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PERKIN-ELMER
OPTICAL TECHNOLOGY DIVISION

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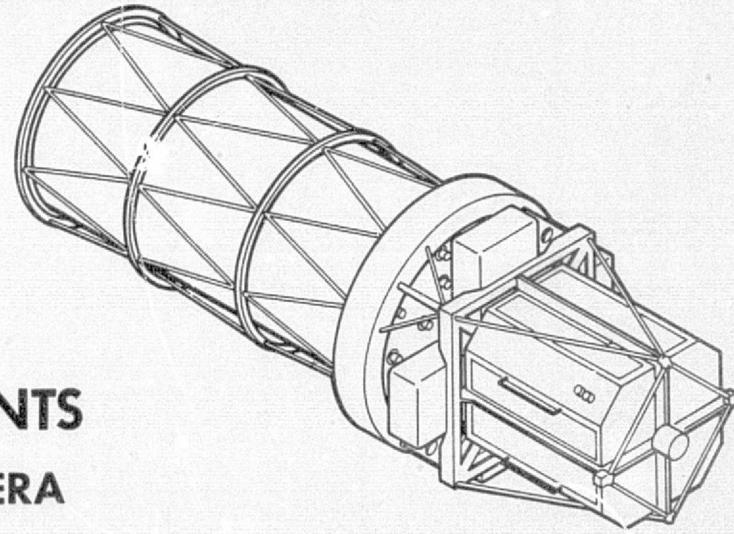
SPACE TELESCOPE PHASE B DEFINITION STUDY FINAL REPORT



VOLUME II-A SCIENCE INSTRUMENTS

f48/96 PLANETARY CAMERA

APRIL 1976

GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

CONTRACT NAS8-29948

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Abstract:

Final Report for the analysis and preliminary design of the f48/96 Planetary Camera for Space Telescope. Camera design for application to the axial module position of the Optical Telescope Assembly.

FOREWORD

This Final Report Volume II-A documents and summarizes, as required by Marshall Space Flight Center (MSFC) Data Procurement Document 395-MA-06, the analysis and preliminary design of an f48/96 Planetary Camera for the Space Telescope. The Final Report also includes Volume I, Executive Summary; Volume II-B, Preliminary Design of the Optical Telescope Assembly; Volume III, Safety Analysis. The results of the Phase C/D Program planning are contained in Perkin-Elmer Reports ER-317, ER-318 and ER-319.

This Science Instrument is designed for an axial module position in the Optical Telescope Assembly. The design was accomplished as part of the ST Phase B Definition Study, Optical Telescope Assembly/Science Instruments for NASA, Marshall Space Flight Center under Contract NAS8-29948. Technical direction for the Science Instrument design was provided by the Goddard Space Flight Center.

Volume II-A reports on the following Science Instruments for Space Telescope:

- f24 Field Camera
- f48/96 Planetary Camera
- Faint Object Spectrograph
- IR Photometer
- Astrometer
- High Speed Point/Area Photometer
- High Resolution Spectrograph.

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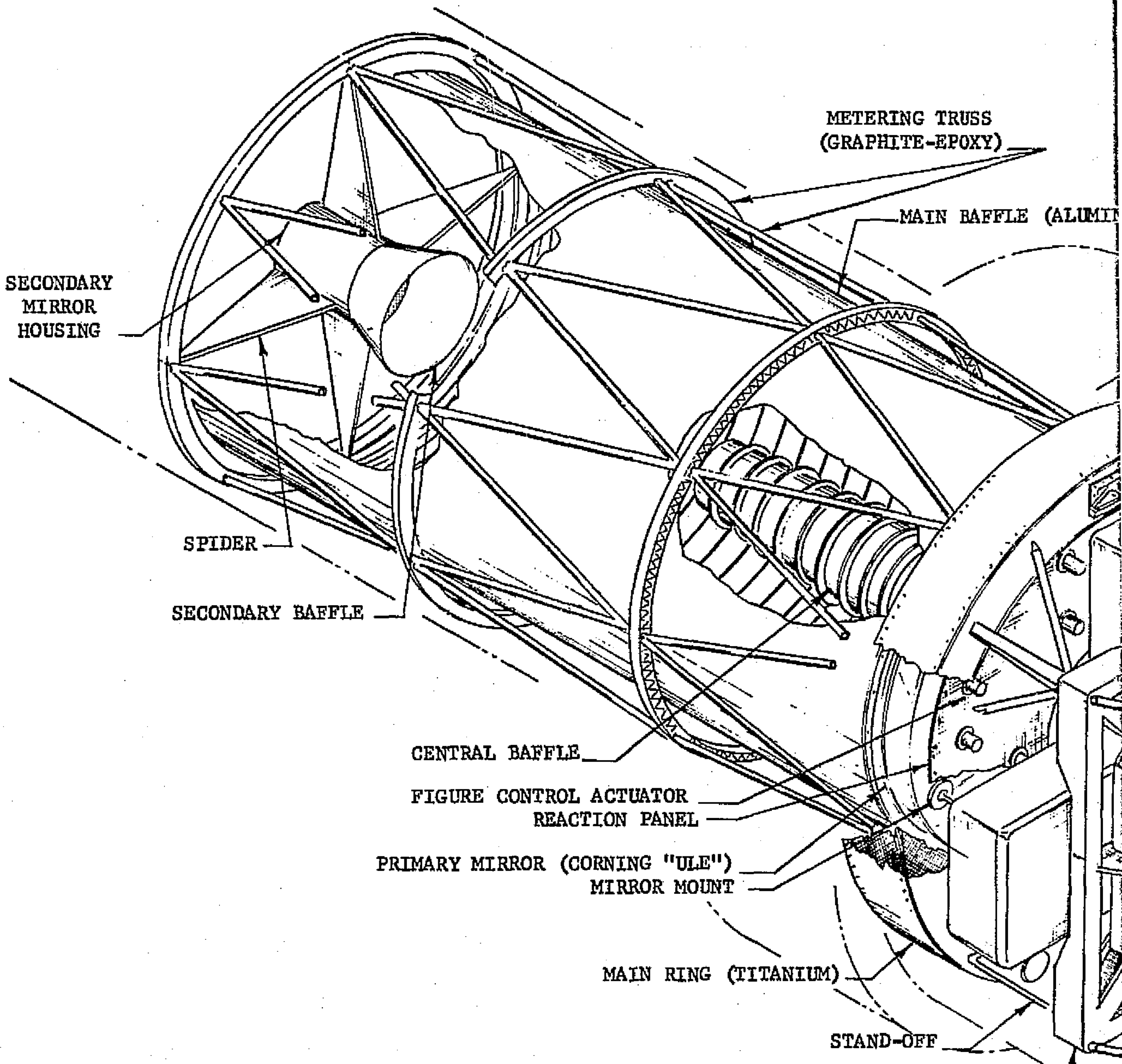

APERTURE	2.4 m	(94.5 IN.)
f/NO.	24	
OVERALL LENGTH	8.8 m	(347 IN.)
MAXIMUM DIAMETER	3 m	(118 IN.)
WEIGHT	2570 Kg	(5665 LB)

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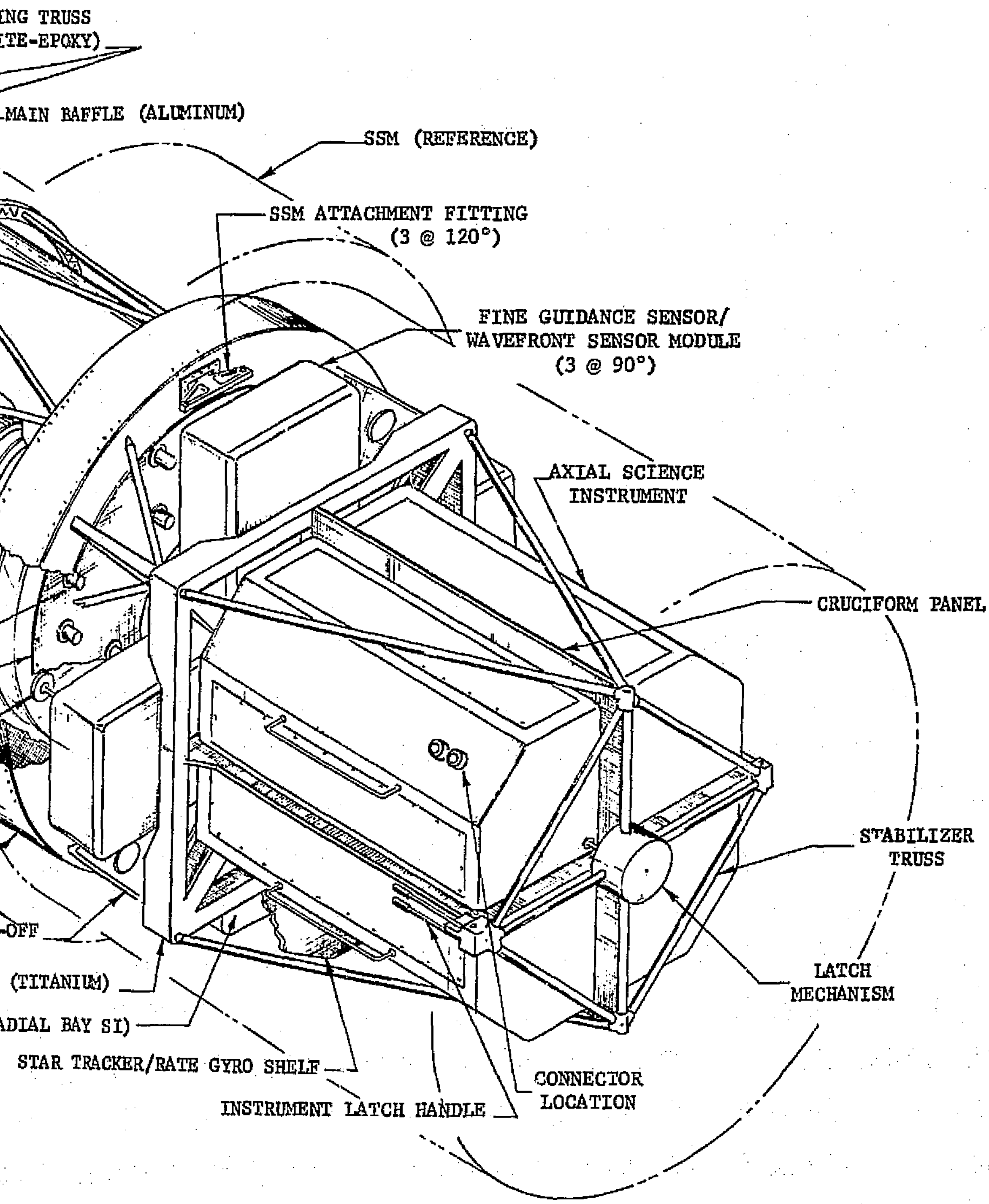

Optical Telescope Assembly
With Science Instruments

FOLDOUT FRAME 2

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GLOSSARY

BFL	Back Focal Length
CCD	Charged Coupled Device
EFL	Effective Focal Length
FGS	Fine Guidance Sensor
FID	Final Instrument Definition (document)
FOS	Faint Object Spectrograph
FOV	Field of View
FPS	Focal Plane Structure
GSFC	Goddard Space Flight Center
HRC	High Resolution Camera
HRS	High Resolution Spectrograph
HSAP	High Speed Point/Area Photometer
LED	Light Emitting Diode
MSFC	Marshall Space Flight Center
MTF	Modulation Transfer Function
opd	Optical Path Difference
OTA	Optical Telescope Assembly
OTA/SI	OTA with Integrated Science Instruments
PCS	Pointing Control System
PDS	Power Distribution System

GLOSSARY (Continued)

SI	Science Instrument
SSM	Support Systems Module
ST	Space Telescope
TCS	Temperature Control System
TSU	Thermal/Structural Unit

SECTION 1
REQUIREMENTS

1.1 Performance Requirements

The Planetary Camera is a high-resolution imaging camera, designed to operate with high photometric accuracy (<1%) over a broad spectral region extending from the near U.V. (180 nm) to the near I.R. (1,200 nm). The wavelength region of operation is selected by a filter wheel assembly containing up to 28 filters which may be used singly or in limited combinations. Exposure times of from 10 msec to 5 minutes are controlled by an electrically operated shutter.

The significant performance requirements are tabulated in Table 1-1.

1.2 Interface Requirements

The Planetary Camera is housed in one of the four "axial" bay modules of the OTA; the SI designs are modular so the specific location need not be defined for this design. The location of the axial modules with respect to the OTA and radial bay science instrument (f24 Field Camera) is shown in Figures 1-1 and 1-2. Overall envelope dimensions for the axial module are given in Figure 1-3.

The region of the OTA focal plane allocated to the axial bay instruments is shown in Figure 1-4. The f48/96 Planetary Camera will utilize one of the four fields. The OTA focal plane image characteristics over this region are given in Figure 1-5. Other pertinent design requirements affecting the preliminary design of the Planetary Camera are summarized in Table 1-2.

TABLE 1-1

f48/96 PLANETARY CAMERA PERFORMANCE REQUIREMENTS

Angular Field of View	(f/48) (f/96)	17 x 17 arc-sec 8.5 x 8.5 arc-sec
Angular Resolution	(f/48) (f/96)	0.1 arc-sec Diffraction limited
Positional Accuracy within FOV*		1 arc-sec (rms)
Stability of Line of Sight*		± 0.007 arc-sec
Overall Wavelength Range		180 nm - 1200 nm
Spectral Resolution		$5 \leq \lambda/\Delta\lambda \leq 100$ (28 filters)
Overall Dynamic Range		$(m_V - 3$ to $m_V 16)/\widehat{sec}^2$
Dynamic Range (per Observation)		3000
Minimum Detectable Energy		$m_V 23/\widehat{sec}^2$
Photometric Accuracy		<1%
Exposure Time		10 ms - 5 minutes
Calibration Stability		1% (Tungsten)
Detector		CCD (400 x 400 Pixel - nominal)

*These requirements do not impact SI design. They are translated into OTA and SSM requirements.

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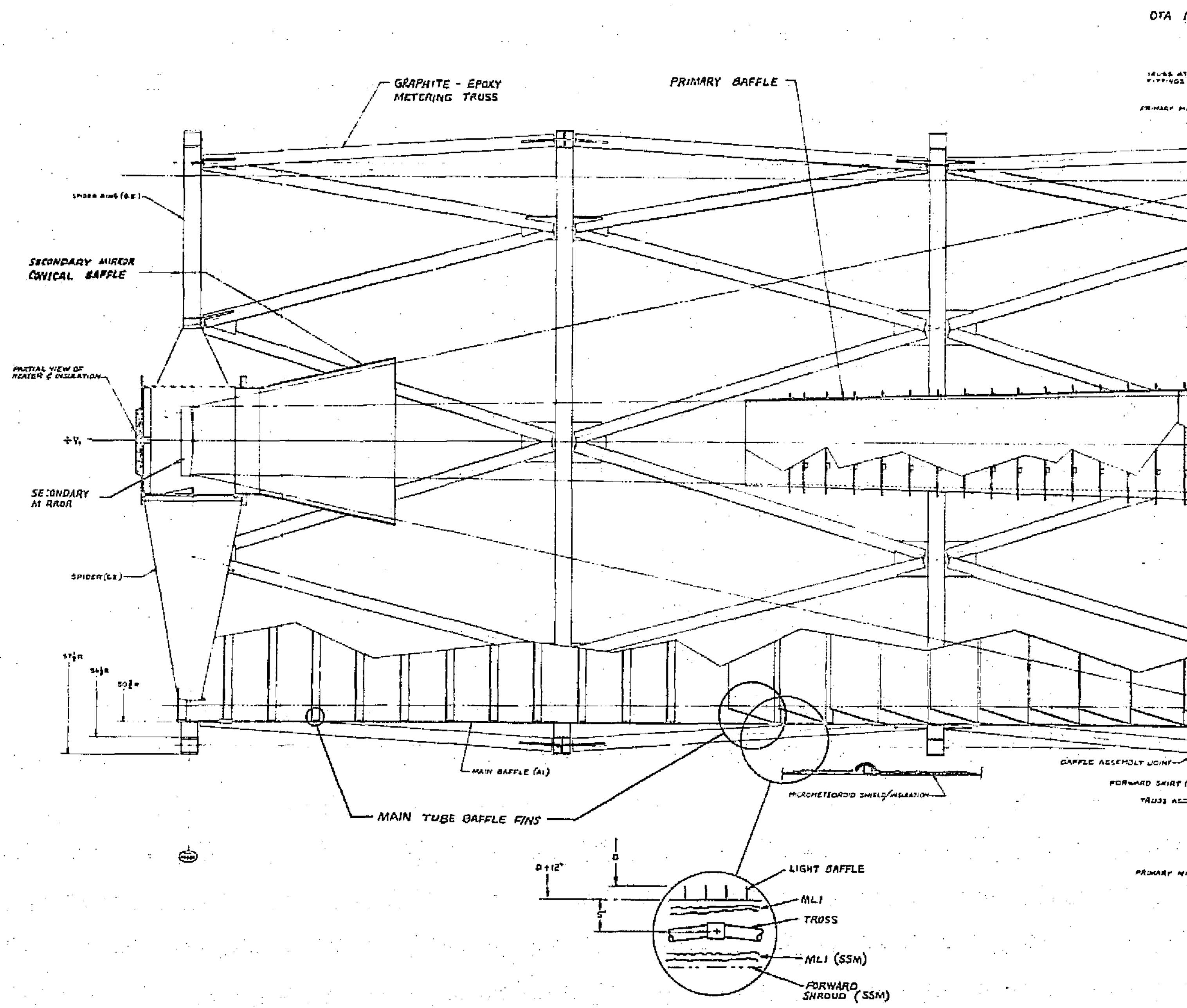

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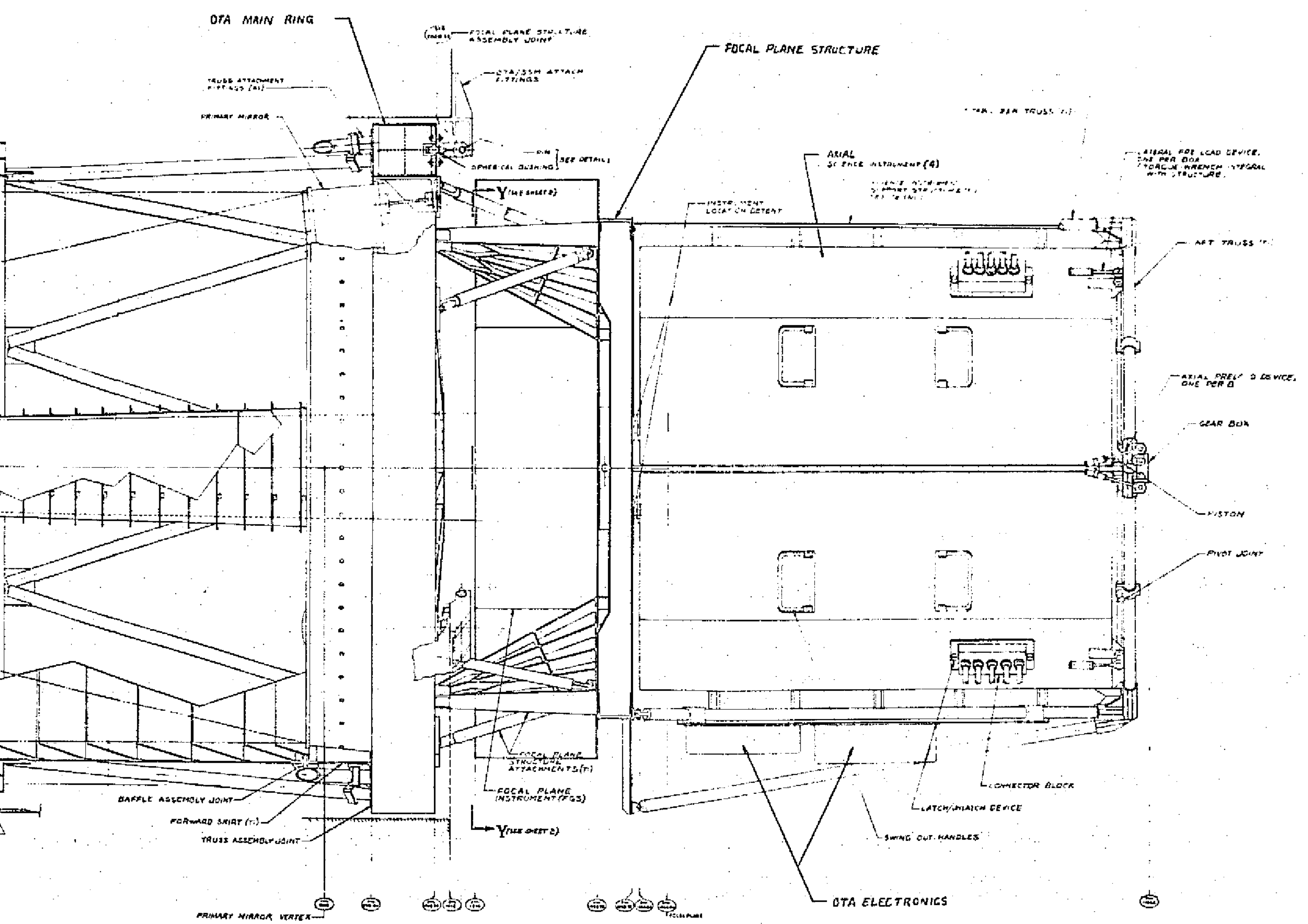

Figure 1-1. 2.4 Meter OTA/SI Conf' uration

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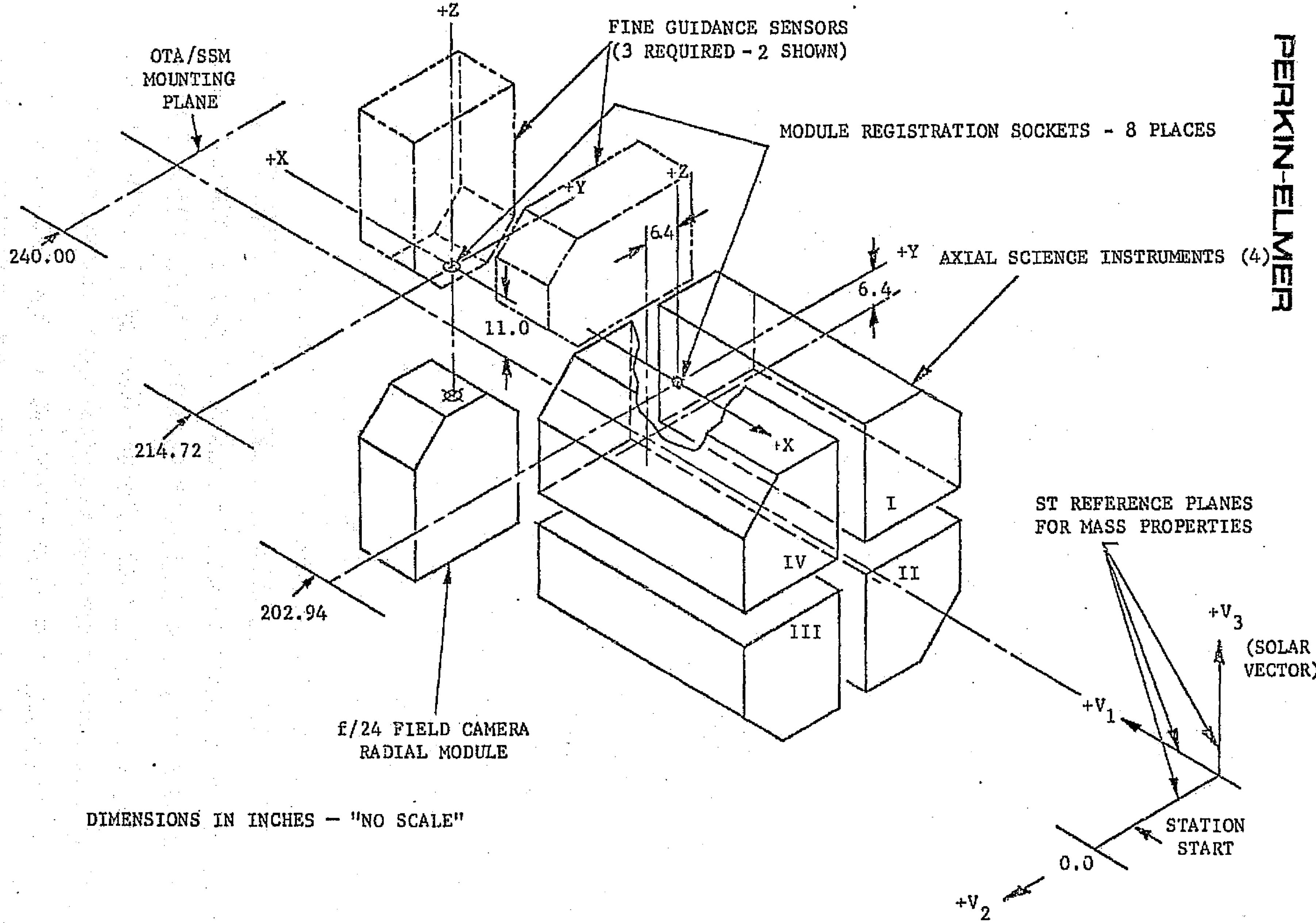


DIMENSIONS IN INCHES — "NO SCALE"

Figure 1-2. SI Radial and Axial Module Orientation

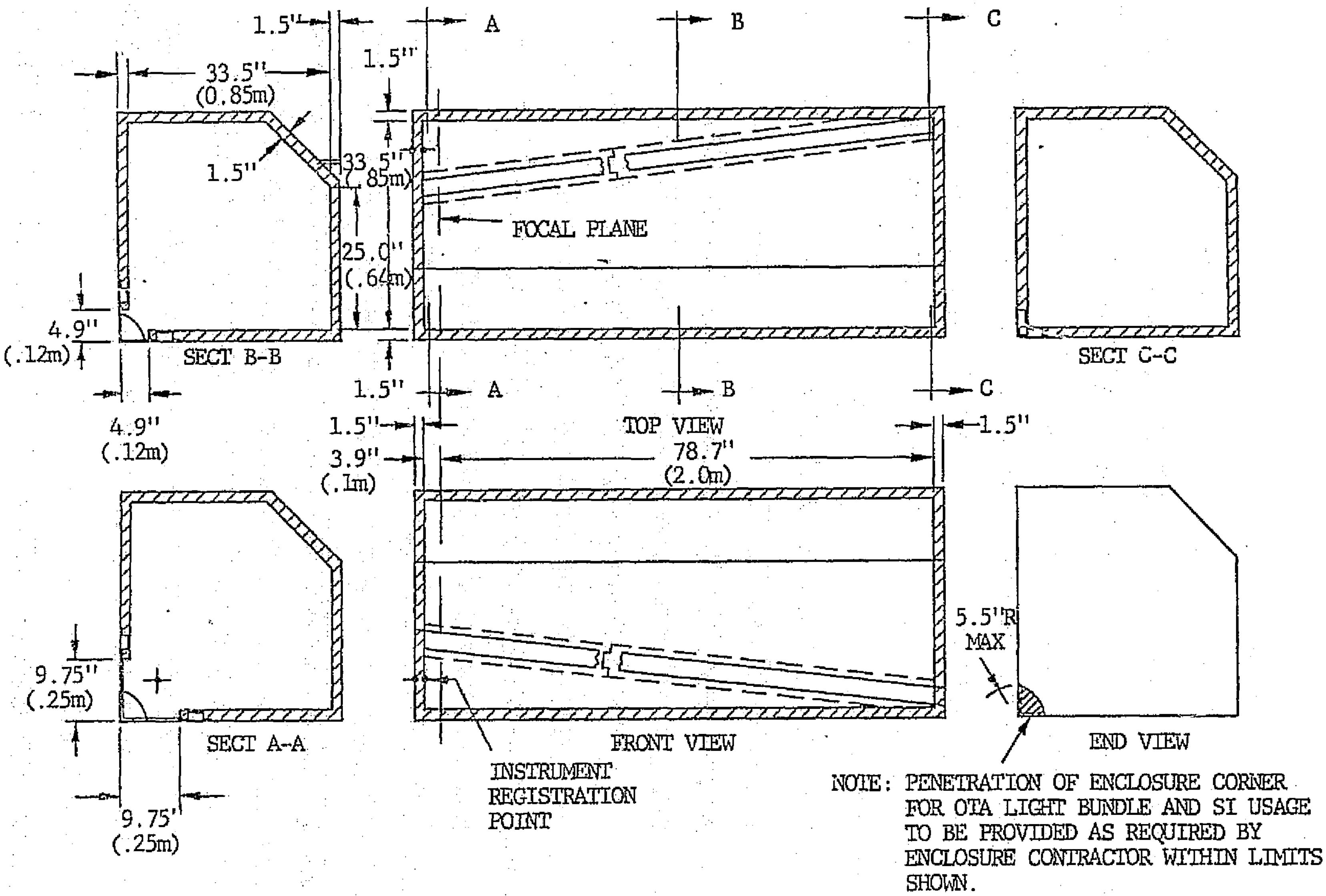


Figure 1-3. Axial SI Enclosure Interior Envelope

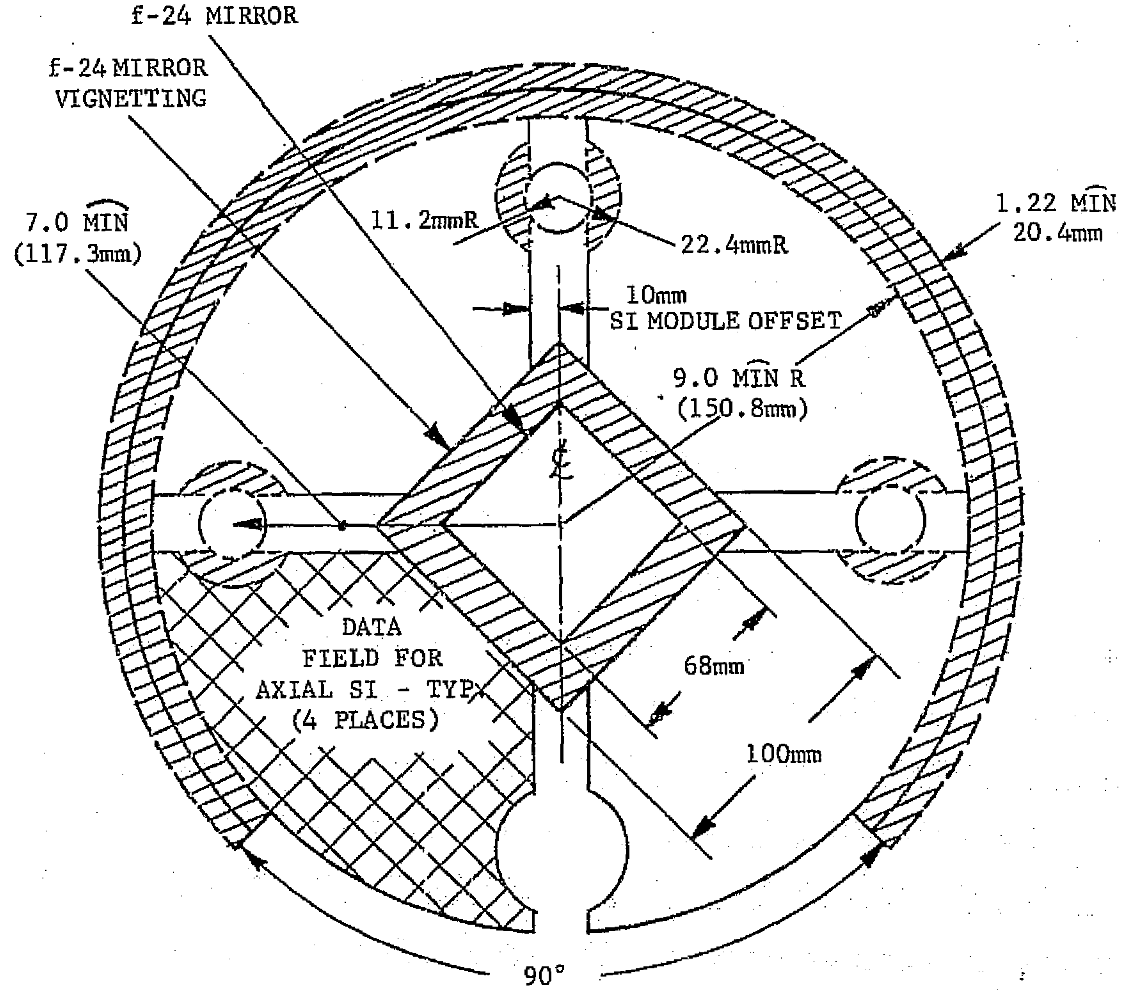
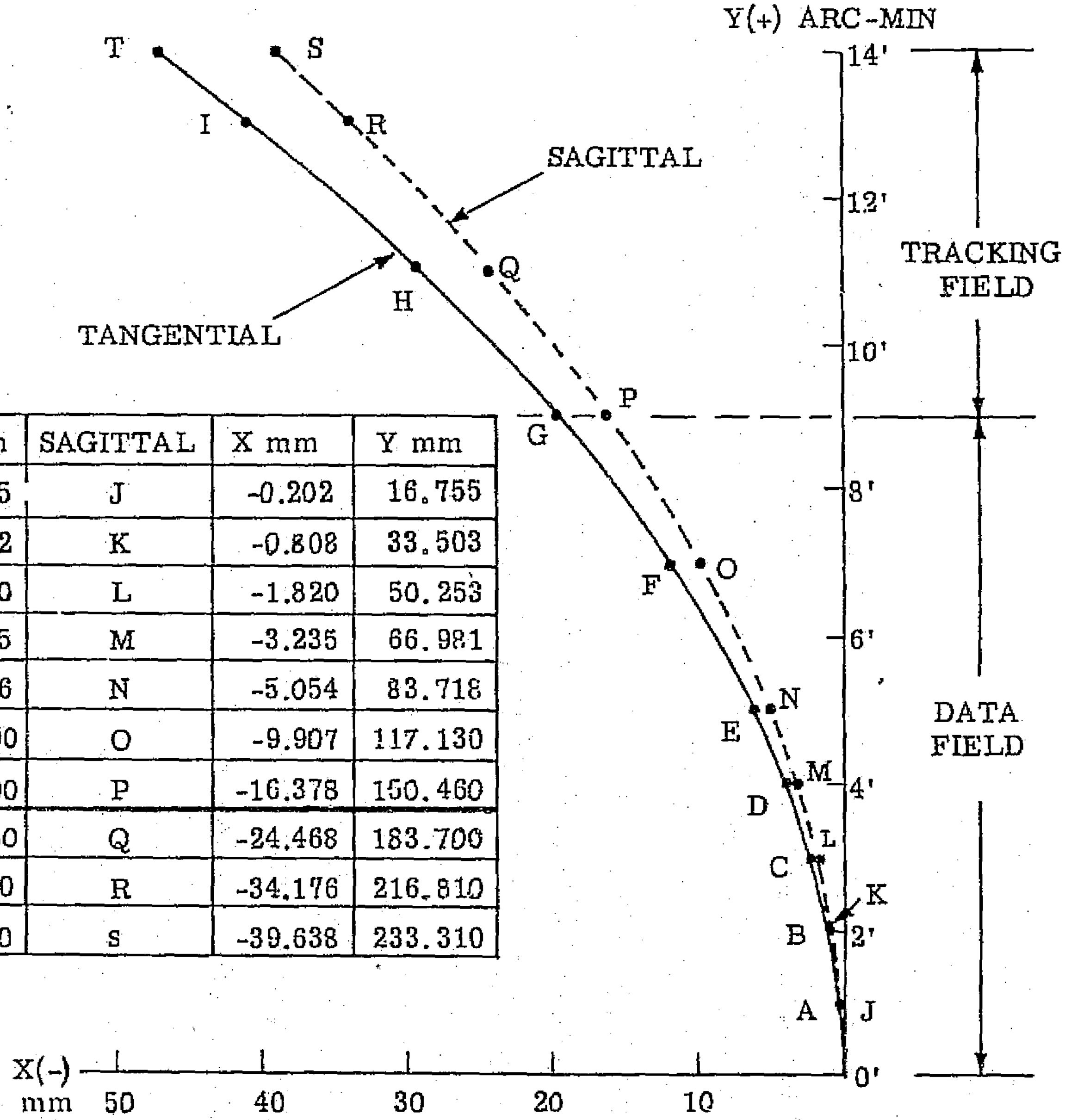


Figure 1-4. f/24 Focal Plane, SI Data Fields



α	TANGENTIAL	X mm	Y mm	SAGITTAL	X mm	Y mm
1.0'	A	-0.244	16.755	J	-0.202	16.755
2.0'	B	-0.976	33.502	K	-0.808	33.503
3.0'	C	-2.197	50.250	L	-1.820	50.253
4.0'	D	-3.905	66.985	M	-3.235	66.981
5.0'	E	-6.102	83.706	N	-5.054	83.718
7.0'	F	-11.962	117.090	O	-9.907	117.130
9.0'	G	-19.776	150.390	P	-16.378	150.460
11.0'	H	-29.552	183.560	Q	-24.468	183.700
13.0'	I	-41.200	216.590	R	-34.176	216.810
14.0'	T	-47.881	233.040	S	-39.638	233.310

Figure 1-5. Focal Plane Topography

TABLE 1-2

DESIGN REQUIREMENTS

Weight, Enclosure	140 pounds (max)
Weight, f48/96 Camera & Optical Bench	150 pounds (max)
Temperature (optics)	66 - 70°F
Conductance to Focal Plane	0.15 Btu/Hr-°F (max)
Radiation to Focal Plane	0.10 Btu/Hr-°F (max)
Voltage	28 VDC ±5 VDC
Maximum Allowable Average Power	150 watts
Reliability	0.85 for 1 year orbital operation

Acceleration Factors (g)

Mission Phase	Equivalent Quasi-Static Limit Loads					
	x_{max}	x_{min}	y_{max}	y_{min}	z_{max}	z_{min}
Launch Release	0.4	-3.4	0.8	-0.8	3.0	-3.0
SRM Cutoff/Separation	2.0	-4.0	0.4	-0.4	0.8	-0.8
Reentry	1.4	0.6	0.7	-0.7	4.0	2.0
Payload Deployment	0.2	-0.2	0.2	-0.2	0.2	-0.2

SECTION 2

PLANETARY CAMERA CONFIGURATION

2.1 General Configuration

The overall layout of the f48/96 Planetary Camera is given in Figure 2-1, sheets 1-4. The two camera systems use separate portions of the OTA science data field and separate two-element optical relays, but share a common port door subassembly, shutter unit and 400 x 400 CCD detector. The key elements of the instrument are

- Port door subsystem
- Shutter subsystem
- Optical relays
- Filter/drive subsystem
- CCD detector assembly
- Calibration subsystem
- Optical bench
- Axial module
- Thermal control subsystem
- Instrument control electronics.

The CCD detector, cooled to -40F, views through the f/48 relay a 17 x 17 arc-sec portion of the OTA field (8.5 x 8.5 arc-sec portion with f/96 relay) centered 92 mm from the optical axis (the f/96 portion is 51.5 mm off axis). This location is just outside the area vignetted by the pick-off

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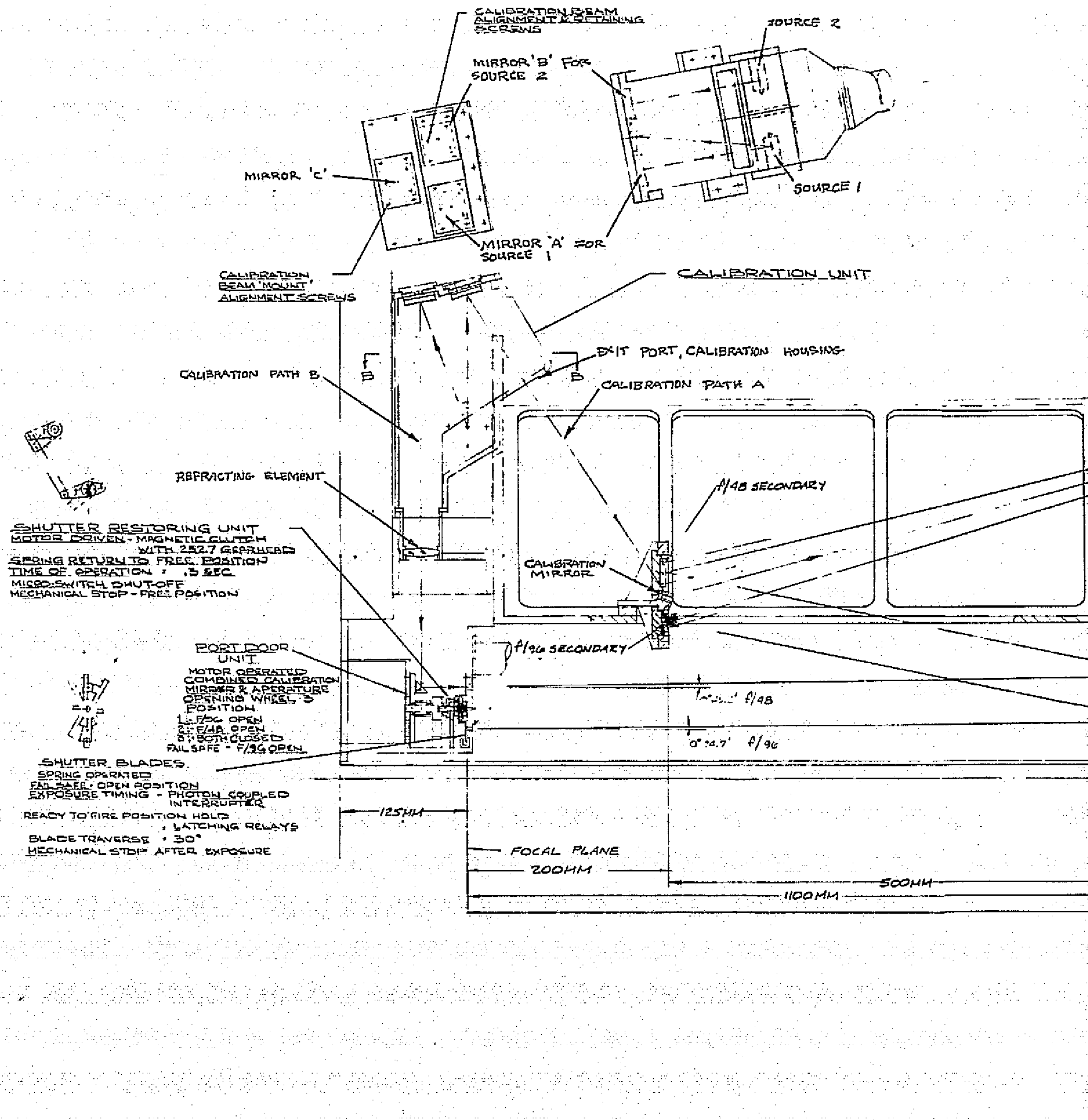

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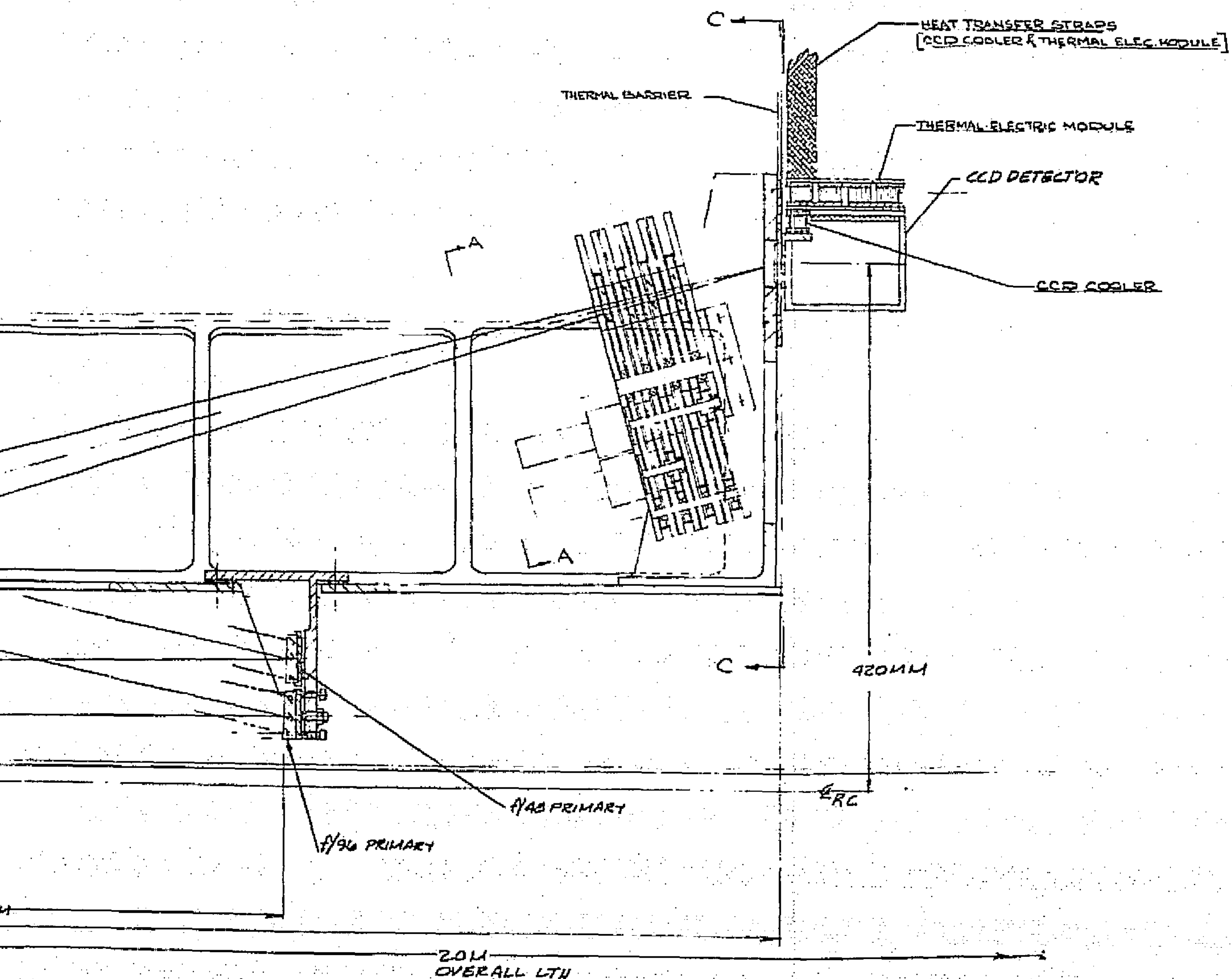

Figure 2.1. (Sheet 1 of 4)
f48/96 Camera Layout

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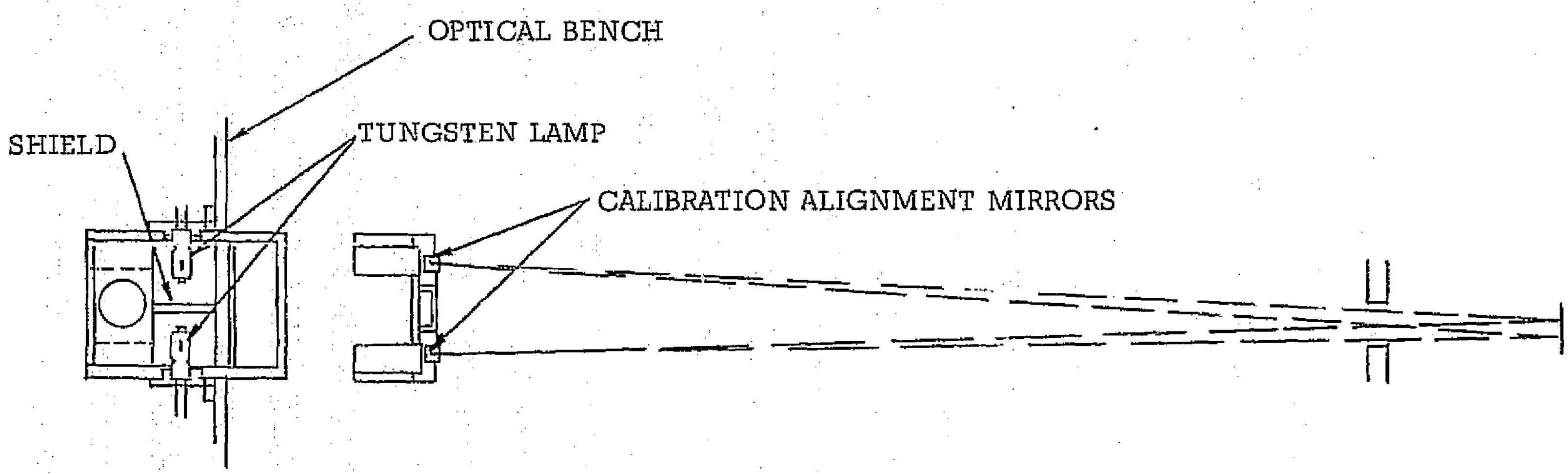
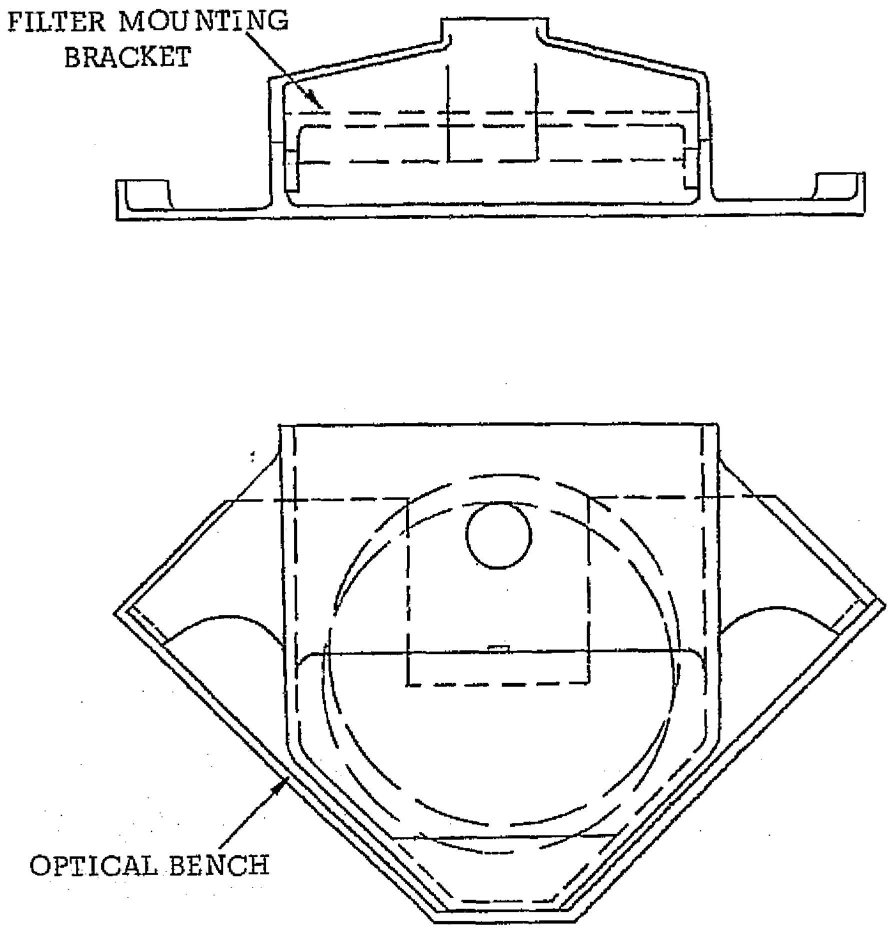


Figure 2-1. (Sheet 2 of 4). f48/96 Camera Layout



Mounting Features and Profile Filter
and CCD Housing

Figure 2-1. (Sheet 3 of 4). f48/96 Camera Layout

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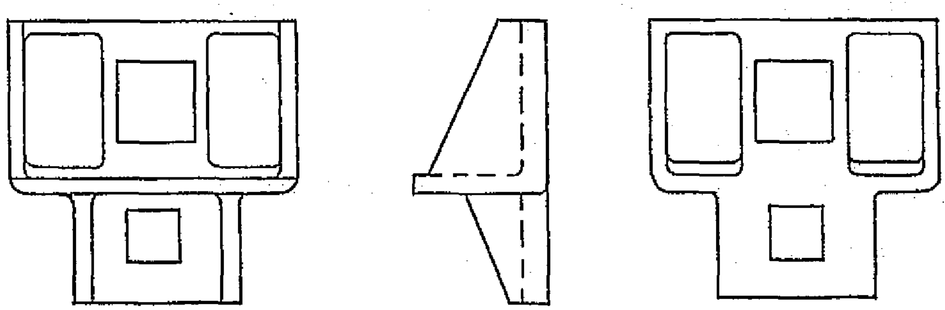


Detail Views - f/48 and f/96 Secondary Mirror Mount
(Calibration Alignment "Mirror-Mount" Incorporated)

Figure 2-1. (Sheet 4 of 4). f48/96 Camera Layout

mirror for the f/24 Field Camera. Details on the optical quality of the OTA focal plane and the optical design are given in Section 3.

All elements of the camera are mounted to the optical bench. The bench has two functions: (1) to maintain the functional elements of the instrument in proper alignment and (2) to position the camera relative to the optical axis and focal plane of the OTA. Additional details of this structure are given in Section 5. The camera is self contained within an axial bay module. The module is replaceable on orbit as described in Section 5. The module also provides the stabilized thermal environment and heat dissipation system for the instrument.

Heat is pumped from the CCD detector by a thermoelectric cooler through copper heat straps to the module outer surface for dissipation to the SSM wall. Current conservative estimates of the power necessary to effect cathode cooling to -40 F are approximately 30W.

The port door is used to close off the instrument when not installed in the ST and during calibration, and it also performs the function of camera selection. The common shutter mechanism is used to control exposure times, and a common filter wheel assembly, with four wheels, each containing seven filter positions, is used to select spectral bandwidth. A tungsten-filament calibration source provides instrument throughput data.

Power, commands, instrumentation and science data are transferred directly between the SSM (Support Systems Module) and the individual science instruments. Consideration of the use of a dedicated science instrument computer or of individual micro processors located within each science instrument is still under study by NASA. The instrument functional block diagram is shown in Figure 2-2.

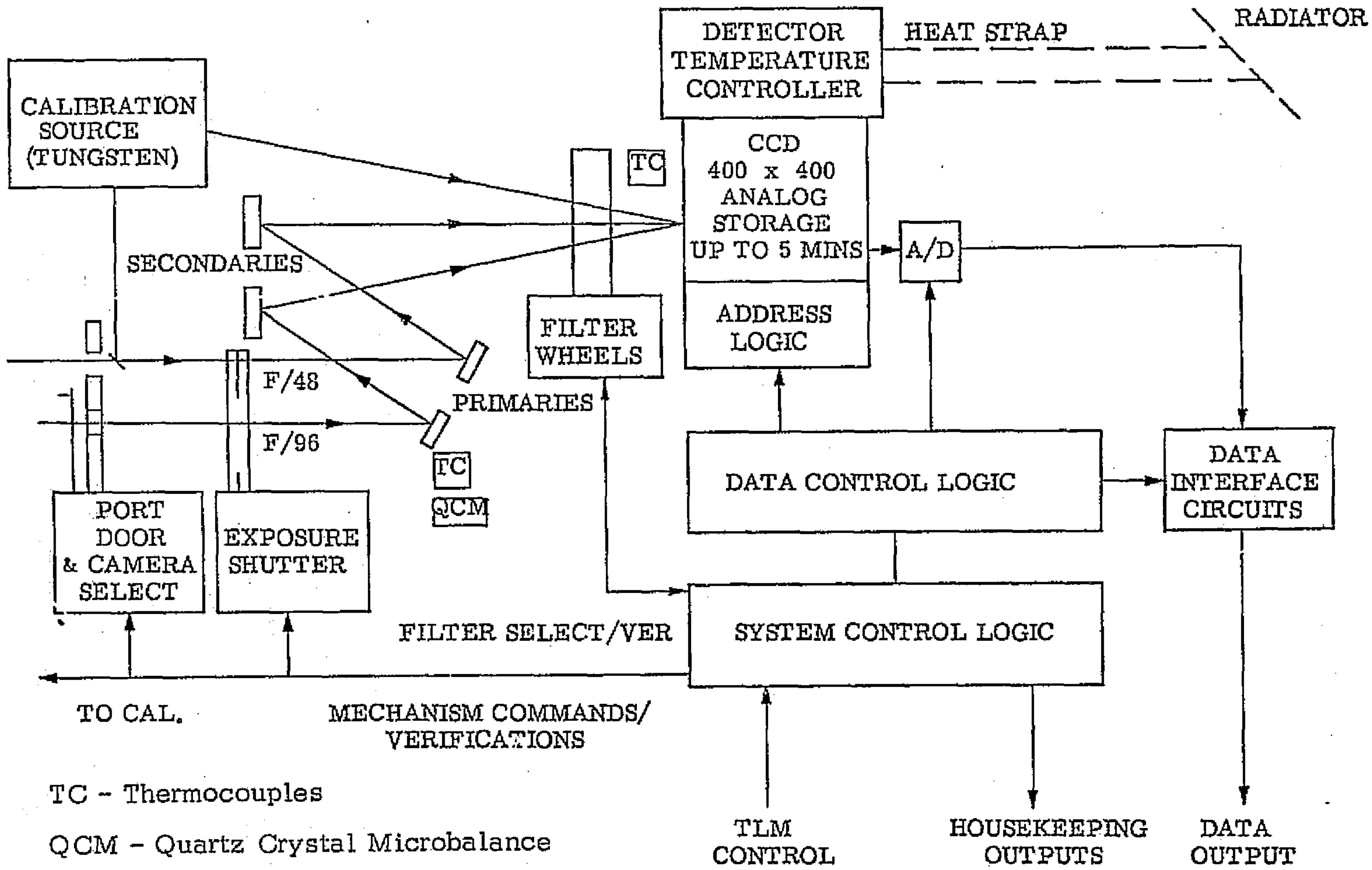


Figure 2-2. Planetary Camera Functional Block Diagram

2.2 Sequence of Operation

2.2.1 Acquisition

The Planetary Camera has a passive role during the acquisition operation. The object or sky area to be viewed is selected and commands given to the ST Pointing Control System to point the line of sight of the OTA at the selected area. The accuracy to which this can be done is dependent on the accuracy to which the object is known but generally will be within 1 to 10 arc-sec rms. The ST is stabilized in this position by the PCS (Pointing Control System); the FGS (Fine Guidance Sensor) in the OTA interferometrically senses any drift away from the selected guide star and sends an error signal to the PCS of the SSM to maintain stabilization.

2.2.2 Normal Operation

Following acquisition of the selected target the following operational sequence is followed:

- Operation of the Filter subsystem to place the selected filter into the optical path. Details of this design and operation are given in Section 2-4.
- Operation of the Shutter subsystem to control the exposure period. Details of this design and operation are given in Section 2-3.
- Following closing of the follower shutter blade (and before resetting of shutters) the detector is read out directly to the ground via the SSM or into data storage on the SSM.
- Resetting of the shutters to the start position.

- Repeat of above sequence - changes will include selection of other filters/transmission gratings, different time exposures and other targets.
- Operation of the TCS (Temperature Control System) to maintain the photo cathode at -40F and the camera optics as defined in the Requirements, Section 1.
- The Port Door is not used (closed) during normal operation of the Camera and is not closed during periods when the camera is not in use. It is closed only during periods of instrument calibration.

2.2.3 Calibration

The Port Door has two functional elements: an aperture and two mirrors for use in calibration. The door rotates through four 90° steps as follows (ref. Section 2-5 for more details)

Position	f/48 Port	f/96 Port
1	calibrate	open
2	closed	calibrate
3	open	closed
4	closed	closed

Calibration is accomplished by executing the following operations:

- Command Port Door to either position 1 or 2, depending on which optical path is to be calibrated.
- Turn on calibration source.
- Operation of the Filter subsystem to place the selected filters into the optical path.

- Read-out detector and transmission of data via SSM to ground station.
- Turn off calibration source.
- Return Port Door to position 1 or 3 if camera is to be operated -- otherwise move to position 4 for standby.

2.3 Shutter Subsystem

Planetary Camera exposure time is controlled by the focal plane shutter mechanism located close to the instrument entrance port approximately 60 mm behind the port door. The mechanism is comprised of two spring-driven shutter blades, separately triggered by the exposure time control electronics. The two shutter blade concept permits good control for the very short time exposures (of the order of 10 milliseconds) and at the same time easily adapts to the longer exposure periods as well. The operational sequence is as follows:

1) Release of the lead shutter blade by command. This opens the optical path to the detector.
2) Release of the follower shutter blade by a second and separate command. This covers the optical path to the detector. The time delay between the two shutter release commands establishes the exposure period.
3) Simultaneous resetting or cocking of both shutter blades to their start positions by a small electric motor drive. The optical path remains covered during this operation.

As shown in Figure 2-3 both entrance ports (f/48 and f/96) are controlled by the same shutter blade. This simplifies the design complexity at the entrance area. Port door positioning defines which camera relay system is in operation.

The lead shutter blade is initially cocked, against a torsion spring, in position to block the optical path. The first exposure control command removes power from the hold solenoid, allowing a spring-driven trigger to disengage from the shutter blade arm. Thus released, the lead shutter moves through a nominal 30° arc about its pivot bearing and exposes the detector to the optical clear aperture. The lead shutter is brought to rest at the end of its travel by an energy absorping stop, shown in Figure 2-3, designed to decelerate the shutter blade without causing excessive vibration of the camera assembly. A light emitting diode (LED) and photo sensor, located near the end of the shutter travel senses the completion of the operation and provides instrumentation data of this event. The LED is driven at very low current, to enhance reliability and to reduce its light output to the minimum required to operate the photo diode sensor. The entire light-source/sensor assembly is located remote from the camera entrance aperture and is well baffled to prevent stray light from entering the camera optical train.

A second command, triggered after the required exposure period has transpired, provides power to the follower shutter blade solenoid, actuating its release trigger. Also spring driven, this blade similarly rotates to a position covering the detector aperture. A LED and photo diode senses and provides instrumentation data on completion of this event.

The power "off" release of the lead shutter blade provides the shutter subsystem with a fail-safe mode, fail-safe being defined here as a shutter failure with the optical path unblocked. A power failure of the lead shutter command will result in the shutter moving to the open position. The camera can continue in operation following such a failure by either direct controlling of the detector or by initiating exposure control by using the motor driven reset to open

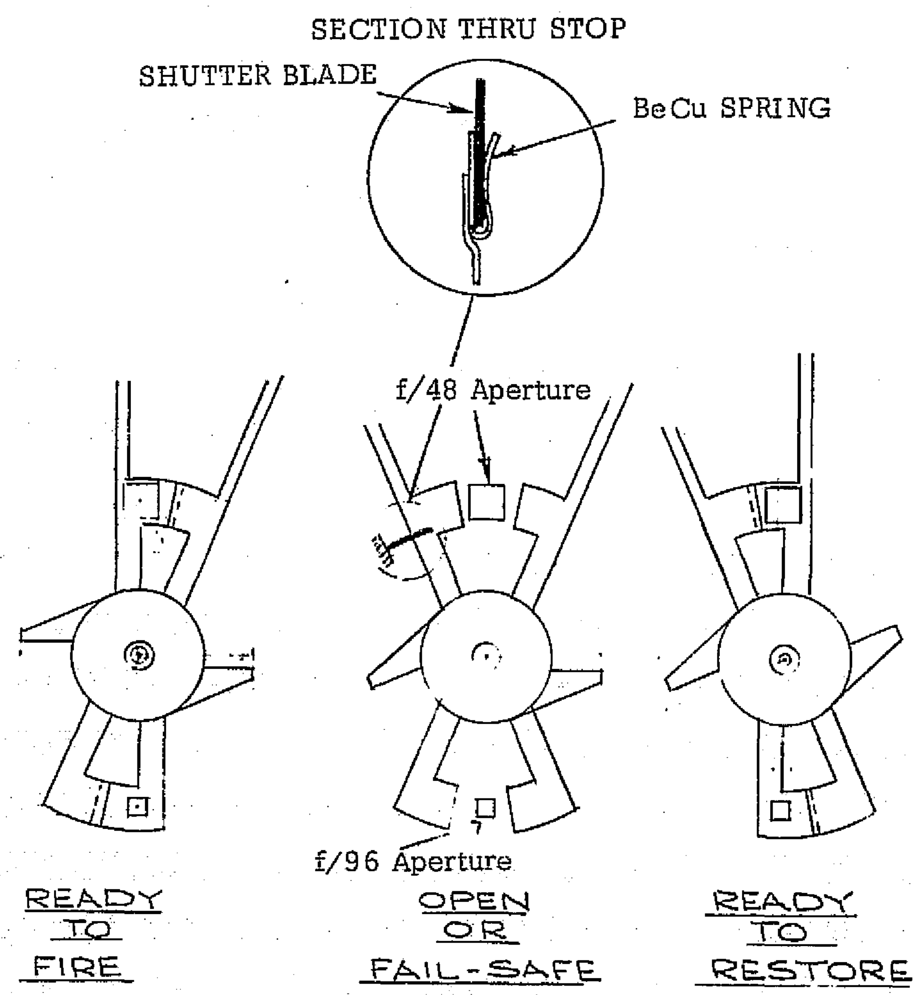


Figure 2-3. Camera Shutter Configuration

the optical path and release of the follower shutter blade to end the exposure. This latter back-up operation mode would preclude very short exposures, i.e. $\lesssim$0.5 seconds.

The resetting of the two shutter blades is accomplished by the action of a small electric motor driven quick-return mechanism which simply pushes both blades into their latched position and then returns to its start position to be ready for the next reset cycle (ref. Figure 2-4).

The design configuration of the shutter subsystem defined above was utilized successfully for many years on the principal camera of the Stratoscope II telescope. Requirements on that program also included exposure periods from 25 ms to hours. No operational failures of this camera shutter or reset mechanism were experienced during many hours of ground test or the several flights of this system. The shutter blades are lightweight, constructed from aluminum, and thus very responsive to their spring drives. The solenoids should be double wound to provide redundancy. There are no critical manufacturing or assembly tolerances in the design; solenoids, motors, magnetic clutches, etc. may be selected from components previously space qualified.

2.4 Filter Wheel/Drive Subsystem

The filter wheel assembly, shown in Figure 2-5, is located immediately ahead of the detector. It contains four (4) independently driven wheels, each wheel containing eight filter positions. In each wheel, one position is open (no filter), and the remaining seven are available for optical elements such as filters, neutral density attentuators, and transmission gratings.

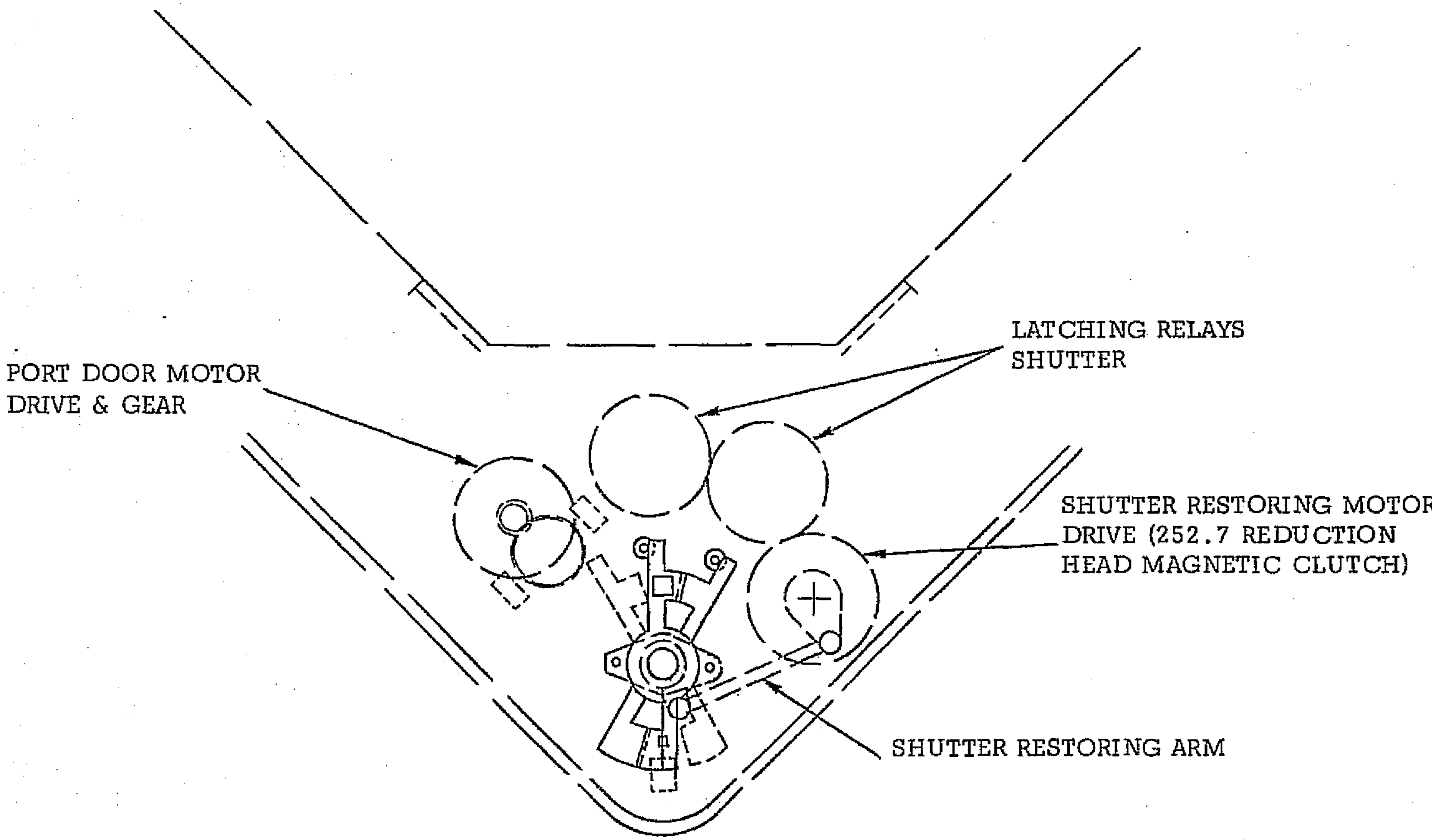
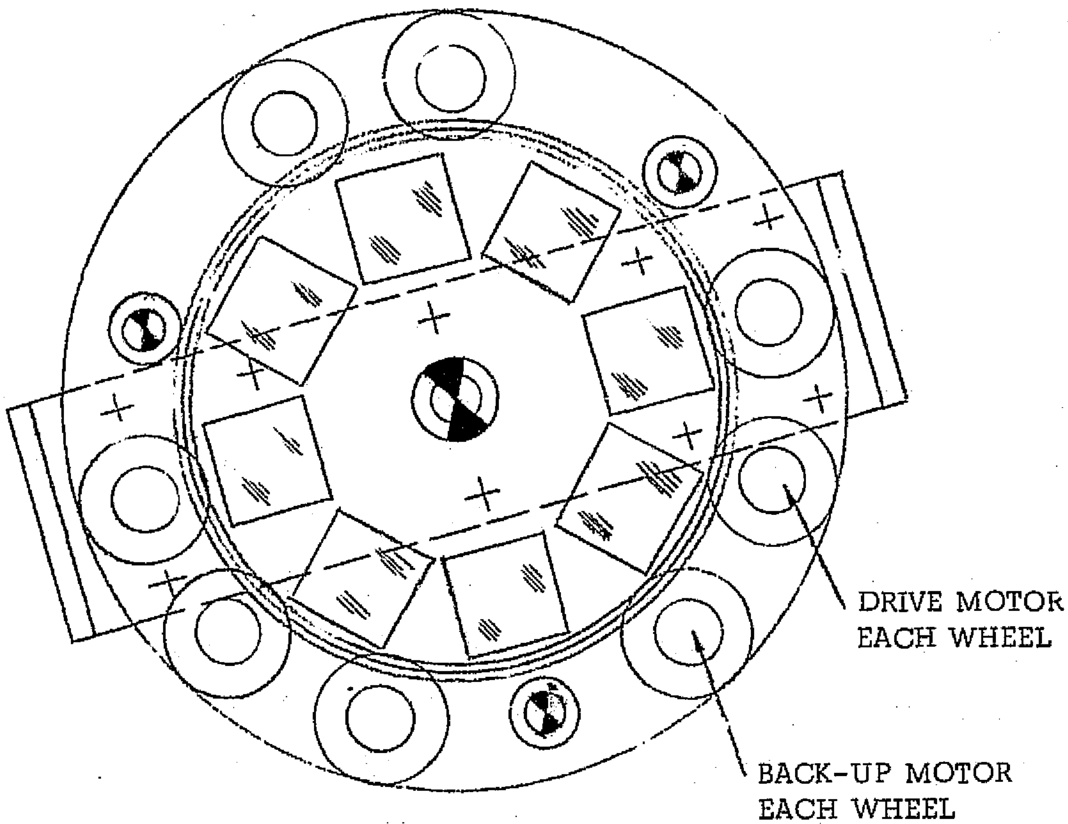


Figure 2-4. Shutter Drive Configuration



Filter Unit
4 Wheels - Motor Driven
8 Positions per Wheel
Position Change Time - .3 sec.

Figure 2-5. Filter Wheel Assembly

Each filter wheel is driven by a redundant pair of electric motors and electromagnetic clutches. Filter wheel rotation is always in the same direction. Indexing time to change from one filter position to the next is approximately 0.3 seconds; therefore, the maximum time required to obtain any filter combination is approximately 2.5 seconds.

The clear aperture of each filter wheel position is 30 mm x 30 mm. Location of the filter assembly close to the detector image plane reduces the need for high optical figure quality in the filter elements, but does require that the filters be uniform in their spectral transmissivity characteristics. Since the filter elements are placed in a converging optical bundle, their presence affects the focal plane location. This effect is proportional to filter element thickness, but for typical filter thicknesses (a few mm), it is well within the f/48 focus tolerance.

Each of the filter wheels has eight stop positions, each position being identified with the filter or optical element located at that point. Commands are sent simultaneously to each of the four wheels. Detents at each "filter" position ensure a uniform "centering" of the element and eliminates the critical requirement for positioning from the motor/magnetic clutch. Eight light emitting diodes/photo sensors (not shown in Figure 2-5) built into the fixed plate on either side of each moving wheel provide instrumentation data on exact rotational position (filter location). As in the case of the shutter timing sensors, these LEDs will be run at low current and optically baffled to eliminate stray light effects.

Two drive motors are provided to each filter wheel -- one is used normally to move the wheel to a selected position, the second serving as a back-up drive system. In the event of the failure of one filter wheel drive, the fail-safe mode of operation is to use the back-up drive motor to rotate that wheel to the "open" filter position. An alternative to this mode of operation is to continue using the filter wheel via the back-up drive with the risk that a second failure (in this back-up drive) would leave the filter wheel inoperative with perhaps an unfortunate filter now permanently lodged in the optical path. The present design contains no provision for clearing this problem via on-orbit maintenance.

The rotating filter wheel concept was judged the most reliable for the camera design, considering the limited space and size and number of filters. Translating or insertion type designs have been used in the past (and were considered) but were not applicable here primarily because of the large number of filters. Perkin-Elmer has used the rotary filter configuration most often and it has proven to be simplest in design and very reliable. There are no special problems -- manufacturing tolerances are nominal and the motors, clutches, bearings, and engineering data sensors are readily qualified from previous space equipment designs.

2.5 Port Door Subsystem

The prime function of this subsystem is to (1) move the calibration mirror into position along the optical path of the camera, (2) seal off background light during the calibration measurements, and (3) provide a means for selection of either the f48 or f96 aperture. The two small mirrors, which fold the calibration source light into the optical axis,are fixed to the port door.

The port door is shown in Figure 2-6 and has an aperture and two calibration mirrors. It rotates about an axis parallel to the optical axis. The door has four positions -- both apertures closed; f/48 open; f/96 open/f/48 calibrate; and f/96 calibrate. The f/96 should point to a dark sky background during the f/48 relay calibration. Power is required to close the door, against a spring preload

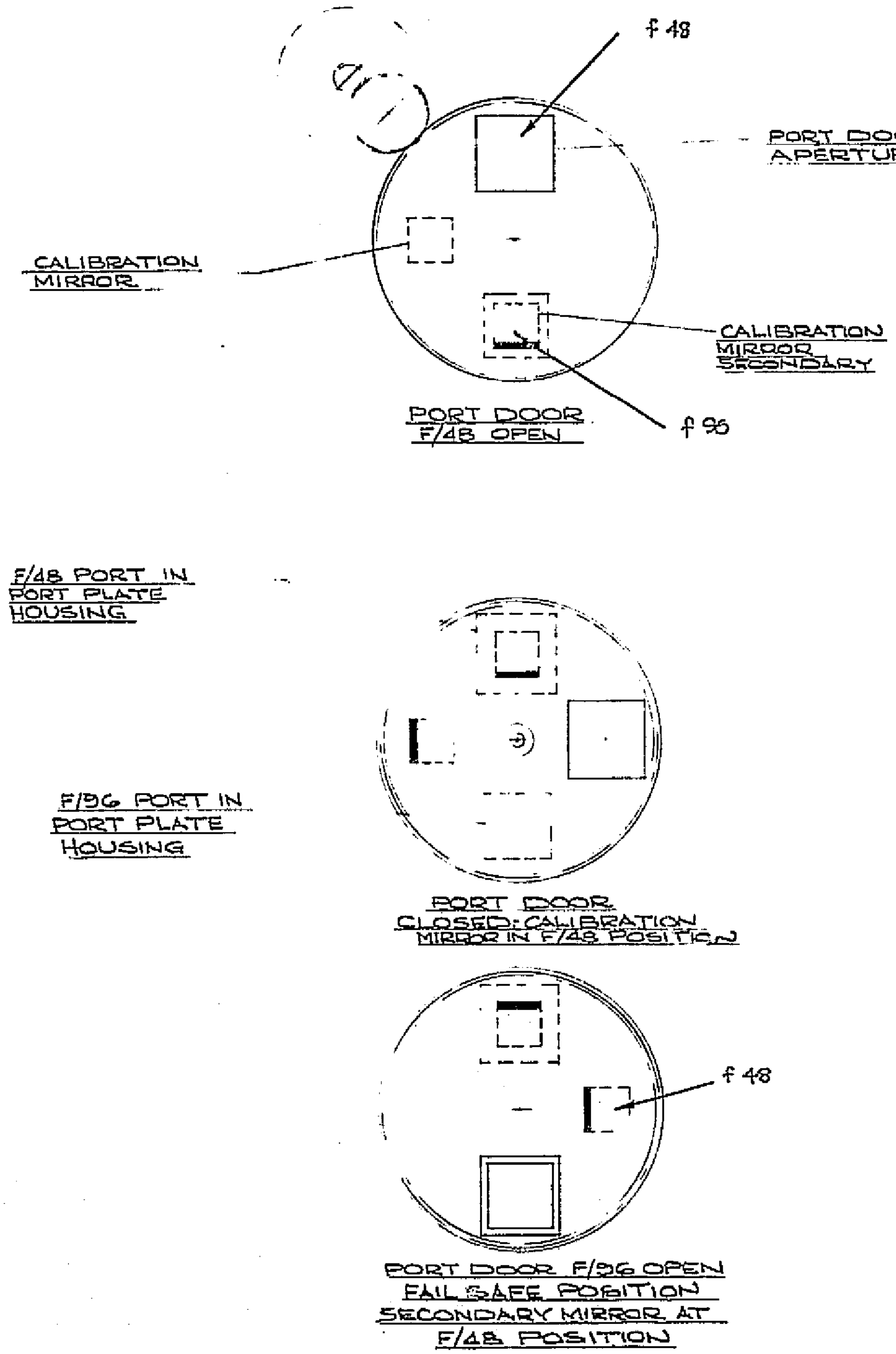


Figure 2-6. Port Door Sequencing

which holds the door in the f/96 camera open position whenever power is removed. In the f/96 open position, the calibration mirror is opposite the f/48 entrance port.

The port door subsystem presents no special problems in either design or manufacture. Tolerances are everywhere nominal. Components to include the motors, clutches, solenoids, etc. are available and readily qualified for this application.

2.6 Maintenance

The Planetary Camera is completely contained within the axial bay module defined in Figure 1-3. The instrument is maintainable on orbit by removal/change-out of the complete module.

The design is such that proper registration of the locator detent on the module (ref. Figure 2-1) with the locator ball (a fixed part of the OTA) and attachment of the module at the two fixed points on the OTA focal plane structure will locate the instrument properly in the design position of the f/24 field. Guides to assist a suited astronaut in the change-out operation are not shown but will be built into both the OTA focal plane structure and the module.

The electrical connectors are located on the outer surface of the module for easy access by the astronaut. They are available space replaceable types which can be opened/closed by a fully suited astronaut.

2.7 Weight and Power Summary

Table 2-1 summarizes the weight and power consumption of the camera, by major subassembly.

Weights have been computed from design drawings wherever appropriate. Manufacturers' weight data has been used in estimating purchased parts.

A typical planetary camera operational power profile is shown in Fig. 2-7.

TABLE 2-1

WEIGHT AND POWER SUMMARY

	WEIGHT (LBS)	POWER (WATTS)
OPTICS	10	-
DETECTOR	15	7
FILTER	14	(15)
SHUTTER	4	(15)
CALIBRATION	5	(15-20)
PORT DOOR	6	(15)
ELECTRONICS	26	24
THERMAL (OPTICS, DETECTOR)	8	30
MOUNTING STRUCTURE	50	-
MODULE	140	-
PLANETARY CAMERA MODULE	278	60 AVERAGE* 90 PEAK

*Allowable power 150 watts.

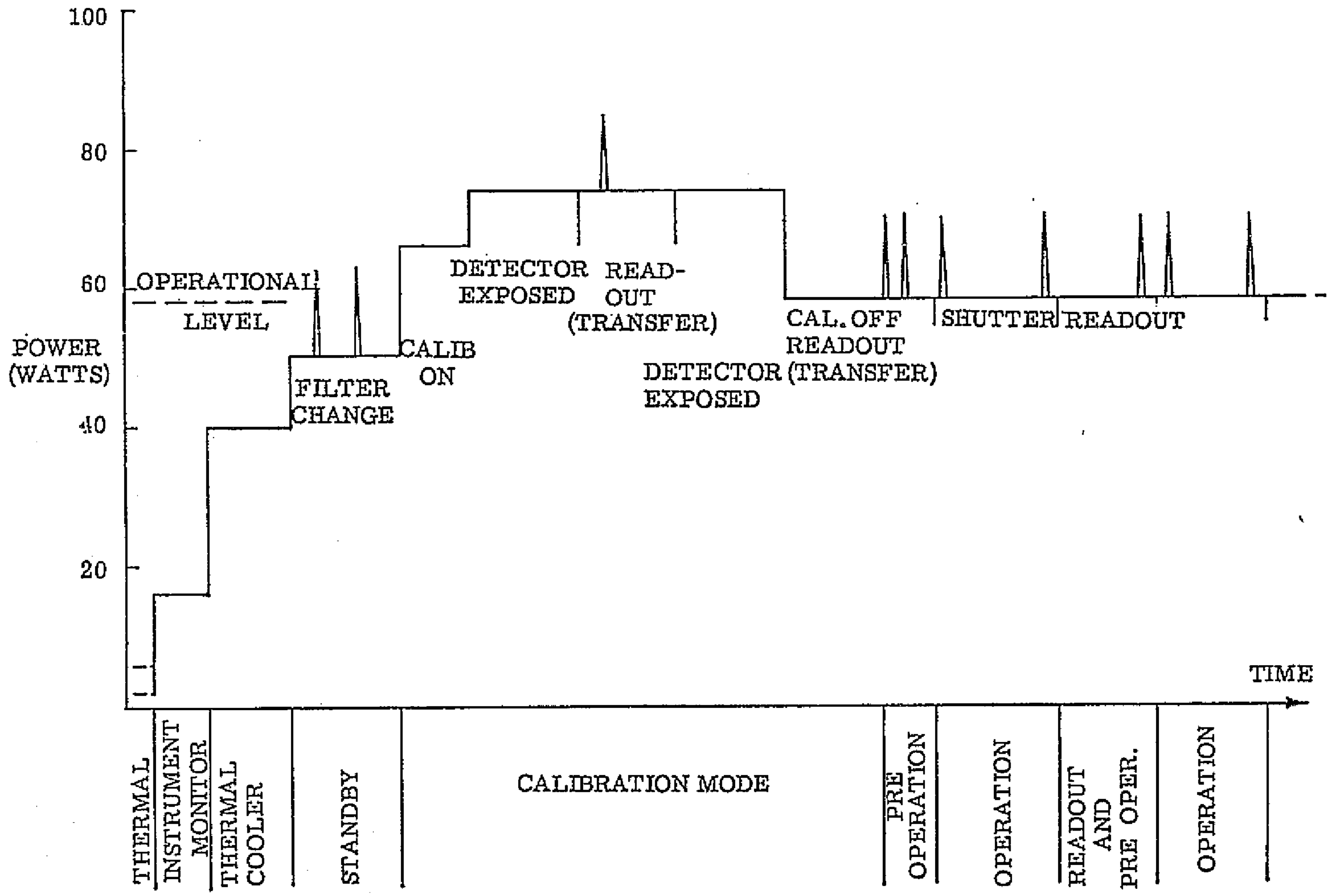


Figure 2-7 Power Profile

SECTION 3

OPTICAL SYSTEM DESIGN

3.1 General

The performance of the f48/96 Planetary Camera depends on the design of the optics of the instrument and the design of the OTA Ritchey-Chretien telescope. Consequently, the contributions of both must be considered in the design. The analysis of instrument performance is from the celestial sphere through the telescope to the camera optical system (its filters and mechanisms) to the detector.

This section of the Final Report is divided into two parts. The optical parameters of the Ritchey-Chretien telescope and its interface with the camera are discussed in Paragraph 3.2. The design of the camera optics, their performance with the telescope, and the characteristic features of the system are discussed in Paragraph 3.3.

3.2 OTA/SI Optical Interface

The optical interface between the OTA (Optical Telescope Assembly) and the SI's (Science Instrument) is considered in five parts:

- OTA/SI performance requirements
- OTA design
- Focal plane access
- OTA image quality/field correction
- Performance-influencing factors

- Optical tolerances
- Pointing jitter
- Stray light.

A summary of OTA minimum performance requirements is given in Figure 3-1. The difference between the design wavefront error of $.05\lambda$ ($\lambda/20$) rms at 632.8 nm and the implied $.074\,\lambda$ ($\lambda/13.5$) rms error required to meet the 60 percent encircled energy requirement in a 0.075 arc-sec radius circle for the OTA provides for hardware contingency.

The portion of the ST performance budget allocated to the OTA is shown in Figure 3-2. The first major division of performance responsibility is between image motion and image quality. The first of these is attributed primarily to the telescope pointing system, while the second is attributed to the quality of the OTA optics.

The optical design prescription for the OTA 2.4 meter Ritchey-Chretien and its first order parameters are summarized in Figure 3-3. The system is composed of two pure conic sections (hyperboloids) and nominally provides a geometrically perfect image on-axis. Off-axis, the system, as with all Ritchey-Chretiens, is afflicted by field curvature and astigmatism. Details of system performance follow, but note that the actual design central obscuration is 31 percent. This is 3 percent less (72 mm of diameter) than the maximum 34 percent allowed. The implied design margin is available for further baffle design, and if not used provides additional performance margin.

The 28 arc-minute unvignetted field of view provided by the Ritchey-Chretien is allocated among the science instruments, pointing system and figure sensors as shown in Figure 3-4. Four 90° unvignetted segments of image are

CALCULATED PERFORMANCE (ON-AXIS)	
ENTRANCE PUPIL DIAMETER	2.4 m
SYSTEM FOCAL RATIO	f/24
DESIGN SYSTEM WAVEFRONT ERROR	.05 λ rms
DESIGN, TEST AND VERIFICATION WAVELENGTH	632.8 nm
CENTRAL OBSCURATION	34% (Maximum)
ENCIRCLED ENERGY	
0.075 ARC-SEC RADIUS	60%
WAVELENGTHS	121.6 nm to 632.8 nm
RESOLUTION	
RAYLEIGH CRITERION	0.1 arc-sec

Figure 3-1. OTA Optical Performance Requirements

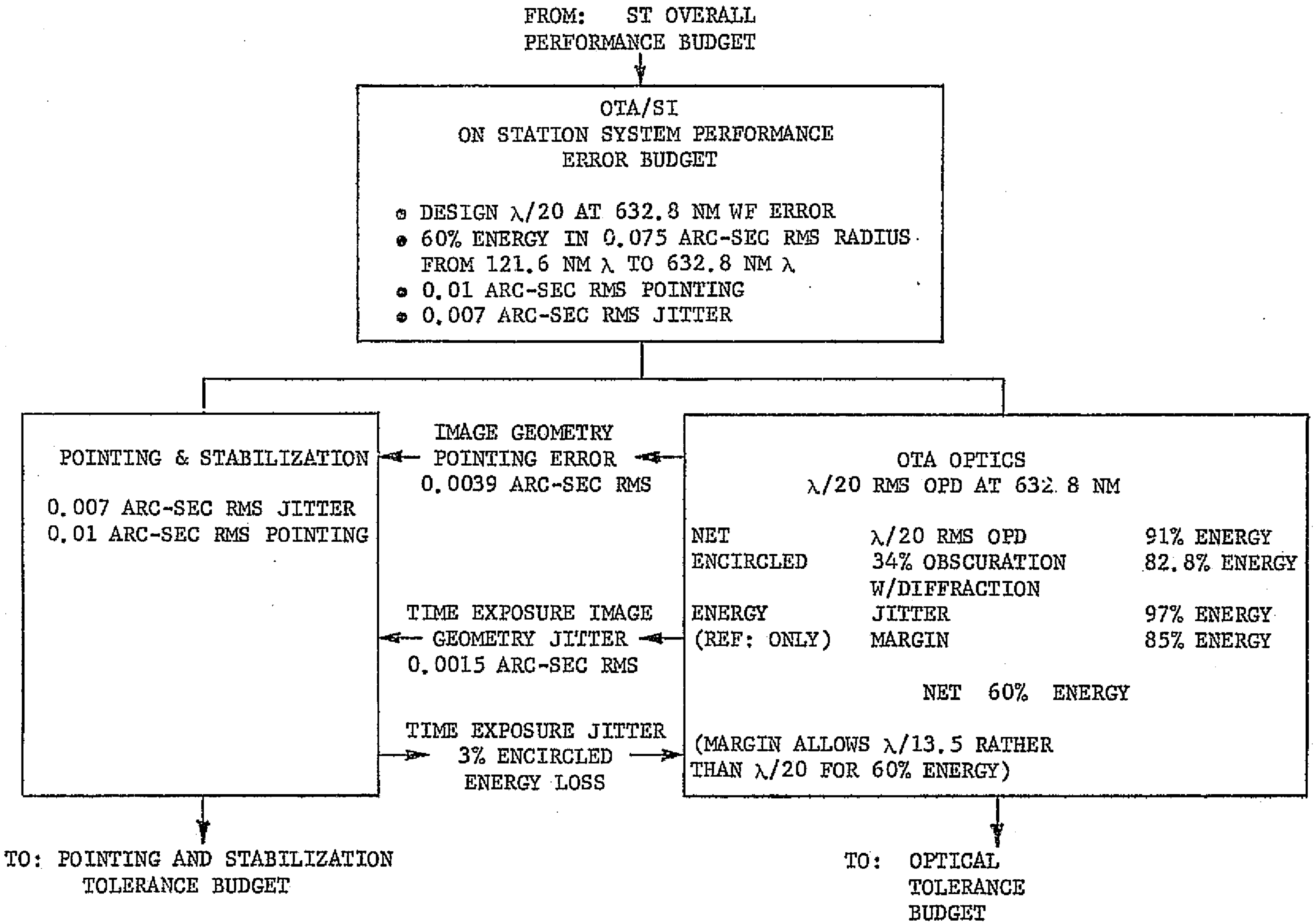
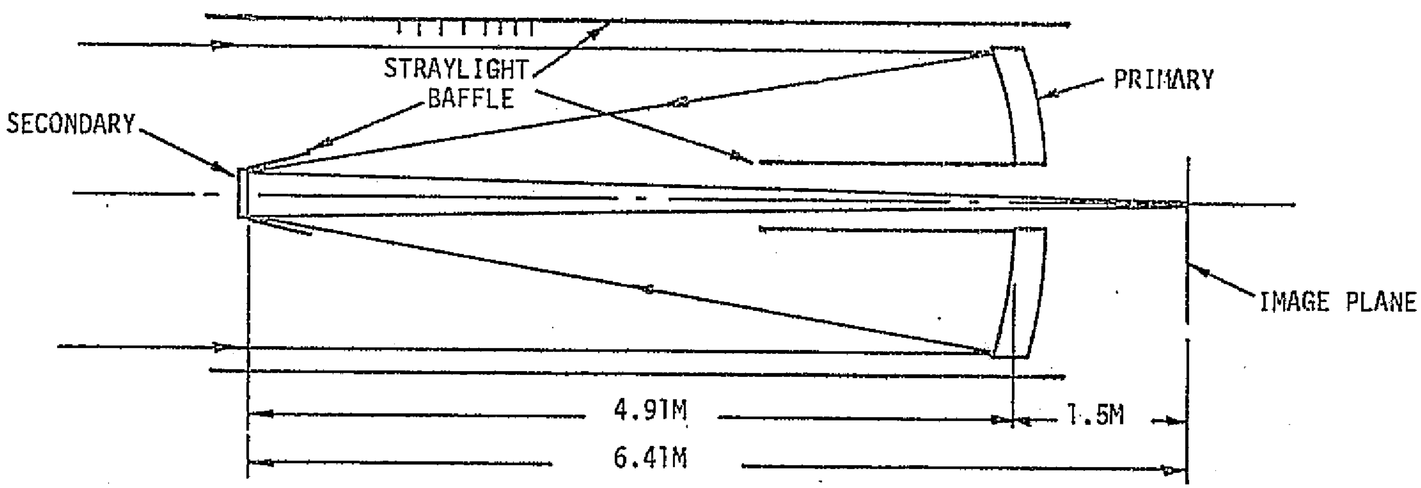


Figure 3-2. OTA/SI Tolerance Budget



Elements

- Primary - ULE Hyperbola, 11.04m Radius, 5.52m EFL, 2.4m Aperture, f/2.3
- Secondary - ULE Hyperbola, 1.358m Base Radius, 10.43 Magnification, 0.31m Aperture, f/2.23

System

o Aperture	2.4 m
o Focal Ratio	f/24
o Linear Obscuration Ratio	0.31
o EFL	57.6 m
o Back Focal Length	1.5 m
o Plate Scale	57.6 mm/mrad (16.76 mm/arc-min)
o Field of View Diameter	467 mmϕ, 8.1 mrad, 28 arc-min
o Data Field Diameter	300 mmϕ, 5.2 mrad, 18 arc-min
o Tracking Field Size	1.5×10^{-5} sr (180 arc-min)^2
o Coating	500Å to 800Å al w/250Å MgF
o Wavelength Range	100 nm to 1 mm
o Spatial Resolution (at 633 nm)	0.48μ rad (0.1 arc-sec) Rayleigh

Figure 3-3. OTA Optical Design

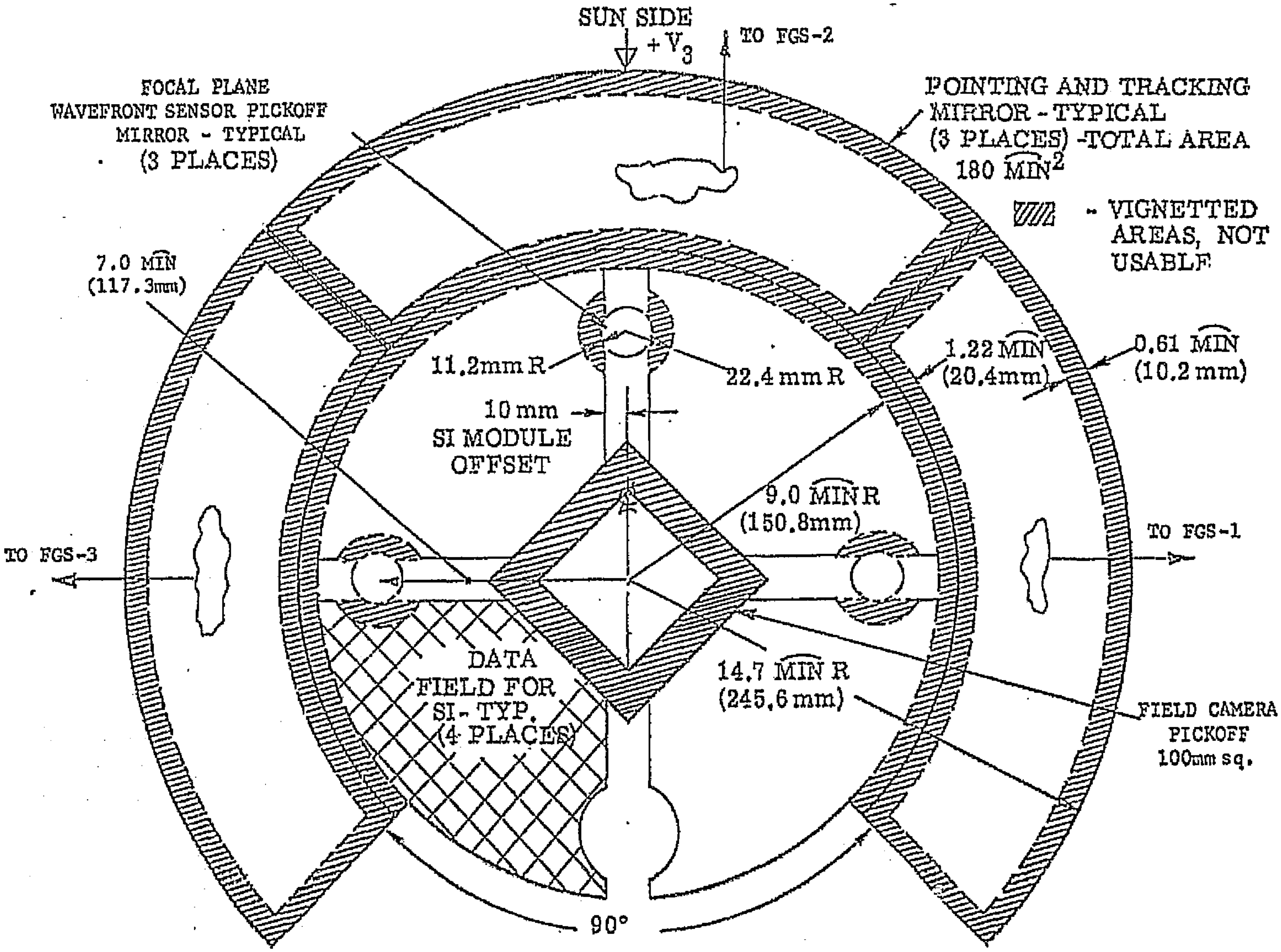


Figure 3-4. f/24 Focal Plane

provided for the axial science instruments. Each extends a maximum of 9 arc-minutes (150 mm) from the OTA optical axis. The fifth science field, taken from the center of the OTA field of view, is allocated to the f/24 Field Camera which is mounted in the OTA radial bay (Figure 1-2). The remainder of the field, from 9 to 14 arc-minutes, is reserved for the offset tracking sensor. The areas of the focal plane made inaccessible by the figure sensor pickoff mirrors and the structural components between instrument modules are also shown.

Within the telescope field of view astigmatism and field curvature are the only significant aberrations present. These aberrations are detailed in Figure 3-5. The astigmatism, field curvature and small amount of distortion of the 2.4 meter ST Ritchey-Chretien are shown in the telescope's f/24 image plane map. Out to a radius of about 4-1/2 arc-minutes compromise foci are available where diffraction-limited image quality can be provided, at 632.8 nm wavelength, for small regions of the focal plane. Beyond this point optical correction must be provided to achieve diffraction-limited quality.

In addition to the aberrations detailed in Figure 3-5, the diffraction effects inherent in the baseline OTA design modify nominal performance. Figure 3-6 summarizes these characteristics and shows their effects on performance. The vertical marks indicate the nominal design points of the parameters for the preliminary design OTA.

Beyond the nominal telescope design performance, the assigned optical tolerances determine the ultimate performance. The tolerance allocation is made so as to achieve .05λ rms at 632.8 nm wavefront error on station. This near diffraction limited performance as provided by the OTA is not universally required by all instruments.

α	TANGENTIAL	X mm	Y mm	SAGITTAL	X mm	Y mm
1.0'	A	-0.244	16.755	J	-0.202	16.755
2.0'	B	-0.976	33.502	K	-0.808	33.503
3.0'	C	-2.197	50.250	L	-1.820	50.253
4.0'	D	-3.905	66.985	M	-3.235	66.981
5.0'	E	-6.102	83.706	N	-5.054	83.718
7.0'	F	-11.962	117.090	O	-9.907	117.130
9.0'	G	-19.776	150.390	P	-16.378	150.460
11.0'	H	-29.552	183.560	Q	-24.468	183.700
13.0'	I	-41.200	216.590	R	-34.176	216.810
14.0'	T	-47.881	233.040	S	-39.638	233.310

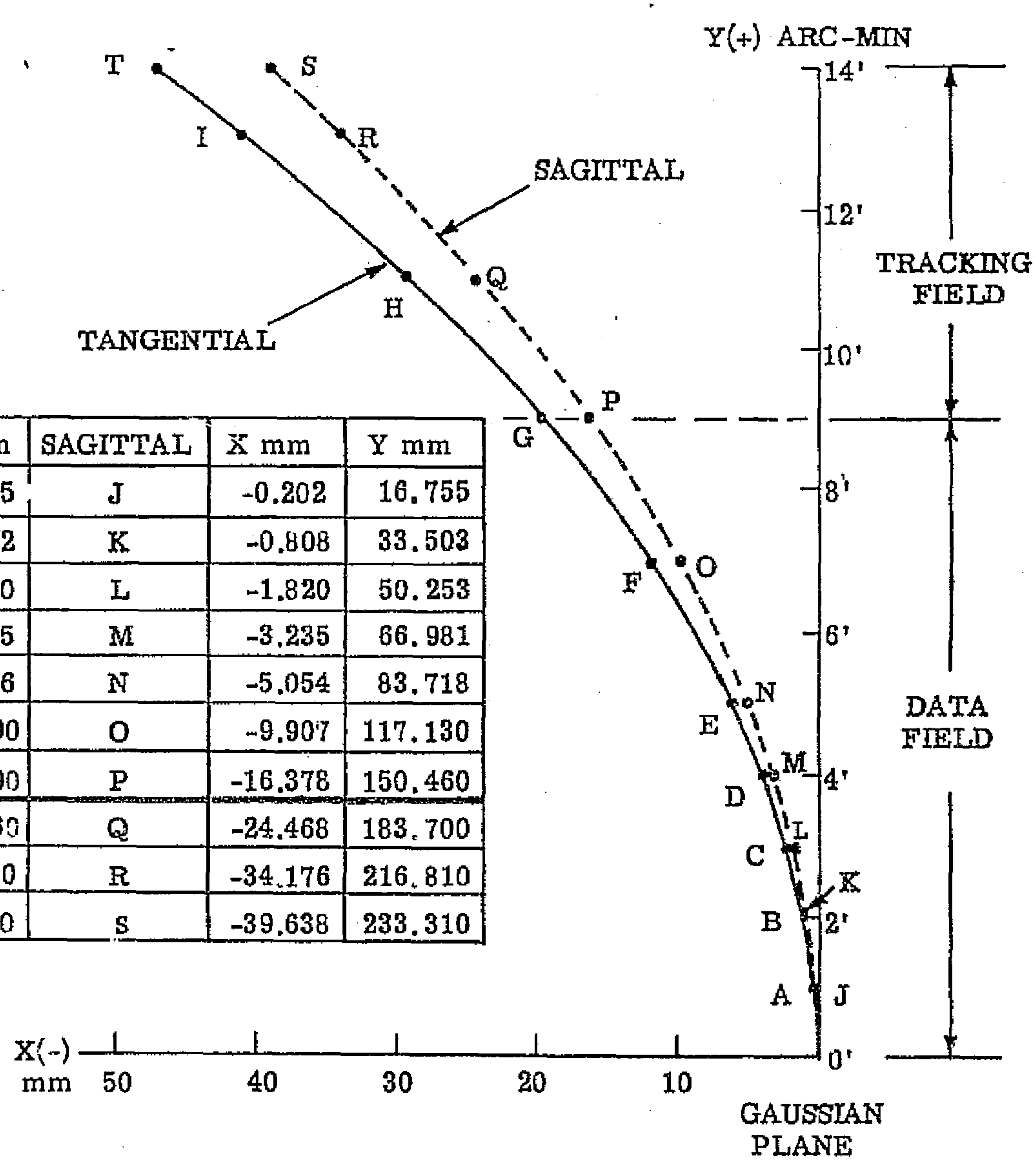
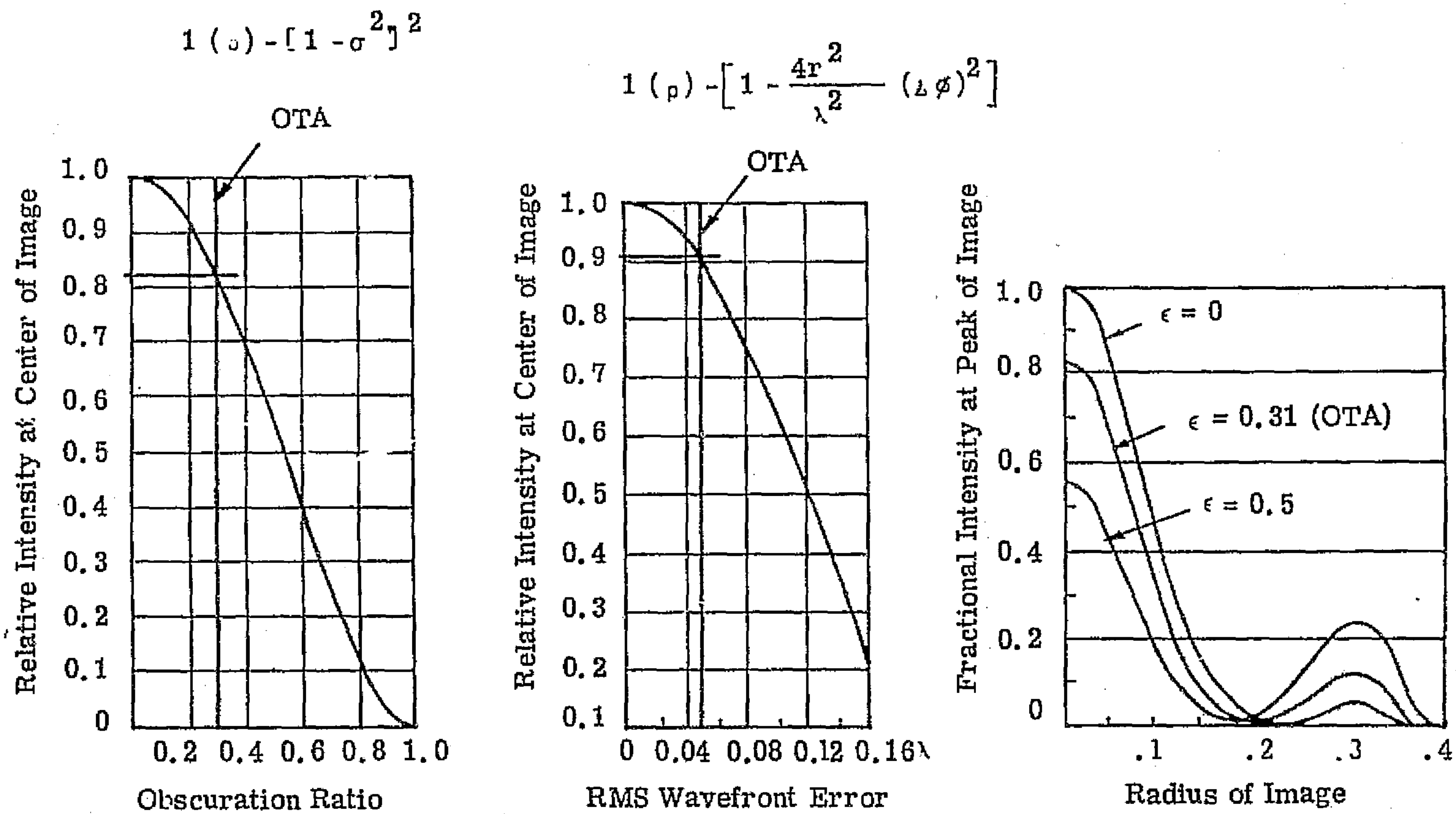


Figure 3-5. Focal Plane Topography



Effect of Central Obscuration

Effect of Wavefront Tolerance

Energy Distribution in the Airy Disk as Function of the Obscuration Ratio

Figure 3-6. OTA Nominal Performance

The instruments are designed and their tolerances are allocated to provide their required performance with the OTA budget taken into account.

The OTA to SI interface tolerances are absorbed into the OTA tolerance budget and do not burden the instrument designs.

The preliminary design optical tolerance budget, as it evolved from the Phase B study is shown in Figure 3-7. It provides for initial ground setup, residuals after orbital corrections and system drifts between calibration periods.

Figure 3-8 is the computed expected performance of the OTA determined by evaluation of the completed preliminary design and is now that system's tolerance budget. Note that the required design performance of $.05\lambda$ rms is slightly exceeded. This may be interpreted as additional design margin or as an increase in the anticipated mean time between required on-orbit OTA re-alignment and re-calibration exercises.

The final set of tolerances defining the OTA/SI interface are the instrument module mounting location accuracies and stabilities. These tolerances are summarized for both the accuracies required for initial instrument placement and for drift over a calibration period in Figure 3-9. The optical wavefront error induced by these tolerances is absorbed into the OTA structures portion of the overall $.05\lambda$ rms wavefront error budget. The numbers represent the accuracy and stability to which the SI modules will be held by the OTA FPS with respect to the OTA. Tolerances within the instrument module, between instrument components and the module mounting points, are included within the instrument budgets.

As an example of how this instrument placement tolerancing philosophy was carried out, focus maintenance is typical. Referring to Figure 3-10, the

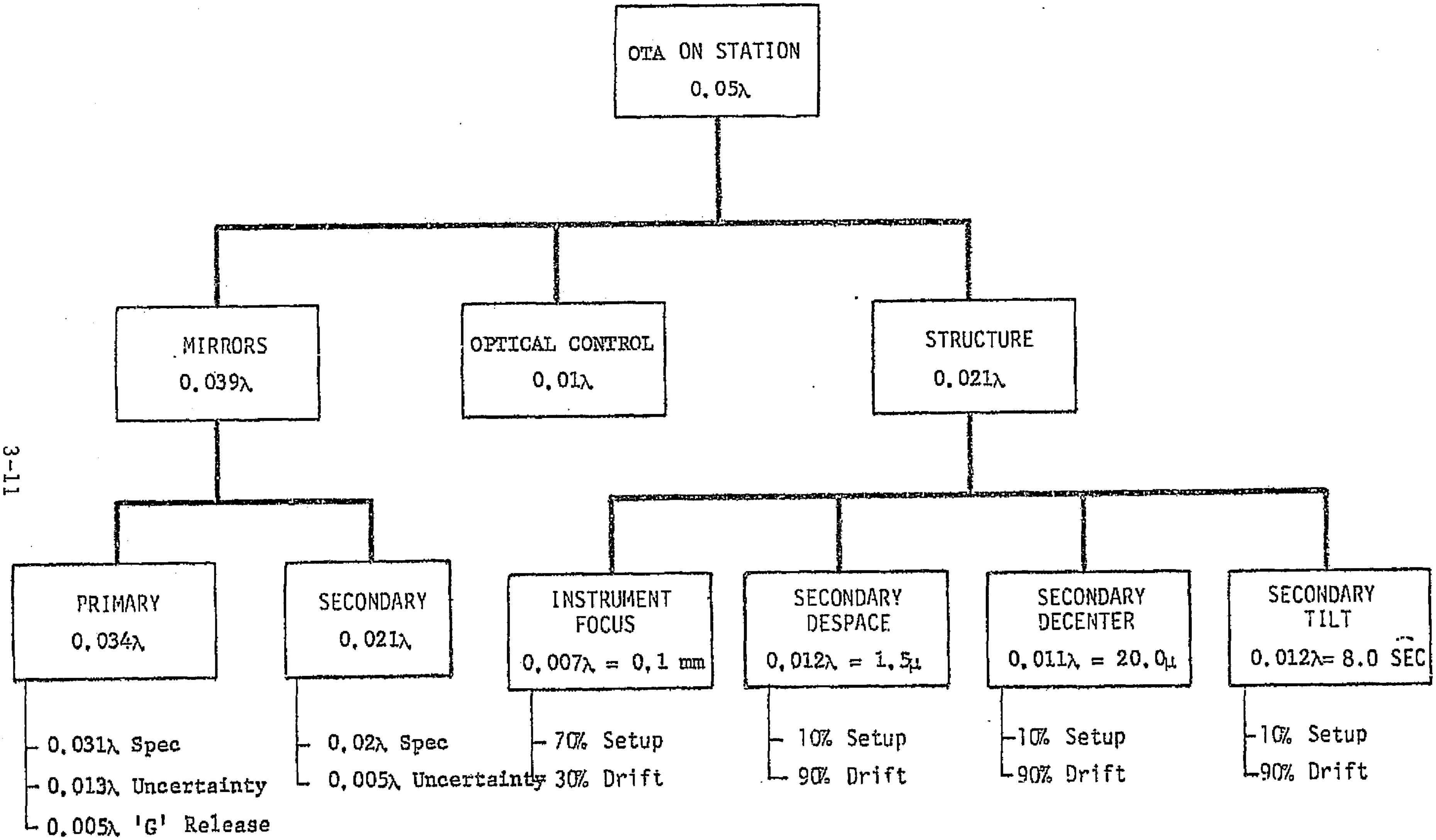


Figure 3-7. OTA Tolerance Budget Preliminary Design

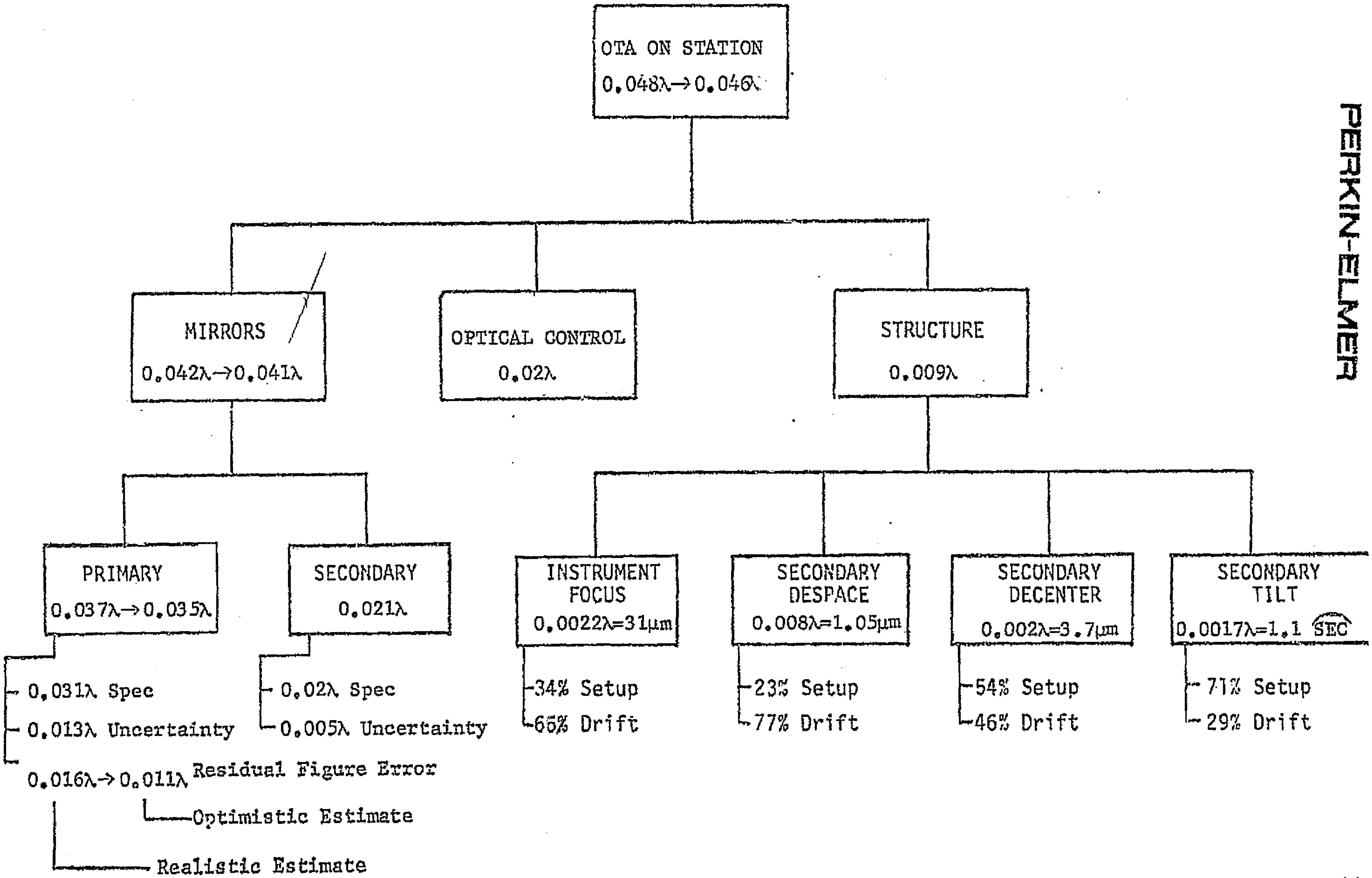


Figure 3-8. OTA Computed Performance Preliminary Design

- SI TO OTA TOLERANCES FOR ON-ORBIT INSTRUMENT REPLACEMENT

$X = \pm 0.1$ mm	$\alpha = \pm 0.5$ mrad
$Y = \pm 0.1$ mm	$\beta = \pm 0.5$ mrad
$Z = \pm 0.026$ mm	$\gamma = \pm 0.5$ mrad

- LONG TERM INSTRUMENT STABILITIES (BETWEEN OTA/SI CALIBRATIONS AND DURING EXPOSURES)

$X = \pm 0.005$ mm	$\alpha = \pm 0.5$ mrad
$Y = \pm 0.005$ mm	$\beta = \pm 0.5$ mrad
$Z = \pm 0.051$ mm	$\gamma = \pm 200$ μrad

- THE INDICATED TOLERANCES PERMIT UTILIZING FULL OTA CAPABILITY

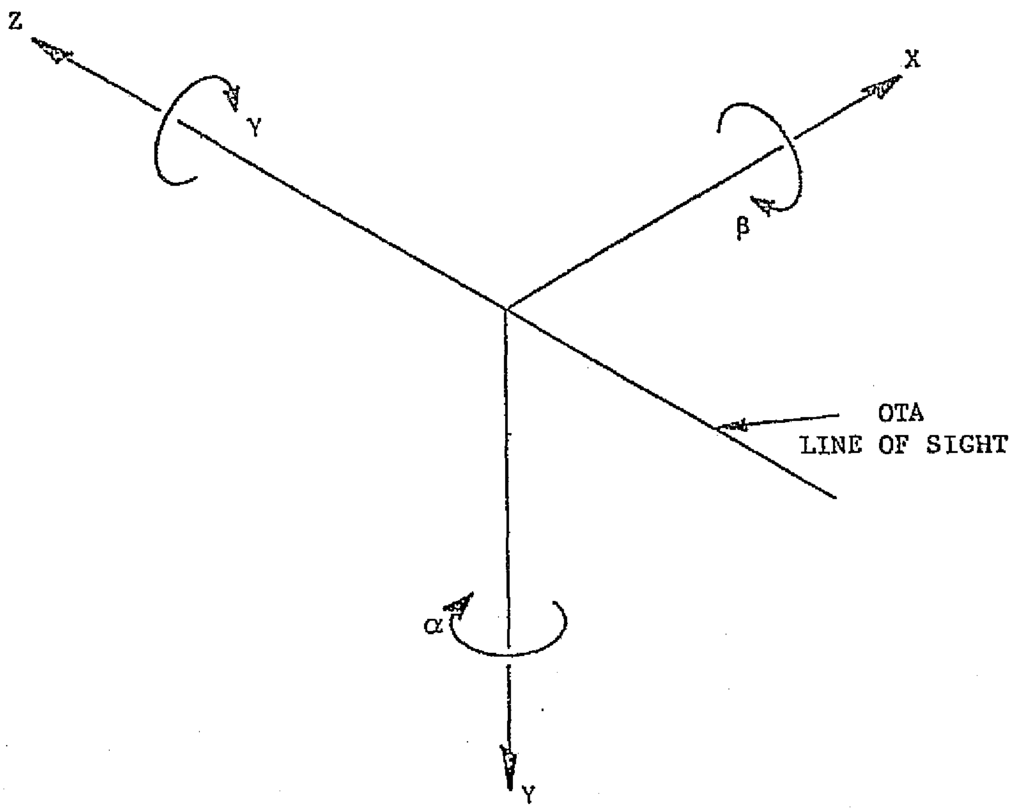


Figure 3-9. SI/OTA Interface Tolerances Allocation

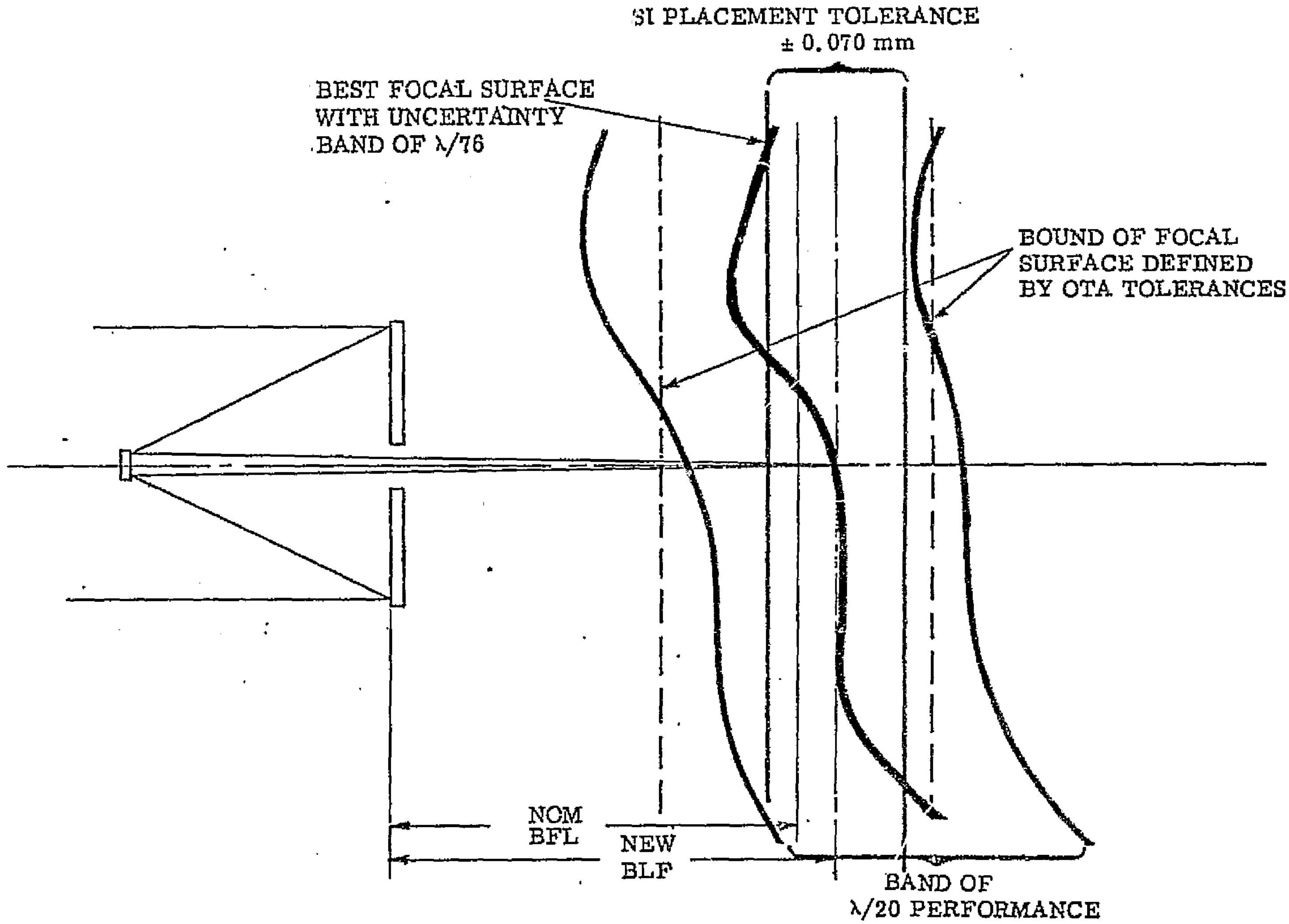


Figure 3-10. Focus Maintenance

depth of focus band of the telescope is shifted and distorted by the OTA allowed tolerances to a controlled maximum. The SI placement band tolerance is established that no matter where the instrument is within that band, it always lies within the focal depth of the telescope. As a result, the instrument is always in focus when installed in the system. The SI focus band is divided between all the OTA elements affecting the focus placement.

3.3 f48/96 Camera Optical Design

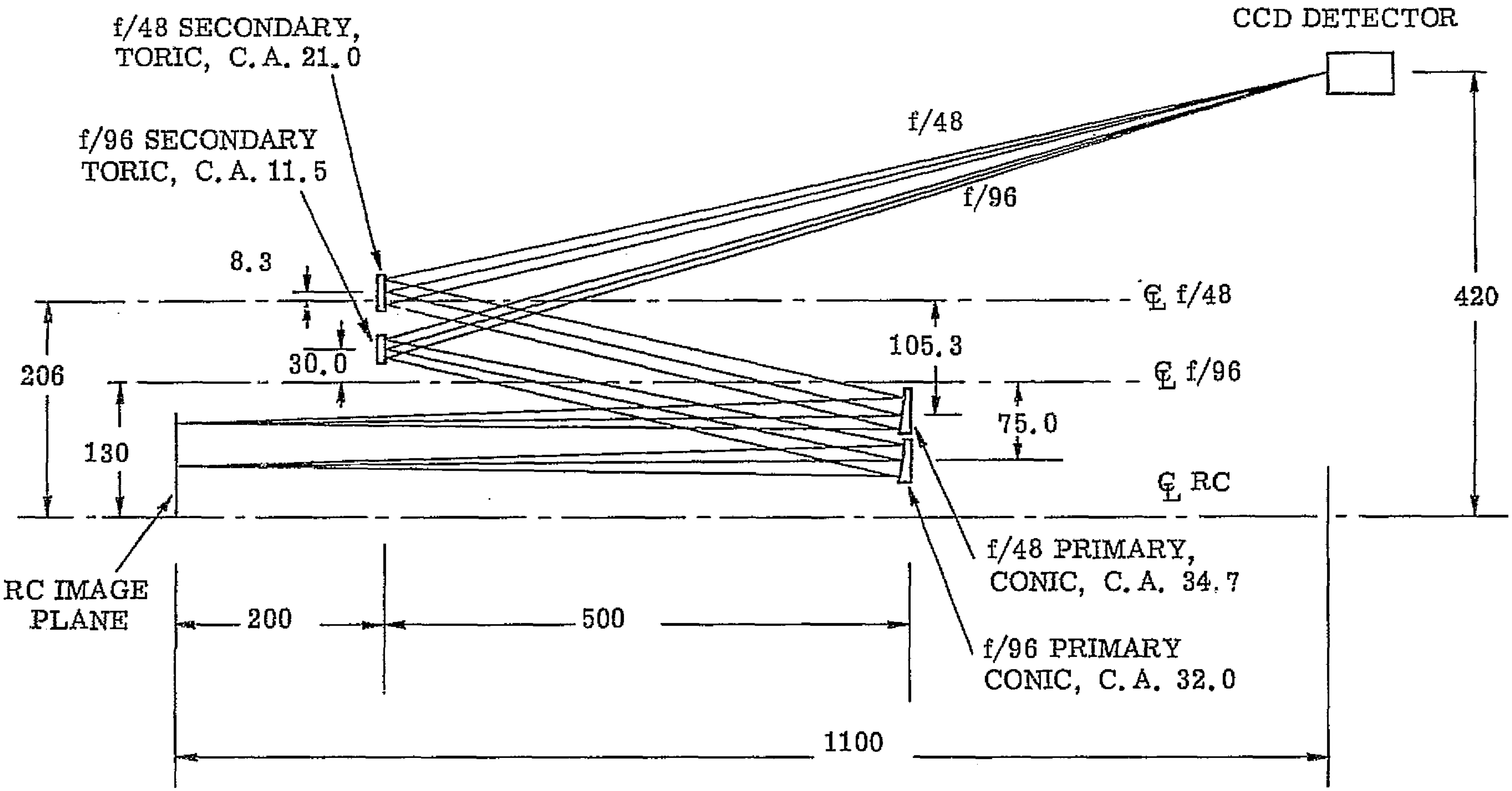
The basic optical form of the f48/96 relay systems is a twin, two-element reflector which corrects the field aberrations of the ST Ritchey-Chretien. The twin systems use different parts of the telescope science focal plane but provide a single image plane. The camera in use is selected by the port door position.

The basic schematic of the camera optical form is shown in Figure 3-11. The f/48 and the f/96 are each two-element optical forms. The primaries and secondaries of the two systems are coplaner with each other. This minimizes mounting and alignment problems. Both systems have one major optical powered conic element followed by a simple toric to correct for the off-axis position of the camera in the Ritchey-Chretien field. The systems were designed with the ST/OTA Ritchey-Chretien and are evaluated with it.

The optical prescription for the two optical trains is given in Figures 3-12 and 3-13. These prescriptions include in them the OTA and represent the exact form in which the systems were analyzed.

The first order parameters of the Planetary Camera system including the OTA Ritchey-Chretien are given in Figure 3-14.

The nominal performance capability of the combined Ritchey-Chretien/



• ALL DIMENSIONS IN MILLIMETERS

Figure 3-11. f/48 and f/96 Relays

NO.	SURFACE	NOTES	RADIUS	SPACING 0.0
1	ASPHER.	OTA Primary	-11040.0000	-4906.0710
2	ASPHER.	OTA Secondary	-1358.0000	6406.1995
3	SPHER.	f/24 focal plane	INF	0.0
4	SPHER.	f/24 focal plane	INF	700.0000
5	ASPHER.	f/96 Primary	-747.8137	-500.0000
6	TORIC	f/96 Secondary	-825.9578	1132.7401
7	SPHER.	f/96 focal plane	INF	-232.7412

TABLE OF ASPHERIC COEFFICIENTS

NO.	E	A(4)	A(6)	A(8)	A(10)
1	-2.298500D-03	0.0	0.0	0.0	0.0
2	-4.968600D-01	0.0	0.0	0.0	0.0
5	1.245750D 00	0.0	0.0	0.0	0.0
6	1.000000D 00	0.0	0.0	0.0	-1.137496D-03

TABLE OF DECENTRATIONS, TILTS AND ROTATIONS

NO.	TYPE	Y-DEC.	Z-DEC.	Y-TILT	Z-TILT	ROT.
1	1	0.0	0.0	-5.000000D-02	0.0	0.0
4	1	1.302400D 02	0.0	0.0	0.0	0.0

Figure 3-12. f/96 Relay Optical Prescription (dimensions in mm)

NO.	SURFACE	NOTES	RADIUS	SPACING
				0.0
1	ASPHER.	OTA Primary	-11040.0000	-4906.0710
2	ASPHER.	OTA Secondary	-1358.0000	6406.1995
3	SPHER.	f/24 focal plane	INF	0.0
4	SPHER.	f/24 focal plane	INF	700.0000
5	ASPHER.	f/48 Primary	-994.6247	-500.0000
6	TORIC	f/48 Secondary	10736.4959	992.4356
7	SPHER.	f/48 focal plane	INF	-92.4247

TABLE OF ASPHERIC COEFFICIENTS

NO.	E	A(4)	A(6)	A(8)	A(10)
1	-2.298500D-03	0.0	0.0	0.0	0.0
2	-4.968600D-01	0.0	0.0	0.0	0.0
5	1.401440D 00	0.0	0.0	0.0	0.0
6	1.000000D 00	0.0	0.0	0.0	1.406740D-04

TABLE OF DECENTRATIONS, TILTS AND ROTATIONS

NO.	TYPE	Y-DEC	Z-DEC	Y-TILT	Z-TILT	ROT.
1	1	0.0	0.0	-9.166670D-02	0.0	0.0
4	1	2.066100D 02	0.0	0.0	0.0	0.0

Figure 3-13. f/48 Relay Optical Prescription (dimensions in mm)

F/96 FIRST ORDER PARAMETERS ON MERIDIONAL PLANE

OBJECT DSTNCE	ENTR. PUP. DIST	FRST. PPAL. PNT	EQV. FCL. LNGTH	SCND. PPAL. PNT	EXT. PUP. DSTNC	IMAGE DISTNCE
INF	0.0	****************	-247200.126802	248100.125662	-84.992328	899.998860
OBJECT HEIGHT	ENTR. PUP. SIZE	OBJT. SPCE. FNO	TRACK LENGTH	IMGE. SPCE. FNO	EXT. PUPL. SIZE	IMAGE HEIGHT
INF	2400.001231	INF	INF	103.000000	-11.822645	-1006.710441
MAGNIFICATION	SEMIANG. FIELD	BACK VTX. DIST	BARREL LENGTH	FRNT. VTX. DIST	SEMIANG. FIELD	DEMAGNIFICATION
0.0	0.233333	INF	1700.128553	2600.127413	-47.366685	INF
APT. STOP SIZE	APT. STOP DIST	FROM SRFCE. NO	*****************	FLD. STOP SIZE	FLD. STOP DIST	FROM SRFCE. NO
2400.001231	0.0	1		-2013.420882	899.998860	6

F/48 FIRST ORDER PARAMETERS ON MERIDIONAL PLANE

OBJECT DSTNCE	ENTR. PUP. DIST	FRST. PPAL. PNT	EQV. FCL. LNGTH	SCND. PPAL. PNT	EXT. PUP. DSTNC	IMAGE DISTNCE
INF	0.0	****************	-115199.929179	116099.940111	31.451483	900.010931
OBJECT HEIGHT	ENTR. PUP. SIZE	OBJT. SPCE. FNO	TRACK LENGTH	IMGE. SPCE. FNO	EXT. PUPL. SIZE	IMAGE HEIGHT
INF	2399.998525	INF	INF	48.000000	-20.020503	-469.146084
MAGNIFICATION	SEMIANG. FIELD	BACK VTX. DIST	BARREL LENGTH	FRNT. VTX. DIST	SEMIANG. FIELD	DEMAGNIFICATION
0.0	0.233333	INF	1700.128551	2600.139482	-27.971268	INF
APT. STOP SIZE	APT. STOP DIST	FROM SRFCE. NO	*****************	FLD. STOP SIZE	FLD. STOP DIST	FROM SRFCE. NO
2399.998525	0.0	1		-938.292168	900.010931	6

Figure 3-14. f48/96 Camera First Order Parameters

Relay optical systems are summarized in Figures 3-15 through 3-18, representing performance as measured at the final detector plane. Aberrations in an optical imaging system are manifest as a spread in the points of intersection of rays from different points in the pupil with the focal plane. Thus, the quality of the optical system may be visualized readily by the lateral aberration curves shown in Figures 3-15 and 3-16. In these curves, for a given field angle, the ray height at the focal plane is plotted against the pupil radius that ray passes through -- normalized to a full pupil radius of 1.0. In such a presentation, a perfect system exhibits a straight line parallel to the abscissa. An out of focus condition is represented as a straight inclined line and aberration as various forms of curvature to the line.

The lateral aberration (H' Tan U') curves of the f/96 camera system (Figure 3-15) demonstrate the encircled energy performance of the f/96 system. Note that 100% of the geometrical energy is contained within a 50μm diameter circle. These values are computed for a point object in an 8.5 arc-sec field in the OTA science field. The system provides this imagery without vignetting.

A similar set of H' Tan U' curves of the f/48 camera system (Figure 3-16) demonstrate the encircled energy performance of that system. Note here, that 100% of the geometrical energy is contained within a 30μm diameter circle. These values are computed for a point object in a 16 arc-sec field in the OTA science field. The system provides this imagery also without vignetting.

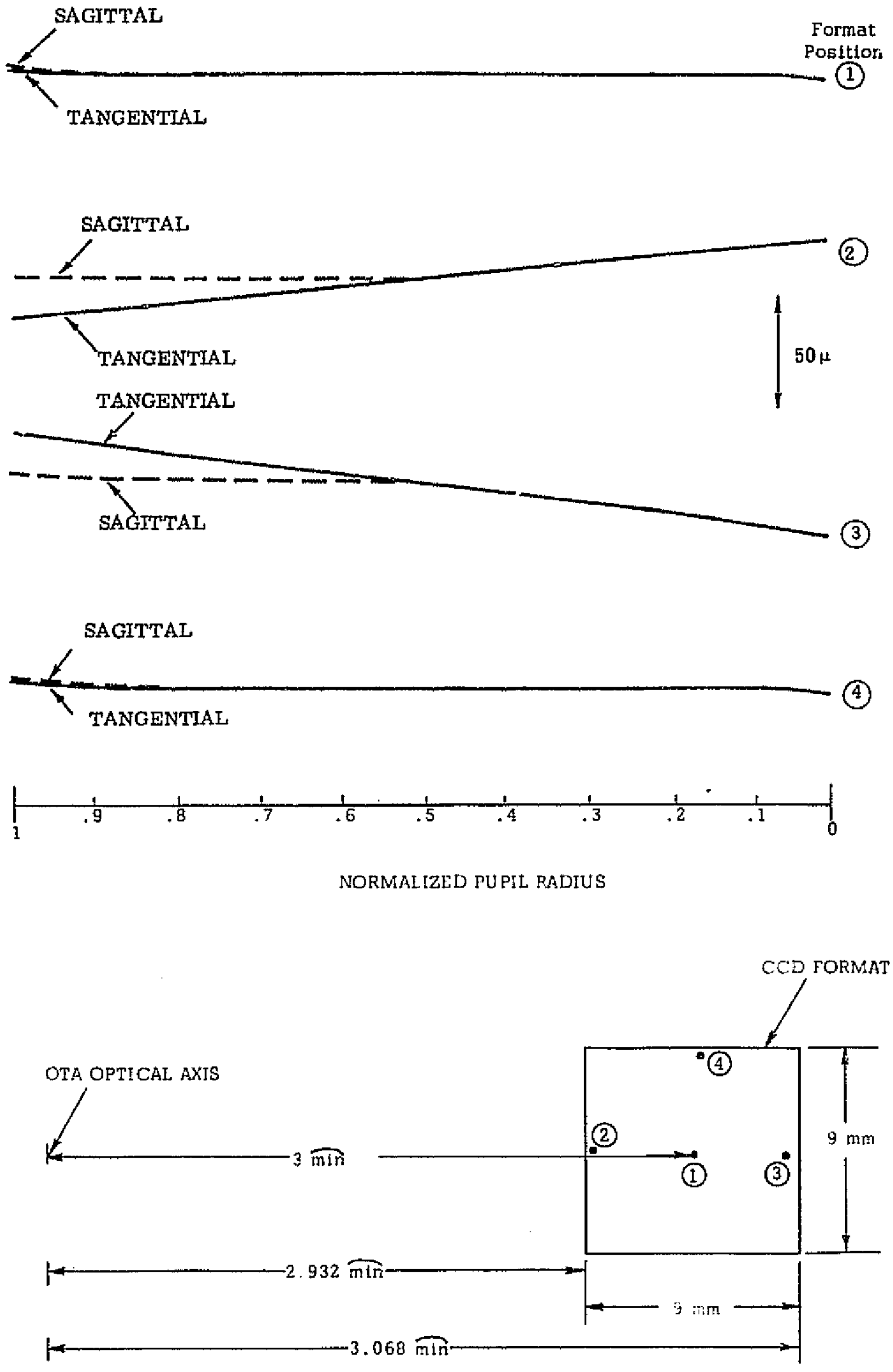


Figure 3-15. f/96 Camera Lateral Aberration Curves

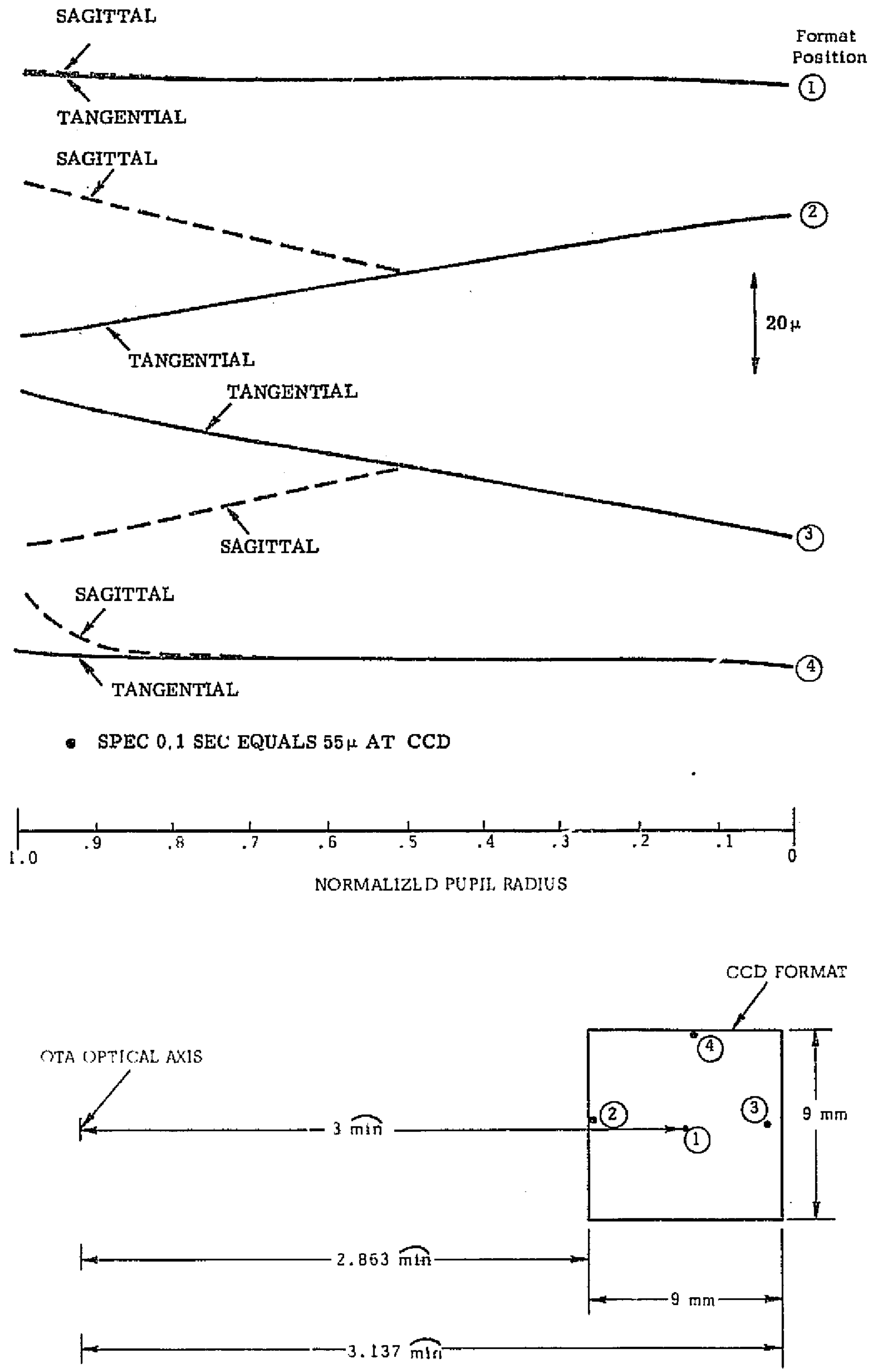


Figure 3-16. f/48 Camera Lateral Aberration Curves

The MTF of the systems are tabulated in Figure 3-17. A significant frequency is 20 line-pairs per millimeter, corresponding to the 25μm pixel size of the CCD. The unobscured and obscured theoretical performance of the systems are shown to compare with the specified response of the CCD. The obscuration is that of the Ritchey-Chretien.

The graphical presentation of the camera MTF in Figure 3-18 shows that performance is close to theoretical. Note the effect of central obscuration. Only the f/48 camera at its extreme field angle is distinguishable from the theoretical curve. However, this performance still provides a comfortable margin for manufacturing tolerances to achieve the specified 0.1 arc-sec resolution.

Figure 3-19 shows the location of the camera fields within the OTA module science field. The formats are those required now by the available CCD detector. The off-axis positions are chosen in conjunction with the optical relays constants and module physical limitations to provide a common focal plane on the CCD.

The optical tolerances assigned to the f/96 and f/48 optical relays are indicated on Figure 3-20. The tolerance budget was established to produce diffraction-limited performance for the f/96 camera and maintain 0.1 arc-sec resolution for the f/48 camera. The individual allocations were made on the basis of manufacturability. The tolerances are within the state-of-the-art. Only parameters having significant impact on optical performance are indicated.

f /96

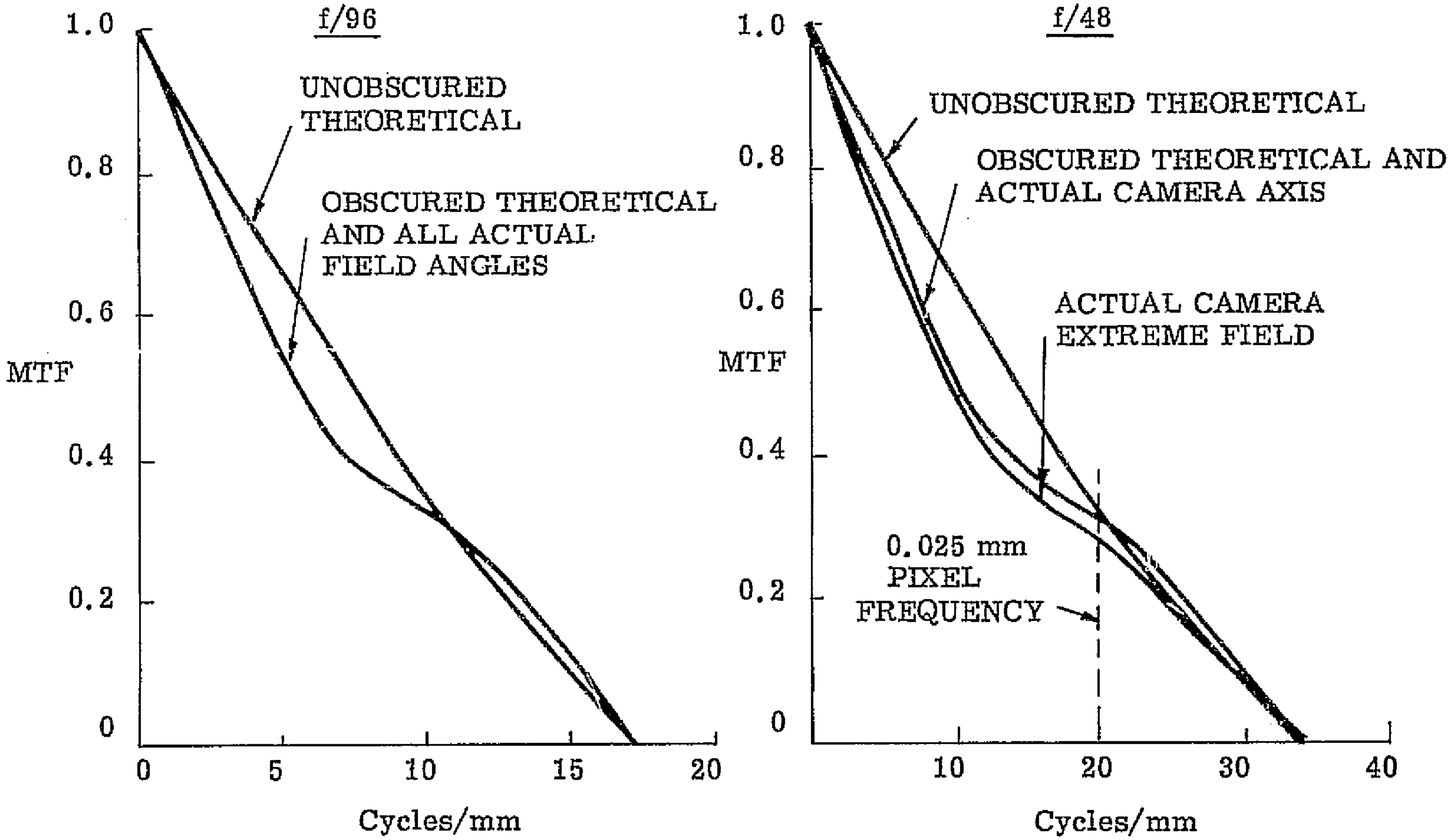
FREQUENCY (LINE-PAIRS/mm)	THEORETICAL UNOBSCURED MTF	THEORETICAL 31% OBSCURED MTF	ACTUAL 2.932 MIN FIELD MTF	ACTUAL 3.0 MIN FIELD MTF	ACTUAL 3.068 MIN FIELD MTF
2.5	0.833	0.769	0.769	0.769	0.769
5.0	0.666	0.541	0.541	0.541	0.540
7.5	0.503	0.391	0.391	0.391	0.391
10.0	0.354	0.324	0.324	0.324	0.323
12.5	0.217	0.238	0.238	0.237	0.237
15.0	0.105	0.116	0.116	0.115	0.114

f/48

FREQUENCY (LINE-PAIRS/mm)	THEORETICAL UNOBSCURED MTF	THEORETICAL 31% OBSCURED MTF	ACTUAL 2.863 MIN FIELD MTF	ACTUAL 3.0 MIN FIELD MTF	ACTUAL 3.137 MIN FIELD MTF
5.0	0.826	0.760	0.733	0.760	0.735
10.0	0.653	0.527	0.478	0.527	0.482
15.0	0.486	0.383	0.349	0.383	0.353
20.0	0.330	0.313	0.284	0.313	0.286
25.0	0.194	0.212	0.193	0.212	0.193
30.0	0.083	0.090	0.088	0.090	0.085

- WAVELENGTH = 632.8 nm
- 20 LP/mm = 25μ PIXEL

Figure 3-17. f48/96 Camera MTF



• WAVELENGTH = 632.8 nm

Figure 3-18. f48/96 Camera MTF Curves

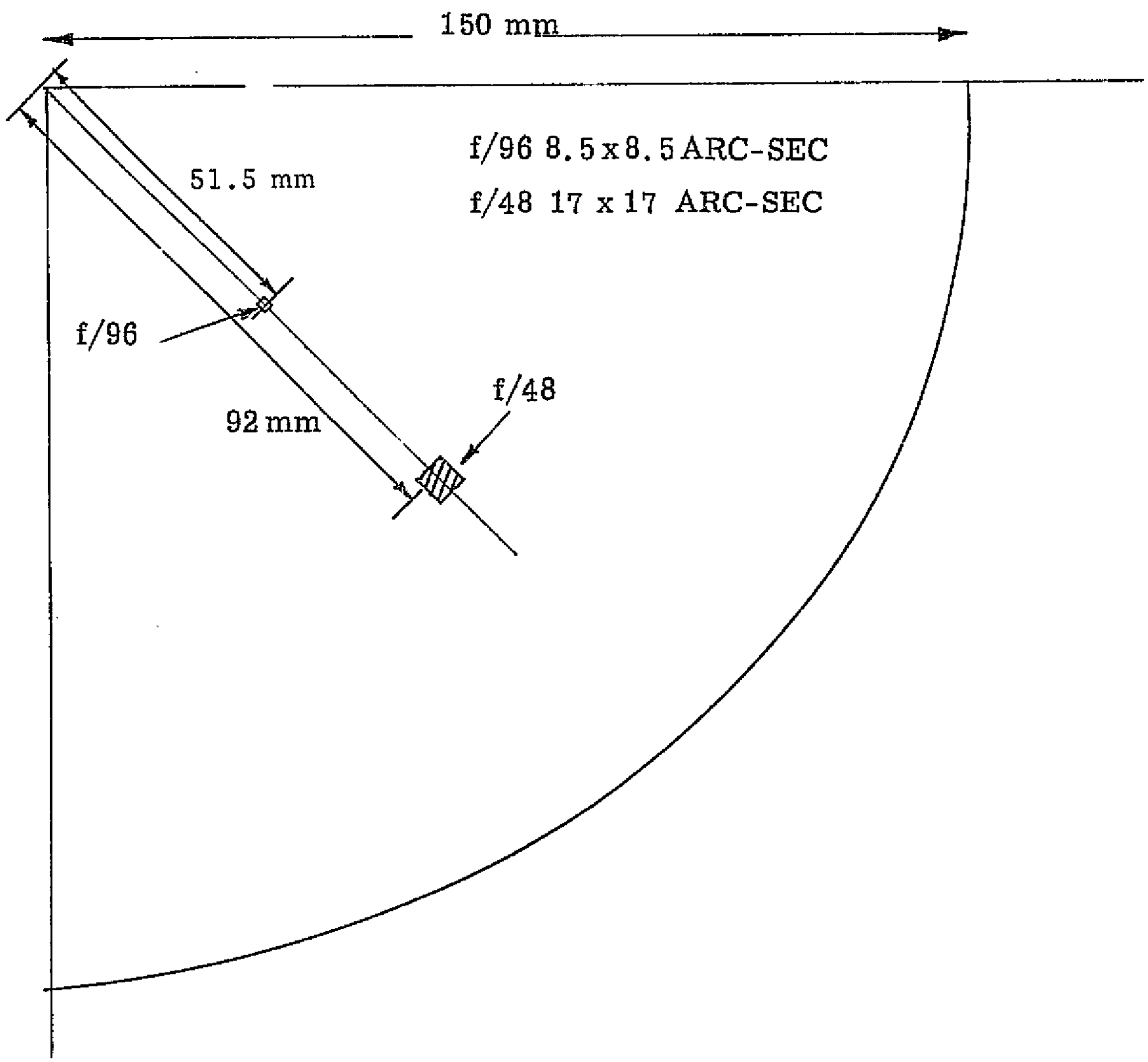
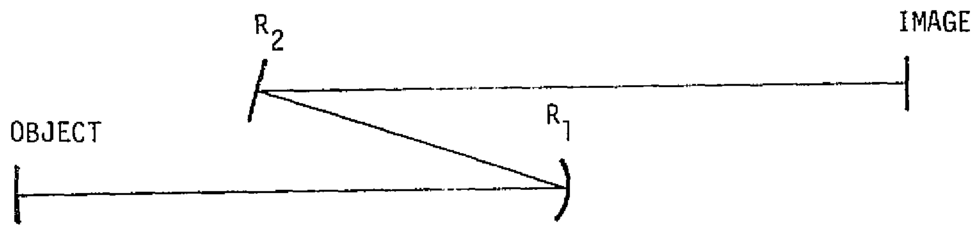


Figure 3-19. Planetary Camera - Location in Data Field

Referring to the tolerance tables of Figure 3-20, the note "refocus" implies that the particular tolerance affects only instrument focus, and can be compensated by correctly positioning the detector at the focal plane during assembly.

The optical throughputs of the f/96 and f/48 cameras plus the Ritchey-Chretien are shown in Figure 3-21. Both systems utilize Aluminum/Magnesium Fluoride coatings. The throughput is reduced by the two-reflection relay, an average of 15% over the transmission of the Ritchey-Chretien alone. At the shortest wavelength, 180.0 nm, transmission is reduced 23%.



f/96

Parameter	Δ	Note	Δ rms OPD
R_1	0.2mm	Refocus	0.007882λ
R_2	0.4mm	Refocus	0.002478
R_1 Figure	λ/200	-	0.010000
R_2 Figure	λ/125	-	0.016000
T(1-2)	0.05mm	Refocus	0.000751
T(1-2)	0.01mm	W/O Refocus	0.000605
Tilt	10 arc-sec	R_1 to R_2	0.000551
Decenter	0.05mm	R_1 to R_2	0.001248
		RSS =	0.020665λ

f/48

Parameter	Δ	Note	Δ rms OPD
R_1	1.0mm	Refocus	0.004288λ
R_2	11.0mm	Refocus	0.000490
R_1 Figure	λ/150	-	0.013333
R_2 Figure	λ/100	-	0.020000
T(1-2)	0.1mm	Refocus	0.000006
T(1-2)	0.01mm	W/O Refocus	0.000332
Tilt	10 arc-sec	R_1 to R_2	0.000538
Decenter	0.1mm	R_1 to R_2	0.002075
		RSS =	0.024517λ

- λ = 632.8 nm
- Only driving tolerances shown
- Focus Drift Negligible

Figure 3-20. f48/96 Camera Optical Tolerances

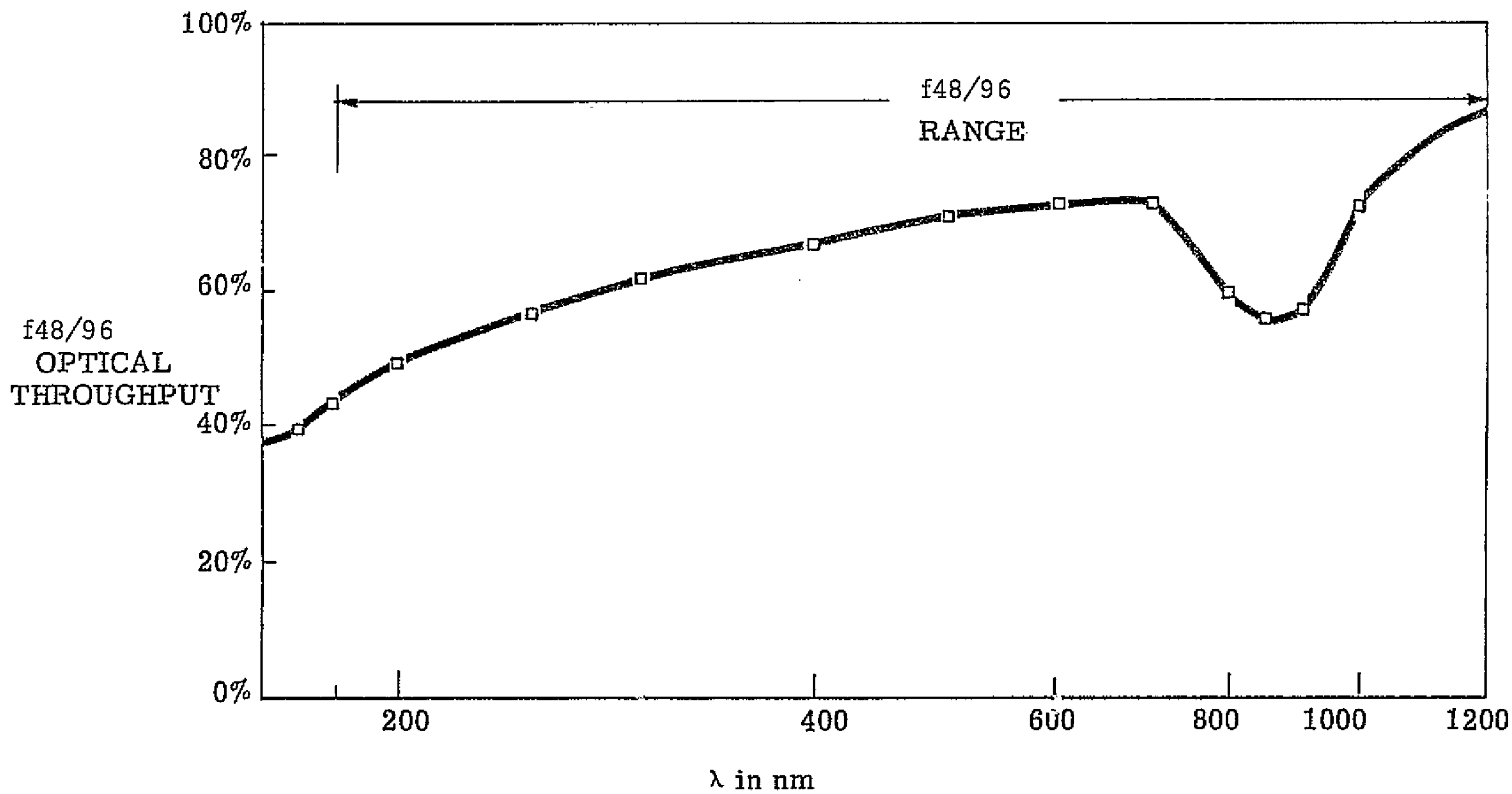


Figure 3-21. Planetary Camera Optical Throughput

SECTION 4
CALIBRATION

4.1 Requirements

The prime requirement of the calibration unit is to provide a measurement of the uniformity of the CCD detector format. Absolute calibration of the detector and the throughput of the optical system is then performed using celestial sources.. Long term reliability is a requirement of the calibration design. It must be fail-safe in operation so that the camera remains operative in the event of calibration subsystem failure.

4.2 Calibration Unit Design

The calibration subsystem, shown in Figure 2-1, permits a double mode of operation with a minimum of complexity. The prime subunit is a source illuminator which provides two calibration tungsten sources. Source output data is shown in Figure 4-1. The tungsten sources are imaged through adjacent exit ports of the calibration housing, each source using a concave mirror operated off-axis. Both light bundles are directed along Path A, Figure 2-1, to the detector format by a small mirror mounted onto the structure which supports the secondary mirror of the f/48 and f/96 relays (ref. Figure 2-1, sheets 1 and 2). This provides two calibration beams ($\sim$f/48 and $\sim$f/96), both of which must uniformly illuminate the detector format. The position of the two calibration alignment mirrors permits use of the filters (or an open filter position) without any vignetting from their off-axis location. Calibration can thus be initiated simply by energizing the sources -- no mechanisms are required; nothing is inserted into the optical path.

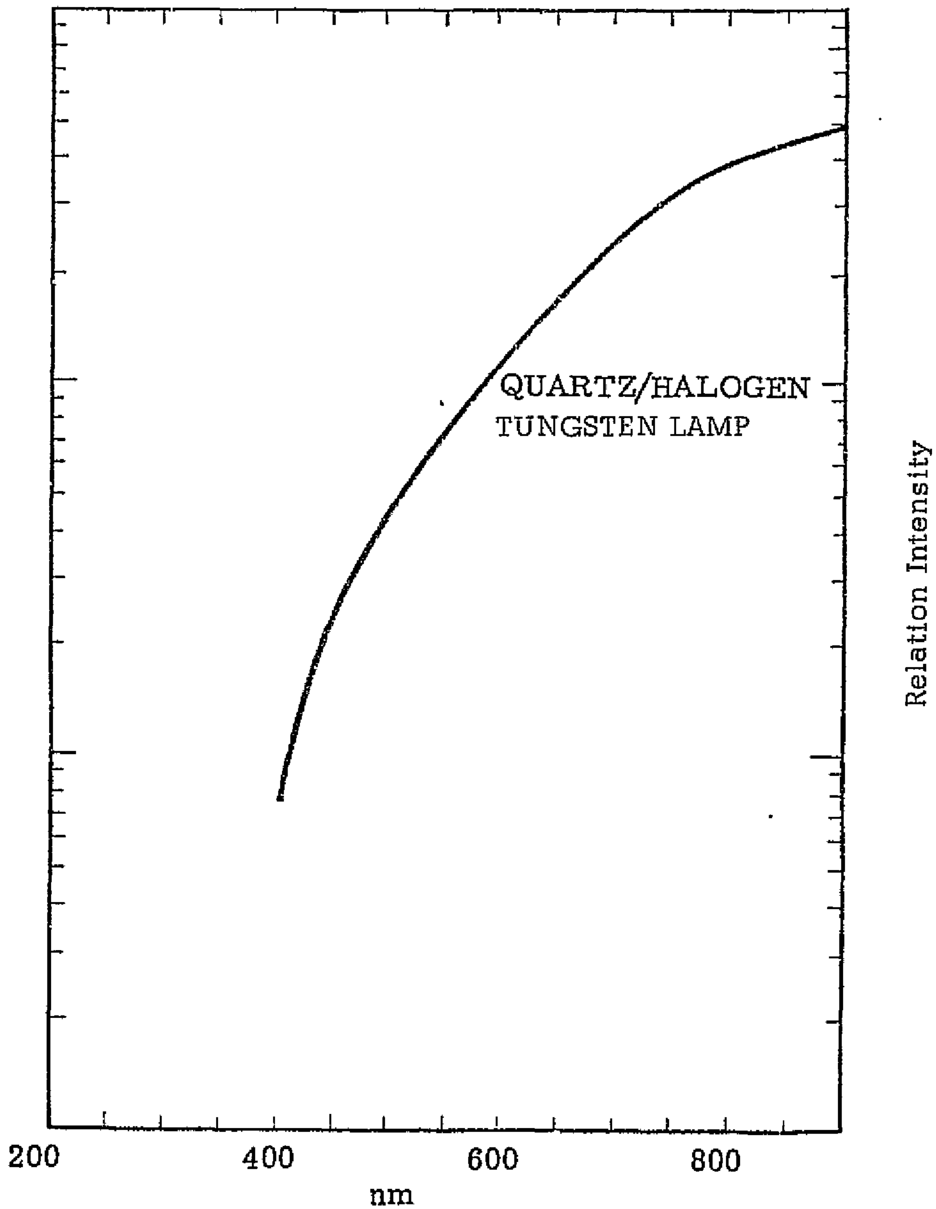


Figure 4-1. Typical Calibration Source Spectral Intensities

One of the calibration sources (Source 1 is shown in Figure 2-1) also provides a throughput measurement for the optical relay. An additional concave mirror, mirror "C", directs the light along path "B" toward the entrance port of the camera where a mirror mounted on the Port Door redirects the bundle into the instrument along the nominal input path. A weak refracting optical element located adjacent to the calibration mirror reimages the mirror "C" to be analogous to the secondary of the OTA to provide an effective f/24 input bundle. This provides an additional input to the detector, from a calibration source, through the relay optics. Relay optics throughput can thus be measured by differential measurements using the two calibration modes. This measurement is not significantly sensitive to source variations.

The sources identified are standard tungsten sources which provide the spectral range and intensity needed for the calibration. Hollow cathode sources, which provide selectable spectral outputs, may also be used. A hydrogen lamp would provide a spectral range 170-380 nm while other gases give selectable outputs ranging to beyond 800 nm. The power requirements are similar to the standard lamps with operating consumption being less than 10 watts.

4.3 Operation

The calibration unit as described is relatively simple and has only one moving part (calibration mirror), which does not involve the detector test, the prime mode of operation of the calibrator. For the prime test, that of measuring the uniformity of the detector, the camera shutter is closed so that the second path through the f48/96 relays is prevented and the detector is uniformly irradiated. The time of the exposure is controlled by either rotation of the filter unit or by on-off control of the detector. These methods are adaptable for relatively long exposures so that shuttering accuracy is not required. If shorter exposures are required, the addition of shutters at the calibration exit ports can be introduced. These were not felt to be required for a uniformity test since the latter may be performed at various levels using the filter array.

The second path, via the f/48 or the f/96 relay utilizes the control of the shutter at the entrance aperture. The shutter exposure time provides an additional radiation level at the detector and permits measurement of the throughput of the optics using knowledge of the test features of the calibration unit. This unit can also be used to verify the reciprocity and linearity features of the detecting chain by varying the shutter times.

SECTION 5
STRUCTURAL / THERMAL DESIGN

5.1 Structural Requirements/Interface with OTA

Figure 3-4 defines the configuration of the focal plane of the OTA. It shows that the central 18 arc-min diameter (12.06 inches) at the focal plane is allocated as the science data field for the five science instruments with allowance for a central 0.8 inch cruciform shaped area given to spacing between instruments and for structure. The f/24 Field Camera is allocated the 100 mm x 100 mm (4 inch square) central portion of the field with the remaining portion of the data field equally allocated in approximate 90° sections to each of the four axial science instruments. The focal plane structure (FPS) with instrumentation is shown in Figure 1-1.

The OTA focal plane, beyond the 18 arc-min data field, extends out to a 29.4 arc-min diameter (19.65 inches). As shown, three 90° sections of this portion of the field are given as tracking field to the three Fine Guidance Sensors.

The prime requirements for the FPS are as follows:

- Maintain its locating surface (to which all instrumentation is attached) with respect to the optical axis to within a tolerance of 0.1 mm and with respect to the curved focal plane with a tolerance of 0.07 mm (ref. Section 3-2).
- Provide a means for registering all focal plane instrumentation to this mounting surface. In the case of the science instruments,

the registration design must allow for repeatability of registration after orbital removal and replacement.

- Provide a stable surface, i.e., prevent relative motion between the science instruments and the Fine Guidance Sensors.

Because of the nature of ST, as a long-lived National Observatory facility, and the varying requirements of the present, and as yet undefined future, science instruments, the tolerances established for the FPS are driven by essentially the requirements of the most sensitive anticipated SI.

The structural design of each science instrument must therefore be developed from a review and consideration of the performance of the OTA and the tolerances associated with the reference ball detent, to provide a science instrument optical system to the extent required to achieve the performance specification.

Within the general OTA configuration, the requirement of an instrument module is that it achieve the following:

- Provide a mounting reference to the ball detent - and flexible connection to two other points on the OTA structure.
- Enclose and protect the science instrument.
- Provide a thermal environment both to stabilize the instrument and provide a means of dissipating heat to the SSM.

Within each module an optical bench is provided onto which the key elements of the instrument are mounted and aligned.

5.2 Axial Module

The OTA axial module envelope is shown in Figure 1-3. The module is referenced to the OTA focal plane (and located in the x, y and z directions) by a ball detent on the forward surface of the module. The module is held into this ball detent by a force retention system, located on the module rear surface directly opposite the ball detent, exerting a force on the module into the ball detent. A pin/slot device on the front module surface prevents rotation of the module.

The axial module is constructed of aluminum and is estimated to weigh ~140 pounds. The mounting forces (~4000 pound preload) will introduce some deflections into the box, but the mounting method for the interior optical bench will prevent these forces from bending the optical mount. The outer surface of the module serves as a radiating surface for the dissipation of instrument heat; the ball detent attachment to the focal plane structure must conduct very little of this heat into this structure. The FPS is temperature controlled at $70^{\circ}F \pm 2$ and the stability of the science instruments to the Fine Guidance Sensors is dependent on avoiding both temperature changes and gradients in this structure.

5.3 Optical Bench

The optical bench for the planetary camera provides a strain-free, rigid base integral with the instrument elements and permits ready access/installation of the instrument into the axial module. The optical bench is shown in Figure 5-1. The bench is securely tied to the module at the forward ball detent position and is additionally supported near the rear by two axially compliant flexures. This arrangement locates the instrument with respect to the ball detent while preventing module preload forces (or forces resulting from external temperature changes) from introducing misalignment of the optical elements.

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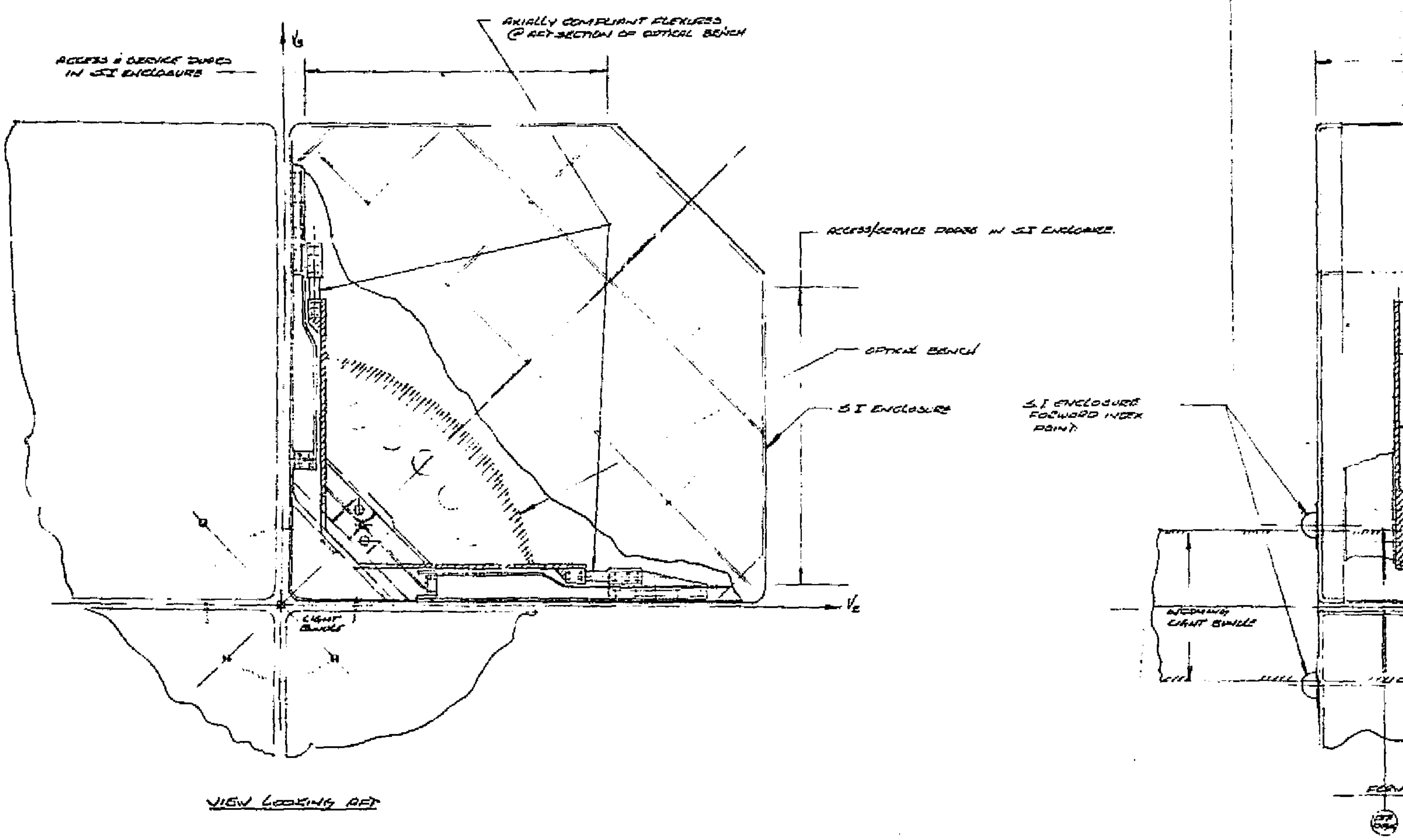
PERKIN-ELMER

INTERNAL OPTICAL BENCH

- UNIQUE DESIGN FOR EACH SCIENCE EXPERIM
- ATTACHES TO ENCLOSURE IN A (NEAR) STATICAL DETERMINANT MANNER



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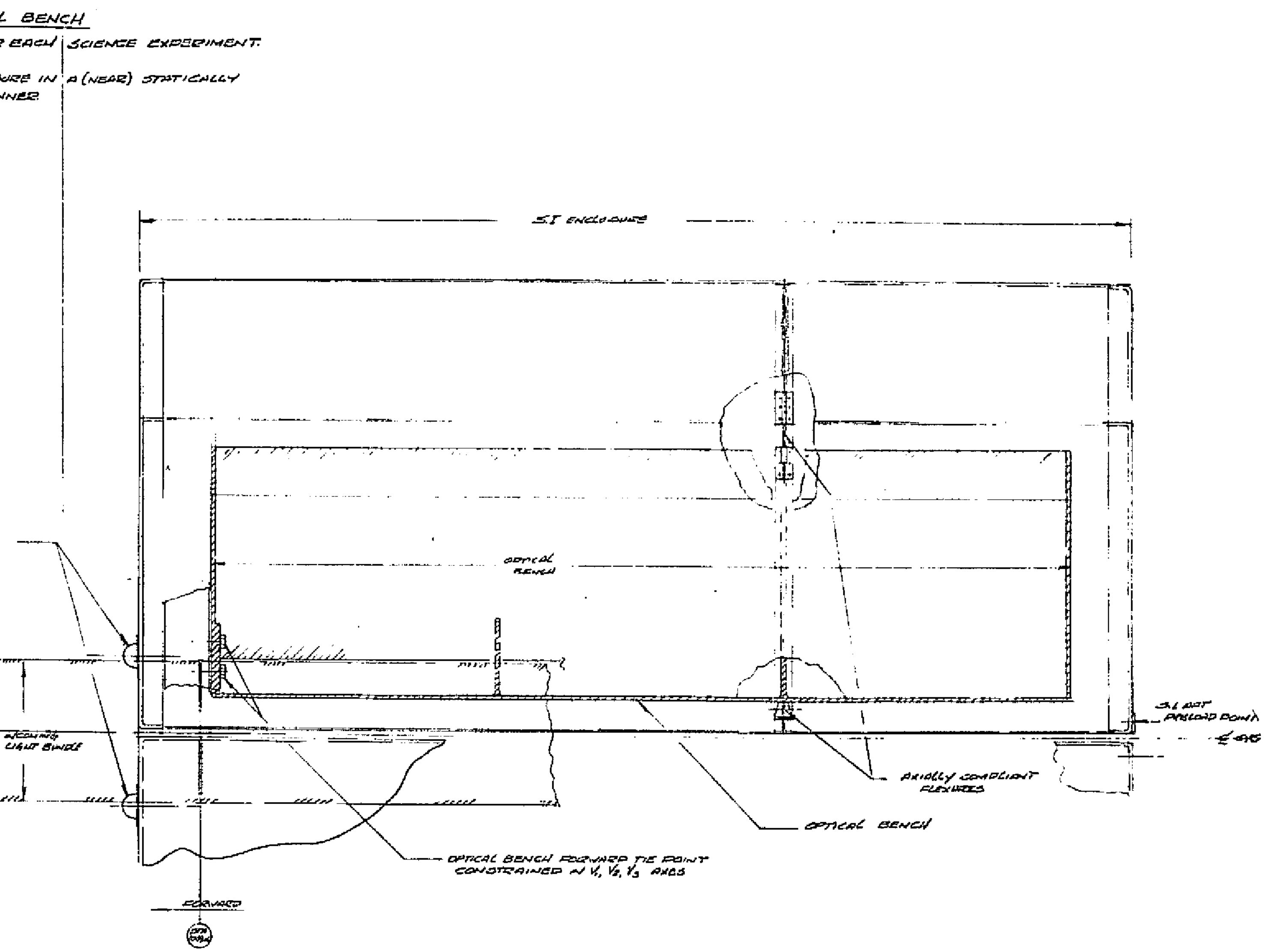


Figure 5-1. Internal Optical Bench

5.4 Alignment with OTA Focal Plane Structure

The design of the focal plane structure was driven by configuration requirements. Structural performance was achieved by material selection and member sizing, having first defined the mechanical or configuration constraints. The structure is designed to accommodate the four large axial science instrument modules and four radial bay modules. Three of the radial bay modules are for fine guidance sensor instrumentation, and the fourth contains the f/24 Field Camera (ref. Figure 1-2). All of the science instrument modules (both axial and radial) are replaceable on orbit by a suited astronaut.

The principal design requirements for the focal plane structure are derived from the OTA system focus budgets and fine pointing accuracies. Focus shift allowed during an observation is 30 μm total for this structure. This is achieved by using titanium and stabilizing the temperature of the structure to $\pm 2^{o}$F. Half of the fine pointing error (0.005 arc-second) is budgetted for thermal effects during an observation. At the f/24 focus, 0.005 arc-second is equivalent to 1.4 μm which then becomes the limit for any lateral change between a science instrument and its controlling star tracker (fine guidance sensor). This requirement is satisfied with a low expansion (Invar) mounting plate on the focal plane structure which is the mechanical reference for both the FGS and the SI modules.

The deflection of the center of the focal plane structure, relative to the primary mirror vertex, is .050 mm with the system vertical and with four 500 pound SI's installed. If this were permitted to exist as a gravity-release error, only 0.5 μm of secondary mirror motion would be required to correct it on-orbit. The 0.25 mm axial position tolerance is correctable with a 2 μm secondary shift.

Figure 5-2 shows the relative locations of the ball detents on the FPS Invar ring, these detents serving to accurately locate the science instruments to the fine guidance sensors and both to the optical axis/focal plane of the OTA. The four axial science instrument detents are identified as D_A and the four radical detents (one for the f/24 Camera, the other three for the 3 Fine Guidance Sensors) identified as D_R. The structural path between the axial and radial detent is not directly loaded by the preload force. This preserves alignment after a removal/ replacement cycle. This is accomplished by mounting the radial detent on a short intercostal outboard of the P, -P, P, ... forces. Thus, the radial detents, D_R, will follow and be located by the axial detents, D_A.

5.5 Thermal Design Requirements

The thermal design requirements for the f48/96 Planetary Camera in the OTA axial bay are as follows:

- Cooling of CCD detector to -40F.
- Thermal stabilization of the camera optical system at 70°F±2 to maintain alignment and focus.
- Rejection of heat from the camera (~60 watts) to the SSM aft shroud.

5.6 OTA/SI Thermal Interfaces

The thermal interfaces of the f48/96 Camera with the OTA and the SSM are shown in Figure 5-3 and are defined as follows:

- Camera interface with focal plane structure is adiabatic.
- Aft shroud rear wall (141) is essentially adiabatic.
- Aft shroud wall (101, 121) temperatures are:
  - Maximum average temperature +7°F
  - Minimum average temperature -40°F
  - Maximum temperature variation per orbit ±5°F.

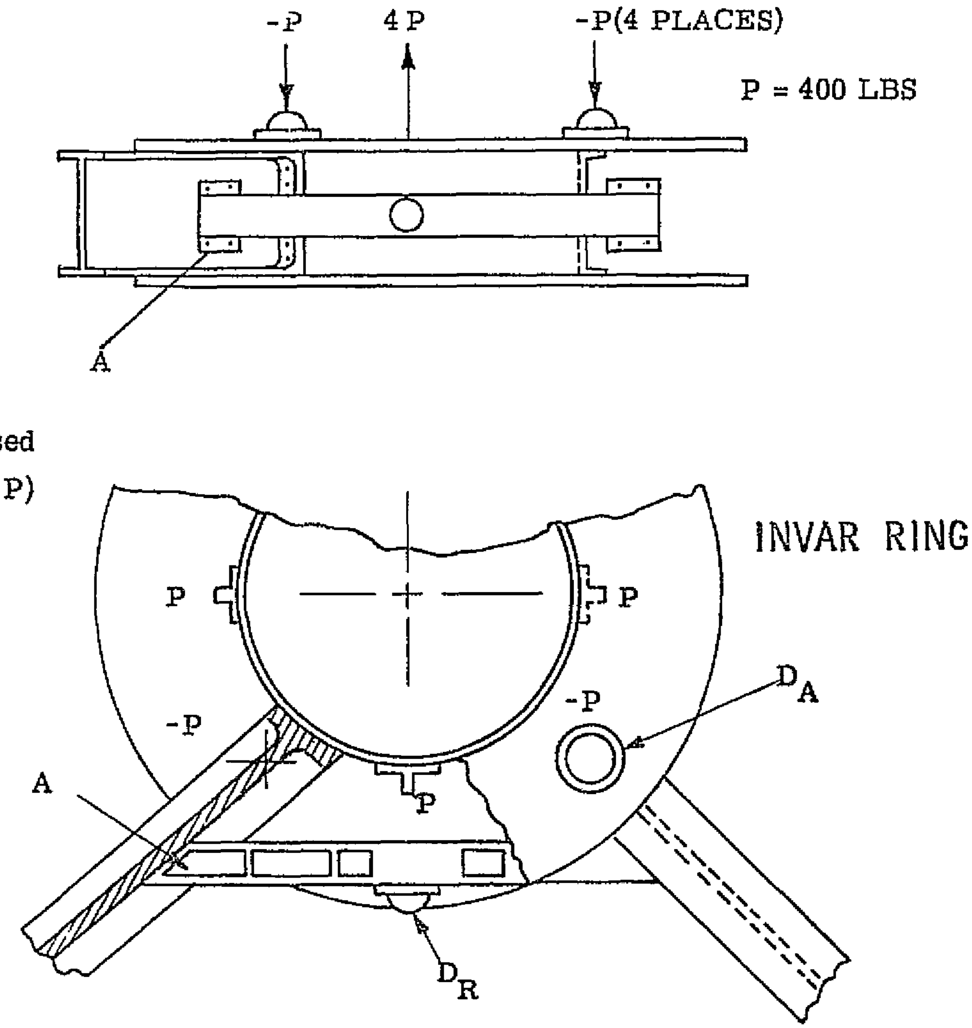
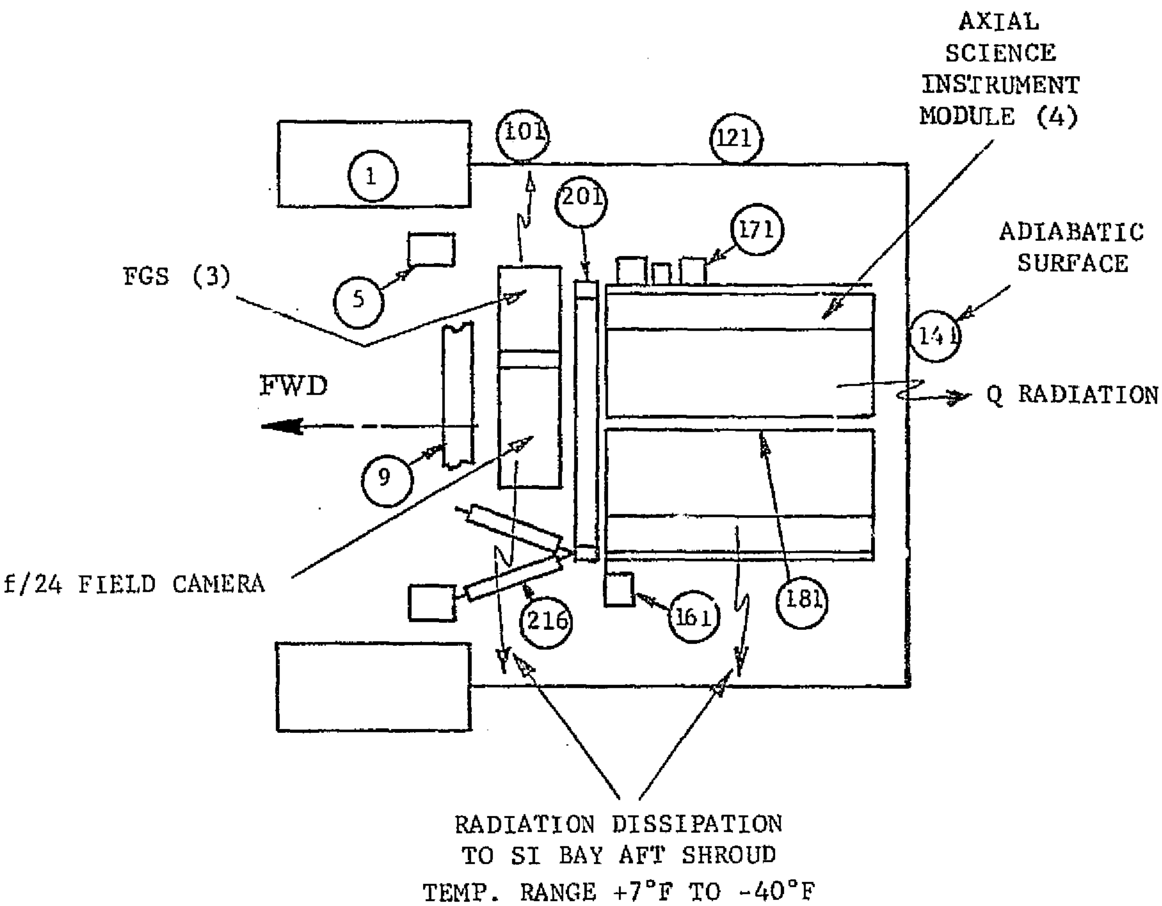


Figure 5-2. Detent/Preload Load Path



1	SSM
5	MOUNTING RING
9	ACTUATOR STRUCTURE
101	AFT SHROUD INNER WALL - FORWARD
121	AFT SHROUD INNER WALL - REAR
141	AFT SHROUD REAR WALL
161	SSM REF. GYRO
171	OTA ELECTRONICS
181	SPAR
201	FOCAL PLANE STRUCTURE
216	FPS SUPPORT BRACKETS AND STRUTS

Figure 5-3. Science Instrument Thermal Interfaces

Figure 5-4 illustrates the design configuration for rejection of heat from the axial module. The +V3 side of the telescope is nominally maintained toward the sun. The four modules are insulated on the +V3 and -V3 sides and from each other. All heat from the axial science instruments is rejected to either the +V2 or -V2 sides of the instrument bay shroud. This configuration has the capability to dissipate in excess of the allowed 150 watts, regardless of ST roll angle, as long as the SSM maintains the temperature conditions noted above. An earlier analysis had shown that a roll of $\pm 30^{\circ}$ would cause higher SSM shroud temperatures and this would limit SI best dissipation to $\sim$100 watts. This limited power condition, if required, can be avoided by proper design of the aft shroud and the thermal shields.

Figure 5-5 defines the nominal power which must be rejected from the Science Instrument area. It includes power dissipation not only from the five Science Instruments but also from the OTA/SI electronics, SSM gyros and star trackers and the OTA fine guidance sensor (ref. Figure 2-1). Figure 5-6 relates the wall temperature of the axial SI module to the power which can be radiantly rejected as a function of the wall temperature of the SSM aft shroud.

All OTA structural members which interface with the science instruments whose dimensional stability is critical to good SI performance are maintained at $70^{\circ}F \pm 2$. This includes the OTA main ring and the focal plane structure to which all the SI's are mounted.

SI and other component module exterior walls facing the SSM aft shroud generally should have high emissivity exterior surfaces to maximize the radiative heat transfer from the module to the aft shroud.

5.7 f48/96 Camera Thermal Design

The key features of the Planetary Camera thermal design are:

- The camera optics operate at $70^{\circ}F \pm 2$ at all times. This provides

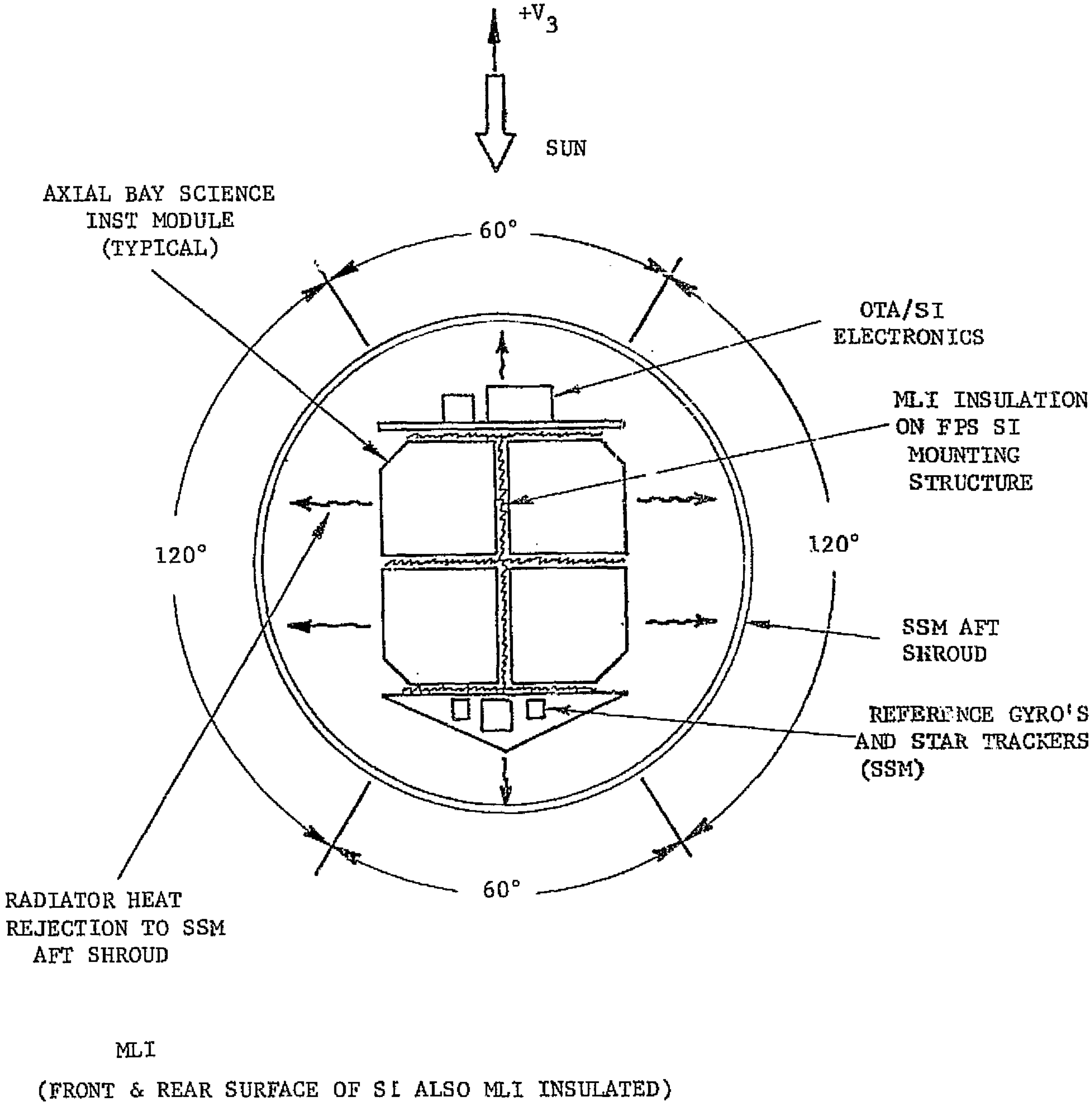


Figure 5-4. Axial Science Instrument Heat Rejection

TABLE 5-5

OTA/SI HEAT REJECTION TO SSM AFT SHROUD

ITEM	HEAT REJECTION (WATTS)	
	MAXIMUM	TYPICAL
SCIENCE INSTRUMENTS (4)	400	300/400
FINE GUIDANCE SENSOR MODULES (3)	195	130
OTA ELECTRONIC CONTROLS	50	40
HEATED FOCAL PLANE STRUCTURE	100	40
REFERENCE GYROS AND STAR TRACKERS (SSM EQUIPMENT)	45	45
TOTAL	790	555/655

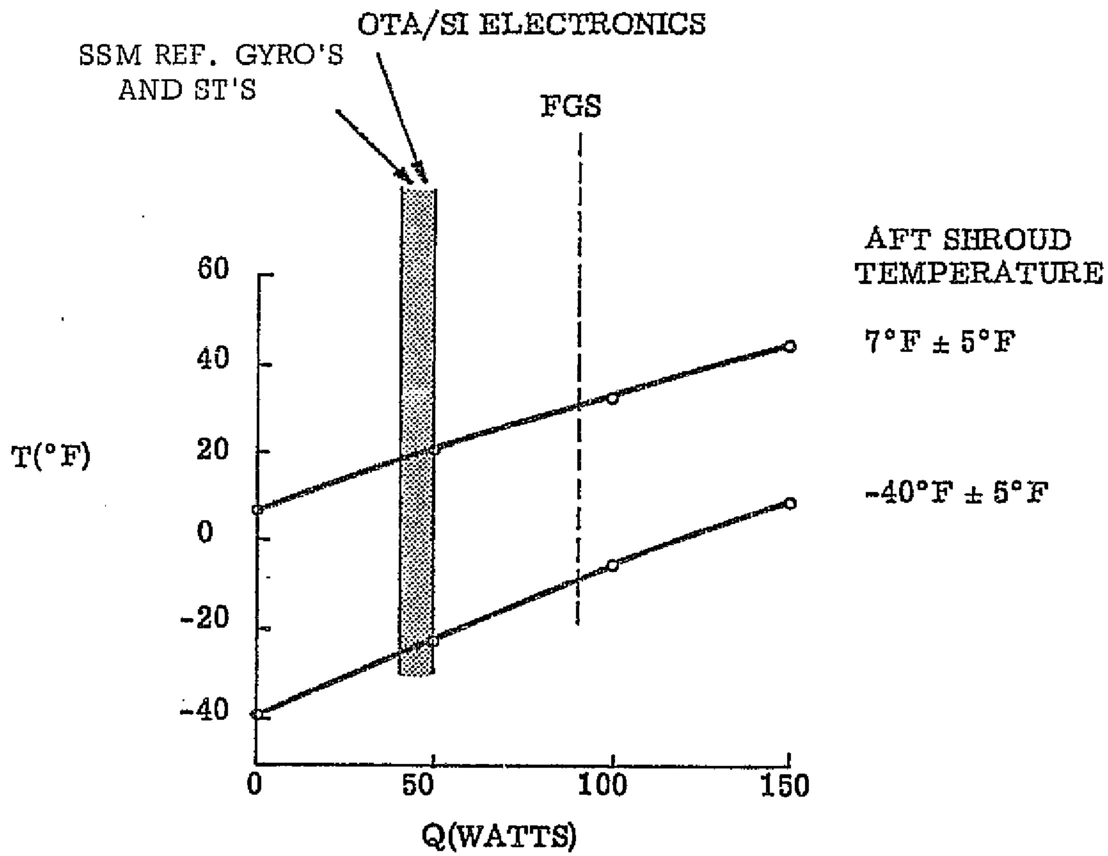


Figure 5-6. SI Surface Temperature vs Heat Rejection

isothermal relationships between manufacturing, alignment, test and operation and also minimizes contamination deposition on the optics. Individual heaters and thermostats will be located on the optical bench as required to insure temperature control.

- The CCD detector operates at -40°F. Thermoelectric modules are used to provide this cooling.
- The calibration subsystem imposes a short term heat load, but this does not adversely affect performance or stability.
- Thermocouples are used on the optical mounts, the optical bench and the detector assembly for monitoring and control. Platinum thermocouples will be used for both control and diagnostic purposes since they meet the required temperature tolerance and have long life characteristics.
- Electronic units are located away from the instrument proper and are enclosed for thermal control/contamination assurance.

Power, dissipated from the detector and instrument electronics, is rejected to the wall of the SI module by radiation, thermoelectric cooling and conduction. The heat from the SI module exterior wall is rejected radiatively to the SSM aft shroud wall. The +V2 or -V2 wall, depending on final module location in the OTA, must radiate the 37 watts from the detector package plus an additional 24 watts from other heat sources inside the camera. These other heat sources include:

- Temperature Control System Electronics
- Camera Control Electronics
- Motor, Solenoid, Magnetic Clutch Power
- Local Thermal Control Heaters

- Calibrator Source Power (periodic).

A 25°F SI wall will radiate 60 watts to a 7°F aft shroud inner wall if the IR emissivity ($\mathcal{E}$) of each surface is 0.9. This $t = .9$ is conservative and readily obtained in the IR range of wavelengths.

The heat rejection from the camera container wall can be estimated from

$$Q = \sigma\bar{e}\, AF \left[T_{f/24}^{4} - T_{AS}^{4} \right]$$

where

$\bar{e} \simeq 0.8$ (each surface $\equiv 0.9$)

and

$AF \cong 19.4\ ft^2$ (maximum axial container exterior surface area seen by the aft shroud).

Therefore:

$$Q = (0.1713 \times 10^{-8})\ (0.8) \left[(19.4)\ (\overline{485}^{4} - \overline{467}^{4}) \right]$$

$$= (2.65 \times 10^{-8})\ (709 - 476) \times 10^{-8}$$

$$= 205\ \text{BTU/hour}$$

$$= 60\ \text{watts.}$$

If the exterior surface is 25°F (485°R) then a net of 60 watts may be rejected to the aft shroud at 7°F (467°R).

Heat straps are used to provide good thermal contact between the thermoelectric module and the SI module wall.

A schematic layout of the CCD package with the integral thermoelectric cooler is shown in Figure 5-7. The two-stage thermoelectric module provides a separate cold finger for cooling the CCD; the cooler first stage removes heat from the CCD driver. The heat flows -- about 0.1 watts for the CCD and about 7 watts for the driver -- require an input of about 30 watts to the cooler to increase the hot

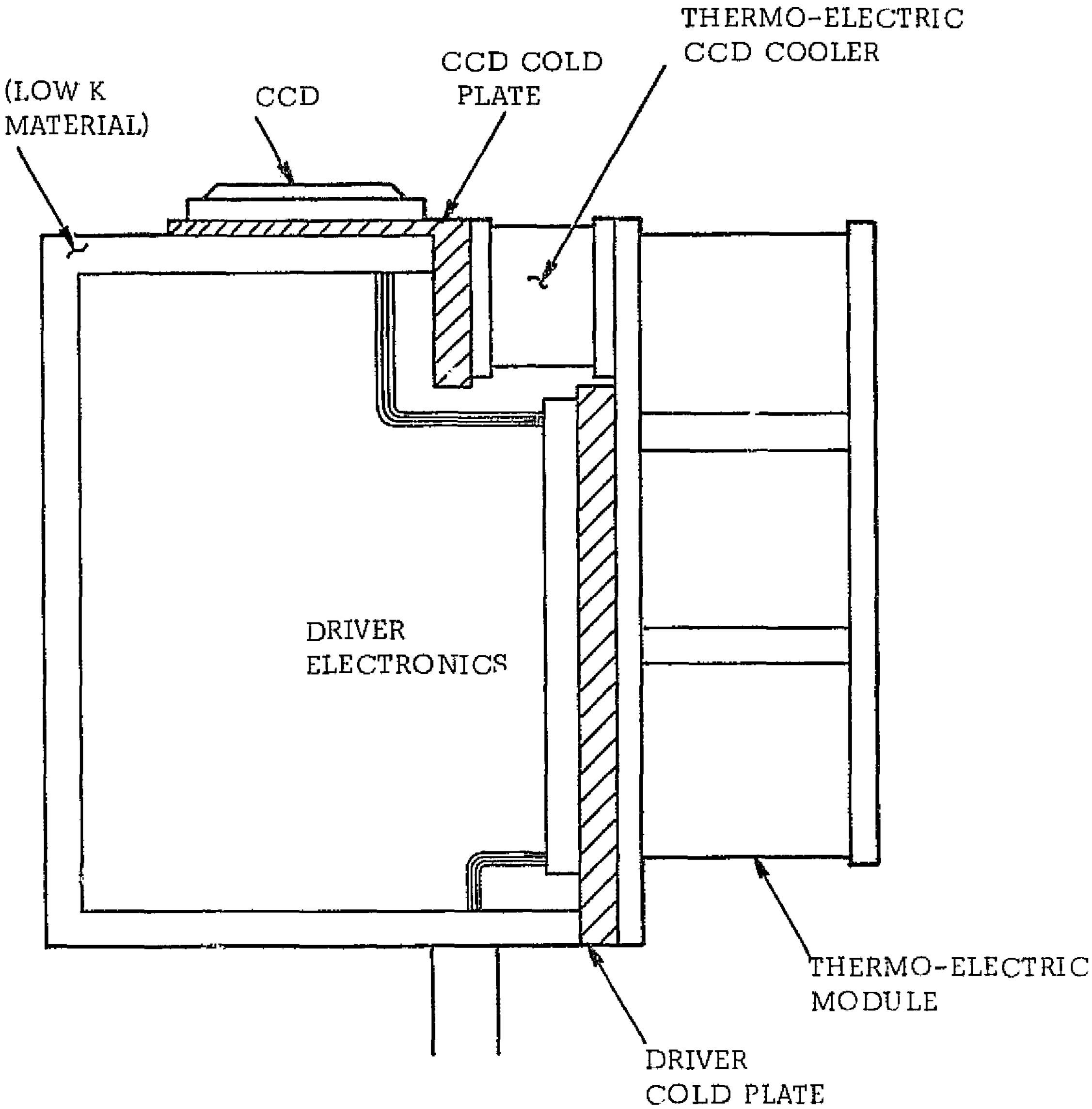


Figure 5-7. CCD and CCD Driver Cooling Unit

junction temperature to 30°F. The thermoelectric cooler has the capacity to maintain the CCD at or below -40°F (~230°K) at all ST operation conditions.

The CCD detector system thermal characteristics may be summarized as follows:

- Double thermoelectric module provides (two stage)
  - Separate finger cooler for CCD
  - Larger unit for total detector unit.
- High thermal conductivity material for CCD and driver
  - Low power CCD and high power driver are thermally insulated by frame material (low K)
  - Finger arrangement permits <-40°F CCD operation.
- Thermocouples at CCD finger provide monitoring.
- Heat straps conduct heat to outer wall
  - Two straps, one for each V2 wall of SI module.

It is planned to use heat straps to conduct the heat from the thermoelectric cooler hot junction to the SI wall. An additional 24 watts from close-mounted camera electronics are also conducted to the SI wall. The nominal operating SI heat load of 60 watts is radiated to the aft shroud wall.

The aft shroud inner wall temperature limits may widen beyond the present spec range of +7°F to -40°F. If this potential heat sink temperature change occurs, the proposed heat straps will be replaced by heat pipes which will act as thermal valves to limit the heat flow variations from the SI for different operating conditions.

The design layout of the planetary camera is shown in Figure 2-3. This layout shows the remote location of the CCD relative to the camera optics. This arrangement provides considerable latitude in positioning insulation to minimize parasitic heat leaks to the CCD package.

The layout also shows the separate compartment used to house camera electronic packages, including the TCS electronics. This separate mounting provides easy access for electronic maintenance and a direct heat flow path from the electronic packages to the SI wall without interference with the thermal stability of the optical bench. Small individual heaters totaling 3 watts will be mounted on the optical bench to enhance temperature uniformity if needed.

SECTION 6
POWER, COMMAND AND DATA HANDLING

6.1 Power Interface

As noted in Section 1, the instrument will operate from a supply of 28VDC±5, and will be limited to a maximum orbital average power consumption of 150 watts. The power requirements, broken down by subsystem, were summarized in Section 2, Table 2-2.

Perkin-Elmer, at the Preliminary Design Review on July 15 and 16, (1975) recommended the power interface to the science instruments shown in Figure 6-1. The rationale for this approach was:

1. To avoid a multi-line power interface with the SSM.
2. Provide earlier verification of power distribution system and interface.
3. Eliminate the requirement for a SSM PDS simulator during OTA/SI testing.

NASA is currently considering the alternative of having the SSM provide all electrical distribution boxes (mounted within the SSM) with the individual science instrument providing any additional control, regulation or sequencing peculiar to the SI through a distributor box mounted within the SI.

6.2 Command Interface

The Planetary Camera contains a command decoder, which receives and decodes commands from the SSM. Commands may be classified as "discrete" or "variable word". Discrete commands are single pulses used to initiate or terminate an event. Variable word commands are multi bit digital streams that specify

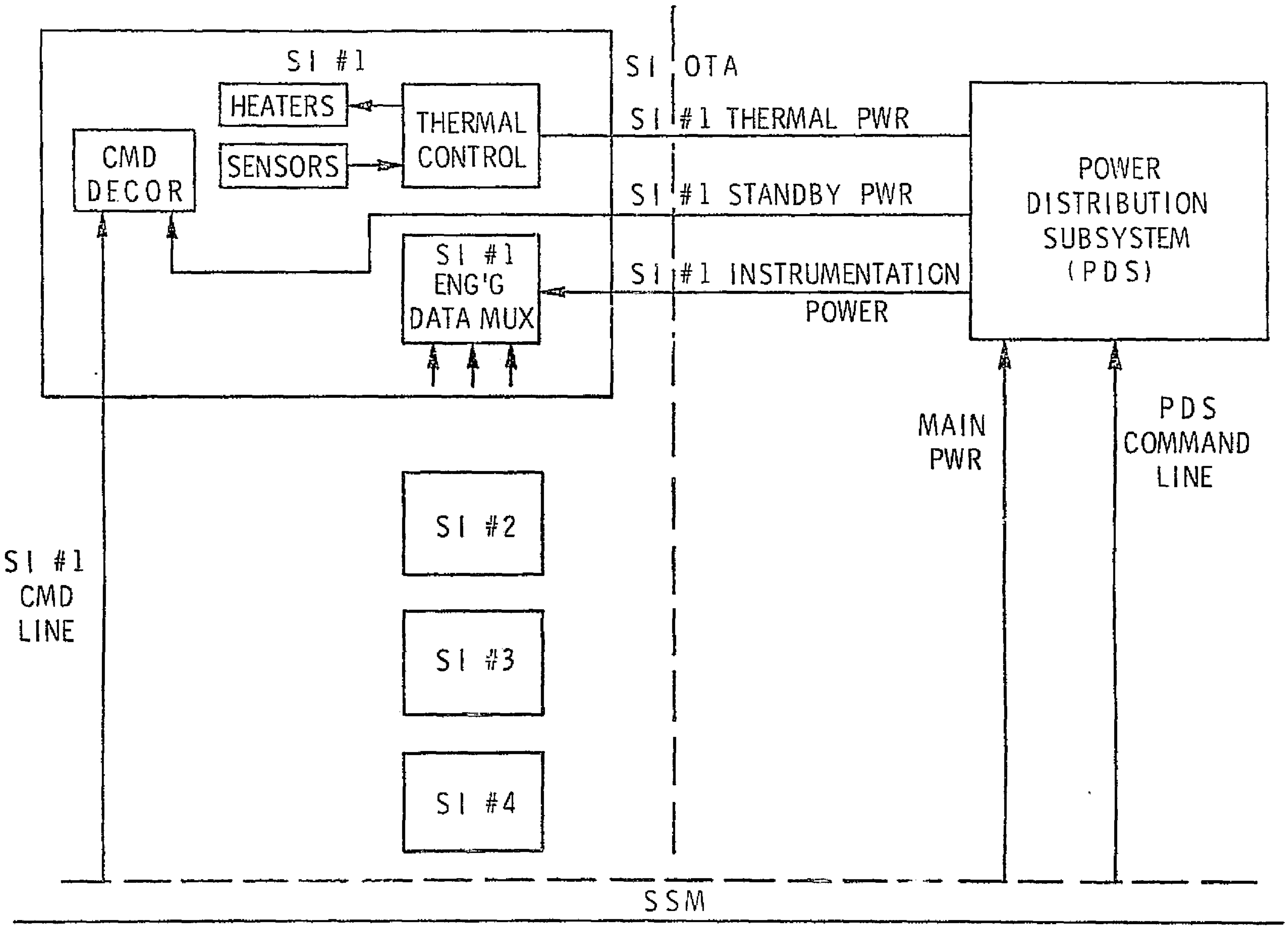


Figure 6-1. Power Interface

a setting value, or a position or some other analog variable. The actual setting (to the value specified by a variable word) will be initiated using "load" and "execute" discrete commands.

The camera command concept is illustrated in Figure 6-2. This system provides maximum operational flexibility with minimum on-board sequencing. A command sequence and requirements list is given in Appendix A.

6.3 Data Interface

Data is broadly classified as "engineering" or "science" data, some engineering data being necessary to the scientist to aid in his interpretation and understanding of the science data. Engineering data, indicating the current status of the camera subsystems (filter wheel, shutter, calibration sources, gains, etc.) and identified as "Header" data, is interleaved with the science data and transmitted to ground over the data link.

A general description of the OTA/SI data system philosophy is shown in Figure 6-3. The instrumentation list is also given in Appendix A.

Engineering data is provided by the camera instrumentation subsystem, the concept of which is shown in Figure 6-4. The required sensors, or transducers, form the analog signals which, after buffering and scaling, are multiplexed, digitized and output to the telemetry unit. Header data is also sent to the Data unit for interleaving with science data.

The address and timing control logic section controls the readout of the pixels and analog to digital conversion of the video signal. Synchronization with the SSM data handling system could be accomplished via this section.

C.2

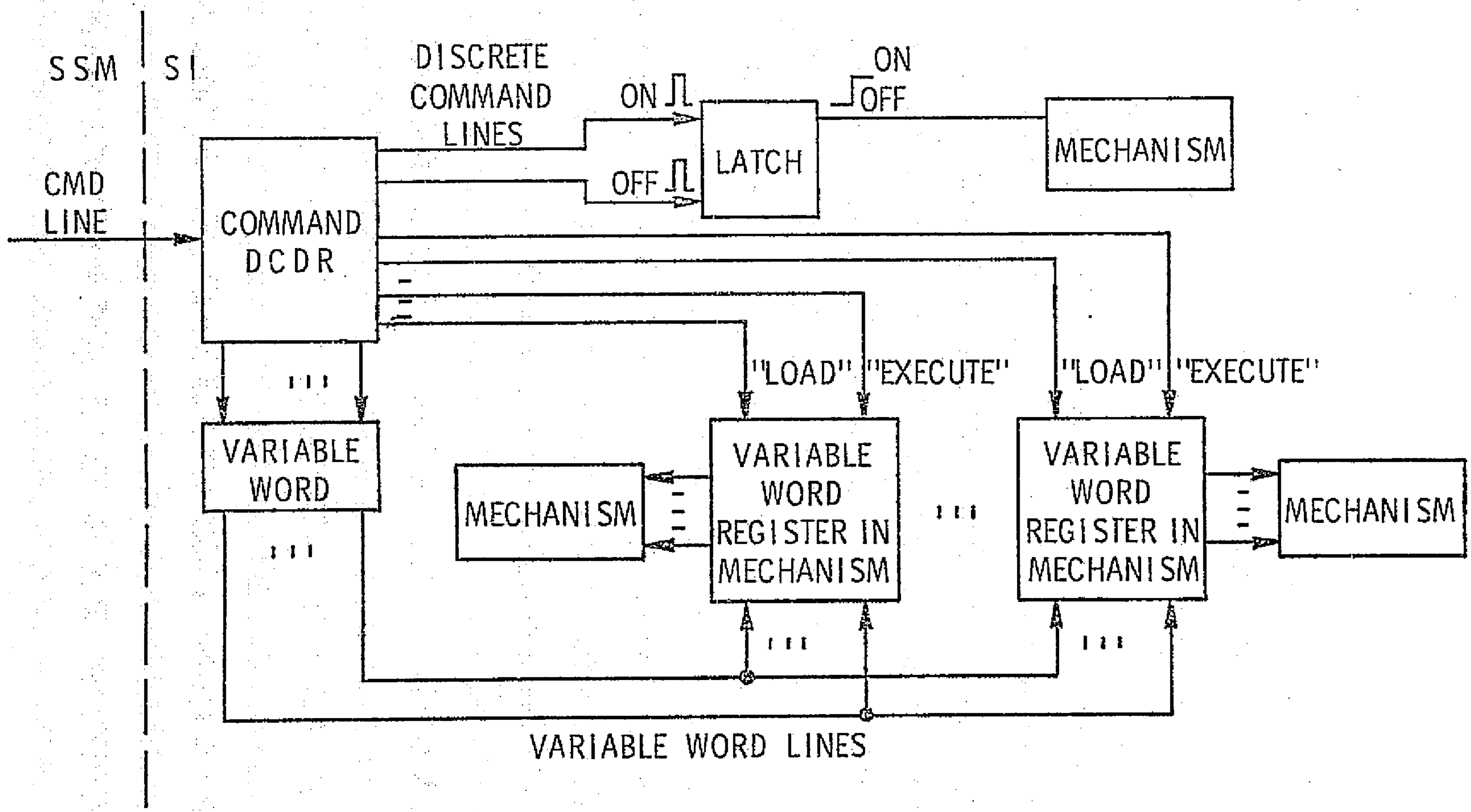


Figure 6-2. Command Concept

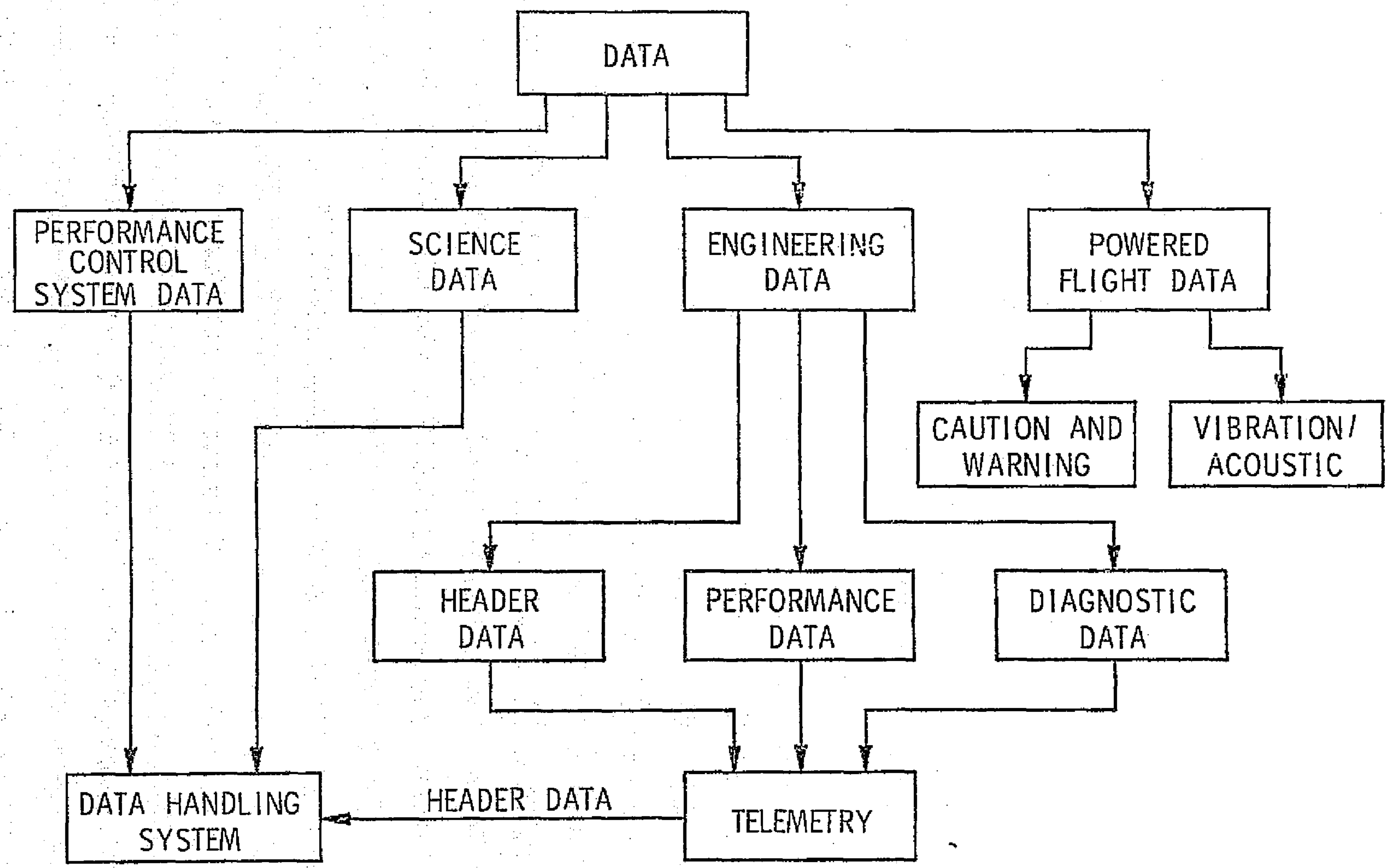


Figure 6-3. Data Terminology and Flow

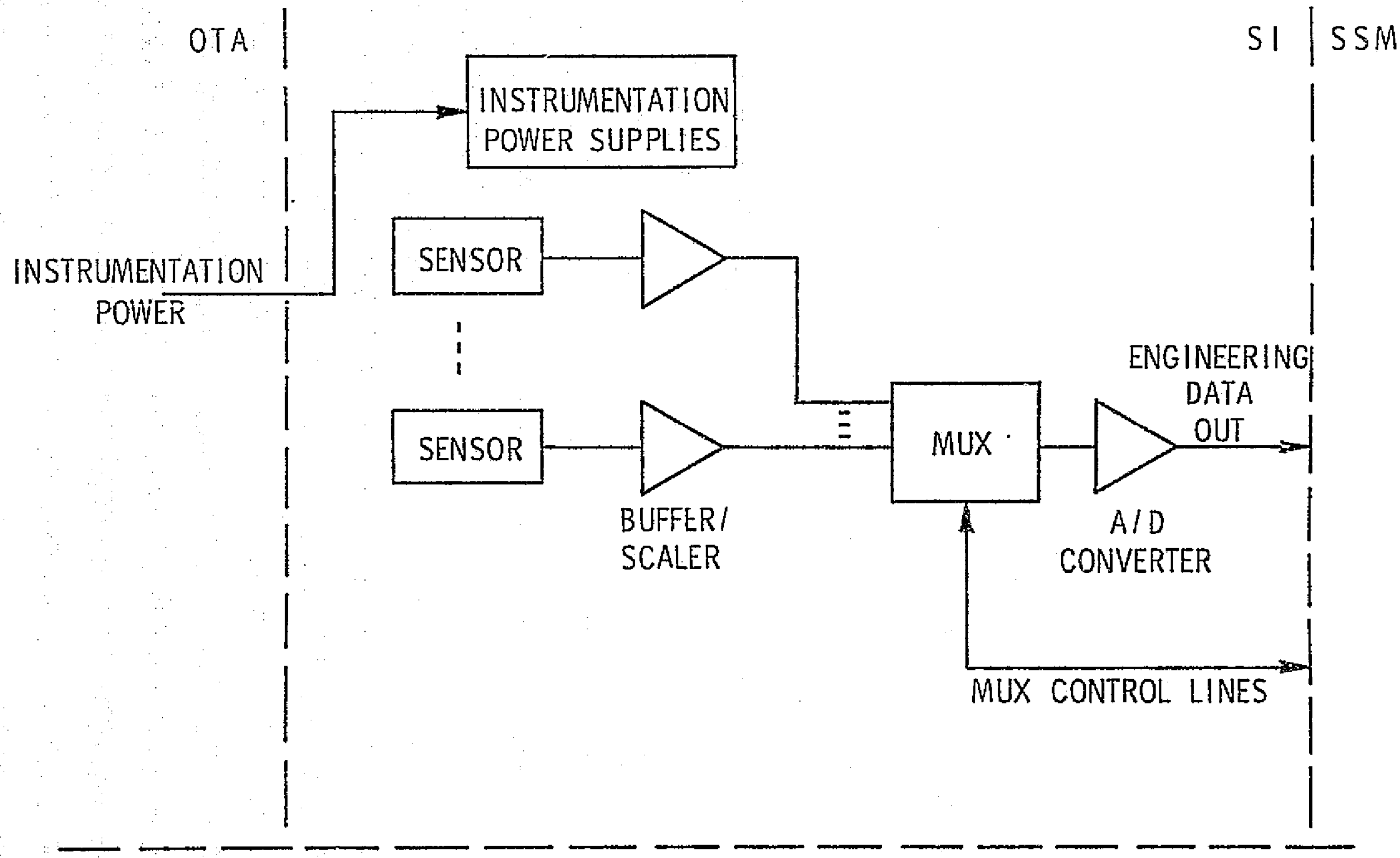


Figure 6-4. SI Engineering Data Concept

The S/H (sample and hold amplifier) section samples the video signal and holds the signal amplitude while the analog to digital converter (A/D) digitizes the signal to a 10 bit digital word. The serial output word rate will be 500K bits/sec.

The SI data interface control section interfaces with SSM communication and data handling subsystem (C & DH) to transmit the science data.

SECTION 7
RELIABILITY

7.1 Requirements

Revised ST project guidelines define a reliability goal for the f48/96 Planetary Camera of 0.85 for the first year of operations. It is anticipated that the duty cycles of the camera will be approximately 10-20%; for planned high resolution requirements such as the observation of galactic centers and for special opportunities resulting from ST observations with the f/24 Field Camera.

7.2 Reliability Analysis

The standby (or dormant) failure rate of the instrument has been assumed to be one-tenth of the active failure (planned useage) primarily because of the electrical and electronic components. For an instrument whose duty cycle is D and whose failure rate is λ, the duty cycle failure rate λ_{dc} is determined by the following equation:

$$\lambda_{dc} = \lambda_a (D) + \lambda_s (1 - D)$$

where

λ_a = failure rate

λ_s = standby failure rate

Failure rates are defined for the camera at the module level in Table 7-1. These failure rates were compiled by TRW for Perkin-Elmer earlier in the Phase B study (Reference P-E Report #11880, OTA/SI Conceptual Design Report, 1 April 1974). The main source for failure rates were estimates used on:

- Apollo Telescope Mount (ATM)
- Seasparrow Naval Low Level Light TV Project
- Planning Research Corp. orbital data on Vidicon Tubes*
- EMR Report –

  Failure Rates, Reliability Prediction, Failure Mode Effects and Critical Analysis, Photo multiplier Tube Packaged Assembly

  25 February 1969.

Assuming an exponential failure rate;

$$R = e^{-\lambda_{dc} t}$$

where t = 1 year (8760 hours) and λ_{dc} is taken from the Table 7-1, we find

(1) for a 10% duty cycle

$$R_t = e^{-(7142)\,(8760)\,(10^{-9})}$$

$$= e^{-.0625639}$$

$$= 0.93935 \text{ for 1 year mission}$$

(2) for a 20% duty cycle

$$R_t = e^{-(10004)\,(8760)\,(10^{-9})}$$

$$= e^{-.08763504}$$

$$= 0.9161 \text{ for 1 year mission.}$$

Therefore it is concluded that proper selection of components and attention to reliability in the design will permit attainment of the design goal.

*Addendum to Reliability Data from In-Flight Spacecraft 1958-1972, Report #0-1874, Bean & Bloomquist, AD906048L, 30 November 1972.

TABLE 7-1

f48/96 PLANETARY CAMERA

FAILURE RATE DATA

FAILURES/BILLIONS HOURS

Subassembly	DC	λa	λs	λdc
Sensor Unit	10-20%	23500	2350	4465-6580
Command Control Telemetry (CC&T) Elect.	10-20%	8300	830	1577-2324
Opto/Mechanical Unit	10-20%	1100	1100	1100-1100
Total	10-20%	32900	4280	7142-10004

SECTION 8

TEST AND INTEGRATION

8.1 Testing of the Planetary Camera

The f48/96 Planetary Camera will be qualified and acceptance tested as a subsystem prior to its integration into the OTA. This testing will follow the plan defined in GSFC Report #X-604-74-290, GSFC Integration, Test and Evaluation Plan for ST Focal Plane Assembly. Major components and subassemblies will undergo development testing as required to support the detailed design. Such testing will include breadboard testing of electronic circuits, temporal stability measurements of calibration sources and sensitivity/uniformity measurements of detectors.

Test objectives/requirements for each phase (development, subassembly, instrument level and integration with the OTA) are shown in Figure 8-1. Required testing is defined as follows:

<u>Optics</u>

Both the two element f/48 relay and the f/96 relay will be tested for figure quality and reflected opd values; the 28 element filter assembly will be tested for transmitted opd values. This requires a typical wavefront analyzer unit (collimator interferogram) and standard reduction software to assess wavefront peak to peak and rms data at various wavelengths. This testing is performed with the optical elements both unmounted and mounted in their system configuration.

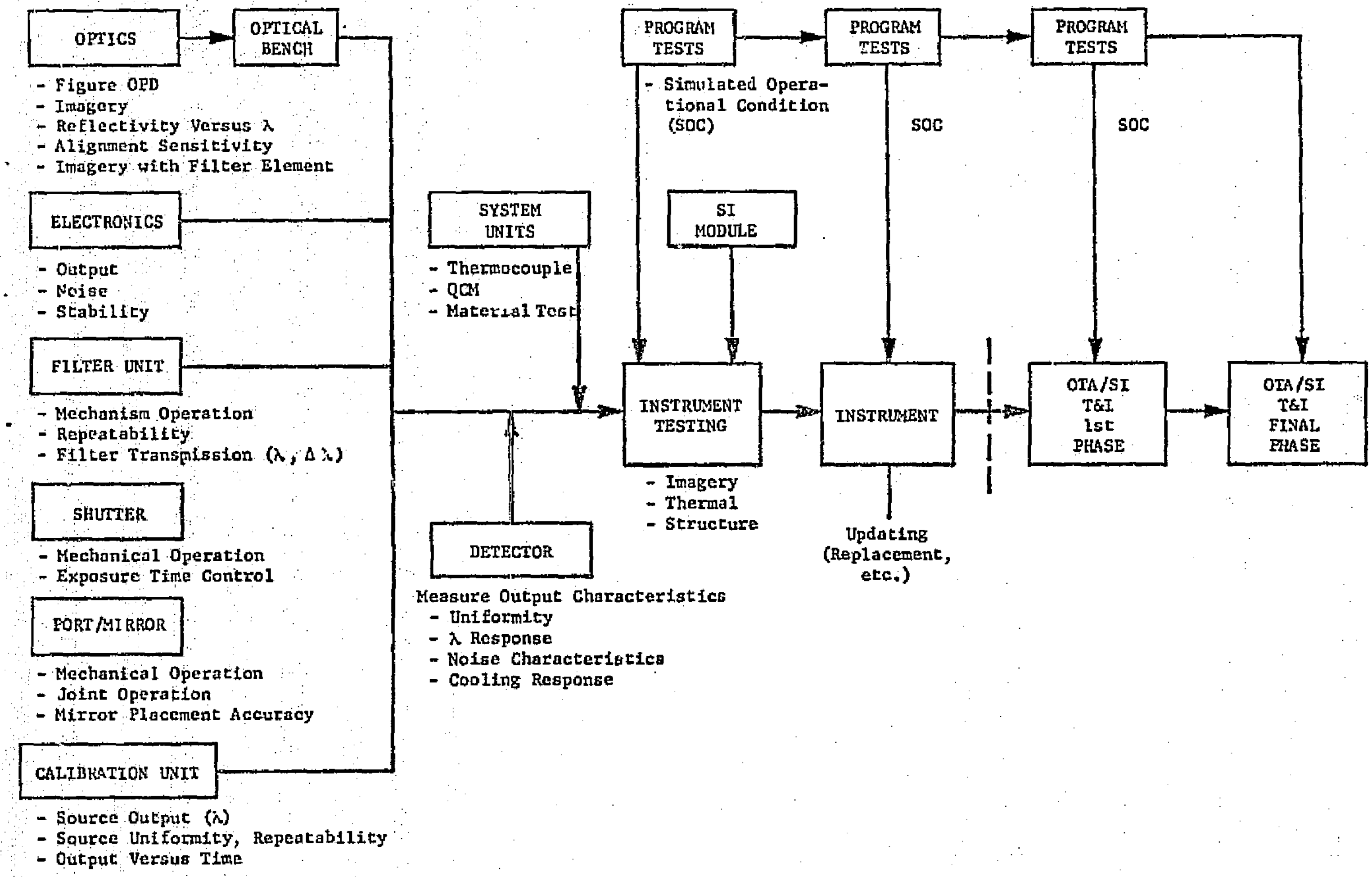


Figure 8-1 Planetary Camera Integration and Test Flow

The calibration mirrors must also be tested in an analagous manner. The imaging optics, used to irradiate the detector are required to be of known uniform throughput, but are not required to provide high image quality.

Mechanical

The mechanical testing will include the alignment and repeatability characteristic of the port door, filter, and shutter units as well as stability of the mounting to be used to support the detector.

At the SI system level, mechanical tests will be directed toward determining that the Planetary Camera, installed in the axial bay module box, is properly aligned, and retains that alignment during vibration and repeated installation/removal cycles on the OTA focal plane structure. The OTA FPS thermal structural unit at GSFC will be used for these tests.

Electronics

Electronic subsystems and components will be subject to considerable development testing in support of detail design work, and will confirm design predictions of power comsumption, thermal stability, gains, signal to noise ratio, etc.

As individual components and circuit boards are brought together, tests will include vibration, and electromagnetic interference and compatibility. Failure modes and back-up systems will be confirmed.

8.2 Camera Qualification & Integration with OTA

As noted in Section 8-1 qualification testing will be conducted at GSFC. Figure 8-2 gives the schedule of key milestones for the instrument design, assembly, and testing as well as its delivery to the OTA contractor for integration.

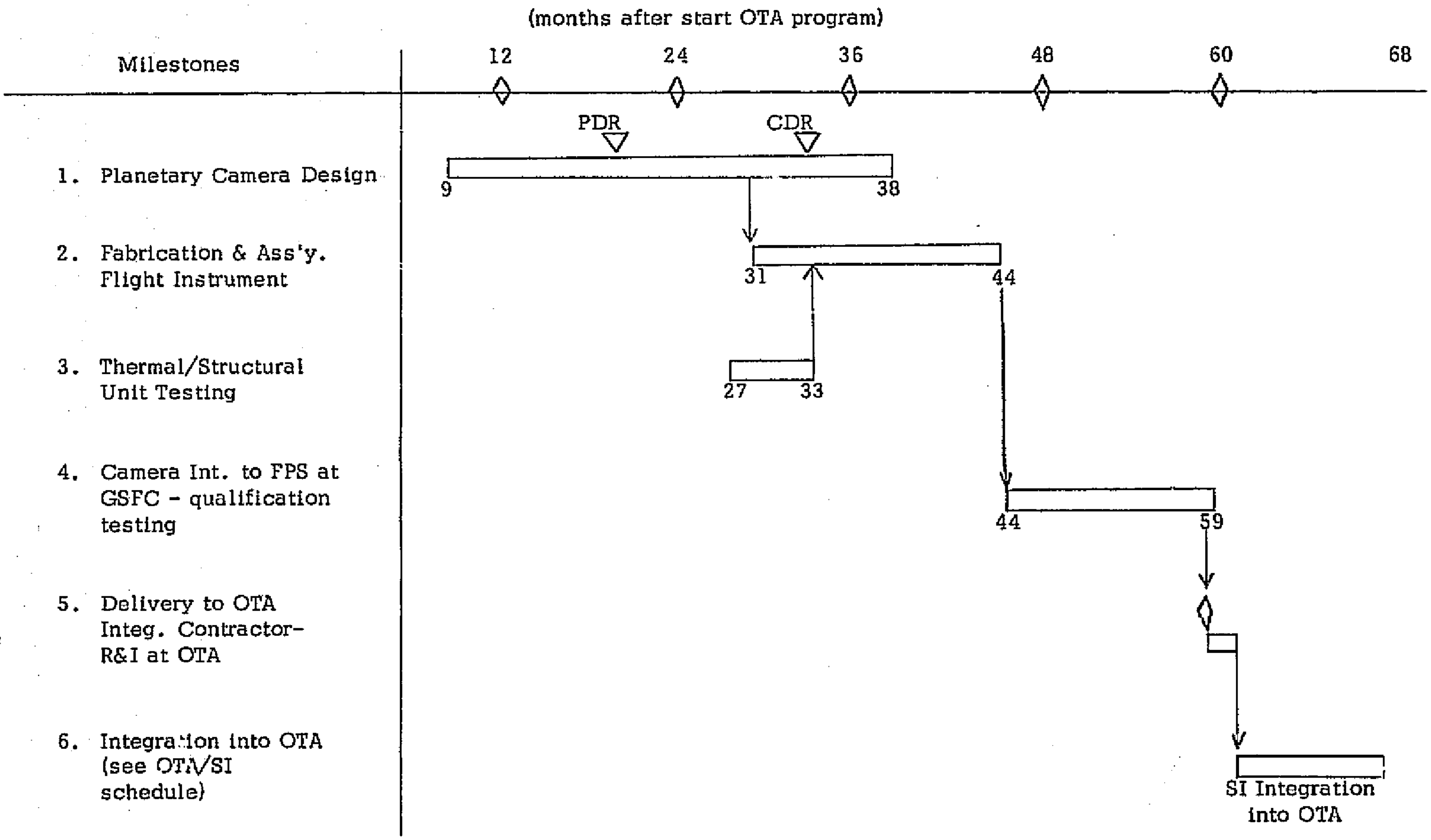


Figure 8-2. f48/96 Planetary Camera Development & Qualification Schedule

The instrument contractor will provide, starting at month 27 a structural/thermal model of the camera to GSFC. GSFC will integrate this model with a focal plane structure provided by the OTA contractor. This FPS will be, as far as possible, a duplicate of the FPS being designed for the OTA. GSFC will integrate the TSU instrument models into the FPS and conduct a series to tests of this assembly to verify the thermal/structural design of the camera. This testing information will be input to the continuing design of the camera.

The completed Planetary Camera will be delivered to GSFC at month 44 of the program. GSFC will integrate the SI's into the FPS and again conduct the tests defined in Report #X-604-74-290. This testing program will qualify the individual instruments - at the conclusion of this test sequence they will be certified as accepted flight instruments for delivery to OTA integration. The SI contractor will participate in and support the testing program at GSFC.

Figure 8-3 defines the schedule for the integration of the Planetary Camera (and all other SI's) into the OTA. Months 60 and 61 are provided for the receiving and inspection of the camera at the OTA integration site. Following acceptance it will be integrated into the OTA by the OTA contractor. The tests defined in Table 8-1 will be conducted on the OTA/SI assembly during the period months 62-68.

Figure 8-6 illustrates the interface confirmation sequence for the development/integration of the science instruments. MSFC, as prime contractor, will accept the SI enclosures. They will be supplied to GSFC which will accept/ forward the enclosures to the individual contractors. The completed instrument will go to GSFC for environmental/qualification tests as described, and will be accepted by MSFC prior to integration into the OTA.

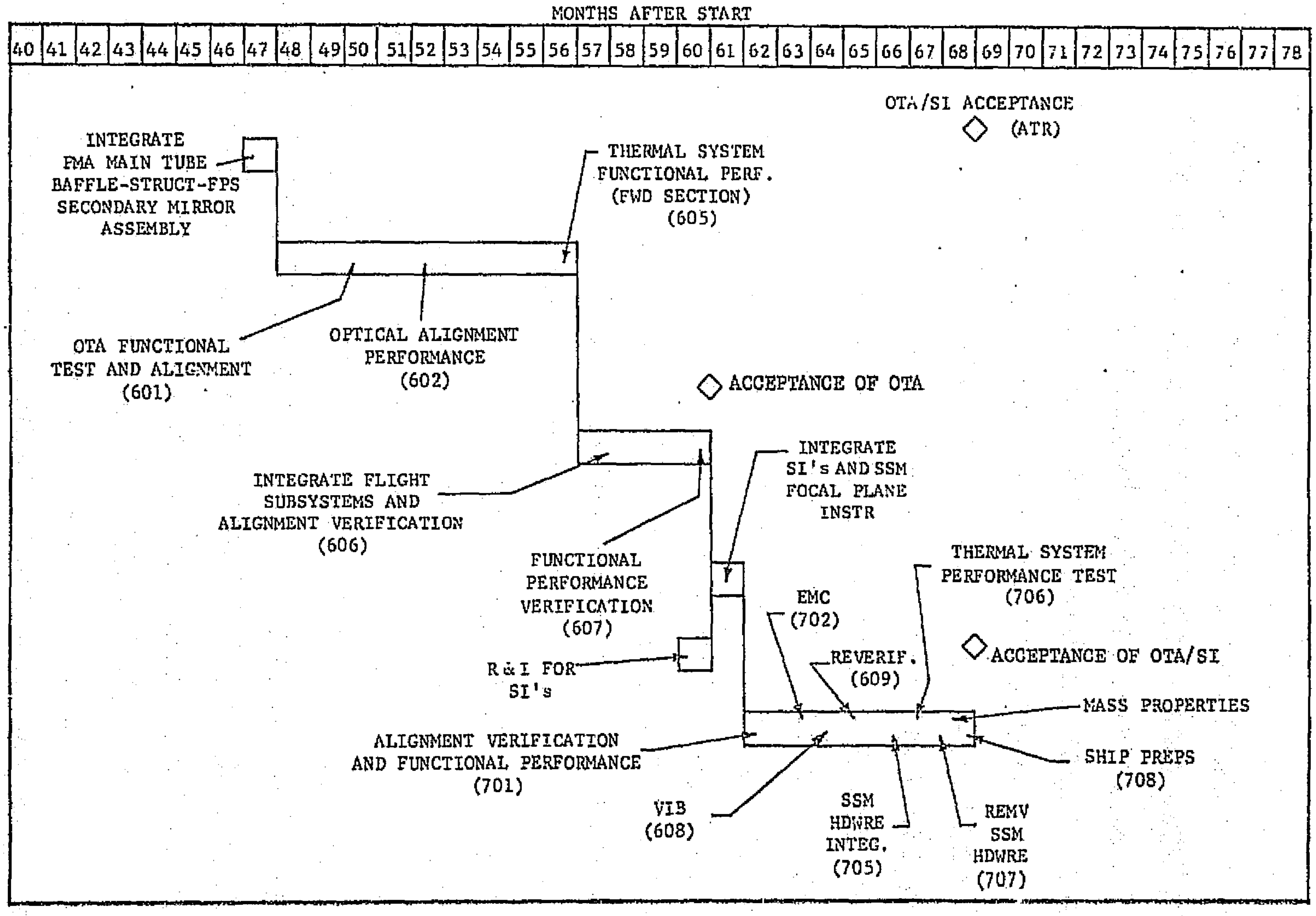


Figure 8-3. OTA and OTA/SI Test Sequence

TABLE 8-1

OTA/SI VERIFICATION TESTS

Test #	Title	Testing/Special Test Equip.
701	Alignment Verification and Functional Performance	The OTA with all science instruments installed will be installed in a thermal/vac test chamber as shown in Fig. 8-4. Using the 72" collimator as shown in Fig. 8-5, the SI's will be verified for alignment and function.
702	EMC	Limited EMC testing will be conducted during Test 701. Test will be limited to monitoring of busses and critical signal lines.
608	Vibration	OTA/SI assembly removed from chamber, subjected to acceptance level vibration.
609	Re-verification of Functional Performance	Return OTA/SI to test chamber and repeat Test 701 to insure system functional after the vibration test.
705	Integration of SSM Hardware	Install SSM Flight Forward Shroud, simulated SSM section and SSM Flight Aft Shroud.
706	Thermal System Performance Test	Test to verify the optical performance of OTA/SI under simulated thermal environment. Also to verify thermal interface between SSM and OTA/SI. This includes stability of optical metering truss and power dissipation from the SI area. The test will also verify SI power requirements. Test will be conducted with OTA/SI vertical in test chamber, with 72" collimator input and with thermal simulation of space environment as shown in Fig. 8-4.
707	Removal of SSM Hardware	Following test 706, the SSM Flight hardware is removed.
708	Mass Properties Verification	Verification of Flight OTA/SI.

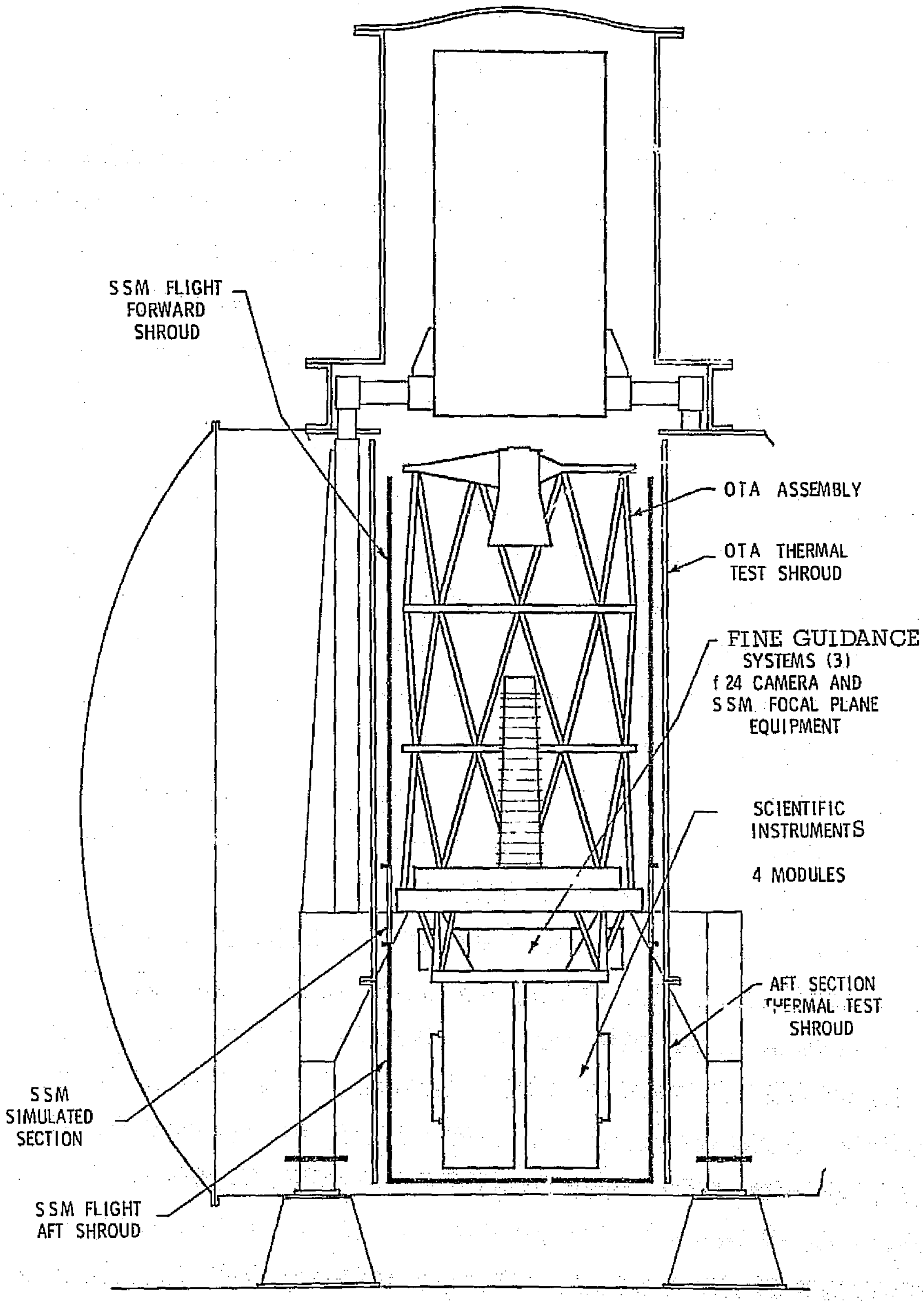


Figure 8-4. OTA/SI Thermal System Performance Test

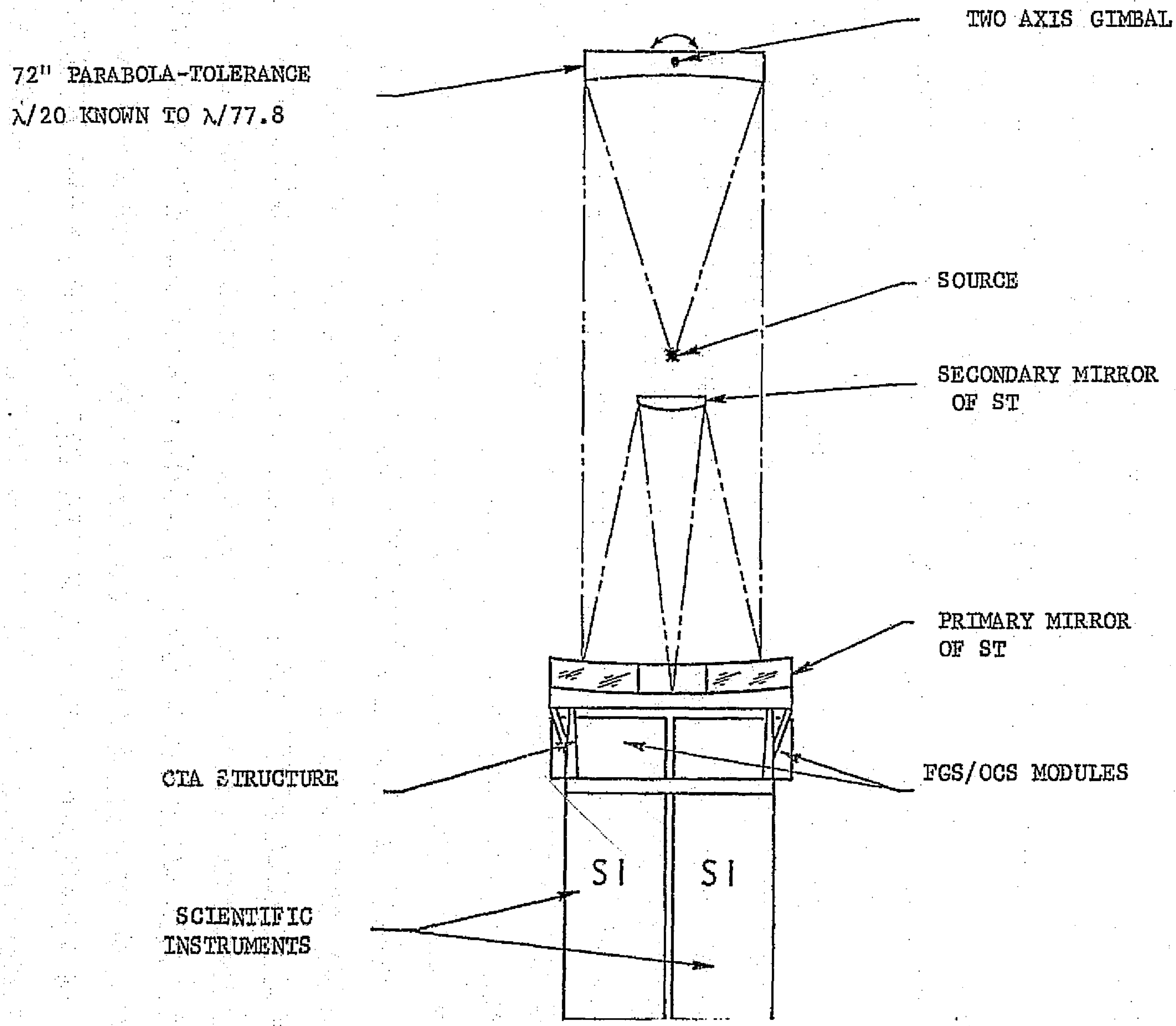


Figure 8-5. 72" Collimator System Test Configuration

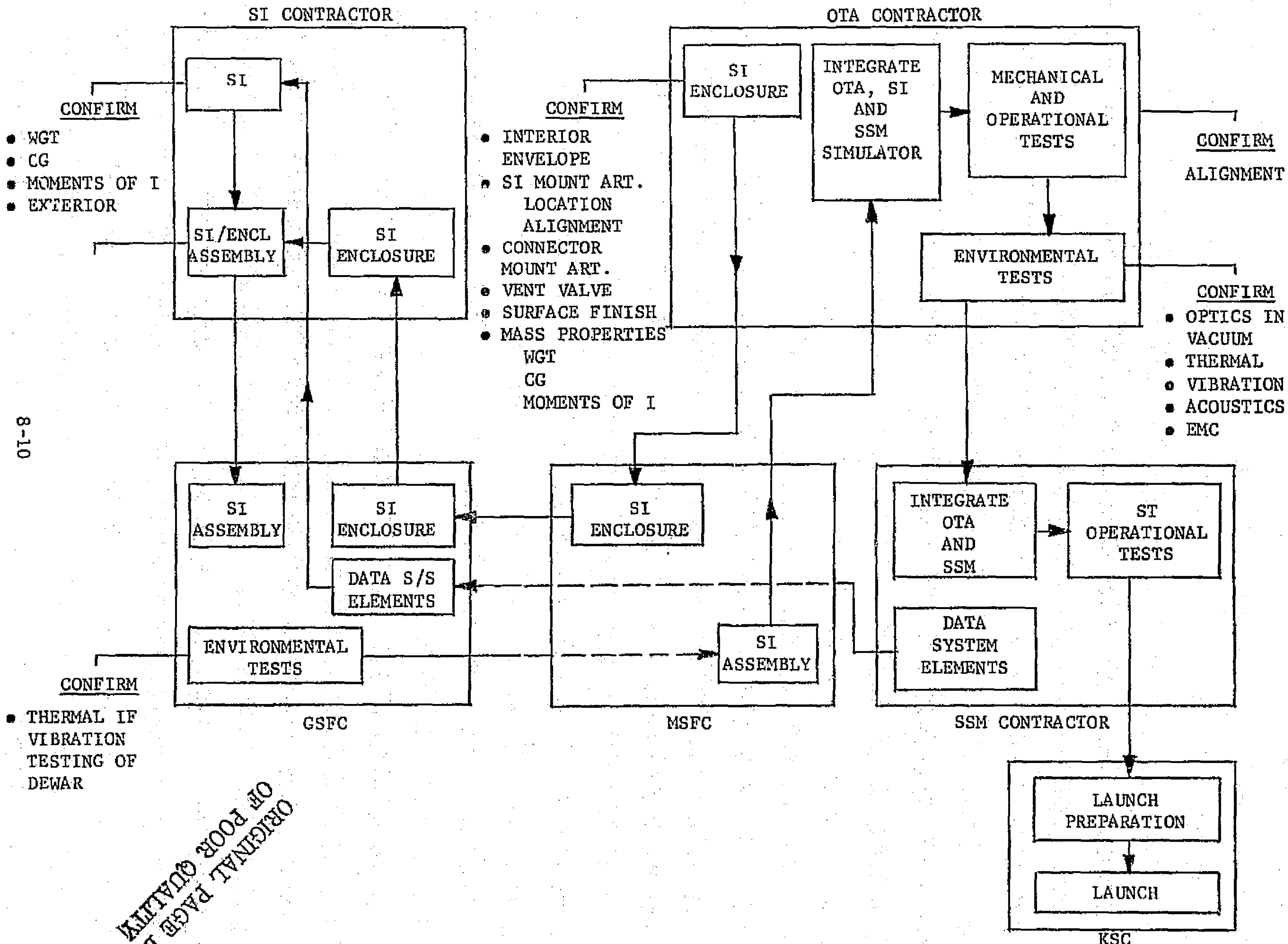


Figure 8.6. OTA/SI Interface Confirmation

8.3 Environmental Control Requirements for Planetary Camera

Figures 8-7 and 8-8 define the environmental conditions which are required during all ground handling of the Planetary Camera: assembly, testing, refurbishment and transportation. The importance of this high resolution Camera to successful ST performance demands a highly reliable design. Because of the long period of ground integration and test, it is critical that high levels of cleanliness and careful control of temperature and humidity be maintained. As integration moves to a higher level and ST system size makes such control more difficult, special effort will be required to provide and use covers to protect the camera when not undergoing actual test or checkout.

Environmental Parameter		Limits	Max Rate of Change	Remarks
Air Temperature, Ambient Dry Bulb		65°F to 78°F	20°F/Hr	
SI Equipment Temperature		65°F to 78°F	10°F/Hr	For operational requirements, see Paragraph 3.5.6.
Relative Humidity Ambient Air		<50%	N/A	Note A.
Cleanliness Ambient Air	SI/SI Encl. Integ.	10,000 Max.	N/A	
	OTA/SI Integ.	10,000 Max.	N/A	Fed Std. 209 - See Note B
	SSM Integ.	10,000 Max.	N/A	
Cleanliness SI		Class 200, Level B	N/A	
Cleanliness SI Enclosure Viewing the SI		MIL-STD-1246A	N/A	At the time of integration of the SI with the SI enclosure.

NOTES:

A. During thermal vacuum testing, repressurization shall be controlled to prevent any condensation on OTA/SI surfaces or particulate matter back-stream.

B. During OTA/SI to SSM integration, operations which would expose the interior of the OTA/SI to the ambient environment shall be performed in a Class 10 K environment. Operations which do not expose the OTA/SI interior to the ambient environment may be performed in a Class 100K environment. Appropriate seals and closures on the OTA/SI or plastic tents supplied by HEPA filtered blowers shall be considered as meeting the intent of this requirement.

Figure 8-7. General Environments for the SI Within the SI Enclosure (Handling, Including Factory, Refurbishment)

Environmental Parameter	Limits	Rate of Change - Max	Remarks
Air Temperature, Ambient Dry Bulb	50°F to 90°F	20°F/Hr	
Relative Humidity	<50%	N/A	Note A
Cleanliness - Conditioned Air	100,000		Fed Std 209 - Note B

NOTES:

A. No condensation shall be allowed on any exposed surface of OTA/SI equipment at any time.

B. During transportation, interior of OTA/SI to be closed off to maintain class 10K environment internally while exposed to class 100K environment externally.

Figure 8-8. Transportation Environment Requirements for SI's

APPENDIX A

f48/96 Planetary Camera
Command and Instrumentation Lists

TABLE A-1

COMMAND SEQUENCES AND COMMAND REQUIREMENTS

COMMAND SEQUENCE - f48/96 PLANETARY CAMERA

SEQUENCE	FUNCTION
Instrumentation Mode	Instrumentation System Only On
Thermal Control	Bring instrument on-line to thermal operating temperature
Standby	LVPS On
	Instrumentation System On
	Command System On
	TLM System On
Acquisition Initialize	N/A
Acquisition Execute	N/A
Calibrate Initialize	Set Variables (mechanisms, voltages, exposure)
Calibrate Execute	Expose, Store, Transfer
Operate Initialize	Set variables (as in calibrate initialize)
	Open port door to f/48 or f/96
Operate Execute	Expose, store, transfer

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Table A-1. (Continued)

COMMAND REQUIREMENTS - f48/96 Planetary Camera

COMMAND	STEPS	BITS/ VARIABLE WORD	DISCRETE COMMANDS
(1) Instrumentation Mode			
PC Instrumentation Power On			1
PC Instrumentation Power Off			1
(1) Thermal Control			
PC Thermal Power On			1
PC Thermal Power Off			1
Standby			
(1) PC Standby Power On			1
(1) PC Standby Power Off			1
PC Main Power On			1
PC Main Power Off			1
Acquisition Initialize	N/A		
Acquisition Execute	N/A		

(1) Via Power Distribution Subsystem (PDS) in OTA

Table A-1. (Continued)

COMMAND REQUIREMENTS - f48/96 Planetary Camera

COMMAND	STEPS	BITS/ VARIABLE WORD	DISCRETE COMMANDS
Calibrate Initialize			
Filter Wheel #1	8	3	
Filter Wheel #2	8	3	
Filter Wheel #3	8	3	
Filter Wheel #4	8	3	
Exposure Time	10 msec to 300 sec	16	
Port Door Close			1
Shutter Open			1
Shutter Close			1
Scan Size .	256	8	
Scan rate	256	8	
Amplifier gain	256	8	
Reset			1
Calibrate Lamp Voltage	1000	10	
Load (one for each variable word)			9
Execute (one for each variable word)			9

Table A-1. (Continued)

COMMAND REQUIREMENTS - f48/96 Planetary Camera

COMMAND	STEPS	BITS/ VARIABLE WORD	DISCRETE COMMANDS
Calibrate Execute			
Calibrate Start			1
Exposure Interrupt			1
Exposure Restart			1
Transfer Start			1
Transfer Stop			1

Table A-1. (Continued)

COMMAND REQUIREMENTS - f48/96 Planetary Camera

COMMAND	STEPS	BITS/ VARIABLE WORD	DISCRETE COMMANDS
Operate Initialize			
Filter Wheel #1	8	3	
Filter Wheel #2	8	3	
Filter Wheel #3	8	3	
Filter Wheel #4	8	3	
Exposure Time	10 msec to 5 min	16	
Port Door Open to f/48			1
Port Door Open to f/96			1
Scan Size	256	8	
Scan rate	256	8	
Amplifier gain	256	8	
Reset			1
Load (one for each variable word)			8
Execute (one for each variable word)			8

Table A-1. (Continued)

COMMAND REQUIREMENTS - f48/96 Planetary Camera

COMMAND	STEPS	BITS/ VARIABLE WORD	DISCRETE COMMANDS
Operate Execute			
Operate Start			1
Exposure Interrupt			1
Exposure Restart			1
Transfer Start			1
Transfer Stop			1

Table A-1. (Continued)

COMMAND REQUIREMENTS - f48/96 Planetary Camera

COMMAND	STEPS	BITS/ VARIABLE WORD	DISCRETE COMMANDS
Contingency Commands			
Filter wheel #1 retract			1
Filter wheel #2 retract			1
Filter wheel #3 retract			1
Filter wheel #4 retract			1
Port door retract			1
Shutter retract			1
Lamps off			1
Reserve		20	15

Table A-2.

INSTRUMENTATION LIST - f48/96 Planetary Camera

SIGNAL DESCRIPTION	SIGNAL TYPE	RANGE	ANALOG ACCURACY	NUMBER OF BITS	SAMPLE RATE (EACH BIT)
Main Power Monitor	D	on/off		1	1 sps (1)
Main Power Voltage	A	tbd	1%	8	1 sps (1)
Main Power Current	A	tbd	1%	8	tbd (3)
Thermal Mode	D	on/off		1	1 sps (1)
Standby Mode	D	on/off		1	1 sps (1)
Calibrate Mode	D	on/off		1	1 sps (1)
Operate Mode	D	on/off		1	1 sps (1)
Filter Wheel #1	D	9 discrete positions		9	1 sps (2)
Filter Wheel #2	D	9 discrete positions		9	1 sps (2)
Filter Wheel #3	D	9 discrete positions		9	1 sps (2)
Filter Wheel #4	D	9 discrete positions		9	1 sps (2)
Port door	D	4 discrete positions		4	1 sps (1)
Exposure time setting	D	as commanded		16	1 sps (1)
Exposure time reading	D	sec - hrs.	µsec	32	1 sps (2)
Shutter	D	open/close		2	1 sps (1)

Table A-2. (Continued)
INSTRUMENTATION LIST - f48/96 Planetary Camera

SIGNAL DESCRIPTION	SIGNAL TYPE	RANGE	ANALOG ACCURACY	NUMBER OF BITS	SAMPLE RATE (EACH BIT)
Scan rate setting	D	as commanded		8	1 sps (2)
Scan rate reading	A	tbd	1%	8	tbd (1)
Scan size setting	D	as commanded		8	1 sps (2)
Scan size reading	A	tbd	1%	8	tbd (1)
Scan	D	on/off		1	tbd (1)
Amplifier gain setting	D	as commanded		8	1 sps (2)
Calibrate lamp voltage setting	D	as commanded		10	1 sps (2)
Calibrate lamp voltage reading	A	tbd	1%	8	1 sps (1)
Transfer	D	on/off		1	1 sps (1)

Table A-2. (Continued)
INSTRUMENTATION LIST - f48/96 Planetary Camera

SIGNAL DESCRIPTION	SIGNAL TYPE	RANGE	ANALOG ACCURACY	NUMBER OF BITS	SAMPLE RATE (EACH BIT)
Thermal sensors (20 X 8 bits)	A	tbd	.1 - .25°C	160	1 sps (1)
LVPS voltages (6 X 8 bits)	A	tbd	1%	48	1 sps (1)
LVPS currents (6 X 8 bits)	A	tbd	1%	48	tbd (3)
Reserve for final design definition				45	
Reserve for diagnostics				45	
(Requirements for the reserves are currently being developed.)					