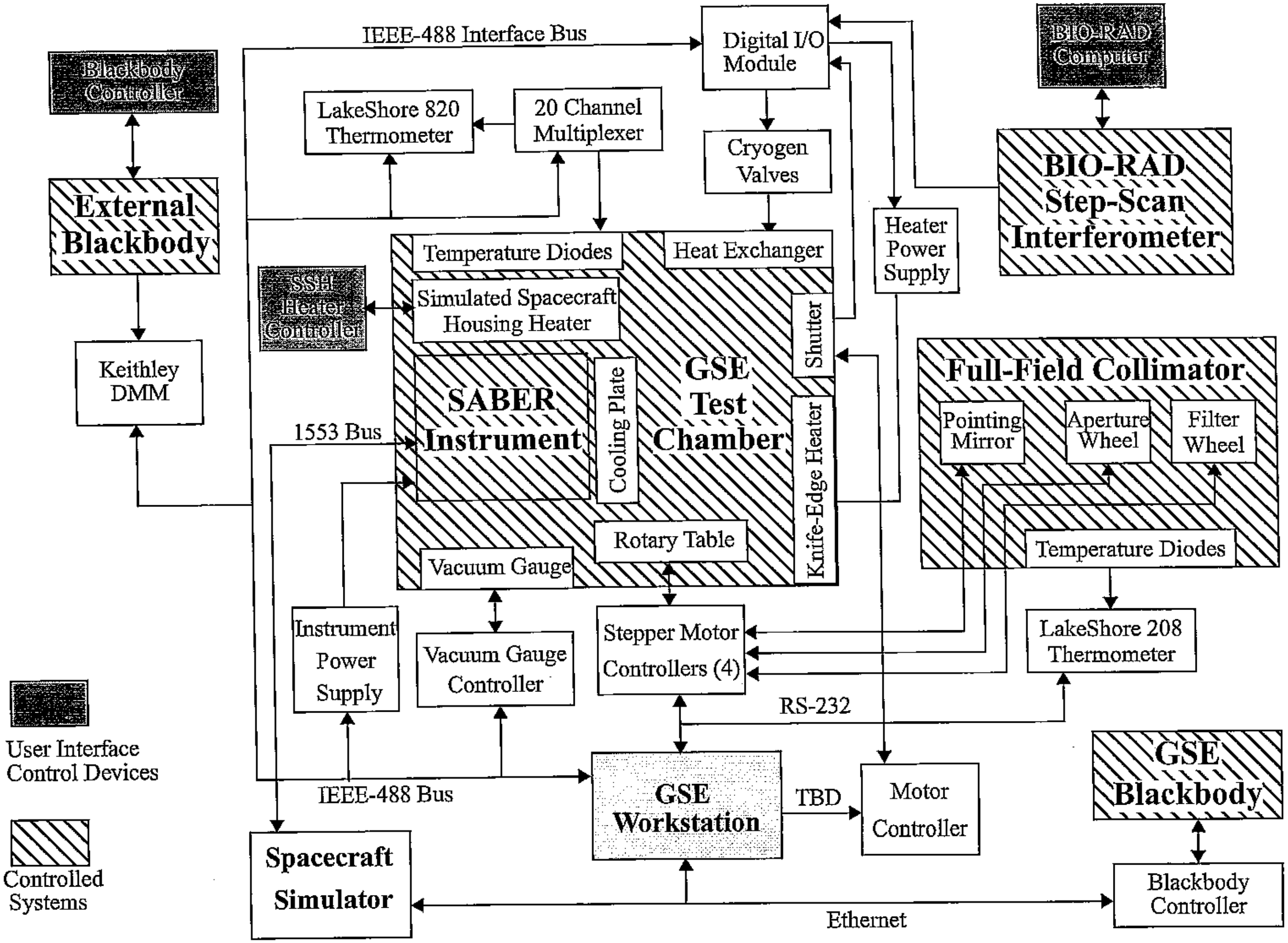
Electrical GSE & GSE Software

Electrical GSE

- GSE Workstation and all wiring and devices between it and:
    - SABER Instrument
    - GSE Test Chamber
    - Full Field Collimator
    - Full Aperture Blackbody
    - Step-Scan Interferometer
    - Other Test and Calibration Sources

  (Industry standard busses and devices used to reduce delivery risk)
- Other electrical devices used to support ground operation of the instrument

SABER Electrical GSE Interface Block Diagram



GSE Workstation

- Sun Sparcstation with two monitors running the Solaris 2.5 (Unix) operating system
    - Platform chosen to take advantage of SDL's existing control software, programming expertise, and data analysis environment.
    - Dual monitor configuration allows a test conductor to more easily monitor the instrument and GSE hardware status during instrument calibration.
- 4 Gbytes of on-line storage for instrument data and GSE data logs
- 4mm Tape drive for data archival
- Printer
- C, C++, and Fortran Compilers
- PostgreSQL relational database
- RS/1, PV~Wave, and BBN Cornerstone data analysis software

GSE Electrical Interfaces

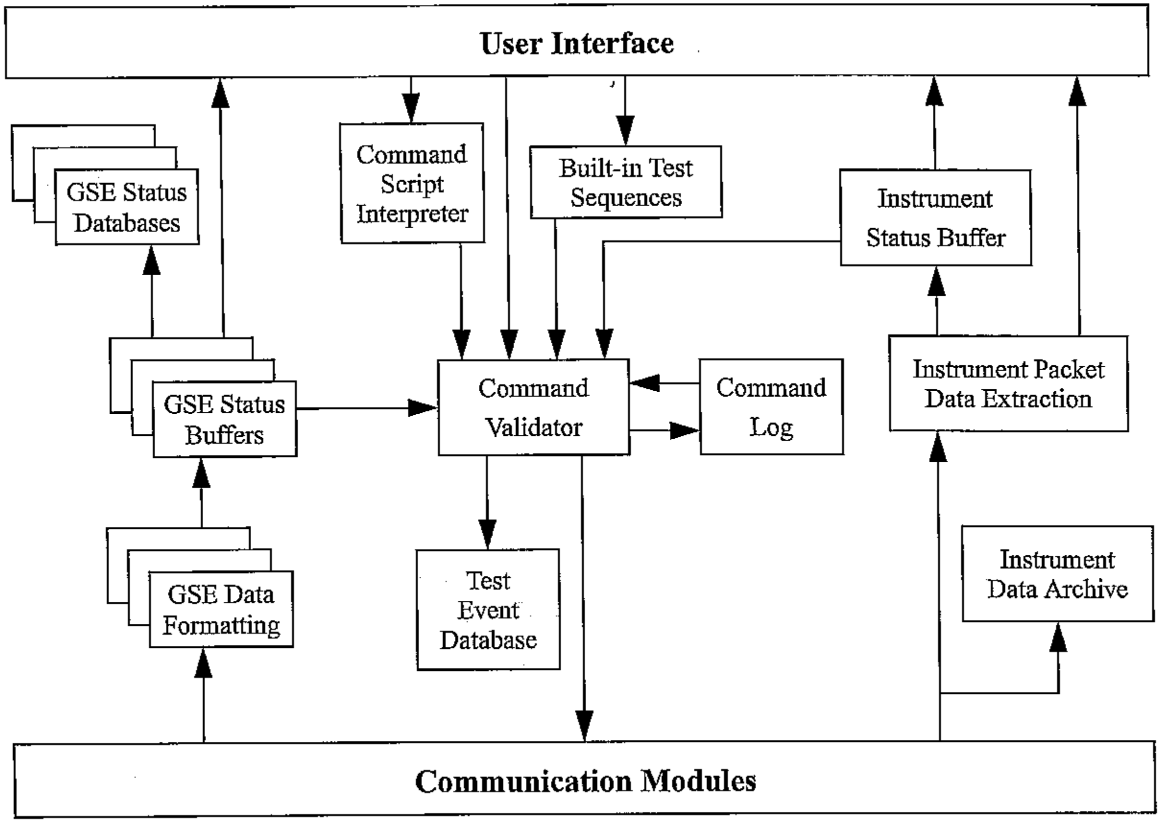
- Instrument
  - Power - The GSE workstation controls an instrument power supply over an IEEE-488 bus
  - Commands - Instrument commands are sent over an ethernet connection to a spacecraft simulator (supplied by APL). The spacecraft simulator communicates with the SABER instrument over a 1553 bus.
- GSE Test Chamber
  - Knife-edge heater - The knife-edge heater is turned on and off by setting bits in a digital I/O module over an IEEE-488 bus.
  - Shutter - Commands are sent to the shutter's motor controller over a TBD link
  - LN2 heat exchangers - The flow of LN2 is controlled by vales which are turned on and off by a digital I/O module over an IEEE-488 bus
  - Rotary Table - The position of the rotary table is set by a stepper motor controller which communicates with the GSE workstation over an RS-232 serial connection.
  - Temperature Diodes - A 20 channel multiplexer cycles through the test chamber diodes and sends the output to a diode reader. Both the diode reader and the multiplexer communicate with the GSE workstation over an IEEE-488 bus.
  - SSH Heater - The simulated spacecraft housing heater has an independent controller which is not interfaced with the GSE workstation. The SSH temperature is monitored by the GSE workstation.

GSE Electrical Interfaces (Cont.)

- Full Field Collimator
  - Pointing Mirror - The position of the pointing mirror is determined by a positioning table which is operated by a stepper motor controller over an RS-232 serial link.
  - Aperture/Filter Wheel - are positioned by TBD stepper motors over a TBD link.
  - Temperature Diodes - An 8 channel diode scanner reads the diode temperatures and communicates with the GSE workstation over an RS-232 connection.
- Full Aperture Blackbody
  - Controller - the full aperture blackbody controller communicates with the GSE workstation over an ethernet link.
- Step-Scan Interferometer
  - Step Pulse - At each step of a scan, the BIO-RAD step-scan interferometer sends a sync pulse to trigger data collection. The GSE workstation receives these pulses through a digital I/O module on the IEEE-488 bus.
- External Blackbody
  - Temperature Monitor - Temperature of the external blackbodies is monitored by reading a thermocouple with a Keithly digital Multimeter. The thermocouple reading is sent to the GSE workstation over an IEEE-488 interface.

GSE Software

- Allows a user to control and monitor the SABER instrument and GSE hardware
- Records Instrument data and GSE status information



GSE Software Data Flow

GSE Software (Cont)

- Graphical User Interface
  - •Main window contains all instrument monitor and control elements.
  - •GSE control windows will be displayed as required for a given test.
  - •For each command sent, the GUI shows whether that command has been executed by the appropriate device.
  - •Only the most pertinent GSE status information will be displayed. All available information will be recorded and can be accessed immediately from a database.
- .Command and Data Handling
  - •All Commands are validated in the current software context before being executed
  - •All Instrument data is recorded and archived
  - •Each instrument power-on command starts a new instrument data file
  - •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 status data is logged to database tables and is immediately available by other workstations on the network
- Test Event Database
  - •Test events will be logged with an entry in a test event database which will include
    - A unique test identifier
    - Instrument data location (file name and position) of first sample
    - Number of samples for this test
    - Sensor and GSE status information

GSE Software (Cont)

- Representative statistics (mean and standard deviation) of science data for each test will be computed and stored in the test event database. This will allow a data analyst to search for test events with specific data characteristics.

- Automation
  - Built in test sequences allow predetermined and repetitive command sequences to be performed more quickly and reliably.
  - The GSE software will also read and execute commands from command scripts
  - Execution of built-in sequences and scripts can be paused, stopped, restarted, or aborted.

SABER INSTRUMENT
FABRICATION, INTEGRATION AND TEST

Steven Brown

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FABRICATION, INTEGRATION AND TEST

Overview

Fabrication

- Mechanical / Structural
  - Design Team
  - Design Facilities
  - Machine Shop
- Electrical
  - Design Team
  - Design Facilities
  - Fabrication

FABRICATION, INTEGRATION AND TEST
Overview

Integration and Test

- Engineering and Development Tests
    - Description of Engineering and Development Tests
    - Sample of some Engineering and Development Tests
- Proto-Flight Tests
    - Test Plans and Procedures
    - Test Reports
    - Proto-Flight Tests
- Test Matrix
- Integration and Test Flow
- Personnel Organization Chart
- Facilities
    - Clean Rooms
    - Optical Bench
    - Shaker Equipment
    - Thermal Vacuum Equipment
    - Test and Calibration Support Equipment

FABRICATION
Mechanical / Structural

Mechanical and Structural Design Team for SABER

- Core Team assigned to SABER project for duration of project
  - Engineers and Designers will follow project from start to finish
  - Engineers work directly with designers, technicians, machinists, etc.
  - Designers are considered fully part of the team
- Optical Design
  - Roy Esplin & John Stauder
- Mechanical Design & Analysis
  - Steve Folkman & Mehrdad Roosta - Engineering and Analysis
  - Dave McLain & Pete Brunson - Design / Drawings
- Thermal Design & Analysis
  - Clair Batty & Scott Jensen
- Experienced Machinists working in Machine Shop

FABRICATION
Mechanical / Structural

Mechanical Design and Fabrication Facilities at Space Dynamics Laboratory / Utah State University

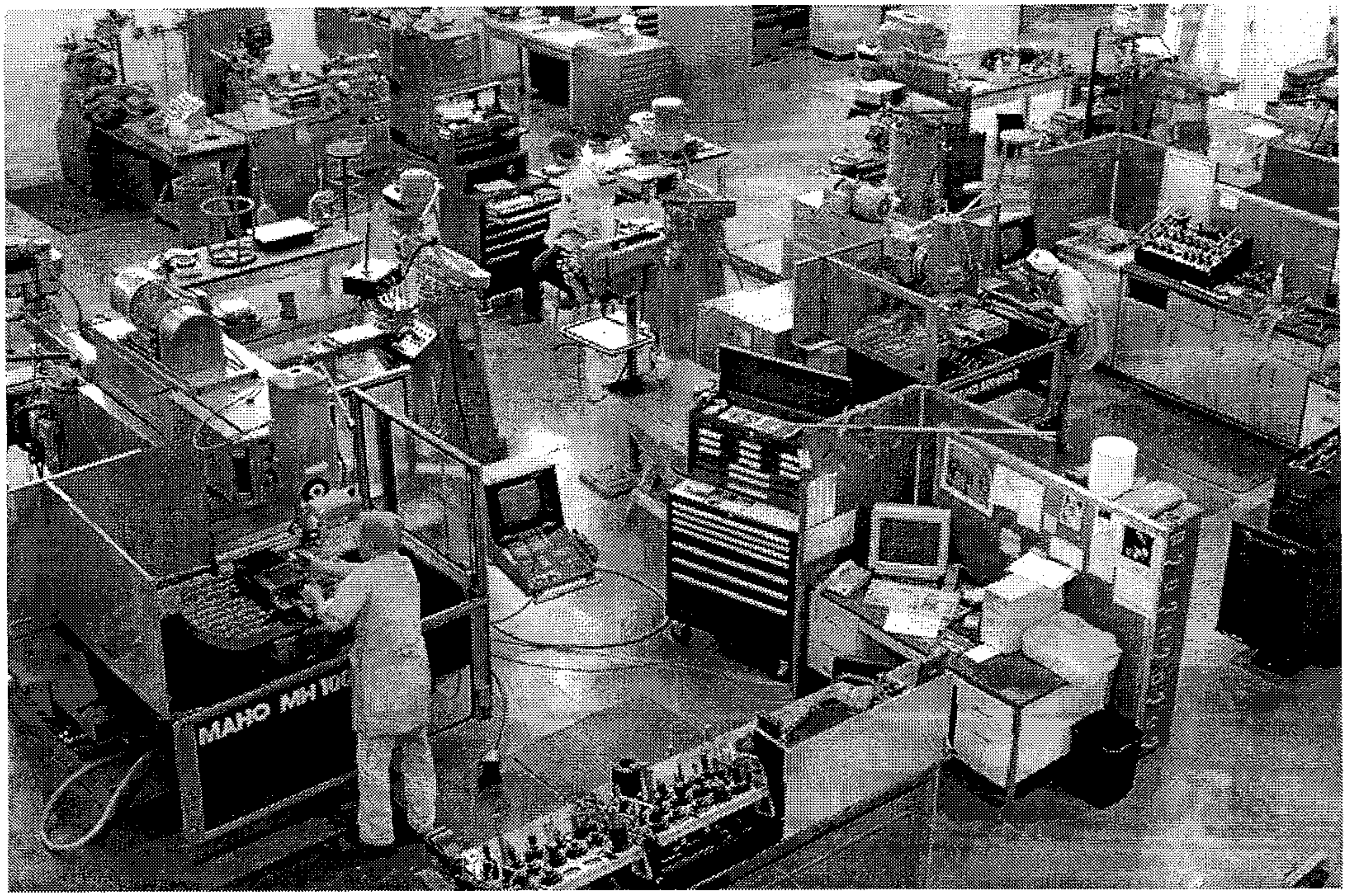
- Design Facilities
  - Software
    - OSLO: Optical Ray Tracing, analysis, and optimization
    - APART: Straylight Analysis
    - NEVADA, SINDA, ORBITAL WORKBENCH: Thermal Analysis and Design
    - NASTRAN: Structural Analysis
    - ACAD, IDEAS: Mechanical Design, Drawings
- Machine Shop
  - Mitutoyo Height Gage and Test Indicator
  - Mitutoyo Height Gage Probe
  - BH710 Mitutoyo CMM Inspection Machine
  - MH600T MAHO Milling machine, computer controlled
  - MH1000T MAHO Milling machine, computer controlled
  - TREE Milling Machine with digital readout

FABRICATION
Mechanical / Structural

Mechanical Design and Fabrication Facilities at Space Dynamics Laboratory / Utah State University

- Machine Shop (continued)
  - Four Small Milling Machines with digital readouts
  - Metal Bandsaw
  - Cutoff Bandsaw
  - 48SL Sand Blaster
  - Mechanical Shear
  - Two 2 ton hoists
  - Metal Lathe
  - Engine Lathe
  - Heliarc Welder
  - Welder
  - 10” Monarch Lathe
  - Monarch Lathe
  - Large Grinder
- Some large items will be machined out of house

SDL MACHINE SHOP

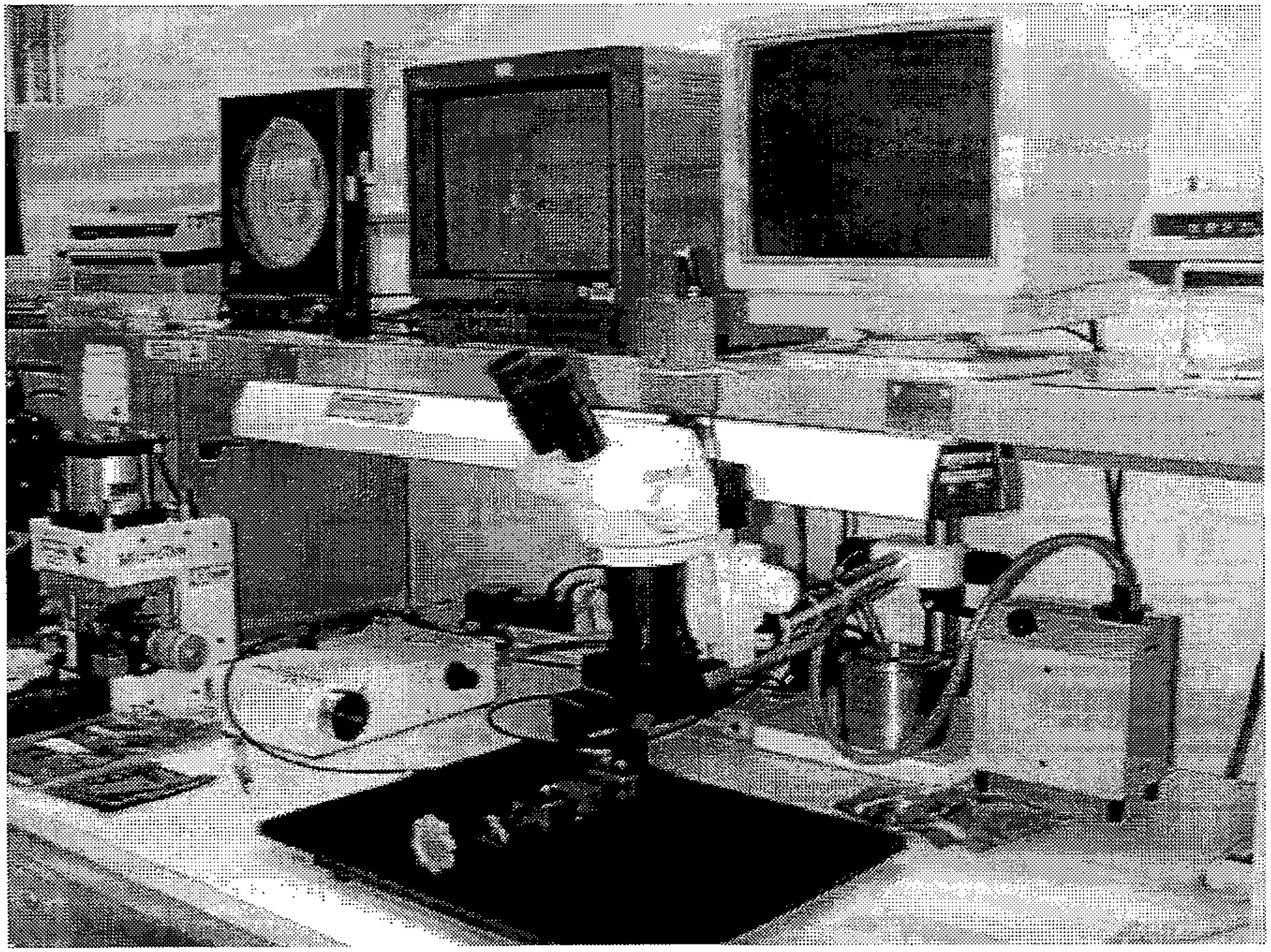


FABRICATION
Electrical

Electrical Design Team for SABER
- Mark Jensen & Jay Ballard
- Technicians assigned for duration of project

Electrical Design and Fabrication facilities at Space Dynamics Laboratory / Utah State University
- Design Facilities
  - Software
    - Pspice: Circuit simulation
    - MatLab: Simulation, Modeling
    - MathCAD: Modeling
    - Pcad: schematic capture, PC board layout
    - Orcad: schematic capture
    - Viewlogic and Actel Design Tool: VHDL design and simulation
- Fabrication
  - Certified PC board fabrication out of house
  - NASA Certified personnel and lab facilities for PC board Assembly
  - Microscopic video inspection of circuit board assemblies
  - Automated facilities for SMT fabrication and rework

SDL VIDEO PC BOARD INSPECTION STATION



INTEGRATION AND TEST

Engineering and Development Tests

Engineering and Development Tests

- Conducted during design phase and early in integration phase
- Design and Manufacturing Verification
- No formal test plan required
  - Logbooks or travelers will follow flight assemblies
  - Engineering notebooks maintained on tests
- Summary Reports
  - Summary of significant results
  - Include test data
  - Conclusions of test

Sample of Engineering and Development Tests

- Characterization of signal conditioning filter response to step function
- Push / Pull stress tests on support struts and mounting fixtures
- Scan mirror / controller tests
- Focal plane support system development tests
- Optics Mount development tests
- Jitter Tests
- Tests to verify GSE and Calibration Equipment function, accuracy, etc.
- NIST calibration verification tests

INTEGRATION AND TEST
Proto-Flight Tests

Proto-Flight Tests

- Performed at Integrated Instrument Level
- Includes Functional, performance, environmental, and calibration testing
- Formal Test Plans and Procedures
- Test Levels
  - Exceed expected lifetime environments
  - Low enough to maintain flight integrity of flight equipment
- Tests conducted under direction of system engineer

INTEGRATION AND TEST

Proto-Flight Tests

Test Plans and Procedures

- Development by engineering team under direction of system engineer
- 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

INTEGRATION AND TEST
Proto-Flight Tests

Test Reports

- Preliminary Report of initial results
  - Due 10 days following the test
  - Telephone, Fax or E-mail
- Final Report
  - Due six months after test completion
  - Shall include
    - Filled-in 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

INTEGRATION AND TEST

Proto-Flight Tests

Proto-Flight Tests

- Structural Integrity: (Sine Burst)
  - Sine Burst Vibration Test Levels
    - Thrust axis 15.5 g @ 24 Hz
    - Lateral axis 8.5 g @ 24 Hz

- Workmanship: (Random Vibration)
  - Random Vibration Test Spectra
    - Three Axes
    - Test Duration 1.0 min/axis Overall Level 14.1 Grms

Frequency (Hz.)	Acceleration (G^2/Hz.)
20	0.026
20-50	+6.0 dB/Oct.
50-800	0.160
800-2000	-6.0 dB/Oct.
2000	0.026

INTEGRATION AND TEST

Proto-Flight Tests

Proto-Flight Tests (cont.)

- Sine Survey
  - Test Conditions

• Frequency Range	10 - 500 Hz.
• Level	0.25 G
• Duration	10 Oct/min
• Test in 3 orthogonal axes	

- Cover Deployment

- EMC/EMI: subcontract to NTS

- Alignment

INTEGRATION AND TEST

Proto-Flight Tests

Proto-Flight Tests (cont.)

- Thermal Vacuum Balance

- Thermal Vacuum Cycle and Survival Temperature Test
  - Test Conditions

Test Parameter	Parameter Value
Pressure	<10-4 torr
Survival Temperature Limit	-34°X to +60°X
Operational Temperature Limit	-29°X to +55°X
Stability	< 3 °X/hr
Soak time	4-hour minimum
Cycles	1 survival and a minimum of 6 operational

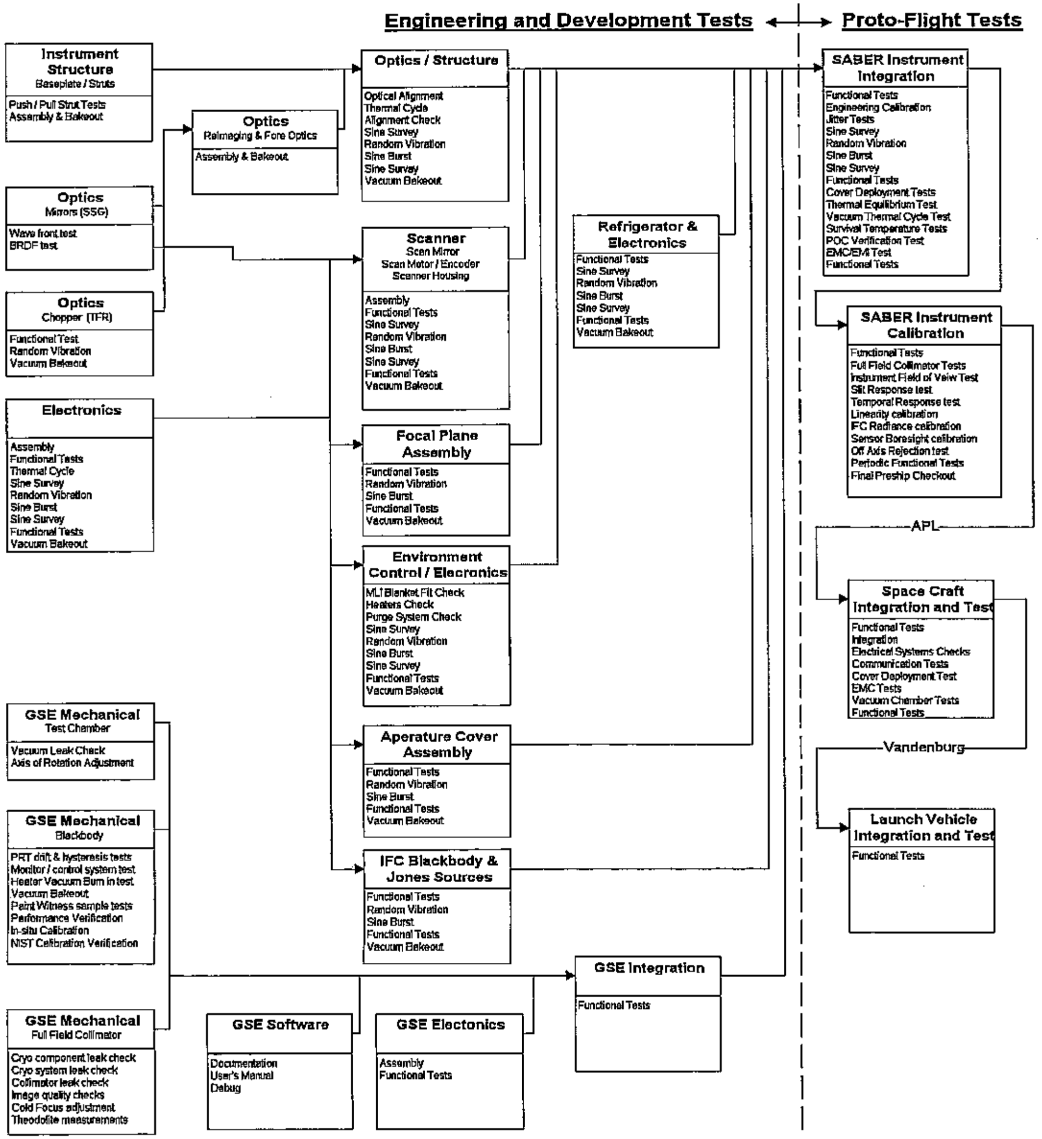
INSTRUMENT TEST MATRIX

Legend

X = Test Performed
A = Analysis
S = Subcontractor Performed Test

Hardware Description	Functional Tests	EMC/EMI		Sine Burst	Random Vibration	Aperture Cover Deploy	Static Load	Mass	Moments of Inertia	Center of Gravity	Alignment		Vacuum Bakeout	Thermal Vacuum Balance	Thermal Vacuum Cycle		Cryogenic Cycle	Calibration	Development
Protoflight Testing																			
Fully Integrated Instrument	X	X		X	X	X		X	A	A	X			X	X			X	
Engineering Testing																			
Support Structure				X			X												
Optics Assembly								X	A	A									
Telescope	X							X	A	A	X		X						X
Baffle/Aperture Cover Assy						X		X	A	A			X						X
Scan Mirror Assembly	X				S			X	A	A					S			S	X
Chopper	S			X	X			S	A	A					S				X
IFC Blackbody								X					X						
Jones Sources								X					X						
Cryogenic Assembly								X	A	A							X		
FIST Assembly								X	A	A			X						X
Detector Subassembly	S			S	S			S			S		S				S		
Filter Subassembly				S	S			S					S				S		
Thermal Link								X					X						X
Refrigerator	S			S	S			X	A	A			X		X				
Optics Radiator Assembly								X	A	A			X						
Base Plate & Support Structure								X	A	A			X						X
Instrument Electronics Assy	X			X	X			X	A	A			X		X				
RFE Assembly	X			X	X			X	A	A			X		X				
Cable Assemblies								X					X						

INTEGRATION AND TEST FLOW



Engineering and Development Tests ←|→ **Proto-Flight Tests**

Instrument Structure
Baseplate / Struts
Push / Pull Strut Tests
Assembly & Bakeout

Optics
Reimaging & Fore Optics
Assembly & Bakeout

Optics
Mirrors (SSG)
Wave front test
BRDF test

Optics
Chopper (TFR)
Functional Test
Random Vibration
Vacuum Bakeout

Electronics
Assembly
Functional Tests
Thermal Cycle
Sine Survey
Random Vibration
Sine Burst
Sine Survey
Functional Tests
Vacuum Bakeout

Optics / Structure
Optical Alignment
Thermal Cycle
Alignment Check
Sine Survey
Random Vibration
Sine Burst
Sine Survey
Vacuum Bakeout

Scanner
Scan Mirror
Scan Motor / Encoder
Scanner Housing
Assembly
Functional Tests
Sine Survey
Random Vibration
Sine Burst
Sine Survey
Functional Tests
Vacuum Bakeout

Focal Plane Assembly
Functional Tests
Random Vibration
Sine Burst
Functional Tests
Vacuum Bakeout

Environment Control / Elecronics
MLI Blanket Fit Check
Heaters Check
Purge System Check
Sine Survey
Random Vibration
Sine Burst
Sine Survey
Functional Tests
Vacuum Bakeout

Aperature Cover Assembly
Functional Tests
Random Vibration
Sine Burst
Functional Tests
Vacuum Bakeout

IFC Blackbody & Jones Sources
Functional Tests
Random Vibration
Sine Burst
Functional Tests
Vacuum Bakeout

Refrigerator & Electronics
Functional Tests
Sine Survey
Random Vibration
Sine Burst
Sine Survey
Functional Tests
Vacuum Bakeout

GSE Mechanical
Test Chamber
Vacuum Leak Check
Axis of Rotation Adjustment

GSE Mechanical
Blackbody
PRT drift & hysteresis tests
Monitor / control system test
Heater Vacuum Burn in test
Vacuum Bakeout
Paint Witness sample tests
Performance Verification
In-situ Calibration
NIST Calibration Verification

GSE Mechanical
Full Field Collimator
Cryo component leak check
Cryo system leak check
Collimator leak check
Image quality checks
Cold Focus adjustment
Theodolite measurements

GSE Software
Documentation
User's Manual
Debug

GSE Electonics
Assembly
Functional Tests

GSE Integration
Functional Tests

SABER Instrument Integration
Functional Tests
Engineering Calibration
Jitter Tests
Sine Survey
Random Vibration
Sine Burst
Sine Survey
Functional Tests
Cover Deployment Tests
Thermal Equilibrium Test
Vacuum Thermal Cycle Test
Survival Temperature Tests
POC Verification Test
EMC/EMI Test
Functional Tests

SABER Instrument Calibration
Functional Tests
Full Field Collimator Tests
Instrument Field of Veiw Test
Slit Response test
Temporal Response test
Linearity calibration
IFC Radiance calibration
Sensor Boresight calibration
Off Axis Rejection test
Periodic Functional Tests
Final Preship Checkout

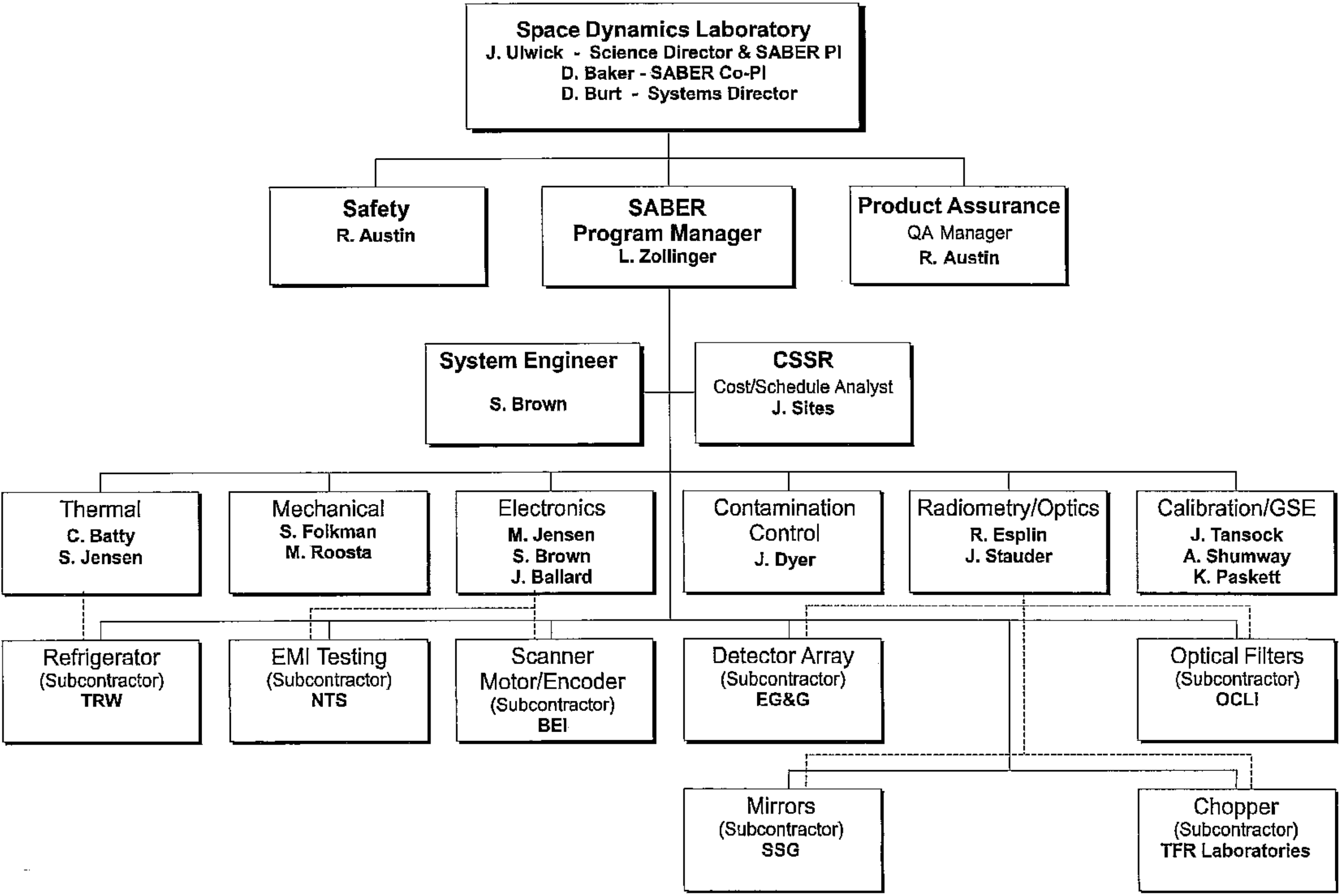
APL

Space Craft Integration and Test
Functional Tests
Integration
Electrical Systems Checks
Communication Tests
Cover Deployment Test
EMC Tests
Vacuum Chamber Tests
Functional Tests

Vandenburg

Launch Vehicle Integration and Test
Functional Tests

INTEGRATION AND TEST
Personnel



Space Dynamics Laboratory
J. Ulwick - Science Director & SABER PI
D. Baker - SABER Co-PI
D. Burt - Systems Director

Safety
R. Austin

SABER
Program Manager
L. Zollinger

Product Assurance
QA Manager
R. Austin

System Engineer
S. Brown

CSSR
Cost/Schedule Analyst
J. Sites

Thermal
C. Batty
S. Jensen

Mechanical
S. Folkman
M. Roosta

Electronics
M. Jensen
S. Brown
J. Ballard

Contamination Control
J. Dyer

Radiometry/Optics
R. Esplin
J. Stauder

Calibration/GSE
J. Tansock
A. Shumway
K. Paskett

Refrigerator
(Subcontractor)
TRW

EMI Testing
(Subcontractor)
NTS

Scanner Motor/Encoder
(Subcontractor)
BEI

Detector Array
(Subcontractor)
EG&G

Optical Filters
(Subcontractor)
OCLI

Mirrors
(Subcontractor)
SSG

Chopper
(Subcontractor)
TFR Laboratories

INTEGRATION AND TEST
Facilities

Clean Room Facilities

- RP1
  - High Bay Clean Tent: Class 100
  - Optical Clean Room: Class 100
- RP2
  - Clean tents: Two Class 100 tents
  - Precision Cleaning Lab: Class 1000
    - Clean tent in Precision Lab: Class 100
- RP3
  - Clean Room: Class 10, 50% humidity
  - Pass Through Floor Clean Room: Class 10 , 50% humidity
- RP4
  - Clean Tents: Two Class 100 tents, 50% humidity

Optical Bench Facilities

- Ealing 4'x8' Honeycomb Table with Class 100 Clean Tent
- Ealing 4'x20' Honeycomb Table with Class 100 Clean Tent and overhead crane
- Clean Bench
- Dewar with window for cold optical testing

INTEGRATION AND TEST
Facilities

Shaker Equipment

- Ling Dynamics System shaker head and amplifier (pulse type amp)
  - Capable of 7000 lb force
  - Sine, random, sine on random, sine dwell, random on random, shock
- Gen Rad computer controller / monitor
- Slip table
- MB Shaker head with Ling Dynamics System amplifier (class AB amp)
  - Capable of 3500 lb force
  - Sine and random
- Spectral Dynamics Computer controller / monitor

Thermal Vacuum Equipment

- Two Large Thermo-Vac Chambers for vacuum bakeout and vacuum thermal cycle tests.
- One Small Thermo-Vac Chamber for use on smaller parts or subassemblies

INTEGRATION AND TEST
Facilities

Space Dynamics Laboratory Supplied Support Equipment for Testing and Calibration

- Vacuum Pumps
  - Balsers 4 inch pumping system
  - Leybold 8 inch pumping system
- Cryogen Dewars and fill lines
- Lakeshore 208 temperature monitors
- Rank Taylor Hobson Alignment Telescope
- T4 Theodolites
- Four IR Industries blackbodies (model 101B or 101C)
- KAYE ice point reference cell
- Bio-rad step scan interferometer (model 60A)
- Liquid nitrogen dewar for nitrogen purge gas with high pressure gas fitting
- ATA (nitrogen purged antechamber)

INTEGRATION AND TEST
Facilities

Space Dynamics Laboratory Supplied Support Equipment for Testing and Calibration (continued)

- Lakeshore temperature data acquisition system
  - Cryogenic temperature monitor (model 820)
  - Sensor Scanner (model 8085)
  - Cryogenic temperature monitor (model 208)
- TOPAZ power conditioner
- 16 inch parabolic collimator with 100 inch focal length
- 18 inch fused silica window
- 22 inch reference flat mirror with 2 axis gimbal
- 4 inch gold Labshore integrating sphere
- MIC-1 LUPI (long unequal path interferometer)
  - FASTVAI Fast Code interferogram reduction software
- SPAS Chamber
  - will be modified for NIST TXR GSE Blackbody calibration
- Jarret Triple point reference cell

FABRICATION, INTEGRATION AND TEST
Summary

Fabrication

- Personnel and facilities are available for mechanical and electrical design and fabrication

Integration and Test

- Assurance that the SABER Instrument meets science and environmental specifications
  - Test catagories have been defined
    - Engineering and Development tests
    - Proto-Flight tests
  - Necessary tests have been planned
    - Test levels are established
    - Equipment is available or being procured
  - Complete record of tests performed for all flight assemblies
  - Guidelines for developing test procedures have been made
  - Guidelines for producing test reports have been established

Calibration Test Schedule

Joe Tansock

December, 10, 1996

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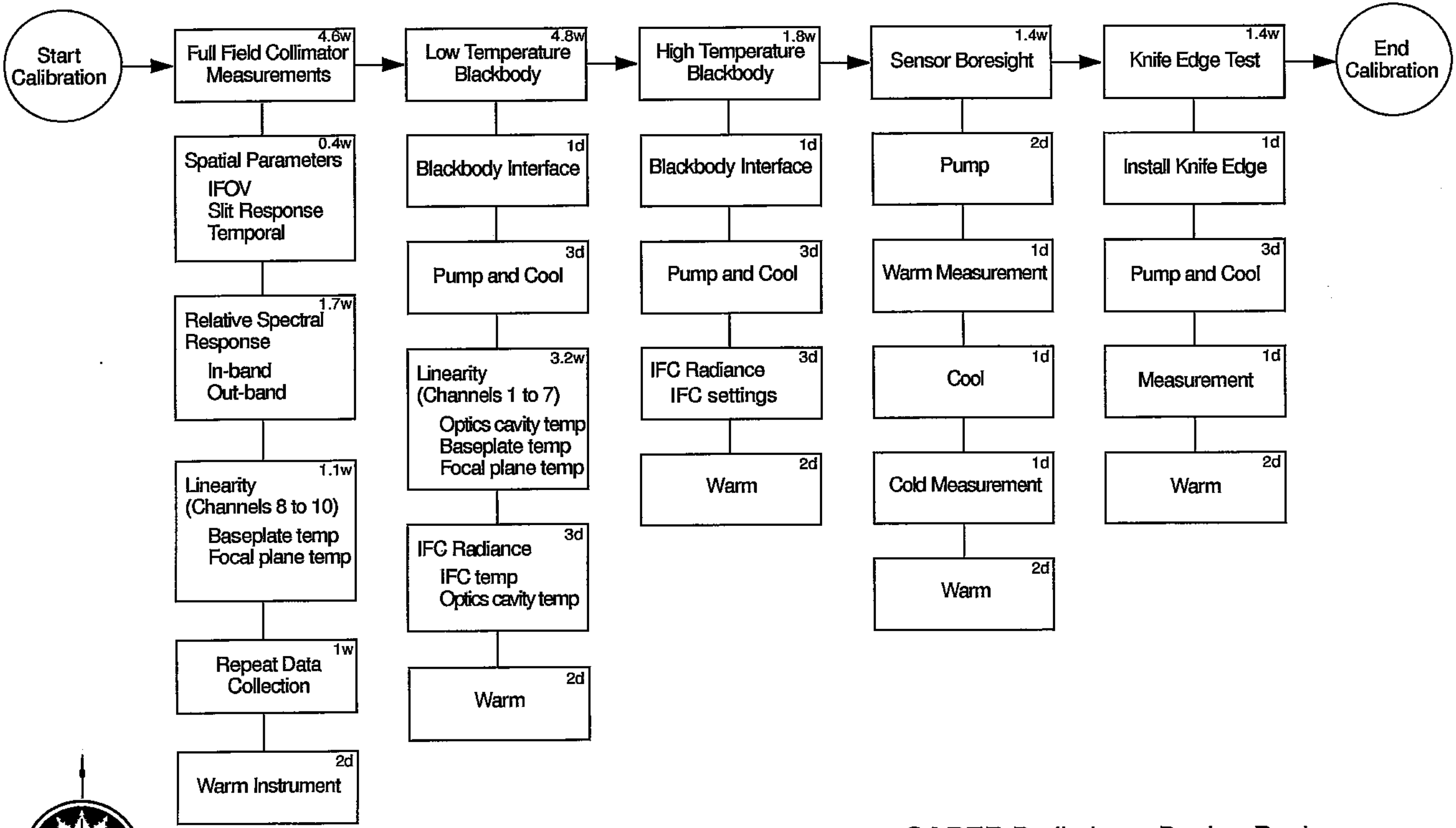
SABER Calibration Test Schedule

- Current schedule
  - 18 weeks for engineering pre-calibration testing
    - Instrument check-out
    - Mini engineering calibration (~10 weeks)
  - 14 weeks for calibration testing
    - Formal calibration
- Calibration schedule assumes full functional test with full field collimator before start of calibration testing

SABER Calibration Test Schedule



Start Calibration

- Full Field Collimator Measurements 4.6w
  - Spatial Parameters 0.4w
    - IFOV
    - Slit Response
    - Temporal
  - Relative Spectral Response 1.7w
    - In-band
    - Out-band
  - Linearity (Channels 8 to 10) 1.1w
    - Baseplate temp
    - Focal plane temp
  - Repeat Data Collection 1w
  - Warm Instrument 2d
- Low Temperature Blackbody 4.8w
  - Blackbody Interface 1d
  - Pump and Cool 3d
  - Linearity (Channels 1 to 7) 3.2w
    - Optics cavity temp
    - Baseplate temp
    - Focal plane temp
  - IFC Radiance 3d
    - IFC temp
    - Optics cavity temp
  - Warm 2d
- High Temperature Blackbody 1.8w
  - Blackbody Interface 1d
  - Pump and Cool 3d
  - IFC Radiance 3d
    - IFC settings
  - Warm 2d
- Sensor Boresight 1.4w
  - Pump 2d
  - Warm Measurement 1d
  - Cool 1d
  - Cold Measurement 1d
  - Warm 2d
- Knife Edge Test 1.4w
  - Install Knife Edge 1d
  - Pump and Cool 3d
  - Measurement 1d
  - Warm 2d

End Calibration

SABER INSTRUMENT CONTAMINATION CONTROL

James S. Dyer

December 10, 1996

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SABER CONTAMINATION CONTROL
Instrument Design and Fabrication

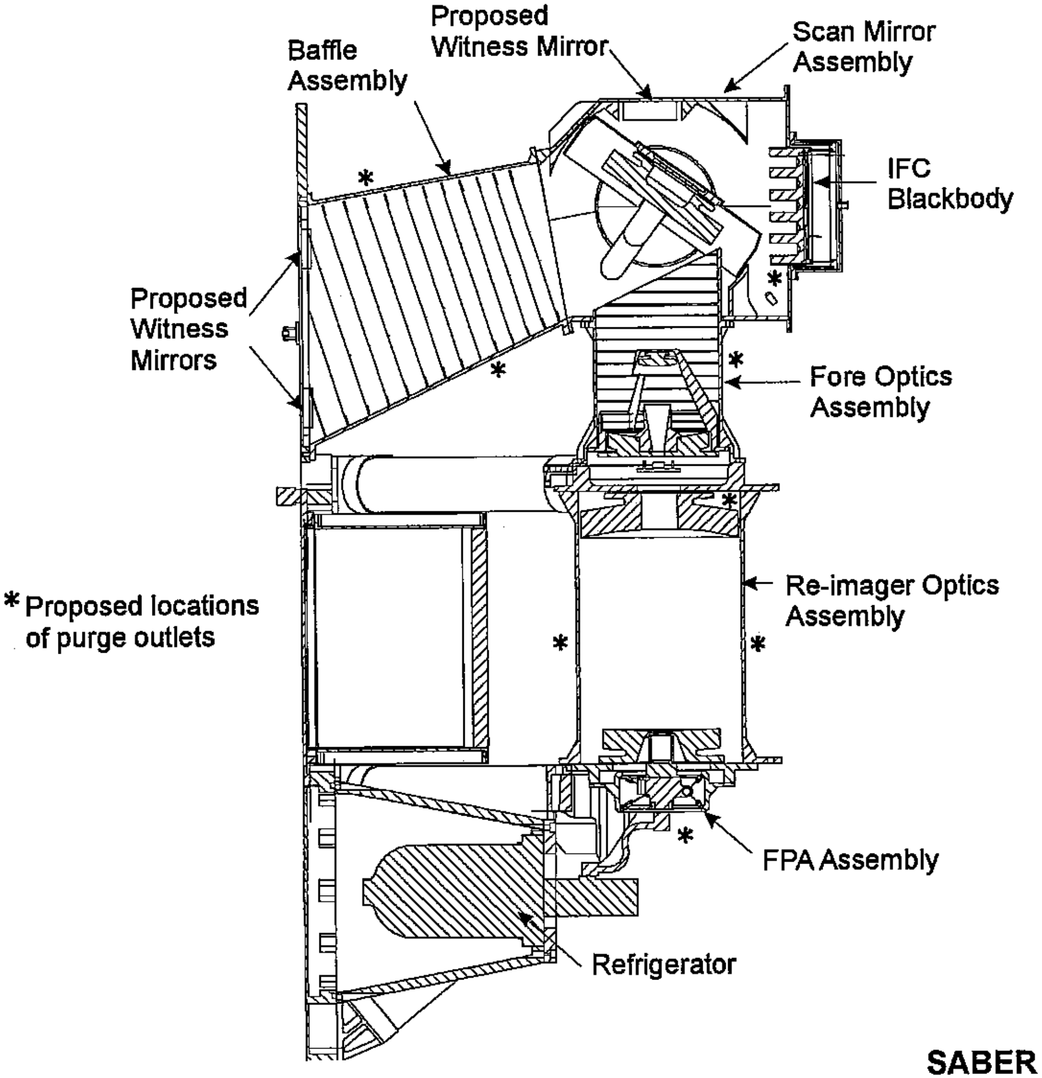
Mirror Cleanliness Requirements

- Stray light analyses indicates Level 200 (on-orbit) required for scan mirror and primary and secondary mirrors
  - Requirement based on goal of NRR $\leq 1\%$ total signal
  - Level 100 mirrors can be maintained during sensor development at SDL/USU
- BRDF will be tested prior to installation
- Propose to use witness mirrors to monitor mirror degradation
  - Witness mirror behind scan mirror will be "worst case" environment
  - Witness mirrors mounted on cover will monitor contamination of optical compartment
- Film deposition shall be less than 0.5 μ to avoid loss of IR reflectance or increase in BRDF
  - Water deposition not expected at 200 K
  - Organic films will be controlled by materials selection and vacuum bakeout

Optical Compartment Cleanliness Requirements

  - Strict process control and vacuum bakeout of painted parts
  - Level 300 or better for painted surfaces
  - Level 200 or better for metallic surfaces

SABER CONTAMINATION CONTROL
Witness Mirrors & Purge Outlet Locations



SABER CONTAMINATION CONTROL
MLI Outgassing

CONCERN: **Detector Assembly is an Isolated Cold Finger Surrounded by Outgassing Non-metallic Materials**

- Water is the predominant condensible outgassing species
- MLI is a significant source of water vapor that will readily condense on surfaces < 140 K
  - H_2O condensation on thermal link and focal plane ass'y increases heat load
  - H_2O condensation on cold surfaces changes emissivity (and increases heat load)
  - Codensatiion on window can cause IR tranmission loss
- Glassford, *et. al.* provide outgassing as f(t, T) for double-aluminized Mylar and Dacron net (Ref. JVST A, Vol.2, p.1370, (1984)
  - Pre-baking MLI at 335-340 K for 24 hr. can reduce long term outgassing rate (measured 1 week later) by > 1 order of magnitude.
- Operational Remedy: Effective bakeout of sensor should precede cold tests
  - Propose sensor bakeouts at 315-320 K for approx. 72 hrs
  - Bakeout efficiency can be quantitatively tested using QCMs in ASTM 1559 chamber
  - Real-time water deposition on window can be monitored using detector channels 8 & 9
  - Dry N_2 purge will be required to prevent reabsorption of water vapor when vented to atmospheric pressure

SABER CONTAMINATION CONTROL

Instrument Requirements

ELEMENT	CONTAMINATION GOALS	CONTAMINATION HAZARDS	DESIGN REMEDIES	OPERATIONAL REMEDIES
Mirrors	• Level 100 pre-launch • Level 200 on-orbit • < 0.5 µm of IR-absorbing films	• particulates and NVR • cryo deposits	• isolation from contamination sources • filtered purge of compartments • barriers to particulate migration	• wet-cleaning techniques prior to installation • BRDF prior to installation • sensor evacuation, bakeout, backfill, and purging procedures • witness mirrors • environmental control
Optical compartments	• Level 300 for painted surfaces • Level 200 for metallic surfaces • low outgassing	• redistribution of particulates to mirrors • organic films from non-metallics	• established painting, curing, and cleaning procedures • filtered purge of compartments • barriers to particulate migration	• pre-assembly cleaning • high temperature vacuum bakeout of painted parts • sensor evacuation, bakeout, backfill, and purging procedures • witness mirrors • environmental control
Focal plane assembly	• Level 100 internal • Level 200 Kevlar support • <0.1 % obscuration of detectors • < 0.5 µm of IR-absorbing films	• cryofrosts - especially H_2O condensation on window • particulates • thin films	• neon-filled sealed detector housing	• microscopic cleaning and inspection during focal plane buildup • TBD focal plane bakeouts • sensor evacuation, bakeout, backfill, and purging procedures • re-evaporate ice film from window by shutting off refrigerator, if necessary

SABER CONTAMINATION CONTROL
Instrument Requirements
(cont.)

ELEMENT	CONTAMINATION GOALS	CONTAMINATION HAZARDS	DESIGN REMEDIES	OPERATIONAL REMEDIES
Refrigerator assembly	• Level 300 • minimum water outgassing	• particulate migration onto window • water deposition on window • excess heat load by emissivity changes due to water condensation	• restricted path to detector window • optimized blanketing around cold link	• sensor evacuation, bakeout, backfill, and purging procedures • re-evaporate ice film by shutting off refrigerator, if necessary
Multilayer insulation	• visibly clean • minimum water outgassing	• primary source of water outgassing	• internal MLI purge manifold • hydrophobic outer "bag"	• sensor evacuation, bakeout, backfill, and purging procedures
Aperture cover	• Level 200 internal • Level 300 external pre-launch	• particulates	• easy cleanability • low contamination wax actuator	• pre-assembly cleaning • protective cover
Radiators	• Level 300 pre-launch • Level 750 on-orbit	• degradation of thermal properties by contamination	• thermal design can tolerate anticipated degradation	• pre-launch protective cover
Electronics and cables	• visibly clean • low outgassing	• outgassing source nearest sensor	• restricted path to detector window	• thermal-vacuum bakeout to reduce outgassing

SABER CONTAMINATION CONTROL

Requirements to Support Spacecraft Integration and Testing

Dry N_2 Purge Supply Required at All Facilities and Operations!

- **Prior to Spacecraft Integration:**
  - Class 10,000 environment requested to support preparation for functional test
  - Better than Class 10,000 requested to support door deployment test and post-shipping inspection of mirror cleanliness
- **During Spacecraft Integration:**
  - Class 10,000 environment during sensor installation
  - Spacecraft air conditioning should be Class 10,000
- **During Spacecraft Testing (After Instrument Integration)**
  - SABER optiics isolated from external contamination by continuous N_2 purge and internal HEPA air conditioning
  - Sensitive external surfaces (aperture cover and radiators) can be protected by bagging or removable covers
  - Environmental requirements can be relaxed to Class 100,000
  - Should maintain external spacecraft cleanliness ≤ Level 750

ALGORITHM DEVELOPMENT AND DATA PRODUCTS FOR THE *SABER* EXPERIMENT

MARTY MLYNCZAK
NASA LANGLEY RESEARCH CENTER

JIM RUSSELL
HAMPTON UNIVERSITY

SABER **PRELIMINARY DESIGN REVIEW**

DECEMBER 10-12, 1996
LOGAN, UTAH

OUTLINE

- Brief review of SABER measurement requirements
- Discuss SABER data products
- Algorithm development:

  Radiative transfer calculation in the non-LTE environment

  Geophysical information retrieval from SABER measurements
- Define necessary work (modeling, lab measurements) needed for SABER data analysis
- Summary

SABER MEASUREMENT REQUIREMENTS

The overarching TIMED goals are to quantify the thermal structure in the 60-180 km region and to understand the energy balance of this region

These two goals are tightly coupled because it is the energetics which determines the thermal structure

The TIMED region is also unique in that chemistry and the transport of chemical energy plays a crucial role in the energy/thermal balance

The SABER measurements are chosen to elucidate the thermal structure, key chemical components, and the energy balance by direct measurement of processes by which energy gain and loss can be determined

SABER MEASUREMENT REQUIREMENTS

Key energy gain and loss mechanisms:

Radiative/Chemical
- Solar heating (Ultraviolet, visible, near-ir)
- Infrared cooling (CO_2, NO, O_3, H_2O)
- Exothermic Chemical Reactions
- Airglow Energy Loss ($O_2(^1\Delta)$, $O_2(^1\Sigma)$, CO_2(4.3μm)
- Chemiluminescent emission (OH(υ))
- Particle precipitation (for $z > 100$ km)

Dynamical processes
- Turbulence
- Gravity Wave Breaking, etc.

The temperature and terms associated with Radiative/Chemical sources and sinks of energy are measurable

A goal of SABER is to quantify the thermal structure and the major radiative and chemical sources and sinks of energy, thus allowing the next effect of dynamics on the thermal structure to be inferred

SABER MEASUREMENTS

SABER Measurements	Geophysical Information
CO_2 (15 μm)	Temperature, Radiative Cooling
O_3(9.6 μm)	Ozone, Solar Heating, Radiative Cooling
H_2O (6.7 μm)	Water vapor, Radiative Cooling, Chemistry
NO (5.3 μm)	Radiative Cooling
CO_2(4.3 μm)	Dynamical tracer
OH(1.6 μm)	Chemical heating, chemistry, airglow loss
OH(2.0 μm)	Chemical heating, chemistry, airglow loss
O_2(1.27 μm)	Ozone, solar heating, airglow loss

These measurements enable a virtually complete description of solar heating, radiative cooling, chemical heating, and airglow losses in addition to the thermal structure

The dynamical tracers (CO_2, H_2O) provide additional information on dynamics

SABER DATA PRODUCTS

There are numerous data products that will be derived from the SABER measurements.

Two classes of data products, Routine and Analysis
Routine: Regularly produced
Analysis: Requires additional processing/work/modeling

SABER "Routine" Data Products

- KINETIC TEMPERATURE (T_K)
- OZONE (O_3)
- WATER VAPOR (H_2O)
- EXCITED STATE ABUNDANCES/Volume Emission Rates
  - $NO(\upsilon)$
  - $OH(\upsilon = 7, 8, 9)$
  - $OH(\upsilon = 3, 4, 5)$
  - $O_2(^1\Delta)$

SABER DATA PRODUCTS

"Analysis" Products

- Constituent Abundances:
  - CO_2 (100-160 km)
  - O (80-100 km)
  - H (80-100 km)

- Cooling Rates
  - CO_2(15 μm)
  - NO (5.3 μm)
  - O_3 (9.6 μm)
  - H_2O (6.7 μm and far-infrared)

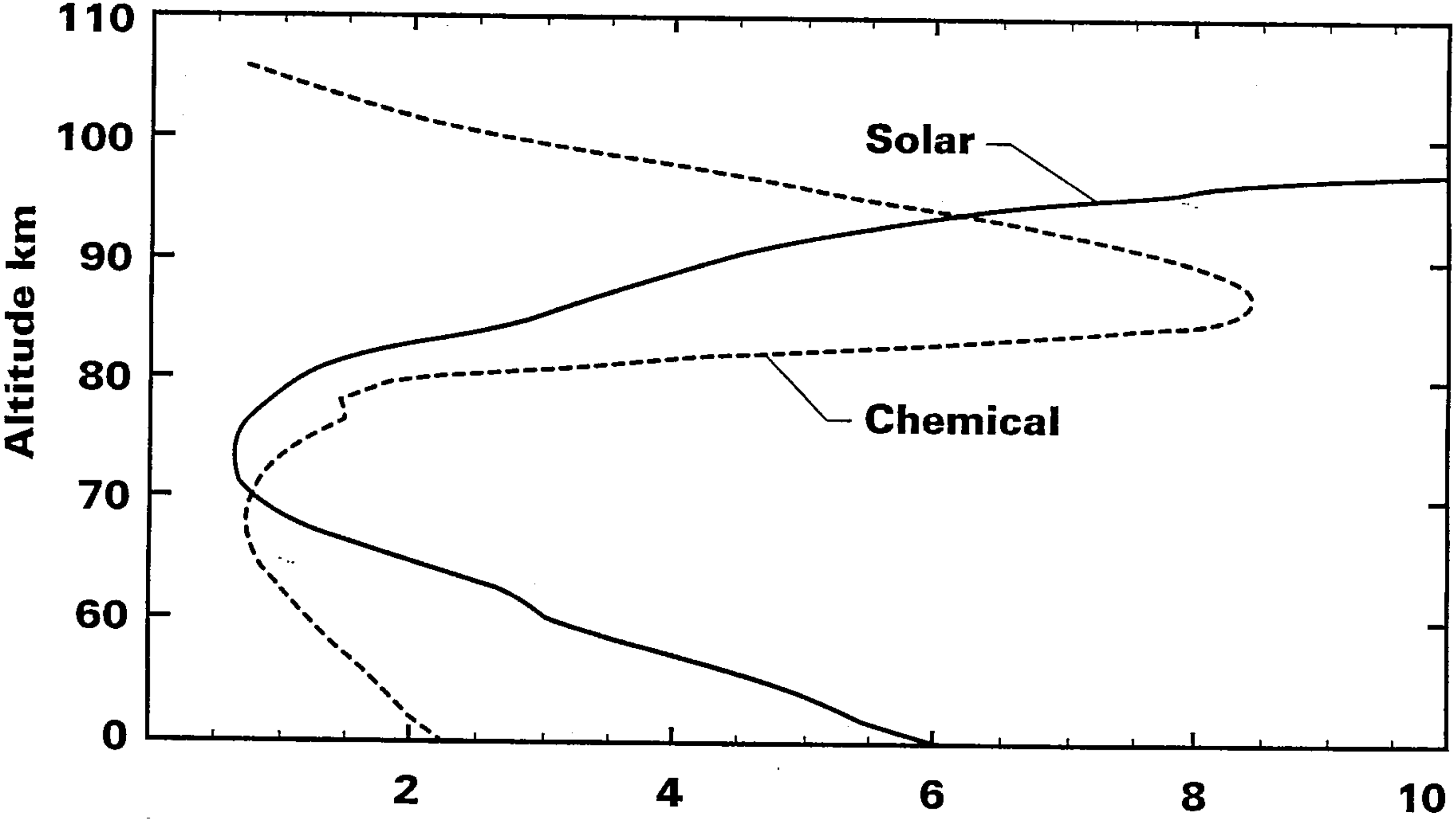
- Solar Heating Rates
  - O_3 (Hartley, Huggins, Chappuis, and other UV)
  - O_2 (Schumann-Runge, Ly-α, Herzberg, Atmospheric Bands)
  - CO_2 (near-ir)

SABER DATA PRODUCTS

"Analysis" Products (continued)

- Chemical Heating Rates
  - $H + O_3$ -> $OH + O_2$
  - $O + O + M$ -> $O_2 + M$
  - $O + O_2 + M$ -> $O_3 + M$
  - $O + OH$ -> $H + O_2$
  - $H + O_2 + M$ -> $HO_2 + M$
  - $O + O_3$ -> $O2 + O_2$
  - $OH + O_2$ -> $HO_2 + O$
- Airglow/Chemiluminescent Emission/Heating Efficiencies
  - $O_2(^1\Delta)$ (Hartley band solar heating)
  - $OH(\upsilon = 7,8,9)$
  - $OH(\upsilon = 3, 4, 5)$

Daily average heating



Heating Rate K/Day

(after Mlynczak and Solomon, 1993)

Example of a SABER Analysis Product

Thermospheric cooling by NO(υ) emission:

NO emission at 5.3 μm is thought to be the single largest radiative cooling mechanism in the thermosphere (125-200 km)

SABER measurements of NO limb emission, when inverted, give the total of energy loss per unit volume per unit time from NO

NO must be produced in an excited state in order to radiate

Many processes can result in NO excitation

- Excitation by collisions with atomic oxygen
- Excitation by absorption of upwelling radiation
- Excitation by chemical reaction

The NO molecule, once excited, will radiate independently of excitation process, resulting in a removal of energy from the atmosphere

However, only the energy associated with collisional excitation results in a true cooling (i.e., a change in the local kinetic temperature)

Example of a SABER Analysis Product

In order to derive the cooling rate from the SABER measurements of energy loss, additional modeling must be employed to enable estimation of the non-collisional excitation processes

In addition, since the cooling rate is proportional to the energy loss rate divided by the density, a value of the density must be provided

SABER won't measure density in the thermosphere, so this must be provided by a model calculation

Furthermore, the cooling rate (K/day) depends on the heat capacity, which is a function of composition, requiring additional model calculations of thermosphere composition (O, N, N_2, O_2 etc)

The additional information needed to derive NO cooling can not be done in a 'routine' processing manner -- it will require intense study and iterations with the TIME-GCM model

SABER Algorithm Development

Virtually all of the SABER measurements in the TIMED core region (60-180 km) are of non-LTE radiative emission

The pertinent radiative transfer equation for SABER limb viewing is

$$R = \int_{\nu_1}^{\nu_2} \int_{x} J_{\nu}(x)\, \partial\tau_{\nu}(x)\, d\nu$$

Where J is the source function and $\partial\tau$ is the transmittance gradient

Under LTE J is identical to the Planck Blackbody Function evaluated at the local kinetic temperature

Under LTE, lower state populations are described by the Boltzmann distribution at the local kinetic temperature

Under conditions of non-LTE, neither of these statements is true

ALGORITHM DEVELOPMENT

There are 2 challenges to the interpretation of SABER data:

1. Be able to calculate rapidly and accurately the limb radiance for a specified non-LTE condition

2. Understanding the physical and chemical processes which result in the non-LTE energy level populations in the SABER-observed emissions and accurately modeling them

SABER Algorithm Development

Radiative transfer calculation in non-LTE environment:

Calculations must be rapid and extremely accurate (0.5% or better)

Approach:

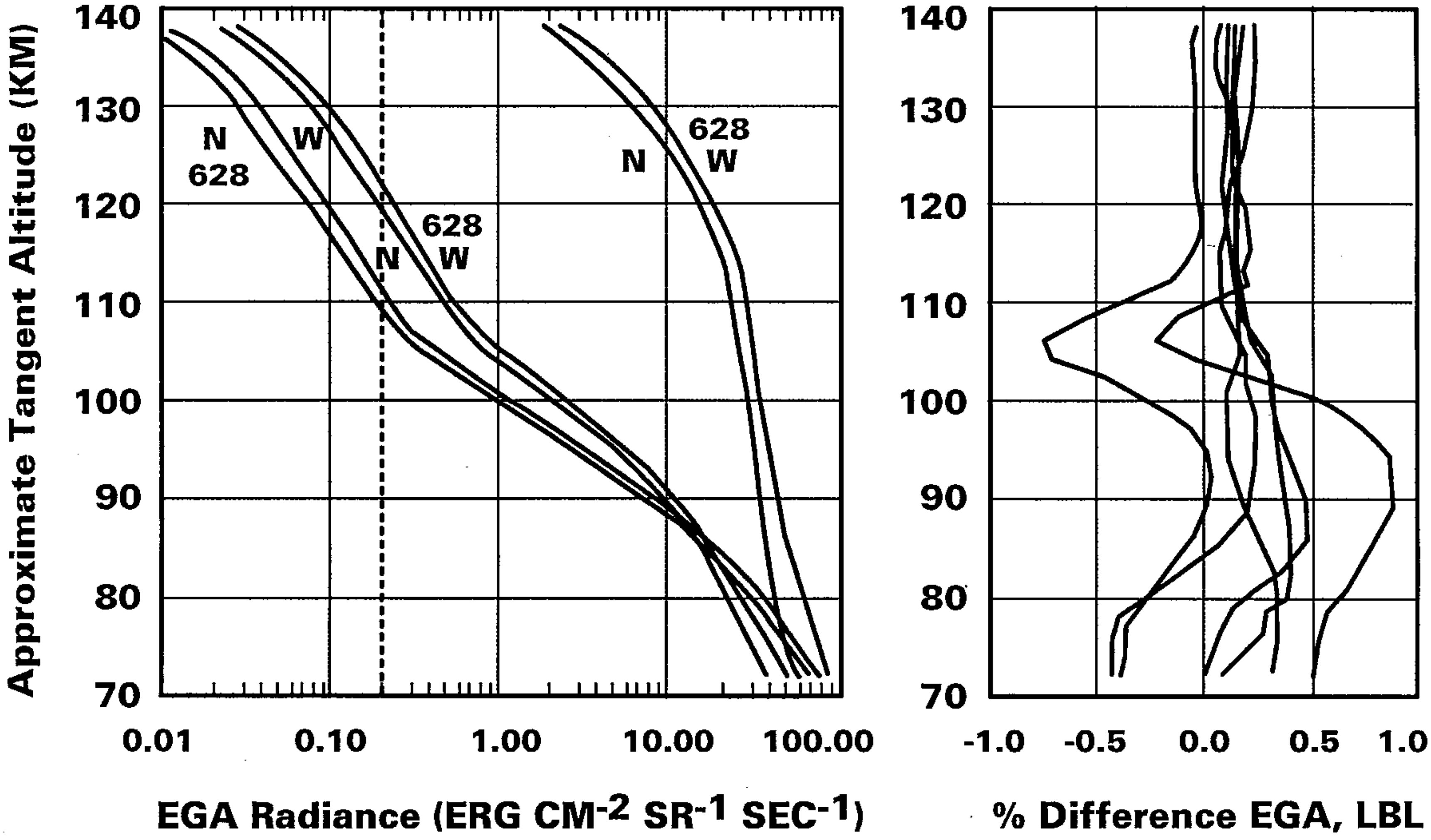
Extend the Emissivity Growth Approximation (Gordley and Russell) developed for LTE conditions (e.g., LIMS) to handle non-LTE

Involves adjusting lower-state populations in the calculation of transmittances for non-LTE populations

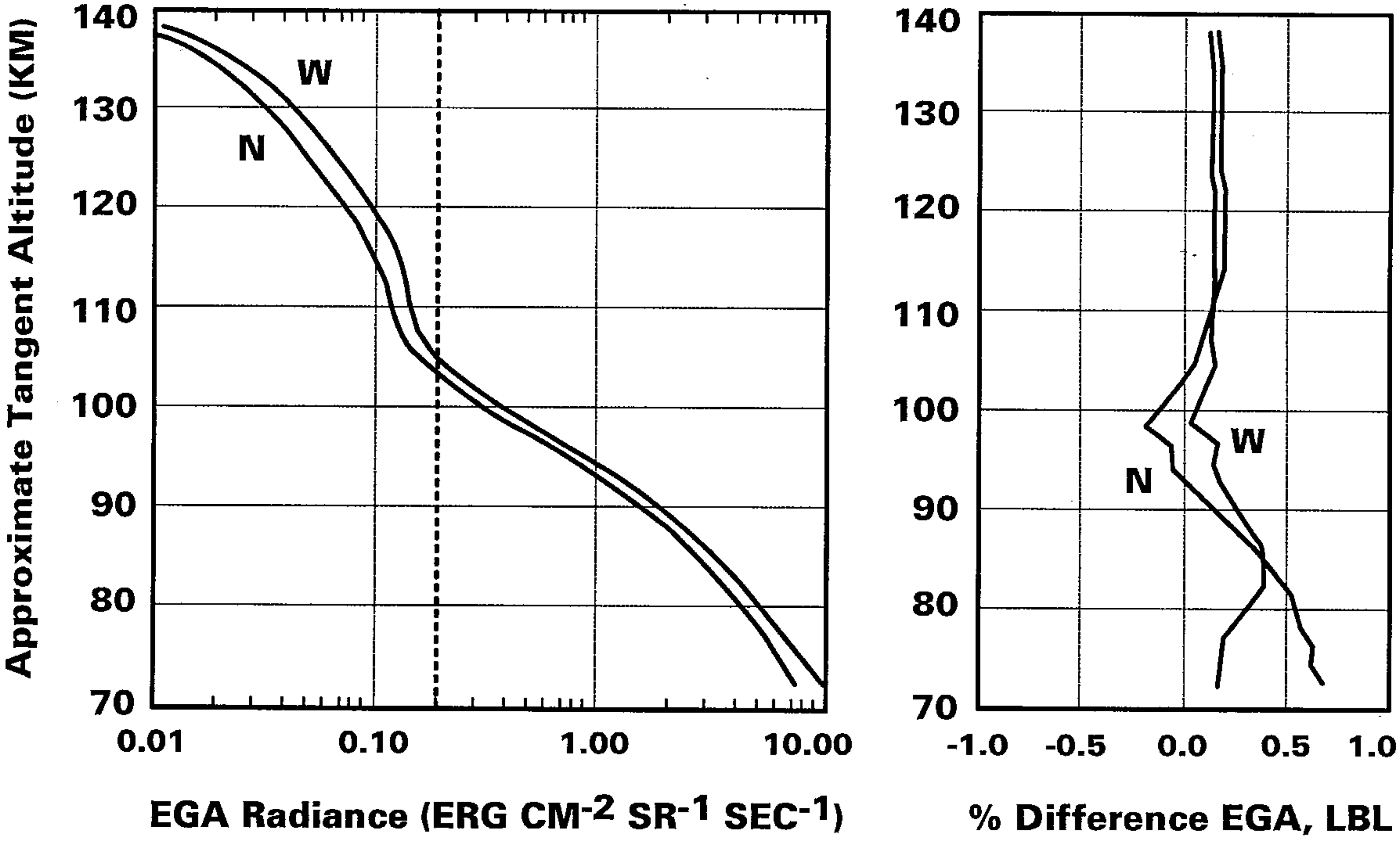
Adjustment/Correction depends on degree of departure from LTE, but is independent of wavelength for a given band/transition

Technique now developed and demonstrated for all SABER channels (Mlynczak et al., JGR, 1994)

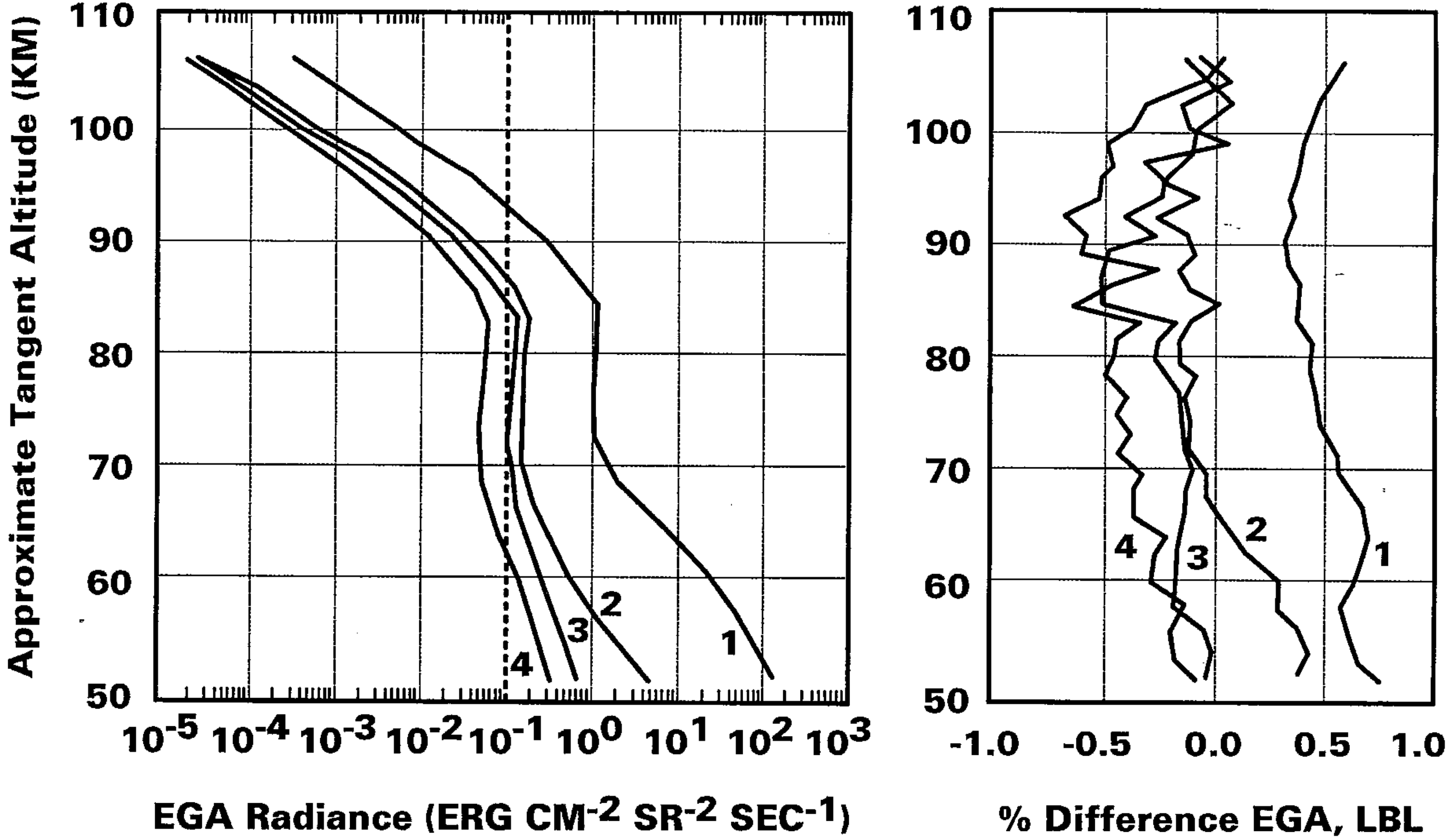
CO_2 (01101-->00001), Day



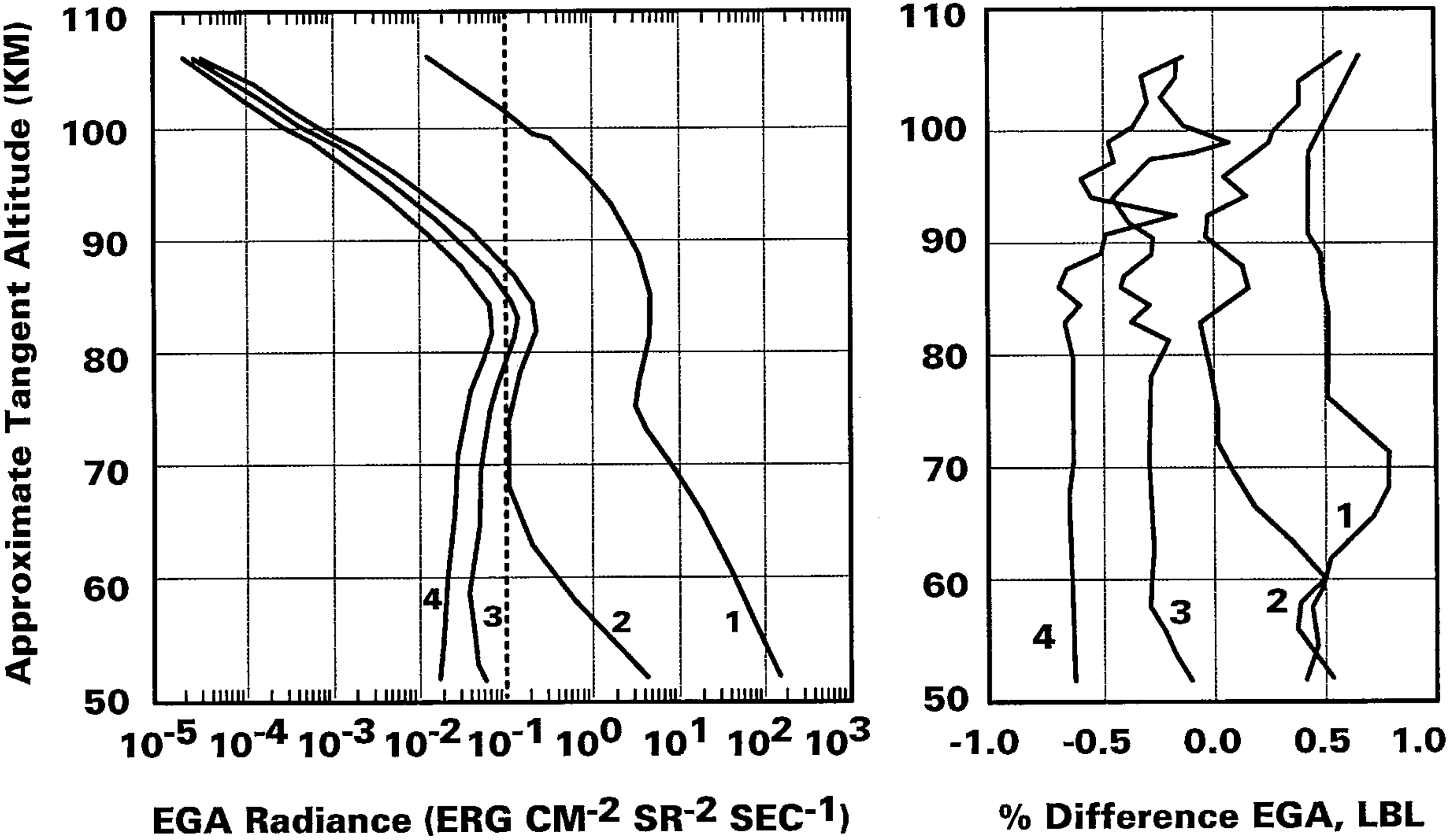
CO_2 (02201-->01101), Day



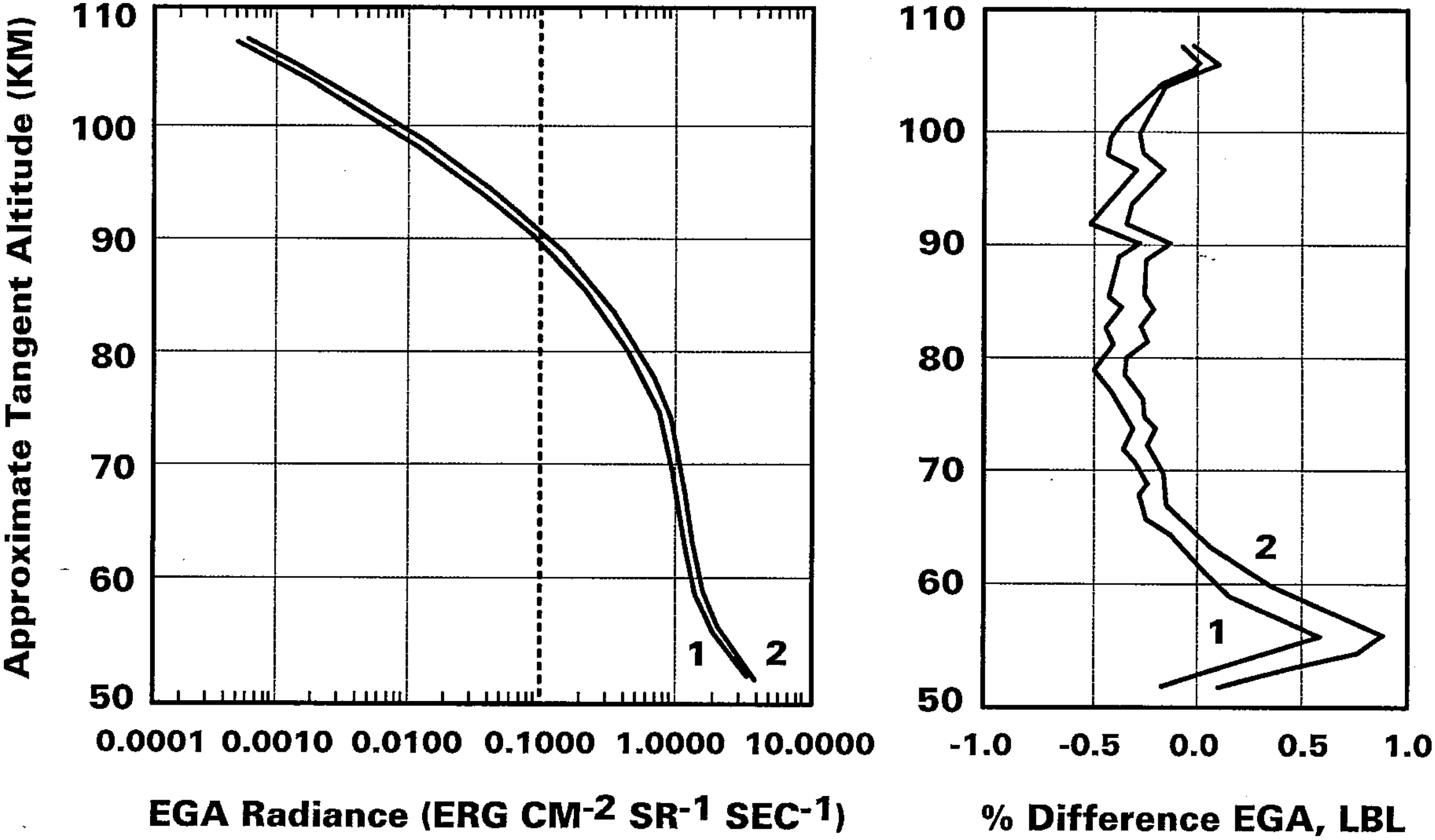
Ozone Day, 925-1141 CM^{-1}



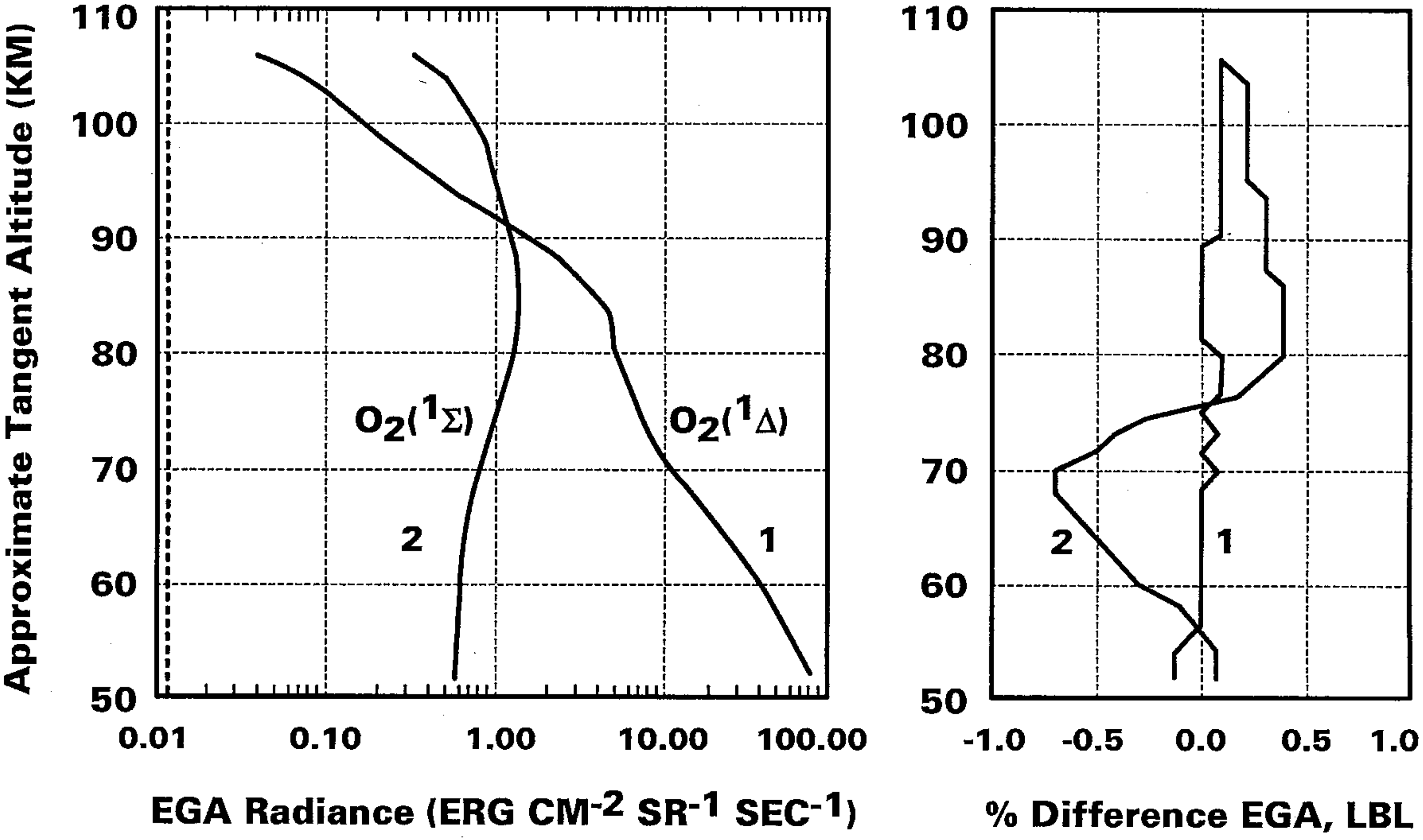
Ozone Night, 925-1141 CM^{-1}



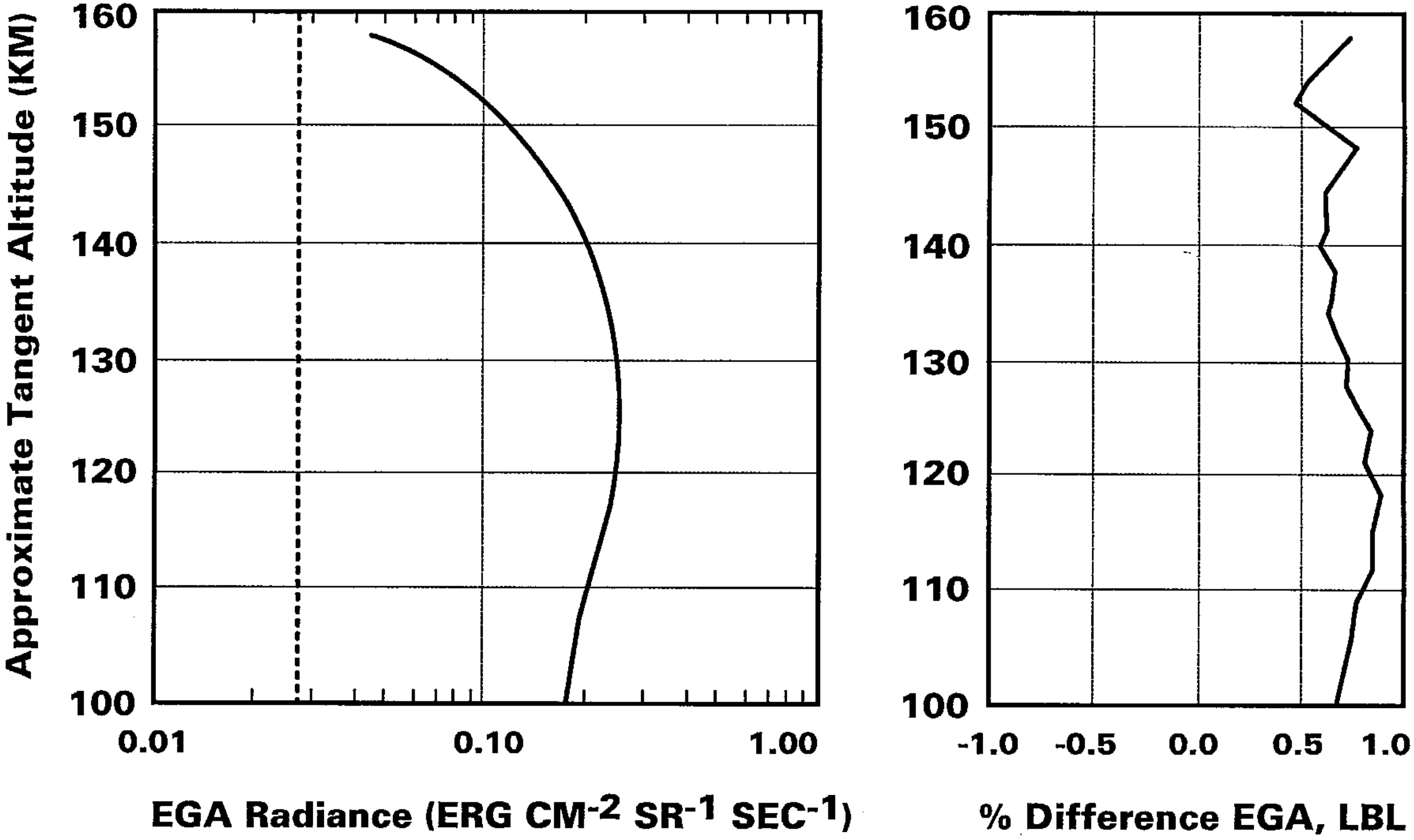
Carbon Dioxide Day, 925-1141 CM^{-1}



Molecular Oxygen Dayglow



Nitric Oxide (NO) Day, 1775-1925 CM^{-1}



C-29

SABER Algorithm Development

The key to deriving SABER data products (Routine or Analysis) will be having comprehensive models of the radiative, chemical, and collisional processes by which the observed molecules exchange energy with their surroundings

The models describe the population of various excited states of a given molecule by explicitly accounting for all known energy gains and losses

The resulting populations, are different than expected based solely on the ambient kinetic temperature

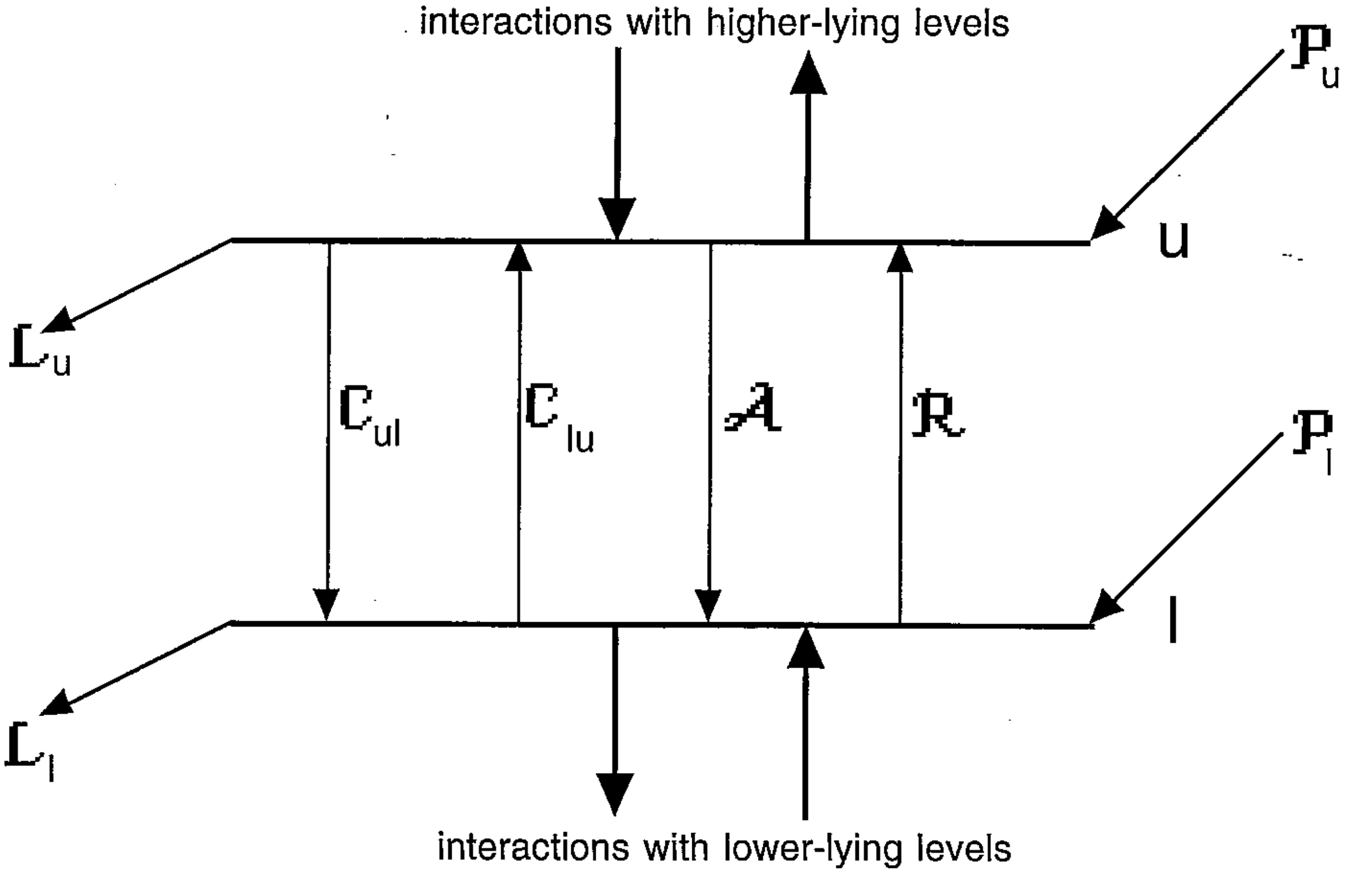
The models provide source functions and transmittance corrections for use in inverting the radiative transfer equation to derive T, O3, etc.

These “non-LTE models” are non-trivial to develop and implement

Members of the SABER science team possess comprehensive, peer-reviewed “non-LTE” models for each SABER-observed molecule

The main C/D task in algorithm development is to develop algorithms for deriving geophysical information (T, O3, etc) by applying these models

EXCITATION AND QUENCHING PROCESSES



Collisional excitation	$\mathfrak{C}_{ul}$	*Collisional quenching*	$\mathfrak{C}_{lu}$
Radiative absorption	$\mathfrak{R}$	*Spontaneous emission*	$\mathfrak{A}$
Chemical pumping	$\mathfrak{P}_i$	*Chemical reaction*	$\mathfrak{L}_i$

SCAN 10

SABER Algorithm Development

Derivation of Geophysical Information from SABER:

General Flow (Example of O_3 at 9.6 μm):

1 Non-LTE Model Calculation of Vibrational Temperatures

2 "First Guess" of Ozone abundance

3 Limb Emission Radiative Transfer Calculation

4 Agreement with Measured Radiance?

5 Adjust ozone concentration

6 Go to step 3 until convergence

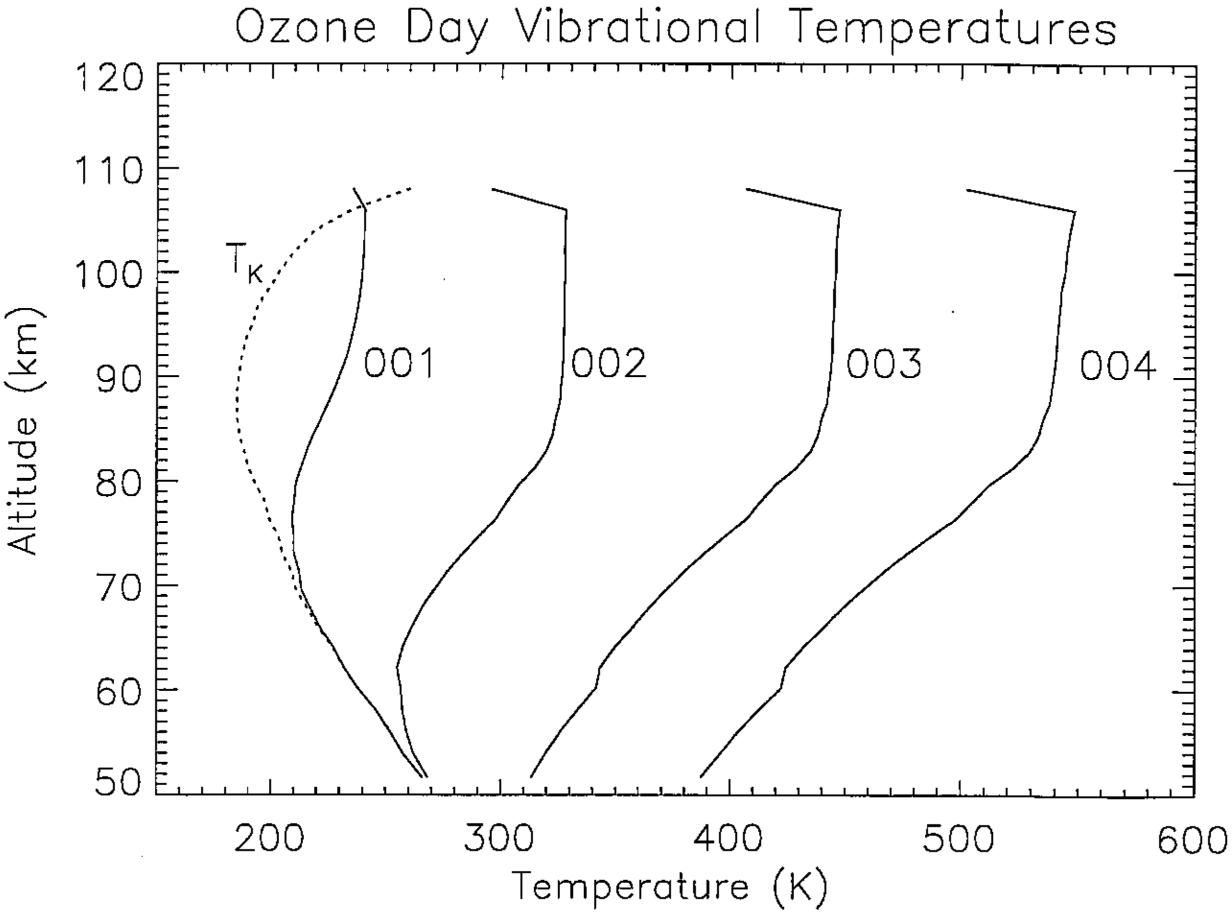
7 Calculate Tvib (Step 1) and compare with original

8 Iterate with new Tvib as necessary

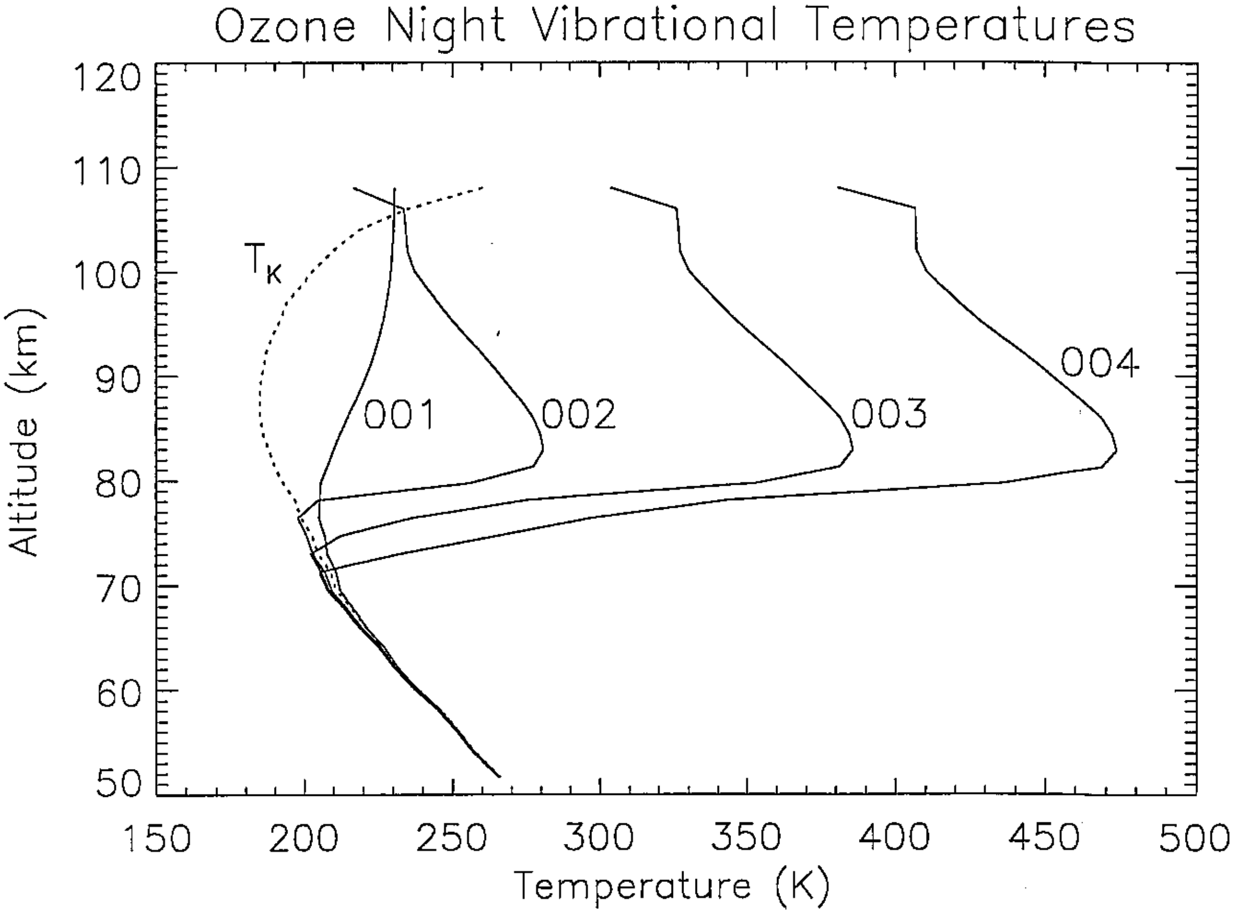
SABER Non-LTE MODEL STATUS

SABER Channel	Geophysical Data	Model
CO_2 (15 μm)	T_K, cooling rate	Lopez-Puertas et al., QJRMS, 1992
Ozone (9.6 μm)	O_3, solar heating, ir cool	Mlynczak and Drayson, JGR, 1990
H_2O (6.7 μm)	H_2O, cooling rate	Lopez-Puertas et al., JGR, 1995
NO(5.3 μm)	NO(υ), cooling rate	Picard et al. (numerous JGR)
CO_2 (4.3 μm)	CO_2 abundance	Lopez-Puertas et al., JGR, 1989
OH (1.6 μm)	H, chemical heating	Mlynczak and Solomon, JGR 1993, 1991
OH (2.0 μm)	H, chemical heating	Mlynczak and Solomon, JGR, 1993, 1991
$O_2(^1\Delta)$ (1.27 μm)	O_3, O, energy loss	Mlynczak et al. , JGR, 1991, 1993

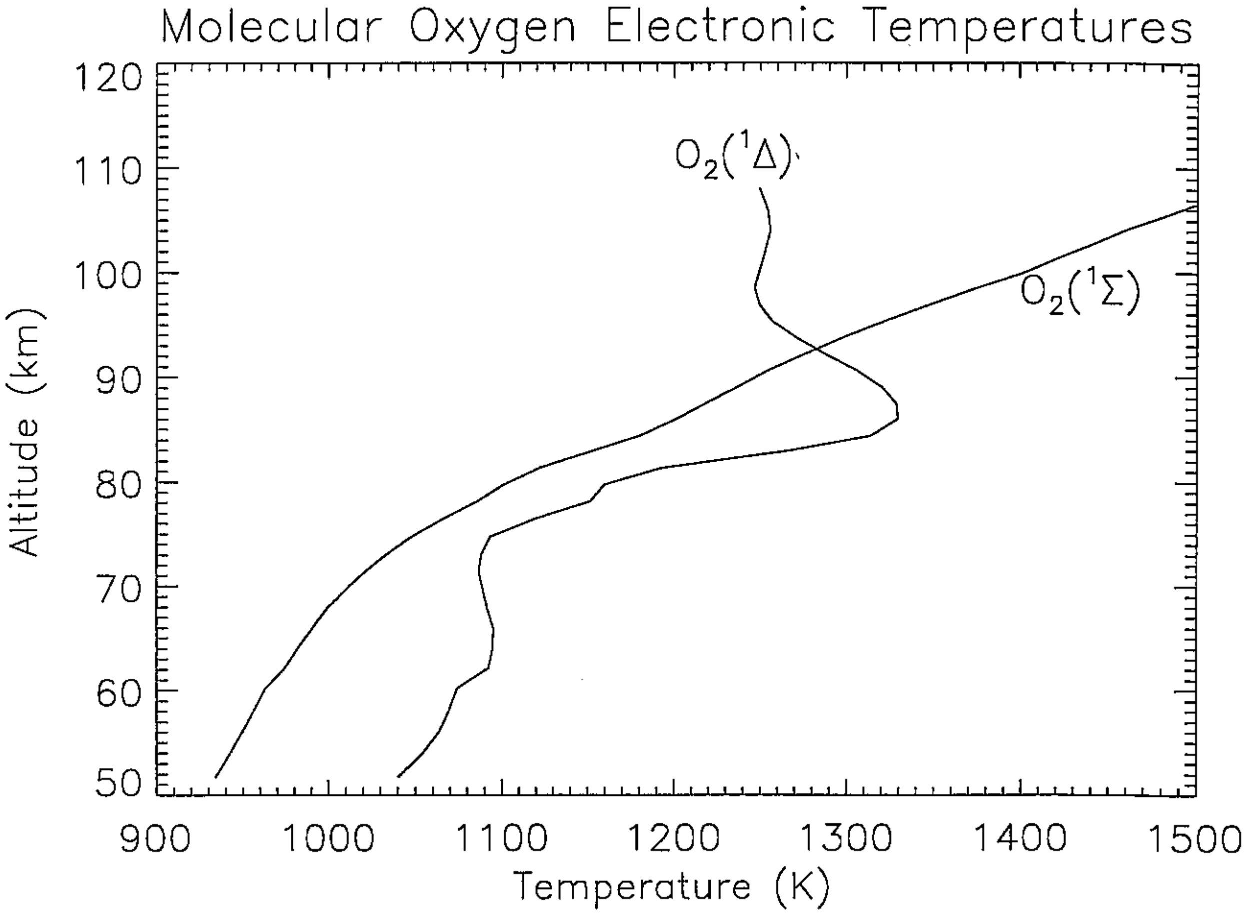
JGR = Journal of Geophysical Research
QJRMS = Quarterly Journal of the Royal Meteorological Society



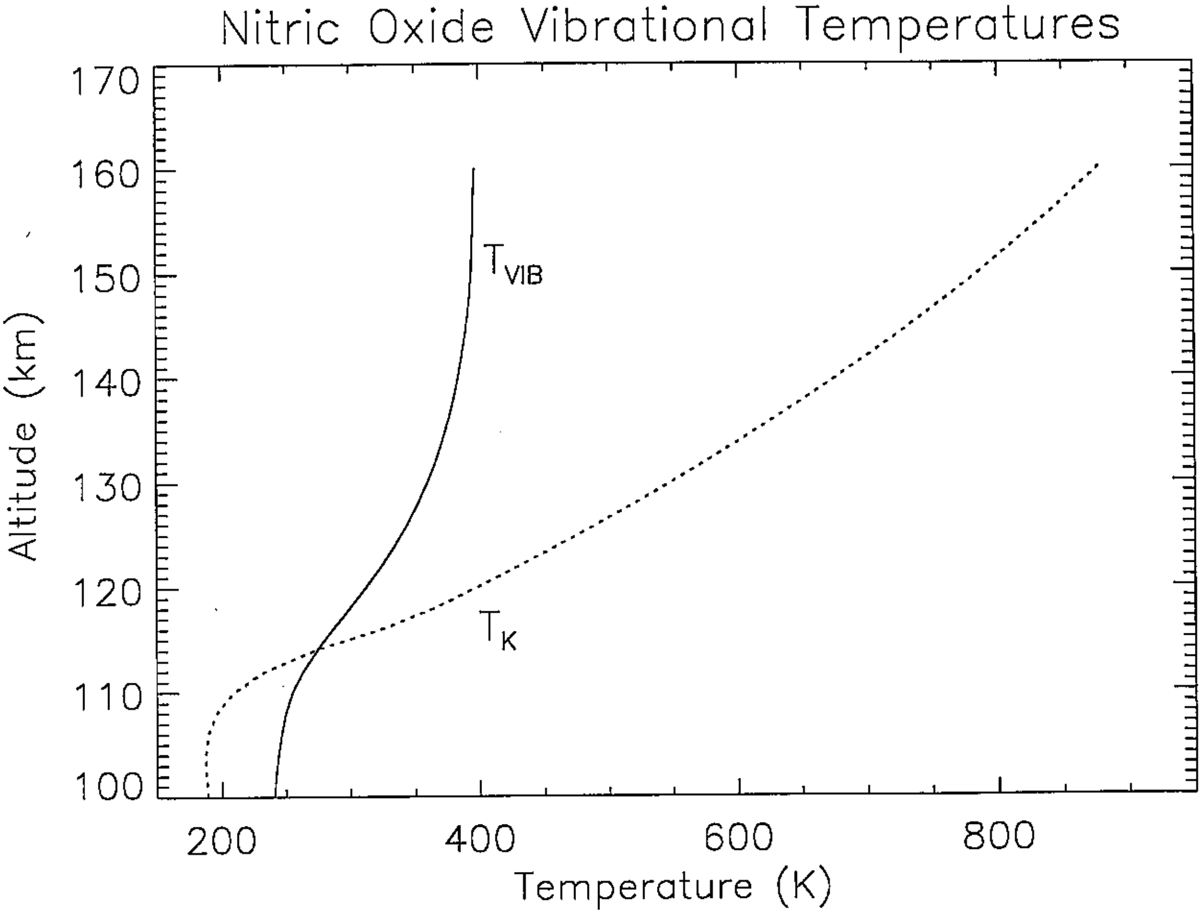
After Mlynczak et al., 1994



After Mlynczak et al., 1994

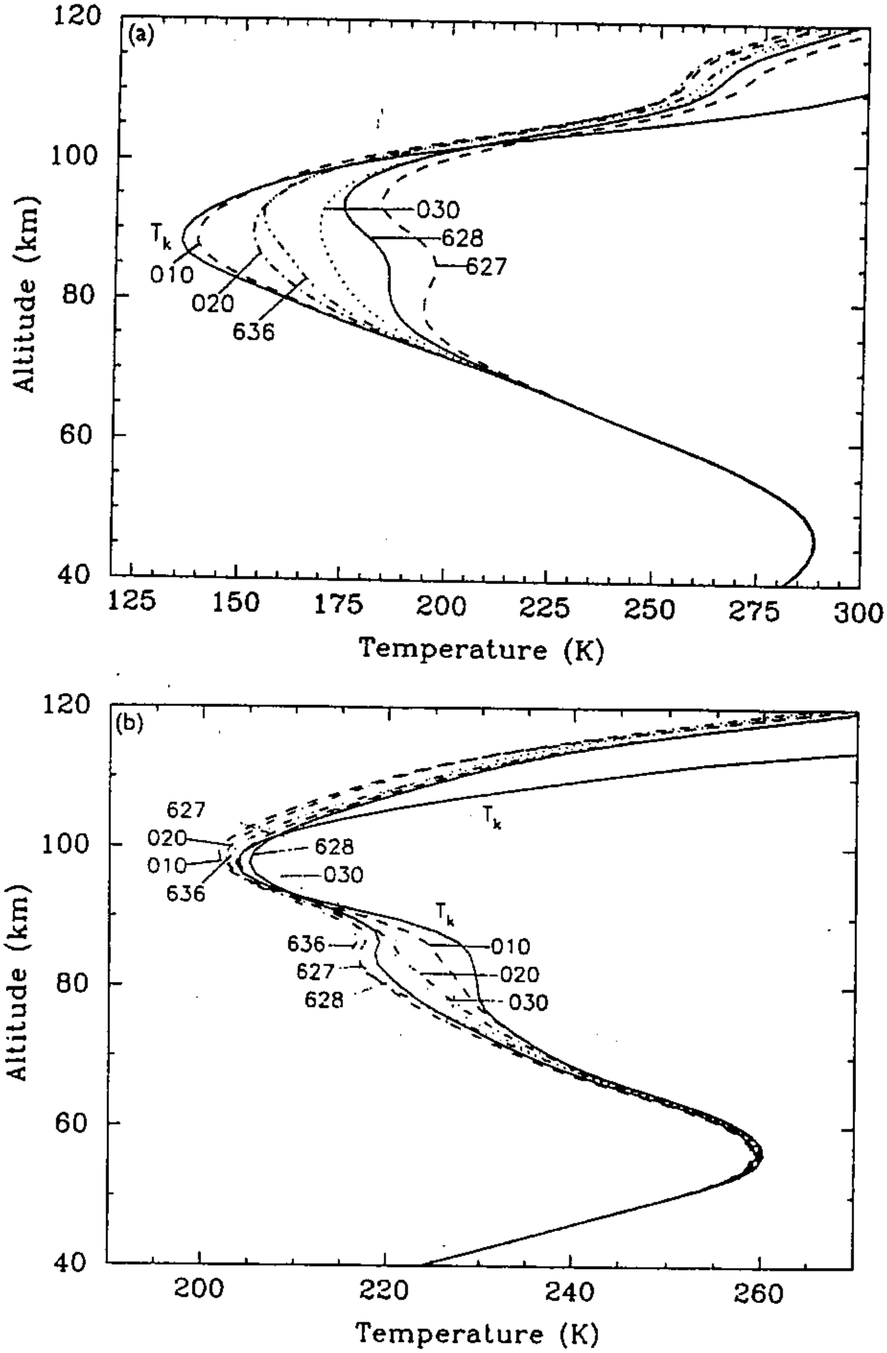


After Mlynczak et al., 1994



After Mlynczak et al., 1994

CO_2 Vibrational Temperatures



After Lopez-Puertas et al., 1992

SABER DATA ANALYSIS -- ADDITIONAL NEEDS

Non-LTE models require a priori specification of numerous parameters (e.g., Einstein coefficients for spontaneous emission, collisional quenching rates, etc.) for calculating vibrational temperatures supplied to the temperature and constituent processes

Uncertainties in these "rate constants", which are often supplied from laboratory measurement, degrade the accuracy of the SABER derived products

We are undertaking, species by species, an analysis and sensitivity study of the key parameters in each non-LTE model.

The purpose is to recommend, in formal publications, the accuracy to which the key rates must be known to achieved the desired accuracies of the SABER measurements

An example has already been published for the $O_2(^1\Delta)$ channel
[Mlynczak and Olander, GRL, 1995]

Preliminary results for the O_3 9.6 μm channel are being presented next week at a special Session of the American Geophysical Union [Mlynczak et. al, 1996]

SABER ALGORITHMS: SUMMARY

SABER measurements and data products are sufficient to meet TIMED goals of thermal structure and energy balance

Limb radiative transfer calculation approaches/techniques for non-LTE are developed

Non-LTE/Statistical Equilibrium Models exist for all SABER channels

All transfer calculation approaches (Non-LTE EGA, and Line-by-Line) and Non-LTE models have been published in the peer-reviewed literature

We are in the process of a formal error analysis of SABER measurements to identify areas of improvements in key kinetic and spectroscopic rate coefficients used in non-LTE models

Application of the existing calculation techniques and non-LTE models into formal temperature and constituent retrieval algorithms is now underway and will constitute the major ‘science’ effort during Phase C/D.

SOFTWARE DEVELOPMENT PLAN

Larry Gordley

GATS Inc.
28 Research Drive
Hampton, VA 23666
(757) 865-7491

December 1996

GATS Software Development Plan

Major Tasks

Personnel and Responsibilities

Hardware and Software Environments

Quality Assurance and Methodology

Schedule

GATS Software Development Task

Processing Phase	Major Functions	Code Source
POC System Development	RT data aquisistion POC GUI Command Scripts	New/SAGE III
Level 0	Display	HALOE, SAGE III
	Data Formatting	SAGE III
	Ingest	New
Test & Calibration	GSE Data Management	New
	Data Analysis	New/LIMS
Level 1a	Reformatting	SAGE III
	Trending Tools	HALOE
	Auxiliary Access & Merge	New

Software Development Tasks

Processing Phase	Major Functions	Code Source
Level 1b		
	Calibration	LIMS
	Conditioning	
	Bad data filtering	New
	FOV	LIMS
	Profile alignment	LIMS
	Spacecraft motion	New/LIMS
	Off-axis scattering	New
	Time delay	LIMS
	Data averaging	New
	Boresight correction	New
	Earth oblateness	LIMS
	Special Calibration	
	Lunar	New
	Roll-up	New
	IFC T change	New

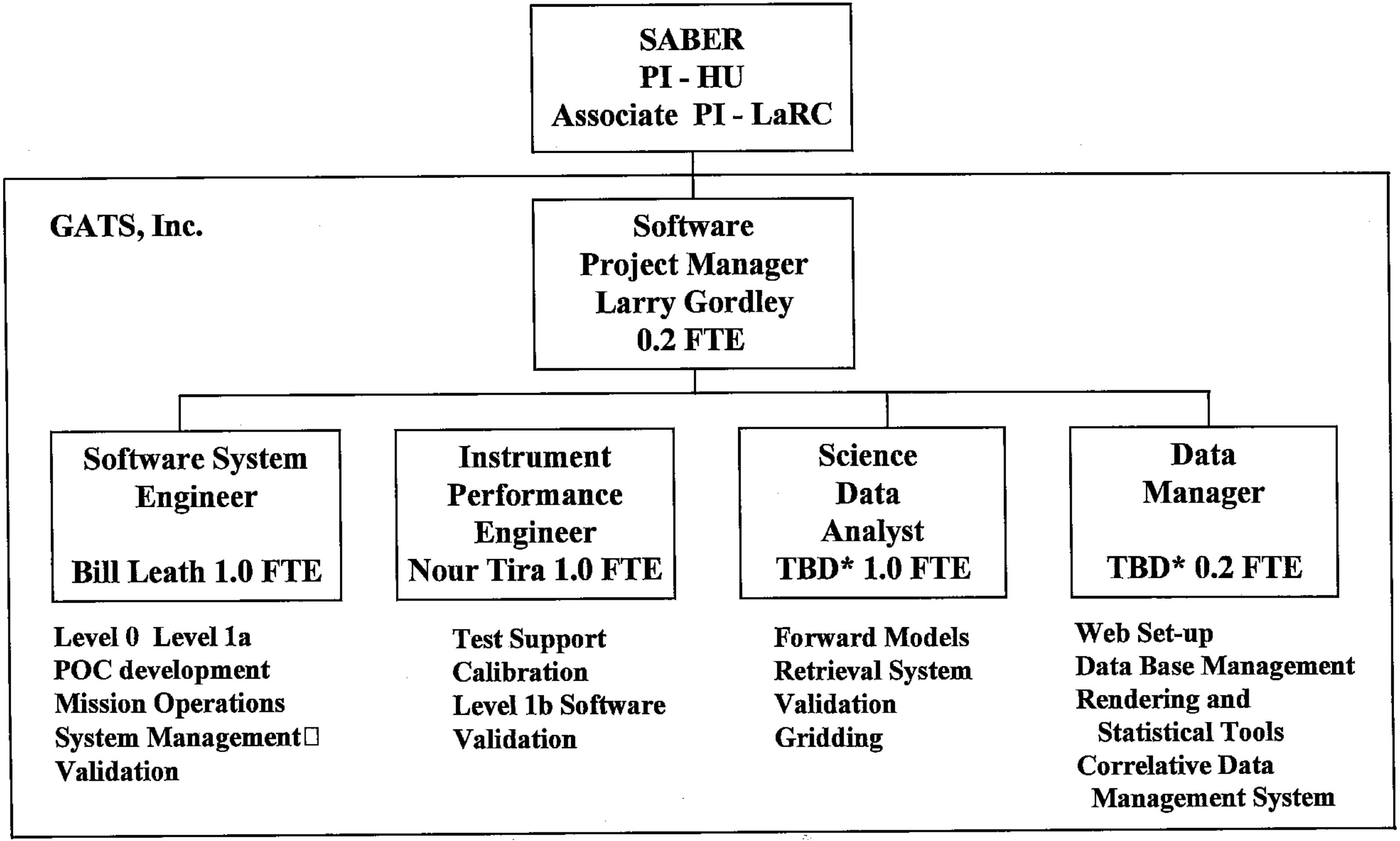
Software Development Tasks

Processing Phase	Major Functions	Code Source
Level 2a Processing (routine products)		
	Forward model	BANDPAK
	Volume emission rate inferrals	LIMS
	LTE parameters retrievals	LIMS
	Non-LTE parameters retrievals	New
Level 2b Processing (analysis products)		
	Forward model	BANDPAK
	Cooling rates	New
	Non-LTE retrievals requiring auxiliary models	New
	Heating rates	New

Software Development Tasks

Processing Phase	Major Functions	Code Source
Level 3 Processing - Gridding		
	Will be major changes for some products due to diurnal characteristics	LIMS/New
Validation		
	Rendering software	HALOE
	Data base management	HALOE
	Correlative data management	HALOE
	Statistical analyses	HALOE
Access-Web Based		
	Data ingest and access	HALOE
	Project information data base	HALOE/SABER
	Image generation	HALOE

• SOFTWARE DEVELOPMENT ORGANIZATION



SABER
PI - HU
Associate PI - LaRC

GATS, Inc.

Software
Project Manager
Larry Gordley
0.2 FTE

Software System Engineer

Bill Leath 1.0 FTE

- Level 0 Level 1a
- POC development
- Mission Operations
- System Management□
- Validation

Instrument Performance Engineer
Nour Tira 1.0 FTE

- Test Support
- Calibration
- Level 1b Software
- Validation

Science Data Analyst
TBD* 1.0 FTE

- Forward Models
- Retrieval System
- Validation
- Gridding

Data Manager

TBD* 0.2 FTE

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

*	Experienced personnel available but not yet assigned
FTE	Full Time Equivalent

Hardware & Software Environment

Hardware

Local networked PC's

Magnetic disk plus optical storage

T1 internet connection is sufficient for data transfer

Printers - Color and black & white

Notes:

- Storage is minimal by todays standards
- GATS, Inc. rates include desktop computer facilities for employees. No further computational resource is necessary for routine processing (through level 2a plus level 3). Computational requirements for level 2b (analysis products) is still TBD.
- A storage system for local archive of all products, and the necessary computational resources for all processing, will be established at LaRC.
- Level 2b phase E processing facilities requirements are still TBD and these will be defined in phase C/D.

Software

NT environment for POC

UNIX environment for science

C, FORTRAN, JAVA/JAVASCRIPT, IDL (Interactive Data Language), WebServer, CVS (configuration control package), POSTGRESS (data base management package), S^3 (a GATS structured system module controller)

Note:

- C, FORTRAN, IDL and server software must be purchased.

Quality Assurance

- Are striving to follow ISO 9000 guidelines - the 20 standards
- Have developed a system that is consistent with the team size and cost constraints, but yet achieves the characteristics of
    - Documented
    - Controlled
    - Auditable
    - Monitored
    - Improved
    - Effective
- Attributes
    - Efficient
    - Automated
    - Neatly integrated into development methodology
    - Sufficient
- Currently documenting the system
- Company Quality Assurance Officer - Mr. Earl Thompson

- Methodology Includes
  1. Documented and controlled requirements
  2. System level design reviews
  3. Detailed design reviews
  4. Structured and modular coding methods and tools
  5. A configuration control system for code, documents and test cases
  6. Documented and reviewed testing at both unit (module) and system level
  7. Data quality monitoring
  8. Code documentation which includes purpose, a user guide, structure charts, input and output descriptions

Requirements

Requirements will be documented and put under the CVS (Concurrent Version System) version control software package. These documents will be kept online and accessible over the Web by project personnel. The close working relationship with the science team insures that requirements will be reliably communicated in a timely fashion.

System Design Reviews

Design reviews include a system description and purpose, functional and data flow diagrams, and function and data description. At the hardware level, it will also include hardware requirements and suggested components. For a system of software modules, it will include structure charts and module purpose, inputs and outputs. Design review dates and document references will be logged into the subject software prologues.

Detailed Design Reviews

Detailed design reviews will be conducted for critical module or system interfaces. Reviews for independent modules will be held on an as needed basis. For small tasks, detailed review, test review and certification will be combined in one review. All detailed design reviews will be logged in the subject code prologues.

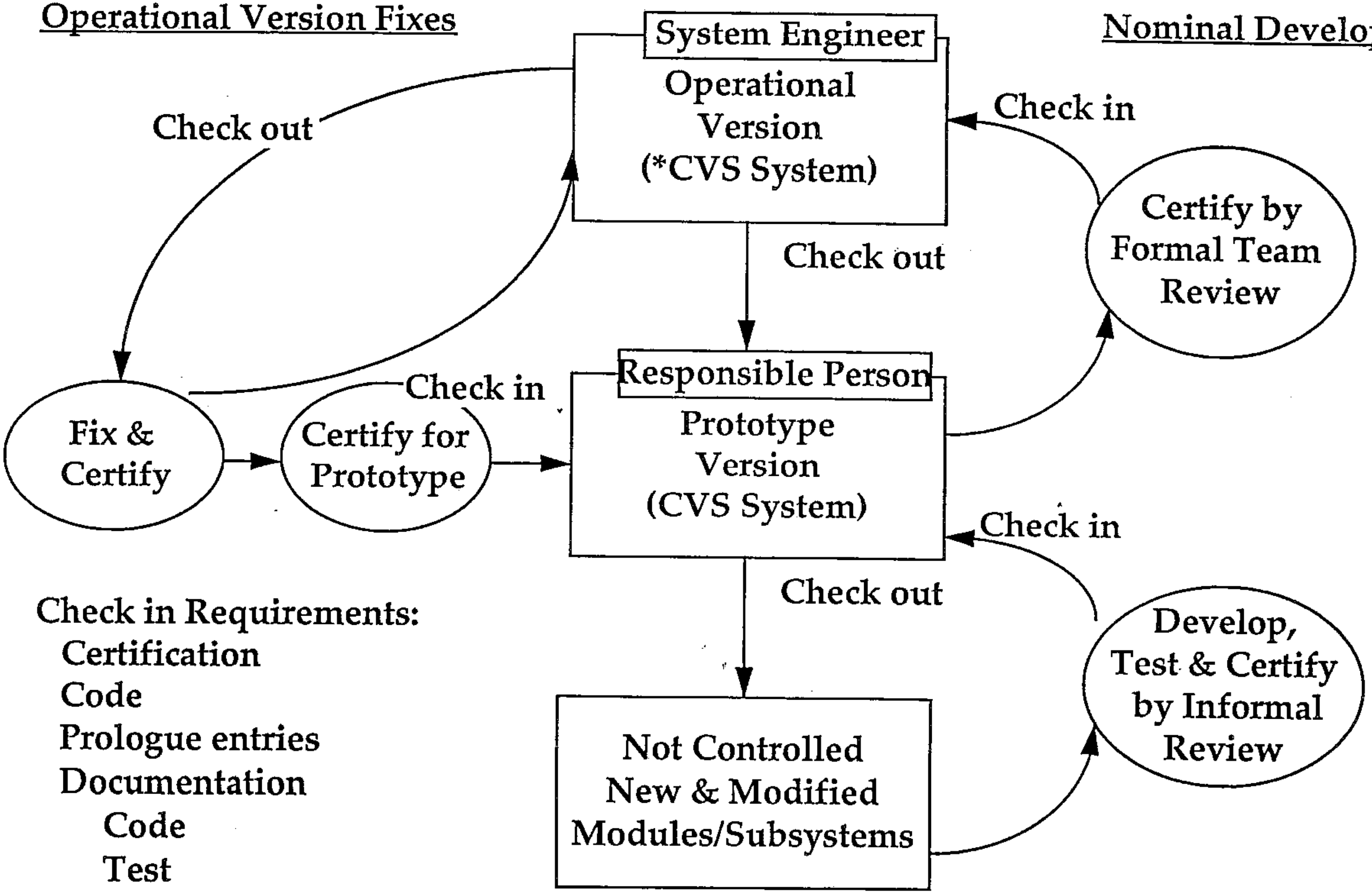
Coding Methods

Coding methods will follow structured top down methodologies. The standard GATS prologue form will be used (see attached example) with QA information logged in the prologues. These logs will include reviews, document references , responsible person, code corrections, code improvements, tests and certifications. Code modules will be written for clarity with comments where clarity dictates. PDL (Program Design Language) is optional.

Configuration Control

- Managed using the software package CVS
- Documents kept under control:
  - Requirements
  - System descriptions (reference)
  - User guides
  - Code
- Three tier system
  - Operational - Current static operational version
  - Prototype - New version under development
  - Research - Modules not yet under configuration control

GATS Configuration Control System



Operational Version Fixes

Nominal Development

System Engineer
Operational
Version
(*CVS System)

Check out

Check in

Certify by
Formal Team
Review

Check out

Fix &
Certify

Certify for
Prototype

Check in

Responsible Person
Prototype
Version
(CVS System)

Check in

Check out

Develop,
Test & Certify
by Informal
Review

Not Controlled
New & Modified
Modules/Subsystems

Check in Requirements:
- Certification
- Code
- Prologue entries
- Documentation
  - Code
  - Test
  - Requirements

*CVS (Concurrent Version System) a version controlsoftware package

Processing System Overview

- Instrument Calibration
- Integration and Test
- Mission Operations
- Science Data Processing
- Validation
- Archive and Access Systems

Configuration Control
CVS Sample File

```
C $Id: main.f,v 2.1 1994/07/08 17:52:23 jcburt Exp $
```

Id is a CVS variable containing the filename, version, date/time and userid of the person who most recently modified the file.

```
C
C Module:     /home/jcburt/doc/dummy.for
C
C Author:     John C Burton
C
C Date:       1994/04/05  16:00:00
C
C--------------------------------------------------------------------
C
C Modification History:
C
C $Log: main.f,v $
```

Log is a CVS variable that is updated each time the file is checked in. It automatically prepends the most recent log entry to the loglist. At minimum a log entry contains the version number, date/time and userid of the person checking the file in. The version numbering scheme will be based on a convention that will distinguish between changes, fixes, prototype code and production processing code. An example 4 digit numbering scheme might look like:

<major>.<minor>.<change>.<fix>

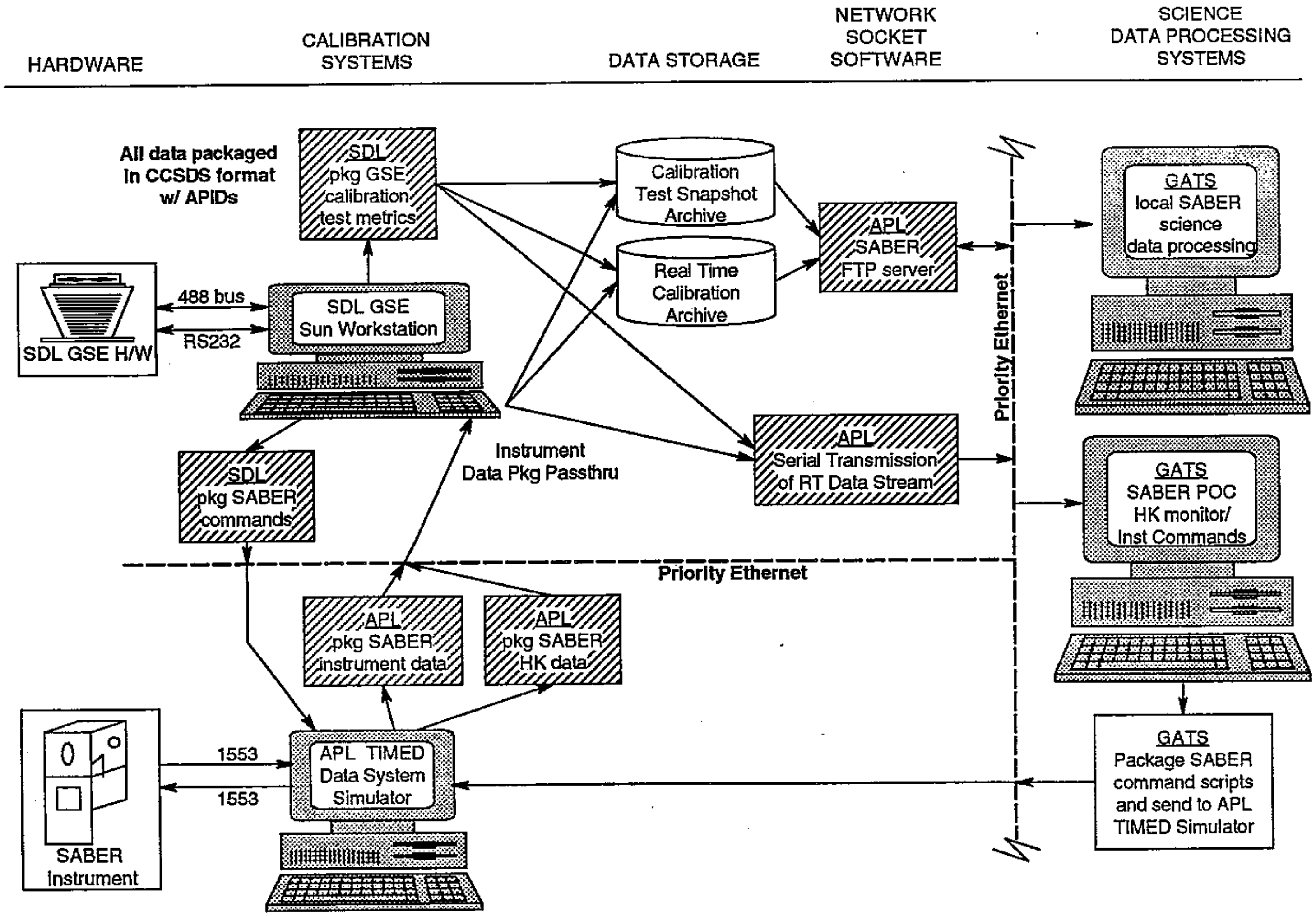
where:

<major> =3D Release Number
<minor> =3D Revision of the release and type of code
=3D even =3D> Production Code
=3D odd =3D> Prototype Code
<change> =3D Change or enhancement
<fix> =3D Bug fix

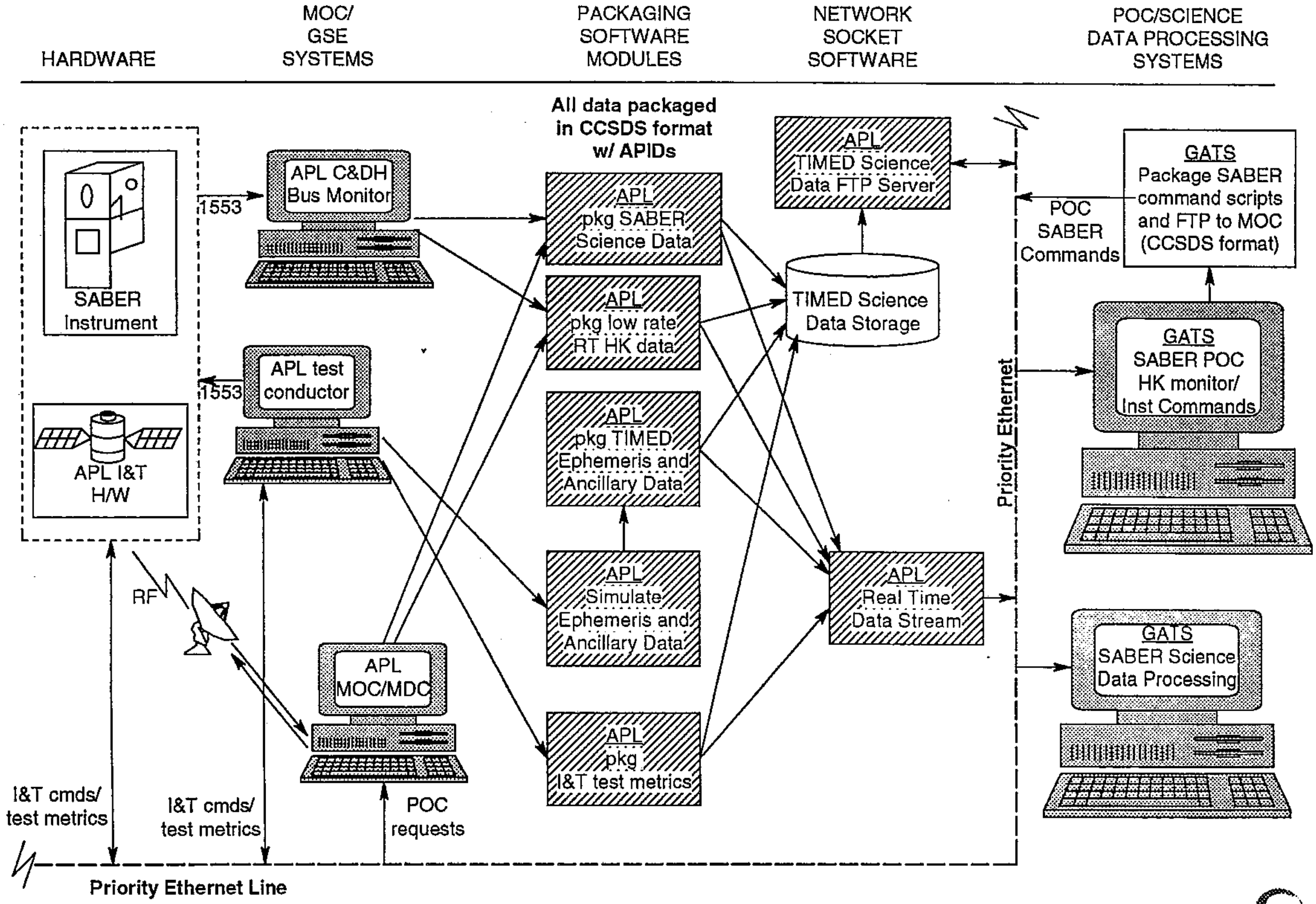
```
C Revision 2.2  1994/07/08  17:52:23  jcburt
C   TEST,REVIEW - Completed final code testing & acceptance review
C           BTM & LLG Reviewing
C           Test procedure available in /home/jcburt/doc/codetest.doc
C           Results available in /home/jcburt/doc/results.doc
C
C Revision 2.1.1.2  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-----------------------------------------------------------------------
C
C Routine:      Dummy
C
C Written By:   John Burton   Wed Nov 20 10:01:40 1996
C
C Purpose:      Example of CVS
C
C-----------------------------------------------------------------------
```

```
C
      IMPLICIT NONE
      IMPLICIT AUTOMATIC (a-z)
C
C    INPUT Parameters:
C
       DOUBLE                 !  double precision variable type
     &           x,            ! latitude, meters
     &           y             ! longitude, meters
C
C   OUTPUT Parameters:
C
      DOUBLE
     &          z               ! altitude, meters
C
C   Include Files:
C

C
C   Constants (PARAMETER Statements):
C

C
C   Explicitly Declared Local Variables:
C

C
C   Executable Code:
C

     Z = Function(X,Y)

     RETURN
     END             !  Subroutine Dummy
```

Saber Calibration Data Flow



Integration and Testing Data Flow



HARDWARE

MOC/ GSE SYSTEMS

PACKAGING SOFTWARE MODULES

NETWORK SOCKET SOFTWARE

POC/SCIENCE DATA PROCESSING SYSTEMS

All data packaged in CCSDS format w/ APIDs

SABER Instrument

APL I&T H/W

1553

1553

APL C&DH Bus Monitor

APL test conductor

APL MOC/MDC

RF

APL pkg SABER Science Data

APL pkg low rate RT HK data

APL pkg TIMED Ephemeris and Ancillary Data

APL Simulate Ephemeris and Ancillary Data

APL pkg I&T test metrics

APL TIMED Science Data FTP Server

TIMED Science Data Storage

APL Real Time Data Stream

Priority Ethernet

POC SABER Commands

GATS Package SABER command scripts and FTP to MOC (CCSDS format)

GATS SABER POC HK monitor/ Inst Commands

GATS SABER Science Data Processing

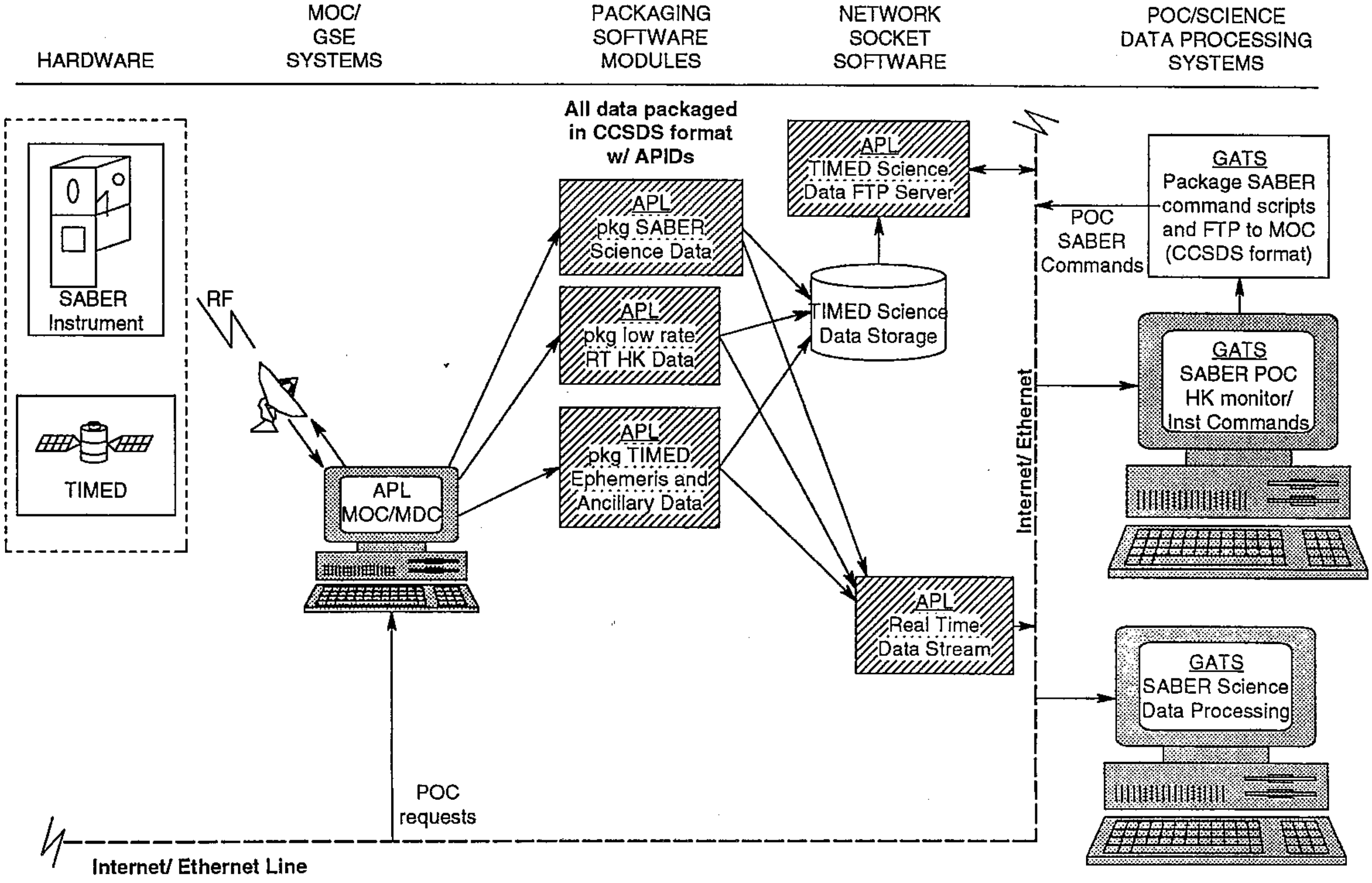
I&T cmds/ test metrics

I&T cmds/ test metrics

POC requests

Priority Ethernet Line

Mission Operations/Payload Operations Data Flow



HARDWARE

MOC/
GSE
SYSTEMS

PACKAGING
SOFTWARE
MODULES

NETWORK
SOCKET
SOFTWARE

POC/SCIENCE
DATA PROCESSING
SYSTEMS

SABER
Instrument

TIMED

RF

APL
MOC/MDC

**All data packaged
in CCDSS format
w/ APIDs**

APL
pkg SABER
Science Data

APL
pkg low rate
RT HK Data

APL
pkg TIMED
Ephemeris and
Ancillary Data

APL
TIMED Science
Data FTP Server

TIMED Science
Data Storage

APL
Real Time
Data Stream

Internet/ Ethernet

POC
SABER
Commands

GATS
Package SABER
command scripts
and FTP to MOC
(CCSDS format)

GATS
SABER POC
HK monitor/
Inst Commands

GATS
SABER Science
Data Processing

POC
requests

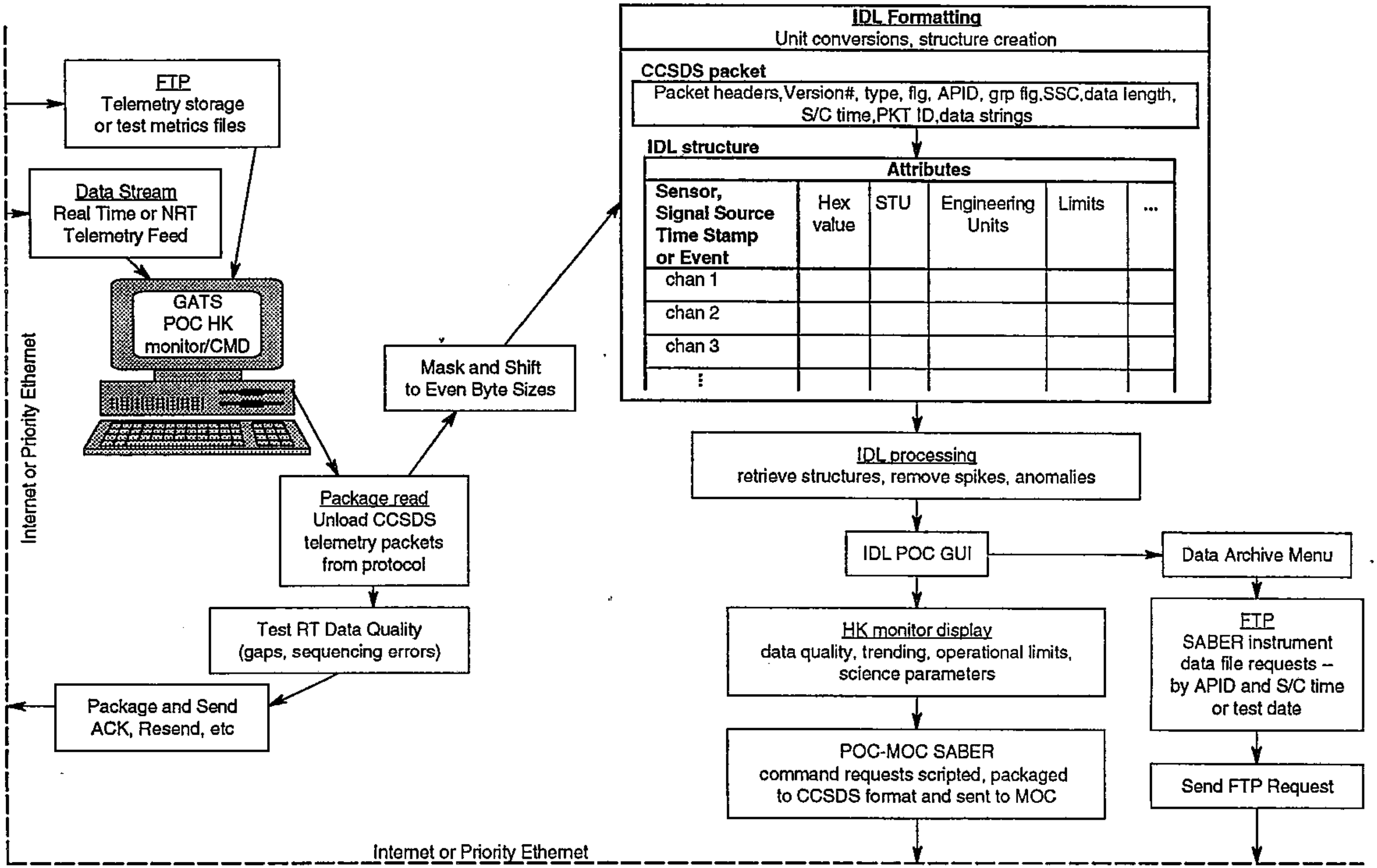
Internet/ Ethernet Line

Payload Operations Center Data Flow

ETHERNET TRAFFIC

POC/SCIENCE DATA SYSTEMS

POC / GATS SOFTWARE



Internet or Priority Ethernet

FTP
Telemetry storage or test metrics files

Data Stream
Real Time or NRT Telemetry Feed

GATS POC HK monitor/CMD

Package read
Unload CCSDS telemetry packets from protocol

Test RT Data Quality (gaps, sequencing errors)

Package and Send ACK, Resend, etc

Mask and Shift to Even Byte Sizes

IDL Formatting
Unit conversions, structure creation

CCSDS packet
Packet headers,Version#, type, flg, APID, grp flg,SSC,data length, S/C time,PKT ID,data strings

IDL structure

Attributes					
Sensor, Signal Source Time Stamp or Event	Hex value	STU	Engineering Units	Limits	...
chan 1					
chan 2					
chan 3					
⋮					

IDL processing
retrieve structures, remove spikes, anomalies

IDL POC GUI

Data Archive Menu

HK monitor display
data quality, trending, operational limits, science parameters

FTP
SABER instrument data file requests – by APID and S/C time or test date

POC-MOC SABER
command requests scripted, packaged to CCSDS format and sent to MOC

Send FTP Request

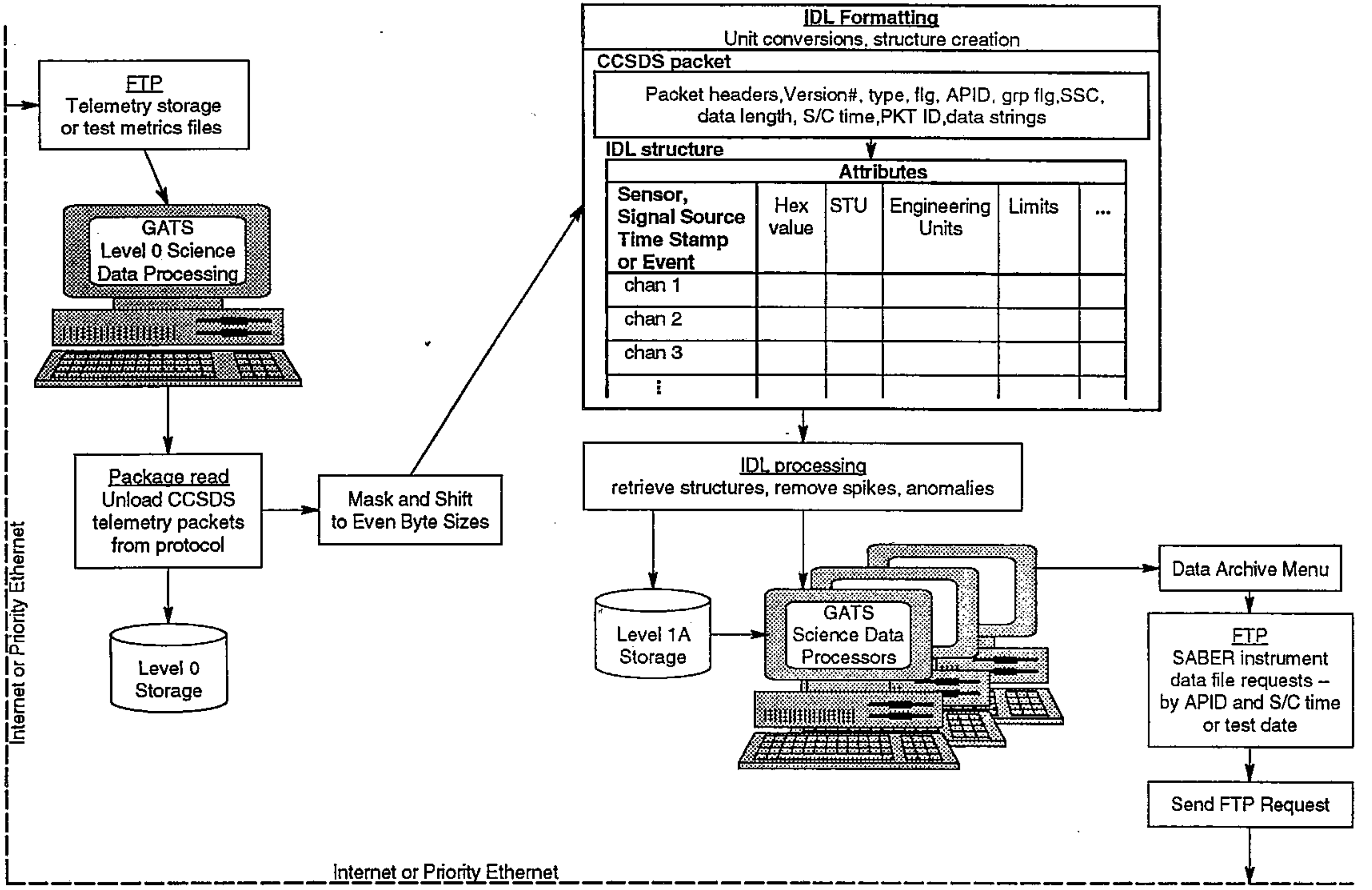
Internet or Priority Ethernet

SABER Level 0 to 1A Science Data Flow

ETHERNET TRAFFIC

POC/SCIENCE DATA SYSTEMS

POC / GATS SOFTWARE



FTP
Telemetry storage or test metrics files

GATS
Level 0 Science Data Processing

Package read
Unload CCSDS telemetry packets from protocol

Level 0 Storage

Mask and Shift to Even Byte Sizes

IDL Formatting
Unit conversions, structure creation

CCSDS packet

Packet headers,Version#, type, flg, APID, grp flg,SSC, data length, S/C time,PKT ID,data strings

IDL structure

Attributes					
Sensor, Signal Source Time Stamp or Event	Hex value	STU	Engineering Units	Limits	...
chan 1					
chan 2					
chan 3					
⋮					

IDL processing
retrieve structures, remove spikes, anomalies

Level 1A Storage

GATS Science Data Processors

Data Archive Menu

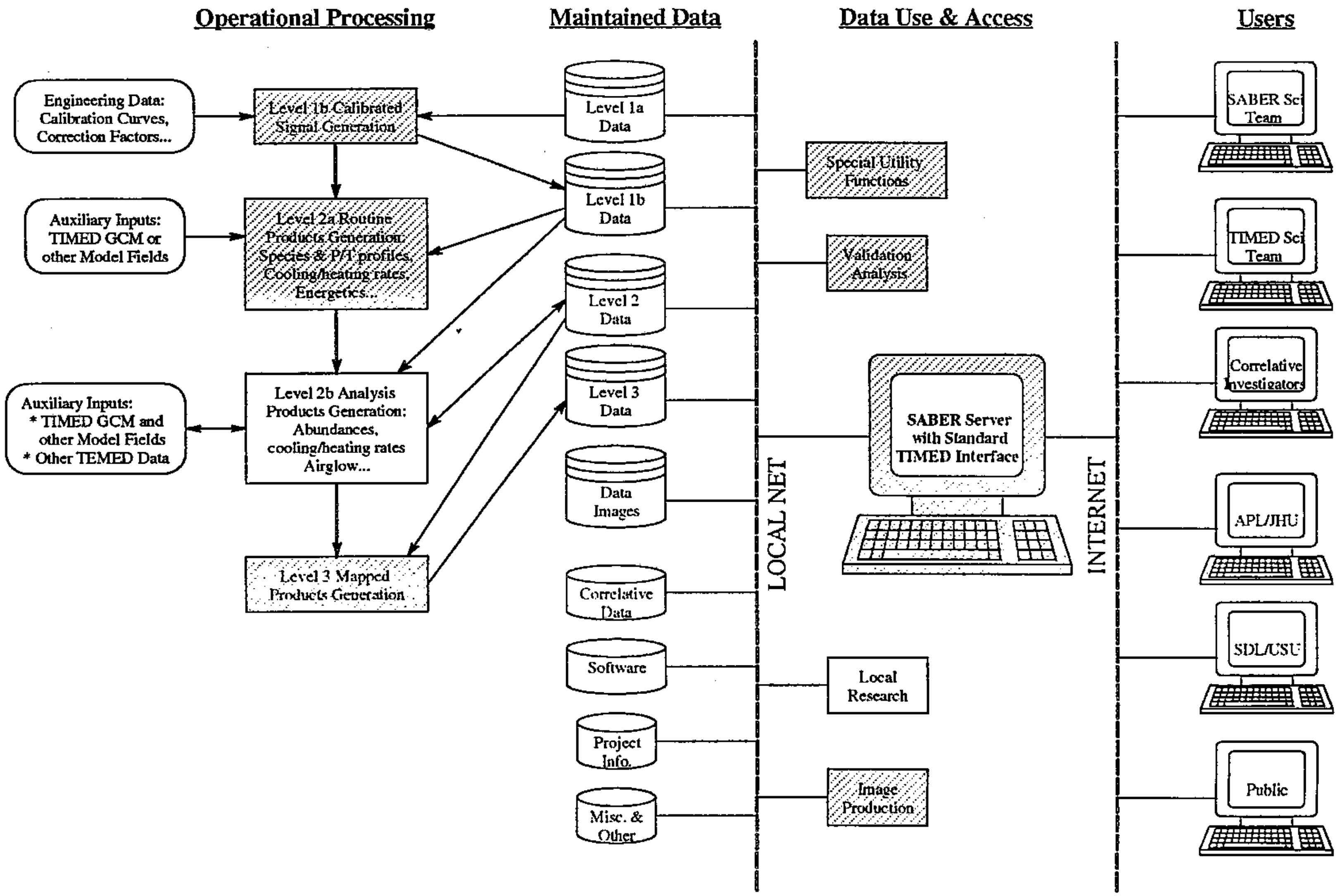
FTP
SABER instrument data file requests -- by APID and S/C time or test date

Send FTP Request

Internet or Priority Ethernet

Internet or Priority Ethernet

SABER Level 1b through 3 Processing Steps and Data Access



Operational Processing

Engineering Data: Calibration Curves, Correction Factors...

Level 1b Calibrated Signal Generation

Auxiliary Inputs: TIMED GCM or other Model Fields

Level 2a Routine Products Generation: Species & P/T profiles, Cooling/heating rates, Energetics...

Auxiliary Inputs:
- TIMED GCM and other Model Fields
- Other TEMED Data

Level 2b Analysis Products Generation: Abundances, cooling/heating rates Airglow...

Level 3 Mapped Products Generation

Maintained Data

Level 1a Data

Level 1b Data

Level 2 Data

Level 3 Data

Data Images

Correlative Data

Software

Project Info.

Misc. & Other

LOCAL NET

Data Use & Access

Special Utility Functions

Validation Analysis

SABER Server with Standard TIMED Interface

Local Research

Image Production

INTERNET

Users

SABER Sci Team

TIMED Sci Team

Correlative Investigators

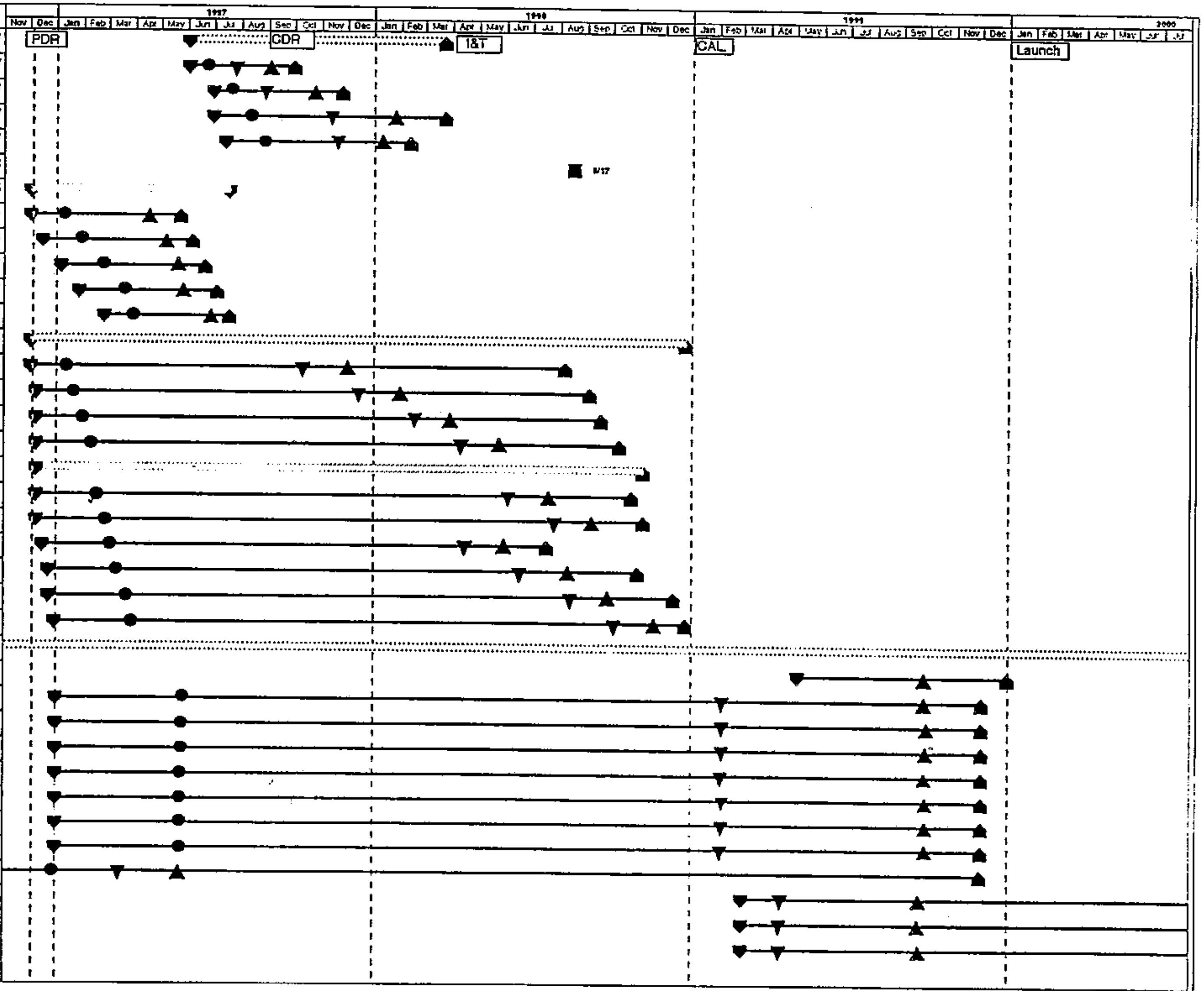
APL/JHU

SDL/USU

Public

SABER PDR, 12/96, Logan, Utah

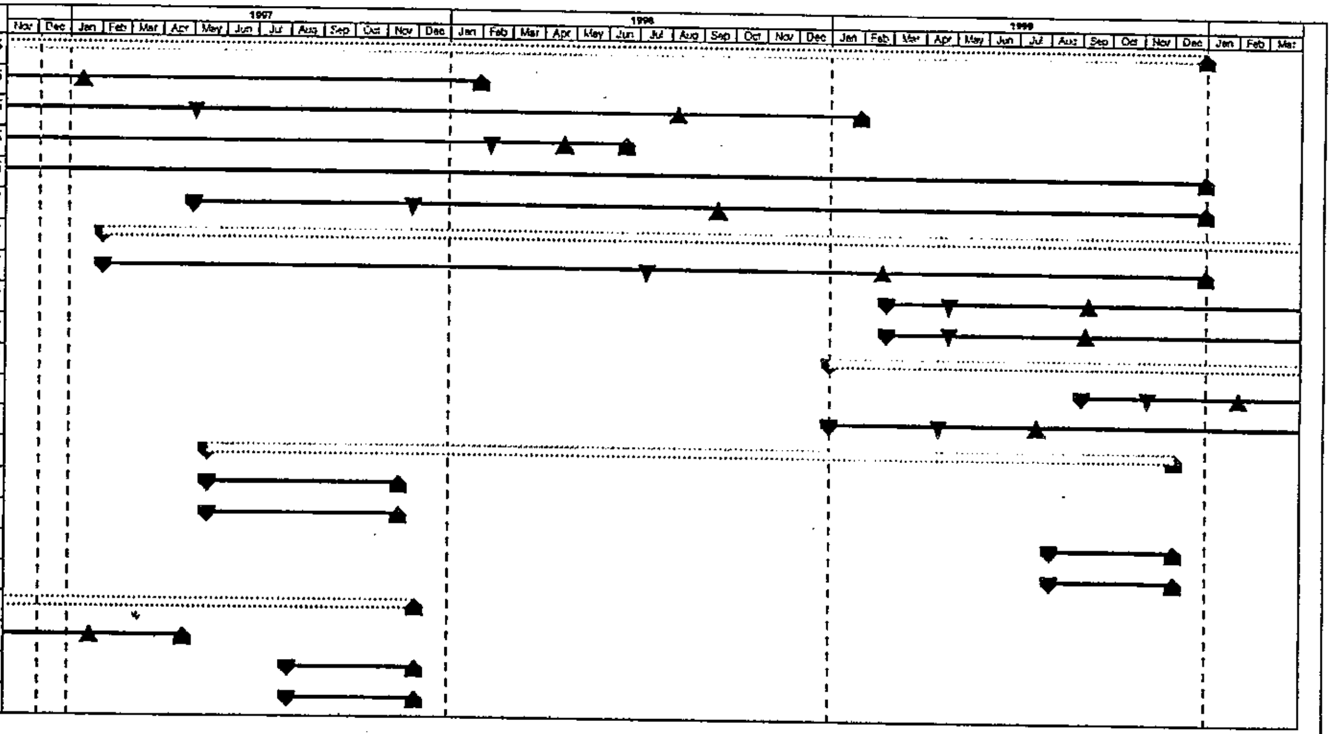
ID	Task Name	Duration	Start
1	**POC System Developmen**	**211d**	6/2/97
2	RT data acquisition	17.4w	6/2/97
3	Data quality S/W	21.2w	6/30/97
4	POC GUI/Menus	38.2w	6/30/97
5	Command Scripts	30.6w	7/14/97
6	**POC Test**	**0d**	8/17/98
7	**Level 0 - 1a**	**165d**	12/2/96
8	Prototype Simulation	25w	12/2/96
9	Level 0 data acquisition	25w	12/16/96
10	Reformat data Pkgs	24w	1/6/97
11	Level 1a data processing	23w	1/27/97
12	Storage retrieval setup	21w	2/24/97
13	**Test & Calibration**	**540d**	12/2/96
14	Linearity	88w	12/2/96
15	Relative Spectral Respons	91w	12/9/96
16	IFOV	93w	12/9/96
17	MTF	96w	12/9/96
18	Absolute radiance	500d	12/9/96
19	Channels 1-7	98w	12/9/96
20	Channels 8-10	100w	12/9/96
21	Sensor Offset	83w	12/16/96
22	Detector position	97w	12/23/96
23	Knife Edge Response	103w	12/23/96
24	Slit Response	104w	12/30/96
25	**Level 1b Code**	**1241d**	3/1/96
26	Bad data filtering	35w	5/3/99
27	FOV	152.2w	1/1/97
28	Spacecraft motion	152.2w	1/1/97
29	Off-axis scattering	152.2w	1/1/97
30	Time delay	152.2w	1/1/97
31	Data averaging	761d	1/1/97
32	Boresight correction	152.2w	1/1/97
33	Profile alignment	152.2w	1/1/97
34	Earth oblateness	195.6w	3/1/96
35	Lunar calibration	92w	3/1/99
36	Roll-up	92w	3/1/99
37	IFC Temp. change	92w	3/1/99
38			



Project:
Date: 12/4/96

Start ▼
Requirements Definition ●
System Design Reviews ▼
S/W Testing Begins ▲
Delivery of Version 1 ☗
Summary ▼—▼
progress ▼—☗

ID	Task Name	Duration	Start
38	**Level 2a Code**	**1001d**	**3/1/96**
39	Forward model sett	501d	3/1/96
40	Forward model sett	761d	3/1/96
41	Volume emission r	601d	3/1/96
42	Retrieval-LTE	1000d	3/4/96
43	Retrieval-NLTE	697d	5/1/97
44	**Level 2b Code**	**1000d**	**2/3/97**
45	Retrieval	760d	2/3/97
46	Cooling rates	463d	2/24/99
47	Heating rates	463d	2/24/99
48	**Level 3 Code**	**501d**	**1/1/99**
49	New Gridding	328d	9/1/99
50	Old Gridding	347d	1/1/99
51	**Validation**	**665d**	**5/15/97**
52	Statistical Analysis	132d	5/15/97
53	Rendering Softwar	132d	5/15/97
54	Correlative Manag	88d	8/2/99
55	Database Manager	88d	8/2/99
56	**Archive and Access**	**457d**	**3/1/96**
57	Document Databas	299d	3/1/96
58	Ingest & Data Acc	87d	8/1/97
59	Image generation	87d	8/1/97



Project: Date: 12/4/96	Start ▼ Requirements Definition ●	System Design Reviews ▼ S/W Testing Begins ▲	Delivery of Version 1 ☗ Summary ▼—▼	progress ▼—☗

Page 2

SABER PDR, 12/96, Logan, Utah

PRODUCT ASSURANCE

RICHARD AUSTIN

December 10, 1996

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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 8, Assurance Management Plan, and DRD 11, Configuration Management Plan

- **Overview**

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

SUBCONTRACTOR CONTROL

- SDL's subcontractors are required to comply with SDL's Product Assurance Plan
- Exceptions to SDL's Product Assurance Plan shall be negoiated between the subcontractor and SDL
- Periodic audits to the subcontractors will be performed by SDL to assure compliance to the Product Assurance Plan
- SDL will perform source inspection for final acceptance testing and buy-off

DELIVERABLE DATA REQUIREMENTS

- **Product Assurance Plan**
  - Preliminary prior to SRR
  - Final 30 days after PDR
- **Parts and Materials Lists**
  - Preliminary prior to PDR
  - Updates at CDR and PSR
- **Safety Checklist at CDR**
- **Acceptance Data Package at PSR**
  - As-built configuration list
  - Parts and materials list
  - Formal acceptance test reports
  - Approved waivers

SAFETY

- **Precautions shall be taken for protection of personnel safety**
  - Review of potentially hazardous or dangerous materials and processes

- **Provisions shall be taken for protection of deliverable hardware**
  - Review of potential electrical and mechanical interface hazards
  - Protection against uncontrolled environments
  - Protection against electrostatic discharge (ESD)
  - Provide for appropriate handling procedures and fixtures, including proof testing of fixtures.

- **A Safety Checklist shall be prepared for each subsystem**

EEE PARTS SELECTION CRITERIA

- **Grade 1 parts**
  - MIL-M-38510 class S microcircuits
  - MIL-S-19500 JANS semiconductors
  - S failure rate level, established reliability, passive and electromechanical parts

- **Grade 2 parts**
  - 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 M 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 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 on an in-house 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 Table 2 or 3 require justification and approval
- Nonmetallic materials shall meet the following outgassing requirements in accordance to 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**
- **Configuration control of drawings and specifications shall be governed by:**
  - SDL/90-011, Drawing Procedure
  - SDL/90-010, Drawing Change Control Procedure
- **Drawing changes (ECOs) shall be reviewed and approved by:**
  - Cognizant engineer
  - Quality assurance
  - Documentation control group (release, filing, and distribution)
- **System requirements, management plans, and other contract documents shall be maintained under configuration control**
- **Configuration changes to these documents shall be approved by:**
  - SDL Program Manager
  - SDL Quality Assurance
  - LaRC Representative
  - SDL Documentation control group

QUALITY ASSURANCE

- **Traceability**
  - Purchasing and receiving records maintained for all parts and materials
    - Certificate of conformance including lot control
  - Computer records for all as-built flight hardware will be maintained
  - Parts and materials tracked for each detail part and assembly
  - Forward and backward traceability capability

- **Controlled stockroom**
  - Computer records of all controlled parts will be maintained
  - Locked storage cabinets for all controlled flight parts
  - ESD protection for static sensitive parts
  - Limited access

QUALITY ASSURANCE (cont.)

- **Manufacturing control**
  - Cognizant engineer and technician assigned to a particular component and subsystem throughout the life of the program
  - Shop travellers will be used to document history of work operations, inspections, and tests
  - Quality assurance will verify compliance, traceability, and workmanship of flight hardware
- **Training and certification**
  - Required for all welding, soldering, and ESD operations
  - Trained and skilled personnel will be used for all operations
  - Records of certified personnel maintained by quality assurance

QUALITY ASSURANCE (cont.)

- **QA inspections**
  - Receiving inspection
  - In-process inspection
  - Final inspection

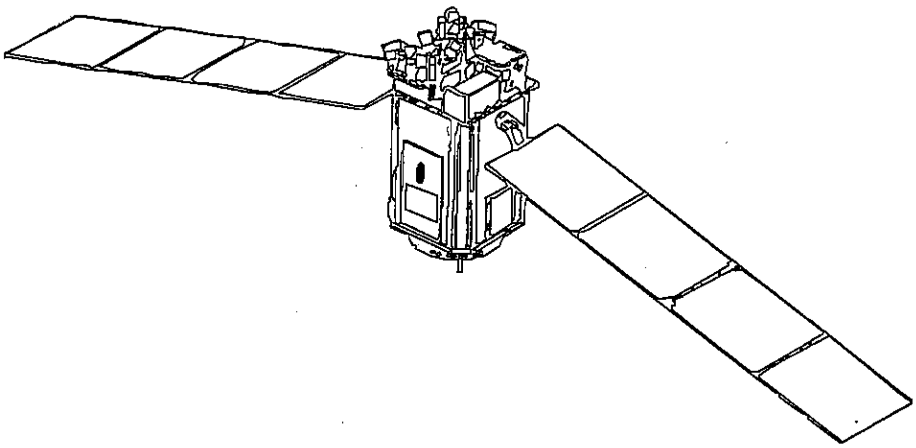
- **Testing**
  - Testing will be performed as specified in the SABER Master Test Plan, SDL/95-021
  - Engineering level testing will be recorded in laboratory notebooks
  - All test tests called out in the statement of work will be referenced on shop traveller
  - Functional and environmental test results will be recorded and maintained by the cognizant project engineer on test data sheets
  - Records of formal acceptance testing will be maintained by Quality Assurance

QUALITY ASSURANCE (cont.)

- **Nonconformance control**
  - All nonconformances shall be documented:
    - In laboratory notebooks during prototype and engineering development
    - On discrepancy reports for flight hardware
  - SDL will send a monthly DR summary report to Larc
  - 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
  - Waivers will be submitted to LaRC for approval where there is a deviation from safety, performance, reliability, weight, interface, or basic contract requirements

SDL/96-067

SABER
Preliminary Design Review
Cost Schedule and Descope

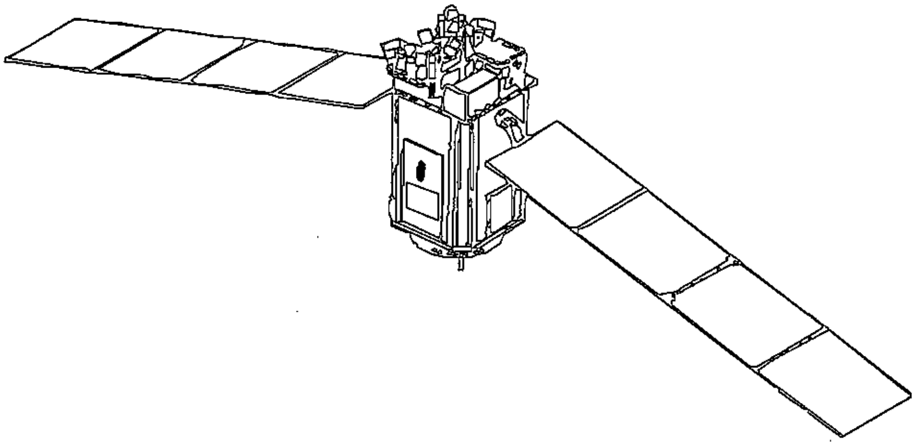


Contract No. NAS1-20467
December 12, 1996

SPACE DYNAMICS LABORATORY
UTAH STATE UNIVERSITY LOGAN, UTAH 84321-1942

SDL/96-067

SABER
Preliminary Design Review
Cost Schedule and Descope



Contract No. NAS1-20467
December 12, 1996

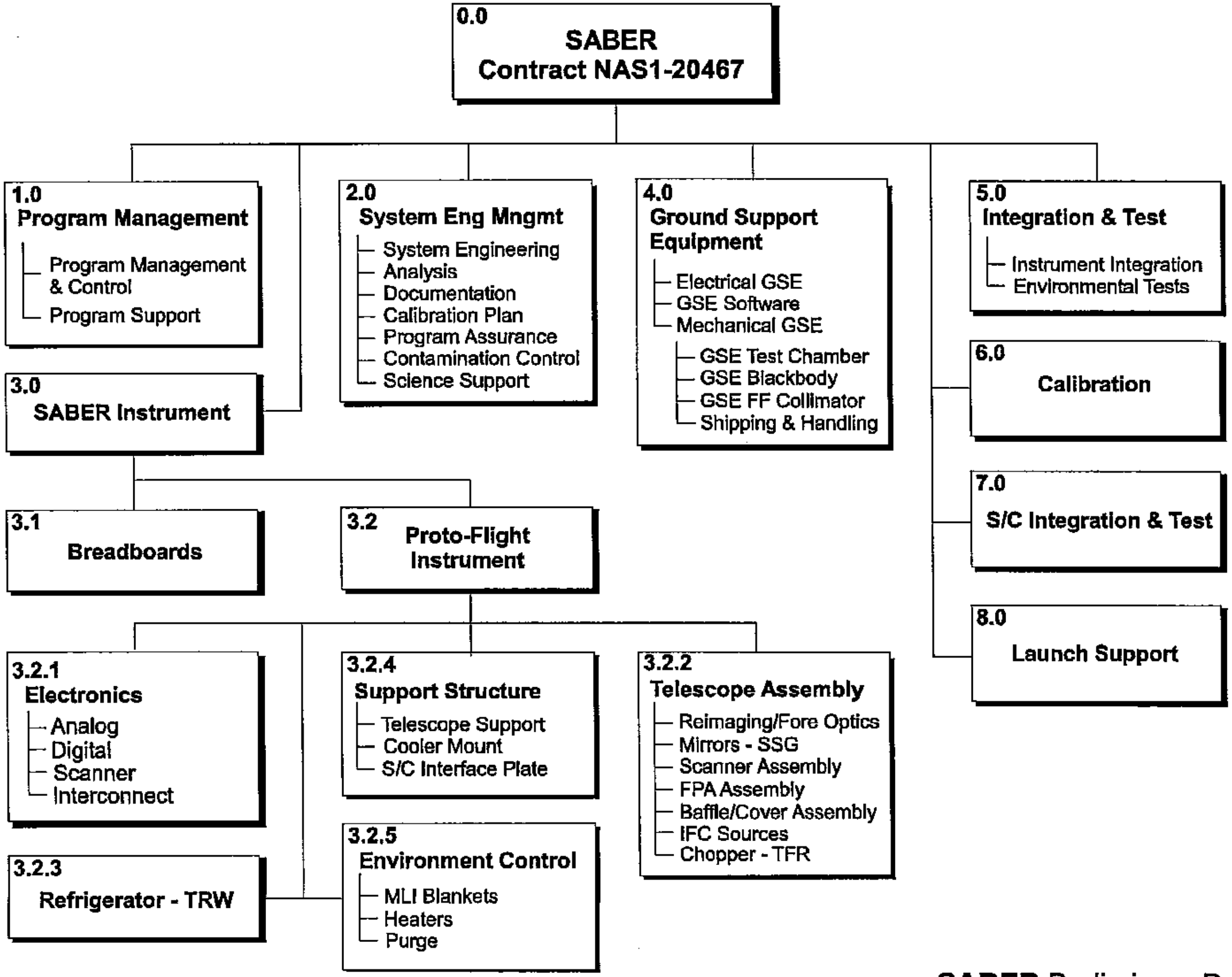
SABER PROJECT WBS & SCHEDULE

Lorin Zollinger

December 12, 1996

Phone: (801) 755-4275
Fax: (801 755-4299
E-Mail: lorin.zollinger@sdl.usu.edu

SABER WBS Key Elements



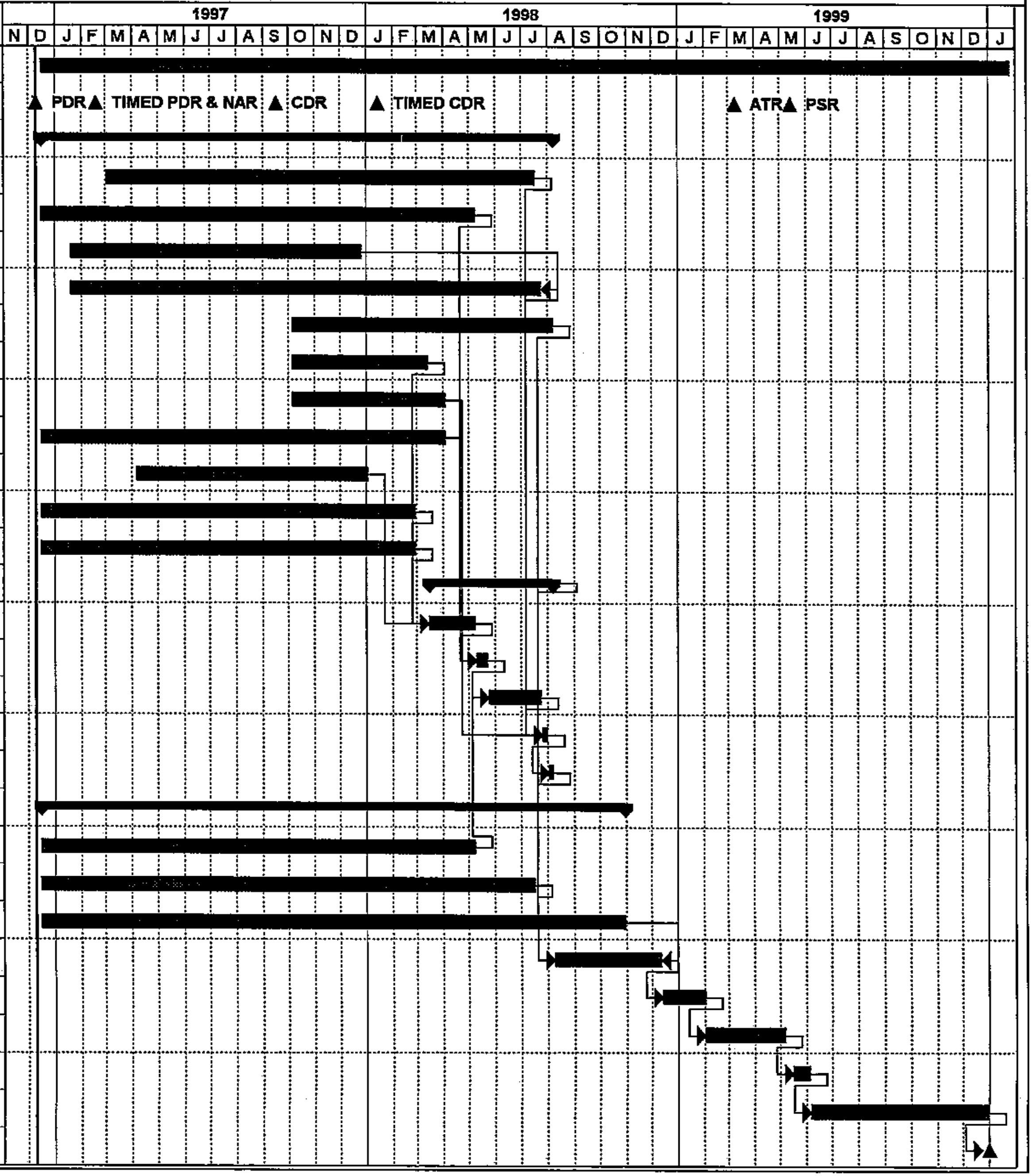
- **0.0 SABER Contract NAS1-20467**
  - **1.0 Program Management**
    - Program Management & Control
    - Program Support
  - **2.0 System Eng Mngmt**
    - System Engineering
    - Analysis
    - Documentation
    - Calibration Plan
    - Program Assurance
    - Contamination Control
    - Science Support
  - **3.0 SABER Instrument**
    - **3.1 Breadboards**
    - **3.2 Proto-Flight Instrument**
      - **3.2.1 Electronics**
        - Analog
        - Digital
        - Scanner
        - Interconnect
      - **3.2.2 Telescope Assembly**
        - Reimaging/Fore Optics
        - Mirrors - SSG
        - Scanner Assembly
        - FPA Assembly
        - Baffle/Cover Assembly
        - IFC Sources
        - Chopper - TFR
      - **3.2.3 Refrigerator - TRW**
      - **3.2.4 Support Structure**
        - Telescope Support
        - Cooler Mount
        - S/C Interface Plate
      - **3.2.5 Environment Control**
        - MLI Blankets
        - Heaters
        - Purge
  - **4.0 Ground Support Equipment**
    - Electrical GSE
    - GSE Software
    - Mechanical GSE
      - GSE Test Chamber
      - GSE Blackbody
      - GSE FF Collimator
      - Shipping & Handling
  - **5.0 Integration & Test**
    - Instrument Integration
    - Environmental Tests
  - **6.0 Calibration**
  - **7.0 S/C Integration & Test**
  - **8.0 Launch Support**

SABER Project Schedules

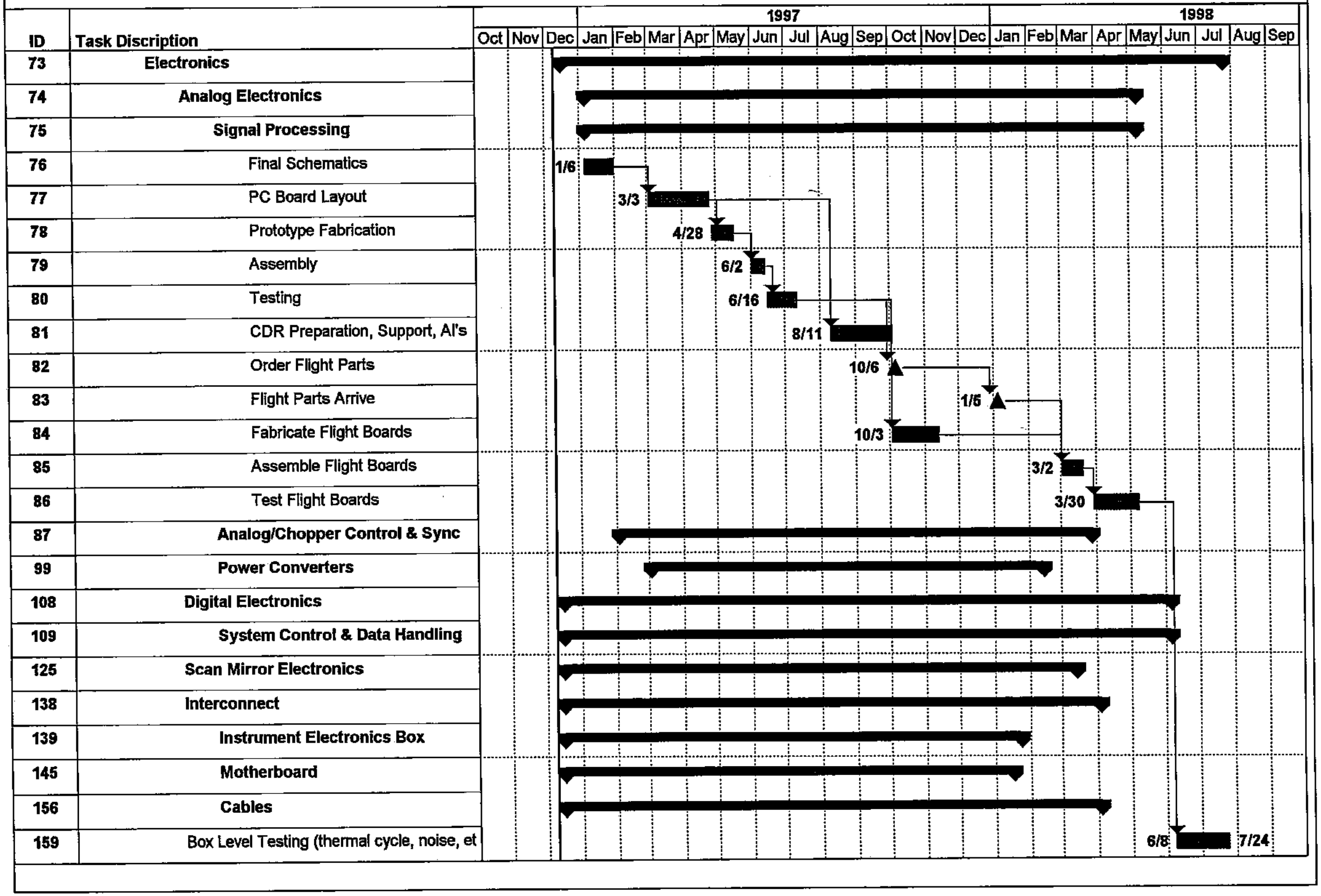
- **SABER Project uses Microsoft Project scheduling software**
  - This tool used to create the SABER project plan
  - Organize and track project tasks
  - Allows setting a baseline and tracking progress against the baseline
  - Set task constraints,relationships and dependcies
  - Easliy modified as project guidelines and funding profile changes
  - Shared electronicly with LaRC on a regular basis
- **Following schedule is a tenative Phase CD baseline schedule**
  - Based on present (soft) project guidelines and funding expectations

SABER Phase CD Top Level Schedule

ID	Task Discription
1	Program Management & System Engineering
2	**Reviews**
9	**Protoflight Instrument**
10	Electronics, Fab & Test Prototype & Flight
11	Motor/Encode BrassBd, Flight Fab & Test (BEI)
12	Filter Frame Assy Prototype & Flight (OCLI)
13	Detector Assy Prototype & Flight (EG&G)
14	Refrigerator Fabrication & Test (TRW)
15	Mirror Fabrication & Test (SSG)
16	FIST Fabrication & Assembly
17	IFC Blackbody Design, Fab & Test
18	Chopper, Fab Prototype & Flight (TFR)
19	Structures, Design, Fab & Assemble
20	Telescope Design, Fab, Integrate & Test
21	**Instrument Integration & Test**
22	Assemble & Align Tele w/Structure
23	Integrate Scanner w/Telescope & Align
24	Image Quality & Boresight Test Warm & Cold
25	Mount & Align FPA & Lyot Stop
26	Warm Focus/Boresight Test (Ch 10)
27	**Ground Support Equipment**
28	Test Chamber Design, Fab & Test
29	Full Field Collimator Design, Fab & Test
30	Blackbody Design, Fab & Test
31	Engineering Testing & Pre-Calibration
32	Environmental Tests
33	Calibration
34	Ship, Unpack & Test
35	Spacecraft I&T, Pre-Launch Support
36	Launch



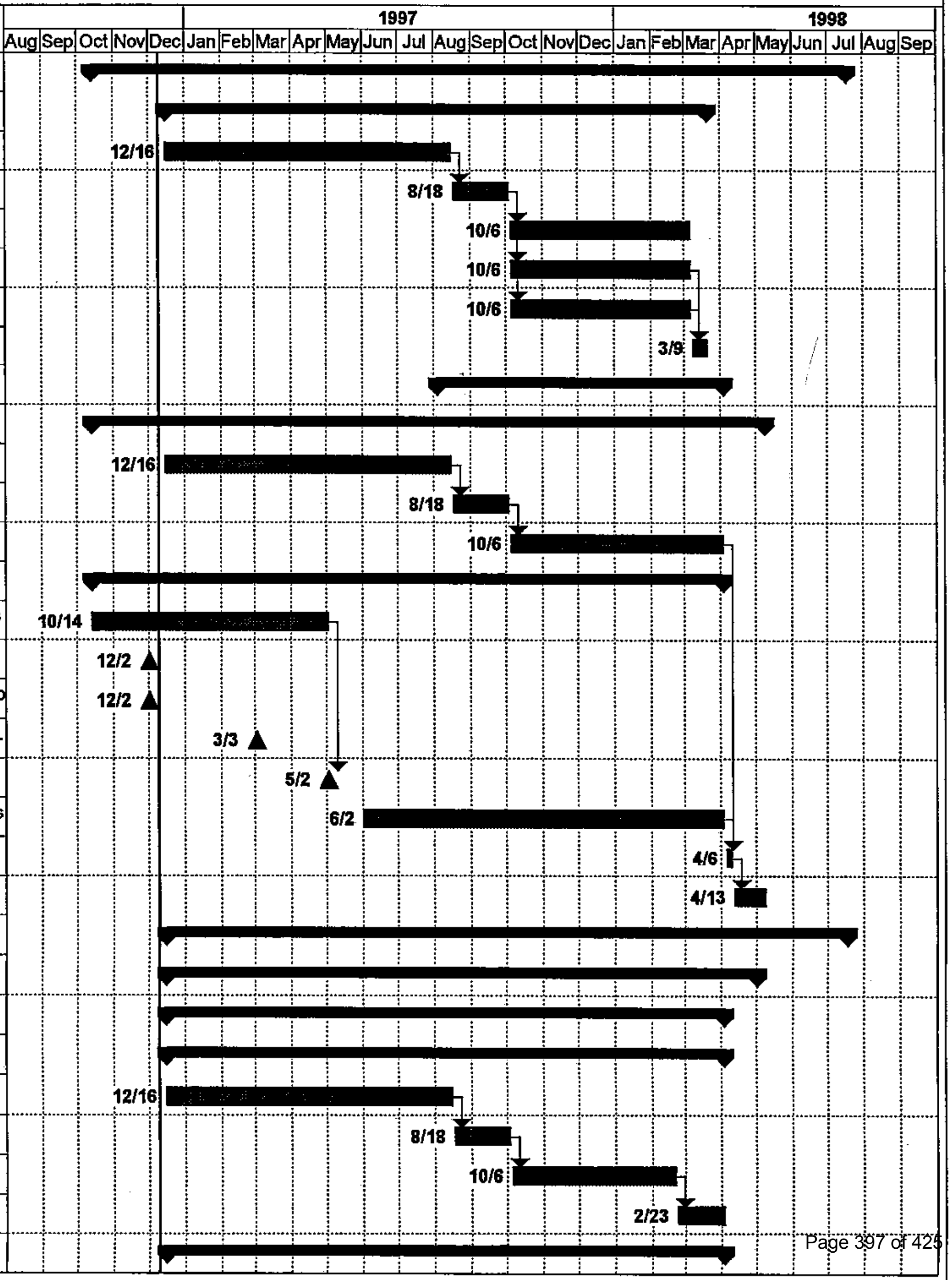
Instrument Electronics



ID	Task Discription
73	**Electronics**
74	**Analog Electronics**
75	**Signal Processing**
76	Final Schematics
77	PC Board Layout
78	Prototype Fabrication
79	Assembly
80	Testing
81	CDR Preparation, Support, AI's
82	Order Flight Parts
83	Flight Parts Arrive
84	Fabricate Flight Boards
85	Assemble Flight Boards
86	Test Flight Boards
87	**Analog/Chopper Control & Sync**
99	**Power Converters**
108	**Digital Electronics**
109	**System Control & Data Handling**
125	**Scan Mirror Electronics**
138	**Interconnect**
139	**Instrument Electronics Box**
145	**Motherboard**
156	**Cables**
159	Box Level Testing (thermal cycle, noise, et

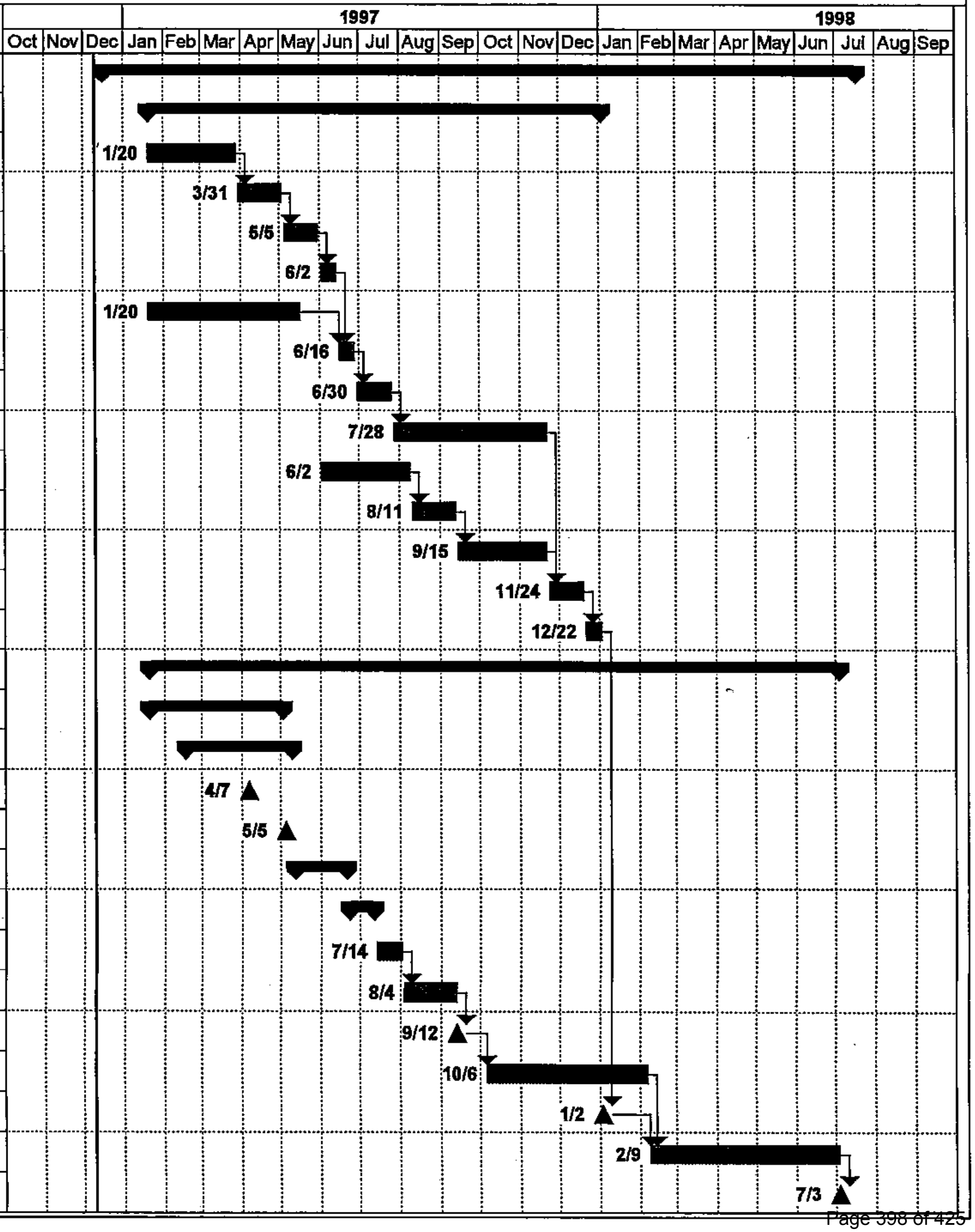
Telescope, Scanner, & IFC

ID	Task Discription
160	**Telescope**
161	**Reimaging & Fore Optics**
162	Final Design
163	CDR Preparation, Support, AI's
164	Reimager Fab
165	Fore Optics Fab & Assemble
166	Fab Alignment Fixtures
167	Align Fore Optics Assembly
168	**Mirrors - SSG**
173	**Scanner Assembly**
174	Final Design
175	CDR Preparation, Support, AI's
176	Scanner Housing Fab & Assemble
177	**Motor/Encoder Assembly - BEI**
178	Build Brassboard Motor/Encoder As
179	Outline/Interface Drawings
180	Mass Properties, Design Life, Reliab
181	Release Top Assy, Schematics, etc.
182	Motor/Encoder Brassbd Delivery
183	Build/Test Flight Motor/Encoder Ass
184	Integrate M/E & Housing
185	Scanner Testing
186	**FPA Assembly**
240	**Baffle & Cover Assembly**
245	**IFC Sources**
246	**IFC Blackbody**
247	Final Design
248	CDR Preparation, Support, AI's
249	Fabricate
250	Assemble & Test BB
251	**IFC Jones Source**



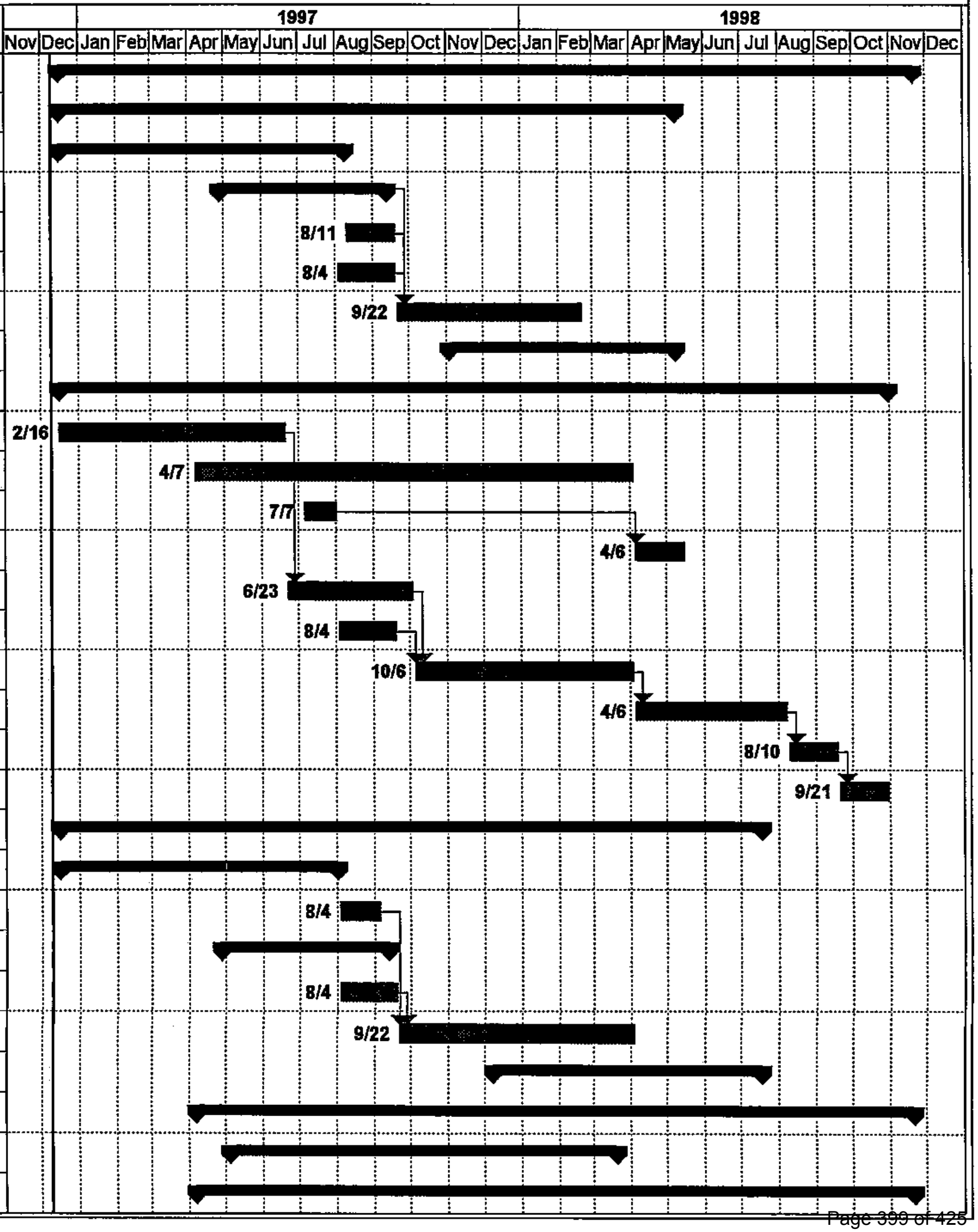
Detector Assembly

ID	Task Discription
186	**FPA Assembly**
187	**Filters & Frame Assembly- OCLI**
188	Procure Prototype Substrates
189	Process Substrates
190	Coat Prototype Filters
191	Prepare Filters for Mounting
192	Fab Prototype Frame & Baffle
193	Assemble Proto Filter Frame Assy
194	Finalize Filters & Frame Designs
195	Fabricate Flight Filter Frame Assy.
196	Procure Flight Substrates
197	Process Substrates
198	Coat Flight Filters
199	Assembly Filter Frame Flight Units
200	Filter Frame Environmental Tests
201	**Detector Assembly- EG&G**
202	**Procurement**
207	**Fabrication**
211	Filter Assy Engineering Data
212	Receive Baffle Plate
213	**Initial Assembly**
217	**Filter Assembly**
222	Final Assembly & Test
223	Flight Design
224	Detector Assembly CDR
225	Flight Detector Assy Fab
226	Filter Assembly Delivered
227	Flight Unit Assembly & Test
228	Deliver Detector Assembly



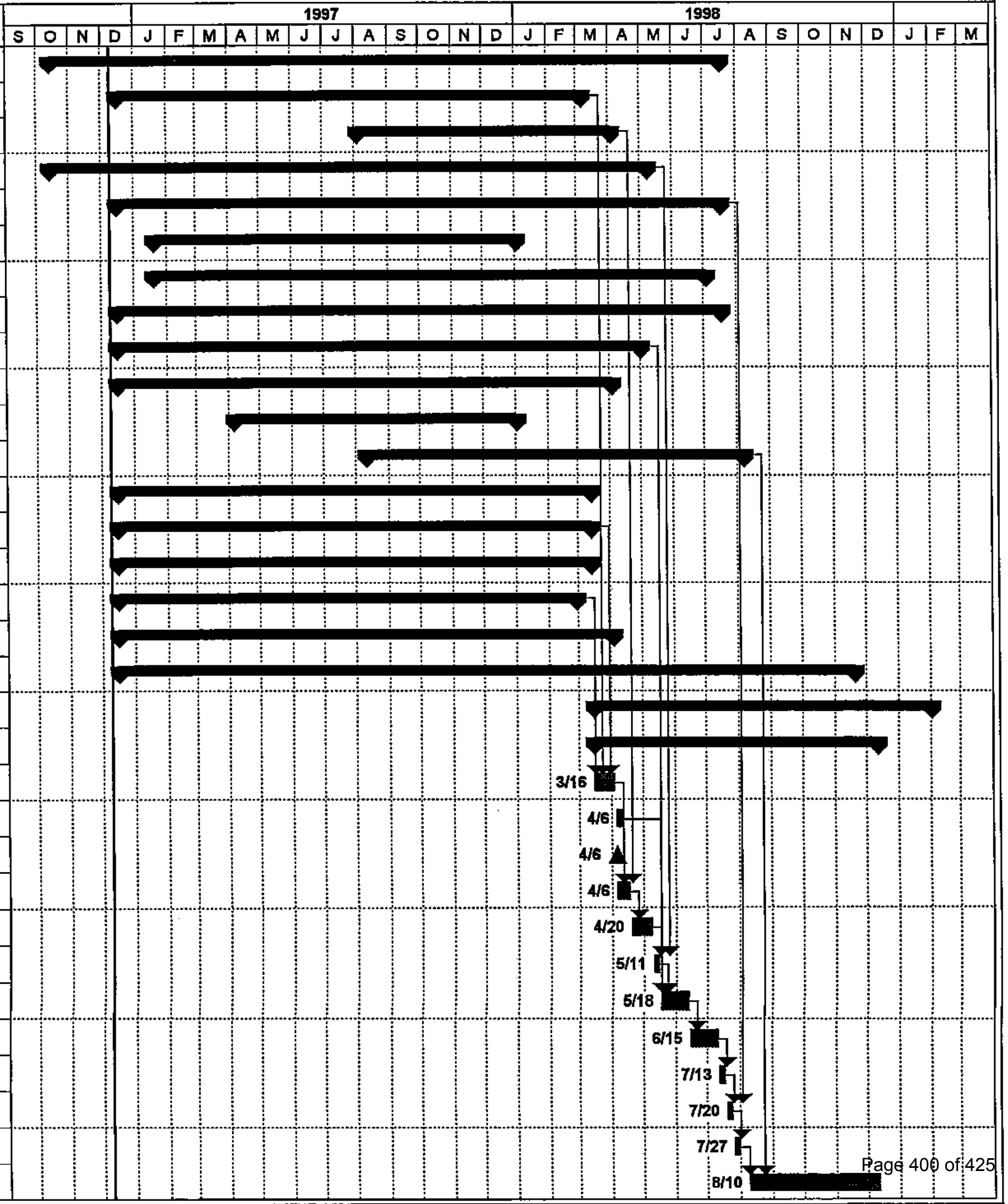
Ground Support Equipment

ID	Task Discription
316	**GSE, Mechanical**
317	**GSE Test Chamber**
318	**Finalize Design**
327	**Production Drawings**
331	Final Quotes/Order Parts
332	CDR Prep & Support
333	Fabricate
334	**Assemble & Test**
339	**GSE Blackbody**
340	Finalize Design
341	GSE BB Software
342	Design SPAS Test Chamber Fixtures
343	Fab SPAS Test Chamber Fixtures
344	Production Drawings
345	CDR Prep & Support
346	Fabrication
347	Assemble & Test
348	BB Insitu Calibration
349	NIST TRX Cal. Check
350	**GSE Full Field Collimator**
351	**Finalize Design**
357	Final Quotes/Order Parts
358	**Production Drawings**
363	CDR Prep & Support
364	Fabrication
365	**Assemble & Test**
372	**GSE, Shipping & Handling Fixtures**
373	**Handling Fixtures**
377	**Transportation Fixtures**



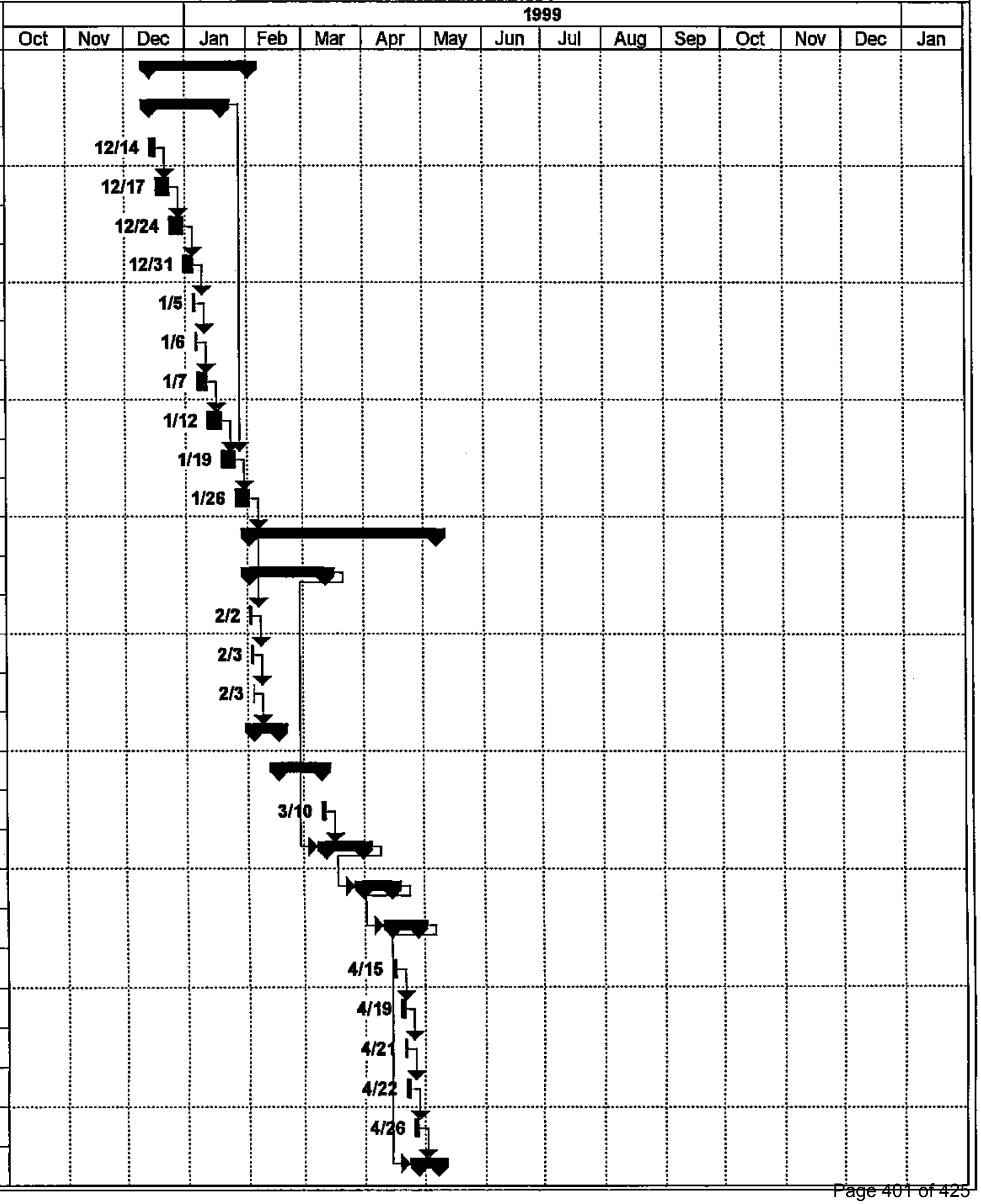
Integration

ID	Task Discription
160	Telescope
161	Reimaging & Fore Optics
167	Mirrors - SSG
172	Scanner Assembly
185	FPA Assembly
186	Filters & Frame Assembly- OCLI
200	Detector Assembly- EG&G
228	FPA Assembly - SDL
239	Baffle & Cover Assembly
244	IFC Sources
254	Chopper - TFR
258	Refrigerator & Electronics - TRW
262	Support Structures
263	Telescope Support Structure
268	Cooler Mount
273	S/C Interface Plate (SIP)
278	Environment Control
292	GROUND SUPPORT EQUIPMENT
380	INTEGRATION AND TEST
381	Instrument Integration
382	Assemble & Align Reimage Tube w/Structure
383	Mount Alignment Cube
384	S/C Simulator Delivered
385	Assemble & Align Reimage Optics
386	Assemble & Align Reimage & Fore Optics
387	Integrate Scanner w/Telescope & Align
388	Image Quality & Boresight Test Warm
389	Image Quality & Boresight Test Cold
390	Shake & Boresight
391	Mount & Align FPA & Lyot Stop
392	Warm Focus/Boresight Test (Ch 10)
393	Engineering Testing & Pre-Calibration



Test & Calibration

ID	Task Discription
396	**Environmental Acceptance Testing**
397	**Thermal & Structural Testing**
398	Full Functional Test
399	Thermal Vacuum Balance
400	Thermal Vacuum Cycle
401	Full Functional Test
402	Sine Burst
403	Abbreviated Function Test
404	Random Vibration
405	Full Functional Test
406	**EMI Tests - NTS**
407	Full Functional Test
408	**CALIBRATION**
409	**FFCOL measurements**
410	IFOV
411	Slit Source
412	Temporal
413	**RSR**
419	**Linearity**
425	Warm
426	**Low Temp BB Measurements**
434	**High Temp BB Measurements**
441	**Sensor Boresite**
442	Pump
443	Warm measurement
444	Cool
445	Cold measurement
446	Warm
447	**Knife Edge Measurement**



SABER Cost Management and Reporting

- **SDL will establish and maintain a time-phased baseline budget by WBS for Phase CD**
- **SDL will continue to submit the NASA 533 series of financial reports and will include subcontractor reports as required**
- **SDL will contunue to submit C/SSR performance reports monthly**
  - C/SSR System approval by DoD, USAF, SDIO/BMDO and NASA
  - Experience on SPIRIT II, SPIRIT III, SPAS III Contracts
  - Performance measurement system reports will provide budgeted costs, actual cost, work performed and variance analysis
  - Work accomplished is measured against the baseline and can be assessed objectively

SABER Funding, Descope & Cost Estimate

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December 12, 1996

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SABER Funding Guidelines

- **"Build to Cost"**
  - SABER Phase C/D cost allocation is $13.3M in FY 1995 dollars
  - SABER re-proposal in August 1996 was $1.3M over guideline
    - Cost growth in science algorithm development & mission operations. software development
  - SABER has submitted a descope plan to APL for consideration by OSS as part of the overall TIMED plan
  - Some cost savings have been realized
  - Some reassignment of cost between Phase C/D and E is being considered at the program level
- **No official funding profile guidelines beyond FY 1997**
  - FY 1997 funding guidelines received (Phase B $230K / Phase C/D $3.3M)
  - Date for availability of C/D funds uncertain (Target is April)
  - SABER has requested early funding of long lead subcontracts

SABER Descope Plan

- **Descope plan consists of 10 descope options**
  - 5 recommended for implementation at this time
  - 1 recommended for study
  - 4 **not** recommended for implementation

SABER Descope Options

No.	Description	Impact	Cost FY 95
1	Reduction of SDL science algorithm development support	Results in a shift of atomic oxygen and atomic hydrogen derivations from routine to analysis products. Development to begin in late in Phase C/D or in Phase E	$150K
2	Reduction of PL science algorithm development support	Shifts development of thermospheric CO_2 retrieval algorithms to Phase E; making it an analysis product. Temperature retrieval technique will be developed by the Associate PI, and Phillips Laboratory support with more detailed models of CO_2 (15 μm) will be brought in later in Phase C/D. There is no reduction in the overall mission science products.	$66.5K
3	Elimination of spare cryogenic cooler	Elimination of the second cooler will necessitate using the flight cooler for developmental testing. Additional documentation and controls will be required to maintain the cooler's flight qualification. This will result in some reduction of the apparent savings ($230K) of eliminating the second cooler. There is also increased risk to the project in the event of a failure of the mission critical flight cooler.	$201K
4	Reduction of SDL on site support for launch	Contractor presence could be reduced or eliminated during launch vehicle integration and launch when SABER hardware is not directly involved. Supplemental support by LaRC personnel could be provided at lower manpower and travel cost to the project. Fewer, less qualified, or no instrument personnel will be present during non-critical evolutions. This could result in delays responding to instrument anomalies, anomalous responses during prelaunch activities	$106K

SABER Descope Options

No.	Description	Impact	Cost
5	Reduction of SDL on site support for spacecraft integration and test	Contractor presence could be reduced or eliminated during periods of spacecraft I&T when SABER hardware is not directly involved. Supplemental support by LaRC personnel could be provided at lower manpower and travel cost to the project. The transportation to per diem ratio for SDL is approximately 6:1 where for LaRC it is about 1:1, so LaRC personnel could be used cost effectively to supplement contractors for short high activity periods. Fewer, less qualified, or no instrument personnel will be present during non-critical I&T evaluations. This could result in delays responding to changing I&T needs, delays responding to instrument anomalies, anomalous responses during I&T being overlooked.	**$106K**
6	Simplify calibration approach	Potential loss of tractability to NIST standard, or reduction in absolute radiometric accuracy	**$20K - $100K**
7	Elimination of the full functional test following instrument shipment to APL	Elimination of the full functional test following shipment of the instrument to APL does not change or reduce the development of hardware, software or test procedures. It eliminates the packaging and shipping of the test chamber and ancillary equipment to APL, manpower to setup and checkout the chamber, the costs for expendables at APL. It would effect the duration but probably not the manpower required to perform the test, and would have only a small effect on the travel costs. Without this test we will have little or no indication of the condition of the instrument cooler, FPA, optics, or blackbody until the spacecraft TV test. We would have little or no chance to recover from a failure that occurred during shipping.	**$20K**
8	Elimination of the 3 mid-wavelength channels 5, 6, 7	Elimination of the 3 mid-wavelength channels 5,6, 7 results in the elimination of H_2O, NO, and CO_2 (4.3 μm) measurements. Significant loss of SABER science. NO - lose measure of largest thermospheric radiative cooling mechanism CO_2 - lose dynamical tracer in thermosphere. NO and CO_2 together with other TIMED data offer first chance to observe thermospheric dynamics (through a tracer), and to provide magnitude of primary radiative cooling mechanism. H_2O - lose key odd-hydrogen source gas in lower mesosphere - seriously impacts ability to further understanding of O_3 chemistry.	**$178K**

SABER Descope Options

No.	Description	Impact	Cost
9	Elimination of short wavelength channel 10	Elimination of channel 10 results in the elimination of $O_2(^1\Delta)$ measurement. Critical reduction of SABER science. Lose daytime O_3 (inferred from $O_2(^1\Delta)$). Lose primary method of inferring atomic oxygen. Lose ability to determine, by measurement, solar heating efficiency in Hartley band of ozone. Lose (because of loss of inferred 0) several chemical heating rate mechanisms in the lower thermosphere. Therefore, lose key information on mesosphere chemistry and energetics	**$167K**
10	Elimination of the 3 short wavelength channels 8,9,10	Elimination of the 3 short wavelength channels 8,9,10 results in the elimination of O_2 and OH measurements. SABER will not meet its own stated minimum science requirements/goals. Devastating science loss. In addition to that stated for $O_2(^1\Delta)$ channel alone, SABER loses capability to infer H concentration. Lose ability to determine, by measurement, the magnitude of chemical heating by $H + O_3 \rightarrow OH^* + O_2$, thought to be single largest source of heating in 80-100 km region. Lose odd-hydrogen chemistry and coupling with O_3. Lose large scale dynamics (planetary waves) visible in global maps of the airglow.	**$302K**

SABER Cost Estimate

- **Phase C/D plans and estimates based on following guidelines and assumptions**
  - Limited FY-1997 C/D funding will be received by January 1997
  - Full FY-1997 C/D funding will be available by April 1, 1997
  - Continuous funding as requested will be received in FY 1998, 1999, & 2000
  - We will deliver the proto-flight SABER instrument to APL by June 1, 1999
  - The TIMED mission will launch January 2000
- **SABER cost based on "bottoms-up" estimate of flight hardware development, technical contract management, and science costs**
- **Parametric cost analysis using the PRICE™ model, compared favorably with "bottom-up" estimates**
- **SDL revised cost estimate based on PDR baseline will be received 45 days after PDR**
- **MS Project schedule and spreadsheet based costing developed during Phase B will allow us to plan "what if" scenarios for changing guidelines**

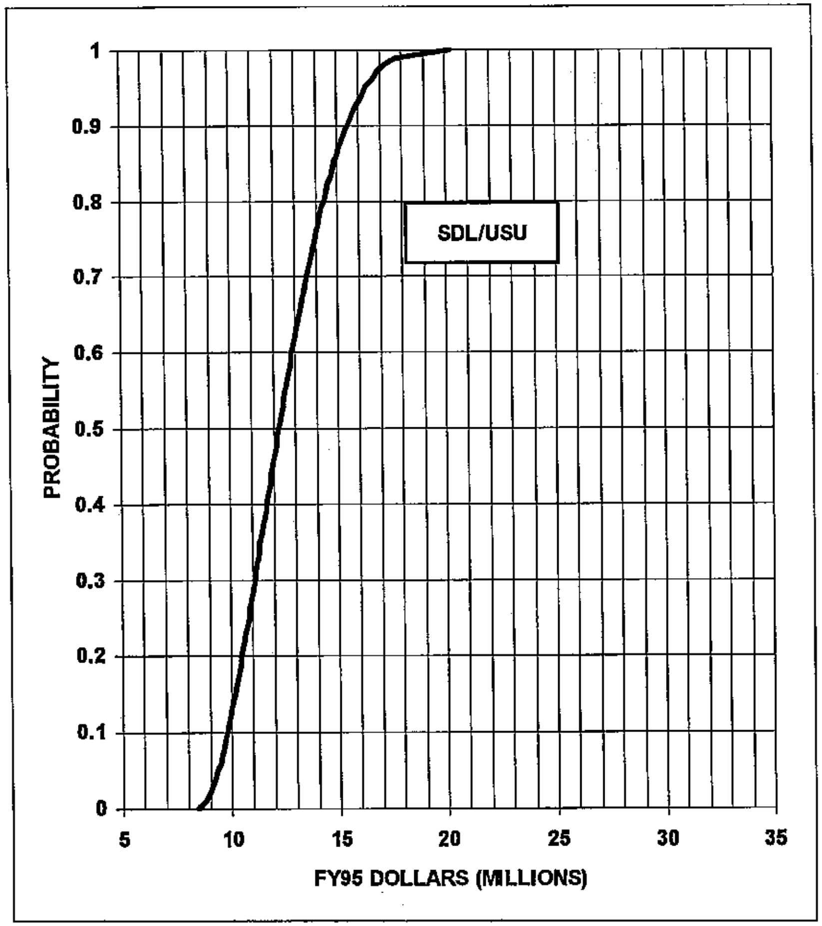
Parametric Model Results

SDL/USU PARAMETRIC COST ESTIMATE

8/27/96

		1995 $	
	Low	**Mean**	**High**
SABER Instrument			
Flight Instrument #1	$5,432,483	$8,572,962	$14,605,600
Flight Software	$0	$0	$0
Total Instrument	$5,432,483	$8,572,962	$14,605,600
GSE			
Hardware	$472,390	$745,475	$1,270,052
Software	$148,023	$479,202	$927,877
Total GSE	$620,412	$1,224,676	$2,197,929
Spacecraft Integration and Test	$213,424	$558,826	$1,243,021
Launch and Flight Operations*	$135,756	$135,756	$135,756
LaRC Science Team/Program Support*	$2,016,000	$2,016,000	$2,016,000
Total Phase C/D	**$8,418,075**	**$12,508,220**	**$20,198,306**

Parametric Model Results



PERCENTILE	SDL/USU
0.90	$15.5
0.80	$14.4
0.70	$13.6
0.60	$12.9
0.50	$12.3
0.40	$11.7
0.30	$11.1
0.20	$10.5
0.10	$9.8

SABER Total Phase C/D Cost

Re-Proposal (FY 1995 Dollars)

	Labor			Other Direct	Project Total
	Civil Service		Contract		
WBS Elements	Hours	Cost	Cost		
1.0 SABER Instrument Contract				$12,557,011	$12,557,011
9.0 Project Management & Engineering Support					
9.1. Project Management & Control	11960	$ -	$ -	$ -	$ -
9.2. Engineering Support	0	$ -	$ -	$ -	$ -
9.2.1Thermal & Cryogenics	5200	$ -	$ -	$ -	$ -
9.2.2 Mechanical, Structural & Test	4160	$ -	$ -	$ -	$ -
9.2.3 Pointing & Controls	3640	$ -	$ -	$ -	$ -
9.2.4 Electronics, Software & GSE	6240	$ -	$ -	$ -	$ -
9.2.5 Calibration	0	$ -	$ 86,000	$ -	$ 86,000
9.2.6 Quality Assurance	1560	$ -	$ -	$ -	$ -
10.0 Flight Data Management					
10.1 Modeling & Algorithm Development					
10.1.1 LaRC Workforce	16640	$ -	$ -	$ -	$ -
10.1.2 HU	0	$ -	$ 153,327	$ -	$ 153,327
10.1.3 SDL Science	0	$ -	$ 225,000	$ -	$ 225,000
10.1.4 Phillips Lab	0	$ -	$ 210,000	$ -	$ 210,000
10.2 Data Retrieval Software Development					
10.2.1 Level 0-1 Software Development	0	$ -	$ 202,000	$ -	$ 202,000
10.2.2 Level 1-2 Software Development	0	$ -	$ 288,000	$ -	$ 288,000
10.2.3 Flight Data Mgmt. Software	0	$ -	$ 120,000	$ -	$ 120,000

SABER Total Phase C/D Cost

Re-Proposal (FY 1995 Dollars)

	Labor			Other Direct	Project Total
	Civil Service		Contract		
WBS Elements	Hours	Cost	Cost		
11.0 Mission Operations					
11.1 Mission Operations Management	0	$ -	$ -	$ -	$ -
11.2 MO Software Development	0	$ -	$ 240,000	$ -	$ 240,000
12.0 Scientific Investigations					
12.1 HU (Russell)	0	$ -	$ -	$ -	$ -
12.2 SDL (Espy)	0	$ -	$ -	$ -	$ -
12.3 SDL (Baker)	0	$ -	$ -	$ -	$ -
12.4 SDL (Ulwick)	0	$ -	$ -	$ -	$ -
12.5 Phillips Lab (Picard)	0	$ -	$ -	$ -	$ -
12.6 NOAA (S. Solomon)	0	$ -	$ -	$ -	$ -
12.7 NCAR (Garcia)	0	$ -	$ -	$ -	$ -
12.8 NCAR (Robel)	0	$ -	$ -	$ -	$ -
12.9 NRL (Siskind)	0	$ -	$ -	$ -	$ -
12.10 W&M (Mlynczak)	0	$ -	$ -	$ -	$ -
Total without LaRC Program Support	49399	$ -	$ 1,524,327	$12,557,011	$14,081,337
Program Support		$ 538,034			$ 538,034
Total Category Cost	49399	$ 538,034	$ 1,524,327	$ 12,557,011	$ 14,619,371

SABER Total Phase C/D Cost

Re-Proposal (Real Year Dollars)

WBS Element	Total FY 1997	Total FY 1998	Total FY 1999	Total FY 2000	Project Total
1.0 SABER Instrument Contract	$ 2,271,614	$ 8,455,381	$ 2,767,787	$ 652,830	$ 14,147,612
9.0. Project Management & Engineering Support					
9.1. Project Management & Control	$ -	$ -	$ -	$ -	$ -
9.2. Engineering Support	$ -	$ -	$ -	$ -	$ -
9.2.1Thermal & Cryogenics	$ -	$ -	$ -	$ -	$ -
9.2.2 Mechanical, Structural & Test	$ -	$ -	$ -	$ -	$ -
9.2.3 Pointing & Controls	$ -	$ -	$ -	$ -	$ -
9.2.4 Electronics, Software & GSE	$ -	$ -	$ -	$ -	$ -
9.2.5 Calibration	$ 32,386	$ 44,865	$ 18,646	$ -	$ 95,896
9.2.6 Quality Assurance	$ -	$ -	$ -	$ -	$ -
10.0 Flight Data Management					
10.1 Modeling & Algorithm Development					
10.1.1 LaRC Workforce	$ -	$ -	$ -	$ -	$ -
10.1.2 HU	$ 49,462	$ 52,161	$ 71,091	$ -	$ 172,714
10.1.3 SDL Science	$ 60,723	$ 84,122	$ 87,402	$ 22,703	$ 254,950
10.1.4 Phillips Lab	$ 56,675	$ 78,514	$ 81,576	$ 21,189	$ 237,953
10.2 Data Retrieval Software Development					
10.2.1 Level 0-1 Software Development	$ 45,340	$ 62,811	$ 93,229	$ 29,060	$ 230,440
10.2.2 Level 1-2 Software Development	$ 77,726	$ 107,676	$ 111,875	$ 29,060	$ 326,336
10.2.3 Flight Data Mgmt. Software	$ 32,386	$ 44,865	$ 46,615	$ 12,108	$ 135,973

SABER Total Phase C/D Cost

Re-Proposal (Real Year Dollars)

WBS Element	Total FY 1997	Total FY 1998	Total FY 1999	Total FY 2000	Project Total
11.0 Mission Operations					
11.0 Mission Operations Management	$ -	$ -	$ -	$ -	$ -
11.2 MO Software Development	$ 64,771	$ 89,730	$ 93,229	$ 24,216	$ 271,947
12.0 Scientific Investigations					
12.1 HU (Russell)	$ -	$ -	$ -	$ -	$ -
12.2 SDL (Espy)	$ -	$ -	$ -	$ -	$ -
12.3 SDL (Baker)	$ -	$ -	$ -	$ -	$ -
12.4 SDL (Ulwick)	$ -	$ -	$ -	$ -	$ -
12.5 Phillips Lab (Picard)	$ -	$ -	$ -	$ -	$ -
12.6 NOAA (S. Solomon)	$ -	$ -	$ -	$ -	$ -
12.7 NCAR (Garcia)	$ -	$ -	$ -	$ -	$ -
12.8 NCAR (Robel)	$ -	$ -	$ -	$ -	
12.9 NRL (Siskind)	$ -	$ -	$ -	$ -	$ -
12.10 W&M (Mlynczak)	$ -	$ -	$ -	$ -	$ -
Total without LaRC Program Support	$ 2,691,082	$ 9,020,123	$ 3,371,450	$ 791,166	$15,873,821
Program Support	$ 152,940	$ 158,203	$ 163,671	$ 139,081	$ 613,895
Total Category Cost	$ 2,844,022	$ 9,178,326	$ 3,535,120	$ 930,247	$ 16,487,716

SABER Total Phase E Cost

Re-proposed (FY 95 Dollars)

	Labor			Other Cost	Phase E Total
	Civil Service		Contract		
WBS Elements	**Hours**	**Cost**	**Cost**		
9.0 Project Management & Engineering Support					
9.1. Project Management & Control	14300	$ -	$ -	$ -	$ -
9.2. Engineering Support					
9.2.1Thermal & Cryogenics	0	$ -	$ -	$ -	$ -
9.2.2 Mechanical, Structural & Test	0	$ -	$ -	$ -	$ -
9.2.3 Pointing & Controls	0	$ -	$ -	$ -	$ -
9.2.4 Electronics, Software & GSE	0	$ -	$ -	$ -	$ -
9.2.5 Calibration	0	$ -	$ -	$ -	$ -
9.2.6 Quality Assurance	0	$ -	$ -	$ -	$ -
10.0 Flight Data Management	0	$ -	$ -	$ -	$ -
10.1 Modeling & Algorithm Development					
10.1.1 LaRC Workforce	15600	$ -	$ -	$ -	$ -
10.1.2 HU	0	$ -	$ -	$ -	$ -
10.1.3 SDL Science	0	$ -	$ -	$ -	$ -
10.1.4 Phillips Lab	0	$ -	$ -	$ -	$ -
10.2 Data Retrieval Software Development					
10.2.1 Level 0-1 Software Development	0	$ -	$ 192,000	$ -	$ 192,000
10.2.2 Level 1-2 Software Development	0	$ -	$ 387,744	$ -	$ 387,744
10.2.3 Flight Data Management Software	0	$ -	$ 161,560	$ -	$ 161,560

SABER Total Phase E Cost

Re-proposed (FY 95 Dollars)

	Labor			Other Cost	Phase E Total
	Civil Service		Contract		
WBS Elements	Hours	Cost	Cost		
11.0 Mission Operations					
11.1 Mission Operations Management	0	$ -	$ 320,000	$ 90,848	$ 410,848
11.2 Mission Operations Software Developmen	0	$ -	$ -	$ -	$ -
12.0 Scientific Investigations					
12.1 HU (Russell)	0	$ -	$ 431,806	$ -	$ 431,806
12.2 SDL (Espy)	0	$ -	$ 192,493	$ -	$ 192,493
12.3 SDL (Baker)	0	$ -	$ 192,493	$ -	$ 192,493
12.4 SDL (Ulwick)	0	$ -	$ 115,496	$ -	$ 115,496
12.5 Phillips Lab (Picard)	0	$ -	$ 307,988	$ -	$ 307,988
12.6 NOAA (S. Solomon)	0	$ -	$ 192,493	$ -	$ 192,493
12.7 NCAR (Garcia)	0	$ -	$ 192,493	$ -	$ 192,493
12.8 NCAR (Robel)	0	$ -	$ 115,496	$ -	$ 115,496
12.9 NRL (Siskind)	0	$ -	$ 192,493	$ -	$ 192,493
12.10 W&M (Mlynczak)	0	$ -	$ 303,176	$ -	$ 303,176
Total without LaRC Program Support	29899	$ -	$ 3,297,730	$ 90,848	$ 3,388,578
Program Support		$ 275,000			$ 275,000
Total Category Cost	29899	$ 275,000	$ 3,297,730	$ 90,848	$ 3,663,578

SABER Total Phase C/D Cost

Proposed Descope & Adjustments (FY 95 Dollars)

	Labor			Other Direct	Project Total
	Civil Service		Contract		
WBS Elements	Hours	Cost	Cost		
1.0 SABER Instrument Contract				$12,071,857	$12,071,857
9.0 Project Management & Engineering Support					
9.1. Project Management & Control	11960	$ -	$ -	$ -	$ -
9.2. Engineering Support	0	$ -	$ -	$ -	$ -
9.2.1Thermal & Cryogenics	5200	$ -	$ -	$ -	$ -
9.2.2 Mechanical, Structural & Test	4160	$ -	$ -	$ -	$ -
9.2.3 Pointing & Controls	3640	$ -	$ -	$ -	$ -
9.2.4 Electronics, Software & GSE	6240	$ -	$ -	$ -	$ -
9.2.5 Calibration	0	$ -	$ 86,000	$ -	$ 86,000
9.2.6 Quality Assurance	1560	$ -	$ -	$ -	$ -
10.0 Flight Data Management					
10.1 Modeling & Algorithm Development					
10.1.1 LaRC Workforce	16640	$ -	$ -	$ -	$ -
10.1.2 HU	0	$ -	$ 107,508	$ -	$ 107,508
10.1.3 SDL Science	0	$ -	$ 75,000	$ -	$ 75,000
10.1.4 Phillips Lab	0	$ -	$ 143,500	$ -	$ 143,500
10.2 Data Retrieval Software Development					
10.2.1 Level 0-1 Software Development	0	$ -	$ 202,000	$ -	$ 202,000
10.2.2 Level 1-2 Software Development	0	$ -	$ 288,000	$ -	$ 288,000
10.2.3 Flight Data Mgmt. Software	0	$ -	$ -	$ -	$ -

SABER Total Phase C/D Cost

Proposed Descope & Adjustments (FY 95 Dollars)

	Project Totals				
	Labor			Other Direct	Project Total
	Civil Service		Contract		
WBS Elements	Hours	Cost	Cost		
11.0 Mission Operations					
11.1 Mission Operations Management	0	$ -	$ -	$ -	$ -
11.2 MO Software Development	0	$ -	$ -	$ -	$ -
12.0 Scientific Investigations					
12.1 HU (Russell)	0	$ -	$ -	$ -	$ -
12.2 SDL (Espy)	0	$ -	$ -	$ -	$ -
12.3 SDL (Baker)	0	$ -	$ -	$ -	$ -
12.4 SDL (Ulwick)	0	$ -	$ -	$ -	$ -
12.5 Phillips Lab (Picard)	0	$ -	$ -	$ -	$ -
12.6 NOAA (S. Solomon)	0	$ -	$ -	$ -	$ -
12.7 NCAR (Garcia)	0	$ -	$ -	$ -	$ -
12.8 NCAR (Robel)	0	$ -	$ -	$ -	$ -
12.9 NRL (Siskind)	0	$ -	$ -	$ -	$ -
12.10 W&M (Mlynczak)	0	$ -	$ -	$ -	$ -
Total without LaRC Program Support	49399	$ -	$ 902,008	$12,071,857	$12,973,865
Program Support		$ 538,034			$ 538,034
Total Category Cost	49399	$ 538,034	$ 902,008	$ 12,071,857	$ 13,511,899

SABER Total Phase C/D Cost

Proposed Descope & Adjustments (Real Year Dollars)

WBS Element	Total FY 1997	Total FY 1998	Total FY 1999	Total FY 2000	Project Total
1.0 SABER Instrument Contract	$ 2,887,127	$ 7,509,639	$ 2,652,985	$ 515,254	$ 13,565,004
9.0. Project Management & Engineering Support					
9.1. Project Management & Control	$ -	$ -	$ -	$ -	$ -
9.2. Engineering Support	$ -	$ -	$ -	$ -	$ -
9.2.1Thermal & Cryogenics	$ -	$ -	$ -	$ -	$ -
9.2.2 Mechanical, Structural & Test	$ -	$ -	$ -	$ -	$ -
9.2.3 Pointing & Controls	$ -	$ -	$ -	$ -	$ -
9.2.4 Electronics, Software & GSE	$ -	$ -	$ -	$ -	$ -
9.2.5 Calibration	$ 32,386	$ 44,865	$ 18,646	$ -	$ 95,896
9.2.6 Quality Assurance	$ -	$ -	$ -	$ -	$ -
10.0 Flight Data Management					
10.1 Modeling & Algorithm Development					
10.1.1 LaRC Workforce	$ -	$ -	$ -	$ -	$ -
10.1.2 HU	$ -	$ 52,161	$ 71,091	$ -	$ 123,252
10.1.3 SDL Science	$ -	$ 58,885	$ 26,221	$ -	$ 85,106
10.1.4 Phillips Lab	$ 34,005	$ 54,959	$ 57,103	$ 16,951	$ 163,019
10.2 Data Retrieval Software Development					
10.2.1 Level 0-1 Software Development	$ 45,340	$ 62,811	$ 93,229	$ 29,060	$ 230,440
10.2.2 Level 1-2 Software Development	$ 77,726	$ 107,676	$ 111,875	$ 29,060	$ 326,336
10.2.3 Flight Data Mgmt. Software	$ -	$ -	$ -	$ -	$ -

SABER Total Phase C/D Cost

Proposed Descope & Adjustments (Real Year Dollars)

WBS Element	Total FY 1997	Total FY 1998	Total FY 1999	Total FY 2000	Project Total
11.0 Mission Operations					
11.0 Mission Operations Management	$ -	$ -	$ -	$ -	$ -
11.2 MO Software Development	$ -	$ -	$ -	$ -	$ -
12.0 Scientific Investigations					
12.1 HU (Russell)	$ -	$ -	$ -	$ -	$ -
12.2 SDL (Espy)	$ -	$ -	$ -	$ -	$ -
12.3 SDL (Baker)	$ -	$ -	$ -	$ -	$ -
12.4 SDL (Ulwick)	$ -	$ -	$ -	$ -	$ -
12.5 Phillips Lab (Picard)	$ -	$ -	$ -	$ -	$ -
12.6 NOAA (S. Solomon)	$ -	$ -	$ -	$ -	$ -
12.7 NCAR (Garcia)	$ -	$ -	$ -	$ -	$ -
12.8 NCAR (Robel)	$ -	$ -	$ -	$ -	
12.9 NRL (Siskind)	$ -	$ -	$ -	$ -	$ -
12.10 W&M (Mlynczak)	$ -	$ -	$ -	$ -	$ -
Total without LaRC Program Support	$ 3,076,583	$ 7,890,997	$ 3,031,149	$ 590,324	$14,589,053
Program Support	$ 152,940	$ 158,203	$ 163,671	$ 139,081	$ 613,895
Total Category Cost	$ 3,229,523	$ 8,049,199	$ 3,194,820	$ 729,406	$ 15,202,948

SABER Reproposal (8/31/96)SDL FY 95

	Cost Component											Total WBS Element Cost
	Labor				Other Direct Cost							
	Staff		Student		Travel	Parts & Materials	Machine Shop	Subcontracts		Other	Equipment	
WBS Elements	Hours	Cost	Hours	Cost				< $25,000	> $25,000			
1.1 Program Management & Control	8970	$ 250,341	0	$ -	$ 257,607	$ -	$ -	$ -	$ -	$ 30,238	$ -	$ 538,186
2.1 System Engineering	3120	$ 98,093	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 8,465	$ -	$ 106,559
2.2 Analysis												
2.2.1 Thermal Analysis	3233	$ 120,900	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 10,434	$ -	$ 131,334
2.2.2 Structural Analysis	1768	$ 76,814	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 6,629	$ -	$ 83,443
2.2.3 Optical & Radiometric Analysis	1560	$ 67,817	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 5,853	$ -	$ 73,669
2.3 Documentation	13017	$ 330,588	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 28,530	$ -	$ 359,118
2.4 Calibration Planning	3744	$ 76,473	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 6,600	$ -	$ 83,072
2.5 Product Assurance	2687	$ 54,897	4853	$ 28,143	$ -	$ -	$ -	$ -	$ -	$ 7,166	$ -	$ 90,206
2.6 Contamination Control	1872	$ 58,861	1647	$ 12,179	$ -	$ 41,117	$ -	$ -	$ -	$ 6,131	$ -	$ 118,287
2.7 Science Support	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3.1 Breadboards	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3.1.1 FPA Breadboard	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3.1.2 Scanner Breadboard	1560	$ 29,153	0	$ -	$ -	$ 4,826	$ 20,077	$ -	$ -	$ 2,516	$ -	$ 56,572
3.1.3 Electronic/Detector Breadboard	1343	$ 24,004	0	$ -	$ -	$ 4,826	$ 3,346	$ -	$ -	$ 2,159	$ -	$ 34,335
3.1.4 Mass Model & Cooler Mount	1387	$ 24,886	0	$ -	$ -	$ -	$ 20,077	$ -	$ -	$ 21,179	$ -	$ 66,142
3.2 Protoflight Instrument												
3.2.1 Electronics												
3.2.1.1 Analog Electronics	3709	$ 85,393	0	$ -	$ -	$ 73,892	$ -	$ -	$ -	$ 7,369	$ -	$ 166,654
3.2.1.2 Digital Electronics	4160	$ 73,058	0	$ -	$ -	$ 44,346	$ -	$ -	$ -	$ 6,305	$ -	$ 123,708
3.2.1.3 Scan Mirror Electronics	1993	$ 42,865	0	$ -	$ -	$ 14,782	$ -	$ -	$ -	$ 3,699	$ -	$ 61,346
3.2.1.4 Interconnecting & Packaging	2392	$ 38,675	0	$ -	$ -	$ 14,782	$ 13,402	$ -	$ -	$ 14,226	$ -	$ 81,085
3.2.2 Telescope Assembly												
3.2.2.1 Reimaging & Fore Optics	6361	$ 131,086	0	$ -	$ -	$ 6,877	$ 53,606	$ -	$ -	$ 16,757	$ -	$ 208,326
3.2.2.2 Mirrors - SSG	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 282,626	$ -	$ -	$ 282,626
3.2.2.3 Scanner Assembly	3189	$ 55,179	0	$ -	$ -	$ 5,666	$ 80,409	$ -	$ -	$ 10,206	$ -	$ 151,461
3.2.2.3.9 BEI - Scanner	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 160,781	$ -	$ -	$ 160,781
3.2.2.4 FPA Assembly												
3.2.2.4.1 Detectors - EG&G	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 827,195	$ -	$ -	$ 827,195
3.2.2.4.2 Optical Filters - OCLI	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 646,100	$ -	$ -	$ 646,100
3.2.2.4.3 FPA Assembly - SDL	2825	$ 62,179	0	$ -	$ -	$ 6,216	$ 26,803	$ -	$ -	$ 5,366	$ -	$ 100,565
3.2.2.5 Baffle Assembly	1976	$ 42,161	0	$ -	$ -	$ 13,308	$ 26,803	$ -	$ -	$ 9,083	$ -	$ 91,355
3.2.2.6 IFC Sources	2687	$ 44,143	0	$ -	$ -	$ 5,862	$ 13,402	$ -	$ -	$ 3,810	$ -	$ 67,216
3.2.2.7 Chopper - TFR	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 65,283	$ -	$ -	$ 65,283
3.2.3 Cooler Assembly												
3.2.3.1 Refrigerator - TRW	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 1,187,566	$ -	$ -	$ 1,187,566
3.2.3.2 Cooler Mount	1924	$ 42,168	0	$ -	$ -	$ -	$ 26,803	$ -	$ -	$ 9,083	$ -	$ 78,054
3.2.4 Support Structure												
3.2.4.1 Composite Structure - COI	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 136,690	$ -	$ -	$ 136,690
3.2.4.2 Support Structure - SDL	4091	$ 76,541	0	$ -	$ -	$ 3,082	$ 20,102	$ -	$ -	$ 17,494	$ -	$ 117,220
3.2.5 Environmental Control	1387	$ 22,611	0	$ -	$ -	$ 25,217	$ -	$ -	$ -	$ 1,951	$ -	$ 49,779
4.1 Electrical GSE	607	$ 9,256	0	$ -	$ -	$ 85,076	$ -	$ -	$ -	$ 171	$ 30,405	$ 124,908
4.2 GSE Software	1820	$ 37,074	3120	$ 23,024	$ -	$ 26,462	$ -	$ -	$ -	$ 5,186	$ -	$ 91,746

	Cost Component											Total WBS Element Cost
	Labor				Other Direct Cost							
	Staff		Student		Travel	Parts & Materials	Machine Shop	Subcontracts		Other	Equipment	
WBS Elements	Hours	Cost	Hours	Cost				< $25,000	> $25,000			
4.3 Mechanical GSE												
4.3.1 GSE Test Chamber	4437	$ 79,880	0	$ -	$ -	$ 133,487	$ 56,940	$ -	$ -	$ 6,894	$ -	$ 277,201
4.3.2 GSE Blackbodies	5200	$ 95,436	0	$ -	$ -	$ 72,653	$ 43,555	$ -	$ -	$ 8,236	$ -	$ 219,880
4.3.3 GSE Full Field Collimator	3033	$ 54,412	0	$ -	$ -	$ 102,458	$ 30,153	$ -	$ -	$ 4,696	$ -	$ 191,720
4.3.4 GSE Shipping Container & Handling Fixtures	1369	$ 24,661	0	$ -	$ -	$ 11,806	$ -	$ -	$ -	$ 13,017	$ -	$ 49,484
5.1 Integration & Test	33019	$ 629,996	2427	$ 17,952	$ -	$ 12,964	$ 40,201	$ -	$ -	$ 77,693	$ -	$ 778,805
5.2 Environmental Test												
5.2.1 Environmental Testing (In-house)	520	$ 9,306	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 17,132	$ -	$ 26,438
5.2.2 EMI Testing - NTS	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 15,703	$ -	$ -	$ 15,703
6.0 Calibration	7696	$ 159,073	2080	$ 15,421	$ -	$ 16,286	$ -	$ -	$ -	$ 15,059	$ -	$ 205,838
7.0 S/C Integration & Test	5685	$ 131,081	0	$ -	$ 11,208	$ -	$ -	$ -	$ -	$ 11,312	$ -	$ 153,601
8.0 Launch Support	2756	$ 64,838	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 5,596	$ -	$ 70,434
Unburdened Total	147097	$ 3,223,898	14126	$ 96,718	$ 268,815	$ 725,991	$ 475,680	$ -	$ 3,321,942	$ 406,241	$ 30,405	$ 8,549,691
Fringe Benefits	0	$ 1,163,818	0	$ 3,869	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,167,687
Program Support 2.49%	0	$ 109,254	0	$ 2,505	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 111,759
Program Support 1.86%	0	$ 81,612	0	$ 1,871	$ -	$ -	$ -	$ -	$ 61,788	$ -	$ -	$ 145,271
Overhead @ 39%	0	$ 1,785,647	0	$ 40,935	$ 104,838	$ 283,137	$ 185,515	$ -	$ 24,097	$ 158,434	$ -	$ 2,582,604
Total Category Cost	0	$ 6,364,229	0	$ 145,898	$ 373,654	$ 1,009,128	$ 661,195	$ -	$ 3,407,828	$ 564,675	$ 30,405	$ 12,557,011

DRAFT SABER Descope (11/13/96)SDL FY 95

	Cost Component											Total WBS Element Cost
	Labor				Other Direct Cost							
	Staff		Student		Travel	Parts & Materials	Machine Shop	Subcontracts		Other	Equipment	
WBS Elements	Hours	Cost	Hours	Cost				< $25,000	> $25,000			
1.1 Program Management & Control	8970	$ 250,341	0	$ -	$ 193,684	$ -	$ -	$ -	$ -	$ 30,238	$ -	$ 474,262
2.1 System Engineering	3120	$ 98,093	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 8,465	$ -	$ 106,559
2.2 Analysis												
2.2.1 Thermal Analysis	3233	$ 120,900	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 10,434	$ -	$ 131,334
2.2.2 Structural Analysis	1768	$ 76,814	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 6,629	$ -	$ 83,443
2.2.3 Optical & Radiometric Analysis	1560	$ 67,817	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 5,853	$ -	$ 73,669
2.3 Documentation	13017	$ 330,588	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 28,530	$ -	$ 359,118
2.4 Calibration Planning	3744	$ 76,473	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 6,600	$ -	$ 83,072
2.5 Product Assurance	2687	$ 54,897	4853	$ 28,143	$ -	$ -	$ -	$ -	$ -	$ 7,166	$ -	$ 90,206
2.6 Contamination Control	1872	$ 58,861	1647	$ 12,179	$ -	$ 41,117	$ -	$ -	$ -	$ 6,131	$ -	$ 118,287
2.7 Science Support	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3.1 Breadboards	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3.1.1 FPA Breadboard	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3.1.2 Scanner Breadboard	1560	$ 29,153	0	$ -	$ -	$ 4,826	$ 20,077	$ -	$ -	$ 2,516	$ -	$ 56,572
3.1.3 Electronic/Detector Breadboard	1343	$ 24,004	0	$ -	$ -	$ 4,826	$ 3,346	$ -	$ -	$ 2,159	$ -	$ 34,335
3.1.4 Mass Model & Cooler Mount	1387	$ 24,886	0	$ -	$ -	$ -	$ 20,077	$ -	$ -	$ 21,179	$ -	$ 66,142
3.2 Protoflight Instrument												
3.2.1 Electronics												
3.2.1.1 Analog Electronics	3709	$ 85,393	0	$ -	$ -	$ 73,892	$ -	$ -	$ -	$ 7,369	$ -	$ 166,654
3.2.1.2 Digital Electronics	4160	$ 73,058	0	$ -	$ -	$ 44,346	$ -	$ -	$ -	$ 6,305	$ -	$ 123,708
3.2.1.3 Scan Mirror Electronics	1993	$ 42,865	0	$ -	$ -	$ 14,782	$ -	$ -	$ -	$ 3,699	$ -	$ 61,346
3.2.1.4 Interconnecting & Packaging	2392	$ 38,675	0	$ -	$ -	$ 14,782	$ 13,402	$ -	$ -	$ 14,226	$ -	$ 81,085
3.2.2 Telescope Assembly												
3.2.2.1 Reimaging & Fore Optics	6361	$ 131,086	0	$ -	$ -	$ 6,877	$ 53,606	$ -	$ -	$ 16,757	$ -	$ 208,326
3.2.2.2 Mirrors - SSG	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 282,626	$ -	$ -	$ 282,626
3.2.2.3 Scanner Assembly	3189	$ 55,179	0	$ -	$ -	$ 5,666	$ 80,409	$ -	$ -	$ 10,206	$ -	$ 151,461
3.2.2.3.9 BEI - Scanner	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 160,781	$ -	$ -	$ 160,781
3.2.2.4 FPA Assembly												
3.2.2.4.1 Detectors - EG&G	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 848,057	$ -	$ -	$ 848,057
3.2.2.4.2 Optical Filters - OCLI	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 646,100	$ -	$ -	$ 646,100
3.2.2.4.3 FPA Assembly - SDL	2825	$ 62,179	0	$ -	$ -	$ 6,216	$ 26,803	$ -	$ -	$ 5,366	$ -	$ 100,565
3.2.2.5 Baffle Assembly	1976	$ 42,161	0	$ -	$ -	$ 13,308	$ 26,803	$ -	$ -	$ 9,083	$ -	$ 91,355
3.2.2.6 IFC Sources	2687	$ 44,143	0	$ -	$ -	$ 5,862	$ 13,402	$ -	$ -	$ 3,810	$ -	$ 67,216
3.2.2.7 Chopper - TFR	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 65,283	$ -	$ -	$ 65,283
3.2.3 Cooler Assembly												
3.2.3.1 Refrigerator - TRW	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 991,421	$ -	$ -	$ 991,421
3.2.3.2 Cooler Mount	1924	$ 42,168	0	$ -	$ -	$ -	$ 26,803	$ -	$ -	$ 9,083	$ -	$ 78,054
3.2.4 Support Structure												
3.2.4.1 Composite Structure - COI	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3.2.4.2 Support Structure - SDL	4091	$ 76,541	0	$ -	$ -	$ 36,908	$ 20,102	$ -	$ -	$ 17,494	$ -	$ 151,046
3.2.5 Environmental Control	1387	$ 22,611	0	$ -	$ -	$ 25,217	$ -	$ -	$ -	$ 1,951	$ -	$ 49,779
4.1 Electrical GSE	607	$ 9,256	0	$ -	$ -	$ 85,076	$ -	$ -	$ -	$ 171	$ 30,405	$ 124,908
4.2 GSE Software	1820	$ 37,074	3120	$ 23,024	$ -	$ 26,462	$ -	$ -	$ -	$ 5,186	$ -	$ 91,746

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	Cost Component											Total WBS Element Cost
	Labor				Other Direct Cost							
	Staff		Student		Travel	Parts & Materials	Machine Shop	Subcontracts		Other	Equipment	
WBS Elements	Hours	Cost	Hours	Cost				< $25,000	> $25,000			
4.3 Mechanical GSE												
4.3.1 GSE Test Chamber	4437	$ 79,880	0	$ -	$ -	$ 133,487	$ 56,940	$ -	$ -	$ 6,894	$ -	$ 277,201
4.3.2 GSE Blackbodies	5200	$ 95,436	0	$ -	$ -	$ 72,653	$ 43,555	$ -	$ -	$ 8,236	$ -	$ 219,880
4.3.3 GSE Full Field Collimator	3033	$ 54,412	0	$ -	$ -	$ 102,458	$ 30,153	$ -	$ -	$ 4,696	$ -	$ 191,720
4.3.4 GSE Shipping Container & Handling Fixtures	1369	$ 24,661	0	$ -	$ -	$ 11,806	$ -	$ -	$ -	$ 13,017	$ -	$ 49,484
5.1 Integration & Test	33019	$ 629,996	2427	$ 17,952	$ -	$ 12,964	$ 40,201	$ -	$ -	$ 77,693	$ -	$ 778,805
5.2 Environmental Test												
5.2.1 Environmental Testing (In-house)	520	$ 9,306	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 17,132	$ -	$ 26,438
5.2.2 EMI Testing - NTS	0	$ -	0	$ -	$ -	$ -	$ -	$ -	$ 15,703	$ -	$ -	$ 15,703
6.0 Calibration	7696	$ 159,073	2080	$ 15,421	$ -	$ 16,286	$ -	$ -	$ -	$ 15,059	$ -	$ 205,838
7.0 S/C Integration & Test	4125	$ 99,144	0	$ -	$ 11,208	$ -	$ -	$ -	$ -	$ 8,556	$ -	$ 118,909
8.0 Launch Support	1326	$ 38,170	0	$ -	$ -	$ -	$ -	$ -	$ -	$ 3,294	$ -	$ 41,464
Unburdened Total	144107	$ 3,165,293	14126	$ 96,718	$ 204,892	$ 759,817	$ 475,680	$ -	$ 3,009,971	$ 401,183	$ 30,405	$ 8,143,959
Fringe Benefits	0	$ 1,142,276	0	$ 3,869	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,146,145
Program Support 2.49%	0	$ 107,258	0	$ 2,505	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 109,763
Program Support 1.86%	0	$ 80,121	0	$ 1,871	$ -	$ -	$ -	$ -	$ 55,985	$ -	$ -	$ 137,977
Overhead @ 39%	0	$ 1,753,030	0	$ 40,935	$ 79,908	$ 296,329	$ 185,515	$ -	$ 21,834	$ 156,462	$ -	$ 2,534,013
Total Category Cost	0	$ 6,247,978	0	$ 145,898	$ 284,799	$ 1,056,146	$ 661,195	$ -	$ 3,087,791	$ 557,845	$ 30,405	$ 12,071,857