

Oceanographic Scanner System Design Study

Volume I
BSR 3129
October 1971
Ann Arbor, Michigan

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**Aerospace
Systems Division**

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Volume I

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**Aerospace
Systems Division**

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CONTENTS

	<u>Page</u>
1. INTRODUCTION	1-1
1.1 BACKGROUND	1-2
1.2 REQUIREMENTS	1-2
1.3 STUDY RESULTS SUMMARY	1-2
2. SYSTEM DESCRIPTION AND PERFORMANCE	2-1
2.1 SYSTEM DESCRIPTION	2-1
2.2 SYSTEM PERFORMANCE SUMMARY	2-9
3. COLLECTING AND SCANNING OPTICS DESIGN	3-1
3.1 IMAGE SPACE SCANNER CONCEPT	3-2
3.2 OPTICAL ANALYSIS AND RAY TRACE STUDY	3-4
3.3 OPTICAL ARRANGEMENT	3-17
3.4 OPTICAL EFFECTS OF BEARING TOLERANCES	3-22
4. SCAN ASSEMBLY DESIGN	4-1
4.1 GROUND SCAN PATTERNS AND DUTY CYCLE SELECTION	4-2
4.1.1 Analysis of the Scan Pattern	4-2
4.1.2 Parametric Relationships for the Scan Pattern	4-6
4.1.3 Duty Cycle Selection	4-7
4.1.4 Timing Relationships and their Relation to Duty Cycle	4-11
4.2 SCAN MIRROR ROTOR ASSEMBLY	4-16
4.3 SCAN ROTOR BEARINGS	4-16
4.4 SCAN CONTROL REQUIREMENTS	4-19
4.5 SCAN CONTROL DESIGN	4-23
4.5.1 Motor and Motor Control	4-23
4.5.2 Encoder	4-29
4.5.3 Scan Control Error Analysis	4-29
4.6 SCAN ASSEMBLY PERFORMANCE ANALYSIS	4-32

CONTENTS (CONT.)

	<u>Page</u>
5. CALIBRATION TECHNIQUE	5-1
5.1 VISIBLE INFRARED SOURCES	5-1
5.2 SOLAR REFERENCE	5-5
5.3 THERMAL REFERENCE SOURCES	5-5
5.3.1 Physical Description	5-7
5.3.2 Thermal Design Description	5-9
6. SPECTROMETERS	6-1
7. DETECTORS, PREAMPLIFIER, AND SENSITIVITY ANALYSIS	7-1
7.1 SIGNAL POWER AT THE DETECTOR	7-2
7.3 DETECTOR SELECTION	7-6
7.3 PHOTOMULTIPLIER TUBES	7-9
7.4 SILICON DETECTORS	7-11
7.4 HgCdTe DETECTORS	7-15
7.6 PERFORMANCE SUMMARY	7-16
8. DETECTOR CODERS	8-1
8.1 IR BANDS	8-1
8.2 THERMAL BAND DETECTOR COOLING	8-2
9. ELECTRONICS SUBSYSTEM DESIGN	9-1
9.1 ANALOG PROCESSOR	9-3
9.1.1 Video Processor	9-4
9.1.2 Sampler	9-4
9.1.3 Analog Processor Design	9-6
9.2 ANALOG TO DIGITAL CONVERSION	9-11
9.2.1 Design Considerations	9-11
9.2.2 A/D Converter Functional Description	9-13
9.3 DATA BUFFER	9-15
9.4 FORMATTER	9-19
9.4.1 Downlink Format	9-19
9.4.2 Functional Description	9-22

CONTENTS (CONT.)

	<u>Page</u>
9.5 TIMING AND CONTROL	9-27
9.5.1 Scan Parameter vs. Master Timing Relationships	9-28
9.5.2 Timing and Control Concept No. 1	9-32
9.5.3 Timing and Control Concept No. 2	9-35
9.5.4 Summary	9-35
9.6 CALIBRATION SOURCE CONTROL	9-37
9.7 POWER CONVERSION AND DISTRIBUTION, ELECTRONICS SUBSYSTEM	9-39
9.7.1 Power Requirements	9-39
9.7.2 Design Considerations	9-39
10. MECHANICAL DESIGN	10-1
10.1 GENERAL	10-1
10.2 COLLECTING OPTICS AND SCANNER ASSEMBLY	10-1
10.2.1 Collecting Optics Assembly	10-1
10.2.2 Scanner Assembly	10-2
10.3 SPECTROMETER ASSEMBLY	10-7
10.3.1 Overland Spectrometer and Detector Assembly	10-7
10.3.2 Oceanographic Spectrometer and Detector Assembly	10-11
10.3.3 Band 7 Passive Coder Detector Installation	10-11
10.4 PASSIVE COOLER ASSEMBLY	10-12
10.5 ELECTRONICS PACKAGING AND MOUNTING	10-19
10.6 STRUCTURES AND MATERIAL	10-26
11. THERMAL CONTROL	11-1
11.1 ELECTRONICS SUBSYSTEM THERMAL CONTROL	11-1
11.2 OVER-ALL STRUCTURE THERMAL CONTROL	11-7
12. SYSTEM MODULATION TRANSFER FUNCTION (MTF)	12-1
12.1 MTF OF THE SCANNER STAGES	12-1
12.2 COMPARISON OF INTEGRATE-AND-HOLD WITH SAMPLE- AND-HOLD TECHNIQUES	12-6
12.3 OVER-ALL SCANNER MTF CURVES	12-9

CONTENTS (CONT.)

	<u>Page</u>
13. INTERFACES	13-1
13.1 SPACECRAFT INTERFACES	13-2
13.2 DATA TRANSMISSION AND GROUND RECEIVING SITE INTERFACES	13-5
13.3 GDHS INTERFACES	13-7
13.3.1 GDHS Operation Summary	13-7
13.3.2 OSS Tape Formats Through the GDHS	13-15
13.3.3 Modification Required to Accept a Conical Scan Pattern	13-20
13.3.4 Conclusions	13-25
APPENDIX A OVERLAND SPECTROMETER DESIGN	A-1
APPENDIX B DATA BUFFERING - UTILIZING MOS SHIFT REGISTERS	B-1
APPENDIX C DATA BUFFERING USING A PLATED WIRE MEMORY	C-1
APPENDIX D DATA DEMULTIPLEXER	D-1
APPENDIX E PRELIMINARY STRUCTURAL ANALYSIS	E-1
APPENDIX F THERMAL ANALYSIS	F-1
APPENDIX G OCEANOGRAPHIC SPECTROMETER	G-1
APPENDIX H SOLAR CALIBRATION	H-1
APPENDIX I SOLID CRYOGEN DETECTOR CODING SYSTEM	I-1

ILLUSTRATIONS

<u>Figure</u>	<u>Title</u>	<u>Page</u>
2.1-1	Schematic Diagram of the OSS Scanner	2-3/2-4
2.1-2	OSS Optical Schematic	2-5/2-6
2.1-3	Field Stop Characteristics	2-8
3.1-1	Image Space Conical Scanner Principle	3-3
3.2-1	Blur Circle Comparison - Primary Only, 2nd Primary- Secondary Combination	3-5
3.2-2	Distance of Ray From Focal Point Vs. Distance of Ray From Center of Primary Mirror	3-7
3.2-3	Spot Diagrams Showing Off Axis Performance of the Telescope	3-8
3.2-4	Blur Circle Due to Defocussed Field Stop	3-9
3.2-5	Blur Circle Due to Mirror Separation	3-10
3.2-6	Blur Circle Due to Decentered Primary	3-12
3.2-7	Blur Circle Due to Decentered Secondary	3-13
3.2-8	Blur Circle Due to Tilted Primary	3-14
3.2-9	Blur Circle Due to Tilted Secondary	3-15
3.2-10	Image of a Resolution Element	3-16
3.3-1	Schematic Layout of Scanner Optics	3-18
3.3-2	Image Plane Conical Scanner Optical Arrangement	3-19
3.3-3	Obscuration Effects	3-20
3.4-1	Registration Errors	3-23
3.4-2	Rotor Misalignment (Case a)	3-24
3.4-3	Registration Due to Rotation θ a), Angular Relationships, b) Mis-registration	3-26
4.1-1	Parameters Determining the Scan Pattern	4-3
4.1-2	Positional Errors Arising from Errors in Knowledge of the Spacecraft Attitude	4-5
4.1-3	Ground Scan Pattern Parameters	4-6
4.1-4	Relationships Between Duty Cycle and Other Factors	4-8
4.1-5	Alternate Memory Modes of Operation	4-10
4.1-6	Block Diagram of the Motor Speed Control	4-15
4.2-1	Scanner Bearing Mount Concept	4-17
4.4-1	Scanning Errors (Scan-to-Scan)	4-21
4.4-2	Scanning Errors (Cell-to-Cell)	4-22
4.5-1	Typical AC Motor—Encoder System and Control	4-25

ILLUSTRATIONS (CONT.)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
4.5-2	Typical DC Motor—Encoder System and Control	4-28
5.1-1	Relative Signal Vs. Reflectivity Band 1 (0.5 to 0.6 Micron)	5-2
5.1-2	Reflective Band Calibration Source	5-4
5.2-1	Solar Direction	5-6
5.3-1	OSS Black Body Form Factor	5-8
5.3-2	Profile Section View of OSS Black Body	5-8
5.3-3	OSS Black Body Cold Structure and Radiator Assembly	5-10
6-1	Image Plane Field Stop	6-2
6-2	Spectrometer Optical Schematics	6-3
7.2-1	Photomultiplier Tube Response	7-7
7.4-1	Quantum Efficiency of Silicon Photodiodes	7-12
7.4-2	Preamplifier Design for Silicon Detectors	7-13
8.1-1	IR Band Detector Radiator Configuration	8-3
8.1-2	IR Bands 5 and 6 Detector Radiator Performance	8-4
8.2-1	Passive Cooler Field of View Limits	8-5
8.2-2	Thermal Band Passive Radiation Cooler Configuration	8-7
8.2-3	Thermal Band Passive Radiation Cooler Performance	8-9
9-1	Typical Electronics Channel	9.1-3
9.1-1	Integrate-Hold-Dump Cycle	9.1-5
9.1-2	Analog Processor Functional Block Diagram	9-7
9.1-3	Analog Processor Functions	9-8
9.1-4	Analog Processor	9-9
9.2-1	Functional Block Diagram of Analog-to-Digital Converter (Successive Approximation Type)	9-14
9.3-1	Illustrating Data Buffering	9-16
9.4-1	Telemetry Link Data Format	9-20
9.4-2	Demultiplexer Output Tape Format	9-21
9.4-3	Telemetry Link Frame Structure	9-23
9.4-4	Minor Frame Data Organization: OCS Bands 1 through 24; OLS Bands 2, 3, 5 and 6	9-24
9.4-5	Formatter Functional Block Diagram	9-26
9.5-1	Timing and Control Concept No. 1	9-29
9.5-2	Timing and Control Concept No. 2	9-30
9.5-3	Scanning Mechanisms	9-31
9.5-4	Variations of Scan-Mechanism Look-Angle With Time: Concept No. 1	9-33
9.5-5	Integration Area Variation (Concept No. 1 or 2)	9-34

ILLUSTRATIONS (CONT.)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
9.5-6	Variation in Dwell Angle as a Function of Scan-Mechanism Look-Angle: Concept No. 2	9-36
9.6-1	Calibration Source Control	9-38
9.7-1	Power Distribution	9-42
10-1	Over-all OSS Scanner Layout	10-3/10-4
10-2	Calibration Source Installation	10-5/10-6
10-3	Solar Reference Reflector Configuration	10-8
10-4	Spectrometer Assembly	10-9/10-10
10-5	Overland Detector Assembly	10-13/10-14
10-6	Oceanographic Detector Assembly	10-15/10-16
10-7	Passive Cooler Assembly	10-17/10-18
10-8	Electronics Assembly	10-21/10-22
10-9	Hybrid Distribution on Circuit Cards - Bands 2, 3, 5, and 6	10-23
10-10	Hybrid Distribution on Circuit Cards - Bands 1, 4, and 7	10-24
11-1	Thermal Control Configuration	11-2
11.1-1	Electronics Module Mounting Arrangement	11-3
11.1-2	Electronics Module Radiator	11-5
11.1-3	Electronics Module Radiator Performance	11-6
12.1-1	System MTF Block Diagram	12-2
12.1-2	MTF Curves for the Individual Scanner Stages	12-4
12.1-3	Variation in MTF of the IFOV Around a Scan Line	12-5
12.2-1	MTF Curves Normalized to the Reciprocal of the Square Root of the Noise Bandwidth	12-7
12.2-2	Comparison of Weighting Functions (Phase Effects)	12-8
12.3-1	Over-All Scanner MTF Curves	12-10
13.1-1	Present Rocking Mirror Scanner Physical Interface	13-3
13.1-2	Image Plane Conical Scanner Physical Interface	13-4
13.3-1	Principal Elements in the GDHS	13-8
13.3-2	Current MSS Framing Format on the EBR	13-9
13.3-3	MSS Tape Format for Input to the GDHS	13-10
13.3-4	HDDT Tape Formats for the MSS	13-12
13.3-5	MSS-CCT Format	13-13
13.3-6	MSS VTR Control Block Diagram	13-14
13.3-7	Relation Between a Minor Frame and the Input Tape to Bulk Processing	13-16
13.3-8	Modifications to the GDHS When Generating Bulk Imagery	13-17
13.3-9	Alternative CCT Formats and Corresponding GDHS Modifications	13-18/13-19
13.3-10	MSS Electronic Framing to Provide 10% Overlap	13-21
13.3-11	EBR Writing Distance as a Function of Frame Size and Duty Cycle	13-23

ILLUSTRATIONS (CONT.)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
13.3-12	OSS Bulk Imagery Format Using a New EBR	13-24
13.3-13	Conical Data Format Using Present EBR	13-26
13.3-14	Effects of Frame Shrinkage on Resolution	13-27
A-1	Overland Spectrometer Detector Planes	A-2
A-2	Dispersion Curve for 60° Fused Quartz Prism	A-3
A-3	Spot Diagram for Prism and Lens Combination	A-8
A-4	Collimator Optimization From Telescope to 10-in. Paraboloid	A-14
A-5	Overland Spectrometer Optical Schematic	A-17
A-6	Dall-Kirkham Blur Circle	A-18
A-7	Off-Axis Paraboloid Blur Circle	A-21
A-8	Design of Lens	A-26
A-9	Spot Diagram for 3.1-in. Lens (24°C, 2.4μ)	A-27
A-10	Spot Diagram for 3.1-in. Lens (10°C, 2.4μ)	A-28
A-11	Spot Diagram for 3.1-in. Lens (24°C, 1.6μ)	A-29
A-12	Spot Diagram for 3.1-in. Lens (10°C, 1.6μ)	A-30
A-13	Energy Distribution Curve	A-32
A-14	Spot Diagram of Spectrometer Only - Through Center and Corner of Field Stop	A-37
A-15	Spot Diagram of Rays Through Center of Field Stop	A-38
A-16	Spot Diagram at Corner of Band 5 Cells From Corner of Field Stop - 1.6 μm, 24°C	A-38
A-17	Overland Spectrometer Slit Functions	A-40
A-18	Telescope and Spectrometer Spot Diagram on Band 3 Cell	A-42
A-19	Telescope and Spectrometer combined at 1.6 μm - Spot Diagram on Band 5 Cell	A-43
B-1	MOS Shift Registers	B-3
B-2	MOS Dynamic Shift Registers	B-4
B-3	"Read While Write" Method	B-6
B-4	MOS Data Buffer	B-9
B-5	Data Buffer and Formatter	B-10
B-6	MOS Data Buffering for One Channel	B-11
B-7	Bands 2, 3, 5 and 7 - Hybrid Package Electronics	B-13
B-8	Band 7 - Hybrid Package Electronics	B-14
B-9	Bands 1 and 4 - Hybrid	B-15
C-1	Plated Wire Data Buffer	C-2
D-1	Demultiplexer Functional Block Diagram	D-2
D-2	Demultiplexer Preliminary Signal Callout	D-4

ILLUSTRATIONS (CONT.)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
F-1	Radiator Surface Earth View Factor - 500 n.mi Orbit	F-2
F-2	Basic Radiator Temperature Performance as a Function of Surface Absorptance to Emittance Ratio	F-3
F-3	IR Band Second Surface Mirror Radiator Performance	F-7
F-4	Thermal Reference Sources Radiator System Schematic Diagram	F-9
F-5	Thermal Reference Sources Radiator Performance	F-12
F-6	Electronics - PCM Radiator Performance	F-15
F-7	Electronics Module Radiator	F-18
F-8	Electronics Module Construction	F-20
F-9	Thermal Band Passive Cooler Interior Surface Description	F-22
F-10	Thermal Band Passive Radiation Cooler Performance	F-28
G-1	Oceanographic Spectrometer Design Data	G-8
G-2	Oceanographic Spectrometer	G-9
H-1	Orbit Appearance	H-3
H-2	Yearly Orbital Variation	H-3
H-3	Sun Calibration	H-4
H-4	Orbital Geometry	H-5
H-5	Solar Direction Angles	H-7
H-6	Solar Direction Angles	H-9
H-7	Scan Direction	H-11
H-8	Mirror Reflection	H-11
H-9	Mirror Normal Direction	H-12
H-10	Reflection Direction	H-12
I-1	Estimated Solid Cryogen System Weights and Volumes	I-2
I-2	Solid Cryogen System Schematic Description	I-4

TABLES

<u>Table</u>	<u>Title</u>	<u>Page</u>
1.2-1	Technical Requirements for the OSS	1-3
2.1-1	OSS Scanner Characteristics	2-2
2.2-1	OSS Performance Summary	2-10
3.2-1	Misalignment Tolerances	3-6
4.1-1	Possible Data Rates Divisible by 6 and 13 With 13 as the Highest Prime Number	4-13
4.1-2	System Parameters Dependent Upon Duty Cycle and Data Rate	4-14
4.4-1	Accuracy Requirements	4-20
6-1	Dual Mode Multispectral Scanner Spectral Bands	6-4
7.1-1	Overland Detector Signal Power	7-3
7.1-2	Oceanographic Detector Signal Power	7-4
7.6-1	Performance Summary - Overland Mode	7-17/7-18
8.2-1	Critical Surface Thermal/Optical Characteristics	8-8
9-1	Electronic Design Requirements	9-2
9.2-1	Analog-to-Digital Converter Considerations	9-12
9.3-1	Data Buffer Requirements	9-17
9.3-2	MOS Shift Register and Plated Wire Memory Comparison	9-19
9.4-1	Telemetry Format Summary	9-25
9.7-1	Power Consumption Table	9-40
9.7-2	Electronics Subsystem Power Requirement	9-41
10-1	Hybrid Module Summary	10-20
10-2	Circuit Board Summary	10-25
10-3	Weight Summary	10-27
A-1	Spectrometer System Comparison on Basis of Imager Optics	A-19
A-2	Transmission of Possible Materials	A-23
A-3	Selecting Possible Materials	A-24
A-4	Effect of Wavelength, Back Focal Distance, and Input Beam Angle on Blur Circle	A-34
A-5	Transfer Efficiency of Light Guides	A-35
F-1	Phase Change Material Selection	F-17
F-2	Thermal Band Passive Cooler Surface Characteristics	F-24
F-3	Passive Cooler Thermal Analysis Model Description	F-27
G-1	Angular Dispersion vs. Collimator Diameter	G-3

TABLES (CONT)

<u>Table</u>	<u>Title</u>	<u>Page</u>
G-2	Total Focal Plane Aberrations	G-4
G-3	Imaging Lens Focal Length	G-5
G-4	Variance of Detector Size According to Focal Ratio	G-6
G-5	Blur Circle/Detector Size	G-6
I-1	Typical Characteristics of Common Cryogens	I-3

SECTION 1

INTRODUCTION

1.1 BACKGROUND

The objective of this contract was to conduct a preliminary design of a multi-spectral scanner system that would fulfill the anticipated oceanographic survey requirements and with simple modifications would also satisfy other earth resources survey requirements. Although an actual spacecraft was not designated, the study was constrained to have minimum impact on the Earth Resources Technology Satellite (ERTS) spacecraft and the associated Ground Data Handling System (GDHS).

The performance requirements for this scanner were developed by Bendix during a prior company-funded study (Phase A - Preliminary Analysis, BSR 2902) which analyzed the general remote sensing requirement for all the scientific disciplines, including both overland and oceanographic applications.

Prior to initiating the preliminary design of this scanner, an investigation of scanning techniques was conducted and a scan mechanism selected which is most suitable for space applications. The results of this investigation were presented at a preliminary design review held at NASA (GSFC) and subsequently published in January 1971 under this contract. (See Phase B - Concept Review and Selection).

After selecting the scan techniques, a full design of an MSS has been carried out which, with minimum modifications, interfaces to the ERTS spacecraft and the GDHS.

The original contract included the preparation of hardware development plans and a panchromatic band in place of the overland bands. However, a subsequent contract change deleted the need to supply these plans, and substituted an investigation of techniques to increase the system duty cycle to a value above 50% and a breadboard effort to investigate variations in scan velocity. The results of the increased duty cycle study and the breadboard are fully reported in Volume II of this report. Under Bendix-sponsored support full breadboarding of the collecting optics and two channels of electronics has also been performed and is also discussed in Volume II.

1.2 REQUIREMENTS

The initial Bendix study (Phase A - Preliminary Analysis, BSR 2902) analyzed the general remote sensing requirements for all the scientific disciplines, including both overland and oceanographic applications. This study established certain criteria upon which the MSS design is based and indicated that the spatial and spectral resolution requirements of an MSS for overland purposes differ markedly from those for oceanographic purposes. Overland applications require high spatial resolution and relatively low spectral resolution while the reverse is true for oceanographic applications where a spectral resolution of 100 to 300Å is required throughout the visible range of the spectrum. The oceanographic scanner (OSS) is required to satisfy the requirements of both applications. It is therefore a dual mode instrument with the spectral band selection shown in Table 1.2-1; this table also gives the required spatial resolutions. In its oceanographic mode of operation, two of the overland bands are used together with the 24 low spatial resolution bands. Thus, in this mode of operation, some high spatial resolution data are available for the mapping of the coast and the investigation of near shore processes.

Table 1.2-1 gives further requirements for the OSS. It is, of course, desirable to have maximum sensitivity, and to provide spectral calibration obtainable from reference sources incorporated into the optical subsystem. It is also necessary that the data be spatially and spectrally registered. Spectral registration is obtained using a spectrometer, but no specification has been given for spatial registration. Design goals of 10% of one instantaneous field of view (IFOV) have therefore been taken for both line-to-line underlap/overlap and cell-to-cell registration on adjacent scan lines.

A severe restraint on the design of the OSS was that it should have minimum impact on the existing ERTS subsystems. The satellite imposes weight, power, data rate (Table 1.2-1), and envelope requirements, the latter of which is most severe when packaging the optics to obtain a maximum collecting area and hence a high sensitivity. The Ground Data Handling Station (GDHS) being developed for the ERTS A/B missions must also be carefully considered for the data processing technique to be used. In particular, this impacts on the duty cycle, timing control implementation and data format. The necessary data format changes to accommodate the additional bands demand some modifications to the receiving site equipment. Because of the interface restraints on this system, several compromises are required in the areas of optical arrangement, package design, and data handling.

1.3 STUDY RESULTS SUMMARY

During the early stages of the program, Bendix surveyed several candidate scanning techniques and selected an image plane conical scan mechanism as suitable

TABLE 1.2-1
TECHNICAL REQUIREMENTS FOR THE OSS

Band	Channels	Wavelength (μ)		Bandwidth (μ)	Band (Single Channel)	λ ($\text{\AA}$)	
1	6	.5	.6	0.1	1	4000	4160
2	6	.6	.7	0.1	2	4160	4320
3	6	.7	.8	0.1	3	4320	4480
4	6	.8	1.1	0.3	4	4480	4640
5	6	1.55	1.75	0.2	5	4640	4800
6	6	2.2	2.4	0.2	6	4800	4960
<u>Thermal</u>					7	4960	5120
					8	5120	5280
					9	5280	5440
7	2	10.4	12.6	2.2	10	5440	5600
<u>Spatial Resolution</u> (IFOV)					11	5600	5760
Bands 1-6		200 ft. (0.066 M Rads)			12	5760	5920
Band 7		600 ft. (0.2 M Rads)			13	5920	6080
Oceanographic (1-24)		1200 ft. (0.4 M Rads)			14	6080	6240
Note: Oceanographic mode includes two overland bands plus the thermal band.					15	6240	6400
					16	6400	6560
					17	6560	6720
					18	6720	6880
					19	6880	7040
					20	7040	7200
					21	7200	7360
					22	7360	7520
					23	7520	7680
					24	7680	7840
$\Delta \lambda$ for All Bands is 160 $\text{\AA}$							
Weight < 200 lb				NE $\Delta\rho$ < 1%			
Power < 250 W				NE ΔT 1° at 300°K			
Orbit 496 n. miles Sun Sync				Dath Rate 15 Mb/sec $\pm$ 1/2%			
Swath Width 100 n. miles				Life in Orbit > 1 year			
<u>Interfaces:</u> All aspects of the ERTS A/B missions.							

for space applications where the angular FOV is small.* This concept scans a conic section on the ground by scanning a circle in the image plane of the collecting optics; it has the advantages of an inherently high duty cycle and small scan mechanism. The alternatives considered were an object plane linear, an object plane conical and an image plane linear scan mechanism. The first two involve large scan mechanisms, and though the object plane linear scan mechanism provides a linear scan pattern, it has an unacceptably low duty cycle unless an oscillating mirror system is used. However, the difficulties of precisely controlling the motion of a large oscillating mirror make this approach unattractive. The case of a linear image plane scanner with a high duty cycle is the ideal, but a suitable system has yet to be conceived which will do this with the required resolution, duty cycle, and with an all-reflective optical system.

Apart from its small inertia and inherently high duty cycle, the selected scan mechanism is relatively insensitive to misalignments which would result in spatial registration errors. This is shown analytically in Sections 3.4 and 4.4 (which covers the motor/motor control technique selection), and has also been adequately demonstrated on the breadboard of the scan mechanism discussed in Volume II of this report. The breadboard has resulted in optical measurements of registration errors which can arise from motor speed variations and bearing run out. The small inertia of the scan mechanism also implies that very little angular momentum compensation is required. The scan mechanism rotates at 1024 rpm and causes an angular momentum of about 0.023 ft-lb-sec. If necessary, this can readily be compensated for by a small counter-rotating mass either driven from the main motor or from a small subsidiary motor appropriately situated in the envelope.

The line of sight swept out by the scan mechanism is a cone with its apex at the scanner. The scan pattern is therefore an arc of a conic section. The conic section selected is an ellipse such that the scan arc passes through the nadir since this minimizes positional errors which arise from spacecraft attitude and altitude uncertainties. The scan pattern has been fully investigated to adjust the cone semi-angle, duty cycle, and number of cells along a scan arc, etc., to be compatible with the resolution, swath width, and ease of timing control implementations (Section 4).

The collecting optics and spectrometers have been designed (Sections 3, 6 and Appendices A and G) and fully evaluated by ray-tracing on programs developed at Bendix. Ray-tracing has also been used to investigate the permissible tolerances on optical parameters such as defocus, primary to secondary mirror separation and misalignments. Further, under the Bendix sponsored breadboard effort, see Volume II of this report, the optical performance of the collecting optics has been

* Phase B - Preliminary Analysis.

demonstrated to be entirely satisfactory. An integral part of the optical subsystem is the insertion of calibrated sources and blackbody references for calibration purposes; these are described in Section 5 and Appendix H, which shows the insertion of solar calibration at suitable points in the orbit.

Appropriate detectors, Section 7, have been selected for all the bands and an S/N analysis has been carried out. The resulting values are given in the next section, and are realistic, though the choice of HgCdTe detectors for bands 5 and 6 of the overland mode is dependent on the satisfactory development of HgCdTe detectors at the shorter wavelengths. The state of the art is such that both HgCdTe and InAs detectors would give approximately the same performance for these bands. However, InAs detectors are relatively well developed, and HgCdTe detectors, designed for a high sensitivity at these wavelengths, are subject to a low bandwidth which is also a function of the level of illumination falling on the detector. Nevertheless, HgCdTe has the potential of providing a higher performance than InAs for bands 5 and 6 and has therefore been selected, though InAs may be a more natural choice at the present time. The performance analysis of Section 7 provides an evaluation of the S/N ratio for all the bands. This analysis is supplemented with calculations of the modulation transfer function, Section 12, which also gives the rationale for the choice of sampling the signal using an integrate-and-hold circuit.

The bands which are most sensitive to preamplifier noise are those which use silicon detectors. Low noise, high bandwidth preamplifiers have been designed and built for multispectral scanners manufactured at Bendix, and their performance (Section 7) is such that they would also be suitable for the OSS.

The complete electronics for each channel has been designed (Section 9) and, under Bendix-sponsored support, two channels of electronics including an analog processor, A/D converter and buffer have been breadboarded. Their operation has proved satisfactory and has resulted in considerably lower power requirements than at first envisaged. In particular, the breadboarding of MOS (Appendix B) and plated wire memories (Appendix C) for the buffer has shown that a MOS buffer is preferable, requiring considerably less power.

The interface considerations between the scanner and the ERTS spacecraft have led to the complete mechanical design and packaging of the scanner in the available envelope (Section 10). However, due to the unfavorable interface, a satisfactory passive cooler design (Sections 8, 11 and Appendix F) has not been achieved and an active cryogenic cooler (Appendix I) has been considered as an alternative. A thermal and structural analysis of the configuration (Appendix E) has also been performed to determine the sensitivity of the system to temperature changes and gradients, maximum stress levels under 20-g ultimate loads and the selection of materials. This is most important in consideration of the optical tolerances which have to be held.

Full consideration of the GDHS interface has been made when selecting the duty cycle, data formats (Sections 4, 13 and 9.4), timing and control implementation (Section 9.5) and modifications to the receiving site equipment (Appendix D). The OSS provides more bands and hence more data than the GDHS is designed to process. Some modifications to the GDHS are therefore necessary to accept OSS data, but these modifications have been minimized where possible by appropriate design of the scanner. A particular modification to the GDHS is that, for the OSS, it must accept a conical scan pattern rather than a linear one; this is discussed in Section 13.3.

SECTION 2

SYSTEM DESCRIPTION AND PERFORMANCE

2.1 SYSTEM DESCRIPTION

The OSS, a dual-mode multispectral scanner, is capable of satisfying both overland and oceanographic requirements. Figure 2.1-1 is a schematic diagram of the complete system showing all the major components; Figure 2.1-2 shows an orthographic projection of the optical system; and Table 2.1-1 summarizes the design parameters. These figures show that radiation from the scene is reflected by a large Martin (folding) mirror onto the primary mirror of the collecting optics which forms an image of the scene in between the two scan mirrors of the scan mechanism. The scan mechanism scans a circle of the primary image plane by using the outer scan mirror to reflect the incoming bundle of rays onto the central scan mirror, which then reflects the rays to the secondary mirror of the collecting optics. In this way, the secondary mirror is always used on-axis, and therefore good aberration correction can be obtained, provided there is an effective aperture at the center of curvature of the primary.

The image-forming bundle of rays from the secondary is brought to a focus at the field stop after being reflected by a folding mirror. The field stop (Figure 2.1-3(a)), which forms the instantaneous field of view (IFOV), is divided by a wedge mirror (Figure 2.1-1) so that the high-resolution section is reflected to the prism spectrometer used for spectral dissection of the overland bands. The low-resolution section of the IFOV passes directly to a dichroic beam splitter which reflects the visible wavelength region to the oceanographic spectrometer and transmits the thermal wavelengths. The thermal bands are imaged directly onto two HgCdTe detectors ideally cooled to below 100°K by a passive radiation cooler. However, this may not be possible and a cryogenic cooler is a viable alternative.

The conflicting spatial and spectral resolution requirements of the two modes of operation necessitate the use of two different spectrometers. A prism is adequate for the overland spectrometer in which a dichroic mirror is used after the prism to separate the near-IR bands 5 and 6 from the visible bands 1 through 4. Bands 5 and 6 are then imaged onto cooled detectors while bands 1 through 4 are imaged onto silicon detectors for band 4 and a fiber-optic array which leads to photomultiplier tubes for bands 1 through 3.

TABLE 2.1-1

OSS SCANNER CHARACTERISTICS

<u>Overland Mode:</u>	Bands 1 through 6 plus thermal band 7		
<u>Oceanographic Mode:</u>	24 oceanographic bands, thermal band 7, plus overland bands 1 and 4		
	<u>Overland</u>	<u>Oceanographic</u>	<u>Thermal</u>
Spatial Resolution (IFOV)	0.066 mrad	0.4 mrad	0.2 mrad
at 500 n. mi altitude	200 ft	1200 ft	600 ft
Preamplifier bandwidth	300 kHz	50 kHz	100 kHz
Video processor bandwidth	300 kHz	300 kHz	100 kHz
Integration time	4.4 μ sec	26.4 μ sec	13.2 μ sec
Noise bandwidth	96 kHz	16 kHz	32 kHz
MTF at frequency 0.5/IFOV	0.40	0.46	0.44
Dwell time	5.2 μ sec	31.2 μ sec	15.6 μ sec
Cells per scan line	3552	592	1184
Scan mechanism:	Image plane conical		
Swath width:	100 n. mi at 500-n. mi altitude		
Scan pattern:	Elliptical, passes through nadir		
Arc length:	118.5 n. mi		
Cone semi-angle:	6°46'		
Motor speed:	17.066 Hz		
Data rate:	14.976 Mbps		
Duty cycle:	31.57%		
No. of channels:	38		
Level of conversion:	6 bits		
Bits per scan:	Overland mode 729,000 Oceanographic mode 360,000		
Calibration sources:	Two internal visible-IR sources, two internal blackbodies, solar reference		
Calibration samples:	12 of each source per scan		
Buffer type:	Dynamic MOS shift registers		

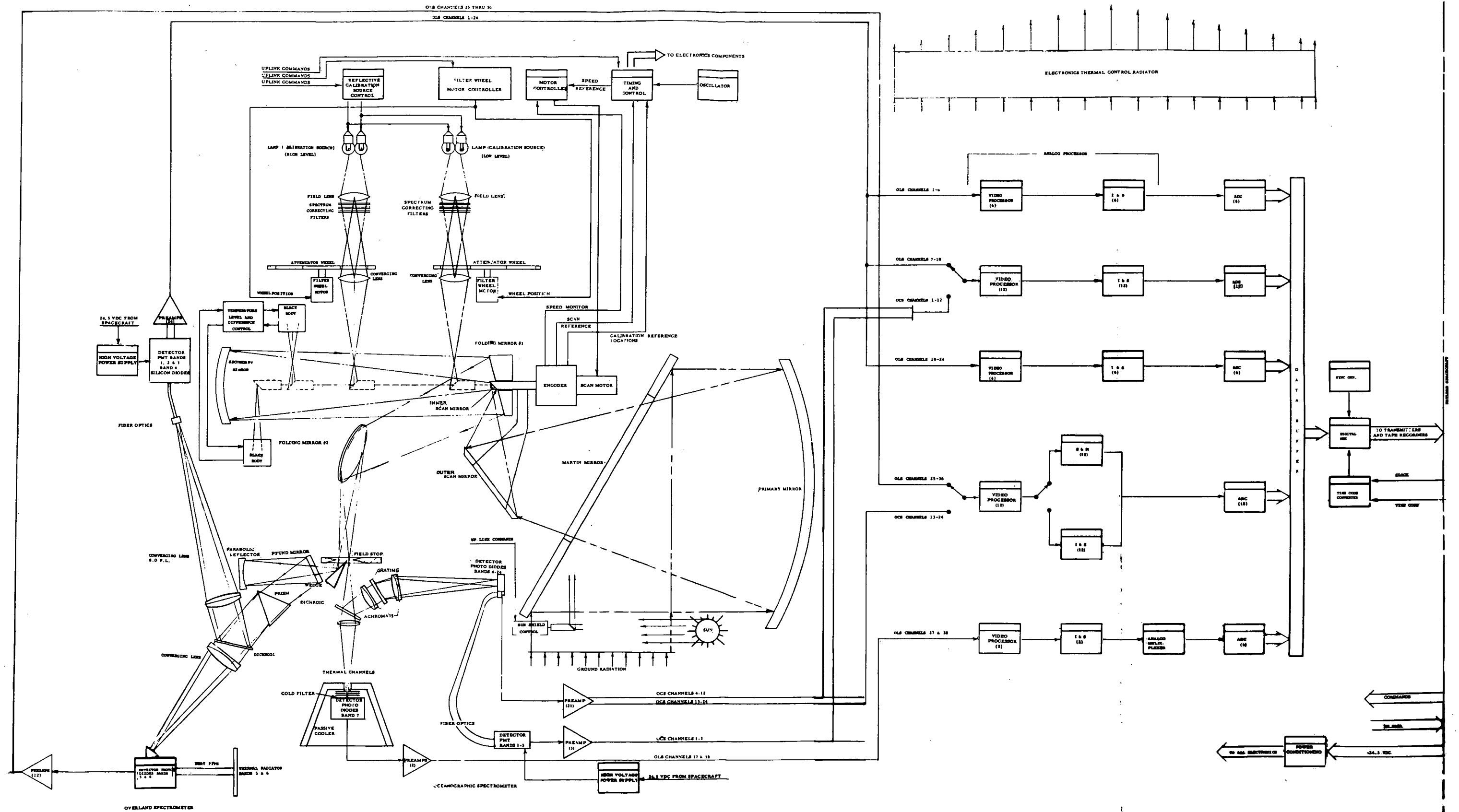


Figure 2.1-1 Schematic Diagram of the OSS Scanner

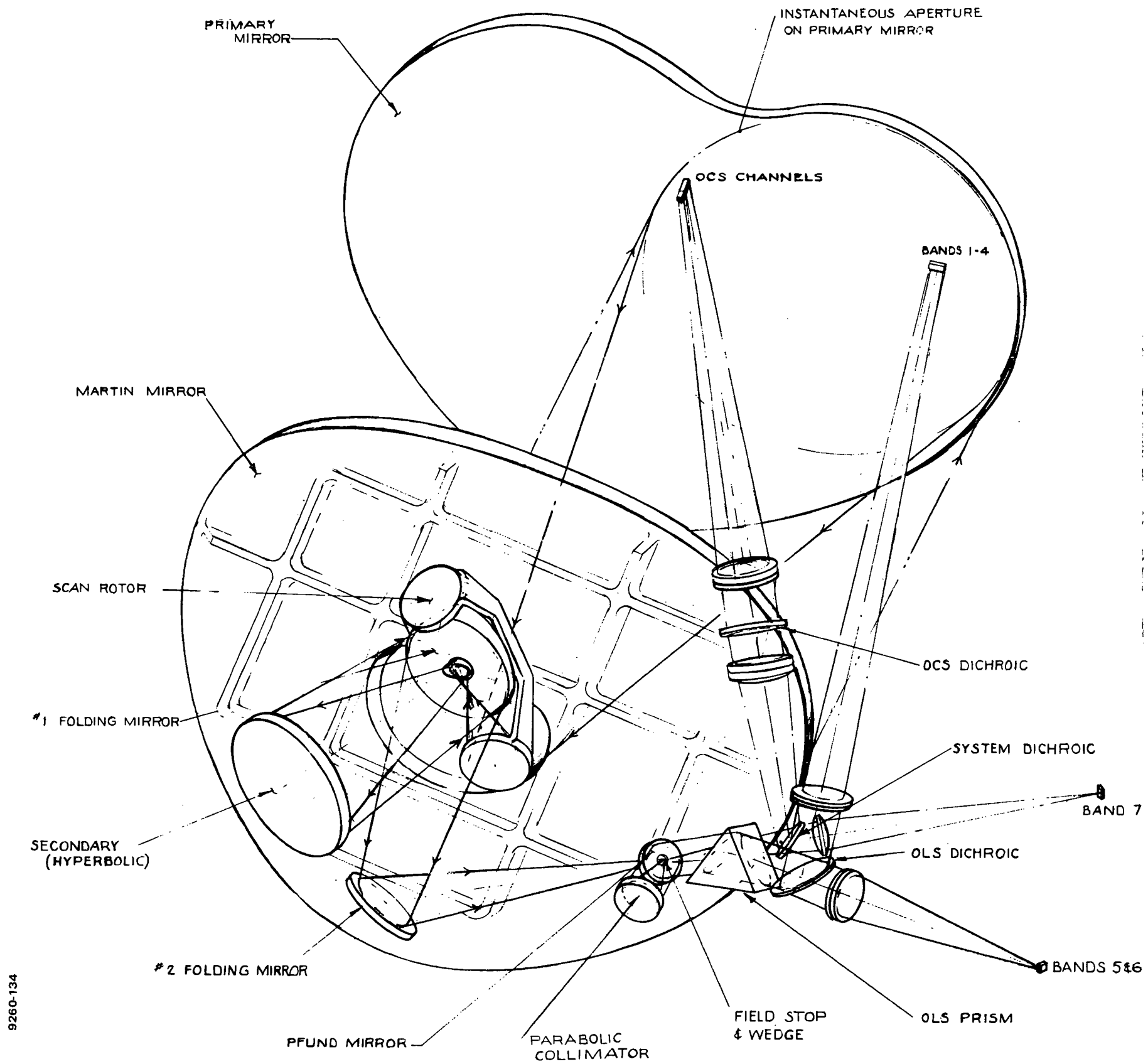


Figure 2.1-2 OSS Optical Schematic

It is necessary to use a grating spectrometer to obtain the high spectral resolution required for the oceanographic mode of operation. The large IFOV, which forms the entrance slit to the spectrometer, is imaged on an array of silicon photo diodes plus three optical fibers in the exit focal plane. The silicon detectors are used for bands 4 through 24, while the fiber optics lead to photo-multiplier tubes which are used for bands 1 through 3.

The spatial resolutions for the overland and oceanographic modes, Table 2.1-1, are 200 ft and 1200 ft, respectively. Thus, to avoid high bandwidth requirements and a change of scan speed between the two modes of operation, and also to maintain compatibility with the ERTS system interfaces, six lines are scanned in parallel per sweep of the scan mechanism during the overland mode of operation, Figure 2.1-3(b). This is achieved by using a spatial array of six detectors per spectral band to divide the image of the field stop formed in the back focal plane of the overland spectrometer into 6 IFOVs. The result is a total of 38 channels of electronics corresponding to the six detectors for each of the six high-resolution spectral bands, plus two more for the thermal band 7 which has a resolution of 600 ft. There are also 38 channels of electronics required in the oceanographic mode of operation where the 24 channels used for bands 2, 3, 5, and 6 are now used for the 24 oceanographic bands. Switching between the two modes of operation is thus performed on command by switching the inputs to the electronics which follow the preamplifiers, there being one preamplifier for every detector. The use of electronics common to both modes of operation has been used as far as possible to minimize the electronics design, power, and packaging requirements.

The signals from the preamplifiers, Figure 2.1-1, pass through video processors which provide additional gain plus automatic gain control and dc offset corrections. The signals then pass through integrate and hold (I&H) circuits except for bands 5 and 6 of the overland mode of operation which pass through sample and hold (S&H) circuits for the reasons set out in Sections 7 and 12. The integration time principally determines the noise bandwidth which is about 96 kHz and 16 kHz for the overland and oceanographic modes, respectively. The sampled values held at the output of the I&H (or S&H) circuits pass through analog multiplexers, 6-bit A/D converters, and thence to a data buffer prior to formatting and transmission or storage on tape.

Calibration is provided by calibration sources for the visible and near-IR bands, and by blackbodies for the thermal bands. They are all viewed by all the channels once per sweep of the scan mirror and the appropriate data are transmitted with the video data. To simplify the video processor design, high- and low-calibration sources are provided to cover all bands. The levels defined by these sources then define the dynamic range of the system, since the low calibration

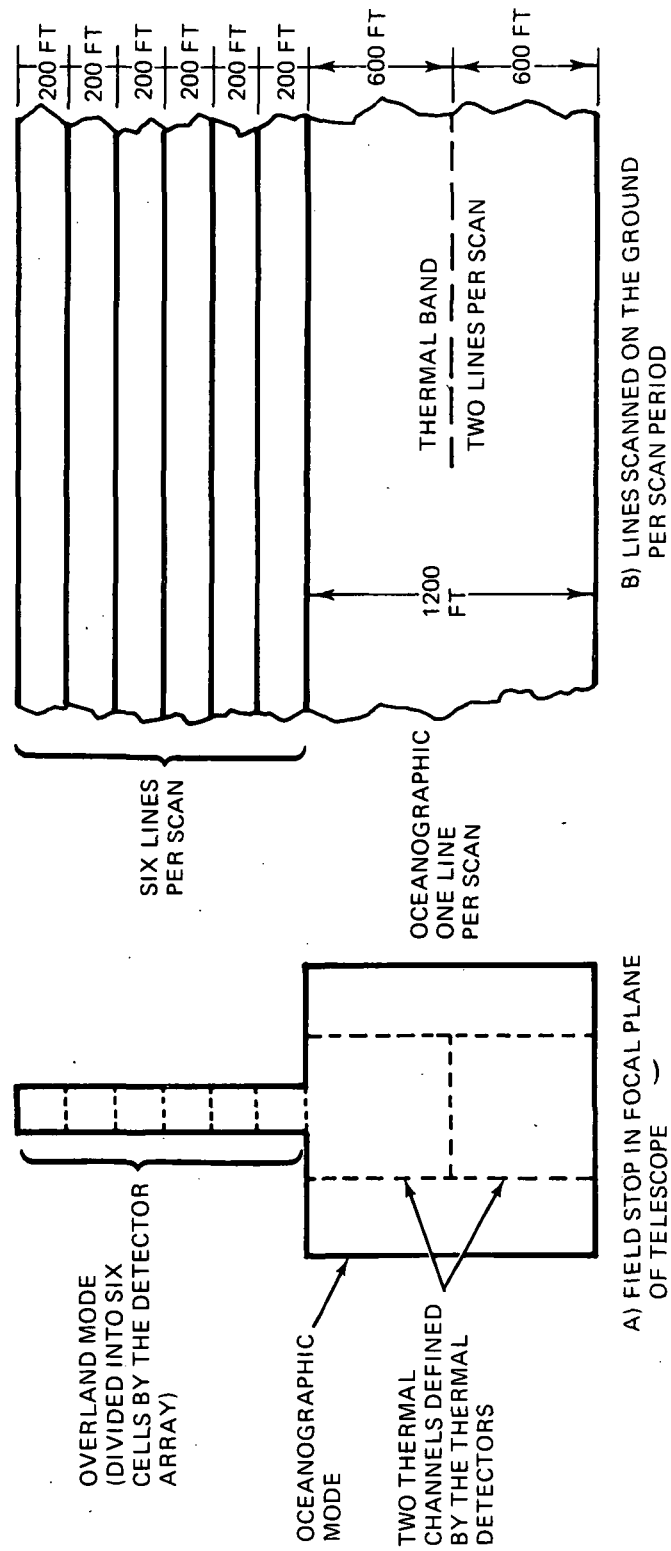


Figure 2.1-3 Field Stop Characteristics

level is always electronically adjusted to correspond to the second level on the A/D converters while the high calibration level corresponds to the 62nd level. These levels are used to set the dc offset and gain of the video processor. It follows that the signal range is confined to the range between low and high calibration. This range can be selected on command by switching different attenuating filters, Figure 2.1-1, into the optical path between the calibration sources and the scan mechanism. The available ranges should give full coverage of the different conditions (atmospheric, illumination, and scene) which would be encountered. However, the number of ranges required will be greatly limited by the noise level of the system, since there is no need to have more than the last two bits in the noise. Allowance is also made for solar calibration by means of a small mirror which can be introduced into the optical path on command during suitable periods of the orbit.

The scan duty cycle (31.5%) and dwell time (5.2 μ sec) are determined from considerations of the GDHS interface and timing control requirements. The data format is selected for its high degree of compatibility with the input data tape to the GDHS. In this format, one-third of the video data is transmitted in real time while the remaining two-thirds are stored for transmission during the non-active portion of the duty cycle; this also simplifies the design and operation of the buffer. The timing control is directly derived from a reference clock and ensures that the data rate is within $\pm 1/2\%$ of 15 Mbps as required by the ERTS system. The dwell time, integration time, and sampling intervals are hence very precisely controlled as divisors of the reference crystal oscillator. The motor speed is also slaved to the reference oscillator via an encoder which has two tracks. The first track is used to control the motor speed, while the second track has only one bar which is used as a scan start reference and is the only timing control information taken from the encoder for the electronics.

2.2 SYSTEM PERFORMANCE SUMMARY

The performance characteristics of most importance to the analysis of multi-spectral data are S/N ratios for all bands, spectral registration, and spatial registration. Spectral registration errors are minimal since a spectrometer is used for the spectral dissection of the bands, and the integration and sampling times are precisely clocked. The only appreciable error that arises is in variations of the preamp and video processor bandwidths; these variations will have little effect since the bandwidths are large compared with the information bandwidth.

Table 2.2-1 gives a summary of the S/N ratios for all bands, including values for $NE\Delta\rho$ and $NE\Delta T$, the noise equivalent reflectance and temperature difference for the oceanographic and thermal bands respectively; $NE\Delta\rho$ is the scene reflectance divided by the S/N ratio. The calculations, Section 7, take into account

TABLE 2.2-1

OSS PERFORMANCE SUMMARY

Overland				Oceanographic					
Band	λ (μ)	Detector	S/N ($\rho = 1$)	Band	Central λ (μ)	Detector	Reflectivity ρ	S/N	NE $\Delta\rho\%$
1	0.5 - 0.6	PMT	79	1	0.409	PMT	0.052	24	0.22
2	0.6 - 0.7	PMT	72	2	0.424	PMT	0.048	25.9	0.185
3	0.7 - 0.8	PMT	47	3	0.440	PMT	0.046	32.8	0.14
4	0.8 - 1.1	Si (Pv)	140	4	0.456	Si (Pv)	0.046	11.5	0.40
5	1.55 - 1.75	HgCdTe	89.5	5	0.478	Si (Pv)	0.048	14.6	0.33
6	2.2 - 2.4	HgCdTe	53.4	6	0.488	Si (Pv)	0.049	16.8	0.29
Thermal Band 7	10.4 - 12.6	HgCdTe	NE ΔT at 300°K 0.52	7	0.504	Si (Pv)	0.041	16.4	0.25
Spatial registrations % of the overland IFOV: a) Line-to-line underlap/overlap: < 4% b) cell-to-cell on adjacent scan lines: < 6% Weight: 140 lb Power: 137 W				8	0.520	Si (Pv)	0.040	17.0	0.235
				9	0.536	Si (Pv)	0.036	18.0	0.20
				10	0.552	Si (Pv)	0.036	19.7	0.18
				11	0.568	Si (Pv)	0.034	19.6	0.17
				12	0.589	Si (Pv)	0.032	19.8	0.16
				13	0.600	Si (Pv)	0.026	17.5	0.15
				14	0.616	Si (Pv)	0.026	17.0	0.14
				15	0.632	Si (Pv)	0.024	18.7	0.15
				16	0.648	Si (Pv)	0.023	15.7	0.15
				17	0.664	Si (Pv)	0.023	15.7	0.14
				18	0.680	Si (Pv)	0.022	15.5	0.14
				19	0.696	Si (Pv)	0.022	15.4	0.14
				20	0.712	Si (Pv)	0.021	14.8	0.15
				21	0.728	Si (Pv)	0.020	13.7	0.15
				22	0.746	Si (Pv)	0.020	13.4	0.15
				23	0.760	Si (Pv)	0.020	13.3	0.15
				24	0.776	Si (Pv)	0.020	13.7	0.15

Rayleigh scattering in the atmosphere, the optical efficiency, detector responsivities (or appropriate figure of merit) and all noise sources which are of appreciable magnitude. The performance of the oceanographic bands is seen to be considerably better than that required by the contract which specifies for values of $NE\Delta\rho < 0.5\%$.

Table 2.2-1 also gives values for spatial registration errors which can arise from bearing runout and motor speed fluctuations. They are again seen to be well within the design goals of 10% for both line-to-line underlap/overlap and cell-to-cell registration errors on adjacent scan lines.

Apart from the passive cooler, all other aspects of the system should perform satisfactorily. In particular, the performance of the optics, preamplifiers for the silicon detectors, video processors, A/D converters and buffer have all been breadboarded, with the results that the designs are adequate. The passive cooler designed during the contract is not expected to cool the thermal and near-IR detectors to a sufficiently low temperature, but an active cryogenic cooler has been investigated. This device would maintain the required temperatures for at least one year's operation.

Final weight (Section 10.6) and power (Section 9.7) requirements partly based on extensive breadboarding of the electronics are also given in Table 2.2-1. The power requirement is considerably less than that originally estimated and is largely a result of experience with low power components used in the breadboard. The weight is also well within the permissible limit of 200 lbs. specified in the contract.

SECTION 3

COLLECTING AND SCANNING OPTICS DESIGN

The arrangement of the collecting and scanning optics constitutes the heart of the OSS multispectral scanner. The image space conical scanning technique was selected during the course of a previously held concept review because of its mechanical simplicity, uniform scanning capability, and relatively high duty cycle.

This section briefly reviews the image space scanning principle, presents the results of ray trace studies to analyze off-axis performance and determines misalignment tolerances, shows the optical component arrangement to minimize obscuration and change of obscuration, and analyzes the optical effects of scan mechanism bearing run-out tolerances on scan line registration.

3.1 IMAGE SPACE SCANNER CONCEPT

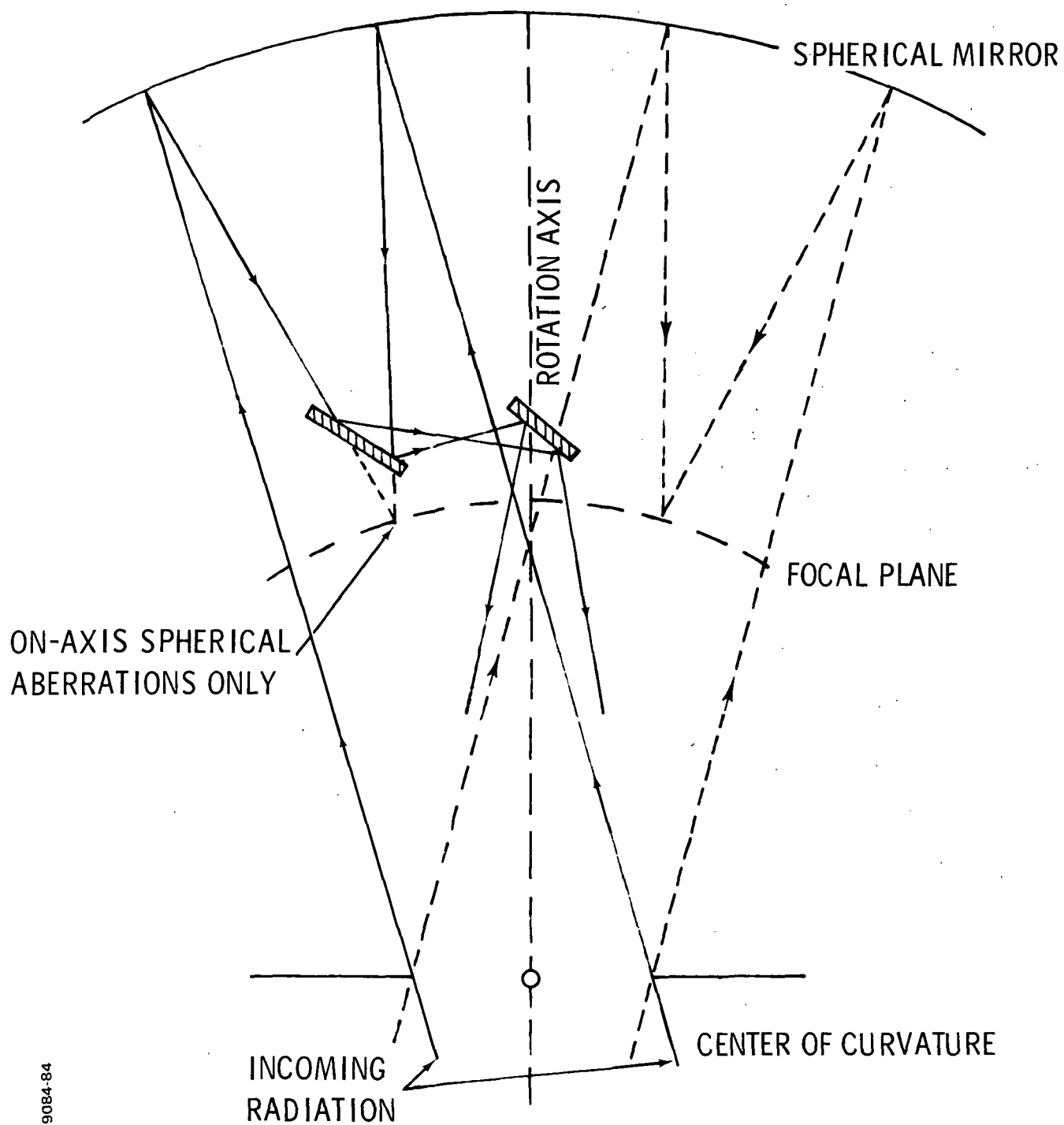
During the early part of the design study a number of different types of scanning concepts were reviewed to select one which would best fit the OSS applications (Concept Review and Selection, BSR 3061, January 1971). An image space conical scanning technique was chosen because it is capable of a relatively high duty cycle, is mechanically simple, and is capable of producing a uniform and repeatable scanning motion.

Figure 3.1-1 shows the basic concept in which a stationary set of optics produces an image surface and a pair of rotating mirrors sequentially project each element of a circular arc of the image at the field stop of a spectrometer.

A spherical collector with an aperture stop at its center of curvature is able to form an image of an infinitely remote object whose quality is independent of the angle of incidence and only affected with spherical aberration. Another stationary optical component (a secondary mirror) placed on the axis of the symmetry then corrects for the spherical aberration of the primary mirror. The image surface is also a sphere, concentric with the collector. Thus, the image of a circular scan on the ground is a circle on the image sphere parallel to the object plane. The center axis of this circle is designated the "main axis of symmetry."

The scanning mechanism successively picks up light bundles, the focii of which correspond to points on the image circle, and folds them on a common axis, the main axis of symmetry. The folding is achieved by means of two mirrors on a rotor arm. The first mirror directs the beam towards the common main axis and the second one folds it so that the optical axis coincides with the main axis of symmetry. The size of the rotor scanning mechanism is roughly determined by the extent of the image of a scan line in the focal plane of the collector. Due to the optimum position of the two folding mirrors, the crossover of the light bundle is between them. The rotation of this couple of mirrors about the main axis of symmetry then provides the scanning function with a small and mechanically simple scanning mechanism.

The maximum duty cycle of this system is 50%; however, for reasons discussed in Section 4-1, a practical value of about 33% has been selected. Different methods of multiplying the pickups per revolution of the rotor to increase the total duty cycle have been considered and will be the subject of further study.



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Figure 3.1-1 Image Space Conical Scanner Principle

3.2 OPTICAL ANALYSIS AND RAY TRACE STUDY

The description of the scanner concept in Section 3.1 made clear that the collector of the scanner optics has to be a spherical mirror. It was also pointed out that the optical aberration caused by this mirror can be corrected to a significant degree by an optical element placed on the main axis of symmetry following the scanning mechanism.

This section will give a description and an analysis of the optical system, taking into consideration the off-axis performance and the influence of possible misalignments.

The theoretical evaluations were made with the use of a ray trace program developed and written at Bendix Aerospace. The first task was to find a correcting element for the spherical collector. The result of an optimization process is demonstrated by Figure 3.2-1 which shows two blur circles both generated by 113 rays traced through the system. The first one represents the best focus of the primary alone and the second one was generated after introducing a correcting mirror which was a concave hyperbola. The correction results in an improvement factor greater than one hundred as seen from the fact that all 113 rays in the second spot diagram are represented by only one cross.

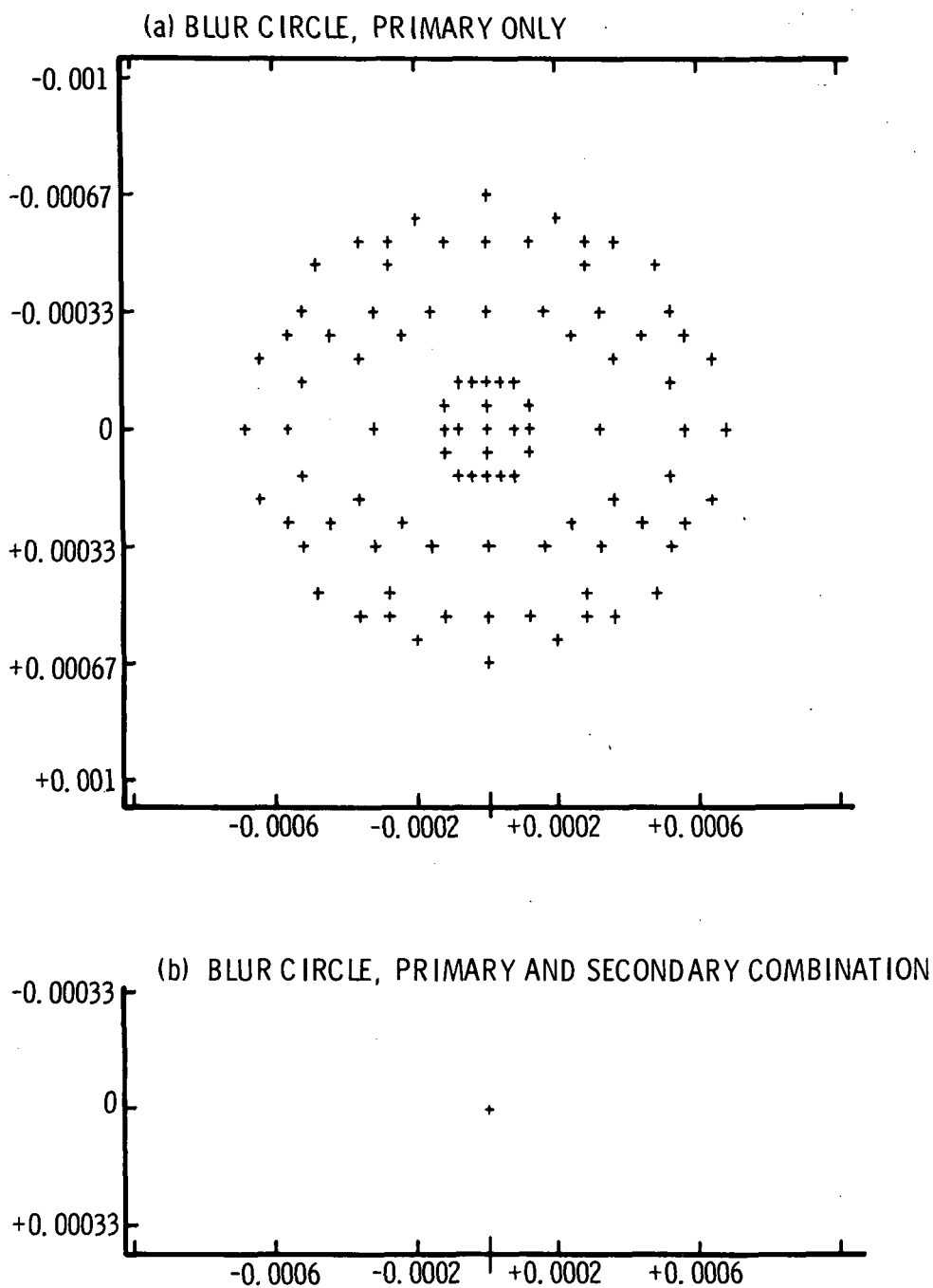
The two mirrors may be described as follows:

1. PRIMARY

- a. Shape: Sphere
- b. Radius of curvature: 40.0 in.

2. SECONDARY

- a. Shape: Hyperbola
- b. Eccentricity: 1.223
- c. Radius of curvature at the vertex: 7.1482 in.
- d. Mirror separation: 25.0 in.
- e. Backfocus: 12.5 in.



NOTE: BOTH AXES OF FIGURES ARE OFF-AXIS DISTANCE OF RAYS IN RADIAN

Figure 3.2-1 Blur Circle Comparison - Primary Only, and Primary-Secondary Combination

9260-24

f. Total focal length: 49.8 in.

A further idea of the way the two mirrors complement one another to form a corrected system is indicated by Figure 3.2-2. The graph shows where a ray leaving the primary at various distances from the optical axis penetrates the focal plane of the system.

The radial energy distribution of the blur circle in the focal plane of the optimized telescope as determined from the computer program telescope is:

Percentage of Energy	(rads)	Diameter (in.)
100%	$3.10 \cdot 10^{-5}$	$1.55 \cdot 10^{-3}$
90%	$2.88 \cdot 10^{-5}$	$1.44 \cdot 10^{-3}$
80%	$2.54 \cdot 10^{-5}$	$1.27 \cdot 10^{-3}$
70%	$1.94 \cdot 10^{-5}$	$0.97 \cdot 10^{-3}$

As a criterion for the allowable size of the blur circle, it will be required that more than 80% of the energy fall within a circle having a diameter no greater than about one-half of the instantaneous field of view, i. e., one-half of 6.6×10^{-5} rad.

The spot diagrams of Figure 3.2-3 demonstrate the off-axis performance of the telescope. The analysis revealed that the degradation of the blur circle up to 2×10^{-4} rad. off-axis, is still tolerable. For comparison, the off-axis position of the outer detector of the 6 detector array is 1.65×10^{-4} rad.

The sensitivity of this two mirror system to various kinds of misalignments is shown in Table 3.2-1. The admissible tolerances are determined by the particular misalignment which still provides a satisfactory blur circle. (Misalignment effects caused by the scanning mechanism will be treated in later sections.)

TABLE 3.2-1

MISALIGNMENT TOLERANCES

Defocussed Field Stop: +0.005 in. (Figure 3.2-4)
-0.010 in.
Mirror separation: +0.010 in. (Figure 3.2-5)
-0.002 in.

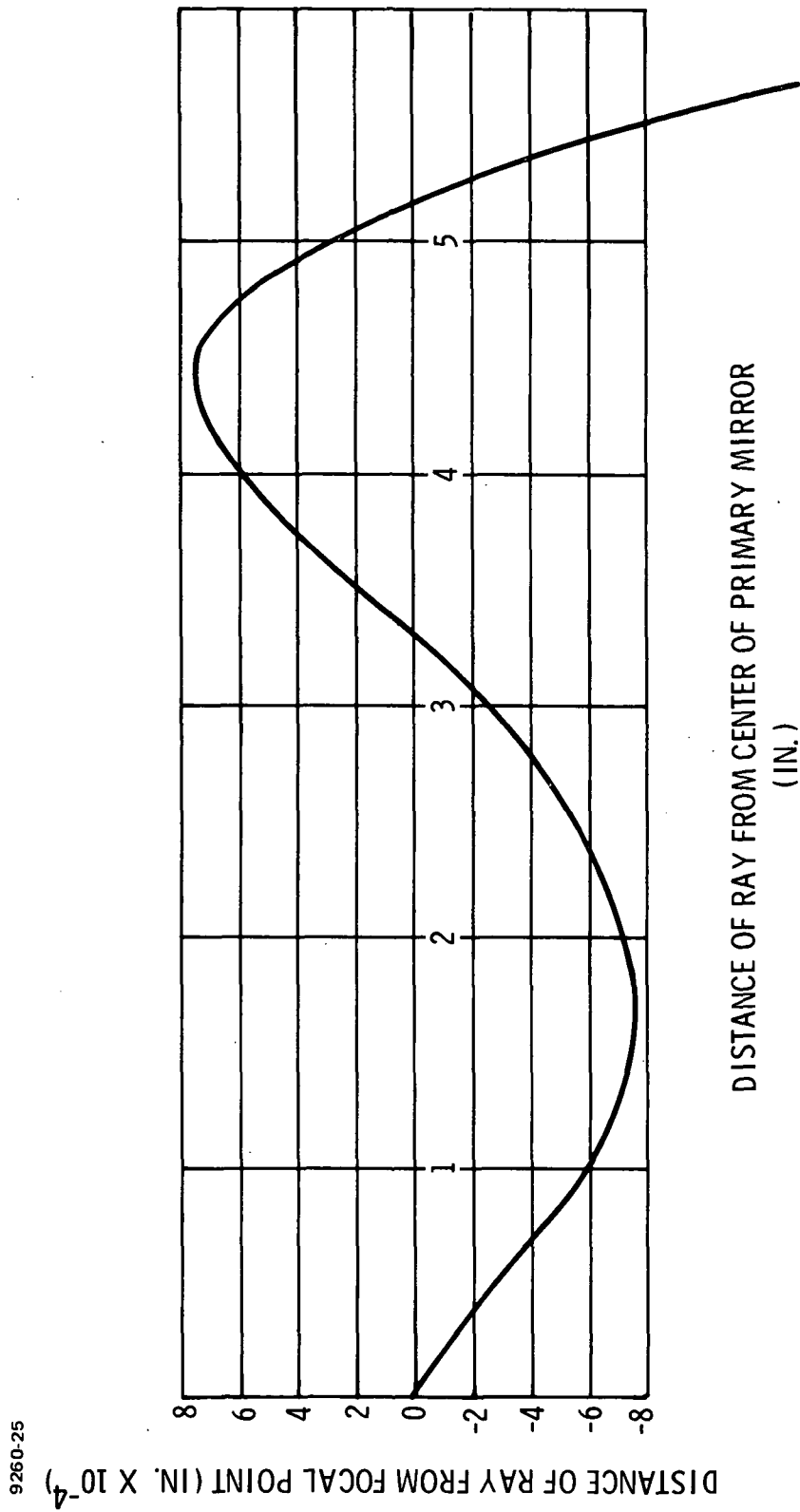


Figure 3.2-2 Distance of Ray From Focal Point vs.
Distance of Ray From Center of Primary Mirror

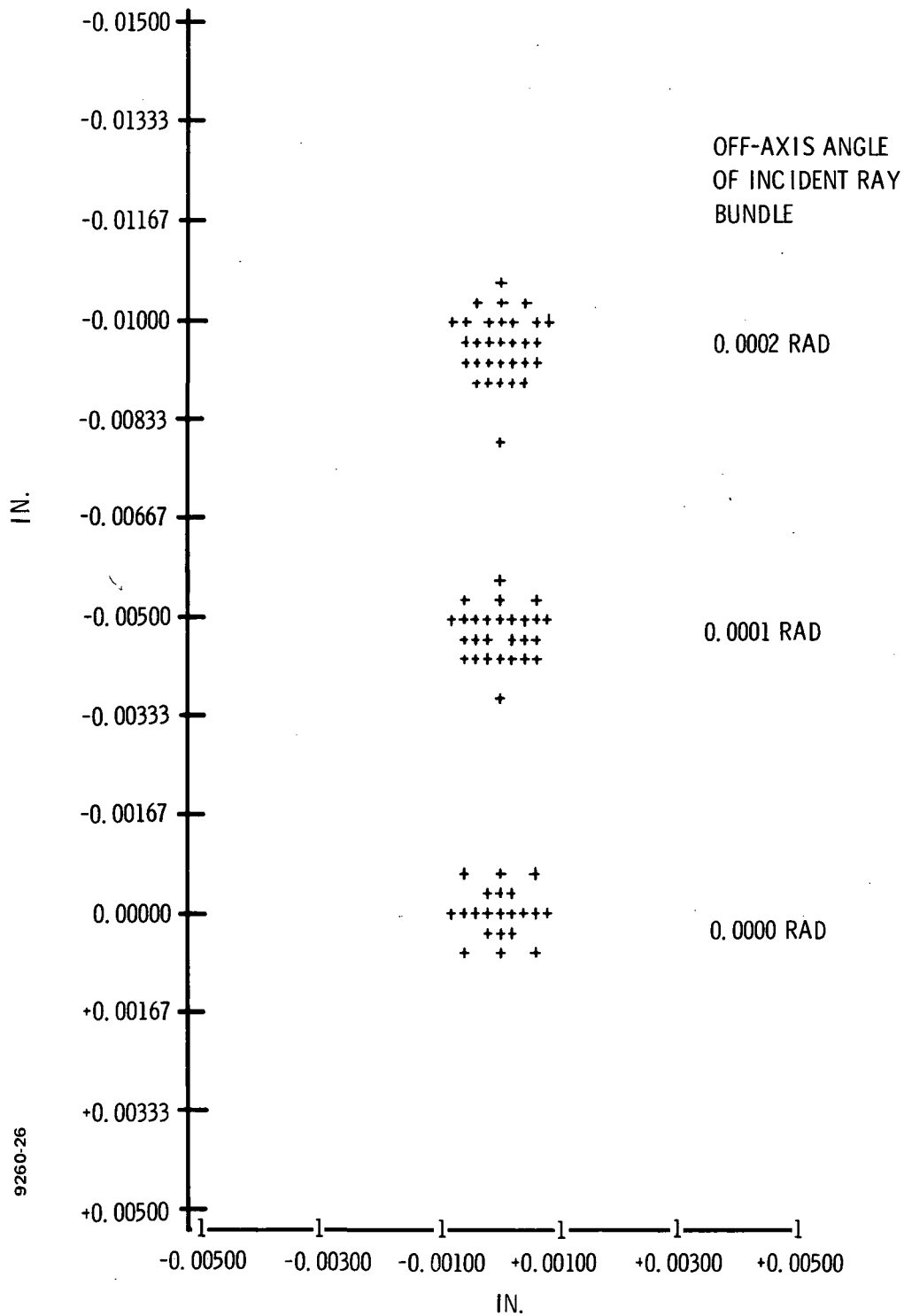


Figure 3.2-3 Spot Diagrams Showing Off Axis Performance of the Telescope

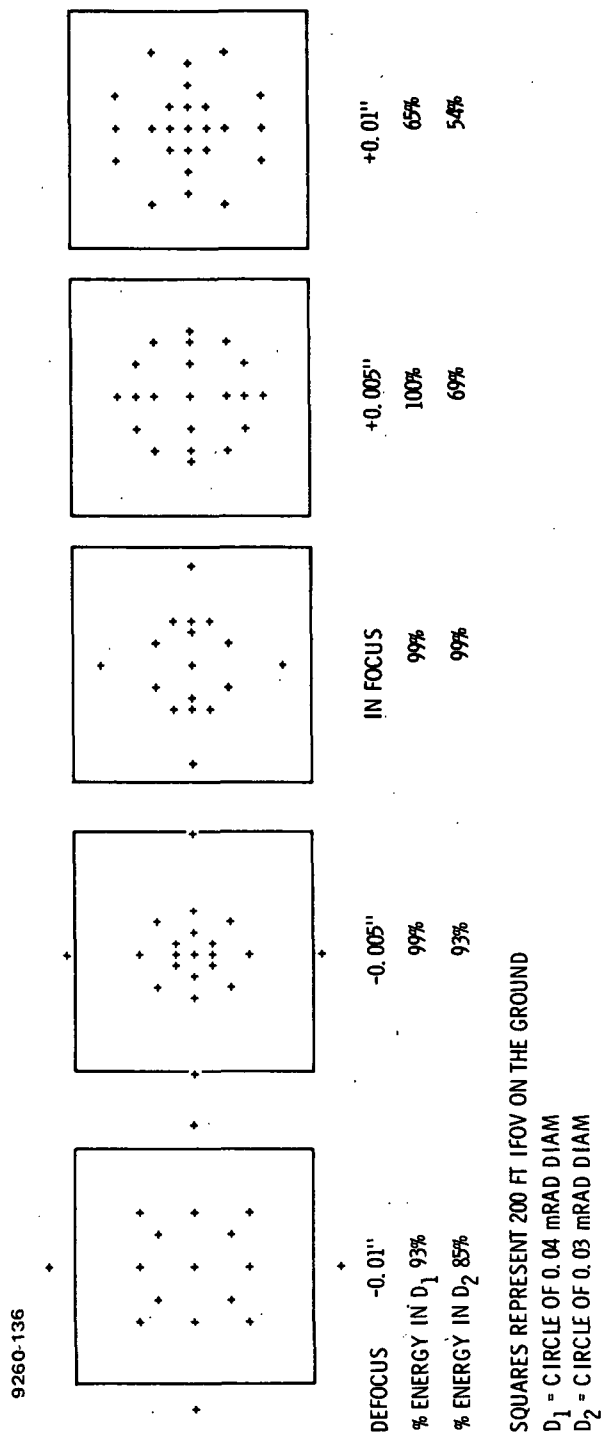


Figure 3.2-4 Blur Circle Due to Defocussed Field Stop

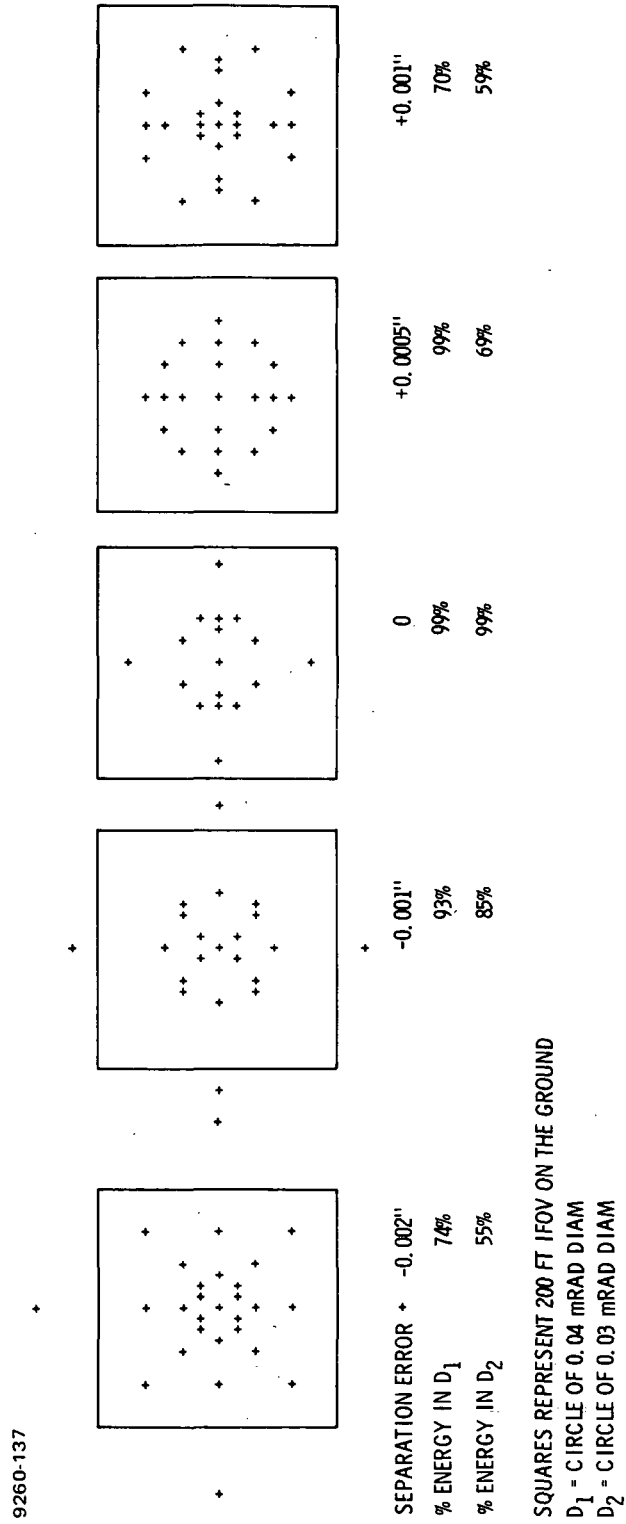


Figure 3.2-5 Blur Circle Due to Mirror Separation

Decentered Primary: 0.020 in. (Figure 3.2-6)

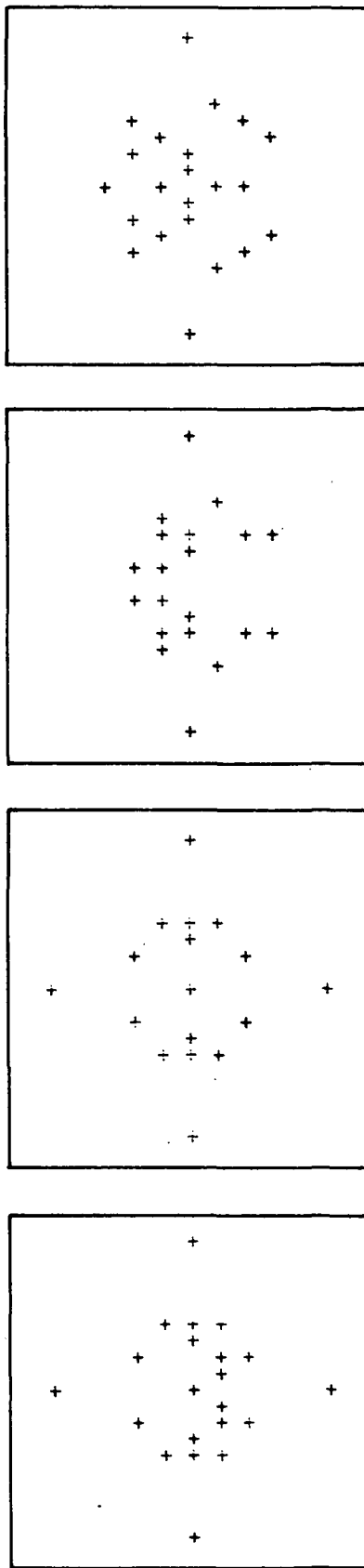
Decentered Secondary: 0.050 in. (Figure 3.2-7)

Tilted Primary: 3.3 min (Figure 3.2-8)

Tilted Secondary: 3.3 min (Figure 3.2-9)

Finally, a spot diagram is presented in Figure 3.2-10 which represents the image of a 200 x 200-ft resolution element in the focal plane of the telescope. Directly below this figure is an overlay to the same scale which shows the energy distribution from this resolution element. The center square represents an ideal image of the resolution element. It can be seen that the blurring of this image is very small, implying a small amount of optical "crosstalk" due to the collecting optics.

9260-138



CENTERING ERROR = 0

0.01"

0.02"

% ENERGY IN D_1 99%

98%

86%

% ENERGY IN D_2 99%

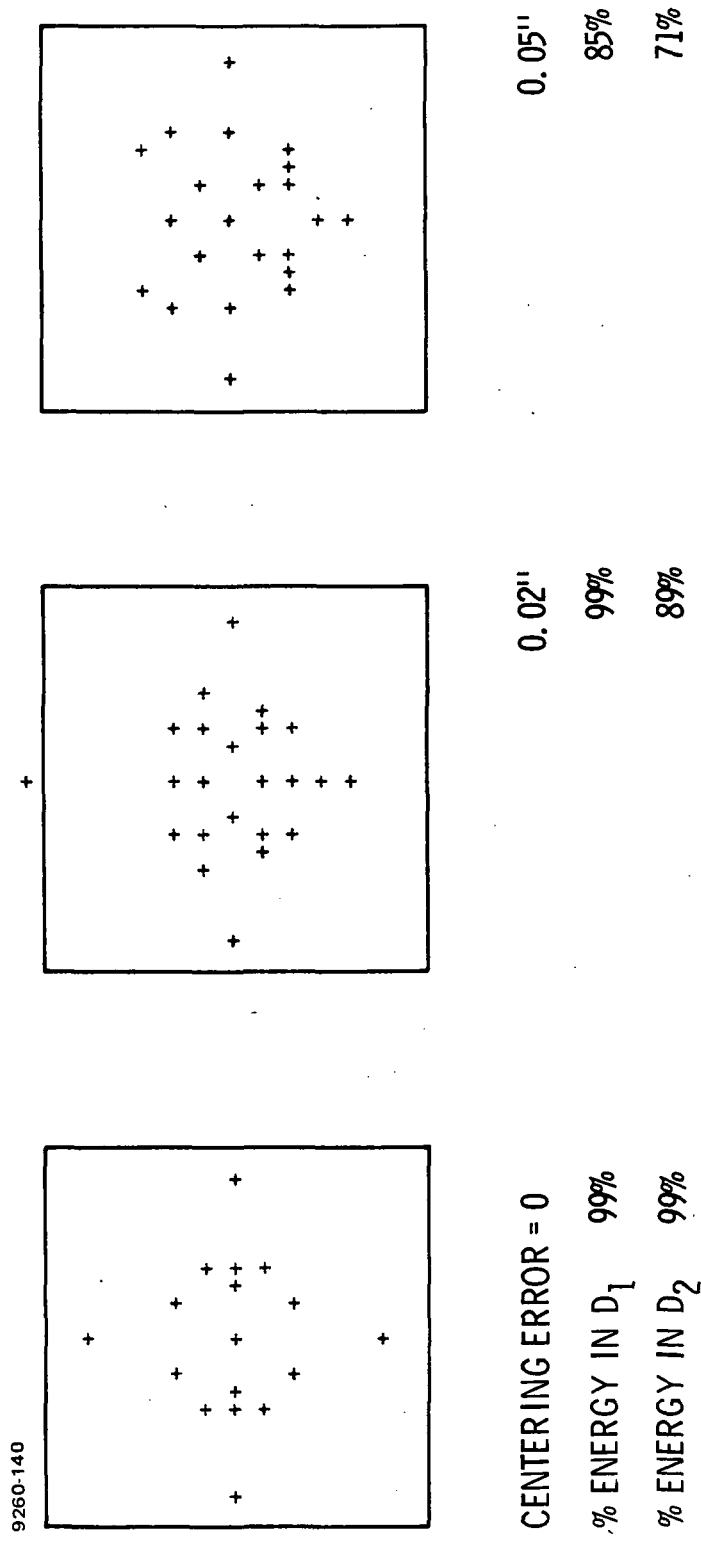
88%

79%

SQUARES REPRESENT 200 FT IFOV ON THE GROUND

 D_1 = CIRCLE OF 0.04 mRAD DIAM D_2 = CIRCLE OF 0.03 mRAD DIAM

Figure 3.2-6 Blur Circle Due to Decentered Primary



SQUARES REPRESENT 200' IFOV ON THE GROUND
 D_1 = CIRCLE OF 0.04 mRAD DIAM
 D_2 = CIRCLE OF 0.03 mRAD DIAM

Figure 3.2-7 Blur Circle Due to Decentered Secondary

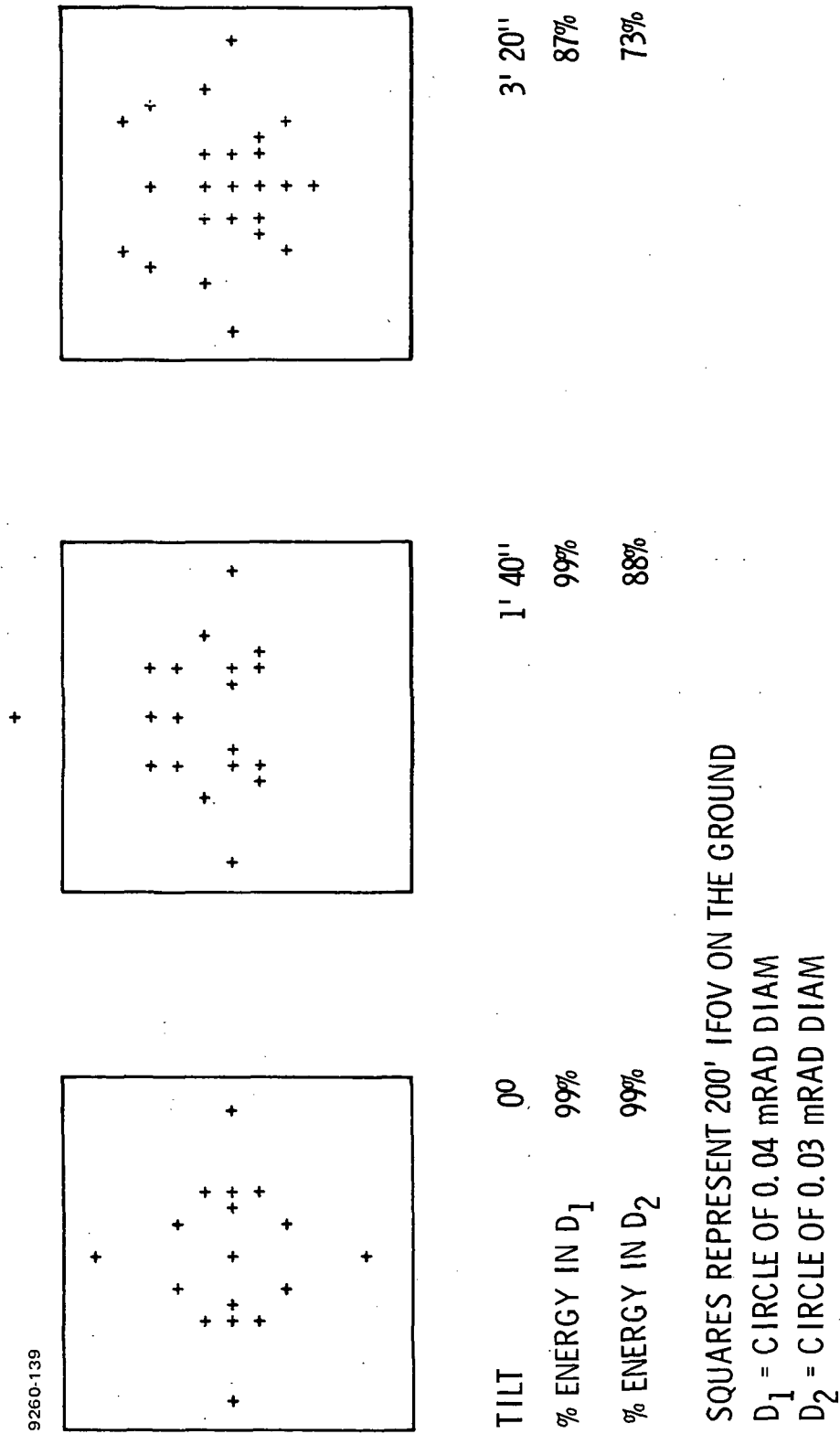


Figure 3.2-8 Blur Circle Due to Tilted Primary

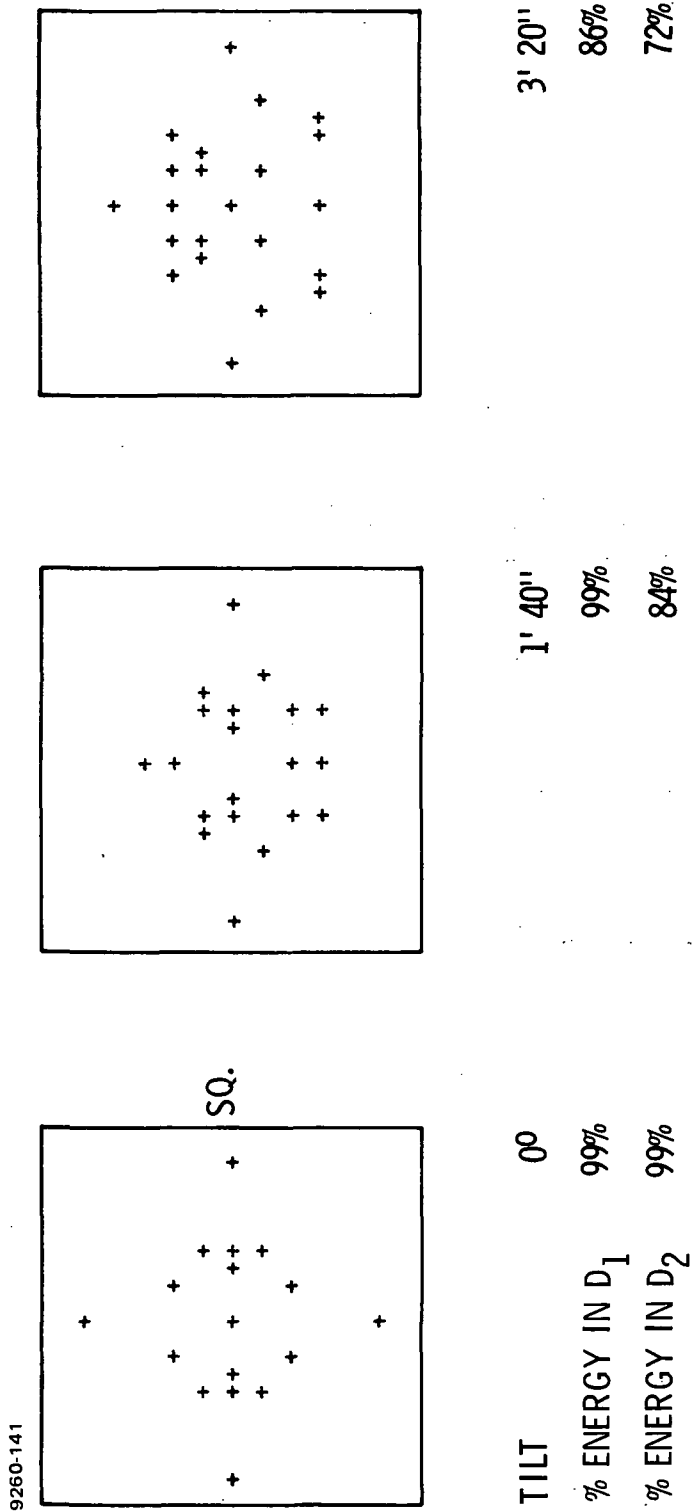


Figure 3.2-9 Blur Circle Due to Tilted Secondary

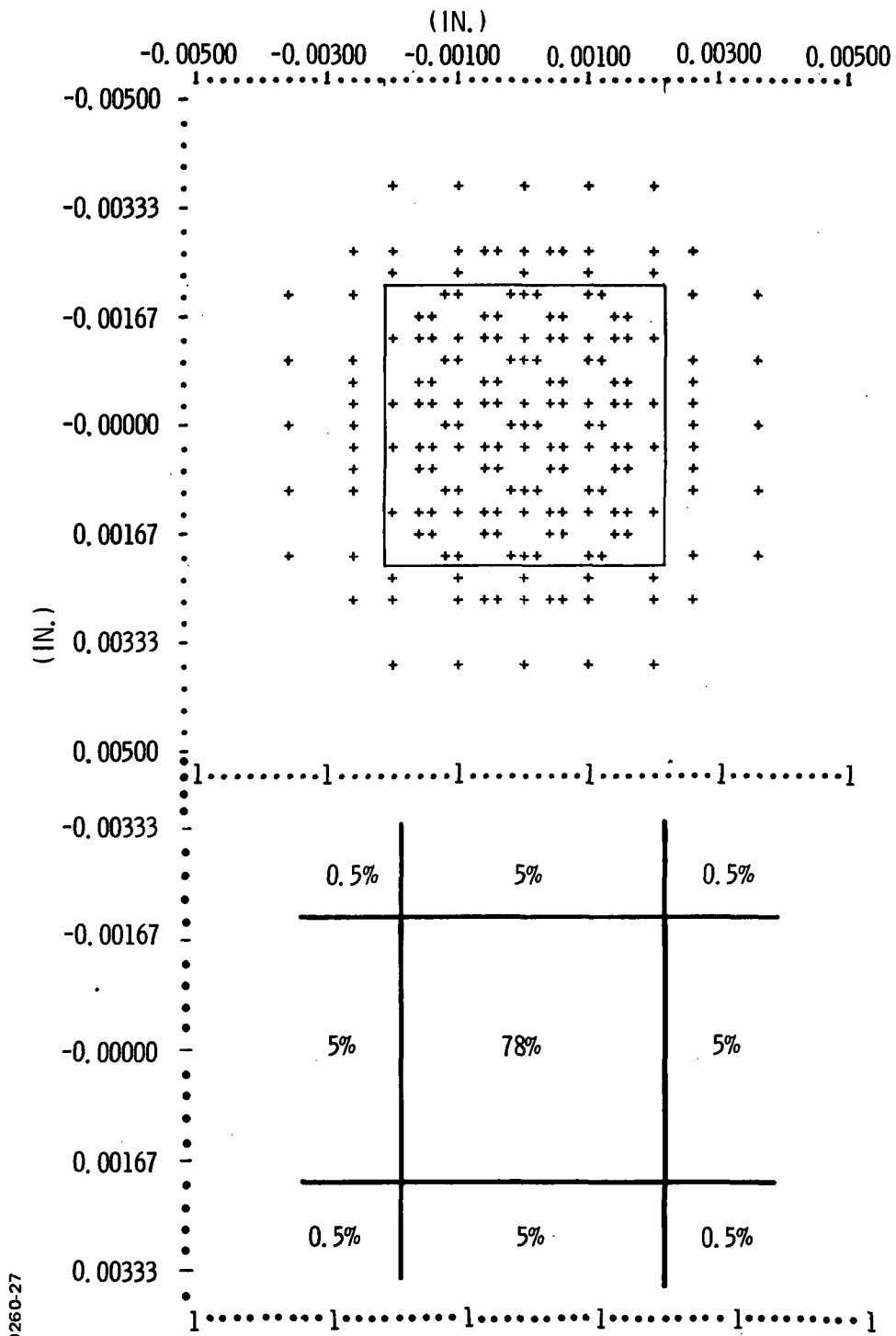


Figure 3.2-10 Image of a Resolution Element

3.3 OPTICAL ARRANGEMENT

Figure 3.3-1 shows the optical arrangement from the primary to the focal plane of the telescope. In addition to the already described components, a folding mirror is mounted with respect to the primary as an astronomical Martin telescope, and is therefore called a Martin mirror. The purpose of this mirror, placed between primary and scan mechanism is to:

1. Make the entire system as compact as possible.
2. Minimize the obscuration.
3. Avoid changing obscuration during a scan.
4. Simplify the injection of the calibration sources.

The focus of the primary is placed between the outer and the center mirror of the rotor. The exact position is determined by the maximum size of the center-mirror which causes a central obscuration within the reflected light cone leaving the secondary. This reflected cone finally can either be folded back through a hole at the center of the secondary as shown in Figure 3.3-1 or in any other direction as shown in Figure 3.3-2 wherever it is more convenient with respect to the spectrometer.

The two different sources of obscuration, the hole in the Martin mirror (Figure 3.3-2) and the obscuration generated by the center mirror of the rotor were the subjects of optimization.

The chief ray of the light cone changes its position within the hole of the Martin mirror during one scanning process period. This results in a change in the geometric relations between the obscuration pattern and the cross section of the light bundle. The central obscuration, since generated on the main axis of symmetry behind the scanning mechanism, always remains equal in size and eccentric to the circular cross section of the light bundle. The optimization now has to be performed to achieve a minimum amount and a minimum change in the obscuration caused by the interplay between the two kinds, the moving and the non-moving obscuration.

Figure 3.3-3 shows a schematic drawing of this interplay. The precise shape of the hole was generated by a computer program and optimized with regard to its size and its position within the light bundle. The condition for causing no changing obscuration is that the pattern of the hole always must fall entirely within the corresponding bundle of light. After this is achieved, the next requirement is to

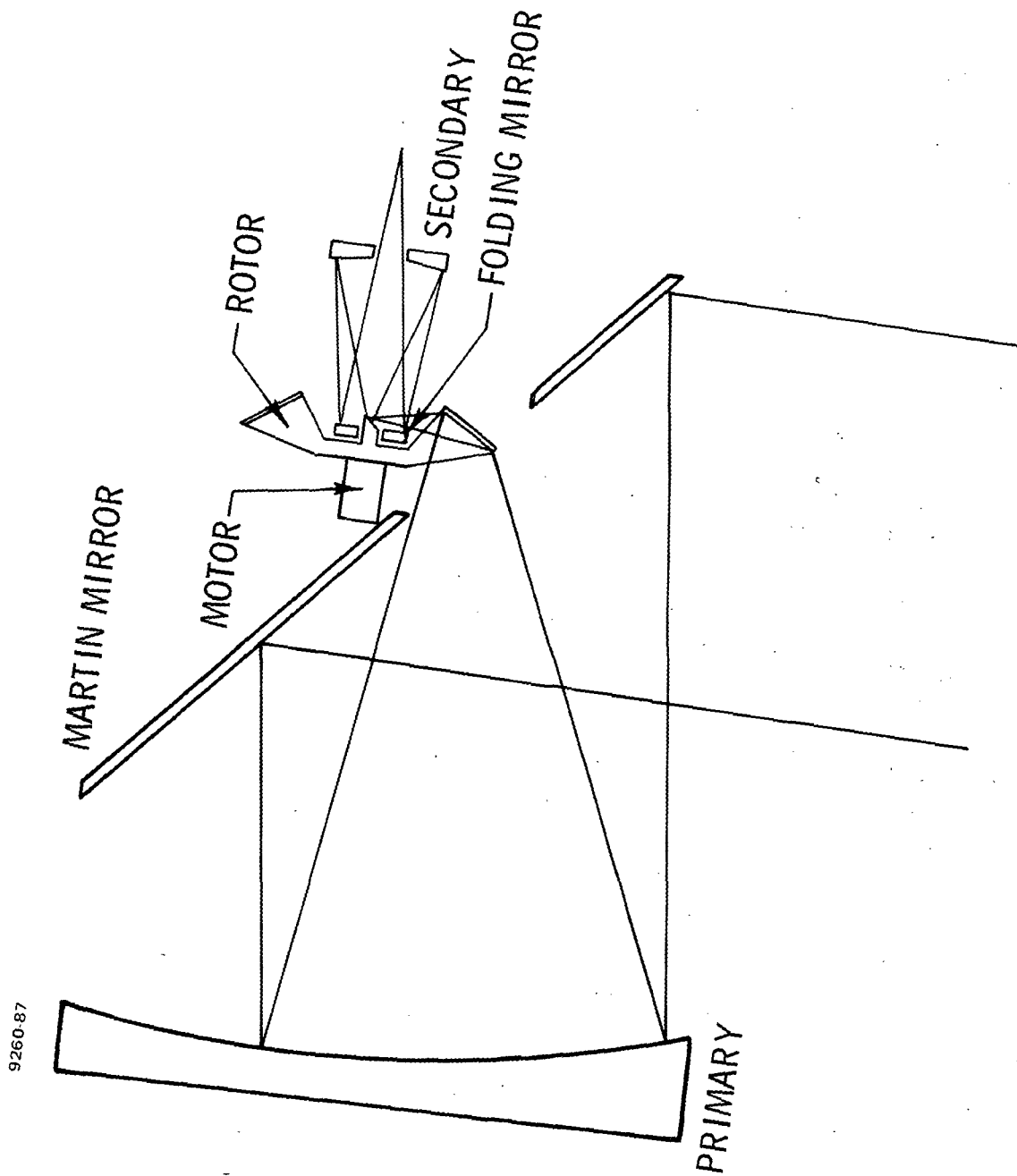
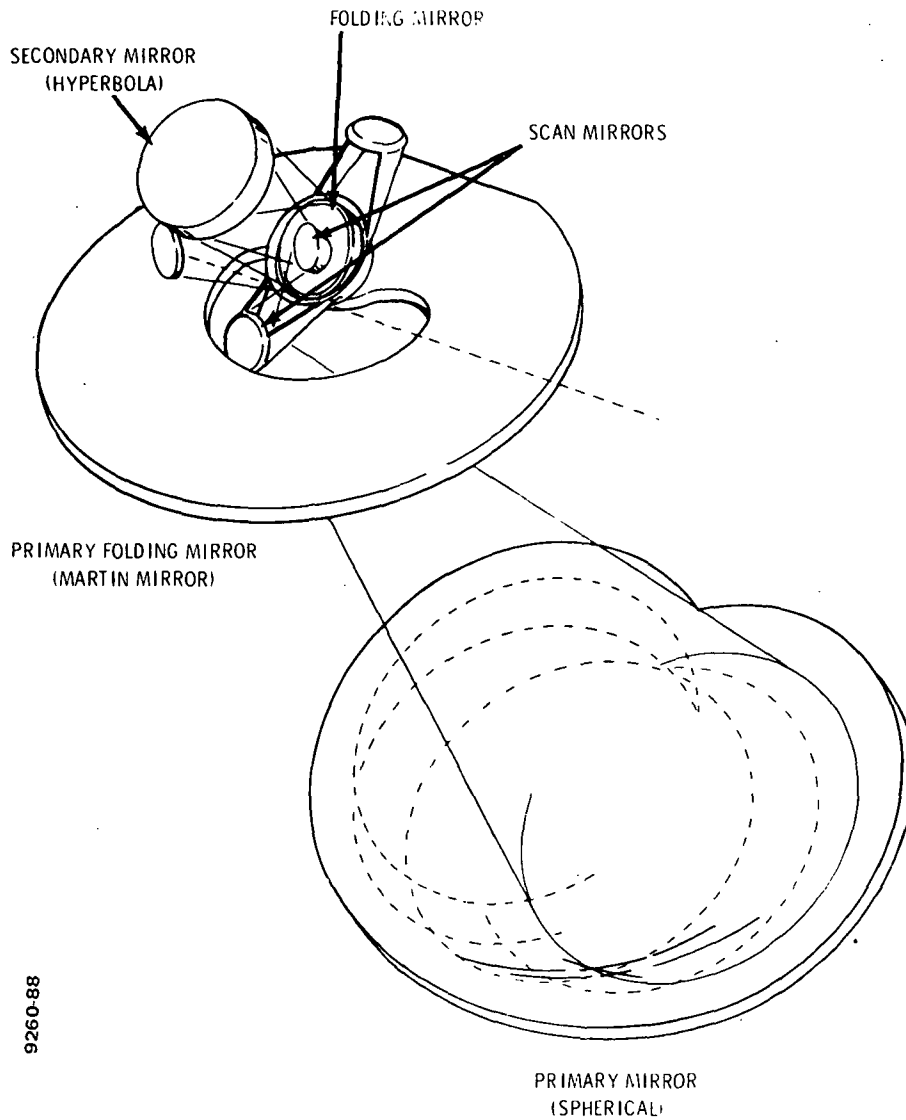


Figure 3.3-1 Schematic Layout of Scanner Optics



9260-88

Figure 3.3-2 Image Plane Conical Scanner Optical Arrangement

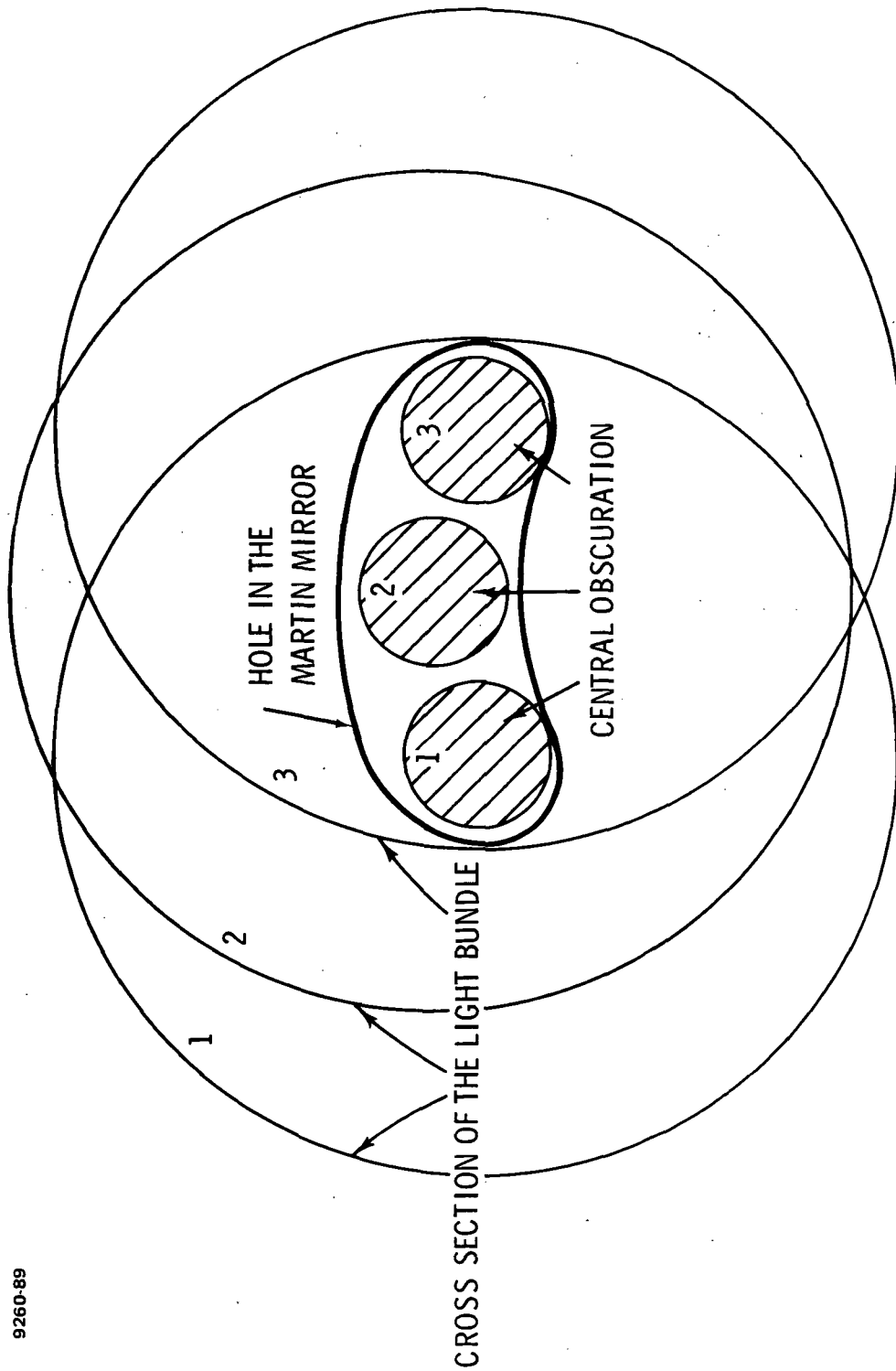


Figure 3.3-3 Obscuration Effects

diminish the central obscuration sufficiently in order always to move within the obscuration pattern caused by the hole.

After optimization, a total amount of obscuration of about 21% and a change of less than 0.5% of the whole cross section was achieved.

3.4 OPTICAL EFFECTS OF BEARING TOLERANCES

The most sensitive part of the scanner system with respect to misalignment and misregistration is the scan mechanism consisting of the rotor arm, motor, and bearings. The following paragraphs provide an analysis of these effects followed by a summary of their magnitudes for expected bearing runout. The possible misalignments of the rotor arm which can cause registration errors due to bearing runout are Figure 3.4-1(a):

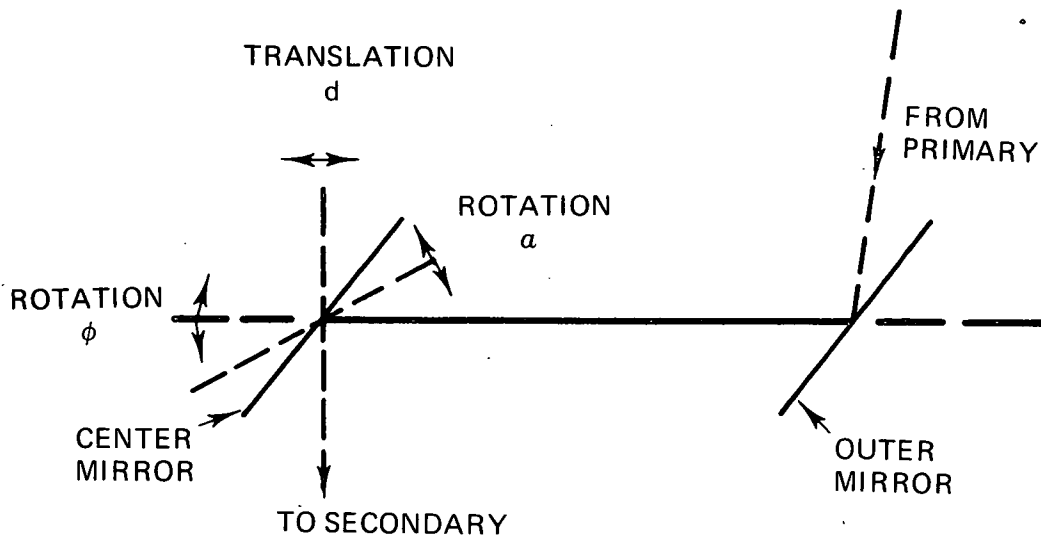
1. A translation, d , of the rotor which results in line-to-line underlap/overlap errors.
2. A rotation, α , of the rotor about an axis perpendicular to the main axis of symmetry and perpendicular to the line that connects the centers of the scan mirrors. This also causes line-to-line underlap/overlap errors.
3. A rotation, ϕ , of the rotor about the line which connects the centers of the scan mirrors. This results in cell-to-cell registration errors between adjacent scan lines.

To analyze the effects of these misalignments, consider the two scan mirrors being connected together with fixed geometrical relationships with respect to one another. In a well aligned system, the focal point of the primary and the image of the field stop seen in the secondary coincide at the point F, Figure 3.4-2, whereas a misalignment of the rotor results in a separation of these points, F_1 and F_2 in Figure 3.4-1(b). This separation can be divided into two components: (1) Δz parallel to the optical axis which causes a defocus error and (2) Δx perpendicular to the optical axis which causes a registration error.

Figure 3.4-1(b) depicts the errors that arise from a translation of the rotor from which it is seen that the mirror configuration compensates for the misalignment. Assuming that θ , the cone semi-angle, is small it is readily shown, after some geometrical and trigonometrical manipulation, that

$$\Delta x = d(1 - \cos \theta) \quad (3.4-1)$$

For the OSS scanner, $\theta = 6^\circ 40'$ so that $\Delta x \approx 0.007 d$, which shows that a translational misalignment causes a negligible registration error.



(a) ROTOR MISALIGNMENTS CAUSING REGISTRATION ERRORS

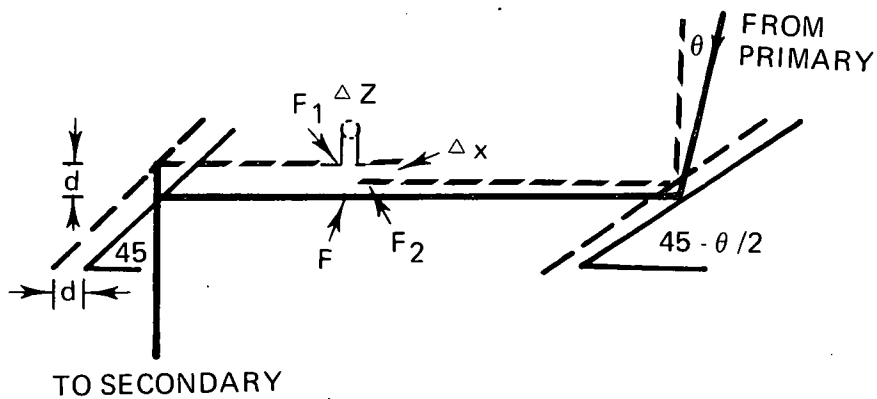
(b) REGISTRATION ERRORS DUE TO DISPLACEMENT d .

Figure 3.4-1 Registration Errors

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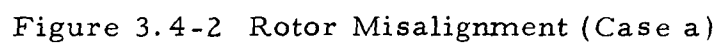


Figure 3.4-2 illustrates the registration error which arises from the rotational misalignment α in Figure 3.4-1(a). The points F_1 and F_2 are located on parallel lines and it can be shown that, if α is a very small angle,

$$\Delta x = \Delta z = s\alpha \quad (3.4-2)$$

where s is the distance between the two mirrors.

Lastly, Figure 3.4-3 illustrates the registration errors arising from the rotational misalignment ϕ in Figure 3.4-1(a). It is first necessary to calculate the angular deviation, δ , of a ray reflected from a mirror due to the misalignment which is a rotation about the line connecting the centers of the scan mirrors. With reference to Figure 3.4-3(a), O is the center of a mirror while O_1 and O_2 are the reflected rays in a well aligned and misaligned system respectively; OA and OB are the corresponding normals. b is the angle between the normal and the line connecting the two mirrors. The relation between δ , ϕ and b can be written as

$$\cos \delta = \sin 2b \cos \phi$$

However, b is $\pi/4$ for the center mirror and close to $\pi/4$ for the outer mirror. Hence a good approximation for the OSS is that

$$\delta = \phi$$

The resulting registration and defocus errors, Figure 3.4-3(b) are then seen to be

$$\Delta x = s\delta = s\phi \quad (3.4-3)$$

$$\Delta z = 0$$

Equations 3.4-1 through 3.4-3 give the registration errors arising from the misalignments given at the beginning of this section. The errors may be related directly to angular registration errors, $\Delta\gamma$, in object space by the equation

$$\Delta\gamma = \frac{\Delta x}{f} \quad (3.4-4)$$

For the two angular misalignments, to which the system is most sensitive, the angular registration error is then

$$\Delta\gamma = \frac{s}{f} \times \text{angular misalignment}$$

where f = the focal length of the primary mirror

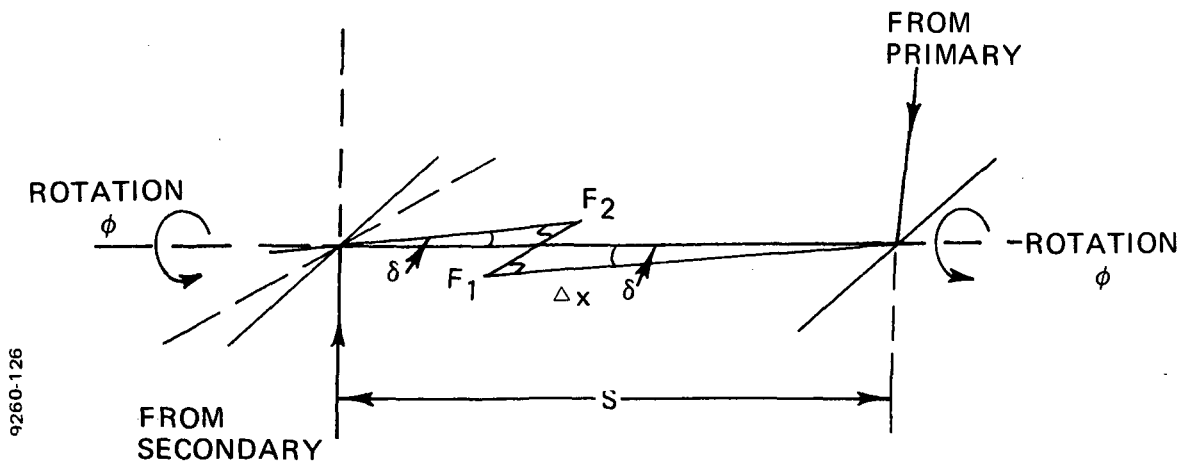
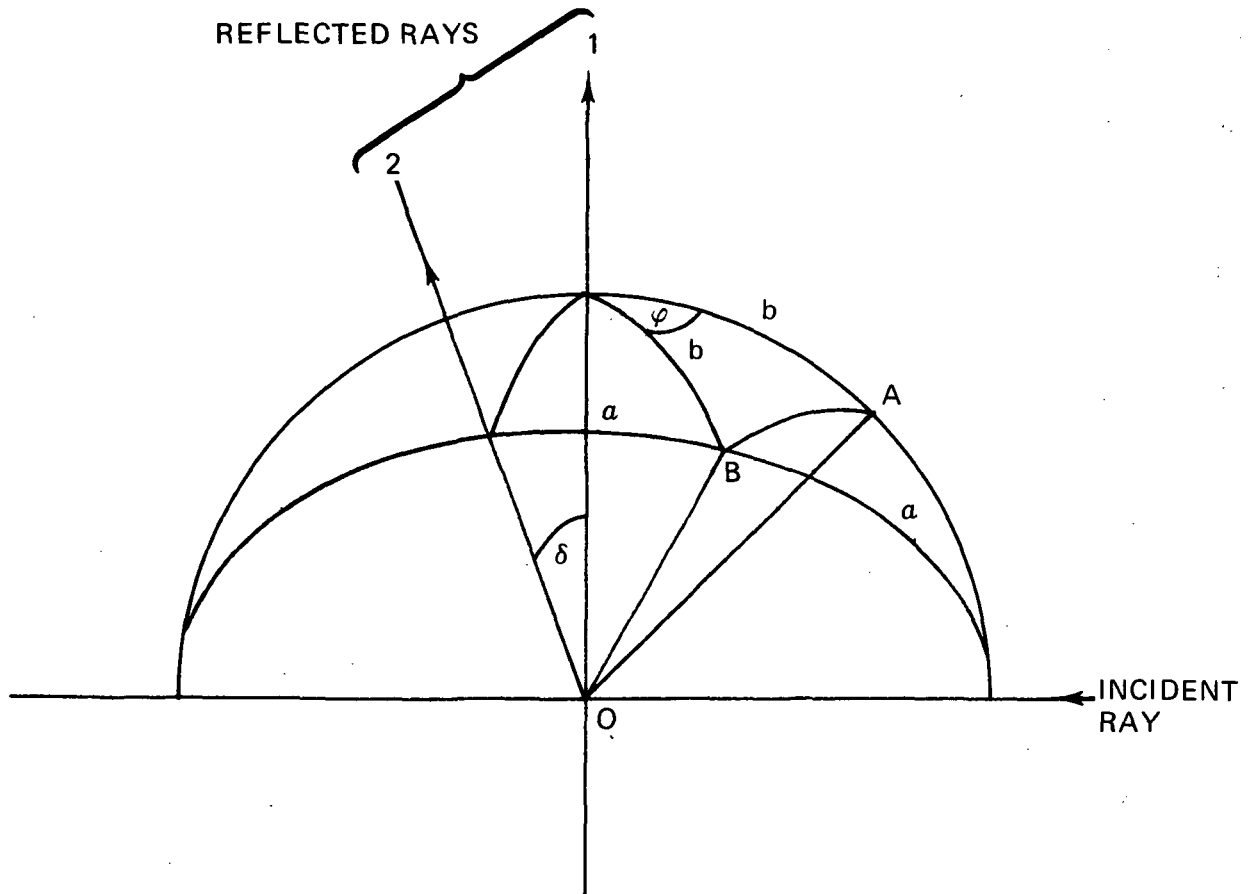


Figure 3.4-3 Registration Due to Rotation ϕ , a) Angular Relationships
b) Mis-registration

That is to say the registration errors are the misalignment errors reduced in the ratio of the rotor arm radius to the focal length of the primary. This ratio in turn equals the tangent of the cone semi-angle. For the OSS scanner, the IFOV is 66μ rad so that a 10% registration error corresponds to a value of $\Delta\gamma = 6.6 \mu$ rad. Further, $s = 2.5$ in. and $f=20$ in. and substituting these values into equations 3.4-1 through 3.4-4 gives the following misalignments which would cause a 10% registration error:

1. Translational: $d = 0.019$ in.
2. Rotational: $\alpha = 53 \mu$ rad
3. Rotational: $\phi = 53 \mu$ rad

In order to meet these tolerances with a bearing separation of 3 in., the maximum permissible bearing runout is then 160μ in. This is well within the state-of-the-art of bearing technology, and discussions with manufacturers have lead to a radial bearing runout of 50μ in. as acceptable for at least one year of continuous operation. The resulting peak registration errors should therefore be about 3.3% of one IFOV for both cell-to-cell registration on adjacent scan lines and line-to-line underlap/overlap.

SECTION 4

SCAN ASSEMBLY DESIGN

The scan assembly consists of the motor, motor control (including a shaft encoder), and the scan mirror rotor arm. The selection of the design parameters for this assembly is closely tied to many of the key design parameters of the system. These factors are discussed in this section.

The first topic considers the ground scan patterns and the relationships to duty cycle selection, data rate, scan motor speed, resolution cell size, and swath width.

Next, the rotor assembly mechanisms and rotor bearing provisions are described. Considerable attention is given to the technique for precise control of the scan motor as well as the motor selection itself.

Finally, an analysis of the various registration errors due to the scan mechanism is presented.

4.1 GROUND SCAN PATTERNS AND DUTY CYCLE SELECTION

In a conical scanner, the line of sight of a detector is swept out during one rotation of the scan mechanism to form a cone with its apex at the scanner. Neglecting the Earth's curvature, the scan pattern on the ground is then the interception of a plane with a cone, forming either a circle or an ellipse. The choice of scan pattern recommended by Bendix is that the cone be tilted so that the scan arc is elliptical and passes through the nadir since this minimizes positional errors arising from pitch, roll, yaw, and altitude variations.

The only other scan pattern considered is a circular one where the cone axis is vertical and has the sole advantage that the positional errors, the IFOV, and the atmospheric thickness between the scanner and the ground are constant around a scan arc. However, the positional errors for this case are all larger than their corresponding means for a scan arc through the nadir whereas the departures of the latter scan pattern from a circle are very small. Oversampling for both scan patterns, therefore, occurs to virtually the same extent towards the scan ends, and the choice of the scan pattern does not effect the complexity of the scanner design.

To establish some of the system parameters, it is necessary to investigate the equation of the conical scan pattern as a function of the rotor position, and the equations for doing this are outlined in the following sections. These sections will also cover the equations relating cone semi-angle (θ), duty cycle (δ), swath width (D), arc length (s), and the arc width (X) for a scan pattern passing through the nadir, since they are all inter-related and impact directly on the scanner design and Ground Data Handling Station (GDHS).

4.1.1 Analysis of the Scan Pattern

A general conical scan pattern can readily be plotted as shown in Figure 4.1-1 (a) by evaluating the direction cosines of the line of sight of the detector (L , M , N) and then finding the point of intersection (x , y) of that line of sight with the ground for an altitude, H , via the equation:

$$(x, y) = \left(\frac{L}{N} H, \frac{M}{N} H \right) \quad (1)$$

(L , M , N) are dependent on the cone semi-angle, θ and the spacecraft altitude, and may be calculated from the direction cosines, (α , β , γ) of the line of sight of a detector when the axis of the cone is vertical. In terms of the angles θ and ϕ , through which the rotor has turned, (α , β , γ) are given by:

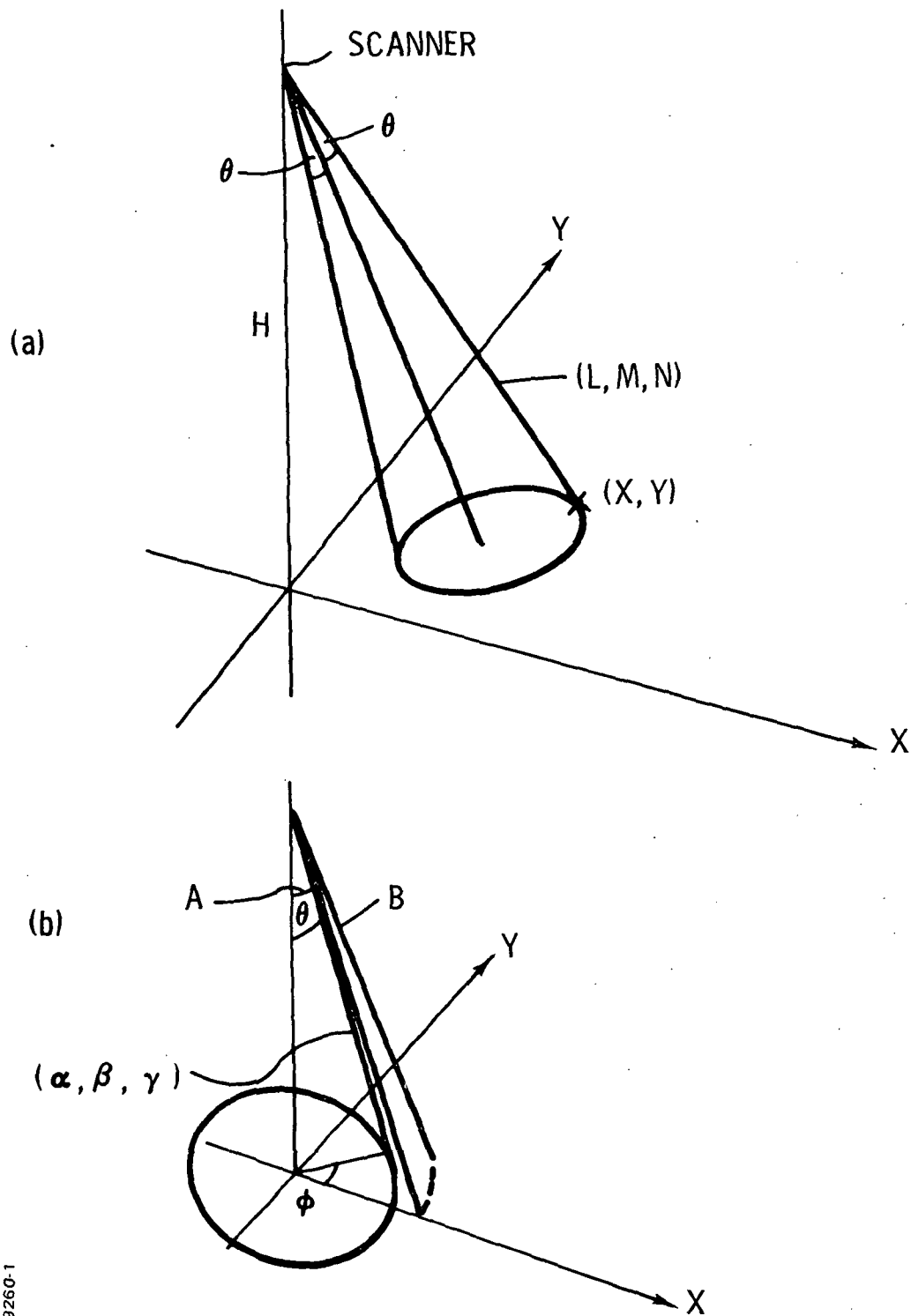


Figure 4.1-1 Parameters Determining the Scan Pattern

$$\begin{bmatrix} \alpha \\ \beta \\ \gamma \end{bmatrix} = \begin{bmatrix} \sin \theta \cos \phi \\ \sin \theta \sin \phi \\ \cos \theta \end{bmatrix} \quad (2)$$

If the cone axis is now tilted through a rotation A about the x axis and a rotation B about the y axis as shown in Figure 4.1-1 (b), the new direction cosines of the line of sight, (L, M, N), are:

$$\begin{bmatrix} L \\ M \\ N \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos A & \sin A \\ 0 & -\sin A & \cos A \end{bmatrix} \begin{bmatrix} \cos B & 0 & \sin B \\ 0 & 1 & 0 \\ -\sin B & 0 & \cos B \end{bmatrix} \begin{bmatrix} \alpha \\ \beta \\ \gamma \end{bmatrix} \quad (3)$$

For a given cone semi-angle, θ , equations 1 through 3 permit the conic section to be plotted as a function of the rotor angle, ϕ , but care must be taken to ascertain which portion of the conic section relates to the active data taking period. Positional errors due to pitch, roll, and yaw can be readily obtained from the above equations by the appropriate differentiations, while errors due to altitude variations are given by: $1000 N/(1 - N)^{1/2}$ ft per 1000 ft altitude. These errors are tabulated in Figure 4.1-2 as a function of the rotor position for a 33% duty cycle and the specific cases of a linear scan, a circular scan and an elliptical scan which passes through the nadir.

It is seen that the latter case considerably reduces the positional errors due to yaw and altitude variations, and is therefore preferable to a circular scan pattern, though the uniform resolution around a circular scan is lost. For the particular case of a scan pattern which passes through the nadir, it is readily shown that the eccentricity, e , and semi-major axis, a , of the ellipse are given by the equations:

$$e = \tan^2 \theta \quad (4)$$

$$a = \frac{H}{2} \tan 2 \theta \quad (5)$$

In the OSS scanner, θ is $6^\circ 40'$ so that $e = 0.0137$ and for a 496 n. mi. orbit, $a = 357,000$ ft. The difference between the semi-major and semi-minor axes of the ellipse is then only 32.5 ft and the scan pattern actually departs from a circle by no more than 0.01%.

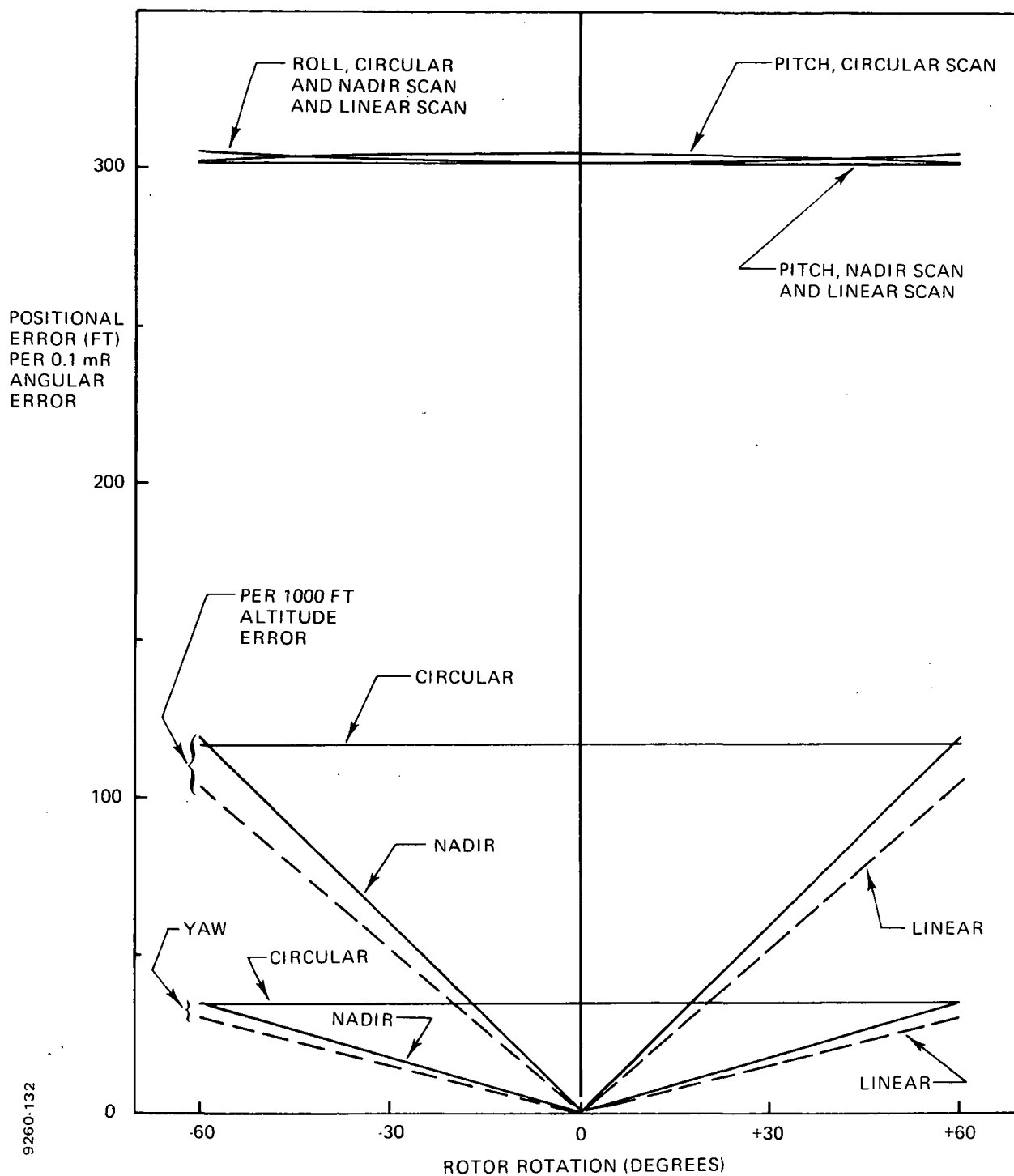


Figure 4.1-2 Positional Errors Arising from Errors in Knowledge of the Spacecraft Attitude

4.1.2 Parametric Relationships for the Scan Pattern

For a scan pattern passing through the nadir, it is a simple matter to relate such parameters as duty cycle, cone semi-angle, swath width, arc width to one another. The scan pattern (Figure 4.1-3) is obtained from Equations 1 through 3 by setting $A = 0$ and $B = \theta$ in Equation 3, and if 2ϕ is the active portion of the rotor resolution then ϕ determines the duty cycle by the equation:

$$\phi = \pi\delta \quad (6)$$

If y in equation (1) is now equated to half the swath width, D , the following equation relating D , θ , and δ results:

$$\sin^2 \theta [1 + \cos(\pi\delta)] + \frac{2H}{D} \sin \theta \sin(\pi\delta) - 1 = 0 \quad (7)$$

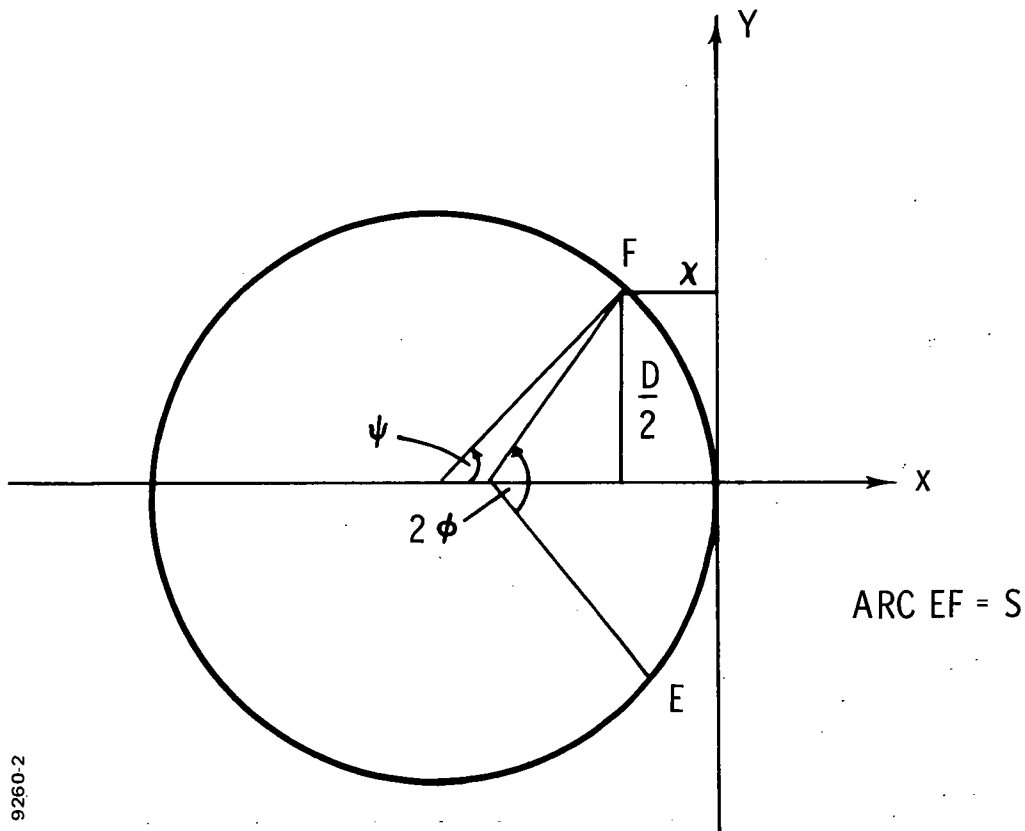


Figure 4.1-3 Ground Scan Pattern Parameters

This is a quadratic equation in $\sin \theta$, and permits the cone semi-angle for a given swath width, altitude, and duty cycle to be precisely determined. The arc width, x , is also readily found since it equals the abscissa, x , in Equation 1, and can be expressed in terms of the duty cycle to give:

$$x = \frac{\sin \theta \cos (\pi \delta - \theta)}{\sin^2 \theta \cos (\pi \delta) + \cos^2 \theta} H \quad (8)$$

Lastly, the arc length, s , can be found by first calculating the angle, ψ , subtended by the half swath width at the center of the ellipse. Again using equations 1 through 3 and 4, 5, and 6, ψ is readily found by evaluating the expression:

$$\tan \psi = \frac{y}{a - x} = \frac{2M}{\tan 2\theta - 2L} \quad (9)$$

Using the equation for an ellipse in polar coordinates and using the approximation that e is small, the arc length is then given by:

$$s = 2b \left[\psi + \frac{e^2}{4} \left(\psi + \frac{1}{2} \sin 2\psi \right) \right] \quad (10)$$

where b is the semi-minor axis of the ellipse.

The dwell time for a sampling distance equal to the IFOV, d , is:

$$T_d = 6\delta d^2/vs \quad (11)$$

The above equations cover all the ground parameters required for the scanner design and its impact on the Ground Data Handling Station (GDHS). In particular, Equations 7 through 11 permit the dwell time to be plotted as a function of duty cycle as indicated in Figure 4.1-4 (a), whereas Equation 8 is of use in the GDHS to determine the writing distance required on the Electron Beam Recorder (EBR) to generate the conical scan pattern as shown in Figure 4.1-4 (b). Equation 10 provides the arc length, and hence the number of cells, N_c , around a scan for a given sampling interval as in Figure 4.1-4 (c).

4.1.3 Duty Cycle Selection

When considering the design of a scanner, it is preferable to have a high duty cycle since this implies a long dwell time, T_d , and a long data collection time. Some very desirable consequences of a high duty cycle are:

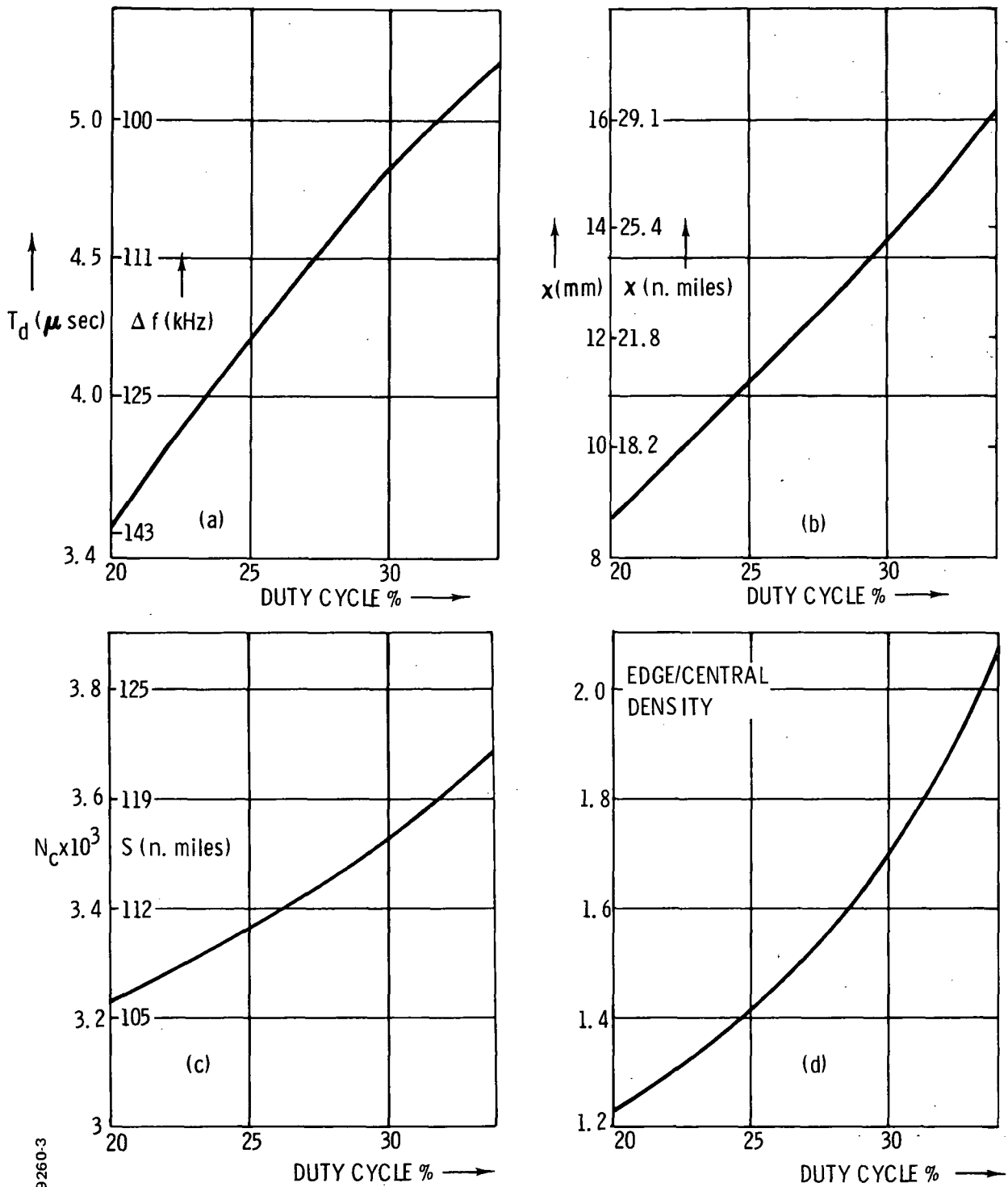


Figure 4.1-4 Relationships Between Duty Cycle and Other Factors

1. The electronic bandwidth is decreased resulting in a low noise bandwidth, Δf , and hence a high system sensitivity. See Figure 4.1-4 (a).
2. The A/D converters and memory need not operate fast, reducing power consumption.
3. The memory storage capacity would be decreased with a proportionate drop in the power consumption.

On the other hand, a high duty cycle results in a greater curvature to the scan sweep which is undesirable for the GDHS causing:

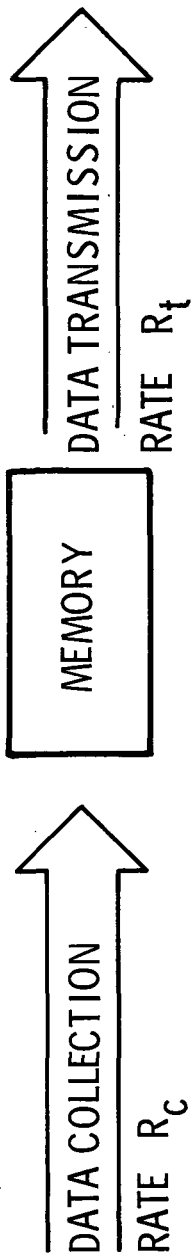
1. Increased oversampling towards the scan edges and correspondingly more cells around a scan sweep as in Figure 4.1-4(d).
2. A greater writing distance on the Electron Beam Recorder (EBR) in order to generate a conical scan as in Figure 4.1-4 (b).

The variation of the above parameters with duty cycle (Figure 4.1-4) are based on a 200 ft sampling distance and scan line separation. The oversampling is expressed as the ratio of the edge to center sampling density which obeys a $\sec \theta$ law. Figure 4.1-4 does not provide a clear cut choice of duty cycle, but it should be borne in mind that the available power is severely limited and the noise is very sensitive to increased bandwidths. Further, the current EBR in the GDHS cannot accept any curvature to the scan lines without a change in the format of the framed imagery (Section 14.4). It follows that a new EBR with a larger writing aperture will be needed if the GDHS is to accept a conical scanner.

However, the actual choice of duty cycle is greatly limited due to timing, implementation, and data format considerations which dictate that only certain narrow ranges of duty cycle are possible. To see how this arises, it should first be noted that the data transmission rate, R_t , is limited to 15 Mbps $\pm 1/2\%$ (established by the communication system) whereas the average data collection rate for the OLS is close to 14 Mbps. It follows that the video data must account for nearly all of the transmitted bits, the remaining bits being used for calibration, ancillary data, and pre-amble.

Secondly, plated wire and MOS Memories have been considered for the buffer; a MOS memory requires considerably less power than a plated wire and is therefore selected. There are then two ways of transmitting the data (Figure 4.1-5). Either all data passes through the memory or a fraction, f , is sent real time, while the rest is stored for transmission while video data is not being collected. In the first case, since the memory can operate in read only or write only

(a)

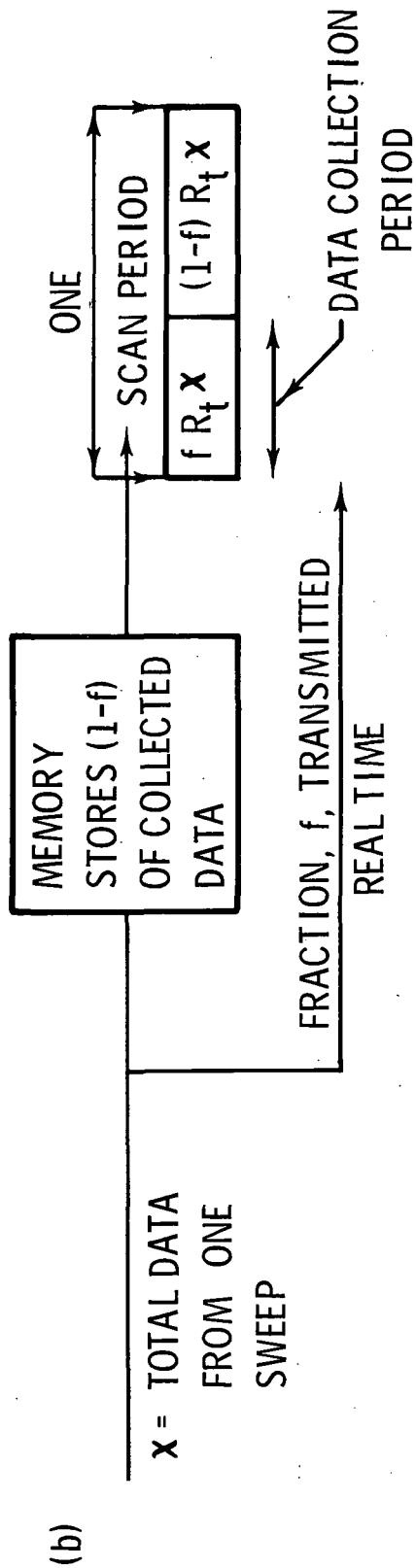


$$\text{DUTY CYCLE, } \delta \approx \frac{R_t}{R_C} = \frac{1}{n} \quad (n = 1, 2, 3, \dots)$$

ALL DATA PASSES THROUGH THE MEMORY

BSR 3129

4-10 (I)



FRACTION, $\delta \approx f$
SOME DATA ARE SENT REAL TIME

Figure 4.1-5 Alternate Memory Modes of Operation

modes, and not read while write, the range of values for the ratio of memory input data rate, R_c , to its output data rate, R_t , is limited. For this application, implementation considerations covering memory word length, speed of operation of the memory, and complexity of the logic almost restrict the ratio R_c/R_t to be an integer which immediately implies that duty cycles somewhat less than $1/2$, $1/3$, $1/4$, $1/5$ etc., only, are practical.

Using the second approach (the one selected by Bendix), the duty cycle is close to the value of the fraction, f , which is sent real time, and is restricted by data format considerations. (See Sections 9.4 and 13.4.) At the receiving site, the data is formatted onto a 28-track tape for input to the GDHS. Twenty-five of the tracks are used for video data on the basis of one channel per track with the exception of the two thermal channels which are formatted onto one track. The remaining 24 tracks are available for 36 channels of data from the OSS scanner. To provide an acceptable input tape to the GDHS, one scan sweep of data is divided into two parts: first, 12 channels are recorded followed by the remaining 24 channels which implies sending one-third of the video data real time, and a duty somewhat less than one-third. An alternative explanation for the possible values of f is to note that it is desirable to send the data for an integral number of bands real time; separating the data in time for any one band is most undesirable on consideration of the confusion which it would cause in the GDHS. This fact in conjunction with the six high resolution bands implies duty cycles of $1/6$, or $1/3$ of which $1/3$ is preferable.

To summarize, a duty cycle close to 33% is chosen since the advantages to the design and sensitivity performance of the scanner outweighs the disadvantage of high curvature to the scan lines. As already noted, a new EBR is required in the GDHS if an appreciable duty cycle is to be achieved and the new EBR can be designed to have the required writing area.

4.1.4 Timing Relationships and Their Relation to Duty Cycle

The previous section has outlined the reasons for selecting a duty cycle close to 33%. In this section, timing, control, and data link considerations are shown to have a direct relationship to the duty cycle. Thus, if B_c , B_{cal} , and B_{hk} are, respectively, the number of data, calibration, and house keeping bits transmitted per scan period, T_p , the duty cycle is given by:

$$\delta = \frac{B_c}{a (B_c + B_{cal} + B_{hk})} \quad (12)$$

where a is a constant, being the ratio of the input to output data rates of the buffer; for the OSS, $a = 3$ for the reasons discussed in the previous section. B_{hk} includes sync words and any other ancillary data transmitted, some of which comprises pre-amble. Since the selected timing control technique (Section 4.5) runs all timing operations referenced directly to the system oscillator, the duty cycle, scan period, number of cells around a scan, N_c , and the data rate, R_c , are closely related by the equation:

$$T_d = \frac{\delta}{N_c} \quad T_P = \frac{b C}{a R_t} = \frac{78}{R_t} \quad (13)$$

where b is the encoding level (6 bits) and C is the number of effective channels of data transmitted per dwell time. C is determined by the actual number of channels, 38, rounded to 39 to be divisible by $a=3$ for data transmission and format considerations (Sections 9.4 and 13.4). At the same time, T_P is directly related to the IFOV, d_f , along the flight direction:

$$T_P = 6 d_f / V \quad (14)$$

where V is the spacecraft velocity.

For a given sampling distance along a scan line, N_c is related to the duty cycle as shown in the previous section (Figure 4.1-4(c) and values of N_c , δ , T_P , d_f must then be found which satisfy all the above relationships and permit a data rate of $15 \text{ Mbps} \pm 1/2\%$. It is also desirable that the selected value of R_t should contain no large primes and that the motor speed, f_s , is a suitable factor of the data rate. R_t must also be divisible by six and 13 since these numbers are required to generate a data word (six bits) and the dwell time, 13 data words. Further restricting R_t to have primes of 13 or less provides the possible data rates given in Table 4.1-1, of which the lower primes of the number 14,976,000 are preferred. This immediately determines the dwell time from equation 13, and it remains to select δ , T_P and N_c with appropriate values for the IFOV and the motor speed. All the inter-relationships mentioned above can only be met if the IFOV is adjustable by a small amount (2 or 3%). The resulting selected values are summarized in Table 4.1-2, the last parameter being the product $N_D \cdot N_{ENC}$ which is relevant to the motor speed as shown in the following paragraph.

One revolution of the rotor arm is divided into an integral number of samples so that the duty cycle can be written as:

$$\delta = \frac{N_c}{a (N_c + N_{cal} + N_{hk})} \quad (15)$$

However, the motor speed is controlled directly by the system oscillator in the fashion depicted in Figure 4.1-6. A phase locked loop is provided between the encoder output and the data rate which is divided by a factor N_D so that it equals the frequency output from the encoder, $f_s \cdot N_{ENC}$, where N_{ENC} is the number of encoder pulses per revolution. Thus,

$$R_t / N_D = f_s \cdot N_{ENC} \quad (16)$$

and equations 13, 15, and 16 can be re-arranged to provide the relationship:

$$N_D \cdot N_{ENC} = b \cdot C (N_c + N_{cal} + N_{hk}) \quad (17)$$

Suitable choice of N_c , N_{CAL} , N_{HK} permits the motor control mechanism to be adjusted for simplest design by appropriate choice of $N_D \cdot N_{ENC}$ and maintains the value shown in Table 4.1-3.

TABLE 4.1-1

POSSIBLE DATA RATES DIVISIBLE BY 6 AND 13
WITH 13 AS THE HIGHEST PRIME NUMBER

	Prime Number						Data Rate (R_t) - BPS
	2	3	5	7	11	13	
Exponent	10	2	3	0	0	1	14,976,000
	5	1	1	4	0	1	14,982,240
	4	8	0	0	1	1	15,011,568
	3	1	4	1	1	1	15,015,000
	5	3	0	0	3	1	14,949,792
	2	4	2	0	1	2	15,057,900
	7	2	0	1	1	2	14,990,976
	2	5	0	1	0	3	14,948,388

TABLE 4.1-2

SYSTEM PARAMETERS DEPENDENT UPON DUTY CYCLE
AND DATA RATE

Duty Cycle	31.57%
Dwell Time	5.208 μ sec
Noise Bandwidth	96 kHz
Data Rate	14.976 Mbps
Rotor Speed	17.066 revs/sec
Sampling Distance	202.8 ft
IFOV (Flight Direction)	206.5 ft
Arc Length	118.5 n. mi
N_C	3552
N_{CAL}	12
N_{HK}	86
$N_D \cdot N_{ENC}$	$2^2 3^3 5^4 13$
Cone Angle, θ	6° 46'

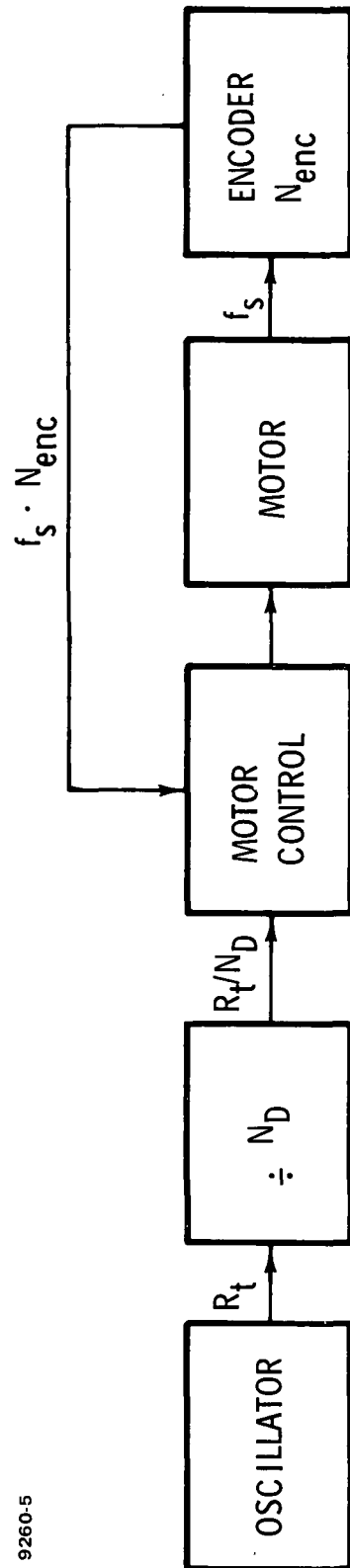


Figure 4.1-6 Block Diagram of the Motor Speed Control

4.2 SCAN MIRROR ROTOR ASSEMBLY

The scan mirror rotor assembly consists of a beam mounted on a motor shaft which supports a mirror to scan the focal surface of the primary mirror and a folding mirror mounted on the rotational axis.

The rotor is designed to be made from aluminum and is symmetrical in shape to reduce the effort required for balancing. The calculated weight of the rotor is 0.20 lb. The uncompensated momentum is 0.0232 ft-lb-sec which is well within the amount allowed for the ERTS spacecraft (0.05 ft-lb-sec).

The scan mirror is made from aluminum plate and is inserted into dovetail slides provided on the rotor. The mirror is positioned and locked in place by means of screws. The center on-axis folding mirror is made from CER-VIT rod stock, cut at a 45° angle and surfaced. The folding mirror is then positioned in a cup on the rotor/motor axis and adjustment alignment established. The method of adjustment is to manufacture the cup 0.0012 larger than the diameter of the folding mirror. The cup and folding mirror are coated with an adhesive. The mirror is then inserted in the cup and aligned on an optical bench. After the adhesive is set, the mirror is pinned in position to ensure alignment is maintained. The rotor is then pinned to the motor shaft and the scan mechanism is complete.

4.3 SCAN ROTOR BEARINGS

The scanner concept provides for the scan mirror to be mounted directly to the drive motor shaft. This consolidation permits the scan function to be performed with one set of bearings. Figure 4.2-1 shows a bearing mount concept capable of maintaining the desired rotational tolerances.

The rotating mirror end of the shaft is supported by duplex mounted ABEC 9 angular contact bearings. The bearings can be selected by the bearing manufacturer and positioned to cancel runout to less than 0.0001 in. The axial motion will be limited to less than 0.0001 in. within this same bearing configuration. Preloading is accomplished by built-in preload. When all ball bearing parameters are determined, the bearing manufacturer will prepare the spacer ends by grinding the lapping to provide the desired preload. Both inner and outer races are clamped. The ball separator types and materials will be selected to give best performance with the chosen lubrication.

The opposite end of the motor shaft is supported by a radial contact ball bearing chosen and selected for radial runout to correspond to the moment compensation limits of the duplex bearings. Thus, angular control in the axial direction will be held well within the established runout limits. The inner race will be pressed on

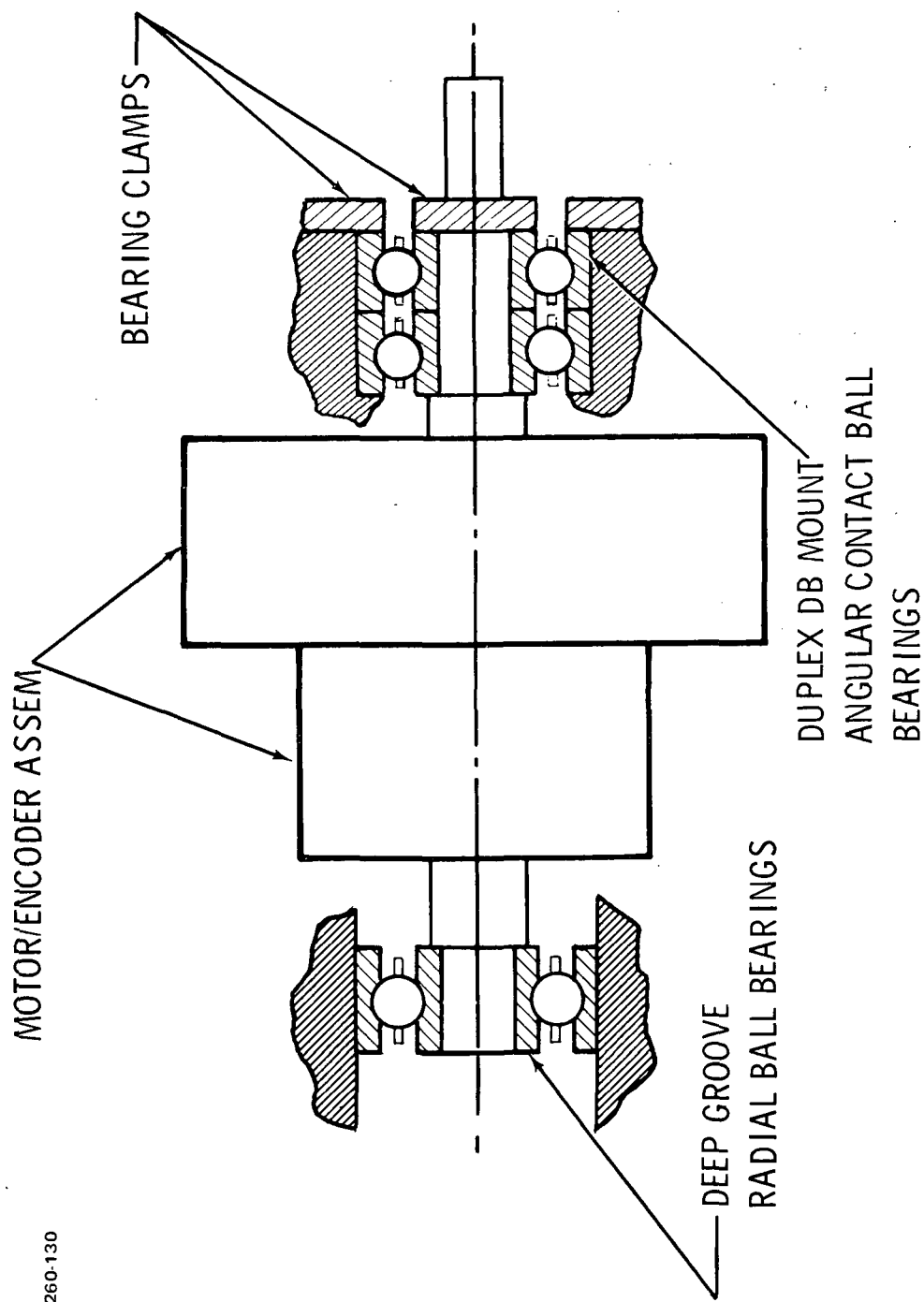


Figure 4.2-1 Scanner Bearing Mount Concept

9260-130

the motor shaft and the outer race will be left free. This will permit self-position compensation for changes due to thermal effects.

The life requirement for the rotor bearings is one year in a space environment. The life expectancy is easily reached with commercial bearings lubricated for in-atmosphere environment. The space environment imposes the requirement for some form of dry lubricant. The most promising lubricants for precision bearings in the space environment are ion gold plating and molybdenum disulfide. A research of published reports and consultation with bearing manufacturers has narrowed the application methods to two: (1) an ion gold coating 4000-6000 angstrom units thick applied to the ball retainer, inner race and outer race, and (2) molybdenum disulfide impregnated plastic retainer such as duroid. In all cases, the bearing material is stainless steel. Consultation with several bearings manufacturers has indicated that the precision and life requirements for the OSS application are within their capabilities.

4.4 SCAN CONTROL REQUIREMENTS

Scan Control is comprised of three distinct elements: the motor which drives the scan rotor assembly, the optical encoder which is attached to the motor shaft, and the motor speed control electronics. A necessary input to the scan control is the output of the system reference oscillator.

The nominal scanner rotational velocity is 1024 rpm, or 17.066 rps. Since there are a total of 11250 cells in a complete revolution, the dwell time corresponding to each cell is 5.2 μ sec. This is the time base which is used by the timing and control to clock off one cell width integration interval. Assuming a circular scan, which introduces a negligible error for this system, each cell corresponds to a rotation of the scan mechanism of 115.2 sec of arc.

Certain self-imposed accuracy requirements have been placed on the scan control, consistent with overall system requirements. These are defined in terms of actual instantaneous rotor shaft position relative to theoretical position, as determined by the master timing. It is assumed that the drift of the master oscillator is negligible. The requirements are listed in Table 4.4-1. The first is that at no time during a 30 minute interval will the actual shaft position differ from the theoretical shaft position by more than 25 arc sec. The second is that during any 58.6 millisecond time period (one shaft revolution) the change in deviation between actual and theoretical shaft position will not exceed 25 arc sec. The third is that during any 5.2 μ sec time period (one cell time) the change in deviation between actual and theoretical shaft position will not exceed 15 arc sec.

The effect of these requirements can easily be interpreted relative to the registration cells of the system. The first assures the absolute long-term synchronization of the motor with the reference oscillator. The scanner velocity will be constant ensuring that deviations in overlap/underlap (Figure 4.4-1) from the nominal design values will be minimal. It also ensures that synchronization with the timing and control electronics will be achieved, and will minimize long term scan path drift. The second assures that misregistration of cells from one scan sweep to the next (Figure 4.4-1) will be no greater than 25 arc sec, or 22% of a cell. It has a secondary effect on overlap/underlap between adjacent scan sweeps. The third ensures that the angular width of the area clocked off by the timing and control as one integration area is within 15 arc sec (13%) of a true cell width (Figure 4.4-2).

TABLE 4.4-1

ACCURACY REQUIREMENTS

Time Period	Time Period Corresponds to	Maximum Deviation Between Actual and Theoretical Shaft Position	Effect of Requirement
30 min.	30,000 scan	25 arc sec	Assures Synchronization between scan reference pulse and data handling equipment - minimizes long-term drift of scan path and deviation from nominal overlap or underlap.
58.6 m sec	Single revolution of rotor	25 arc sec change in deviation	Maintains image registration between successive scans. Minimizes overlap or underlap from nominal overlap or underlap.
5.2 μ sec	One cell time	15 arc sec change in deviation	Maintains cell to cell integration area integrity.

Note: Angular rotation corresponding to one cell is 115.2 arc sec

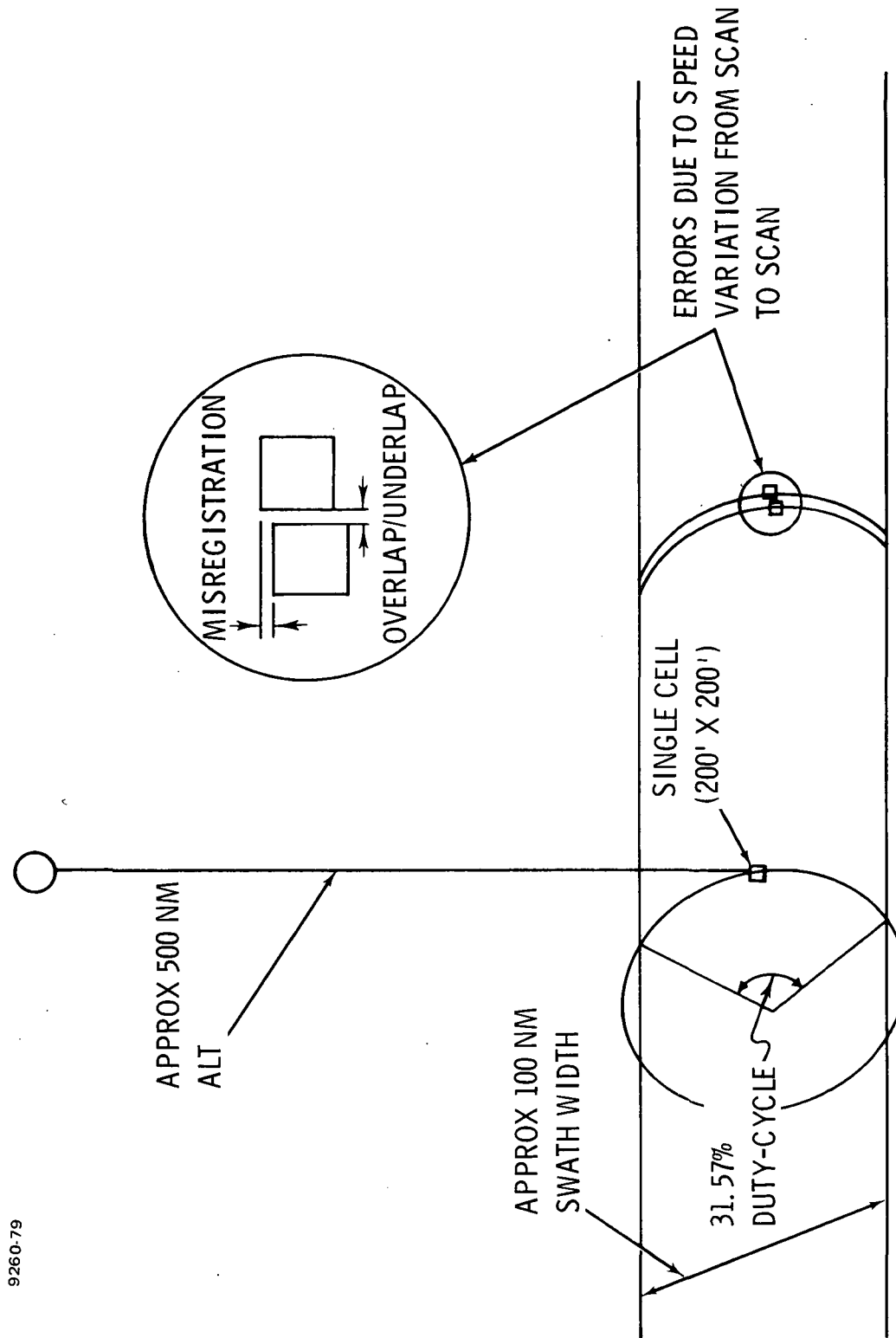


Figure 4.4-1 Scanning Errors (Scan-to-Scan)

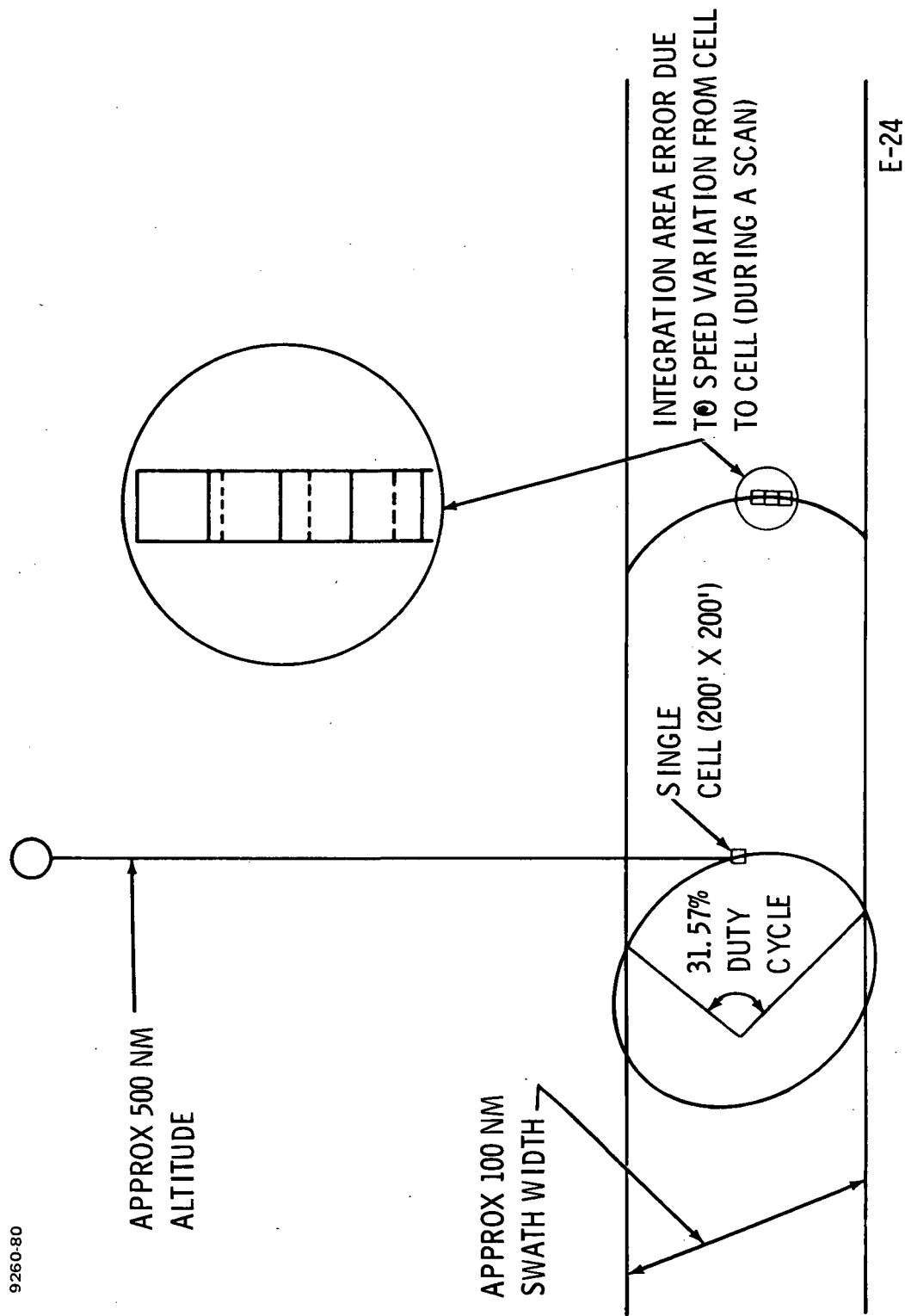


Figure 4.4-2 Scanning Errors (Cell-to-Cell)

4.5 SCAN CONTROL DESIGN

To maintain the scan line accuracies described in Section 4.4, tight motor speed control will be necessary. The elements of the scan control will be discussed in two separate sections: Motor and Motor Control (Section 4.5.1) and Encoder (Section 4.5.2). An error analysis of the design which is to be implemented will then be discussed (Section 4.5.3).

4.5.1 Motor and Motor Control

In broad terms, the requirements on the scan control dictate the use of a "synchronous" type of motor/motor control system - that is, one that is locked absolutely to the system reference oscillator. Of the many types of electric motors available, two were chosen as being worthy of a detailed analysis: the ac hysteresis synchronous motor, and the brushless dc motor.

4.5.1.1 Hysteresis Synchronous

The hysteresis synchronous motor was chosen for analysis rather than other types of ac synchronous motors because of its inherent smoothness of operation. This smoothness is largely attributable to the continuous cobalt steel alloy rotor. On the other hand, the reluctance synchronous motor employs a squirrel cage rotor with discrete poles in the form of asymmetrical lamination punchings inside the rotor or saliencies in the form of flats on the outer periphery of the rotor. Synchronous inductor motors employ permanent magnet rotors. Both of these will clearly exhibit more serious cogging effects during rotation than will the hysteresis type.

A hysteresis synchronous motor, as the name implies, is locked to the driving frequency; a given motor design (i. e., number of poles) and a given driving frequency will provide a rotor speed determined by the following equation.

$$f_s = 120 \times f/p$$

where f_s is rotor speed in rpm

f is driving frequency in cps

p is the number of motor poles

Naturally, synchrononization cannot be attained instantaneously. But hysteresis synchronous motors are able to accelerate relatively high inertia loads to synchronous speed in a relatively short time. Also, their starting torque is approximately

equal to full-load torque. Starting is accomplished as follows: when a voltage is applied to the stator a magnetic pole of a polarity that is attracted by the stator pole forms in the rotor. Then, as the stator field rotates, the rotor follows, and ultimately locks to the stator field. If there is no load, the rotor poles will align exactly with the rotating stator poles, the torque angle (angle between the rotor and stator poles) will be zero. Application of a load will cause the rotor poles to lag the stator poles and a torque angle will develop. The larger the load, the larger the angle that is necessary to meet the torque requirements. Clearly, continuously changing load characteristics will result in a continuously changing phase relationship between the motor input and shaft position. A motor control system has been developed to correct for this phase shifting and is shown in Figure 4.5-1. The pulse train output of the reference oscillator is counted down and used to drive the motor. An incremental encoder is mounted on the rotor shaft and outputs a pulse train, P_E , with a certain frequency, f_E . The reference oscillator drives another frequency divider which provides a pulse train P_R with a frequency equal to f_E . The leading (or trailing) edge of each pulse from P_E is compared phase-wise with the same edge of the corresponding pulse from P_R . The comparator outputs a signal which varies the length of the counter which drives the motor, effectively changing the driving frequency, and hence, the motor speed. When no signal is output from the phase comparator (indicating phase lock of the pulse edges) the counter driving the motor is at its nominal value. The change in frequency will be very small, and will occur for short time periods since only a minor phase shift is required; the motor itself provides the basic velocity control.

Since a hysteresis synchronous motor is capable of phase control, as well as offering built-in velocity control, it would seem to be a likely choice for the OSS Scanner. However, an inherent characteristic limits the motor's desirability. If the load requirements increase, for instance, the motor will tend to increase the torque angle to obtain the required torque input. When the motor is slowing down, however, it cannot cease deceleration at exactly the correct torque angle corresponding to the load. It passes beyond that angle, develops more than the required torque, and accelerates. It will again go beyond the proper angle, and the entire process will repeat. The result will be damped oscillations about the proper point. This oscillation is called hunting or flutter. If a special motor is designed with additional damping incorporated, the flutter can be held as low as ± 26 arc sec, but this exceeds what is necessary to meet the accuracy requirements discussed in Section 4.4. No motor control system has been found which is capable of meeting those requirements using a hysteresis synchronous motor.

4.5.1.2 Brushless DC

An ordinary brush-type dc motor is clearly unacceptable for a long life, satellite application. Commutation of this type of motor is by a sliding contact,

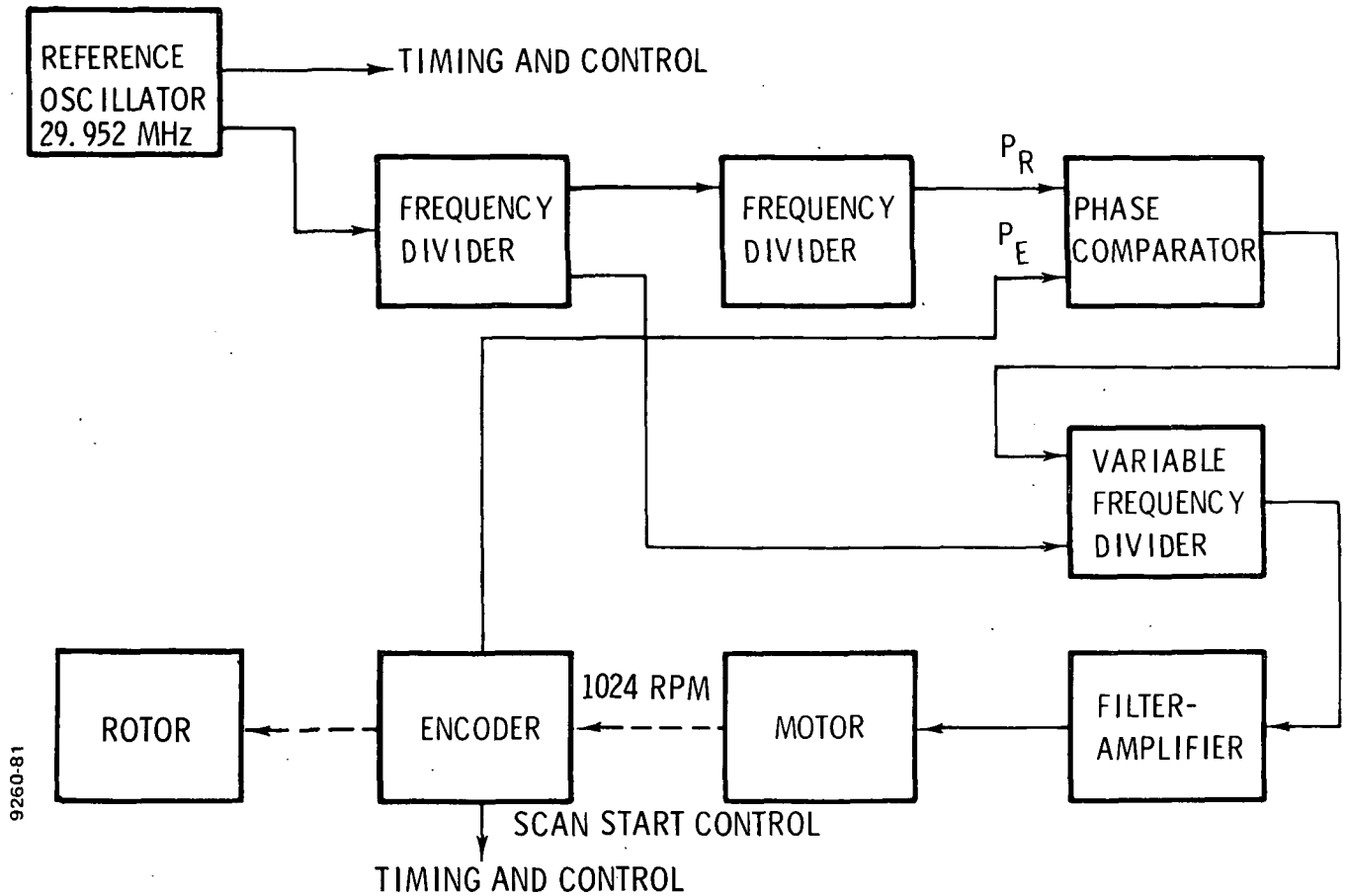


Figure 4.5-1 Typical AC Motor-Encoder System and Control

switching operation accompanied by friction, arcing (resulting in electromagnetic interference), mechanical noise, and brush wear. Many different techniques, however, are currently available to provide electronic commutation of a dc motor thereby eliminating the brushes and their associated problems. The armature and field of a brushless dc motor are actually reversed from those of an ordinary dc motor. The rotor is a permanent magnet (or several permanent magnets, depending on the design), and the stator is a series of two or more windings which are energized in such a way that a torque is exerted on the rotor causing it to rotate and follow the stator field.

A typical electronic commutation technique utilizes light emitters and photo transistors, both held stationary with respect to the motor housing. Mounted on the rotor is a light shield that allows only one phototransistor (in one design) to be illuminated at a time. As each sensor is illuminated it "turns on" a solid state switch, which powers a corresponding stator winding. A torque is exerted on the rotor causing it to rotate. After a certain rotation, the light to the first sensor is cut off by the light shield and a second phototransistor is illuminated. The first switch is correspondingly turned off, and a second one turned on energizing a second stator winding. The rotor is again torqued in the same direction and "chases its tail" to provide continuous rotation.

It is important to note a basic difference between the dc motor and the ac synchronous motor at this point. In the ac motor the stator windings are driven by a power source with a particular frequency resulting in a particular rotor speed. The rotor must follow at the proper synchronous speed, and torque is developed by the creation of a proper torque angle as previously discussed. In the brushless dc motor, however, the stator field windings are driven by electronic circuitry which varies its input as a function of rotor position. The torque output of the motor as well as its speed is determined by resistance of the field, voltage across the field (or current through it), and air gap flux. No hunting is necessary to find a proper torque angle, and hence, no relatively uncontrollable flutter is present.

In another electronic commutation technique, a resolver is attached to the rotor shaft and is driven by an oscillator. It provides a signal proportional to the input, at the input carrier frequency, modulated with a trigonometric function of the angular position of the rotor. The output of each of the two resolver phases is demodulated, amplified, and connected to the corresponding motor winding.

Still another electronic commutation technique utilizes Hall effect devices mounted in the stator to sense the magnetic field of the permanent magnet rotor. These devices output a voltage proportional to the magnetic field passing through them, thus providing rotor position information. In a typical design, there are four stator windings, equally distributed, and two Hall effect elements spaced 90°

apart. When the rotor is turning at a constant speed, two sine waves 90° out of phase will be generated by the Hall elements. If those signals are amplified and inverted, four amplified sine waves in quadrature will be generated. These four voltages can then be applied to the four stator windings in the correct phase relationship.

Other commutation techniques are possible, but the three presented here are the most popular. Of these three, the first exhibits characteristics most like an ordinary dc brush type motor. Only a fraction of the windings are energized at any instant, resulting in relatively low efficiency, and widely varying torque sensitivity. The second is capable of a much smoother torque output than the first, but like the first, requires a relatively large volume to allow for the mechanical devices necessary for commutation. The last technique provides a very smooth ripple free torque output, and can be built in an extremely small volume with low weight. Since the space available for the motor is very limited in the OSS scanner, the last technique is the one which will be employed.

A speed control system for the dc motor (either brush-type or brushless) has undergone an extensive development and testing program. It utilizes hybrid digital/analog servo techniques, and is shown in Figure 4.5-2.

The command and feedback control inputs are pulse trains from the reference and from the encoder respectively. The reference pulse train is obtained by counting down the output of the reference oscillator to some convenient frequency, f_r . The encoder is an incremental type, with resolution determined by the following equation:

$$N = 60 \times f_r / f_s$$

where N is the number of encoder lines per turn

f_r is the reference frequency in pulses per second

f_s is required motor speed in rpm

Both the reference and encoder pulse trains are passed through pulse shaping circuitry so that they are compatible with the input requirements of the velocity/phase comparator.

The velocity/phase comparator receives the reference and encoder pulse trains and compares them via frequency-phase logic. Its initial task is to provide frequency lock. It does this by generating an error signal related to the magnitude of the frequency difference between the reference and encoder inputs. This digital

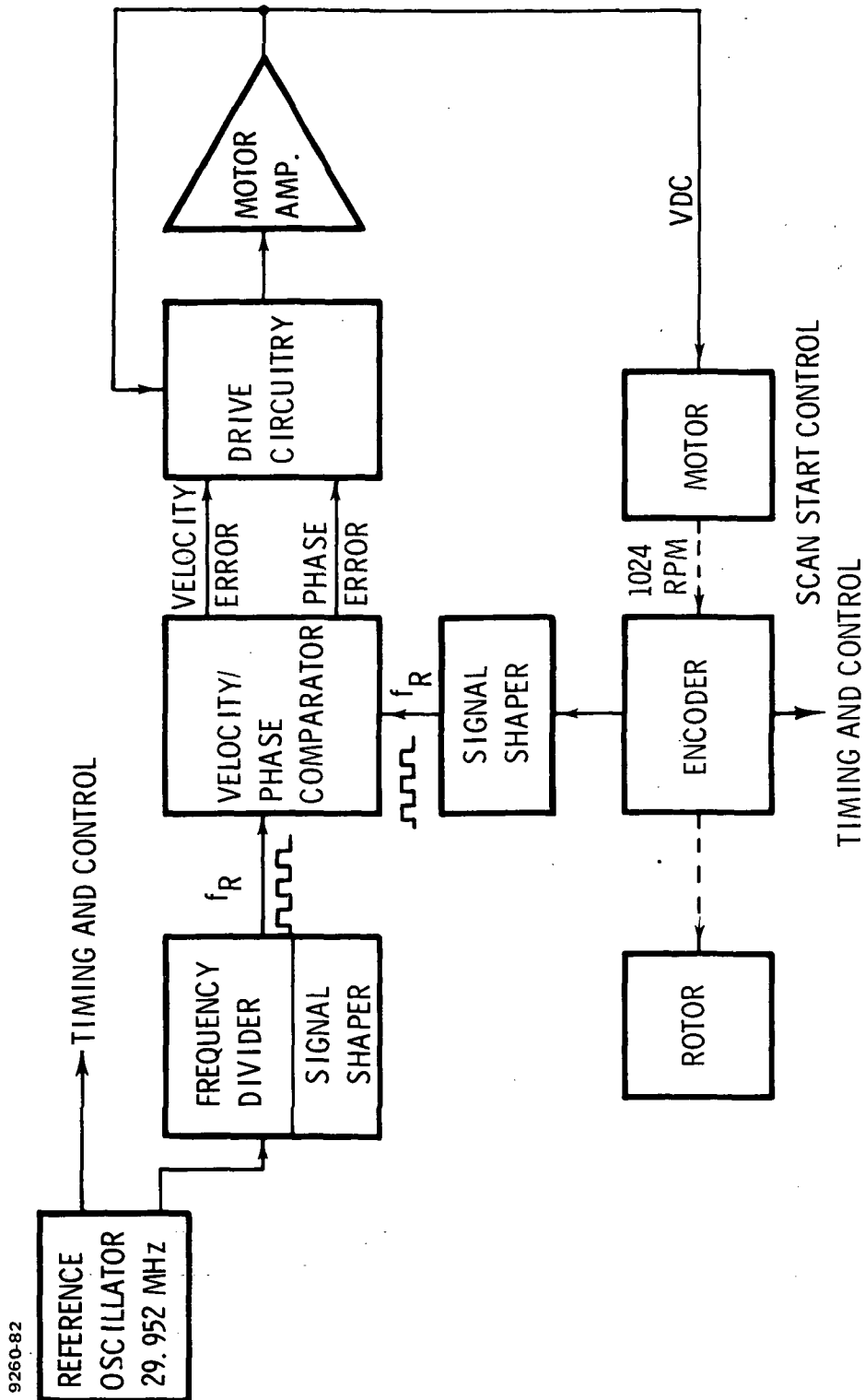


Figure 4.5-2 Typical DC Motor-Encoder System and Control

signal is converted to an analog signal, amplified, and input to the drive circuitry. The result is a dc motor operating as a synchronous motor, locked to the driving frequency.

When the frequency lock is achieved, the comparator effectively switches on an additional phase-lock mode of operation, comparing the phase shift between the reference pulses and encoder pulses. This may be thought of as a fine tuning of the initial frequency-lock. A signal is generated which is proportional to the phase difference, and combined with the signal necessary to provide frequency-lock. The result is a tightly controlled phase-locked loop.

4.5.2 Encoder

A major contributor to the overall accuracy of the scan control is the accuracy achievable in the encoder. If the encoder provides incorrect information regarding the position of the shaft at any instant, the motor control system will accept this as correct information, and will provide a signal which results in an error in the actual shaft position corresponding to the encoder error. Clearly, the encoder accuracy must be greater than the overall accuracy requirement of the complete scan control system.

An incremental optical encoder will be used in the proposed design. It will have a main track to provide motor control information consisting of N lines. Two photo-detector assemblies will be incorporated, mounted 180° apart, to provide greater accuracy. There will be additional track on the encoder disc. It will contain a single line and will provide information necessary for scan start control. Fine tuning of the scan start control pulse relative to the actual position of the rotor can be provided in the scanner electronics circuitry.

4.5.3 Scan Control Error Analysis

The basic premise used in the design of the scan control is that a perfect source of timing information (a stable oscillator) is available as a reference. Clearly this is not exactly correct, but the errors contributed by the drift of the reference oscillator are so small (on the order of 0.0005%) that they may be neglected. The error contribution of the scan control system, then, can be defined in terms of the positional synchronization of the rotor with the reference frequency. Two sources of errors will be examined separately and then combined to obtain the overall error contribution of the scan control.

Assuming an accurate feedback control signal from the encoder, the scan control electronics will contribute a certain amount of positional inaccuracy. With reference to Figure 4.5-2, it should be noted that the error signals output from the

velocity/phase comparator are digital signals. The drive circuitry includes a digital to analog conversion function - providing pure dc voltage proportional to velocity and phase error. This conversion is updated on a pulse-to-pulse basis relative to the reference frequency. According to the sampling theorem, the achieved electrical bandwidth is half the frequency of the reference signal. For the OSS Scanner the reference frequency will be on the order of 110 kHz, yielding a very wide band, and, by design, high gain, control loop. The drive circuitry also includes stabilization circuits which apply phase, velocity, and acceleration control in proper proportions, and with proper frequency characteristics, to optimize the closed loop performance of the control loop. In addition, the drive circuitry includes motor driver circuits which supply correct excitation to the motor to maintain constant shaft velocity. Feedback is provided from the output of the motor amplifier so that the driver and motor are operated in secondary, closed-loop manner - which linearizes the torque output characteristic and virtually eliminates the electrical time constant of the motor windings.

If the torque disturbance is applied to the shaft, the phase relationship between the reference signal and encoder signal will change, altering the phase error signal. In closed loop operation, the maximum electrical phase shift is given in the following equation:

$$P_e = 360/K_p$$

where P_e is electrical phase shift in degrees

K_p is electrical phase lock gain.

The corresponding mechanical phase shift is given in the following equation:

$$P_n = P_e / N$$

where P_n is mechanical phase shift in degrees

N is the encoder line density.

A typical value of phase-lock gain, achievable with proper dynamic stabilization, is on the order of 40 dB. If the encoder line density is 6480 lines per revolution, the maximum phase shift, in arc seconds, is shown in the following equation:

$$\begin{aligned} P_n &= (360) (60) (60) / (6480) (100) \\ &= 2.0 \text{ arc seconds} \end{aligned}$$

This, then, is the error contribution of the scan control electronics.

Now, if perfect scan control electronics performance is assumed, the positional error due to encoder inaccuracies can be calculated. Four separate sources of error need to be considered in the encoder: inaccurate spacing of lines on the disc, inaccuracies in centering of the disc, disc distortion, and temperature effects. The magnitude of each of these is as follows:

1. It is currently possible to manufacture encoder discs on a specially designed circle dividing machine with line-to-line spacing accuracies of 0.3 seconds of arc.
2. Disc centering errors can be eliminated through the use of two detector assemblies on the same track, spaced 180° apart.
3. Disc distortion is on the order of 0.02 in. or 2 sec of arc.
4. Temperature effects on the electronics in the range of -60°F to +165°F have been shown to be equivalent to 1.04 sec of arc.

Since these errors are statistically independent they can be combined as in the following equation:

$$E_E = [(0.3)^2 + (0)^2 + (2.0)^2 + (1.04)^2]^{1/2}$$

$$= 2.3 \text{ arc sec}$$

This, then, is the error contribution of the encoder.

The errors inherent in the scan control can now be calculated. Again, the errors due to the control electronics is statistically independent of the error contribution of the encoder. Hence, the total error is as calculated in the following equation:

$$E_T = [(2.0)^2 + (2.3)^2]^{1/2}$$

$$= 3.01 \text{ sec of arc}$$

This error can be interpreted as follows: at any instant during the lifetime of the system, the actual rotor shaft position shall be within 3.01 arc sec of the theoretical shaft position relative to the reference frequency. Clearly, each of the three requirements discussed in Section 4.4 will be met.

4.6 SCAN ASSEMBLY PERFORMANCE ANALYSIS

The scan assembly consists of the scan control (motor, encoder, and controller) and the scan mechanism (shaft, bearings, and scan rotor). The performance of this assembly can be discussed in terms of the scan line accuracies achievable with the chosen design.

In Section 4.5.3, it was determined that the positional accuracy of the scan control was ± 3.01 arc-seconds. In Section 4.3, it was determined that bearing runout results in an effective positional accuracy of ± 5.0 arc-seconds. Since these two errors are statistically independent, they can be combined as follows:

$$[(3.01)^2 + (5.0)^2]^{1/2} = 5.84$$

Thus, the maximum positional accuracy of the scan assembly is ± 5.84 arc-seconds.

Within each scan, the accuracy of the position of the edges of each cell is of importance. This positional accuracy controls the integration area integrity of each cell as well as the geometric registration of contiguous cells in adjacent scans. For both of these, the maximum error will be double the positional accuracy of the assembly, or 11.68 arc-seconds in the extreme case where errors at the cell boundaries are in opposite directions. Since each cell is 115.2 arc-seconds in width, the maximum error will be approximately 10% of a cell. However, the deviation of the placement of each cell from its nominal position, it should be noted, will still be a maximum of 5.84 arc-seconds. Because the motor will be synchronized with a stable reference, these errors will not accumulate during operation of the system.

The deviation from nominal overlap-underlap between adjacent scans is also of importance. Because scanning velocity will be essentially constant at its nominal value, only bearing runout errors need be considered. (See Section 4.5.) These errors will be a maximum of 5 arc-seconds, or approximately 5% of a cell.

Other factors affecting integration area integrity, geometric registration, and overlap-underlap are oscillator drift and integration control. These are discussed and shown to be negligible in Section 9.5.

SECTION 5

CALIBRATION TECHNIQUE

To assure radiometric accuracy, it is essential that a continuous check be made on the band-to-band accuracy of the multispectral scanner. For comparison with other data, the absolute system sensitivity is also required. Calibration is achieved by presenting various artificial targets to the spectrometer on each revolution of the scan mirror. Four reference targets are used; two visible-infrared sources will simulate the lowest and highest radiances expected from the scene and two blackbodies, or thermal emissive sources, will bracket the expected temperature range of the target.

5.1 VISIBLE INFRARED SOURCES

To improve the system accuracy, calibration sources are used to minimize the dynamic range of the digitization and stabilize the electronics gain. The source signals are not simply recorded and their readings transferred to the ground for data analysis but they perform an active function in the spacecraft. As described in Section 9.1, the calibration sources control the gain and offset such that the predicted incoming signal fills the digitization range of the electronics. The range will be a few bits greater than the source setting to allow for transmission of the source readings. Filters are used to change the source outputs to simulate the upper and lower scene radiances. Accurate prediction of these radiances is made by the use of curves such as those shown in Figure 5.1-1. The figure displays the signal strength at the scanner as a function of the target reflectivity for several solar zenith angles. The zenith angles, Z , have been limited to the range 30° to 80° , as 30° is the lower limit for the ERTS sun-synchronous orbit and 80° is a practical upper limit. For this wavelength band and for larger wavelengths the curves are almost linear. The signal at the zero ground reflectivity is shown for the somewhat ideal case of a Rayleigh atmosphere. All the curves originate at almost the same point because for bulk scattering, such as from the atmosphere, the scattering toward the zenith has only a small dependence on the zenith angle. The reflectance ranges of plants or rocks demonstrate that the expected signal range can be determined from the known range of zenith angle over the target area. These curves are simplified as they apply for Rayleigh scattering only, so for more accurate range setting they must be extended to include aerosol, or Mie, scattering.

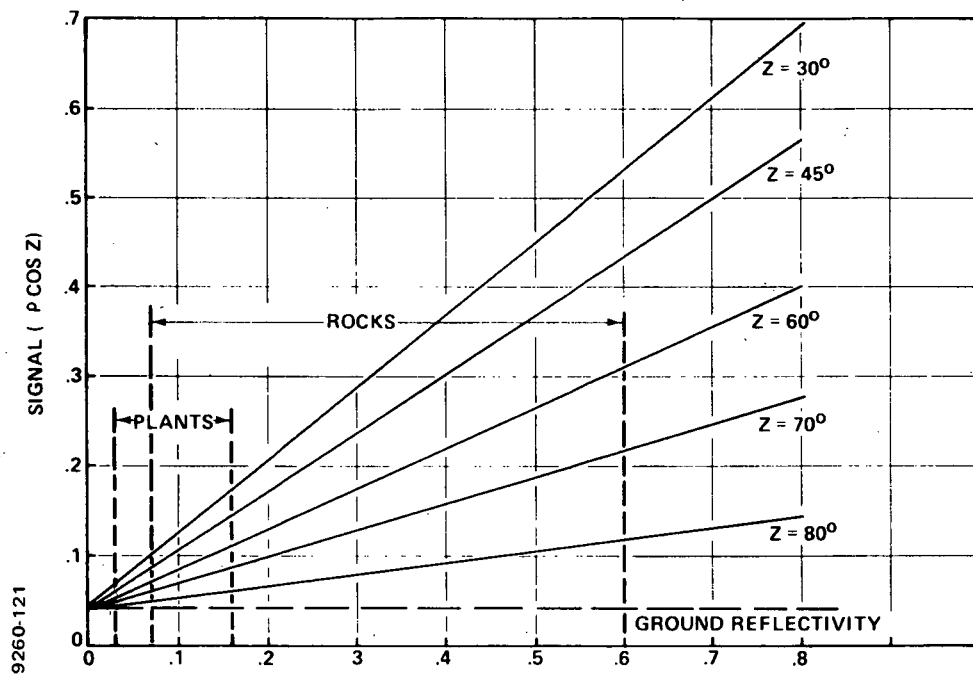


Figure 5.1-1 Relative Signal vs. Reflectivity Band 1
(0.5 to 0.6 Micron)

Although aperture-filling sources are ideal for radiometric accuracy, they become impractically large for space use. Thus, the calibration sources used are field filling rather than aperture filling and simulate the entrance beam by being injected at a point where the beam is narrow. Each visible infrared source projects an image at the focal plane of the primary mirror to be scanned during the inactive portion of the rotor movement.

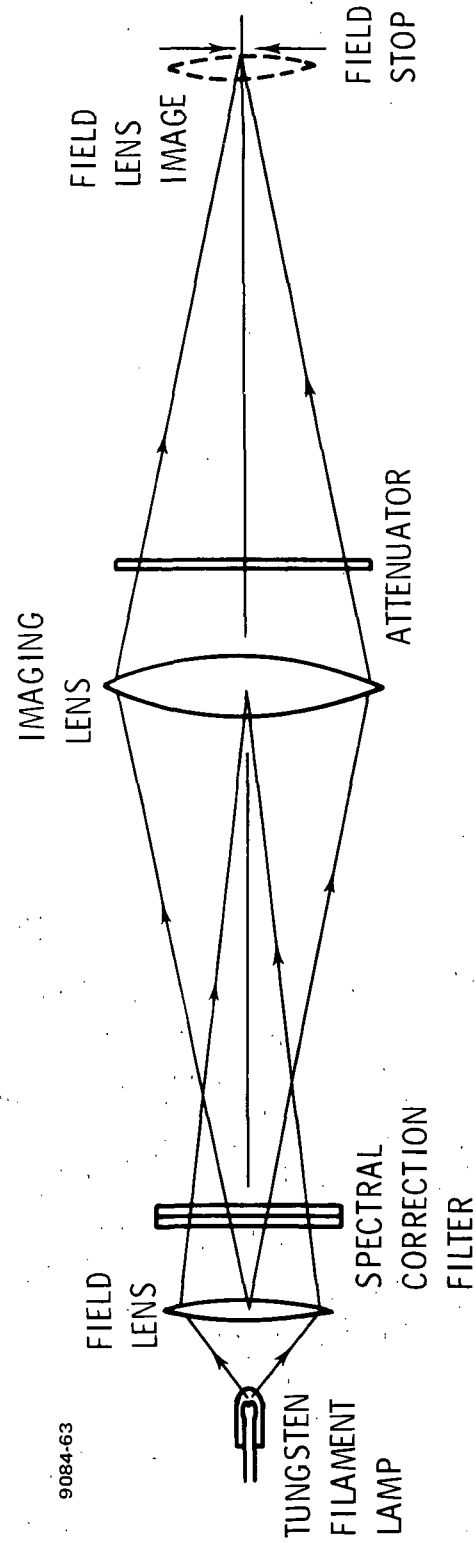
Spectral energy covering all wavelengths from 0.5 to $2.4\ \mu$ is supplied by a low-power (approximately 1 W) tungsten lamp. A suitable one is a General Electric T-1A510 subminiature. The lifetime of the lamp will be increased by 400% to 1.6×10^5 hr by reducing the filament current 5% below the design value (to a color temperature of 2000°K). An unimportant loss in luminous efficiency will result. As the source is a single point system failure, lamp redundancy will be provided in a flight system.

A homogeneous source of illumination is obtained by imaging the field lens into the image plane of the telescope primary mirror. The system dimensions ensure that the cone of light from the imaging lens simulates the telescope entrance beam.

Use of only the central portion of the image ensures that chromatic aberration is not a problem. The separation between the two lenses determines the size of the image at the field stop. Because of the small space available close to the primary focal plane, a fiber optics bundle will be used to inject the radiation.

Two stages of filtering are used (Figure 5.1-2). Color filters are used to convert the 2000°K spectrum to a better solar simulation. A Schott BG-13 spectrum-shaping filter shifts the peak output of the lamp to shorter wavelengths and a KG-4 heat absorbing filter decreases the IR output. As the different varieties of target (e.g., sea water, forest, and snow) will vary by more than an order of magnitude in reflectivity, various stages of neutral attenuation will provide a correspondence between source and scene radiance for the selected target. Several stages of attenuation, using a variable density mesh, will be used and a stepper motor will rotate the attenuator turret.

Absolute and relative calibration of the scanner will be achieved by transfer calibrating the lamp against a high-accuracy tungsten filament lamp traceable to NBS. Short term stability of the lamp will be achieved by using a stabilized current supply.



SPECTRAL RANGE: 0.5 - 2.5 MICRONS

SOURCE COLOR TEMP: 2000°K

SPECTRAL FILTERS: BG -14 AND KG - 4

Figure 5.1-2 Reflective Band Calibration Source

5.2 SOLAR REFERENCE

Over a period of one year, the signal from the calibration source will gradually decrease because of the slow deposition of tungsten on the lamp envelope and a degradation of the optical coatings. Some means of inflight calibration is required. The sun can be used as a constant radiance source to be viewed once each orbit and provide a signal for direct comparison with the internal source signal. This is made possible by the nature of the sun synchronous orbit; the plane of which maintains a constant orientation to the earth-sun line except for the solar declination variations. By locating a small mirror (or mirrors) in the scanner aperture, a combination of the orbital motion and the scan sweep will ensure that the sunlight reaches the spectrometer field stop at some point in each orbit. The point must occur when the scanner sees the dark surface of the earth free from atmospheric reflection and when the sun is not obscured by either earth or atmosphere. There is an 18° orbital angular range over which this condition is achieved after the spacecraft crosses the terminator. For this angular zone the direction of the sun has been calculated for the range of solar declinations, and for a 30-min launch window and an orbit having the following parameters: eccentricity = 0, orbital inclination = 99° , and altitude = 495 n. mi. The results are shown in Figure 5.2-1. * Each vertical trace describes the variation of solar azimuth and altitude (with respect to the spacecraft horizontal) for a particular orbit, and the family of curves 1 to 7 shows the variation of the azimuth with declination ($-23.5^\circ < \delta < 23.5^\circ$) and launch azimuth ($35^\circ < \alpha < 42^\circ$). Each horizontal trace represents the direction of the scan arc as it is reflected off the solar reference mirror. It is seen that the limits of the scan for one mirror are insufficient to cover all possible orbits. Two mirrors, however, whose normals have the altitude and azimuths given by F and E, respectively, will ensure that the sun is observed each orbit for any possible orbit. As the sun has an angular diameter of 8.7×10^{-3} radians, it will be seen on a total of 29 consecutive scan sweeps (each 0.3×10^{-3} radians) each orbit. As the high resolution aperture moves across the solar equator, the sun will be seen for 170 elements.

5.3 THERMAL REFERENCE SOURCES

For accurate thermal calibration two black body sources of known temperature and emissivity are used to provide reference data. The two blackbody sources are mounted on the secondary optics package and maintained at temperatures which cover the expected target temperature range. Each black body source contains an active surface fabricated of aluminum honeycomb and painted with high emissivity paint. Passive cooling is utilized in conjunction with heaters to maintain the set temperature. Platinum resistance thermometers in each active surface monitor the temperature and permit feedback control of temperature and temperature difference.

* For the mathematical analysis see Appendix H.

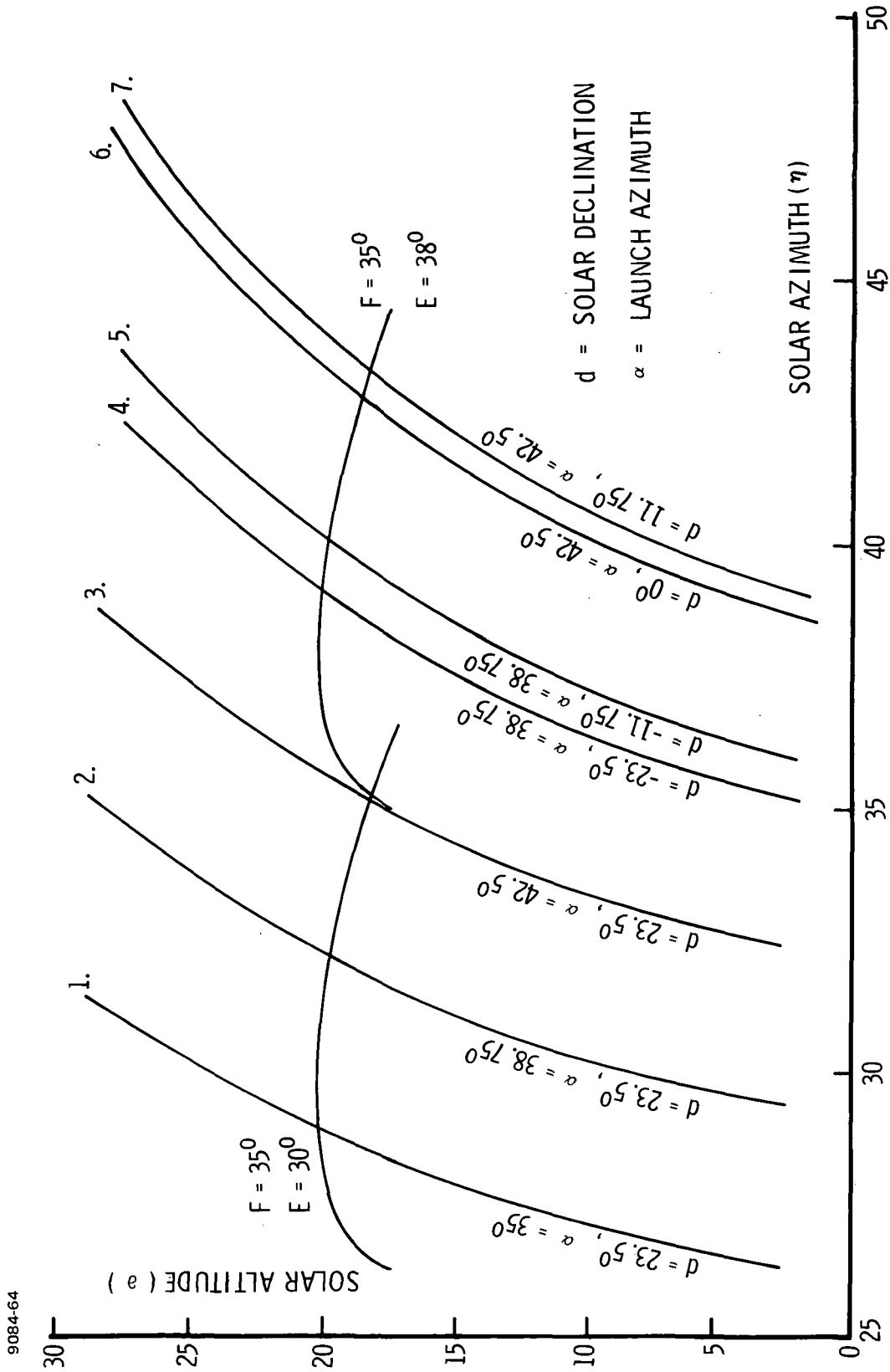


Figure 5.2-1 Solar Direction

The two black body sources are identical in design and construction with individual temperature control achieved by the proper combination of heating and passive cooling. Coarse temperature control is provided by coupling both black bodies to a common radiator surface through the use of a cold structure. Thermal conductance between each black body and the cold structure is matched to provide gross operating temperature of each.

Fine temperature control of each black body is achieved by use of the heaters to furnish the necessary incremental heating upon demand of the heater control circuits. With this concept low power consumption, minimum weight and volume, high reliability and temperature stability are achievable with minimum design complexity. This approach does require a high degree of thermal insulation and heat transfer control between the OSS instrument and the black body sources. (See Appendix F.)

5.3.1 Physical Description

The basic form factor of the black body calibration sources is shown in Figure 5.3-1. The small size of the black body is dictated by the limited space available on the secondary optics package and requires the use of a focused beam upon the active face. An aperture of 0.25 in. dia is provided for optical access to the active face. The opposite end of the black body provides the necessary interface to the cold structure and radiator system. Attachment to the secondary optics package is accomplished with four fasteners through the outer case of the black body. The basic dimensions of the black body calibration source are 2.0 x 2.5 x 1.62 in. resulting in a volume of less than 5.0 cu in. excluding cabling and connector requirements. Weight of each unit is estimated to be approx 0.25 lbs.

Figure 5.3-2 presents a profile section view of the black body identifying the principal interior features. The outer case is fabricated of aluminum with two types of insulation used to provide thermal isolation to the interior components. The active face of the black body is fabricated of aluminum honeycomb painted with high emissivity black paint and is 0.5 x 0.5 in. sq and approx 0.5 in. lengthwise. The honeycomb active face is attached to a solid aluminum plate of similar dimensions. This solid plate contains the platinum resistance thermometers for accurate temperature sensing and control.

A molded film heater encasing the solid aluminum plate is used for maintaining active face temperature. The passive cooling cold structure interface is provided at the rear face of the solid aluminum plate. Thermal isolation of the active face, solid aluminum plate, and cold structure interface from the outer case is provided by a combination of multi-layer insulation and high density molded insulation (VESPEL, nylon fiberglass, or similar material).

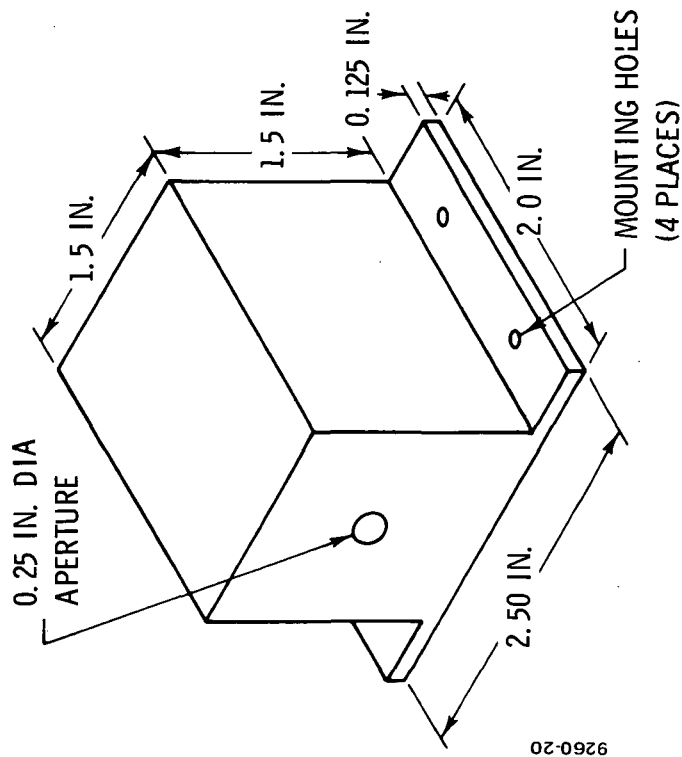


Figure 5.3-1 OSS Black Body Form Factor

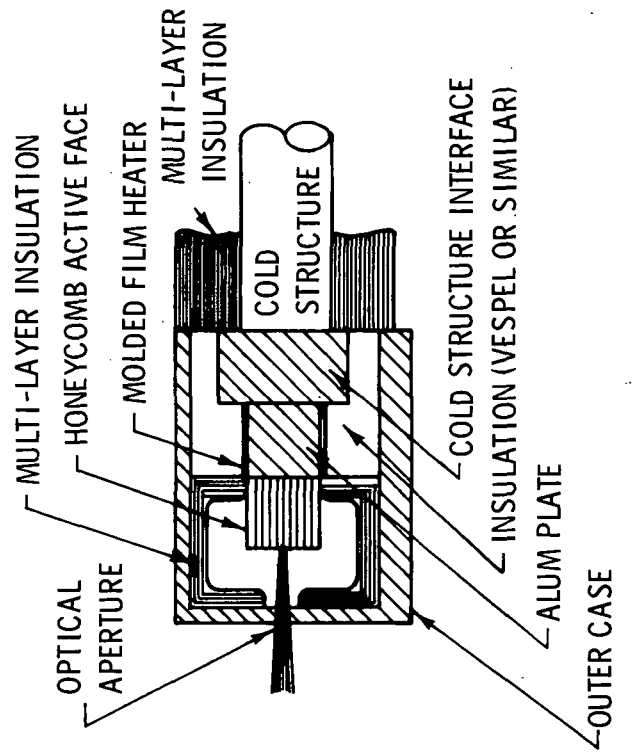


Figure 5.3-2 Profile Section View of OSS Black Body

The cold structure is shown in Figure 5.3-3 and provides the necessary coupling between the black body and the radiator system. The protection of the cold structure from the surrounding OSS components is provided by a multi-layer insulation shroud fabricated of approx 40 layers of 0.25 mil aluminized mylar. This shroud is continuous between the black body and the radiator system and is a critical component. The cold structure is presently envisioned as a combination yoke and low temperature heat pipe connecting the black body to the radiator and is approx 18 in. long.

5.3.2 Thermal Design Description

The operating characteristics which governed the thermal design of the black bodies and set by system considerations are identified as follows:

1. Temperature
 - a. Low temperature unit: $260^{\circ}\text{K} \pm 1^{\circ}\text{K}$
 - b. High temperature unit: $300^{\circ}\text{K} \pm 1^{\circ}\text{K}$
2. Emissivity
 - a. ≥ 0.990 over wavelength band of 10μ to 13μ
 - b. ≥ 0.950 over wavelength band of 0.5μ to 2.4μ .
3. Active surface temperature gradient; 0.5°K max
4. Sensed temperature accuracy: $\pm 0.1^{\circ}\text{K}$.

In addition to the above specific requirements, OSS systems consideration dictates that low power consumption techniques be implemented wherever possible. The black body design as presented herein is minimal in power consumption and semi-passive in concept.

Continuous heat rejection from both black bodies is provided by a common radiator system with a design dissipation level of 4.0 W (2.0 W per black body). The radiator is mounted directly beneath the Band 7 passive radiation cooler on a framework which also supports the Band 5 and 6 radiator. The radiator is 48.0 in. sq in area and is composed of 1.0 x 1.0 in. second surface mirrors mounted to an aluminum plate. At the design dissipation level the radiator temperature is predicted to vary between 249°K (day-time) and 246°K (night-time) throughout the orbit. Thus the minimum ΔT existing between the low temperature black body and the radiator will be approx 11°K . This arrangement establishes the gross temperature control of the black bodies.

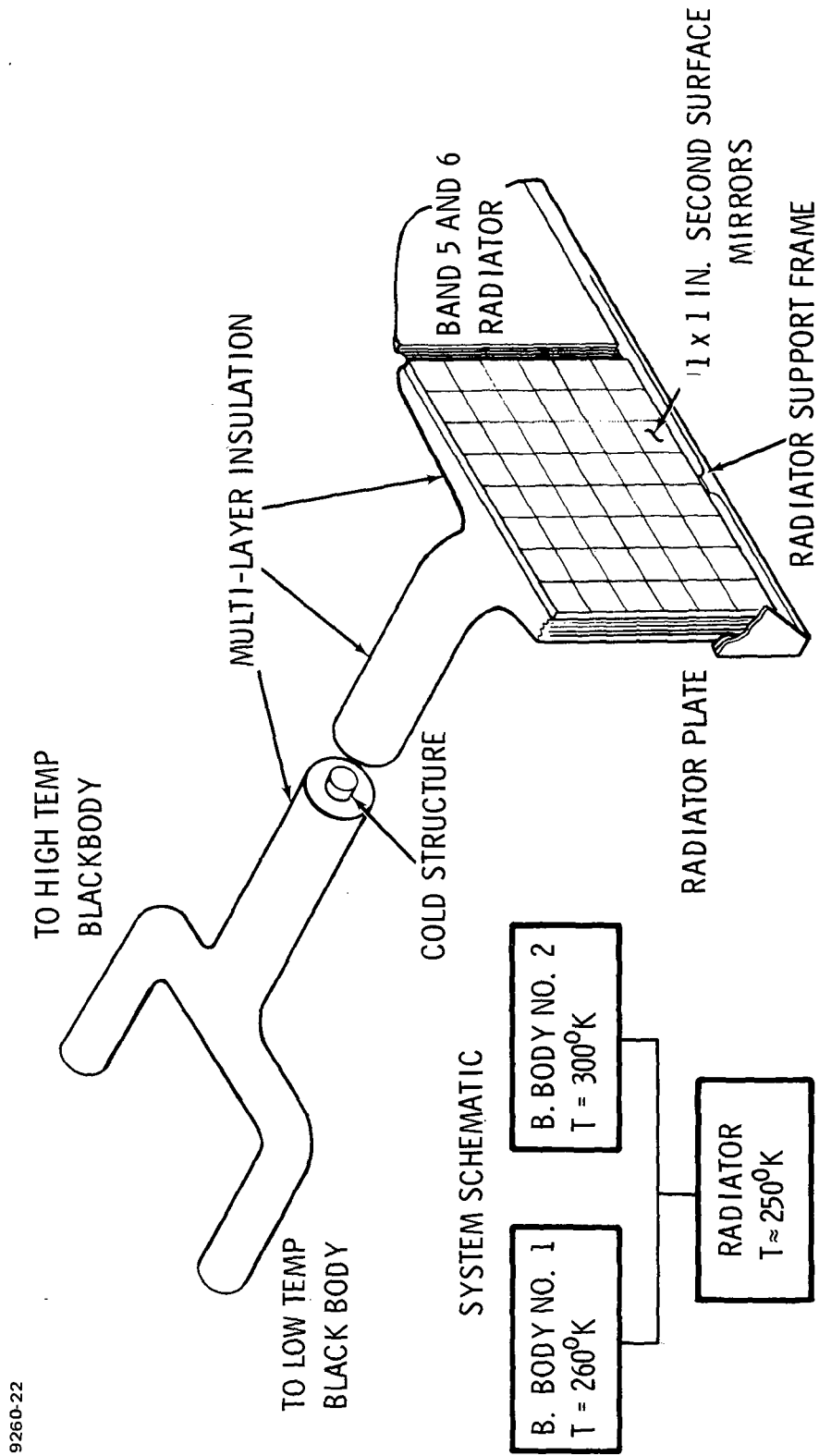


Figure 5.3-3 OSS Black Body Cold Structure and Radiator Assembly

Fine temperature control is accomplished through the use of the black body heaters to provide the necessary additional heat to each unit. To maintain the respective temperatures ($260^{\circ}\text{K} \pm 1^{\circ}\text{K}$ and $300^{\circ}\text{K} \pm 1^{\circ}\text{K}$) with a balanced heat flow into the cold structure each leg of the cold structure is thermally "matched" to its particular black body by material and dimensional tradeoffs. This technique allows complete interchangeability of the black bodies.

SECTION 6

SPECTROMETERS

The telescope projects an image at a focal plane field stop which defines the field of view of two independent spectrometers. The different characteristics of the overland and oceanographic systems are separated by using the stop shown in Figure 6-1. The overland section, when imaged back on the ground, represents an area of 200 by 1200 ft, which allows the scanning of six 200-ft scan lines on each revolution of the scan mechanism. The oceanographic element is a 1200-ft square at the ground and will scan the same swath as the overland bands but separated in time by the period of one scan revolution. Thus, the thermal band, produced by imaging the oceanographic field stop onto detectors whose areas correspond to 600 ft, can be registered directly with the low resolution aperture or, by using a time delay, with the overland bands. For a linear scan, the two apertures could be located side by side and they would scan the same target zone, although at slightly different times, and registration between the two could be achieved. For a conical pattern, however, this will be the case at the center of the scan only. At all other points, the slit will be moving at an angle differing from 90° to the line of flight, until at the edge of the swath the slit is moving at 30° to the line of flight and adjacent slits would scan different areas. Therefore, the two slits must be located one above the other.

Located directly behind the field stop is a reflecting wedge whose apex divides the beam between overland and oceanographic spectrometers. The choice of the spectral dispersion elements depends upon the wavelength range, the spatial resolution, and the spectral resolution. The large wavelength range and the small spectral dispersion make a prism the suitable dispersing element for the first six overland bands. The oceanographic bands are a factor of 7 narrower than the overland, and as the lower spatial resolution (by a factor of 6) makes greater dispersion necessary to separate each band image, the dispersion must be increased by a factor of about 42. As the wavelength range is small, a diffraction grating makes an ideal dispersing element.

The designs of the overland and oceanographic spectrometers are considered in detail in appendices A and G respectively so a brief description only of the selected designs will be given here.

The spectrometer designs are shown in Figure 6-2; the wavelength ranges of their bands and the spatial resolutions are given in Table 6-1. In the overland

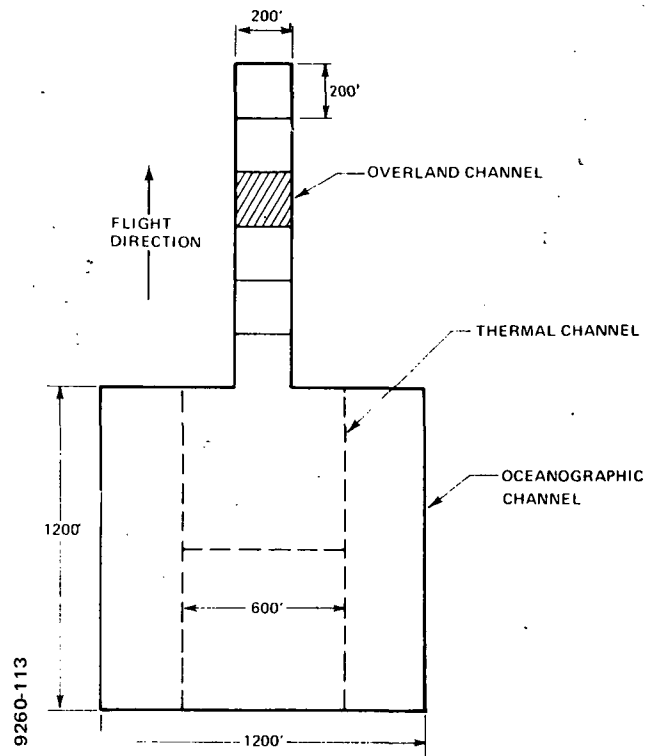
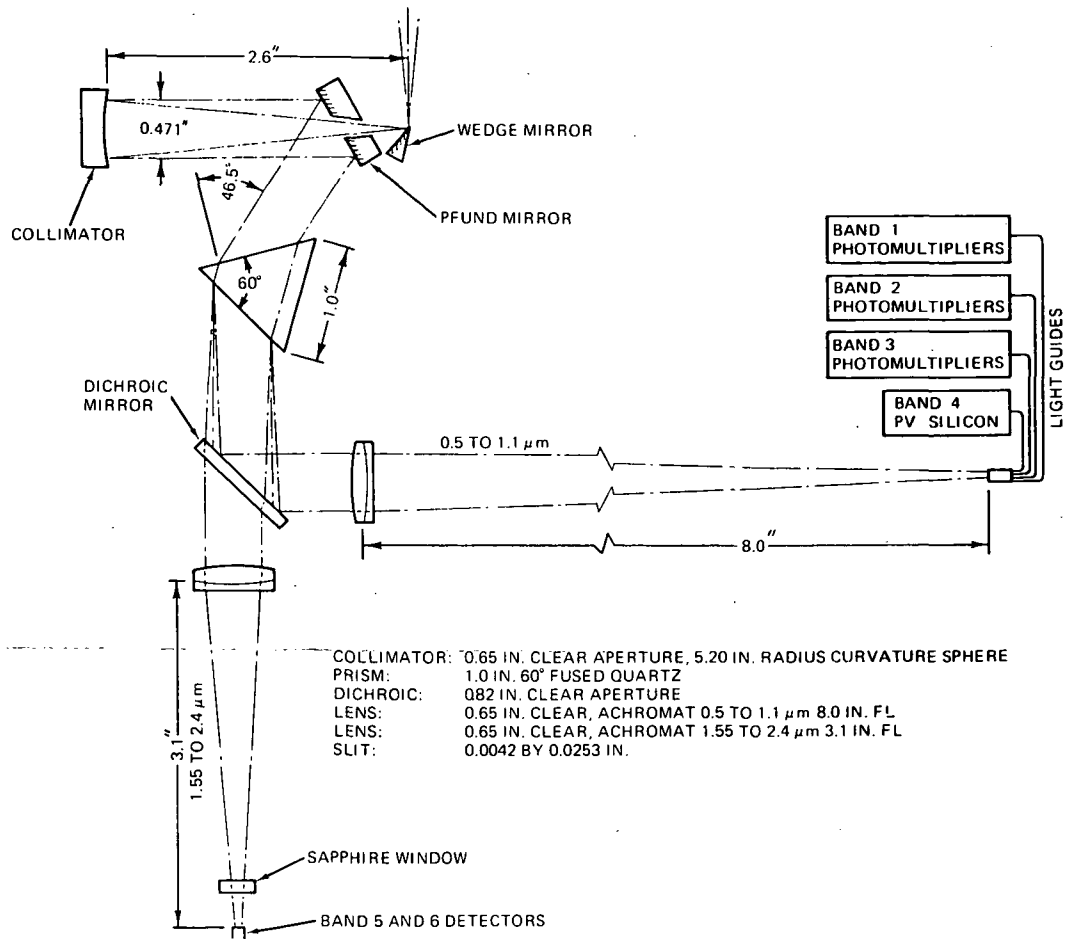
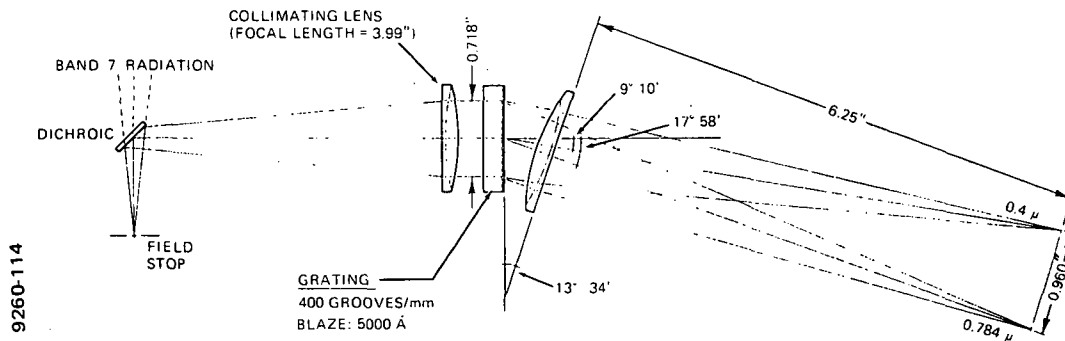


Figure 6-1 Image Plane Field Stop



OVERLAND SPECTROMETER



OCEANOGRAPHIC SPECTROMETER

Figure 6-2 Spectrometer Optical Schematics

9260-114

TABLE 6-1

DUAL-MODE MULTISPECTRAL SCANNER SPECTRAL BANDS

<u>Overland</u>				<u>Oceanographic</u>	
<u>Band</u>	<u>Channels</u>	<u>Wavelength</u> (Microns)	<u>Bandwidth</u> (Microns)	<u>Band</u> (Single Channel)	<u>λ (Angstroms)</u>
1	6	0.5 - 0.6	0.1	1	4000 - 4160
2	6	0.6 - 0.7	0.1	2	4160 - 4320
3	6	0.7 - 0.8	0.1	3	4320 - 4480
4	6	0.8 - 1.1	0.3	4	4480 - 4640
5	6	1.55 - 1.75	0.2	5	4640 - 4800
6	6	2.2 - 2.4	0.2	6	4800 - 4960
<u>Thermal</u>				7	4960 - 5120
	2	10.4 - 12.6	2.2	8	5120 - 5280
<u>Spatial Resolution</u> Bands 1 - 6 200 ft. (0.066 M Rads) Band 7 600 ft. (0.2 M Rads) Oceanographic (1 - 24) 1200 ft. (0.4 M Rads)				9	5280 - 5440
				10	5440 - 5600
				11	5600 - 5760
				12	5760 - 5920
				13	5920 - 6080
				14	6080 - 6240
				15	6240 - 6400
				16	6400 - 6560
				17	6560 - 6720
				18	6720 - 6880
				19	6880 - 7040
				20	7040 - 7200
				21	7200 - 7360
				22	7360 - 7520
				23	7520 - 7680
				24	7680 - 7840
				$\Delta \lambda$ For All Bands is 160 Å	

Mode 1. All Overland Bands, 1 - 7

Mode 2. All Oceanographic Bands, 1 - 24
Plus Overland Bands, 1, 4 and 7.

system, a Pfund collimator is used to send the beam to a fused silica prism which disperses the radiation. To simplify the lens design and to separate the detectors which require cooling from the uncooled ones, a dichroic filter is used to reflect the four short-wavelength bands (0.5 to 1.1 μ) and transmit Bands 5 and 6 (1.55 to 1.75 μ and 2.2 to 2.4 μ). Two achromatic doublet lenses image the bands into their respective focal planes. For each band there are six detectors - one for each element of the field stop.

For Bands 1, 2, and 3 (Table 6-1), the focal plane is dissected by a fiber-optics array which conducts the energy to 18 independent photomultiplier tubes. By means of a prism on each tube face, the energy is injected into the face at an incident angle larger than the critical angle so that multiple total internal reflections return the radiation several times to the photocathode, giving a quantum efficiency enhancement. A photocathode has very low efficiency beyond 1.8 μ , so a silicon photovoltaic detector has been selected for band 4. This detector also uses short light pipes (1 in.) to remove the energy from the focal plane. The best state-of-the-art detectors for bands 5 and 6 are fabricated from InAs which require cooling to provide adequate performance. These detectors are arranged in the form of arrays and will be cooled at least 150°K, and preferably 120°K. The same temperature would apply to HgCdTe detectors if these are available with better performance at the time of the scanner construction.

The oceanographic spectrometer shown in Figure 6-2(b) is of relatively simple design. A dichroic filter is used to separate, by transmission, thermal Band 7 which is reimaged by an antireflection coated germanium lens onto a cooled HgCdTe detector. Passive radiation cooler can be used, but in this case a more complex conical design is required to reduce the temperature to below 100°K, with 90°K as a design goal. The 24 visible bands are dispersed by the grating, and achromatic doublet lenses are used to collimate and image the light. The detection at the shorter wavelengths is performed using photomultiplier tubes and quantum efficiency enhancement. The higher quantum efficiency of silicon makes it a more suitable detector beyond about 0.47 μ . The linear dispersion of the grating makes it possible to use a single array of 0.040-in. square silicon detectors.

Use of spectrometers, each with a single field stop, ensures that the spectral bands are in perfect registration, and the use of two stops allows the spectrometers to operate independently or simultaneously. There are two modes of operation either of which can be selected electronically. With 38 channels of data we can select the overland Bands 1 to 7, each of which has an array of six detectors except for thermal Band 7 which has only two, or we can select the 24 oceanographic bands plus overland Bands 1 and 4 (or others if desired) and the thermal Band 7. Hence, the dual-mode capability is provided.

SECTION 7

DETECTORS, PREAMPLIFIER, AND SENSITIVITY ANALYSIS

The key to achieving high sensitivity performance in the scanner, i. e., a high signal to noise ratio (S/N), is in selecting the best detectors for the various spectral bands which the state-of-the art affords; then through careful design, minimizing the additional noise contributions due to the subsequent electronic amplification stages.

This section deals with the analysis of the signal and noise power presented to the detectors, the detector selection, the design of the preamplifier, and the determination of the resulting S/N output.

7.1 SIGNAL POWER AT THE DETECTOR

Tables 7.1-1 and 7.1-2 summarize the information used to calculate the energy falling on each of the overland and oceanographic detectors. For the overland mode columns 3 through 10 list the contributions to the optical efficiency of each component used in the scanner and spectrometer with the obscuration included. The total optical efficiency is given in column 11. The efficiency has been maximized by using the minimum number of components and making each as efficient as possible. Because of the large number of reflections, enhanced silver coatings have been used on the mirrors for a maximum reflectivity. The values in column 3 are for Denton vacuum FSS-99 silver coating. The prism losses are mainly due to surface reflection with a small component from internal transmission. The dichroic filter (column 7) is more effective in reflecting the short wavelengths (Bands 1 to 4) than in the transmission of the longer wavelengths (Bands 5 and 6). The lens transmission (column 8) assumes the use of anti-reflection coatings. The fiber optics transmission (column 9) is discussed in the spectrometer design (Appendix A). The obscuration is minimized by the system configuration and is almost entirely caused by the elongated aperture in the Martin mirror.

The solar irradiance for each band falling on 1 cm² normal to the incident sunlight outside of the atmosphere is calculated using values given in the AFCRL Handbook of Geophysics and Space Environments (1965). The atmospheric transmission has been computed for a sun angle of 45° which gives a total air mass for the incident and reflected radiation of $m = 2.4$. The signal falling on each detector can now be computed using the equation:

$$P_D = \frac{H A \rho \epsilon t \cos Z}{\pi}$$

where:

H = solar irradiance for the band. ($\text{W cm}^{-2} \Delta\lambda^{-1}$)

A = collector area (cm^2)

ϵ = optical efficiency

t = atmospheric transmission

Z = solar zenith angle

and the surface reflectivity, ρ , is unity.

TABLE 7.1-1
OVERLAND DETECTOR SIGNAL POWER

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Band	Wavelength ($\Delta\lambda$)	Silver Mirror Reflectivity (Deston FSS-99)	Number of Reflections	Reflection Efficiency	Prism	Bands 5, 6 Separation Dichroic	Lens	Fiber Optics	Obscuration	Total Optical Efficiency	Solar Irradiance Outside Atmos. ($\text{W cm}^{-2} \Delta\lambda^{-1}$)	Atmos. Trans. ($n = 45^\circ$) ($m = 2.4$)	Signal Power at Detector $P_D = \frac{H A_o^2 \epsilon \cos Z}{r}$ ($p = 1.0$)
1	0.5-0.6	0.98	9	0.83	0.90	0.90	0.98	0.70	0.78	0.36	1.93×10^{-2}	0.47	2.14×10^{-9}
2	0.6-0.7	0.98	9	0.83	0.90	0.95	0.98	0.70	0.78	0.38	1.63×10^{-2}	0.53	2.16×10^{-9}
3	0.7-0.8	0.98	9	0.83	0.90	0.95	0.98	0.67	0.78	0.36	1.28×10^{-2}	0.60	1.82×10^{-9}
4	0.8-1.1	0.975	9	0.81	0.90	0.95	0.98	0.70	0.78	0.37	2.48×10^{-2}	0.72	4.35×10^{-9}
5	1.55-1.75	0.98	9	0.83	0.90	0.85	0.97	-	0.78	0.48	3.96×10^{-3}	0.66	8.25×10^{-10}
6	2.2-2.4	0.98	9	0.83	0.90	0.85	0.97	-	0.78	0.48	2.41×10^{-3}	0.66	5.01×10^{-10}
7	10.4-12.6	0.985	8	0.85	Dichroic 0.85	-	0.97	-	0.78	0.55	$\frac{L(\lambda)}{\Delta T = 1^\circ\text{K at } 300^\circ\text{K}}$ -0.89×10^{-4}	0.90	$\frac{L(\lambda) A_o^2 \epsilon}{r}$ 3.67×10^{-10}

Area of collector, $A_c = 670 \text{ cm}^2$

Instantaneous field of view, $\sigma = 6.6 \times 10^{-5} \text{ rads. } (2.0 \times 10^{-4} \text{ for band 7})$

TABLE 7.1-2

OCEANOGRAPHIC DETECTOR SIGNAL POWER

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Band	Central λ ($\Delta\lambda = 160 \text{ \AA}$)	Silver Reflectivity (Denton, Vacuum FSS - 99)	Efficiency for 7 Reflections	Dichroic	2 Lenses	Grating (5000 $\text{\AA}$ Blaze)	Obscuration	Fiber Optics	Total Optical Efficiency	H_{λ} Solar Irradiance Outside Atmosphere ($\text{W m}^{-2} \Delta\lambda^{-1}$)	Atmospheric Transmission $\theta = 45^\circ, m = 2.4$	Ocean Reflectivity (ρ)	Signal Power at Detector $P_D = \frac{H_{\lambda} t \cos Z A \phi^2 \epsilon \rho}{\pi}$
1	4080	0.92	0.56	0.80	0.95	0.55	0.78	0.80	0.15	30.48	0.33	0.052	1.89×10^{-10}
2	4240	0.93	0.60	0.80	0.95	0.60	0.78	0.80	0.17	30.51	0.35	0.048	2.10×10^{-10}
3	4400	0.95	0.70	0.80	0.96	0.63	0.78	0.80	0.21	33.02	0.37	0.046	2.84×10^{-10}
4	4560	0.96	0.75	0.80	0.97	0.67	0.78	-	0.30	34.40	0.40	0.046	4.57×10^{-10}
5	4720	0.96	0.75	0.81	0.97	0.69	0.78	-	0.32	34.27	0.42	0.048	5.34×10^{-10}
6	4880	0.97	0.81	0.82	0.97	0.72	0.78	-	0.36	32.35	0.43	0.049	5.91×10^{-10}
7	5040	0.97	0.81	0.83	0.97	0.74	0.78	-	0.38	31.38	0.46	0.041	5.42×10^{-10}
8	5200	0.97	0.81	0.84	0.97	0.74	0.78	-	0.38	30.80	0.48	0.040	5.42×10^{-10}
9	5360	0.98	0.87	0.85	0.97	0.72	0.78	-	0.40	31.70	0.50	0.036	5.50×10^{-10}
10	5520	0.98	0.87	0.85	0.97	0.72	0.78	-	0.40	31.18	0.51	0.036	5.51×10^{-10}
11	5680	0.98	0.87	0.85	0.97	0.72	0.78	-	0.40	30.40	0.53	0.034	5.28×10^{-10}
12	5840	0.98	0.87	0.85	0.97	0.71	0.78	-	0.40	30.47	0.54	0.032	5.08×10^{-10}
13	6000	0.98	0.87	0.85	0.97	0.71	0.78	-	0.40	29.92	0.56	0.026	4.20×10^{-10}
14	6160	0.98	0.87	0.85	0.97	0.70	0.78	-	0.39	28.07	0.57	0.026	3.91×10^{-10}
15	6320	0.98	0.87	0.85	0.97	0.69	0.78	-	0.39	27.20	0.58	0.024	3.56×10^{-10}
16	6480	0.98	0.87	0.85	0.97	0.68	0.78	-	0.38	26.07	0.59	0.023	3.24×10^{-10}
17	6640	0.98	0.87	0.85	0.97	0.67	0.78	-	0.37	25.12	0.60	0.023	3.09×10^{-10}
18	6800	0.98	0.87	0.85	0.97	0.66	0.78	-	0.37	24.22	0.61	0.022	2.90×10^{-10}
19	6960	0.98	0.87	0.85	0.97	0.65	0.78	-	0.36	23.40	0.62	0.022	2.77×10^{-10}
20	7120	0.98	0.87	0.85	0.96	0.64	0.78	-	0.35	22.46	0.63	0.021	2.51×10^{-10}
21	7280	0.98	0.87	0.85	0.95	0.62	0.78	-	0.34	21.43	0.63	0.020	2.21×10^{-10}
22	7440	0.98	0.87	0.85	0.95	0.60	0.78	-	0.33	20.63	0.64	0.020	2.10×10^{-10}
23	7600	0.98	0.87	0.85	0.95	0.59	0.78	-	0.32	19.76	0.64	0.020	1.95×10^{-10}
24	7760	0.98	0.87	0.85	0.95	0.59	0.78	-	0.32	19.20	0.65	0.020	1.92×10^{-10}

In Table 7.1-2 a similar procedure has been used to find the signal power at the detector for each of the oceanographic bands. In this case, the grating efficiency is taken from published data for a diffraction grating blazed for 5000 Å. The signal power at each detector is based on the estimated ocean reflectivities listed in column 13.

Thus, Tables 7.1-1 and 7.1-2 show, for each band, the derivation of the signal powers which are used in the performance calculations.

7.2 DETECTOR SELECTION

The selection of detectors for the seven spectral bands of the overland mode has been made with sensitivity as the primary selection criterion. Photomultiplier tubes have been selected for the first three bands since these bands all operate at wavelengths where photomultiplier tubes have respectable quantum efficiencies (especially when full advantage of quantum enhancement is taken), while the photo emissive surface is the most sensitive photon detector. Bialkali photocathodes will be used for Bands 1 and 2. (Figure 7.2-1 shows the measured responsivity averaged over two tubes.) From this figure, it is seen that quantum efficiency enhancement, obtained by using an input prism mounted on the photocathode set more than doubles the responsivity. A multialkali photocathode will be used for Band 3 to provide optimum sensitivity at the longer wavelength.

Band 4 spectrally straddles the peak responsivity of silicon which can be designed to have a quantum efficiency of greater than 80% at its peak and represents the most sensitive detector for this band. The normal use of silicon as a photodiode, driving a well designed preamplifier, is still more sensitive than the newer avalanche mode of operation, and therefore, is selected.

Two detector types, HgCdTe and InAs, offer high sensitivities for Bands 5 and 6. HgCdTe has been selected during this study since it potentially has a higher sensitivity than In As. However, HgCdTe, compositionally tuned to operate with the required detectivity at these wavelengths, is still in the development stage. The detector action of this material is bulk photoconductivity, and at the highest level of detectivity it has a high photoconductive gain.

This means that the responsive time constant of the material is long, and therefore, impacts on the frequency response of the system. Peaking the frequency response of the preamplifier will compensate to some extent since the detectivity of the material has a wide bandwidth, but this does not compensate for changes in the responsive time constant as a function of detector illumination. The frequency response of Bands 5 and 6 is further improved since the signal on Bands 5 and 6 is sampled-and-held rather than integrated-and-held. Thus, the over-all system response remains acceptable and the noise bandwidth is determined principally by the detector bandwidth. In comparison, the detector action of InAs is photovoltaic, and presents no bandwidth problem. InAs has another advantage in that it is operated with zero bias, and therefore, introduces no joule heating load to the detector and cooler. Hence, if HgCdTe detectors operating at these wavelengths with the expected sensitivity are not available at the time of hardware construction, InAs with reduced sensitivity would be the natural choice and all channels would then contain integrate-and-hold circuits for the reasons set out in Section 12.2.

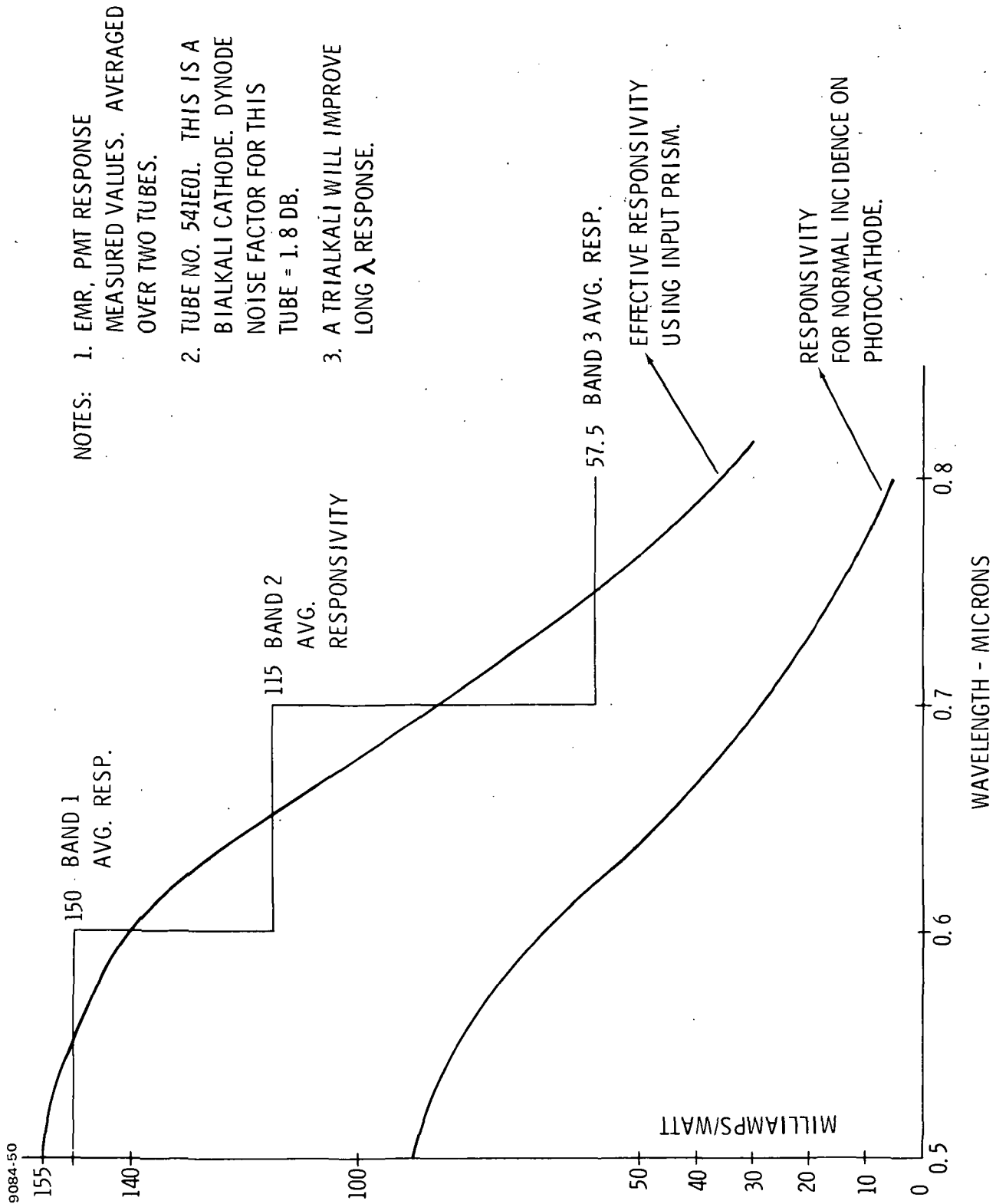


Figure 7.2-1 Photomultiplier Tube Response

The detector tradeoff for Band 7 is between the well developed HgCdTe and the newer PbSnTe. The well developed detector (HgCdTe) is selected since no sensitivity gain currently is offered by PbSnTe, although the latter being photovoltaic does theoretically have a $\sqrt{2}$ sensitivity advantage.

The detectors for Bands 5, 6 and 7 provide increased sensitivity when operating at low temperatures, the actual operating temperature being a tradeoff between sensitivity and the capabilities of passive radiation coolers. The maximum useful operating temperature for HgCdTe in Bands 5 and 6 is about 150°K, but 120°K is the design goal. The sensitivity of Band 7 falls off rapidly at temperatures above 100°K, so this temperature is taken as the maximum permissible with a design goal of 90°K. The D* used for this band is compatible with a temperature of 100°K.

The detector choice for the oceanographic mode of operation is photomultiplier tubes for the first three bands only, since the number of tubes otherwise becomes excessive. These bands are the ones where PMTs provide the greatest increase in sensitivity over silicon. Silicon detectors are used for the remaining 21 bands.

7.3 PHOTOMULTIPLIER TUBES

Due to the high gain of PM detectors, shot noise and noise due to the dynode statistics are much greater than preamp noise sources at the input to the preamplifier. Therefore, it is only necessary to consider these two noise sources when calculating the signal-to-noise ratio for the bands which use PM detectors. Because of the large number of photons impinging on the detector, the dark current can be neglected compared with the signal current. The S/N ratio may then be calculated in the following manner: the signal current, I_s ; due to the scene radiance at the detector, P_D , is:

$$I_s = \frac{q\lambda (QE)}{hc} P_D \quad (7.1)$$

while the total current due to all incoming radiation

$$I_R = \frac{q\lambda QE}{hc} (P_D + P_A) \quad (7.2)$$

where q = electronic charge (coulomb)

QE = detector quantum efficiency

λ = central wavelength of the band

h = Planck's constant

c = velocity of light

P_D = power at detector from the ground

P_A = power at detector from the atmosphere

The shot noise on the signal current must be calculated as the shot noise on I_R and is given by:

$$I_{N1} = (2 q I_R \Delta f)^{1/2} \quad (7.3)$$

where Δf = noise bandwidth

The noise due to dynode statistics results from randomness in the electron multiplication. All primary electrons will not emit the same number of secondary electrons which, therefore, fluctuates causing additional noise at the anode.

This degradation may be expressed as a noise factor which is 1.8 dB on the bialkali photocathodes currently being used. But it is expected that this will be reduced to 1.2 dB. The noise factor, N_f , is defined by the equation:

$$N_f = \frac{I_{N1}^2}{[(QE) I_R]^2 (G_T)^2} \quad (7.4)$$

where G_T = PM tube gain

The S/N ratio is then given by:

$$S/N = \frac{I_S}{N_f I_{N1}} = \left[\frac{\lambda (QE)}{2 N_f hc \Delta f} \cdot \frac{P_D}{P_A + P_D} \right]^{1/2} \quad (7.5)$$

and this equation is used to derive the appropriate S/N values given in Table 7.6-1 of Section 7.6.

7.4 SILICON DETECTORS

The silicon detectors will be P or N types, which allow the very low, dark current levels required to be achieved by using a surface grown passivation layer. Thus, a guard ring construction is not required and peripheral sensitivity cutoff can be made sharp. Figure 7.4-1 gives a plot of quantum efficiency vs. wavelength for typical silicon photodiodes; also shown are curves representing the maximum transmissivity of a silicon surface antireflection coated with SiO_2 vs λ , and the net quantum efficiency that may be expected.

For silicon detectors, in contrast to PM tubes, noise sources from both the detector and preamplifier must be considered since they are comparable; the total mean square noise current being the sum of the mean square noise currents resulting from the various significant noise sources discussed below. To obtain maximum responsivity, the detectors are operated with a reverse bias. The resultant dark current, I_D , contributes full shot noise plus $1/f$ noise. Allowing for a $1/f$ noise corner at 350 Hz, this noise current may be computed from:

$$I_{N2} = \sqrt{2.2 q I_D \Delta f} \quad (7.6)$$

There will also be a shot noise contribution from the signal current in each channel which is given by Eq 7.3 in Section 7.3. The remaining noise arises from the preamplifier and can often be the limiting performance parameter in video systems. Achieving optimum results within given constraints is not impossible, once some solid theoretical ground rules are established.

Unfortunately, much of the noise theory developed in the communications field is not applicable to video systems because one does not deal with a constant impedance signal source and receiver, but rather with a capacitive current or charge generator. Furthermore, the information from the source must be collected over a relatively wide band as dictated by the over-all resolution requirements of the system and not over a relatively narrow band optimally located in the frequency spectrum.

The noise produced by the silicon detector is principally the shot noise on the dark current. For a premium detector, this dark current should be not more than one nanoampere under operating conditions; hence, it is imperative that the input leakage current of the amplifier be small in comparison. The design (Figure 7.4-2) found to be most suitable for obtaining wide bandwidths and low noise is a current mode amplifier, designed to operate in a shunt feedback configuration.

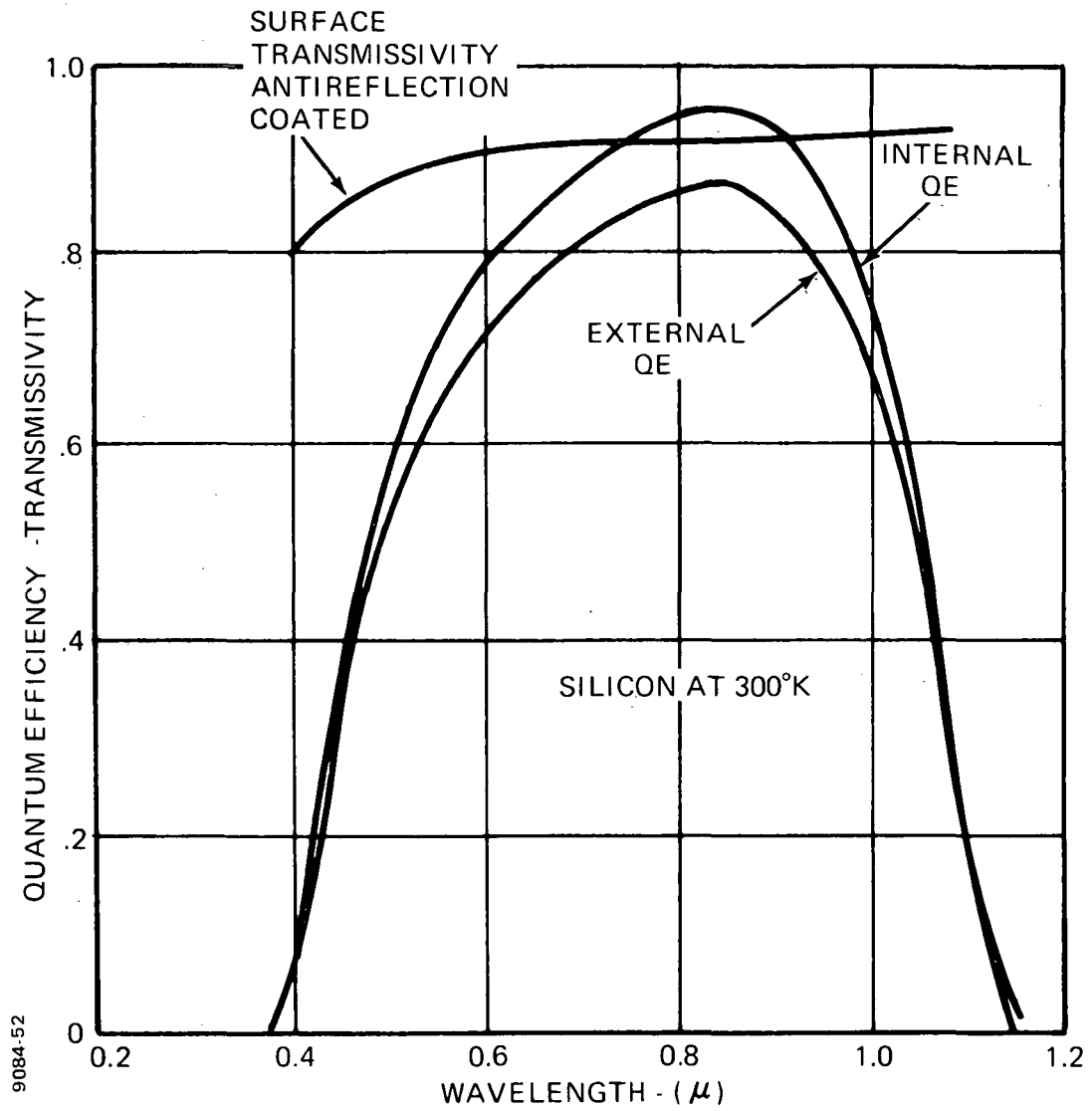


Figure 7.4-1 Quantum Efficiency of Silicon Photodiodes

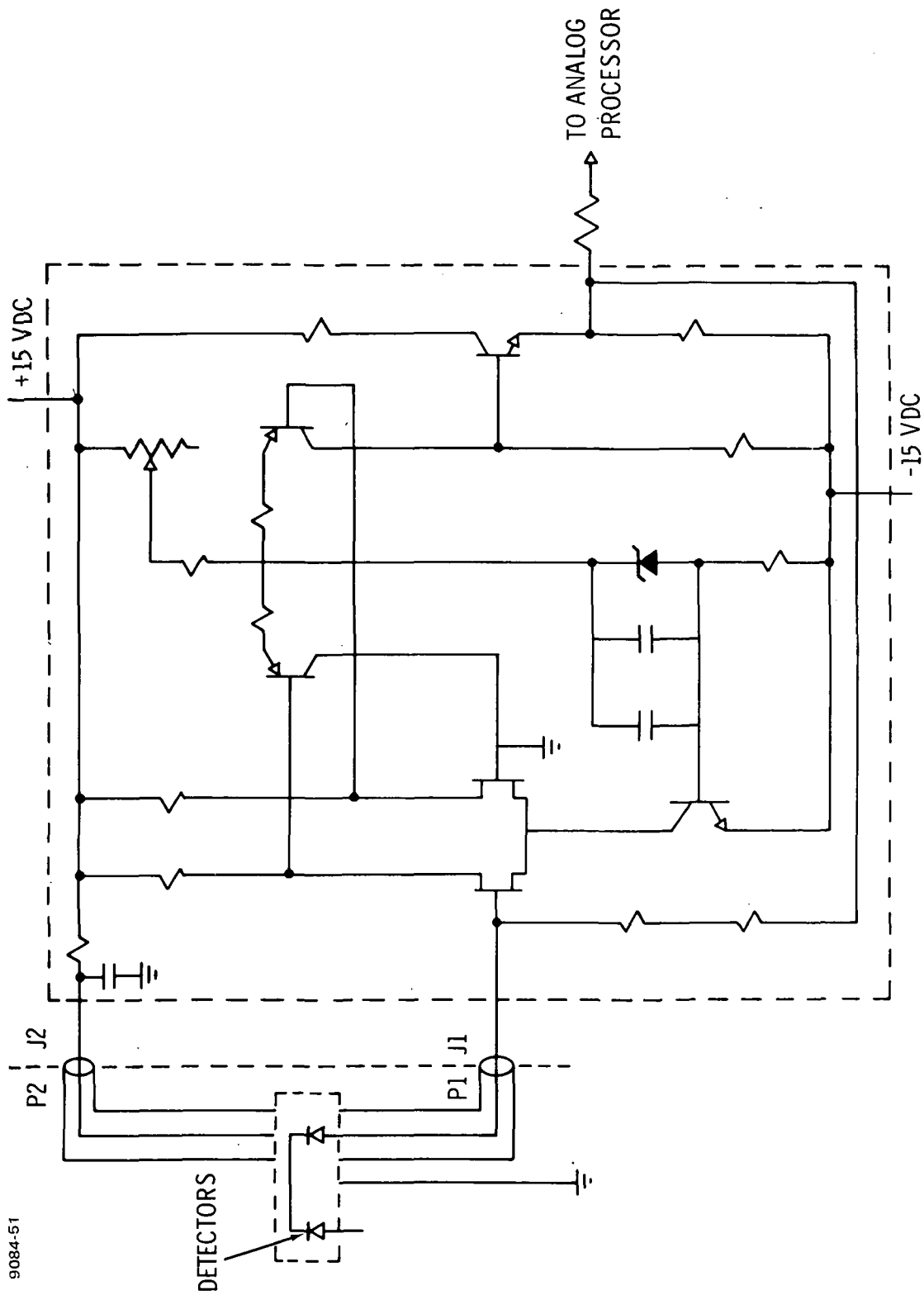


Figure 7.4-2 Preamp Design for Silicon Detectors

This design is similar to an inverting operational amplifier with a feedback resistor, R_f , from the output to the input. The transfer function of the amplifier for the video bandwidth is expressed as a transimpedance equal to R_f . When used with an FET input stage (i. e., negligible input leakage current), this type of amplifier has two basic noise components: one due to the thermal noise of the feedback resistor and a second due to the input noise voltage.

The thermal noise on the shunt feedback resistor, R_f , is given by:

$$I_{N3} = \frac{4K T_{Rf} \Delta f}{R_f} \quad (7.7)$$

where T_{Rf} = operating temperature of R_f

k = Boltzmann's constant

The minimum noise will result from the largest value of R_f . However, R_f has a parasitic shunt capacitance which imposes a limit on R_f so the video bandpass can be maintained flat and free from phase changes over the video frequency range. Typically, the required bandwidth can be met using a $10 \text{ M}\Omega$ feedback resistance which has a noise contribution from the above equation of $1.25 \times 10^{-11} \text{ A}$ at the input.

The selected preamp has a field effect transistor at the input to minimize the amplifier contribution to the total noise. This input FET is a 2N5564 which has a high transconductance and keeps the input noise voltage low, since this noise acts on the capacitance at the input to produce the major amplifier noise contribution at the output. The amplifier recently developed at Bendix has an equivalent input noise current with an electrically simulated detector of $1.54 \times 10^{-11} \text{ A}$ for the system noise bandwidth. This is within 22% of the thermal noise level as determined above and will only be significantly bettered by using higher transimpedances or cooling the feedback resistor.

The S/N values calculated for the bands using silicon detectors (Table 7.6-1, Section 7.6) are obtained by determining the signal current from Eq 7.1 and evaluating the noise as the RMS value of the measured preamp noise and the shot noise on the signal and the dark current using Equations 7.3 and 7.6.

7.5 HgCdTe DETECTORS

The simplest approach to evaluating the signal-to-noise ratio for HgCdTe detectors is to use the D^* equation.

$$S/N = \frac{P_D D_\lambda^*}{F_n A_D \Delta f} \quad (7.8)$$

where A_D = area of the detector

D_λ^* = detector figure of merit

F_n , the preamp noise figure, should be less than 1.1 for Eq 7.8 to be valid and this should be possible with proper preamp design. The photoconductive gain and the radiative lifetime are inversely proportional to one another so that the system requirements of high detectivity and short time constant are conflicting. In fact a $D^*\tau$ constant at a particular temperature is a good approximation to reality for a particular temperature and varying doping levels.

The poor frequency response of HgCdTe associated with the high D^* can be compensated to a certain extent by scaling the preamplifier response. However, care must then be taken to ensure that preamp noise does not become excessive.

For Band 7, the detector temperature will ensure that the detector performance is essentially background noise limited, but this will not be the case for Bands 5 and 6. For these bands thermal noise is dominant and will determine the final performance. The values for D^* given in Table 7.6-1 of the following section assume satisfactory development of HgCdTe as a detector at the shorter wavelengths and are consistent with the manufacturers expectations.

7.6 PERFORMANCE SUMMARY

Table 7.6-1 gives the expected S/N values for all bands using measured values for the detector responsivity and the preamplifier noise where possible. For the overland mode of operation, the values of P_D , $P_D/(P_D + P_A)$, and the S/N ratio assume a ground reflectivity ρ of 1.0 for which case the effect of the atmosphere is relatively small. In the oceanographic mode, however, the reflectivity of the ocean is less than 5% throughout the spectral range of the scanner. The values for the S/N ratio have been calculated for the ocean reflectivities given in Table 7.6-1. The noise equivalent reflectance $NE\Delta\rho$ is sometimes used in place of the S/N ratio and values for $NE\Delta\rho$ are therefore also given for the oceanographic mode. $NE\Delta\rho$ is defined as the reflectance difference which will cause a signal equal to the noise. It is numerically defined by the equation:

$$NE\Delta\rho = \frac{\rho}{(S/N)}$$

TABLE 7.6-1
PERFORMANCE SUMMARY

OVERLAND MODE											
Band	$\Delta\lambda$ (μ)	Detector	P_D (nW)	$\frac{P_D}{P_D + P_A}$ ($\rho = 1.0$)	Responsivity R_λ (A/W)	Δf (kHz)	Dynode Statistics Noise Factor	I_s (nA)	I_R (nA)	I_N (pA)	S/N ($r = 1.0$)
1	0.5 - 0.6	PMT	2.14	0.943	0.150	96	1.2 dB	0.32	0.34	4.04	79
2	0.6 - 0.7	PMT	2.16	0.968	0.115	96	1.2 dB	0.248	0.256	3.46	72
3	0.7 - 0.8	PMT	1.82	0.982	0.0575	96	1.2 dB	0.105	0.107	2.23	47
4	0.8 - 1.1	Si (Pv)	4.35	0.99	0.55		Preamp Noise I_D	0.239	2.42	17.0	140
							15.4 pA				
							Preamp Noise Factor				
							Area (sq mm)				
5	1.55 - 1.75	HgCdTe	0.825	1.0	$7 \cdot 10^{11}$	96	1.1	0.0355			89.5
6	2.2 - 2.4	HgCdTe	0.501	1.0	$8 \cdot 10^{11}$	96	1.1	0.0484			53.4
7	10.4 - 12.6	HgCdTe	0.367	1.0	$4 \cdot 10^{10}$	32	1.1	0.152			$\frac{NI\Delta T}{0.52}$
OCEANOGRAPHIC MODE											
PHOTOMULTIPLIER TUBES											
Band	λ (μ) ($\Delta\lambda = 160 \text{ \AA}$)	ρ	P_D (nW)	$\frac{P_D}{P_D + P_A}$	R_λ (mA/W)	I_S (10^{-12} A)	I_R (10^{-12} A)	I_N (10^{-12} A)	Δf (kHz)	Dynode Statistics Noise Factor	S/N $NI\Delta f$
1	4080	0.052	0.189	0.16	140	26.5	159	0.111	16	1.2 dB	24
2	4240	0.048	0.210	0.185	140	28.0	152	0.108	16	1.2 dB	25.9
3	4400	0.046	0.284	0.210	140	39.6	188	0.121	16	1.2 dB	32.8
SILICON DETECTORS $\Delta f = 16 \text{ kHz}$											
Band	λ (μ) ($\Delta\lambda = 160 \text{ \AA}$)	ρ	P_D (nW)	$\frac{P_D}{P_D + P_A}$	R_λ mA/W	I_S (pA)	I_R (pA)	I_N (pA) (Shot)	I_N (pA) (Dark Current)	I_N (pA) (Preamp)	S/N $NI\Delta\rho$
4	0.4560	0.046	0.457	0.23	177	80.8	350	1.34	2.26	6.5	11.5
5	0.4720	0.048	0.534	0.25	192	102	408	1.44	2.26	6.5	14.6
6	0.4850	0.049	0.591	0.265	2000	118	445	1.5	2.26	6.5	16.8
7	0.5040	0.041	0.542	0.282	212	115	408	1.44	2.26	6.5	16.4
8	0.5200	0.040	0.542	0.300	220	119	396	1.42	2.26	6.5	17.0
9	0.5360	0.036	0.550	0.315	230	126	400	1.43	2.26	6.5	18.0
10	0.552	0.036	0.551	0.330	250	138	408	1.45	2.26	6.5	19.7
11	0.568	0.034	0.528	0.342	260	137	400	1.43	2.26	6.5	19.6
12	0.584	0.032	0.508	0.352	273	139	396	1.42	2.26	6.5	19.8
13	0.600	0.026	0.420	0.365	290	123	338	1.31	2.26	6.5	17.5
14	0.616	0.026	0.391	0.380	305	119	316	1.27	2.26	6.5	17.0
15	0.632	0.024	0.356	0.392	320	117	298	1.23	2.26	6.5	16.7
16	0.648	0.023	0.324	0.405	340	110	252	1.13	2.26	6.5	15.7
17	0.664	0.023	0.309	0.413	358	110	263	1.76	2.26	6.5	15.7
18	0.680	0.022	0.290	0.429	377	109	254	1.13	2.26	6.5	15.5
19	0.696	0.022	0.277	0.440	395	108	246	1.12	2.26	6.5	15.4
20	0.712	0.021	0.251	0.454	415	104	230	1.08	2.26	6.5	14.8
21	0.728	0.020	0.221	0.470	434	96	202	1.03	2.26	6.5	13.7
22	0.744	0.020	0.210	0.485	450	94	193	1.00	2.26	6.5	13.4
23	0.760	0.020	0.195	0.500	478	93	186	1.00	2.26	6.5	13.3
24	0.776	0.020	0.192	0.512	500	96	187	1.00	2.26	6.5	13.7

SECTION 8

DETECTOR COOLERS

Passive detector cooling can be provided for the two IR band detectors and the single thermal band detectors. However, temperature requirements for these detectors are stringent and result in using highly specialized passive cooling methods and implementation of maximum thermal isolation from the OSS instrument. Severe packaging constraints dictated by the ERTS spacecraft configuration provide a difficult radiator or cooler packaging and mounting problem for all three bands. The result is a limited cooling capacity for the IR bands and the thermal band detector which is considered to be unsatisfactory if the required performance is to be obtained. The following sections and Appendix F describe a passive cooler capable of cooling bands 5 and 6 detectors to 195°K and the band 7 detector to 110°K . However, 150°K is considered as the maximum permissible temperature for bands 5 and 6 with 120°K as a design goal, while 100°K and 90°K are the corresponding values for band 7 (see Section 7.5).

Passive coolers capable of providing the required temperatures have been designed, * but they would not be compatible with the restricted packaging volume and field of view (FOV) available in the ERTS spacecraft. An entirely satisfactory solution to the design of a passive cooler for the OSS has yet to be found. However, an active cryogenic cooling system, as described in Appendix I, is a viable alternative to the passive cooler. It is capable of cooling the detectors to the design goals of 120°K and 90°K , respectively; would greatly ease the packaging problems; and could have at least a 1-year operating lifetime. On the other hand, a passive cooler has an indefinite lifetime and is about 10 lb less heavy. These advantages of the passive cooler make it highly desirable, but if it is preferred, a reduction in the performance of bands 5, 6, and 7 can be expected.

8.1 IR BANDS

The location of the detectors in the spectrometer require the use of an intermediate cold structure to connect the detectors to a radiator. Thus, the interconnecting structure must be of high thermal conductance to couple efficiently the radiator to the detector array. An effective insulation and support structure is also required to minimize extraneous thermal loads from the surrounding OSS components.

*"Design of a Dual Patch Multi-Element Radiant Cooler," R. V. Annable and J. F. Lodder. (ITT), Phase 1, Final Report, Contract NAS5-21132.

The radiator/cold structure arrangement which evolved from these considerations is presented in Figure 8.1-1. A conventional second surface mirror radiator of 48-sq in. area is mounted in a common support structure shared with the black-body calibration source radiator. By mounting the entire unit beneath the thermal band passive radiation cooler, the radiator looks in the antisolar direction normal to the plane of the orbit. The mounting bracket is configured to prevent direct solar radiation impingement, and a multilayer blanket is used to control the view to the underside of the radiation cooler and spacecraft torus section.

The cold structure terminates on the back of the radiator surface and is routed into the interior of the OSS instrument at the spectrometer. Thermal insulation is provided to the radiator back and all along the cold structure by use of multilayer superinsulation. The extraneous heat leak associated with this mounting arrangement, cold structure, and insulation is estimated to be 0.45 W (see Appendix F for analysis).

Figure 8.1-2 presents the estimated radiator temperature characteristics as a function of total power dissipation and orbit condition for the IR Band radiator/cold structure arrangement. The orbital day-night temperature swing is approximately 7°K. The "daytime" radiator temperature determines the ΔT allowable within the cold structure since the detector upper limit is 150°K. At the design dissipation level of 0.54 W, a minimum ΔT of 4°K is allowable within the cold structure; however, it is desirable to maintain the smallest possible ΔT . Ideally the cold structure should be a low temperature heat pipe. Heat pipes are available for application in this temperature range, and since operation occurs under near-isothermal conditions, it is recommended that the cold structure be a low-temperature heat pipe.

8.2 THERMAL BAND DETECTOR COOLING

Cooling of the thermal band (band 7) detector is accomplished using a passive radiation cooler having a precise orientation with respect to the spacecraft and orbital plane to maintain the maximum clear space view at all times. The selection of a passive cooler to cool the thermal band detector to its operating temperature is dictated primarily by weight and power restrictions as well as the poor performance-lifetime characteristics of more active cooling methods. The use of passive coolers to meet temperature requirements of the thermal band detector does, however, involve some technical risk due to many factors related to materials, analysis, and design state-of-the-art development problems.

The available FOVs in the horizontal and vertical planes are shown in Figure 8.2-1 and are critical to the passive cooler design. The restrictions imposed by the ERTS spacecraft are especially severe because of the mounting of the

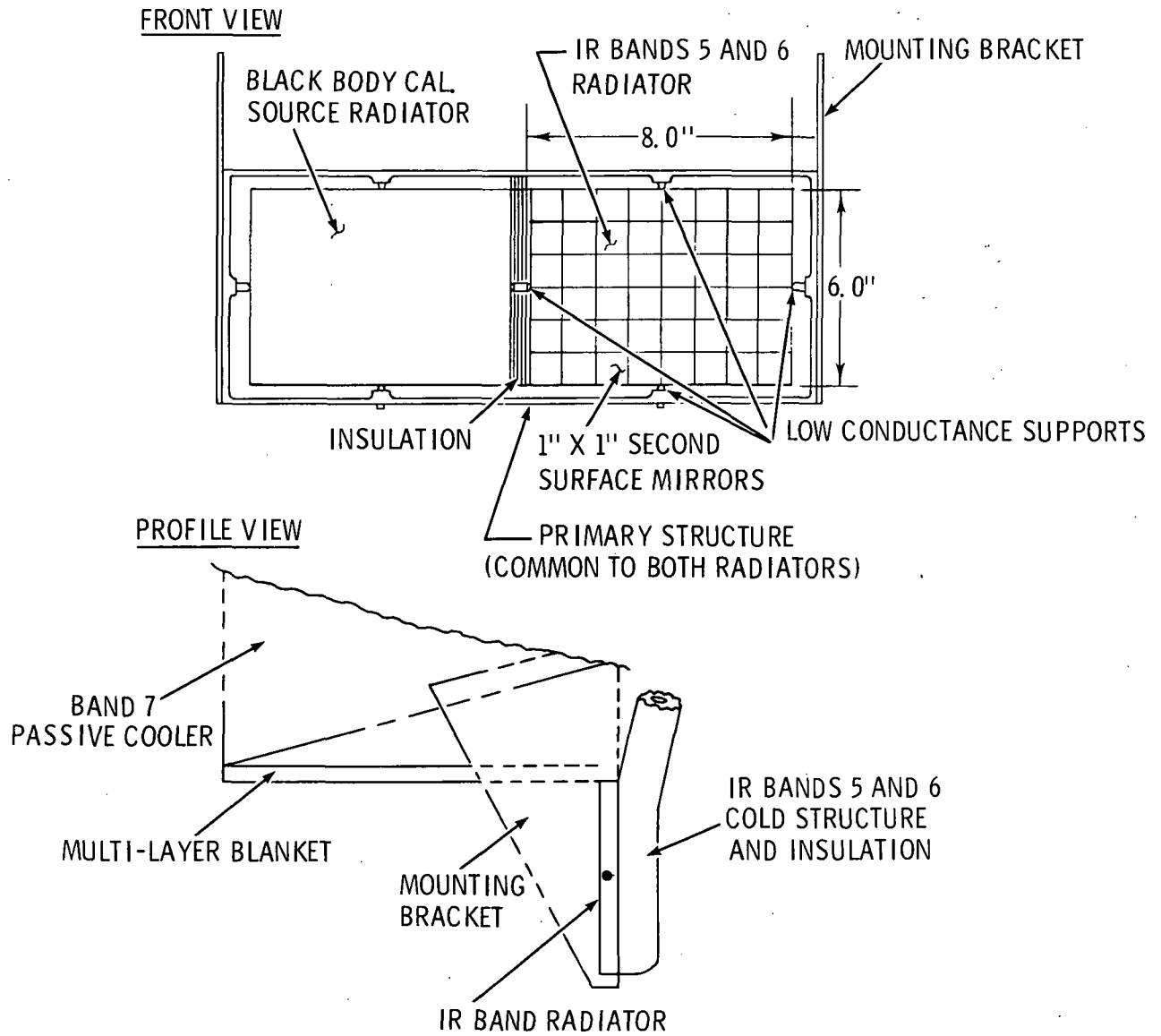
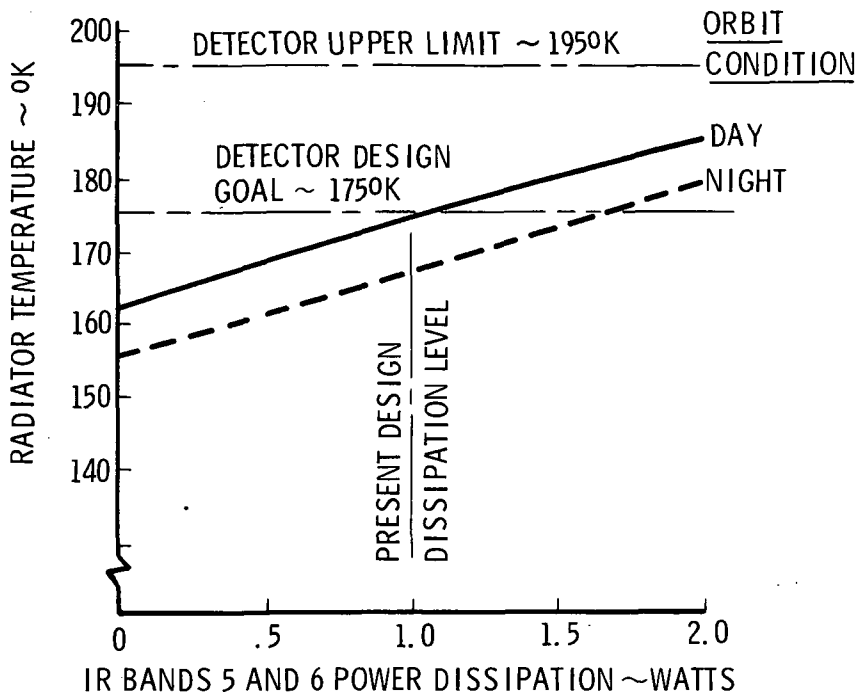


Figure 8.1-1 IR Band Detector Radiator Configuration

IR BANDS 5 AND 6 DETECTOR RADIATOR PERFORMANCE :



NOTE: DISSIPATION LEVEL INCLUDES THE FOLLOWING ESTIMATES:

1. DETECTOR SELF-HEATING	0.002 WATTS
2. DETECTOR LEAD HEAT LEAK	0.085 WATTS
3. OPTICAL PATH HEAT LOAD	0.100 WATTS
4. LOW CONDUCTANCE SUPPORT HEAT LEAK	0.100 WATTS
5. COLD STRUCTURE AND INSULATION HEAT LEAK	0.350 WATTS
6. RADIATOR MOUNTING HEAT LEVEL	0.350 WATTS
TOTAL	0.987 WATTS

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Figure 8.1-2 IR Bands 5 and 6 Detector Radiator Performance

(A) ORBIT AND SPACECRAFT CONSTRAINTS

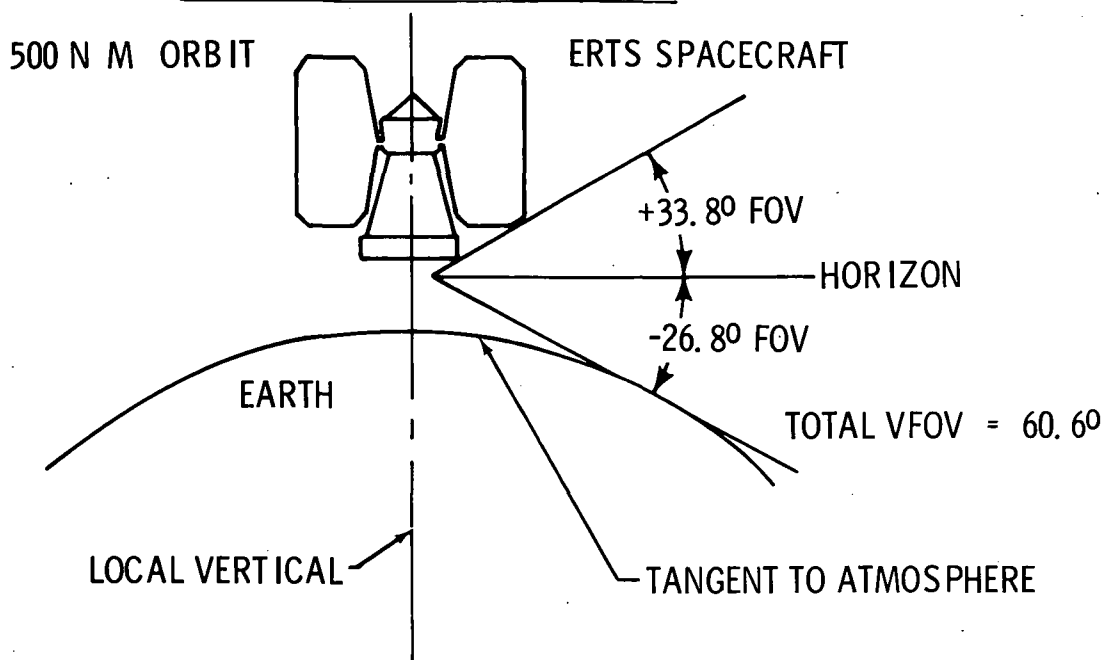
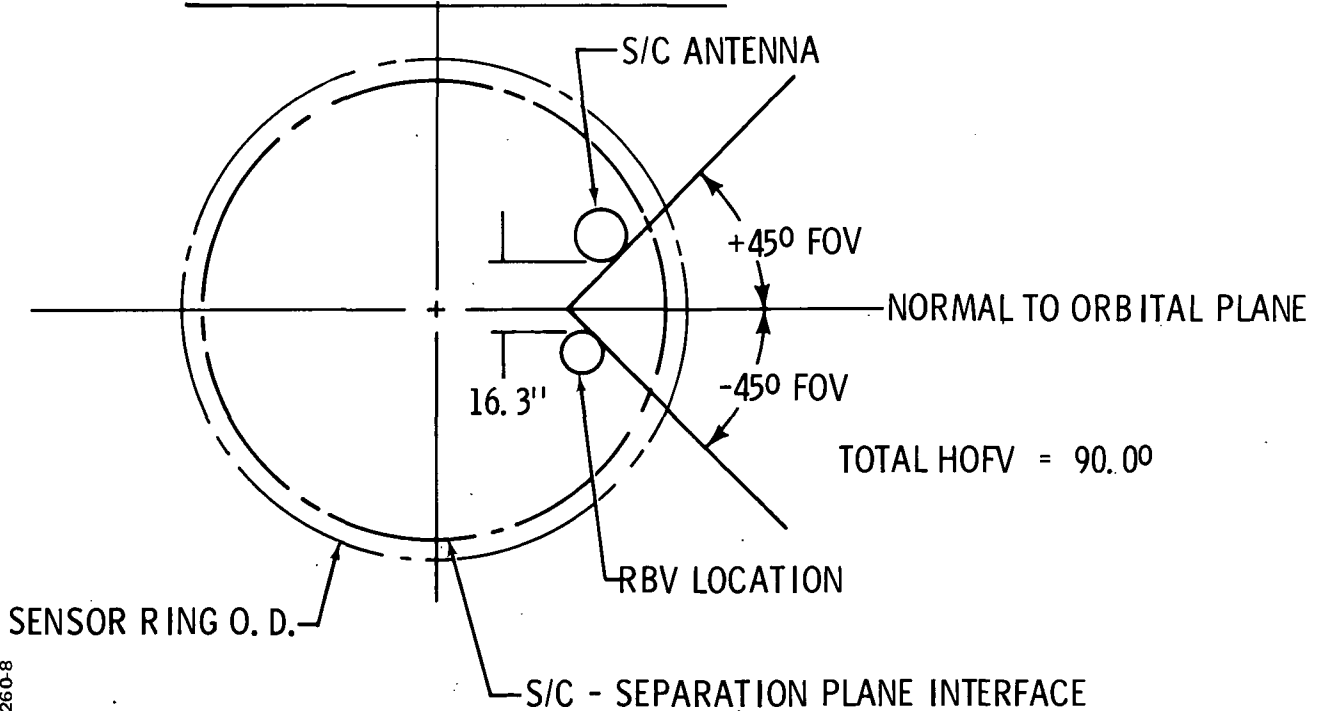
VERTICAL FIELD OF VIEW LIMITSHORIZONTAL FIELD OF VIEW LIMITS

Figure 8.2-1 Passive Cooler Field of View Limits

cooler beneath the torus section of the spacecraft and the location of the solar cell panels. The end result is an FOV in the vertical plane of 60.6° and the horizontal FOV limitation is 90° . These space view limitations combined with dimensional restrictions imposed by spacecraft protuberances and the launch vehicle clearances all combine to reduce, to some extent, the performance of a passive radiation cooler.

Figure 8.2-2 presents the thermal band passive radiation cooler configuration as evolved during the study period. The complexity of the detailed design of the cooler is such that only the major features are identified in the figure. To achieve a detector operating temperature of 100°K or less (Section 7.6) a complex thermal isolation configuration is required which must provide optical access to the detector while attempting to maintain near perfect isolation from surrounding heat sources. The passive cooler configuration of Figure 8.2-2 utilizes conduction and radiation isolation techniques both in geometry and selection of materials for critical surfaces and components. (See Appendix F for analysis.)

The passive cooler is a single-stage rectangular cone configuration having two auxiliary second-surface mirror type radiators in addition to the detector radiator. The primary structure is an aluminum outer cone containing the cooler mounting provisions and it is encased in a multilayer superinsulation shroud. The first-stage auxiliary radiator is attached to the outer cone and is designed to reject the heat load reaching the outer cone via conduction and radiation from the OSS instrument and other exterior sources. The interior cone, an optical specular reflector, is supported from the outer cone with low conductance supports and also protected from radiation by a multilayer superinsulation blanket. The interior cone is the primary shield for the detector radiator and is configured to optimize the clear space view of the radiator.

The detector radiator is constructed of aluminum honeycomb painted with high-emittance black paint and is suspended from an inner suspension frame with eight 3-mil stainless steel wires. The thermal band detector is fastened to the backside of this radiator within the suspension ring in line with the optical path. The inner suspension frame serves as the mounting structure for the second-stage auxiliary radiator around the periphery of the detector radiator. The inner suspension frame is mounted to the outer suspension frame by means of four stainless steel low-conductance standoff isolators. This outer suspension frame is connected to the main support frame through low-conductance supports. Multilayer superinsulation blankets are used throughout this assembly to minimize radiant interchange between components. The second-stage auxiliary mirror is designed to "detour" all extraneous thermal loads away from the detector radiator wire suspension system and develop minimum inner suspension frame temperatures.

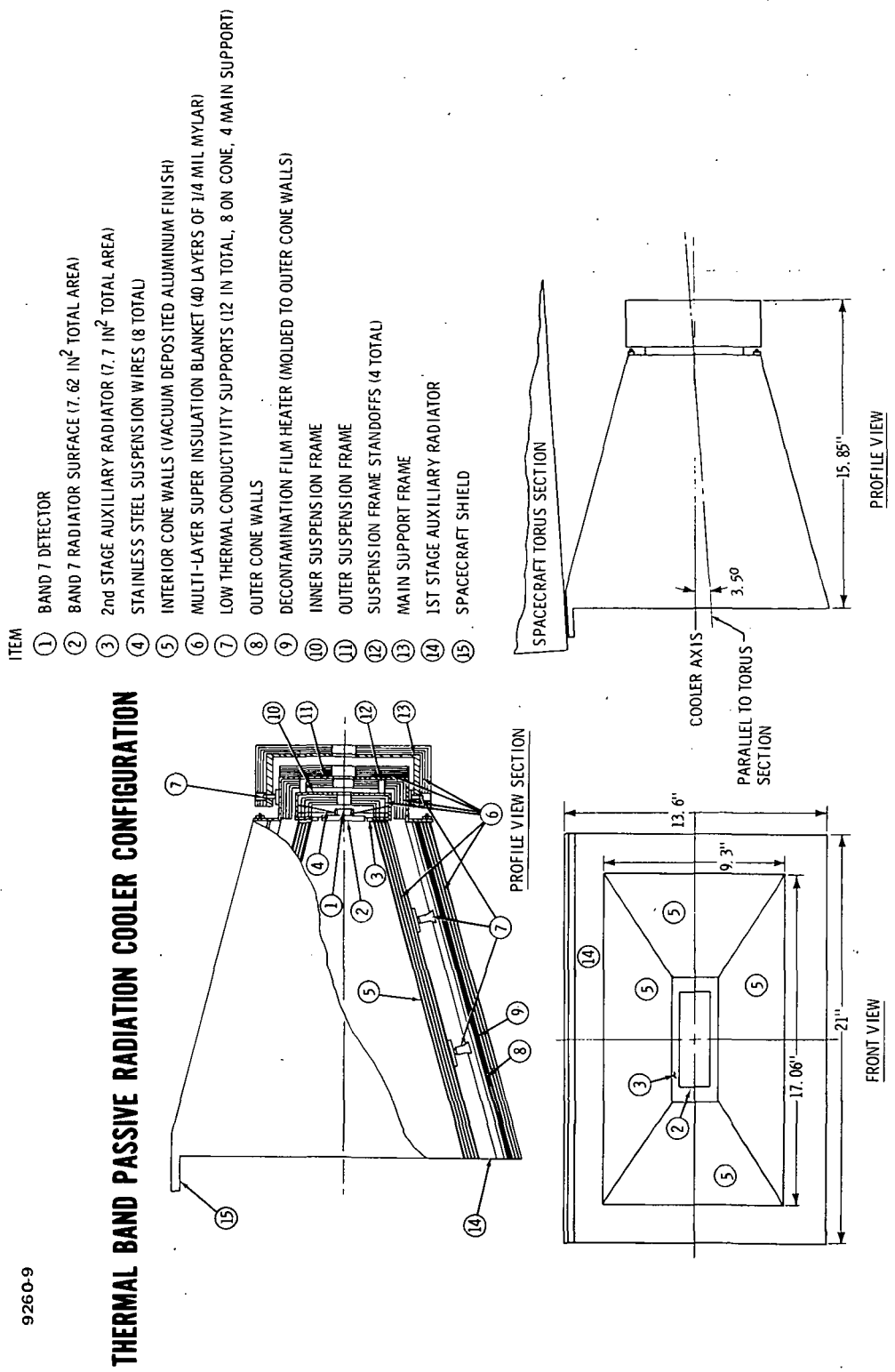


Figure 8.2-2 Thermal Band Passive Radiation Cooler Configuration

Detailed thermal analysis of the passive cooler was performed with typical thermal/optical characteristics assumed for the critical surfaces. In all cases, values for surface emittance or α/ϵ ratios were realistic or conservative. Table 8.2-1 lists emittance values used for the most critical surfaces.

TABLE 8.2-1

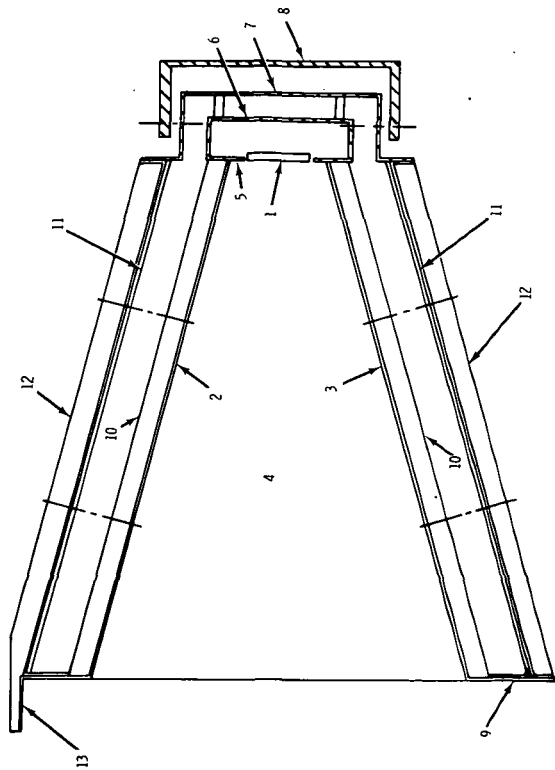
CRITICAL SURFACE THERMAL/OPTICAL CHARACTERISTICS

Surface	Material	Emittance
1. Detector radiator	Aluminum honeycomb painted with high emittance black paint	0.98
2. Cone interior walls	Vacuum-deposited aluminum upon electrodeless nickel-plated substrate	0.05
3. Auxiliary radiators	Vacuum-deposited silver on fused silica	0.81
4. Multilayer blankets	1/4-mil aluminized mylar	0.10

The thermal analysis effort for the radiation cooler configuration was used to guide the design of the passive cooler and to substantiate the concepts employed to provide the required isolation. A summary of the results of this analysis is presented in Figure 8.2-3 for three basic conditions which correspond to a baseline, a nighttime orbit, and a daytime orbit condition. The baseline condition is used to establish a reference point for temperature performance evaluation purposes and assumes the cooler is connected to the spacecraft with no other heat inputs.

The results of the analyses indicate that the design radiator temperature (110°K maximum) is not achievable in either a nighttime or a daytime orbit condition. It was determined that this is due to the small earth view available to the interior top surface of the cone which receives sufficient earth-associated thermal radiation to elevate the interior cone temperature to an unacceptable level. The cone walls in turn reradiate to the detector radiator at a level which is sufficient to raise the radiator temperature above its maximum permissible value. To eliminate this problem, a shield is required which will block the earth view to the cone interior. The shield configuration required has not been determined since it

9260-10



ITEM	CONDITION A TEMP (°K)	CONDITION B TEMP (°K)	CONDITION C TEMP (°K)
1 RADIATOR	78.2	111.3	114.5
2 CONE INTERIOR TOP	85.8	122.2	125.5
3 CONE INTERIOR BOTTOM	85.8	120.8	124.5
4 CONE INTERIOR SIDES	85.8	121.2	124.7
5 2ND STAGE AUXILIARY RADIATOR	80.0	114.5	117.5
6 INNER SUSPENSION FRAME	81.7	116.4	119.7
7 OUTER SUSPENSION FRAME	150	205	228
8 MAIN SUPPORT FRAME	300	300	300
9 1ST STAGE AUXILIARY RADIATOR	148.8	205	228
10 INTERIOR BLANKET	92.2	141.7	156
11 OUTER CONE	150	205	228
12 EXTERIOR BLANKET	186.5	219	247
13 SPACECRAFT SHIELD	147.5	206.5	230

CONDITION A: BASELINE CONFIGURATION WITH COOLER CONNECTED TO SPACECRAFT. NO DIRECT EARTH EMISSION OR EARTH REFLECTED SOLAR HEAT LOAD TO COOLER. ALSO NO ELECTRONIC OR OPTIC LOAD TO RADIATOR.

CONDITION B: BASELINE CONFIGURATION WITH COOLER CONNECTED TO SPACECRAFT. ESSENTIALLY A "NIGHT-TIME" CONDITION WITH DIRECT EARTH EMISSION BUT NO EARTH REFLECTED SOLAR HEAT LOAD TO COOLER. AN ELECTRONIC AND OPTICS HEAT LOAD OF 5.5 MW IS PRESENT ON THE RADIATOR.

CONDITION C: BASELINE CONFIGURATION WITH COOLER CONNECTED TO SPACECRAFT. "DAYTIME" CONDITION WITH BOTH DIRECT EARTH EMISSION AND EARTH REFLECTED SOLAR HEAT LOAD TO COOLER. AN ELECTRONIC AND OPTIC HEAT LOAD OF 5.5 MW IS PRESENT ON THE RADIATOR.

Figure 8.2-3 Thermal Band Passive Radiation Cooler Performance

must be developed in conjunction with other constraints relative to OSS instrument position, etc. Thermal analysis of the effect of earth shielding indicates the detector radiator temperature would decrease by approximately 10°K for both daytime and nighttime orbit conditions. Such a decrease would bring the detector temperature to an acceptable level and provide satisfactory cooler operation at all times.

Contamination of the passive radiation cooler is recognized to be a difficult problem. Provisions have been incorporated for a decontamination heater (of molded film type) to be attached to the outer cone of the passive cooler. The purpose of the heater is to supply sufficient heat to elevate periodically the temperature of the detector radiator to approximately 300°K and drive off undesirable contaminants deposited from the spacecraft and OSS instrument outgassing products. The exact details of the heater system are undefined; however, activation must be upon ground command and a thermal "short circuit" established between the outer and interior cones to ensure adequate heat transfer from the heater to the interior cone walls. The implementation of this concept may require either thermostatic activation of bimetallic conduction elements, a thermal switch, or similar mechanisms. The decontamination provisions could also be incorporated into the earth shield arrangement. Several possible and feasible methods are available, but selection cannot be made without a more detailed investigation and analysis of the entire contamination problem.

SECTION 9

ELECTRONICS SUBSYSTEM DESIGN

In a previous report* which defined the preliminary requirements for a spaceborne MSS, it was determined that sensor data should be digitized prior to the first recording process if data fidelity and registration are to be maintained. Since multichannel data must be recorded and/or transmitted on a single channel, these video signals must be processed, digitized, and multiplexed in the spacecraft. This section will discuss the considerations which led to the selection of each electronic technique. The scanner system described is designed to operate in either of two operational modes as determined by an uplink command: overland or oceanographic. The electronic design requirements applicable to each mode are defined in Table 9-1 along with other pertinent basic design parameters. Uplink commands allow selection of either real-time or delayed data transmission.

The digital data handling method was chosen for many reasons. The most important of these are: (1) the facility of the digital system to allow data to be transmitted over the complete scan period rather than just during the active scan time and (2) the ability to guarantee the fidelity and time registration of the data even though the data are subsequently processed through several communications links and storage devices. Video data from the spectral detectors will be sampled, digitized, and temporarily stored before being transmitted. The high instantaneous rate at which a multispectral scanner produces data may be incompatible with normally available data transmission links, but by buffering the scanner data before transmission it can effectively be transmitted at a lower rate rather than at the instantaneous rate.

Signal processing and data handling methods are heavily influenced by the characteristics of the selected spaceborne multispectral scanner system. Of particular importance are the collection rate and quantity of data that are collected during a given scan interval as compared to the capabilities of the spaceborne tape recorder and/or the data transmission link. The quantity of data obtained from the multispectral scanner is influenced by scanner IFOV, resolution element size, spacecraft height and velocity, and level of digital conversion. These parameters

* Bendix Aerospace Systems Division, Multispectral Scanning System for Earth Resources Remote Sensing From Space, Phase A-Preliminary Analysis, BSR 2902.

TABLE 9-1
ELECTRONIC DESIGN REQUIREMENTS

	Overland Mode		Oceanographic Mode		
	1-6	7	1-24	Bands 25 & 26 (Overland Mode) Bands 1 & 4	Band 27 (Overland Mode) Band 7
No. of Channels	36	2	24	12	2
Ground Resolution (ft)	200	600	1,200	200	600
Cell Time, T_d (μ sec)	5.2	15.6	31.2	5.2	15.6
No. of Cells/Scan	3,552	1,184	592	3,552	1,184
Video Band-Width (kHz)	300	100	50	300	100
Transmission Data Rate (Mbps)	14,976			14,976*	

*Includes Blanks and Dead Spaces

determine the time available to scan an element T_d (dwell or cell time), an interval which determines the required A/D conversion rate and data buffer speed (Sections 4.1 and 9.5).

A functional block diagram of a typical single electronics channel used in the selected system is presented in Figure 9-1. By uplink command, video data from either an oceanographic or overland Mode preamplifier can be routed to an analog processor where it is sampled in one of two ways: either by an integrate and hold, or by a sample and hold circuit. In general, the choice depends upon the detector capability for a given spectral region and the operational mode (overland or oceanographic) of the system. Sampled data which are held constant at the sampler output for a complete element period are converted to 6-bit digital words and stored in the data buffer. Buffering permits the data to be transmitted at an average rate rather than at its instantaneous collection rate. Data from the buffer are time-multiplexed with frame sync and ancillary data in the data formatter. The formatter transmits serially these time-multiplexed digital data to either the video tape recorder or to the downlink transmitter.

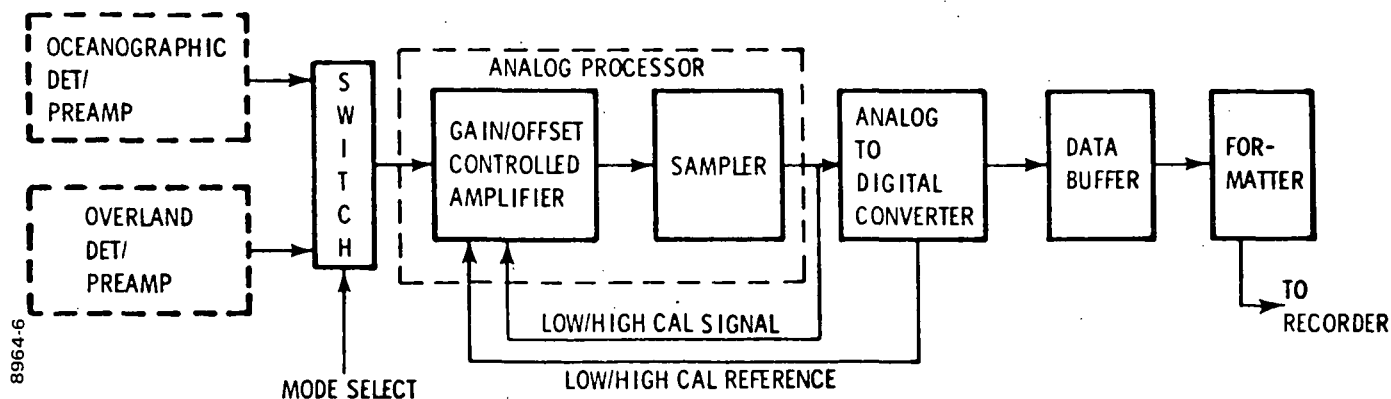


Figure 9-1 Typical Electronics Channel

9.1 ANALOG PROCESSOR

The analog processor accepts the signal from the detector preamplifiers and conditions it by amplification and dc offset prior to sampling the signal with an integrate and hold circuit. The analog processor thus has two prime functions - video processing and sampling. The analog processor design takes into account the following considerations:

1. Detector variations vs. temperature

2. Gain and offset control
3. Noise bandwidth
4. Modulation transfer function (MTF)
5. Factors contributing to data registration errors.

9.1.1 Video Processor

The design of the electronics is such that knowledge of the expected scene radiance levels will permit the design to be optimized, thus allowing maximum use of the data link. One relatively simple method of accomplishing this is to arrange the calibration source levels (high calibration and low calibration) so that the maximum and minimum excursions of scene radiance lie at or between the two calibration source levels. Then at the output of the analog processor, the high calibration and low calibration signal levels define the signal extremes. The A/D converter will thus digitize only the variable portion of the signal. This procedure removes a known dc component of the signal, thus providing optimized signal resolution by the A/D.

To accommodate the wide range of scene radiance levels which may occur (such as between arid regions and tropical regions), appropriate optical filters, suitable to the region, are inserted between the calibration source and the scanner mechanism (see Section 5). Changes of these calibration source filters imply a change in gain and dc offset of the signal, if the signal excursions are to be matched to the A/D input range.

9.1.2 Sampler

The sampler establishes the noise bandwidth and electronic MTF of the signal. It also provides a signal suitable for A/D conversion as required for an operational MSS.

It is desirable to minimize the noise bandwidth while at the same time maintaining the electronic MTF as near 100% as possible out to $1/2 T_d$ (where T_d is the integration period). Also, it is necessary that there be no variation in phase from channel to channel to eliminate electrical misregistration.

A video processor followed by an integrator using an "integrate-hold dump" cycle for period T_d best satisfies these requirements. This circuit requires stable gain and offset control. Its 70.7% MTF point is located near a frequency of $\frac{0.5}{T_d}$

and is primarily determined by the integration time. The integration cycle is shown in Figure 9.1-1.

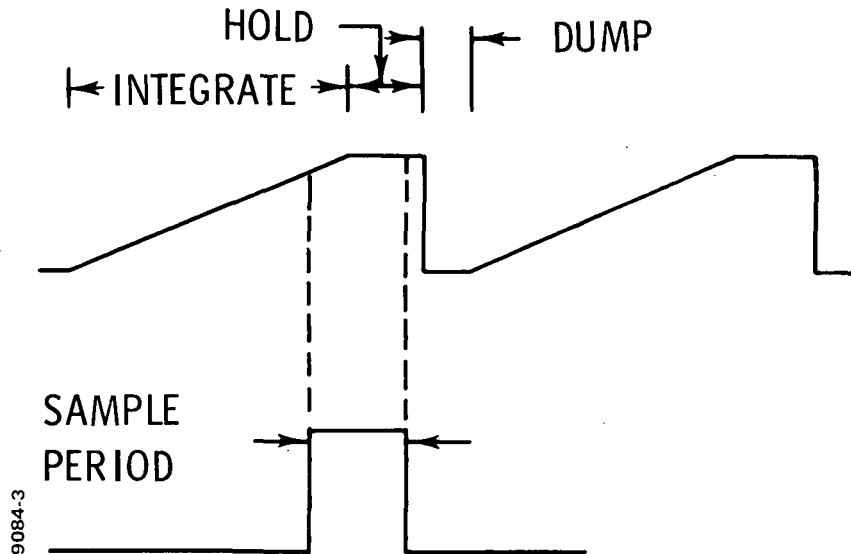


Figure 9.1-1 Integrate-Hold-Dump Cycle

Therefore, with accurate control of the integration period, MTF channel-to-channel tracking is easily obtained. Timing for the integration period is obtained from the reference oscillator and is therefore very precise.

The integrate-hold-dump circuit MTF follows a $\frac{\sin x}{x}$ roll-off characteristic and thus has a narrower noise bandwidth than a simple single pole filter with a 6-dB/octave rolloff.

Multiple pole filters have a narrower noise bandwidth than the integrate hold-dump circuit; however, their phase shift becomes more unpredictable on a channel-to-channel basis. Thus, if a common signal, such as a step function, were applied to several channels, the response to this signal could be different. The variation in response time contributes directly to the misregistration error. Therefore, such filters are not used except for Bands 5 and 6.

Bands 5 and 6 in the overland mode have a unique problem compared with the other bands, in that the rise times of the available detectors are slow, resulting in a low modulation transfer function (MTF) (Section 7.5). An improved MTF

for these bands can be achieved by performing a "sample and hold" rather than an "integrate and hold" function. It is also necessary to increase the bandwidth of the previous bandwidth limiting stages. In the event suitable detectors become available for these bands, the integrate and hold circuit is preferred.

9.1.3 Analog Processor Design

Figure 9.1-2 is a block diagram of the analog processor. It has the capability of meeting all the preceding requirements and will interface with all detector preamp types. The functions of the analog processor are shown in Figure 9.1-3.

It should be noted that proper operation of the automatic control loops is not dependent upon receiving a signal by scanning the ground. The signals used are those obtained while scanning the calibration sources. Figure 9.1-4 is a more detailed block diagram of the analog processor. The integration time constants of the control loops are very long compared to the duration of calibration source scanning. Thus, any low level noise is integrated out, and the control voltage is the result of many samples of the calibration source.

The analog processor accepts a signal from the detector preamps and conditions the signal for A/D conversion. The conditioning includes the following steps:

1. Amplify the signal from the preamp
2. Automatically calibrate dc offsets and amplifier gain
3. Sample the signal for A/D conversion.

As can be seen in Figure 9.1-3, the signal contains two discrete levels (high cal and low cal) and the signal of the active scan period. The active scan signal amplitude lies between the "hi cal" and the "low cal" levels. This relationship has been established by judicious tailoring of the spectral output of the calibration sources. The signal is amplified and clamped so that the low cal level is set at a level corresponding to two "least significant bits" (LSBs) above the lower limit of the A/D conversion and the hi cal level set at a value corresponding to two LSBs below the maximum input level of the A/D conversion. This signal is sampled at 5.2- μ sec increments in the overland mode and 31.2- μ sec increments in the oceanographic mode.

As can be seen in Figure 9.1-2, the signal passes through a variable gain amplifier which has an integrated circuit amplifier whose gain is controlled by a dc level from the automatic calibration control loop. Subsequent amplifier stages provide a constant amount of additional gain.

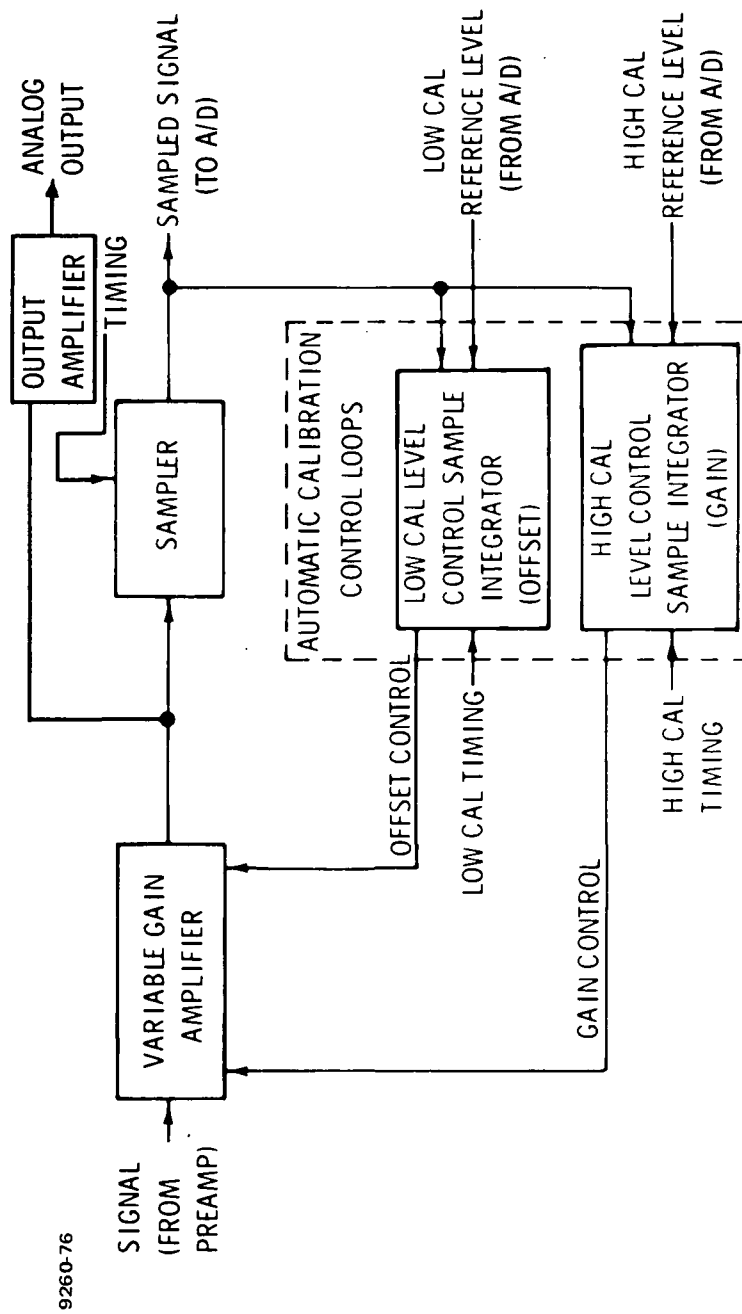


Figure 9.1-2 Analog Processor Functional Block Diagram

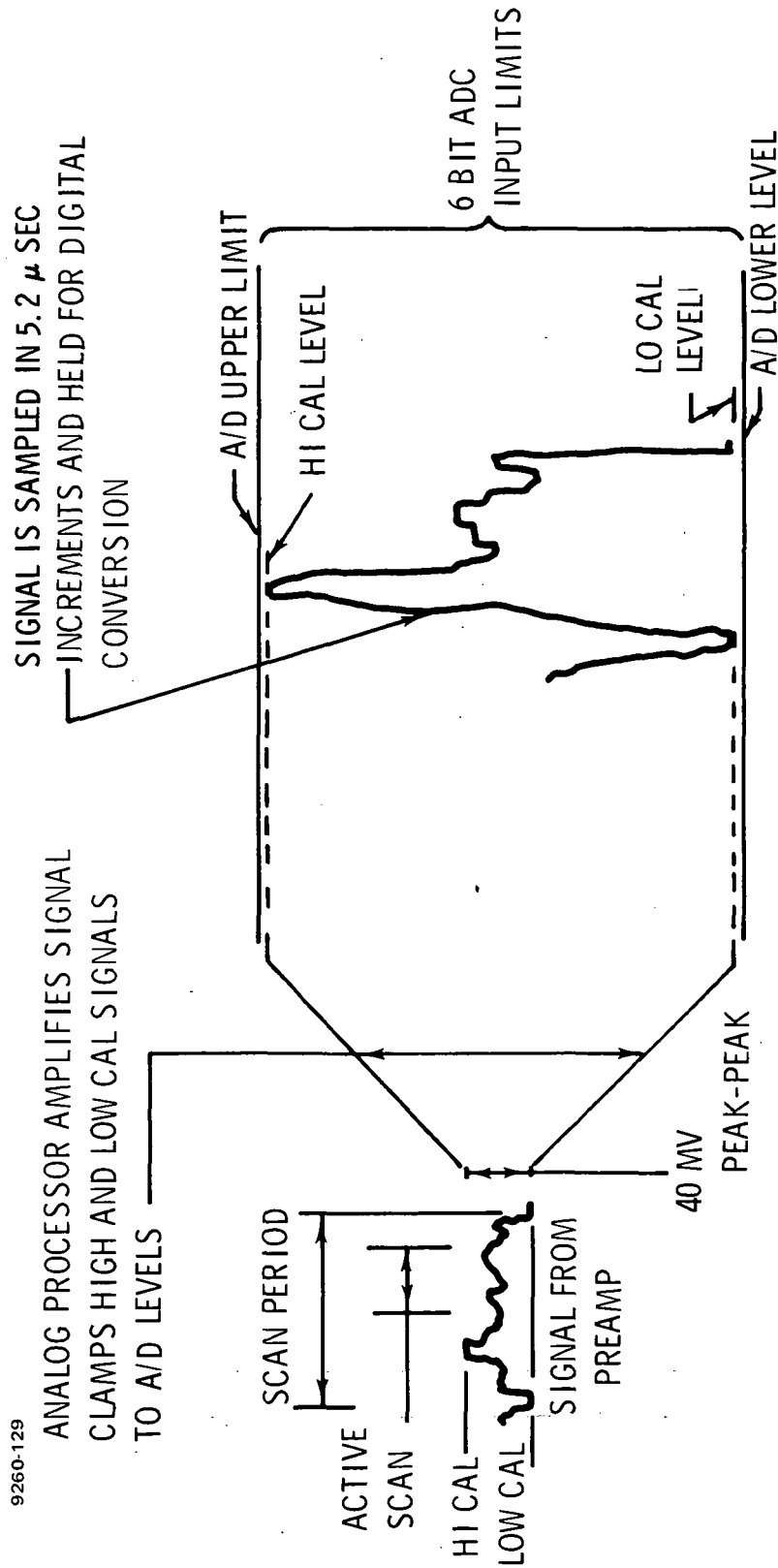


Figure 9.1-3 Analog Processor Functions

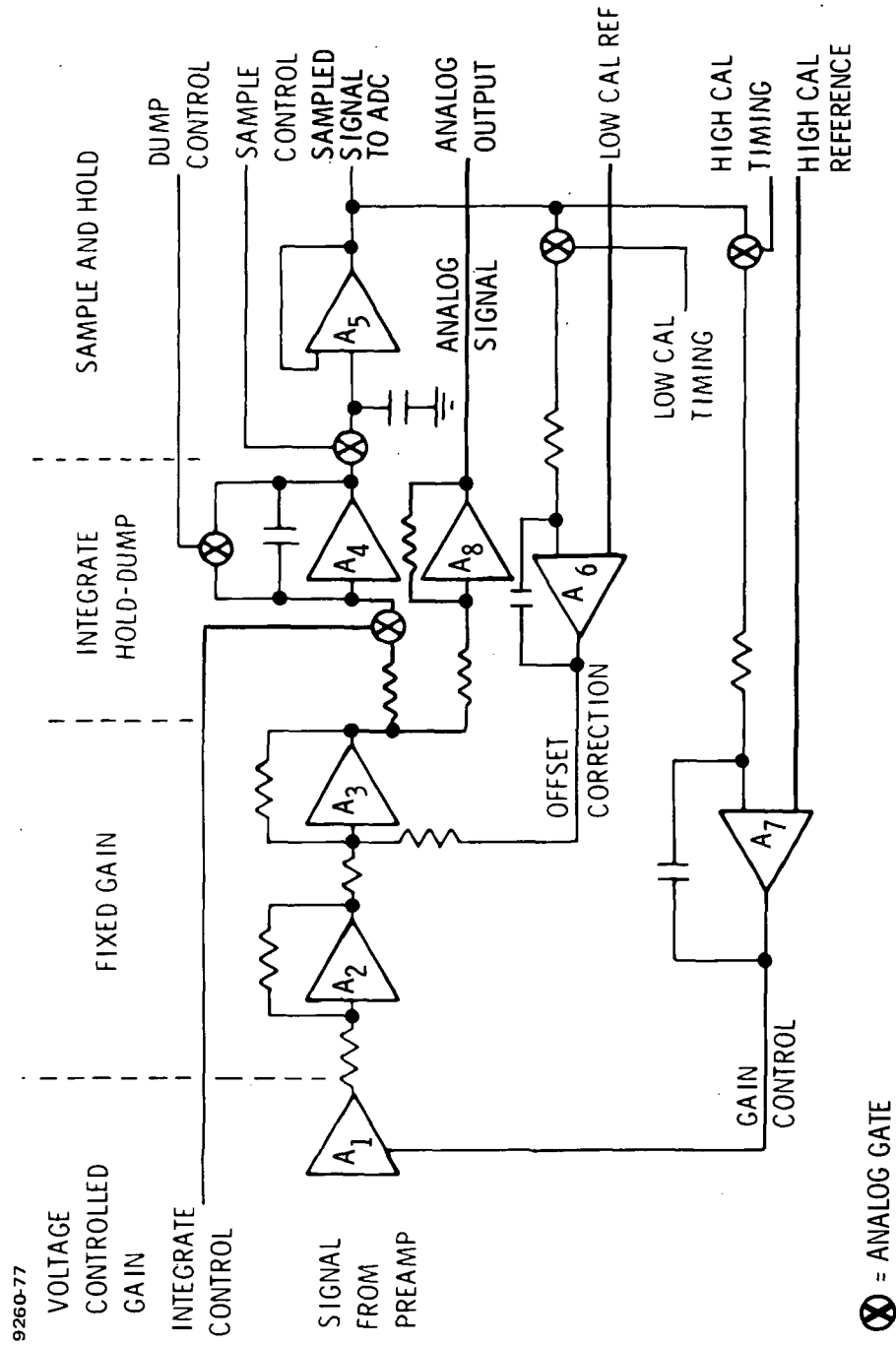


Figure 9.1-4 Analog Processor

The sampler consists of two stages. The first stage can be operated in either of two modes: (1) simple bandpass-limited amplifier or (2) an integrator following an integrate-hold-dump cycle. The second stage is a sample and hold circuit which samples and holds the signal.

When operating in the amplifier mode, the two circuits perform a sample and hold function while in the integrator mode the two circuits perform an integrate and hold function. A common design will therefore meet the requirements of all bands.

As shown in Figure 9.1-4, the sampler is contained within the feedback control loops which set the gain and offset of the processor. The effect of this is to cancel out any errors which may occur in the amplification and sampling processes. The low cal reference and high cal reference levels are obtained from the A/D conversion by directly setting the A/D conversion to the appropriate state (see Section 9.2 for A/D conversion detailed description), thus matching the analog processor gain and offset levels to the A/D conversion analog range. The advantages of this circuit arrangement are:

1. There are no trimpots throughout the analog processor or A/D conversion.
2. There are no specially selected parts.
3. The system is automatically adjusted for aging effects.
4. The analog errors through the analog processor and A/D conversion are approximately $1/16$ of a least significant bit (LSB) or less and can therefore be ignored.
5. The combination of automatic calibration control and judicious design of the calibration sources with a 6-bit ADC results in a system which optimizes the use of the 6-bit encoding capability.

9.2 ANALOG-TO-DIGITAL CONVERSION

Two basic reasons for preferring digital over analog data handling are: (1) ability to guarantee the fidelity and time registration of data from channel-to-channel and (2) ability to permit data transmission over the complete scan interval rather than during the active scan interval only. The former permits geometrically more accurate "pictures", the latter permits a lower data transmission rate for a given number of cells per scan interval. Channel-to-channel time registration is assured by sampling the data in all 38 channels simultaneously: i. e., data from each channel are sampled and held for subsequent analog to digital (A/D) conversion.

9.2.1 Design Considerations

The OSS system has 38 analog channels of data which must be digitized. This may be accomplished by utilizing:

1. One A/D for the entire system (common connector).
2. One high speed, high power A/D for several channels, (two converters/band).
3. One low speed, low power A/D per channel (dedicated converters).

A speed vs. power trade-off analysis was performed for the three approaches with the results being shown in Table 9.2-1. In general, speed is directly related to power consumption. For a successive approximation A/D, power vs. speed trade-offs can be made for each of the three basic elements of this type of A/D:

1. Logic elements (high speed TTL, standard TTL, and lower power TTL)
2. Current ladder and switches
3. Differential comparator.

The initial design utilized method two in which the existing Multispectral Scanner and Data System (MSDS) 8-bit A/D design was modified for 6-bit operation. By utilizing transistors which are faster than those in the MSDS design, an A/D conversion in 0.5 μ sec is possible. This permits the use of a single A/D for every three or four OSS channels, provided that both analog multiplexing and digital demultiplexing functions are included. Each A/D consumes about 1.7 W of power.

The use of dedicated A/Ds for each of the electronic channels is not practical unless their power dissipation is very small. It is estimated that the power required

TABLE 9.2-1
ANALOG-TO-DIGITAL CONVERTER CONSIDERATIONS

Approach	Type (6 Bit)	Channels Per ADC	Max Bit Rate (Bits/ μ Sec)	Capability of ADC (Bits/ μ Sec)	Power Req/ADC (W)	System Power Req. (W)
Common Converter	Parallel	38	51.8	120	15	15
Two Converters Band	Successive Approximation (High Speed)	3	3.8	12	1.3	17
Dedicated Converter	Successive Approximation (Low Speed)	1	1.36	2	0.27	10.2

for the MSDS converter can be reduced to about 270 mW provided that: (1) low power TTL logic is utilized, (2) the current switches are modified so that the currents are reduced by a factor of ten, (3) a lower power differential comparator is incorporated, and (4) the R-2R-4R ladder is replaced by an R-2R ladder with reduced operating voltages. Circuits were breadboarded to verify the effects of these changes.

The parallel A/D was not constructed, however, an analysis of its power-speed characteristics was performed. Only one such A/D would be required per system. It would be comparable on a power/bit basis to 13 high speed successive approximation A/Ds. Again, the analog multiplexing and digital demultiplexing would be required. This approach, however, was not selected for the OSS system because it requires state-of-the art components and design techniques, and because of its high power consumption.

Approach 3 is the selected approach because it results in the lowest system power and the highest system reliability, since each channel of electronics is independent of all others having its own A/D. The only penalty resulting from this choice is the increased number of components; however, adequate space is available to package these components using hybrid microelectronics.

9.2.2 A/D Converter Functional Description

The OSS analog-to-digital converter (A/D) is of the successive approximation type. The functional block diagram is shown in Figure 9.2-1. It is a six-bit A/D and, thus, will encode the analog data into 64 possible levels (2^6).

Functionally, the A/D plays a question and answer game. Therefore, the A/D has two basic parts: (1) logic - which poses the question and provides memory, and (2) an analog section that converts the question into an analog signal (digital-to-analog converter) such that a decision can be made by the differential comparator.

The "differential comparator" is an analog differential amplifier with a TTL logic compatible output. It decides if the measured signal is "more-than" or "less-than" the reference level voltage generated through the summing resistor. The current sources are scaled in a binary fashion (I , $I/2$, $I/4$ --- $I/32$) so that voltages of IR and $IR/32$ correspond to the "most significant bit" (MSB) and the "least significant bit" respectively. If all of the current sources are switched off then the voltage is 0.0 V which corresponds to the zero scale of the A/D. Likewise if all of the switches are on, the voltage is $\frac{63}{32} IR$.

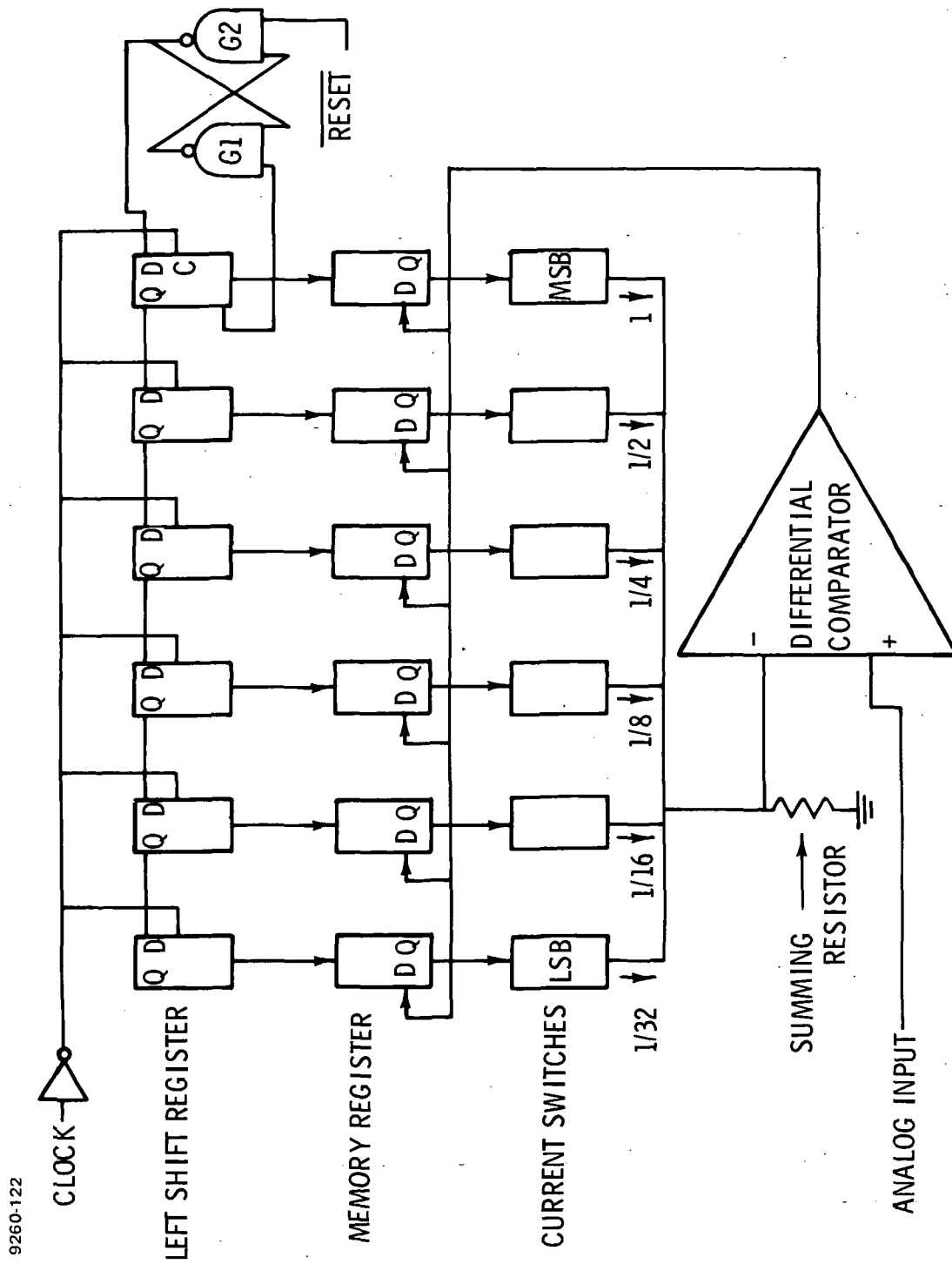


Figure 9.2-1 Functional Block Diagram of Analog-to-Digital Converter (Successive Approximation Type)

TABLE 9.3-1

DATA BUFFER REQUIREMENTS

	Oceanographic Mode	Agricultural Mode
Data Collected (Bits Per Scan)	360,000	792,000
Storage Required (Bits)	86,400	518,400

	Plated Wire Memory	MOS Shift Registers
Memory Word Length (Bits)	72	144
Number Memory Locations	7,200	3,600
Memory Cycle Time (μ sec) (Read or Write)	1.2	1.2

Techniques Available

- Dynamic MOS Shift Registers
- Static MOS Shift Registers
- Bi-Polar Shift Registers
- Plated Wire Memory
- Magnetic Core Memory
- Magnetostrictive Delay Line

only two-thirds of the data. In the first case, all data pass through the buffer with the input and output rates being related according to the duty cycle of the scanner as shown by Figure 9.3-1. For the second case, one-third of the data are transmitted in real time while the remaining data are buffered so that they can be transmitted between active scan periods. The latter approach is the one recommended for the OSS scanner.

The heart of the data buffer is the type of memory employed. Techniques which are available for memory construction are listed in Table 9.3-1. Of these, only two techniques can be used for this application: dynamic MOS shift registers and the plated wire memory. Discussions relative to these two techniques are contained in Appendices B and C. The key characteristics for each of these buffer types are shown in Table 9.3-1. Two techniques, magnetic core and bipolar shift registers, were rejected because of their relatively high power requirements. Magnetostrictive delay lines have delay characteristics which are sensitive to temperature changes and were therefore not considered. Static MOS shift registers can be considered for applications where small quantities of data are stored.

In comparing the two types of memory implementations, many considerations are necessary. These include: (1) physical packaging, (2) calibration data handling, (3) relative importance of weight, volume, and power, (4) data formatting, and (5) relative reliability.

A plated wire memory can be centrally located and is able to handle calibration data in exactly the same manner as active scan data. On the other hand, the dynamic MOS data buffer may be physically distributed, but it requires different techniques such as the use of MOS static shift registers for storage of calibration data. The weight, volume, and power of an OSS Data Buffer are listed in Table 9.3-2. The table indicates that the MOS memory requires less volume and power and weighs less than the plated wire memory. A MOS dynamic shift register data buffer was therefore selected for the OSS Scanner.

TABLE 9.3-2

MOS SHIFT REGISTER AND PLATED WIRE
MEMORY COMPARISON

Type of Buffer	MOS Data Buffer	Plated Wire Memory
Weight	5	25
Volume	400 in. ³	628 in. ³
Power	18	27

9.4 FORMATTER

The function of the formatter is to time-multiplex the digitized video and calibration data with that ancillary data required by the ground demultiplexing and processing operations. Two basic types of ancillary data are transmitted: synchronizing codes used in the data demultiplexer (Appendix D), and the spacecraft time code used to identify the geographical location of the data collected. The resulting multiplexed telemetry data time-sequence has been chosen to simplify the design of the demultiplexer to the greatest extent consistent with spacecraft power considerations. Since the prime function of the demultiplexer is to convert the down link format into the output tape format required by the Ground Data Handling Station (GDHS); the telemetry-data time-sequence is, in part, determined by the characteristics of the GDHS. (See Section 13.4.)

9.4.1 Downlink Format

The telemetry-link data-format of Figure 9.4-1 was constructed so that seven bands of data could be processed with minimum modifications to the present GDHS which is designed to process 5 bands. To this end, data from bands 1, 4 and 7 are transmitted in real-time (as it is generated) while that from bands 2, 3, 5 and 6 are stored and then transmitted during the "dead" portion of the scan interval. Also, present GDHS philosophy assumes that controlled precursors (gaps) exist in the demultiplexer output data, and hence, in the demultiplexer-tape format immediately prior to the line-scan and mid-scan codes (Figure 9.4-2). These gaps are retained in this format, and correspond to those in the telemetry-link data format.

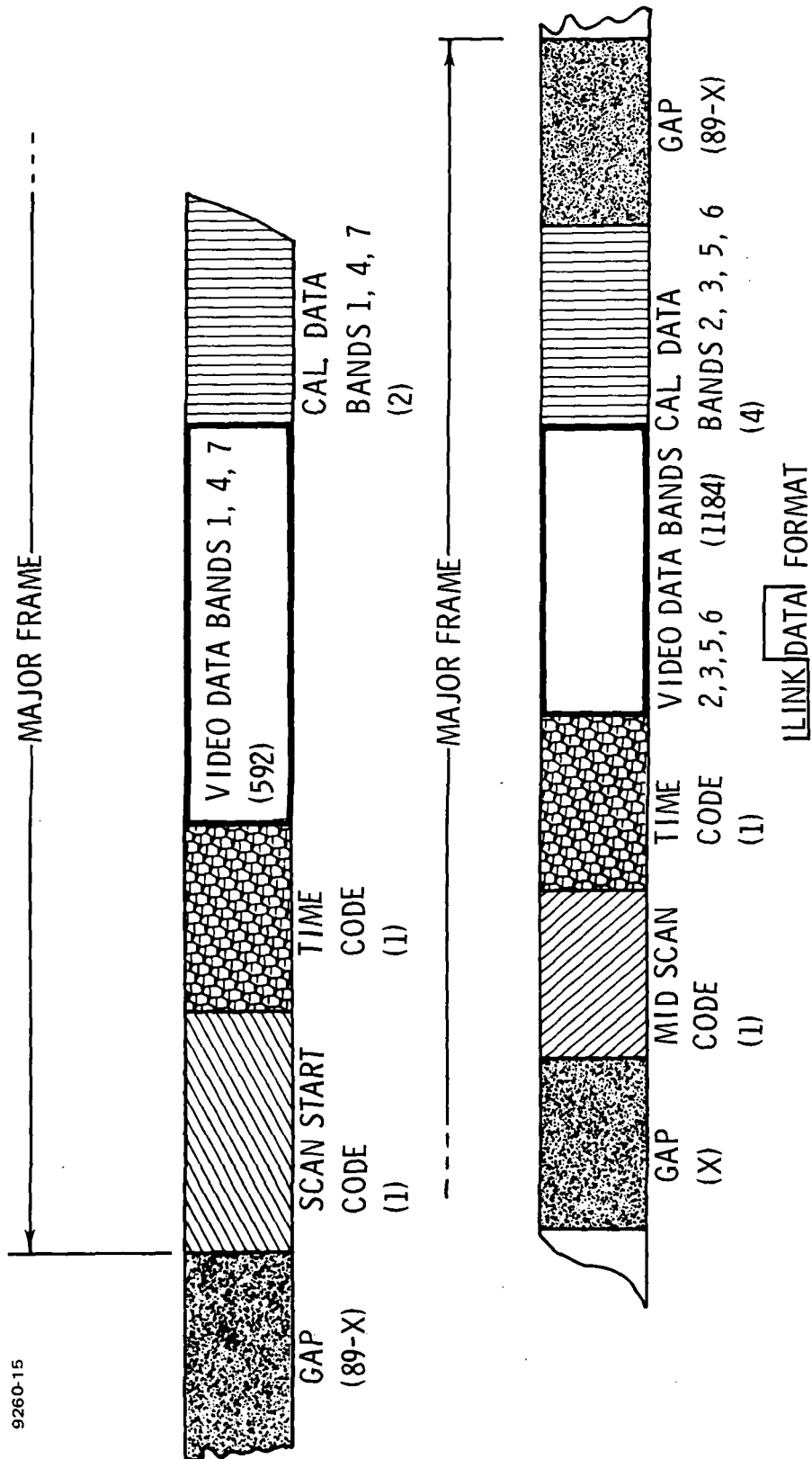


Figure 9.4-1 Telemetry Link Data Format

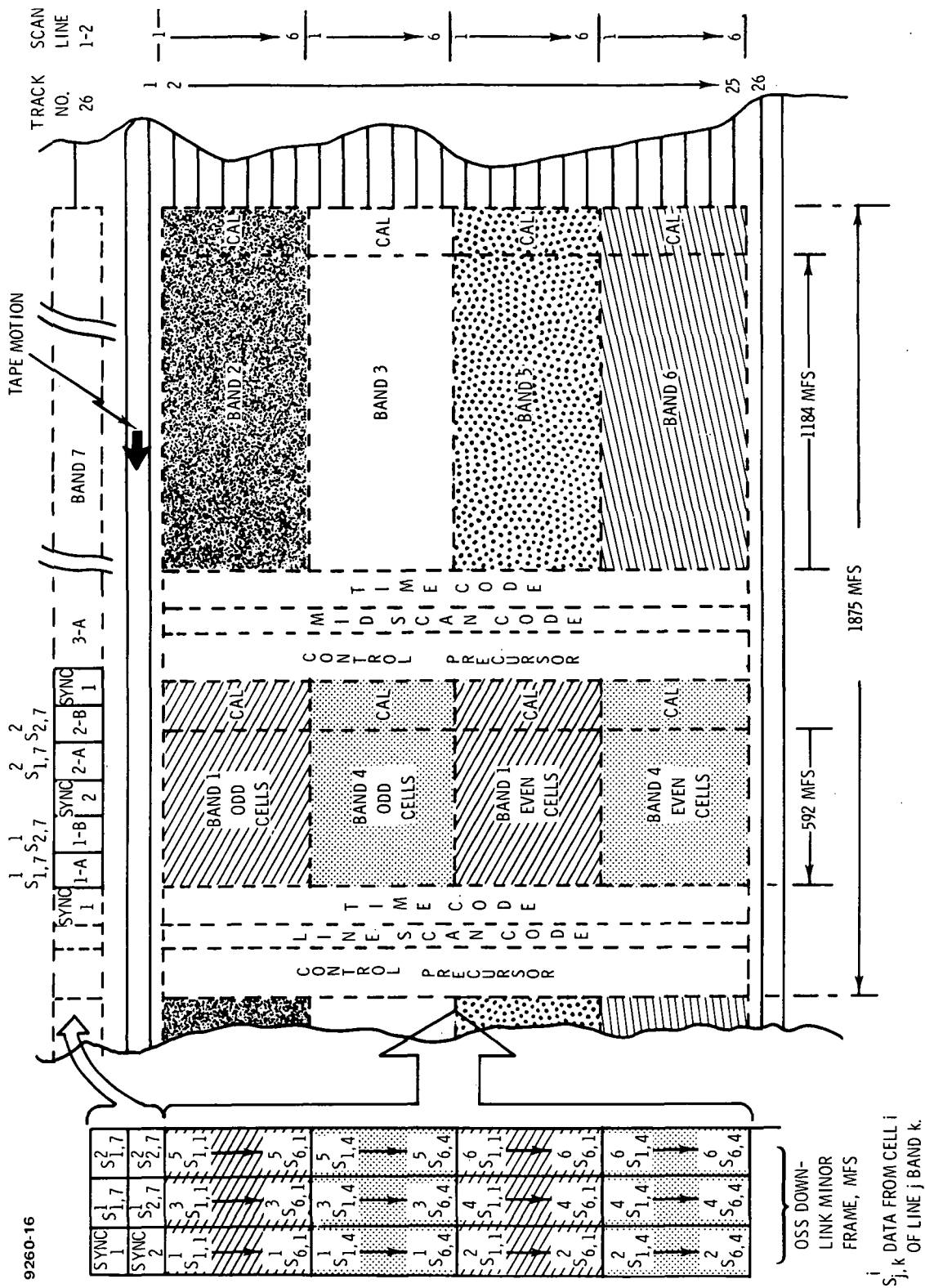


Figure 9.4-2 Demultiplexer Output Tape Format

Furthermore, scan-start and mid-scan codes are included to enable the GDHS to independently process data from band set 2, 3, 5 and 6 or Band set 1 and 4 so that all the data can be handled on the 25-track tape.

Complete independence of these two processing operations is assured by repeating the time code after both the line-scan and mid-scan sync codes and by transmitting the calibration data associated with each set of bands immediately following the video data from that set.

Figures 9.4-3 and 9.4-4 display the detailed structure of the proposed telemetry-link major frame. A major frame, by definition, includes all data transmitted during one scan interval. Its length in bits is determined principally by: (1) the specified tolerance of $15 \text{ Mbps} \pm 0.5\%$ on the transmission data rate; (2) scanner design parameters such as resolution, number of channels, and duty factor; and (3) the required data format. A major frame is identically equal to the ratio of the data-rate and the scanner rotational speed. The detailed relationships between these factors are discussed in Section 4.1. Considerations of the above, using the data format of Figure 9.4-1, led to a frame length of 877,500 bits. To assure proper Demultiplexer synchronization (Appendix D), and maximize compatibility with the ERTS Ground Data Handling Station; the major frame was subdivided into 1875 minor frames of the type illustrated in Figures 9.4-3 and 9.4-4. A summary of the telemetry format is contained in Table 9.4-1.

A minor frame composed of a time sequence of 78 six-bit words is, for convenience, displayed in three rows of 26 words each. The start of each minor frame is marked by the insertion of a 12-bit (two words) minor frame sync code. Word transmission order is read in all cases from left to right and from top to bottom. Cell-data transmission order is specified for each band-set and for both the oceanographic and agricultural operational modes. The notation, S_{jk}^i , denotes the digitized data from the i th cell of scan line j and the k th spectral band.

9.4.2 Functional Description

A functional block-diagram representation of the formatter is given in Figure 9.4-5. Its precise operation depends to a certain degree on whether a plated wire or MOS type data buffer is used. From the standpoint of cost and power, they are equivalent since only control code routing is involved.

Data from the data buffer and analog-to-digital converters are multiplexed along with the sync and scan control codes in the digital multiplexer. The time code is then inserted to complete the formatting operation. The parallel-to-serial converter is basically a number of parallel-in serial-out shift registers connected in cascade. Data which appear at the register inputs correspond to the outputs

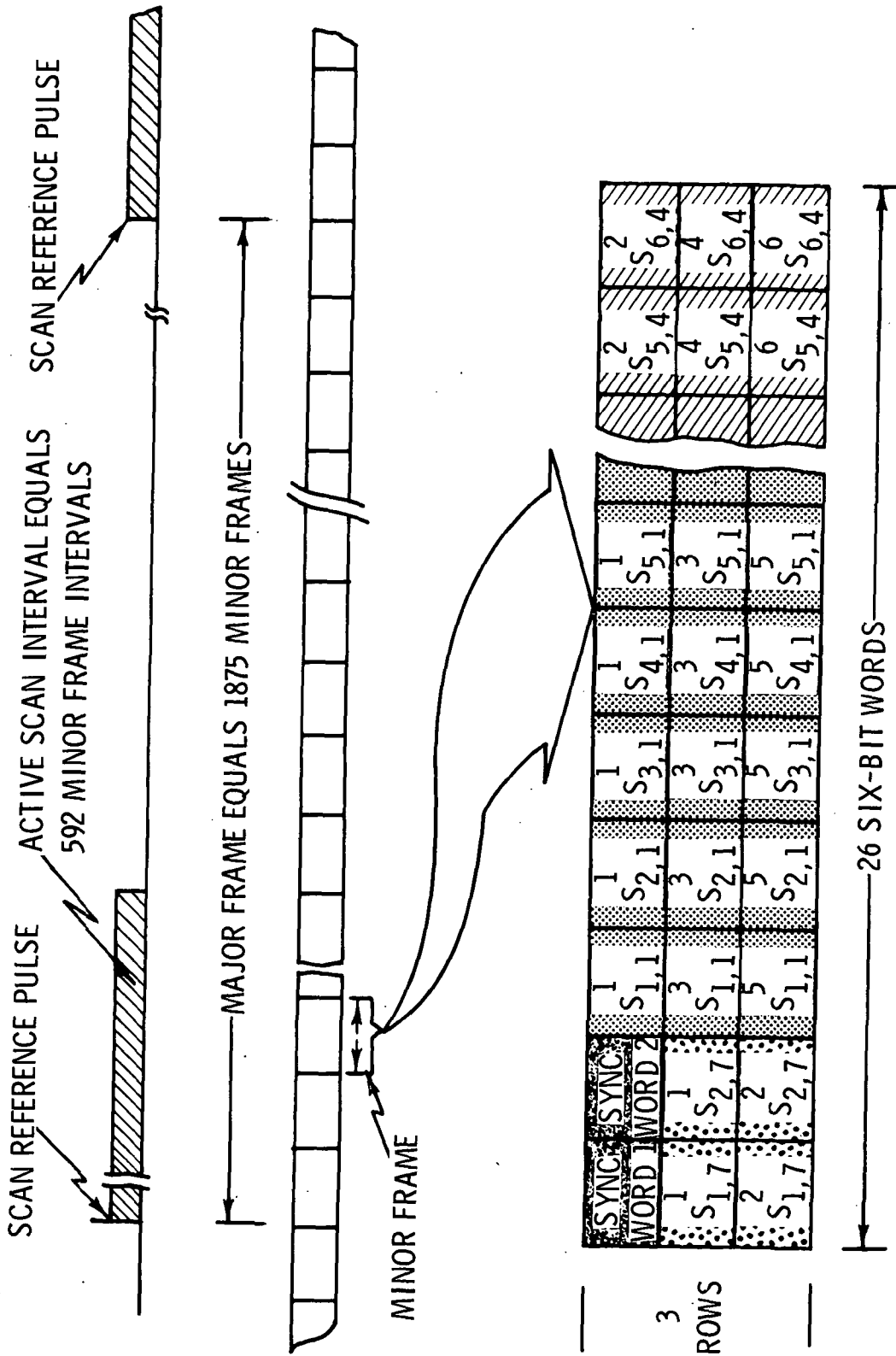


Figure 9.4-3 Telemetry Link Frame Structure

9260-18

SYNC WORD 1	SYNC WORD 2	1 $S_{1,2}$	1 $S_{2,2}$	1 $S_{6,2}$	1 $S_{1,3}$	1 $S_{5,6}$	1 $S_{6,6}$
		2 $S_{1,2}$	2 $S_{2,2}$	2 $S_{6,2}$	2 $S_{1,3}$	2 $S_{5,6}$	2 $S_{6,6}$
		3 $S_{1,2}$	3 $S_{2,2}$	3 $S_{6,2}$	3 $S_{1,3}$	3 $S_{5,6}$	3 $S_{6,6}$

TYPICAL MINOR FRAME FOR BANDS 2, 3, 5, 6 (OVERLAND BANDS)

$$S_{j,k}^i = \text{CELL } i \text{ OF LINE } j, \text{ BAND } k$$

SYNC WORD 1	SYNC WORD 2	1 $S_{0,1}$	1 $S_{0,2}$	1 $S_{0,3}$	1 $S_{0,4}$	1 $S_{0,21}$	1 $S_{0,22}$	1 $S_{0,23}$	1 $S_{0,24}$
		2 $S_{0,1}$	2 $S_{0,2}$	2 $S_{0,3}$	2 $S_{0,4}$	2 $S_{0,21}$	2 $S_{0,22}$	2 $S_{0,23}$	2 $S_{0,24}$
		3 $S_{0,1}$	3 $S_{0,2}$	3 $S_{0,3}$	3 $S_{0,4}$	3 $S_{0,21}$	3 $S_{0,22}$	3 $S_{0,23}$	3 $S_{0,24}$

TYPICAL MINOR FRAME FOR BANDS 1-24 (OCEANOGRAPHIC BANDS)

$$S_{j,k}^i = \text{CELL } i \text{ OF LINE } j, \text{ BAND } k$$

Figure 9.4-4 Minor Frame Data Organization: OCS Bands 1 through 24; OLS Bands 2, 3, 5 and 6

TABLE 9.4-1

TELEMETRY FORMAT SUMMARY

	Number of Minor Frames	Number of Words	Number of Bits
Major Frame	1875	146,250	877,500
Video Data	1776	138,528	831,168
Calibration Data	6	468	2808
Time Code	2	156	936
Scan Start Code	1	78	468
Mid Scan Code	1	78	468
Controlled Precursors (Gaps - Two Required)	89	6942	41,652

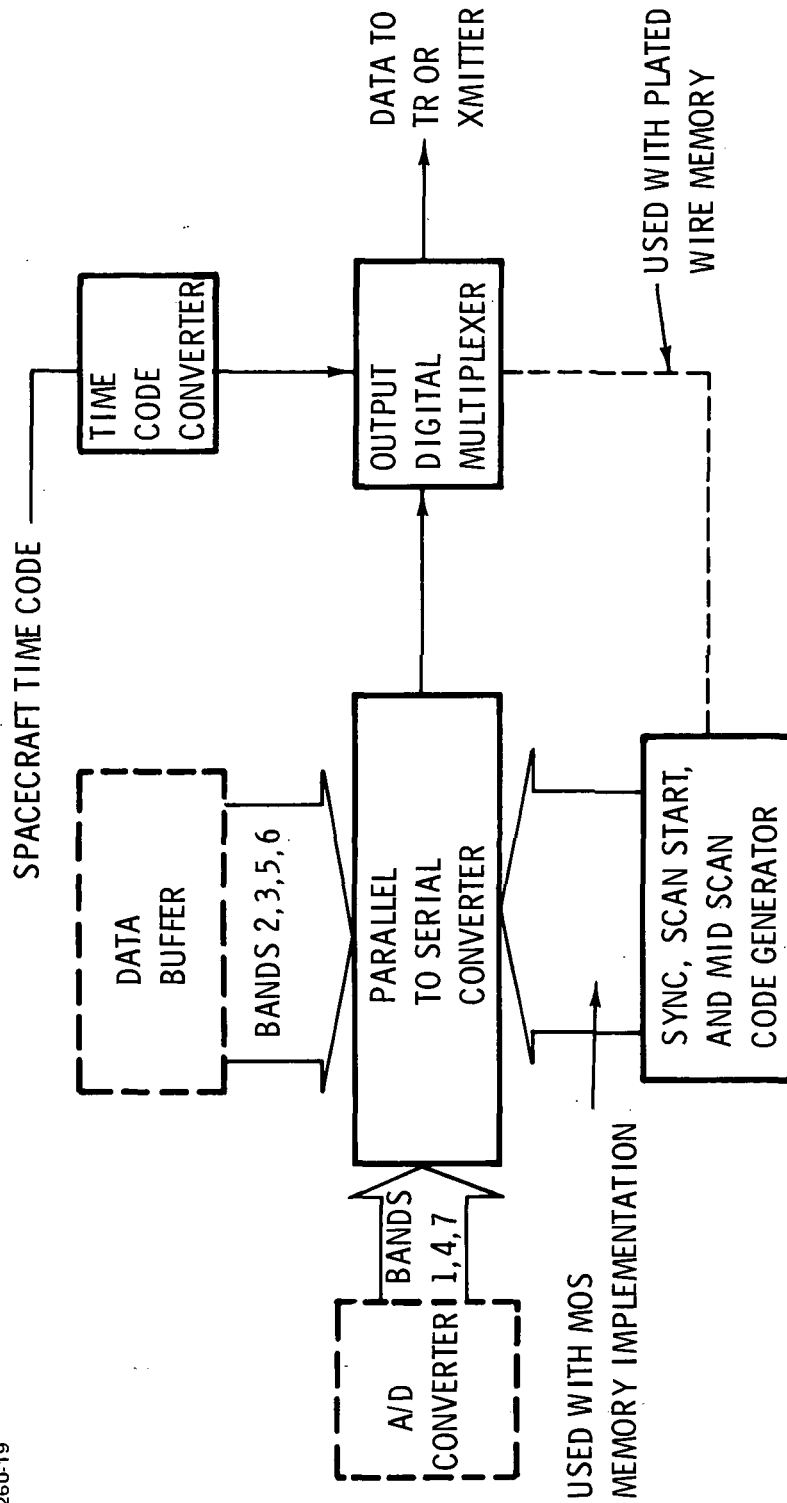


Figure 9.4-5 Formatter Functional Block Diagram

from a set of digital multiplexing gates. These gates are controlled by enable signals from the master timing and control unit so that the data which appears at their output is in proper time sequence. The time code converter transforms the spacecraft time code from a pulse-duration modulated form to the non-return-to-zero (NRZ) form required by the output digital multiplexer.

9.5 TIMING AND CONTROL

The timing and control unit provides the basic timing and control functions required to assure the scanner operational characteristics listed in Table 4.1-3 of Section 4.1. These functions include: (1) the development of a pulse train which serves as a reference for the scan-motor controller; (2) the generation of a master clock; (3) the generation, using the master clock, of all timing and control signals required by the analog processing units, the digital buffers, and the formatting units; (4) the synchronization of video data collection with the encoder scan reference pulse; and (5) the identification of calibration data. This unit in combination with the motor control system described in Section 4.5 furnishes all the scanner system timing and control functions.

Operationally, a master clock train derived directly or indirectly from a crystal oscillator is employed to slice the scan period into an integral number of time intervals called dwell times. Ideally, the end points defining each of the 11,250 equal-valued scan-mechanism look-angle intervals. Because perfect scan-motor controllers and scanning mechanisms are not available, the actual look angle at each of these time points deviates from its ideal value by an amount dependent on the manner in which the master clock is obtained. Each dwell interval (time) is further subdivided into 78 intervals for convenience: timing and control signals at 78 precise locations within a dwell interval and of any one of 78 discrete pulse widths may be obtained. Thus, timing and control signals for implementations using MOS registers or plated wire random access memories may be easily generated. Each dwell time corresponds to the time required to transmit 13 six-bit data words: i. e., 78 bits of data.

The discussions in Section 4.1 indicate that dwell time T_d is related to five parameters: (1) the data transmission rate R_t , (2) the instantaneous field of view in the flight direction d_f , (3) the spacecraft velocity V , (4) the scanner duty cycle (31.57%), and (5) the number of cells per scan N_c (3552). Quantitatively, the relationship is:

$$T_d = \frac{6 d_f}{N_c V} = \frac{78}{R_t}$$

From this expression and the foregoing discussion, it follows that dwell time is a discrete multiple of the data rate period, $1/R_t$, or some submultiple thereof. The specified data transmission rate of $15 \pm 0.5\%$ Mbps, therefore, leads to the selection of a 29.952 MHz crystal-controlled master oscillator. This frequency choice provides a symmetrical data clock and permits the realization of a scanner with parameters listed in Table 4.1-3 of Section 4-1.

9.5.1 Scan Parameter vs Master Timing Relationships

The method selected to establish the phase relationship between the instantaneous scan-mechanism look-angle and the timing and control master clock is that method which optimizes minimization of a number of system errors: i.e., geometric cell-cell misregistration, integration - area, integration time, and radio-metric errors.

Two different concepts for developing the master clock to scan-mechanism look-angle phase relationships were considered; both concepts were subjected to a preliminary analysis during the study. These approaches are diagrammed in block form in Figures 9.5-1 and 9.5-2. Timing and control Concept No. 1 employs a master clock which is derived directly from a highly stable crystal controlled oscillator whose output is f_o while using a divider to obtain the scan motor controller reference-pulse train f_r . On the other hand, timing and control Concept No. 2 obtains its master clock by multiplying, using a phase lock loop the output from the encoder. The reference pulse train is obtained in the same manner as for Concept No. 1.

Before discussing these two concepts, a brief explanation of the required terminology and symbology is presented. Figure 9.5-3 illustrates the so called elliptical scan concept along with one of its degenerate forms, i.e., the elliptical scan trace in Figure 9.5-3 (a) becomes the circular scan trace of Figure 9.5-3 (b) when the scan cone axis passes through the spacecraft nadir point.

The discussion is carried out in terms of the circular trace since it is a bit easier to visualize and since the resulting errors are less than one to two percent. These errors will not affect the validity of the argument since the two systems are being compared in a qualitative manner only.

Several parameters are of particular importance in the discussion: (1) the scan-mechanism look direction, (2) the scan-mechanism look-angle, (3) the arc lengths, and (4) the angular misregistration. The element being scanned at any instant is specified in terms of a rotating vector whose initial point coincides with the moving intersection-point produced by the scanning-cone axis and the spacecraft nadir trace. This vector defines the instantaneous scan-mechanism look direction.

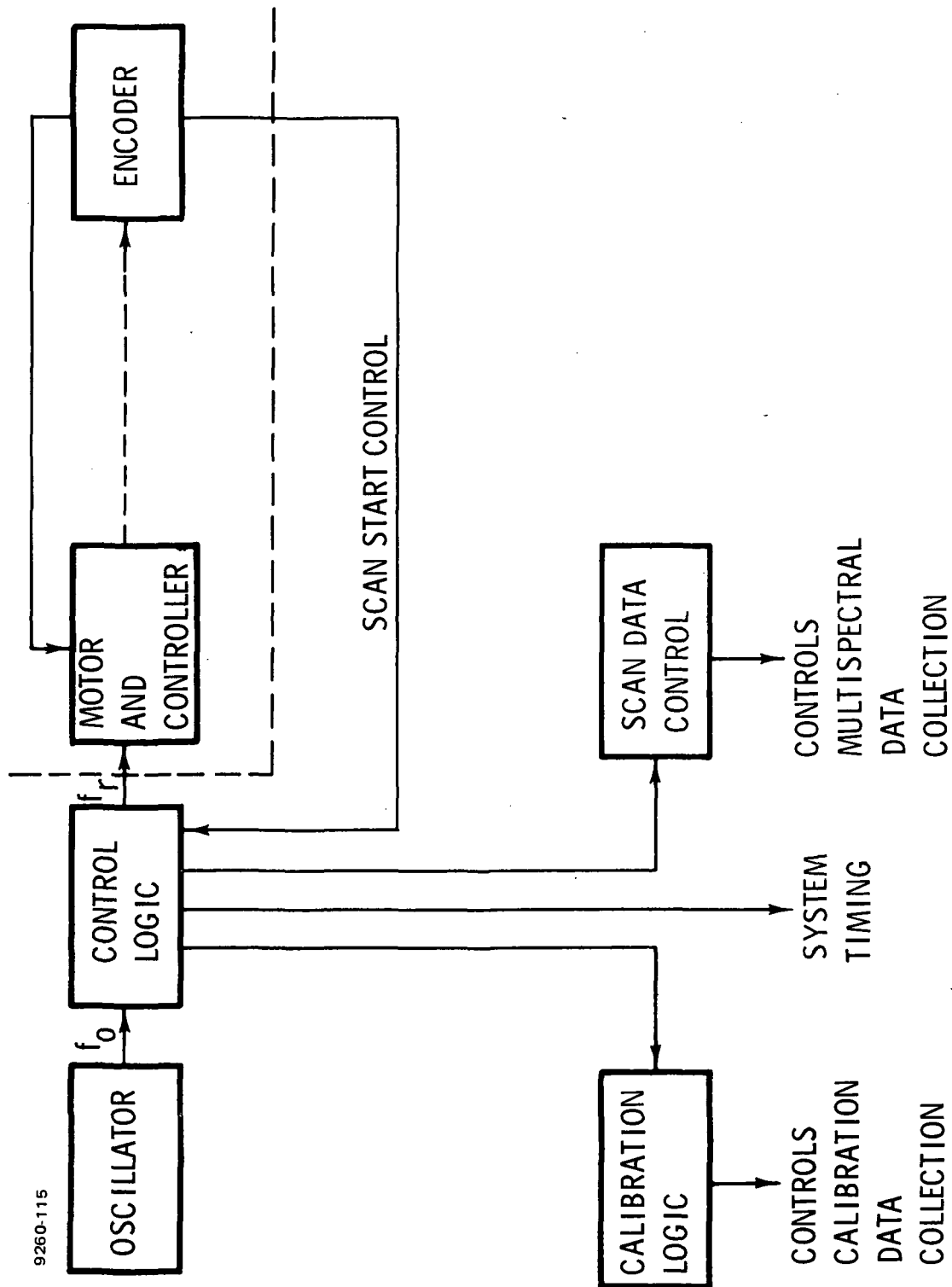


Figure 9.5-1 Timing and Control Concept No. 1

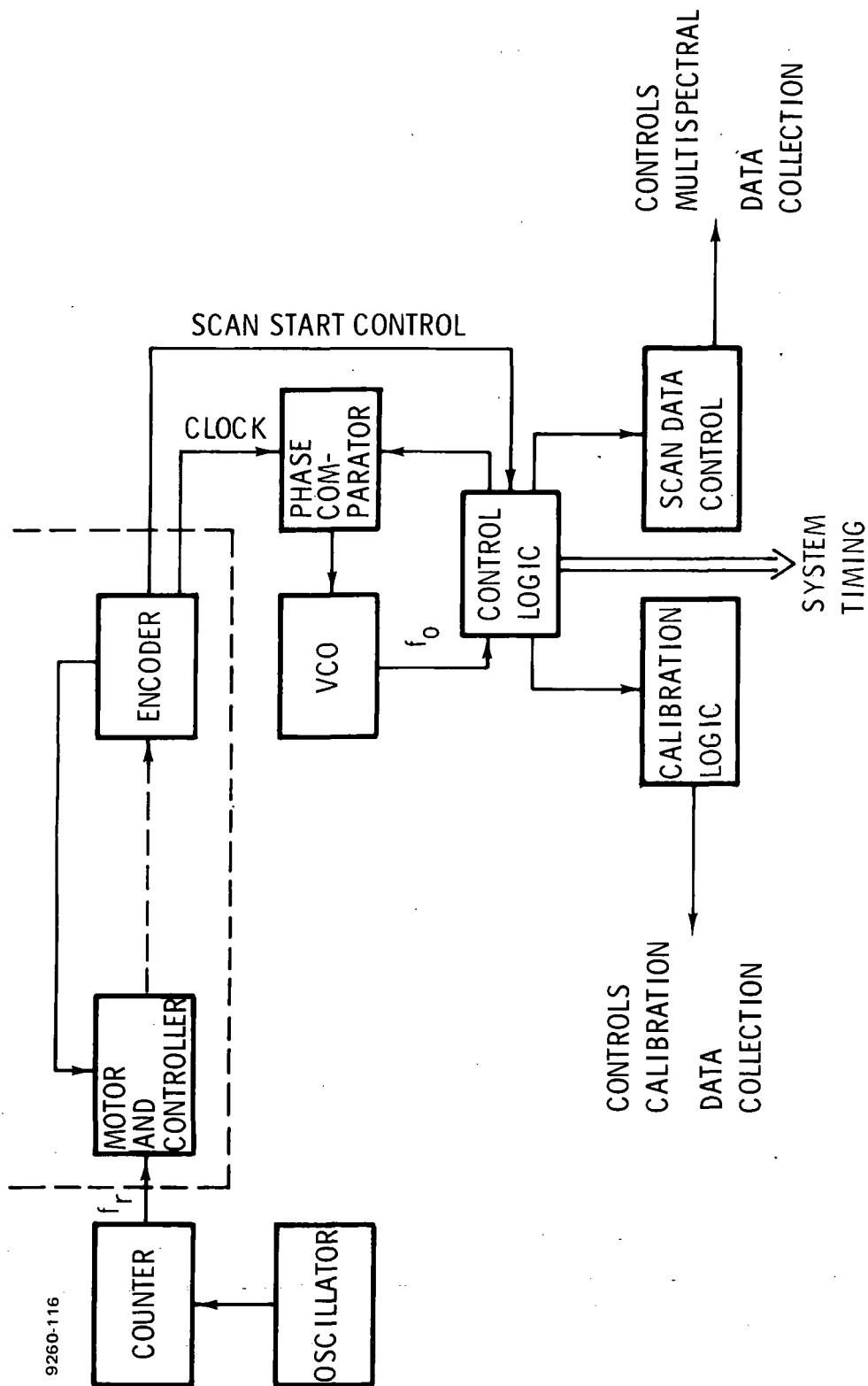


Figure 9.5-2 Timing and Control Concept No. 2

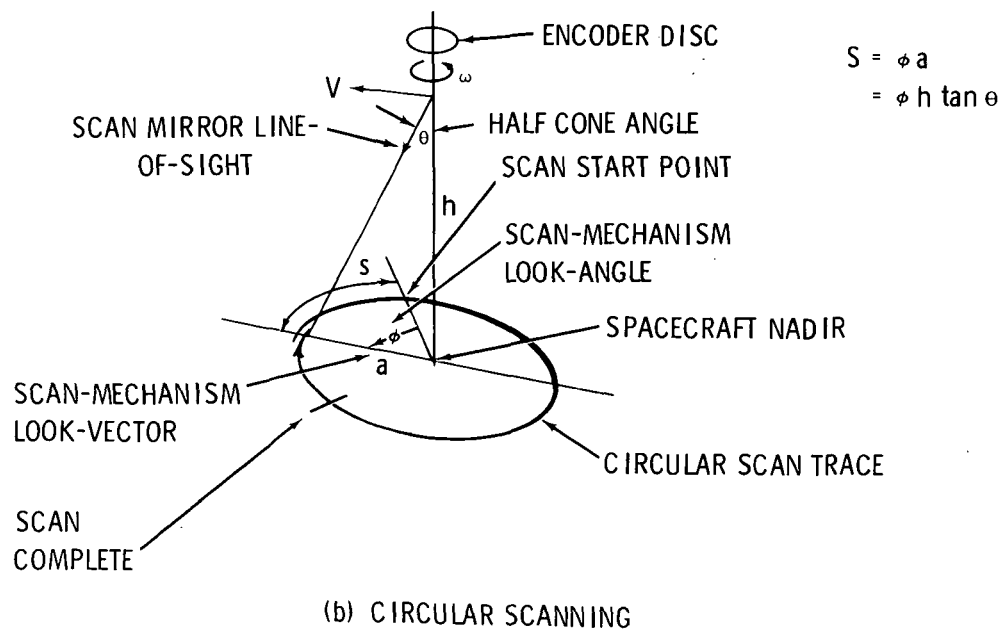
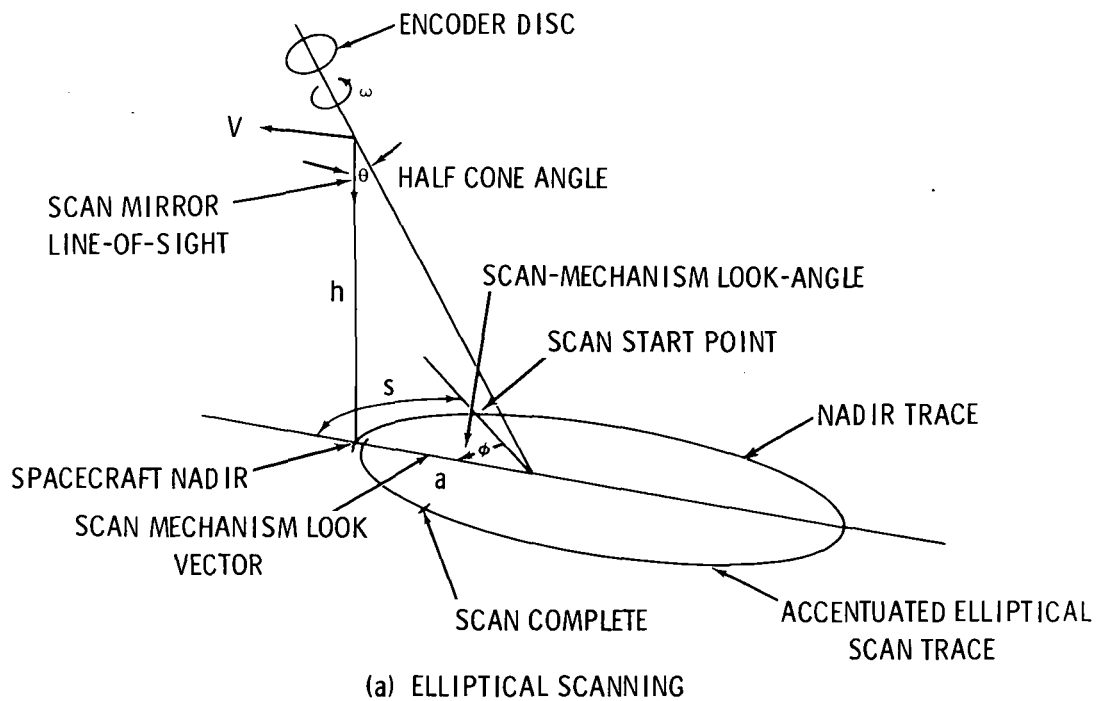


Figure 9.5-3 Scanning Mechanisms

Vector rotation is discussed in terms of the angle ϕ , the scan-mechanism look-angle. In the absence of scan mechanism errors, this angle is identical to the angle of rotation of the encoder disc when the circular scanning case is assumed.

The dwell angle is defined as that angular interval generated by the scan mechanism during a given dwell time. Angular misregistration of a cell is defined in terms of the angular displacement of the leading end-point of a dwell interval from its ideal position. Finally, from Figure 9.5-3, one obtains for the cell length Δs :

$$\Delta s = \Delta \phi h \tan \theta$$

where h is the spacecraft altitude.

It follows that the total area of the cell from which radiant energy is received is given by:

$$A = \Delta s (\text{IFOV}) = \Delta \phi (\text{IFOV}) h \tan \theta = K \Delta \phi$$

where IFOV is the instantaneous field of view of the optics in the flight direction. This area is called the integration area.

9.5.2 Timing and Control Concept No. 1

If the implementation shown in Figure 9.5-1 contained a perfectly stable oscillator, then the control logic would divide the time axis into uniform time intervals or dwell times. With this assumption, the integration time for each cell is constant and no electrical integration error results since the integration time constant was selected to match this time interval. Hence variations in dwell time do not occur, dwell time induced radiometric errors do not exist. If several additional assumptions are made, the scan-mechanism look-angle ϕ is a linear function of time so only that radiant energy within the angular cell ($\phi_2 - \phi_1$) is integrated (Figure 9.5-4). These additional assumptions are: (1) the optical encoder pulse train is "perfectly" locked to f_r , (2) a perfect optical encoder is employed, and (3) no errors are introduced by the motor/rotor combination. However, the various imperfections associated with reliable motor controllers, disc encoders, and scanner mechanism will, in general, cause the scan-mechanism look-angle to be a non-linear function of time, as for example, $\phi_1(t)$ of Figure 9.5-4. As illustrated, both angular misregistration and integration area errors result.

The relationship between the integration area error and the change of angular misregistration is depicted in Figure 9.5-5. It appears, therefore, that the energy

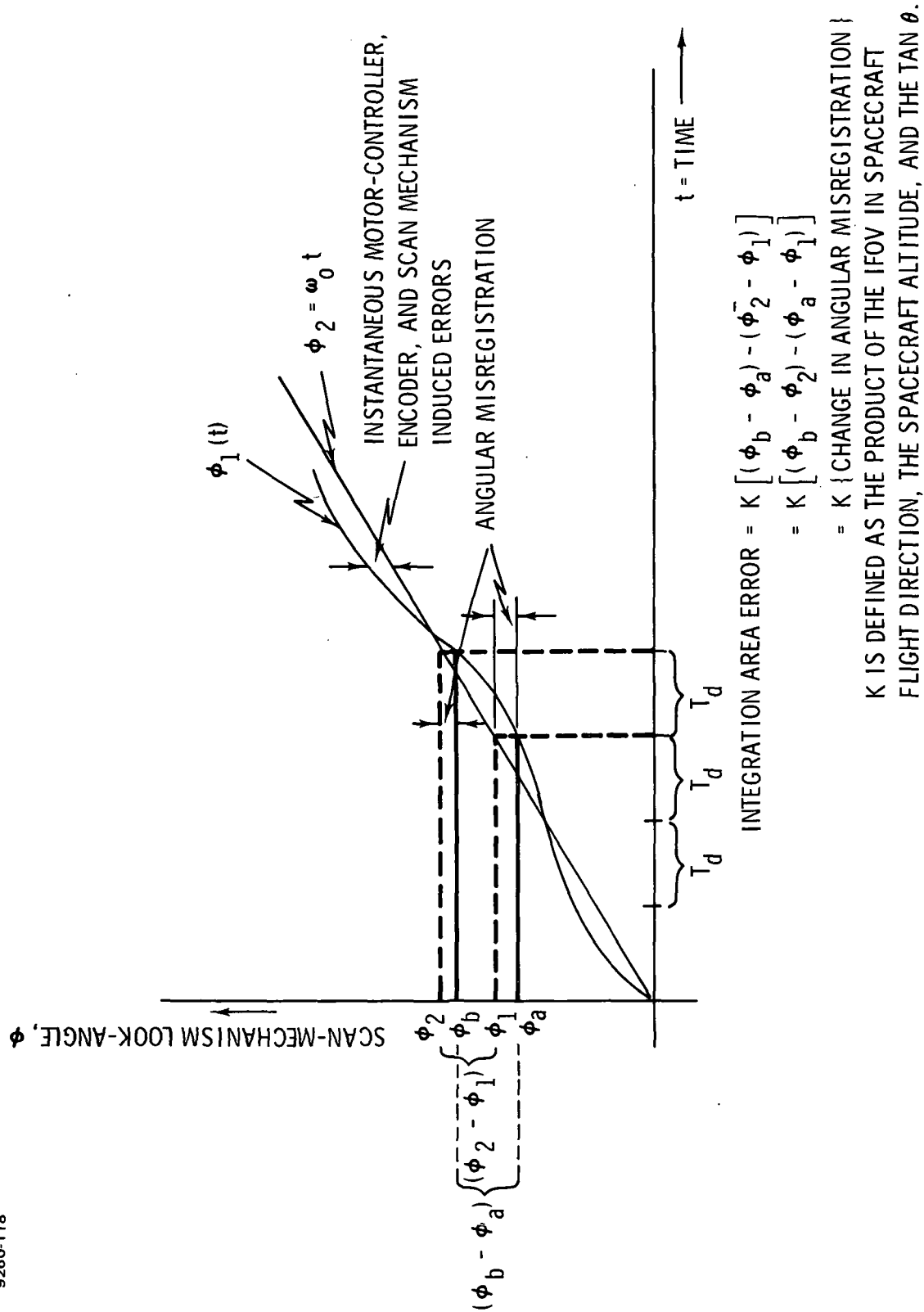
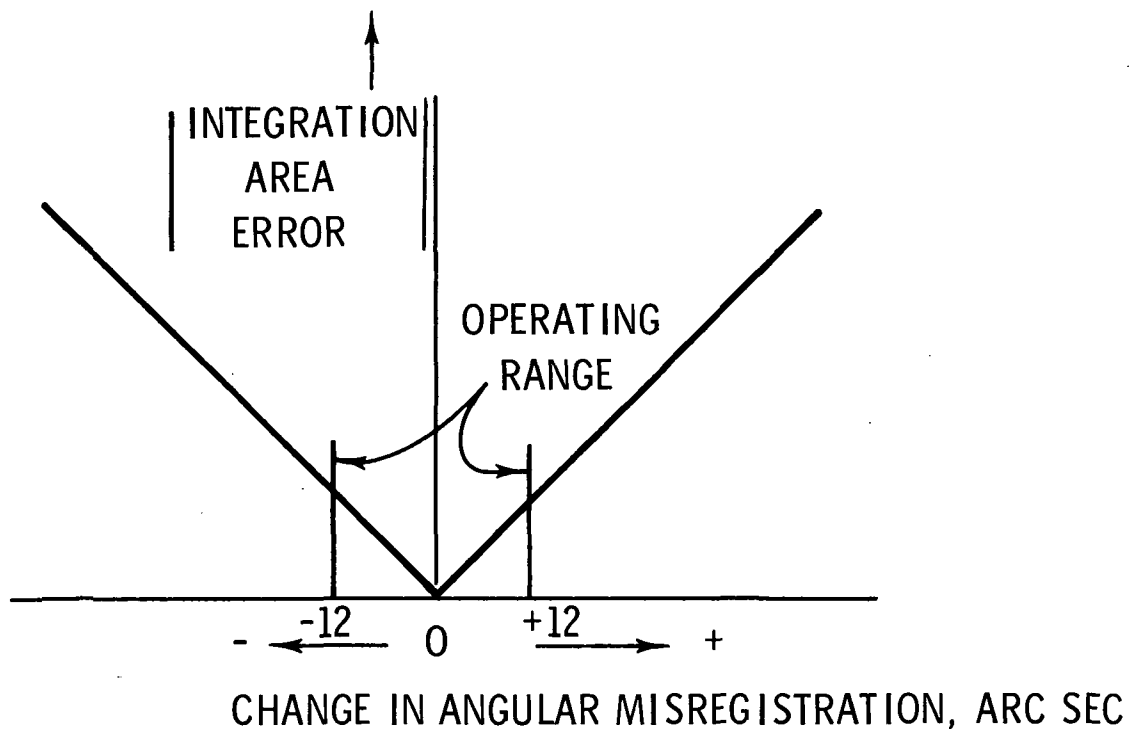


Figure 9.5-4 Variations of Scan-Mechanism Look-Angle with Time: Concept No. 1

collected for any one cell specified by a given T_d is in error because the energy collected is from a cell which is both displaced and of improper size. Therefore, radiometric errors seem to depend, not only on the angular misregistration, but on the rate of change of this parameter as well. When a good quality crystal oscillator is used (drifts less than 0.1 to 5 parts per million), radiometric errors are due primarily to these parameters; integration time variations are negligible.



9260-119

Figure 9.5-5 Integration Area Variation (Concept No. 1 or 2)

9.5.3 Timing and Control Concept No. 2

A second concept is illustrated in Figure 9.5-2. Here the oscillator output is divided down to obtain a reference frequency f_r equal to the encoder pulse train frequency. A clock frequency derived from the encoder is multiplied in a phase locked loop to obtain a master clock frequency, f_o , which is used to time all scanner operations. To simplify this discussion, the relationship between the scan-mechanism look-angle $\phi(t)$ and a multiplied version, $\alpha(t)$, of this angle is presented in Figure 9.5-6. Two curves are shown. The linear curve represents a system with no phase locked loop, encoder, or scan-mechanism induced errors; the other curve represents a system containing a combination of all of these errors. The dashed lines graphically connect an illustrative angular cell of desired length (measured in the scanning direction) to its desired dwell angle via the linear curve. The solid lines indicate that system errors cause a cell of angular length $(\phi_b - \phi_a)$ to be generated by the actual dwell angle $(\alpha_b - \alpha_a)$ rather than one of proper length $(\phi_2 - \phi_1)$. Again, as for Concept No. 1, a linear relationship of the form shown in Figure 9.5-5, exists between the integration area error magnitude and the change in either the angular misregistration or angular dwell time. Thus, the two concepts bear strikingly similar relationships as far as integration area error versus change in angular misregistration is concerned. They differ only in that Concept No. 2 substitutes a phase locked loop error for the motor controller error of Concept No. 1.

When the dwell angle of Concept No. 2 is interpreted in terms of real time, one finds that it is subject to all error components discussed above plus those introduced by the motor controller along with those attributable to oscillator stability. Conversely, dwell time errors of Concept No. 1 are determined solely by the stability of the crystal oscillator; a small perturbation. Thus, electrical integration errors can be appreciably greater for Concept No. 2 than for Concept No. 1; i. e., one might anticipate appreciably higher errors in radiometric measurements if Concept No. 2 is used. Ultimately, the difference in radiometric measurements obtained from the two systems depends on the degree to which the above five errors types can be reduced and/or made to cancel each other.

9.5.4 Summary

In Sections 4.5 and 4.6 it was shown that the scan control introduces no more than 3.01 arc sec of error. It was also pointed out that the scan mechanism might introduce an additional statistically independent error of 5 arc sec in angular misregistration. When these two are combined in a rms fashion, one finds that the angular misregistration can vary over a range of ± 6 arc sec. Therefore, the maximum variation in angular misregistration during any dwell time should not exceed ± 12 arc sec (e. g., the angular misregistration could change from -6 to +6 arc sec

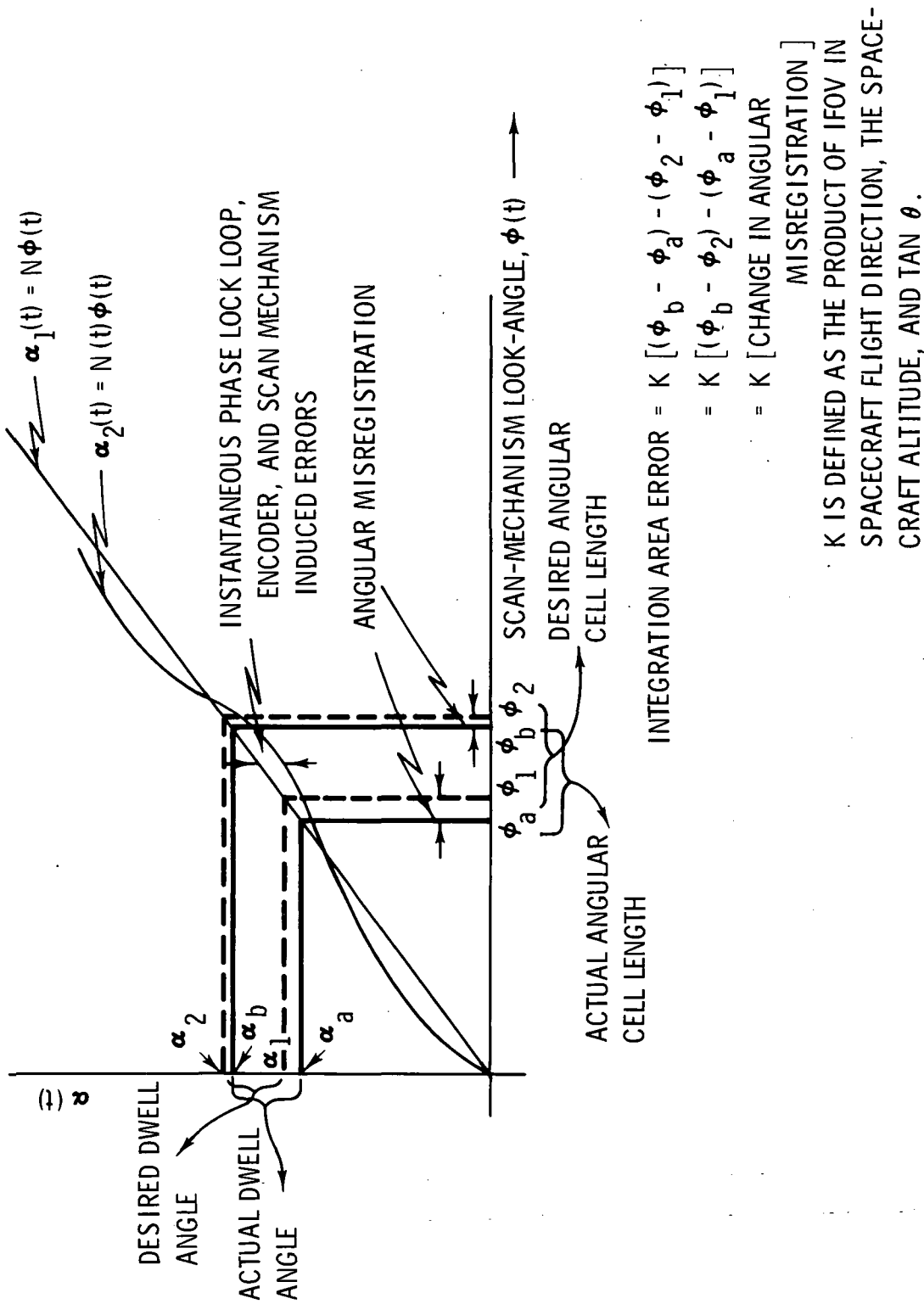


Figure 9.5-6 Variation in Dwell Angle as a Function of Scan-Mechanism Look-Angle: Concept No. 2

in a dwell time) indicated in Figure 9.5-5 for either system. Actually, the integration area and misregistration errors for Concept No. 2 appear to be appreciably less than for Concept No. 1. This follows since a phase locked loop with a narrow band-pass and high gain acts as a noise filter. On the other hand, the radiometric error characteristics of Concept No. 2 appear to be inferior. Because of the importance of radiometric accuracy, the specified high accuracy on the data rate, and the reduced number of components (phase lock loop not necessary); Concept No. 1 has been chosen for the OSS system.

9.6 CALIBRATION SOURCE CONTROL

The calibration sources introduce a known energy level through the optical system during the nonactive scan period, providing a "self calibration" signal. A discussion of the way the blackbody temperatures are controlled is contained in Section 5.2. Incandescent lamps are used to provide both high and low ultraviolet-visible spectral sources.

For spectral integrity, the filament temperature must be accurately controlled. This may be achieved by close control of the current through the lamp. The circuit in Figure 9.6-1 has been selected for the OSS system. This circuit provides accurate control of the current while providing protection for the lamp from over-voltage due to loss of feedback signal during the checkout and test routines. For reliability purposes redundant lamps and controllers are provided for the both high and low calibration sources.

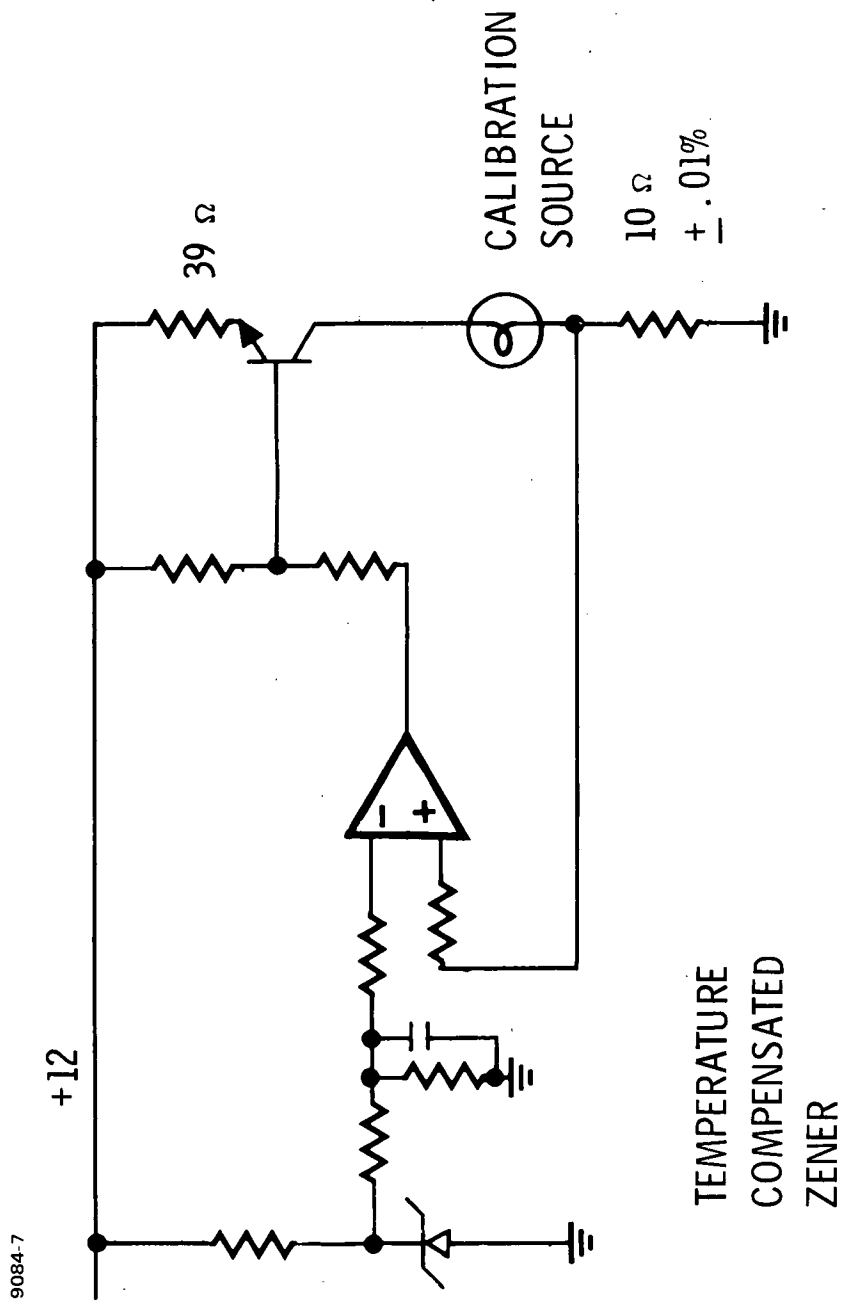


Figure 9.6-1 Calibration Source Control

9.7 POWER CONVERSION AND DISTRIBUTION

9.7.1 Power Requirements

All units requiring conditioned power receive it from the power conversion and distribution unit, except for the high voltage power required by the PMTs. Because of the unique requirement of the PMTs, power converters for these components are located with the PMTs and are therefore not considered as a part of the electronics power conversion and distribution system. Voltage and power requirements for the various functional areas are given in Table 9.7-1. A 92.9 W total of conditioned power is required. Nine different voltages are required; however, because it is desirable to isolate analog and digital circuits, separate analog and digital ± 5 V power will be provided as well.

Power consumption for the various electronic channels is given in Table 9.7-2. This breakdown corresponds to the packaging concept described in Section 10. It should be noted, however, that Table 9.7-2 does not include the power required for the preamplifiers, PMTs, or calibration sources.

9.7.2 Design Considerations

The following description of the spacecraft power interface is given in the NIMBUS E & F Experiment Interface Requirements manual:

1. The available dc power is regulated -24.5 ± 0.5 V dc and unregulated -26.5 to -37.8 V dc. Experiments should use the regulated bus for required power. However, unregulated power may be utilized upon approval of the GSFC Spacecraft Manager (motors, solenoids, etc. should use unregulated power).
2. DC-DC converters must be used to isolate the signal ground from the power return.
3. All power lines and power returns must be wired to a connector separate from other electrical signals.

Regulated power is required for all the OSS electronics. Figure 9.7-1 shows how two power converters are utilized to distribute to the various electronic units. Converter A, which has six output branches, supplies the analog portion of the electronics and preamplifiers. The three branches in converter B accommodate the logic portion of the scanner electronics. The motors use -24 V power. Although it is possible to utilize only one converter, the use of separate converters for the

TABLE 9.7-1
POWER CONSUMPTION TABLE

+	Preamplifier	Analog Processor	A/D Converter	Data Buffer	Formatter	Motor And Control	Timing And Control	Total Power
+ 5 V Reg		3.8	1.7			0.5		6.0
-5 V Reg		4.2	1.7		0.1			6.0
+7.5 V		1.6						1.6
+15 V	9.6		1.5					11.1
+22 V			2.9					2.9
-15 V	9.6							9.6
+5 V		8.0	2.2	8.6	7.0		10.0	35.8
-5 V				6.0	0.1			6.1
-12 V		4.8		4.0				8.8
-24 V						5.0		5.0
Total Power	19.2	22.4	10.0	18.6	7.2	5.5	10.0	92.9

TABLE 9.7-2

ELECTRONICS SUBSYSTEM POWER REQUIREMENT

Function	Power Dissipation Per Unit (W)	Quantity Required	Total Power Dissipation (W)
Bands 2, 3, 5 and 6 Electronics	1.41	24	33.8
Bands 1 and 4 Electronics	0.8	12	9.6
Band 7 Electronics	0.9	2	1.8
Switch Drivers	2.9	2	5.8
Timing and Control	3.33	3	10.0
Formatter (Includes Time Code Gen.)	2.4	3	7.2
Motor Control	5.5	1	5.5
		Total	73.7

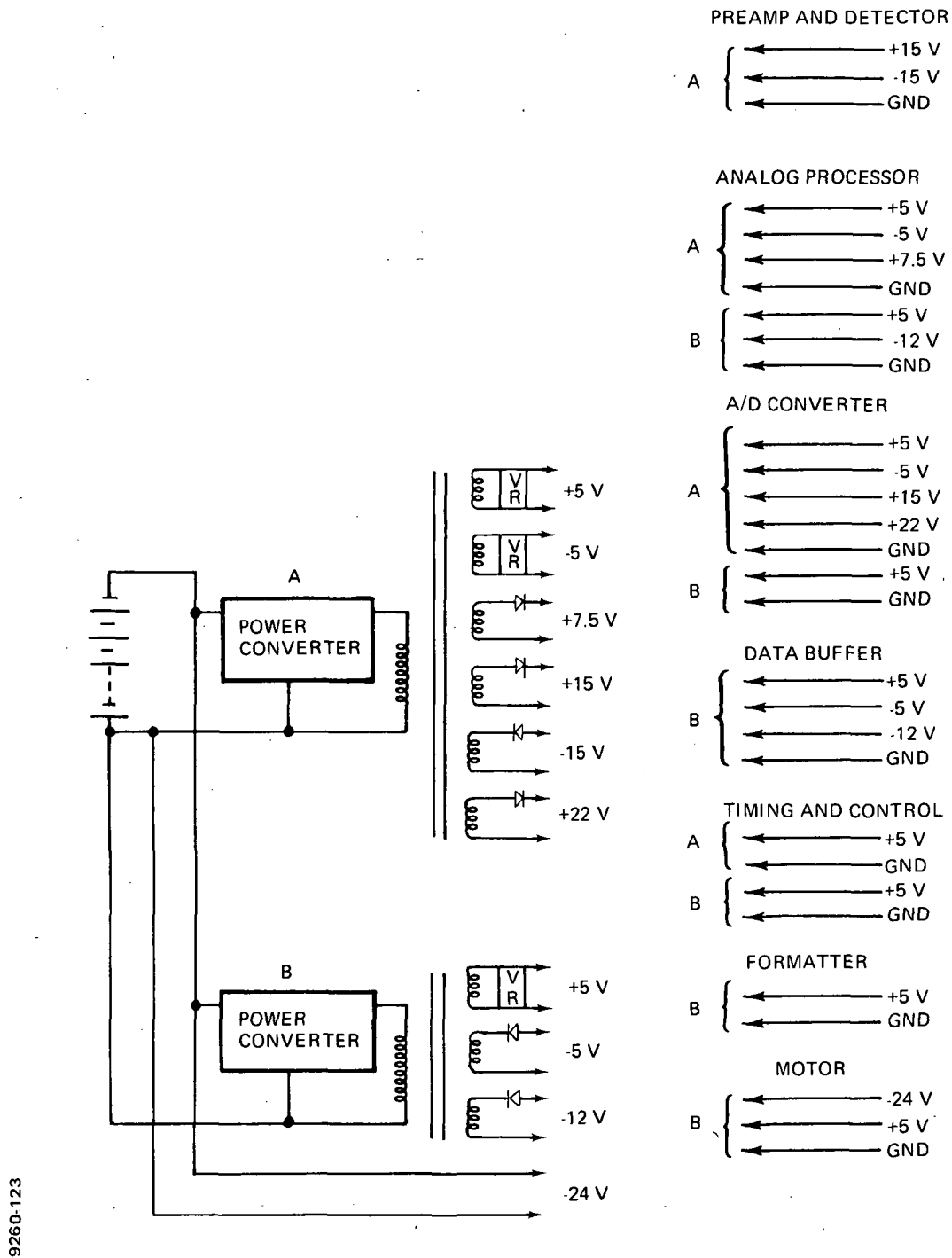


Figure 9.7-1 Power Distribution

analog and digital circuitry minimizes the effect of logic generated switching noise on the analog circuits.

Generally, voltage regulators, which are connected to the output of the converter, will degrade the efficiency of the over-all power unit. Since the $-24.5 \text{ V} \pm 0.5 \text{ V}$ power bus is well regulated, few additional regulators are required. There are four main areas of power converter circuits where losses occur: converter circuits, switching transistors, transformers, voltage regulators, and rectifier diodes. Therefore, the choice of transistors and transformer cores, as well as the required regulation and operating frequency, determines converter efficiency. Operation at a lower frequency generally reduces the loss in the transistors, but this increases the size of the transformer core which results in a unit that is larger and heavier.

For space application, where efficiency and size are important, the operating frequency of the converter will be about 15 kHz. Typically, an over-all converter efficiency of about 65% can be expected. With state-of-the art components and design techniques, an efficiency of 70 to 75% can be achieved. Higher efficiency than this is difficult to achieve because of the requirement to provide regulated low voltage such as the $+5 \text{ V}$.

Because of the manner in which multispectral data are collected, it is conceivable that some circuits could be de-energized between the active scan periods. The active scan period is about 19 ms while the nonactive scan period is about 38 ms. It would appear that such a duty cycle might permit significant power savings if power switching techniques were utilized. Since the analog circuits must operate while the calibration signals are being received, the effective duty cycle is significantly less than the basic scanner duty cycle. The majority of the timing and control circuits and the data buffer must, of course, be powered continuously. After examining the matter in detail it was determined that a power saving of only about 5% could be achieved. The added complexity to incorporate power switching for such a small saving was not considered to be a worthwhile tradeoff; thus, power switching is not incorporated in the OSS scanner.

Assuming a power converter efficiency of 70%, 105 W of prime power is required for the electronics subsystem and an additional 27 W are required for the preamplifiers, plus 5 watts for the PMT's and calibration sources. The total power requirement for the OSS scanner is thus 137 watts.

SECTION 10

MECHANICAL DESIGN

10.1 GENERAL

The inclusion of the OSS multispectral scanner on the ERTS spacecraft establishes the requirement for complete interchangeability with the existing ERTS installation provisions. An examination of available space was made taking into account the existing experiments and spacecraft components. This study resulted in establishing a noninterfering volume available to the scanner. A series of layouts were made to determine the most efficient use of this volume in terms of the OSS scanner concept. Figure 10-1 is a general over-all layout of the OSS scanner assembly showing how the assembly is arranged so as to be compatible with the ERTS spacecraft interfaces.

The scanner consists of three major modules: collecting optics assembly, electronics assembly, and passive cooler assembly. These three major modules are fastened to a base frame which will interface with existing spacecraft attachment points. As may be noted, the OSS dual-mode multispectral scanner is complete within itself and does not require separate electronic mounting provisions in the spacecraft torus structure. Therefore, the electrical and associated mechanical interfaces with the spacecraft are greatly minimized. The over-all estimated weight of 139.4 lb is considerably less than that planned for the currently existing scanner. The actual displaced volume is 5.9 cu ft, comparable to the present scanner. The enclosure for the OSS scanner is constructed of laminated mylar which combines the functions of enclosure and insulation.

10.2 COLLECTING OPTICS AND SCANNER ASSEMBLY

The collecting optics and scanner assembly is a major module consisting of the collecting optics assembly, scanner assembly, and spectrometer assembly. These units can be fabricated, aligned, and tested separately before final assembly and alignment of the complete scanner instrument.

10.2.1 Collecting Optics Assembly

The major structure for the collecting optics and scanner module is formed around the Martin and primary mirrors. A structure of aluminum sheet metal is

constructed (Figure 10-1) in a tubular shape with mounting provisions for the Martin and primary mirror. A thermal analysis of this tube structure indicates that very little dimensional instability is experienced throughout the expected temperature range (see Appendix E). The Martin (folding) mirror is fixed in position and can be adjusted. The primary mirror will be made of CER-VIT braced by means of a rib like structure on the face opposite the mirror side. Provisions for mounting would be cast in at the time the mirror blank is formed. The Martin mirror will be made of beryllium and will be rib structured in the same manner as the primary mirror. Beryllium was chosen because of its light weight and high strength. The optical alignment requirements for the OSS configuration necessitates mounting the scanner on the Martin mirror. The choice of beryllium for the Martin mirror has advantages over CER-VIT in weight, machinability, and strength.

10.2.2 Scanner Assembly

The scanner assembly provides the scan mechanism and completes the telescope by containing the secondary mirror as well. In the image space scan concept, the scanner simply consists of a rotor with the scan mirror attached and a brushless dc motor to rotate it (see Section 4.5). A bracket fabricated from aluminum provides for mounting the scanner to the Martin mirror.

The secondary mounting tube is constructed of aluminum with adjustable mounting provisions for the secondary mirror and a fixed mount for the first folding mirror. A cut-out on one side permits image entry from the scan mirror to the center on-axis mirror. The secondary mirror adjustment is achieved by positioning the front face of the mirror with a wave spring. Three set screws are positioned to apply pressure on the back face of the mirror against the wave spring. The degree of pressure on each set screw will establish the angular position on the mirror. A second folding mirror constructed of CER-VIT is attached to the secondary mounting tube. The position is such as to reflect the first folding mirror image to the field stop located in the spectrometer assembly. A thermal analysis indicated stability within the required limits for the secondary mirror. To prevent deflections, due to thermal excursions, of the second folding mirror from producing an offset at the field stop, the secondary mirror assembly was mounted on the Martin mirror. To facilitate this mounting arrangement, an arch-shaped bracket was designed of aluminum. The secondary mirror assembly is mounted in the center of the arch. The two legs of the arch are attached to the Martin mirror which, positionally, is very stable. The calibration sources, both reflective and emissive, are also attached to the mounting arch so as to be visible to the scanner during non-data taking periods (Figure 10-2).

The emissive source is constructed by attaching a honeycomb structure to a base material of copper and coated with a low emission material (see Section 5.2).

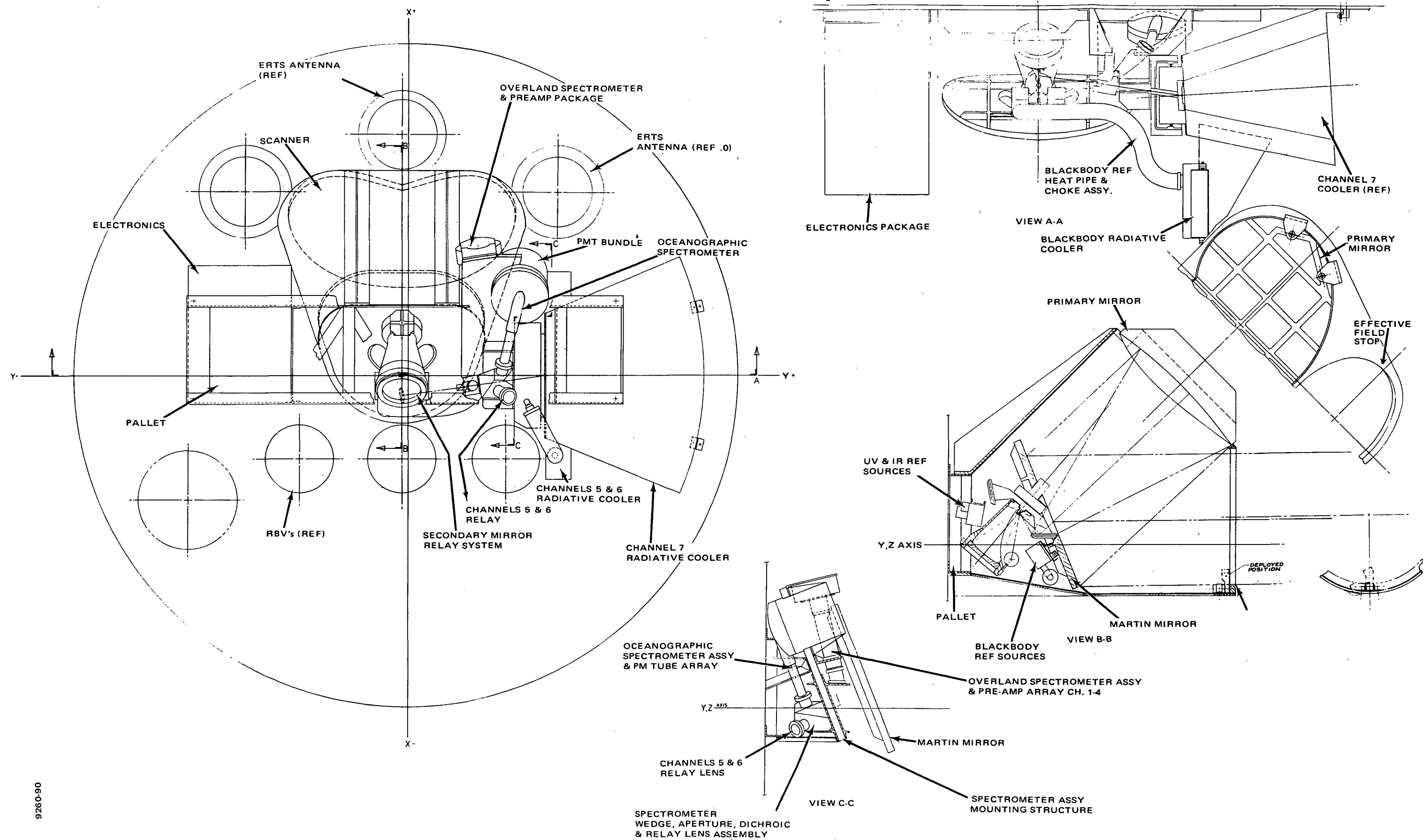
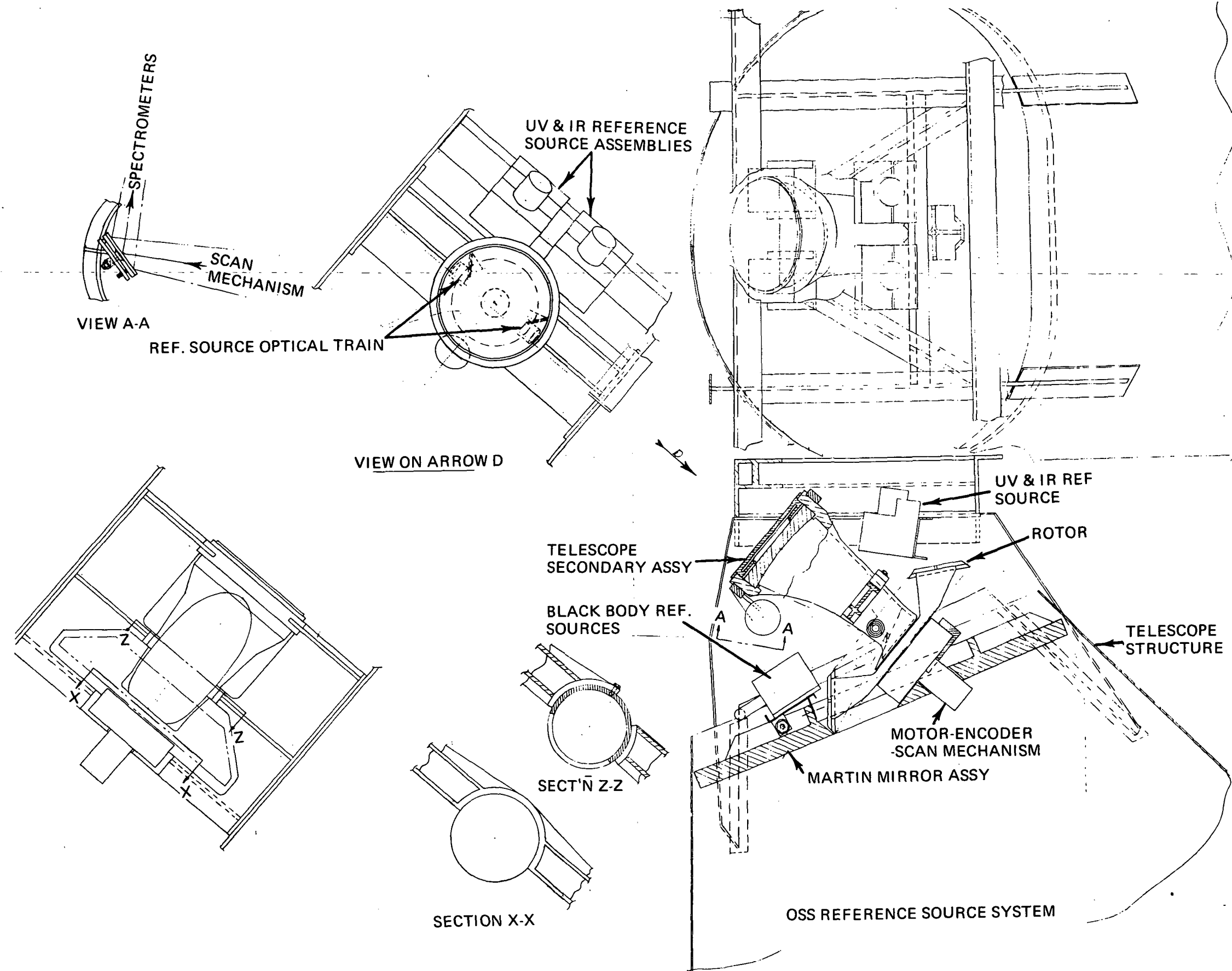


Figure 10-1 Over-all OSS Scanner Layout



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Figure 10-2 Calibration Source Installation

The reference area is enclosed in a laminated mylar container complete with mounting provisions. By using the super insulation shell as the enclosure, simplification of construction can contribute to lower costs and weight savings.

The reflective source consists of a reference lamp, filters, optical elements stepping motor and housing. As in the emissive source, two reflective sources are used, each set to a specific level. The lamp and optical elements are mounted in an aluminum tube.

Remote changing of filters is accomplished with a filter wheel and a stepping motor drive. The filter wheel assembly is attached to the aluminum tube and permits inserting the filters into the optical path. Because of the light weight of the filter wheel, the stepping motor can be direct drive. After installation of the calibration sources, the secondary mirror assembly is mounted to the Martin mirror. Final alignment of the telescope/scanner mechanism is achieved through the individual adjustment capability in the mirror mounts. With the telescope in adjustment, the sun calibration mirror can be positioned and checked out.

The sun calibration mirror (Figure 10-3) is attached to the tube-like shroud of the collecting optics assembly (Ref Section 5.3). The sun mirrors are mounted on a bar attached to the shaft of a stepping motor. This permits retraction of the sun mirror to reduce obscuration and storage of the mirror shield.

10.3 SPECTROMETER ASSEMBLY

The spectrometer assembly combines both the overland and oceanographic spectrometers as one major assembly attached to the collecting optics and scanner assembly (Figure 10-4). The spectrometer is comprised of the common optics assembly, overland spectrometer, overland detector assembly, oceanographic spectrometer, and oceanographic detector assembly.

The image from the telescope enters the common optics assembly through the field stop and is split by means of a wedge. Band 7 is split off from the overland data image by a dichroic mirror and imaged on the Band 7 detectors in the passive cooler.

10.3.1 Overland Spectrometer and Detector Assembly

The image for the overland spectrometer is split off by the wedge located in the common optics assembly. This image is reflected to a parabolic reflector, returned to the Pfund mirror, and reflected through a dispersion prism. A dichroic mirror located in the optical path after the prism passes thermal Bands 5 and 6 to a detector plate cooled by a thermal radiator. The reflected bands are imaged by

9260-93

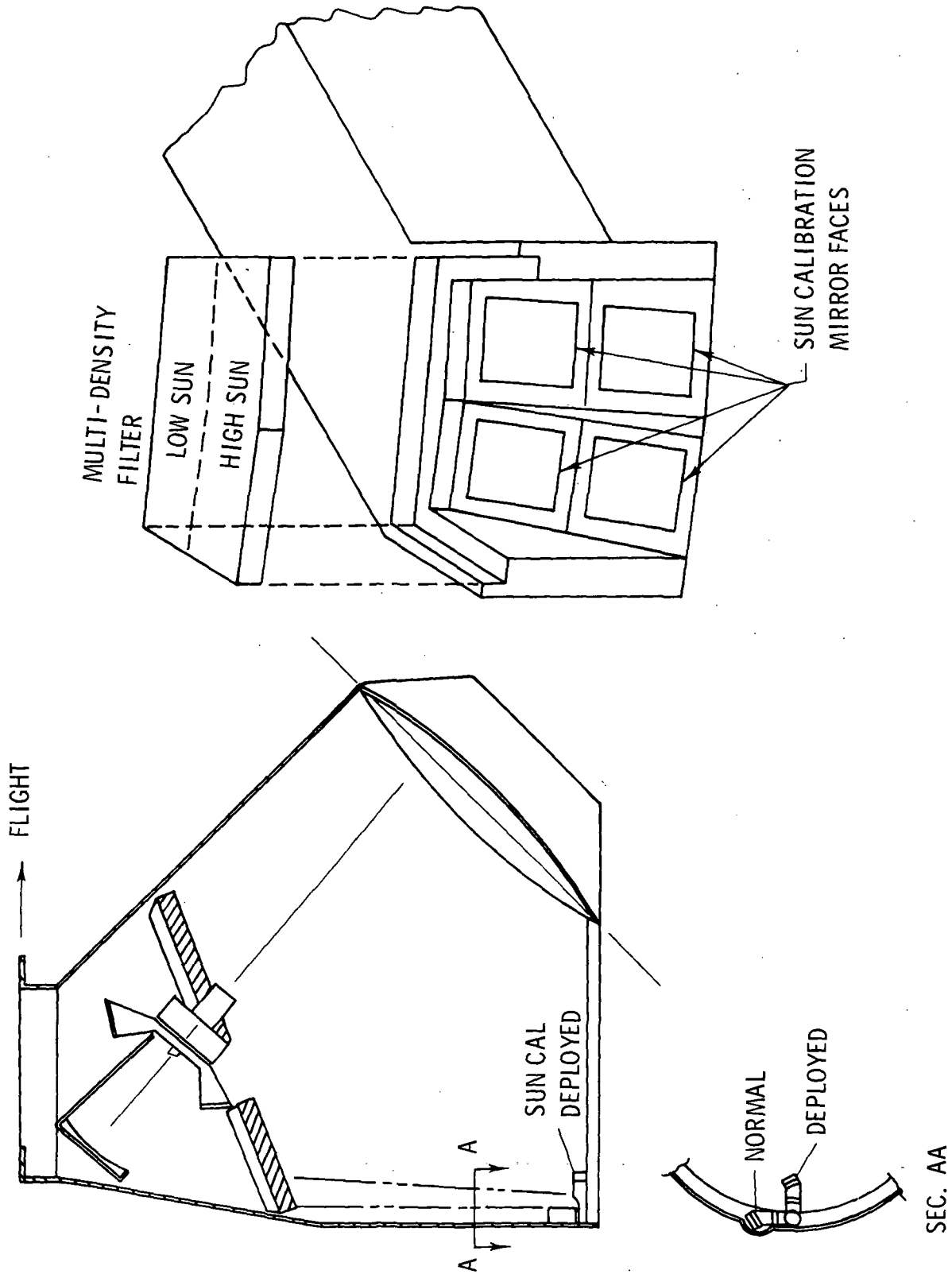
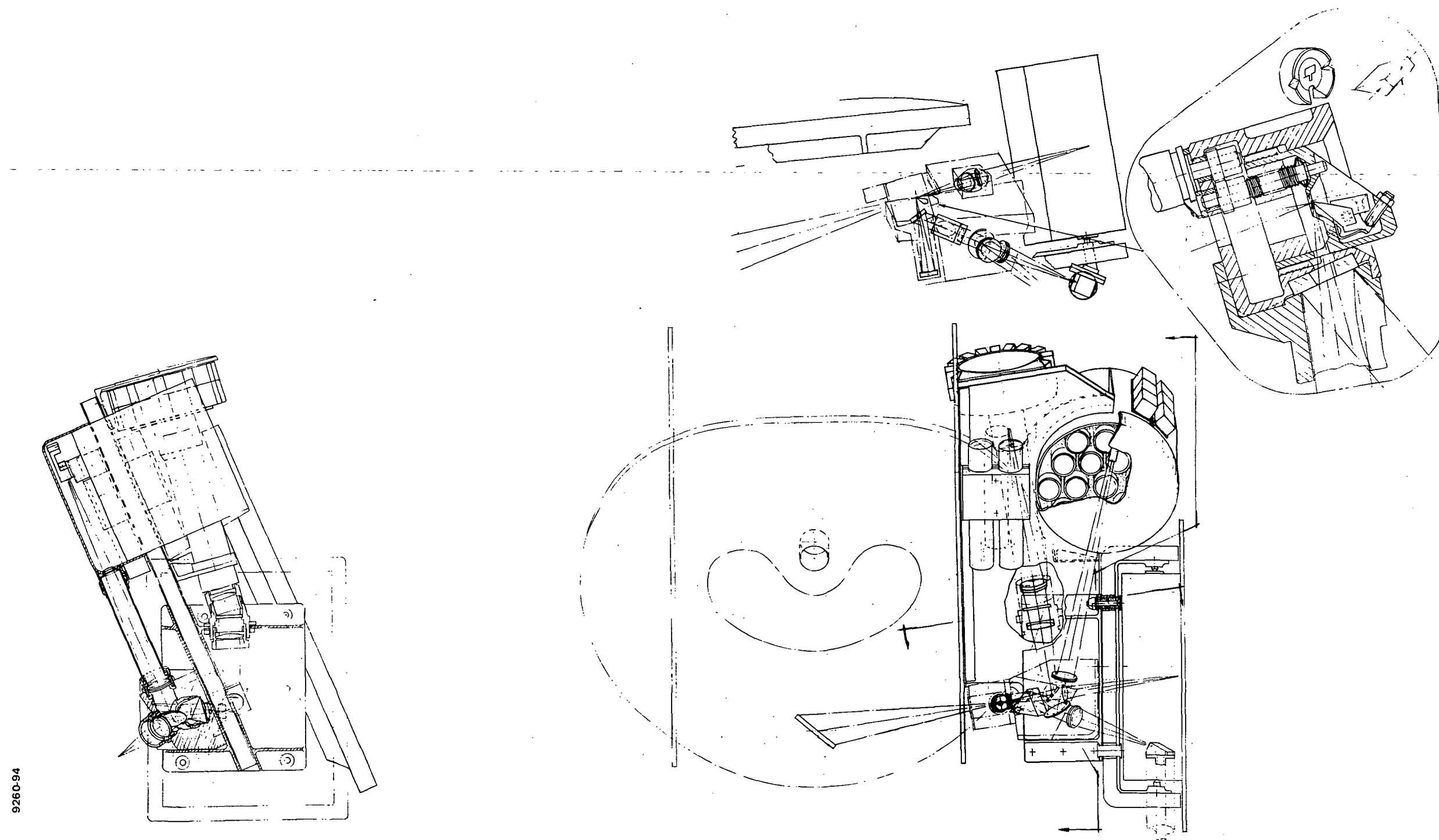


Figure 10-3 Solar Reference Reflector Configuration



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Figure 10-4 Spectrometer Assembly

a lens on the detectors of Bands 1, 2, 3 and 4 in the detector assembly. The detector assembly (Figure 10-5) provides mounting for the 18 PMTs and six solid-state detectors.

An adjustable mount for the detector array, consisting of the six channels of solid-state detectors and 18 channels of fiber-optics elements, compensates for any mechanical misalignment. Construction material is primarily aluminum with a more stable material such as Invar being used for mounting of imaging elements and the dispersion prism where position stability is important.

The photomultiplier tubes (PMTs) and their preamps are mounted in 3/4-in. diameter by 4-in. long aluminum tubes. The PMT assemblies are in turn mounted in a large aluminum container. A common high voltage power supply is located on the spectrometer chassis and provides high voltage power to the PMTs. The fiber optics are individually attached to each PMT assembly as a final assembly operation.

10.3.2 Oceanographic Spectrometer and Detector Assembly

The image for the oceanographic spectrometer is split by a dichroic mirror, passing the thermal band (7) to the thermal detectors in the passive cooler and reflecting oceanic Bands 1 through 24 to an achromatic collimator and transmission grating. The dispersed beam is then focused on the detector array located in the detector assembly. The detector assembly provides for a solid-state detector array and fiber optics for three PMT assemblies. The detector array is completely adjustable. The dispersion grating and lens elements are mounted in a common tube of Invar for stability. The preamps for the solid-state detectors are located in a ring surrounding the detector array. This arrangement provides for short equal length connections from the detectors to the preamps. Figure 10-6 is a general layout for the oceanographic mode detector assembly.

10.3.3 Band 7 Passive Cooler Detector Installation

The detector portion of the passive cooler assembly (Figure 10-7) is removable from the cone. At this point, the detector assembly is attached to the spectrometer along with the common optics drive assembly. Thermal analysis of the passive cooler detector assembly disclosed that detector position changes were likely when the cooler is functioning and the detectors are at operational temperature. Because of this condition, a focus drive was devised for re-imaging purposes (view A, Figure 10-4). The radial change in detector position would be very slight due to the load symmetry resulting from the steel mounting wires. However, due to accumulative effects, the axial location of the detector could change and affect system operation. The ability to adjust the field stop position has the added advantage of a final focus capability in that the field stop position can be changed to locate it at the focal plane.

With final alignment of the spectrometer assembly complete, the spectrometer is attached to the collecting optics and scanner assembly. When this operation is completed, all the system optical components are aligned as one complete assembly and are then ready to be attached to the base frame.

10.4 PASSIVE COOLER ASSEMBLY

The passive cooler assembly is primarily the Band 7 detector cooler. However, due to its location, the radiators for Bands 5 and 6 as well as the emissive calibration source are included in the basic framework (see Section 8.2).

The basic Band 7 passive cooler consists of a rectangular cone with mounting provisions for Bands 5 and 6 radiator and emissive calibration source radiator and detector housing for Band 7. As noted in Section 10.3.3, the detector housing was made separable, primarily to facilitate alignment of the detectors with the spectrometer assembly.

The detector chip is located on a radiator surface suspended from the second-stage radiator suspension frame by eight steel wires. The interior of the suspension frame is insulated by a laminated mylar shell. The radiator side of the first stage is a very highly reflective surface. The inner suspension frame is supported by standoffs extending from the outer suspension frame. The outer suspension frame is sandwiched between molded mylar insulators. The outer suspension frame is supported by standoffs from the main support frame which is again insulated by a laminated mylar shell. Thus, the second stage becomes a super-insulated radiator assembly containing Band 7 detectors.

The first-stage cone, which attaches to the outer suspension frame, consists of an aluminum structure insulated with laminated mylar. The interior surface of the cone is a vacuum-deposited aluminum finish. The first-stage auxiliary radiator is mounted on the opening edge of the cone and consists of a series of mirrors for the reflective surface. The inner and outer cones are separated by means of low thermal conductivity supports.

Radiators for Bands 5 and 6 and emissive calibration sources are attached to the frame provided on the cone of the Band 7 cooler. These radiators are approximately 48 sq. in. in area and are constructed of mylar insulation, aluminum honeycomb, and aluminum plate. The radiators are connected to the detectors by means of heat pipes. The radiator surface uses 1-in. square second-surface mirrors as a radiator face. The same type of low thermal conductance supports are used for mounting as in the Band 7 cooler.

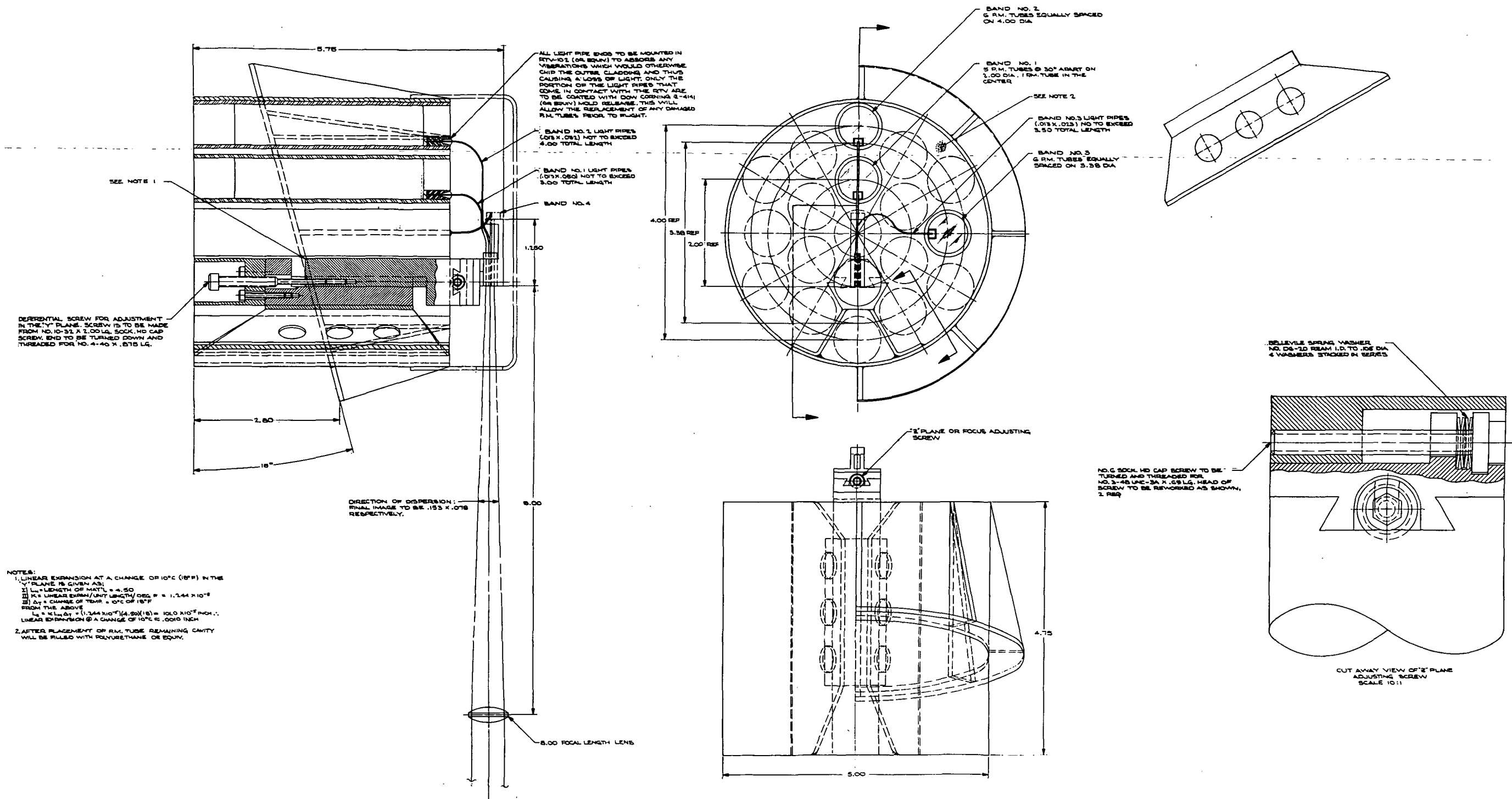


Figure 10-5 Overland Detector Assembly

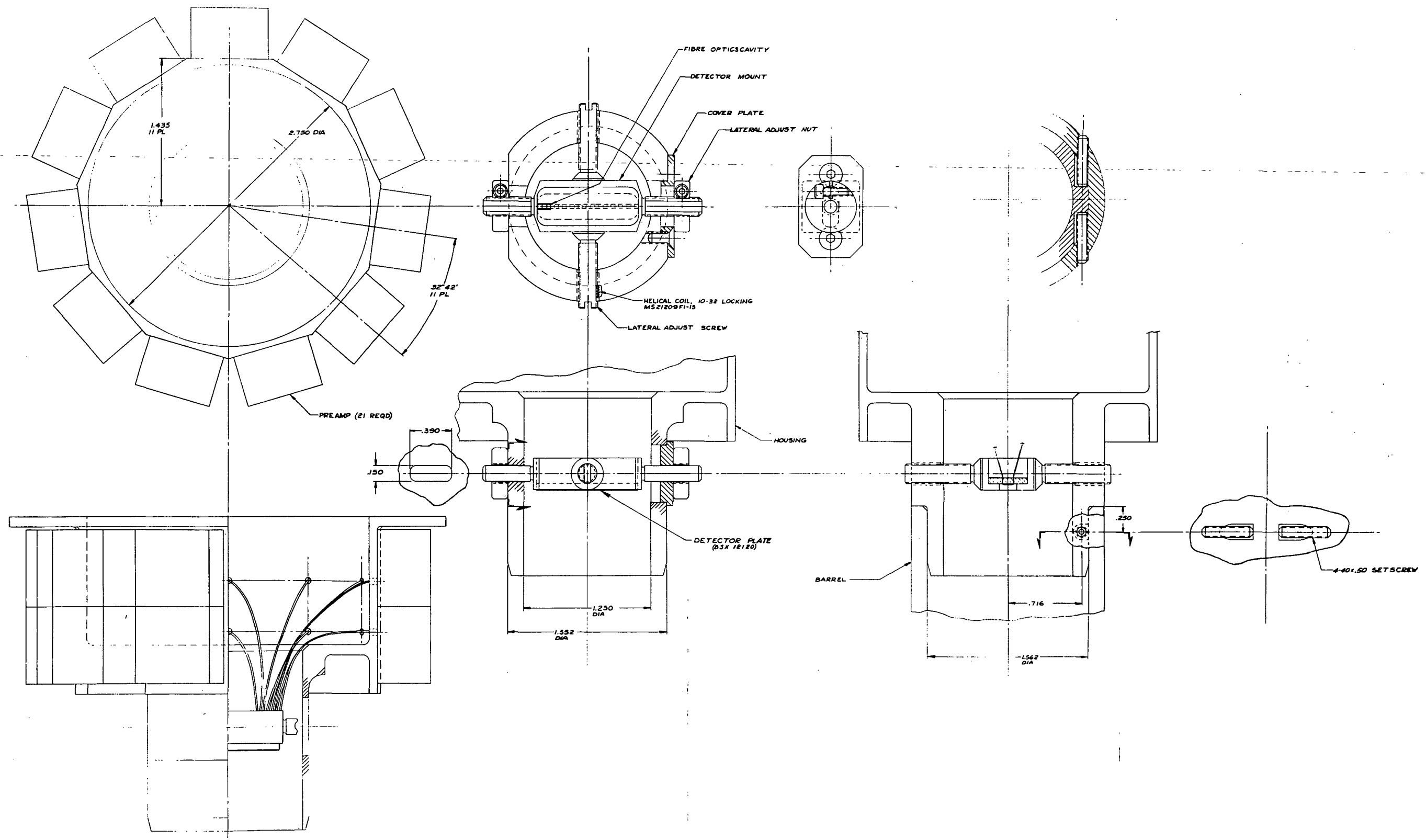


Figure 10-6 Oceanographic Detector Assembly

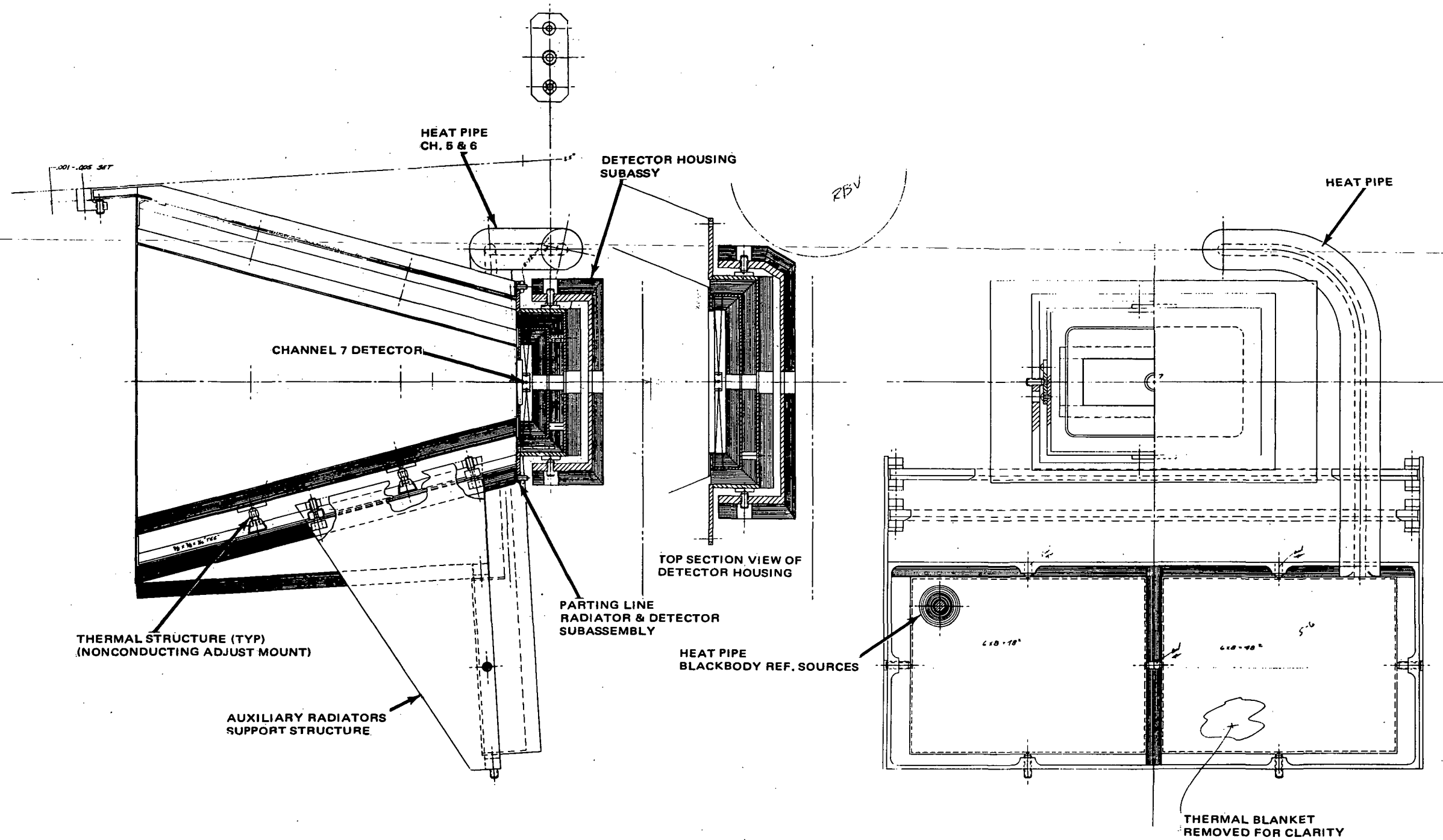


Figure 10-7 Passive Cooler Assembly

10.5 ELECTRONICS PACKAGING AND MOUNTING

All of the dual-mode scanner electronics are mounted on the same base frame provided for the collecting optics and scanner assembly. This results in the complete scanner being attached to the spacecraft without requiring electronics to be located in other areas on the spacecraft.

The electronics are contained in a box-like structure measuring 12 x 13 x 14.5 in. (Figure 10-8). The box is divided into two major sections. The upper portion contains all the processing circuitry with provisions for 54 plug-in circuit cards, all interconnect wiring is provided in the lower end of the section. The lower section provides for the power conversion unit and specific control function circuits. All interface connectors to the spacecraft are located in the lower section. Particular attention has been given to accessibility in order to monitor the unit completely during the test.

The quantity of electronics required on OSS because of the added spectral bands requires the use of hybrid module techniques. In general, a 1 1/4 x 1 1/4 in. container has been chosen as a typical size. The component density within the hybrid has been considered in circuit selection and represents good manufacturing practice. Table 10-1 represents a breakdown of the OSS circuits into hybrid types including the quantity required per system.

The circuit card compartment of the electronic assembly provides for a total of 54 plug-in cards. Presently, 49 cards are used, allowing provisions for five additional cards for future growth. The circuit card is planned to be multilayer to provide for the necessary hybrid interconnections. The tradeoff in favor of multilayer was made in terms of circuit card size and the number of interconnections required. Figures 10-9 and 10-10 are typical hybrid module distributions with the routing and number of interconnects required. The plug-in card concept was chosen over hardwiring primarily to assist final adjustments and test. A plug-in card is far easier and less expensive to remove than a wired-in card. By means of a jumper card, the circuit card can be removed from the assembly, yet tested with the complete electronics assembly, and all interconnects are available as test points. With this convenience, a very detailed examination of circuits is possible resulting with assurance that the electronics assembly is functioning as required. Table 10-2 is a summary of the number of circuit cards used. The quantity column represents the number of identical circuits within each card type. Thus, the entire system comprises eight different card types.

The lower portion of the electronics assembly is primarily power conversion circuits, input and output connectors, and cable space for interconnections for the circuit cards. All interconnections in the lower section will be wire wrap, this

TABLE 10-1

HYBRID MODULE SUMMARY

Function	Circuit	Can Type	Can Size(in.)	Pin Arrange-ment (No. of sides)	Qty Req'd.	
					Chan	System
Analog Processor	AGC	Platform	1.3 x 1.8	2	1	38
	Control Loop	Platform	1.3 x 1.8	2	1	38
	Level Shifter	Platform	1 1/4 x 1 1/4	2	1/6	
	Analog	Platform	1.3 x 1.8	2	1	37
ADC	Digital	Vertical	1.2 x 1.9	3	1	37
	Bands 2, 3, 5 and 6	Platform	1 1/4 x 1 1/4	2	3	72
	Bands 1 and 4	Platform	1 1/4 x 1 1/4	3	1	12
	Band 7	Platform	1 x 1	3	1	2
Time Code Gen	Control	Platform	1 1/4 x 1 1/4	2		1
	Storage	Platform	3/4 x 1 1/4	2		2

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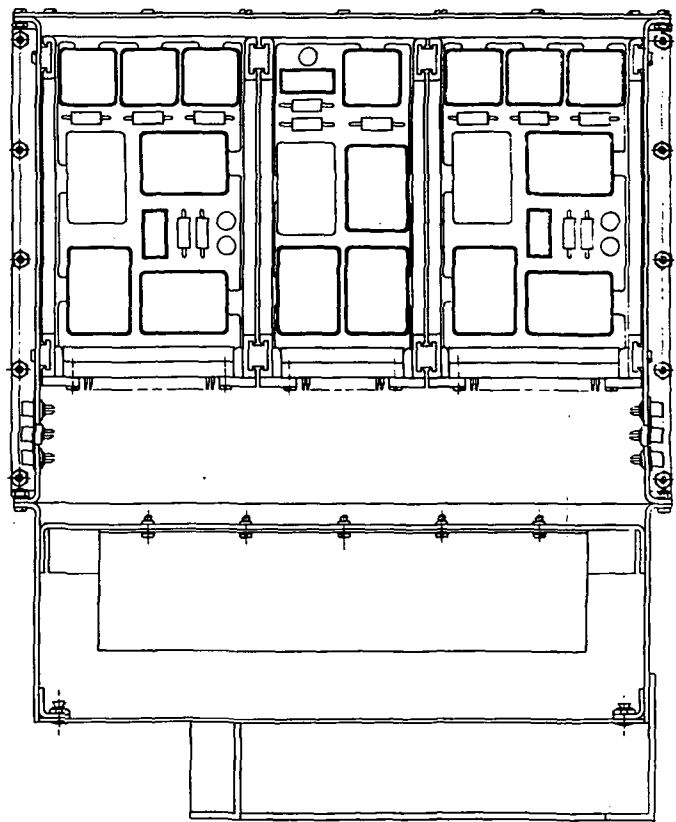
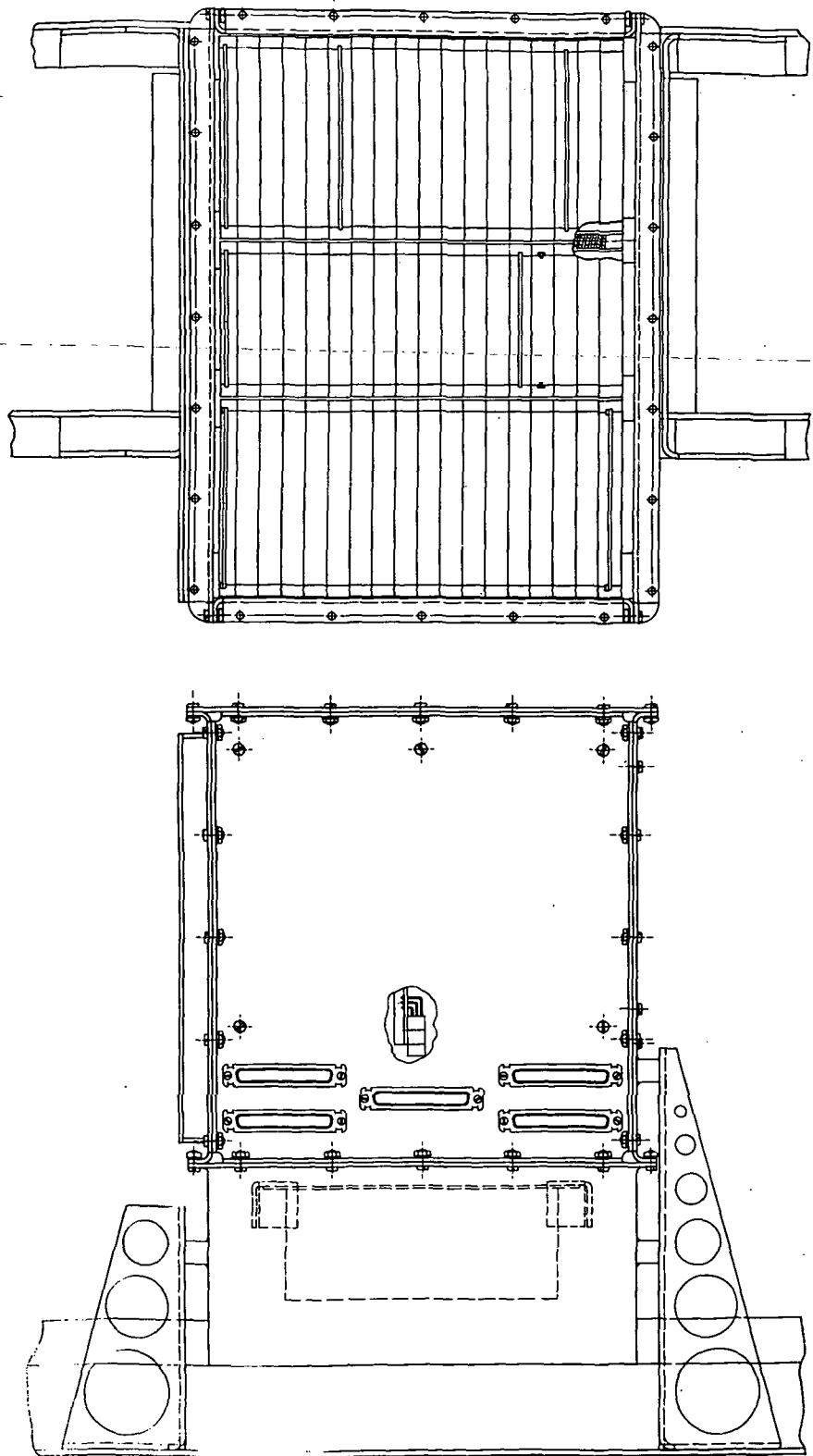


Figure 10-8 Electronics Assembly

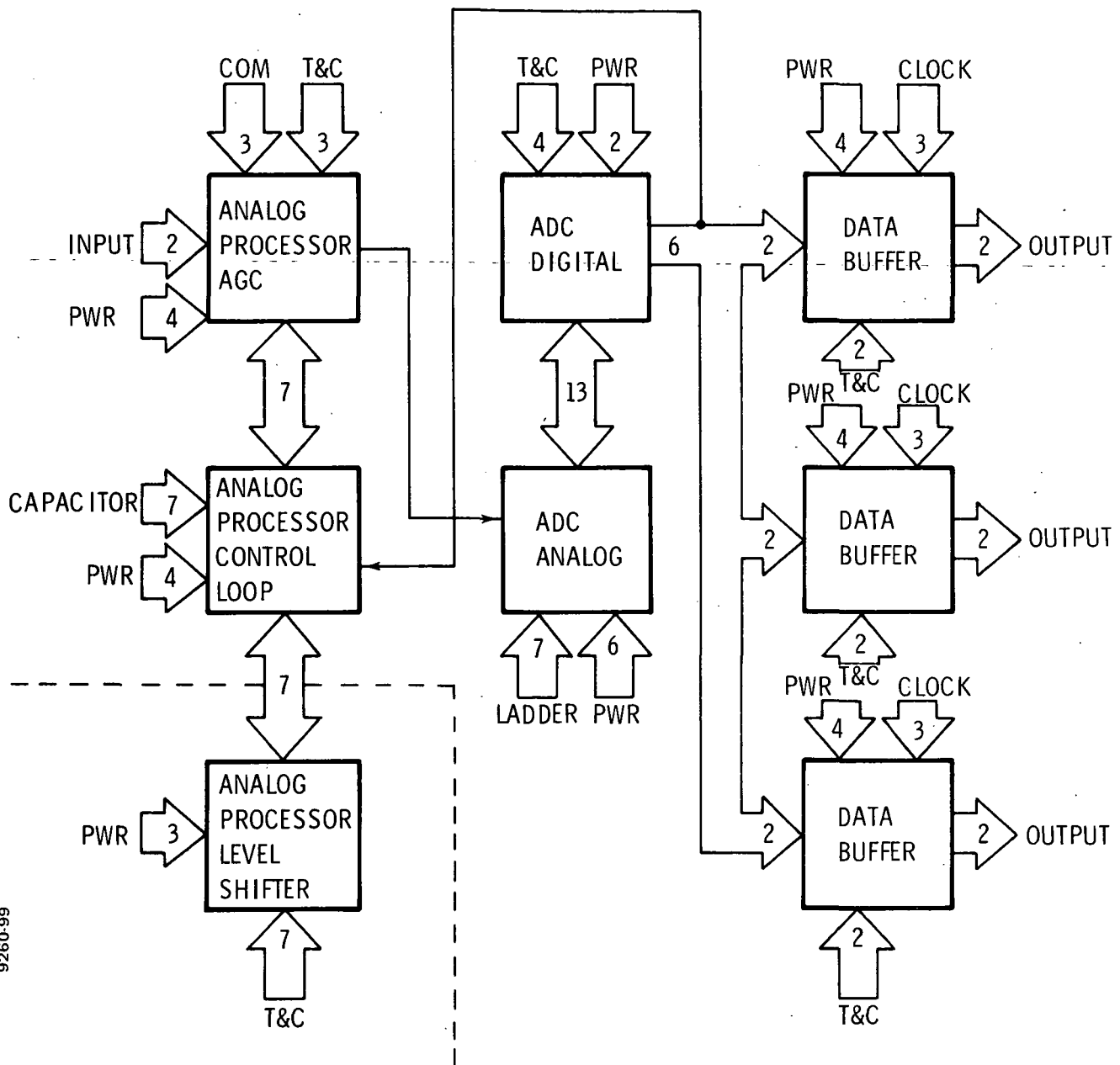


Figure 10-9 Hybrid Distribution on Circuit
Cards - Bands 2, 3, 5 and 6

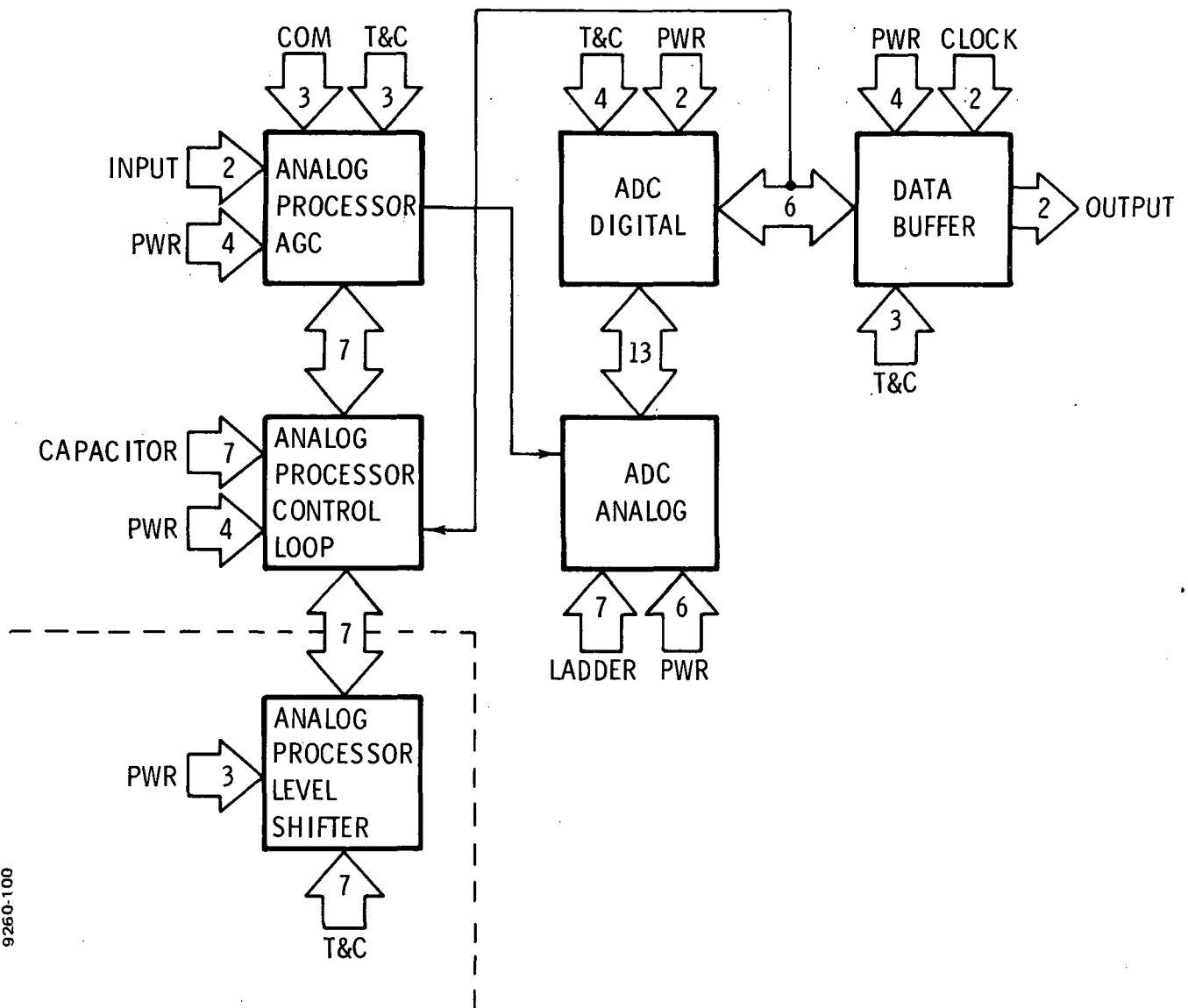


Figure 10-10 Hybrid Distribution on Circuit Cards -
Bands 1, 4, and 7

TABLE 10-2

CIRCUIT BOARD SUMMARY

Function	Quantity Required
Bands 2, 3, 5 and 6 Circuit Board	24
Bands 1 and 4 Circuit Board	12
Band 7 Circuit Board	2
Level Shifter	2
Timing and Control	3
Formatter (Includes Time Code Generator)	3
Motor Control	2
Power Converter	1

again provides convenient access to the terminal pins for test points.

General construction of the electronics module container is sheet aluminum. The circuit cards are supported by metal guides which serve as a thermal conductor. The circuit board guides are fastened to aluminum bars for support as well as for thermal transfer to the radiator. The box is constructed in two sections; each can be completely assembled, joined by cables, and tested with all key circuit points exposed. After test completion, the two sections are joined together, forming a single unit electronic assembly.

The thermal radiator (Ref. Section 7.2) is located on the face of the electronics assembly and is exposed to earth radiation and deep space. All internal electronics unit structure is terminated at the cooler mounting wall.

10.6 STRUCTURES AND MATERIAL

A preliminary structural analysis of the OSS concept was made to serve as a design guide in working out the concept mechanical details. This analysis is contained in Appendix E.

As the OSS design progressed and structural analysis data became available, the concept evolved into a complete functional design. The apparent weak points in the structure were corrected as the design effort progressed.

Table 10-3 shows the final weight distribution, including structure, which is representative of the flight unit.

TABLE 10-3
WEIGHT SUMMARY

Item	Detail Weight (Lb.)	Total Assembly Weight (Lb.)
1. Basic Structure		9.0
2. Collecting Optics Assembly		48.7
Primary Mirror	14.9	
Martin Mirror	0.3	
Secondary Mirror	0.6	
Secondary Mirror Structure	3.7	
Primary Mirror Structure	7.2	
Folding Mirrors (2)	0.3	
Insulation/Enclosure	9.1	
3. Scan Assembly		2.0
Rotor	0.2	
Motor	1.8	
4. Calibration Sources		5.1
Emissive (2)	1.6	
Reflective (2)	3.1	
Sun Mirror	0.4	
5. Spectrometer Assembly		12.1
OLS Spectrometer	2.8	
OLS Detector Assembly	3.7	
OCS Spectrometer	2.8	
OCS Detector Assembly	2.3	
Common Optics Assembly	.5	
6. Passive Coolers		14.5
Band 7	10.0	
Bands 5 and 6	2.2	
Emissive Calibration Sources	2.3	
7. Electronics Assembly	0	48.0
Total		139.4

SECTION 11

THERMAL CONTROL

The basic OSS thermal control concept is passive in concept to minimize power consumption, maintain low weight and volume, and provide maximum reliability over the design life of the instrument. Where possible, separate individual thermal control systems have been implemented to accommodate high heat dissipation components or meet special cooling requirements. In each of these applications, basic thermal isolation between the components and primary structure has been provided to reduce undesirable mutual heat transfer to a low level. The over-all concept also uses a multilayer superinsulation shroud to control random and orbital-associated cyclic thermal radiation to the OSS instrument. In addition, a basic level of thermal decoupling from the ERTS spacecraft has been implemented to prevent overloading of its thermal control system.

Figure 11-1 presents the OSS thermal control configuration in schematic form. Each component is identified with a required temperature range to be maintained. Also, the primary mode of heat transfer between components and the isolation requirements are shown at each major interface. Basic radiator types with their appropriate view requirements are also included.

11.1 ELECTRONICS SUBSYSTEM THERMAL CONTROL

Thermal control of the electronics subsystem is accomplished by use of a phase change material (PCM) radiator system to provide controlled heat rejection and stabilized subsystem temperatures throughout the orbit. This method of thermal control is possible through the use of a single electronics subsystem module mounted to the OSS instrument primary structure and containing all major heat dissipating electronic components. The cyclic heat load generated is absorbed by the PCM and rejected to space at a controlled rate by a single radiator surface. The radiator and PCM are integral with one side of the electronic subsystem module structure and are thermally connected to the various circuit boards through the module structure and circuit load mounting strips. Temperature variation of the electronics subsystem module is estimated to be 7°K or less throughout the orbit (see Appendix F for detailed analysis).

The electronics module is shown in Figure 11.1-1 with the orientation to the ERTS spacecraft and OSS structure as indicated. The module's primary structure is of aluminum construction and is attached to the OSS instrument

9260-11

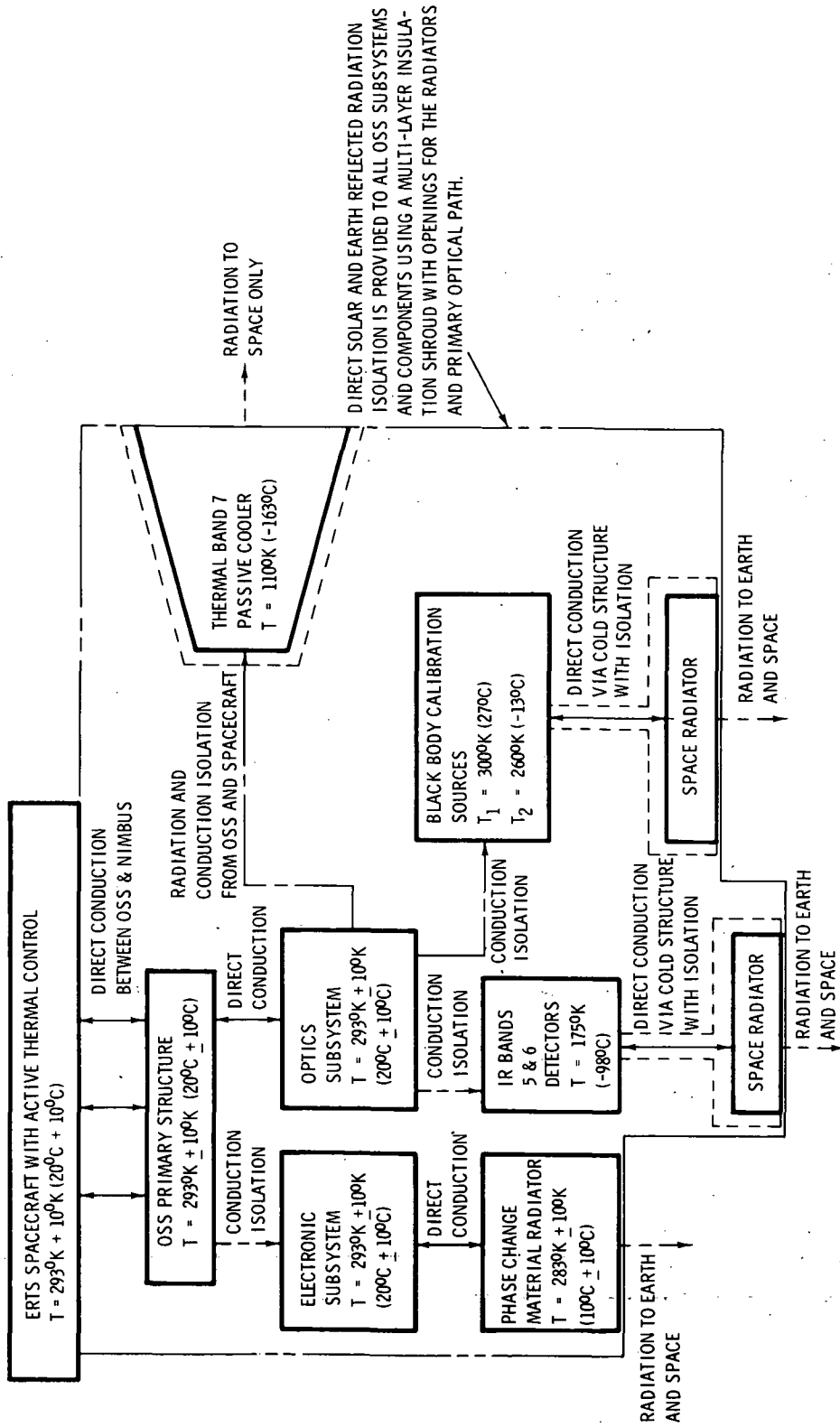


Figure 11-1 Thermal Control Configuration

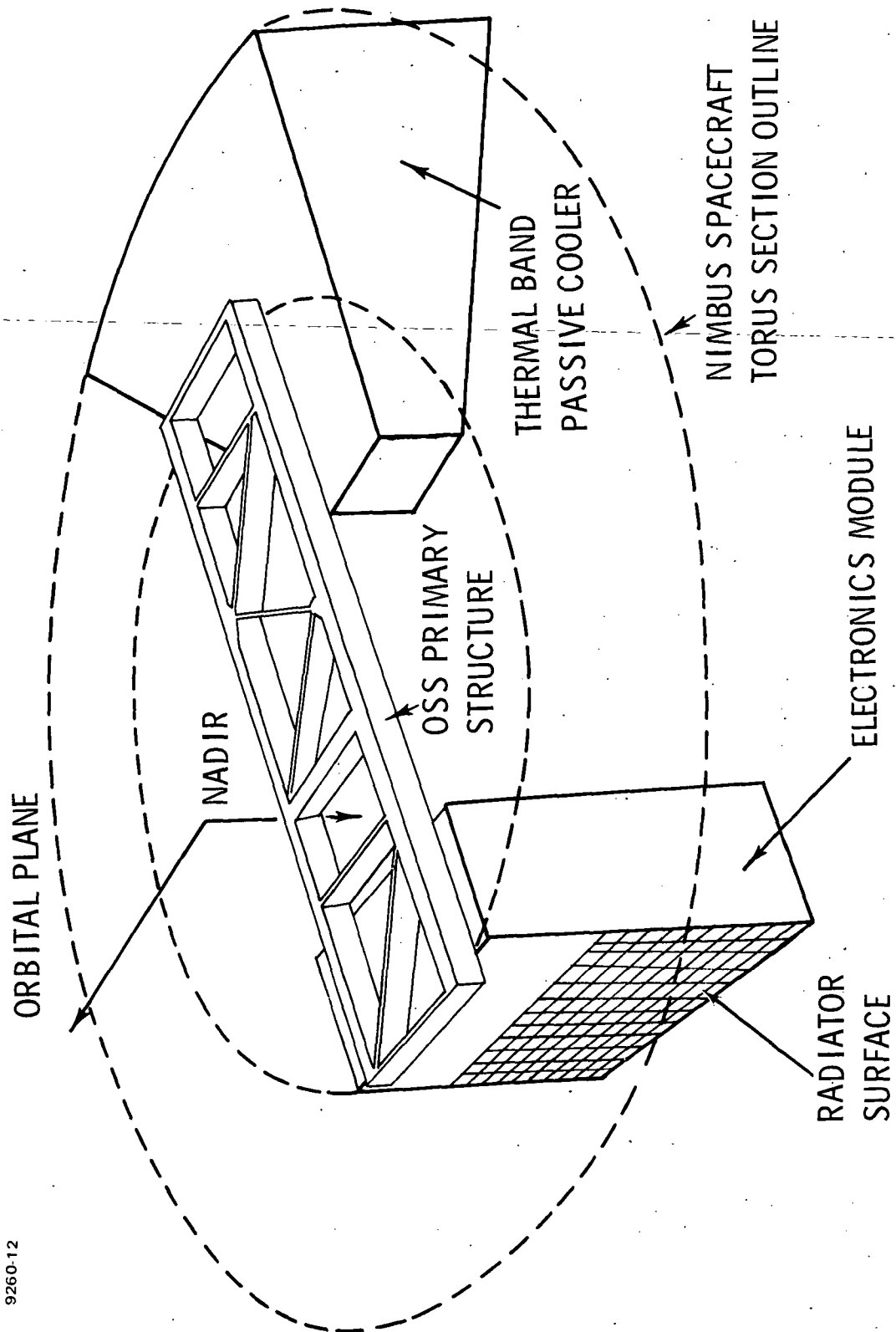


Figure 11.1.1-1 Electronics Module Mounting Arrangement

structure at six points with thermally isolated fasteners. One side of the module structure forms the integral PCM radiator system as shown in Figure 11.1-2. The radiator surface is a second surface mirror type for long-term stability of its thermal/optical characteristics in the space environment. It is the only surface of the electronic module which is not encased in a multilayer superinsulation blanket (≈ 40 layers of 1/4-mil aluminized mylar). The blanket is used to control direct and reflected solar heat inputs and direct earth-emitted heat input to the electronics module to a low level.

The module structure is maintained at approximately the same temperature as the OSS instrument structure and the ERTS spacecraft; however, heat transfer to the electronics module is minimized by use of thermal isolator type fasteners. This method of providing thermal decoupling between the electronics module and the spacecraft prohibits overloading of the spacecraft thermal control system and allows each subsystem to operate under near isothermal conditions with minimum influence upon the others.

Heat transfer within the electronics module is accomplished primarily by conduction from the individual circuit boards through the mounting strips and surrounding structure to the PCM radiator. A secondary conduction path is present through the connectors and cabling to the structure. The total heat load is conducted through the structure to the radiator which is sized according to the average heat dissipation. The heat of fusion of the PCM is used to provide the mechanism for maintaining the average dissipation level throughout the orbit and permits the module to operate at near isothermal conditions regardless of the orbit condition (day or night) or power consumption level.

The PCM radiator is constructed of aluminum plates, aluminum honeycomb case, PCM, and the second surface mirrors. The honeycomb cells are filled with the PCM and closed off with the aluminum plates. The second surface mirrors are applied to one of the aluminum plates to form the exterior surface of the radiator. Figure 11.1-2 shows the general construction details of both the electronics module and radiator.

Predicted thermal performance characteristics of the PCM radiator and electronics module combination are presented in Figure 11.1-3. The orientation of the radiator surface along with the thermal/optical characteristics of the second surface mirrors provide minimum day-night swing of the radiator surface temperature at the average electronics power dissipation level. The temperatures within the module are well within the design requirement of $293 \pm 10^\circ\text{K}$ and are considered to be slightly low. This is a result of being conservative on the amount of radiator surface required. Final adjustment of the module temperatures can easily be accomplished by masking the radiator surface to a slightly smaller exposed area to match the finalized power dissipation levels.

RADIATOR DESCRIPTION AND ELECTRONICS MODULE CONSTRUCTION PROFILE VIEW

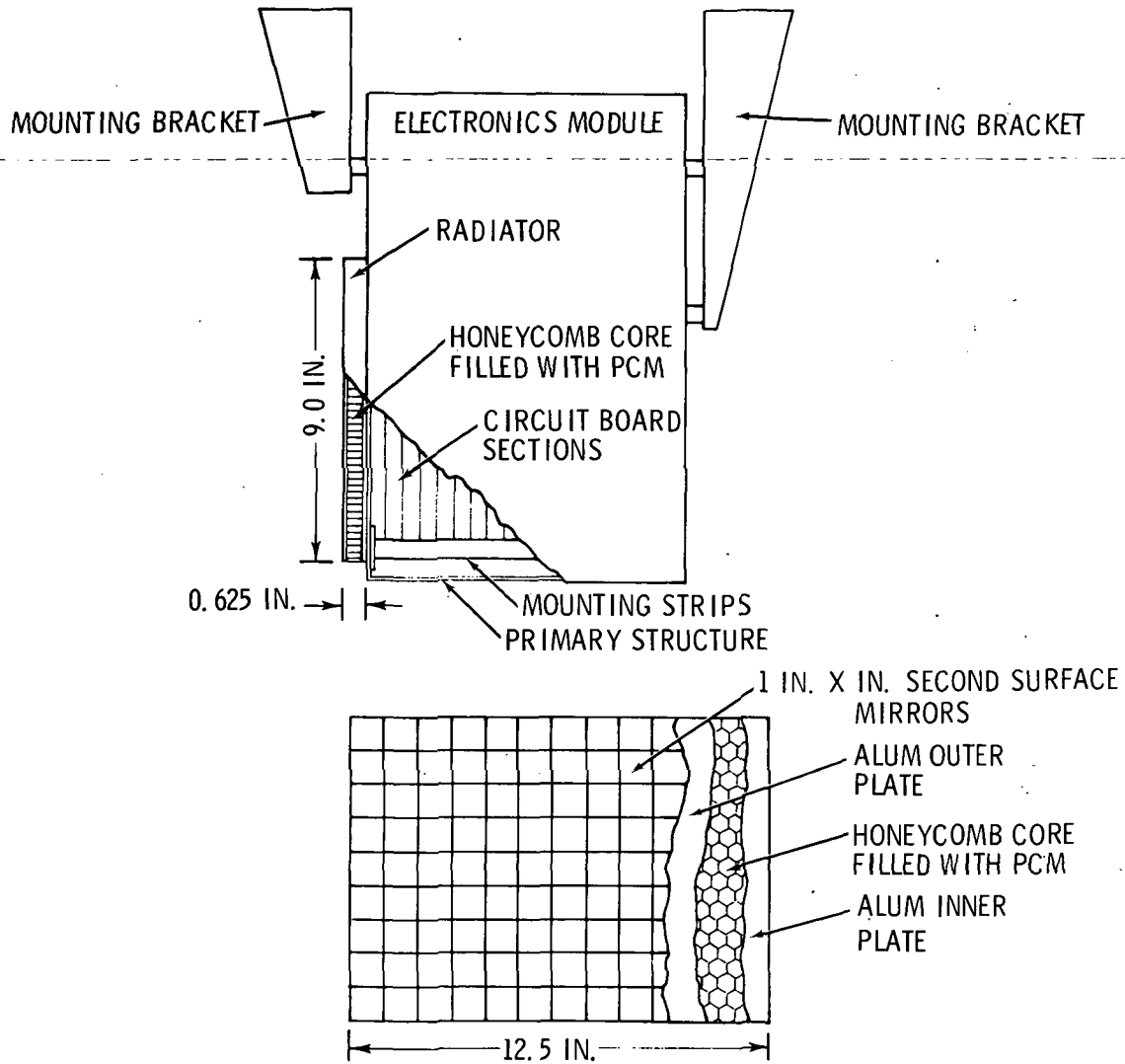


Figure 11.1-2 Electronics Module Radiator

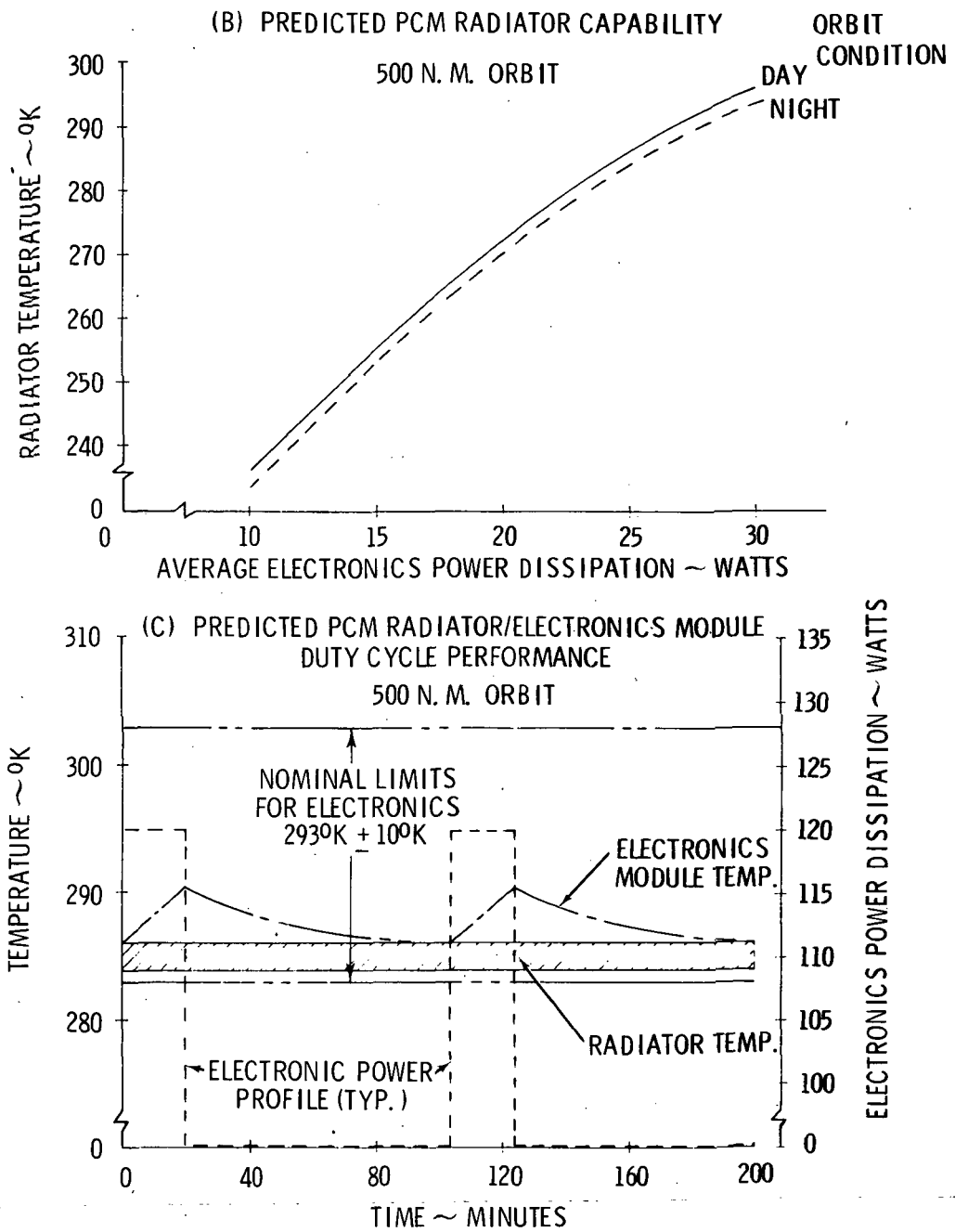


Figure 11.1-3 Electronics Module Radiator Performance

11.2 OVER-ALL STRUCTURE THERMAL CONTROL

Thermal control of the OSS primary structure is accomplished through the use of good conduction coupling to the ERTS spacecraft in conjunction with encasing the OSS instrument within a large multilayer superinsulation blanket shroud. The primary structure is effectively coupled to the ERTS thermal control system and protected by the shroud from direct and reflected radiation from the sun, earth, and spacecraft. High-heat-dissipation OSS components such as the electronics subsystem module are provided with self-contained thermal control systems for effective isolation from the OSS structure. With the direct conduction coupling between the ERTS and its fully active thermal control system and large thermal mass, the OSS structure and spacecraft will be at approximately the same temperature indefinitely. Any small residual heat inputs to the structure from OSS components will be sufficiently small to be within the reserve capacity of the spacecraft's thermal control system throughout the orbit.

The basic concept involved in the OSS structure thermal control is presented in Figure 11-1 and identifies the various thermal control interfaces and temperature requirements between the OSS instrument and the ERTS spacecraft. By providing separate thermal control for all major OSS heat-dissipating components, the structure is subjected to a low thermal load easily controlled by the spacecraft. In this manner, the aluminum structure becomes near isothermal and approximately the same temperature as the ERTS spacecraft. This approach provides excellent long-term OSS structure temperature stability with a minimum temperature gradient between critical optical components.

SECTION 12

SYSTEM MODULATION TRANSFER FUNCTION (MTF)

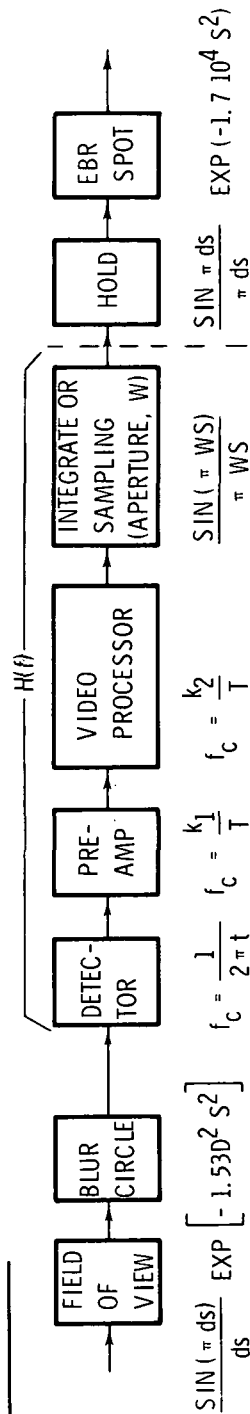
12.1 MTF OF THE SCANNER STAGES

The frequency scale given in all figures in this section is in the dimensionless units $ds = Tf$ where d is the (IFOV), s is the spatial frequency, T is the dwell time, and f is the temporal frequency. To obtain the required frequency, divide the scale in the figures by d or T , respectively.

A block diagram of the system components which contribute to the Modulation Transfer Function (MTF) is shown in Figure 12.1-1, together with the appropriate frequency response functions. For the purposes of this study, the optical blur circle is assumed to be Gaussian in form so that 80% of the energy falls within its diameter D , which is determined from the results of a ray trace program. The detector, preamplifier, and video processor are all represented by single-pole Butterworth filters whose 3-dB cutoff frequencies, f_c , are given under the appropriate blocks in Figure 12.1-1. The values of f_c for these three stages are determined by the detector time constant t and the constants k_1 and k_2 , which are design parameters specifying the relationship between f_c and the reciprocal of the dwell time. The values of k_1 and k_2 are listed beneath the preamp and video processor blocks for the different stages which have to be considered. Bendix proposes to use an integrate-and-hold (I and H) stage following the video processor for the reasons set out in the following sections, in which case it is desirable that the constants k_1 and k_2 should be large enough for the preamp and video processor frequency response terms to have little effect on the over-all MTF of the system. However, using Hg:Cd:Te detectors for Bands 5 and 6 implies that a sample and hold circuit should be used for these bands. This arises since the time constant of Hg:Cd:Te detectors is inversely related to their sensitivity so that a high sensitivity implies a low frequency response. The use of a sample-and-hold circuit instead of an integrate-and-hold circuit then compensates for the low frequency response of the Hg:Cd:Te detector. Use of In:As detectors for Bands 5 and 7 would, on the other hand, provide a high frequency response enabling all channels to have an integration stage.

9260-83

MTF ALONG A SCAN



OVERLAND MODE	BANDS 1-4	$f_c \gg \frac{1}{T}$	$k_1 = 1.5$	$k_1 = 1.5$	$W = 0.85 d$	(INTEGRATE AND SAMPLE)
OCEANOGRAPHIC MODE	BANDS 5 AND 6	$f_c \sim \frac{1}{3T}$	$k_1 = 1.5$	$k_2 = 1.5$	$W \ll d$	
MTF NORMAL TO A SCAN		$f_c \gg \frac{1}{T}$	$k_1 \gg 1.5$	$k_2 \gg 1.5$	$W = 0.85 d$	
NOISE BANDWIDTH:						$\Delta f_n = \int H(f) ^2 df = 0.5/T_d$

KEY: d = FOV ON GND D = BLUR CIRCLE DIA f_c = 3 dB CUT-OFF FREQUENCY T = DWELL TIME

Figure 12.1-1 System MTF Block Diagram

Final detector selection for a flight unit would be based on maximum sensitivity according to the then state-of-the-art of detector technology.

The broken line after the integration or sampling stage (Figure 12.1-1) marks the output of the scanner, and the MTF at this point is representative of the response for the actual data points. However, when the signal is used to generate images on film in the ground data station, the sampled value is held for a period equal to the sampling interval, and corresponds to an integration over the dwell time. Lastly, the response of the electron beam recorder (EBR) spot is considered and is Gaussian in form.

The MTF curves for each stage in the scanner are given in Figure 12.1-2 from which it is seen that the dominant factors are the IFOV and the integration stage. The blur circle lowers the response by only 10% at a bar width of 200 ft while the preamp and video processor each lower the response by 5% at this frequency. Lowering the response for these stages by using a value of $f_c = 1/T$ means that each stage lowers the response at a 200-ft bar width by 10% which is considered marginal in view of the number of stages involved. Figure 12.1-2 also shows the response of a filter with $f_c = 1/3T$ which is the expected detector response for Bands 5 and 6 due to the relatively long time constant for the Hg: Cd:Te detectors being used.

In a conical scanner, the MTF varies by a small amount around a scan line since the ground is being scanned; for example, by a diamond aperture when the scan line makes an angle of $\theta = 45^\circ$ with the flight direction (Figure 12.1-3). Thus the MTF of the IFOV is given by the equation:

$$M(s) = \sin(\pi ds) / \pi ds \quad (12.1-1)$$

when: $\theta = 0^\circ$ and by:

$$M(s) = \sin\left(\frac{\pi}{\sqrt{2}} ds\right) / \left(\frac{\pi}{\sqrt{2}} ds\right) \quad (12.1-2)$$

when $\theta = 45^\circ$. These two curves are shown in Figure 12.1-3 from which it is evident that the MTF of the scanner does not change appreciably around a scan arc. The diamond aperture ($\theta = 45^\circ$) provides a slightly higher response at high frequencies since it is weighted towards its center.

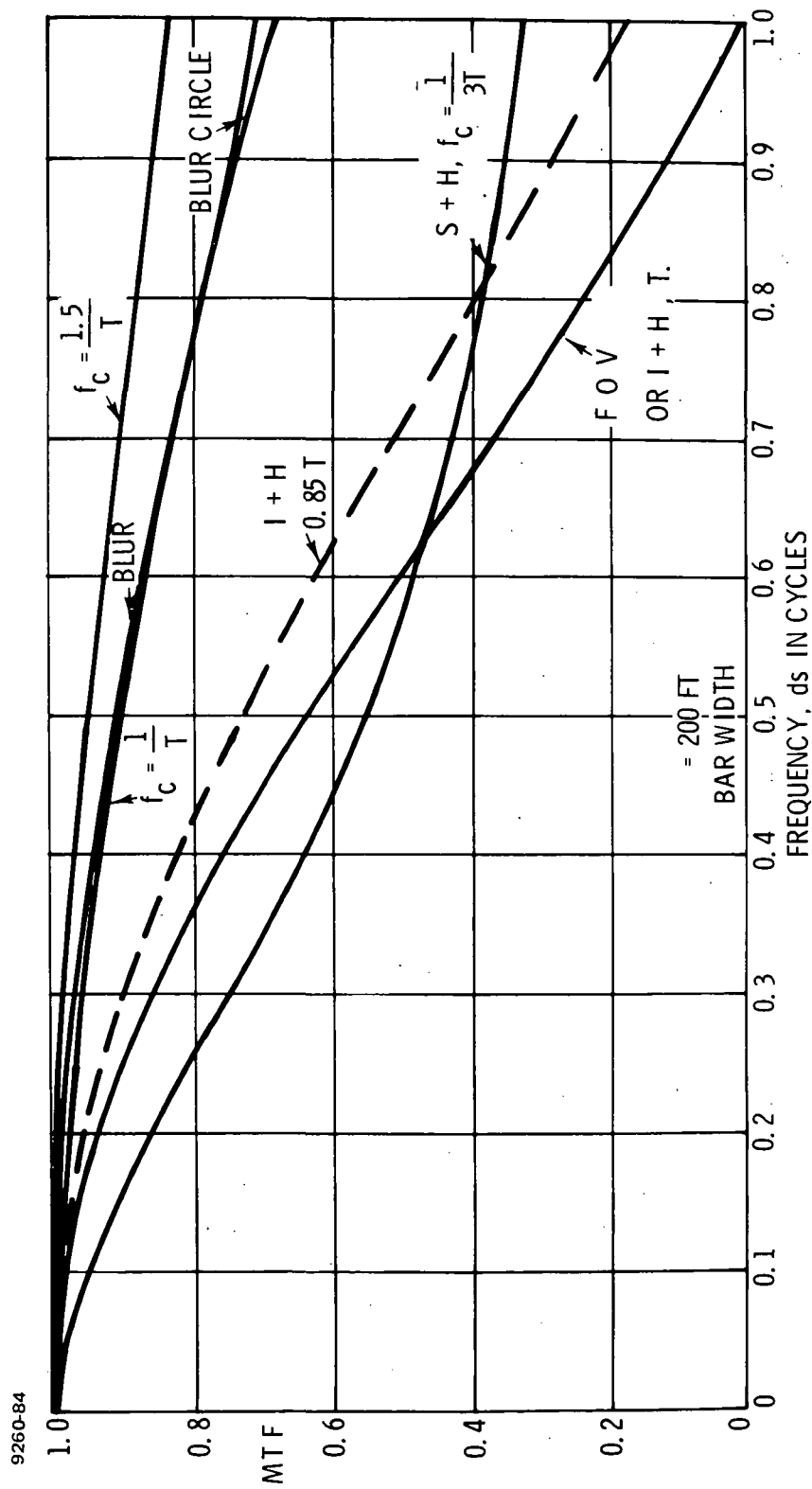


Figure 12.1-2 MTF Curves for the Individual Scanner Stages

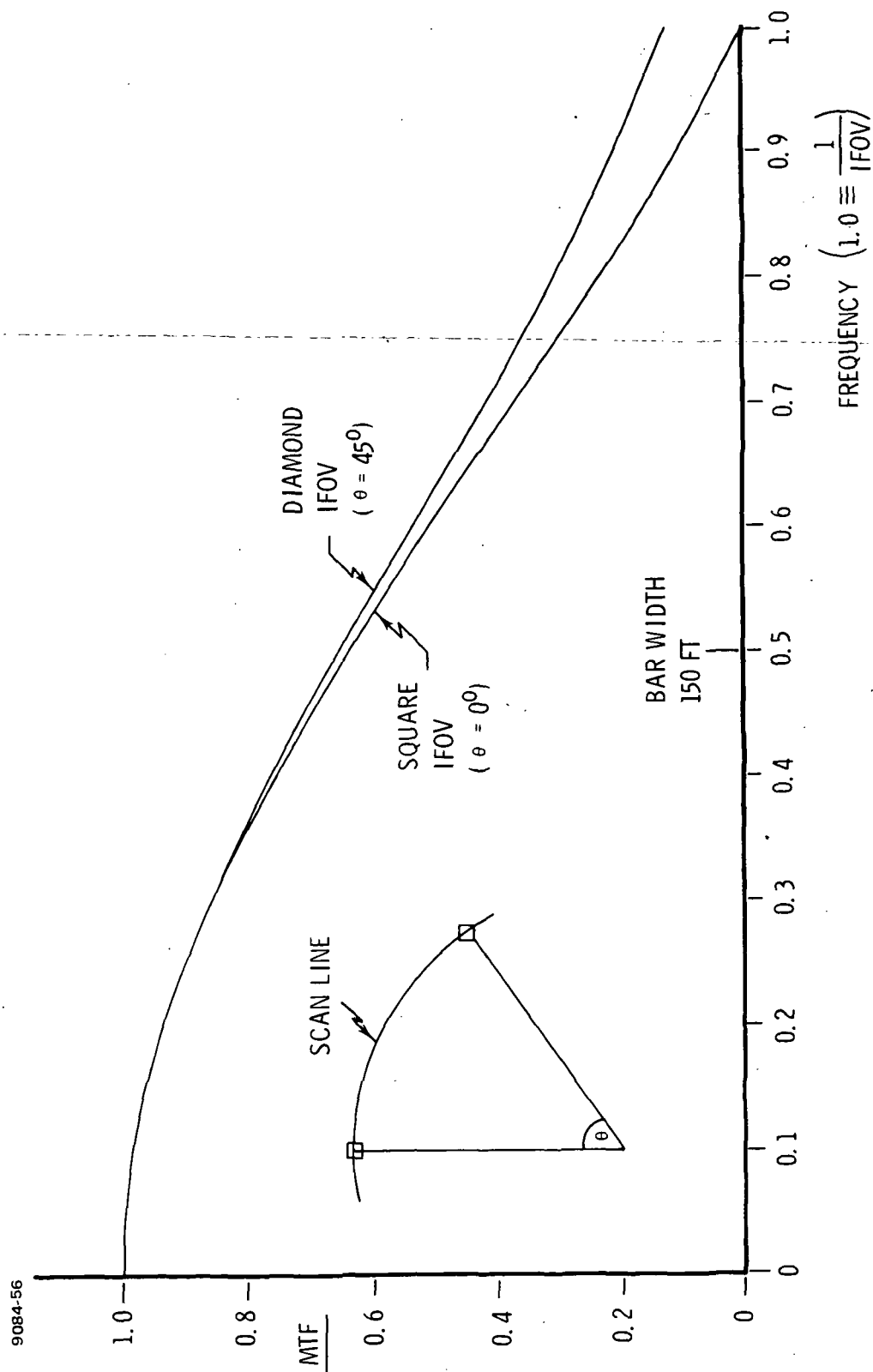


Figure 12.1-3 Variation in MTF of the IFOV Around a Scan Line

12.2 COMPARISON OF INTEGRATE-AND-HOLD WITH SAMPLE-AND-HOLD TECHNIQUES

The signal may be sampled in two ways. It is possible either to filter the signal to have a 3-dB cutoff frequency at $0.5 / T$ or below and then sample the signal at intervals of T or less (S and H), or to integrate the signal and sample it at the end of the integration period (I and H). Assuming that the sampling interval for both cases is the same, there are two reasons for selecting an I and H system over an S and H system associated with: (1) the equivalent noise bandwidth and (2) the sensitivity of the system to phase effects causing misregistration. The equivalent noise bandwidth Δf for the two systems is given by:

$$\text{S and H} \qquad \Delta f = \frac{\pi}{2} f_c \qquad (12.2-1)$$

$$\text{I and H} \qquad \Delta f = 0.5 / T_I \qquad (12.2-2)$$

where T_I is the integration time. To a reasonable approximation, the noise level is proportional to $\sqrt{\Delta f}$ so that the S/N ratio is proportional to $1/\sqrt{\Delta f}$ for a given signal level. The response of the system and the S/N ratio can then be displayed on one graph by plotting the MTF curves normalized to $1/\sqrt{\Delta f}$ as shown in Figure 12.2-1. It is immediately evident that the S/N ratio is about 25% poorer for an S and H system with $f_c = 0.5/T$ than for an I and H system integrating for the dwell time, though the resolution is somewhat better at high frequencies. In practice, the Bendix scanner will integrate the signal over a period of $0.85T$, the remaining 15% of the dwell time being used to sample the signal and dump the integrator. The resulting curve is shown dotted in Figure 12.2-1 and is seen to still have an appreciably better S/N ratio while having a frequency response in the region $0.5/T$ to $0.8/T$ which is comparable with the S and H system. The curve for an S and H system with $f_c = 1/3T$ is also shown in Figure 12.2-1 and is relevant to Bands 5 and 6 where an S and H system is chosen since the detectors already filter the signal, and the loss in resolution implied by also integrating the signal would be undesirable.

An estimate of the sensitivity of the two systems to phase effects can be seen by investigating the locations of the mean of the weighting function, Figure 12.2-2. Taking the sampling instant to coincide with the trailing edge of the IFOV, the I and H weighting function is symmetrical with its mean located at $t = 0$; the integration time can be accurately clocked so that there should be no appreciable misregistration occurring from band to band. With an S and H system on the other hand, the weighting function is much more unsymmetrical and the mean of the weighting function is located at time:

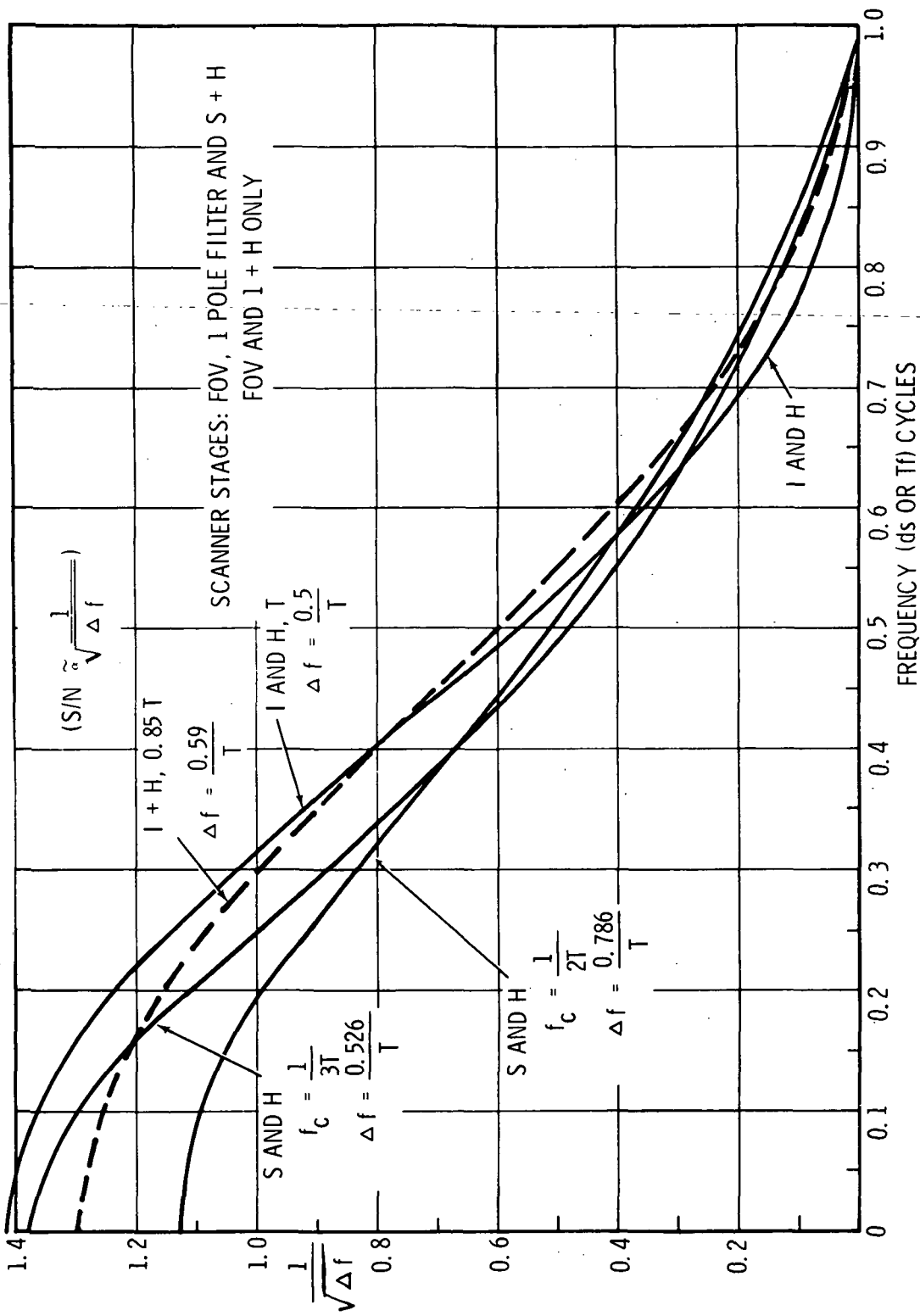


Figure 12.2-1 MTF Curves Normalized to the Reciprocal of the Square Root of the Noise Bandwidth

$$\bar{t}_s = \frac{T}{2} - \frac{1}{2\pi f_c} \quad (12.2-3)$$

Since $\bar{t}_s$ is dependent on f_c , the mean of the weighting function will vary from band to band with variations in f_c , resulting in misregistration. The variation $\Delta \bar{t}_s$ in $\bar{t}_s$ due to Δf_c in f_c is given by:

$$\Delta \bar{t}_s = \frac{1}{2\pi f_c} \frac{\Delta f_c}{f_c} \quad (12.2-4)$$

and it follows that if $f_c = 1/2T$, then an error of 10% in f_c from band to band will cause misregistration of about $0.032T$, or 3.2% of an FOV from band to band; this form of misregistration is highly undesirable from a data analysis point of view. An I and H system is less sensitive to band-to-band misregistration and the I and H weighting function also collects radiation in a relatively symmetrical fashion.

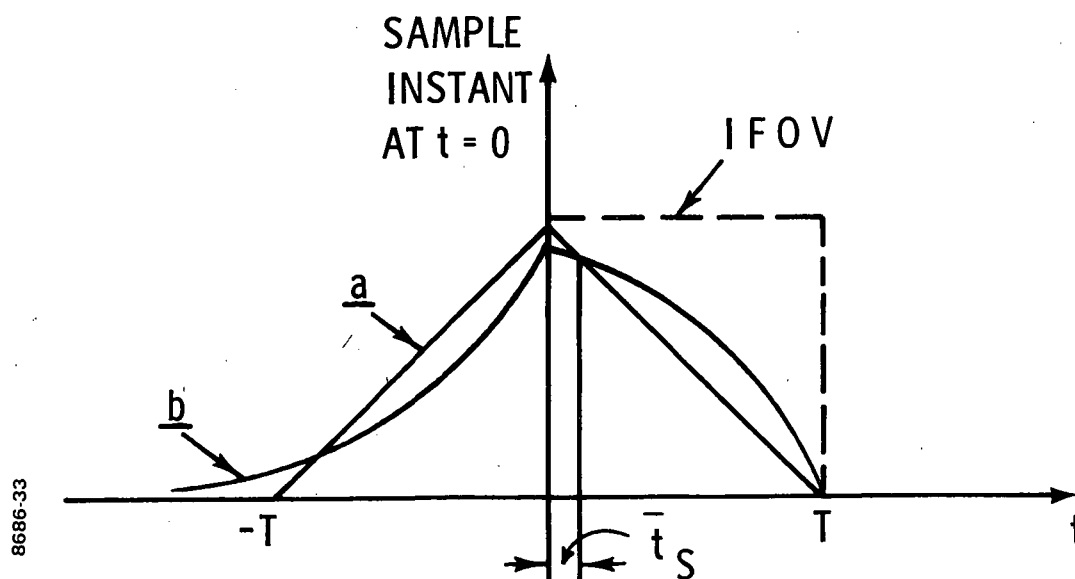


Figure 12.2-2 Comparison of Weighing Functions (Phase Effects)

12.3 OVER-ALL SCANNER MTF CURVES

The resultant MTF of the scanner is obtained by multiplying the functions given in Figure 12.3-1 for each stage together. At the scanner output, the MTF curves for the two modes of operation are shown in Figure 12.3-1. The MTF to a scan line is somewhat higher than that along a scan line since the electronic stages do not have a component in that direction. However, the blur circle, normal to a scan line is somewhat higher than that along a scan line since the electronic stages do not have a component in that direction. However, the blur circle, of the oceanographic mode is not affected to the same extent as the overland mode by the video processor stage since the same bandwidth is used in both modes, while the dwell time differs by a factor of six between them.

The expected response through the ground data handling station onto film is shown as the last curve in Figure 12.3-1 for the overland mode along a scan line. Again, the response of the EBR will have little effect on the MTF normal to a scan line.

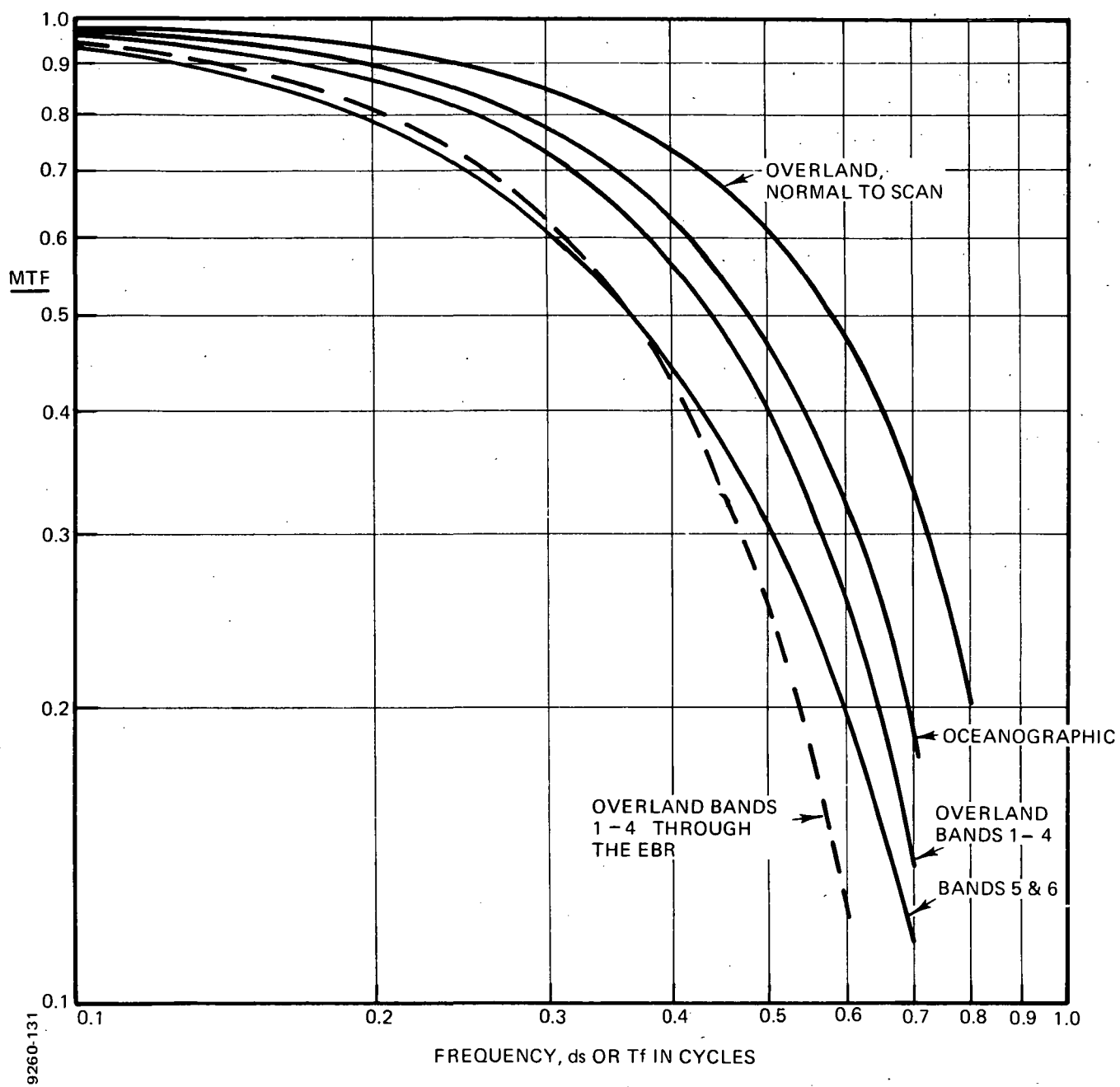


Figure 12.3-1 Over-all Scanner MTF Curves

SECTION 13

INTERFACES

Obviously, many interfaces are to be considered between the ERTS system and the multispectral scanner instrument itself. This design study could not deal with each one extensively, nor were detailed interface data available for such a study. Therefore, a selection was made of those major interface areas considered most basic and crucial to the accommodation of the OSS scanner and attention was directed toward them.

The physical interfaces between the scanner instrument and the spacecraft were examined in terms of direct interchangeability, size, form factor, weight and power. The other major interface areas are concerned with the handling of the output data. These interfaces arise because of the additional data produced as a result of the two additional bands in the overland mode and the re-arrangement of data channels in the oceanographic mode.

It was necessary to resort to data buffering because of the constraint on data link capacity at about 15 Mbps. Data format changes were required which, in turn, affected the Data Demultiplexer at the ground receiving sites and the data tape format. Finally, these changes had an influence on the ground data handling system. The approach, of course, was to suggest methods which would result in minimum modifications to the existing system.

13.1 SPACECRAFT INTERFACES

The multispectral scanner presently designed for ERTS A establishes the interface requirements for the OSS concept. Figure 13.1-1 is an outline drawing with basic envelope dimensions. The present scanner is mounted on a pallet furnished as part of the spacecraft. A thermal blanket, provided for insulation of the spacecraft's bottom surface, envelopes the scanner.

The OSS concept (Figure 13.1-2) is attached to the spacecraft in the same location as the present scanner. The mounting pallet is furnished as part of the OSS scanner and attaches to the spacecraft using the same mounting bolts. The insulation blanket is no longer required to cover the scanner, since the scanner enclosure is the insulation blanket.

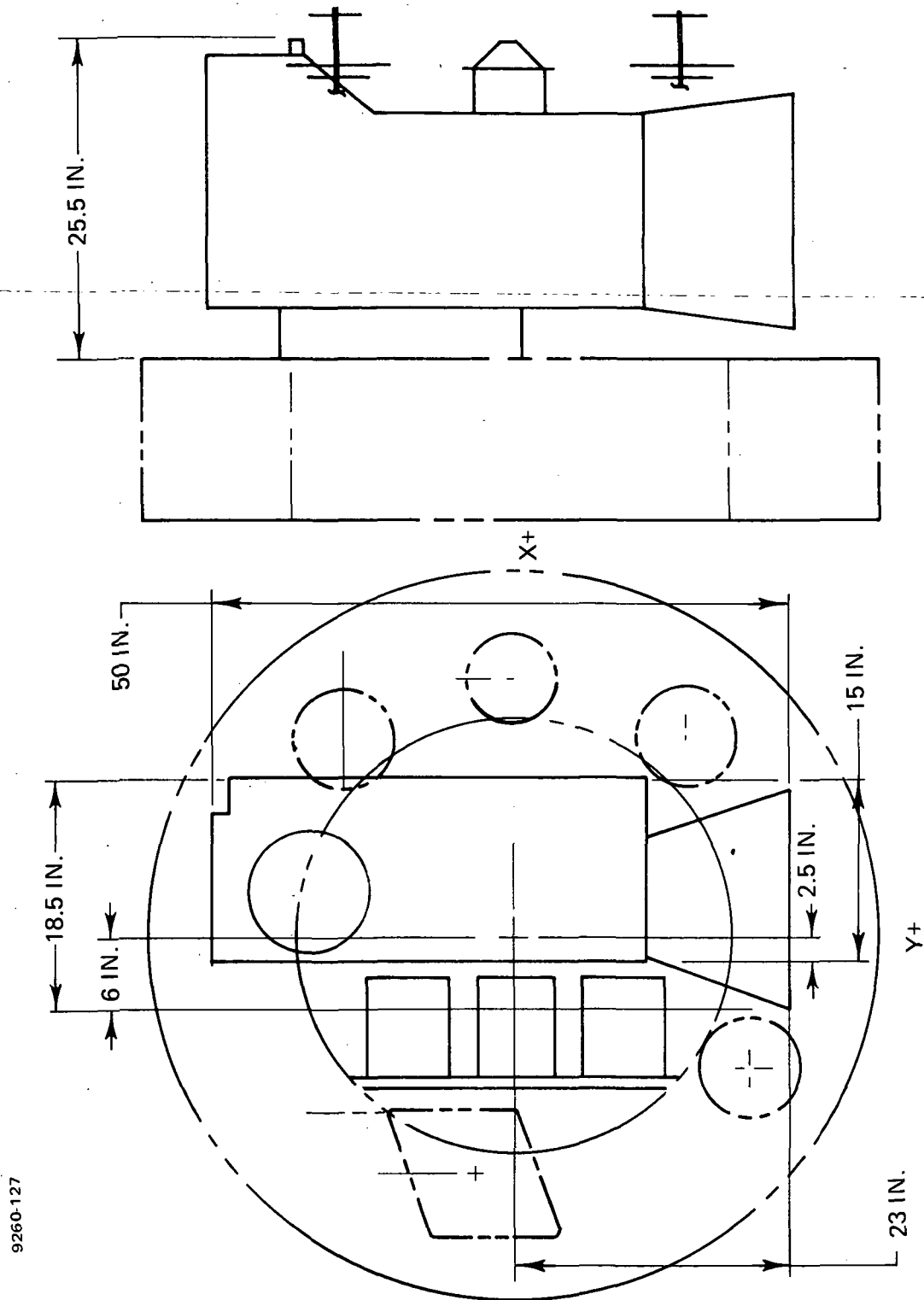
A careful review of spacecraft and payload component positions was made and the OSS scanner will fit the present scanner location without interfering with any part of the present experiment concept. Radiation patterns of the antennas were obtained and reviewed. The OSS scanner is free of any projections in the radiation patterns, however, actual tests would have to be conducted to determine if the change in the outline of the scanner would cause any disturbance.

The OSS scanner electronics is located in the scanner assembly and therefore, does not require use of the electronic bays in the spacecraft torus. To reduce the interchange effect, junction boxes located in the electronics bays which are used by the present scanner are recommended. The electrical interface with the spacecraft can then be accomplished with very little disturbance. The existing spacecraft wiring can be terminated in the junction boxes. The cables from the OSS scanner electronics would also terminate in their respective junction boxes.

The method of handling the thermal control of the OSS scanner is discussed in Section 11.

The weight of the OSS scanner is 139.4 lbs (refer to Section 10.6) as against the present system weight of 153.9 lbs. The major reasons for the lighter weight of the OSS design is that the thermal shield functions as the enclosure and considerable weight reduction was obtained in the scan mechanism. The possibility of a change in CG of the OSS scanner and the present design could exist. The weight advantage of the OSS design would provide for CG adjustment, if necessary.

The power requirement for the OSS scanner is 137.0 W (refer to Section 9.7) as compared with the allocated 70 W for the present design. The primary reasons for the power increase over the present design is the 200-ft resolution capability instead of the 260 ft for the present system, reduced duty cycle due to the conical scan technique, more data resulting from the two additional spectral bands, and buffering to match the present data link which is limited to approximately 15 Mbps. Therefore, the increase in the power requirements is largely due to increased capability of the OSS scanner instrument.



9260-127

Figure 13.1-1 Present Rocking Mirror Scanner Physical Interface

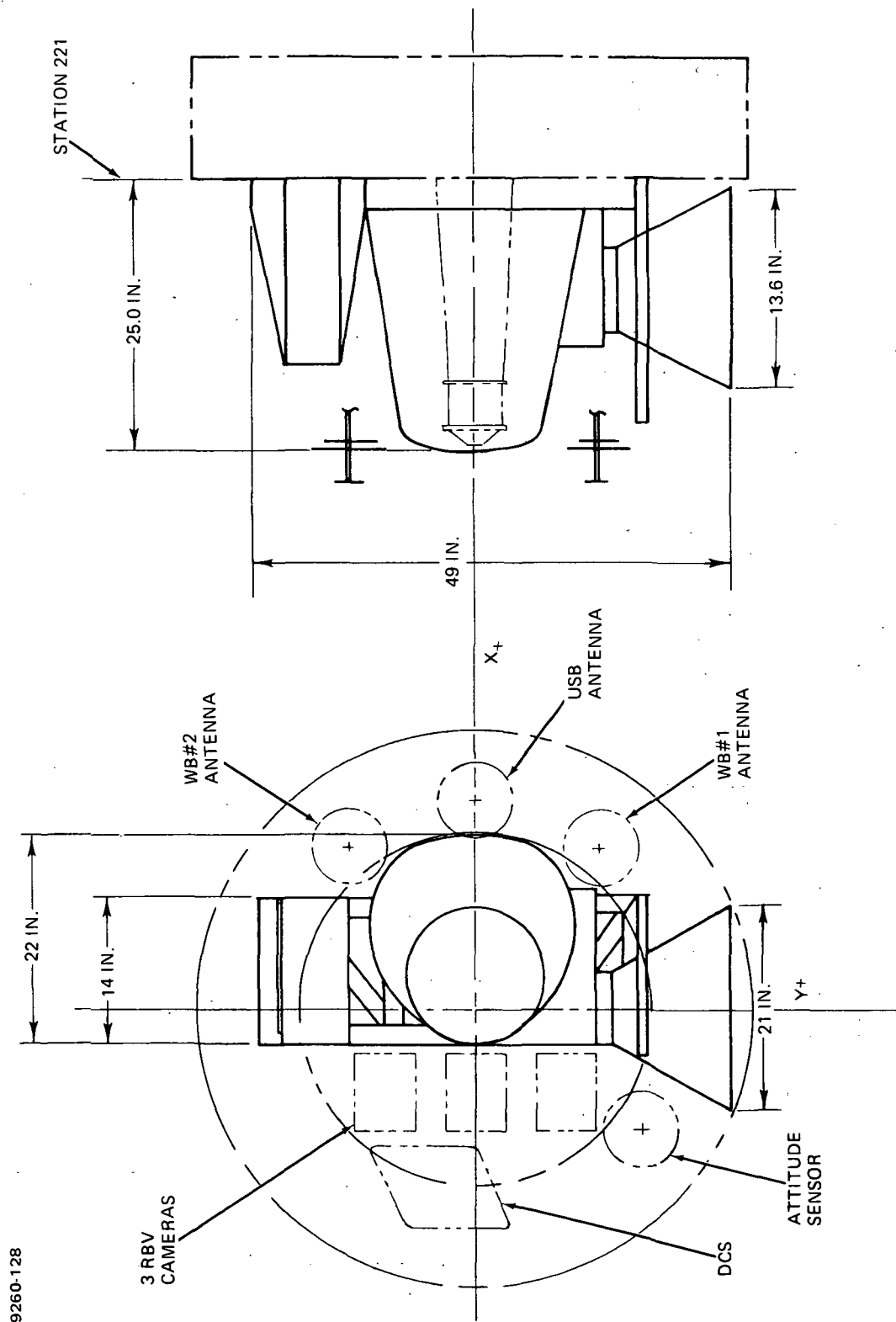


Figure 13.1-2 Image Plane Conical Scanner Physical Interface

13.2 DATA TRANSMISSION AND GROUND RECEIVING SITE INTERFACES

Two basic constraints determine the nature of the data interfaces at various points in the data transmission link: the $\pm 0.5\%$ tolerance on the 15 MHz telemetry link data-rate and the input data-format structure required to minimize modifications to the Ground Data Handling Station. The data-rate tolerance was adopted and the scanner was configured in terms of duty factor, scan period, cells per scan, and data handling to be compatible with this rate. This tolerance is dictated by such downlink component characteristics as those of the bit synchronizer in the Stadan receiver.

A ground data handling station input-data format was developed which would minimize the redesign required in the Ground Data Handling Station equipment while increasing its capability to handle the two additional bands of data collected when the scanner operates in the overland mode. As detailed in Section 13.3, the format illustrated in Figure 9.5-2 was selected because of an inherent characteristic of the present ground data handling equipment: i. e., data from each channel or input tape track remains intact while being processed. This means that a given processor output can be made to correspond to data which are computer selected from a prescribed data input track.

Two scan codes are introduced into the format of Figure 9.5-2 to assist the computer in making this decision. In the oceanographic mode of operation, oceanographic bands 1 through 24 are recorded in place of overland bands 2 through 6. Introduction of time codes immediately following the line scan and mid scan codes permits increased processor throughput since only that tape portion containing interesting data need be examined.

The telemetry link frame structure and data format illustrated in Figures 9.5-3 and 9.5-4 were selected to simplify the receiving site demultiplexer design: i. e., minimize the equipment required to convert the down link data-stream into the twenty-five track data-tape input required by the Ground Data Handling Equipment. In addition, the telemetry frame was structured to optimize the relationships between resolution, swath width, duty factor, dwell time, and channel capacity.

Implementation of the above data interfaces will require redesign of the Data Demultiplexer located at the receiving site. Functionally, this unit converts the formatted spacecraft data received from the Stadan receiver into twenty-five channels which are recorded on 25 tracks of a multitracked magnetic tape. Operation proceeds along the following lines: Upon receipt of the scan start code, a 6-bit line start code is recorded on all output tape tracks while the first 78 bits of data (spacecraft time-code) are being received. This time-code data is dumped into 25 6-bit output registers (one for each track) after which it is shifted onto tape while the next 78 bits of data are being received. This process continues on a 78-

bit basis so that the incoming data is laid across the output tape tracks as illustrated in Figure 9.4-2. The indicated controlled precursors (gaps) are required for proper operation of the Ground Data Handling Station. An example of how the data demultiplexer might be implemented is presented in Appendix D.

A downlink minor frame containing the first three samples of data from bands 1, 4 and 7 are used in Figure 9.4-2 to show the correspondence between the input minor frame data location and its placement on the output tape. The three columns represent the corresponding rows in Figure 9.4-3. Time increases from top-to-bottom and left to right when reading the down link minor frame while the tape is moving from right to left. Each S_{jk}^i represents a 6 bit data word from the i th cell, scan line j , band k which is recorded on the numbered tape track diagrammed immediately to its right. As illustrated, the data from band 7 must be stored so that it can be time multiplexed onto tape track 26.

13.3 GDHS INTERFACES

The ground data handling station (GDHS) for ERTS is designed to receive and operate on data from an existing 4- or 5-band multispectral scanner, designated as MSS. Any new and improved scanner will provide a different input to the GDHS unless its design parameters and capabilities are identical to the MSS, and the different input will necessarily require some modifications to the GDHS. The OSS scanner described in the previous sections differs from the MSS in that it has the extended capabilities of more spectral bands and two modes of operation, while the scan pattern is conical in form rather than linear. In Section 13.3.2, the modifications required to accept the OSS data format will be discussed and it will be shown that the format has been selected to minimize its impact on the GDHS. Section 13.3.3 then discusses the modifications required of the Electron Beam Recorder (EBR) to generate framed imagery with the conical scan pattern. However, before discussing the modifications required for the GDHS to accept the OSS scanner, the following section will review the principal operating modes of the GDHS.

13.3.1 GDHS Operation Summary

The main unit of interest for this discussion is the bulk processing element, Figure 13.3-1, which receives the input data tape and provides two outputs for the MSS data. The first output is to generate bulk imagery of the data using the EBR for input to photo processing and the precision processing element. The film format is shown in Figure 13.3-2 from which it is seen that the imagery is framed within 55.5- by 60-mm areas bounded by tick marks and separated by annotation blocks which contain a grey scale and parametric information such as band number, time code, etc. The actual image area is nominally 53 by 55 mm and represents an area approximately 100 n. mi square on the ground. The actual size, shape and position of each image area within a frame is dependent on positional corrections programmed into the EBR to compensate for such parameters as the spacecraft attitude, etc.

In its second mode of operation, 5 to 10% of the data (selected by the user from the imagery) is transferred by bulk processing to high density digital tape (HDDT) for input to the special processing element, Figure 13.3-1, where the data undergo radiometric corrections and are output on computer compatible tape for the user. The input data tape format, Figure 13.3-3, comprises 28 tracks of which 24 tracks are used for the six samples of Bands 1 through 4 collected each dwell time, 1 track is used for the thermal band, Band 5, and the other tracks are used for ancillary data. The data words for tracks 1 through 24 are directly related to the order in which the samples are taken by the scanner which is depicted in the inset

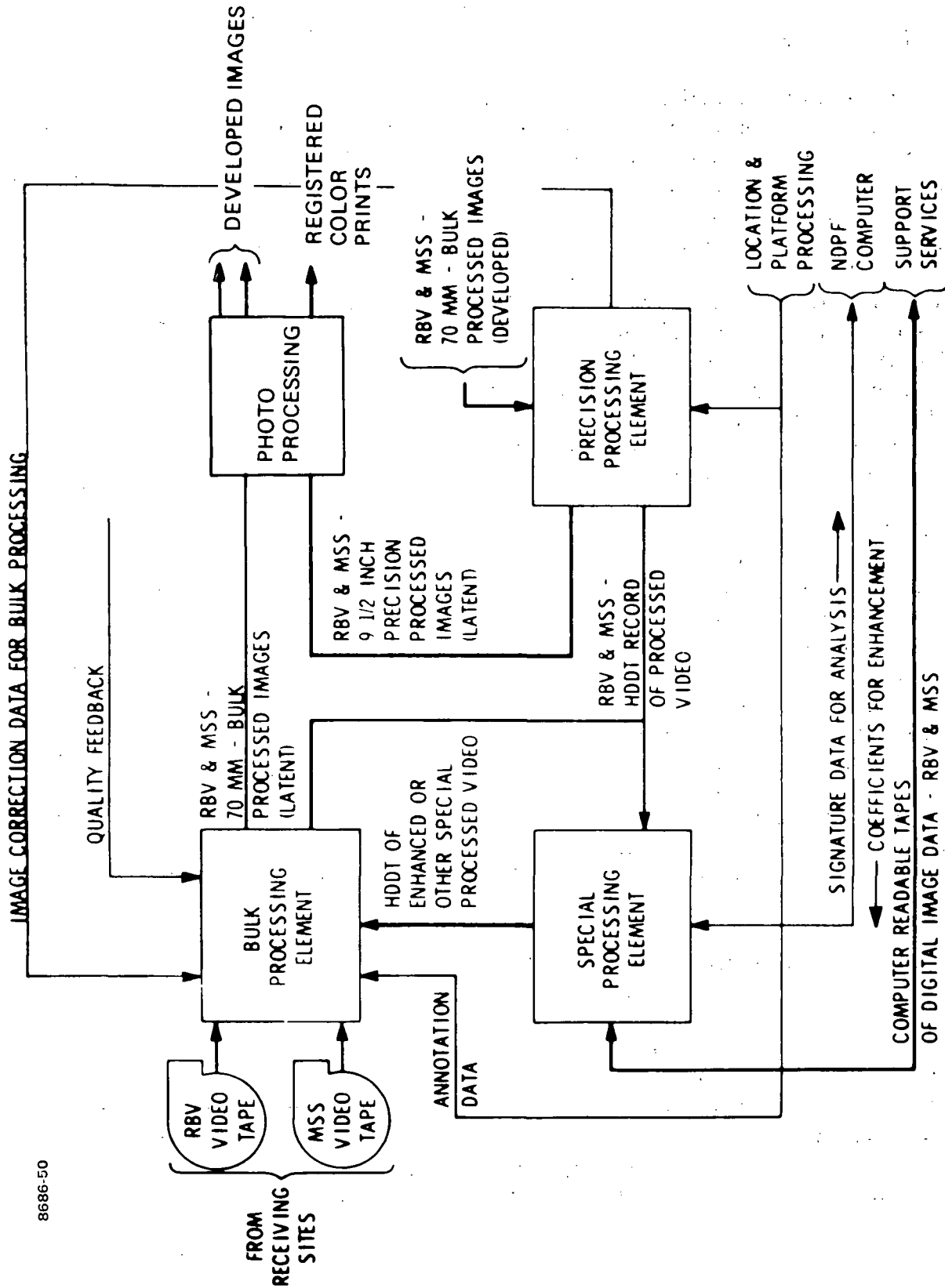


Figure 13.3-1 Principle Elements in the GDHS

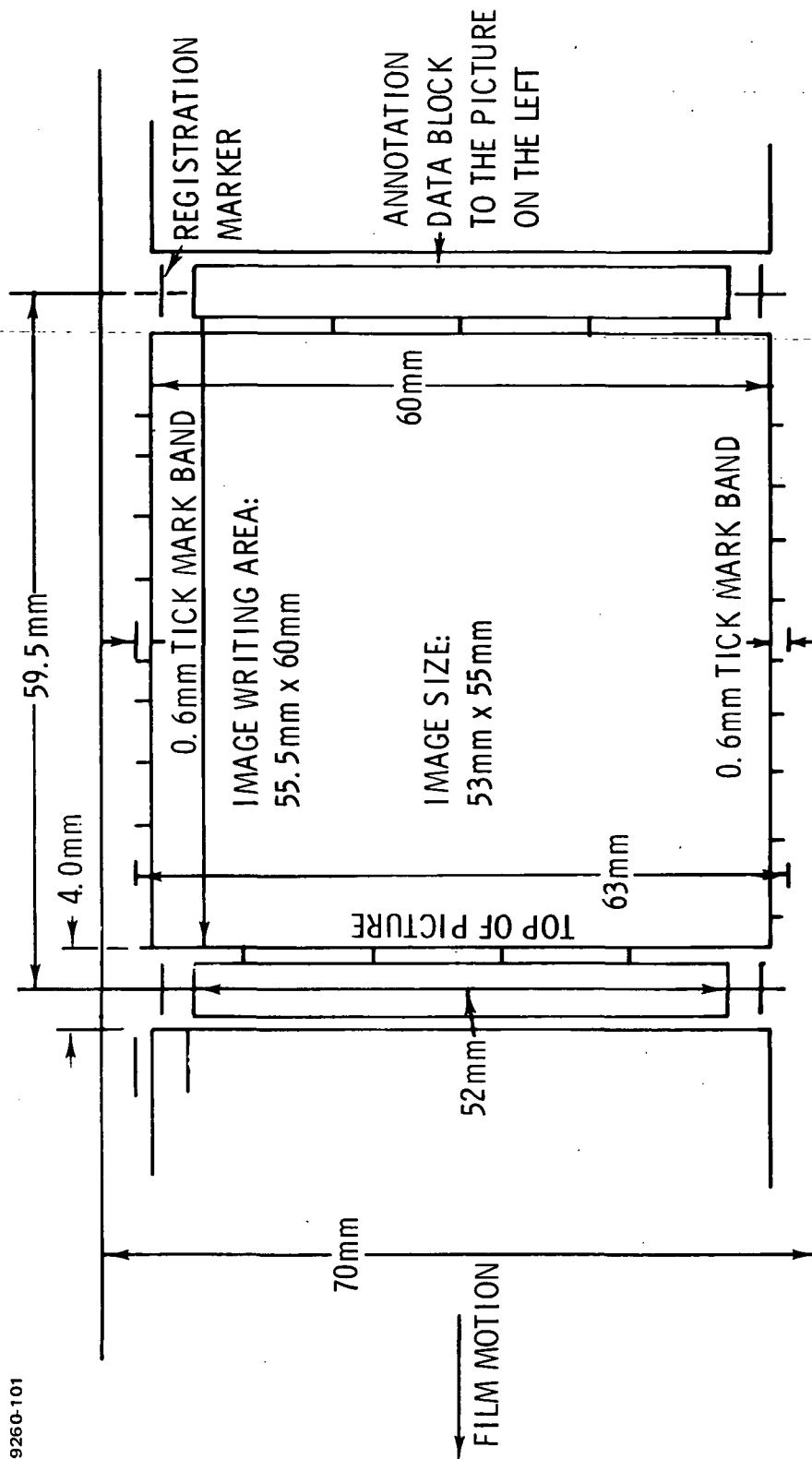
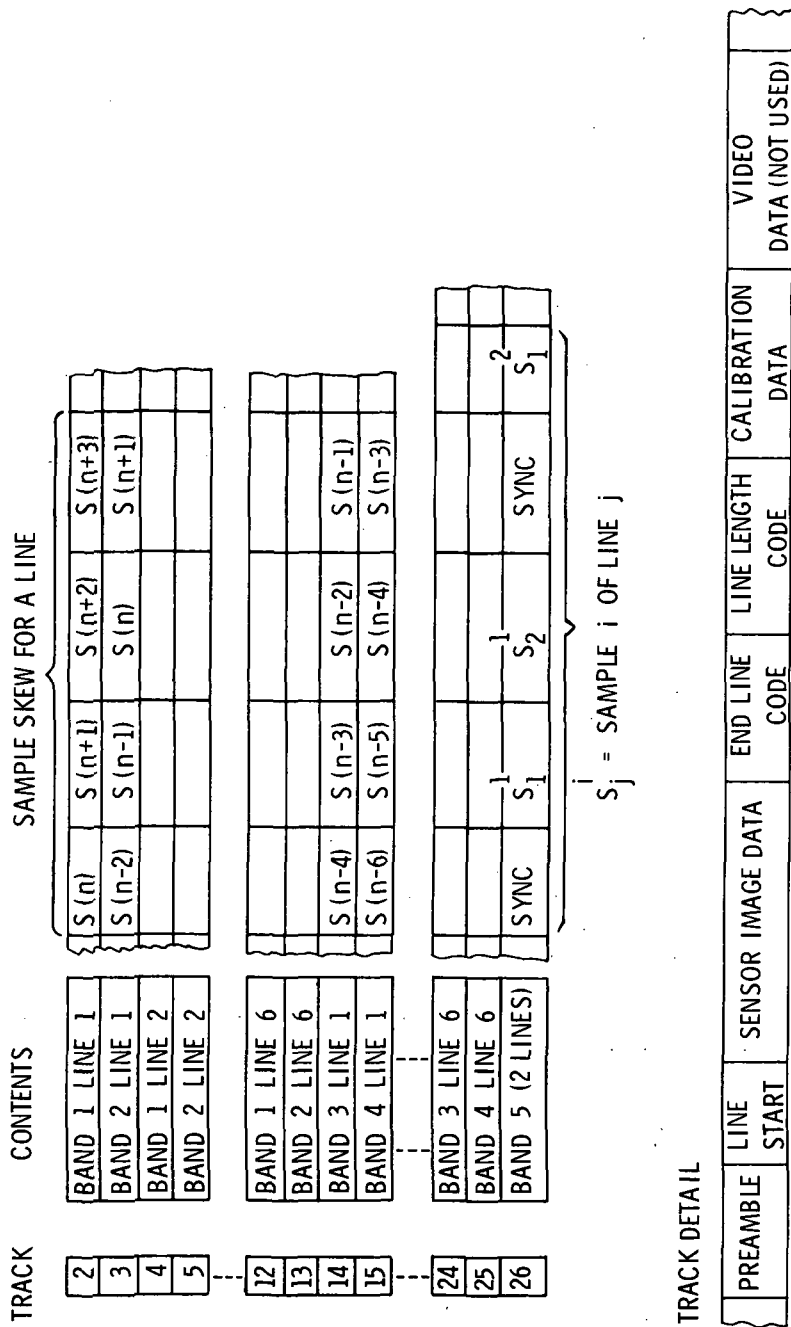


Figure 13.3-2 Current MSS Framing Format on the EBR

9160-102



MSS DETECTOR ARRAY AND SAMPLING ORDER

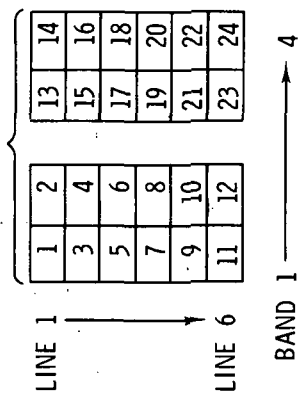


Figure 13.3-3 MSS Tape Format for Input to the GDHS

on Figure 13.3-3. Each detector on the MSS corresponds to a different spatial region on the ground since a spectrometer is not used for spectral separation. A consequence of this is that a skew equivalent to two cells occurs between bands on the input data tape; this skew is not present on the OSS scanner. Figure 13.3-3 also shows that each data track contains the data from one line of one band (i. e., there is one track per channel), and this feature is fundamental to the operation of the GDHS.

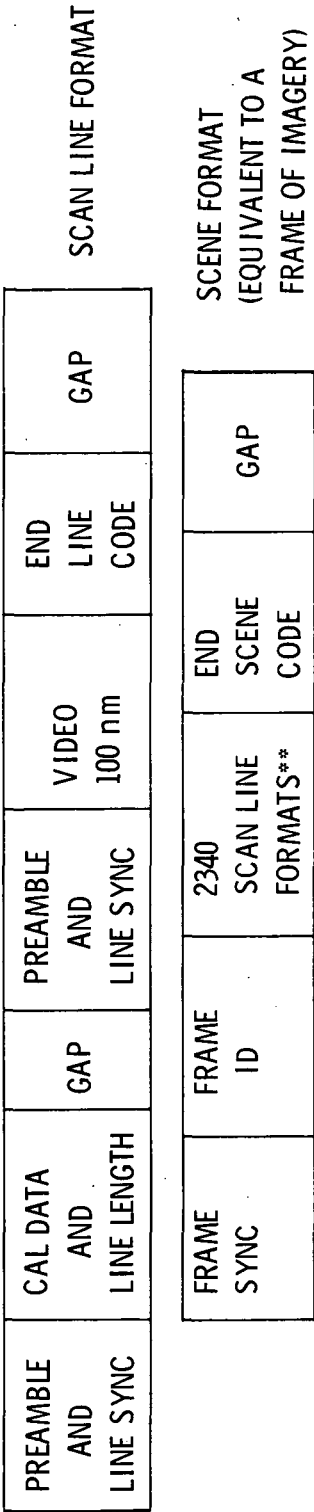
Transferring the input data to HDDT in bulk processing includes several operations. Principally, six lines of data are input in parallel as they are collected by the scanner. These six lines are transformed to a serial format on HDDT (Figure 13.3-4), which contains 4 tracks; that is, one track per band. The line length code is required to specify the number of samples in the following line of video data since this number varies due to fluctuations in the speed of the scan mirror; this would not be required for the OSS scanner.

Finally, the computer compatible tape (CCT) format is shown in Figure 13.3-5. One tape contains data for a 100 by 25 n. mi ground area, or a quarter of a frame of bulk imagery. The multispectral data are interleaved on the CCT as shown in Figure 13.3-5.

The main unit in bulk processing which has to be considered for the above operations is the MSS Video Tape Reader Control (MSS-VTR-CTL), Figure 13.3-6. With reference to Figure 13.3-6, the following key points of operation will be referred to in the following sections:

- Key 1: The input tape is run once for each band to generate bulk imagery of all bands and once more to generate HDDT.
- Key 2: When generating bulk imagery, Memory A is filled with 6 lines of data and Memory B is filled while reading from A.
- Key 3: The whole of 6 lines of data are stored in the memory when transferring the data to HDDT.
- Key 4: The input to the memory is 36-bit bytes; each byte comprises six 6-bit data words from one track.
- Key 5: The memory can store a maximum of 3600 ground cells of all bands.
- Key 6: Each track on the input tape passes through the system and can be regarded as being processed independently.

9260-103



**PLUS 780 BAND 5 SCAN LINE FORMATS MULTIPLEXED ACROSS 4 TRACKS FOR ERTS-B

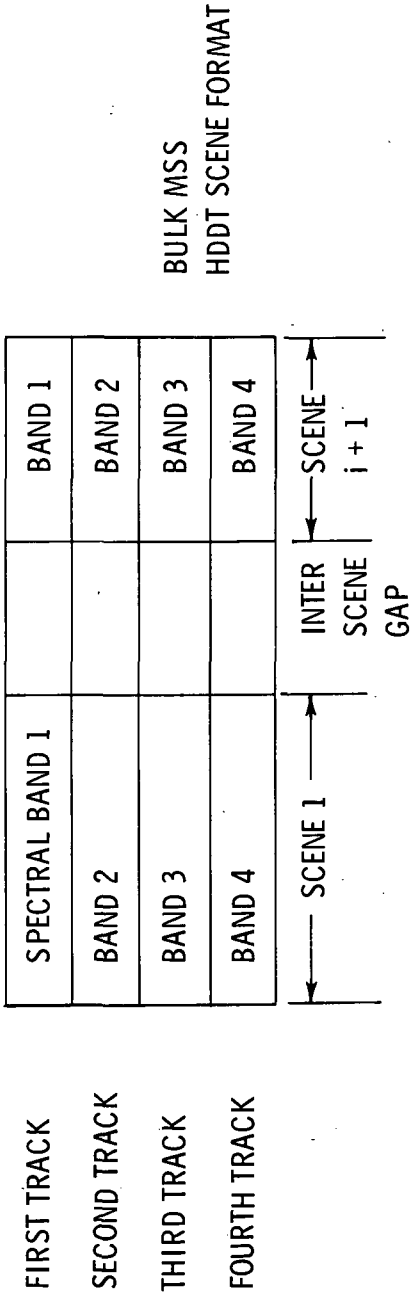


Figure 13.3-4 HDDT Tape Formats for the MSS

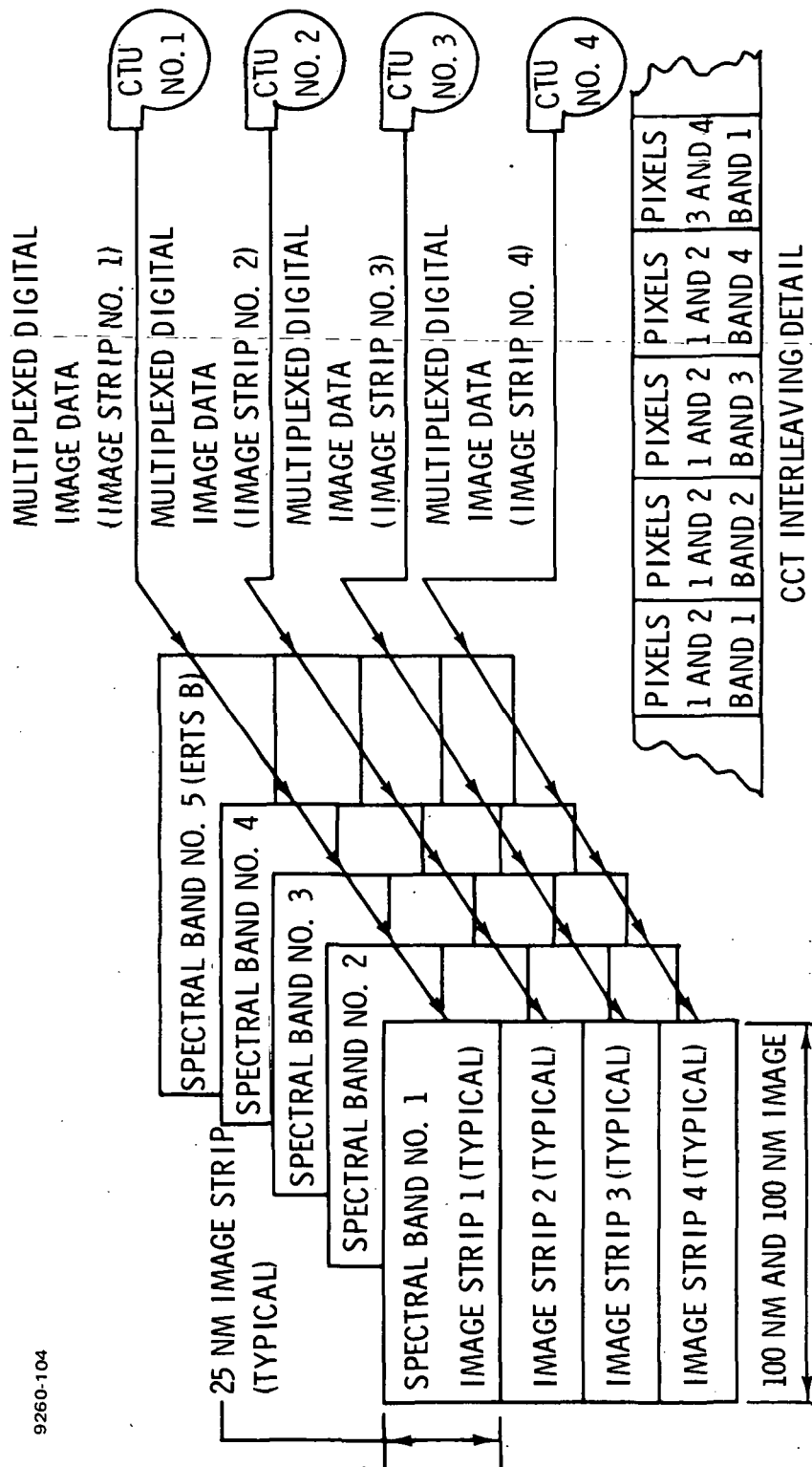


Figure 13.3-5 MSS-CCT Format

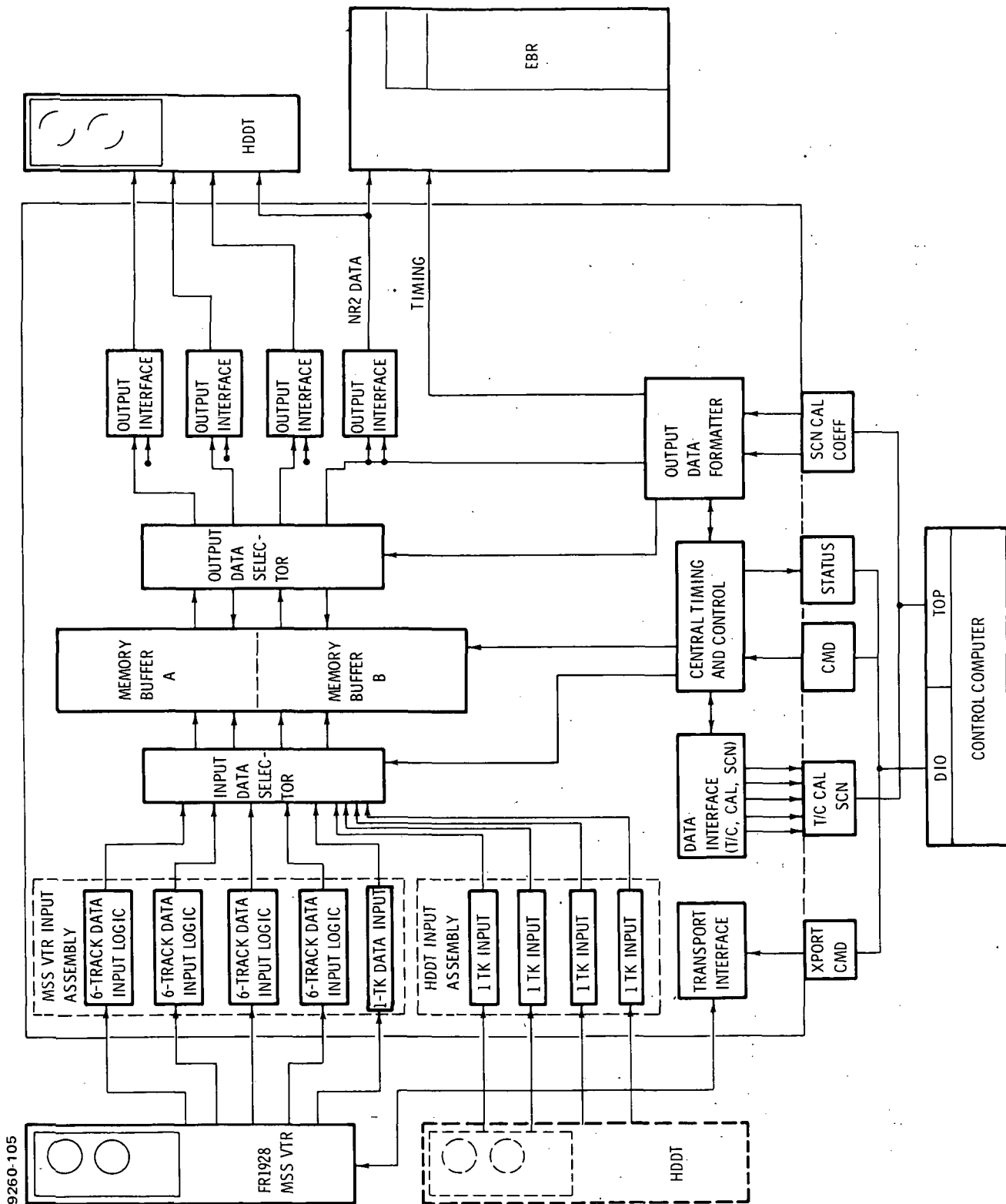


Figure 13.3-6 MSS VTR Control Block Diagram

Key 7: The system can handle 6 calibration samples. This number can be increased in multiples of 6 at the minor addition of hold registers and hardware to take the data out of the memory.

Key 6 is fundamental to minimizing the modifications to the GDHS, and is a major consideration in the OSS format. This fact can be used to advantage, provided the input tape format comprises major frames prefixed by a 6-bit line sync code plus two 6-bit time codes and suffixed by a gap of a few data words to ensure acquisition of the sync word denoting the start of the next major frame.

13.3.2 OSS Tape Formats through the GDHS

The OSS telemetry format is broken up into minor frames of 78 6-bit words as indicated in Section 9.4 and Figure 13.3-7. Bands 1, 4 and 7 are sent in real time followed by Bands 2, 3, 5 and 6 or the 24 oceanographic bands. Each minor frame is formatted onto the input data tape to the GDHS at the receiving site (see Section 13.2 and Appendix D), as shown in Figure 13.3-7. With this input data tape, the GDHS may recognize either the Line Start Code (LSC) or the Mid Scan Code (MSC) as the start of a major frame.

When generating bulk imagery, except for a slight modification as to which track corresponds to which channel, it is seen that Bands 2, 3, 5 and 6 or the oceanographic bands will pass through the GDHS with minimal changes to the GDHS (Figure 13.3-8). Thus, the MSS-CTR-CTL will: (1) recognize the MSC as line sync, (2) receive time code, data and calibration samples, and (3) treat all that follows as a gap until the next MSC is received. Bands 1 and 4 can be treated in the same way, recognizing LSC as line sync except that each band is split onto two tracks, holding odd and even samples, respectively. Hence, each memory byte (key 4) must comprise three samples from each of two tracks requiring the memory to operate twice as fast. This does not appear to be feasible, but this problem can be circumvented by forming memory bytes in units of six samples from a track and then reading out two memory words at a time, passing them through shift registers and multiplexing the 12 samples to give a continuous set. The appropriate hardware must be added to the GDHS.

When providing HDDT for special processing, it is evident that Bands 2, 3, 5 and 6 can pass straight through the GDHS to provide HDDT and CCT in the current formats. However, it is not possible to incorporate all 7 bands appropriately interleaved on CCT without modifications to the GDHS which does not have the capacity to handle all 7 bands of 6 lines of data at once (key 5). The possible CCT formats which can be generated with small programming and hardware alterations are depicted in Figure 13.3-9(a). The only way to process all 7 bands

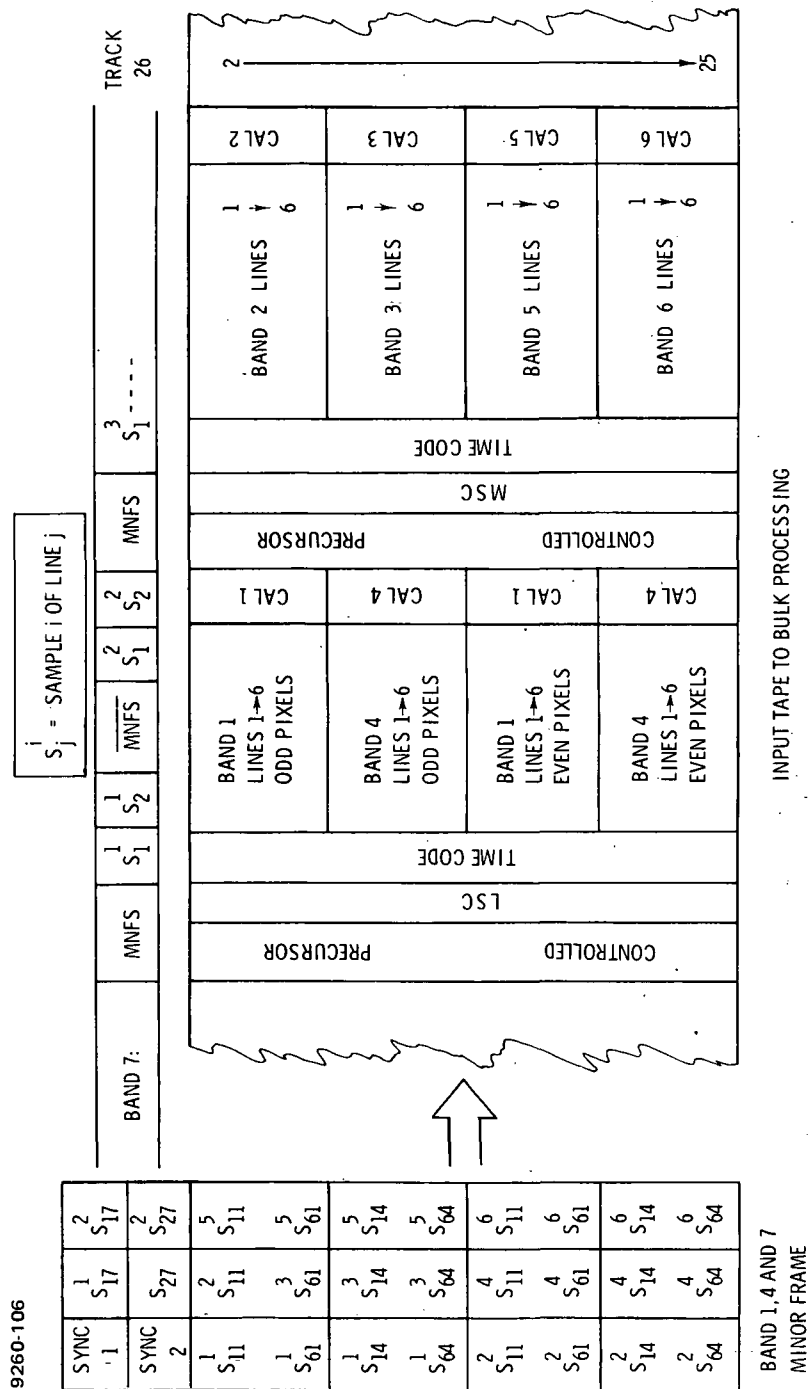


Figure 13.3-7 Relation Between a Minor Frame and the Input Tape to Bulk Processing

9260-107

TO ACCEPT	MODIFICATIONS (EXCLUDING THE EBR)
BANDS 1, 4 (OLS)	RE-PROGRAMMING THE MSS-VTR-CTL PLUS THE ADDITION OF A SHIFT REGISTER AND MULTIPLEXER TO THE MEMORY OUTPUT LOGIC.
BANDS 2, 3, 5, 6, 7 (OLS) OR 1 - 24 (OCS)	RE-PROGRAMMING THE MSS-VTR-CTL ONLY.

Figure 13.3-8 Modifications to the GDHS When Generating Bulk Energy

9260-108a

a) OVERLAND MODE OF OPERATION																										
CCT FORMAT		GDHS/USER IMPACT																								
1. 2 TAPES SPECTRALLY INTERLEAVED (PREFERRED APPROACH)		EXTRA RUN OF THE INPUT TAPE PLUS SOME RE-PROGRAMMING																								
1	<table><tr><td>SAMPLE</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>3</td></tr><tr><td>BAND</td><td>2</td><td>2</td><td>3</td><td>3</td><td>5</td><td>6</td><td>6</td><td>2</td><td>2</td><td>3</td><td>3</td></tr></table>	SAMPLE	1	2	1	2	1	2	1	2	1	2	3	BAND	2	2	3	3	5	6	6	2	2	3	3	THE USER MUST ACCEPT TWO TAPE INPUTS TO OBTAIN THE SIGNATURE OF ONE PIXEL IN ALL BANDS
SAMPLE	1	2	1	2	1	2	1	2	1	2	3															
BAND	2	2	3	3	5	6	6	2	2	3	3															
2	<table><tr><td>SAMPLE</td><td>1</td><td>2</td><td>1</td><td>2</td><td>3</td><td>4</td><td>3</td><td>4</td><td></td><td></td><td></td></tr><tr><td>BAND</td><td>1</td><td>1</td><td>4</td><td>4</td><td>1</td><td>1</td><td>4</td><td>4</td><td></td><td></td><td></td></tr></table>	SAMPLE	1	2	1	2	3	4	3	4				BAND	1	1	4	4	1	1	4	4				
SAMPLE	1	2	1	2	3	4	3	4																		
BAND	1	1	4	4	1	1	4	4																		
2. ONE TAPE, PARTIAL SEPTCRAL INTERLEAVING		RE-PROGRAMMING ONLY																								
<table><tr><td>SIX LINES OF BANDS 1 AND 4</td><td>SIX LINES OF BANDS 2, 3, 5, 6,7</td></tr></table>		SIX LINES OF BANDS 1 AND 4	SIX LINES OF BANDS 2, 3, 5, 6,7	USER MUST STORE AT LEAST SIX LINES OF TWO BANDS TO HAVE THE SIGNATURE OF ONE PIXEL IN ALL BANDS																						
SIX LINES OF BANDS 1 AND 4	SIX LINES OF BANDS 2, 3, 5, 6,7																									
3. ONE TAPE, ALL BANDS SPECTRALLY INTERLEAVED		EXTENSIVE HARDWARE CHANGE TO THE MSS-VTR MEMORY AND LOGIC. EXTENSIVE RE-PROGRAMMING IN BULK AND SPECIAL PROCESSING.																								
<table><tr><td>SAMPLE</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td></tr><tr><td>BAND</td><td>1</td><td>1</td><td>2</td><td>2</td><td>3</td><td>3</td><td>4</td><td>4</td><td>5</td><td>6</td></tr></table>		SAMPLE	1	2	1	2	1	2	1	2	1	2	BAND	1	1	2	2	3	3	4	4	5	6	MOST SATISFACTORY TO THE USER		
SAMPLE	1	2	1	2	1	2	1	2	1	2																
BAND	1	1	2	2	3	3	4	4	5	6																

Figure 13.3-9 Alternative CCT Formats and Corresponding GDHS Modifications

9260-108b

b) OCENOGRAPHIC NODE OF OPERATION

CCT FORMAT		GDHS/USER IMPACT
4. ONE TAPE, PARTIAL SPECTRAL INTERLEAVING		RE-PROGRAMMING FOR HIGH RESOLUTION BANDS ONLY USER MUST STORE ONE LINE OF 24 BANDS TO HAVE THE SPECTRAL SIGNATURE OF ONE PIXEL.
5. ONE TAPE, SPECTRAL INTERLEAVING EVERY SIX PIXELS (PREFERRED FORMAT)		RE-PROGRAMMING IN BULK AND SPECIAL PROCESSING USER NEED STORE ONLY SIX PIXELS OF 24 BANDS.

Figure 13.3-9 Alternative CCT Formats and Corresponding GDHS Modifications (Cont.)

is to process 6 lines of Bands 1 and 4 followed by 6 lines of Bands 2, 3, 5 and 6. The user would then have to either store at least 6 lines of 2 bands of data before obtaining all bands for one sample (Figure 13.3-9, Format 2) or accept two data tapes obtained by making an extra pass of the input tape to the GDHS, Format 1. The latter option is felt to be preferable.

The CCT formats for the oceanographic data depicted in Figure 13.3-9(b) can be obtained, again utilizing the fact that each track on the input tape corresponds to one channel and is processed as such (key 6). Again, the user must store a lot of data to obtain all bands for one sample, but this can be reduced to only 6 samples of each band, Format 5. Here, bytes from the MSS-VTR-CTL memory have been read out across all 24 tracks rather than one line of 4 tracks at a time. Since each byte contains 6 samples (key 4) the bands become interleaved every 6 samples. This format would require reprogramming in the VTR-CTL and in the special processing element. As for the overland mode, the high resolution bands (1 and 4) cannot be processed at the same time as the other 24 bands without extensive modifications to the GDHS, but separation of the high and low resolution bands on tape every 6 lines should be quite acceptable to the user of oceanographic data.

13.3.3 Modifications Required to Accept a Conical Scan Pattern

The main output from bulk processing is framed imagery of all data on 70-mm film. The imagery is produced by an electron beam recorder (EBR), which provides 53- by 55-mm images inside a 55.5- by 60-mm frame area (Figure 13.3-2). First-order positional corrections are carried out, annotation plus tick marks are provided, and there is a 10% overlap between frames. The principal features of the EBR operation are that the film is in continuous motion, and the 10% overlap is generated by writing a line in the overlap area on one frame, then immediately rewriting that line on the next frame by switching the beam to the required index position (Figure 13.3-10). It is evident from Figures 13.3-2 and 13.3-10 that the EBR must have a minimum writing aperture in the direction of the film motion which is governed by the largest distance through which the beam has to be switched. The current EBR has a maximum writing distance in this direction of 16 mm, which is fully taken up by the 10% overlap, the annotation and tick marks between frames, an extra writing distance for positional corrections, and an allowance for film motion. Therefore, there is no space available for writing a conical scan line on the present EBR with the current format.

A second aspect of frames formed by writing conical scan lines is that the frames will be curved unless some care is taken to square them off. It is important to do this since the main input to the precision processing element (Figure 13.3-1) is the framed imagery from bulk processing. Precision processing

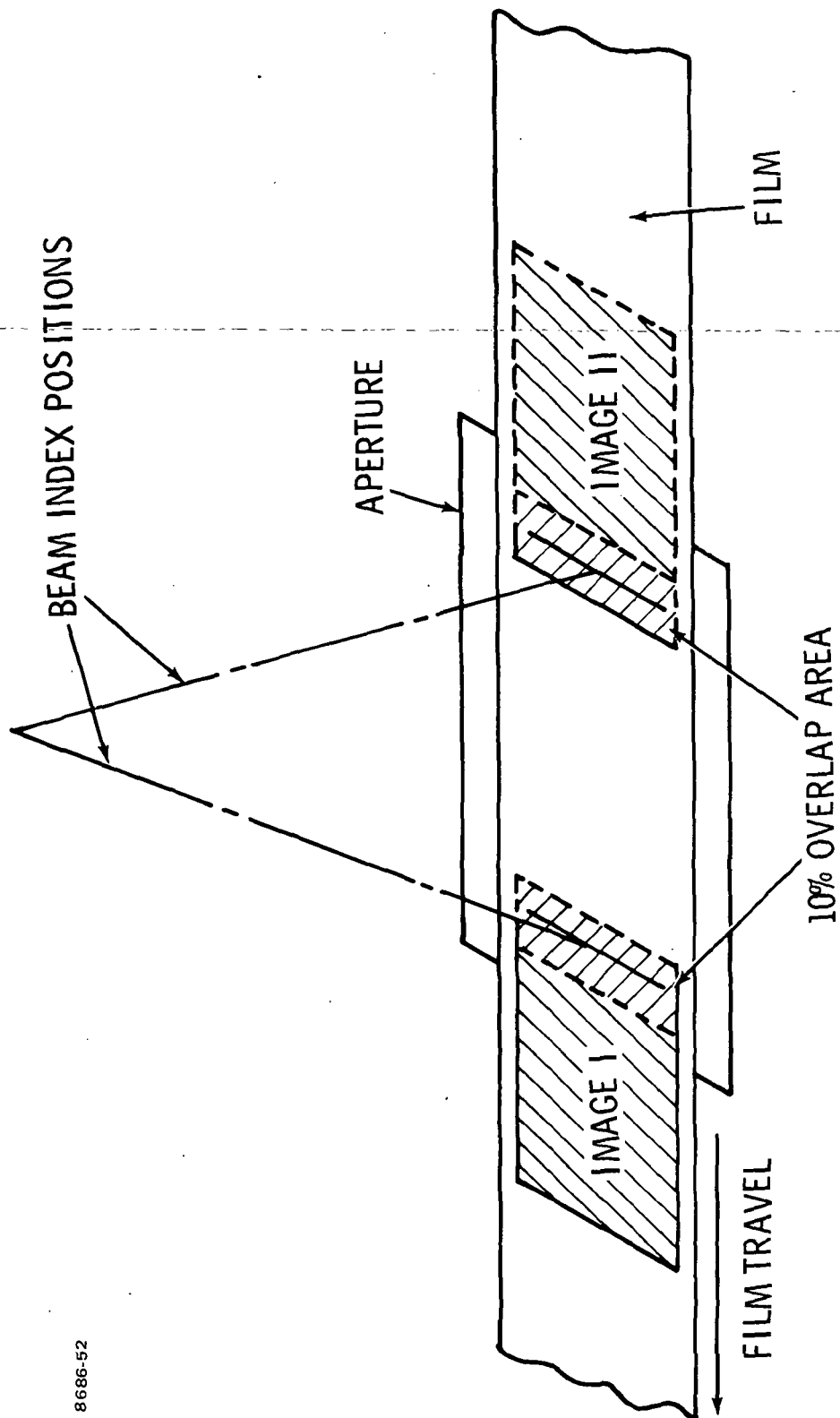


Figure 13.3-10 MSS Electronic Framing to Provide 10% Overlap

8686-52

rescans the imagery to make final positional corrections, and square frames imply that no alterations to the precision processing element will be required. Square frames will also remain compatible with the photographic processing subsystem which provides $10^6:1$ scaled images on a 9 1/2-in. format for the user; curved frames would no longer fit inside the 9-in. format, requiring modifications throughout the whole subsystem.

From the preceding paragraphs, it follows that if the same format is to be preserved, then the EBR writing aperture must be considerably increased. An EBR with a larger aperture has been recommended by Bendix in the past, and it is further recommended here. The increased size of the aperture required to generate a conical scan (Figure 13.3-11) is a function of duty cycle and frame size. (These curves are plotted for a circular scan, and it should be noted that the writing distance for an elliptical scan through the nadir will be fractionally less.) Figure 13.3-11 shows that a 55-mm frame and 33% duty cycle requires a conical writing distance of 15.9 mm, so that the required EBR aperture must be at least 32 mm in order to generate frames with conical scan lines and a 10% overlap from frame to frame. Basically this requires a new EBR, but Bendix is of the opinion that an EBR with the extended capabilities envisaged here is likely to be very useful for future programs and would be a most desirable asset to the GDHS.

Assuming that a second EBR is made available, the framing scheme for a conical scan pattern is illustrated in Figure 13.3-12; line 1 is the last arc written on the first frame, but only the required fractions of the arcs are sequentially written on the second frame in order to provide a square format. For example, line 2 is written on the first frame; then the electron beam is switched to rewrite line 2 on frame 2, except that by quenching the electron beam over the central portion of the line, this undesired portion is not written. The process continues until the overlap area is complete and square frames are provided. This is indicated in Figure 13.3-12 from which it is seen that some lines, such as line 3, will be partially written on both frames, while line 4 will be partially written on the first frame and fully written on the second frame. Bulk imagery formed in this way will be on the same format as that planned for the present MSS. However, it will involve some additional programming to the EBR controls in order to:

1. Generate a conical sweep
2. Quench the electron beam over the correct periods in the region of overlap
3. Modulate the beam intensity according to $\sec \phi$ to ensure uniform exposure across the film.

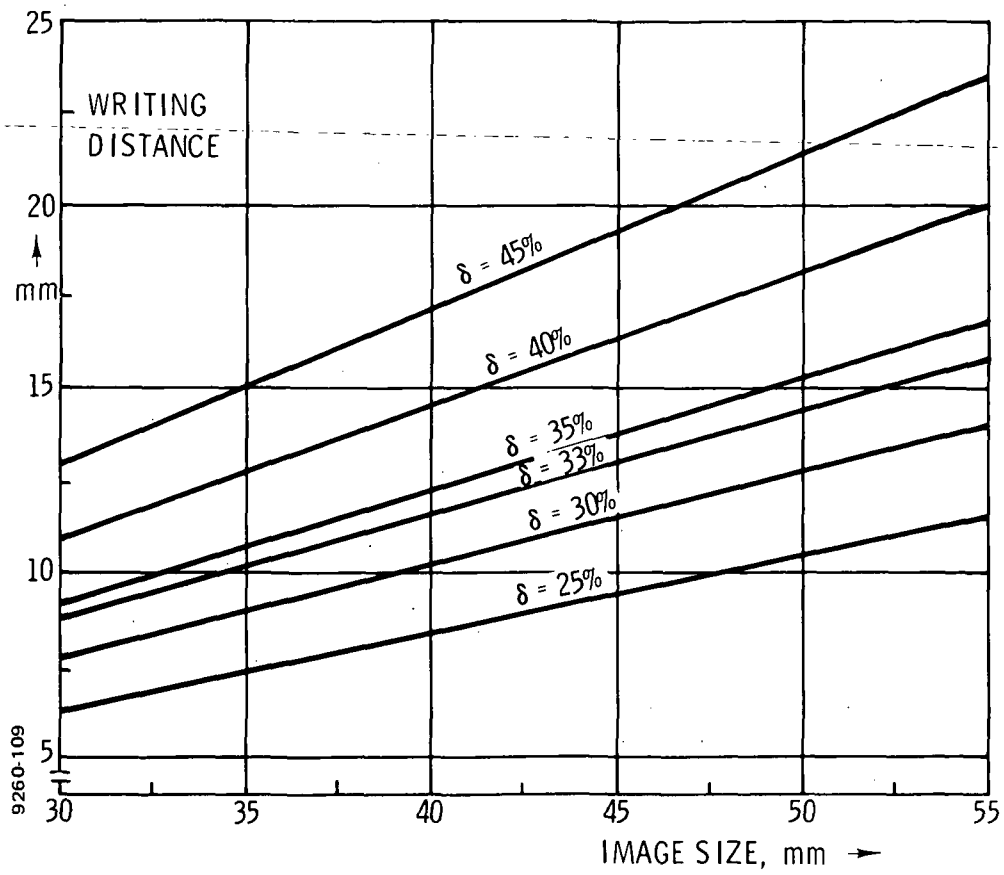


Figure 13.3-11 EBR Writing Distance as a Function of Frame Size and Duty Cycle

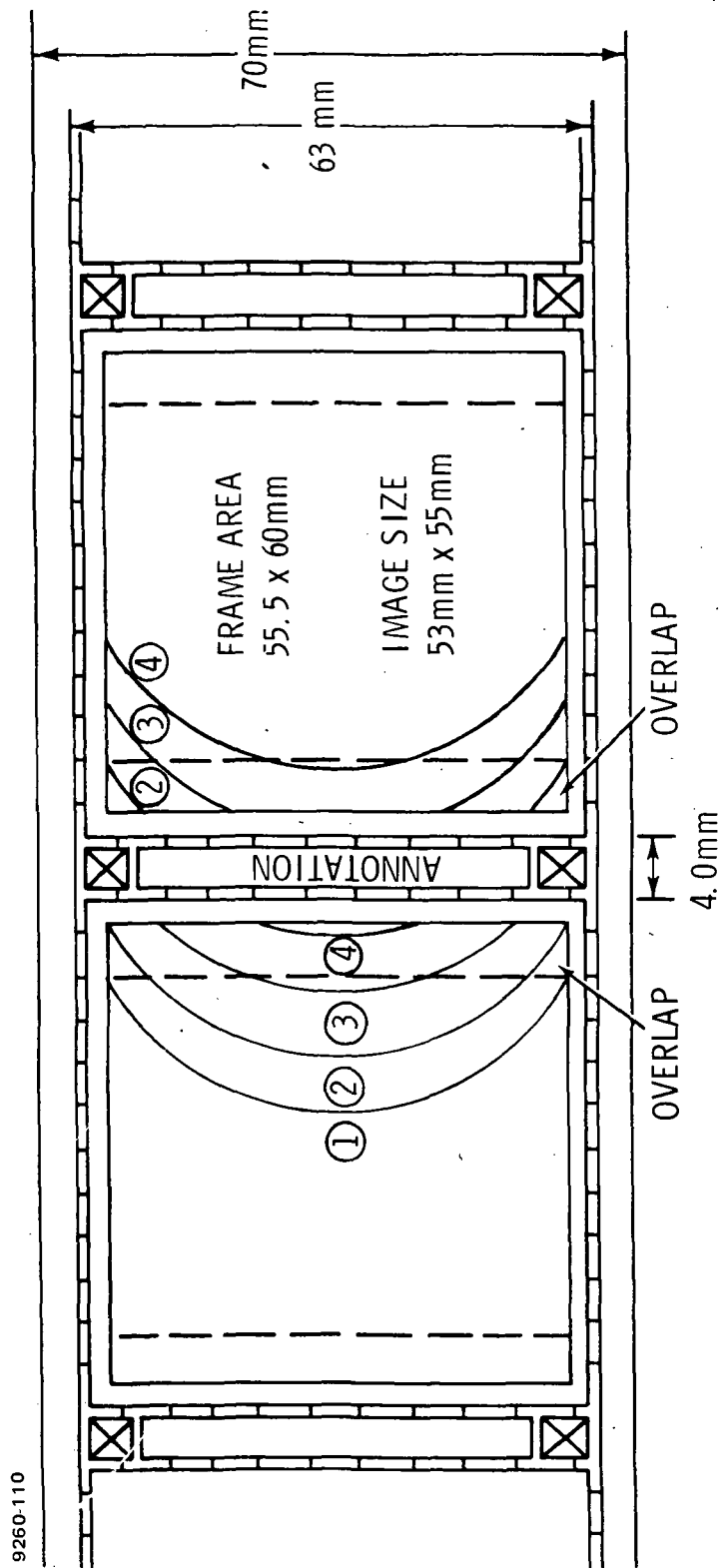


Figure 13.3-12 OSS Bulk Imagery Format Using a New EBR

The need to modulate the beam intensity arises from the scan curvature causing overlap toward the scan ends which results in oversampling. Since 6 scan lines are recorded per scan by the MSS, care may have to be taken to program correctly both the conical sweep and the intensity modulation for each of the 6 scan lines.

An alternative framing scheme (Figure 13.3-13) is possible if the present EBR has to be used to write conical scan lines, but considerable alterations in the format have to be made. First, the annotation block is moved to the side of the frames rather than falling between frames, which makes it necessary to shrink the frame size from 55 to 40 mm. Adjacent frames can then be separated only by a single line of tick marks, while the smaller frame size (Figure 13.3-11) implies that only 11.6 mm are required to write a conical scan line. However, there still is not enough space to also write the overlap, which has to be completely dispensed with. The change in format for this scheme will require modifying the precision enlarger in photo processing to provide the required prints scaled $10^6:1$ relative to the ground, plus a scale change in precision processing for rescanning the film. But the scale change in precision processing can be readily accommodated by adjusting a gain control, which already exists to take into account variations of the frame size arising from altitude variations in the orbit. The reduced frame size also implies that there will be a reduction in resolution, as indicated by the MTF curves shown in Figure 13.3-14. The response of the EBR spot is much better than that of the scanner so that the loss in resolution due to the smaller frame size is minimal, as shown by the lower two curves. The advantages of retaining the currently planned format were considered greater than the disadvantage of obtaining a new EBR with a larger writing area; hence, this alternative was discarded.

13.3.4 Conclusions

The previous sections have shown that the OSS tape format is acceptable to the GDHS with minor hardware changes. These changes amount to some additional hold registers and a small multiplexer to accept the larger number of calibration samples (key 7), 12 instead of 6, and to accept the format of Bands 1 and 4 on the input tape. All other modifications, except for the EBR, are reprogramming in bulk and special processing. The extent of the reprogramming depends on the final CCT format required by the user.

Replacing the current EBR with one with a larger writing area may be the most costly change, but should also be a desirable asset for the future.

The fact that the GDHS has to handle considerably more data for the OSS scanner implies that the throughput will be reduced. The extent of the reduction depends on the mode of operation and user requirements. For example, if bulk

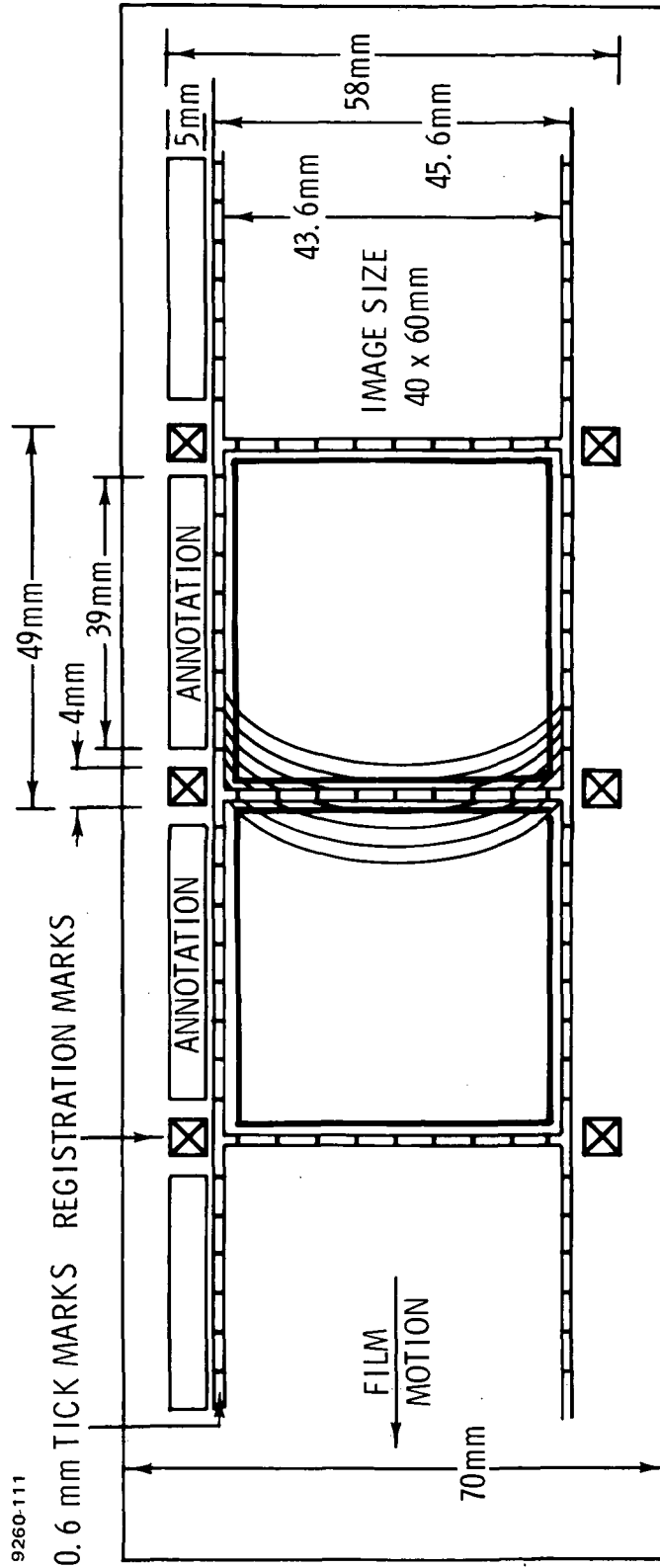


Figure 13.3-13 Conical Data Format Using Present EBR

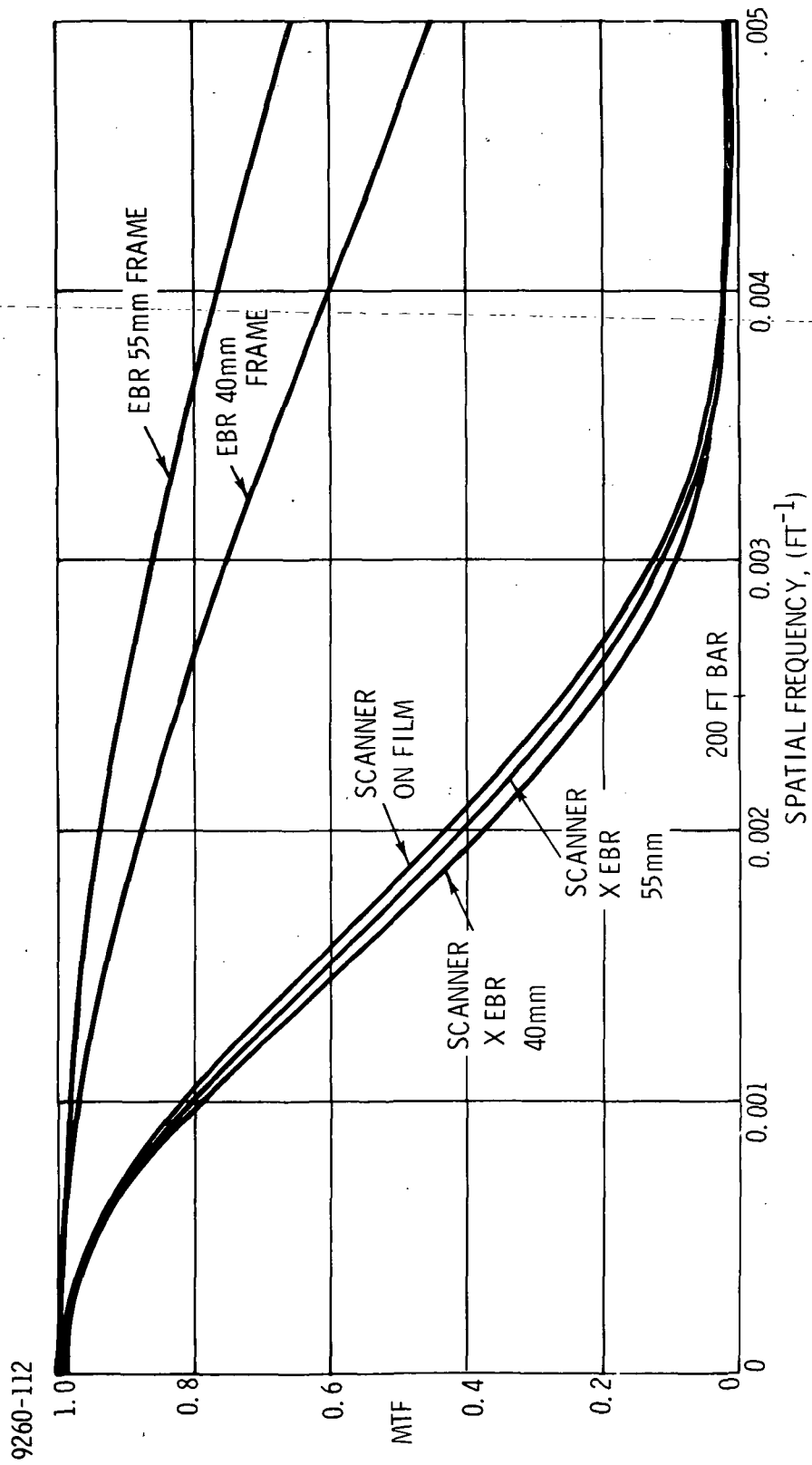


Figure 13.3-14 Effects of Frame Shrinkage on Resolution

imagery of all bands is required, the input tape must be run 7 times (key 1) for the overland mode and 27 times for the oceanographic mode. However, it is doubtful if this would be done for oceanographic data due to the closeness of the spectral bands and consequent similarities between bands. Without a detailed discussion with the user followed by a closer investigation of the GDHS parameters, it is impossible to say to what extent throughput will be affected, but it should be in the region of the ratio of the amount of data supplied to it for the OSS compared with that for the MSS, i. e. , 1.7 for the overland mode and 0.8 for the oceanographic mode.

APPENDIX A

OVERLAND SPECTROMETER DESIGN

A.1 REQUIREMENTS OF SPECTROMETER

A.1.1 Performance

The spectrometer must cover the range from 0.5 to 2.4 μm in six bands (some of which are not contiguous) with band widths of 0.10, 0.20, and 0.30 μm , (Figure A-1). The entrance slit of the spectrometer is also the field stop for the telescope viewing the earth, so the slit size of 0.0042 by 0.0253 in. is set by the earth field of view specified (66 microradians) and the telescope focal length (64 in.). The length of the slit encompasses six resolution elements corresponding to the view on six simultaneous scans of the earth.

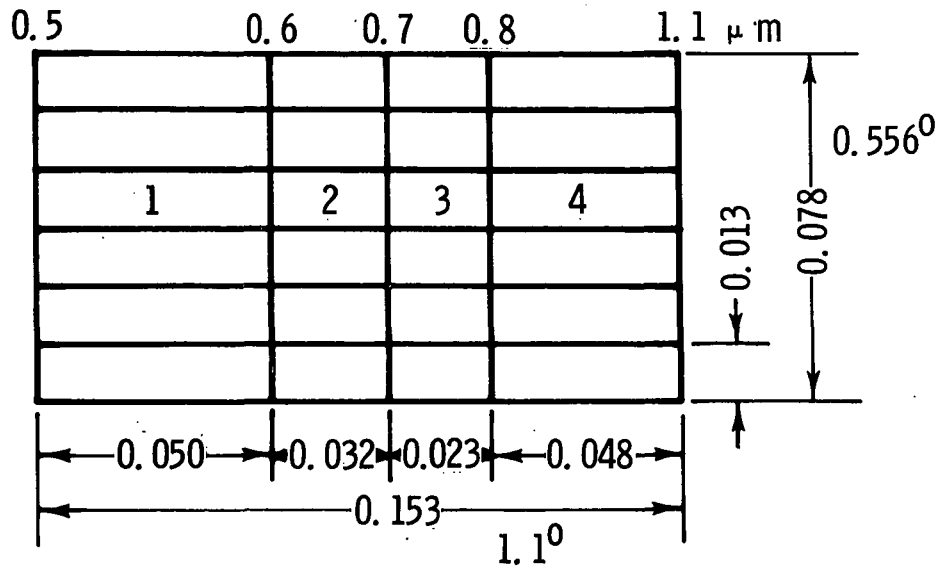
The multiplicity of scan elements demands that the spectrometer have good spatial resolution along the length of the slit (i.e., perpendicular to dispersion and parallel to flight path). The width of a spatial resolution element at the spectrometer image plane is 1.625 milliradian, and for reasonably small crosstalk between scan lines, the total aberrations should not greatly exceed half this. The diffraction limit blur diameter at the spectrometer image is 0.1235 m rad, at 0.60 μm and 0.494 m rad at 2.4 μm . Aberrations of the telescope must be included.

Aberrations of the telescope need not be added to those of the spectrometer in the dispersion direction, because there need be no spectral resolution within the slit. The angular dispersion has been made large enough so that for the worst case (0.7 to 0.8 μm), the aberrations of the spectrometer can be as large as 1.25 m rad., without crosstalk to non-adjacent bands (Figure A-2).

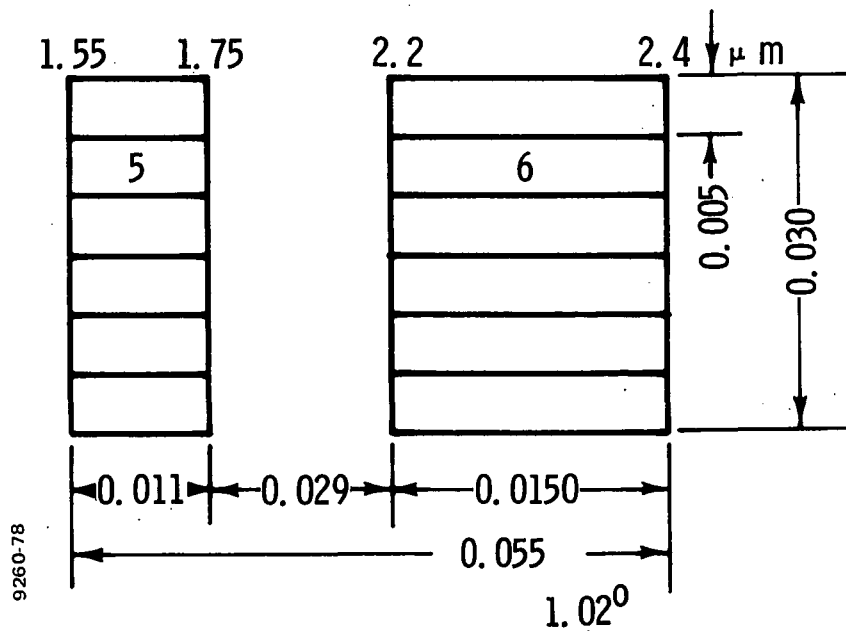
Efficient transfer of light through the system is important to meet minimum detectable change of ground reflectance specifications. Thus, the fewest possible elements with maximum transmittance or reflectance must be used.

A.1.2 Environmental

For qualification, the instrument must withstand 95% humidity for 24 hr at 30°C; temperature cycling from - 5 to +45°C; 15.3 g acceleration for one minute along two axes, and vibration testing. During use, its temperature will cycle from



BANDS 1-4 8 IN. LENS

Figure A-1 Overland Spectrometer Detector Planes
(Dimension in inches)

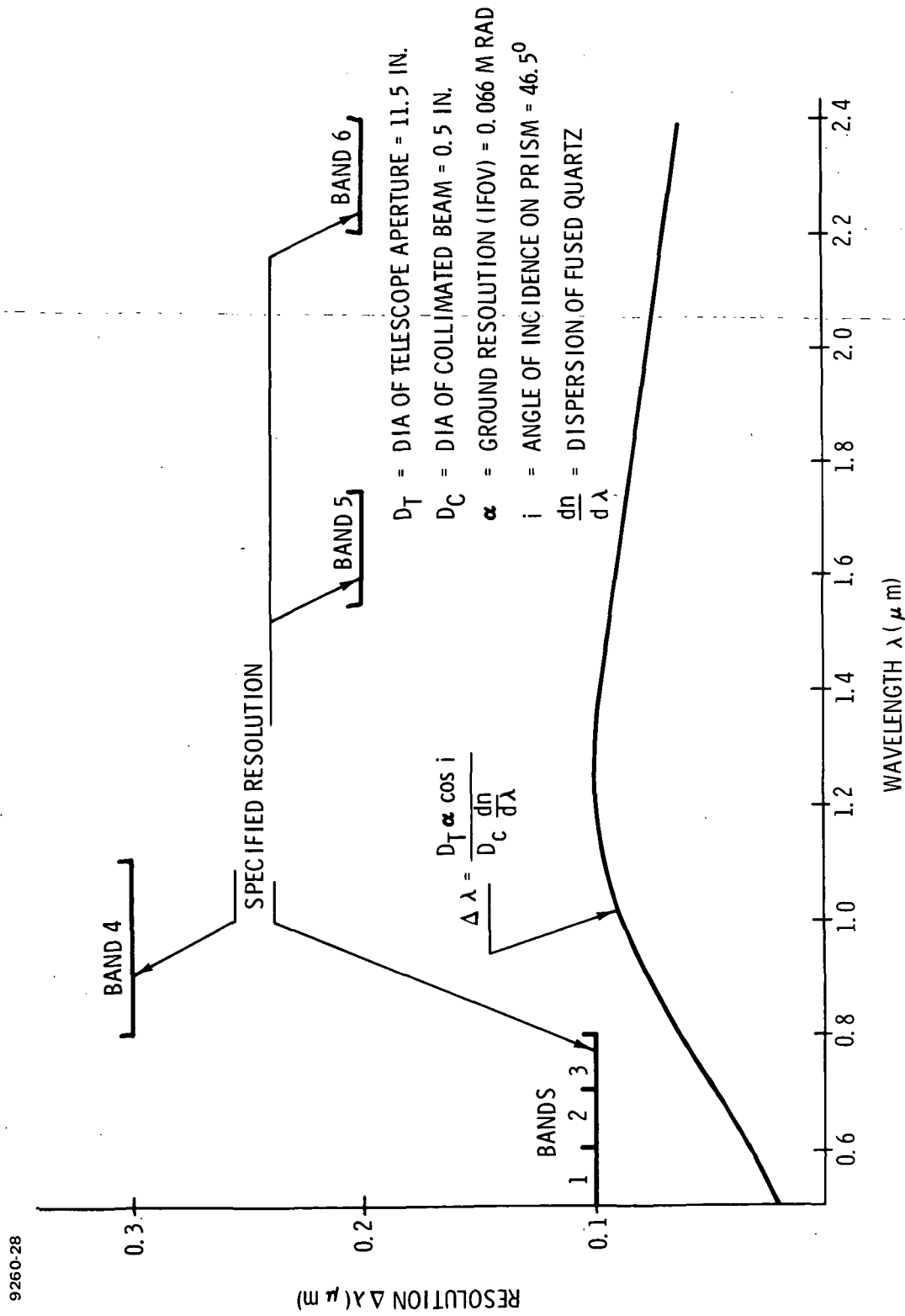


Figure A-2 Dispersion Curve for 60° Fused Quartz Prism

10 to 30°C during each orbit. It will traverse the Van Allen Belt and be exposed to penetrating radiation of perhaps 10^7 to 10^8 ergs per gram, assuming shielding of 1 gram/cm² (0.094 in. Al.).

The temperature cycling indicates a need to consider and minimize its effect on alignment. The acceleration indicates a need to calculate stress on thin elements, and permanent distortion of structure holding optical elements in alignment. The radiation dose is sufficient to cause severe transmission loss in optical glass. The effect on fused quartz should be less than 2%, if very high purity material is used. The effect on acrylic plastic should be only a few percent loss. The effect on polystyrene should be negligible.

A.2 DISPERSIVE ELEMENT

A.2.1 Choice of Dispersive Elements

A prism was chosen instead of a diffraction grating or interferometer because the spectral range of 0.50 to 2.4 μ m could be handled more simply and with higher transmission efficiency. Alternatively, the spectral range could have been covered with two diffraction gratings having efficiencies about 45% at the ends of their ranges. A single grating could have been used to cover the entire spectral range by using both first and second orders, but accepting grating efficiencies of about 32% at the ends of the range. In both grating applications, a dichroic mirror would be necessary to split the spectrum with accompanying transmission and reflection losses. An additional problem occurs if the first and second orders of just one grating were used, because the dichroic must then break the spectrum at 0.80 μ m. The bands are contiguous at 0.80 μ m, but the dichroic mirror is not a perfect filter (having a 6% "cut in" slope), so it would contribute to crosstalk between bands 3 and 4. Crosstalk reducing filters might be required in addition to the dichroic mirror.

A 60° fused quartz prism's external transmission is about 91% at 0.5 μ m, with internal transmission about 99% for the median path out to about 2.4 μ m. The dispersion of prism materials changes about as our resolution requirements change with wavelength, so the long wavelength detector size is minimized, an advantage for signal to noise ratio. The reflections at the surface of the prism will cause some polarization of the light, which may be a disadvantage, but this occurs with gratings also.

Either a Kessler prism or a combination of prisms of different materials can be used so that one wavelength of the range will go through the prism undeviated, while the rest are appropriately dispersed. This might offer some advantage by giving straight line mechanical constructions; however, there is no current need for, or advantage in the feature. Another combination of prism materials can be used to give

nearly linear dispersion with wavelength; however, this appeared to be a disadvantage in consideration of the way the overland mode bandwidth specifications change with wavelength, and the need to minimize the size of long wavelength detectors. Constant deviation prisms appear to offer no advantage for a spectrometer whose output must include many wavelengths at the same time.

The most suitable prism material appears to be fused quartz for the following reasons:

1. High transmittance throughout the spectral range of interest
2. Low index of refraction for minimal surface reflections
3. Low thermal coefficient of expansion
4. High chemical stability
5. Widely used optical material available from several sources
6. One of the most uniform and largest $dn/d\lambda$ of common materials
7. The fused quartz curve of $(dn/d\lambda)$ as a function of wavelength comes fairly close to matching our resolution specifications.

The fused quartz must be very pure and have less than 5 ppm of the OH radical to avoid absorption at 1.38 and 2.22 μm . The requirements for prism material should be striae grade A and inclusion number 5 or better as defined in MIL-G-174A. "Infrasil 1" and "Suprasil W" fused quartz appear suitable both from the standpoint of transmission and inclusions are grade A for striae. "General Electric 125" meets the transmission requirements, but not the optical quality. "General Electric 151" meets the optical requirements, but not the transmission at 2.22 μm .

A 60° prism vertex angle was chosen as the best trade-off between increased Fresnel losses as the angle increases, against the necessity for larger beam diameter as the angle decreases; and after consideration that 60° fused quartz prisms are stock items with suppliers.

It can be shown that at minimum deviation:

$$\frac{d\theta}{dn} = \frac{2 \sin(\alpha/2)}{\cos i}$$

where α = prism vertex angle

This equation indicates that the $(d\theta/dn)$ of a 60° prism will be 1.578 times that of a 45° prism, both at $1.0 \mu\text{m}$ wavelength. It follows from the minimum bandwidth equation,

$$\Delta\lambda = \frac{D_T \alpha}{D_c \frac{d\theta}{dn} \frac{dn}{d\lambda}}$$

that the beam diameter must be increased by a factor of 1.578 if a 45° prism is used. The increased beam diameter requires increased collimator and imager diameter, with proportionate increase in focal length all of which will result in increased spectrometer size.

The internal transmission losses of the prism will be independent of the vertex angle as long as bandwidth, $\Delta\lambda$, is held constant, since the base thickness of the prism must remain constant. The base thickness, in turn, will remain constant because the beam diameter must expand proportionately as the vertex angle decreases to keep bandwidth constant.

Fresnel losses were calculated for prisms at minimum deviations for $1.0 \mu\text{m}$, as follows:

45°	0.930 transmission
60°	0.912 transmission

Of course, Fresnel losses increase more rapidly for prism angles greater than 60° and larger indices of refraction.

A.2.2 Prism Aberrations

The effect of temperature on spectrum position was calculated, assuming that all parts remained in place exactly, and only the refractive index of fused quartz changed in accordance with Malitson's data from J.O.S.A. 55, 1209 (1965). If the temperature drops from 20° to 10°C , the spectrum will shift about 0.00052 in. towards the long wavelength end in band 5. The shift will amount to about 4.6% of band 5 length. In Band 3 the spectrum will shift about 0.00115 in., which is about 5% of Band 3, the smallest band in length. A rise in temperature to 30°C will give equal changes in the opposite direction.

Slit image curvature was calculated according to the formula of Kingslake, Vol V, p. -15. The radius of curvature of the image was calculated as 7.26 in., and since the end of the slit is only 0.039 in. from the axis, (with 8 in. imager lens), the slot only deviates 0.0001 in. from a straight line.

The slit is 44.6 wavelengths wide at 2.4 μm and 8 times the critical slit width that limits minimum resolution (for a completely incoherent source), as described in Kingslake, Vol V, p. 67.

Some aberration results from incompletely collimated light passing through a prism. The astigmatic portion of the aberration is zero for rays passing through the prism at minimum deviation (i. e., making equal angles with the prism faces when entering and leaving the prism). Inasmuch as the prism is operated at minimum deviation, for 0.98 μm rays, and other wavelengths are close to minimum deviation, negligible astigmatism can be assumed. As long as the collimator stays in focus to the ends of the slit, other prism aberrations will not exist.

A ray trace through the prism and 8.0 in. lens showed no discernible increase in blur of the lens because of passage of the light through the prism. (Figure A-3) may be compared with the blur diameters in Table A-4 of Section A-4.5.2. The wavelength 0.98 μm was chosen as the one for minimum deviation through the prism for the following reasons:

1. 0.98 μm is close to the center of the spectral range, but is displaced in the direction highest resolution was required.
2. At 0.98 μm , the dispersion of quartz is changing at nearly its slowest rate, so the maximum number of wavelengths are close to minimum deviation.

Wavelengths shorter than 0.98 μm will go through the prism at an angle such that if continued far enough, they would intercept the prism base. It is necessary to avoid this by having sufficient space between the beam and prism base. The smallest stock quartz prisms are one inch on a side, which allows more than enough space.

A.2.3 Resolution, Spectral and Spatial

At the output of the spectrometer, the range of wavelengths present at a single point in the spectrum is considered the minimum bandwidth achievable, and is the product of the range of angles incident on the dispersive element with its angular dispersion:

$$\Delta\lambda = \Delta\theta \frac{d\lambda}{d\theta}$$

But in our system, a telescope with a field of view α and diameter D_T , working into a collimator with beam diameter D_C , and assuming the same $f/$ for telescope and collimator:

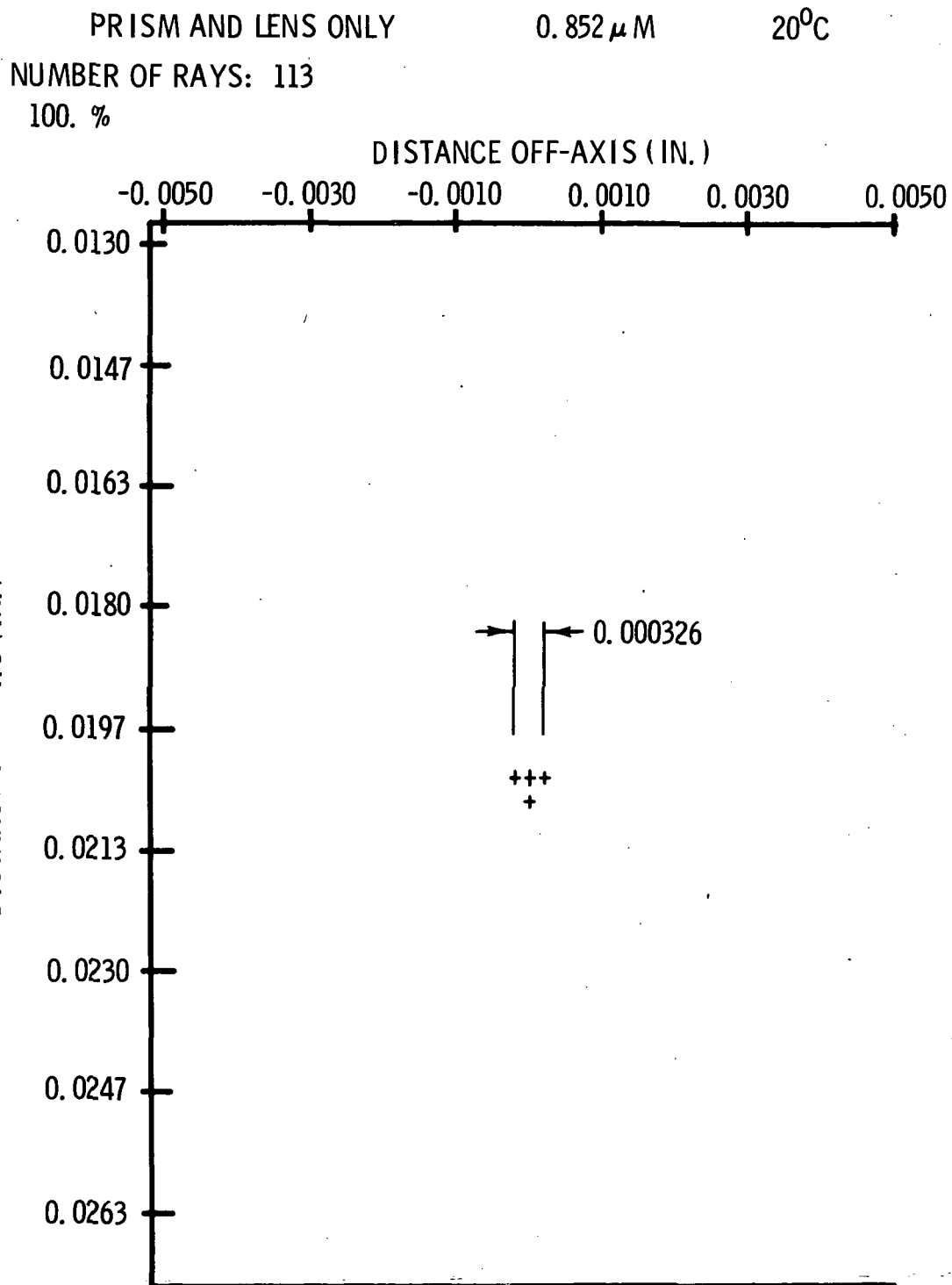


Figure A-3 Spot Diagram for Prism and Lens Combination

$$\Delta\theta = \alpha \frac{D_T}{D_C}$$

$$\therefore \Delta\lambda = \alpha \frac{D_T}{D_C} \frac{d\lambda}{d\theta} = \frac{\alpha D_T}{\frac{d\theta}{d\lambda} D_C}$$

If a prism is used:

$$\frac{d\theta}{d\lambda} = \frac{d\theta}{dn} \frac{dn}{d\lambda}$$

According to Kingslake, Vol V, p. 11, if a 60° prism is used at minimum deviation and i is the angle of incidence:

$$\frac{d\theta}{d\lambda} = \frac{1}{\cos i} \frac{dn}{d\lambda}$$

$$\therefore \Delta\lambda = \frac{D_T \alpha \cos i}{D_C \frac{dn}{d\lambda}}$$

The $\Delta\lambda$ is plotted against wavelength for fused Silica in Figure A-2 to show that spectral resolution specifications have been met.

A less obvious tradeoff is that between spectral and spatial resolution. If $d\theta/d\lambda$ is decreased while everything else in the system is held constant, the space in the image plane occupied by a spectral band will decrease, while the space of the spatial resolution element will remain the same. On the other hand, if the focal length of the collimator is decreased, the angular subtense and size of the spatial resolution element will increase relative to dispersion, but since it is necessary to maintain the same f /number, the D_C will decrease, thereby increasing $\Delta\lambda$. None of these changes is helpful in decreasing the effect of telescope aberrations on spatial resolution. It would be possible to make some slight change in form factor of detector elements by accepting larger $\Delta\lambda$, if low aberration spectrometer optics are used.

A.3 CRITERIA AND CHOICE OF COLLIMATORS

A.3.1 Specification

1. Focal length: 2.60 in.
2. Beam diameter: 0.495 in.

3. Clear aperture: 0.65 in.
4. Blur diameter: 0.125 milliradian (visible light on axis)
5. Central obscuration: less than 25% of dia
6. Source size: 0.0042 by 0.0253 in.
7. Spectral range: 0.52 to 2.4 μ m with focal length constant to $\pm$ 0.001 in.

A.3.2 Refractors

A lens would have the following advantages:

1. It is less sensitive to angular misalignment than are mirrors, and small translations relative to the prism have no effect; however, translations relative to the slit must be held within 0.001 in.
2. It can be contained in one package.
3. There is no central obscuration with its associated light loss and diffraction.

A lens would have the following disadvantages:

1. It cannot be made perfectly achromatic for the range of wavelengths.
2. Lens transmission losses can be expected to be larger than the reflection losses of mirrors.
3. There would be the uncertainty associated with development of a lens beyond present state-of-the art.
4. A lens would be more expensive than a mirror, costing perhaps \$4000 for design and perhaps \$1500 to \$2000 per copy.
5. There is the possibility of unwanted reflections causing ghost images.

A vendor survey disclosed that three reputable manufacturers are willing to undertake design and construction of such a lens. Use of two lenses of identical material was investigated, and it was concluded that such a combination could not be made achromatic, except in the limited sense that Ramsden and Huygens oculars are achromatic. The longitudinal secondary spectrum (LSS) (i.e., maximum deviation

from nominal focal length) for a wide variety of optical materials was calculated and a choice of a BAK-1 and KzFs-5 glasses combination was made based on manufacturing considerations and environmental resistance as well as on optical performance. The above combination has an LSS of 0.000662 in. with a 2.6 in. focal length lens. The resultant blur diameter in an $f/5.56$ system would be 0.000119 in. or 0.0458 milliradian. These are within our blur requirements, but do not take into consideration other sources of blur which may not be perfectly corrected, such as spherical aberration and higher order aberrations. Before a definite decision on use of a lens is made a complete design should be made (at least a preliminary design).

In principle it is possible to use simple lenses of the same material as the prism and form a well focused image in a flat plane, provided the collimator is working at an $f/\text{no.}$ large enough so the half-angle in radians of the incoming beam is equal to its sine and tangent, to the accuracy required. The only difficulty with this arrangement is that the image plane is severely tilted with respect to the optical axis. This is unacceptable when the light must go through a glass envelope to a photocathode or a lens to a detector, and would require a stairstep arrangement of a fiber optic image detector. In principle it should be possible to correct the image plane tilt by adding a prism close to the image plane. When the dimensions of the prism are calculated, it is found to require a path length difference of 1.726 in. in a height of 0.355 in. A single isosceles triangle with the above dimensions would have an internal reflection leading to equal path lengths for all rays. A more complex prism is conceivable, but would then extend so far from the focal plane that the rays of different wavelength would not be adequately separated. Use of lenses with a direct vision or a Kessler prism would make possible a spectrometer 13 in. long from slit to image plane in a straight tube about one inch in diameter.

A. 3.3 Dall-Kirkham Collimator

It is possible in principle to use a Dall-Kirkham mirror assembly as a collimator. The possibility was investigated using a Bendix developed computer program. The program automatically varies primary radius of curvature in steps and computes obscuration and blur circle radius in radians for spherical aberration. Radii of curvature from 4.0 to 1.4 in. were investigated in steps of 0.2 in. The longer radii gave acceptable blur, but obscuration was 0.446 at 4.0 in. At 1.4 in. rad, blur had risen to 3.0 m rad dia and obscuration was still an unacceptable 0.271. The calculations were all made with eccentricity zero because communication with Ferson Optics had suggested that if calculations showed a Dall-Kirkham with spherical primary would perform satisfactorily, they could aspherize it enough to overcome the manufacturing defects and meet calculated performance; that is, manufacturing defects would degrade calculated performance as much as aspherizing would improve it. Ray tracing showed that alignment between the two mirrors is very critical, and

alignment with the slit is critical, but alignment of the whole assembly with the prism is not critical. The Dall-Kirkham is clearly not suitable for use as a collimator with this short focal length.

A.3.4 Off-Axis Paraboloid

An off-axis paraboloid would be suitable as a collimator and has the advantages of simplicity and no obscuration. It has half the reflection losses of two mirror systems. Its disadvantages are:

1. It appears to be incompatible with the geometry of the scanner output.
2. The short focal length makes it difficult to get appreciable distance off the paraboloid axis without unacceptable blur.
3. Manufacturing limitations on off-axis paraboloids result in blur circles of at least 0.001 in. equivalent to 0.385 m radian at this focal length.

A.3.5 Spherical and Pfund Mirrors Combination

This combination appears to be the most suitable collimator. Its advantages are:

1. The geometry fits into the scanner.
2. Spherical aberration of an $f/5.56$ mirror is only 0.045 mrad, less than half its diffraction limit in visible light. (The off axis angle to the end of the slit is only 4.8 mrad, so the off-axis aberrations will be negligible.)
3. The mirrors are relatively inexpensive.

The disadvantages are the critical dimensions and tolerances required:

1. Central obscuration of the Pfund mirror must be less than 25% of the beam diameter, or about 0.117 in. to stay completely within the obscuration of the scanner.
2. The center of the Pfund mirror front must be less than 0.70 in. from the slit for the beam to be small enough to pass thru the 0.117 in. hole. This requires very close spacing.

3. Angular alignment of both mirrors is critical, and must be stable after setting and in flight within ± 0.2 mrad in the plane of dispersion and ± 0.1 mrad perpendicular to the plane of dispersion. Mirror movement of 0.1 mrad will displace the image 0.12 of the IFOV in the flight direction.
4. Translation of the mirror along the flight path of 0.0015 in. is tolerable, and along the dispersion direction .0027 in. is tolerable.
5. Translation of the collimating mirror along its axis will cause some defocussing. A ray trace showed that if the collimator is moved 0.0010 in. farther from optimum focus, the blur diameter will increase from 0.0462 to 0.1158 mrad [still an acceptable diameter].

The collimator must take light from the telescope image at the field stop and make it as nearly perfectly collimated as possible. The eccentricity and radius of curvature to do this were determined by ray tracing. The image input to the collimator was formed by the telescope, with a spherical primary of 40 in. rad of curvature, a hyperbolic secondary with an eccentricity of 1.37 and a radius of curvature 7.6239. The effectiveness of collimation was measured by the size of the blur circle produced by a mathematical paraboloid receiving the output of the collimator. The paraboloid was located at the same distance from the collimator as the more distant imager lens, 5.65 in. The distance from telescope secondary to collimator was held constant at 18.6 in., requiring a focal length of 2.6 in. from the collimator. Using a radius of curvature of 5.2 in., the eccentricity was varied from 0 to 2.3, with best results between 1.75 and 2.3, but only equal to a spherical collimator with a 5.208 in. rad of curvature.

Using a radius of curvature of 5.208 inches the eccentricity was varied up to 1.0 with results poorer at 1.0 or 0.5 than zero. Using an eccentricity of zero (sphere), the radius of curvature was varied from 5.200 to 5.210 with an optimum found at 5.208 inches. Of 197 rays traced, 93.9% were within a 0.0062 in. dia (Figure A-4) and 89.9% of 197 rays within a 0.0060 inch diameter.

The telescope has 93.9% of 197 rays within a .0020 inch diameter. The geometric magnification of .0020 inch by collimator and 10 inch paraboloid would be $.0020 \times 10/2.6 = .00769$ inch, so some improvement in imaging has been made by the collimator.

A.4 CRITERIA AND CHOICES OF IMAGER OPTICS

The choice of imager optics is complicated by the fact that two different image sizes are needed to accommodate three different detector types. The detectors for

9260-30

NUMBER OF RAYS: 197

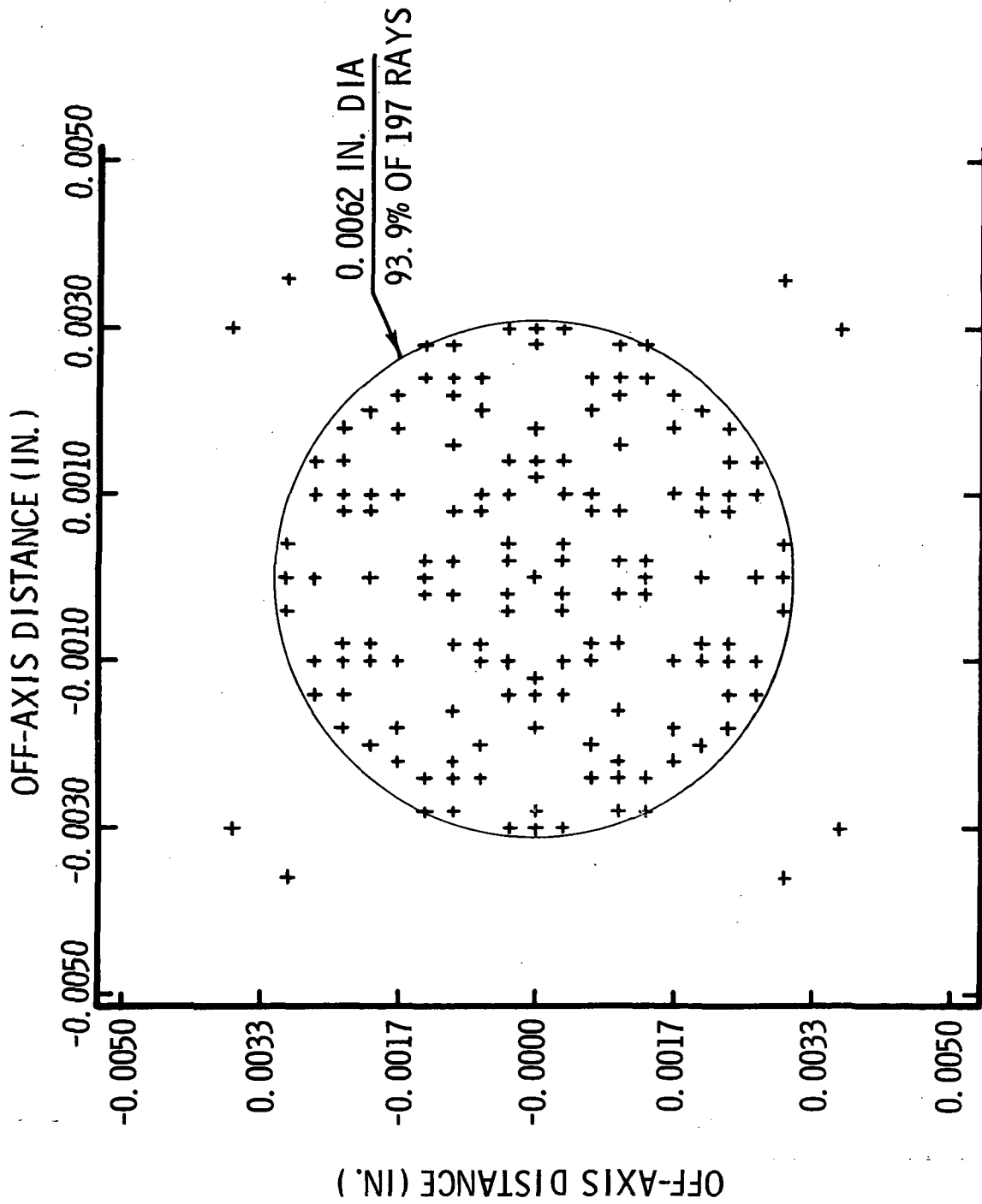


Figure A-4 Collimator Optimization from Telescope to 10-in. Paraboloid

Bands 5 and 6 must be as small as possible to minimize noise. The smallest active area dimension currently available is 0.004 in. with 0.001 in. min separation between cells so that a total cell width of 0.005 in. is needed in the flight direction. Cell width is 1.625 milliradians so a 3.075 (~ 3.1) in. focal length imager is required for Bands 5 and 6. The Band 4 detectors are photo-voltaic silicon and can be made the same size as Band 1 thru 3 detectors without undue noise. The Band 1 thru 3 detectors are photomultipliers and must be coupled to the image plane by either light guides or mirrors. In either case a fairly large image is desirable to minimize losses between cells, because dead space between cells is a constant 0.001 inch. The optimum focal length for cells 1 through 4 is 8 in., resulting in a cell width of 0.013 in. in the flight direction.

A.4.1 Choices of Imager Optics

The usual solution to the need for different image sizes is to use the focal length imager necessary for the largest image and insert field lenses in its image plane to reduce the image sizes as appropriate. The solution is not applicable to this case because the field lenses produce an image of the imager and would completely mix up the six channel images.

Another approach would be to use an immersion lens. The demagnification required is $0.005/0.013 \text{ in.} = 1/2.60$. The demagnification of an immersion lens equals its index of refraction, so a most suitable material would be Texas Instruments 1173 glass with an index of 2.64 at $2.0 \mu\text{m}$. There is a problem in obtaining optical contact between the immersion lens and detector material, and there would be an increase in the heat load on the detector cooler.

Another possibility would be to use an array of six cone condensers for each band. This idea was abandoned because manufacture of such a device would be extremely difficult or impossible. It would be an additional heat load because it must be very close to the detectors.

A very feasible approach is to collect the light from Bands 5 and 6 with a reducing relay lens some distance behind the image plane of the images, and re-image on detectors of the desired size. A field lens at the first image plane is not necessary because of the large relative aperture of the imager. The disadvantages of the system are:

1. Aberrations in Bands 5 and 6 are significantly worsened by the relay lens.
2. The beams of light from the two bands must go through the relay lens off center so that spherical aberration is increased significantly over that in the selected solution.

3. If a relay lens requiring 3.6 in. between first and second image planes (about as much space as the selected solution) is used, it will operate at an equivalent aperture of $f/2$. If the distance from first image plane to detector is increased to 10 in. the equivalent aperture is still only $f/2.8$. The selected solution lens for Bands 5 and 6 is the equivalent of $f/5.53$.
4. The space limitations would almost certainly require use of a folding mirror with accompanying increased alignment problems.

The selected solution is to split Bands 5 and 6 from 1 through 4 with a dichroic mirror located after the prism (Figure A-5), and then use lenses of different focal length for the two groups of bands. The significant disadvantage of the dichroic mirror is its light loss, which is about 10% for reflection to Bands 1 through 4, and 6 to 11% (not considering two mirrors eliminated) for transmission to Bands 5 and 6, as compared with a system with Bands 5 and 6 split off at the first image plane, and a reducing relay lens. Although the relay lens is eliminated with the dichroic, an imaging lens of equal transmission must be added so the lens does not enter the calculation. The advantages of dichroic splitting are:

1. The range of off-axis angles to be covered by one imager is reduced from 1.5 to 0.55° . This would reduce the aberrations considerably, if an off-axis paraboloid were used as an imager as shown in Figure A-6.
2. The range of wavelengths to be covered on any one lens is reduced from 0.5 through $2.4 \mu\text{m}$ to 0.5 through 1.1 and 1.55 through $2.4 \mu\text{m}$. The narrow ranges can be covered adequately with cemented doublet lenses.
3. Alignment problems of the spectrometer are simplified in most cases. Translation of the dichroic in its own plane has no effect, of course. Translation of the dichroic in any other direction will shift the channels of Bands 1 through 3, if mirrors are used for imaging. Translation of the dichroic by small amounts in any direction will have no effect if lenses are used for imaging. In any case, rotation of the dichroic will cause movement of the Band 1 through 4 channels, and must, therefore, be restricted to ± 0.1 milliradians corresponding to movement $\pm 12\%$ of a spatial resolution element, or 7% of Band 3 length. Movement of the Band 5 and 6 channels will be a second order effect of dichroic movement.

The imager optics are compared in Table A-1.

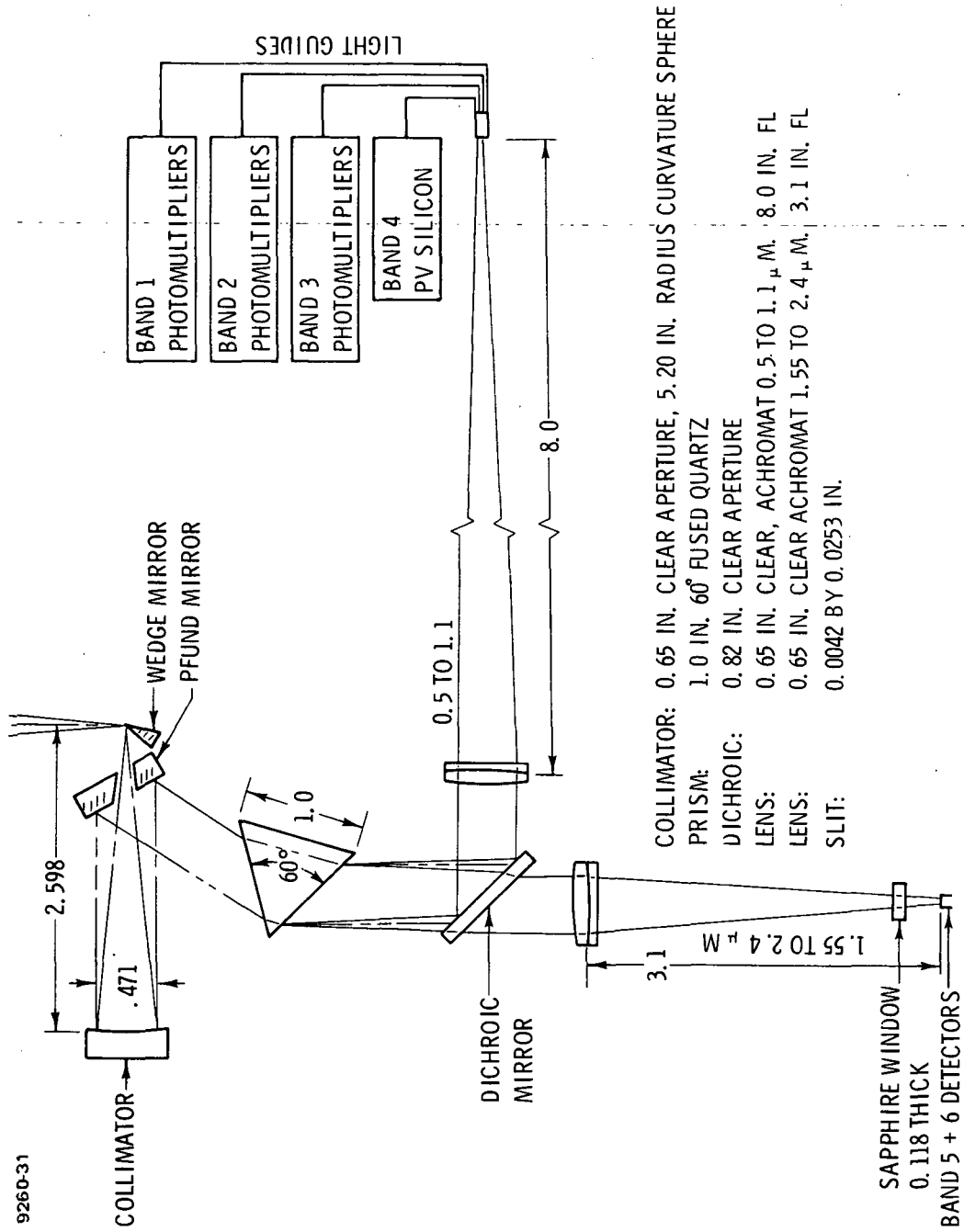


Figure A-5 Overland Spectrometer Optical Schematic

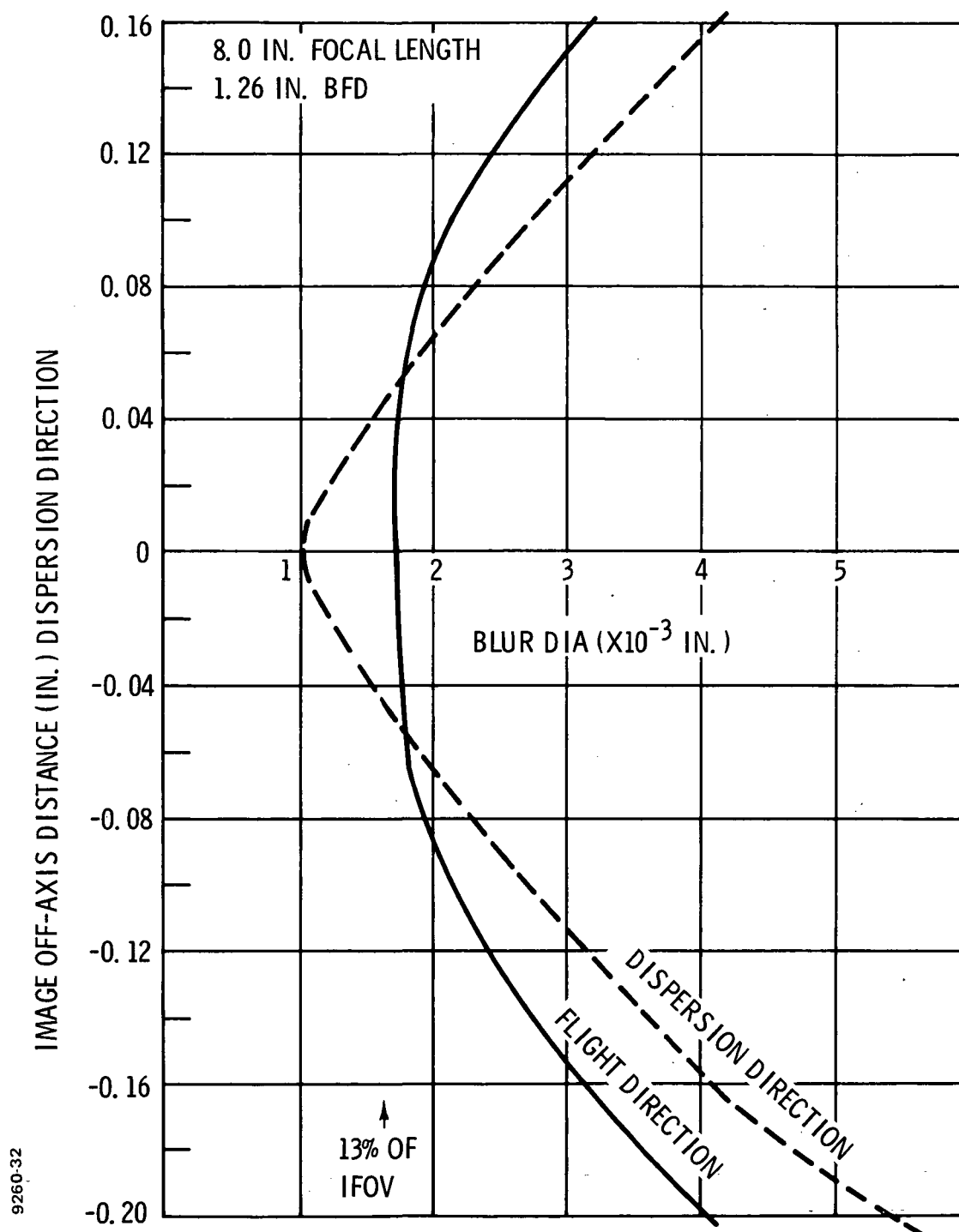


Figure A-6 Dall-Kirkham Blur Circle

TABLE A-1
SPECTROMETER SYSTEM COMPARISON ON BASIS OF IMAGER OPTICS

IMAGER SYSTEM

Parameters	Spherical and Pfund Mirrors	Dall-Kirkham Mirrors	Off-axis paraboloid Mirrors	Refractive Achromats
Number of elements	two	two in one unit	one	two in one unit two units
Light Efficiency	80%	80%	90%	80%
Obscuration	8%	20%	0	0
Alignment	very critical	easy after set assembled	critical	relatively easy
Size	Largest 11 by 3 in.	Most compact 4 by 3 in.	Fairly compact 8 1/2 x 3 in.	Moderate
Blur Dia Axial	0.0046 m rad	0.213 mrad	0.0145 mrad	8.0 in. lens 0.0425 mrad 3.1 in. lens 0.52 mrad
.025 radian off-axis Parallel to dispersion	0.0046	0.704 mrad	0.088	blur is approx the same as above at 9 mrad off axis
Normal to dispersion	0.0046	0.519	0.078	Recommended system. Dichroic loss included with light efficiency.
Remarks	Spherical aberration of imager mirror only.	Can improve resolution by worsening obscuration. The secondary mirror and its support will add diffraction aberration.	Actual performance likely to be worse than ray trace values above, but one can focus to improve perpendicular resolution at expense of resolution parallel to the dispersion.	

A.4.2 Dall-Kirkham

It is possible to design a Dall-Kirkham having obscuration of 0.116 from its secondary mirror, but with additional uncalculated obscuration caused by elongation of the hole in the primary. The Dall-Kirkham is the most compact imaging system. For example, the image surface would be just 2 1/2 inches from the prism vertex. However, a ray trace of the design with a Bendix program indicated an on-axis blur circle .0015 inch diameter; and at .025 radian off axis .00563 inch in a flat focal plane, or .00346 inch in a curved focal plane. Another design with secondary obscuration 0.1287 had a blur diameter of .00345 at .025 radian off axis in an arbitrary flat focal plane. Blur circle versus off-axis angle characteristics are shown for this system in Figure A-6. It was therefore concluded that the Dall-Kirkham was not a good choice for an imager.

A.4.3 Spherical and Pfund Mirrors Combination

The remarks about the combination as a collimator apply equally to use as an imager. The folding back with the Pfund mirror puts the prism approximately at the center of curvature of the spherical mirror so that the coma and astigmatism are eliminated. The result is a system that can be manufactured to be diffraction limited. Unfortunately, the obscuration caused by the slot in the Pfund mirror does not match the other obscuration in the system. The most serious difficulty is lack of space to fit it into the system.

A.4.4 Off-Axis Paraboloid

The off-axis paraboloid (OAP) appears most suitable for the imager if mirror optics are used. The system is relatively compact. The light efficiency will be high if only one surface can be used; unfortunately, it appears that a folding mirror must be added to get the system and detectors into the available space, so there would be as many mirrors to be held in alignment and waste light as in the Pfund system.

Ray trace results as to blur diameter are shown in Figure A-7 indicating a blur less than the diffraction limit for visible light on axis. Blur in the dispersion direction could be improved at the expense of blur in the flight direction by changing the angle of tilt of the image plane; however, it is believed the relationship shown is best, because the blurs are nearly the same percentage of channel width as of IFOV. If the image plane were normal to the central ray from the off-axis paraboloid, (that is, on the normal spherical image surface) the blur size would be the same in both flight and dispersion directions. The ray trace graphed was made with light coming at an angle characteristic of the end of the slit. This has no significant effect on blur circle except to worsen it for the on-axis image, which would otherwise have a blur $\sim 10^{-8}$ inch diameter.

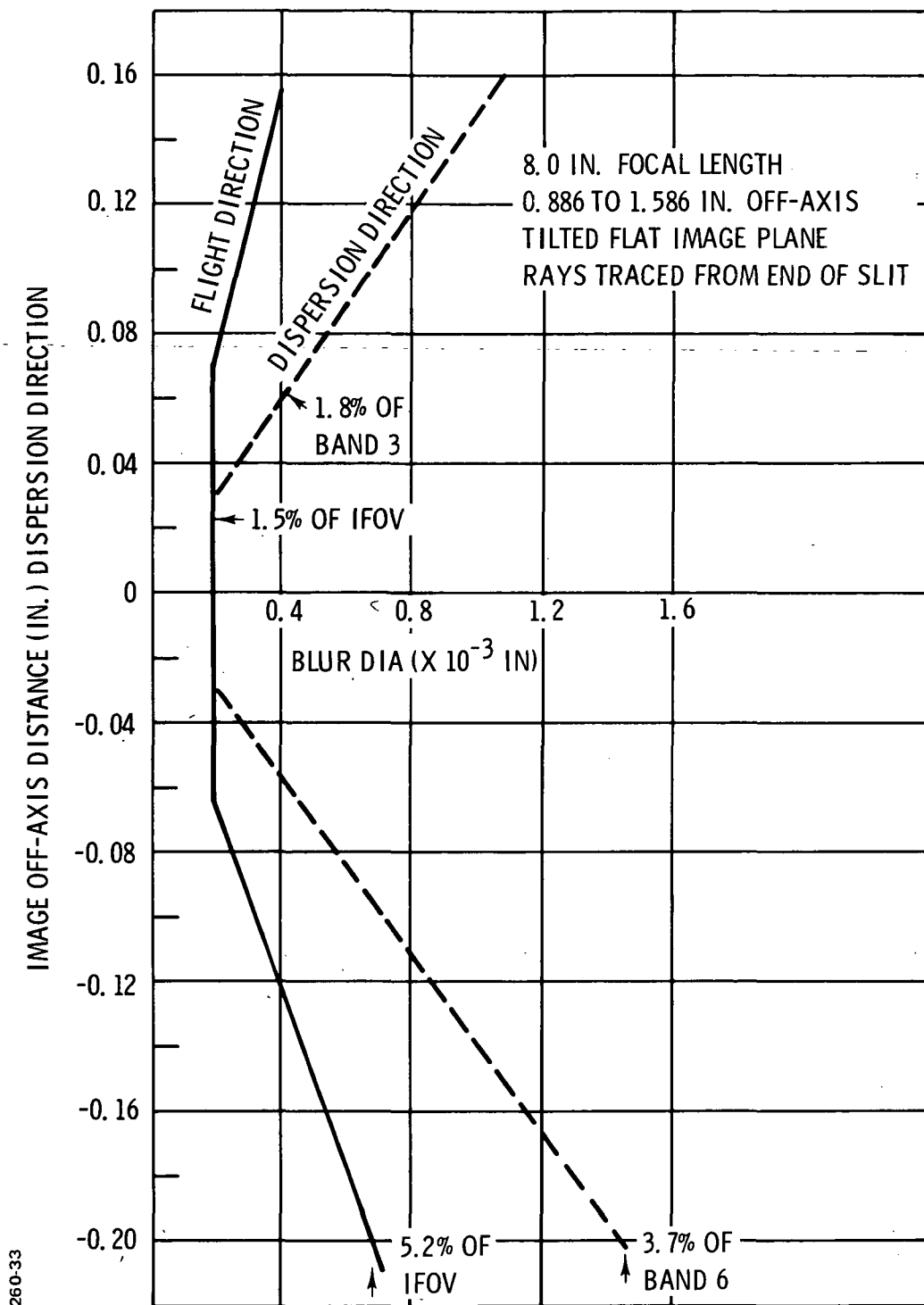


Figure A-7 Off-Axis Paraboloid Blur Circle

The same requirement for angular stability applies to the off-axis paraboloid as all other mirrors of the spectrometer, ± 0.2 m radians in the dispersion direction and ± 0.1 m radian in the flight path direction. Translation of the OAP .005 in. along the optical path toward its image does not quite double the blur diameter, and shifts the image 0.0338 of the width of band 3. Evidently this amount of translation would be acceptable. Translations of ± 0.010 inch in other directions appear tolerable because of the small angle of incidence of light on the mirror. Translation of the prism relative to the OAP can be relatively large, ± 0.050 inch.

A.4.5 Refractors

The remarks about refractive collimators generally apply to imagers, with the exception that if a dichroic is used to split off bands five and six, the design of the lenses becomes much more simple, cheap and predictable. The cost per copy would probably be under \$500. The transmission of cemented doublets would be about 89% at $0.546 \mu\text{m}$ and 93% at $1.6 \mu\text{m}$.

Use of lenses is advantageous compared to mirrors because the image is unmoved by small rotations of the lens (around its nodal points), and by small translations of the prism relative to the lens. Translation of the detectors relative to the lens will cause blurring for axial movements and a direct image position shift for lateral movements. The amounts of translation to cause noticeable blurring or a shift of the image across 10% of a spatial resolution element are tabulated below:

Focal Length Lens	3.1 in.	8.0 in.
allowable axial translation	$\pm .001$ in.	$\pm .003$ in.
allowable lateral translation	$\pm .0005$ in.	$\pm .0013$ in.

A.4.5.1 Design of the 3.1-in. Lens

No suitable lenses were available as catalog items, therefore, a preliminary design effort was made to verify that a cemented doublet lens could be designed for the need, and its characteristics ascertained.

The spectral range from 1.55 to $2.4 \mu\text{m}$ restricts the number of materials that can be used. If water soluble materials are eliminated, the number is quite small. Most glass and fused quartz contain impurities that absorb at longer wavelengths within this range. Of all the fused quartzs available, only Suprasil W and Infrasil 1 have the requisite purity and optical homogeneity. There are a number of Schott infrared glasses to be considered. The crystalline materials CaF_2

(fluorite) and MgO (periclase) are insoluble for all practical purposes, and not birefringent. Such grown crystals are free of bubbles and optically homogeneous. The polycrystalline materials are not satisfactory because they scatter light of wavelength shorter than $2.0 \mu\text{m}$ causing significant attenuation at the short wave end of our range. Silicon, arsenic trisulfide glass, and TI 1173 glass would be advantageous because their large index of refraction makes spherical aberration negligible, but it was not possible to find an anti-reflection coating that will allow covering the spectral range with as good transmission as uncoated low index materials. OCLI did not want to coat CaF_2 because they did not believe the thickness of MgF_2 required by the wavelength could be made to adhere, and the improvement would be small anyhow. Transmission of possible materials is compared in Table A-2.

TABLE A-2
TRANSMISSION OF POSSIBLE MATERIALS

Lens Transmission at $1.6 \mu\text{m}$ unless noted			
Materials	Conditions	Fresnel Transmission	Fresnel plus internal trans.
$\text{CaF}_2 - \text{SiO}_2$	uncoated cemented doublet	0.932	0.93
$\text{CaF}_2 - \text{SiO}_2$	uncoated air spaced doublet	0.878	
Irtran 3 - SiO_2	uncoated cemented doublet	0.932	0.79
As_2S_3	coated simple lens	~ 0.95	
TI 1173	coated simple lens	~ 0.95	
$\text{As}_2\text{S}_3 - 1173$	coated cemented doublet	~ 0.94	
BAK1 - BK7	uncoated cemented doublet	0.916	0.895
BAK1 - BK7	uncoated cemented doublet $2.4 \mu\text{m}$	0.918	0.741
$\text{CaF}_2 - \text{MgO}$	uncoated cemented doublet $1.6 \mu\text{m}$	0.894	
Irtran 2	coated simple lens $2.4 \mu\text{m}$		0.66

In any case, there remains the problem of chromatic aberration. To allow for chromatic aberration in simple lenses it would be necessary to tilt the image plane 29.2° for arsenic trisulfide, 36.1° for 1173 glass and 56.7° for fused quartz. If, instead of tilting the detectors, the focal plane of the lens were midway between bands 5 and 6 the blur diameter at 1.55 and 2.4 μm would be 0.0026 in. Correction of chromatic aberration is worthwhile for other reasons as it offers the opportunity for some correction of spherical aberration and coma. The chromatic aberration of a positive lens can be corrected by a negative lens if their focal lengths are in the ratio of their dispersive powers. If the positive lens is shaped for minimum spherical aberration and the negative lens for maximum, there will be some off-setting and consequent reduction of spherical aberration. A systematic approach to selecting the combination of materials is by calculating longitudinal secondary spectrum (LSS) as explained and tabulated below (Table A-3). Certain apparently good materials had to be eliminated for other reasons. Monocrystalline MgO is not grown in this country, BK-7 loses transmission at longer wavelengths; use of a low index material like quartz with a high index material like arsenic trisulfide is undesirable because of the Fresnel reflection loss at the interface.

TABLE A-3
SELECTING POSSIBLE MATERIALS

Positive Element	Negative Element	LSS (ΔF)
Servofrax A _{s2} S ₃	TI 1173 glass	-0.00329 in.
Servofrax A _{s2} S ₃	SiO ₂ (fused)	-0.00918
CaF ₂ (mono)	Moliton (A _{s2} S ₃)	-0.0850
CaF ₂ (mono)	SiO ₂ (fused)	-0.000935
CaF ₂ (mono)	Mg O (Irtran 5)	-0.0001833
MgO (Irtran 5)	SiO ₂ (fused)	-0.00222
BAK1	BK7	-0.001554
CaF ₂ (mono)	BAK1	-0.000059

LSS (change of focal length) was calculated for several promising materials using the standard formula $LSS = F (P_1 - P_2) / (V_1 - V_2)$ with a focal length, F of 3.1 in. P_1 and P_2 are the partial dispersions and V_1 and V_2 the Abbe numbers of the materials under consideration. The indexes of refraction at 1.6, 2.0 and 2.4 μm were used.

The combination of monocrystalline CaF_2 and fused SiO_2 was chosen for further design effort because of its resistance to radiation and low LSS and low Fresnel loss through low index of refraction. The focal lengths of positive and negative elements were calculated from the formulas:

$$f_1 = F_T \frac{V_1 - V_2}{V_1} \quad f_2 = F_T \frac{V_1 - V_2}{V_2}$$

An initial value for the first radius of curvature was obtained from the formula for a simple lens of minimum spherical aberration. The other radii of curvature were calculated from the thin lens formula and a series of lenses having input radius of curvatures ranging from 1.25 to 2.00 in. were calculated and ray traced with a computer program. All had undercorrected spherical aberration causing blur diameters ranging from 0.001423 to 0.00206 in. The blur is undercorrected because of the small difference in index of refraction between CaF_2 and SiO_2 . If these materials are assembled as an air spaced doublet, the blur diameter can be much reduced by use of shorter negative radii of curvature on the negative element. The additional air glass surfaces would almost double the transmission loss, so this course was not followed. The diffraction limited blur diameter for the spectrometer through this lens is 0.00102 in. at 1.6 μm and .00153 at 2.4 μm , so little motivation remains for improvement, although the CaF_2 and MgO combination appears promising. The focal length (in conjunction with a sapphire window) was 0.0008 in. shorter at 2.4 than 1.6 μm . The lens design is shown in Figure A-8 (a).

Focal length of the lens is affected by temperature because both index of refraction and radius of curvature change with temperature. The design was made and ray traced with indices for 24°C. It was again ray traced with indices and radii of curvature for 10° with the thought that this would give adequate impression of what could be expected in the specified range of 10 to 30°. Spot diagrams are shown in Figures A-9 through A-12, and the results are tabulated below.

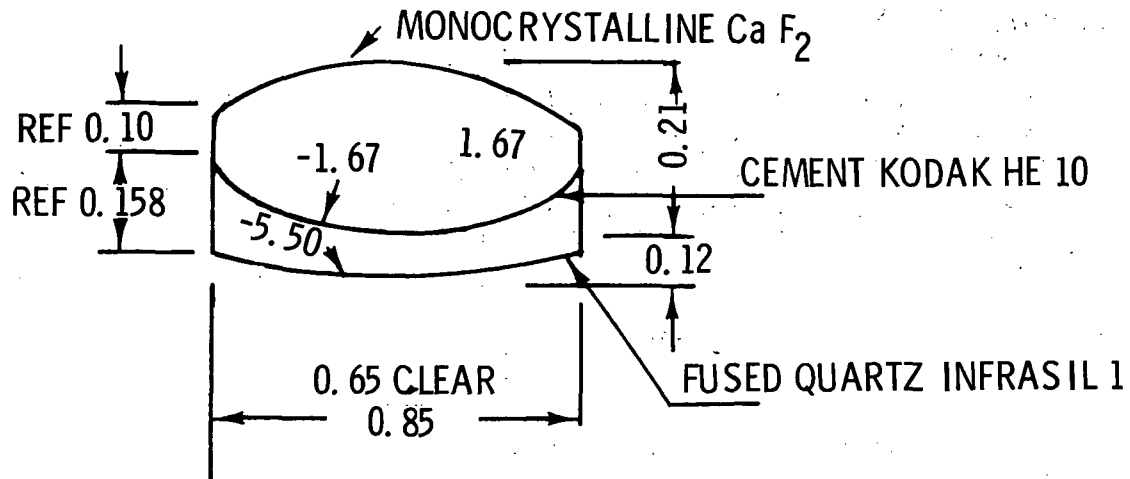
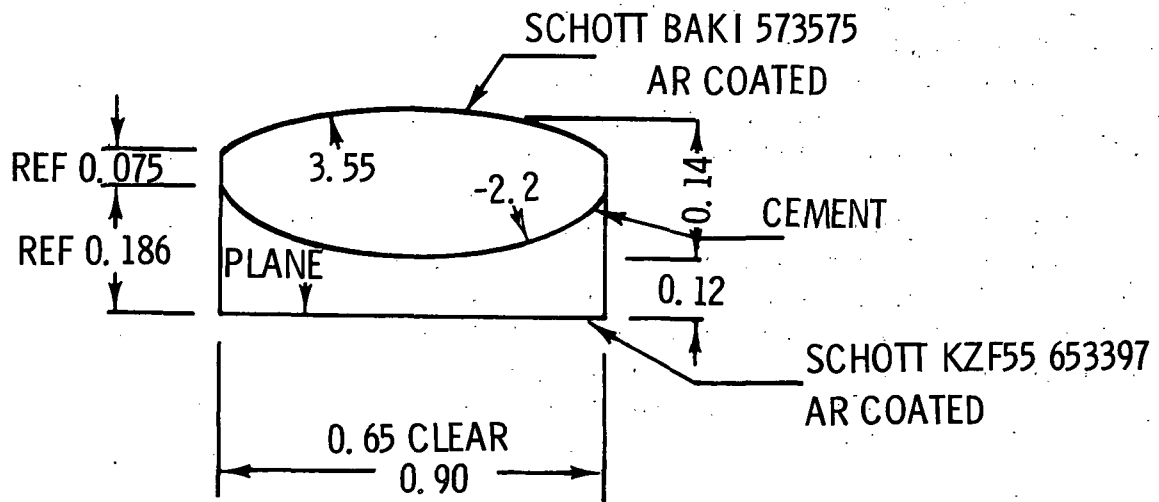
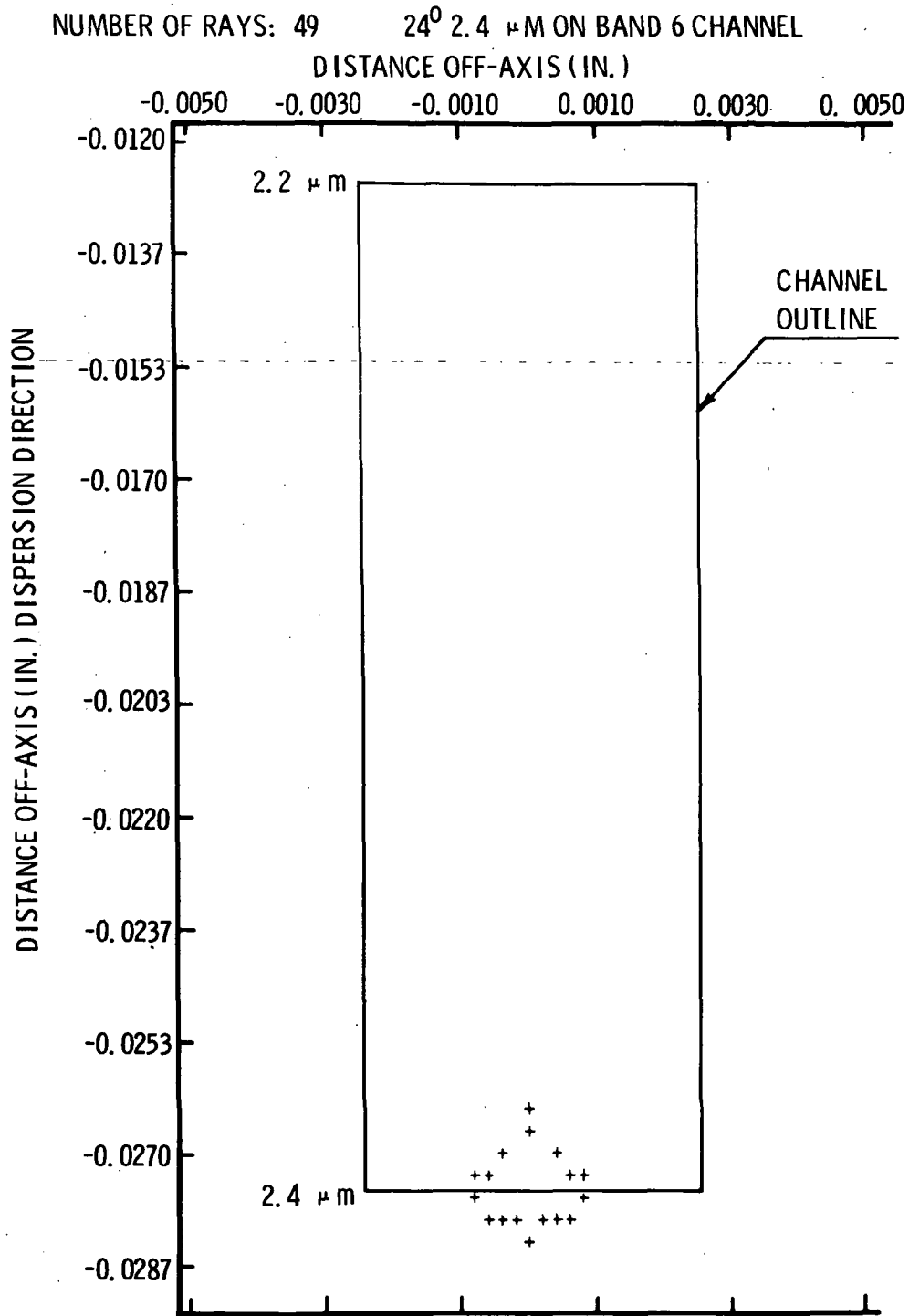
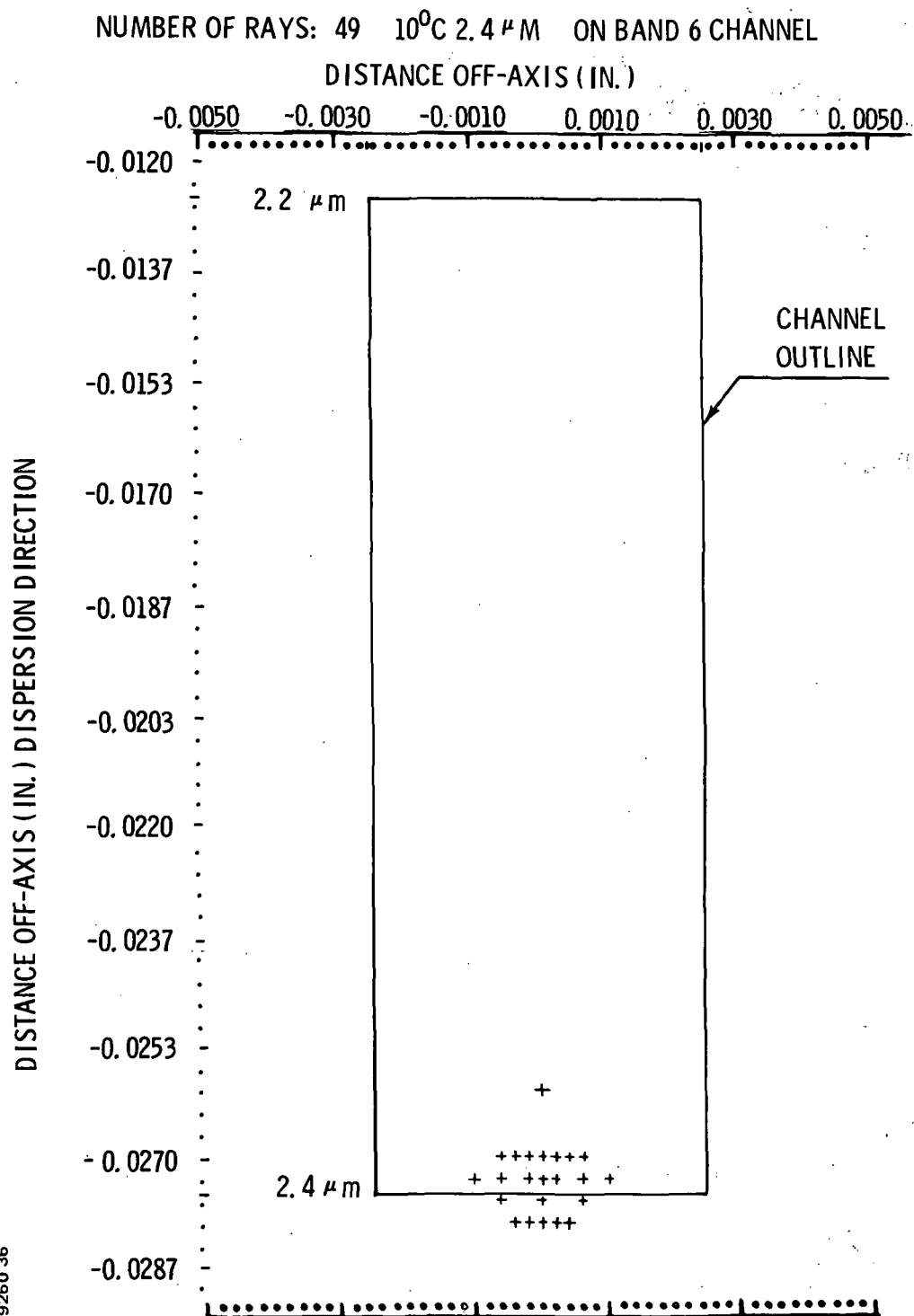
(a) 3.1-IN. FOCAL LENGTH LENS 1.55 TO 2.4 μM (b) 8-IN. FOCAL LENGTH LENS 0.5 TO 1.1 μM

Figure A-8 Design of Lens



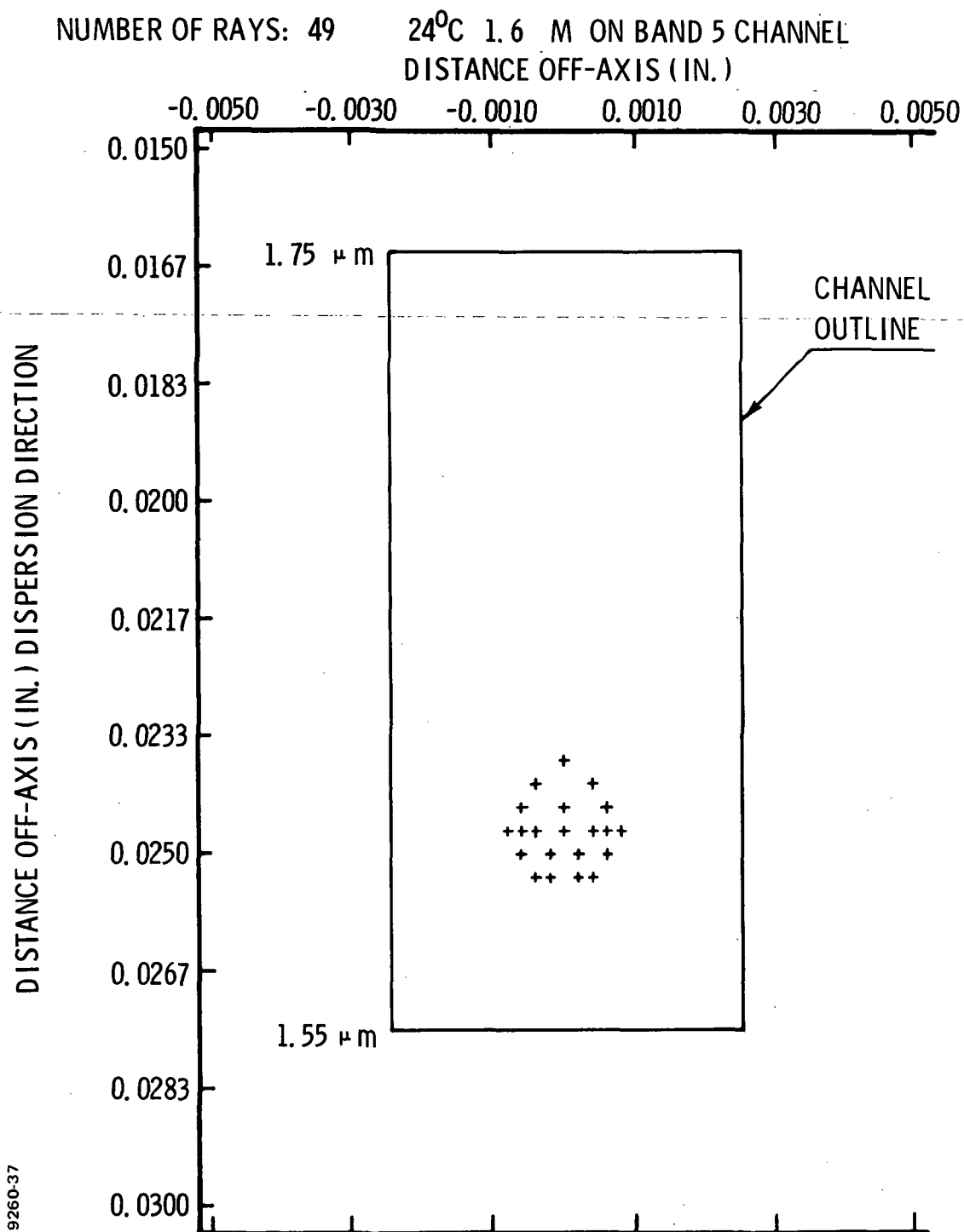
9260-35

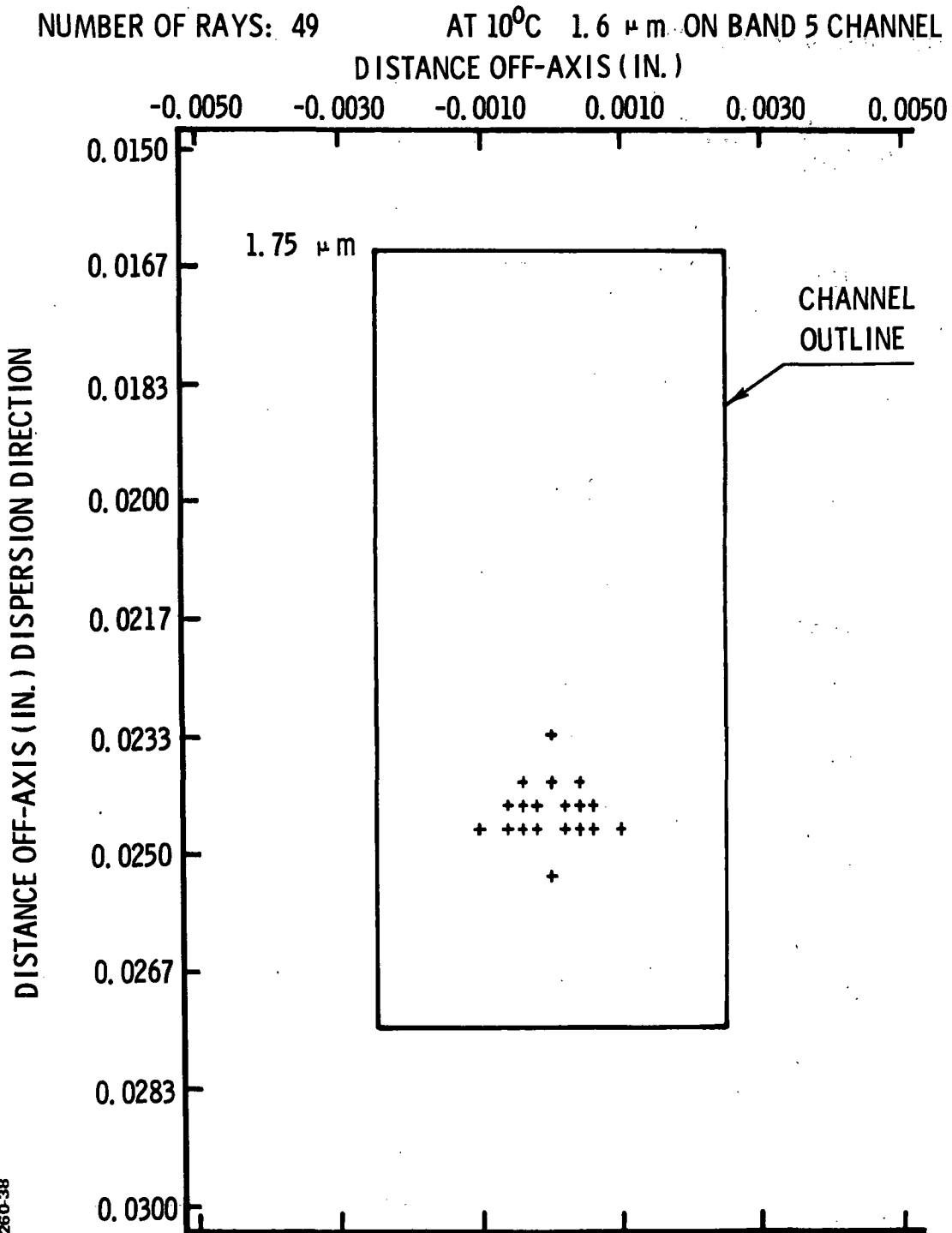
Figure A-9 Spot Diagram for 3.1-Inch Lens (24°C, 2.4μ)



9260 36

Figure A-10 Spot Diagram for 3.1-Inch Lens (10°C, 2.4μ)

Figure A-11 Spot Diagram for 3.1-in. Lens (24°C, 1.6 μ)



9260-38

Figure A-12 Spot Diagram for 3.1-in. Lens (10°C, 1.6 μ)

Blur Diameter in Flight Direction and ΔF to Return to Minimum Blur

Temp	1.6 μm		2.4 μm	
	blur dia	ΔF	blur dia	ΔF
24°	0.0015 in.	+ 0.0005 in.	- 0.0015 in.	- 0.0003 in.
10°	0.0019	- 0.0024	- 0.0021	- 0.0035

The effect on blur diameter of removing or increasing the thickness of the sapphire window was investigated. There was only a reduction of blur from 0.001482 to 0.001457 in. when the window was increased from 0.118 to 0.518 in. thickness. (Back focal distance was adjusted for minimum blur in each case.)

Data for an energy distribution curve (Figure A-13) and geometrical modulation transfer graph (Figure A-13) were obtained with the National CSS Inc., ACCOS V computer program. The energy distribution curve was based on 208 rays at each of 1.6, 2.0 and 2.4 μm wavelength. The modulation transfer graph as shown is the product of the moduli from the geometric MTF and the moduli from a universal MTF curve for a diffraction limited lens.

Fused quartz and CaF_2 are resistant to space radiation and will not require shielding.

A.4.5.2 Design of the 8 in. Lens

The same materials that were used in the 3.1 in. lens would be suitable for the 8 in. lens; however, it would be more economical to use glass instead of CaF_2 . A survey of LSS for several glasses led to a choice of BAK1 and KZFS5 as a reasonable compromise between LSS (0.00126 in.) and glass stability. BAK1 is slightly influenced by high relative humidity and temperature, so a change in the surface of the glass will occur. KZFS5 will show surface attack after a few hours of temperature cycling from 40 to 50°C in a water-saturated atmosphere. It will be stained by 12 min exposure to acid. These glasses will require special handling and care in manufacture, but their anti-reflection coatings should protect them in actual use. It will be necessary to protect the edges of the lens, either by coating or seals incorporated with the mount. It will be necessary to shield the glass from space radiation. Internal transmission of both glasses is 0.999 for a 0.196 in. thick sample from 0.546 to 1.375 μm . Fresnel reflection losses would reduce transmission of the cemented doublet to about 89% at 0.546 if not coated.

The same design procedure used for the 3.1 in. lens was used for this lens. Results of a ray trace using indexes of refraction at 20°C gave blur diameters

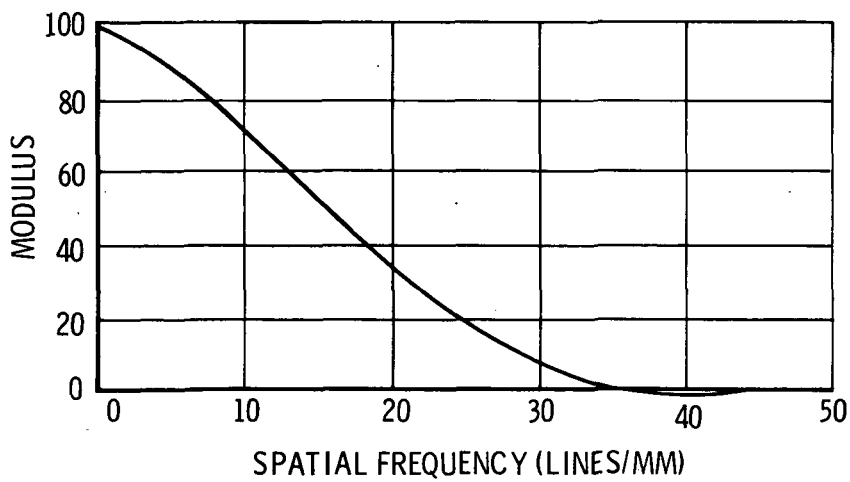
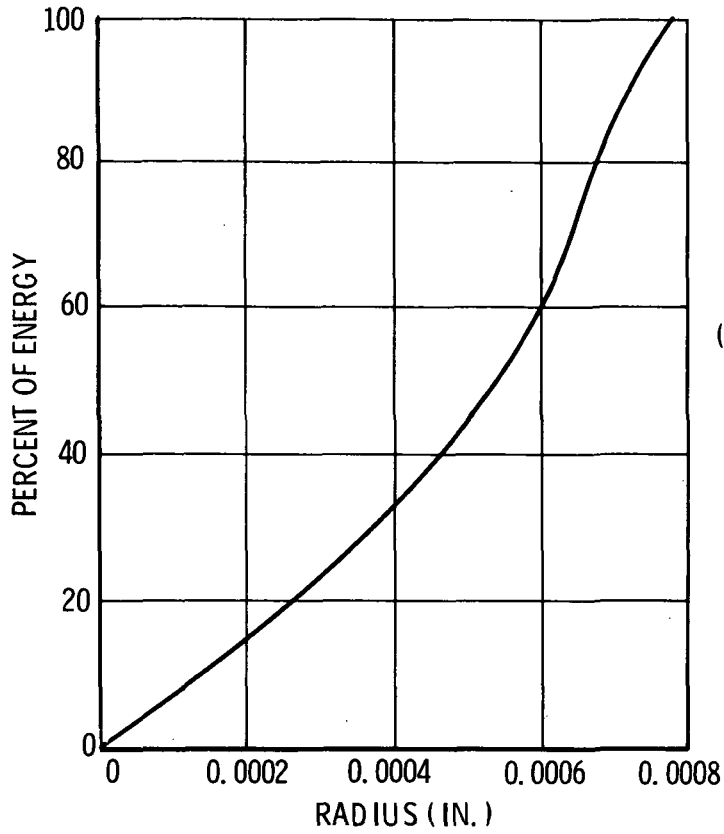


Figure A-13 Energy Distribution Curve

in the dispersion direction as listed in Table A-4. The deviation is the median position off-axis of the image spot with an input angle of 0.00958 radians, so it is a verification that the focal length is the required 8 in. as well as being representative of the input angles for the wavelength extremes.

Diffraction limit of this lens is 0.820 milli in. at $0.50\ \mu\text{m}$, so the blur diameters are more than satisfactory. The blur is a result of over-corrected spherical aberration. The optimum back focal distance appears to be 7.827 in. Design of the lens is shown in Figure A-8 (b).

A new computer search of all Schott glasses, and the more useful infrared materials, produced a list of 20 material combinations having better LSS than the above; however, most had some reason for disqualifying them. The most promising combination is Schott ZK1 and calcium fluoride.

A.5 TRANSMISSION FROM IMAGE PLANE TO DETECTORS

For the case of band 5 and 6, the bands are separated in space from the other bands, and the detectors can simply be put in the image plane of the imager. There is a problem with bands 1 through 4 because they are contiguous, while the detectors for bands 1 thru 3 are photomultipliers, $3/4$ in. dia. The problem was solved very satisfactorily for the Bendix built NASA 24-channel Multispectral Scanner by use of mirrors in the image plane to reflect the light in three different directions to photomultipliers. A system that is good with three photomultipliers appears unmanageable with respect to geometry, alignment, and space requirements when applied to 18 photomultipliers and six silicon detectors.

The most satisfactory method for transferring energy to the photomultipliers appears to be use of light guides or fiber optics. This technique has been used in the Bendix EMSIDE Scanner and other spectrometers. It has the advantage of eliminating any requirements for alignment of the detectors with the image plane. Path lengths are short (1.25 to 4.0 in.). Transmission is high throughout the range 0.5 to $1.1\ \mu\text{m}$, if glass fibers are used, but if plastic fibers or guides are used, there are drops in transmission around $.7\ \mu\text{m}$ and $.9\ \mu\text{m}$. These drops are not the most serious loss, however. The most serious loss of energy is because of the (packing fraction) space around the light conducting fiber cores. The packing fraction loss comes from both the cladding on individual fibers and guides and from the fact that most fibers are round.

The sum of the packing losses will average about 25%. In theory the cladding need only be a few wavelengths thick, so the percentage loss would decrease as fibers were made larger. However, the cladding gets thicker for mechanical reasons as the fibers get larger, and remains a constant 15% of cross sectional area.

TABLE A-4

EFFECT OF WAVELENGTH, BACK FOCAL DISTANCE AND
INPUT BEAM ANGLE ON BLUR CIRCLE

Wavelength	Back Focal Distance	Blur Dia.	Input Beam Angle	Deviation
0.546 μm	7.823	0.5954 m in.	0	0
	7.825	0.4546	0	0
	7.8261	0.3790	0	0
	7.827	0.4106	0	0
	7.827	0.379	0.00958 radian	0.07677 in.
	7.830	0.5156	0	0
	7.833	0.6206	0	0
	7.836	0.7256	0	0
0.852 μm	7.825	0.441	0	0
	7.826	0.3710	0	0
	7.827	0.3398	0	0
	7.828	0.3748	0	0
1.014 μm	7.822	0.7386	0	0
	7.824	0.5988	0	0
	7.827	0.3890	0	0
	7.827	0.359	0.00958	0.07671
	7.828	0.3190	0	0
	7.829	0.3468	0	0
	7.830	0.3818	0	0
	7.833	0.4874	0	0
	7.835	0.5568	0	0

It would be possible to save packing fraction by use of rectangular fibers or single conductor guides. A thorough survey of vendors indicated that only Bendix mosaics had square glass fiber optics. The saving was less than anticipated because epoxy is used to hold the fibers together, and the fibers do not line up perfectly at the end of a row. The effective core area is about 80%. The input-output Fresnel reflection losses, plus transmission through 5 in. of fibers would lose about 20% of the light, leaving a total transmission of about 64%.

The loss between fibers can be eliminated by use of rectangular light guides each the full size of a channel, i.e., 0.013 by 0.023 to 0.050 in. Glass would not be flexible in this size but plastic would, and has the additional advantage of being resistant to radiation. (Polystyrene core fiber optics showed no transmission loss after 10^4 R of gamma radiation, whereas transmission loss had increased by 60 to 70% with radiation glass fibers.) Any radiation induced scintillations in the plastic will be of too short wavelength to affect the detectors. A calculation of the integrated average transmission for each of the four bands was made using the data for a Welch-Allyn fiber optic bundle 12 in. long of acrylic clad polystyrene. Allowance was made for the varying lengths of guide as noted, and it was assumed that total end losses would be only 6% because of very small Fresnel losses at the end coupled to the photomultiplier tube. It is assumed that the input end of the light guides would be properly polished. The calculation is summarized in Table A-5.

TABLE A-5

TRANSFER EFFICIENCY OF LIGHT GUIDES

Band	1	2	3	4
length	3.0 in.	4.0 in.	3.5 in.	1.25 in.
transmission	0.726	0.712	0.673	0.716

Dupont makes a fiber optic material of acrylic clad with a lower index material. This had the advantage of lower Fresnel end losses, but acrylic is much more radiation sensitive than polystyrene, in addition to the bands noted for polystyrene. Dupont is not willing to make it in rectangular cross section.

It will be necessary to have opaque spacers, perhaps 0.001 in. thick between channels to eliminate cross talk in the array. The light guides will be connected to the photomultiplier tubes through prisms that will internally reflect the light so it will enter the glass substrate supporting the photocathode and be trapped within the substrate by total internal reflection, resulting in several passes at the photocathode and increased efficiency. The resulting efficiency enhancement has been calculated to be approximately two at $0.4 \mu\text{m}$ and 5 at $0.7 \mu\text{m}$.

A.6 EVALUATION

A.6.1 Slit Function

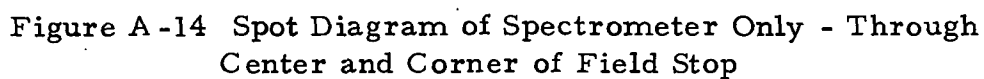
The efficiency and effectiveness of the system depends in a large part on the spectral resolution. The resolution of a spectrometer is likely to vary from band to band, so it is commonly portrayed graphically as a slit function. The slit function is the convolution of the spectrometer slit image with each of the detector elements. The wavelengths at which response in the band begins, and reaches maximum are of interest and marked on the slit function graph. In order to predict the slit function it is necessary to know the slit image size as enlarged by geometric aberrations and diffraction. It is assumed that the effective total of geometric aberrations and diffraction will be the square root of the sum of their individual squares.

In a system of many elements, the total geometric aberrations can only be arrived at by ray tracing continuously from slit to detector. The spot diagrams of two ray traces at $0.852 \mu\text{m}$ are shown in Figure A-14. The first ray trace follows a ray through the center of the slit all the way to the spectrometer image plane. The second ray was started at the corner of the slit (field stop) to represent worst-case conditions. The dimensions shown on the diagram were obtained from actual ray trace coordinates with the same data input on the plot, and represent the 100% blur diameter in the dispersion direction exactly. The dispersion direction diameter did not change as the spot moved along the edge of the slit. Worst-case diameter in the flight direction was 0.00653 in. These blurs are larger than that for the prism and lens alone as previously seen in Figure A-3, because the light is imperfectly collimated. It is believed that the collimator presently represents the best compromise design; however, a more sophisticated design may be possible.

When calculating the slit function, varying amounts were added to the blur diameter determined by ray trace to allow for chromatic aberration as the slit function moved away from $0.852 \mu\text{m}$. The amount added reached a maximum of .0001 in. at $0.50 \mu\text{m}$.

Spot diagrams (Figures A-15 and A-16) were also made of the spectrometer alone at $1.6 \mu\text{m}$ going through the center and a corner of the field stop (spectrometer slit). The slit center was displaced 0.002 and 0.0125 in. from the telescope focal point.

The diffraction limit blur is the largest component of total blur and must be calculated at each boundary wavelength. It is well-known that the diffraction limit in units of wavelength of a lens is:



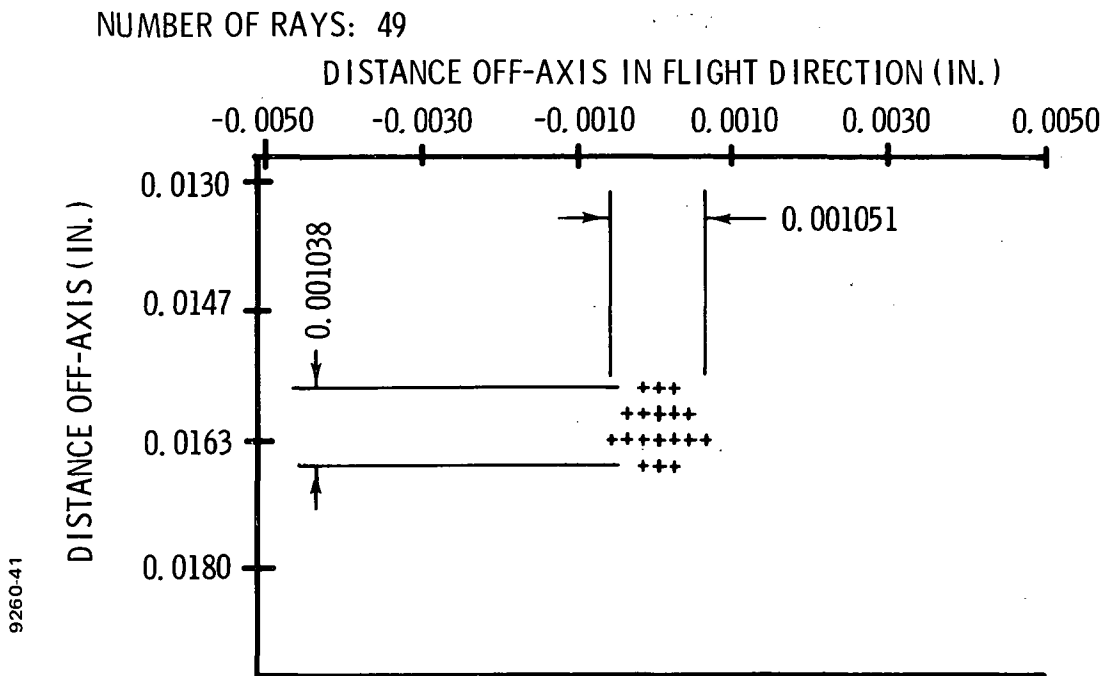
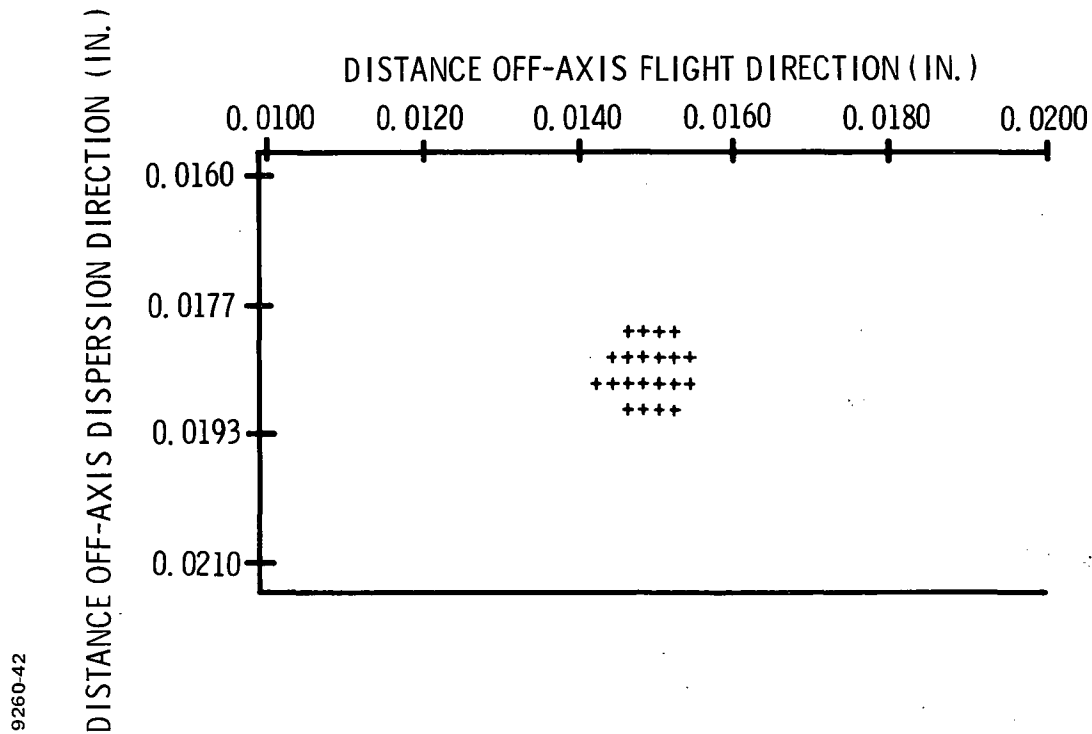


Figure A-15 Spot Diagram of Rays thru Center of Field Stop

Figure A-16 Spot Diagram at Corner of Band 5 Cells from Corner of Field Stop - $1.6 \mu\text{m}$, 24°C

$$B = 2.44 \lambda (f/)_I$$

$$\text{where: } (f/)_I = F_I/D_I$$

F_I = focal length of imager

But D_I is not the clear diameter of the imager, rather it is the diameter of a single collimated beam thru the imager. Therefore, $D_I = D_C$, the diameter of the collimated beam, and:

$$D_C = F_C/(f/)_T$$

where: F_C is focal length of the collimator

$(f/)_T$ is relative aperture of the telescope

substituting in the equation for $(f/)_I$ above

$$(f/)_I = (f/)_T F_I/F_C$$

$$B = 2.44 (f/)_T F_I/F_C$$

It will be noticed that the first three terms alone of this equation give the diffraction limit at the image plane of the telescope, and the last two terms are the magnification within the spectrometer. Thus it can be seen that the diffraction limit is set by the $f/$ of the telescope and only magnified by other elements in the system (so long as they are large enough not to limit the beam).

Once the total blur at a wavelength has been calculated, it is added to the width of a perfect slit image. The slit image plus blur, multiplied by $d\lambda/d\ell$ (wavelength change per unit length along the image plane) gives the total wavelength change from zero to maximum response of the band in question. (This would not be true if a detector were smaller than the image plus blur.) If the detectors were perfectly contiguous, the response of one would begin at the same wavelength its neighbor's response began to drop. Unfortunately, this cannot be achieved in practice, so there will in fact be some separation, probably 0.001 in. at 0.6, 0.7 and 0.8 μm , which results in 0.0025 to 0.00486 μm dead space between bands which will be noted in Figure A-17.

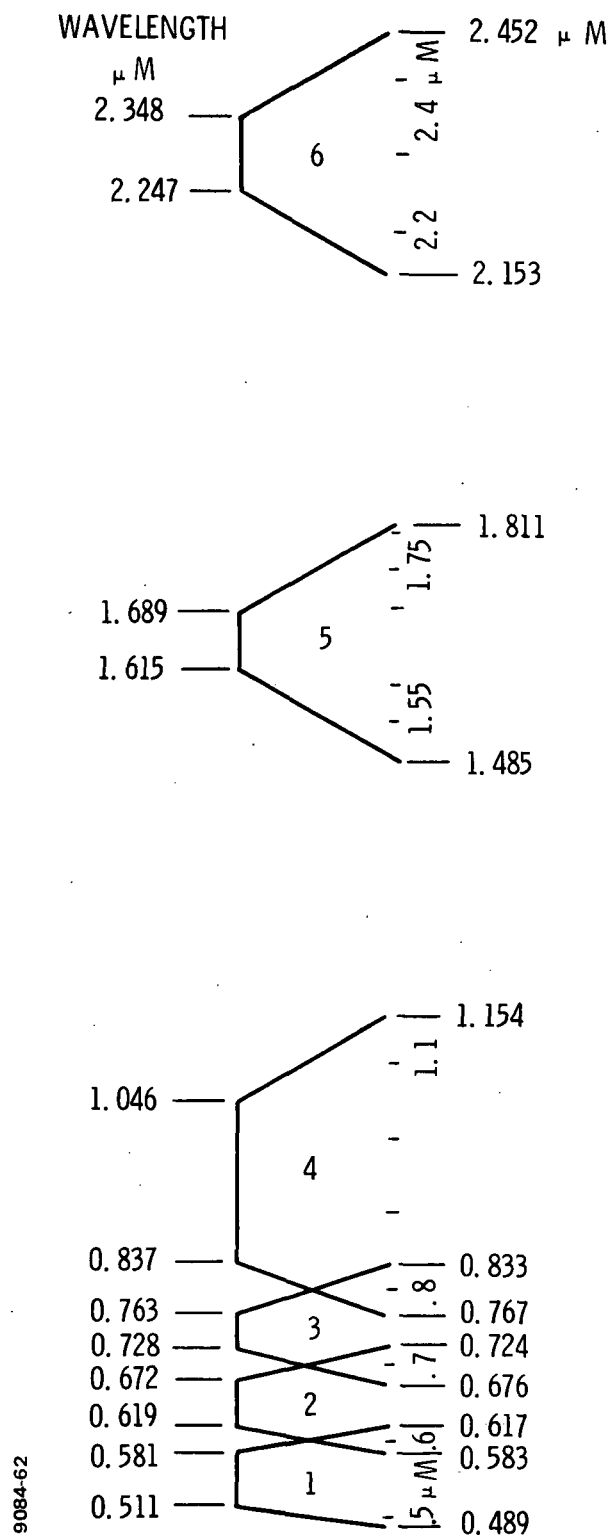


Figure A-17 Overland Spectrometer Slit Functions

The linear dispersion $d\lambda/d\ell$ changes with wavelength because it is a function of $dm/d\lambda$. As noted in the appendix for a 60° prism at maximum deviation

$$\frac{d\lambda}{d\ell} = \frac{d\lambda}{d\theta} \frac{1}{F_1} = \frac{d\lambda}{dn} \frac{dn}{d\theta} = \frac{1}{F_1} \frac{\cos i}{F_1}$$

where F_1 is focal length of the imager

i is the angle of incidence on the prism

In as much as $d\lambda/dn$ is changing with wavelength, $d\lambda/d\ell$ will change and a calculation is required at each boundary wavelength. The values of $d\lambda/dn$ were obtained from n and λ values given in the Willow Run Laboratories Report 2389-11-S.

A.6.2 System Ray Trace

In order to estimate the spatial resolution, a ray trace was made starting with the telescope and ending at the spectrometer image plane. Indices of refraction for $0.825 \mu\text{m}$ were used. The angle between the axis of the 8 in. lens and the outgoing prism surface normal was 47° . The beam was 0.01838 in. off-axis in the lens, and had a dia of 0.4958 in. A total of 197 rays were traced through the system, and 93.9% fell inside a 0.0052 in. dia circle in the image plane. A 0.0050 in. circle contained 83.8% of the rays. This is considered a very satisfactory resolution as may be seen in Figure A-18 showing the spot diagram superimposed on the smallest detector cell.

A similar ray trace was made for the system through the 3.1 in. lens with indices of refraction for $1.6 \mu\text{m}$ at 24°C . The angle between the lens axis and outgoing prism face was 45.6° . The beam had a dia of 0.4952 in. and was 0.0074 in. off-axis in the lens. A total of 197 rays was traced through the system and 98.5% fell inside a 0.0025 in. circle. This is a satisfactory result as may be seen in Figure A-19 showing the spot diagram superimposed on the smaller detector cell.

It seems probable that further improvement in spot diameter could be obtained, either by improving the collimator or optimizing the design of the lenses for the collimation of the actual beam into them. The beam from the collimator is diverging slightly, being 0.4877 in. dia at the collimators, but 0.4957 in. at the 8 in. lens and 0.4952 in. at the 3.1 in. lens. This corresponds to a beam divergence of 0.00039 radian.

Before construction, it would be desirable to make system ray traces at other wavelengths and temperatures. It would also be desirable to investigate the effect on the image of the field stop by varying the input angle to the telescope.

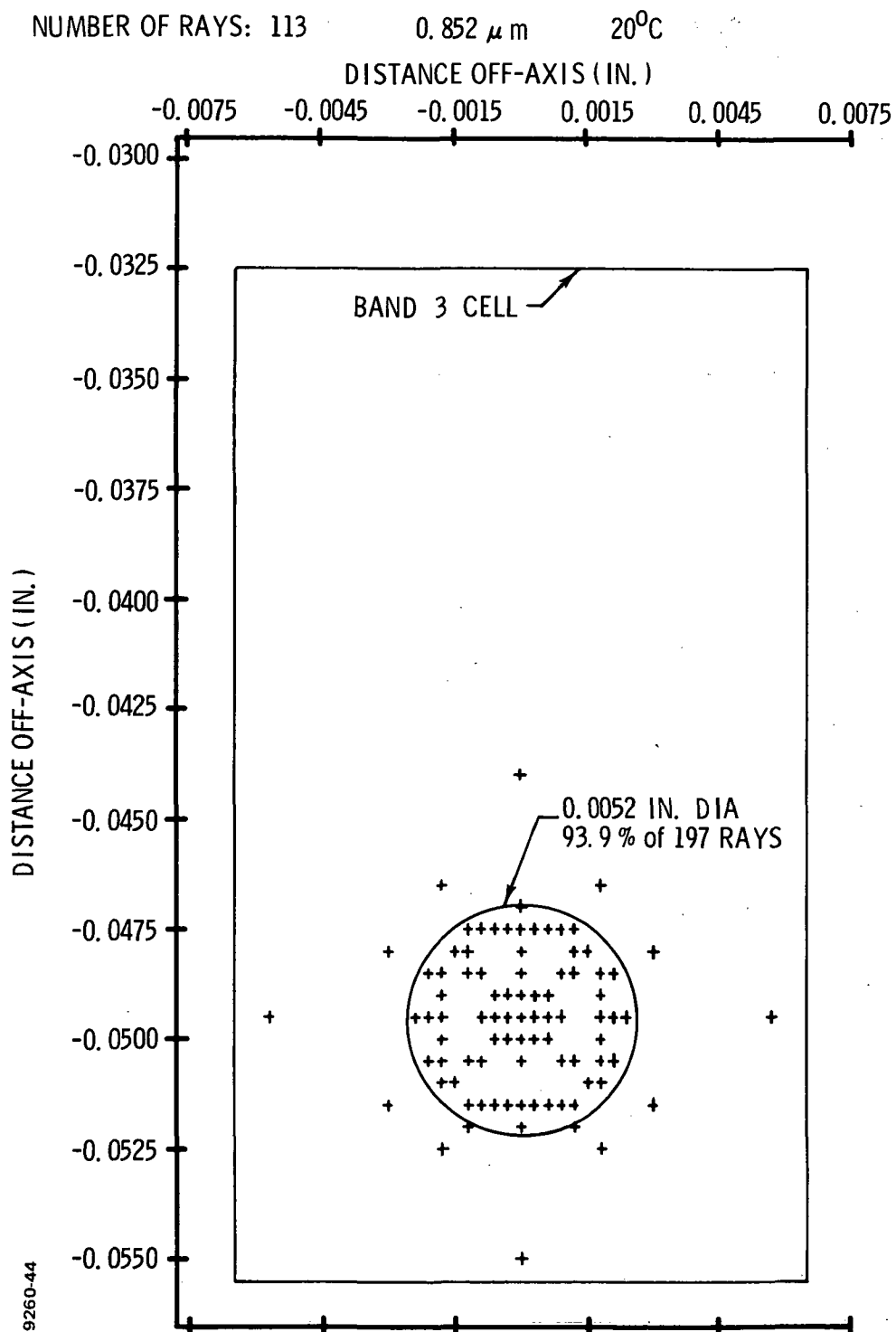


Figure A-18 Telescope and Spectrometer Spot Diagram on Band 3 Cell

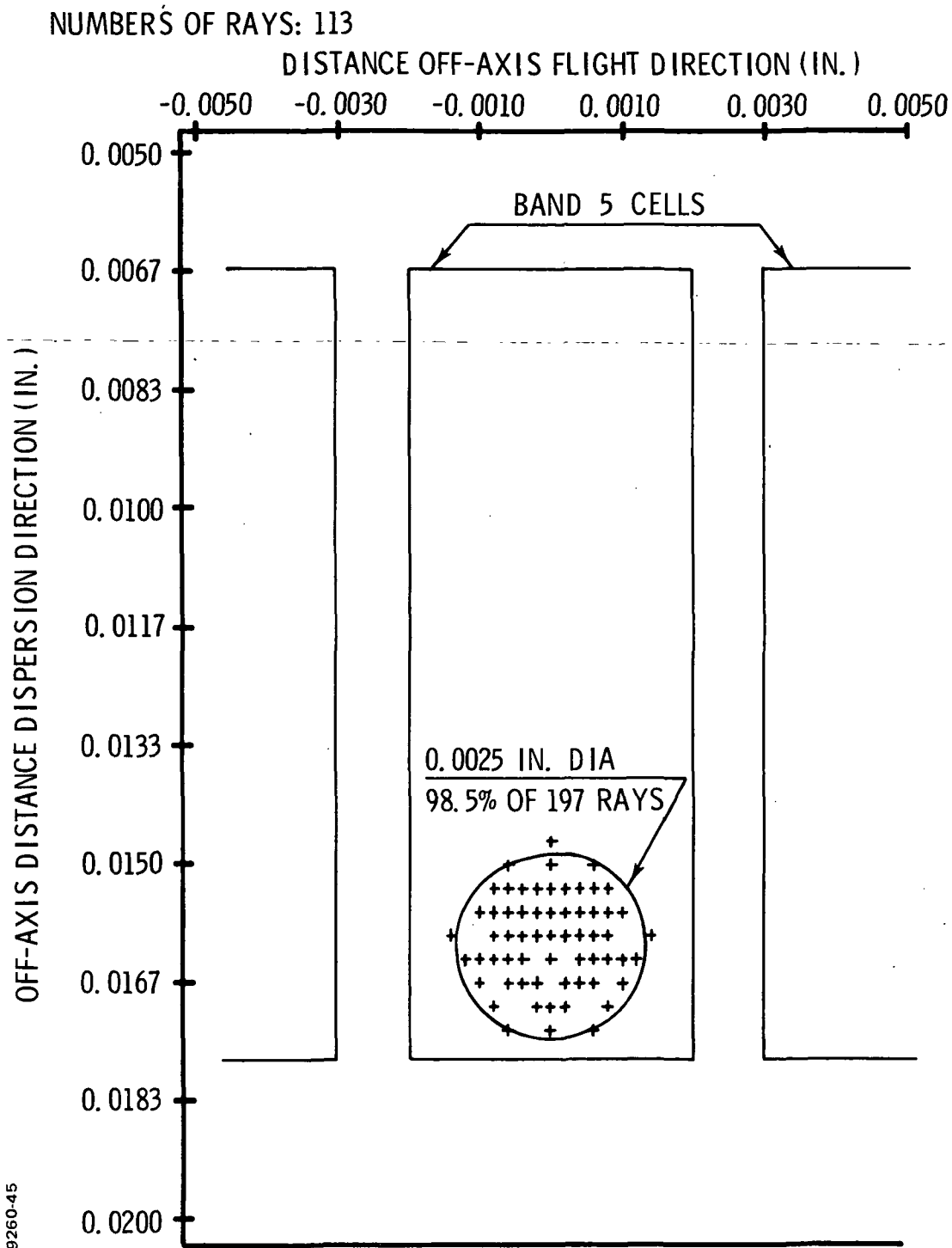


Figure A-19 Telescope and Spectrometer Combined at 1.6 μm
Spot Diagram on Band 5 Cell

APPENDIX B

DATA BUFFERING - UTILIZING MOS SHIFT REGISTERS

B. 1 INTRODUCTION

The Metal Oxide Semiconductor (MOS) shift register is able to transfer large amounts of data while consuming less power and occupying less space than the same circuit made with bipolar transistors. Shift registers can be either static or dynamic. Static registers allow the shifting operation to stop and hold the data indefinitely. Dynamic registers, however, require continuous operation, since the data must be refreshed for long-term storage. Dynamic registers are ideally suited for use as a multispectral scanner data buffer because the data is continually "refreshed" and because of their inherently lower power.

The following is a discussion of both dynamic and static registers as they apply to the OSS Scanner.

B. 2 BASIC MOS STRUCTURE

The four functional parts of an MOS transistor are the source, the drain, the gate, and the substrate. The device is an almost ideal switch since, when the gate and source potential are equal, no current flows between the source and drain; however, when the gate voltage, with respect to the source, is raised to a critical level (threshold voltage), the transistor turns "on" and current can flow from source to drain. The threshold voltage is negative on the gate of the p-type MOS transistor to establish an electrostatic field which inverts the n-material under the gate to a p-channel between the source and drain.

The threshold voltage of an MOS transistor is the most important process-dependent device parameter. In most cases, it is desirable to have a process that produces low threshold voltages. An integrated circuit (IC) with low threshold transistors will operate at lower power supply voltage than a high voltage circuit. Of even greater desirability is the fact that these circuits are directly compatible with bipolar ICs. The following is a list of MOS structures and their corresponding threshold voltage:

<u>Structure</u>	<u>Threshold Voltage</u>
p-MOS	2.0-2.5 V
Silicon gate	1.8-2.2 V

MNOS*

1.5-2.5 V

As the MOS industry matures, the silicon gate technology will be the one most widely used. Three major causes point to this conclusion:

1. Silicon gate technology produces high yield
2. Silicon gate transistors can operate at higher speeds
3. Silicon gate ICs are compatible with other technologies.

B.3 TYPES OF MOS SHIFT REGISTERS

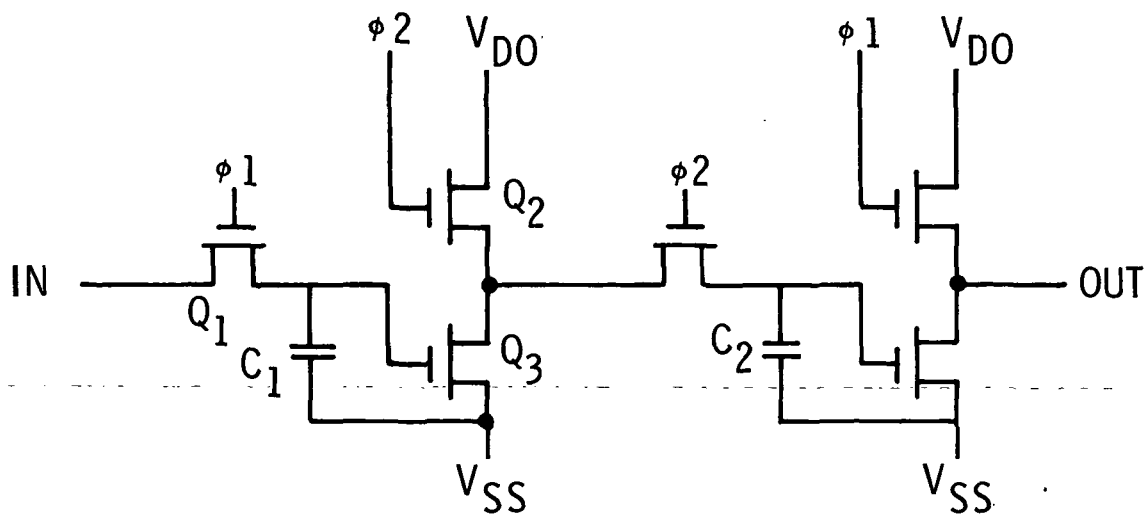
As mentioned, two types of MOS shift registers are available: static and dynamic. Dynamic shift registers are simply inverters connected in series by clocked gates. Because the information is held in the register by the charge on capacitors instead of in latched flip-flops, a minimum operating frequency is required. The minimum operating frequency is dependent on temperature and is approximately 400 Hz at 25°C. The static shift registers do not require a minimum operating frequency, therefore, data can be held in storage indefinitely.

The dynamic shift register can be either ratio or ratioless. The basic dynamic inverters, ratio and ratioless, are shown in Figure B-1. In the ratio type, the output of the inverters is determined by the ratio of the resistance of the pull-down device and the load device. This type utilizes clocked inverters, where dc power is dissipated only during the "1" portion of the clock cycle. On the other hand, the ratioless or powerless type has no dc current path regardless of data stored or the state of the clock. In some high frequency applications, this type can offer a significant savings in power dissipation and reduction in chip area. One drawback in the ratioless shift register is that it requires a 4-phase clock; therefore, four clock drivers are needed. Figure B-2 indicates some of the different dynamic shift registers available.

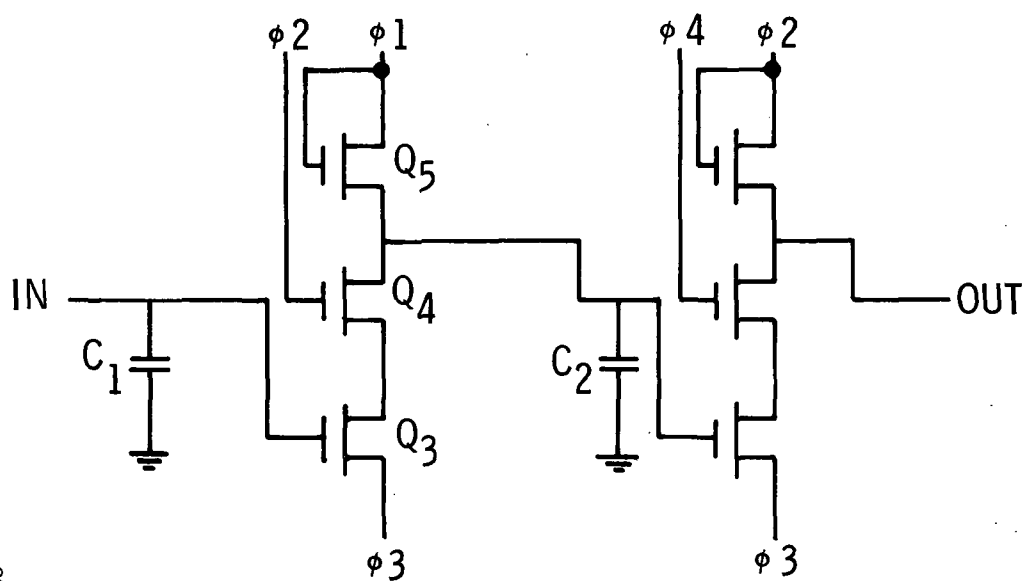
Most of the dynamic shift registers can be interfaced directly with bipolar devices. To accomplish a single MOS to bipolar or bipolar to MOS interface, an external discrete resistor is needed. The size of the resistor is dependent on the output characteristics of the device and the operating frequency.

The basic static shift register is a dynamic shift register with a clocked feedback loop around the inverter. Most static shift registers require a single phase

*Metal - Nitride - Oxide - Silicon



"RATIO" INVERTERS



"RATIO LESS" INVERTERS

Figure B-1 MOS Shift Registers

9260-46

MANU-FACTURER	SIZE BITS/CHIP	PROCESS	NO. OF CLOCKS	POWER DISSIPATION	MAXIMUM DATA RATE
COLLINS	1024	P-MOS	4	200 μ W/BIT @ 1 MHz	1 MHz
ELECTRONIC ARRAY	512	P-MOS	2	120 μ W/BIT @ 2 MHz	5 MHz
FAIRCHILD	512	SILICON GATE	2	500 μ W/BIT @ 2 MHz	2 MHz
INTEL	1024	SILICON GATE	2	100 μ W/BIT @ 1 MHz	5 MHz
NATIONAL	512	P-MOS	2	150 μ W/BIT @ 1 MHz	2 MHz
SIGNETICS	1024	SILICON GATE	2	100 μ W/BIT @ 1 MHz	10 MHz
TEXAS INSTRUMENT	1024	P-MOS	4	90 μ W/BIT @ 1 MHz	5 MHz

9260-47

Figure B-2 MOS Dynamic Shift Registers

clock, thereby, making the register easier to control. The major drawback of the static shift register is that it dissipates more power and requires more chip area than the dynamic type.

B.4 DISCUSSION OF MOS BUFFERING TECHNIQUES

The optimum MOS data buffer configuration depends upon the amount of data collected, the duty cycle, and the data rates. "Read or write, " and "read while write" are two main approaches.

The "read or write" method is used in small duty cycle applications. In this method, the data are written in at a write rate which is equal to $1/\text{cell period}$. At the end of the active scan, the data are read out at a slower rate. The read rate will be some multiple of the transmission rate. Data multiplexing can be implemented in some applications to increase the data rate without proportionally increasing the power dissipation. By operating the shift registers in parallel, the input-output rates can be multiplied by the number of parallel lines. The maximum data rate is limited by the speed with which TTL circuits can detect and reassemble the outputs of the parallel register.

The "read while write" method (Figure B-3) makes it possible to increase the duty cycle without greatly increasing the output transmission rate. This method requires that the data buffer write in new data while it is reading out old data. The data buffer is made up of a discrete number of IC shift registers. During the read-write overlap, the physical registers near the input would be clocked at a faster rate than those near the output. As the new data progresses through the registers, additional registers would have to be clocked at the higher rate, fewer at the lower rate. In other words, the faster clock is sequenced into the series of shift registers, while the slower clock is sequenced out.

B. 5 CLOCK DRIVER TECHNIQUE

Proper design of the MOS clock driver circuits can reduce both power dissipation and component count. Both power and cost can be cut by reducing the operating frequency. The energy needed to charge and discharge load capacitance in any driver is:

$$P_{\text{transient}} = C V^2 f$$

where C is the load, V the voltage change, and f the repetition rate. Total power

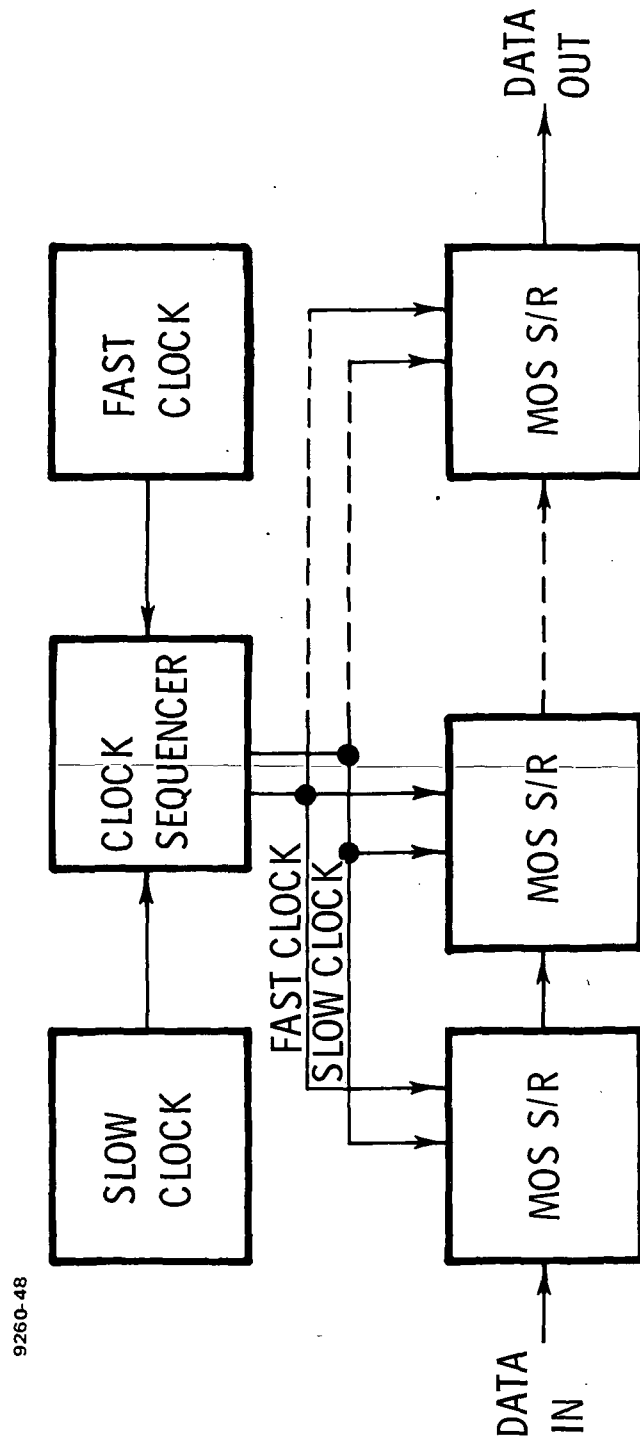


Figure B-3 "Read While Write" Method

dissipation is the sum of load and internal power consumption.

Some precautions must be taken when designing clock drivers. Since the drivers sink and source large currents, they require adequate power supply decoupling. In large systems, clock-line layouts should be adjusted to avoid excessive clock ringing. To avoid malfunction caused by excessive overshoot, the transitions may have to be clamped with a germanium diode or other low impedance termination.

The drive requirements of any clock driver are a function of the system's characteristics: speed, ambient temperature, voltage swing, drive circuitry, and stray wiring capacity. By knowing the maximum peak output current of the clock driver the maximum load driving capability can be calculated from:

$$C_L \text{ max} = \frac{(I \text{ max}) t_r}{V \text{ max}}$$

where $I \text{ max}$ is the maximum load current rating of the device, t_r is the pulse rise time, and $V \text{ max}$ is the maximum clock voltage swing. For example, a clock driver with a driving capability of 1.5 amp and a clock voltage swing of 16 V can drive approx 3000 pF of capacitance.

The clocking circuitry can generally be assembled from off-the-shelf logic and clock driver circuits. The clock-driver can be implemented by using either integrated circuits or discrete components. A hybrid circuit using both IC and discrete components can be used.

B. 6 POWER SAVING CONSIDERATIONS

The following is a discussion of techniques used to reduce power consumption in MOS shift registers. The amount of power dissipated in the shift registers is proportional to the frequency of operation, interface circuitry, clock amplitude and pulse width.

The power dissipation of an MOS shift register is proportional to its shifting rate. By reducing the data rate through a shift register the total power dissipation can be reduced. One method of reducing the MOS data rate without reducing the output transmission data rate is by data multiplexing, i. e., routing data through parallel shift registers.

Furthermore, by reducing the data rate, the transient power dissipation of the clock driver is reduced. The average transient power drawn from the supply is independent of the rise time of the clock drive signal but is proportional

to the clocking rate. This is shown as a linear relationship in the formula, $P_D = f C_L V^2$, where f is the frequency of the clock, C_L is the load capacitance, and V is the amplitude of the clock.

The clock duty cycle and amplitude also have a direct relationship to power dissipation. Power dissipation can be reduced by reducing either the duty cycle or the clock amplitude. Most MOS devices have a minimum pulse width requirement of approx 150 nsec and a minimum peak-to-peak clock amplitude of 15 V.

Another method of reducing power dissipation when using MOS shift registers which require interface resistors, is to increase the size of these resistors. At the maximum data rate, 5 MHz, the MOS shift registers require a 4.7 k Ω resistor for MOS interfacing. At lower frequencies, the resistor value can be increased as long as the $R_L C_L$ time constant is not greater than $0.16 \left(\frac{1}{\text{data rate}} \right)$.

When the MOS shift register is interfaced with transistor-transistor logic (TTL) and is operating at data rates below 2 MHz, the power dissipation can also be reduced by using low power TTL. The interface resistor value can be increased from 3 k Ω when using standard TTL to 24 k Ω when using low power TTL.

B. 7 RECOMMENDED DESIGN

Figure B-4 is a block diagram of the three types of configurations used in the MOS data buffer. Data from Bands 2, 3, 5 and 6 are stored in MOS dynamic shift registers while data from Band 7 is stored in D-type flip flops. Data from Bands 1 and 4 are transmitted directly. Calibration data from all Bands are stored in MOS static registers. Figure B-5 is a detailed drawing of the complete MOS data buffer.

Figure B-6 is a schematic of the data buffer used in Bands 2, 3, 5 and 6. The design uses Intel 1024 and 512 Bit/Chip MOS shift registers. These shift registers consist of normally off P-channel MOS devices integrated on a monolithic chip. The use of low voltage circuitry minimizes power dissipation and facilitates interfacing with bipolar integrated circuits. These registers can be driven directly by standard bipolar integrated circuits or by MOS circuits. The design of the output stage provides driving capability for both MOS and bipolar ICs. The hybrid clock driver, National Semiconductor's NH0025, is designed to be driven by either TTL line driver or buffer and has the capability of driving approximately 15 Intel devices.

Calibration data from all bands are stored in static shift registers such as the RCA CD4006 COS/MOS shift register or equivalent. This type of device is recommended for the calibration data buffer because of power considerations

Figure B-4 MOS Data Buffer

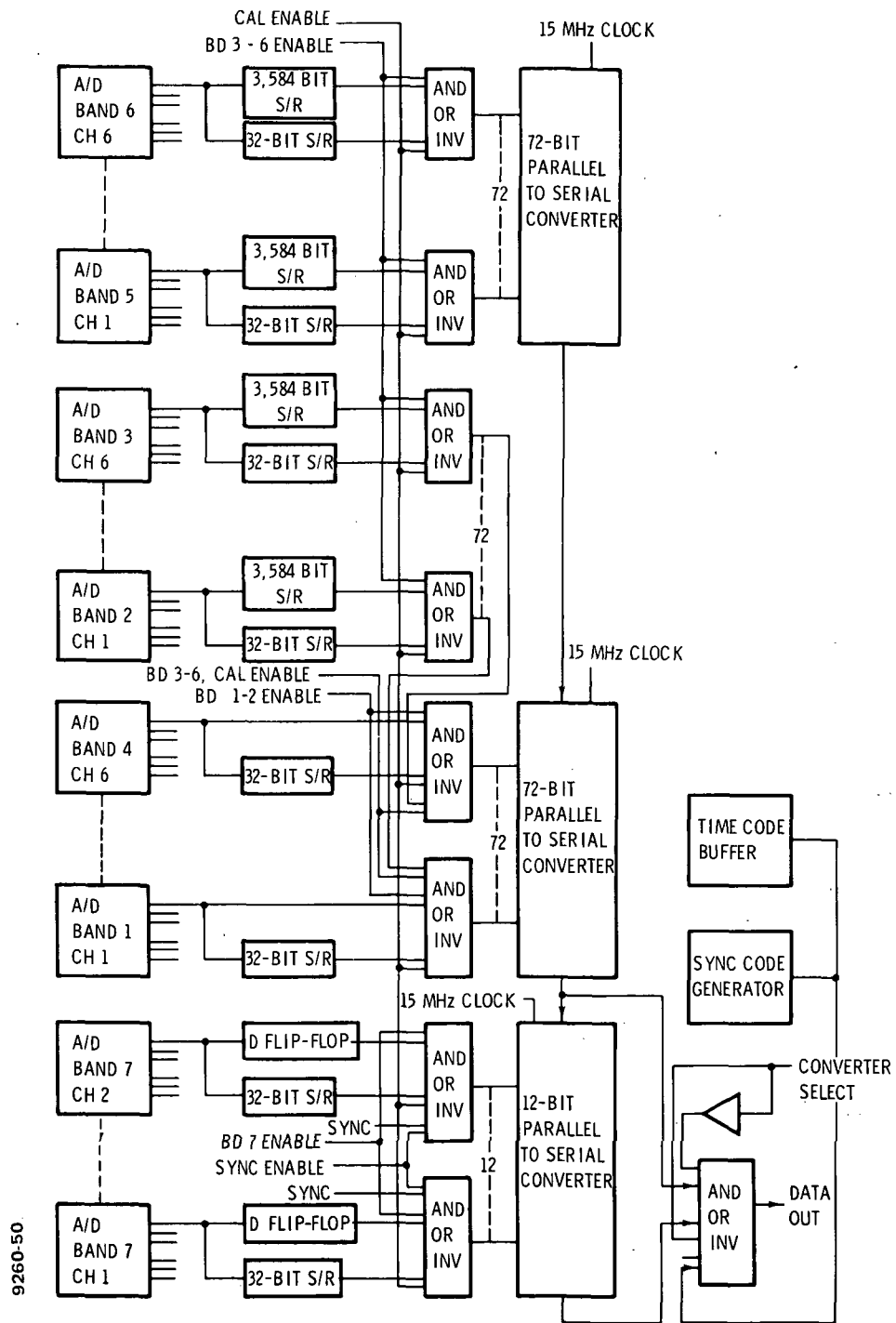
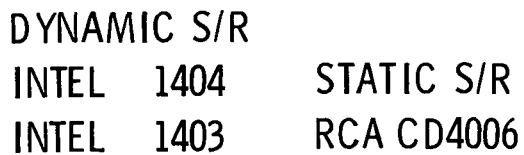


Figure B-5 Data Buffer and Formatter



B-11 (I)

(discussed in the next section). If dynamic shift registers are utilized additional timing and control circuits are required so that the shift registers can be continually recycled.

Each of the three types of configurations are packaged in special thick film hybrid packages. The area that is sectioned in Figure B-7 indicates the electronics that are contained in the hybrid cans for Bands 2, 3, 5 and 7. Figures B-8 and B-9 show how the electronics for Bands 1, 4 and 7 are packaged. The following table indicates the type, size and quantity of all hybrid cans:

<u>Circuit</u>	<u>Can Size</u>	<u>Quantity Channel</u>	<u>Required System</u>
Band 2, 3, 5 and 7	1 1/4 x 1 1/4	3	72
Band 1 and 4	1 1/4 x 1 1/4	1	12
Band 7	1 x 1	1	2

B. 8 POWER DISSIPATION CALCULATIONS

This section contains the calculations that were used to determine the total power dissipation in the MOS data buffer. The following parameters were used in these calculations:

Scan duty cycle = 31.5%
 Clock duty cycle = 10%
 Write data rate = 194 kHz
 Read data rate = 97 kHz

The quantity of each device type is shown below:

<u>Device</u>	<u>Quantity</u>
1404	432
1403	72
NH0025	35
54L74	6
CD4006	456

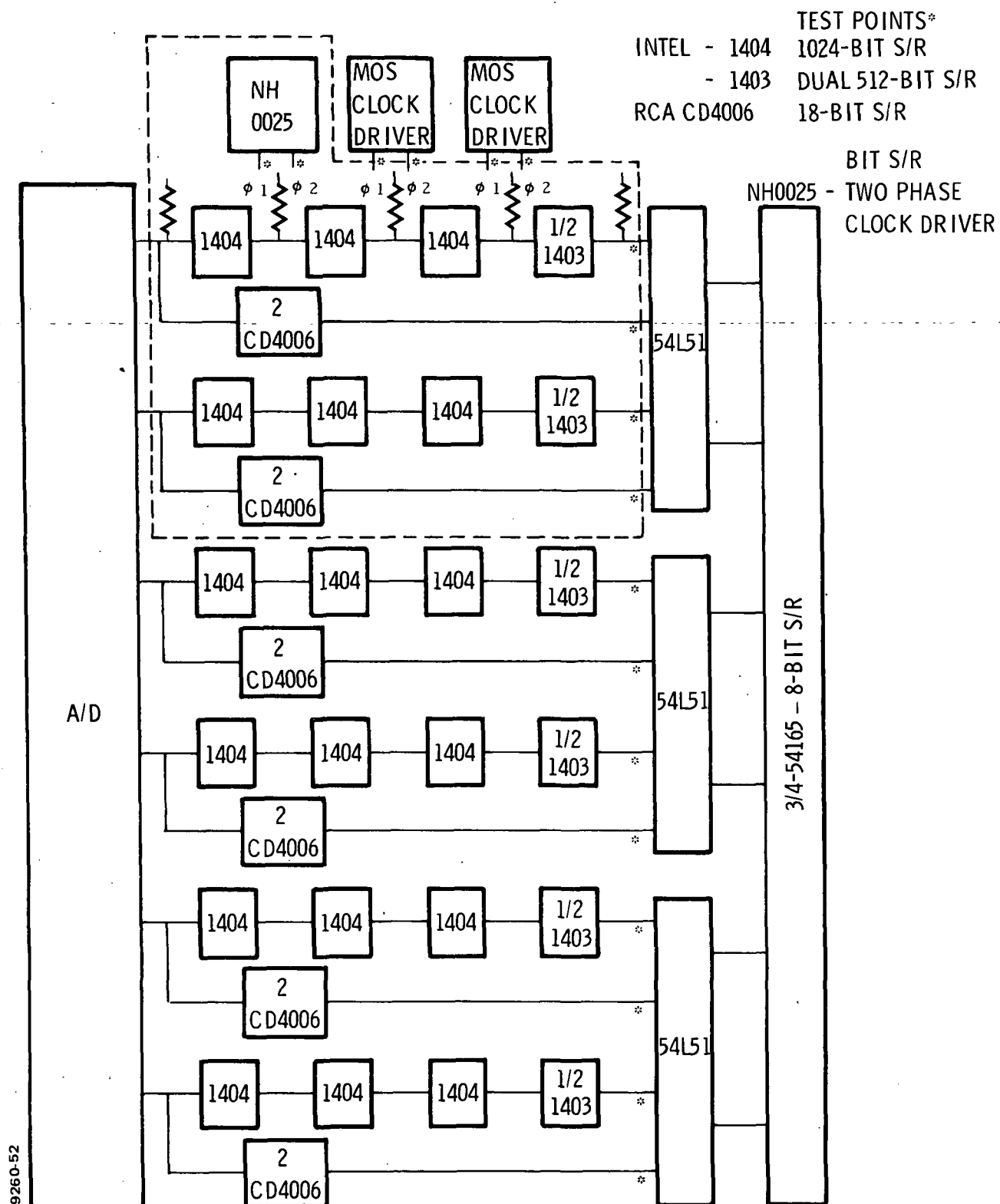
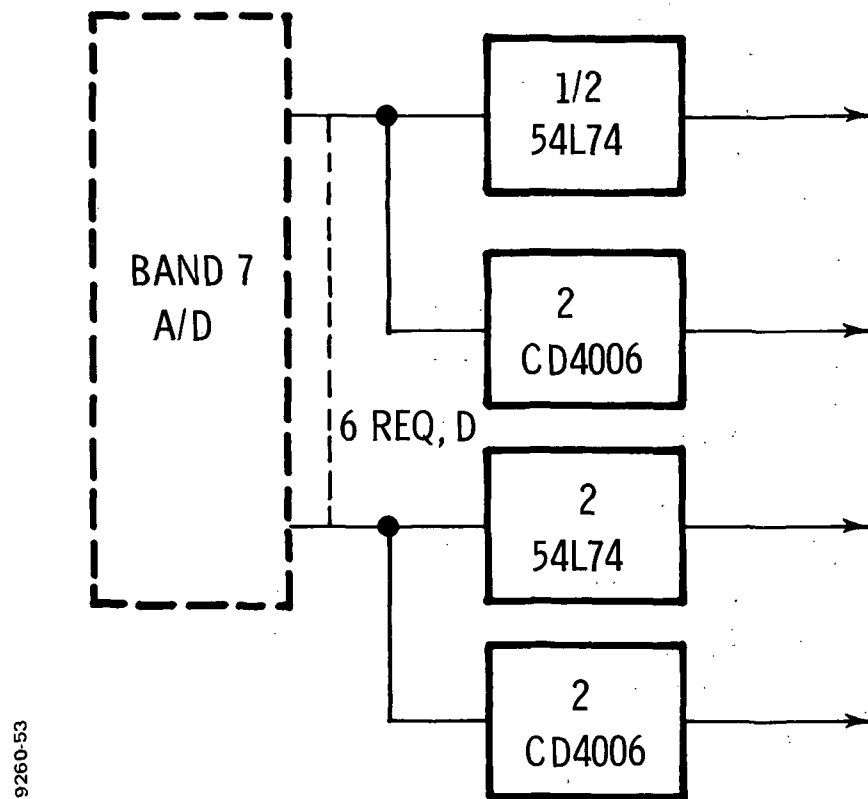
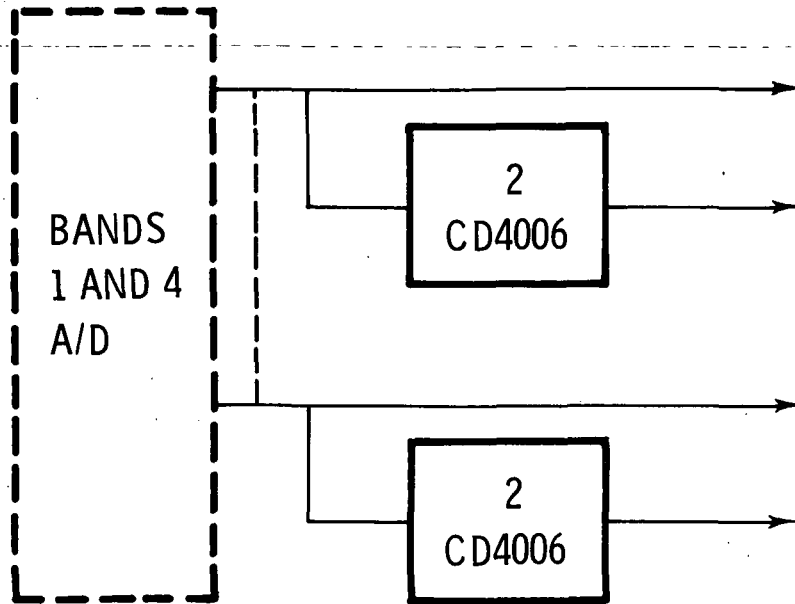


Figure B-7 Bands 2, 3, 5 and 7 - Hybrid Package Electronics



T 1 - 54L74 DUAL D-TYPE FLIP-FLOP

Figure B-8 Band 7 - Hybrid Package Electronics



9260-54

RCA - CD4006

18-BIT COS/MOS SHIFT REGISTER

Figure B-9 Bands 1 and 4 - Hybrid

The calculations are divided into five areas. Each area represents the power dissipation of each type of component in the MOS data buffer.

A. Dynamic Shift Registers (Intel 1404 and 1403)

From Figure B-8 it can be seen that the power dissipation per Intel device is 22 mW at 194 kHz and 10 mW at 96 kHz. Total number of devices is 504.

194 kHz and 31.5% duty cycle

$$P = (22 \text{ mW}) (504) (0.315) = 3.5 \text{ W}$$

96 kHz and 63.0% duty cycle

$$P = (10 \text{ mW}) (504) (0.63) = 3.2 \text{ W}$$

Total power dissipation for the devices is 6.7 W.

B. Interface Resistors

<u>Size</u>	<u>Quantity</u>	<u>Total Power</u>
30 k Ω	432	1.4W
20 k Ω	144	0.8W

C. Clock Drivers (National Semiconductor NH0025)

Total power dissipation of a MOS clock driver is the sum of the transient and internal power dissipations.

1. Transient power dissipation

$$a) P_{TR} = V^2 f C_L \text{ where } V = 15, f = 194 \text{ kHz and } C_L = 2000 \text{ pF}$$

$$P_{TR} = (15)^2 (194 \times 10^3) (2000 \times 10^{-12}) = 87.5 \text{ mW}$$

With a 31.5% duty cycle and a total of 35 devices, the power dissipation during the write period is:

$$P = (87.5 \text{ mW}) (35) (0.315) = 1.07 \text{ W}$$

$$b) P_{TR} = V^2 f C_L \text{ where } V = 15 f = 97 \text{ kHz and } C_L = 2000 \text{ pF}$$

$$P_{TR} = (15)^2 (97 \times 10^3) (2000 \times 10^{-12}) = 43.3 \text{ mW}$$

With a 63% duty cycle and a total of 35 devices, the power dissipation during the period is:

$$P_{TR} = (43.7 \text{ mW}) (35) (0.63) = 1.07 \text{ W}$$

c) Total transient power dissipation in the clock drivers is 2.14 W

2. Internal Power dissipation

dc power dissipation per device

$$P_{dc} = \frac{V^2 (\text{Duty Cycle})}{10^3}$$

V = 15 V, clock's duty cycle = 10%

$$P_{dc} = \frac{(15)^2 (0.1)}{10^3} = 22.5 \text{ mW}$$

Total dc power dissipation in the clock drivers is

$$P_{dc} = (22.5 \text{ mW}) (35) = 790 \text{ mW}$$

The total clock power dissipation is:

$$\begin{aligned} P_{\text{total}} &= P_{TR} + P_{dc} \\ &= 2.14 \text{ W} + 0.79 \text{ W} \\ &= 2.93 \text{ W} \end{aligned}$$

D. Calibration Data Buffers

1. Static Shift Registers (National Semiconductors MM4051) Power dissipation per device is 170 mW.

The system requires 114 devices; therefore, the total power dissipation is:

$$\begin{aligned} P &= (170 \text{ mW}) (114) \\ &= 19.4 \text{ W} \end{aligned}$$

2. Dynamic Shift Registers (National Semiconductor MM410)

At 100 kHz, the power dissipation per device is 10 mW. The system requires 114 devices, therefore, the total power dissipation is:

$$\begin{aligned} P &= (10 \text{ mW}) (114) \\ &= 1.14 \text{ W} \end{aligned}$$

3. COS/MOS Static Shift Registers (RCA CO 4006)

At 100 kHz, the power dissipation per device is 4 mW. Quiescent power dissipation is 0.1 mW. The system requires 456 devices. Assuming a

10% duty cycle, the total COS/MOS power dissipation is:

$$\begin{aligned}
 P &= (4 \text{ mW}) (456) (0.10) \\
 &= 182.4 \text{ mW} \\
 P &= (0.1 \text{ mW}) (456) (0.90) \\
 &= 41.0 \text{ mW} \\
 P_{\text{total}} &= 182.4 \text{ mW} + 41.0 \text{ mW} \\
 &= 223.4 \text{ mW}
 \end{aligned}$$

When using COS/MOS circuits, the system requires additional interface elements. Fairchild 9624 interface gate has a "gate on" power dissipation of 30 mW and a "gate off" power dissipation of 5 mW. The system will require 456 gates, therefore, the total gate power dissipation is:

$$\begin{aligned}
 P_{\text{On}} &= (30 \text{ mW}) (456) (0.10) \\
 &= 1.368 \text{ W} \\
 P_{\text{Off}} &= (5 \text{ mW}) (456) (0.90) \\
 &= 2.052 \text{ W} \\
 P_{\text{Total}} &= 3.42 \text{ W}
 \end{aligned}$$

The total power dissipation for the calibration buffer using COS/MOS circuits is:

$$\begin{aligned}
 P_{\text{Total}} &= 1.7 \text{ W} + 0.13 \text{ W} \\
 &= 1.83 \text{ W}
 \end{aligned}$$

E. Low power D-type flip-flop 54L74

Power dissipation per device 15 30 mW while the total dissipation is:

$$\begin{aligned}
 P &= (30 \text{ mW}) (6) \\
 &= 180 \text{ mW}
 \end{aligned}$$

Total power dissipation of the MOS data buffer is the sum of individual amounts in parts A through E.

Total power dissipation is 17 W.

APPENDIX C

DATA BUFFERING UTILIZING A PLATED-WIRE MEMORY

Since the Bit collection rate is about three times the data transmission rate (a 31.57% duty cycle), approximately two-thirds of the data collected during the active-scan interval must be stored. Several storage media are suitable candidates for this function; the two prime contenders are plated wire and MOS shift registers. This appendix describes plated-wire random-access memories along with their use in a data buffer; MOS implementations are covered in Appendix B. These implementations were considered since they require relatively modest power, have useful speed specifications, and can operate reliably over the required temperature range.

A plated-wire memory can be visualized as a functional block with a set of data input, a set of control input, and a set of data output terminals. The control inputs include a set of address lines which select a location into or out of which data is to be transferred, a read-write control which conditions the memory to retrieve or store data, and a cycle initiate which initiates a memory sequence cycle. A write (store) memory sequence (write cycle) consists of: (1) applying new data and the required address to their respective inputs, (2) allowing sufficient time for these inputs to stabilize, (3) enabling the write operational mode, and (4) issuing a cycle initiate pulse. After a period equal to the cycle time, the store operation will have been completed and another memory cycle may be initiated. Similarly, data previously stored in a specified memory location may be retrieved by addressing that location, enabling a read operational mode, and issuing a cycle initiate pulse. Data from the addressed location will be available in a time interval equal to the memory access time. Again, memory cycle time determines the interval which must be allowed before the next operation is initiated.

Several parameters are useful when evaluating random-access memories for possible use in a given application: the number of memory locations required, the number of bits that can be stored in a given location (memory word length), and the memory cycle time. During the study, several manufacturers were contacted relative to the availability of plated-wire random-access memories which would be applicable to OSS. The results indicate that memories having cycle times of 800 nsec, word lengths of a hundred bits, and storage capacities of 7200 locations are practical. Estimated power requirements for such memories are in the range of 200 W or less.

A possible buffer implementation employing a plated-wire memory is illustrated in Figure C-1. Data from Bands 1, 4 and 7 which are acquired during an active scan

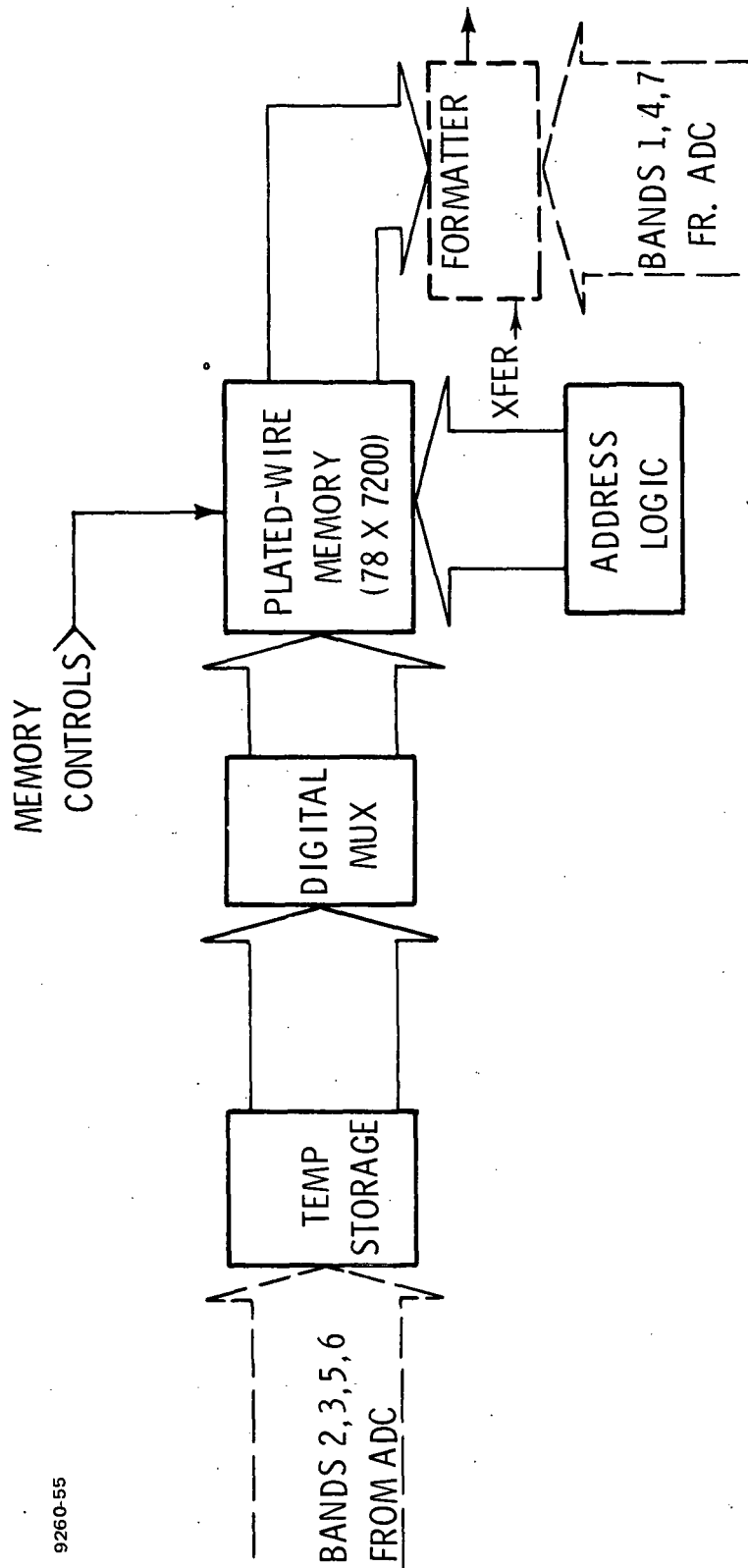


Figure C-1 Plated Wire Data Buffer

interval (Figure 9.4-3) is dumped directly into the formatter while data from Bands 2, 3, 5 and 6 are stored in a plated-wire memory. Two 72-bit memory words are stored each dwell time. Since only 800 nsec is required to store each memory word, data from temporary storage can be time multiplexed into memory in two 72-bit word groups. In the overland mode, each band produces six 6-bit data words per dwell time so that two bands produce the data contained in every other memory word; therefore, two sequential memory locations are addressed each dwell time. Since dwell time corresponds to 78 output-data bit-intervals, 78 bits of data may be transmitted during this interval. Memory read-out is timed to transfer one memory word to the formatter each dwell time. Thus, space is made available for the minor frame sync codes and for Band 7 data. A time-staggered memory-to-formatter transfer pulse train may be used if sync is to be introduced in accordance with Figure 9.4-3.

Since an analog-to-digital conversion time of 3.5 to 4 msec is anticipated, temporary storage for at least 72 if not 144 bits may be required at the memory input. Ultimately, the requirement for temporary storage will depend on the worst-case analog-to-digital conversion time which can be realized. Should such storage elements be required, they should be incorporated in the analog-to-digital converter package.

APPENDIX D

DATA DEMULTIPLEXER

D.1 INTRODUCTION

The prime function of the Data Demultiplexer is to demultiplex the Multispectral Scanner (MSS) data which are received from the Stadan receiver into twenty-five data channels and record the data from each channel on unique previously-assigned tape tracks. The signal received from the ERTS spacecraft transmitter is demodulated in the Stadan receiver and used to : (1) recover the MSS data in non-return-to-zero level (NRZ-L) form and (2) generate a 14.976 MHz data clock. These two Stadan output signals become inputs to the Demultiplexer. In addition, monitor functions permit determination of the Demultiplexer operational status, a capability provided by combining an A-scope presentation of the output video data with a status display which indicates the current operational mode.

Applicable input and output data formats are discussed in Sections 9.4 and 13.3 and diagrammed in Figures 9.4-1 through 9.4-4. System constraints which determine the details of these formats are covered in Sections 4.1 and 13.3.

D.2 FUNCTIONAL DESCRIPTION

A functional block diagram of the Demultiplexer is given in Figure D-1 where it is displayed in terms of eight well defined functions. These functions include a: (1) control code detector, (2) major frame synchronizer, (3) minor frame synchronizer, (4) master timing and control unit, (5) data formatter, (6) output code generator, (7) monitoring unit, and (8) tape recorder. The input data stream is continuously examined in the control code detector.

When a code sequence consisting of a preamble followed by a scan start code is found, the major frame synchronizer generates a master reset which sets the multiplexer to its control state if it is not already there. At the same time, a major frame lock signal is generated. The initialized master timing and control unit generates, in proper time sequence, the necessary timing and control signals which are required to demultiplex the incoming data onto 25 properly formatted tape tracks via the data formatter.

Comparison between the state of the master timing unit and the time of arrival of the minor frame sync code is made by the minor frame synchronizer. Should

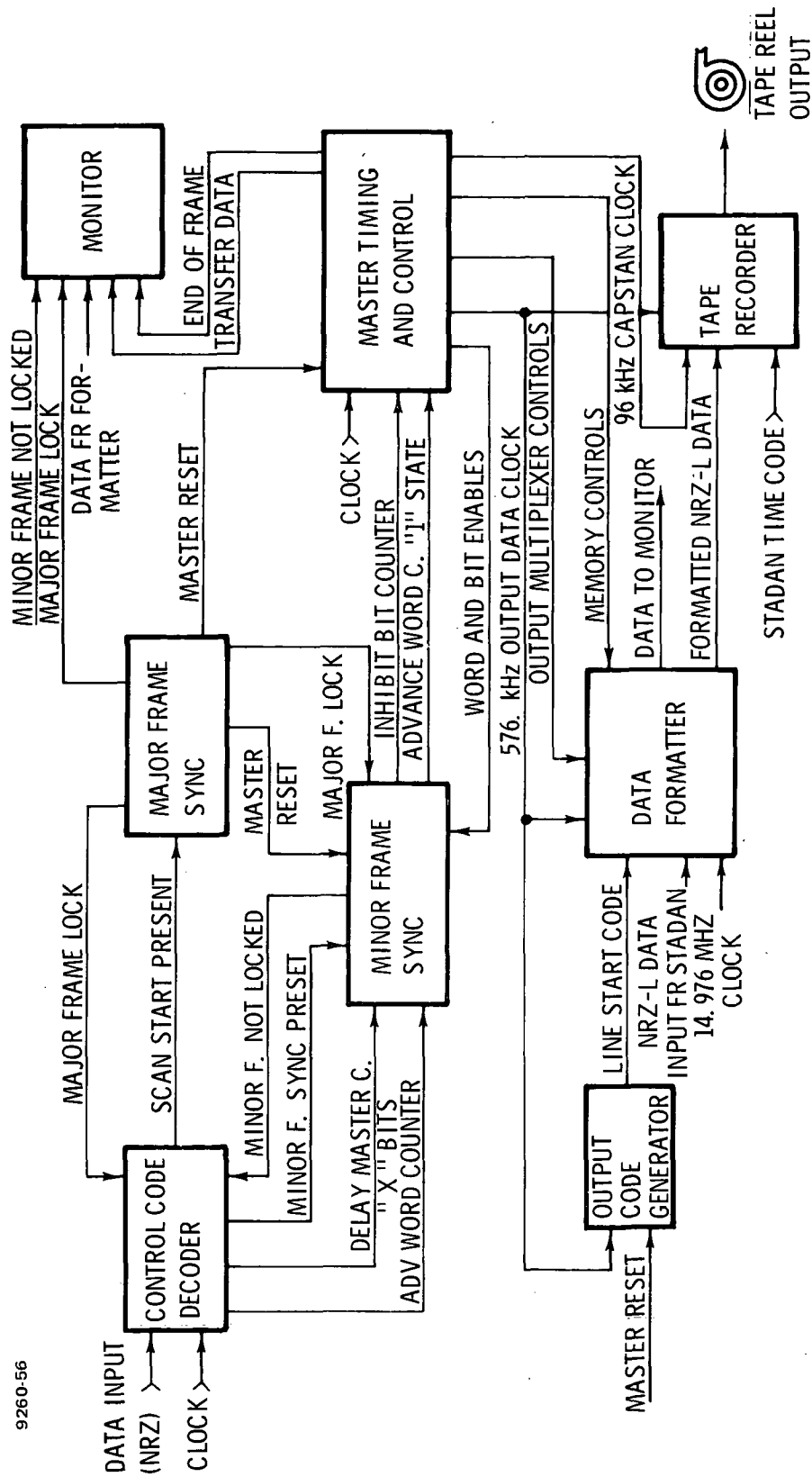


Figure D-1 Demultiplexer Functional Block Diagram

discrepancies be detected, controls to the master timing and control unit will advance and/or retard the timing to compensate for this discrepancy.

D. 2. 1 Master Timing and Control

The master timing and control unit which provides complete control of the demultiplexer is designed around a cascade of three counters: a bit counter, a word counter, and a minor frame counter. Bit and word time intervals are formed by decoding the proper states of these counters to obtain the appropriately labeled enable signals. Certain data routing controls (E1, E2, and E3 of Figure D-2, for example) are developed in binary storage elements, control flip-flops, which are in turn set or reset by decoded counter states. In addition, dividers are used to develop both the output-data and recorder-capstan clocks from the high-frequency input clock. Provisions are incorporated which assure that all circuitry including these dividers are in a prescribed initial state at the beginning of each major frame. Performance of this initializing function requires a master reset, a signal developed in the major frame synchronizer. Provisions are made to inhibit the bit counter and to advance the word counter; these operations require inputs from the minor frame synchronizer.

D. 2. 2 Synchronization

Synchronization of the Data Demultiplexer to the data stream arriving from the Stadan receiver (bit synchronizer) is accomplished in two steps: (1) secure major frame synchronization and (2) maintain minor frame sync. Minor frame sync automatically occurs at the start of each major frame (scan-interval). However, it could be lost at any time during the following 1875 minor frames: a major frame consists of 1875 468-bit minor frames. Should some condition in the downlink delay or advance the data x-bit intervals with respect to that anticipated by the Data Demultiplexer, minor synchronization will be lost, the data delay or advance determined, and the Demultiplexer state adjusted accordingly.

Synchronization involves three functions: the control code decoder, the major frame synchronizer, and minor frame synchronizer. Functional operation proceeds as follows: the control code detector senses the major frame sync (scan start) code which enables the major frame synchronizer. A major frame lock signal is developed along with a master reset, the former enables the minor frame synchronizer while the latter initializes the complete Demultiplexer. Initialization of the Demultiplexer should simultaneously establish minor frame sync, a condition indicated by a low minor-frame-not-locked signal. The minor frame synchronizer immediately starts and continues to examine the input data stream during those demultiplex states when the minor frame sync code should be present. If four consecutive non-occurrences of the minor frame code are detected, the minor-frame-not-locked signal goes high and the minor frame search mode is entered. In this

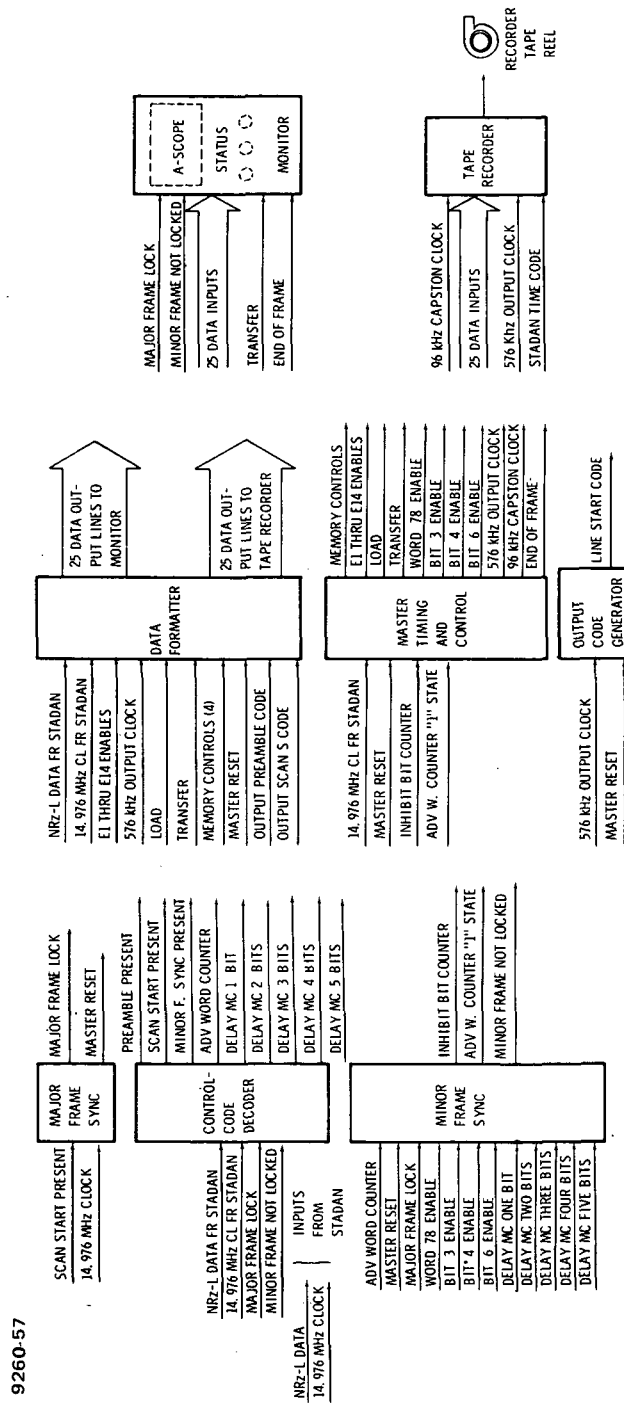


Figure D-2 Demultiplexer Preliminary Signal Callout

operational mode, the control code decoder examines the incoming data through an 18-bit window which is centered about the anticipated data arrival time. Data lead or lag (in bit-intervals) with respect to the multiplexer state is determined and used to generate two commands: inhibit bit converter for X-bits and advance word counter. Should the demultiplexer state lag the minor sync code by y-bits, the word counter is advanced one count while the bit counter is inhibited for 6-y counts. Conversely, should the frame sync code lag the multiplexer state by a x bits, the bit counter (master counter) is inhibited for x counts. Minor frame sync is reestablished and the system returns to the minor-frame-locked mode.

D. 2. 3 Data Formatter

The data formatter demultiplexes the input data to form 25 data streams which are, in turn, multiplexed with the line start and mid scan codes. Each data stream is recorded on a unique tape track and is made available for display on the monitor. Functionally, the formatter consists of a 156-bit serial-in parallel-out register, 25 6-bit parallel-in serial-out registers, a 36 x 1200 random access memory and a digital multiplexer. The random access memory along with additional temporary storage is required so that the data from band 7 can be reformatted and placed on a single track. (See the format in Figure 9.4-2).

A six-bit line start code is recorded simultaneously on each tape track immediately following reception of the scan start code while the first 156 data bits are being shifted into the input register. Just after the 6th line-start bit has been recorded, this data is transferred in parallel into the output registers (each 6-bit data word is routed to the appropriate register). As the first 156 data bits go onto tape, the second group of 156 bits is shifted into the input register, etc.

D. 2. 4 Monitor

The monitor consists of an A-scope presentation of a selected tape recorder input along with a display of the Demultiplexer status. One anticipates digital control of the x-axis.

APPENDIX E

PRELIMINARY STRUCTURAL ANALYSIS

This appendix contains a summary of the structural analysis performed on the OSS image space scanner. The analysis is preliminary in nature and concerns itself primarily with the following four major areas: - - - - -

1. Maximum stress levels under 20 G ultimate loads.
2. Deflections and rotations of critical mirror elements due to 10°C temperature differential over entire structures.
3. Recommendations with regard to selection of materials.

The basic support pallet, mirror assembly, and radiation cooler were investigated with regards to stresses, deflections, materials, and weights. The detailed assumptions for structural modeling are contained in the basic analysis. For cases where the analysis showed the need for structural design modification, these modifications were made and incorporated in the over-all design.

PREPARED BY RJ THOMAS
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 REVISED BY _____

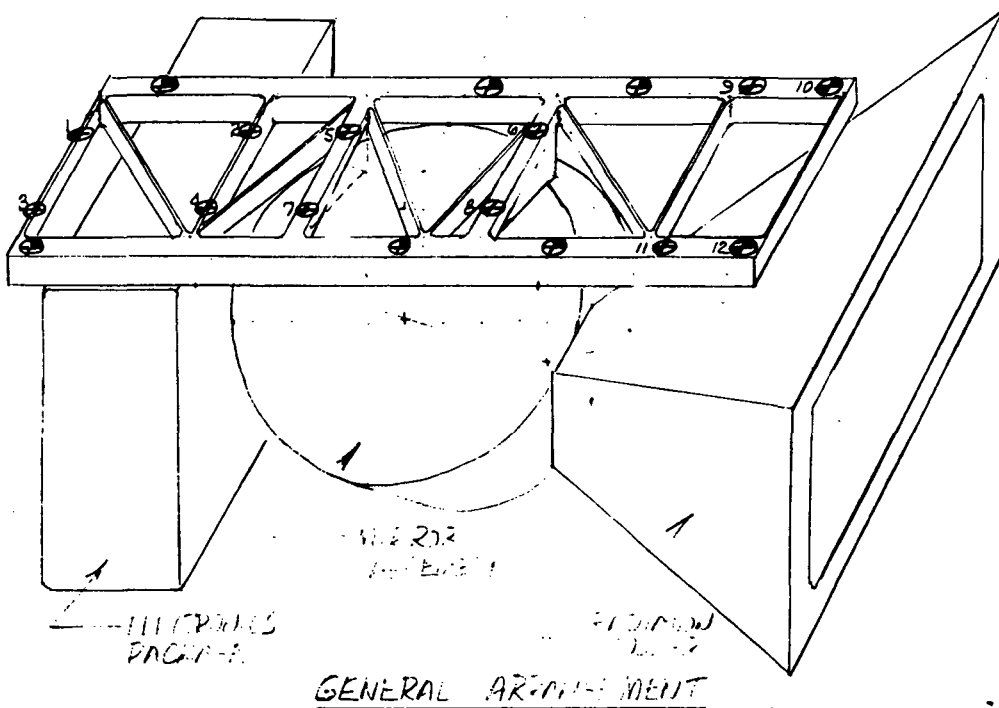
ENGINEERING REPORT



Aerospace
Systems Division

DATE 9 JAN 71 PAGE 1-1
 REPORT No. 5
 MODEL OSS

IMAGE PLANE CONICAL SCANNER —
PRIMARY SUPPORT PALLET —

MATERIAL REQ.

- ① 7079-T651 (AMS 4024 C)
- ② 7075-T6
- ③ 7178-T6

WT. EST.

- (1) ELECTRONICS 67.0 LB
- (2) MIRROR ASSEMBLY 30.
- (3) RADIATION COOLER 10.
- (4) SUPPORT PALLET 6.

TOTAL
WEIGHT

176.0 LB

PREPARED BY R. J. THOMAS
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 REVISED BY _____

ENGINEERING REPORT

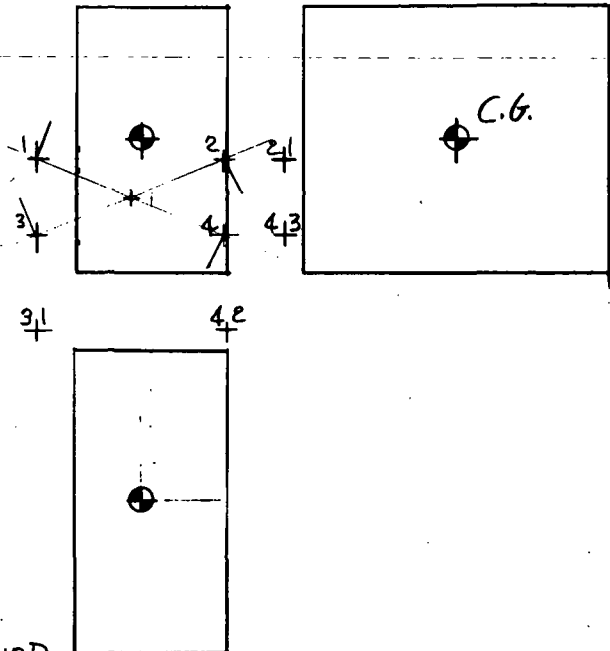
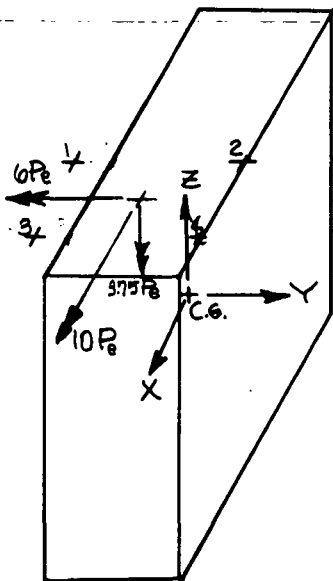


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DATE 9/14/71 PAGE 1-2
 REPORT No. 5
 MODEL 055

ELECTRONICS PACKAGE -

$$VOL = 14 \times 7 \times 16 = 1568 \text{ IN}^3$$



$$\begin{aligned} P_{1x} &= (.25 - .15) P_e = .10 P_e & P_e &= .10 P_e \\ P_{1y} &= (.25 + .05) P_e = .30 P_e & P_e &= .30 P_e \\ P_{1z} &= (.25 - .75 - .55) P_e = -1.05 P_e & P_e &= -1.05 P_e \\ P_{2x} &= (.25 + .15) P_e = .40 P_e & P_e &= .40 P_e \\ P_{2y} &= (.25 + .05) P_e = .30 P_e & P_e &= .30 P_e \\ P_{2z} &= (.25 - .75 + .55) P_e = .05 P_e & P_e &= .05 P_e \\ P_{3x} &= (.25 - .15) P_e = .10 P_e & P_e &= .10 P_e \\ P_{3y} &= (.25 - .05) P_e = .20 P_e & P_e &= .20 P_e \\ P_{3z} &= (.25 + .75 - .55) P_e = .45 P_e & P_e &= .45 P_e \\ P_{4x} &= (.25 + .15) P_e = .40 P_e & P_e &= .40 P_e \\ P_{4y} &= (.25 - .05) P_e = .20 P_e & P_e &= .20 P_e \\ P_{4z} &= (.25 + .75 + .55) P_e = 1.55 P_e & P_e &= 1.55 P_e \end{aligned}$$

WHERE,

P_e = WEIGHT OF ELECTRONICS

LOADING OF 1.0g IN
X, Y, & Z DIRECTIONS.

P_{ij} = REACTION AT i
IN THE j DIRECTION

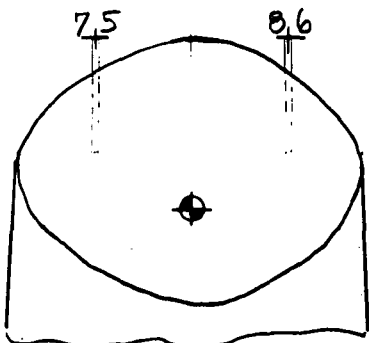
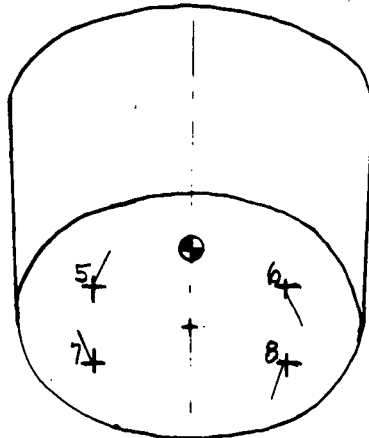
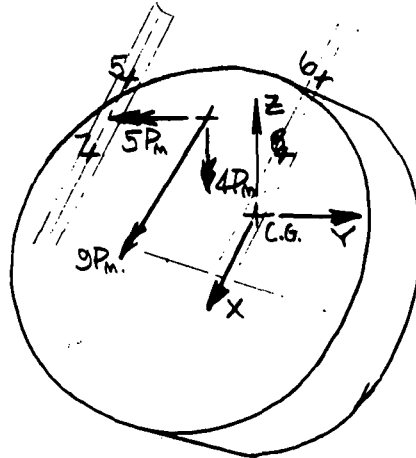
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DATE 9 JAN 71 PAGE 1-3
 REPORT No. 5
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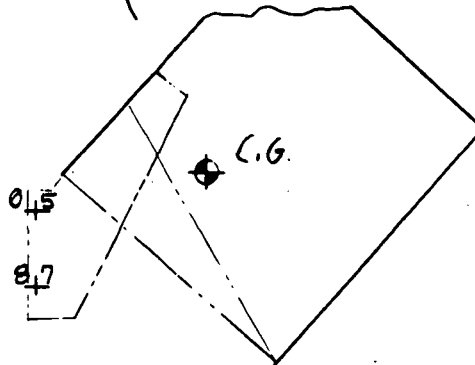
MIRROR PACKAGE-

$$\begin{aligned} P_{5x} &= (.25 - .20) P_m = .05 P_m \\ P_{5y} &= (.25 + .05) P_m = .30 P_m \\ P_{5z} &= (.25 - .45 - .60) P_m = -.80 P_m \end{aligned}$$

$$\begin{aligned} P_{6x} &= (.25 + .20) P_m = .45 P_m \\ P_{6y} &= (.25 + .05) P_m = .30 P_m \\ P_{6z} &= (.25 + .45 - .60) P_m = .10 P_m \end{aligned}$$

$$\begin{aligned} P_{7x} &= (.25 - .20) P_m = .05 P_m \\ P_{7y} &= (.25 - .05) P_m = .20 P_m \\ P_{7z} &= (.25 - .45 + .60) P_m = .40 P_m \end{aligned}$$

$$\begin{aligned} P_{8x} &= (.25 + .20) P_m = .45 P_m \\ P_{8y} &= (.25 - .05) P_m = .20 P_m \\ P_{8z} &= (.25 + .45 + .60) P_m = 1.30 P_m \end{aligned}$$



* WHERE P_m = WEIGHT OF
MIRROR ASSEMBLY

LOADING OF 1.0 g IN
X, Y, & Z DIRECTION.

P_{ij} = REACTION AT i
IN THE j DIRECTION.

BxA 542

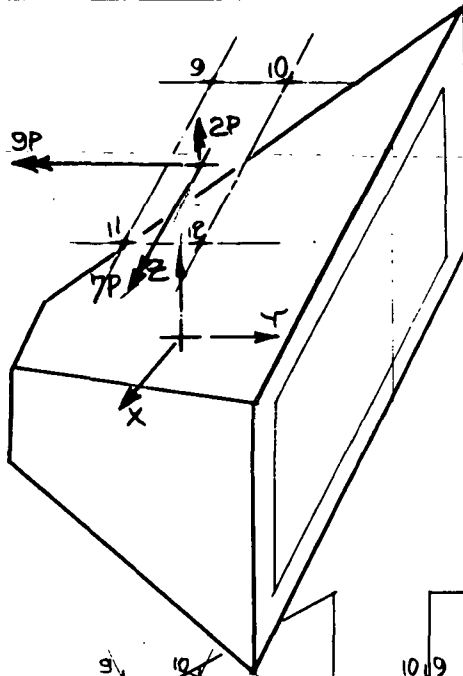
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ENGINEERING REPORT



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Systems Division

DATE 9 JAN 71 PAGE 1-4
 REPORT No. 5
 MODEL OSS

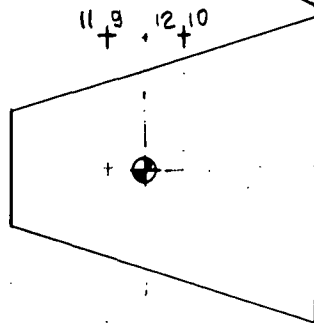
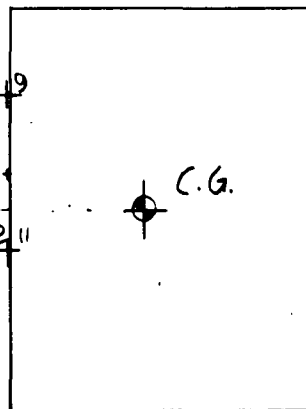
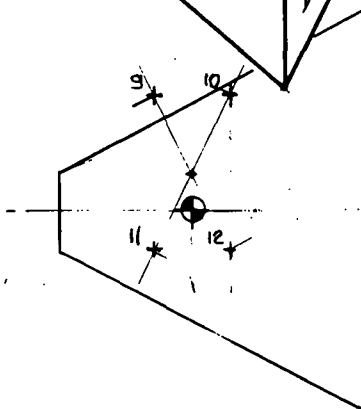
RADIATOR PACKAGE-

$$\begin{aligned} P_{9x} &= (.25 + .05) P_R = .30 P_R \\ P_{9y} &= (.25 - .10) P_R = .15 P_R \\ P_{9z} &= (.25 - .90 - .55) P_R = -1.20 P_R \end{aligned}$$

$$\begin{aligned} P_{11x} &= (.25 - .05) P_R = .20 P_R \\ P_{11y} &= (.25 - .10) P_R = .15 P_R \\ P_{11z} &= (.25 + .90 - .55) P_R = .60 P_R \end{aligned}$$

$$\begin{aligned} P_{12x} &= (.25 + .05) P_R = .30 P_R \\ P_{12y} &= (.25 + .10) P_R = .35 P_R \\ P_{12z} &= (.25 - .90 + .55) P_R = -.10 P_R \end{aligned}$$

$$\begin{aligned} P_{10x} &= (.25 - .05) P_R = .20 P_R \\ P_{10y} &= (.25 + .10) P_R = .35 P_R \\ P_{10z} &= (.25 + .90 + .55) P_R = 1.70 P_R \end{aligned}$$



* WHERE P_R = WEIGHT OF
RADIATION COOLER

LOADING OF 1.0 g IN
X, Y, & Z DIRECTION

P_{ij} = REACTION AT i
IN THE j DIRECTION.

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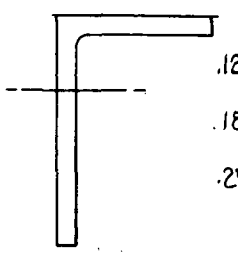
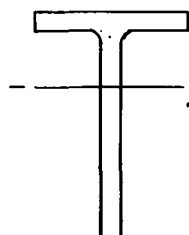
ENGINEERING REPORT



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Systems Division

DATE 13 JAN 71 PAGE 1-5
 REPORT No. 5
 MODEL OSS

TYPICAL MEMBER CROSS SECTIONS (REF. PG 1-6.)

BEAM NOS.	CROSS SECTION	AREA	I_y	I_z	$I_{y/z}$	$I_{y/z}$	J	L	WT.
* 1-15		.295	.065	.023	15.4	30.5	.0014	78	2.3
* 16-28		.188	.034	.00022	22.1	300.	.0009	85	1.6
* 29-34		.295	.065	.010	15.4	50.	.0014	16	0.5

TOTAL. 4.4 LB.

AS A FIRST ITERATION AT DETERMINING STRENGTH AND DEFLECTION CHARACTERISTICS OF PRIMARY SUPPORT STRUCTURE, THESE GENERAL CROSS-SECTIONS WILL BE ASSUMED.

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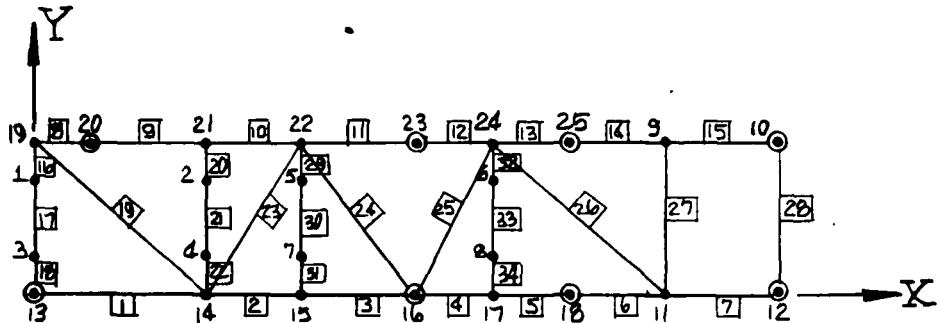
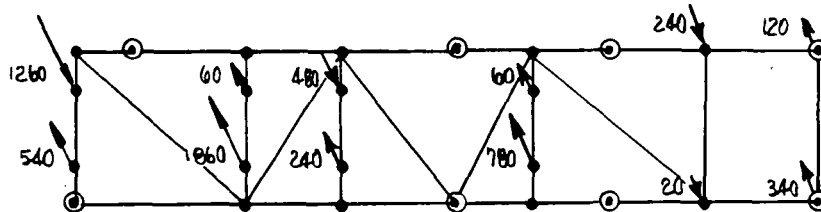
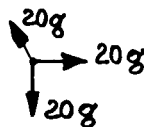


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DATE 13 JAN 74 PAGE 1-6
 REPORT No. 5
 MODEL OSS

IMAGE PLANE CONICAL SCANNER:STRESS-DEFL. ANALYSIS FOR PRIMARY SUPPORT STRUCTURESTRUCTURAL MODEL (GRIDSAP-STRUPAK MODEL)SCALE $\frac{1}{8}$

⊙ ≡ TIE-DOWN POINT.

Z - LOADING (GRID)

GENERAL NODAL MODEL - THESE ARE THE INPUT
 LOADS DUE TO $20g X + 20g Y + 20g Z$ LOADING.

* GRIDSAP-STRUPAK COORDINATES

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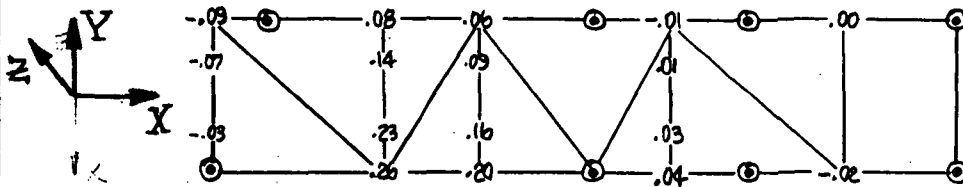


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DATE 3/4/71 PAGE 1-7
 REPORT No. 5
 MODEL 055.

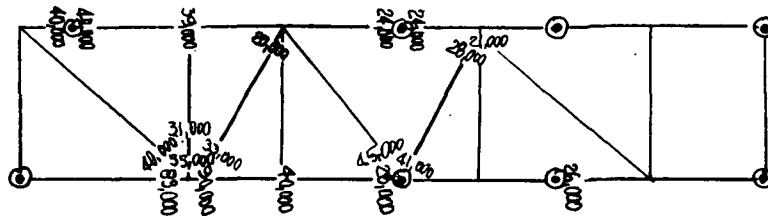
STRESS-DEFL. RESULTS FROM "GRIDSAP" ANALYSIS

(1.) Z-DEFLECTIONS RESULTING FROM $20g X + 20g Y + 20g Z$ LOADS.



RESULTING BENDING LOAD

(2.) STRESSES (ABOVE 20,000 PSI) FROM $20g X + 20g Y + 20g Z$ LOADS.



COMMENTS:

BENDING STRESSES AND DEFLECTIONS ARE HIGH IN LOCALIZED AREA. SECTIONS WILL BE MODIFIED FROM FIRST ITERATION RUN USING "EASE" COMPUTER PROGRAM RUN FOR NEW ANALYSIS.

ENGINEERING REPORT



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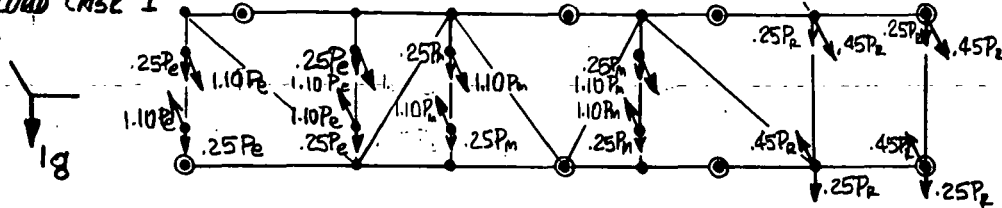
DATE 14 JAN 71 PAGE 1-8
REPORT No. 5
MODEL OSS

LOADING CONDITIONS (1.0g)
(LOAD CASES FOR "EASE" RUN)

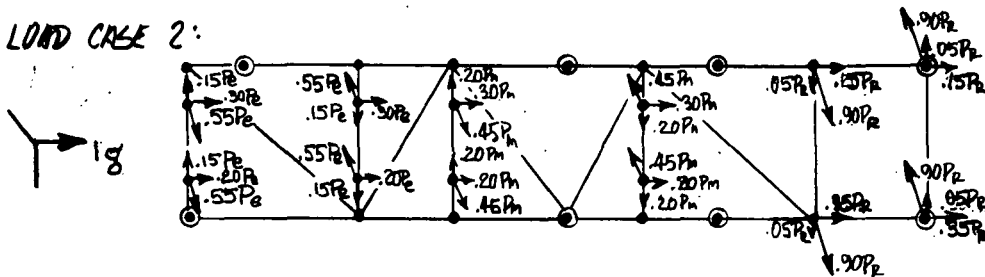
$P_e = \text{WT. OF ELECTRONICS PKG.}$

$$P_m = \text{WT. OF MIRROR ASSEMBLY}$$
$$P_R = \text{WT OF RADIATOR ASSY.}$$

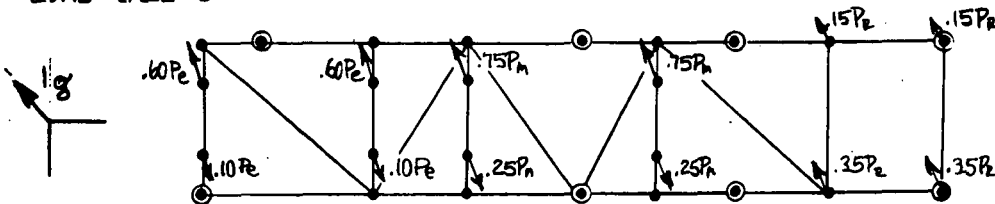
LOAD CASE 1:



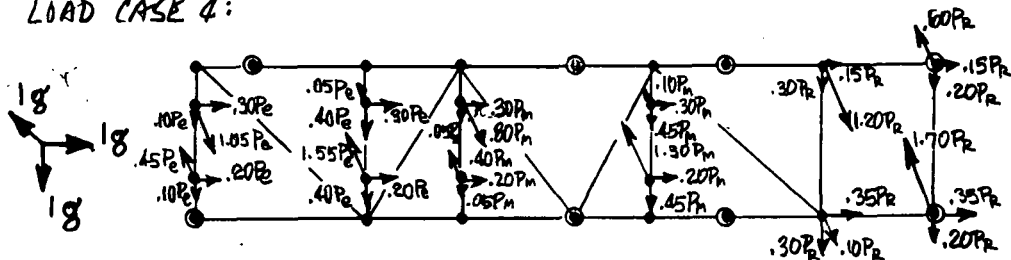
LOAD CASE 2:



LOAD CASE 3:



LOAD CASE 4:


$$\begin{array}{rcl} 20P_1 & = & 1200 \text{ 元} \\ 20P_2 & = & 600 \text{ 元} \\ 20P_3 & = & 200 \text{ 元} \end{array}$$

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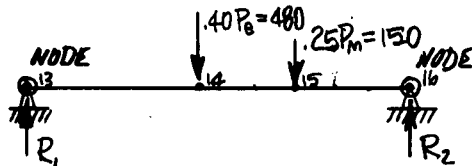
ENGINEERING REPORT



Aerospace
Systems Division

DATE 14 JUL 71 PAGE 1-9
 REPORT No. 5
 MODEL QSS

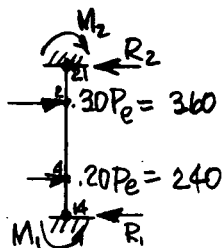
APPROX. WORST CASE IN-PLANE LOADING:



$$R_1 = \frac{(480)(11) + (150)(6)}{20} = 310 \text{ LB.}$$

$$\sigma_{b,14} = \frac{M_{14} c}{I} = (310)(9)(30.5) = 85,000 \text{ PSI.}$$

PREVIOUS COMPUTER RUNS WERE FOR
 OUT OF PLANE LOADING & DEFLECTIONS.
 SIMPLE BEAM ANALYSIS IS USED
 HERE TO DETERMINE IN-PLANE
 LOADING & STRESSES.



$$R_1 = \frac{Wb^2}{l^3} (3a+b) = \frac{(240)(6)^2(3.2+6) + (360)(2)^2(3.6+2)}{8^3} = 260 \text{ LB}$$

$$M_1 = W \frac{ab^2}{l^2} = \frac{(240)(2)(6)^2 + (360)(6)(2)^2}{8^2} = 405 \text{ IN-LB.}$$

$$M_{max} \approx 405$$

$$\sigma_{b,14} = M_{max} \frac{c}{I} = (405)(300) = 121,500 \text{ PSI.}$$

HENCE BOTH SECTIONS SHOULD BE MODIFIED
 SINCE $\sigma_{max, ALLOW} \approx 50,000 \text{ PSI.}$

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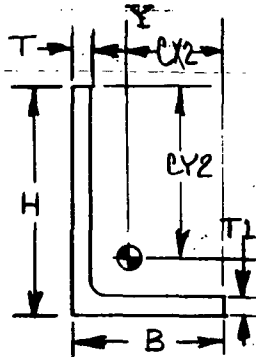
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Systems Division

DATE 5/10/71 PAGE 1-10
 REPORT No. 5
 MODEL OSS

MOMENT OF INERTIA
 PROPERTIES FROM STRUPAK-
 STANSECT CALCULATIONS:

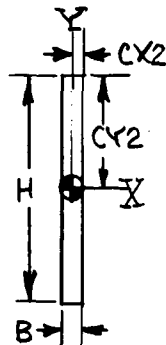
H	B	T	T ₁	CX2	CY2
AREA	I _x	I _y	(I _x /CY2)	(I _y /CX2)	J

L WT



①	1.5	1.0	.12	.12	.75	1.00		
	.285	.065	.024	15.4	31.3	.0013		
②	1.5	1.0	.18	.18	.73	.98		
	.417	.093	.033	10.4	22.2	.0040		
③	1.5	1.0	.18	.25	.69	1.02		
	.475	.097	.041	10.5	16.8	.0066		

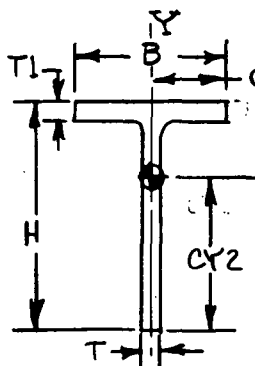
38. 1.1



④	1.5	.12	—	—	.06	.75		
	.180	.034	.0002	22.0	286.	.00082		
⑤	1.5	.18	—	—	.09	.75		
	.270	.050	.00073	15.0	123.	.0027		
⑥	1.5	.25	—	—	.125	.75		
	.375	.070	.00195	11.0	64	.0070		

28. 0.5

56. 1.5



⑦	1.5	1.0	.12	.12	.50	1.00		
	.285	.065	.010	15.4	50.	.0013		
⑧	1.5	1.0	.18	.18	.50	.98		
	.417	.093	.016	10.5	31.3	.0041		
⑨	1.5	1.0	.12	.18	.50	1.06		
	.338	.071	.015	14.9	33.3	.0024		

16 0.5

⑩	1.5	1.0	.25	.25	.71	.96		
SECT. ABOVE	.562	.120	.042	8.0	17.0	.0100		

40. 2.3

5.948

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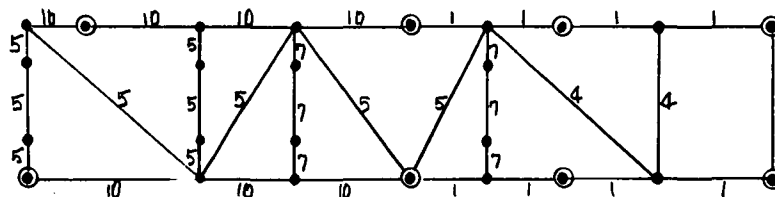
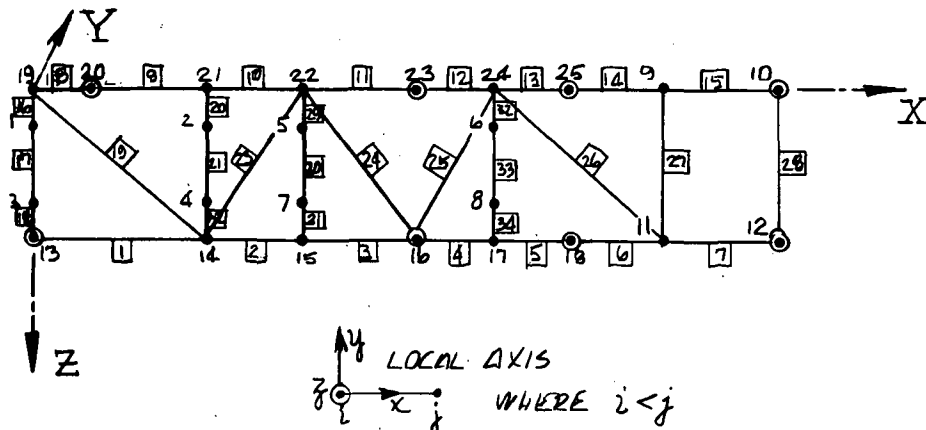
ENGINEERING REPORT



Aerospace
Systems Division

DATE 19 JAN 71 PAGE 11
 REPORT No. 5
 MODEL OS8

THIS IS A SECOND ITERATION RUN USING A
 REVISED STRUCTURAL MODEL FOR "EASE" STRESS ANALYSIS.



NO'S. REFER TO PARTICULAR CROSS SECTIONS ON PG. 10.

* EASE (PRIMARY SUPPORT STRUCTURE) COORDINATES.
 "ELASTIC ANALYSIS FOR STRUCTURAL ENGINEERS".

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ENGINEERING REPORT



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Systems Division

DATE 22 JAN 71 / PAGE 1-12
 REPORT No. 5
 MODEL QSS

A CONSERVATIVE INTERACTION EON. FOR COMBINED
 BENDING, SHEAR, & AXIAL LOAD IS —

$$M.S. = \frac{1}{[(R_a + R_b)^2 + R_s^2]^{1/2}} - 1$$

	MATERIAL	F_{T1}	F_{T2}
①	7079-T651	73,000	63,000
②	7075-T6	75,000	66,000
③	7178-T6	80,000	70,000

SPOT CHECK "EASE" COMPUTER RUN FOR M.S. (ULT. LOADING.)

LOAD CASE NO.	BEAM NO.	BEAM TYPE	M	V	A	σ_b	σ_v	σ_a	M.S.
5	2	10	-4741	-79	12	-38,000	—	—	.92
5	4	1	2713	38	-65	42,000	—	—	.73
5	16	5	2265	-341	437	50,000	+1,000	2000	.40
5	16	5*	492	1381	-437	60,000	5,000	-2000	.18
5	20	5*	-493	187	107	-61,000	1000	1000	.21
8	2	10	-5233	-79	12	-42,000	—	—	.74
8	4	1	2924	38	-65	45,000	—	—	.62
8	16	5*	-492	868	-437	-60,000	3000	-2000	.16
8	20	5*	-493	-294	107	-61,000	-1000	1000	.22

1 THESE ARE SELECTED RESULTS FROM COMPUTER RUN.
 THE BENDING MOMENTS APPEAR TO BE THE WORST
 CASES FROM PRINTOUT. MINIMUM MARGIN OF SAFETY
 CAN BE SEEN TO BE .21.

* REFERS TO LOCAL Z-AXIS (OUT OF PLANE).

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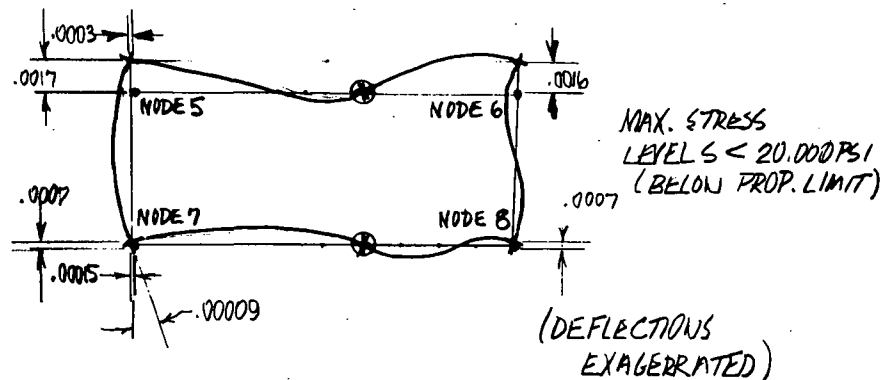
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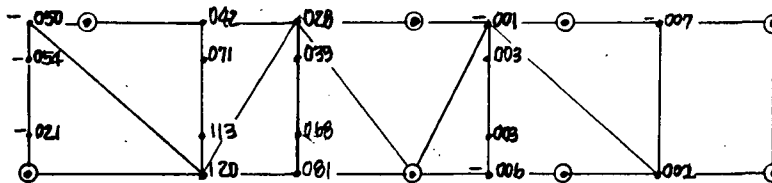
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Systems Division

DATE 25/10/71 / PAGE 13
 REPORT No. 5
 MODEL OSP

DEFLECTIONS OF PICK-UP POINTS FOR PRIMARY
MIRROR ASSEMBLY UNDER UNIFORM ΔT OF 10°C .



FROM THE SECOND ITERATION "EASE" COMPUTER
RUN (UNDER A 20% ULTIMATE LOADING CONDITION)
THE MAXIMUM OUT OF PLANE DEFLECTIONS
(IN AND OUT OF PLANE OF PAPER) WERE FOUND
TO BE —



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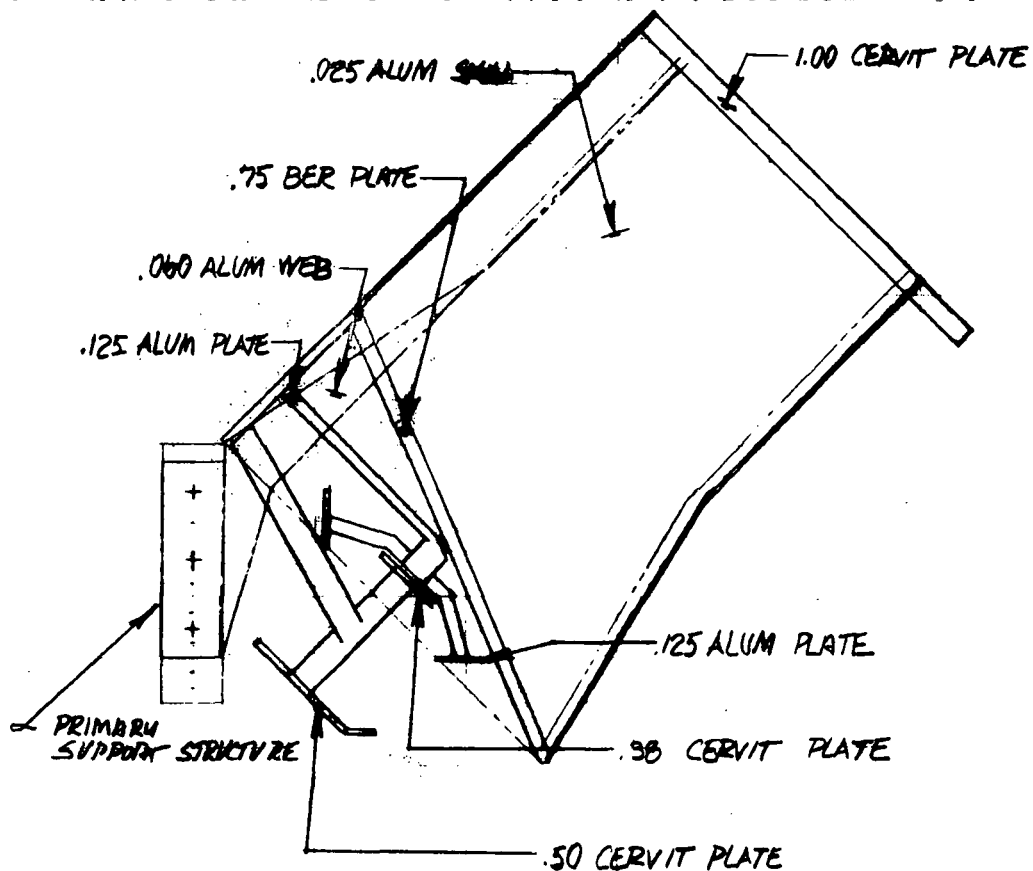
ENGINEERING REPORT



Aerospace
Systems Division

DATE 4 FEB 71 PAGE 1-1
 REPORT No. 6
 MODEL OSS

OSS-IMAGE PLANE CONICAL SCANNER
 (FOR "EASE" STRUCTURAL ANALYSIS PROGRAM)
MIRROR ASSEMBLY-



GENERAL ARRANGEMENT & MATERIALS
 USED FOR MIRROR ASSEMBLY
 SCALE 1/5

TOTAL WEIGHT = 31.4 LB.

BxA 842

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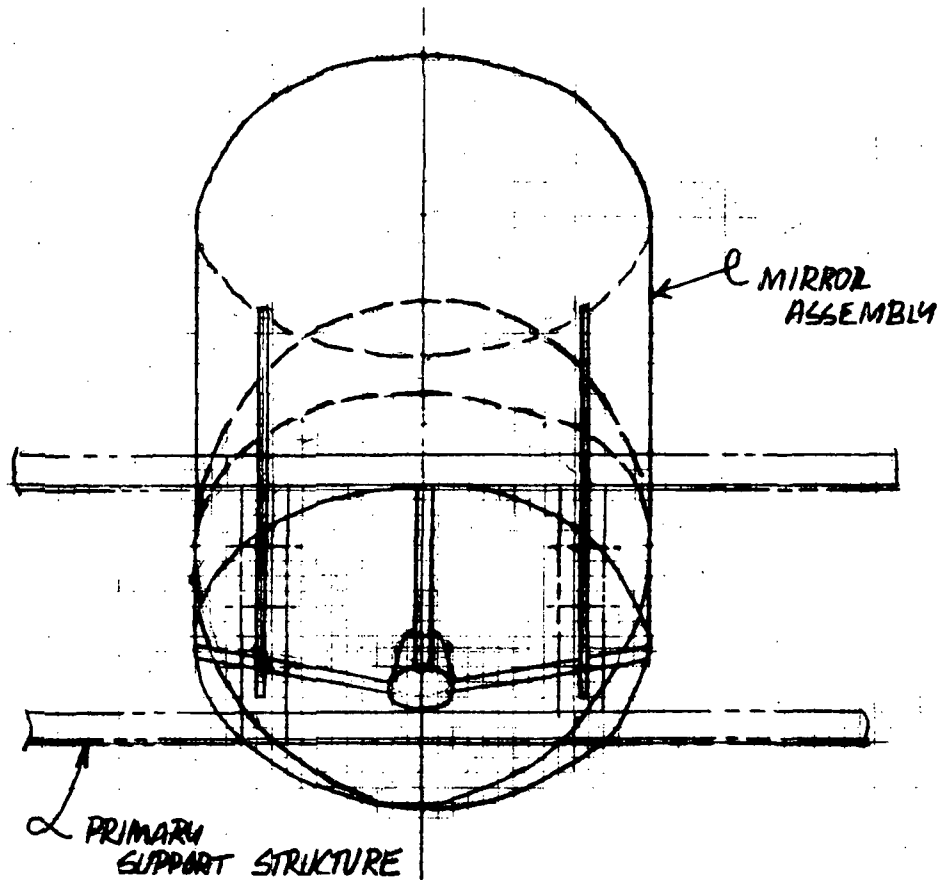


ADVANCED
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CORPORATION

DATE 4 FEB 71 PAGE 1-2
REPORT NO. 6
MODEL QSS

MIRROR ASSEMBLY-

(VIEW LOOKING DOWN FROM SUPPORT PALLET)



8-A 50

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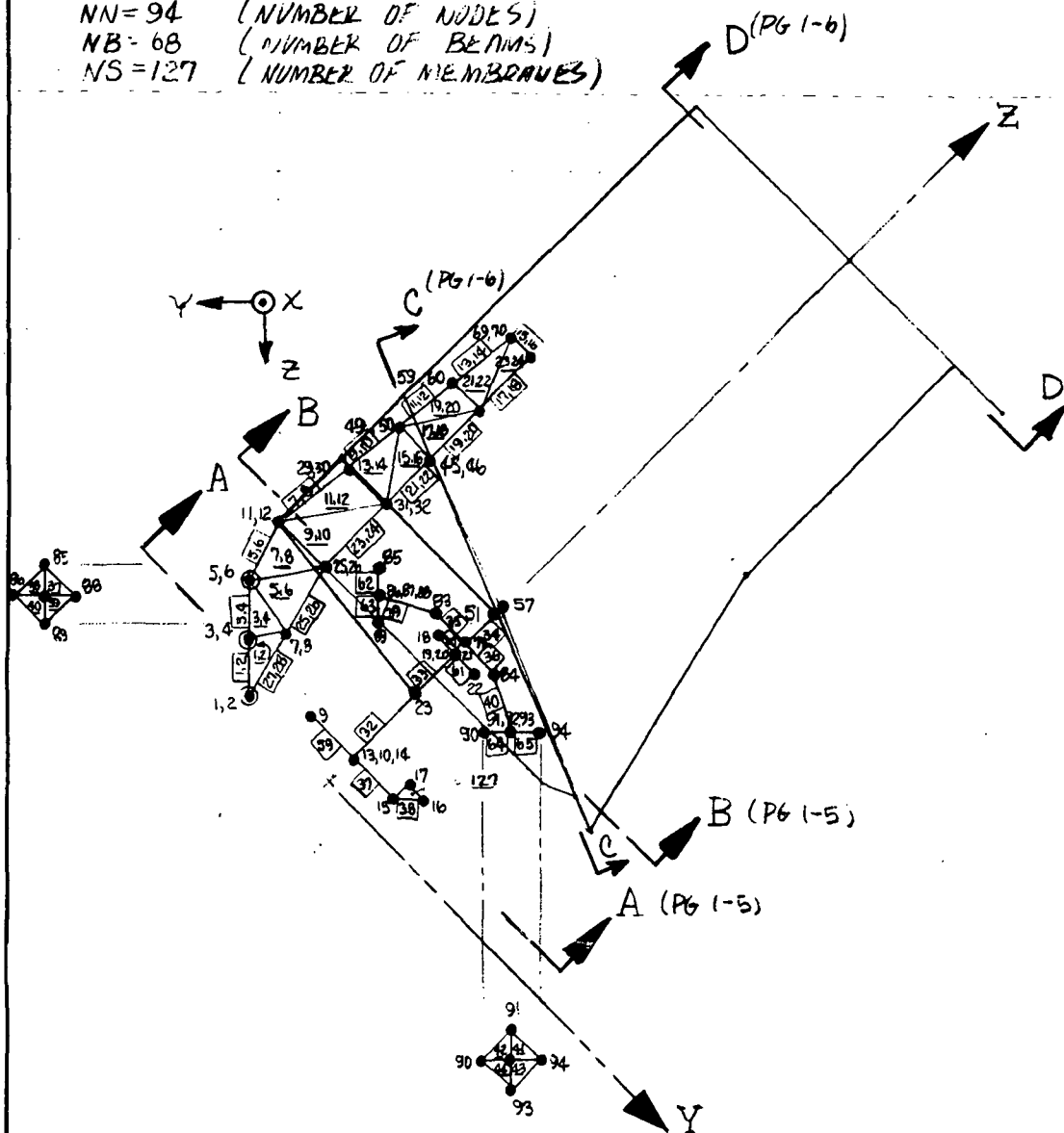


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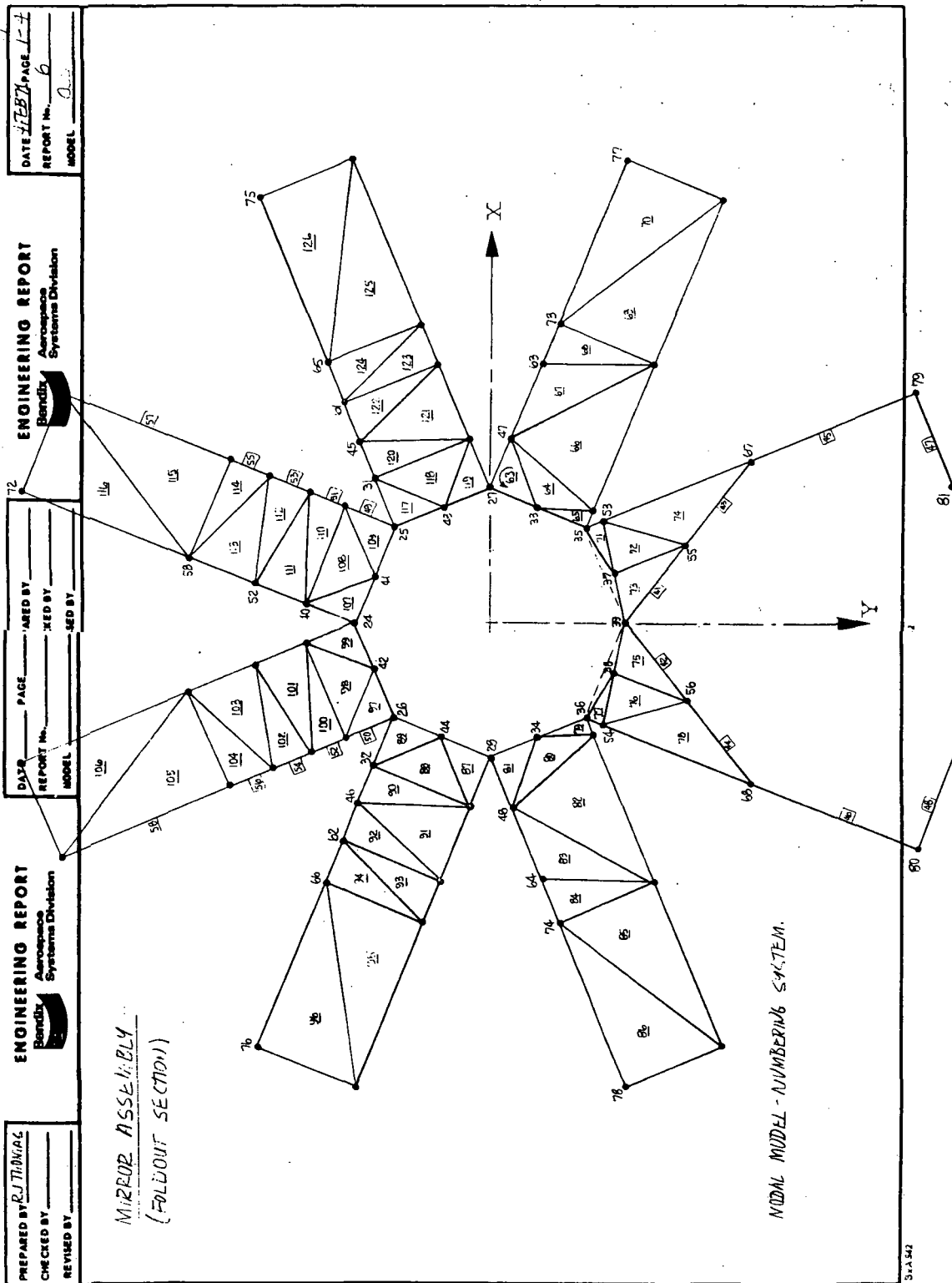
DATE 4 FEB 71 PAGE 1-3
 REPORT No. 6
 MODEL OSS

'EASE' NUMBERING SYSTEM (NODAL MODEL)-

NN=94 (NUMBER OF NODES)
 NB=68 (NUMBER OF BEAMS)
 NS=127 (NUMBER OF MEMBRANES)



BxA 542



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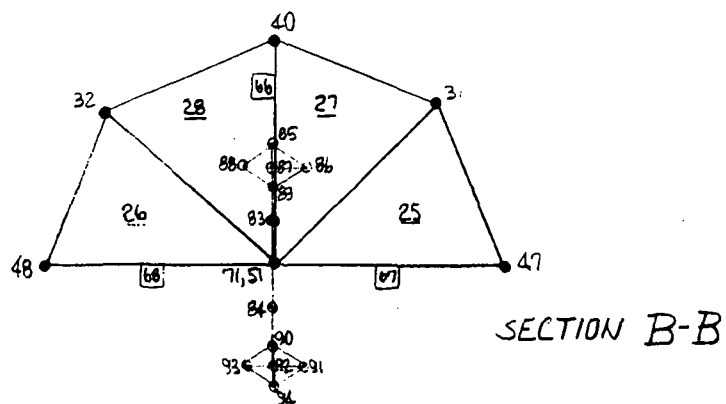
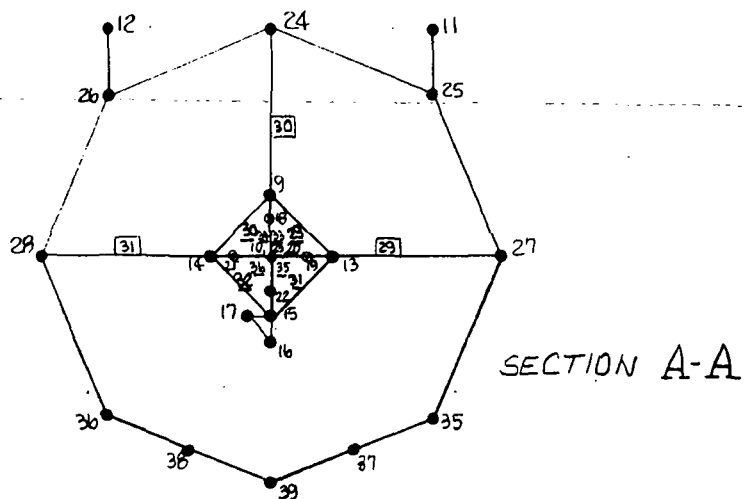
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DATE 4 FEB 71 PAGE 1-5
 REPORT No. 6
 MODEL QSS

MIRROR ASSEMBLY —



NODAL MODEL-NUMBERING SYSTEM

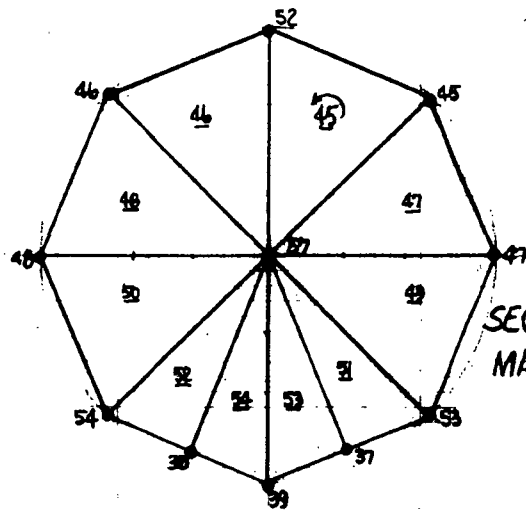
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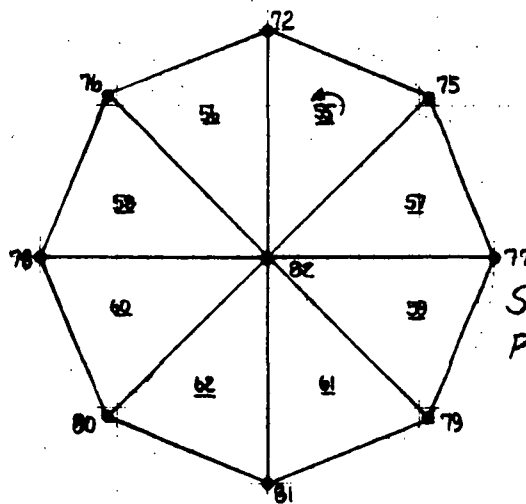


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DATE 4 FEB 77 PAGE 1-6
 REPORT NO. 6
 MODEL CSS



SECTION C-C
MAIN FOLDING MIRROR



SECTION D-D
PRIMARY MIRROR

INODAL MODEL - NUMBERING SYSTEM.

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Systems Division

DATE 1 FEB 71 PAGE 1-7
 REPORT No. 6
 MODEL QSS

TYPICAL CROSS-SECTIONS USED TO MODEL MIRROR ASSEMBLY—

NO.	SECTION	SIZE	AREA	CY	CZ	IY	IZ	F_y/C_z	F_z/C_y	J	A _y	A _z
1		1x1 x .066	.122	.73	.73	.012	.012	61.	61.	.00019	.061	.061
2		1.5 x .120	.180	.060	.75	.034	.0021	26.	300.	.00002	.030	.180
3		R=1.5 theta=.60 t=.050	.235	1.5	.95	.051	.266	19.	6.	.00020	.166	.166
4		R=1.5 t=.050	.470	1.5	1.5	.532	.532	3.	3.	1.064	.332	.332
5		.75 x .32	.240	.38	.16	.0017	.016	95.	33.	.00825	.240	.120
6		.5 x .12 x .1037	.120	.50	.25	.0025	.030	100.	17.	.0050	.060	.120
7		1.405 x .0030	.113	.51	.39	.0151	.0015	26.	340.	.0006	.025	.050

THESE SECTIONS WERE USED TO MODEL THE MIRROR ASSEMBLY
 SHOWN IN PAGES 1-3 THRU 1-6.

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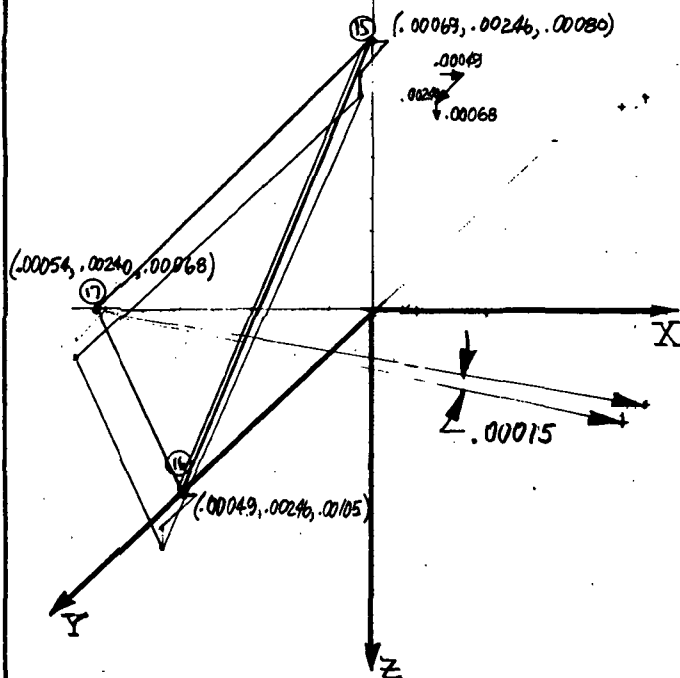


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DATE 10 FEB 71 PAGE 2-1
 REPORT No. 6
 MODEL ASS

CALCULATE ANGULAR SHIFT DUE TO $10^{\circ}\text{C } \Delta T$.

(FOR SMALL FOLDING MIRROR - NODES 15, 16, 17. SEE PG. 2-5)



X_i	Y_i	Z_i
15	0.00	2.00
16	0.00	2.71
17	-0.71	2.00

ORIGIN TRANSLATED TO (.00320, 1.71)

X_i	Y_i	Z_i
15	0.00	0.00
16	0.00	0.71
17	-0.71	0.00

10°C DEFL. POSITION (COORD.)

15	.00069	.00246	-.70920
16	.00049	.71246	.00105
17	-.70946	.00240	.00068

THESE CALCULATIONS ARE PERFORMED TO ASCERTAIN
 RELATIVE MOTIONS BETWEEN SMALL FOLDING MIRROR
 AND SPECTROMETER APERTURE.

(FOR REF. ORIENTATION SEE PG. 1-3.)

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DATE 10 FEB 71 PAGE 2-2
 REPORT No. 6
 MODEL QSS

CALCULATE NORMAL VECTOR TO SURFACE 15-16-17

$$\vec{V}_{17-15} = 0.71 \hat{i} + 0.00 \hat{j} - 0.71 \hat{k}$$

$$\vec{V}_{17-16} = 0.71 \hat{i} + 0.71 \hat{j} + 0.00 \hat{k}$$

$$\vec{V}_{17-16-15} = \vec{V}_{17-15} \times \vec{V}_{17-16} = \begin{bmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0.71 & 0.00 & -0.71 \\ 0.71 & 0.71 & 0.00 \end{bmatrix}$$

$$= (0.71)^2 \hat{i} - (0.71)^2 \hat{j} + (0.71)^2 \hat{k}$$

$$= .50410 \hat{i} - .50410 \hat{j} + .50410 \hat{k}$$

ALSO, $|\vec{V}_{17-16-15}| = [3(.50410)^2]^{1/2}$

$$= (.76235043)^{1/2}$$

$$= .873127$$

CALCULATE NORMAL VECTOR TO DEFLECTED SURFACE

$$\vec{V}_{17-15_f} = .71015 \hat{i} + .00006 \hat{j} - .70988 \hat{k}$$

$$\vec{V}_{17-16_f} = .70995 \hat{i} + .71006 \hat{j} + .00037 \hat{k}$$

$$\vec{V}_{17-16_f-15_f} = \vec{V}_{17-15_f} \times \vec{V}_{17-16_f} = \begin{bmatrix} \hat{i} & \hat{j} & \hat{k} \\ .71015 & .00006 & -.70988 \\ .70995 & .71006 & .00037 \end{bmatrix}$$

$$= [(.6776)(.00037) - (.71006)(-.70988)] \hat{i}$$

$$+ [(-.70988)(.70995) - (.00037)(.71015)] \hat{j}$$

$$+ [(.71015)(.71006) - (.00006)(-.70995)] \hat{k}$$

$$= (.00000 + .491957) \hat{i} - (.49188 + .00023) \hat{j} + (.50249 + .00042) \hat{k}$$

$$= .50406 \hat{i} - .50424 \hat{j} + .50421 \hat{k}$$

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DATE 10 FEB 71 PAGE 2-3
 REPORT No. 6
 MODEL OSS

$$\begin{aligned}
 \text{ALSO, } |\vec{V}_{17-16, 15_F}| &= [(.50406)^2 + (.50424)^2 + (.50421)^2]^{1/2} \\
 &= [(.254076 + .254258 + .254225)]^{1/2} \\
 &= (.762559)^{1/2} \\
 &= .873247
 \end{aligned}$$

$$\begin{aligned}
 \text{NOW } \vec{A} \cdot \vec{B} &= |A||B| \cos \alpha \\
 \text{OR } \cos \alpha &= \frac{\vec{A} \cdot \vec{B}}{|A||B|}
 \end{aligned}$$

$$\begin{aligned}
 \vec{V}_{17-15-16} \cdot \vec{V}_{17-15-16_F} &= (.50410)(.50406) + (.50410)(.50424) + (.50410)(.50421) \\
 &= .254097 + .254187 + .254172 \\
 &= .762456
 \end{aligned}$$

HENCE,

$$\begin{aligned}
 \cos \alpha &= \frac{\vec{V}_{17-15-16} \cdot \vec{V}_{17-15-16_F}}{|\vec{V}_{17-15-16}| |\vec{V}_{17-15-16_F}|} \\
 &= \frac{.762456}{(.873127)(.873247)}
 \end{aligned}$$

$$\begin{aligned}
 \text{COULD BE ERROR IN} & \\
 6^{\text{th}} \text{ DECIMAL PLACE} &= 1.0000013
 \end{aligned}$$

OR,

$$\alpha_{\text{MAX}} = .0016 \text{ RADIANS}$$

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$$\frac{|\vec{V}_{17+16+15+}|}{|\vec{V}_{17+16+15}|} = \frac{.873127}{.873247} = 0.999863$$

HENCE,

$$.999863 \vec{V}_{17+16+15+} = .503991 \hat{i} - .504171 \hat{j} + .504141 \hat{k}$$

$$\alpha_x \approx \frac{.00003}{.71} \approx .000042$$

$$\alpha_y \approx -\frac{.00011}{.71} \approx -.000155$$

$$\alpha_z \approx -\frac{.00011}{.71} \approx -.000155$$



$$\cos \alpha_x = \frac{y}{(y^2 + z^2)^{1/2}}$$

$$\cos \alpha_y = \frac{z}{(x^2 + z^2)^{1/2}}$$

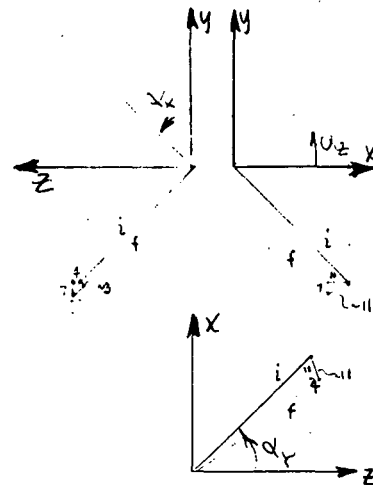
$$\cos \alpha_z = \frac{x}{(x^2 + y^2)^{1/2}}$$

$$\alpha_x = .000042 \text{ RAD/ANS}$$

$$\alpha_y = -.000155 \text{ RAD/ANS}$$

$$\alpha_z = -.000155 \text{ RAD/ANS}$$

ROTATION IN x & z DIRECTIONS



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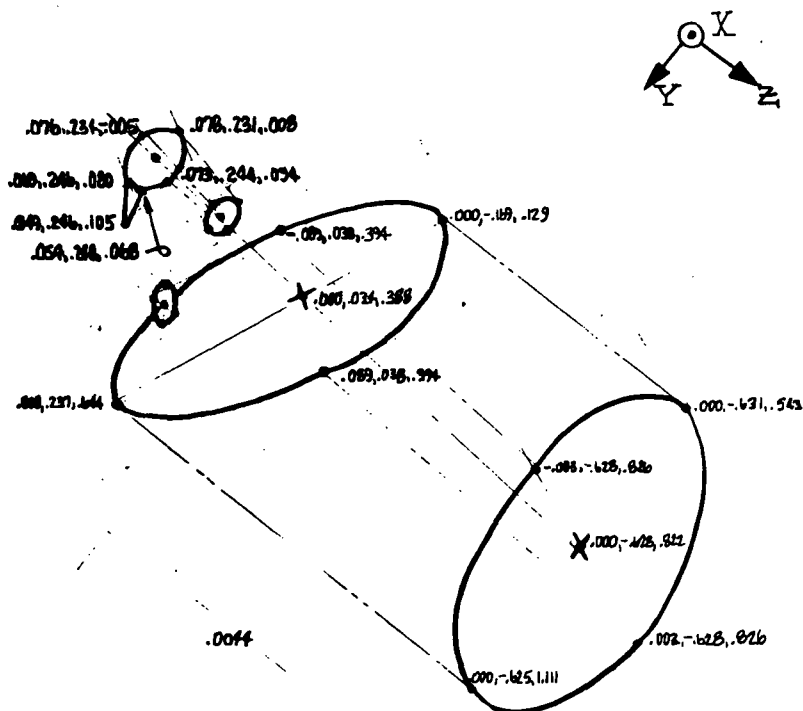
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DATE 16 FEB 71 PAGE 2-6

REPORT No. 6

MODEL 055

THERMAL VARIATIONS OF MIRROR ELEMENTS DUE TO 10°C UNIFORM ΔT : ($\times 10^2$)



(.XXX.,YYY.,ZZZ) INDICATES RELATIVE DISPLACEMENT OF NODE TO GLOBAL COORDINATES (X,Y,Z).

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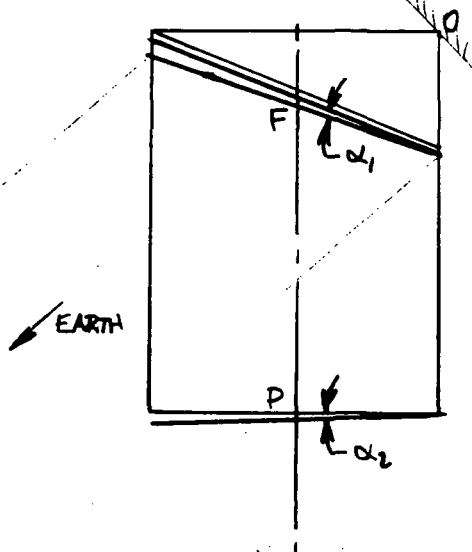
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Systems Division

DATE 22/3/71 PAGE 2-7
 REPORT No. 6
 MODEL 088

CHECK RELATIVE DEFLECTIONS OF FOLDING MIRROR
AND PRIMARY MIRROR.



$$\begin{array}{r} .00644^* \\ - .00129 \\ \hline .00515 \end{array} \quad \alpha_1 \approx \frac{.00515}{16} \approx .00032 \text{ RADIANS}$$

$$\begin{array}{r} .01111^* \\ - .00543 \\ \hline .00568 \end{array} \quad \alpha_2 \approx \frac{.00568}{15} \approx .00034 \text{ RADIANS}$$

THE RELATIVE ANGULAR DEFLECTION BETWEEN THE FOLDING MIRROR "F" AND THE PRIMARY MIRROR "P" IS NEGLIGIBLE. APPARENTLY THE "CAN" ARRANGEMENT BEHAVES AS A RIGID BODY AND PIVOTS ABOUT POINT "O".

* FROM EASE COMPUTER OUTPUT.

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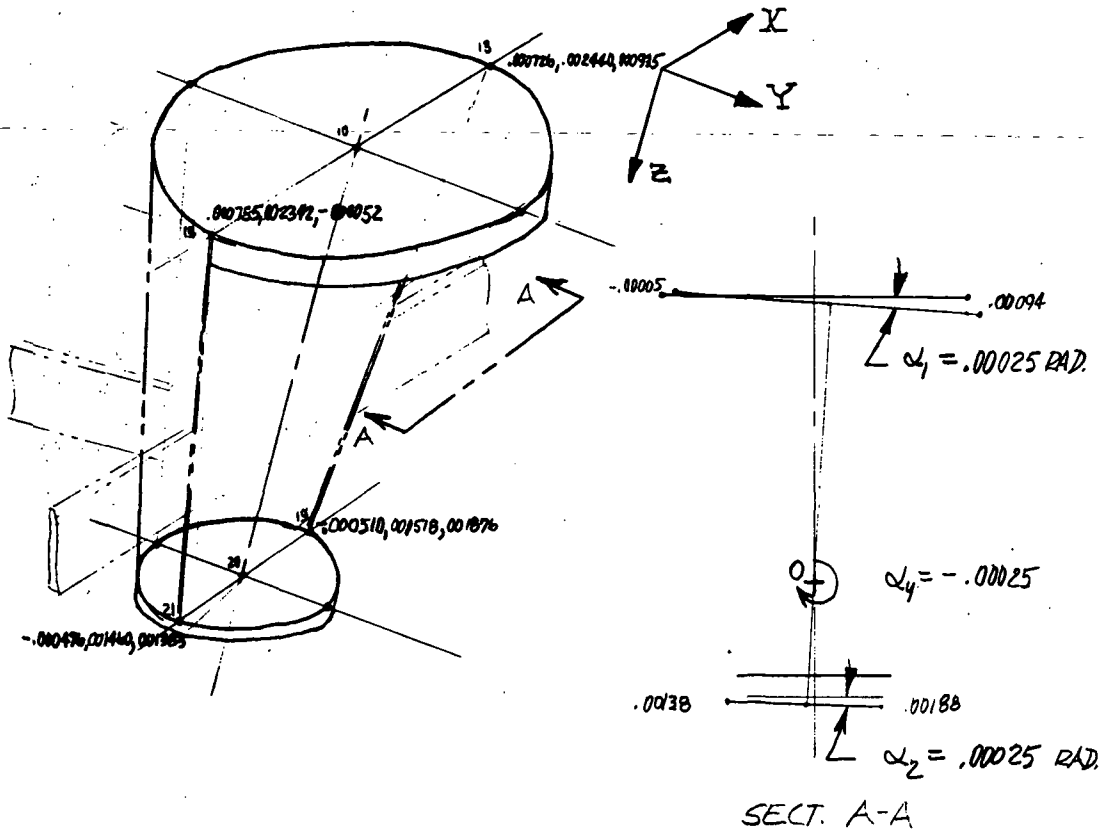
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Systems Division

DATE 24 FEB 71 PAGE 2-8
 REPORT No. 6
 MODEL QSS

DEFLECTIONS DUE TO $10^{\circ}\text{C } \Delta T$



$$\alpha_1 = \frac{0.00094 + 0.00005}{2} = \frac{0.00099}{2} = 0.00025$$

$$\alpha_2 = \frac{0.00188 - 0.00138}{2} = \frac{0.00050}{2} = 0.00025$$

THE UNIT APPARENTLY BEHAVES AS A RIGID BODY
 ROTATING ABOUT POINT O BY 0.00025 RADIAN.

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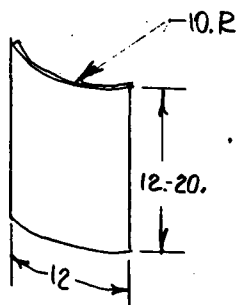


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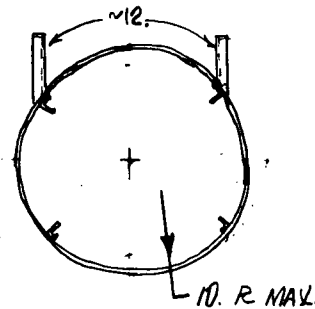
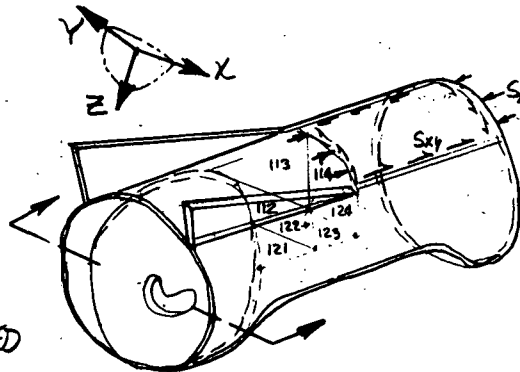
DATE 17 FEB 71 PAGE 3-1
 REPORT No. 6
 MODEL Q55

CHECK BUCKLING STRENGTH OF SKIN PANELS
SUPPORTING PRIMARY MIRROR.

ASSUME SKIN PANEL OF
SHAPE —



.025 ALUM.
SIMPLY SUPPORTED
ALL SIDES.



FROM BRUHAI (CHAPT. C9) —

AXIAL COMPRESSIVE STRENGTH:

$$Z = \frac{b^2}{rE} (1 - \nu_e^2)^{1/2} = \frac{12^2}{10(.025)} = 576$$

$$\frac{r}{t} = \frac{10}{.025} = 400$$

$$\Rightarrow K_c = 250 \quad (\text{REF. FIG. C.9.1})$$

$$F_{cr} = \frac{K_c \pi^2 E}{12(1 - \nu_e^2)} \left(\frac{t}{b}\right)^2 = (250)(10^7) \left(\frac{.025}{12}\right)^2 = 10,800 \text{ PSI.}$$

ALLOWABLE COMP.
STRESS ON PANEL
BEFORE BUCKLING

SHEAR BUCKLING STRENGTH:

$$Z = 576 \quad a/b = 20/12 \approx 2$$

$$\Rightarrow K_s = 80 \quad (\text{REF. FIG. C.9.4.})$$

$$F_{scr} = \frac{K_s \pi^2 E}{12(1 - \nu_e^2)} \left(\frac{t}{b}\right)^2 = (80)(10^7) \left(\frac{.025}{12}\right)^2 = 3,510 \text{ PSI.}$$

ALLOWABLE SHEAR
STRESS ON PANEL
BEFORE BUCKLING.

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DATE 17 FEB 71 PAGE 3-2
 REPORT NO. 6
 MODEL OSS

FROM EASE COMPUTER OUTPUT MAX. COMPRESSIVE
 AND SHEAR STRESSES UNDER COMBINED 20 g
 ULT. LOAD CONDITIONS WERE FOUND TO BE —

LOAD CASE	Sxx	ELEMENT NO.	Syy	ELEMENT NO.	Sxy	ELEMENT NO.
5	SMALL	—	900 PSI	124	1450 PSI	103-104
6	900 PSI.	94	1750 PSI.	121 TO 123	1650 PSI.	112 TO 114
8	SMALL	—	1400 PSI.	112 TO 123	1400 PSI.	112 TO 114

UNDER COMBINED COMPRESSION & SHEAR THE EQUATION
 FOR MARGIN OF SAFETY IS: (EQU C.9.4)

$$M.S. = \frac{2}{R_L + (R_L^2 + 4R_S^2)^{1/2}} - 1 \quad .3E \frac{t}{R} = .3(607) \frac{.025}{10}$$

$$= 7500 \text{ PSI.}$$

WHERE $R_S = \frac{f_s}{F_{scr}}$ & $R_L = \frac{f_c}{F_{scr}}$

ELEMENT 112 LOAD CASE 6 APPEARS TO BE WORST CASE

$$R_S = \frac{1650}{3500} = 0.47$$

$$R_L = \frac{1400}{10,800} = 0.13$$

$$M.S. = \frac{2}{0.13 + (0.13^2 + 4 \times 0.47^2)^{1/2}} - 1 = \frac{2}{0.13 + .95} - 1 = 0.85$$

HENCE MINIMUM MARGIN OF SAFETY FOR .025 ALUM
 SKIN PANELS APPEARS TO BE 85%.

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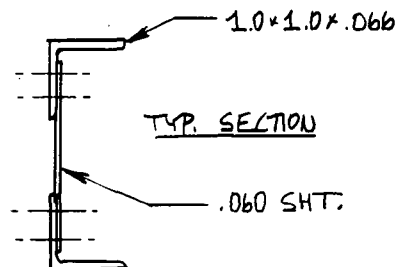
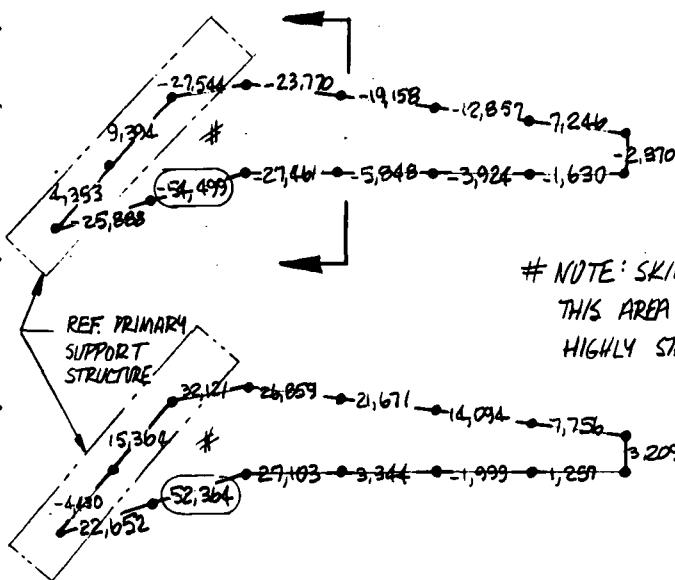
DATE 19 FEB 71 PAGE 4-1
 REPORT No. 6
 MODEL OSS

CHECK "PICK UP SUPPORT FRAMES" ON PRIMARY MIRROR
 SUBASSEMBLY FOR MAX. STRESSES —

BEAM MAX. STRESS LOAD CASE

1	4,353	8
2	-4,430	5
3	9,394	5
4	15,364	6
5	-27,544	5
6	32,121	6
7	-23,770	5
8	26,859	6
9	-19,158	5
10	21,671	6
11	-12,857	5
12	14,094	6
13	7,246	6
14	7,756	6
15	-2,370	5
16	3,209	6
17	-1,630	6
18	1,257	6
19	-3,924	6
20	-1,999	7
21	-5,848	6
22	3,344	5
23	-27,461	8
24	27,103	5
25	-54,499	6
26	52,364	5
27	-25,888	6
28	22,652	6

(20g COMBINATION-ULT. - LOAD CASES)



IN GENERAL STRESSES

DO NOT APPEAR CRITICAL.

MAX. STRESSES.

THIS AREA SHOULD BE "BEEPED UP"

TO AVOID STRESSES BEYOND ELASTIC LIMIT
 SINCE PERMANENT STRAIN IS INTOLERABLE.

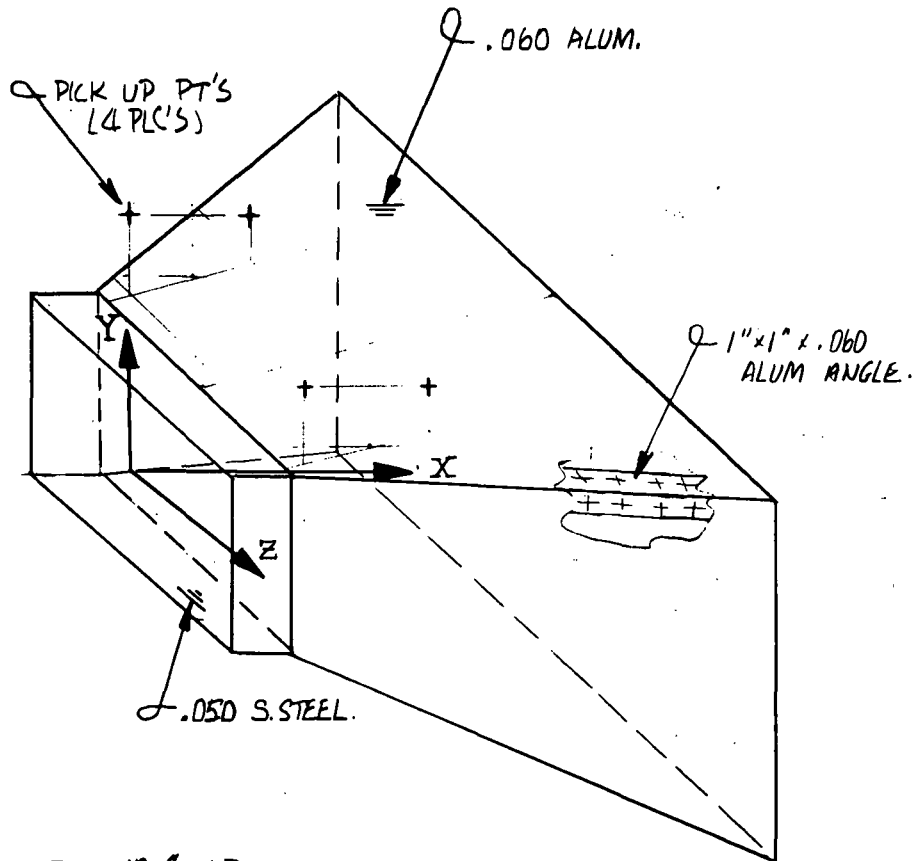
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DATE 21 MAR 71 PAGE 1-1
 REPORT No. 7
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OSS - RADIATION COOLER

TOTAL WT. = 10.4 LB.

GENERAL ARRANGEMENT OF
RADIATION COOLER

BxA542

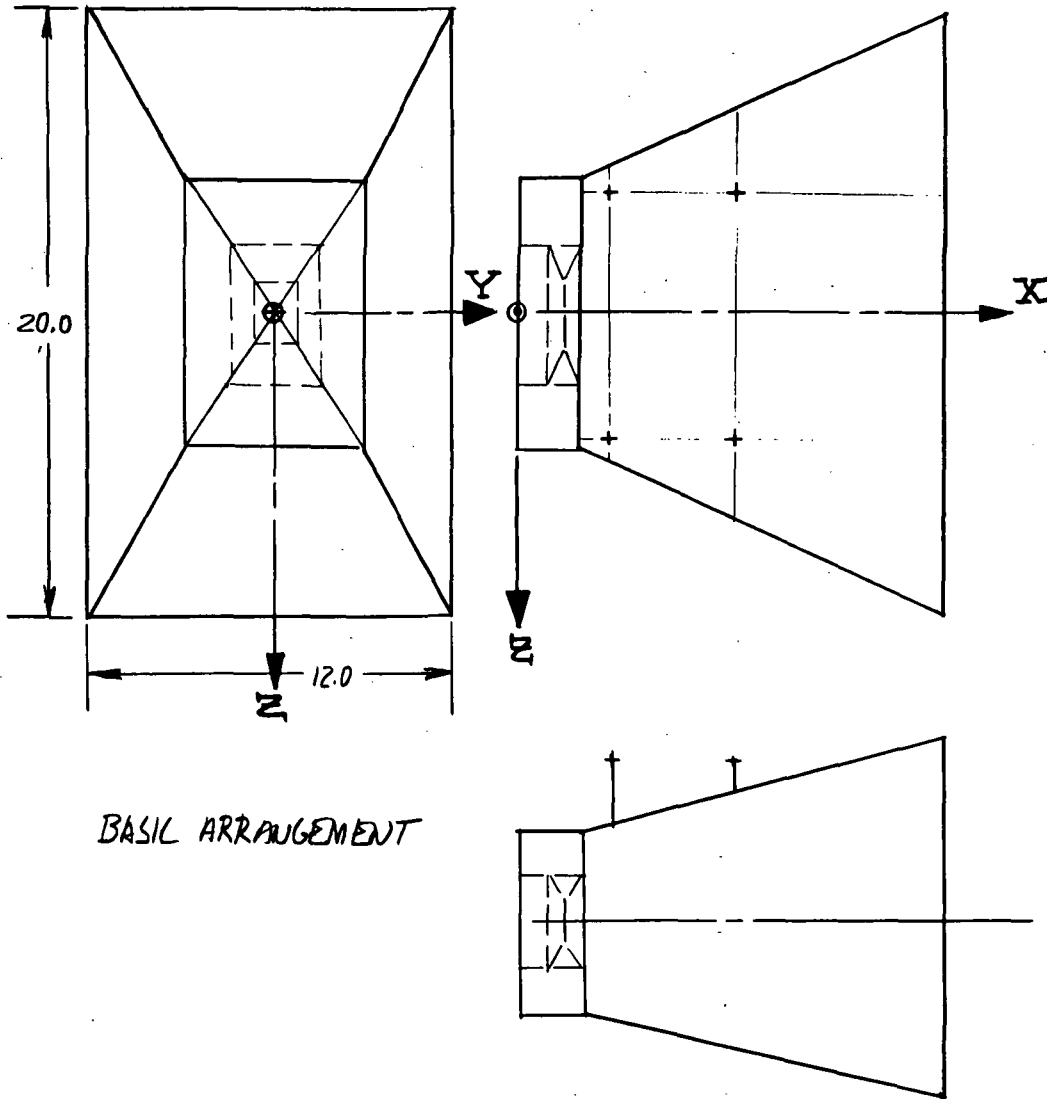
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33
DATE 21 MAR 71 PAGE 1-2
REPORT No. 7
MODEL OSS

OSS- RADIATION COOLER- BASIC DIMENSIONS-

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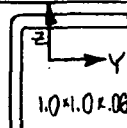
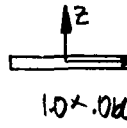
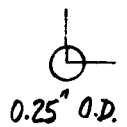
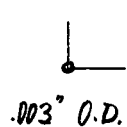
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Aerospace
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OCEANOGRAPHIC SCANNER-IMAGE PLANE SCANNER- RADIATION COOLER-

BEAM NO'S.	CROSS SECTION	AREA	A_y	A_z	I_y	I_z	$\bar{y}/I_y$	$\bar{z}/I_z$	J
1-28 (AL) 29-52 (S.S.)		.120	.060	.060	.012	.012	60.8	60.8	.00014
53-62 (AL) 63-78 (S.S.)		.060	.060	.000	.0002	.00500	1500.	100.	.00007
79-86 (S.S.) 95		.04920	.04920	.04920	.00019	.00019	658.	658.	.00038
87-94 (S.S.)		.00001	.00000	.00000	.00000	.00000	0	0	.00000

THESE ARE BASIC CROSS-SECTIONS USED TO
STRUCTURALLY MODEL RADIATION COOLER FOR
"EASE" COMPUTER ANALYSIS.

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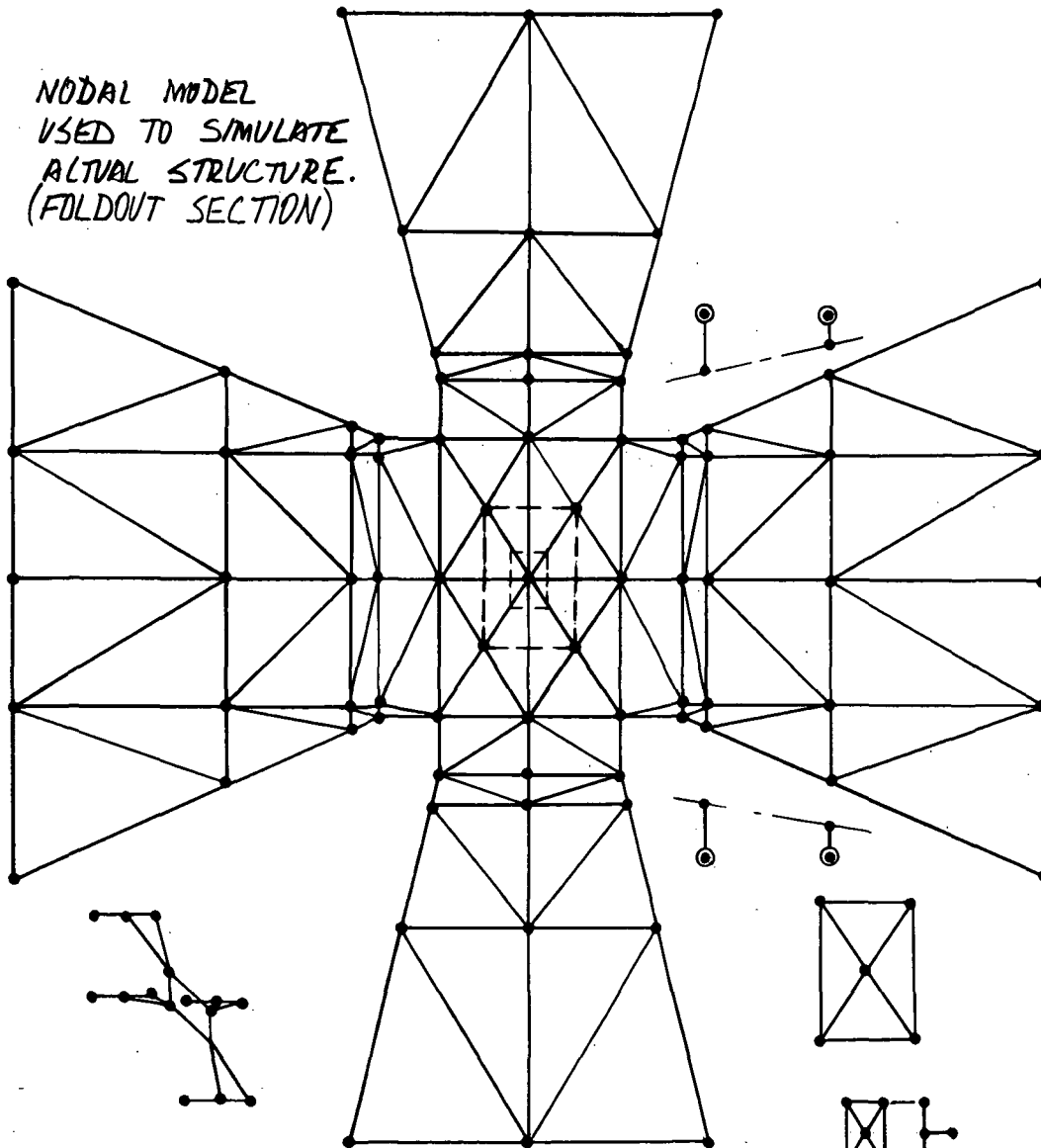
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DATE 2/11/67 ³⁵ PAGE 1-4
REPORT No. 7
MODEL OSS

OSS - RADIATION COOLER

'EASE' COMPUTER STRUCTURAL MODEL

NODAL MODEL
USED TO SIMULATE
ACTUAL STRUCTURE.
(FOLDOUT SECTION)



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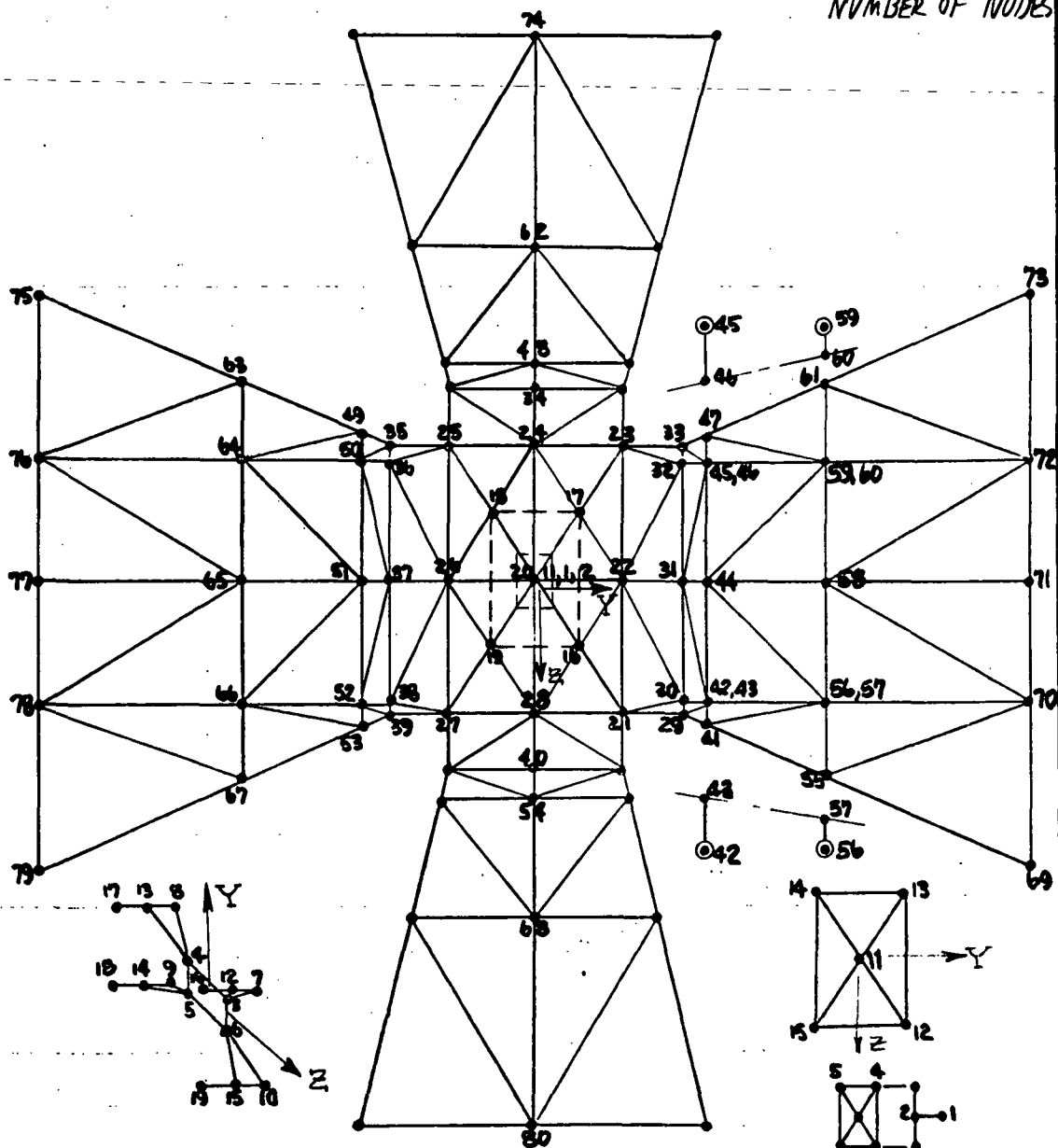


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DATE 21 MAR 71 PAGE 1-5
 REPORT No. 7
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OSS - RADIATION COOLER -
NODAL NUMBERING SYSTEM -

$NN = 80$
 NUMBER OF NODES



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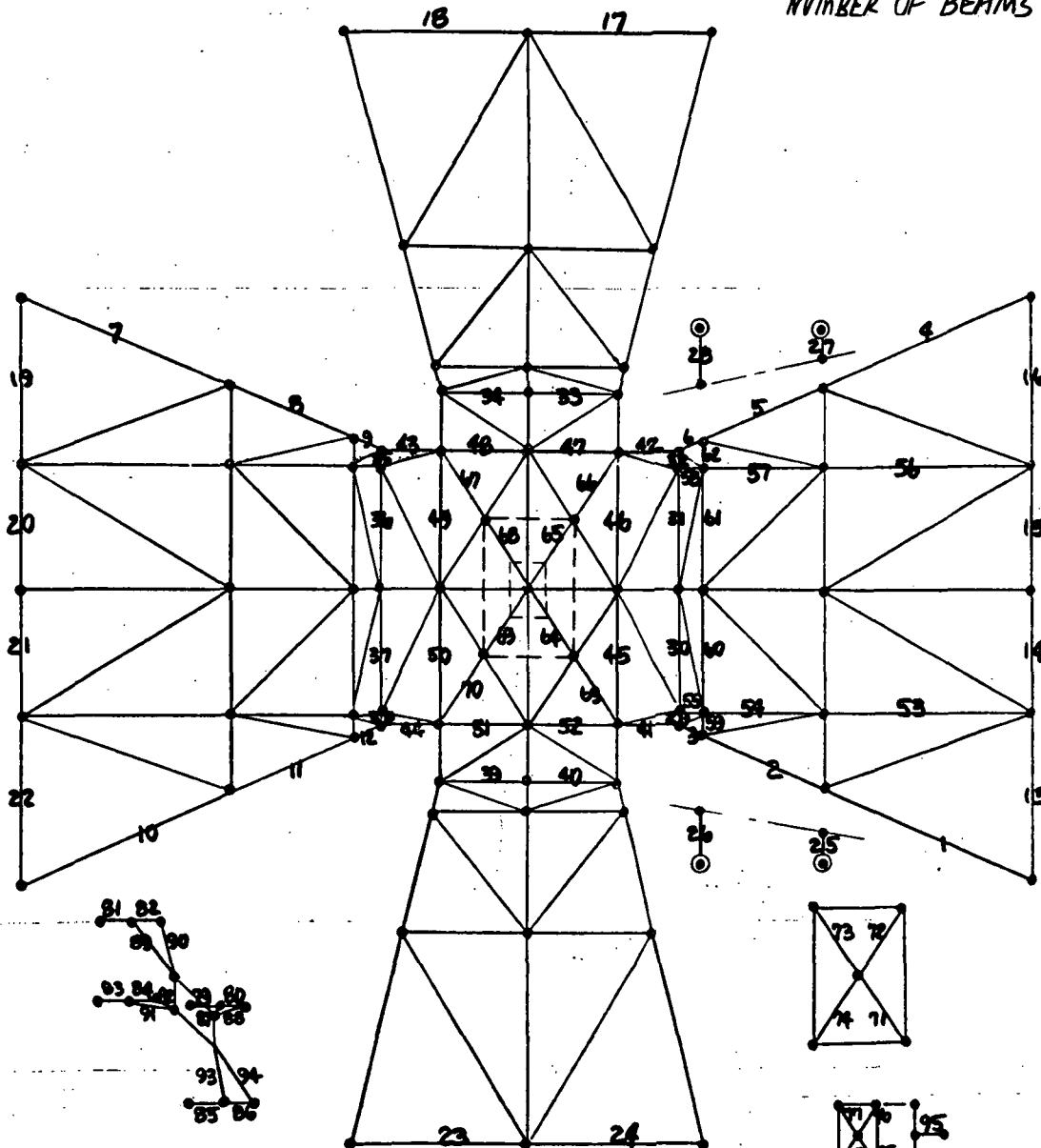


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DATE 21 MAR 77 PAGE 1-6
 REPORT No. 7
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OSS - RADIATION COOLER-
BEAM NUMBERING SYSTEM

NB = 95
 NUMBER OF BEAMS



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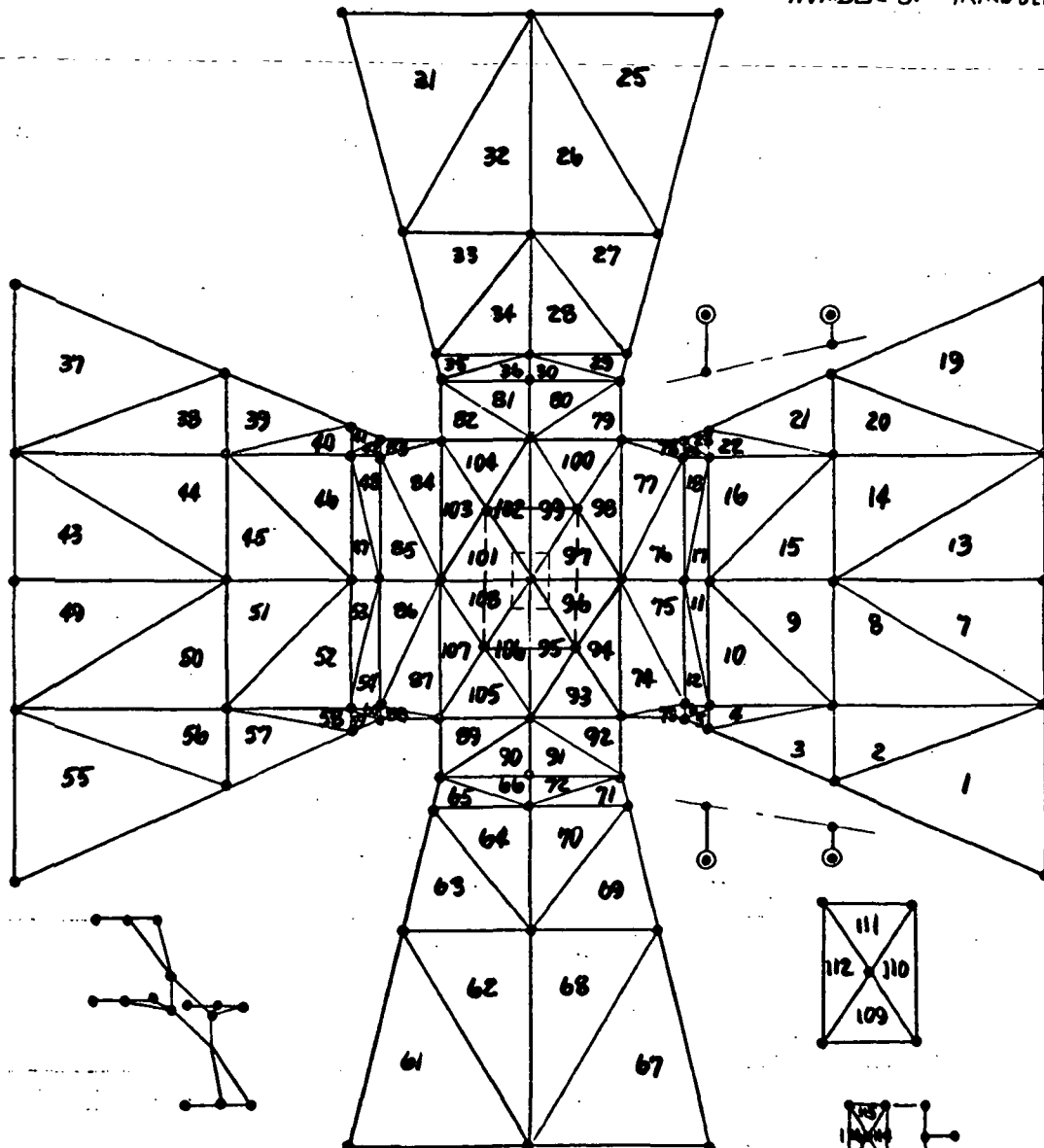


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DATE 21 MAR 71 PAGE 1-7
 REPORT No. 7
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OSS - RADIATION COOLER -
TRIANGLE NUMBERING SYSTEM

NT = 116
 NUMBER OF TRIANGLES



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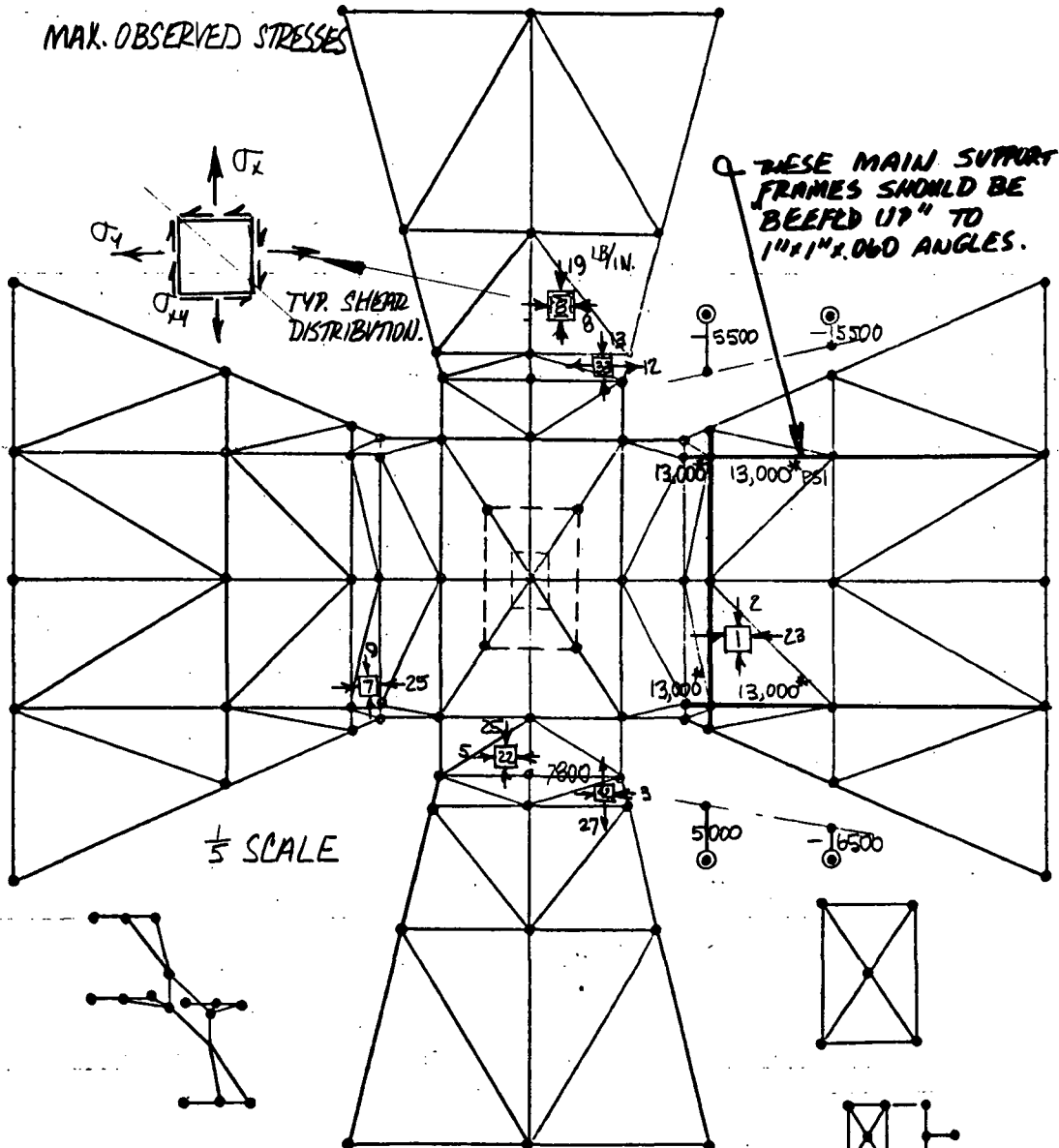
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DATE 22 MAR 71 PAGE 2-1
 REPORT No. 7
 MODEL OSS

OSS - RADIATION COOLER

LOAD CASE 5 - 20.G X + 20.G Y LOADING -

MAX. OBSERVED STRESSES



* ASSUMING FRAMES BEEFED UP TO 1 1/2" x 1" x .060 ANGLES.

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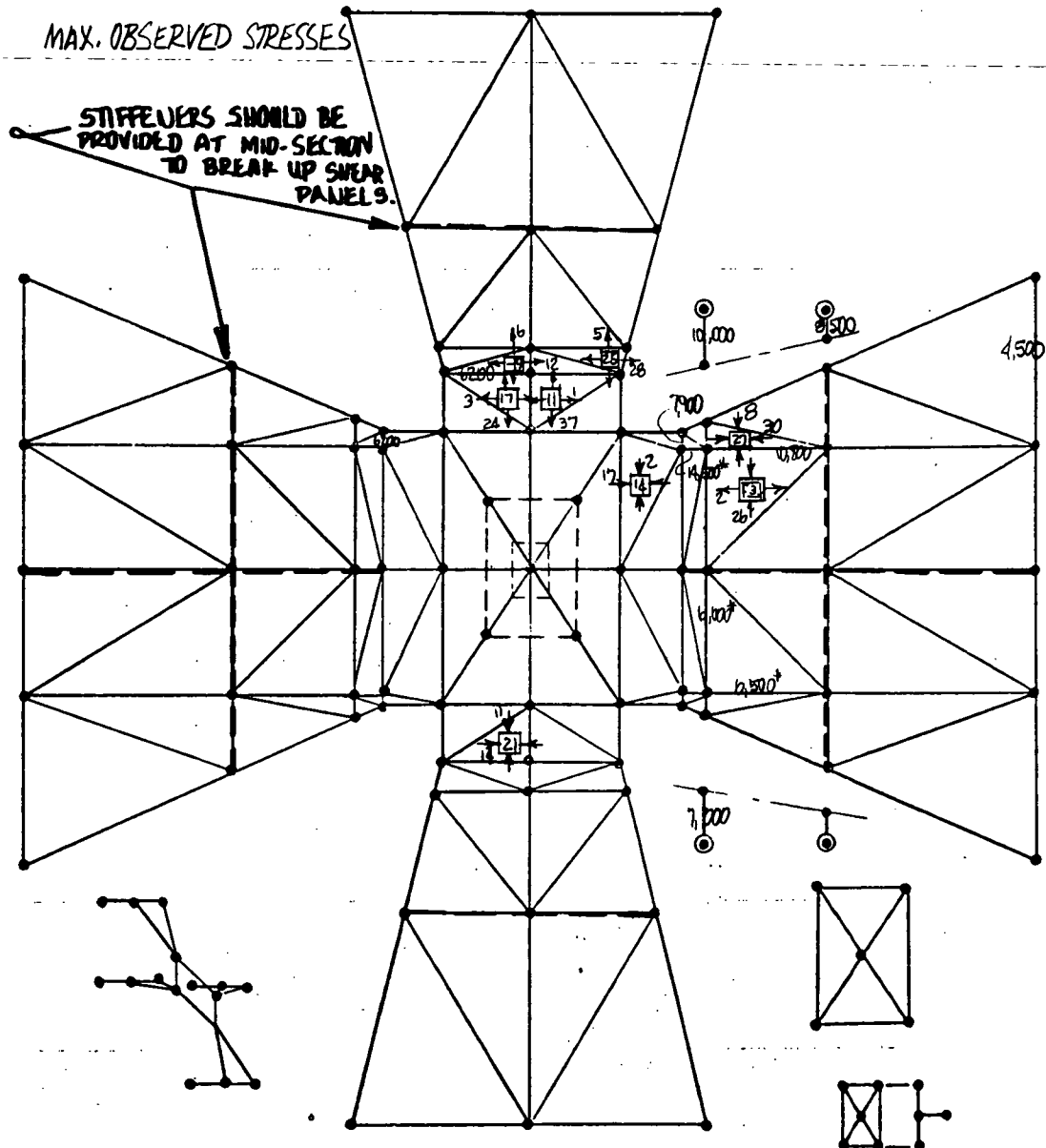


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DATE 22 MAR 71 / PAGE 2-2
 REPORT No. 7
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LOAD CASE G-: 20. G X + 20. G Z LOADING



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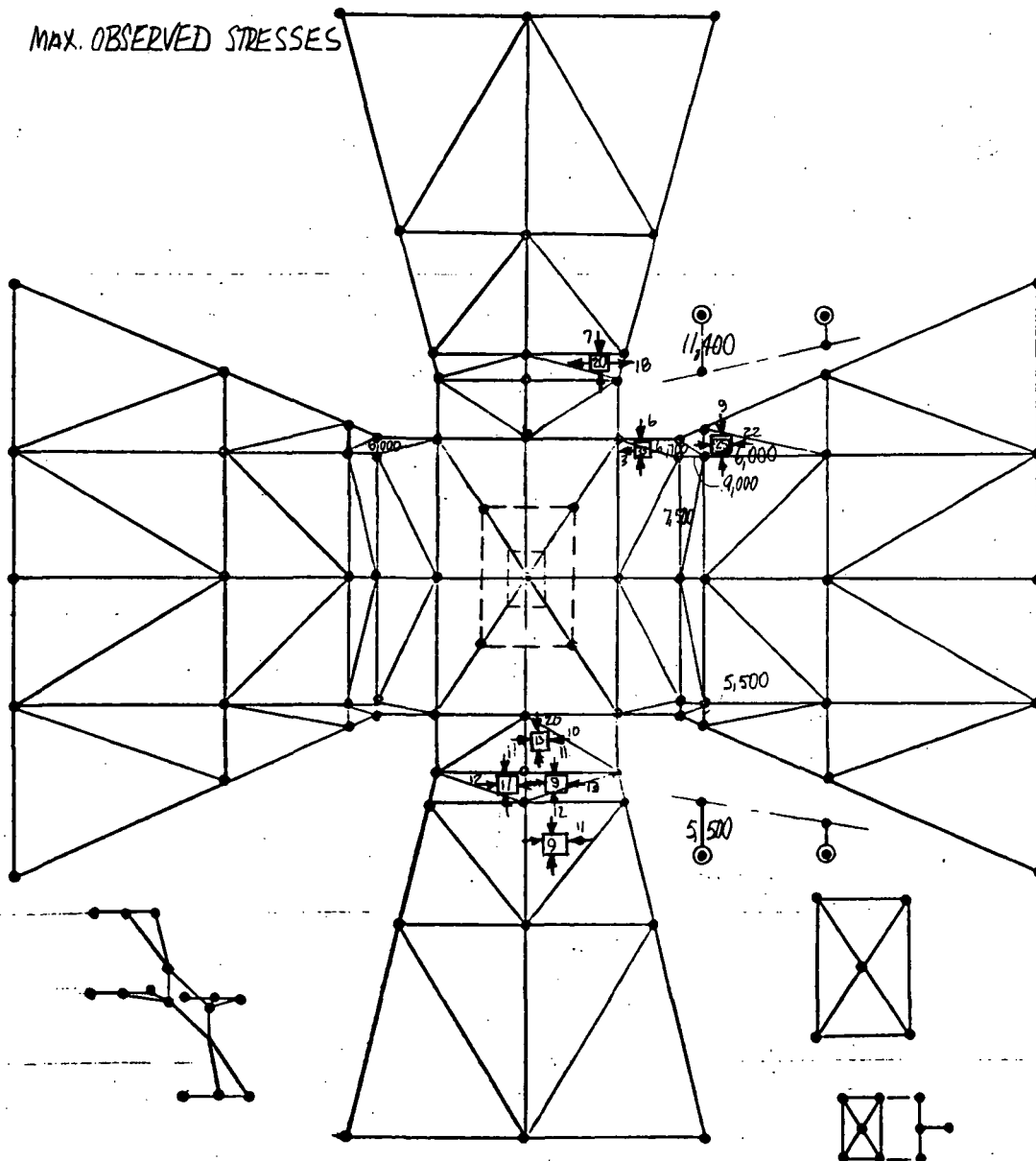
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DATE 22 MAR 71 PAGE 2-3
 REPORT No. 7
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OSS - RADIATION COOLER

LOAD CASE 7 - : 20. G Y + 20. G Z LOADING -

MAX. OBSERVED STRESSES



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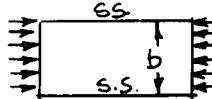
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 REPORT No. 7
 MODEL OSS

CALCULATE BUCKLING STRENGTH OF FLAT SHEET
IN COMPRESSION & SHEAR.

FOR SIMPLY SUPPORTED FLAT PLATE UNDER
COMPRESSION THE EQU. FOR ELASTIC INSTABILITY
IS APPROX. —

$$\sigma_{cr} = 3.68 E \left(\frac{t}{b}\right)^2 \quad (\text{REF PG. C.5.1-2 BRUHN})$$

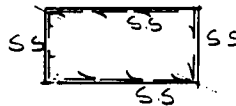
$b \equiv$ LOADED EDGE



THE CRITICAL ELASTIC SHEAR BUCKLING STRESS FOR
FLAT PLATES IS GIVEN BY —

$$\tau_{cr} = 5.06 E \left(\frac{t}{b}\right)^2 \quad (\text{REF PG. C.5.6-7 BRUHN})$$

$b \equiv$ SHORTEST EDGE



THE MARGIN OF SAFETY UNDER COMBINED SHEAR &
COMPRESSION IS GIVEN BY — (PG. C.5.9 FOR GRAPH)

$$M.S. = 2 \left[R_c + (R_c^2 + 4R_s^2)^{1/2} \right]^{-1} - 1$$

↑ THESE ARE CALCULATIONS PERFORMED TO
DETERMINE MARGIN OF SAFETY OF SKIN
PANELS ON RADIATION COOLER.

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DATE 22 MAR 71 PAGE 2-5
 REPORT No. 7
 MODEL OSS

ASSUMING SHEAR PANELS TO BE BROKEN UP INTO SECTIONS AS ILLUSTRATED ON PAGE 2-2, MAX. DIMENSIONS OF ALUMINUM PANELS UNDER CONSIDERATION WOULD BE APPROX. 6" x 7" (CONSERVATIVELY 7" x 7" WILL BE ASSUMED).

HENCE, ALLOWABLE COMPRESSIVE BUCKLING STRESS WILL BE—

$$\sigma_{cr} = (3.68)(10^7) \left(\frac{.050}{7} \right)^2 = 1875 \text{ PSI.}$$

ALLOWABLE SHEAR BUCKLING STRESS WILL BE—

$$\tau_{cr} = (5.06)(10^7) \left(\frac{.050}{7} \right)^2 = 2575 \text{ PSI.}$$

FOR THE STAINLESS STEEL SHEETS THE PANELS ARE APPROX. 2" x 6".

HENCE, ALLOWABLE COMPRESSIVE BUCKLING STRESS WILL BE—

$$\sigma_{cr} = (3.68)(10^7) \left(\frac{.060}{6} \right)^2 = 3680 \text{ PSI.}$$

ALLOWABLE SHEAR BUCKLING STRESS WILL BE—

$$\tau_{cr} = (5.06)(10^7) \left(\frac{.060}{6} \right)^2 = 5060 \text{ PSI.}$$

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DATE 23 NOV 64 PAGE 2-6
 REPORT No. 7
 MODEL QSS

THE FOLLOWING LIST IS A TABULATION OF WHAT APPEAR TO BE THE WORST STRESS CONDITIONS FROM THE "EASE" COMPUTER RUN UNDER COMBINED 20.6. ULT LOAD CONDITIONS (ILLUSTRATED PGS 2-1, 2, 3)

LOAD TRNGL CASE NO.	q_{xx}	q_{yy}	q_{xy}	σ_x	σ_y	τ_{xy}	σ_{cz}	τ_{cz}	M.P.x	M.S.y
5 10	2	23	1	40	460	20	1875	2575	HIGH	HIGH
28	19	8	8	380	160	160			"	"
29	13	12	33	260	240	660			"	"
54	9	25	7	180	500	140			"	"
71	27	3	42	540	60	840			.98	"
6 16	26	2	3	520	40	60			HIGH	"
22	8	30	27	160	600	540			"	1.07
29	5	28	5	100	560	100			"	HIGH
36	6	12	19	120	240	380			"	"
7 22	9	22	25	180	440	500			"	"
29	7	18	20	140	360	400			"	"
66	11	12	11	220	240	220			"	"
70	12	11	9	240	220	180			"	"
72	11	13	9	220	260	180			"	"
5 90	5	25	22	83	417	367	3680	5060	HIGH	HIGH
6 80	37	1	11	616	16	183			"	"
81	24	3	17	400	50	284			"	"
90	11	14	21	163	233	350			"	"
7 78	6	3	33	100	50	550			"	"
91	10	20	13	167	334	217			"	"

AS CAN BE SEEN FROM ABOVE TABULATIONS
 THE MINIMUM MARGIN OF SAFETY IS
 APPROXIMATELY 0.98.

APPENDIX F

THERMAL ANALYSIS

F.1 RADIATOR DESIGN AND PERFORMANCE

The basic radiator sizing and temperature performance estimates for all conventional radiator configurations anticipated for OSS component thermal control were developed from a common set of equations and earth view factors. All of these radiators have a vertical orientation (the normal to the radiator surface is at a right angle to the spacecraft radius vector) to minimize the earth view factor and maintain low direct earth-emitted and earth-reflected solar heat loads. The OSS orbital parameters provide radiator-earth view factors as shown in Figure F-1 where the attitude angle (γ) has values from 0° to 90° ($\gamma + 0^\circ$ is a horizontal radiator). With the combination of low radiator-earth view factors and the opportunity to shield or orient the radiators from direct solar heat load, all OSS applications result in vertically oriented radiators of minimum size and viewing normal to the orbital plane.

Figure F-2 presents the basic radiator temperature performance characteristics as a function of radiator absorptance (α) and emittance (ϵ) characteristics for vertically oriented radiators and OSS orbital conditions. The total heat load to the radiator is composed of earth-emitted and earth-reflected solar heat. The information was developed from the following basic equation for any arbitrary orbiting radiator surface:

$$q_e + q_r + q_i + q_s = \epsilon_r \epsilon_e F_e + \epsilon_r (1 - F_e) A \sigma T_r^4$$

where:

- q_e = direct earth-emitted heat load
- q_r = earth-reflected solar heat load
- q_i = arbitrary internal heat load
- q_s = direct solar heat load
- ϵ_e = earth emissivity (0.9)
- ϵ_r = radiator emissivity

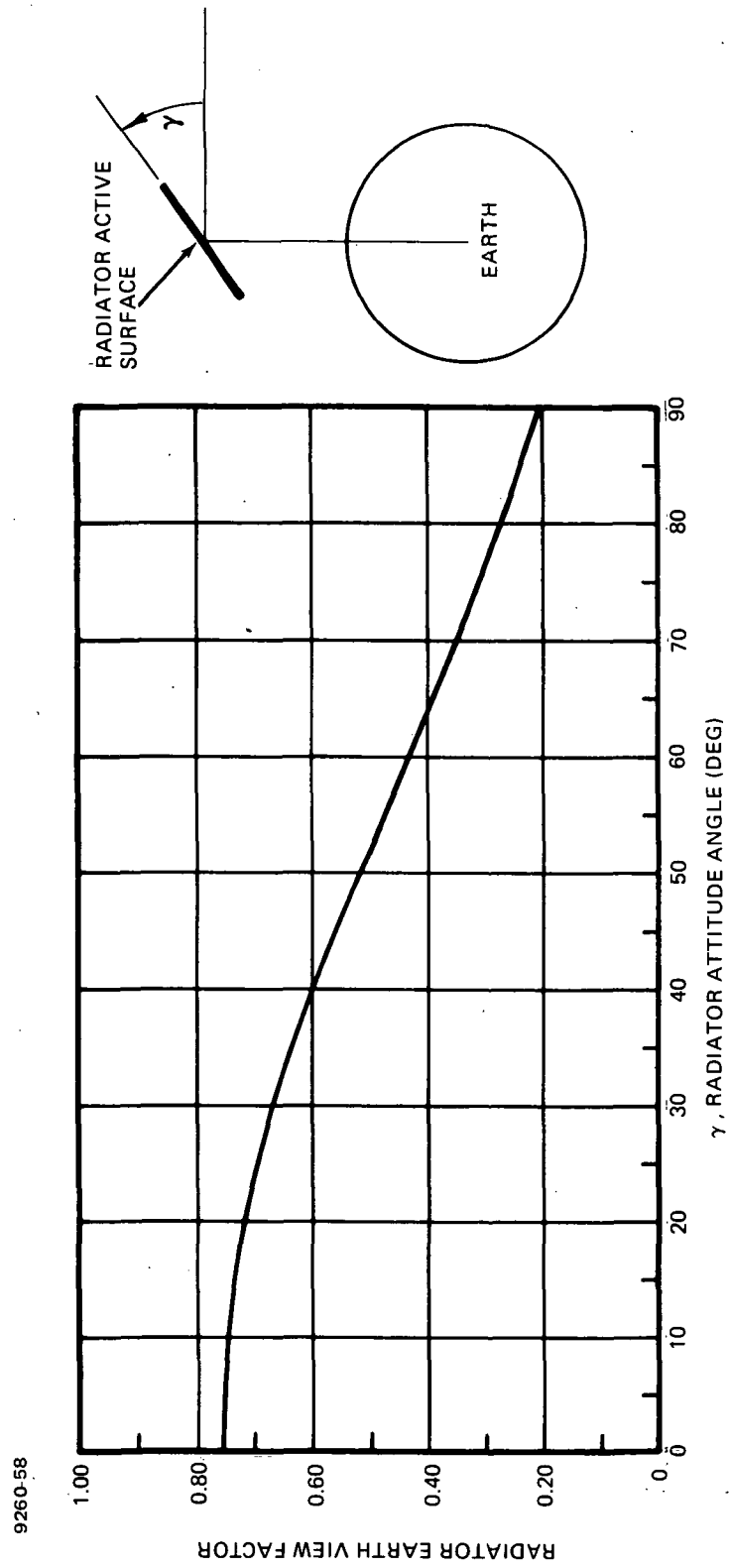


Figure F-1 Radiator Surface Earth View Factor - 500 n. mi Orbit

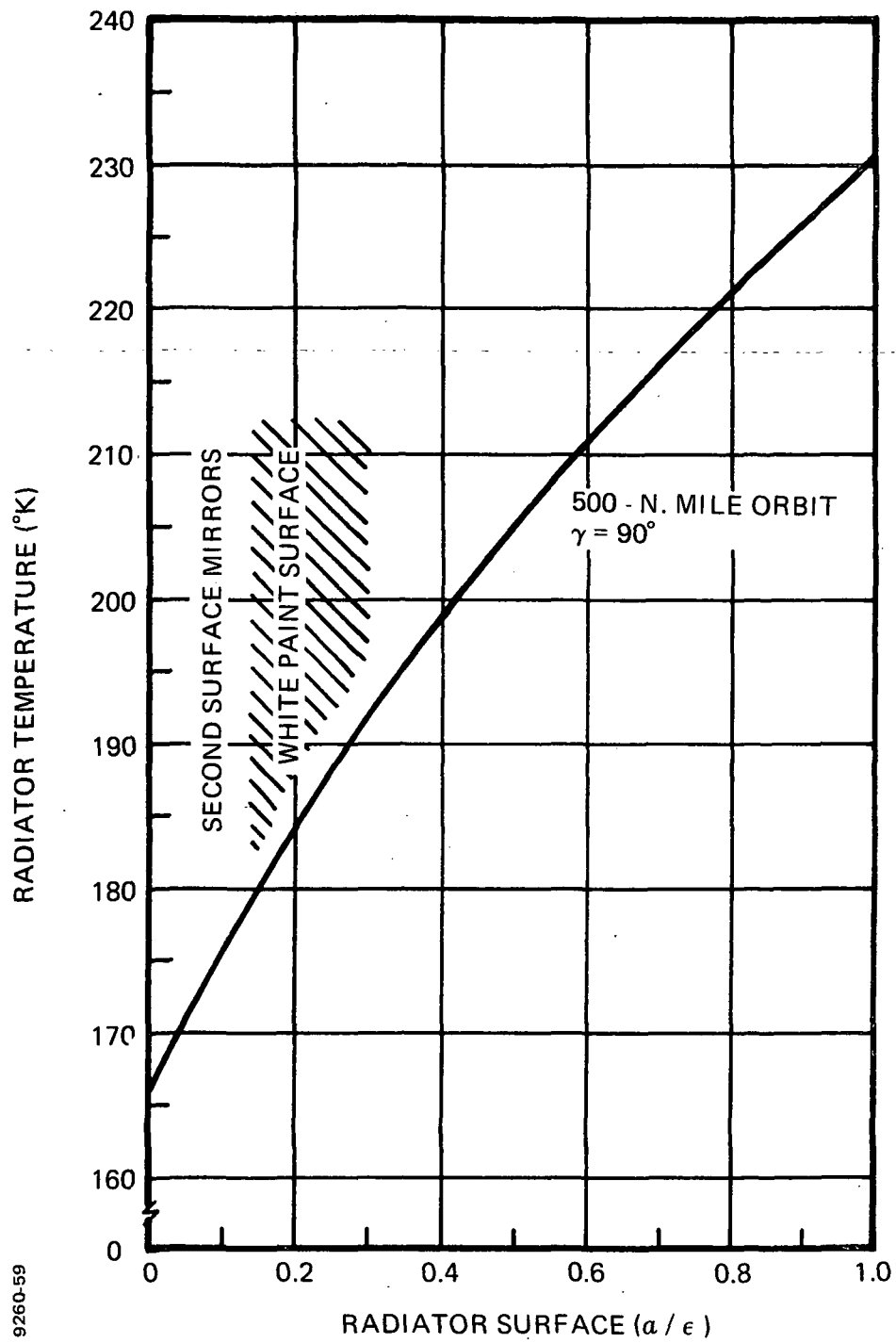


Figure F-2 Basic Radiator Temperature Performance as a Function of Surface Absorptance to Emittance Ratio

F_e = radiator to earth view factor

A = radiator surface area

σ = Stefan-Boltzmann constant (0.1714×10^{-8} Btu/hr-ft² - °R⁴)

T_r = radiator absolute temperature.

The earth-reflected solar heat load was calculated from the equation:

$$q_r = \alpha A F_e S$$

where: α = earth albedo (0.4 typical value)

α = radiator surface absorptance

A = radiator surface area

F_e = radiator to earth view factor

S = solar heat flux (442 Btu/hr-ft²)

and the earth-emitted heat from the equation

$$q_e = \epsilon_e \epsilon_r A F_e \sigma T_e^4$$

where: ϵ_e = earth emissivity (0.9)

ϵ_r = radiator emissivity

A = radiator area

F_e = radiator to earth view factor

σ = Stefan-Boltzmann constant

T_e = earth mean temperature (251°K).

The minimum radiator temperature possible is identified in the figure by the $\alpha/\epsilon = 0$ point and is the minimum allowable radiator temperature without shielding from direct earth-emitted heat load. It is essentially a "nighttime" orbit condition. The information contained in Figure F-2 is basic to any conventional radiator design under the external heat loads, earth view factor,

and orbit geometry previously discussed. It is obvious that the most desirable radiator absorptance and emittance characteristics are those which result in low α/ϵ values. Materials possessing low α/ϵ values are required for minimum area radiators.

For OSS requirements, second surface mirror radiators were selected as the basic design. These mirrors, composed of vacuum-deposited silver on fused silica, have α/ϵ values of 0.1 or less in a nominal condition. With proper cleanliness and fabrication procedures, α/ϵ values as low as 0.07 to 0.072 are realistic even though the higher value is used as the more common design value. Reasons for selecting the second surface mirror radiators were:

1. Excellent long-term stability in space environment
2. Low α/ϵ values
3. Low weight
4. Readily applied to radiator substrate material.

The final sizing of each radiator surface is dependent upon the individual subsystem heat load, design operating temperature, and thermal isolation requirements. Estimates of subsystem heat loads are based upon several sources and are considered to be conservative. Further refinement is not possible without a more detailed design study. The effectiveness of the insulation and isolation techniques has been estimated based upon experience with ALSEP Program test and flight hardware results and is considered to be realistic. Each radiator design is described in the following sections of this appendix.

F.2 IR BAND DETECTOR RADIATOR

The IR band detector radiator is designed to accommodate a very small detector array heat load, and in addition, the heat leaks associated with the support structure, insulation, and electrical leads are considerations. The total heat load rejected by the IR band radiator is estimated to be approximately 0.54 W and is broken down as follows:

	<u>Watts</u>
1. Detector array self-heating	0.002
2. Detector lead heat leak	0.085

3.	Optical path heat load	0.100
4.	Low conductance supports heat leak	0.100
5.	Cold structure support and insulation heat leak	<u>0.250</u>
Total Radiator Heat Load		0.537

Of the total heat leak to the radiator, only 0.187 W (or 35%) is directly attributed to the detector array and associated optics. The radiator area was selected for the total heat load from the information presented in Figure F-3 and considerations of the space available for radiator mounting. A radiator area of 0.333 sq. ft. was selected as a compromise between temperature/area/mounting requirements. The ΔT (4°K) existing between the detector array upper temperature limit (195°K) and the daytime radiator temperature is considered to be a minimum for satisfactory operation. Any value less than this is considered unrealistic since the ΔT must occur between the detector array and the radiator surface and will be primarily associated with the heat pipe cold structure arrangement.

Additional cooling capacity for the IR band detector array could be realized only by reduction in power dissipated or increased in the radiator since, because of the location of the detector array within the spectrometer, reduction of power dissipated does not appear feasible, leaving increased radiator size as the only alternative. With the present radiator mounting arrangement, an additional 0.1 to 0.2 sq ft of radiator area is possible by reconfiguration, if necessary. The study configuration does show the feasibility for obtaining the required cooling capacity using a conventional radiator system. The radiator study shows that detector array operating temperatures of 175°K are unrealistic with a conventional design unless elaborate shielding is developed to eliminate both the earth-emitted and the earth-reflected heat loads. Such a configuration is a basic passive solar design, and the OSS configuration is not compatible for two such coolers. An alternative to incorporate the IR band detector array into the same passive cooler envelope as used for the thermal band detector is unrealistic due to the unacceptable high heat load which would result with the present optical layout. The proposed IR band detector cooling arrangement does represent a reasonable configuration using a conventional radiator of minimum cost and complexity. Further study and design effort would provide additional refinements to the concept for application to a flight system.

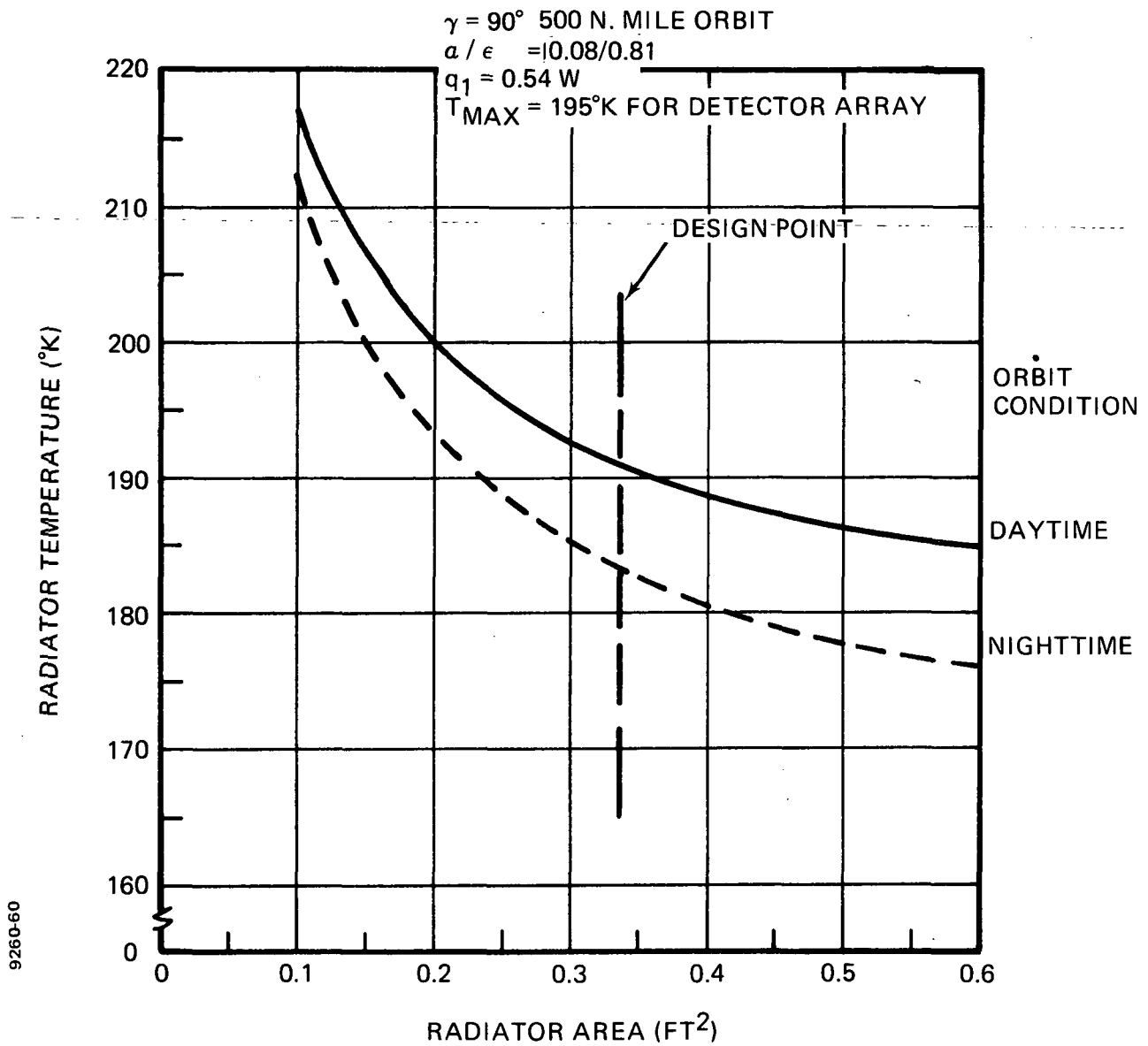


Figure F-3 IR Band Second Surface Mirror Radiator Performance

F.3 THERMAL REFERENCE SOURCES RADIATOR

The two blackbody thermal reference sources require a radiator configuration similar to that used for the IR band detector array in that the sources are remotely located within the OSS optics package and have a restricted envelope for mounting. The radiator system for the thermal reference sources must accommodate relatively high heat loads since active heating elements are employed in the blackbody design; however, radiator operating temperatures are somewhat flexible within the limits imposed by the source temperatures. A major design feature in the blackbody thermal control concept is the use of a single radiator to heat sink both sources.

To implement the radiator system, the heat flow in each leg upstream of the common low temperature heat pipe must be balanced by proper matching of the leg conductances. A schematic diagram of the blackbody thermal control concept with each leg identified by blackbody temperature requirements is shown in Figure F-4. The temperature difference between the 260°K blackbody and the 300°K blackbody must be accounted for in the leg conductances. Assuming a radiator temperature of 250°K and an isothermal heat pipe, the total temperature differences in each leg are:

$$\Delta T_1 = 260 - 250 = 10^\circ \text{K}$$

$$\Delta T_2 = 300 - 250 = 50^\circ \text{K}$$

Leg conductances are then defined by:

$$C_1 = \frac{\Delta q_1}{\Delta T_1}$$

$$C_2 = \frac{\Delta q_2}{\Delta T_2}$$

where: q = leg heat flow

c = leg thermal conductance.

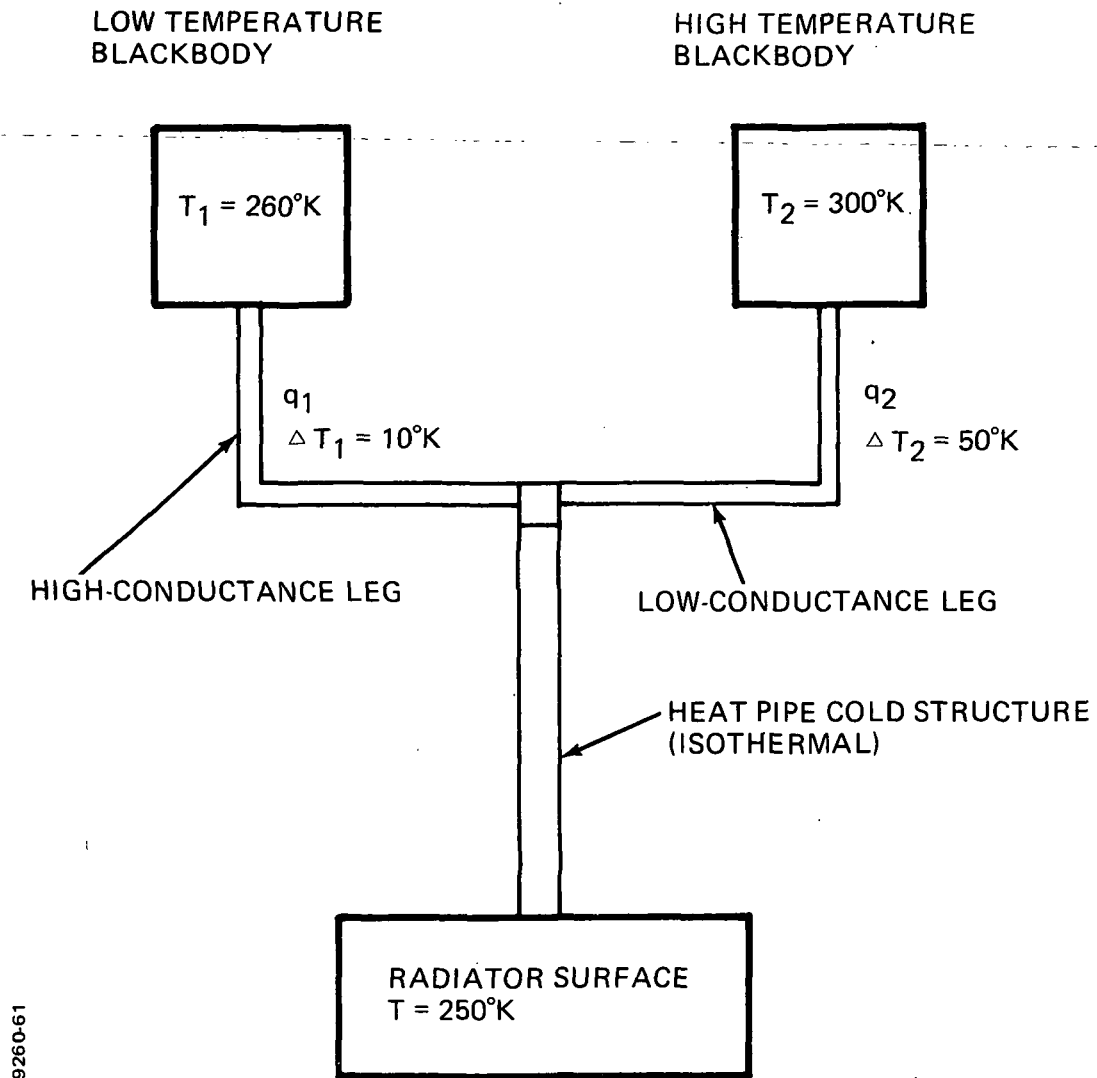


Figure F-4 Thermal Reference Sources Radiator System Schematic Diagram

C is also defined by:

$$C = \frac{kA}{\ell}$$

where:

k = material thermal conductivity

A = heat flow path cross-section area

ℓ = heat flow path length.

The matching criteria must be based upon the heat flow to be allowed in each leg. For example, if the heat flows are to be equal then relative conductances are defined by:

$$\frac{C_1}{C_2} = \frac{\Delta T_2}{\Delta T_1}$$

or written as:

$$\frac{k_1 A_1}{\ell_1} \frac{\ell_2}{k_2 A_2} = \frac{\Delta T_2}{\Delta T_1}$$

Assuming $\ell_1 = \ell_2$, then:

$$\frac{k_1 A_1}{K_2 A_2} = \frac{\Delta T_2}{\Delta T_1}$$

Substituting for ΔT_1 and ΔT_2 :

$$\frac{k_1 A_1}{k_2 A_2} = \frac{50}{10} = 5.0$$

Both the material k value and heat flow path area can be selected to achieve the ratio of 5:0. Leg lengths also may be variables if desired; however, the lesser number of variables is preferred. A feasible combination would be legs of dissimilar materials and the same heat flow path area. Aluminum and common steel are two acceptable materials since their thermal conductivities are of the proper ratio, i. e., approximately 100/20. Considerable flexibility exists in the matching, depending upon the heat flow criteria selection. For reasons of interchangeability, an equal heat flow is highly desirable.

The radiator size is based upon a nominal 4-W dissipation level from the blackbodies, and associated heat leaks as a total value. This is considered to be relatively conservative, since the heater power consumption will not be continuous but intermittent as required to maintain blackbody temperature. The radiator system must be capable of a considerably higher heat rejection rate to provide good blackbody temperature stability. The actual blackbody heat leak and dissipation level is estimated to be of the order of 1.0 to 1.5 W under normal operating conditions. The heaters automatically supply the difference on demand to maintain the blackbody set temperature and differential.

The estimated temperature performance of the blackbody radiator system is presented in Figure F-5 for a 0.33-sq ft radiator surface area. The radiator is identical in dimensions and construction to the IR band detector radiator and is mounted in the same structure beneath the thermal band passive cooler. Low conductance supports are used to prevent mutual interchange between radiators. Because of the relatively high thermal loading, the "day-night" temperature swing of the blackbody radiator is approximately 2°K at the nominal operating condition. This low value also contributes to good temperature stability of the blackbodies.

F.4 ELECTRONICS SUBSYSTEM

The thermal control of the electronics subsystem uses a phase change material (PCM) radiator system and multilayer superinsulation blankets to maintain near constant temperatures within the electronics module throughout an orbit. The mounting of the electronics module subjects the exterior surfaces to a variety of solar and earth related thermal loading conditions at any given point in the orbit. The use of multilayer superinsulation blankets minimizes the amount and variation in these heat loads which penetrate to the module structure; however, they are of sufficient importance to require incorporation into the electronics subsystem thermal analysis and PCM radiator design.

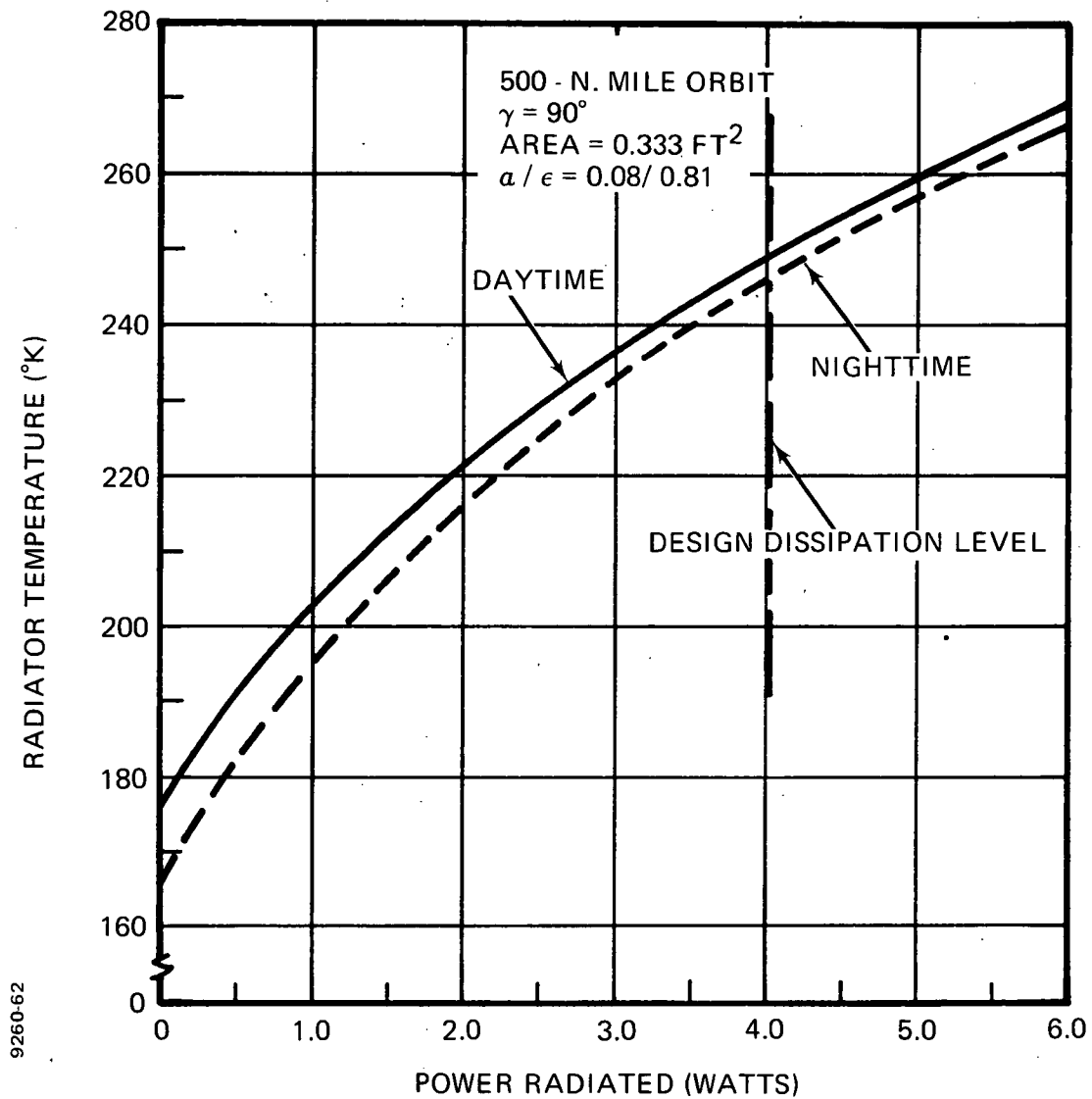


Figure F-5 Thermal Reference Sources Radiator Performance

The primary heat load in the design of the PCM radiator is the average power dissipation in the electronics module. At the nominal power consumption of 120 W, the average dissipation for the PCM radiator is calculated from the following equation:

$$q_e = q \left(\frac{t}{t_o} \right)$$

where:

q_e = average electronic dissipation

q = nominal power consumption

t = power consumption time

t_o = orbit period.

For the OSS electronics subsystem:

$$q_e = 120 \times \frac{20}{103} = 23.30 \text{ W}$$

In addition to the average electronic dissipation, the effects of multilayer superinsulation and electrical lead heat leaks were also estimated. With assumed α/ϵ characteristics of 0.2/0.37 for the multilayer blankets, the net heat transfer through these surfaces was estimated for a nominal interior temperature of 293°K. The thermal conductivity value (k) of the multilayer blankets was assumed to vary from 10^{-3} Btu/hr-ft² - °R-ft for a sunlight condition to 10^{-4} Btu/hr-ft² - °R-ft for a nighttime condition.

Since the majority of the multilayer blanket is not in direct sunlight, the net heat leak for both the day and night orbit conditions results in a decreased radiator heat load. Heat leak values of -2.4 W for the day condition and approximately -3.0 W for the night condition were estimated to exist due to the multilayer blanket exposure. The net effect of all heat leaks is to lower the average electronic dissipation level for radiator design to a day condition of 22 W and a night condition of 21 W. Those heat leaks attributed to earth-related heat loads on the radiator surface (second surface mirrors: $\alpha/\epsilon = 0.08/0.81$) are also included in the following heat load summary:

Heat Source	Day (W)	Night (W)
Electronics (avg)	23.3	23.3
Multilayer blanket	-2.4	-3.0
Electric leads	0.0	-0.5
Radiator surface	1.4	0.7
Misc	-0.3	+0.5
Net Heat Load	22.0	21.0

The day-night heat load estimates result in the radiator temperature performance of Figure F-6 as a function of average heat dissipation and a radiator area of 0.958 sq ft. The day-night temperature swing is a nominal 2°K under all conditions. The information presented in this figure indicates the radiator temperature will be at the lower temperature limit (283°K) of the electronics module.

The PCM is used to store the majority of the heat released during the power-on portion of the electronics duty cycle. This is achieved by the melting of the PCM through utilization of its heat of fusion characteristics. To function properly, the amount of PCM necessary need not be greater than that which can be solidified during the power-off portion of the orbit. The total heat released is calculated by:

$$E = \left(\frac{t}{60} \right) q$$

where:

E = heat released

t = power-on time

q = nominal power consumption.

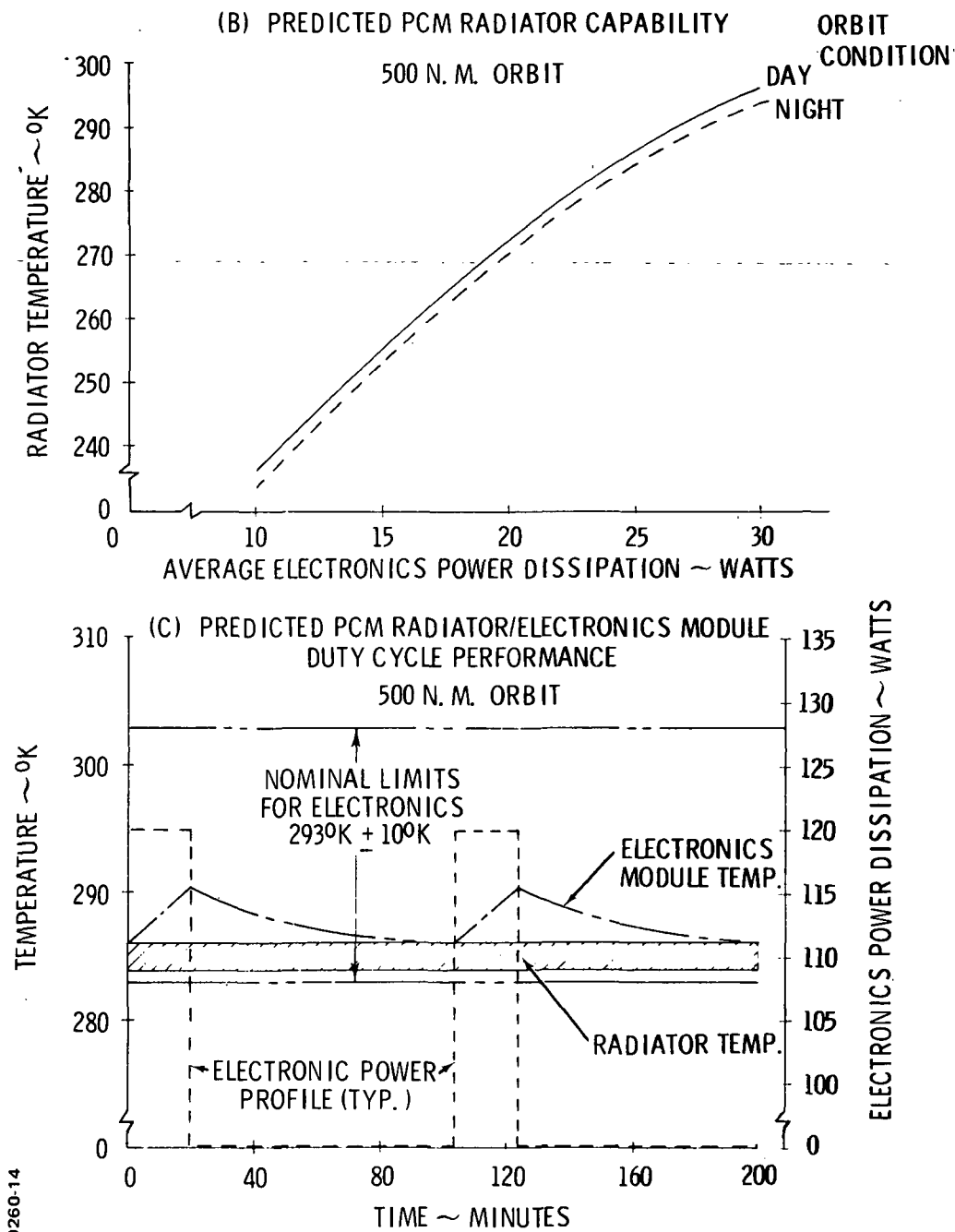


Figure F-6 Electronics—PCM Radiator Performance

For the OSS and a 120-W power consumption level, the total heat releases is:

$$E = \frac{20}{60} \times 120 = 40 \text{ W-hr or } 136.5 \text{ Btu}$$

The amount of heat involved in the solidification process is:

$$E_s = \frac{(t_o - t)}{60} q_r$$

or

$$E_s = \frac{83}{60} \times 22.0 \times 3.413 = 104 \text{ Btu}$$

where:

E_2 = heat released during solidification of PCM

t_o = orbit period

t = power on time

q_r = avg radiator dissipation.

The difference between heat values ($136.5 - 104.0 = 32.5 \text{ Btu}$) contributes to the temperature excursions of the entire electronics subsystem module components and structure. The PCM weight is readily determined from the heat and typical heat of fusion value by;

$$W_{\text{pcm}} = \frac{104}{100} = 1.04 \text{ lb}$$

The weight of the PCM is the maximum amount which can be solidified on a continuing basis from orbit to orbit. Since some excursions in electronics module temperature are allowable, the amount of PCM should be no greater than this value. The PCM must have a melting temperature higher than the nominal

radiator temperature and within the temperature excursions allowed the electronics module. Several candidate PCMs are available which fit the OSS radiator requirement for heat of fusion and melting point temperature characteristics. Characteristics of typical PCMs are presented in Table F-1 and illustrate the wide range available.

TABLE F-1

PHASE CHANGE MATERIAL SELECTION

Phase Change Material	Chemical Formula	Density (lb/cu in.)	M. Point ($^{\circ}$ F) ($^{\circ}$ K)	Heat of Fusion (Btu/lb)
1. Tridecane	$C_{13}H_{28}$	0.0274	21 (266.9)	96
2. Tetradecane	$C_{14}H_{30}$	0.0276	42 (278.5)	98
3. Hexadecane	$C_{16}H_{34}$	0.0279	66 (291.9)	101
4. Octadecane	$C_{18}H_{38}$	0.0279	82 (300.8)	105
5. Elcosane	$C_{20}H_{42}$	0.0280	99 (310.2)	107
6. Tetracosane	$C_{24}H_{50}$	0.0281	124 (324.1)	109

Construction of the PCM radiator (Figure F-7) is designed to minimize core, void fraction problems, and loss of apparent thermal conductivity of the radiator. The many parallel conductive paths available using an aluminum honeycomb core filled with PCM provides greater operating efficiency and tends to alleviate any zero gravity induced anomalies in surface wetting or singular PCM accumulation due to surface tension. The basic construction with the PCM-filled honeycomb closed off by aluminium plates should eliminate these problems as well as those associated with PCM contraction and expansion.

RADIATOR DESCRIPTION AND ELECTRONICS MODULE CONSTRUCTION PROFILE VIEW

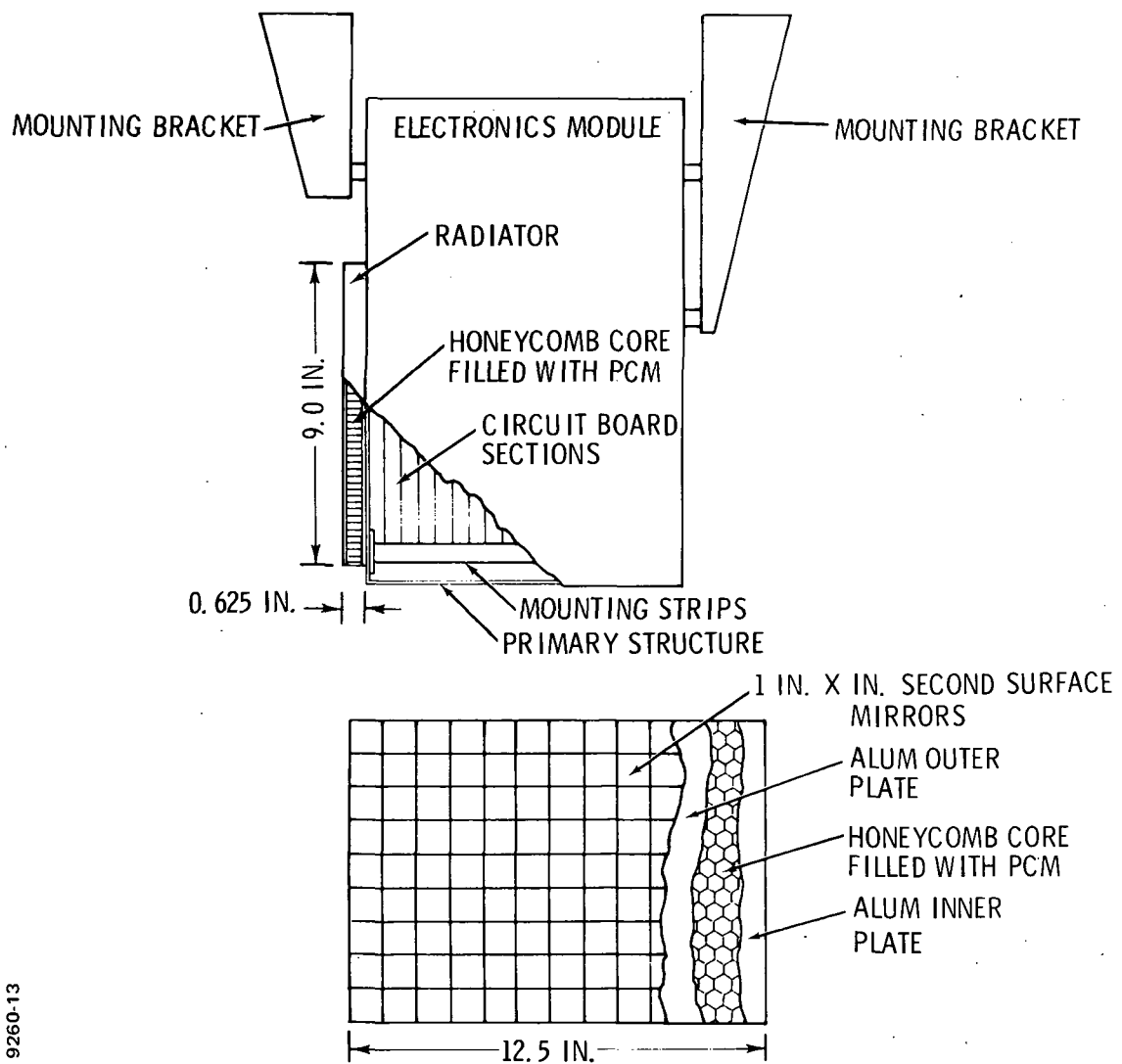


Figure F-7 Electronics Module Radiator

To carry the heat load from the interior of the electronics module to the radiator, the circuit boards are mounted in strips and connectors which are fastened to the outer aluminum shell of the module. Thus, the entire module structure is a heat transfer path between the circuit boards and the radiator subsystem. It is estimated that the thermal conductance of this arrangement is 5.3 Btu/hr/°F. The configuration consists of the equivalent of six strips of aluminum (7/16 x 7/16 x 9 1/4 in. long) and the outer aluminum shell (3/32 in. thick) provides both series and parallel heat transfer paths between circuit boards and the radiator. One wall of the shell is integral to the PCM radiator and all circuit board mounting strips also butt against the wall. The module configuration is presented in Figure F-8 and shows the typical heat flow path available.

F.5 THERMAL BAND PASSIVE COOLER

The detailed analysis of the thermal band passive radiation cooler was performed using the multiple reflection technique to determine heat exchange between surfaces with specular reflection. In this analysis technique, the parameter called the exchange factor replaces the conventional view factor used in diffusely reflecting surface analysis. The exchange factor approach accounts for all radiation heat transfer between the detector radiator and all possible intervening specular surfaces. Conductive heat transfer between the radiator and the OSS instrument and ERTS spacecraft was determined by conventional methods. A major portion of the passive cooler analysis was performed using computer programs for both intermediate and final results. The description of the analysis contained within this appendix covers only the major considerations of the techniques used and the primary results. A bibliography and list of references have been included as a background to the analysis technique. (See Section F.6.)

The mathematical model of the passive cooler that was used to determine steady-state temperature performance employed the Oppenheim radiosity network with modifications to account for surface specularity upon the radiation heat transfer between surfaces. The modification replaces the conventional view factor with an exchange factor in the definition of the space resistance between radiosity nodes. The exchange factor does incorporate knowledge of the view factor in its computation. The final radiosity network used in the analysis also drew heavily upon the experience gained on the ALSEP Program relative to specular interchange effects and radiation heat transfer analysis techniques.

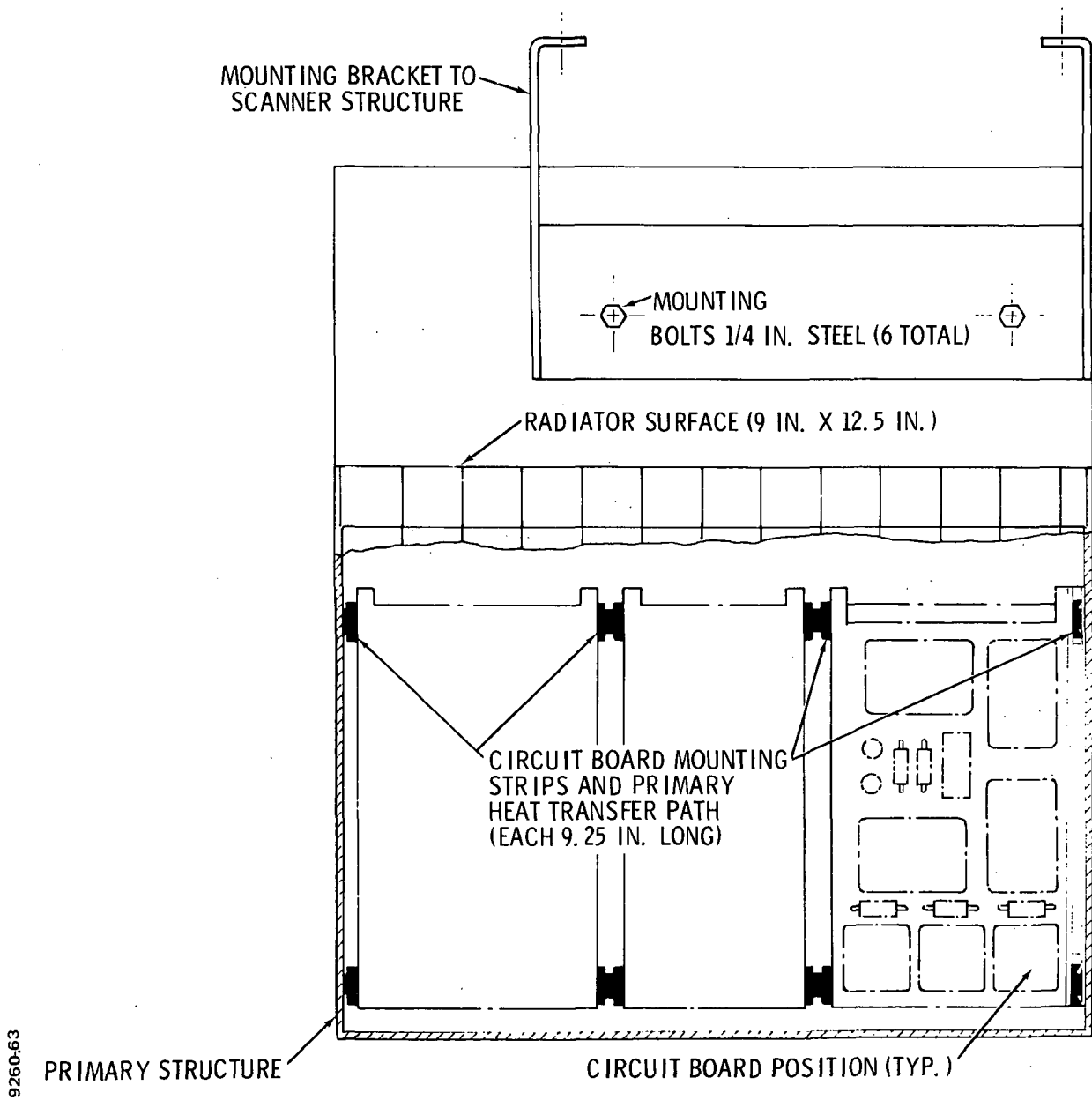


Figure F-8 Electronics Module Construction

The basic cooler interior configuration, the four cone walls, and detector radiator were designed to meet the clear space view requirements of 60.6° in the vertical plane by 90° in the horizontal plane. With the detector radiator sized to an approximate 20-mW dissipation level, the interior walls and radiator surface were defined in a compatible x, y, z coordinate system for the purpose of surface description for the CONFAC II configuration factor computer program. This basic surface description and the coordinate system are illustrated in Figure F-9. With this surface description, images of the cone opening visible to the radiator directly or indirectly via inter-reflections in the cone walls were determined. The CONFAC II program was used to determine all direct and indirect view factors between the radiator, cone walls, cone opening, and the cone opening images.

The equivalent space view of the detector radiator surface is dependent upon the number and quality of the cone opening images viewed in the highly specular, low emissivity cone walls. Cone opening images produced by single reflections are the ideal case; however, the OSS mounting restrictions are not compatible with single reflections. The OSS passive cooler geometry is such that the radiator surface has four complete single reflection images of the cone mouth, four complete second reflection images, eight partial second reflection images, and eight partial third reflection images. This is due to the cone wall angles being compatible with rejection of the extreme incident radiation outside of the design field of view with a maximum of two reflections.

The exchange factors between the radiator, cone walls, and cone opening wherein an intervening specular interchange occurred were calculated according to the following general series form:

$$E_{i-j} = f_o + \rho_{1n}^s f_1 + \rho_{1n}^s \rho_{2n}^s f_2 + \rho_{1n}^s \rho_{2n}^s \rho_{3n}^s f_3 + \text{-----}$$

where:

- E_{i-j} = the exchange factor between surfaces i and j by all possible intervening specular surfaces
- f_o = the direct view factor between surfaces i and j
- f_1 = the first reflection image indirect view factor
- f_2 = the second reflection image indirect view factor
- f_3 = the third reflection image indirect view factor

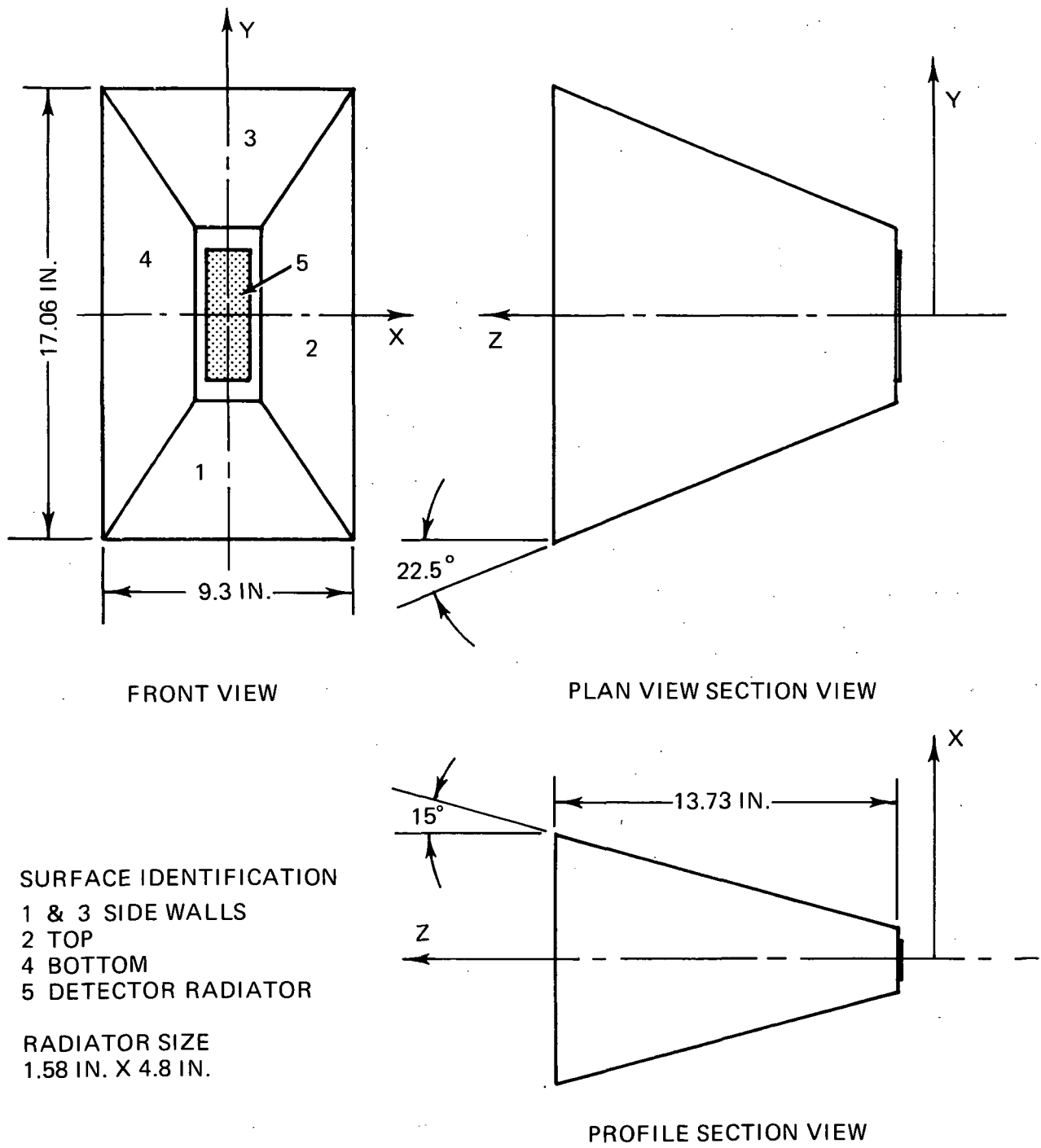


Figure F-9 Thermal Band Passive Cooler Interior Surface Description

ρ_{1n}^s = the specular reflectance value of the surface on which the first of n specular reflections occurs.

ρ_{2n}^s = the specular reflectance value of the surface on which the second of n specular reflections occurs

ρ_{3n}^s = the specular reflectance value of the surface on which the third of n specular reflections occurs.

This exchange factor definition is an approximation and does not include combination diffuse-specular reflectance terms of the form: $\rho_{1n}^d \rho_{1n}^s$, $\rho_{1n}^d \rho_{2n}^s$, etc., which rapidly becomes insignificant contributions to the total factor because of the relative magnitudes of ρ^d (diffuse reflectance) and ρ^s for any given surface. Proof of this comes from the definition of these terms by the equation:

$$1 - \epsilon = \rho = \rho^s + \rho^d$$

where:

ϵ = surface emittance value

ρ = total surface reflectance

ρ^s = specular component of surface reflectance

ρ^d = diffuse component of surface reflectance.

For a highly specular surface, ρ may be 0.95 or greater and ρ^d becomes a small contribution of 0.05 or less. Any exchange factor term involving a $\rho^d \rho^s$ or $\rho^d \rho^s \rho^d$ components thus is very small compared to the total and the approximation is justified.

Table F-2 lists the thermal band passive cooler surfaces and their respective areas, emittance, and reflectance characteristics used in the analysis. In addition, the nominal values for bodies exterior to the cooler and having a contribution to the over-all analysis were also included. Exchange factors have not been listed due to the extreme table size and detailed identification required.

Application of the exchange factors to the Oppenheim radiosity network was accomplished in the definition of the space resistors connecting the radiosity nodes. The common form of the space resistor is:

$$K_{i-j} = \frac{1}{A_i F_{i-j}}$$

TABLE F-2

THERMAL BAND PASSIVE COOLER SURFACE CHARACTERISTICS

Surface	Area (Ft ²)	Emittance	Reflectance		Material or Surface Type
			Diffuse	Specular	
1. Detector Rad.	0.053	0.98	0.02	---	Black Painted Aluminum Honey- comb
2. Interior cone top surface	1.137	0.05	0.05	0.90	Specular Reflector
3. Interior cone bottom surface	1.137	0.05	0.05	0.90	Specular Reflector
4. Interior cone right side	0.581	0.05	0.05	0.90	Specular Reflector
5. Interior cone right side	0.581	0.05	0.05	0.90	Specular Reflector
6. Second stage radiator	0.055	0.81	0.19	---	Second Surface Mirrors
7. First stage radiator	0.844	0.81	0.19	---	Second Surface Mirrors
8. Multilayer superinsulation	---	0.10	0.90	---	1/4 mil Alumin- ized Mylar
9. All aluminum surfaces	---	0.05	0.95	---	Polished or vacuum deposited

where:

K_{i-j} = the space resistor between radiosity nodes i and j; A_i is area of surface i

F_{i-j} = the diffuse view factor which surface i has of surface j; the replacement of F_{i-j} by E_{i-j} results in the definition:

$$K_{i-j} = \frac{1}{A_i E_{i-j}}$$

where E_{i-j} is as previously defined for specular surfaces. Completion of the radiosity network incorporating the node surface resistance was accomplished in the conventional method of the Oppenheim network.

Conduction heat transfer between nodes was assumed to take place according to the relation:

$$q_{i-j} = \frac{T_i - T_j}{R_{i-j}}$$

where:

q_{i-j} = the heat transfer between nodes i and j

T_i = the temperature of node i

T_j = the temperature of node j

R_{i-j} = the conduction resistance between nodes i and j

R_{i-j} is further defined by:

$$R_{i-j} = \frac{l_i}{k_i A_i} + \frac{l_j}{k_j A_j} + \frac{1}{hA}$$

where:

l_i = the distance from center of node i to the interface with node j

l_j = the distance from center of node j to the interface with node i

- k_i = thermal conductivity of node i material
 k_j = thermal conductivity of node j material
 A_i = effective cross-sectional area of the heat transfer path from center of node i to the interface with node j
 A_j = effective cross-sectional area of the heat transfer path from center of node j to the interface with node i
 h = interface conductance
 A_c = interface area.

The conduction and radiosity networks were combined in the Bendix Thermal Analyzer computer program to accomplish the final analysis of the thermal band passive cooler.

The basic nodal description employed in the analysis is identified in Table F-3 in conjunction with the various conduction and radiation resistances of the cooler mathematical model. The cooler was analyzed for three specific conditions, the first of which was a baseline and reference condition. The other two were essentially "nighttime" and "daytime" orbit conditions. The conditions were defined as follows:

1. Baseline: cooler connected to OSS and ERTS spacecraft with no earth-emitted or earth-reflected solar radiation present
2. Nighttime: cooler connected to OSS and ERTS spacecraft with earth-emitted radiation present
3. Daytime: cooler connected to OSS and ERTS spacecraft with earth-emitted and earth-reflected solar radiation present.

Detector-associated and optical path heat loads were assumed to be present upon the detector radiator for all orbit conditions

Results of the cooler thermal analysis are presented in Figure F-10 for each condition simulated with the computer program. In general, the conduction isolation throughout the cooler is satisfactory as indicated by the temperature

TABLE F-3

PASSIVE COOLER THERMAL ANALYSIS MODEL DESCRIPTION

A. Node Identification			
Node No.	Surface		
1	Detector Radiator		
2	Interior Cone Top		
3	Interior Cone Bottom		
4	Interior Cone Left Side		
5	Interior Cone Right Side		
6	Second Stage Auxiliary Radiator		
7	Inner Suspension Frame		
8	Outer Suspension Frame		
14	Spacecraft Shield		
15	First Stage Auxiliary Radiator		
16	Exterior Multilayer Blanket		
17	Spacecraft/OSS Instrument Structure		
18	Earth		
19	Space		
22	Outer Cone		
23	Interior Multilayer Blanket		

B. Conduction Resistors			
Resistor No.	Connecting Node to	Node	Value (°F/Btu/hr)
101	1	7	6775.
114	2	4	2.149
115	2	5	2.149
116	3	4	2.149
123	15	22	0.297
124	14	15	0.963
125	16	22	7.800
126	17	22	852.
127	3	5	2.149
130	2	22	207.8
131	3	22	207.8
132	4	22	207.8
133	5	22	207.8
134	2	23	366.5
135	3	23	366.5
136	4	23	717.0
137	5	23	717.0
138	6	7	7.75
139	7	8	4.87
136	8	22	20.8

C. Radiation Resistors			
Resistor No.	Connecting Node to	Node	Value * (°F/Btu/hr)
1	1	2	506.746
2	1	3	514.488
3	1	4	1158.86
4	1	5	1158.86
5	1	19	1288.49
6	2	3	17.173
7	2	4	49.578
8	2	5	49.578
18	3	4	49.545
19	3	5	49.545
27	3	19	58.178
29	4	5	69.035
37	4	14	251.714
38	4	19	93.845
47	5	14	251.714
48	5	19	93.845
68	14	15	12.894
71	16	17	3.800
80	2	18	38.469
81	2	19	62.824
82	14	18	8.929
83	14	19	49.748
84	15	18	8.937
85	15	19	19.828
86	16	18	2.409
87	16	19	5.316
90	22	23	171.713

* Radiation resistor value based on daytime orbit condition steady-state temperatures. These are computer output values and are temperature dependent.

9260-10

ITEM		CONDITION A TEMP (°K)	CONDITION B TEMP (°K)	CONDITION C TEMP (°K)
1	RADIATOR	78.2	111.3	114.5
2	CONE INTERIOR TOP	85.8	122.2	125.5
3	CONE INTERIOR BOTTOM	85.8	120.8	124.5
4	CONE INTERIOR SIDES	85.8	121.2	124.7
5	2ND STAGE AUXILIARY RADIATOR	80.0	114.5	117.5
6	INNER SUSPENSION FRAME	81.7	116.4	119.7
7	OUTER SUSPENSION FRAME	150	205	228
8	MAIN SUPPORT FRAME	300	300	300
9	1ST STAGE AUXILIARY RADIATOR	148.8	205	228
10	INTERIOR BLANKET	92.2	141.7	156
11	OUTER CONE	150	205	228
12	EXTERIOR BLANKET	186.5	219	247
13	SPACECRAFT SHIELD	147.5	206.5	230

CONDITION A: BASELINE CONFIGURATION WITH COOLER CONNECTED TO SPACECRAFT. NO DIRECT EARTH EMISSION OR EARTH REFLECTED SOLAR HEAT LOAD TO COOLER. ALSO NO ELECTRONIC OR OPTIC LOAD TO RADIATOR.

CONDITION B: BASELINE CONFIGURATION WITH COOLER CONNECTED TO SPACECRAFT. ESSENTIALLY A "NIGHT-TIME" CONDITION WITH DIRECT EARTH EMISSION BUT NO EARTH REFLECTED SOLAR HEAT LOAD TO COOLER. AN ELECTRONIC AND OPTICS HEAT LOAD OF 5.5 MW IS PRESENT ON THE RADIATOR.

CONDITION C: BASELINE CONFIGURATION WITH COOLER CONNECTED TO SPACECRAFT. "DAYTIME" CONDITION WITH BOTH DIRECT EARTH EMISSION AND EARTH REFLECTED SOLAR HEAT LOAD TO COOLER. AN ELECTRONIC AND OPTIC HEAT LOAD OF 5.5 MW IS PRESENT ON THE RADIATOR.

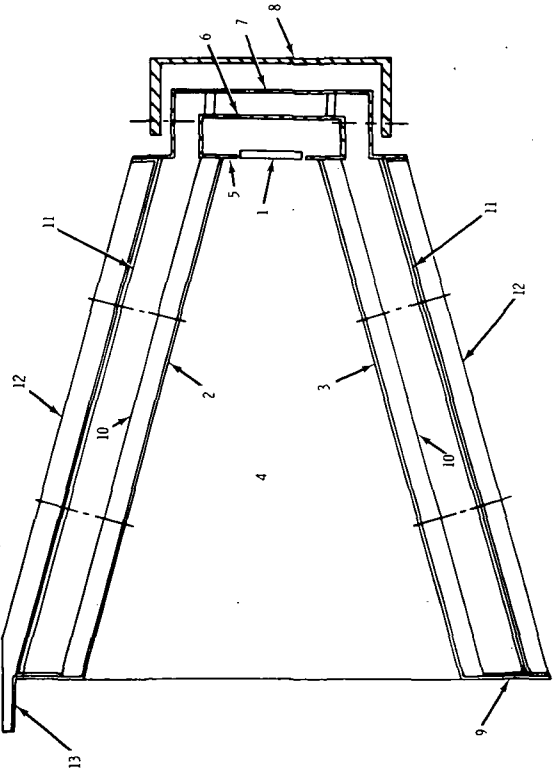


Figure F-10 Thermal Band Passive Radiation Cooler Performance

results for the baseline condition. The residual heat flow to the radiator surface through the stainless steel wire suspension system and detector leads is approximately 0.007 W. The daytime and nighttime condition results indicate excessive earth-emitted and earth-reflected solar radiation reaching the radiator surface by reradiation from the cone walls. The earth view causing this problem is associated with the top interior surface of the cone and can be eliminated by the addition of a shield to the cooler oriented to block the earth view.

Parametric runs simulating this alteration indicate an approximate 10°K decrease in radiator temperature. How the shield is to be implemented within the OSS envelope constraints was not determined. Any suitable technique would have to use an extendable or folding mechanism to deploy the shield after orbit is achieved.

Contamination of the thermal band passive cooler is recognized as a real and difficult design problem with many possible tradeoffs to consider. Provisions for a decontamination heater were incorporated into the passive cooler design using a molded film heater on the outer cone structure. To be effective, the output of this heater must be directed to the inner cone by conduction methods using thermal switches or similar thermostatic activated mechanisms. The problem is considered to be of sufficient complexity in definition, concept, and implementation as to require a separate study effort. Consequently, no effort has been specifically directed during the OSS study period to the most promising solution, since knowledge of types of contaminants from both the OSS instruments and ERTS spacecraft is not available in detail.

F. 6 PASSIVE COOLER ANALYSIS REFERENCES

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APPENDIX G

OCEANOGRAPHIC SPECTROMETER

G. 1 OPTICAL DESIGN

The spectrometer design is based on the relationship between the following parameters:

α , the instantaneous field of view of the scanner
 D_c , the diameter of the collecting optics,
 δ , the angle subtended by the field stop at the collimating lens
 D_ℓ , the diameter of the spectrometer collimating lens,
 $\Delta\lambda$, the desired spectral resolution
 and $\frac{d\theta}{d\lambda}$, the angular dispersion of the dispersing element.

If the throughput is to be conserved, then:

$$\delta D_\ell = \alpha D_c \quad (1)$$

To maintain zero crosstalk between non-adjacent bands the image of the field stop in the spectral plane must be less or equal to the desired spectral resolution $\Delta\lambda$. The angle occupied by radiation of spread $\Delta\lambda$ is given by:

$$\delta = \Delta\lambda \frac{d\theta}{d\lambda} \quad (2)$$

Hence, substituting for δ in equation (1) gives:

$$\Delta\lambda = \frac{\alpha D_c}{\frac{d\theta}{d\lambda} \cdot D_\ell} \quad (3)$$

This is the basic equation which is used to determine D_ℓ for the oceanographic and overland spectrometers.

For a prism the angular dispersion is given by, $\frac{d\theta}{d\lambda} = \frac{B}{b} \frac{dn}{d\lambda}$ where B is the size of the prism base and b is the beam width incident on the prism.

Equation (3) becomes:

$$\Delta\lambda = \frac{\alpha D_c}{\frac{B}{b} \frac{dn}{d\lambda} \cdot D_\ell} \quad (4)$$

Fused silica at 7500 Å has $\frac{dn}{d\lambda} = 0.0198\mu^{-1}$. As $D_c = 11.5$ in. and $b = D_\ell$, the equation gives $B = 14.5$ in. Thus, a prism made from fused silica, or any of the common materials transparent to visible wavelengths, would be impractically large. A grating spectrometer is necessary.

The dispersion of a diffraction grating is given by:

$$\frac{d\theta}{d\lambda} = \frac{m}{d \cos \theta} \quad (5)$$

where: m = the order of interference
 d = groove spacing of the grating
 θ = the angle of diffraction

For a beam at normal incidence ($i = 0^\circ$) the dispersion in a first order spectrum ($m = 1$) is given by:

$$\frac{d\theta}{d\lambda} = \frac{1}{d \cos \theta}$$

Substituting in equation (3) gives:

$$\Delta\lambda = \alpha D_c \cdot \frac{d \cos \theta}{D_\ell} \quad (6)$$

If the dispersion angle is small and the spectrum is close to the grating normal, $\cos \theta \approx 1$, and the term can safely be ignored in this analysis.

Substituting the system design parameters into equation (6) gives:

$$\frac{d}{D_\ell} = 1.37 \times 10^{-4}$$

Hence, the smaller the collimator, the greater the number of grooves per inch (smaller d) the grating will require. In Table G-1 for each value D_ℓ are tabulated the angular dispersion $d\theta$ for one channel, the total angular spread for 24 channels, $\Delta\theta$, and the number of lines per millimeter, N , on the grating.

TABLE G-1

ANGULAR DISPERSION VS. COLLIMATOR DIAMETER

D_ℓ (in.)	d (in.)	$d\theta$ (rads) (1 Channel)	$\Delta\theta$ (rads) (24 Chan)	$\Delta\theta$ ($^\circ$) (24 Chan)	N(lines/mm)
0.5	6.85×10^{-5}	9.20×10^{-3}	0.221	$12^\circ 40'$	575
0.6	8.22×10^{-5}	7.66×10^{-3}	0.184	$10^\circ 32'$	479
0.75	1.03×10^{-4}	6.11×10^{-3}	0.146	$8^\circ 22'$	382
1.0	1.37×10^{-4}	4.60×10^{-3}	0.110	$6^\circ 11'$	287
1.5	2.06×10^{-4}	3.06×10^{-3}	0.074	$4^\circ 13'$	191
1.75	2.40×10^{-4}	2.62×10^{-3}	0.063	$3^\circ 36'$	164

Selection of the most suitable combination of D_ℓ and d depends on the required focal lengths of the collimating and camera lenses and the focal plane aberrations.

G.2 THE COLLIMATING LENS

The focal length of the collimator is given by $f_\ell = F D_\ell$ where F is the focal ratio of the telescope.

G.3 THE IMAGING LENS

The imaging lens will introduce aberrations which are functions of the half angle of the beam spread, $\Delta\theta/2$, and its focal ratio, F_I . Estimates of the aberrations can be obtained using the following formulae (from the Handbook of Military Infrared Technology):

$$\text{Spherical aberration, } \rho_s = \frac{0.067}{F_I^3}$$

$$\text{Coma, } \beta_c = \frac{(\Delta \theta / 2)}{16 (n + 2) F_I^2}$$

$$\text{Astigmatism, } \beta_a = \frac{0.5}{F_I} \cdot \left(\frac{\Delta \theta}{2} \right)^2$$

where n is the refractive index of the lens and β is the angular blur circle. For the purpose of this analysis it is sufficient to assume, as a worst case, that the aberrations add linearly and the total blur circle β is given by

$$\beta = \beta_s + \beta_c + \beta_a$$

In Table G-2 the blur circle is given for the range of dispersion angles for several lens focal ratios.

TABLE G-2
TOTAL FOCAL PLANE ABERRATIONS

F_I	Blur Circle (m rads)					
	12° 40'	10° 32'	8° 22'	6° 11'	4° 13'	3° 36'
2	12.0	11.0	10.0	9.4	8.90	8.75
4	2.70	2.2	1.8	1.48	1.26	1.21
6	1.37	1.05	0.79	0.58	0.44	0.41
8	0.98	0.69	0.49	0.31	0.22	0.21
10	0.68	0.51	0.34	0.22	0.14	0.12

The blur circles can be expressed in inches by multiplying each one by the focal length corresponding to the focal ratio and collimator diameter. Table G-3 gives the imaging lens focal length for each combination.

TABLE G-3

IMAGING LENS FOCAL LENGTH

F_I	Focal Length (in.)					
	$\Delta\theta = 12^\circ 40'$ $D_\ell = 0.5 \text{ in.}$	$10^\circ 32'$ 0.6 in.	$8^\circ 22'$ 0.75 in.	$6^\circ 11'$ 1.00 in.	$4^\circ 13'$ 1.50 in.	$3^\circ 36'$ 1.75 in.
2	1.0	1.2	1.5	2.0	3.0	3.5
4	2.0	2.4	3.0	4.0	6.0	7.0
6	3.0	3.6	4.5	6.0	9.0	10.5
8	4.0	4.8	6.0	8.0	12.0	14.0
10	5.0	6.0	7.5	10.0	15.0	17.5

To be meaningful the aberrations must be expressed as a function of the detector size which is given by:

$$a = \alpha f_T \frac{F_I}{F_\ell}$$

where f_T is the focal length of the telescope and F_I , F_ℓ are the focal ratios of the imager and collimator respectively. But as $f_T = D_C \times F$ and $F = F_\ell$, the detector size, as a function of the imaging lens focal ratio is:

$$a = \alpha D_C F_I \quad (7)$$

Using $\alpha = 0.4 \times 10^{-3}$ radians and $D_C = 11.5 \text{ in.}$ the detector size varies with focal ratio as in Table G-4.

TABLE G-4

VARIANCE OF DETECTOR SIZE ACCORDING TO FOCAL RATIO

Focal Ratio F_I	Detector Size a (in.)
2	9.2×10^{-3}
4	18.4×10^{-3}
6	27.6×10^{-3}
8	36.8×10^{-3}
10	46.0×10^{-3}

The last step in the analysis is the comparison between the detector size and the linear blur circle. Table G-5 gives the ratio of blur circle/detector size

$\frac{(f_I \beta)}{a}$ for the different conditions of focal ratio and collector (or imager) diameter.

TABLE G-5

BLUR CIRCLE/DETECTOR SIZE

F_I	Detector Size (in.)	$\Delta\theta = 12^\circ 40'$ $D_\ell = 0.5$ in.	$10^\circ 32'$ 0.6 in.	$8^\circ 22'$ 0.75 in.	$6^\circ 11'$ 1.00 in.	$4^\circ 13'$ 1.50 in.	$3^\circ 36'$ 1.75 in.
2	9.2×10^{-3}	1.30	1.43	1.63	2.04	2.90	3.32
4	18.4×10^{-3}	0.29	0.29	0.29	0.32	0.41	0.46
6	27.6×10^{-3}	0.15	0.14	0.13	0.13	0.14	0.16
8	36.8×10^{-3}	0.11	0.09	0.079	0.068	0.071	0.078
10	46.0×10^{-3}	0.074	0.067	0.056	0.048	0.045	0.045

The clearest way of displaying this information is to plot the detector size against the imager focal length. For each grating, or each collimator diameter, there is a linear relationship as shown in Figure G-1. The broken lines on the graph show the positions above which the blur circle is less than the detector size and less than 0.1 of the detector size. By selecting any point on the figure all the spectrometer design characteristics can be obtained.

Excessive aberrations will result in increased spectral crosstalk and loss of energy due to radiation falling outside the active area of the detector. Although the criterion is somewhat arbitrary, a blur circle less than 10% the detector size is probably adequate. Thus the spectrometer design will be in the upper section of Figure G-1, and the minimum detector size is 0.031 in. As these bands are pre-amplifier noise limited no loss of signal-to-noise occurs if we select a larger detector at a standard size of 0.040 in. (1 mm). Bausch and Lomb manufacture a standard transmission grating with 400 grooves/mm and a blaze angle for 5000 Å., which falls within the acceptable range of Figure G-1. It has been selected for the spectrometer.

The spectrometer design parameters become:

diffraction grating: 400 grooves/mm
 beam spread: $8^{\circ}48'$
 beam deviation at 4000 Å: $9^{\circ}10'$
 beam deviation at 6000 Å: $13^{\circ}45'$
 beam deviation at 7840 Å: $17^{\circ}58'$
 collimator dia: 0.72 in.
 image focal length: 6.25 in.
 detector size: 0.040 in.

Figure G-2 shows the layout of the spectrometer.

The effect of the varying diffraction angle (the cos term ignored earlier) can be shown to be small. Across the spectrum θ varies from $9^{\circ}10'$ to $17^{\circ}58'$ causing a $\cos \theta$ variation of 3.5%. Thus the spectral bandwidth will vary by about 5 Å between extreme detectors if each one has the same physical size. Also the diffraction angle will slightly reduce the spectral crosstalk between adjacent channels.

G.4 SPECTROMETER LENS DESIGN

So far the design has reduced spherical aberration, coma and astigmatism to acceptable values. Chromatic aberrations, longitudinal and transverse remain. Over the spectral range from 4000 to 8000 Å a doublet lens can adequately remove them. The degree of spherical aberration can be described by the longitudinal

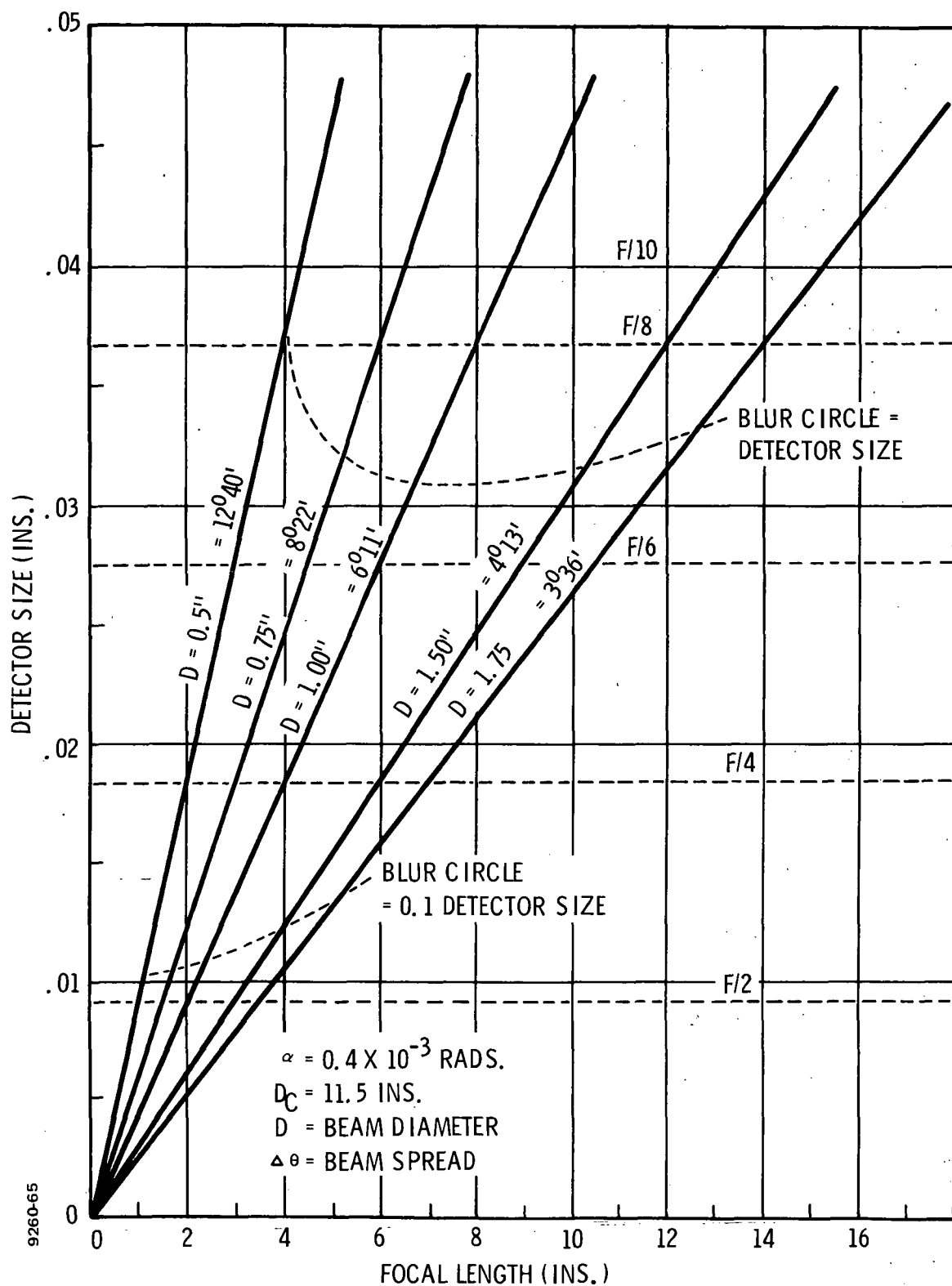


Figure G-1 Oceanographic Spectrometer Design Data

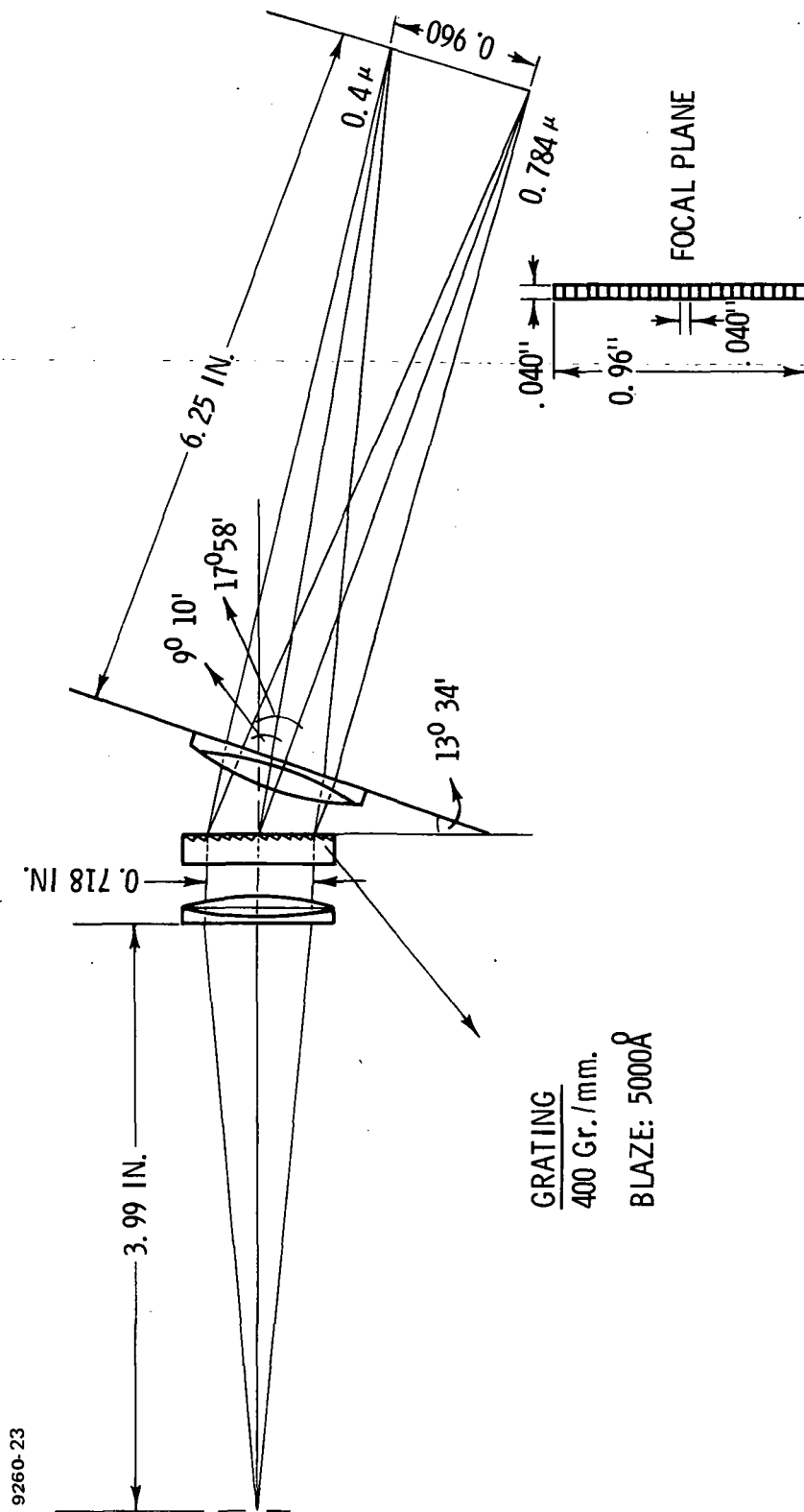


Figure G-2 Oceanographic Spectrometer

secondary spectrum (LSS), which is the focal length difference over the spectral range of interest. It is given by:

$$\text{LSS} = \text{focal length} \left[\frac{P_1 - P_2}{V_1 - V_2} \right]$$

where P_1 , P_2 and V_1 , V_2 are the partial dispersions and dispersions respectively of the two materials of an achromatic doublet. P and V are given by:

$$V = \frac{n_{.6} - 1}{n_{.4} - n_{.8}}$$

and

$$P = \frac{n_{.4} - n_{.6}}{n_{.4} - n_{.8}}$$

where, $n_{.4}$ --- is the refractive index at 0.4μ , etc. For a doublet of borosilicate crown and dense flint glasses, $\text{LSS} = 0.016$ in. The lateral secondary spectrum ($\text{LSS}/\text{focal ratio}$) is 0.0025 in., an acceptably small value. Suitable radii of curvature can be selected for the lenses to minimize the spherical aberration.

G.5 DETECTOR ARRAY

The detector array is a linear array of 24 detectors each 0.040 in. square. Analysis has shown that optimum performance is obtained if Bands 1, 2 and 3 use photomultiplier tubes and Bands 4 to 24 are silicon photodiodes. Bands 1, 2 and 3 are to be removed from the focal plane using solid fiber light guides and conducted to the photocathodes of the PMTs. Bands 4-24 will be a single array of photodiodes.

APPENDIX H

SOLAR CALIBRATION

H.1 ORBITAL CHARACTERISTICS

The Earth Resources Technology Satellite will be placed in a sun synchronous, retrograde orbit having the following parameters:

Eccentricity	: 0
Orbital Inclination	: 99°
Orbital Altitude	: 496 nautical miles
Launch Time	: 9:30 a.m.

Sun synchronous means that the angle between the orbital plane and the earth-sun line remains constant. The synchronism is achieved by using the unsymmetrical gravitational field of the earth to apply a torque to the orbit thus causing it to precess around the polar axis once a year. The precession is called regression of the nodes. A family of orbits with a particular combination of altitude and inclination has a precession period of one year.

For the ERTS the altitude of 496 nm is combined with an orbital inclination of 99° to the Earth's equator, or 9° to the North-South axis. As the orbit is retrograde the E-W movement of the spacecraft is opposite to the rotational direction of the Earth. Thus in the North to South passage (descending node) there is also an East to West movement.

The plane of the orbit can be at any angle to the Earth-sun line depending on the time of launch. A noon launch places the orbital plane along the Earth-sun line and a 6 o'clock launch results in a "twilight" orbit perpendicular to the solar direction. The ERTS is due to be launched at 9:30 a.m. producing an orbital plane angle of 37° . In summer, the satellite orbit, as seen from the sun will have the appearance as shown in Figure H-1. The launch direction is west of south which means a West Coast launch is required. The descending portion of the orbit is sunlit.

H. 2 EFFECT OF SOLAR DECLINATION

Sun synchronism is still not exact, however. The orbital inclination of 9° and the constant precession rate are maintained during changes in the declination of the sun, i. e., during seasonal changes, and the sun sees the orbit from a varying N-S direction. The effect is shown in Figure H-2. The rotational axis of the Earth is inclined at 66.5° to the ecliptic (its orbital plane). Between summer (a) and winter (b) the spacecraft orbit has precessed 180° , but has maintained its 9° angle to the Earth's axis. It is easy to see why the sun intercepts the orbit at a different angle. This variation in solar direction over a period of a year is the most important factor in the design of a sun reference system.

H. 3 SOLAR DIRECTION

To provide a direct solar reference signal to the scanner a small mirror will be used to reflect sunlight to the field stop via the collecting optics at some point in each orbit. As the mirror cannot be aperture filling the scanner must be viewing the dark side of the Earth so that only the sun produces a signal at the detectors. This will limit the sun calibration to orbital sections AB and EF in Figure H-3. In practice, to avoid atmospheric absorption, the zone will be limited to AC if R is the altitude for which significant atmospheric attenuation can occur. The range of w can be determined using:

$$h + R = (H + R) \sin w$$

where H is the satellite altitude and R is the radius of the Earth. If we assume that the atmosphere extends to an altitude of 50 nm and $H = 500$ nm, $R = 3440$ nm., then the minimum value of w is 62° . Hence,

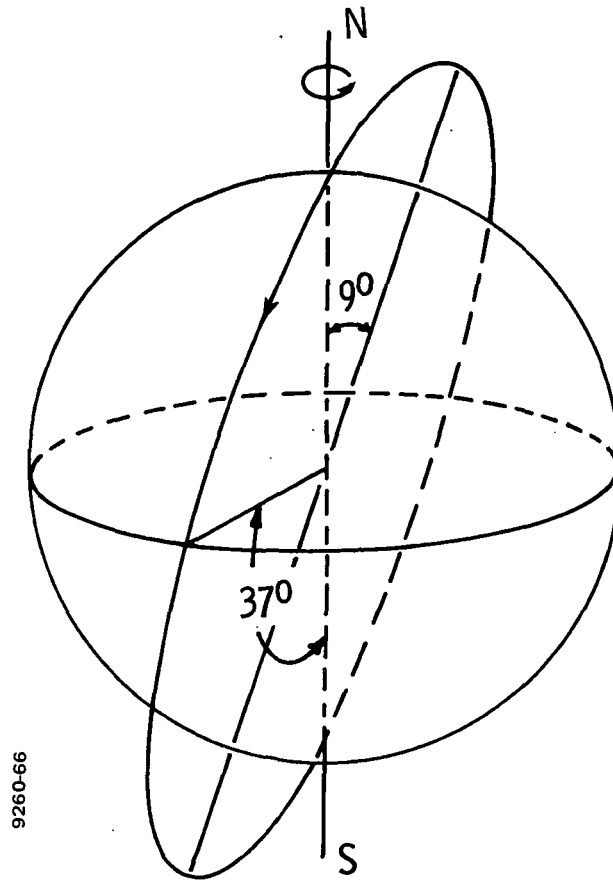
$$62^\circ \leq w \leq 90^\circ$$

The direction of the sun from the satellite must be defined in terms of known angles such as the solar declination, the azimuth of the descending node, the orbital inclination and the location of the satellite in its orbit. The geometry of the situation is illustrated in Figure H-4 where:

S is a unit vector in the direction of the sun from the center of the earth.

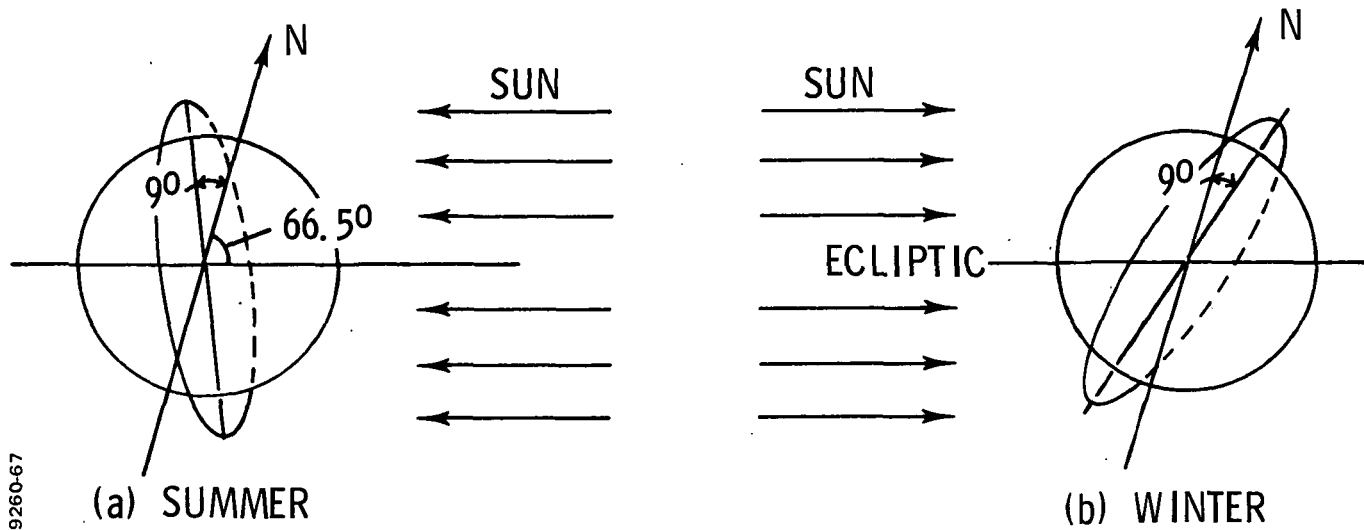
i is a unit vector along the projection of S on the equatorial plane (i is the direction of the sun at the vernal equinox).

K is a unit vector along the Earth's rotational axis.



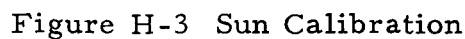
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Figure H-1 Orbit Appearance



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Figure H-2 Yearly Orbital Variation



- The angular relationships between the three co-ordinate systems are defined by:

- H-4 (I)

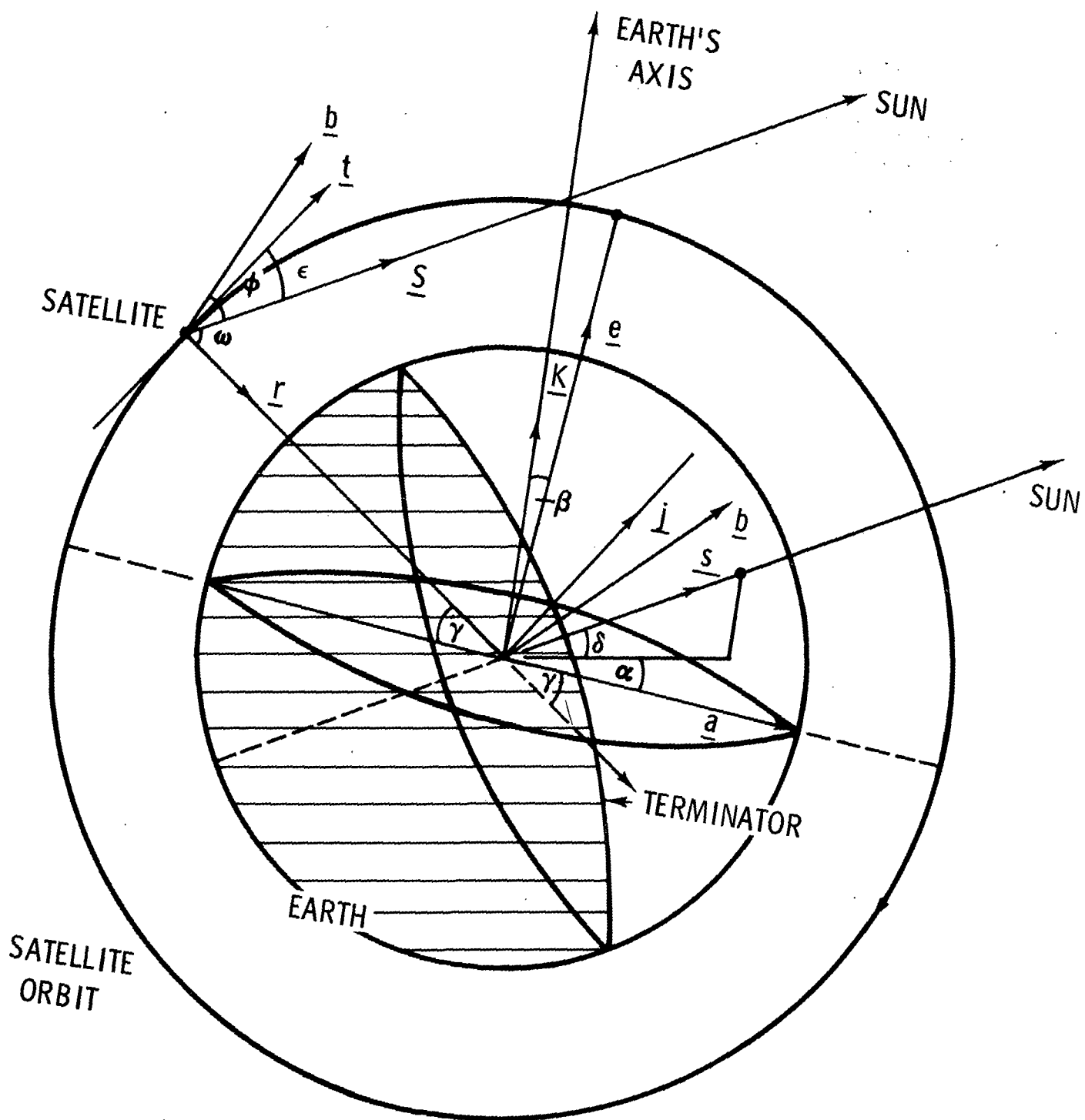


Figure H-4 Orbital Geometry

β , the inclination of the orbital plane to the Earth's axis

γ , the angle defining the location of the satellite in its orbit, measured from the descending node.

The direction of the sun with respect to the satellite is given by the direction cosines; $\cos \theta$, $\cos w$, and $\cos \epsilon$, where:

$$\cos \theta = \underline{S} \cdot \underline{b} \quad (1)$$

$$\cos w = \underline{S} \cdot \underline{r} \quad (2)$$

$$\cos \epsilon = \underline{S} \cdot \underline{t} \quad (3)$$

In the $\underline{i}$, $\underline{j}$, $\underline{k}$ system $\underline{S}$ is given by:

$$\underline{S} = \cos \delta \underline{i} + \sin \delta \underline{k} \quad (4)$$

In the $\underline{a}$, $\underline{b}$, $\underline{c}$ triad $\underline{t}$ is given by:

$$\underline{t} = \sin \gamma \underline{a} + \cos \gamma \underline{c} \quad (5)$$

Also:

$$\underline{r} = \cos \gamma \underline{a} - \sin \gamma \underline{c} \quad (6)$$

and

$$\underline{b} = \underline{t} \times \underline{r} \quad (7)$$

To transfer between co-ordinate systems we can use:

$$\underline{a} = \cos \alpha \underline{i} - \sin \alpha \underline{j} \quad (8)$$

$$\underline{c} = \sin \alpha \sin \beta \underline{i} + \cos \alpha \sin \beta \underline{j} + \cos \beta \underline{k} \quad (9)$$

By solving equations (1) to (9),

$$\cos \phi = \sin \alpha \cos \beta \cos \delta - \sin \beta \sin \delta \quad (10)$$

$$\cos w = \cos \delta (\cos \gamma \cos \alpha - \sin \gamma \sin \beta \sin \alpha) - \sin \delta \sin \gamma \cos \beta \quad (11)$$

$$\cos \epsilon = \cos \delta (\cos \delta \sin \beta \sin \alpha + \sin \gamma \cos \alpha) + \sin \delta \cos \gamma \cos \beta \quad (12)$$

Thus, the direction of the sun can be expressed in terms of known angles. It is more convenient to describe its direction in terms of two angles, its altitude and azimuth with respect to the satellite. In Figure H-5 the solar direction is shown in satellite co-ordinates, direction of flight, $\underline{t}$, the vertical, $\underline{r}$ and the normal to the orbital plane $\underline{b}$. $\underline{S}'$ is the projection of $\underline{S}$ on the $\underline{b}\underline{t}$ plane. The solar direction is given by:

θ , the angle between $\underline{S}$ and the $\underline{b}, \underline{t}$ plane,

and γ , the angle between the projection of $\underline{S}$ on the horizontal plane and the direction of flight.

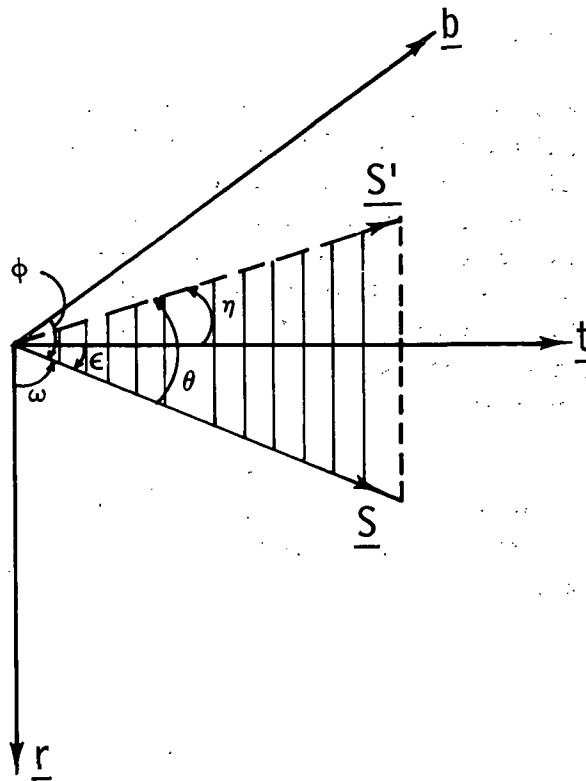


Figure H-5 Solar Direction

These angles are given by:

$$\theta = 90^\circ - w \quad (13)$$

and

$$y = \tan^{-1} \left(\frac{\cos \phi}{\cos \epsilon} \right) \quad (14)$$

θ and y have been computed using the following ranges of input parameters:

Solar declination, S -23.5° to $+23.5^\circ$

Launch Window, α $38.75 \pm 3.75^\circ$

Orbital Position, γ 30° to 120°

Orbital Inclination, β 9°

Typical combinations of θ (the solar vertical angle) and y (solar horizontal angle) are shown in Figure H-6. Each vertical trace represents the direction of the sun as the satellite moves along a particular orbit. There is a different line for each combination of solar declination and launch azimuth. The curves plotted demonstrate the wide range of solar direction for which the calibration must be achieved. Curves 1, 2 and 3 show the effect of varying the launch azimuth for the same solar declination. Curves 2, 4 and 5 cover the range of declinations for the nominal launch azimuth. Six and seven are close to the extreme value of the horizontal angle required.

Figure H-3 was used to demonstrate that the vertical angle had to be between 0 and 28° for sun calibration. This angular range must be further reduced to avoid atmospheric scattering as well as surface reflections. Using Figure H-3, the distance a must be greater than 50 n miles to avoid scattering.

Hence,

$$\cos z = \frac{R - a}{R}$$

which gives a value for z of 10° . Hence, the vertical angle must be between 10° and 28° at the time of solar reference calibration.

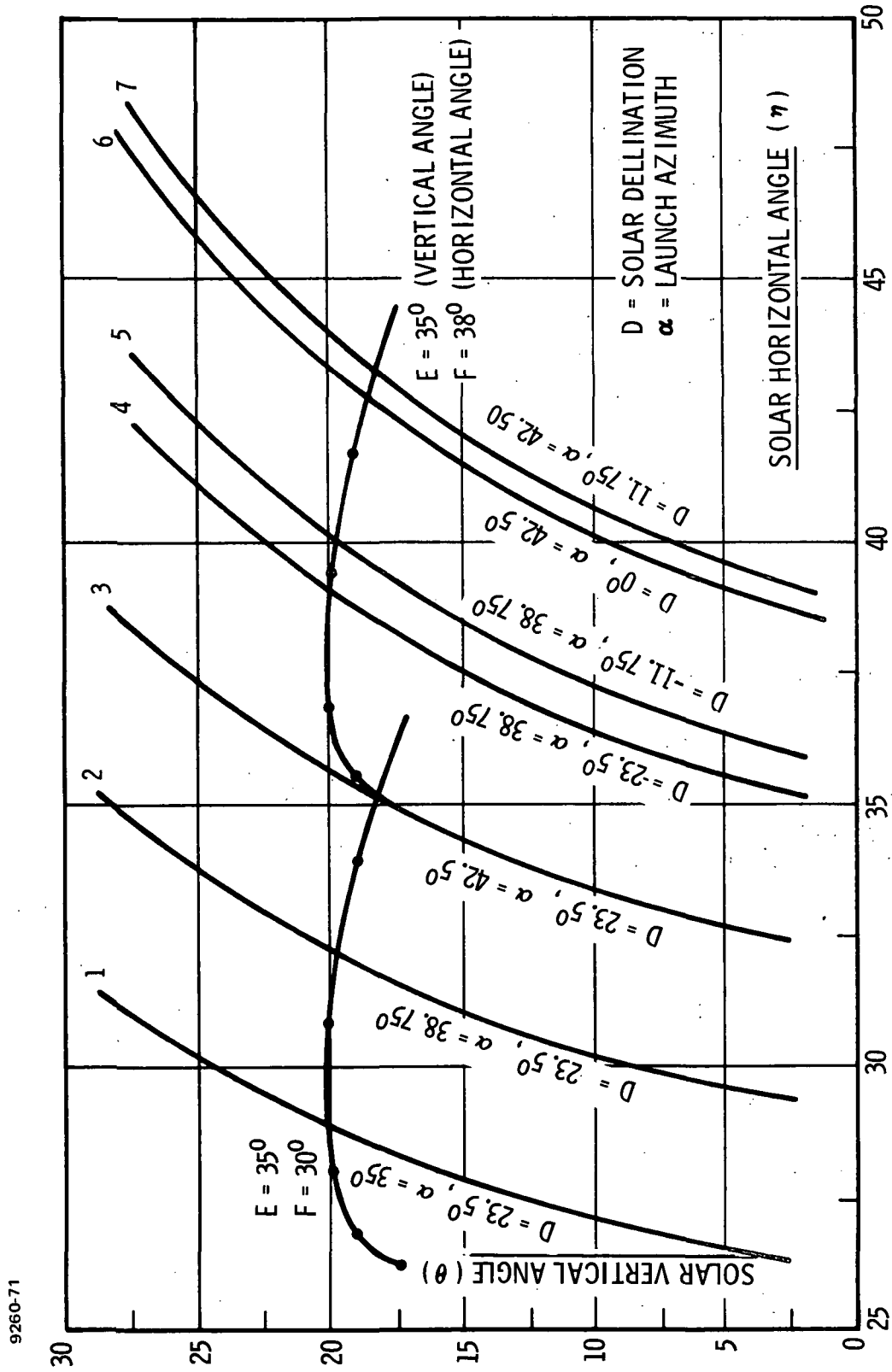


Figure H-6 Solar Direction Angles

H.4 DIRECTION OF SCAN VIEW

To observe the sun, a mirror must be introduced into the scanner aperture so that the direction of view, reflected by the mirror, looks at the sun at the correct point in the orbit.

In Figure H-7 the circle of center 0 is the scan pattern on the ground with the nadir passing through one point on the circle. For the purpose of this analysis, the slight eccentricity of the pattern can be ignored. The angle Δ is the half angle of the scan cone, and ξ defines the location of the scan mirror in its rotation when the instrument looks at point P. The direction of view, unit vector $\underline{v}$, can be expressed as a function of angles Ω and ψ using:

$$\psi = 90^\circ - \Delta/2 \quad (15)$$

and

$$\Omega = \tan^{-1} \left[2 \tan \Delta \sin \frac{\xi}{2} \right] \quad (16)$$

The direction of view $\underline{v}$ is given by:

$$\underline{v} = \sin \Omega \sin \psi \underline{b} - \sin \Omega \cos \psi \underline{t} + \cos \Omega \underline{r} \quad (17)$$

But the direction of view will be changed to $\underline{v}_r$ after reflection from the calibration mirror. Vectors $\underline{v}$ and $\underline{v}_r$ are shown in Figure H-8 where $\underline{N}$ is a unit vector normal to the surface of the mirror. Then:

$$\underline{v}_r = \underline{v} + \underline{\ell}$$

But as $\ell = 2v \cos \sigma = -2 \left| \underline{v} \cdot \underline{N} \right|$

$$\underline{v}_r = \underline{v} - 2 \left| \underline{v} \cdot \underline{N} \right| \underline{N} \quad (18)$$

The vector $\underline{N}$ in the $\underline{r}$, $\underline{t}$, $\underline{b}$ system is shown in Figure H-9 and its direction is defined by the angles e and f .

Then, from Figure H-9:

$$\underline{N} = \cos f \cos e \underline{t} + \cos f \sin e \underline{b} - \sin f \underline{r} \quad (19)$$

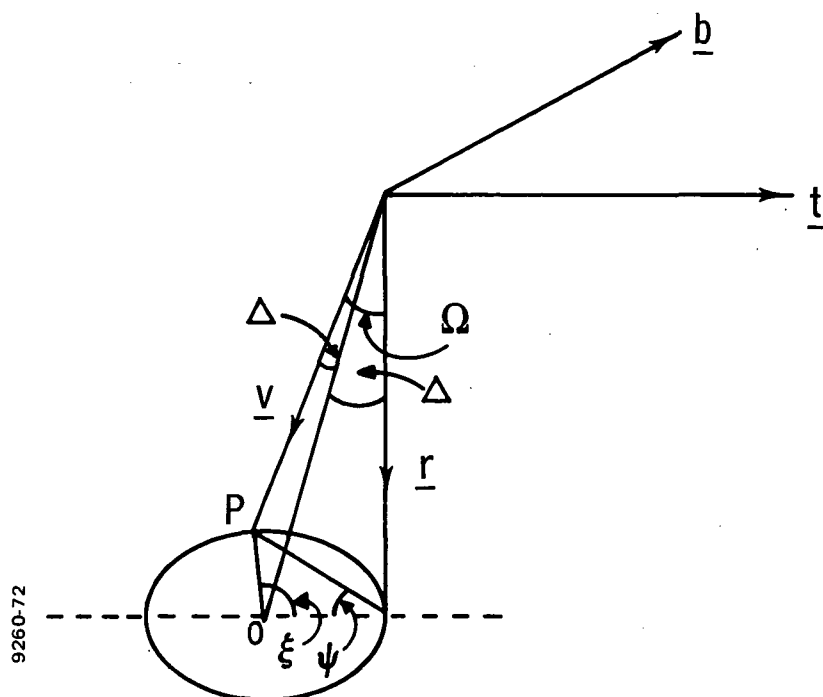


Figure H-7 Scan Direction

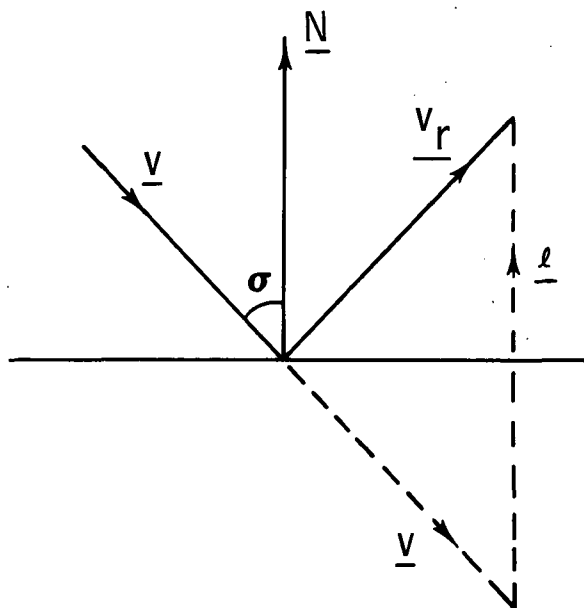


Figure H-8 Mirror Reflection

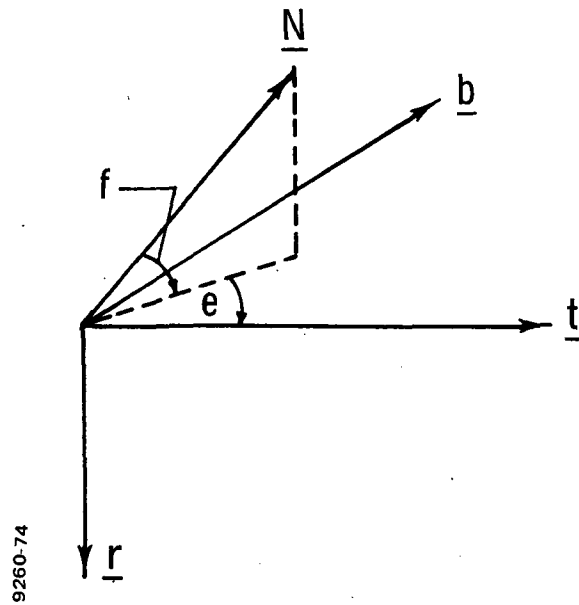


Figure H-9 Mirror Normal Direction

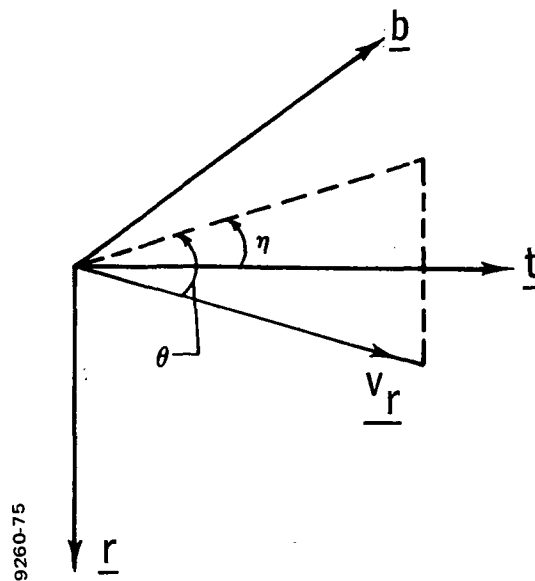


Figure H-10 Reflection Direction

giving,

$$\underline{v} \cdot \underline{N} = \sin \Omega \sin \psi \cos f \sin e - \sin \Omega \cos \psi \cos f \cos e - \cos \Omega \sin f \quad (20)$$

and,

$$\begin{aligned} \underline{v_r} = & (\sin \Omega \sin \psi - 2 \left| \underline{v} \cdot \underline{N} \right| \cos f \sin e) \underline{b} \\ & + (-\sin \Omega \cos \psi - 2 \left| \underline{v} \cdot \underline{N} \right| \cos f \cos e) \underline{t} \\ & + (\cos \Omega + 2 \left| \underline{v} \cdot \underline{N} \right| \sin f) \underline{r} \end{aligned} \quad (21)$$

The direction of reflection $\underline{v_r}$ can be expressed in terms of the altitude and azimuth as for $\underline{S}$. The altitude and azimuth angles are θ and y respectively as shown in Figure H-10. In terms of θ and y ,

$$\underline{v_r} = \cos \theta \cos y \underline{t} + \cos \theta \sin y \underline{b} + \sin \theta \underline{r} \quad (22)$$

Equating terms from (21) and (22) gives:

$$\cos \theta \cos y = -\sin \Omega \cos \chi - 2 \left| \underline{v} \cdot \underline{N} \right| \cos f \cos e \quad (23)$$

$$\cos \theta \sin y = \sin \Omega \sin \chi - 2 \left| \underline{v} \cdot \underline{N} \right| \cos f \sin e \quad (24)$$

$$\sin \theta = \cos \Omega + 2 \left| \underline{v} \cdot \underline{N} \right| \sin f \quad (25)$$

Dividing (24) by (23) gives:

$$y = \tan^{-1} \left[\frac{\sin \Omega \sin \psi - 2 \left| \underline{v} \cdot \underline{N} \right| \cos f \sin e}{-\sin \Omega \cos \psi - 2 \left| \underline{v} \cdot \underline{N} \right| \cos f \cos e} \right] \quad (26)$$

and from (25):

$$\theta = \sin^{-1} (\cos \Omega + 2 \left| \underline{v} \cdot \underline{N} \right| \sin f) \quad (27)$$

Values of θ and y can be found which compare with the range in Figure H-6 by using trial and error values for f and e in equations (26) and (27). As a starting point, when $\xi = 0$, $\psi = 90^\circ$ and $\Omega = 0^\circ$, then:

$$y = e \quad (28)$$

and,

$$\theta = \sin^{-1} (1 - 2 \sin^{-2} f) = \sin^{-1} (\cos 2f)$$

therefore,

$$f = 45^\circ - \frac{\theta}{2} \quad (29)$$

The range of Figure H-6 provides initial values of θ and y and hence trial values of f and e . For a duty cycle of 31.5%, the angle ξ varies from -57° to $+57^\circ$ and the scan cone half angle $\Delta = 6^\circ 46'$. It soon becomes apparent that scanning across a single mirror is unable to satisfy all orbital conditions of launch azimuth and declination. However, the horizontal traces in Figure H-6 show that a combination of two mirrors can satisfy all possible orbits. During the rotation of the scan mechanism the direction of view will move along the line and the sun will be seen at some point in the orbit. The direction of the normals for the mirrors giving the 2 scans in Figure H-6 are:

<u>altitude (f)</u>	<u>azimuth (e)</u>
35°	30°
35°	38°

As the sun has an angular diameter of 8.7×10^{-3} radians it will be seen on a total of 21 consecutive scan revolutions (each 0.4×10^{-3} radians) each orbit and as the low resolution aperture moves across the solar equator the sun will be seen for 21 elements.

APPENDIX I

SOLID CRYOGEN DETECTOR COOLING SYSTEM

An alternate detector cooling technique which is applicable to the OSS detector cooling requirement is the open cycle solid cryogen system. This method uses a stored solid mass of cryogen (hydrogen, methane, nitrogen, argon, or similar solidified gas) in a special pressure controlled dewar. Heat entering from the refrigerated object causes the cryogen to sublime. The sublimation rate and, consequently, the temperature are controlled by regulating the equilibrium vapor pressure surrounding the subliming solid. Both the cryogen and the vapor vented are available as a heat sink for detector or other component cooling purposes.

Depending upon the particular configuration, it is possible to achieve temperature control with few or no moving parts. A complete pneumatic temperature control system is readily implemented by using only the vapors resulting from the cryogen sublimation process. A solid cryogen system offers a relatively low weight and volume system since the latent heat of sublimation is the controlling factor for determining the amount of cryogen required. In addition, there is no need for electrical power decontamination provisions or complex optical path alignment and ancillary equipment. Orbital parameters or spacecraft orientation have minimal effect upon the solid cryogen cooling system.

The selection of the cryogen for a particular cooling application depends upon many factors related to the heat load, operating lifetime nominal temperature condition, as well as cryogen heat of sublimation, triple point temperature, vapor pressure characteristics, density, and other factors. In most applications, the cryogen sublimation should occur 10 to 15°K below the nominal operating temperature condition of the refrigerated component. Table I-1 list some of the more common cryogen materials considered as suitable for space application and includes some of their typical characteristics.

A potential candidate cryogen for the OSS Scanner is methane, which has characteristics compatible with the band 7 detector temperature requirement. Figure I-1 presents the estimated weight and volume characteristics for a methane cryogen system operating under a heat load of 100 mW at 88° K for a lifetime up to 36 months. Significant portions of the weight and volume are insulation and structure with reductions possible if the package outer surface temperature can be reduced as shown. The 100 mW heat load to the cryogen material is composed of both detector heat load and the heat leak from surrounding structure and insulation.

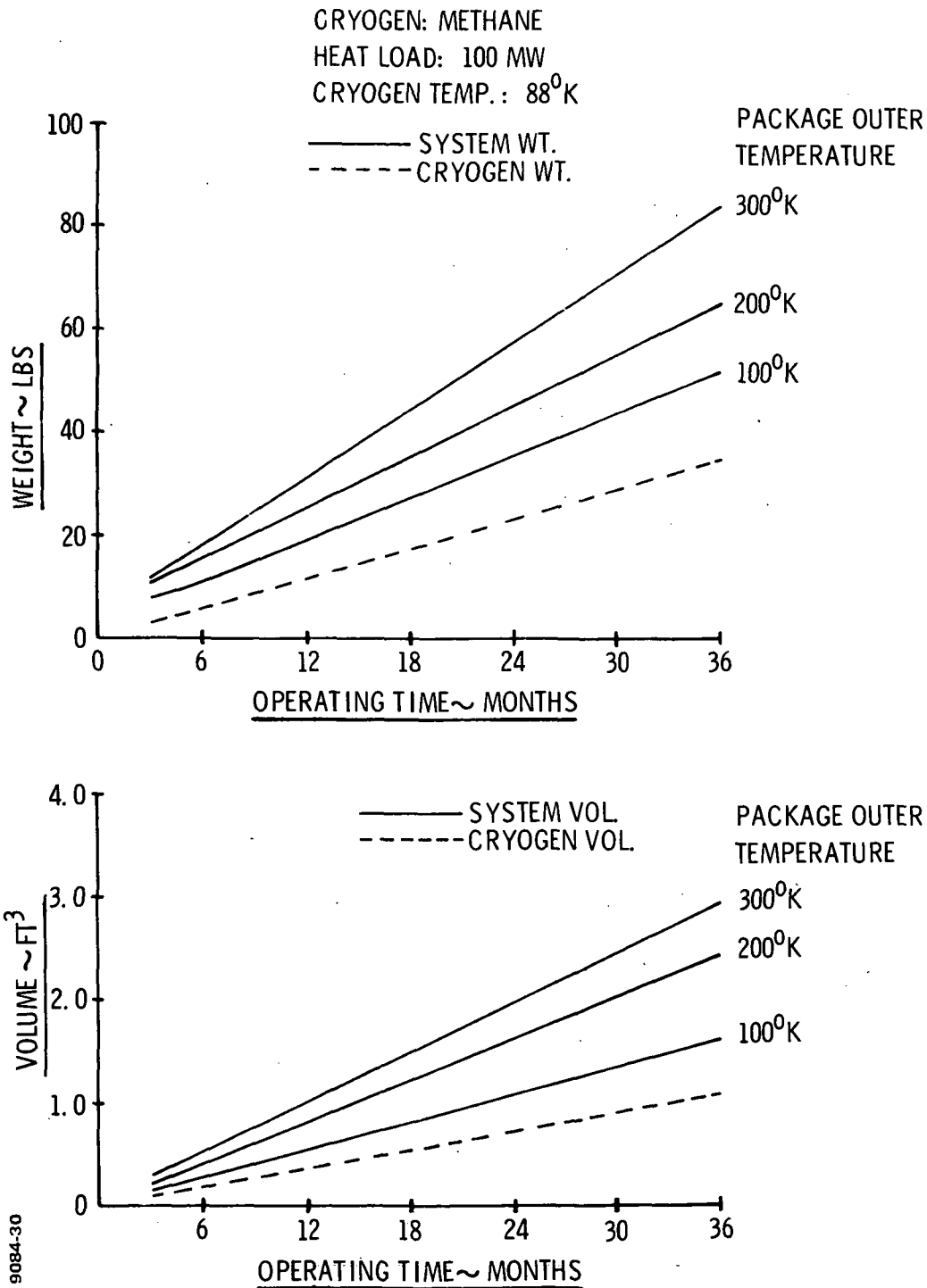


Figure I-1 Estimated Solid Cryogen System Weights and Volumes

TABLE I-1

TYPICAL CHARACTERISTICS OF COMMON CRYOGENS

Cryogen Material	Triple Point Temp ($^{\circ}$ K)	Triple Point Heat of Sublimation (Btu's/lb)	Density (lb/ft ³)	Operating Temperature Range ($^{\circ}$ K)	Operating Vapor Pressure (Torr)
1. Argon	83.8	81.9	101.3	83 - 55	400 - 1
2. Hydrogen	13.81	216.9	5.41	14 - 10	56 - 2
3. Methane	90.6	258.	32.3	90 - 67	80 - 1
4. Neon	24.54	70.2	90.	24 - 16	260 - 1
5. Nitrogen	63.15	103.1	59.1	62 - 47	74 - 1

It is possible to use a single cryogen cooling system to meet the OSS detector cooling requirements for bands 5, 6, and 7 by using to the fullest extent possible both the solid cryogen and its vapors. Such a system would provide cooling in ascending order of detector temperature requirements. For the OSS system, the band 7 detector would be in direct contact with the heat transfer structure of the cryogen. The resulting vapors would be used to cool the detector arrays for bands 5 and 6. Once beyond these detectors, the vapors would then be available for any miscellaneous cooling requirement prior to venting. These vapors may even be used to provide some of the cryogen package thermal protection. A schematic drawing for such a system is presented in Figure I-2 and is intended to illustrate the ascending order of cooling priority using a solid cryogen refrigerator system. Cryogen temperature is maintained in such a unit by means of an orifice and bypass valve to control both vapor flow and pressure surrounding the cryogen.

A brief consideration of a solid cryogen detector cooling for the OSS system has resulted in the following preliminary conclusions:

1. The open cycle solid cryogen system is comparable in terms of total system weight, volume, and configuration flexibility to a passive radiation cooler for 1- to 2- year operating times.
2. The solid cryogen system performance is not dependent on orbit or spacecraft orientation nor is it susceptible to parent spacecraft contamination from outgassing or control system byproducts.

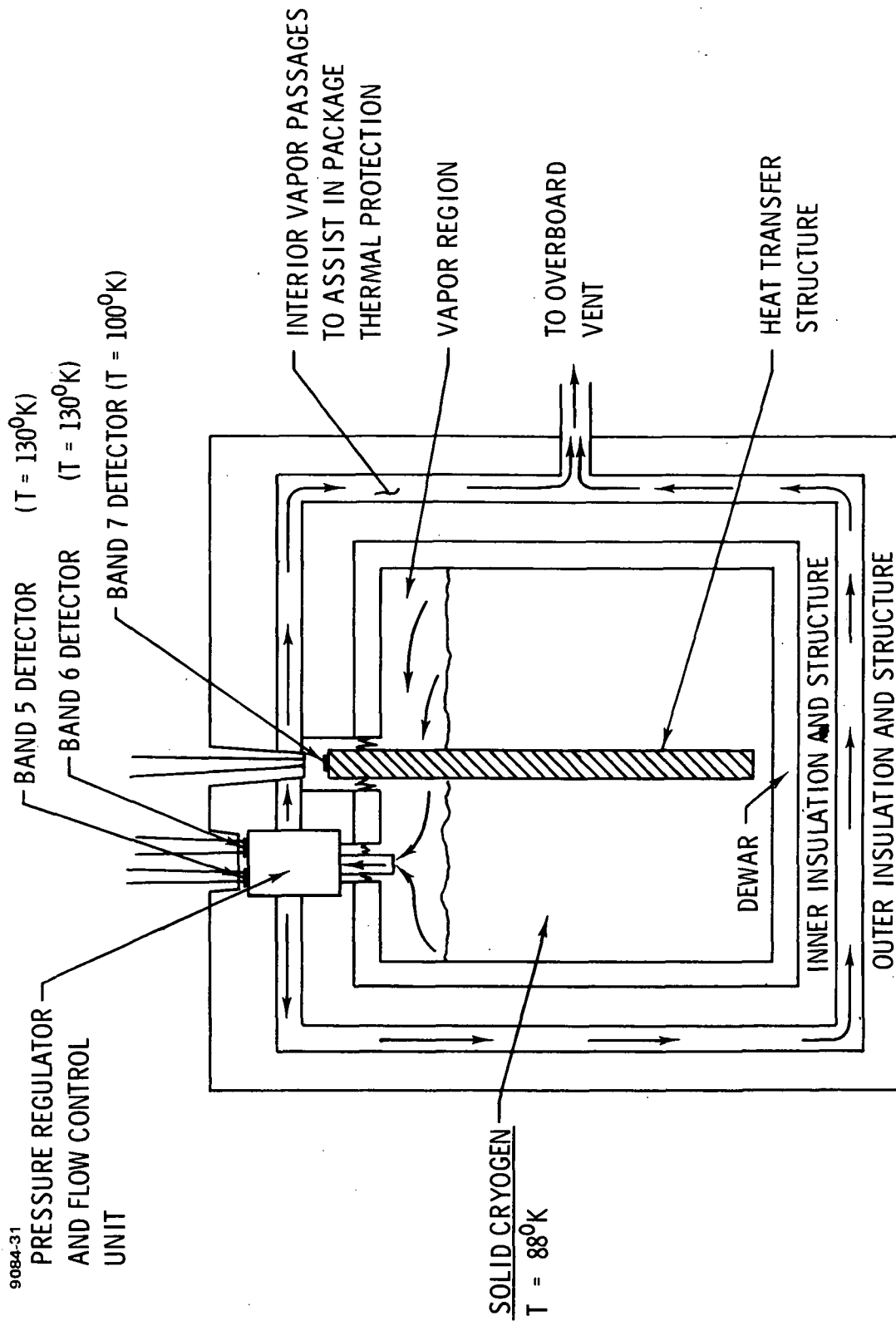


Figure I-2 Solid Cryogen System Schematic Description

3. Control of the solid cryogen system is inherent to its basic sublimation process and, using pneumatic methods, eliminates power requirements, minimizes ancillary equipment, and maintains a stabilized detector temperature throughout the system operating life.
4. Breadboard or development tests of a solid cryogen system can be implemented which can verify system size, control, reliability, and performance without using a solid cryogen mass.
5. Greater flexibility in packaging configuration, detector placement, and integration into the primary optical path is available in the solid cryogen system compared with a passive cooler.
6. The cryogen can be hazardous and require special handling and safety precautions both prior to launch and during storage.
7. Loading of the cryogen must be delayed until a few days before launch.
8. Operating life beyond 3 years does not appear feasible for most orbital scanning systems using the solid cryogen system. Also, the 3-year system is limited to the larger spacecraft usage.