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AEROSOL PHYSICAL PROPERTIES IN THE STRATOSPHERE (APPS) RADIOMETER DESIGN SUMMARY REPORT

by

Carlton R. Gray, E. Albert Woodin, Thomas J. Anderson, Robert J. Magee and George W. Karthas

January 1977

Prepared under Contract No. NAS1-14150 by

The Charles Stark Draper Laboratory, Inc.
Cambridge, Massachusetts 02139

for

NASA
National Aeronautics and Space Administration
This report presents the measurement concepts and radiometer design developed to obtain earth-limb spectral-radiance measurements for the Aerosol Physical Properties in the Stratosphere (APPS) measurement program. The measurements made by a radiometer of this design can be inverted to yield vertical profiles of Rayleigh scatterers, ozone, nitrogen dioxide, aerosol extinction, and aerosol physical properties, including a Junge size-distribution parameter, and a real and imaginary index of refraction. The radiometer design provides the capacity for remote sensing of stratospheric constituents from space on platforms such as the Space Shuttle and satellites, and therefore provides for global measurements on a daily basis.
R-1031

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Approved: Norman E. Sears, Head
NASA/Army
Programs Department

The Charles Stark Draper Laboratory, Inc.
Cambridge, Massachusetts 02139
ACKNOWLEDGMENT

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Publication of this report does not constitute approval of the National Aeronautics and Space Administration of the findings and conclusions contained herein. It is published for the exchange and stimulation of ideas.
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<td>LIST OF REFERENCES</td>
<td>239</td>
</tr>
</tbody>
</table>
SECTION 1

INTRODUCTION

There is growing scientific opinion that physical processes in the earth's stratosphere are of vital importance to man and the biosphere, and that very little is understood of these processes. The Aerosol Physical Properties in the Stratosphere (APPS) measurement program of remote sensing of the stratosphere has recently demonstrated\(^{(1,2)}\) its unique capability for monitoring the atmospheric state and interactions in this region, thus improving man's knowledge of the stratosphere.

The APPS measurement program is designed to invert earth-limb radiance measurements (see Figure 1-1) to obtain vertical profiles of atmospheric state parameters in the stratosphere. The inverted atmospheric state parameters are Rayleigh scatterers, ozone, nitrogen dioxide, aerosol extinction, and aerosol physical properties, including a Junge size-distribution parameter, and a real and imaginary index of refraction.

Simultaneous measurement of more than one atmospheric state parameter in the stratosphere has for years been virtually impossible. More recently, as the scientific community has focused increasing interest on the physical processes, experimental techniques capable of more adequately monitoring this region have evolved. Limb inversion is one of the more promising techniques, with the unique capability of establishing aerosol physical properties which existing remote measurement techniques cannot. In addition, global coverage is extended with the APPS measurement program, as the scan geometry is not tied to a single sun-spacecraft geometry.

Reported herein is the APPS radiometer design (see Figures 1-2 and 1-3), which meets the design requirements for stratospheric monitoring by remote sensing of the limb. Special design features of the APPS radiometer are its dual in-line direct solar calibration, its optical characteristics including off-axis radiation rejection, and its information-processing characteristics for the Space Shuttle and/or sun-synchronous

\* Superscript numerals refer to similarly numbered references in the List of References.
satellite configurations. These design features classify the instrument as a state-of-the-art radiometer design (see Table 1-1).

Figure 1-1. Earth-limb spectral radiance data.
Figure 1-2. APPS radiometer design.
Figure 1-3. Scanning mirror assembly.
Table 1-1. NASA/JPL FLIGHT INSTRUMENTS CATALOG

<table>
<thead>
<tr>
<th>1. INSTRUMENT NAME: (APPS) Aerosol Physical Properties in the Stratosphere</th>
<th>INSTRUMENT CLASS</th>
<th>CATALOG NO.</th>
<th>PAGE</th>
</tr>
</thead>
</table>

2. GENERAL:  
**TYPE** Spectral Radiometer  
**PURPOSE** Global measurements of spatial and temporal variations in Aerosol Physical Properties in the Stratosphere and Mesosphere.

**PRINCIPLE OF OPERATION** The radiometer measures the scattered solar radiation from the earth's limb in selected spectral bands with a single line-of-sight and a finite field of view. Scans of the earth's horizon are obtained from the shuttle or satellite. The measured horizon intensities are encoded on board and telemetered to the ground for inversion processing of aerosol physical properties, ozone density, molecular density and NO2.

3. RESPONSIBLE INDIVIDUALS:  
**TELEPHONE**
- **PRINCIPAL INVESTIGATOR** Carlton R. Gray  
  **ORGANIZATION** C. S. Draper Laboratory, Inc.  
  **PROGRAM MANAGER** Kenneth H. Crumbly  
  **ORGANIZATION** NASA - Langley (AAFE)  
- **FUNDING ORGANIZATION** NASA - Langley (AAFE)  
- **THIS DATA SHEET PREPARED BY** Carlton R. Gray  
  **ORGANIZATION** C. S. Draper Laboratory, Inc.

4. MISSION:  
**SPACECRAFT/AIRCRAFT/OTHER** TBD - Shuttle  
**ORBIT/TRAJECTORY PARAMETERS**

* Potential for outer planet studies and spin stabilized satellites

5. PERFORMANCE:  
**PARAMETERS OBSERVED** Spectral Radiance  
**MEASUREMENT LIMITS** Daylight  
**ACCURACY** Intensity, 0.006% relative, 5.0% absolute  
**RESOLUTION** Angular 0.2 m  
**OBSERVATION RATE** 592.6/sec. for 0.9 sec., 50 limbs per orbit typical  
**DESIGN LIFE** two (2) years  
**DUTY CYCLE** < 1 minute per orbit  
**REDUNDANCY** System backup modes  
**NOTES:** The inverted quantities are aerosol physical properties (density, size, index of refraction - real and imaginary), ozone density, molecular density and NO2.
### Table 1-1. NASA/JPL FLIGHT INSTRUMENTS CATALOG (Cont.)

<table>
<thead>
<tr>
<th>INSTRUMENT NAME (APPs Aerosol Optional Properties in the Stratosphere)</th>
<th>INSTRUMENT CLASS</th>
<th>CATALOG NO.</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>6. STATUS:</strong></td>
<td><strong>OPERATIONAL DATE</strong></td>
<td><strong>TBD</strong></td>
<td></td>
</tr>
<tr>
<td><strong>UNITS BUILT (YEAR)</strong></td>
<td><strong>--</strong></td>
<td><strong>MISSIONS FLOWN (YEAR)</strong></td>
<td><strong>--</strong></td>
</tr>
<tr>
<td><strong>UNITS TO BE BUILT (YEAR)</strong></td>
<td><strong>TBD</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>INSTRUMENT HERITAGE</strong></td>
<td>Based on (MIT/11, X-15) and (LES 8/9) optical design concepts and Parts of Sextant</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**7. PHYSICAL CHARACTERISTICS:** Shuttle Design

**MASS:**
- Beryllium 19.6 kg (43.25 lb)
- Beryllium/Aluminum 24.7 kg (54.42 lb)

**DIMENSIONS:**
- 35.6 x 34.6 x 55.9 cm

**ENVELOPE:**
- STOWED: 35.6 x 34.6 x 55.9 cm
- DEPLOYED: (same)

**OPTICAL DESIGN:** Unobstructed clear field of view of earth limb

**8. REQUIREMENTS/INTERFACE CONSTRAINTS:**

**INPUT POWER:**
- 23.3 watts * D.C., uses no A.C. input A.C., not applicable * Hz

**TEMPERATURE:**
- 288°K

**PHYSICAL LIMITS:**
- VIBRATION: 15 G, random ≤ 2000 Hz
- SHOCK: 50 G, 1/2 cycle, sine 0.2 ms
- ACOUSTIC: TBD
- RADIATION: Shuttle orbital conditions

**MAGNETIC SUSCEPTIBILITY:** TBD

**ATTITUDE (POSITION/RATE):**
- PITCH 1.0°/0.2°
- ROLL 1.0°/1.0°
- YAW 1.0°/1.0°

**ATTITUDE DETERMINATION:**
- PITCH: 0.02°
- ROLL: 1.0°
- YAW: 1.0°

**IN-FLIGHT CALIBRATION:**
- Built in solar calibration, requires < 1 second, automatic or upon command.

**NOTES:**
- Electronic: 11.1 watts
- Scanning Motor: 5.7
- Thermal Control: 6.1
- Expansion: 0.9
- Total: 23.3 watts

**9. COMMUNICATIONS:**

**DOWNLINK:**
- TYPE: Bi-Phase
- FREQUENCY: S-Band
- INFORMATION RATE: 128 Kbps
- DYNAMIC RANGE

**UPLINK:**
- TYPE: Discrete
- FREQUENCY
- BANDWIDTH
- INFORMATION RATE: TBD

**COMMANDS/GROUND CONTROLLABLES:**
- 13 commands

**GROUNDSATION NETWORK:**
- TBD

**THROUGHPUT/PROCESSING TIME:**
- TBD

**SIGNAL PROCESSING:**
- ONBOARD Scheduling
- GROUND Inversion of horizon intensity data - ephemeris data

**NOTES:**
### Table 1-1. NASA/JPL FLIGHT INSTRUMENTS CATALOG (Cont.)

<table>
<thead>
<tr>
<th>INSTRUMENT NAME (APPS) Aerosol Physical Properties in the Stratosphere</th>
<th>INSTRUMENT CLASS</th>
<th>CATALOG NO.</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. SENSOR: SPECTRAL RANGE 300 nm to 850 nm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPECTRAL RESOLUTION 10 nm at eight (8) discrete wavelengths</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DETECTOR TYPE(S) Silicon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DETECTOR OPERATING TEMPERATURE 0° to 25°C</td>
<td>NEP 0.9 x 10⁻¹³ watts/Hz¹/²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COOLING METHOD thermoelectric coolers as mission requires</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DYNAMIC RANGE 10⁶</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOTES:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. OPTICS: TYPE Off axis cassegrain telescope</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FOCAL LENGTH 45.72 cm</td>
<td>CLEAR APERTURE 100 cm²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FIELD OF VIEW: TOTAL 0.2 x 4.0 Mr INSTANTANEOUS not applicable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANGULAR RESOLUTION 0.2 Mr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OPTICAL ELEMENT MATERIAL Beryllium COATING Aluminum - Nickel</td>
<td>electrolytically deposited</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOTES:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. SCAN: METHOD Oscillating mirror</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PATTERN Linear pitch scan SCAN RATE/FRAME TIME 3°/second</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pointing MECHANISM Shuttle - attitude control of pallet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pointing ACCURACY ± 0.5° STABILITY ± .01°/second</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOTES:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. DATA OUTPUT: CONTENT Limb radiance—uW/cm²⋅sr⋅nm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FORMAT Serial binary, 14 bit digital word</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOTES:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 1-1. NASA/JPL Flight Instruments Catalog (Cont.)

<table>
<thead>
<tr>
<th>Instrument Name (APPS)</th>
<th>Instrument Class</th>
<th>Catalog No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerosol Physical Properties in the Stratosphere</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Outline Drawings

#### Block Diagram

#### Footprint

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>s</td>
<td>Distance to Tangent Point</td>
</tr>
<tr>
<td>h</td>
<td>Geophysical Altitude</td>
</tr>
<tr>
<td>a</td>
<td>Altitude Above Tangent Point</td>
</tr>
<tr>
<td>v</td>
<td>Scan Rate</td>
</tr>
</tbody>
</table>

**References:**

- **R. Newell and C. Gray** - Meteorological and Ecological Monitoring of the Stratosphere and Mesosphere, August 1972
- **C. Gray, H. Malchow** - Aerosol Physical Properties from Satellite, July 1973
- **D. Merritt, R. Var** - Horizon Inversion, NASA-CR-112311
- **C. Whitney**
SECTION 2

OPTICAL DESIGN

2.1 INTRODUCTION

Multispectral radiance from scattered solar radiation at the earth's limb is gathered by means of an optical system which contains a telescope with restricted field-of-view, spectral filters, and transfer optics. The telescope uses a reflective objective which focuses an image of the earth's limb onto a restricting focal-plane aperture. The optical radiation passing through the aperture is transferred by a lens into parallel beams which are cascaded down a chain of filters. Behind each filter is a lens which concentrates the image of the aperture onto detectors so that the radiance in each wavelength band may be recorded. A schematic of the optical system is shown in Figure 2-1.

2.2 OPTICS DESCRIPTION AND DESIGN

2.2.1 Objective

The collecting optics chosen for the radiometer is an unobscured (eccentric) Cassegrain telescope consisting of sections of a paraboloid (primary mirror) and a hyperboloid (secondary mirror). This configuration was chosen to obtain the highest possible rejection of off-axis radiance and to be consistent with the desired mechanical size for the APPS radiometer.

The principal dimensions of the objective are (in centimeters):

1) Clear aperture
   (a) Primary diameter—11.4
   (b) Secondary diameter—2.2

2) Equivalent radius of curvature
   (a) Primary radius—61
   (b) Secondary radius—30.5
(3) **Distance along optical axis**
   
   (a) Primary to secondary—25.4
   
   (b) Secondary to focal plane—7.6

2.2.2 **Transfer Lenses**

Transfer lenses have been designed to provide a minimum of divergence to the filter chain of the optical radiation passing through the focal-plane aperture. To keep the number of elements small and the transmittance high, a single lens with one aspheric surface has been chosen. An image of the aperture is formed at a distance of approximately 80 centimeters so that a constant clear-aperture diameter is created throughout the filter chain. The specific image distance is thus governed by the path length required to accommodate the number of filters desired, which has been set at eight. The maximum divergence of the light rays for this optical design was set at ±25 milliradians.

2.2.3 **Filter Chain**

The filter-chain assembly of the APPS design provides for up to eight spectral bands in a cascaded configuration progressing from the ultraviolet to the infrared wavelengths down the train. The mechanical design established thus utilizes a 15-degree angle-of-incidence to each filter, which results from a trade-off between minimizing path length, size, and polarization. Details of the filter characteristics are given in Section 2.5. The assembly accommodates filter discs 30 millimeters in diameter by 3 millimeters thick.

2.2.4 **Detector Lens**

Condensing lenses are required to minimize the size of the detectors. Behind each filter is a double convex singlet of 23-millimeter focal length, which reduces the size of the transmitted beam to fall within the detector area. The curvatures are spherical and are designed in conjunction with the transfer lens.

2.2.5 **Scanning Mirror**

The radiometer was originally designed for use in a spin-stabilized satellite and did not require a built-in scanning mechanism. To extend the use of the radiometer to the Space Shuttle mission, a scanning-mirror
assembly was designed at the outboard end (see Figure 1-3). It is comprised of a housing, a baffle, a plane mirror, and a drive train and motor. The mirror has a clear elliptical aperture approximately 15 centimeters by 12 centimeters, and is driven mechanically through the range ±35 milliradians, which is optically ±70 milliradians. The nominal line-of-sight is directed 111 degrees to the radiometer principal axis to accommodate the negative elevation of the limb from a 500-kilometer Space Shuttle orbit, and to conserve instrument-envelope dimensions.

2.2.6 Detailed Design

The performance of eccentric Cassegrain configurations was first examined using the CSDL automatic lens design programs. The specific design of the APPS optics was accomplished using the ACCOS V program system. The ACCOS V program has the coordinate transformations required to handle the decentered aperture and rotated transfer-lens optical axis, as well as provision for using aspheres of higher-than-conic order. The optical design and analysis programs provide:

1. Optical-surface curvatures.
2. Spacing and thickness of elements.
3. Clear-aperture requirements.
4. Image positions and aberrations.
5. Tolerances on optical parameters.

Table 2-1 is a listing of the optical parts with their approximate dimensions and forms. More details of the transfer and filter lens are shown in Figure 2-2. Tolerances for the objective components are listed in Table 2-2. Tolerances on the remaining optical elements are to be specified during the instrument-development phase.

To obtain the maximum wavelength coverage, all refractive elements have ultraviolet-grade fused-silica substrates. To achieve thermal stability and to provide low mass, the reflective elements have beryllium substrates.

2.2.7 Resolution

The radiometer objective resolution is limited on-axis by diffraction, and produces images due to geometric aberrations at the edge of the field-of-view as shown in Table 2-3. Since the aperture width is much larger than the diffraction limit, only moderate tolerances are required on the optical components. In practice, however, the optical resolution will be determined by the accuracy of fabrication of the
<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>Approximate Size</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Mirror</td>
<td>Beryllium</td>
<td>5-in. dia., 3/4-in. thick</td>
<td>Parabolic sector, EFL = 12 in.</td>
</tr>
<tr>
<td>Secondary Mirror</td>
<td>Beryllium</td>
<td>1-in. dia., 1/4-in. thick</td>
<td>Hyperbolic sector, EFL = 6 in.</td>
</tr>
<tr>
<td>Focal-Plane Aperture</td>
<td>Chromium on Quartz</td>
<td>3/8-in. dia., 1/16-in. thick</td>
<td>Aperture is scribed line on chromium coating protected by cover quartz plate</td>
</tr>
<tr>
<td>Attenuator Filter</td>
<td>Metal on Quartz</td>
<td>1/4-in. × 1/2-in. × 1/8-in. thick</td>
<td>Solar filter and compensator for direct calibration</td>
</tr>
<tr>
<td>Compensation Plate</td>
<td>Quartz</td>
<td>1/4-in. × 1/2-in. × 1/8-in. thick</td>
<td>Solar filter and compensator for direct calibration</td>
</tr>
<tr>
<td>Two-position Mirror</td>
<td>Beryllium</td>
<td>1/2-in. × 1/2-in. × 1/2-in. thick</td>
<td>Two positions — calibration or line of sight</td>
</tr>
<tr>
<td>Transfer Lens</td>
<td>Quartz</td>
<td>7/8-in. dia. × 0.3-in. thick</td>
<td>Single-element asphere</td>
</tr>
<tr>
<td>Flat Mirror</td>
<td>Beryllium</td>
<td>7/8-in. dia. × 0.2-in. thick</td>
<td>Redirection fixed mirror</td>
</tr>
<tr>
<td>Interference Filter</td>
<td>Multilayer on Quartz</td>
<td>1 1/8-in. dia. × 0.18-in. thick</td>
<td>Eight required — one for each waveband</td>
</tr>
<tr>
<td>Filter Lens</td>
<td>Quartz</td>
<td>7/8-in. dia. × 0.2-in. thick</td>
<td>Single-element spherical eight required — all identical</td>
</tr>
<tr>
<td>Scanning Mirror</td>
<td>Beryllium</td>
<td>5-in. × 7-in. × 3/4 in.</td>
<td>Flat</td>
</tr>
</tbody>
</table>
Figure 2-2. Transfer optics.

Table 2-2. Radiometer tolerances.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Change in Parameter</th>
<th>Change in rms Image Radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Mirror to Secondary Mirror Spacing</td>
<td>±0.005 in.</td>
<td>0.00104 in.</td>
</tr>
<tr>
<td>Secondary Mirror to Focal Plane Spacing</td>
<td>±0.005 in.</td>
<td>0.00062 in.</td>
</tr>
<tr>
<td>Decentering of Primary Mirror to Secondary Mirror (Along y Axis)</td>
<td>0.005 in.</td>
<td>0.00051 in.</td>
</tr>
<tr>
<td>Decentering of Primary Mirror to Secondary Mirror (Along x Axis)</td>
<td>0.005 in.</td>
<td>0.00046 in.</td>
</tr>
<tr>
<td>Tilt of Primary Relative to Secondary Mirror (About x Axis)</td>
<td>0.05° (0.87 mrad)</td>
<td>0.00038 in.</td>
</tr>
<tr>
<td>Tilt of Primary Mirror Relative to Secondary Mirror (About y Axis)</td>
<td>0.05° (0.87 mrad)</td>
<td>0.00042 in.</td>
</tr>
</tbody>
</table>

Linear Relation Tolerance to Radius

Image Increase = Image Diameter at Ends of Slit
Table 2-3. Radiometer specifications.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance-Aperture Area</td>
<td>100 cm²</td>
</tr>
<tr>
<td>Effective Focal Length of Primary Optics</td>
<td>45.72 cm (18 in.)</td>
</tr>
<tr>
<td>Field-of-View Through Primary Focal-Plane Aperture</td>
<td>0.2 mrad x 4 mrad (0.0036 in.) x (0.072 in.)</td>
</tr>
<tr>
<td>Radiometer Transmission (Up to and Including Transfer Lens)</td>
<td>22% - 47%</td>
</tr>
<tr>
<td>rms Image Radius of Primary Optics at 0.12 degree (Approx. Ends of Focal Plane Aperture)</td>
<td>0.023 mrad (0.00041 in.)</td>
</tr>
<tr>
<td>rms Image-Radius Transfer Optics at 0.9 degree (Approx. Ends of Focal Plane Aperture)</td>
<td>0.0005 in.</td>
</tr>
</tbody>
</table>

mirrors and alignment of the components. Figure 2-3 shows the optical transfer function of the radiometer comparing the objective and aperture over the first cycle. It can be seen from the curves that the response of the objective optics has a very small effect on the aperture response. The aperture-limited resolution is discussed further in Section 4.

Figure 2-3. Radiometer optical transfer function.
2.3 APERTURES AND FIELD STOPS

2.3.1 Entrance Aperture

The diameter of the radiometer entrance aperture is chosen to give a 100-centimeter$^2$ collecting area. The position of the aperture stop is placed at the surface of the primary mirror to minimize its exposure to off-axis radiation. With the use of the scanning-mirror assembly, however, a more optimum position for the stop would be approximately 30 centimeters in front of the primary vertex. However, such a change would require a repositioning of the transfer-lens aperture stop to a less desirable location.

2.3.2 Focal Plane and Transfer Lens

The field-of-view of the radiometer is defined and limited by a rectangular aperture at the focal plane. It is constructed by etching away material from chromium film deposited on the fused-silica plate. The aperture is protected by a fused-silica cover plate. The width of the aperture, the larger rectangular dimension, is limited to a 4-milliradian field-of-view by the desired solar-calibration technique, by the desired limb-spatial resolution, and by the mechanical size of the filter train. The height of the aperture has the same maximum limitation. The minimum height, however, is limited to 0.1 milliradian because of diffraction. Smaller apertures will cause the transmitted beam to increase beyond the clear aperture of the transfer lens.

The transfer lens produces an image of the objective-aperture stop approximately 8 centimeters beyond the lens. The redirection mirrors are configured to place this image at the first filter in the chain, so that a restricting aperture can be placed at this point to block light scattered by the objective aperture from reaching the detectors.

2.3.3 Detector

The condenser lenses are configured to place an image 0.4 times the focal-plane aperture on the detectors. This arrangement provides the smallest detector size requirement. However, in the case where the detector's area is large enough, the placement of the image slightly beyond the focus of the condenser lenses is desirable to minimize the effect of nonuniform sensitivities within the detector-active area.
2.3.4 Calibration Path

The diffuse calibration path is designed to permit an unvignetted view of a fused-silica diffuser by the transfer optics, filter train, and detectors. This is accomplished by the introduction of a redirection mirror between the secondary mirror and the focal-plane aperture. To duplicate the f/number of the objective, which is set at 4, the transmission diffuser ends up approximately 5 centimeters in diameter, at a location in the radiometer which permits its exposure to direct sunlight.

2.4 BAFFLE STRUCTURES

2.4.1 Objective Cavity

The objective-housing assembly is designed with baffles and light traps to minimize the illumination of the primary and secondary mirrors by optical radiation outside the field-of-view scattered from the housings. The design, as shown in Figure 2-4, represents an effective rejection system. For the Space Shuttle configuration, with the scanning-mirror assembly attached, it may be possible, after scattered-light tests are run, to eliminate some or all of the objective-cavity baffles to reduce the mass of the radiometer. Figure 2-4 shows the criteria lines used to establish the angles and depths of the baffle fins. The design goal was to require the equivalent of three specular reflections of an incoming ray before it arrived at either mirror, for a solar-exclusion angle of 20 degrees. The surface treatment of the baffles is discussed in Section 2.6.

2.4.2 Transfer Region

The aperture plate is to be coated with a chromium film and black oxidized on the transfer-lens side. The radiation incident on the objective side of the aperture plate will be reflected against the internal baffles (between the secondary mirror and the focal plane). Special baffles beyond the focal-plane aperture are not required. All optical-cavity walls should be etched, sand-blasted, or serrated and blackened as defined in Section 2.6.

The third aperture stop, located at the first filter, should be machined during assembly to guarantee its function excluding an image of the illuminated primary-mirror aperture.
Figure 2-4. Baffle design criteria—objective cavity.
2.4.3 Filter Chain

A special light trap is located at the end of the filter chain. The design of this light trap aids in preventing a reflection of spectral radiation not sampled at each discrete filter. This reduces the general illumination of all channels from a large percentage of the reflected solar radiation lying between the filter bandpasses.

2.4.4 Scanning-Mirror Assembly

The design criteria for setting up the baffle positions for the scanning-mirror assembly are shown in Figure 2-5. The baffle length is arbitrarily terminated to keep the dimensions of the radiometer compact. The design allows a 25-degree sun-angle constraint.

2.5 FILTER CHARACTERISTICS

2.5.1 Transmission

The filter type chosen for use on the radiometer is a Fabry-Perot design with fused-silica substrates. Each filter consists of a blocker and a selector. Figure 2-6 shows the transmission bandpasses of a set of typical filters tested during the development of the instrument design. The equivalent integrated bandpasses vary from 10 to 20 nanometers. Both the bandpass and the center wavelength can be chosen to suit the radiometer design and inversion requirements between wavelengths of 250 and 2000 nanometers.

2.5.2 Reflection

The use of interference filters, as opposed to a prism or grating, is made efficient because most of the optical radiation not transmitted by the filters is specularly reflected. The order of the filters, from the ultraviolet to infrared, is chosen because a silver coating, which is preferred for its high reflectance, does not transmit well below 400 nanometers. Therefore, the first one or two filters will employ an aluminum coating to increase the system throughput for the ultraviolet filters. Table 2-4 shows the reflectances of a similar set of interference filters with aluminum coatings. The production filters are expected to have approximately 5-percent-higher reflectances outside their bandpasses.
Figure 2-5. Baffle design criteria—scanning mirror assembly.
Figure 2-6. Typical interference filters—spectral bandpass characteristics.

Table 2-4. Percent reflectance values of Schott interference filters at 10-degree angle-of-incidence.

<table>
<thead>
<tr>
<th>Measurement Wavelength (nm)</th>
<th>403 nm</th>
<th>420 nm</th>
<th>502 nm</th>
<th>596 nm</th>
<th>693 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>28.5</td>
<td>28.5</td>
<td>86</td>
<td>86</td>
<td>86</td>
</tr>
<tr>
<td>500</td>
<td>87</td>
<td>86</td>
<td>64.5</td>
<td>89.5</td>
<td>86</td>
</tr>
<tr>
<td>600</td>
<td>92</td>
<td>92</td>
<td>92</td>
<td>79</td>
<td>92</td>
</tr>
<tr>
<td>700</td>
<td>94</td>
<td>92.5</td>
<td>91.5</td>
<td>91</td>
<td>84</td>
</tr>
<tr>
<td>800</td>
<td>95</td>
<td>95</td>
<td>92</td>
<td>89</td>
<td>89</td>
</tr>
<tr>
<td>900</td>
<td>95</td>
<td>95</td>
<td>92</td>
<td>89</td>
<td>89</td>
</tr>
</tbody>
</table>
2.5.3 Polarization

Optimization studies were performed at CSDL to establish the polarization properties of sample interference filters as a function of angle-of-incidence. A study was made to determine the approximate effects and variability of the polarization of the transmitted beam (see Figure 2-7). The values varied widely depending on the coating and material thickness chosen by the vendor. Table 2-5 shows the measured values at a 15-degree angle-of-incidence for the set of typical interference filters. The polarization values are well within the 10 percent criterion established as an upper limit for the present design. The reflected beams remained essentially unpolarized.

Figure 2-7. Interference filters—polarization characteristics.
Table 2-5. APPS interference filters - polarization characteristics at 15-degree angle-of-incidence.

<table>
<thead>
<tr>
<th>λ (nm)</th>
<th>% (Vendor)</th>
<th>% (CSDL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>3.37</td>
<td>3.5</td>
</tr>
<tr>
<td>350</td>
<td>0.47</td>
<td>1</td>
</tr>
<tr>
<td>400</td>
<td>4.39</td>
<td>4.5</td>
</tr>
<tr>
<td>500</td>
<td>3.48</td>
<td>4</td>
</tr>
<tr>
<td>600</td>
<td>2.25</td>
<td>4</td>
</tr>
<tr>
<td>700</td>
<td>5.77</td>
<td>6</td>
</tr>
<tr>
<td>1000</td>
<td>8.85</td>
<td>9.5</td>
</tr>
<tr>
<td>1000</td>
<td>5.57</td>
<td>Rerun</td>
</tr>
</tbody>
</table>

Reflection path <2% (CSDL).

2.6 COATINGS

2.6.1 Mirrors

The properties of the coatings chosen for the reflective components of the radiometer should have the following features:

(1) Broad-spectral-band reflection.
(2) Low diffuse scattering.
(3) Durability.
(4) Radiation hardness.

To preserve reflectance down to 300 nanometers, vacuum-deposited aluminum with a 1000-angstrom protective coat of magnesium fluoride is chosen. Figure 2-8 shows a comparison of the reflectance of different metals before oxidation, and includes an estimate for the protected aluminum. Higher efficiency multilayer reflective coatings are available, but the bandpass is sacrificed, and higher scattering is usually exhibited. The most advantageous alternative is the use of protected silver, which would provide a gain of approximately 10 percent per surface in reflectance. However, due to its sharp ultraviolet cut-off, the 300-nanometer channel would have to be sacrificed.
2.6.2 Lenses

A similar compromise situation prevails with reflection-reducing coatings for the transmissive elements of the radiometer. High-efficiency coatings for lenses are available which reduce the average reflectance by a factor of 10 over an uncoated surface, but only over a maximum bandwidth of 400 nanometers. A protective coating of magnesium fluoride is advisable, however, to prevent staining of the elements during construction. Figure 2-9 shows the transmission-wavelength trade-off with antireflection coatings. The magnesium-fluoride thickness should be less than 1000 angstroms to enhance the ultraviolet region where both source power and detector sensitivity are low.

2.6.3 Throughput

To calculate the power losses through the radiometer, the most conservative coating performance was assumed: aluminum on mirrors, and uncoated lenses and windows. Table 2-6 shows the percentage of the input power leaving each element of the optical train at the center wavelengths of the filter bandpasses. The detector lenses are shown before the filter chain to simplify the tabulation. A gain in throughput of a factor of 2 for most wavelengths is possible with the use of higher efficiency coatings.
From extensive scattered-light studies, two surface treatments have been found to be suitably low in scattering in the ultraviolet, visible, and near-infrared spectrum:

1. 3M Brand Black Velvet 100 Series paint (with zinc-chromate primer).
2. Black oxide of electroplated copper.

Although the paint has superior absorptions, it is difficult to apply to small cavities, and cannot be used on critical-fit interfaces. The paint treatment has previously been space-qualified and used successfully on telescopes. Specifically, it is recommended that the scanning-mirror-assembly baffles and spacers be painted. The objective-cavity baffles and spacers should be painted if the scanning-mirror assembly is not employed; otherwise, the surfaces should be electroplated. All other surfaces bordering the optical path should have the electroplate
<table>
<thead>
<tr>
<th>Element</th>
<th>Wavelength (nm)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>300</td>
<td>350</td>
<td>400</td>
<td>500</td>
<td>600</td>
<td>700</td>
<td>850</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Nodding Mirror</td>
<td>R 90</td>
<td>90</td>
<td>89</td>
<td>88</td>
<td>87</td>
<td>85</td>
<td>84</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>R 81</td>
<td>81</td>
<td>79</td>
<td>78</td>
<td>76</td>
<td>72</td>
<td>71</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td>R 73</td>
<td>73</td>
<td>70</td>
<td>69</td>
<td>66</td>
<td>61</td>
<td>60</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>Focal Plane</td>
<td>T 67</td>
<td>67</td>
<td>64</td>
<td>64</td>
<td>61</td>
<td>57</td>
<td>56</td>
<td>69</td>
<td></td>
</tr>
<tr>
<td>First Redir. Mirror</td>
<td>R 61</td>
<td>61</td>
<td>57</td>
<td>56</td>
<td>53</td>
<td>48</td>
<td>47</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Transfer Lens</td>
<td>T 56</td>
<td>56</td>
<td>52</td>
<td>52</td>
<td>49</td>
<td>45</td>
<td>44</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>Second Redir. Mirror</td>
<td>R 50</td>
<td>50</td>
<td>46</td>
<td>46</td>
<td>43</td>
<td>38</td>
<td>37</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Detector Lens</td>
<td>T 46</td>
<td>46</td>
<td>42</td>
<td>43</td>
<td>40</td>
<td>36</td>
<td>35</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>1st Filter</td>
<td>R 30/T 15</td>
<td>39</td>
<td>36</td>
<td>38</td>
<td>37</td>
<td>34</td>
<td>33</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>2nd Filter</td>
<td>27/12</td>
<td>32</td>
<td>33</td>
<td>34</td>
<td>32</td>
<td>32</td>
<td>44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd Filter</td>
<td>15/14</td>
<td>29</td>
<td>31</td>
<td>33</td>
<td>30</td>
<td>42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4th Filter</td>
<td>12/17</td>
<td>29</td>
<td>28</td>
<td>28</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5th Filter</td>
<td>12/16</td>
<td>25</td>
<td>25</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6th Filter</td>
<td>13/11</td>
<td>22</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7th Filter</td>
<td>11/11</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8th Filter</td>
<td>13/14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trap</td>
<td>12 11 7 7 10 10 10 13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R: Reflection  T: Transmission
treatment. The diffuse reflectance of the 3M paint is between 2 and 4 percent from 300 to 1000 nanometers, and for the oxide of copper, it is between 4 and 6 percent.

2.7 ALIGNMENT OF OPTICS COMPONENTS

2.7.1 Objective

The focal-plane-aperture assembly is rigidly mounted to the filter-chain assembly, and no adjustment is intended to be provided. The focal-plane-aperture assembly itself acts as a reference for adjustment of focus and alignment of the objective mirrors and transfer lens. The primary and secondary mirrors both have adjustable shims between their mounts and the main housings. The shims are machined for thickness and are tapered to make the aperture appear on-axis and focused at infinity as viewed from the outside by a collimator. These assembly adjustments are provided so severe mechanical tolerances of the primary- and secondary-mirror mounting surfaces are not required.

2.7.2 Transfer Lens

The transfer lens is provided with centering and focus shims to permit the accurate projection of the transferred beam along the desired optical path of the filter train and to set the proper divergence of the beam. The angle can be checked by removing the last filter and observing if the beam is centered. The focus is set to produce an image of the focal-phase aperture approximately 25 centimeters beyond the last filter position.

2.7.3 Detectors

The detector assemblies are adjustable in two directions perpendicular to the optical axis, to guarantee that the sampled radiation is collected by the detector's active area.

2.8 CALIBRATION

2.8.1 Switching Assemblies

Between the secondary mirror and the focal plane is located a calibration-switching assembly, which allows for two modes of direct solar calibration to establish the absolute and relative spectral responses of the radiometer. The solar-calibration technique uses a transmission diffuser or an attenuator. Mechanically, two separate
solenoids are designed to pivot either of the calibration arms, and to place a redirectional mirror and diffuser or an attenuator into the line-of-sight.

2.8.2 Diffuser Path

The redirectional mirror provides a view by the transfer lens and detectors of a transmission-diffusing disc located at the periphery of the housing which can be directly exposed to sunlight. The diffuser is a fused-silica disc opal fired on both sides (by the Kodak process), which is 50 millimeters in diameter by 6 millimeters thick. Figure 2-10 shows the diffusing characteristics of a single opal-fired surface in comparison to fine-ground glass. The double-sided version behaves so similarly to a Lambertian surface that it should provide a variation of signal to the detectors accurately proportional to the cosine of the sun angle from the zenith axis of the disc. It is intended for use at least once each orbit. When the scanning-mirror assembly is employed, a 15-degree restricting cone is placed over the diffuser path and oriented according to the mission profile to optimize the diffuser's exposure to the sun.

![Figure 2-10. Comparison of flashed opal and fine-ground glass from Kodak brochure.](image-url)
2.8.3 Direct Path

The second arm of the switching assembly contains a neutral-density filter, an attenuator, of the reflection type, with an attenuation coefficient of $10^{-5}$, and a positive-meniscus lens to compensate for the focus shift caused by the thickness of the filter. The sun's disc can be viewed directly by the radiometer when the attenuator is in place without damage to the detectors. The attenuated signal is approximately the same value as the maximum limb radiance observable. This mode of calibration is required for certain orbital configurations where the sun is viewed only near the terminator. It also provides the capability for making extinction measurements at sunrise or sunset. The neutral-density filter (attenuator) is mounted diagonally to the optical axis to reflect the major part of the solar radiance through a port onto the objective wall and baffles.
3.1 GENERAL DESCRIPTION

The APPS radiometer mechanical design is based upon an off-axis Cassegrain telescope with a scanning mirror, discrete wavelength detectors, and support electronics that meet the optical and electronic requirements set forth for a Space Shuttle mission. The radiometer's overall dimensions for this specific design are 56 centimeters (22.0 inches) high, 36 centimeters (14.0 inches) deep, and 35 centimeters (13.6 inches) wide with an estimated weight of approximately 19.6 kilograms (43.25 pounds). In the Space Shuttle configuration, the radiometer is designed to be mounted vertically (see Figure 1-2) on a spacecraft pallet, and to scan the earth's limb between -17 and -25 degrees below the local horizontal.

3.2 MECHANICAL-DESIGN REQUIREMENTS

The initial constraints governing the mechanical design were:

(1) 100-cm$^2$ entrance aperture.

(2) 45.72-cm (18.0 inches) effective focal length of primary optics.

(3) 0.2-milliradian $\times$ 4-milliradian instantaneous field-of-view.

(4) Eight wavelength channels in a cascaded optical filter system.

(5) Dual in-line solar calibration.

(6) Provisions for scanning the optical line-of-sight $\pm$4 degrees.

Other design considerations were:

(1) Minimum weight and size.

(2) Space qualification.
3.3 OPTICAL PATH

The optical path of the APPS radiometer is first considered to illustrate the major design features (see Figure 2-1). Collimated energy first enters the forward section of the scanning-mirror assembly, then passes through the forward baffle system and onto the scanning mirror. From there it is redirected through the rear baffle system of the scanning-mirror assembly and the baffle system of the main housing, and onto the primary mirror. The energy collected at the primary mirror is focused towards the front of the instrument and off-axis to the secondary mirror. From the secondary mirror, the energy is reflected back toward the rear of the instrument through the calibration-switch assembly to the focal-plane aperture.

The radiance passing through the focal-plane aperture is then reimaged with the transfer lens, and redirected with mirrors to the first of eight cascaded interference filters. The sampled radiance that then passes through each filter is focused onto a detector with a filter lens. The radiance not sampled by the previous filter is reflected to the next interference filter and detector combination throughout the filter chain at an incident angle of 15 degrees to the normal. The radiance which is not selected is removed at the end of the chain with a light trap.

The calibration-switch assembly permits two modes of direct solar calibration. In the primary calibration mode, a shutter prevents energy from entering through the main path, and accepts energy only through the transmission diffuser which is directed into the focal-plane aperture. The second direct solar-calibration mode is initiated when the calibration-switch assembly activates a mechanical arm with filter (attenuator) attached, thereby placing this attenuator in the main line-of-sight just before the focal-plane aperture.

3.4 MAJOR SUBASSEMBLIES

A description of each of the major subassemblies and subsystems will serve to illustrate the specific APPS radiometer mechanical design.
3.4.1 Main Housing (P/N 236117)*

The main housing serves as a foundation of the APPS radiometer upon which the various subassemblies are attached. The main housing is to be machined from a beryllium billet with an initial weight of about 25.4 kilograms (56 pounds). After machining, the estimated weight of the main housing is about 4.1 kilograms (9 pounds). The end flanges are square to provide mounting lands for the electronic assemblies. The exterior shape between these end flanges is essentially octagonal, with raised bosses for mounting the various subassemblies. These octagonal shapes are used for the large assemblies to optimize weight reduction while maintaining mechanical rigidity through fairly simple machining techniques. Points of attachment are placed at 45-degree intervals near the vertices of the octagon. The spacecraft mounting interface is perpendicular to the end faces and is relieved to accept the three kinematic ball mounts (see Section 3.4.11). The main interior cavity consists of a 19.063±0.013 centimeter (7.505±0.005 inch) diameter bore in the rear section of the housing. A second bore, 14.618±0.013 centimeters (5.755±0.005 inches) in diameter, eccentric to the first bore by 2.222 centimeters (0.875 inch), is in the forward section of the housing. This smaller bore is concentric with the main line-of-sight and accepts the forward baffles. The larger bore accepts the rear baffles, and provides additional volume for the baffles near the primary mirror. A cutout in the surface opposite the mounting plane accepts the filter assembly and the focal-plan assembly.

3.4.2 Primary-Mirror Assembly (P/N 236148)

The primary-mirror assembly consists of the primary mirror, primary-aperture stop, support structure, and machined spaces used for mounting and aligning the primary mirror to the main housing. The primary mirror is an off-axis segment of a parabolic mirror. Three pads are machined and lapped on each of the mating surfaces between the mirror and its supporting structure to provide a three-point mounting system with minimum distortion. In addition to the three attaching screws, there are two dowel pins, one in a hole and the other in a slot, to provide locational accuracy. The supporting structure (P/N 236118) pilots accurately in the main housing, and also serves as a retainer for the rear baffle system. Cemented to the outside of the primary mirror is the primary-aperture stop — a cylindrical component machine with a stop diameter of 11.430±0.013 centimeters (4.500±0.005) inches.

* Drawings referenced by P/N number are included in Section 3.7.
3.4.3 Secondary-Mirror Assembly (P/N 236149)

The secondary-mirror assembly consists of the secondary mirror, support structure, and machined spacer used for mounting and aligning the secondary mirror to the main housing. The secondary mirror is an off-axis segment of a hyperbolic mirror. A single pad is machined and lapped on each of the mating surfaces between the mirror and its support to minimize distortion. A double-dowel pin system provides locational accuracy in a manner similar to that of the primary mirror. The supporting structure (P/N 236146) pilots accurately in the main housing, and is mounted in conjunction with a machined spacer on the assembly to provide the proper axial location.

3.4.4 Calibration-Switch Assembly (P/N 236115)

The calibration-switch assembly consists of a machined housing with integral mounting pads and provisions to accept the components that permit two modes of direct solar calibration. The housing is open on both sides, so that the components may be assembled and calibrated in an exposed state. Closeout panels are added prior to assembly in the instrument. There are two arm assemblies, each actuated by a pull-type solenoid. Each arm is preloaded in the "off" position by an extension spring, and when actuated, rotates 15 degrees about a cantilever-type flexural pivot into a stop on the housing at the "on" position.

The geometry of the system depends on the following design goals:

1. Solenoid travel – Minimum travel near the end of the stroke to provide the maximum force.
2. Flexural pivot rotation – Minimum angular rotation to provide maximum life of pivot.
3. Extension spring force – Enough force to retrain the arms during launch loads, but less than the solenoid actuating force.
4. Physical size – Proper size to meet component requirements of the mirrors, filters, and assembly clearances.

A model of the salient design feature of the calibration-switch assembly has been fabricated (P/N 236107) and tested to optimize the factors mentioned previously.

In addition to the design requirements and constraints listed, control of incoming radiation must be regulated in the normal mode of operation and each of the two solar-calibration modes. During normal operation, there is a linkage and shutter mechanism attached to the end
of the arm containing the diffuser mirror, which prevents energy from the diffuser path from entering the housing. Also, there is a shutter attached to the attenuator arm, which prevents radiation from entering the line-of-sight from the forward baffles in the main housing via the attenuator's exit pupil. Each of these shutters is designed to be closed during the "off" cycle of each switch.

3.4.5 Calibration-Diffuser Assembly (P/N 236114)

This calibration-diffuser assembly consists of a machined housing which contains a redirectional mirror, shroud, and a quartz transmission-diffusing disc. The assembly pilots into the main housing, and is attached by means of two indexing brackets. Normally, the direction of the line-of-sight of the calibration-diffuser assembly is parallel to the radiometer's line-of-sight, which is 21 degrees below local horizontal. However, this assembly may be rotated in increments of 15 degrees pitch angle. The calibration diffuser itself is located against an O-ring when the shroud is attached to the main housing. The inside conical surface of the shroud is serrated to minimize the effect of scattered radiation. A flat redirectional mirror is attached to the support structure through three lapped pads on each component to minimize distortion.

3.4.6 Filter Assembly (P/N 236170)

The filter assembly is the mechanical housing where sampled radiation from the earth's limb is separated into discrete spectral wavelengths and detected. In the initial design stages, the filter-chain configuration was investigated quite thoroughly, because the design of the radiometer depends heavily on the filter chain. At first, a carousel arrangement was considered. In this configuration, the filters were placed in a circular pattern with the reflecting light paths lying in a single plane. Another configuration considered was that similar to the strings on a toy drum. The filters were placed in a circular pattern at each end of the "drum," and the light path ran back and forth between filters along the outside cylindrical surface of the drum. In each of these two configurations, even though the total path length was relatively small, it was felt that the difficulty in machining the parts and assembling them accurately far outweighed the advantages of a short-path-length design.
It was then determined that a cascaded arrangement between two parallel rows of filters would be the simplest to machine and assemble accurately. Other factors within this configuration had to be considered, however. Two basic restraints were:

1. Minimum total-path length - The size and weight of the assembly was directly related to the path length, as the diverging beam required larger components with increased path lengths.

2. Minimum angle-of-incidence - Polarization effects were of concern to the optical designers, and it was stressed that the incident angle should be kept small to minimize these effects. As the angle decreases, however, the path length increases due to the filter-spacing requirements.

Several designs were made using incident angles of 10, 12.5, 15, and 22.5 degrees. Parameters considered were filter diameter, filter spacing, path length, lens focal length, size, and weight. An incident angle of 15 degrees was chosen as being optimum, and subsequently the polarization effects were verified as acceptable by means of a test fixture (P/N 219927).

The present filter-assembly design consists of four machined blocks sandwiched between two cover plates. The two inner blocks house the filters, lenses, and retainers, and the two outer blocks house the detectors and wire harnessing. The two opposing filter blocks are kept parallel by aligning and pinning them to the cover plates. Each filter recess is spaced accurately in the block, and the filters are kept parallel by a ganged retainer which indexes the filters to the interior faces of the parallel blocks. This method of mounting provides for minimum misalignment by relatively simple machining and assembly procedures.

Other notable design features of the filter assembly are:

1. The flat redirectional mirror used to align the radiation from the focal-plane assembly to the filter-assembly optical axis is mounted to the left-hand filter block on three lapped pads. The mirror's compound angle is controlled by machining the mounting surface on a rotary table. The desired compound angle can be obtained accurately with basic 15- and 45-degree angular rotations.

2. The transfer lens located between the focal-plane assembly and the filter-assembly redirectional mirror is retained against an O-ring and spacers which are to be machined at assembly for alignment.
The upper and lower cover plates are machined from 0.952- and 0.635-centimeter (0.375- and 0.250-inch) thick plates, respectively. The stock is relieved to provide an isometric plate construction with 0.318-centimeter- (0.125-inch-) thick webs and ribs. Additional bases are provided for mounting screws.

Six mumetal 0.081-centimeter- (0.032-inch-) thick cover plates enclose the entire assembly to provide magnetic shielding.

Thermal control is provided by eight thermoelectric elements located between the filter assembly and the main housing. Thermal isolation is obtained by the use of four titanium standoffs, each having an outside diameter of 0.508 centimeter (0.200 inch) and a wall thickness of 0.102 centimeter (0.040 inch).

3.4.7 Focal-Plane Assembly (P/N 236189)

The focal-plane assembly is actually a subassembly of the filter assembly, however it is discussed as a separate assembly. The essential parts of the focal-plane assembly are a machined housing, a focal-plane-aperture transfer lens, and a redirectional mirror. The aperture consists of a masked opening 0.0091-centimeter (0.0036-inch) high by 0.183-centimeter (0.072-inch) wide on a coated disc of quartz 0.157-centimeter- (0.062-inch-) thick and protected by a 0.157-centimeter- (0.062-inch-) thick cover plate. This element is mounted in the housing between two retainer shims. These shims are machined at assembly to provide precise axial position of the focal-plane aperture. A flat redirectional mirror is mounted to its support through three lapped pads. The angle of redirection is controlled by machining the mating surfaces. However, more precise location could be obtained, if required, by using an adjustable mounting plate. The housing is indexed to the filter assembly by positioning one edge against the filter-assembly housing and pinning.

3.4.8 Scanning-Mirror Assembly (P/N 236211)

The scanning-mirror assembly is the mechanical housing where radiation from the earth's limb is optically scanned to obtain vertical-radiance profiles. The scanning-mirror assembly, which is specifically designed for Space Shuttle applications, is attached externally to the main housing of the radiometer. The housing is machined from a beryllium billet to a shape that is essentially two intersecting octagons, 19.05 centimeters (7.50 inches) across the flats. Two intersecting bores of 18.427 ± 0.005 centimeters (7.255 ± 0.005 inches) in diameter accommodate the baffles. End plates serve as a baffle retainer and are fastened near the
vertices of the octagon. Two slots 18.098 ± 0.002 centimeters (7.125 ± 0.001 inches) apart are milled in the side walls to accept the mirror supports. Two holes 0.7963 ± 0.0013 centimeter (0.3135 ± 0.0005 inch) in diameter are line bored in each side of the housing to provide an accurate location for the rotational axis of the mirror. The mirror, 12.70 centimeters (5.00 inches) by 15.24 centimeters (6.00 inches) by 1.27 centimeters (0.50 inch), is relieved on the back side to reduce weight and provide mounting lands for the supports.

The mirror is supported on one side by a cantilever-type flexural pivot in a bracket which mounts directly to the housing. On the other side, which is the driver side, a yoke-bracket is used to support the mirror with a second flexural pivot. The mirror is driven by a bracket which is attached to the motor and, in turn, is attached to the mirror through the yoke, thus bypassing the flexural pivot. In this manner, the bearings in the motor-gearhead assembly are relieved of mirror loads.

The assembly procedure for mounting the mirror in the scanning-mirror housing is as follows: The mirror and brackets are assembled so that the stacked height is about 0.013 centimeter (0.005 inch) less than the distance between the milled slots on the housing. This sub-assembly is then inserted, rotating the mirror about 10 degrees for housing clearance, into the milled slots. The stack is then extended to a snug fit with the housing by adjusting the axial location of one of the pivot members. Close-fitting alignment pins are inserted into the line-bored locating holes in the housing, and the mirror supports are fastened to the housing. The alignment pins are then removed, and the motor-gearhead assembly is attached to the mirror bracket and is fastened to the housing. By using this procedure, misalignment between the motor shaft and the axis of the flexural pivot is minimized. The effect of misalignment is further reduced by the fact that the amount of mechanical rotation involved is only ±2 degrees. The mirror is pre-loaded by means of two extension springs attached to each side of the mirror.

Completing the assembly is a back cover plate which encloses the mirror mechanism after assembly. Attachment to the main housing is accomplished through an interface plate which fastens to the main housing.
3.4.9 Baffles

Throughout the radiometer, baffles are used extensively to reduce off-axis scattered radiation. A discussion of the radiometer-baffle system will serve to define its mechanical design, location, and fabrication requirements. For considerations of optical criteria of the baffle system, see Section 2.4. In general, the design features for the baffles are:

1. Baffle thickness = 0.127 centimeter (0.050 inch).
2. Spacer-wall thickness = 0.254 centimeter (0.100 inch) relieved to 0.127 centimeter (0.050 inch).
3. Diametrical clearance between baffle, spacer, and housing = 0.013 to 0.038 centimeter (0.005 to 0.015 inch).
5. Diametrical clearance between baffle point diameter and theoretical aperture = 0.013 to 0.038 centimeter (0.005 to 0.015 inch).

The baffles and spacers are restrained in rotation by a series of dowel pins and slots. Series of baffles and spacers are restrained rotationally by their respective end caps attached to the housing.

A description of the baffles along the line-of-sight, starting from the entrance of the scanning-mirror assembly to the primary mirror, is:

1. P/N 236151, -152, -153, -154, -156, -157, -158 – The first several baffles in the scanning-mirror assembly are a combination baffle and spacer, cylindrical in form. From where the two housing bores intersect, the baffles are chamfered to prevent interference. This occurs on each side of the scanning mirror.
2. P/N 236128 – The first baffle in the main housing is cylindrical with a circular cutout concentric to the outer diameter.
3. P/N 236120 – The secondary baffle consists of a cylinder with cutouts representing the intersection of a cylinder and two cones. The inside surfaces are serrated to minimize stray-light effects.
4. P/N 236132 and 236133 – The next five baffles are flat with cutouts for the calibration-switch assembly and the filter assembly. The optical cutouts in these baffles are the intersections of two circles.
5. P/N 236140 – The next seven baffles are conical in shape with varying cone angles.
P/N 236123, -124, -138, -139 - The end-baffle assembly consists of five conical baffles eccentrically positioned so that the lower edges are in mutual contact. This group is then brazed in place to a cylindrical housing to form the primary-mirror baffle assembly.

3.4.10 Electronics Assemblies

The design, as presented, does not include mechanical drawings of the electronics assemblies which are to be specified during the instrument-development phase. Provisions for electronic-component mounting plates have been incorporated into the design of the housing.

3.4.11 Mounting and Interface System

Definition of Space Shuttle mounting and interface system has not been finalized. However, the mounting system has been designed and may be retrofitted as required. The kinematic mounting system consists of three balls, 1.905 centimeter (0.750 inch) in diameter, mounted in conical seats on one side of the interface. On the other side of the interface, there are three different types of seats: conical, which is the fixed position; V-groove, which allows movement in one direction; and a plane surface, which allows movement in any direction in the mounting plane. The three bolts through each of the balls are preloaded by means of conical spring washers, fixing the instrument position. If any distortion occurs on the mounting plate, either due to thermal effects or dynamic loading, two of the three balls are free to move without loading the optical structure. When the loads are removed, the system will return to its original position.

3.5 MATERIALS

In general, the materials used in this mechanical design are:

(1) Quartz optical elements (except mirrors).
(2) Beryllium mirrors.
(3) Beryllium large housings and parts critical to optical alignment.
(4) Aluminum alloy remaining parts, including baffles, spacers, and brackets.

3.6 FINISHES

All surfaces exposed to the optical path will be blackened, either by applying a treatment of black oxide of electroplated copper or 3M
Brand Black Velvet Series paint, over a zinc-chromate primer (see Section 2). Specific surfaces to be treated are defined in the component and assembly drawings.

3.7 MECHANICAL DRAWINGS

This section contains reduced prints of the mechanical drawings, details, and assemblies.
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**Prepared By:** M. A. Hermann

**Date:** 27 Dec 74

**Checked:**

**Date:**

**CSDL Approved:**

**Date:**

**Approved By Direction Of:**

**Date:**

**Contract No.:** 51993

**Code Ident.:** PL 236117

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THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02138

LINK, DIFFUSER DOOR

MATERIAL: ALUMINUM .060 THK STK
APPLICATION: 6061-T6

SCALE 6/1
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3. REMOVE BURRS AND BREAK SHARP EDGES.
4. IDENTIFY PER MIL-STD-130. BAG AND TAG DO NOT MARK PART.

PART NO. "A" ± "B" ±

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CAPACITOR VALUES ARE IN pF
RESISTOR VALUES ARE IN OHMS
DIMENSIONS ARE IN INCHES
TOLERANCE ON DEGREES, ANGLES, AND LENGTHS ARE IN DEGREES

MATERIAL: ALUMINUM 6061-T6

THE CHARLES STARK DRAFTER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, USA

N. M. 3812

UNLESS OTHERWISE SPECIFIED
CAPACITOR VALUES ARE IN pF
RESISTOR VALUES ARE IN OHMS
DIMENSIONS ARE IN INCHES
TOLERANCE ON DEGREES, ANGLES, AND LENGTHS ARE IN DEGREES

DO NOT SCALE THIS DRAWING

APPLICATION

C 51993 236124

REVISIONS

CONTRACT NO.

DO NOT SCALE THIS DRAWING

胺

SHEET 1 OF
NOTES:
1. INTERPRET DWG PER MIL-D-1000.
2. FINISH: OPTICAL BLACK PER SPEC
   △ TO BE DETERMINED

PART NO. 236125-1
SEE PL

THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02139

DOOR, ATTENUATOR

ALUMINUM
6061-T6 PER
QQ-A-225/8

236115 APPS HND ASSEMBLY USED ON
APPLICATION

236125

REV

C 51993 236125

DRAWING NO.

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**CHECKED:** [Signature]

**CSDL APPROVED:** [Signature]

**APPROVED BY DIRECTION OF:** [Signature]

**CONTRACT NO.** 51993  **PARTS LIST NO.** PL.236126  **REV** SHEET 1 OF 2  **SHEETS**
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NOTES:
1. INTERPRET DWG PER MIL-D-1000.
2. ALL OVER
3. REMOVE BURRS AND BREAK SHARP EDGES .005 MAX.
4. IDENTIFY PER MIL-STD-130. BAG AND TAG DO NOT MARK PART.
5. FINISH: OPTICAL BLACK PER SPEC

△ TO BE DETERMINED

PART NO. 236127-1
SEE PL
NOTES:
1. LIFTEFF DIAM PER WELDING
2. T ALLOW IF UNLESS OTHERWISE SPECIFIED
3. REMOVE BURRS & DERA SHARP EDGES
4. CLEAN AND FILL UNLESS OTHERWISE SPECIFIED
5. PAINT OPTICAL BLACK PER SPEC

TO BE DETERMINED

PART NO.
SEE PL

BARRIER, ENTRANCE

ALUMINUM
6061-T6

THE CHARLES SMEIL HEADQUARTERS, INC.

MANUFACTURED IN CHINA

SPECIFICATION

 sheet 1 of 1
NOTES

1. INTERPRET DWG PER MIL-D-1000.
2. PREFIX UNLESS OTHERWISE SPECIFIED.
3. REMOVE BURRS AND BREAK SHARP EDGES .005 MAX UNLESS OTHERWISE SPECIFIED.

DIMENSION IS TYPICAL 2 PLACES IN OPPOSITE DIRECTIONS.

PART NO. 236129-1
SEE PL
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**Revision Status**

<p>| SHEET | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |</p>
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DASH NO.

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ZONE

1

QUANTITY

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CODE IDENT

PART OR IDENT NO.

236130-11

11522116

1185-020N 0172

SYM

NOMENCLATURE/DESCRIPTION

ARM, SWITCH

HCC LINR 4-40 X .168LG

HCC LINR 2-56X .172 LG

REMARKS

HELICOIL
NOTES:
1. INTERPRET DWG PER MIL-D-1000.
2. ALL OVER UNLESS OTHERWISE SPECIFIED.
3. REMOVE BURRS AND BREAK SHARP EDGES .005 MAX UNLESS OTHERWISE SPECIFIED.
4. SURFACE MARKED "X" SHALL BE SERRATED AS SHOWN IN DETAIL Z (SEE ZONE D-4).
5. THREAD DIMENSIONS AND DESIGNATIONS SHALL BE INTERPRETED PER HANDBOOK H28 AND MIL-STD-9, RESPECTIVELY.
6. FINISH: OPTICAL BLACK PER SPEC.
7. TO BE DETERMINED.
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**LIST TITLE:** Housing, Mirror

**CONTRACT NO.** 51993  
**CODE IDENT.** PL 236134  
**PARTS LIST NO.**  
**REV** SHEET 1 OF 2  
**PARTS LIST** THE CHARLES STARK DRAPER LABORATORY, INC.  
**PREPARED BY**  
**CHECKED**  
**CSLD APPROVED**  
**APPROVED BY DIRECTION OF**  

**NEXT ASSY. USED ON** 236114  
**APPS**
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Additionally, there is a note at the bottom of the image that reads: "78"
NOTES:
1. INTERPRET DIMS PER MIL-D-4000.
2. ALL OVER UNLESS OTHERWISE SPECIFIED.
3. REMOVE BURRS AND BURNISH SHARP EDGES 0.005 MAX UNLESS OTHERWISE SPECIFIED.
4. FINISH OPTICAL BLACK PER SF. A
   A TO BE DETERMINED

PART NO. 236135-1
SEE PL.

MOUNTING PLATE, MIRROR

ALUMINUM 2024-T3
### List Title:

**Mount, Attenuator**

### Revision Status

| SHEET | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
|-------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

### Notes

- **Contract No.:** 51993
- **Parts List No.:** PL 236137
- **Sheet 1 of 2**
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2. MILL OVER UNLESS OTHERWISE SPECIFIED.
3. REMOVE BURRS AND BREAK SHARP EDGES. O.D. MAX UNLESS OTHERWISE SPECIFIED.
4. IDENTIFY PER MIL-STD-180. TAG AND TAG DO NOT WASH PART.
NOTES:
1. INTERPRET DNS PER MIL-D-1000
2. ALL OVER
3. REMOVE BUMPS AND BREAK SHARP EDGES
4. OOS WAX, UNLESS OTHERWISE SPECIFIED
5. DIMENSION 'C' IS TO SHARP CORNER
6. FINISH OPTICAL BLANK PER SPEC

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PART NO. SEE TABLE
SEE PL

BAFFLE, CONICAL
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3. REMOVE BURRS AND BREAK SHARP EDGES LOOS MAX.
   UNLESS OTHERWISE SPECIFIED.
\* 2G641-2 SHALL HAVE \# INSTALLED 18G FROM
   POSITION SHOWN (SEE ZONE E-9).
\* 2G6/41-7 SHALL HAVE SLOT SHOWN IN DETAIL Z LOCATED
   18G FROM POSITION SHOWN (SEE ZONE E-5).
\* FINISH: OPTICAL BLACK PER SPEC \*
\* TO BE DETERMINED

PART NO SEE TABLE
SEE PL 236141

PART NO: 236141

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   • REMOVE RIVETS & BREAK SHARP EDGES
3. FINISH: OPTICAL BLACK, PER SPEC

PART NO.
SEE PL

THE CHARLES STARK DRAFTER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02139

STOP, APERATURE -
APPS

UNLESS OTHERWISE SPECIFIED:
CAPACITOR VALUES ARE IN P/F
RESISTOR VALUES ARE IN OHMS
DIMENSIONS ARE IN INCHES
TOLERANCES ON
DECIMALS
ANGLES
AXES ± .005
± .002
DO NOT SCALE THIS DRAWING

STT. DRAWER
APP

236148
SEE NOTE 1

THE CHARLES STARK DRAFTER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02139

PART NO.
SEE PL

THE CHARLES STARK DRAFTER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02139

STOP, APERATURE -
APPS

UNLESS OTHERWISE SPECIFIED:
CAPACITOR VALUES ARE IN P/F
RESISTOR VALUES ARE IN OHMS
DIMENSIONS ARE IN INCHES
TOLERANCES ON
DECIMALS
ANGLES
AXES ± .005
± .002
DO NOT SCALE THIS DRAWING

STT. DRAWER
APP

236148
SEE NOTE 1

THE CHARLES STARK DRAFTER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02139

STOP, APERATURE -
APPS

UNLESS OTHERWISE SPECIFIED:
CAPACITOR VALUES ARE IN P/F
RESISTOR VALUES ARE IN OHMS
DIMENSIONS ARE IN INCHES
TOLERANCES ON
DECIMALS
# PARTS LIST

**THE CHARLES STARK DRAPER LABORATORY, INC.**
CAMBRIDGE, MASS. 02139

**CONTRACT NO.** 51993
**CODE IDENT.** PL 236143
**PARTS LIST NO.**

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**PREPARED BY** T. ANDERSON
**CHECKED**
**CSDL APPROVED**
**APPROVED BY DIRECTION OF**

**DATE** 1/3/77

**LIST TITILE:** MIRROR ASSY, PRIMARY

**NEXT ASSY. USED ON** 236143 APPS

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NOTES:
Δ TO BE DETERMINED

1. 236110 MIRROR
2. 0.25 DA .51 L4 1/2 HOLE PW 2 RED CEMENT IN PLACE PER SPEC Δ
3. 236146 SUPPORT
4. 6-32 X .50 HD CAP SCREW (Self Locking)

PART NO.
SEE PL

MIRROR ASSY, SECONDARY
APPS

THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02139

UNLESS OTHERWISE SPECIFIED
CAPACITOR VALUES ARE IN µF
RESISTOR VALUES ARE IN OHMS
DIMENSIONS ARE IN INCHES
TOLERANCE ON DECIMALS
ANGLES

236110

NEXT ASSEMBLY
APPLICATION

APPROVED

DO NOT SCALE THIS DRAWING

THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02139

MIRROR ASSY, SECONDARY
APPS

CONTRACT NO.: 1993
DRAWN BY: L. ANDERSON
CHECKED BY: N. COZENS
APPROVED

D 51993 236149

APPROVED

BY DIRECTION

SCALE: 1:1

Sheet 1 of 4
# Parts List

**Contract No.:** 51993  
**Code Ident.:** PL 236125

**List Title:** MIRROR ASSY, SECONDARY

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**Revision Status**

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**Prepared By:** T. Anderson  
**Date:** 1/3/77

**Checked By:**  
**Date:**

**CSDL Approved By:**  
**Date:**

**Approved By Direction Of:**  
**Date:**

**Next Assy. Used On:** 236125  
**Approved:** APPS
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1. MATERIAL: G081-T6 AL ALLOY
2. UNLESS OTHERWISE NOTED:
   a) FINISH
   b) REMOVE BURRS & BREAK SHARP EDGES
   c) FINISH 1 Optical B.L.A.W. PER SPEC.
(a) TO BE DETERMINED

1/2. DIA THRU HOLES
125. DIA THRU HOLES
EQUALLY SPACED ON 1.500 DIA
1/2. DIA THRU HOLES

PART NO.
SEE PL
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△ TO BE DETERMINED
1. INTERPRET DWG PER MIL-D-1000.
PURCHASE PART FROM PIC AND ALTER AS SHOWN.
3. IDENTIFY PER MIL-STD-130. BAG AND TAG. DO NOT MARK PART.

NOTES:
- .18 DIA. EXPANDED REF
- .015 MAX - 45° THIS END ONLY

UNLESS OTHERWISE SPECIFIED: CAPACITOR VALUES ARE IN µF, RESISTOR VALUES ARE IN OHMS, TOLERANCE: ±10% UNLESS OTHERWISE SPECIFIED

MATERIAL: ALUMINUM

MAKE FROM PIC 236163-2 .18
PIN C3-2

THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, U.S.A.

236163-2 .18
236163-1 .40
PART NO. "L"

ALTERED ITEM DRAWING
PART NO. SEE TABLE
NOTES

1. INTERPRET DWG PER MIL-D-1000.

2. REMOVE BURRS AND BREAK SHARP EDGES .005 MAX UNLESS OTHERWISE SPECIFIED.

3. 3/4 AS REQUIRED.

4. IDENTIFY PER MIL-STD-130. BAG AND TAG. DO NOT MARK PART.

ALTERED ITEM DRAWING

PART NO. 236164-1

THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02138

MTG SCREW, SPRING

MAKE FROM SC7CD CAP SCR 2-56UNCX.38LG

UNLESS OTHERWISE SPECIFIED:
CAPACITOR VALUES ARE IN µF
RESISTOR VALUES ARE IN OHMS
ANGLES ARE IN DEGREES
TOLERANCE ON MATERIAL:
COORDINATE SYSTEM

SCALE 4"/DRAWING NO.
REV

APPLICATION

DO NOT SCALE THIS DRAWING

236115 APPS

NXT ASSEMBLY USED ON

APPROVED

DO NOT COPY THIS DRAWING

 acompanhante

THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02138

MTG SCREW, SPRING

MAKE FROM SC7CD CAP SCR 2-56UNCX.38LG

UNLESS OTHERWISE SPECIFIED:
CAPACITOR VALUES ARE IN µF
RESISTOR VALUES ARE IN OHMS
ANGLES ARE IN DEGREES
TOLERANCE ON MATERIAL:
COORDINATE SYSTEM

SCALE 4"/DRAWING NO.
REV

APPLICATION

DO NOT SCALE THIS DRAWING

236115 APPS

NXT ASSEMBLY USED ON

APPROVED

DO NOT COPY THIS DRAWING

acompagnante
NOTES:
1. INTERPRET DWG PER MIL-D-1000.
2. \( \frac{4}{3} \) ALL OVER.
3. REMOVE BURRS AND BREAK SHARP EDGES .005 MAX UNLESS OTHERWISE SPECIFIED.
4. FINISH: OPTICAL BLACK PER SPEC \( \Delta \) TO BE DETERMINED.

PART NO. 236166-1
SEE PL

UNLESS OTHERWISE SPECIFIED:
CAPACITOR VALUES ARE IN \( \mu F \) ECLIPSE 250V.
RESISTOR VALUES ARE IN OHMS.
DIMENSIONS ARE IN INCHES.
TOLE.

MATERIAL:
ALUMINIUM 6061-T6 PER QQ-A-250/8

THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02138

DOOR, DIFFUSER
### LIST TITLE:

**Housing, Switch**

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| SHEET | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
|-------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
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### NEXT ASSY.

236115

### APPS

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NOTES

1. INTERPRET DWG PER MIL-D-1000.
2. ALL OVER UNLESS OTHERWISE SPECIFIED
3. REMOVE BURRS AND BREAK SHARP EDGES .005 MAX UNLESS OTHERWISE SPECIFIED.
4. FINISH: OPTICAL BLACK PER SPEC
5. TO BE DETERMINED

PART NO. 236168-1

SEAT, ATTENUATOR DOOR

ALUMINUM ALLOY 6061-T6
## Parts List

**List Title:** FILTER ASS'Y

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- **Sheet:** 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35

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**Contract No.:** PL 236170

**Parts List No.:** PL236170

**Code Ident.:** 51993

**Prepared By:**

- Date: 12/10/76

**Checked:**

- Date: 

**CSDL Approved:**

- Date: 

**Approved by Direction Of:**

- Date: 

**Next Assy. Used On:**

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△ TO BE DETERMINED
1. INTERFACE 3/4" OD x 1/2" ID 7.5 - 4.0 - 1.5 - 1.0
2. SURFACE SHAL. TO QUALITY EQUIPPED IMPORTS 5.0. NO ORINGS, CLAS. B
3. EDGES TO BE ALIGNED 4.0 - 2.0 - 1.0 - 0.5
4. OPTICAL REQUIREMENTS PER MIL-18020
   A. SURFACE QUALITY 50-20
   B. CLEAR AREAS : 5/8" DA
   C. BOTH EDGES FLATEN, PLAT WITHIN 4° AT 0.01"
   D. BOTH EDGES PARALLEL WITHIN 0.003" E. TRANSMISSION PROPERTIES FOR PARALLEL LIGHT ALONG OPTICAL AXES
      CENTER WAVELENGTH : 420-700 nm
      EMISSION BAND WITH 10% @ 450 nm
      R - INTRANSMISSION GREATER THAN 10% F. BAND PASS SHALL BIND TO
      0.5% TEMI, 0.5° TO 0.01°
      R - PEAK TRANSMISSION @ > 1.00 G. TRANSMISSION AT ANY WAVELENGTH OUTSIDE BAND PASS (FROM 4000 A TO X AND A) LESS THAN 1.0
   6. POLARIZATION OF TRANSMITTED BEAM SHALL NOT EXCEED 0.5° AS DEFINED BY
      (4 x 10^-7) x 10°
6. DESIGN REQUIREMENTS
   A. NO DRAWING OF MATERIALS SHALL BE EXPOSED TO 100% RELATIVE HUMIDITY
      AT 20°C FOR 20 HOURS
   B. NO OPTICAL OR OPTICAL DEVICES SHALL BE EXPOSED TO 100% RELATIVE HUMIDITY
      AT 20°C FOR 20 HOURS
   C. 5.0% DEGRADATION IN R - INTRANSMISSION SHALL BE EXPERIENCED AFTER 2500000 HOURS OF 100% RELATIVE HUMIDITY
   D. 5.0% DEGRADATION IN R - INTRANSMISSION SHALL BE EXPERIENCED AFTER 2500000 HOURS OF 100% RELATIVE HUMIDITY
   E. OPERATING TEMPERATURE 1.0°F TO 150°F
   TO BE DETERMINED

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PART NO. SEE PL

FILTER, LIGHT-APPS

THE CHILTON STONE INNOVATION LABORATORY, INC.

D 59823 236/76
NOTES:
1. INTERPRET DWG. PER MIL-O-1260 # MIL-S-18237
2. ELEMENT ALL UNIFORM, BACK MIL-O-13B TO A
   MATERIAL: 1-46 BRASS PLATED SOLDER
   SOURCE: AMERICAN, INC. - SUFFOLK, NEW YORK
   EMALL, Cont. - BY ML-O-1000
3. CLEAR APERTURE - 0.8000 in DIAM
4. SURFACE QUALITY 40-20 OVER CLEAR APERTURE
5. CENTERING ERROR: 5 MI. MAX. PER M
6. ALL SURFACES MACHINED "P" POLISHED
7. CENTER STOK GUARD
8. IRREGULARITY OF SURFACES TO BE
   NO MORE THAN 1 IN 2.5 IN. HORIZONTAL LENGTH
   OVER THE CLEAR APERTURE
9. COAT POLISHED SURFACES WITH 1000 A
   OF ALK. FOR MIL-C-6710 A.

-- CLEAR APERTURE --

PART NO.
SEE PL
NOTES:
1. INTERPRET DWG PER MIL-D-1000
2. FINISH ALL OVER
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. FINISH: OPTICAL BLACK PER SPEC △
   △ TO BE DETERMINED

PART NO.
SEE PL

THE CHARLES DRAPIER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02139

RETAINER, FILTER LENS
APPS

UNLESS OTHERWISE SPECIFIED
CAPACITOR VALUES ARE IN µF
RESISTOR VALUES ARE IN OHMS
TOPOGRAPHIC CONSIST OF
DEGREES ANGLES
AC 0.05
DO NOT SCALE THIS DRAWING

MATERIAL

E96170
PER QQ-A-351

AL 2024-T4

EXT ASSEMBLY USED ON

APPLICATION

C 51993 236178

REV

SCALE 2/1 SHEET 1 OF
NOTES:
1. INTERPRET DWG PER MIL-D-1000
2. √ FINISH
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. FINISH: OPTICAL BLACK PER SPEC
   △ TO BE DETERMINED

PART NO. SEE PL

RING, LOCKING, FILTER LENS
APPS
NOTES:
1. INTERPRET DWG PER MIL-D-100C
2. SOURCE: PARKER SEAL CO.
   CULVER CITY, CALIF.
   PART NO. 2-022 N-525-60

PART NO.
SEE PL

O-RING
APPS

THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02139

C 51993 236180

UNLESS OTHERWISE SPECIFIED:
CAPACITOR VALUES ARE IN pF
RESISTOR VALUES ARE IN OHMS
DIMENSIONS ARE IN INCHES
TOLERANCE ON DECIMALS
ANGLES IN DEGREES

DO NOT SCALE THIS DRAWING

NEXT ASSEMBLY USED ON
APPLICATION

CONTRACT NO.
SUBJECT DATED
SIGNATURE

APPROVED:
DATE

APPROVED:
DATE

REV

SCALE 2/1
SHEET 1 OF 4
NOTES:
1. INTERPRET DWG PER MIL-D-1000
2. V FINISH
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. FINISH: OPTICAL BLACK PER SPEC
5. TO BE DETERMINED
NOTES:
1. E.G. & G P/N 3
2. FOR OPERATING CHARACTERISTICS
   SEE 3
3. ▲ TO BE DETERMINED

PART NO.

UNLESS OTHERWISE SPECIFIED
CAPACITOR VALUES ARE IN pF
RESISTOR VALUES ARE IN OHMS
DIMENSIONS ARE IN INCHES
TOLERANCES ON
RESISTORS ▲ ±1 %
CAPACITORS ±10 %
ANGLES ±1°

MATERIAL

B THE CHARLES STARK DRAPER LABORATORY, INC.
CONCORD, MASSACHUSETTS, U.S.A.

DETECTOR (PRELIMINARY)
APPS

23G170

NEXT ASSEMBLY USED ON

APPLICATION

B 51993 23G182

REV
NOTES:
1. INTERPRET DWG PER MIL-D-1000
2. √ FINISH
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. PROVISION FOR ELECTRICAL CONTACTS
5. TO BE DETERMINED
6. FINISH √

PART NO. SEE PL

UNLESS OTHERWISE SPECIFIED:
CONNECTOR VALUES ARE IN MILLIAMS
RESISTOR VALUES ARE IN OHMS
DIMENSIONS ARE IN INCHES
TOLERANCE ON DEGREES: ±2°
TOLERANCE ON ANGLES: ±2°

MATERIAL:
AL 2024-T361
PER QQ-A-250/4

PLATE, CONNECTOR, DETECTOR
APPS

THE CHARLES STARK DARPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02139

D 236183

NEXT ASSEMBLY USED ON
APPLICATION

CONTRACT NO.

CHECKED

APPROVED

23G170

51993

236183

REV

1

SHEET 1 OF 1
NOTES:
1. INTERPRET DWG PER MIL-D-1000
2. < FINISH
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. FINISH: OPTICAL BLACK PER "A" TO BE DETERMINED

PART NO.
SEE PL

THE CHARLES STARK DRAPER LABORATORIES, INC.
CAMBRIDGE, MASSACHUSETTS, 02138

RETAINER, DETECTOR
APPS

236170
AL 2024-T351
PER QQ-A-2504

THE CHARLES STARK DRAPER LABORATORIES, INC.
CAMBRIDGE, MASSACHUSETTS, 02138

RETAINER, DETECTOR
APPS

236170
AL 2024-T351
PER QQ-A-2504

THE CHARLES STARK DRAPER LABORATORIES, INC.
CAMBRIDGE, MASSACHUSETTS, 02138

RETAINER, DETECTOR
APPS

236170
AL 2024-T351
PER QQ-A-2504
NOTES:
1. INTERPRET DWG PER MIL-D-1000
2. \# FINISH
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. FINISH; OPTICAL BLACK PER SPEC

SCALE: 4:1

SEE DET Z

PART NO.
SEE PL

ADAPTER, TRANSFER LENS
APPS

THE CHARLES STARK DRAPEE LABORATORY, INC.
CHAMBERS, MASSACHUSETTS, USA

23G186

C 51993

REV

SCALE 2:1

SHEET 1 OF 2
NOTES:
1. INTERPRET DWG PER MIL-D-1000
2. Finish
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. Finish: OPTICAL BLACK PER SPEC A
5. TO BE DETERMINED

PART NO.
SEE PL

RETAINER, TRANSFER LENS
: APPS

THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02139

AL 2024-T4
PER QQ-A-268

C 51993 236187
NOTES:
1. INTERPRET DWG PER MIL-D-1000
2. * FINISH
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. FINISH: OPTICAL BLACK PER SPEC △
5. TO BE DETERMINED

PART NO.
SEE PL

THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02139

RNG, LOCKING, TRANSFER LENS
APPS

C 51993 236188

UNIT: INCHES

SCALE: 2/1

CAMBRIDGE, MASSACHUSETTS, 02139

THE CHARLES STARK DRAPER LABORATORY, INC.

RNG, LOCKING, TRANSFER LENS
APPS

C 51993 236188

UNIT: INCHES

SCALE: 2/1
NOTES:
1. INTERPRET DWG PER MIL-D-1000
2. INSTALL (3) & (11) IN (1) PER MS35537. REMOVE TANGS
3. GRIND THICKNESS OF (6) & (7) TO SUIT
4. SLOT IN (3) TO BE PARALLEL TO TOP SURFACE OF (1)

PART NO. 236189-1
SEE PL 236189

THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02138

FOCAL PLANE ASSY
APPS

UNLESS OTHERWISE SPECIFIED:
CAPACITOR VALUES ARE IN F.
RESISTOR VALUES ARE IN OHMS.
DIMENSIONS ARE IN INCHES.
TOLERANCES ON DECIMALS & ANGLES ARE ±.005.
DO NOT SCALE THIS DRAWING.

APPLICATION: BY DIRECTION
SCALE: 2/1
FACIAL PLANE ASSY 
APP.

CONTRACT NO.

REFERENCE DRAWN
CHECKED
APPROVED

SIZE
51993
DRAWING NO.
236189
REV

NEXT ASSEMBLY
236170
USE OR
APPLY
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LIST TITLE: FOCAL PLANE ASS'Y

PREPARED BY
CHECKED
CSDL APPROVED
APPROVED BY DIRECTION OF

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REVISION STATUS
SHEET 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35

NEXT ASSY. 236170
USED ON

PREPARED DATE 12/10/76
GATE CHECKED
CSDL APPROVED
APPROVED BY DIRECTION OF

REV REVISION DESCRIPTION DATE APVD REV REVISION DESCRIPTION DATE APVD
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<td>MIRROR ASS'Y, 1ST REDIR</td>
<td>P/L 236191</td>
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<td>4-40X.31 LG (CRES)</td>
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<td>1185-02CN-0129</td>
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<td>INSERT, HELICAL COIL</td>
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<td>4-40X1\frac{1}{2} DIA LG</td>
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NOTES:
1. INTERPRET DWG PER MIL-D-1000
2. INSTALL (3) IN (1) PER MS35597, REMOVE TANG

PART NO. 286191-1
SEE PL 286191

MIRROR ASSY, 1ST REDIR.
APPS
**LIST TITLE:**

MIRROR ASS'Y, 1ST REDIR.

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**Revision Status:**

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<td>SUPPORT, MIRROR</td>
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<td>2-56 x 1 DIA LG</td>
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<td>2-SCREW HD CAP</td>
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<td>2-56 x 25 LG (CRES)</td>
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NOTES:
1. INTERPRET DWG PER MIL-D-1000
2. F/Finish
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. FINISH: OPTICAL BLACK PER SPEC
   △ TO BE DETERMINED

PART NO.
SEE PL

UNLESS OTHERWISE SPECIFIED
CAPACITOR VALUES ARE IN µF
INCREASION VALUES ARE IN OHMS
DIMENSIONS ARE IN INCHES
TOLERANCES ON
DIMENSIONS
1/32 ± .0005 = 1"

MATERIAL
236193
APPLICATION
AL 2024-T4
PER QQ-A-246

THE CHARLES STARK DRAFTER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02139

SUPPORT, MIRROR, 1ST REDIR.
APPS

C 51993 236193

SCALE 2/1 SHEET 1 OF 1
NOTES:
1. INTERPRET DWG PER MIL-D-1000
2. BY FINISH
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. FINISH: OPTICAL BLACK PER SPEC △
△ TO BE DETERMINED
NOTES:
1. INTERPRET DWG PER MIL-D-1000
2. #3 FINISH
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. FINISH OPTICAL BLACK PER SPEC. ▲
5. TO BE DETERMINED

PART NO. SEE PL

THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS 02138

RETAINER, ELEMENT
APPS

236196

REVISIONS

UNLESS OTHERWISE SPECIFIED:
CAPACITOR VALUES ARE IN pF
RESISTOR VALUES ARE IN OHMS
DIMENSIONS ARE IN INCHES
TO ERASE ON
DECIMALS:
ANGLES
ALL
4
DO NOT SCALE THIS DRAWING

MATERIAL

AL 2024-T4
PER QQ-A-258

C 55993

BY DIRECTION
SCALE 4:1
NOTES:
1. INTERPRET DWG PER MIL-D-1000
2. *F*inish
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. Finish: OPTICAL BLACK PER SPEC

A. TO BE DETERMINED

PART NO. SEE PL

THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02138

SHIM, INNER
APPS

C 51993 236197

SCALE 4/3
NOTES:
1. INTERPRET Dwg PER MIL-D-1000
2. 8 FINISH
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. FINISH: OPTICAL BLACK PER SPEC
5. TUBE DETERMINED

PART NO.
SEE PL

THE CHARLES STARK DRAFTER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 0139

SHIM, OUTER
APPS

UNLESS OTHERWISE SPECIFIED
CAPACITOR VALUES ARE IN pF
RESISTOR VALUES ARE IN OHMS
DIMENSIONS ARE IN INCHES
TOLERANCE ON
DECIMALS
ANGLES
AXIS

DO NOT SCALE THIS DRAWING

MATERIAL

CONTRACT NO.

DO NOT SCALE THIS DRAWING

APPROVED

DRAWING

DO NOT SCALE THIS DRAWING

APPROVED

APPLICATION

SCALE 2:1

DRAWING NO.

PER QQ-A-26B

REV

THE CHARLES STARK DRAFTER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 0139

SHIM, OUTER
APPS

UNLESS OTHERWISE SPECIFIED
CAPACITOR VALUES ARE IN pF
RESISTOR VALUES ARE IN OHMS
DIMENSIONS ARE IN INCHES
TOLERANCE ON
DECIMALS
ANGLES
AXIS

DO NOT SCALE THIS DRAWING

MATERIAL

CONTRACT NO.

DO NOT SCALE THIS DRAWING

APPROVED

DRAWING

DO NOT SCALE THIS DRAWING

APPROVED

APPLICATION

SCALE 2:1

DRAWING NO.

PER QQ-A-26B

REV
NOTES:

A) INSTALL 3 IN 1 PER MS95557, REMOVE TANK

B) INTERPRET DWG PER MIL-D-1000

PART NO. 236199-1
SEE PL 236199
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**List Title:** MIRROR ASSY, 2ND REDIR.

**Prepared By:**

**Checked:**

**CSDL Approved:**

**Approved By Direction Of:**

**Contract No.:** 51993

**Parts List No.:** PL 236199

**Rev. Sheet 1 of 2 Sheets**

**Next Assy. Used On:** 236170
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<td>1185-02CN-0129</td>
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<td>2-56X1½ DIA LG</td>
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<td>SCREW, HEX SOC HD CAP</td>
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NOTES
1. INTERPRET DWG PER MIL-D-1000
2. ** FINISH
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. FINISH: OPTICAL BLACK PER SPEC

A TO BE DETERMINED
NOTES:
1. INTERPRET DWG. PER MIL-D-1000
2. √ FINISH
3. REMOVE ALL BURRS & SHARP EDGES .005 MAX
4. FINISH: OPTICAL BLACK PER SPEC
Δ TO BE DETERMINED
Notes:
1. INTERPRET DWG PER MIL-D-1000
2. REMOVE BURRS & SHARP EDGES .005 MAX
3. MAKE FROM TUBING, AL 3003-H14, 250 G.D X.022 WALL

Part No.

- Capacitor values are in pF.
- Resistor values are in Ohms.
- Dimensions are in inches.
- Tolerance on decimals and angles.
- Do not seal this drawing.
- Material.

SLEEVE, HOLD-DOWN SCR
APPS
NOTES:

1. INTERPRET DWG PER MIL-D-1000
2. MATERIAL: TITANIUM ALLOY 6AL4V
NOTES:

A. ASSEMBLE (24) and INSTALL (23) Mnt PLATE of (23).
B. ASSEMBLE (23) IN PLATE of (23) ONCE ONLY, AFTER ADJUSTING RING.
C. ASSEMBLE (22) TO COLLET of (23), BUT DO NOT TIGHTEN SCREW NEAR ASSEMBLY (25).
D. ASSEMBLE (25) IN ORDER TO ASSEMBLE (22) IN ORDER TO ASSEMBLE (23).
E. ASSEMBLE (25) TOGETHER, ASSEMBLE (24) TO COLLET of (23), AND DO NOT TIGHTEN SCREW NEAR ASSEMBLY (25).
F. ASSEMBLE (25) TOGETHER, ASSEMBLE (24) TO COLLET of (23), AND DO NOT TIGHTEN SCREW NEAR ASSEMBLY (25).
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PART NO. 2420471

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**REVISION STATUS**

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4. FINISH: OPTICAL BLACK PER SPEC A
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3. FINISH: OPTICAL BLACK PER SPEC △
4. TO BE DETERMINED

G-32 UNC-3A X .36 LG CRES HEX S/C CAP SCR (TAP THRU PIN)

PART NO.
PLATE, CLOSURE
APPS

THE CHARLES STARK DRAPER LABORATORY, INC.
CHAMBER, MASSACHUSETTS, 01909

1/1 SHEET 1 OF
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3. REMOVE BURRS AND BREAK SHARP EDGES .005 MAX UNLESS OTHERWISE SPECIFIED.
4. FINISH: OPTICAL BLACK PER SPEC
5. TO BE DETERMINED

PART NO.

THE CHARLES STARK DRAFER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS, 02138

ALUMINUM
GOGI-TG PER
QQ-A-250/8

APPLICATION

236143 APPS
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AEROSOL PHYSICAL PROPERTIES INSTRUMENT
TEST AND CONTROL PANEL
4.1 ELECTRONIC-SYSTEM REQUIREMENTS

The electronic-detection and signal-processing requirements for the APPS radiometer are governed by the optical characteristics, signal source, and measurement schedule described in the following.

4.1.1 Optical Features

The radiometer's optical system vertically scans the earth's limb with a finite field-of-view, and collects the scattered radiation along the tangent line-of-sight. The collected radiation is then directed to a filter chain where it is sampled in eight discrete spectral bands. Each narrow band of radiation is then focused into separate photodiode detectors. Figure 2-1 is a functional schematic of the radiometer optical train.

There are two additional modes of operation for the radiometer which are actuated by optical switches (movable mirrors). The first, and primary mode of solar calibration, is when the sun directly illuminates the transmission diffuser. Activation of the transmission-diffuser mode optically switches the line-of-sight from the main telescope to the diffuser line-of-sight, and radiance measurements are taken. The second mode of solar calibration is when the line-of-sight of the main telescope directly intersects the sun. During this mode, a neutral-density filter of approximately $10^5$ is switched into the main optical path, and radiance measurements are taken. Direct solar calibration is possible in either one of these two modes.

4.1.2 Signal Sources

The sources of the signal to be measured by the APPS radiometer are multispectral limb profiles of the earth's atmosphere. An illustration of the measurement geometry is shown in Figure 4-1.
Experimentally, as the APPS radiometer scans through the atmosphere, it collects back-scattered solar radiation along the optical line-of-sight at discrete wavelengths. Figure 1-1 illustrates a typical earth-limb-radiance-measurement data set where the intensity of the scattered radiation varies with altitude and wavelength. The measured radiation is dependent upon the absorption and scattering cross sections, and the concentrations of the atmospheric constituents. The variation of the radiance profiles with wavelength, altitude, latitude, season, and measurement geometry, and sun angle provide information to the signal.

4.1.2.1 Spatial Profiles

The spatial frequency cutoff for electronic processing was defined as 1 cycle per kilometer (see Figure 4-2). This specification was based upon the desire to set the spatial frequency near the maximum aerosol spatial structure measured by other direct and indirect remote-sensing techniques in the stratosphere. (3)
4.1.2.2 Aperture Requirements

To maximize the signal-to-noise ratio of the APPS radiometer, the design was optically maximized to the field-of-view and collecting area within the constraints of spatial resolution, calibration techniques to be used and overall instrument size. Therefore, the aperture requirements of the field stop were set in width by the upper spatial frequency of the signal source (see Figure 4-3 and Section 4.2.1). The horizontal dimension (aperture length) was set by the desirability of having the field-of-view of the radiometer subtend less than one half the sun's disk diameter which would more readily allow the direct solar-calibration mode. These requirements fixed the maximum focal-plane aperture to 0.011 degree by 0.22 degree, which corresponds to an altitude resolution of 0.5 kilometer by 10 kilometers at a 500-kilometer observational altitude.

4.1.2.3 Source Intensities and Receiver Input Power

The maximum source intensities of the earth's limb were obtained from Skylab S-191 limb data, except for the near-ultraviolet region, where theoretical intensities were estimated. These intensities are listed in Column 2 of Table 4-1.
Table 4-1. Receiver Characteristics.

<table>
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<tr>
<th>Wave Length (nm)</th>
<th>Maximum Limb Intensity</th>
<th>Radiometer Input Power 100 cm²</th>
<th>Optics Transmission Factor</th>
<th>Receiver Input Power</th>
<th>Receiver Responsivity HUV-1000B</th>
<th>Receiver Signal Voltage Output</th>
<th>Voltage Noise in Output at 25°C</th>
<th>Available Dynamic Range</th>
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<td>Iω (W cm⁻² sr⁻¹ nm⁻¹) / 10⁻⁹</td>
<td></td>
<td>IωR (W cm⁻² sr⁻¹ nm⁻¹) / 10⁻⁹</td>
<td>RI (µV W⁻¹) / 10⁻⁹</td>
<td>Eo V (µV) / 10²</td>
<td>eno (µV) / 10²</td>
<td>Eo/eno for Rf = 10⁻⁹</td>
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<td>7.7</td>
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<td>3.54</td>
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<td>0.89</td>
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<tr>
<td>350</td>
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<td>0.60 (4)</td>
<td>0.98</td>
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(1) Estimated.

(2) Based on Skylab 78B data.

(3) Optical bandwidth = 20 nm for λ = 290 nm
    = 10 nm for all other λ

(4) Very unstable with temperature above 900 nm.

(5) Measured value.
The maximum input radiant power to the APPS radiometer is a function of the source intensity, the clear-aperture area, the solid angle of the field-of-view, and the equivalent optical bandwidths of the filter passband.

\[ I_\omega = I_\lambda A_T \omega_T B_\lambda W \]  

where

- \( I_\lambda \) = Maximum spectral radiance of earth limb
- \( I_\lambda = \mu W/cm^2-srad - \lambda \)
- \( A_T \) = Telescope clear-aperture area = 100 cm\(^2\)
- \( \omega_T \) = Field-of-view solid angle = 0.2 mrad \( \times \) 4.0 mrad = 0.80 \( \times \) 10\(^{-6}\) srad
- \( B_\lambda \) = Effective optical bandwidth = 20 nm for \( \lambda = 300 \) nm
  = 10 nm for all other \( \lambda \)

The input/output characteristics of the receiver system are listed in Table 4-1, and are defined as follows:

(1) Column 1 lists the wavelengths of interest.

(2) Column 2 lists the maximum spectral radiance of the earth’s limb.

(3) Column 3 is the computed input radiant power to the instrument using Eq. (4-1). (The actual receiver input power at the diode detector has to take into account the losses in the optical train.)
(4) Column 4 lists the transmission factors for the optics.
(5) Column 5 lists the input power to the receivers.
(6) Columns 6 through 10 list the photodetector-receiver responsitivity, signal-to-noise ratio, and available dynamic range (see Section 4.3.1).

4.2 ELECTRONIC REQUIREMENTS – ANALOG

4.2.1 Electronic-Bandwidth Requirement

The electronic-bandwidth requirement is determined by:

(1) Angular scan rate, \( \omega = 3 \) degrees per second.
(2) Distance to the target area, \( S = 2524 \) kilometers.
(3) Highest spatial frequency components of the signal source, \( K = 1 \) cycle per kilometer.

where

\[ \Delta f = \omega SK \]
\[ \Delta f = (3^0 \times \frac{\pi}{180^0})(2524)(1) \]
\[ \Delta f = 132 \text{ Hz} \]

The scan rate is governed by two principal requirements, resolution and geographical coverage. These characteristics are related in that:

(1) The 3\( \sigma \) value of the line-of-sight intensity distribution at 20 kilometers is \( \pm 400 \) kilometers.
(2) At \( \omega = 3 \) degrees per second, the ground-track crossing for successive limb scans of a sun-synchronous spin-stabilized satellite is 853 kilometers.

both of which are less than 1000 kilometers, the value used extensively in establishing large-scale distributions of major atmospheric constituents.

If we require that the ground-track motion during a single scan be no more than the cross-track distance covered by the field-of-view of the scanning aperture, then the relation between the scan rate and the orbital rate is (by definition)

\[ \omega_1 S\Delta T \geq \omega_2 R\Delta T \]

where

\[ \omega_1 S\Delta T = 100 \text{ km} = \text{altitude scan} \]
\[ \omega_2 R\Delta T = 10 \text{ km} = \text{cross-track resolution} \]
or

\[ \omega_1 \frac{S}{R} \geq 10 \]

\[ \omega_1 \geq 10 \omega_2 \frac{R}{S} \]

For a 90-minute orbit, \( \omega_2 \) is

\[ \omega_2 = \frac{2\pi}{90 \times 60} = \frac{\pi}{2700} \text{ rad/s} \]

For

- \( R = 6366 \text{ km} \) = earth radius
- \( H_O = 500 \text{ km} \) = observation height
- \( H_T = 20 \text{ km} \) = tangent height

the slant range \( S \) is

\[ S = (2R + H_O + H_T) (H_O - H_T) \]

\[ S = 2524 \text{ km} \]

Therefore, the scan-rate requirement is

\[ \omega_1 \geq 10 \times \frac{\pi}{2700} \times \frac{6366}{2524} = 0.029 \text{ rad/s} = 1.7 \text{ deg/s} \]

A scan rate of 3 degrees per second was chosen for the APPS radiometer design. This rate more than meets the measurement criteria, minimizes the attitude-stabilization requirements, and provides the extensive global coverage desired for large-scale constituent distributions.

4.2.2 Other Electronic Requirements

4.2.2.1 Accuracy

The absolute accuracy of the radiometer's measurements cannot be any better than the absolute calibration standards. Therefore, the absolute accuracy of the receiver will be on the order of 1 percent for each wavelength, with much finer resolution.

4.2.2.2 Resolution and Dynamic Range

Resolution and dynamic range are directly related. Dynamic range is defined as the ratio of the maximum signal to the receiver rms noise. To obtain high resolution in the analysis, a minimum dynamic range of 1000 is desired.
4.3 ANALOG SIGNAL PROCESSING

An analog-signal-processing channel is shown in Figure 4-4. Each of the eight channels consists of a photodiode detector/amplifier combination (radiometer receiver), a low-pass filter, and a sample and hold circuit. The eight channels are time multiplexed into the analog-to-digital (A/D) converter. Seven thermistor networks, which are used to measure the operating temperatures of the radiometer receivers, are also time multiplexed. Each of these analog component specifications is discussed in the following.

![Figure 4-4. Analog signal processing.](image)

4.3.1 Radiometer Receiver

4.3.1.1 Requirements

The receiver characteristics required are:

1. Maximum input radiant power (from Column 5 of Table 4-1).
   \[ I_{\text{in R}} = 1.6 \text{ to } 5 \text{ nanowatts.} \]

2. Bandwidth requirements, \( f \Delta f = 132 \text{ hertz.} \)

3. Detector responsivity over the wavelength regions
   \( 300 \leq \lambda \leq 900 \text{ nanometers.} \)

4. Dynamic range = signal/rms noise = \( E_0/e_{\text{no}} \geq 1000. \)
(5) Detector area > 0.5 millimeter by 1.5 millimeters. The detector area is larger than the focal-plane-aperture image, since it is desirable to keep the measured radiation away from the detector edges.

(6) Temperature Range — The receivers will be purchased under full military specifications which have an operating temperature range, -55°C to +125°C. The actual operating temperature range under which the dynamic range requirements have to be satisfied is -20°C to +25°C.

4.3.1.2 Receiver Selection

The receiver design is shown in Figure 4-5. This low-noise configuration is made possible by the narrow-frequency bandwidth requirements. The receiver consists of an unbiased photodiode operated in the short-circuit photovoltaic mode, an FET input operational amplifier, and a feedback resistor. These three components are mounted on a ceramic-substrate printed circuit. This assembly is then packaged in a gold-plated Kovar case. The case has a quartz window over the ultraviolet-enhanced photodiode. The receiver is offered commercially by EG&G with quartz windows in two models: The HUV-1000B, which consists of an EG&G model UV-100B silicon-photovoltaic photodiode, and a high-performance FET operational amplifier; and the HUV-4000B, which consists of an EG&G model UV-444B silicon-photovoltaic photodiode and a similar high-performance FET operational amplifier. The commercial models for both of these receivers are rated for a temperature range from 0°C to 70°C, and may also be ordered with full military specifications. The electrical specifications for these two receivers are listed in Table 4-2.
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>HAV-1000</th>
<th>HUV-1000B</th>
<th>HAV-4000</th>
<th>HUV-4000B</th>
<th>Units and Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Area</td>
<td>Min</td>
<td>Typ</td>
<td>Max</td>
<td>Min</td>
<td>Typ</td>
</tr>
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<td>Spectral Range</td>
<td>350</td>
<td>1150</td>
<td>200</td>
<td>1150</td>
<td>350</td>
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<tr>
<td>Responsivity at 900 nm</td>
<td>9.0</td>
<td>9.4</td>
<td>11</td>
<td>12</td>
<td>9.0</td>
</tr>
<tr>
<td>Responsivity at 230 nm</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
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<td>Noise Voltage at 20 Hz</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>NEP (900, 20, 1)</td>
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<td>1.11</td>
<td>-</td>
<td>0.87</td>
<td>-</td>
</tr>
<tr>
<td>NEP (230, 20, 1)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Open-Loop Gain</td>
<td>2x10&lt;sup&gt;4&lt;/sup&gt;</td>
<td>2x10&lt;sup&gt;5&lt;/sup&gt;</td>
<td>2x10&lt;sup&gt;4&lt;/sup&gt;</td>
<td>2x10&lt;sup&gt;5&lt;/sup&gt;</td>
<td>5x10&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
<tr>
<td>Bias Current</td>
<td>-</td>
<td>3</td>
<td>50</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Offset Current</td>
<td>-</td>
<td>0.5</td>
<td>-</td>
<td>0.5</td>
<td>-</td>
</tr>
<tr>
<td>Offset Voltage (3)</td>
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<td>10</td>
<td>20</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Offset Voltage Drift</td>
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<td>-</td>
<td>75</td>
<td>-</td>
</tr>
<tr>
<td>Output Resistance</td>
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<td>-</td>
<td>80</td>
<td>-</td>
</tr>
<tr>
<td>Slew Rate</td>
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<td>-</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td>Supply Voltage</td>
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<td>±18</td>
<td>±6</td>
<td>±18</td>
<td>±12</td>
</tr>
<tr>
<td>Supply Current</td>
<td>-</td>
<td>3.4</td>
<td>6.0</td>
<td>-</td>
<td>3.4</td>
</tr>
<tr>
<td>Power Consumption</td>
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<td>102</td>
<td>180</td>
<td>-</td>
<td>102</td>
</tr>
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<td>Operating Temperature</td>
<td>0</td>
<td>-</td>
<td>70</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

(1) Without external trim. (2) Doubles every +10°C. (3) Adjustable to 0 V with external trim potentiometer.
The recommended design for the APPS receiver is a combination of the electronics of the HUV-1000B and the mechanical package of the HUV-4000B. The electronics of the HUV-1000B give us a 10-to-1 advantage over the HUV-4000B in gain-bandwidth product. At the operating temperatures contemplated (-20°C to +25°C), there is very little difference between the two receivers other than the gain-bandwidth product. To maintain good temperature control of the diode and amplifier, the HUV-4000B package is recommended. This package, along with the HUV-1000B package, is shown in Figure 4-6. Note that the HUV-4000B package has much more thermal mass than the HUV-1000B, as well as a large heat-transfer surface on one side of the printed-circuit substrate.

Figure 4-6. EG&G photodiode mechanical specification.
Noise measurements were made on a single HUV-1000B receiver with a $10^9$-ohm feedback resistor. The measurements were made in free air at room temperature after the unit had been allowed to reach thermal stability (approximately 30 minutes). From the peak-to-peak noise, the rms noise is estimated to be 24.5 microvolts per square root of hertz. Allowing for a 20-percent error in this measurement, a worst-case value of 29 microvolts is used to obtain the available dynamic range (see Table 4-1).

Table 4-1 lists the receiver characteristics. Column 6 of Table 4-1 lists the receiver responsivities which were obtained from the published response curves as shown in Figure 4-7. Column 7 lists the receiver output voltage as obtained from the product of the corresponding entries in Columns 5 and 6, and the feedback resistor

$$E_O = I_w R_I R_f$$

TYPICAL RESPONSIVITY VS WAVELENGTH

TYPICAL UV SPECTRAL RESPONSIVITY (UV SERIES)

Figure 4-7. EG&G photodiode responsivities.

Column 8 lists the measured noise, which is not a function of the wavelength of the measured radiation, and therefore is a single entry. The total noise in the output of the receiver is obtained by multiplying the per-unit frequency noise by the square root of the system-frequency bandwidth.
\[ e_{\text{no(total)}} = \left(\frac{e_{\text{no}}}{\sqrt{\Delta f}}\right) \sqrt{\Delta f} = 29 \sqrt{132} = 333 \ \mu V \]

Column 10 lists the ratio of the entries of Column 7 to the system total noise:

Available Dynamic Range = \( \frac{E_o}{e_{\text{no(total)}}} \)

The minimum available dynamic range is 1740 for the wavelengths \( \lambda = 350 \) and 400 nanometers, respectively. Therefore, this receiver and optics design does meet the 1000-to-1 minimum-dynamic-range design specification.

4.3.1.3 Receiver Frequency-Dependent Characteristic

4.3.1.3.1 Gain — The expression for the voltage output of the receiver that takes into account the diode-junction capacitance and the capacitance in the amplifier feedback loop is

\[ |E_o| = \frac{I_{\omega R} R_I}{\left[\frac{1}{R_f} + \frac{1}{A \left(\frac{1}{R_f} + \frac{1}{R_{SH}}\right)}\right]^2 + \omega^2 \left(\frac{C_f + \frac{C_f + C_j}{A^2}\right)^2}^{1/2} \tag{4-2} \]

where

- \( R_f = \) Feedback resistance
- \( R_{SH} = \) Shunt resistance of diode
- \( C_j = \) Diode junction capacitance
- \( C_f = \) Capacitance in parallel with \( R_f \)
- \( \omega = 2\pi f = \) radian frequency
- \( A = \) Open-loop gain of amplifier
- \( I_{\omega R} = \) Receiver-input power
- \( R_I = \) Receiver responsivity (function of \( \lambda \))

For amplifier gains in the order of \( 10^5 \), this expression reduces to

\[ |E_o| = \frac{I_{\omega R} R_I R_f}{(1 + \omega^2 R_{f}^2 C_f^2)^{1/2}}^{1/2} \tag{4-3} \]

\[ = I_{\omega R} R_I R_f \] for low frequencies

\[ = I_{\omega R} R_I X_C \] for high frequencies
The cutoff frequency $f_c$ is defined as

$$f_c = \frac{\omega_c}{2\pi}$$

where

$$\omega_c = \frac{1}{RC_f}$$

or

$$f_c = \frac{1}{2\pi R_f C_f}$$

for

$$R_f = 10^9 \text{ ohms}$$

and

$$f_c = \frac{159}{C_f}$$ \hspace{1cm} (4-4)

where $C_f$ is in picofarads.

Equation (4-4) shows that only a small amount of stray capacitance* between the output and input could severely restrict the available bandwidth of the receiver. For example, a capacitance of 1.2 picofarads limits the bandwidth to 132 hertz, the minimum system bandwidth requirement. Careful circuit layout can limit the stray capacitance to well below 1.0 picofarad.

4.3.1.3.2 Noise — The electronic-circuit model of the operational amplifier and photodiode is shown in Figure 4-8. Figure 4-8 also shows the noise sources for the various parts of this circuit. The definitions of the various components and parameters of the circuit are given in the following.

(1) Photodiode

\[ i_{NL} \] = Current noise from stray light

\[ i_{ND} \] = Johnson noise current of photovoltaic photodiode (due to shunt resistance)

* The feedback resistor has a shunt capacitance of $C_f \leq 0.03$ picofarad.
Figure 4-8. Operational amplifier/photodiode electrical model.

\[ R_{SH} \] = Photodiode shunt resistance

\[ C_j \] = Photodiode shunt capacitance

\[ R_S \] = Photodiode series resistance

(2) **Operational Amplifier**

\[ A_O \] = Noiseless amplifier with frequency-dependent gain

\[ i_{NA} \] = Amplifier input noise current — frequency dependent

\[ e_{NA} \] = Amplifier input noise voltage — frequency dependent

\[ R_{NA} \] = Amplifier input resistance

\[ C_{NA} \] = Amplifier input capacity

(3) **Feedback Resistor**

\[ R_f \] = Feedback resistor — ideal pure resistance

\[ i_{Nf} \] = Johnson noise current of feedback resistor

\[ C_f \] = Total feedback capacitance (include stray, shunt capacitance of \( R_f \), and any added capacitance)
In any photodiode receiver considered here, the diode series resistor $R_S$ is much less than the parallel impedance of $R_{SH}$ and $X_{Cj}$. Also, $C_{NA}$ is negligible compared to $C_j$. Under these conditions, the expression for the output voltage is

$$e_{NT} = Z_T \left[ \left( \frac{e_{NA}}{Z_S} \right)^2 + i_{NA}^2 + i_{NL}^2 + i_{N_{SH}}^2 + i_{N_{f}}^2 \right]^{1/2} \frac{V_{rms}}{\sqrt{Hz}} \quad (4-5)$$

where

$$|Z_T| = \frac{R_f}{\left(1 + \omega^2 C_f R_f\right)^{1/2}}$$
$$|Z_S| = \frac{R_{SH}}{\left(1 + \omega^2 C_j R_{SH}\right)^{1/2}}$$
$$i_{N_{SH}}^2 = \frac{4kT}{R_{SH}}$$
$$i_{N_{f}}^2 = \frac{4kT}{R_f}$$
$$i_{NA}^2 = 2qI_{dc}$$
$$i_{NL}^2 = 2qI_L$$
$$e_{NA}^2 = \text{Mean-square noise of amplifier}$$
$$\text{Equivalent noise voltage generator}$$
$$I_{dc} = \text{Amplifier input bias current}$$
$$I_L = \text{Photodiode current due to stray light}$$

Using these definitions and Eq. (4-5) we get

$$e_{NT} = \frac{R_f}{\left(1 + \omega^2 C_f R_f\right)^{1/2}} \left[ \left( \frac{e_{NA}}{R_{SH}} \right)^2 \left(1 + \omega^2 C_j R_{SH}\right)^2 \right]^{1/2} \quad (4-6)$$

where the $i_N^2$ terms are those in Eq. (4-5).

Finally, with the help of Figure 4-9, which shows the amplifier current and voltage noise as a function of frequency, we are in a position to follow the noise-amplitude rms as a function of frequency.
Figure 4-9. Amplifier noise current and voltage characteristics.

At low frequencies less than 1 hertz, the output-noise voltage is dominated by the amplifier-noise-voltage source $e_{NA}$, which has the characteristic $1/f$ increase. The first frequency break comes at

$$f_1 = \frac{1}{2\pi C_{jR_{SH}}} = \frac{1}{2\pi \times 150 \times 10^{-12} \times 10^8} \approx 10 \text{ Hz}$$

At this frequency, the impedance in series with the amplifier-noise-voltage source $e_{NA}$ starts dropping rapidly (see Eq. 4-6). This increases the input-noise current due to $e_{NA}$. The next frequency break is at the system bandwidth cutoff, $f_2$.

$$f_2 = \frac{1}{2\pi C_{fR_f}} = \frac{1}{2\pi \times 1.2 \times 10^{-12} \times 10^9} \approx 132 \text{ Hz}$$

From Eq. (4-6), the system bandwidth $f_2$ attenuates the noise from both the noise-voltage source and the current source. Above $f_2$, the next frequency effect is the rapid increase in amplifier-noise current, as shown in Figure 4-9. This occurs at a frequency of about 1 kilohertz,
a frequency well above the system bandwidth. The noise as a function of bandwidth will have the response shape shown in Figure 4-10. Note that the effect of the frequency break at $f_1$ is delayed because the voltage-noise source represents only a small part of $e_{NT}$, and it is only when this term is multiplied by a factor of about 10 that it begins to be dominant. The points to be made are:

1. Other terms being equal or better, the amplifier with the lowest input-noise voltage should be used. This is especially true when operating the system at temperatures below 25°C.

2. The output noise of the receiver will be greater near the system-frequency cutoff. Therefore, the dynamic range at these frequencies will not be as good as those in the mid-band frequencies (1 to 30 Hz).

3. The measurement of noise over the system passband includes the noise peaking, and should be used over a spot-check measurement.

![Figure 4-10. Normalized receiver noise characteristics (normalized at 2 Hz).](image)

**4.3.1.4 Receiver Temperature-Dependent Characteristics**

Of the actions that can be taken to improve the signal-to-noise ratio of the receiver (for a given signal input power), none give better results than the lowering of the operating temperature. Lowering the operating temperature 15°C, from 25°C to 10°C would almost halve the rms noise, and therefore double the available dynamic range.

The temperature dependents of the various parameters of the receiver are:

1. The amplifier bias current $I_{dc}$ doubles for each 10°C increase in operating temperature.

2. The shunt resistance of the photodiode has the temperature characteristic shown in Figure 4-11.
(3) The temperature dependence of the photodiode is shown in Figure 4-12.

(4) The temperature coefficient for the feedback resistor $R_f$ is shown in Figure 4-13. For $10^9$ ohms the coefficient is -0.1 percent per degree Celsius.

These four parameters are major contributors to the temperature dependence of the receiver. From these characteristics, all parameters move in a beneficial direction when the operating temperature is lowered. Operation between the temperatures 0 to 15°C is recommended. This is achievable, even in the Space Shuttle vehicle, if thermoelectric coolers are employed. (6)

Figure 4-11. EG&G photodiode shunt resistance versus temperature.

Figure 4-12. EG&G photodiode.
The temperature coefficient of the feedback resistor, and the deviation of photodiode responsivity (Figures 4-12 and 4-13), along with the need to control temperature, dictate the need to measure temperature. This is implemented by the thermistor network shown in Figure 4-4.

4.3.1.5 Receiver-System Errors

The objective of the receiver system is to generate an output voltage that is proportional to the radiation of the earth's limb as a function of tangent altitude, while maintaining the desired altitude resolution and signal-to-noise ratio. To accomplish this with a compact design and realistic operational specifications, the information must pass through a number of less-than-ideal system components. Therefore, analysis of the overall system is desired, since each of these system components will have its own characteristic transfer function.

The transfer functions of all of the system components between the signal source and the A/D converter are linear, and, at least for the duration of a measurement, are time invariant. Therefore, using linear-system theory, the total transfer function from the signal source to the input of the A/D converter can be represented by a single equivalent filter with the amplitude function $A(\omega)$ and the phase function $e^{i\theta(\omega)}$.

This process is shown in Figure 4-14. Figure 4-14(a) illustrates the transfer system with its component features. The input $S_{x,y,z}$ is a three-dimensional source of scattered radiation. However, the line-of-sight radiation is integrated along the dimension $Z$, and the cross-track dimension $Y$ is considered constant for a given altitude and field-of-view. Therefore, the functions $S_{x,y,z}$ and $S_{(Kx,Ky,Kz)}$ reduce to the single-dimensions $S_x$ and $S_{(Kx)}$. Figure 4-14(a) reduces to a single equivalent filter with the Fourier transform as shown in Figure 4-14(b).
WHERE:  $S_{x,y,z} = \text{SPATIAL SIGNAL OF SCATTERED RADIATION — THREE DIMENSIONAL}$

$S_{(Kx,Ky,Kz)} = \text{FOURIER TRANSFORM OF} \ S_{x,y,z}$

$h_i(t) = \text{IMPULSE (SYSTEM) RESPONSE}$

$H_i(\omega) = \text{FOURIER TRANSFORM OF} \ h_i(t); \ i = 1 \ 2 \ 3 \ 4 \ 5$

**Figure 4-14. APPS transfer functions.**

In general, the system functions $H_i(\omega)$ of Figure 4-14(a) are complex frequency functions and can be expressed as

$$H_i(\omega) = A_i(\omega) e^{j\theta_i(\omega)}$$

Therefore, $H(\omega)$ can be written as

$$H(\omega) = A(\omega) e^{j\theta(\omega)}$$

where

$$A(\omega) = \prod_{i=1}^{j} A_i(\omega)$$

$$\theta(\omega) = \sum_{i=1}^{j} \theta_i(\omega)$$

The equivalent filter output is $f_o(t)$. Its Fourier transform is

$$f_o(t) = S(Kx)H(\omega) = S(Kx)A(\omega)e^{j\theta(\omega)}$$

Inasmuch as $f_o(t)$ differs from $S(Kx)$, the measured signal is a distorted rendition of $S_x$.

To obtain $S(Kx)$ from the recorded signal, which is stored digitally and is accessible in the ground computer complex, the signal can be reversed in time and passed through a replica of the equivalent
"Page missing from available version"
4.3.4 Thermistor Network

The thermistor network is based on a design suggested in an Explorer Missions Planners Handbook and is illustrated in Figure 4-15. The excitation voltage for these networks is derived from a temperature-compensated zener diode. This excitation voltage is itself measured by the A/D converter, and is used as a check on the operation and calibration of the measurement system. The requirements of the thermistor are:

(1) **Accuracy:** ±1°C over range -20°C to +35°C determined by the receiver responsivity deviation with temperature ±2°C over range -55°C to +125°C

(2) **Time Constant:** 10 seconds maximum, small compared to one rotation at 3 degrees per second (120 seconds).

4.3.5 Analog Multiplexer

The function of the analog multiplexer is to switch a selected signal into the input of the buffer amplifier while preventing crosstalk from the other 15 signal inputs (see Figure 4-4).

![Figure 4-15. Thermistor network.](image)

4.3.5.1 Multiplexer-Switch Leakage Current

Since all signals are low frequency, all the crosstalk is caused by the dc leakage current in the multiplexer switches. Figure 4-16 shows the equivalent circuit of the multiplexer with one of the inputs switched on and the 15 others switched off. The worst-case condition is when the signal from one of the thermistor networks is switched. It is the worst-case because the equivalent signal-generator output impedance of the thermistor network is far greater than any of the other signal sources.

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The relative magnitude of the impedances shown in Figure 4-16 is such that the following relation holds

\[ R_B \gg R_g \gg R_{ON} \]

The equivalent output impedance of the thermistor network of Figure 4-14 at 35°C is 5000 ohms. Therefore

\[ Z_i \approx R_g = 5000 \, \Omega \]

The voltage generated at point (i) of Figure 4-16 by the total leakage current \(15I_Z\) is

\[ V_i = 15I_Z Z_i = 15I_Z R_g \quad (4-7)\]

This voltage represents an error in the thermistor-network output. This error should be less than the voltage output change for the desired temperature resolution of 0.5°C. The voltage output of the thermistor is

\[ \Delta V_o = \frac{39.2 V_i \Delta R_T}{(R_T + 39.2)^2} \quad (4-8)\]
where

\[ V_i = \text{Zener diode voltage} = 6.2 \text{ V} \]

\[ R_T = \text{Resistance of the thermistor at temperature } T \]

The worst case over the range -20°C to +35°C is at 35°C. For

\[ T = 35^\circ\text{C} \]

\[ \Delta R_T = 132 \Omega \text{ for } \Delta T = 1/2^\circ\text{C} \]

\[ R_T = 6752 \Omega \]

\[ \Delta V_O = \frac{39.2 \times 6200 \times 0.132}{(6.752 + 39.2)^2} = 15 \text{ millivolts} \]

To satisfy the error criterion we have

\[ 15 I_z R_g \leq \Delta V_O = 15 \times 10^{-3} \]

or

\[ I_z \leq \frac{15 \times 10^{-3}}{15 \times 5000} = 200 \text{ nA} \]

A leakage current per switch of 200 nanoamperes over the operating temperature range of -20°C to +35°C is easily achievable with available commercial multiplexers.

4.3.5.2 Switch ON Resistance

The ON resistance of the multiplexer switch is in series with the input resistor of the buffer amplifier. Therefore, any variation in this resistor represents a gain error in the buffer amplifier. However, each analog channel would be calibrated for overall gain so that this error would be taken out. The magnitude of this switch ON resistance should be small compared to the buffer amplifier input resistance, so that any variations due to temperature change would be negligible. One part in 1000 would make it within the accuracy of the buffer amplifier input resistance.

\[ R_{ON} \leq R_B/1000 = 250 \Omega \]

A summary of the analog multiplexer-switch requirements are given in the following.
4.3.5.3 Analog Multiplexer-Switch Requirements Summary

(1) Analog signal input voltage range: 0 - 10 volts.
(2) Switch ON resistance: $R_{ON} \leq 250$ ohms.
(3) Switch OFF state leakage current: $I_z \leq 200$ nanoamperes.
(4) Operating temperature range: $-20^\circ$ to $+35^\circ$C.

4.4 ELECTRONICS DESIGN — DIGITAL

4.4.1 Basic Design Decisions

Initially, it was decided to implement a system concept that was adaptable to various mission requirements. Requirements such as data formatting, coding, mirror drives, temperature measurement and control, and system moding would be better handled by a microprocessor-based system than by fixed control logic. The 500-kilometer sun-synchronous orbits contemplated for the operational vehicles made the radiation requirements low enough so that CMOS could be used.\(^{(9,10)}\) This fact, and the availability of a CMOS microprocessor with a broad line of supporting circuits, including read-only (ROM) and random-access (RAM) memory, encouraged the design of a CMOS-microprocessor-based system. The high-noise-immunity and low-power-consumption properties of CMOS made this choice an attractive one.

4.4.2 System Description

Figure 4-17 is the system block diagram. A detailed drawing of the APPS Electronics System as described is given in the Appendix in drawing P/N 236300. This particular system is designed around the interface requirements of the Space Shuttle vehicle. As such, the system has the following features:

(1) The analog section including all of the system components discussed in Section 4.3 (see Figure 4-17).

(2) Data-output section (see Figure 4-17). This section receives formatted data in binary form from the CPU via the data bus and the three output registers. The transmit clock generator uses a 1024-kilohertz timing signal obtained from the Space Shuttle master timing system to generate the necessary timing for the output encoder. The output encoder is the block named NRZ TO BI-PHASE-L-CONVERTER. This block converts the no-return-to-zero binary output to the required BI-PHASE-L code, as required by the S-band radio-transmission system. The BI-PHASE-L code has a waveform which is ideal for magnetic-tape recording.
Figure 4-17. APPS electrical systems block diagram.
Mirror Drives — Right side of Figure 4-17. This block consists of the drive for the two calibration mirrors and the scanning mirror.

The Instrument-Mode and Mirror-Control Discrete Input Commands — Lower right of Figure 4-17. These are uplink system-control commands, which are monitored by the CPU via the three-state buffers. Included in these discrete inputs is the system-reset command.

Timing Signals from the Space Shuttle Master Timing System — Lower left of Figure 4-17. These two timing signals are:

(a) Greenwich Mean Time (GMT) encoded in IRIG Standard Format B (IRIG-B).

(b) A 1000-hertz square wave synchronized to the IRIG-B signal of item (a).

The CPU receives both of these signals, and uses the 1000-hertz timing signal to decode the IRIG-B time signal. The decoded GMT is then stored in the CPU, and is used to encode blocks of measurement data.

The 1000-hertz signal is divided by 1000. The output of the three-stage BCD divider is available for encoding to a time resolution of 1 millisecond. The last stage of this divider generates CPU interrupt pulses every 1 second. The CPU responds to these interrupts by incrementing the GMT time by 1 second.

These signal inputs are found in the lower left corner of Figure 4-17.

Microprocessor (CPU)

The CPU ties the system together. It has an 8-Bit Bi-Directional Data Bus through which all data and commands enter or leave the system. The CPU has an 8-bit Address Bus which is effectively a 16-Bit Address Bus by using the timing pulses TPA and TPB. The CPU gets its step-by-step instructions from the ROM. It stores and retrieves data from the RAM. The CPU timing pulses MRD and MRW determine the external device READ and WRITE functions. For I/O device control, the CPU has three timing signals, along with the memory read control signal, MRD, allows for the selection of seven input and seven output devices. In Figure 4-17 these I/O device selectors are shown as BCD TO 1 OF 10 selectors. For detailed operation and timing, it is suggested that the Microprocessor User Manual be consulted.(11)

4.5 DATA RATE AND STRUCTURE

The operation of the system is such that the line-of-sight is scanned through the earth's limb at an angular rate of 3 degrees per second. At an orbital altitude of 500 kilometers, this angular scanning rate is equivalent to a tangent altitude scanning rate of 132 kilometers
per second. The spatial signal has an upper frequency limit of 1 cycle per kilometer, which gives an input signal frequency of 132 cycles per second. The sample rate is a strong function of the presampling filter characteristics. A safe estimate for a second-order filter is five samples per cycle, or a sample rate of:

\[ 132 \times 5 = 660 \text{ samples/s} \]

Each sample is made up of eight words, one for each wavelength sensor \( \lambda_1 \ldots \lambda_8 \). The data rate is determined by the sample rate, the number of words per sample, and the encoding scheme or data structure.

An example of a data structure that could be used for this system is shown in Figure 4-18. Each limb scan is identified by a block of data containing the time in days, hours, minutes, and seconds (see Figure 4-18). Each measurement sample consists of eight frames, one for each wavelength, and one frame containing time in milliseconds which identifies the particular sample. In addition to the data or time bits, each frame has 4 bits which identify the data type (radiance, temperature, calibration, voltage, etc.) and 4 bits which identify a particular sensor. The data section of each frame consists of 16 bits, and has room for the data (14 bits) plus 2 bits that can be used for parity checks.

![Figure 4-18. Data structure for a limb scan.](image-url)
With this data structure the data rate is calculated as:

\[
\text{Data Rate} = \text{bits/frame} \times \text{frames/sample} \times \text{samples/s}
\]

\[
= 24 \times 9 \times 660
\]

\[
= 142,560 \text{ bits/s}
\]

A clock rate of 128,000 pulses per second is easily obtainable by counting down the 1,024,000-pulses-per-second timing signal (see Figure 4-17). Using this timing signal allows for a sample rate of 4.5 times the highest system frequency component (132 hertz).

4.6 DISCRETE COMMANDS AND SYSTEM MODING

System control is achieved via the discrete command inputs (see Section 4.4.2.4). These commands are sent from the ground via the telemetry system. An example of a system command list for this system is shown in Table 4-3. Table 4-4 lists the various functions that take place in each of the four instrument modes.

4.7 TEST AND CALIBRATION SYSTEM

4.7.1 Design Philosophy

The objectives of the Test and Calibration System are:

(1) System Objectives

(a) Calibrate the instrument using a known input radiation source.
(b) Test all instrument-operation modes.
(c) Test all input and output channels.
(d) Test the sensitivity of the instrument to power and environment.

(2) Test Modes

These modes are still to be determined. However, during the instrument-development phase, an effort will be made to minimize the number of test modes different from those already available in the instrument.

The design goal was to achieve all of these objectives without adding circuit complexity to that part of the system that is launched into space. Other than test connectors and a small circuit used during the development stage to communicate with a Teletype terminal, this goal was achieved.
Table 4-3. APPS commands from ground control via telemetry.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Up</td>
<td>Turns a Relay On/Off</td>
</tr>
<tr>
<td>Power Down</td>
<td>Reset Microprocessor</td>
</tr>
<tr>
<td>Reset</td>
<td>In</td>
</tr>
<tr>
<td>Calibration Mirror</td>
<td>Retract</td>
</tr>
<tr>
<td>Calibration Mirror</td>
<td>In</td>
</tr>
<tr>
<td>Attenuator Mirror</td>
<td>Retract</td>
</tr>
<tr>
<td>Scanning Mirror</td>
<td>Operate</td>
</tr>
<tr>
<td>Stow</td>
<td></td>
</tr>
<tr>
<td>Automatic</td>
<td>Instrument Mode 1</td>
</tr>
<tr>
<td>Calibration (Transmission Diffuser)</td>
<td>Instrument Mode 2</td>
</tr>
<tr>
<td>Housekeeping</td>
<td>Instrument Mode 3</td>
</tr>
<tr>
<td>Calibration (Solar Attenuator)</td>
<td>Instrument Mode 4</td>
</tr>
</tbody>
</table>

Table 4-4. Instrument Modes

<table>
<thead>
<tr>
<th>Instrument Mode 1 - Automatic</th>
<th>Instrument Mode 2 - Calibration (Transmission Diffuser)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using the radiation measurement of a given wavelength, the microprocessor calculates limb start times and schedules the following tasks:</td>
<td>After having positioned the calibration mirror, using the transmission-diffuser line-of-sight, the microprocessor schedules a series of readings. Each reading consists of a set of radiation measurements and time.</td>
</tr>
<tr>
<td>1. Limb measurements</td>
<td></td>
</tr>
<tr>
<td>2. Albedo measurements</td>
<td></td>
</tr>
<tr>
<td>3. Radiometer calibrations</td>
<td></td>
</tr>
<tr>
<td>4. Temperature measurements</td>
<td></td>
</tr>
<tr>
<td>5. Voltage measurements</td>
<td></td>
</tr>
<tr>
<td>6. Memory testing</td>
<td></td>
</tr>
<tr>
<td>7. Data record and/or telemetry</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Instrument Mode 3 - Housekeeping</th>
<th>Instrument Mode 4 - Calibration (Solar Attenuator)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In this Mode only temperature and voltage measurements are made.</td>
<td>Same as Mode 2 except Direct Solar Calibration is achieved.</td>
</tr>
<tr>
<td></td>
<td>After having positioned the solar attenuator, the microprocessor schedules a series of direct solar-calibration readings. Each reading consists of a set of radiation measurements and time.</td>
</tr>
</tbody>
</table>
4.7.2 Test Signals
4.7.2.1 Instrument Input Test Signals

The input test signals needed to test the instrument are the following:

1. A calibrated light source to test the receivers.
2. A IRIG-B-encoded GMT signal.
3. A 1000-hertz square wave synchronized to the GMT signal.
4. A 1024-kilohertz square wave.
5. Discrete command inputs.

In addition, a source of power equivalent to the spacecraft power, which is controllable over the specified range, is needed.

4.7.2.2 Instrument Output Signals

All output data from the instrument is transmitted to the spacecraft telemetry system over one line in a BI-PHASE-L format.

The only other outputs needed are instrument-power test points so that the radiometer power supplies can be monitored. The teletype input/output is used only during the radiometer-development phase.

4.7.3 Displays and Controls

The displays and controls needed to test and control the system are shown in Figure 4-19.

4.7.3.1 System Power and Reset

At the top right of the control panel is a three-position power switch. This switch is used to select the primary power available at the testing site—28 volts dc or 115 volts 60 Hz. Alongside the Power-Control Switch is the System-Reset pushbutton switch. This switch resets the microprocessor, which, in turn, initializes the system according to the positions of the various control switches on the panel (Mode Select, Multiplexer-Select switch (MUX) Select, etc.).

4.7.3.2 Digital Voltmeter Test Group

This group is located in the upper left corner of the panel. It consists of the following items.

1. On/Off Switch. This switch controls power to the Panel Meter.
Figure 4-19. APPS control panel.
Panel Meter. This is a 4-1/2-digit digital panel meter. The meter inputs are dc, isolated to prevent ground-loop noise. Both the ground and the voltage source of each test point are switched by the Test-Point-Select Switch.

4.7.3.3 Test-Point-Select Switch

This is a 16-position 2-pole switch, which is used to select the inputs to the digital voltmeter. The selected inputs are identified by the Test-Point List located directly under the switch.

4.7.3.4 Mode-Select Group

To command the various instrument operational modes, a Mode-Select switch is needed. This is an eight-position binary-encoded thumbwheel switch. The Mode List is located at the bottom of this group (see Tables 4-3 and 4-4 for descriptions of these modes). A Push-To-Command switch is shown in this group, which has not, at this point, been implemented. The idea behind this switch is to prevent the microprocessor from implementing a false mode while the Mode-Select switch is being manipulated.

4.7.3.5 Data Display and MUX Select

This display and control group is located at the bottom center of the panel. On the right side of this group is located the Multiplexer-Select switch (MUX Select). Directly below is the MUX list. The MUX list is simply the list of inputs to the analog multiplexer (see Section 4.3.5). The present list consists of the eight receivers, seven thermistors, and one reference voltage. The MUX-Select switch is a 16-position switch with a binary-encoded output. It is used internally to identify and strobe the selected data into the data display. The data is not decoded from binary, but is displayed as four hexadecimal digits. Also displayed in this group is the AT Strobe Time in milliseconds. This display, in conjunction with the Start-Time display (located directly above the AT display), represents the precise time that the present displayed data was taken.

Below the DATA display are the DATA-Strobe switches. These switches would be used along with a special test mode set up by the Mode-Select switch. In this special test mode, a particular input would be commanded by the MUX-Select switch. The instant at which the measurements would be taken, would be commanded by the DATA-Strobe switches. In the case of the Auto/Hold switch, a new measurement would be taken every few seconds if the switch is in the Auto position. If
this switch is in the Hold position, a new measurement can be commanded by pushing the Push-To-Strobe button. This feature allows a particular input to be conveniently monitored.

4.7.3.6 GMT-SET

This is a group of nine thumbwheel switches that are used to initialize the microprocessor internal clock. Once these switches are set to the desired start time, this part of the system can be checked by pushing the System-Reset button. When this is accomplished, the GMT-SET data is encoded into the IRIG-B format and transmitted to the APPS Electronics Microprocessor. The microprocessor decodes and stores the GMT time as part of the initialization process. As another part of this initialization process, the microprocessor transmits this start time. This data, encoded at BI-PHASE-L, is received by the Test and Control electronics, where it is decoded into straight binary-encoded decimal, and strobed into the Start-Time display. The first Start-Time display should read within 1 second of the GMT-SET switches. From then on, the Start-Time display will display the real updated or simulated time.

4.7.3.7 Mirror Controls

The Mirror Controls, located on the bottom right of the control panel, are used to override the system operations as called for by the Mode-Select switch.

4.7.4 Test and Control Electronics System and Logic Diagrams

The system diagram for the Test and Control Panel is illustrated in Figure 4-20, P/N 236302. This diagram shows the various subsystems required to implement the test functions as discussed in Section 4.7.3. The implementation of these subsystems in terms of detailed logic design is illustrated in the Test and Control Panel Logic Diagram, P/N 236303.

4.8 POWER

The estimated power needs for the APPS radiometer (not including the Test and Control System) are given in Table 4-5. This estimate includes the power loss in the dc/dc converters. The power converters convert the 28-volt-dc primary power into the +5, +10, +15, and -15 volts dc power used in the digital and linear circuits. The power distribution, grounding and voltage measurements for the APPS radiometer and the Test and Control Panel are illustrated in Figure 4-21, P/N 236304.
Figure 4-20. APPS electronics system test and control panel, system diagram.
Table 4-5. APPS radiometer estimated power.

<table>
<thead>
<tr>
<th>Circuit Dissipation</th>
<th>Power (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+5 Vdc</td>
<td>1400</td>
</tr>
<tr>
<td>+10 Vdc</td>
<td>820</td>
</tr>
<tr>
<td>+15 Vdc</td>
<td>2500</td>
</tr>
<tr>
<td>-15 Vdc</td>
<td>2500</td>
</tr>
<tr>
<td>Total</td>
<td>7220</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assumed Converter Efficiency</th>
<th>65%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Electronics Power (7220/0.65)</td>
<td>11.1 W</td>
</tr>
<tr>
<td>Scanning Motor and Miscellaneous</td>
<td>5.2 W</td>
</tr>
<tr>
<td>Thermal Control</td>
<td>6.1 W</td>
</tr>
<tr>
<td>Expansion</td>
<td>0.9 W</td>
</tr>
<tr>
<td>Total 28-Vdc Primary Power</td>
<td>23.3 W</td>
</tr>
</tbody>
</table>
Figure 4-21. Power distribution grounding and voltage measurement for APPS electronics.
LIST OF REFERENCES


