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A Visible–Infrared Imaging Spectrometer for Planetary Missions

(PIDDP)

Final Report

Contract NASW-4739

prepared for NASA Headquarters
Headquarters Acqusition Division

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1. Introduction

The objective of this effort was to develop an operating breadboard prototype of a two-dimensional visible and near-infrared (0.4–2.5μm) imaging spectrometer, to demonstrate proof of concept for a new class of spectrometer design, for future NASA deep space planetary missions.

The desired scientific objective of this new class of spectrometer is to acquire high-quality hyperspectral maps of planetary objects during spacecraft encounters (orbital or fly-by). Maps of this type will contain sufficient spectral information to define surface composition at a high enough spatial resolution to aide in studying the nature and evolution of planetary objects individually and as part of the solar system overall.

The key design requirement for such a spectrometer is to measure all spectral channels simultaneously. This requirement is necessary to accommodate the temporally transient instantaneous field of view (IFOV) of the ground footprint of an instrument mounted on a moving spacecraft platform. Additional design requirements are: a sufficiently wide FOV to allow wide areal coverage in mapping applications, sufficiently high signal-to-noise ratio (SNR) to allow detection and identification of weak spectral features, and sufficient spectral resolution to allow discrimination of close and potentially overlapping spectral features significant to the end mission. The final design requirements of small volume, low mass, reliable and automated remote operation, as well as low costruction and operating costs, are necessitated by the end application on a spacecraft.

1.1. Background: Imaging Spectrometry

Spectrometry has been used as an effective method of determining and mapping compositional units on solar system objects for decades, ever since the development of efficient optical detectors. It has been long recognized that the reflectance and/or emittance spectra of the rocks, minerals, condensates, and gases composing or covering planetary surfaces provide information about the chemical and physical makeup of those materials, and that this information can be used to test theories about the nature and evolution of the bodies themselves. Pictures of the surface providing only spatial information do not provide direct information on the materials themselves. The spectral domain must be investigated to get that information.

Imaging spectrometry is the direction in which the technique of spectrometric remote sensing has developed in recent years. In this is approach, the spectral flux from an object under study is measured at most or all spatial elements (pixels) in each acquired image. At first, this was done using single detector instruments by measuring the flux in each spectral channel sequentially for a single pixel and then scanning to the next pixel and repeating the process until the entire field of view was mapped. Currently, linear array detectors are used to measure many or all spectral channels simultaneously at each pixel, as the active pixel is scanned over the surface of the object. The optimum instrument will measure all spectral channels and many spatial channels simultaneously, and this is the approach under development at SETS Technology and proposed in this project.

NASA has flown imaging spectrometers on nearly every deep space mission since Voyager: Galileo carries one now, and CRAF, Cassini and Mars Observer each have one in their payloads. The French have flown one successfully to Mars (Phobos Mission) and are preparing to fly an improved version to Mars again (Mars '94 mission). Most mission candidates are being planned with imaging spectrometers in their strawman payloads: Lunar Observer, Near Earth Asteroid Mission (NEAR), and others. NASA's Earth Observation Program has developed and is flying airborne versions of these instruments in preparation for developing a space version. The Department of Defense is also exploiting the technology. Astronomers have used the technique on ground-based telescopes for nearly a century, using photographic detectors. They now use electronic detectors and do true two-dimensional imaging spectrometry in a few cases.

1.2. Project Objective

The objective of this effort was to develop an operating breadboard prototype of a true two-dimensional imaging spectrometer for potential use on orbiting and fly-by spacecraft This involved testing and utilizing such technologies as holographic gratings with partial aberration-correction, two-dimensional detectors, figured linear step filters, miniaturization, and automation.

The key requirement for the instrument design is that all spectral elements be measured simultaneously; otherwise the spectral information becomes confused as the instantaneous field of view moves with respect to the sensor entrance aperture during image acquisition. This requirement excludes theframing camera approach, because the time required to sequentially measure several dozen or several hundred frames (each at a different spectral channel) is too great for the scene to be held stable from an orbiting spacecraft. The second key requirement is that a line of spatial elements (pixels) be imaged simultaneously, so that a wide swath can be mapped while the spacecraft flies by, i.e.while the spacecraft footprint moves over the surface of the object below the orbit of the spacecraft. A push-broom approach is thus indicated. The third key requirement is that the signal-to-noise ratio be high enough (minimally > 100:1 and preferably > 300:1) to clearly identify important weak spectral features and to separate overlapping features. Finally, the instrument must be small, low mass, reliable, and inexpensive to build and operate.

The purpose of the effort was to have available a credible and low-risk design option for an imaging spectrometer for future NASA deep space missions. At the inception of this effort, imaging spectrometers for NASA deep space applications were not modern and the instruments were very heavy and complex, and they did not deliver the area coverage rates and signal-to-noise ratios desired. This effort proposed to build on technologies and design approaches under development at SETS Technology, Inc. to correct for these deficiencies.

1.3. Approach

This project's design approach was to build on prior research done at SETS Technology, Inc. utilizing, as much as possible, existing in-house designs, components and expertise developed under previous instrument development projects. The goal was to provide a new class of imaging spectrometer designs as options for future NASA deep space missions, such as Lunar Observer and NEAR. Available resources from previous projects included two-dimensional array detectors (Si-CCD and HgCdTe), a doubly blazed holographic grating, and point detector test systems.

SETS has prepared designs, acquired key components, and built operating prototypes for for imaging spectrometers in the visible (0.435 μm to 0.835 μm) and shortwave infrared (1.0-2.5 μm) spectral ranges, using a novel design approach which greatly reduces the number of optical elements and thus greatly reduces the size and mass of the instrument. This was done while maintaining the optical throughput of the instrument by using two dimensional array detectors. SETS felt that this design approach met the objectives stated above and demonstrated, through tests of key optical elements, that these designs would produce the desired performance.

Using this design approach, SETS developed a breadboard prototype optimized for the upcoming NASA deep space missions which makes this approach credible for space applications.

The engineering effort utilized:

- Existing engineering designs, developed under previous NASA and other agency funding.
- The experience with the one operating 1.0 - 2.5 μm prototype built so far.
- Results from SETS tests of key optical elements, developed by optical manufacturers with SETS design help.
- Other existing parts and detectors.

Techniques of special concern and effort were:

- Holographic blazed gratings.
- Aberration-compensated/corrected optics.
- Figured linear step filters.
- Two-dimensional VIS and IR detectors.
- Miniaturization of the instrument.
- Design for automated adaptive operation.

These are techniques SETS has used extensively in past efforts to develop electro-optical instrumentation, and imaging spectrometers in particular.

2. Summary of Work Accomplished

2.1 Year 1 (October 1992 through September 1993)

During the first year, the following tasks were completed:

- Reviewed project goals and objectives.
- Reviewed overall design approaches.
- Reviewed design specifications.
- Reviewed design/performance of existing prototype VNIR instrument at telescope.
- Performed detailed survey of available IR array detectors.
- Selected NICMOS3 HgCdTe 256 x 256 array as baseline VNIR detector.
- Completed science review of specifications.
- Finalized system specifications.
- Completed baseline design of electronics to control VIS/VNIR arrays.
- Obtained detailed specifications and operational information from manufacturer on selected VNIR detector.
- Developed preliminary optical design and layout of optics and dewar optical bench.
- Developed preliminary grating design with manufacturer.
- Surveyed available guider cameras and selected baseline camera.
- Developed agreement in principle to cooperate with German Space Group (DLR) in applying electronics microminiaturization technology to this project, at no additional cost to NASA.

During this period, the following tasks were started:

- Survey available VIS/VNIR detector arrays.
- Develop detailed design for manufacture of grating.
- Prepare detailed mechanical design and shop drawings for mechanical subsystem.
- Implement electronics design with DLR of Germany.

The system design parameters shown in Tables 1 and 2were defined to meet the following design requirements:

- Simultaneous collection of spectral channel measurements.
- Broad spectral coverage with 0.5% to 1% spectral resolution.
- High signal-to-noise (S/N), preferably 300:1.
- Broad area coverage.
- Low mass, small size, low power, inexpensive.
- Versatility to acquire and handle data in several modes, using automated control.
- Mechanical stability.

Table 1. System Design Parameters

Spectral Range	0.35–2.50μm
Range 1	0.35–1.05μm
Range 2	0.95–2.50μm
Spectral Resolution	1%
Range 1	5.5 nm/pixel
Range 2	12.1 nm/pixel
Number of Spectral Channels	128 (Range 1) 128 (Range 2)
Signal to Noise Ratio	> 300:1
IFOV	0.5 mrad
Number of Spatial Channels	256 (across track, without scanning)
Platform	Spacecraft
Cooling Scheme	Passive (LN2)
Estimated Volume	14,400cm^3 (30 x 30 x 16 cm)
Estimated Mass	18 kg

Table 2. Subsystem Specifications.

Foreoptics		
Type	All Reflective Cassegrain	
Aperture	5 cm diameter	
Focal Length	50 cm	
Focal Ratio	f/10	
Spectrometer		
Slit Size	50 μm wide x 12.8 mm long	
Dispersion Technique	Holographic Concave Grating, double blazed	
Groove Frequency	Range 1: 165 grooves/mm	Range 2: 68 grooves/mm
Dispersion Efficiency	12%–50%	
Input Focal Ratio	f/10	
Output Focal Ratio	f/3 (Range 1), f/8 (Range 2)	
Detector	Range 1	Range 2
Material	Si CCD UV Enhanced	HgCdTe
Array Dimensions	256 x 256	256 x 256
Pixel Size	15 μm	40 μm
Quantum Efficiency	>20% 0.35-1.05 μm	>50% 1–2.5μm
Operating Temperature	290K	77K
Read Noise	70 e-	400 e-
Dark Current/Full Well	1 e-/sec @ 290K / 3x10^5 e-	5 e-/sec @ 77K / 2-4x10^7 e-

2.2 Year 2 (October 1993 through September 1994)

During the second year, effort concentrated on the following tasks:

- Development of designs for preliminary holographic optical element.
- Evaluation of performance of preliminary holographic optical element designs.
- Preparation of additional optical and mechanical designs.

2.2.1 Problems encountered

Problems were identified with the dual-blazed, single holographic optical element design. This design had been selected over a more classical design (i.e. one with separate gratings for the VIS and VNIR arms) for the advantages of reduced mass and cost, fewer optical elements and increased ruggedness. Unfortunately, with current technological constraints, the single holographic optical element design failed to meet the optical performance specifications for spectral and spatial resolution at a focal ratio required to achieve the desired system SNR. Figure 1 shows the proposed optical system layout for the single holographic element design. Figure 2 shows the geometrical spot sizes achieved at the spectrometer focal plane for an f/4 system of this design. Although the on-axis spot size of 84μm (spatial) x 18μm (spectral) is minimally acceptable, the edge-of-field spot size increases to 350μm x 195μm, far too large for the 40μm x 40μm pixel size of the FPA detector elements.

Another major problem with this design is the overlapping of orders from the two arms (visible and shortwave infrared.) The dual-blazed concept is an attempt to maximize spectrometer optical efficiency by using two coincident gratings ruled on one optical surface. Such a design would use a single optical train to disperse and image two spectrally distinct beams of light. In this case, we wish to image light in the VIS/NIR and SWIR bands. But higher orders (e.g. the third order) of the visible light, diffracting from the infrared grating, were found to be precisely coincident at the output focal plane with the first order of the infrared range. This would be an advantage (increasing the efficiency of the spectrometer) except that these higher-order images are highly aberrated, and the additional light, while increasing the throughput of the system, also enlarges the spot size and so degrades the spatial resolution of the system. Attempts to reduce the aberrations, and/or move the higher-order images, were unsucessful. So, after much design effort, the dual-blazed approach was abandoned.

2.2.2 Solutions proposed

In order to meet the desired optical performance specifications, the following alternate optical designs were proposed.

2.2.2.1 Two-arm dual-grating design

A classic two-arm dual-grating design offers increased assurance of meeting the optical and noise performance specifications demanded by the science requirements. This design increases the number of optical elements (above the number required for the dual-blazed design) complicating the mechanical and optical design, and thus increases mass, volume, and cost. However, this design also provides more parameters for adjustment during the design process, helping to ensure the problem is not overconstrained.

The layout for this design is shown in Figure 3. The design features separate optical paths beyond the input slit for the visible and near-infrared regions of the spectrum, with separate holographic gratings as well as a separate detector array for each spectral region.

2.2.2.2 Dichroic beamsplitter design

A dichroic beamsplitter design avoids the problem of overlapping orders which plagued the original dual-grating design, and still offers the advantage of a single holographic optical element to collimate, disperse and focus the beams in both spectral regions. This design adds the complexity of a dichroic filter and prism assembly, in effect creating a pair of slits, one for the visible light and the other for the infrared light.

The layout of this design is shown in Figure 4.

2.2.2.3 Dual-grating "sandwich" design

A dual-grating "sandwich" design is an innovative but more risky design approach which removes overlapping orders by layering a visible grating on the top surface of a silicon wafer with an infrared grating on the back surface. In this design, the silicon wafer substrate acts as a reflector and blocking filter for the visible light, allowing only the infrared light to reach the back infrared grating. So the infrared grating never gets the chance to scatter visible light onto the output focal plane.

The layout of this design is shown in Figure 5.

2.2.2.4 Transmissive optical element design

A transmissive optical element design improves the optical quality and greatly reduces spot size by allowing near-on-axis focal plane imaging. In this design, a positive power plano-convex or meniscus lens, with a superposed holographic grating surface, performs all the necessary optical functions of collimating, focusing and dispersion. The near-on-axis design improves the spot size for both the visible and infrared spectral regions.

The layout of this design is shown in Figure 6.

2.3 Year 3 (October 1994 through September 1995)

During the third year, effort concentrated on the following tasks:

- Evaluating alternative designs and selecting the one most appropriate.
- Implementating final design.
- Testing and evaluating implemented design.
- Recommending additional designs for other related applications.

3. Recommendations and Conclusions

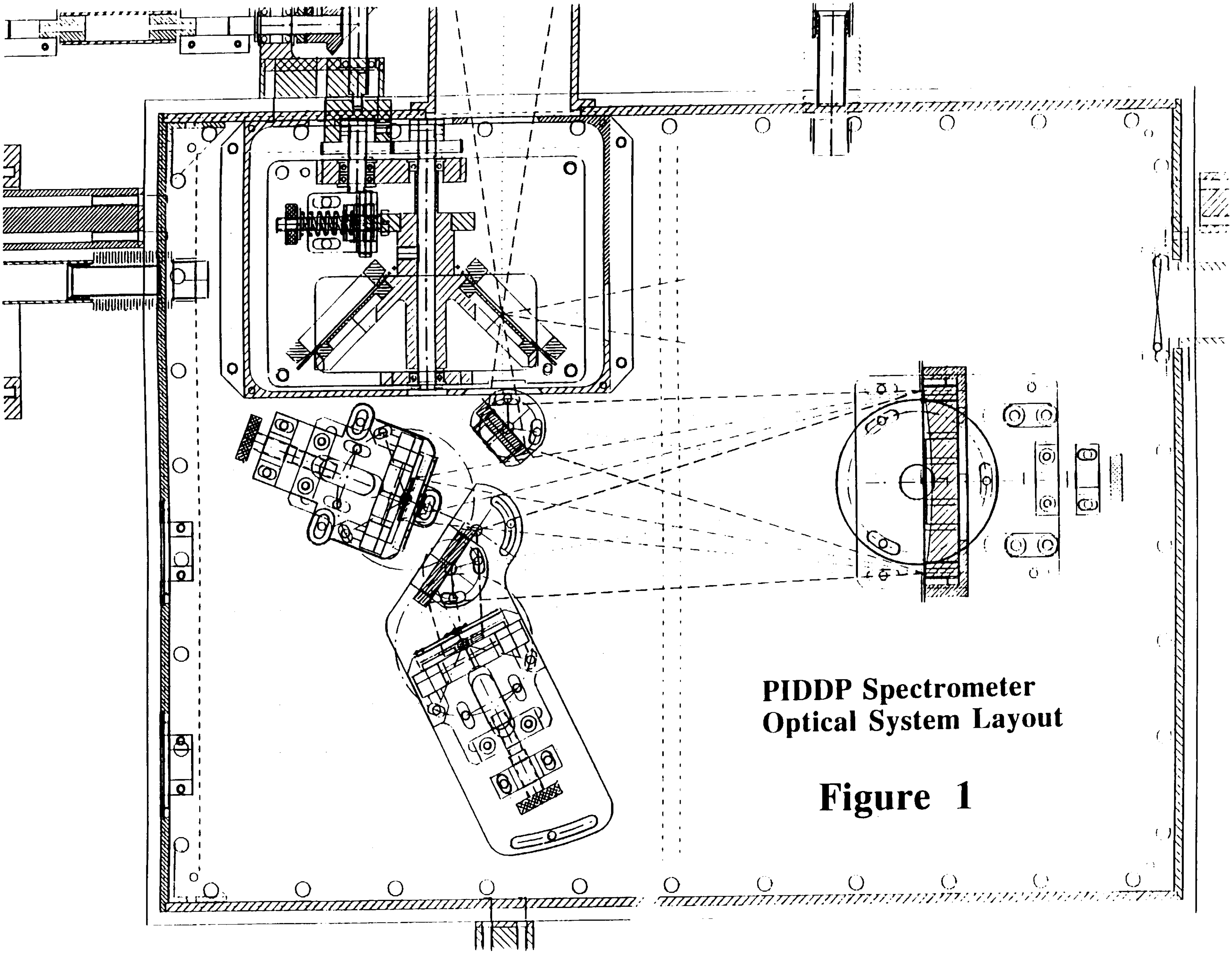
A key design goal of this project was to use a double blazed holographic grating to reduce the number of components required to cover the entire 0.4 µm to 2.5 µm spectral range. Several different double blazed grating configurations were tried during the optical design phase of this project, but none ever produced the required aberration performance, due to superposition of higher order spectra on top of the desired spectra. These higher order spectra always turned out to have large aberration which would degrade the otherwise excellent optical performance of the design. Since the higher order spectra were covering the same wavelength interval as the prime order spectra, these parasitic spectral orders could not be removed with wavelength selective filters in the instrument's focal planes. This this problem was insurmountable using this design approach.

So in practice we chose to advocate a classical dual-arm design, using a dichroic beamsplitter to separate the incoming beam into two broad bands, the visible (0.4 to 0.9 µm) band and the shortwave infrared (0.8 to 2.5 µm) band. This classical approach thus consists of variations of two SETS imaging spectrometers (the AAHIS and DLR spectrometers) integrated into a new instrument, sharing the same foreoptics, slit, and chassis. In the fully developed version of this integrated instrument, both the visible and infrared focal plane arrays would be controlled by one set of electronics hardware and software, producing a compact, broadband hyperspectral imaging spectrometer suitable for further development into a space qualified system.

Despite this negative conclusion, SETS recommends that the dual grating approach be pursued, with the addition of a filter layer between the two grating surfaces which would allow the infrared grating to be illuminated only by infrared light. This would eliminate the superposition of higher order visible light spectra (produced by diffraction of visible light from the infrared grating) onto the fundamental order visible spectra produced by the visible light gratin. In practice, such a dual grating could be produced by etching a dual holographic grating onto the two surfaces of a thin silicon wafer (or onto both surfaces of a thin layer of silicon deposited onto a suitable substrate). In operation, the outer (front) surface of this sandwich structure would scatter both visible and infared light into the desired spectra, and the buried (back) surface would scatter only infrared light, since only the infrared portion of the beam would be transmitted through the silicon layer to reach the second grating. In effect, this design places the wavelength separating filter, not in the input beam nor at the focal plane, but at the grating (i.e. in one of the system's pupil planes). This would eliminate the highly aberrated parasitic orders and restore the optical performance of this simple, yet broadband, single component optical system.

Appendix

The Appendix presents three concept designs for this imaging spectrometer, along with analyses of their optical performance and a drawing of a representative holographic grating to be used in these designs.

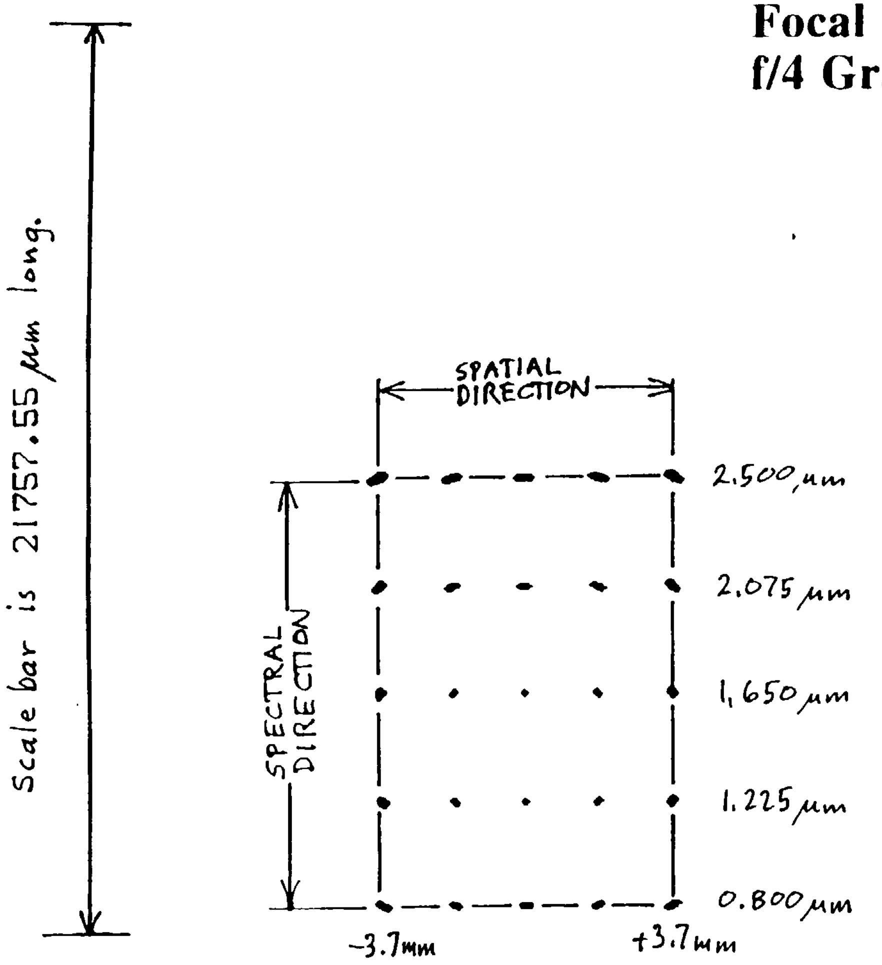


PIDDP Spectrometer
Optical System Layout

Figure 1

Focal Plane Spot Diagram
f/4 Grating, Infrared Arm

Figure 2



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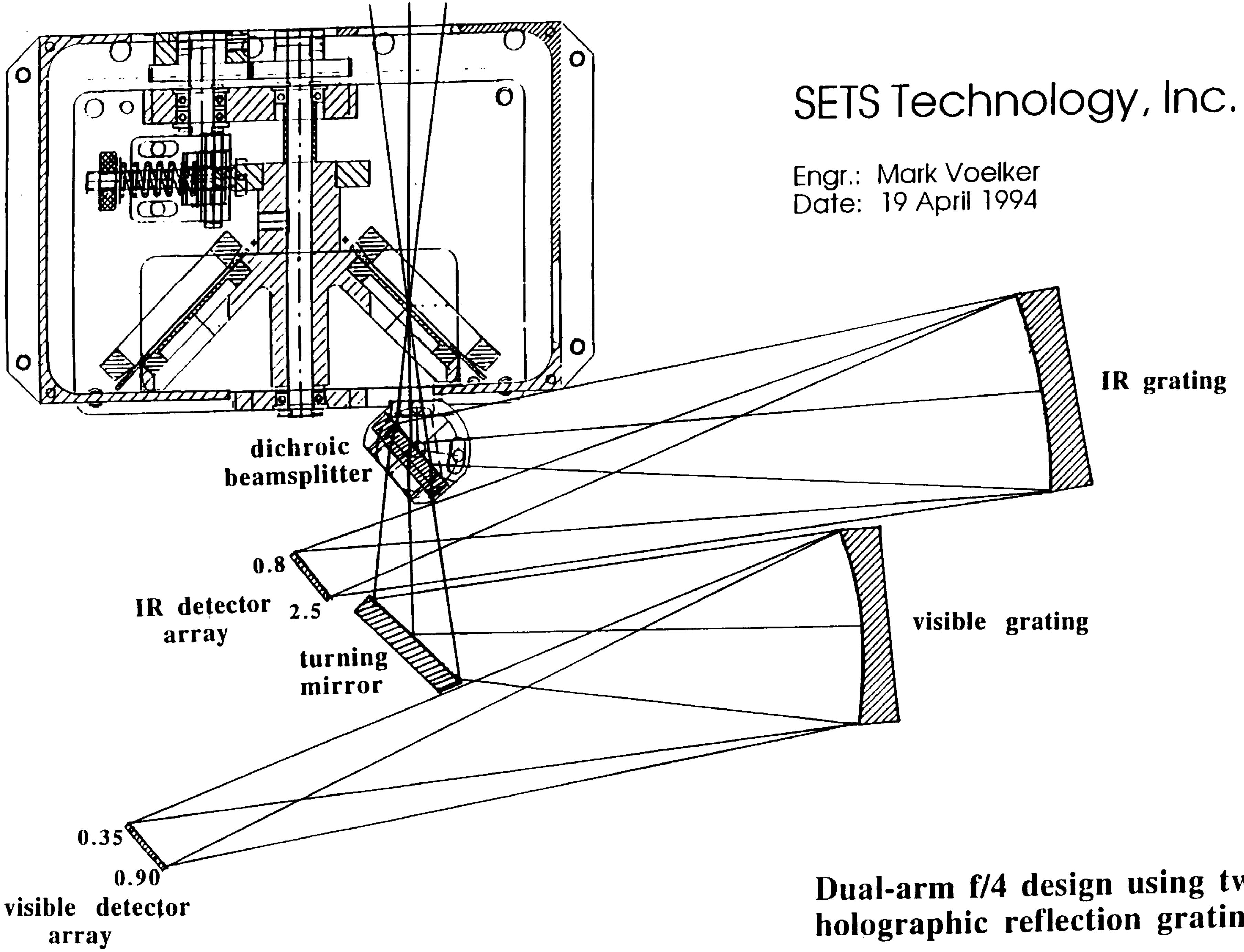
FULL FIELD SPOT DIAGRAM
FILE: 490.137A
MON MAR 28 1994   UNITS ARE MICRONS.
FIELD       :      1
RMS RADIUS  :  1.52E+004
GEO RADIUS  :  1.09E+004
SCALE BAR   : 2.176E+004          REFERENCE   : CHIEF RAY
```

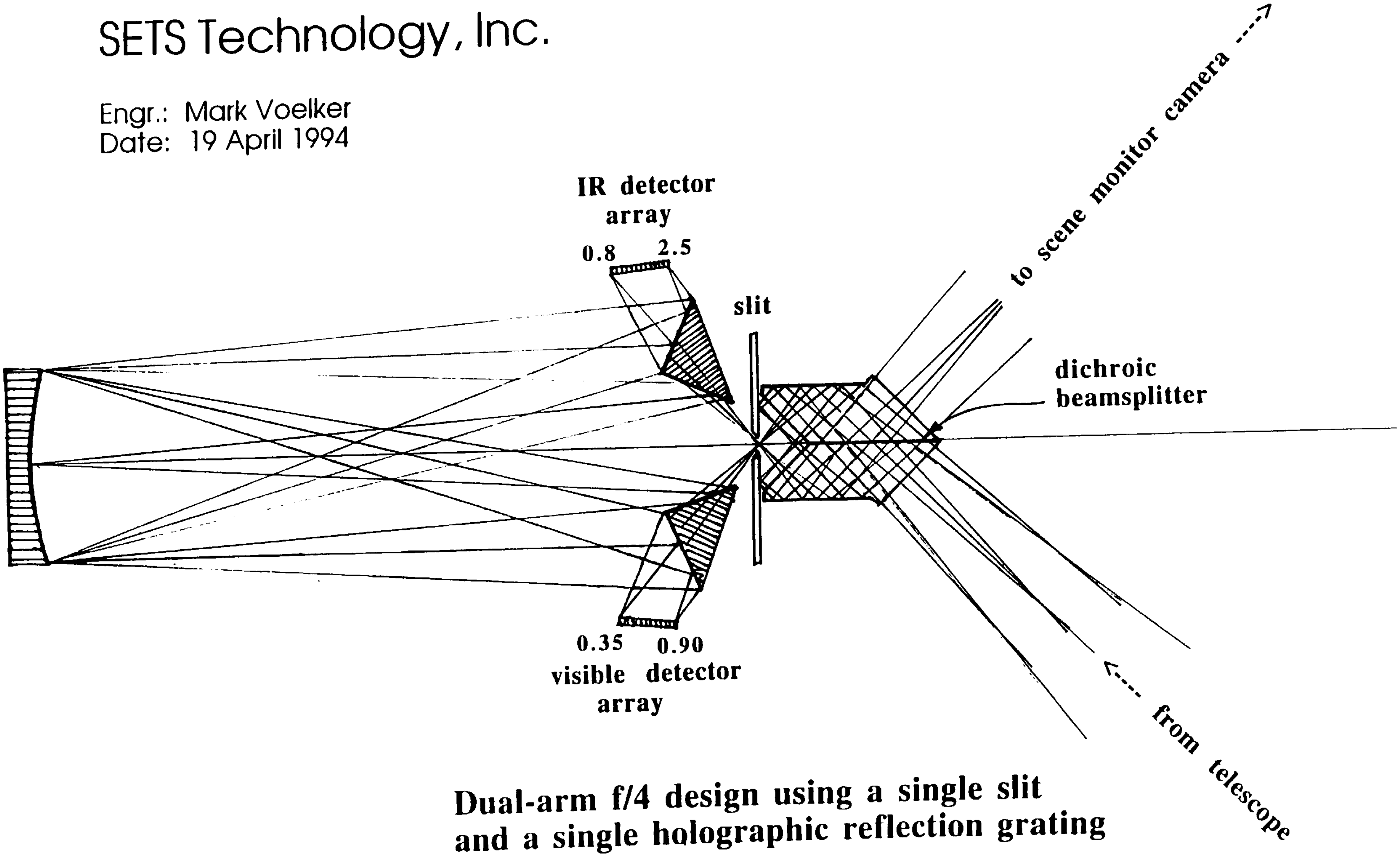


Dual-arm f/4 design using two holographic reflection gratings

Figure 3

SETS Technology, Inc.

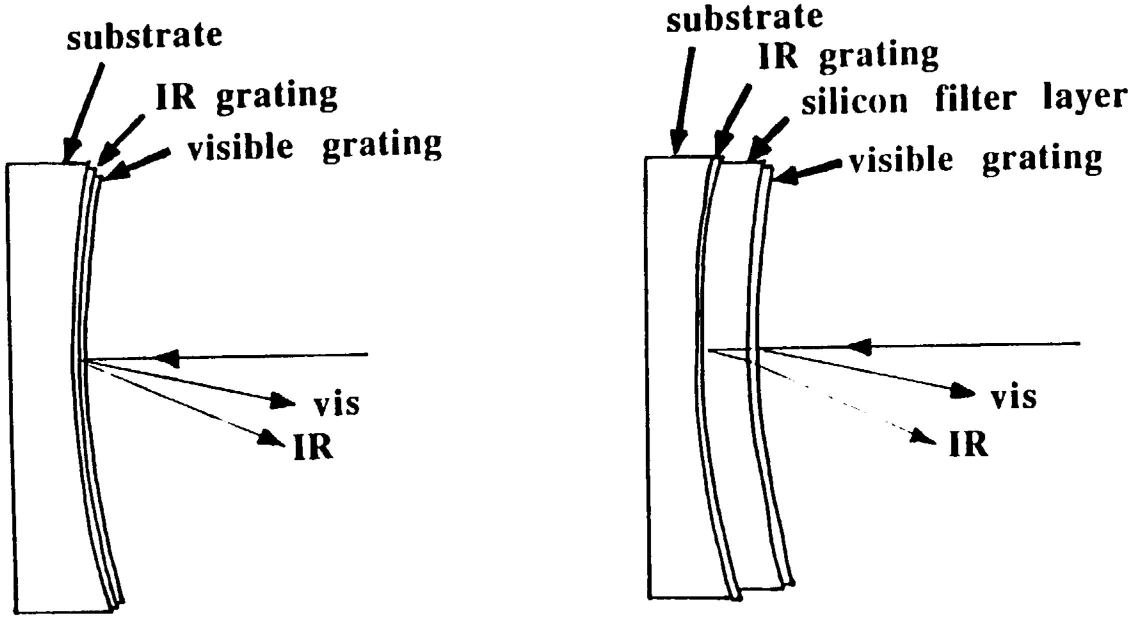
Engr.: Mark Voelker
Date: 19 April 1994



Dual-arm f/4 design using a single slit
and a single holographic reflection grating

Figure 4

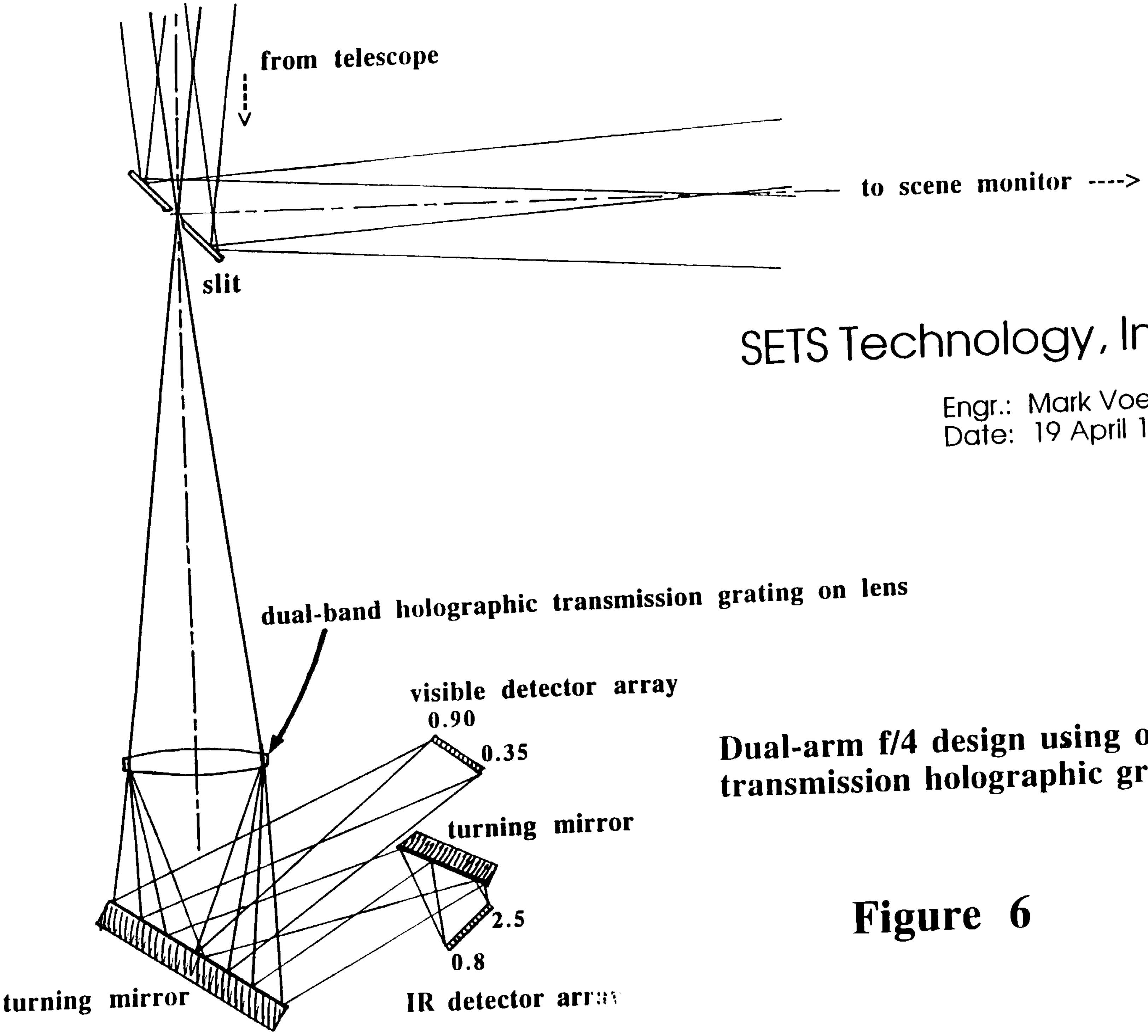
Engr.: Mark Voelker
Date: 19 April 1994



standard dual-band reflective holographic grating

dual-band reflective holographic grating with sandwiched visible-blocking silicon filter layer

Figure 5 Dual-band reflective holographic grating with added silicon filter layer keeps visible light from scattering off of IR grating, reducing order overlap problems.



SETS Technology, Inc.

Engr.: Mark Voelker
Date: 19 April 1994

Dual-arm f/4 design using one transmission holographic grating

Figure 6

CONCEPT 1. DESCRIPTION

The first technique (Concept 1) employs a single concave holographic diffraction grating operating in an over/under low stray light geometry and a custom dichroic beam splitting filter to separate the first order IR spectra from the second order VIS spectra. The over/under or Eagle geometry achieves excellent imaging over the wavebands of interest. American Holographic has several commercial instruments designed using this concept and the addition of some field flattening through aberration correction.

The use of a single grating puts some constraints on the spectral dispersion that can be used, the two spectra are interrelated. The preliminary grating design for this concept is designated 490.101. The focal plane positions are shown in Figures 2 and 3 for the IR and VIS detectors. If the primary spectra is considered the IR detector and wavelengths then the VIS detector should operate in the second order in order to come close to the requested spectral dispersion. The IR detector wants 1000nm to 2500nm or effectively 1500 nm spread over 7.44mm. or an average of 201.6 nm/mm. The VIS specification asks for 350-1050nm or 700nm spread over the same 7.44mm for a reciprocal linear dispersion of 94nm/mm. A single grating cannot achieve both these requirements simultaneously. By using the second order visible spectra, however, a reciprocal linear dispersion of 100.8 nm/mm is achieved in nearly the same focal positions as the IR detector. This focal position is important because all aberration corrections and imaging are related to mλ (m being the order). Thus if the design provides good imaging in the first order at 1500nm it will also have the same imaging in the second order at 750nm. Because the dispersion is not exactly what was requested the 350-1050 nm spectra is spread along only 6.94mm. If SETS would like to change the VIS spectrum to accomodate the IR specifications, the only requirement is that the reciprocal linear dispersion (RLD) be half of the IR spectra for the VIS spectra (e.g. 200nm/mm IR to 100nm/mm VIS).

EFFICIENCY

The use of a single grating to cover a large spectral range always leads to a trade-off with respect to the wavelength or spectral region that has the highest diffractive efficiency. In fact, the actual efficiency requirement is usually a system specification due to the source irradiance and/or the detector sensitivity. Not knowing the system requirements it is assumed that the IR spectrum dominates and the nominal design is peaked at the specified 1700nm. Figure 4 shows the expected efficiency for a sinusoidal groove profile peaked at 1700nm. This profile has a groove depth of 4900 Angstroms and yields the typical scalar first order efficiency of 33.8%. When this grating is used in the second order visible (Figure 5), the efficiency is much lower and actually goes through two zero efficiency points. (These zero efficiency values really don't occur in practice because the grating efficiency is different across the actual blank and averages the effect for a given wavelength.) Figures 6 and 7 show similar efficiency tables for a slightly shallower groove depth. The VIS low efficiency region is now closer to the peak in the solar spectrum with only slightly lower IR efficiency. The shallower groove profile coupled with the enhanced performance from the eventual ion milling of the grating should provide acceptable efficiencies greater than 40% over most of the spectral range.

GRATING SIZE

The standard American Holographic blank size is shown in the enclosed AH Drawing # A-900131 (Figure 8). The material is fine annealed pyrex and we have several blanks currently in stock. The 80 mm clear aperture and 152 mm entrance distance length yield approximately F 1.9 for system collection solid angle.

GRATING SPECIFICATION: 490.101

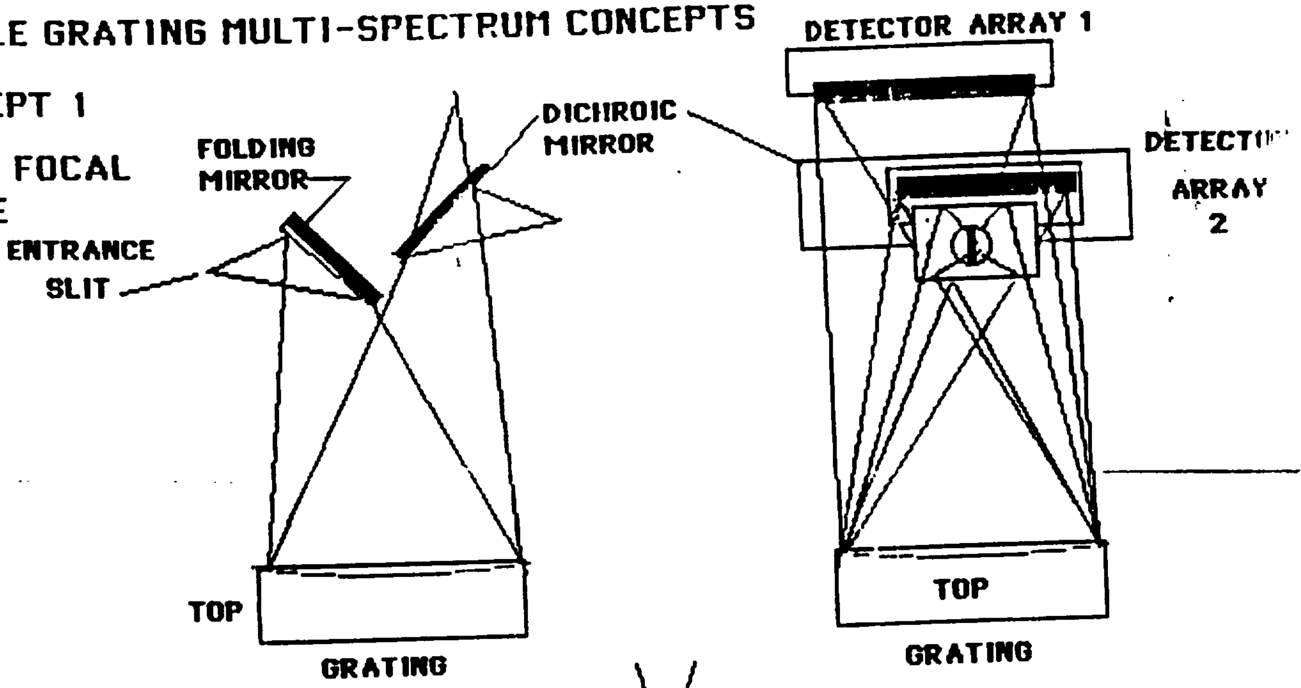
Groove Frequency	32.4 gr/mm
Diffraction Order	1 for IR 1000nm-2500nm
	2 for VIS 350nm-1050nm
Radius of Curvature	152.4 mm
Blank Diameter	85.0 mm
Entrance Slit Distance	152.2 mm
Focal Positions	See Figures 2 & 3
Groove Depth	4000 Angstroms

FIGURE 1

SINGLE GRATING MULTI-SPECTRUM CONCEPTS

CONCEPT 1

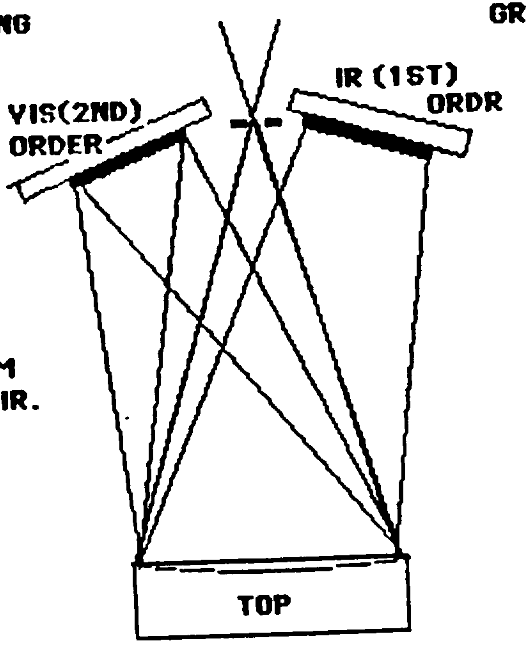
SPLIT FOCAL PLANE



CONCEPT 2

SITE DIFFRACTIVE ORDERS

BOTH DETECTORS MUST BE BLIND TO THE OTHER'S RADIATION. IR BLOCKED FROM VIS, AND VIS BLOCKED FROM IR.



CONCEPT 3

DOUBLE EXPOSURE SHARED APERTURE

BOTH GRATING EXPOSURES ARE OPTIMIZED FOR 1ST ORDER USAGE. TO PREVENT OVERLAP, REQUIRES LARGER VIS CCD DETECTOR.

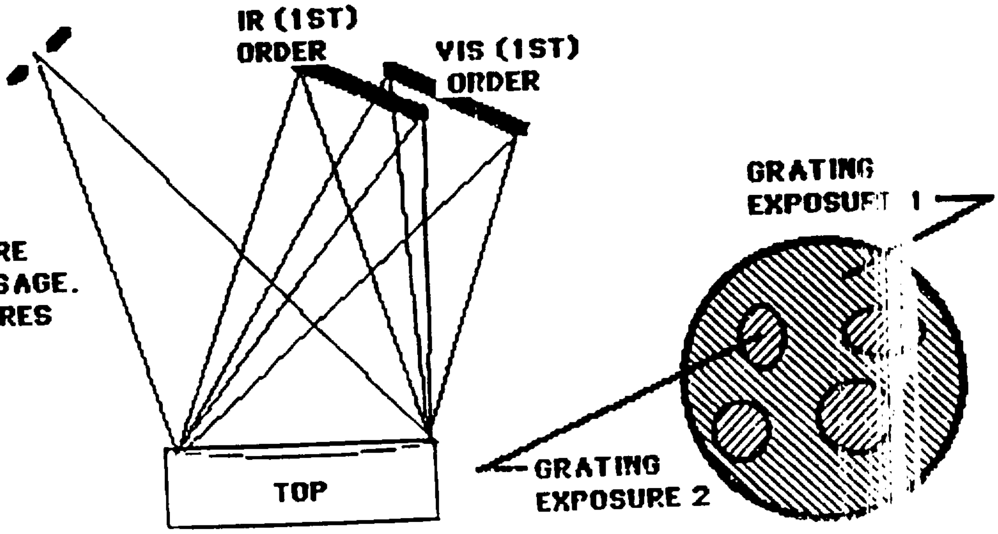


FIGURE 2

```
GRATING FILE DESCRIPTION----------------B$ 490.101

WAVELENGTH (nm)      DIFF ANGLE BETA (deg)      FOCAL LENGTH LB(mm)
  1000.00                  0.23                    152.79
  1050.00                  0.32                    152.80
  1100.00                  0.42                    152.81
  1150.00                  0.51                    152.83
  1200.00                  0.60                    152.84
  1250.00                  0.70                    152.85
  1300.00                  0.79                    152.86
  1350.00                  0.88                    152.86
  1400.00                  0.97                    152.87
  1450.00                  1.07                    152.88
  1500.00                  1.16                    152.89
  1550.00                  1.25                    152.90
  1600.00                  1.35                    152.90
  1650.00                  1.44                    152.91
  1700.00                  1.53                    152.92
  1750.00                  1.62                    152.92
  1800.00                  1.72                    152.93
  1850.00                  1.81                    152.93
  1900.00                  1.90                    152.94
  1950.00                  2.00                    152.94
  2000.00                  2.09                    152.95
  2050.00                  2.18                    152.95
  2100.00                  2.27                    152.95
  2150.00                  2.37                    152.96
  2200.00                  2.46                    152.96
  2250.00                  2.55                    152.96
  2300.00                  2.65                    152.96
                           2.74                    152.96
                           2.83                    152.97
                           2.92                    152.97
  2500.00                  3.02                    152.97

 LENGTH OF SPECTRA           7.434909
 LAMBDA1=       1000         LAMBDA2=        2499.999


  1           GRATING FILE DESCRIPTION----------------B$ 490.101
  2           GROOVE FREQUENCY (gr/mm)----------------N  32.4
  3           DIFFRACTION ORDER------------------------m  1
  4           RADIUS OF CURVATURE(mm)----------------R  152.4
  5           ENTRANCE SLIT DISTANCE (mm)-----------La  152.2
  6           ANGLE OF INCIDENCE (deg)-----------Alpha  1.625
```

FIGURE 3

```
GRATING FILE DESCRIPTION----------------B$ 490.101

WAVELENGTH (nm)      DIFF ANGLE BETA (deg)      FOCAL LENGTH LB(mm)
   350.00                 -0.33                     152.71
   375.00                 -0.23                     152.73
   400.00                 -0.14                     152.74
   425.00                 -0.05                     152.76
   450.00                  0.05                     152.77
   475.00                  0.14                     152.78
   500.00                  0.23                     152.79
   525.00                  0.32                     152.80
   550.00                  0.42                     152.81
   575.00                  0.51                     152.83
   600.00                  0.60                     152.84
   625.00                  0.70                     152.85
   650.00                  0.79                     152.86
   675.00                  0.88                     152.86
   700.00                  0.97                     152.87
   725.00                  1.07                     152.88
   750.00                  1.16                     152.89
 [illegible]               1.25                     152.90
 [illegible]               1.35                     152.90
 [illegible]               1.44                     152.91
   850.00                  1.53                     152.92
   875.00                  1.62                     152.92
   900.00                  1.72                     152.93
   925.00                  1.81                     152.93
   950.00                  1.90                     152.94
   975.00                  2.00                     152.94
  1000.00                  2.09                     152.95
  1025.00                  2.18                     152.95
  1050.00                  2.27                     152.95

 LENGTH OF SPECTRA              6.937709
 LAMBDA1=        350            LAMBDA2=        1050


   1            GRATING FILE DESCRIPTION----------------B$ 490.101
   2            GROOVE FREQUENCY (gr/mm)----------------N  32.4
   3            DIFFRACTION ORDER-----------------------m  2
   4            RADIUS OF CURVATURE(mm)----------------R   152.4
   -            ENTRANCE SLIT DISTANCE (mm)-----------La   152.2
                ANGLE OF INCIDENCE (deg)------------Alpha  1.625
```

FIGURE 4

```
 GRATING DESCRIPTION---       490.101
 WAVELENGTH (nm)            SCALAR Efficiency (%)
      1000.00                          9.56
      1050.00                         13.25
      1100.00                         16.82
      1150.00                         20.12
      1200.00                         23.06
      1250.00                         25.61
      1300.00                         27.75
      1350.00                         29.52
      1400.00                         30.92
      1450.00                         32.01
      1500.00                         32.81
      1550.00                         33.36
      1600.00                         33.69
      1650.00                         33.84
      1700.00                         33.84
      1750.00                         33.70
      1800.00                         33.45
      1850.00                         33.11
      1900.00                         32.70
      1950.00                         32.23
      2000.00                         31.71
      2050.00                         31.16
      2100.00                         30.58
      2150.00                         29.98
      2200.00                         29.36
      2250.00                         28.74
      2300.00                         28.11
      2350.00                         27.48
      2400.00                         26.85
      2450.00                         26.23
      2500.00                         25.62

  1           GRATING DESCRIPTION---------------B$         490.101
  2           START WAVELENGTH (nm)------------L1          1000
  3           END WAVELENGTH (nm)------------- L2          2500
  4           WAVELENGTH STEP(Delta lambda)- — L3          50
  5           ORDER-----------------------------m          1
  6           GROOVE DEPTH,  AUGSTROMS---------- h         4900
```

FIGURE 5

```
 GRATING DESCRIPTION---        490.101
 WAVELENGTH (nm)           SCALAR Efficiency (%)
      350.00                          0.97
      375.00                          0.32
      400.00                          3.54
      425.00                          7.50
      450.00                          9.67
      475.00                          9.38
      500.00                          7.32
      525.00                          4.58
      550.00                          2.12
      575.00                          0.52
      600.00                          0.00
      625.00                          0.52
      650.00                          1.90
      675.00                          3.91
      700.00                          6.28
      725.00                          8.82
      750.00                         11.35
      775.00                         13.75
      800.00                         15.94
      825.00                         17.85
        50.00                        19.48
        75.00                        20.82
      900.00                         21.87
      925.00                         22.65
      950.00                         23.20
      975.00                         23.52
     1000.00                         23.66
     1025.00                         23.63

   1          GRATING DESCRIPTION---------------B$        490.101
   2          START WAVELENGTH (nm)------------L1         350
   3          END WAVELENGTH (nm)------------- L2         1049
   4          WAVELENGTH STEP(Delta lambda)- -- L3        25
   5          ORDER------------------------------m        2
              GROOVE DEPTH,  ANGSTROMS--------- h         4900
```

FIGURE 6

```
 GRATING DESCRIPTION---       490.101
 WAVELENGTH (nm)           SCALAR Efficiency (%)
     1000.00                       24.38
     1050.00                       27.20
     1100.00                       29.44
     1150.00                       31.14
     1200.00                       32.36
     1250.00                       33.18
     1300.00                       33.66
     1350.00                       33.85
     1400.00                       33.81
     1450.00                       33.58
     1500.00                       33.20
     1550.00                       32.71
     1600.00                       32.13
     1650.00                       31.48
     1700.00                       30.78
     1750.00                       30.05
     1800.00                       29.30
     1850.00                       28.53
     1900.00                       27.76
     1950.00                       26.99
     2000.00                       26.23
     2050.00                       25.48
     2100.00                       24.75
     2150.00                       24.03
     2200.00                       23.32
     2250.00                       22.64
     2300.00                       21.97
     2350.00                       21.33
     2400.00                       20.71
     2450.00                       20.10
                                   19.52

  1            GRATING DESCRIPTION--------------B#        490.101
  2            START WAVELENGTH (nm)-----------L1         1000
  3            END WAVELENGTH (nm)------------- L2        2500
  4            WAVELENGTH STEP(Delta lambda)- -- L3       50
  5            ORDER-----------------------------m        1
  6            GROOVE DEPTH,  ANGSTROMS--------- h        4000
```

FIGURE 7

```
 GRATING DESCRIPTION---       490.101
 WAVELENGTH (nm)          SCALAR Efficiency (%)
       350.00                       7.98
       375.00                       9.83
       400.00                       8.29
       425.00                       5.06
       450.00                       2.02
       475.00                       0.27
       500.00                       0.14
       525.00                       1.45
       550.00                       3.79
       575.00                       6.72
       600.00                       9.84
       625.00                      12.87
       650.00                      15.63
       675.00                      17.99
       700.00                      19.91
       725.00                      21.40
       750.00                      22.48
       775.00                      23.19
       800.00                      23.56
       825.00                      23.67
       850.00                      23.54
       875.00                      23.23
       900.00                      22.77
       925.00                      22.20
       950.00                      21.54
       975.00                      20.82
      1000.00                      20.06
      1025.00                      19.28

               GRATING DESCRIPTION---------------B$        490.101
               START WAVELENGTH (nm)------------L1          350
               END WAVELENGTH (nm)-------------- L2         1049
               WAVELENGTH STEP(Delta lambda)- -- L3         25
               ORDER-----------------------------m          2
6              GROOVE DEPTH,  ANGSTROMS--------- h          4000
```

CONCEPT 2

In an attempt to separate the IR and VIS detectors and eliminate the need for the dichroic beamsplitter American Holographic has investigated the possibility of using diffracted orders on opposite sides of the zero order in Concept 2. Keeping the system symmetrical (convenient but not required for the design) the angle of incidence in this design (490.99) was selected to be zero. The IR spectrum focal positions are shown in Figure 9. The detector position is between 1.85 and 4.63 degrees from the entrance slit at a distance of about 152.5 mm from the grating. The detector is nearly perpendicular to the grating normal.

Figure 10 shows the minus one visible spectrum. Again the dispersion is too small to fill the detector and the better dispersion is found in the minus two order (Figure 11). The same discussion as to the relative dispersion applies to this design as that of Concept 1. Thus, the second order spectra goes 350nm-1100nm over 7.42 mm. Notice also that this spectra is closer to the grating and inclined toward grating center. It will also exhibit more curvature because it is the opposite order that was designed with the flatter field.

OVERLAPPING SPECTRA

The largest problem with the Concept 2 design is that each detector must be made blind to the other detector's spectra. Because of the selection of the two dispersions VIS and IR are symmetrical with respect to the opposite diffracted angles, the plus two visible spectra will overlap the desired plus one IR spectra (note: this will always happen and is the basis for Concept 1). Also the minus one IR spectra will overlap the desired minus two VIS spectra. These may or may not be major constraints but will depend upon the sensitivity of each of the chosen detectors and the use of order sorting or color glass filters to correct any overlapping regions.

EFFICIENCY

The only impact upon efficiency of the Concept 2 from the discussions in Concept 1 is that it is probably unlikely that the grating can be blazed for both sides of the normal. Thus one spectra can be made over 40% but the other spectra will probably decrease as the other one increases. The scalar sinsoidal efficiency will still be applicable for either side of the normal as the plus and minus orders have equal efficiencies in the non-blazed case.

GRATING SPECIFICATION: 490.99

Groove Frequency	32.3 gr/mm
Diffraction Order	1 for IR 1000nm-2500nm
	- 2 for VIS 350nm-1100nm
Radius of Curvature	1524 mm
Blank Diameter	85.0 mm
Entrance Slit Distance	152.7 mm
Focal Positions	See Figures 9 & 11
Groove Depth	4000 Angstroms

FIGURE 9

```
GRATING FILE DESCRIPTION---------------B# 490.99

WAVELENGTH (nm)      DIFF ANGLE BETA (deg)      FOCAL LENGTH LB(mm)
   1000.00                 1.85                    152.58
   1050.00                 1.94                    152.60
   1100.00                 2.04                    152.62
   1150.00                 2.13                    152.64
   1200.00                 2.22                    152.66
   1250.00                 2.31                    152.67
   1300.00                 2.41                    152.69
   1350.00                 2.50                    152.71
   1400.00                 2.59                    152.73
   1450.00                 2.68                    152.74
   1500.00                 2.78                    152.76
   1550.00                 2.87                    152.78
   1600.00                 2.96                    152.79
   1650.00                 3.06                    152.81
   1700.00                 3.15                    152.82
   1750.00                 3.24                    152.84
   1800.00                 3.33                    152.85
   1850.00                 3.43                    152.86
   1900.00                 3.52                    152.88
   1950.00                 3.61                    152.89
   2000.00                 3.70                    152.90
   2050.00                 3.80                    152.91
   2100.00                 3.89                    152.93
   2150.00                 3.98                    152.94
   2200.00                 4.07                    152.95
   2250.00                 4.17                    152.96
   2300.00                 4.26                    152.97
   2350.00                 4.35                    152.98
   2400.00                 4.45                    152.99
                           4.54                    153.00
                           4.63                    153.01

 LENGTH OF SPECTRA          7.426886
 LAMBDA1=        1000      LAMBDA2=       2499.999


   1           GRATING FILE DESCRIPTION---------------B# 490.99
   2           GROOVE FREQUENCY (gr/mm)---------------N  32.3
   3           DIFFRACTION ORDER----------------------m  1.
   4           RADIUS OF CURVATURE(mm)---------------R   152.4
   5           ENTRANCE SLIT DISTANCE (mm)----------La   152.7
   6           ANGLE OF INCIDENCE (deg)-----------Alpha  0
```

FIGURE 10

```
GRATING FILE DESCRIPTION----------------E$ 490.99

WAVELENGTH (nm)      DIFF ANGLE BETA (deg)      FOCAL LENGTH LB(mm)
   350.00                  -0.65                  151.90
   375.00                  -0.69                  151.88
   400.00                  -0.74                  151.87
   425.00                  -0.79                  151.85
   450.00                  -0.83                  151.84
   475.00                  -0.88                  151.82
   500.00                  -0.93                  151.80
   525.00                  -0.97                  151.79
   550.00                  -1.02                  151.77
   575.00                  -1.06                  151.76
   600.00                  -1.11                  151.74
   625.00                  -1.16                  151.72
   650.00                  -1.20                  151.71
   675.00                  -1.25                  151.69
   700.00                  -1.30                  151.67
   725.00                  -1.34                  151.66
   750.00                  -1.39                  151.64
   775.00                  -1.43                  151.62
   800.00                  -1.48                  151.61
   825.00                  -1.53                  151.59
   850.00                  -1.57                  151.57
   875.00                  -1.62                  151.56
   900.00                  -1.67                  151.54
   925.00                  -1.71                  151.52
   [illegible]             -1.76                  151.50
   [illegible]             -1.80                  151.49
   [illegible]             -1.85                  151.47
  1025.00                  -1.90                  151.45
  1050.00                  -1.94                  151.43
  1075.00                  -1.99                  151.41

 LENGTH OF SPECTRA             3.585013
 LAMBDA1=        350          LAMBDA2=        1075


  1            GRATING FILE DESCRIPTION----------------B$  490.99
  2            GROOVE FREQUENCY (gr/mm)----------------N   32.3
  3            DIFFRACTION ORDER-----------------------m   -1
  4            RADIUS OF CURVATURE(mm)----------------R    152.4
  5            ENTRANCE SLIT DISTANCE (mm)-----------La    152.7
  6            ANGLE OF INCIDENCE (deg)-----------Alpha    0
```

FIGURE 11

```
GRATING FILE DESCRIPTION----------------B$ 490.99

WAVELENGTH (nm)      DIFF ANGLE BETA (deg)      FOCAL LENGTH LB(mm)
   350.00                  -1.30                   151.67
   375.00                  -1.39                   151.64
   400.00                  -1.48                   151.61
   425.00                  -1.57                   151.57
   450.00                  -1.67                   151.54
   475.00                  -1.76                   151.50
   500.00                  -1.85                   151.47
   525.00                  -1.94                   151.43
   550.00                  -2.04                   151.40
   575.00                  -2.13                   151.36
   600.00                  -2.22                   151.32
   625.00                  -2.31                   151.29
   650.00                  -2.41                   151.25
   675.00                  -2.50                   151.21
   700.00                  -2.59                   151.17
   725.00                  -2.68                   151.13
   750.00                  -2.78                   151.09
   775.00                  -2.87                   151.05
   [illegible].00          -2.96                   151.01
   [illegible]             -3.06                   150.97
   [illegible]             -3.15                   150.93
   875.00                  -3.24                   150.89
   900.00                  -3.33                   150.85
   925.00                  -3.43                   150.81
   950.00                  -3.52                   150.77
   975.00                  -3.61                   150.72
  1000.00                  -3.70                   150.68
  1025.00                  -3.80                   150.64
  1050.00                  -3.89                   150.59
  1075.00                  -3.98                   150.55
  1100.00                  -4.07                   150.50

 LENGTH OF SPECTRA               7.121213
  LAMBDA1=       350          LAMBDA2=        1099.999


   1            GRATING FILE DESCRIPTION----------------B$ 490.99
   2            GROOVE FREQUENCY (gr/mm)----------------N  32.3
   3            DIFFRACTION ORDER-----------------------m  -2
   4            RADIUS OF CURVATURE(mm)----------------R   152.4
   5            ENTRANCE SLIT DISTANCE (mm)-----------La   152.7
   6            ANGLE OF INCIDENCE (deg)------------Alpha  0
```

CONCEPT 3

In order to maximize the design capability of the holographic diffraction grating it would helpful if the two optical spectra could be created by two individual gratings. With the SETS desire to keep only one entrance slit for each spectra there is a little known, but employed in certain commercial instruments, technique of placing two different holographic exposures upon one grating substrate. The gratings are similar in concept to tri-partite gratings in that the grooves are not meant to be in phase. The common technique of sharing the grating aperture with either top half or bottom half being different gratings can be supplemented with either a random mask arrangement or even two complete exposures over the entire substrate. There are moire and sum/difference spectra if the groove frequencies are too close to each other. The advantage to the SETS instrument is that both gratings could be designed to operate in the first order and each could be optimized for the highest efficiency in its spectral range.

This Concept allows the designer a great deal of freedom in the selection of the individual grating design. There is one system suggestion that American Holographic would like to suggest to the SETS design group. If the VIS CCD can be made larger (or selected larger), then the spectra can be spread over a greater angle and there can be a situation with no overlap with the IR detector region. In effect, the first order IR spectra is completely contained within the zero order to 350nm UV spectral region. By slightly inclining the IR grating grooves with respect to the VIS grating grooves the IR higher order spectra can be separated from the first order VIS detector. Such a grating combination is described in Figure 12 and Figure 13 designs 490.102A and 490.102B respectively.

The 490.102A design operates in the minus one order (note: the American Holographic convention is that the angle of incidence is always positive and negative angles are always on the opposite side of the grating normal from the entrance slit). The 7.43 mm spectra is spread over diffraction angles from -7.53 to -10.29 degrees. The 490.102B grating design spreads the 350 to 1050 nm spectra from -10.97 to -21.86 degrees or over 31.48 mm. Thus, the spectra do not physically overlap and the detectors do not have to be butted together. The penalty, of course, is the need for a larger CCD detector. A CCD of a about the right size is available from EG&G Reticon (RA1200J See Appendix A).

Additional designs could be generated for smaller CCD sizes, but the IR spectra would have to be used in the plus one order (on the other side of the normal) and the CCD would have to be insensitive to the minus order IR spectrum.

EFFICIENCY

The efficiency for each exposure can be optimized for the spectral region of use. In a shared aperture approach the area assigned to each grating can also be used to adjust system throughput. If the grating diffracts only to one side of the normal then ion beam milling will enhance both spectra to that side of the normal. Figures 14 and 15 show the expected sinusoidal groove efficiency for both IR and VIS optimized first order designs.

GRATING SPECIFICATION: 490.112A&B

	490.102A	490.102B
Groove Frequency	3[illegible]7	260 gr/mm
Diffraction Order	-1	-1
Radius of Curvature	152.4mm	152.4 mm
Blank Diameter	85.0mm	85.0mm
Entrance Slit Distance	152.2 mm	152.2 mm
Angle of Incidence	5.7 deg	5.7 deg
Focal Positions	Figure 12	Figure 13
Groove Depth	4500 Ang	1400 Ang

FIGURE 12

```
GRATING FILE DESCRIPTION-----------------B# 490.102A

WAVELENGTH (nm)      DIFF ANGLE BETA (deg)     FOCAL LENGTH LB(mm)
   1000.00                 -7.52                   152.01
   1050.00                 -7.62                   152.05
   1100.00                 -7.71                   152.10
   1150.00                 -7.80                   152.14
   1200.00                 -7.89                   152.18
   1250.00                 -7.99                   152.22
   1300.00                 -8.08                   152.26
   1350.00                 -8.17                   152.30
   1400.00                 -8.26                   152.34
   1450.00                 -8.35                   152.38
   1500.00                 -8.45                   152.42
   1550.00                 -8.54                   152.46
   1600.00                 -8.63                   152.50
   1650.00                 -8.72                   152.54
   1700.00                 -8.81                   152.58
   1750.00                 -8.90                   152.61
   1800.00                 -9.00                   152.65
   1850.00                 -9.09                   152.69
   1900.00                 -9.18                   152.72
   1950.00                 -9.27                   152.76
   2000.00                 -9.36                   152.80
   2050.00                 -9.46                   152.83
   2100.00                 -9.55                   152.87
   2150.00                 -9.64                   152.90
   2200.00                 -9.73                   152.94
   2250.00                 -9.83                   152.97
   2300.00                 -9.92                   153.01
   2350.00                -10.01                   153.04
   2400.00                -10.10                   153.08
   2450.00                -10.19                   153.11
   2500.00                -10.27                   153.14

 LENGTH OF SPECTRA             7.420194
 LAMBDA1=       1000          LAMPDA2=        2499.999


  1          GRATING FILE DESCRIPTION----------------B# 490.102A
  2          GROOVE FREQUENCY (gr/mm)----------------N  31.7
  3          DIFFRACTION ORDER-----------------------m  -1
  4          RADIUS OF CURVATURE(mm)----------------R   152.4
  5          ENTRANCE SLIT DISTANCE (mm)-----------La   152.2
  6          ANGLE OF INCIDENCE (deg)-----------Alpha   5.7
```

```
GRATING FILE DESCRIPTION---------------B# 490.102B

WAVELENGTH (nm)      DIFF ANGLE BETA (deg)      FOCAL LENGTH LB(mm)
   350.00                 -10.97                   156.09
   375.00                 -11.35                   156.41
   400.00                 -11.73                   156.74
   425.00                 -12.11                   157.06
   450.00                 -12.49                   157.38
   475.00                 -12.87                   157.70
   500.00                 -13.26                   158.02
   525.00                 -13.64                   158.33
   550.00                 -14.03                   158.64
   575.00                 -14.41                   158.95
   600.00                 -14.79                   159.25
   625.00                 -15.18                   159.55
   650.00                 -15.56                   159.85
   675.00                 -15.95                   160.15
   700.00                 -16.34                   160.44
   725.00                 -16.73                   160.73
   750.00                 -17.12                   161.02
   775.00                 -17.51                   161.31
   800.00                 -17.90                   161.59
   825.00                 -18.29                   161.87
   850.00                 -18.69                   162.15
   875.00                 -19.08                   162.43
   900.00                 -19.47                   162.70
   925.00                 -19.87                   162.97
   950.00                 -20.26                   163.25
   975.00                 -20.66                   163.51
  1000.00                 -21.06                   163.78
  1025.00                 -21.46                   164.05
  1050.00                 -21.86                   164.31

 LENGTH OF SPECTRA              31.48027
 LAMBDA1=        350        LAMBDA2=        1050

                 GRATING FILE DESCRIPTION---------------B# 490.102B
                 GROOVE FREQUENCY (gr/mm)---------------N  240
 3               DIFFRACTION ORDER----------------------m  -1
 4               RADIUS OF CURVATURE(mm)----------------R  152.4
 5               ENTRANCE SLIT DISTANCE (mm)-----------La  152.2
 6               ANGLE OF INCIDENCE (deg)-----------Alpha  5.7
```

FIGURE 14

```
GRATING DESCRIPTION---       490.102
WAVELENGTH (nm)           SCALAR Efficiency (%)
     1000.00                      16.04
     1050.00                      19.70
     1100.00                      22.94
     1150.00                      25.71
     1200.00                      28.01
     1250.00                      29.86
     1300.00                      31.29
     1350.00                      32.36
     1400.00                      33.11
     1450.00                      33.58
     1500.00                      33.81
     1550.00                      33.85
     1600.00                      33.73
     1650.00                      33.47
     1700.00                      33.10
     1750.00                      32.65
     1800.00                      32.13
     1850.00                      31.56
     1900.00                      30.94
     [illegible].00                  30.30
     [illegible].00                  29.63
     2050.00                      28.96
     2100.00                      28.28
     2150.00                      27.59
     2200.00                      26.91
     2250.00                      26.23
     2300.00                      25.57
     2350.00                      24.91
     2400.00                      24.27
     2450.00                      23.63
     2500.00                      23.02

1            GRATING DESCRIPTION---------------B#        490.102
             START WAVELENGTH (nm)------------L1         1000
             END WAVELENGTH (nm)------------- L2         2500
             WAVELENGTH STEP(Delta lambda)- -- L3        50
5            ORDER-----------------------------m         1
6            GROOVE DEPTH,  ANGSTROMS--------- h         4500
```

FIGURE 15

```
GRATING DESCRIPTION---        490.102B
WAVELENGTH (nm)          SCALAR Efficiency (%)
     350.00                     24.38
     375.00                     28.23
     400.00                     30.92
     425.00                     32.63
     450.00                     33.55
     475.00                     33.85
     500.00                     33.70
     525.00                     33.20
     550.00                     32.47
     575.00                     31.58
     600.00                     30.58
     625.00                     29.51
     650.00                     28.42
     675.00                     27.32
     700.00                     26.23
     725.00                     25.17
     750.00                     24.13
     775.00                     23.13
     800.00                     22.16
     825.00                     21.24
     850.00                     20.36
     875.00                     19.52
     900.00                     18.72
     925.00                     17.95
     950.00                     17.23
     975.00                     16.54
        .00                     15.89
       5.00                     15.27
    1050.00                     14.68

  1          GRATING DESCRIPTION--------------B$         490.102B
  2          START WAVELENGTH (nm)-----------L1          350
  3          END WAVELENGTH (nm)------------- L2         1051
  4          WAVELENGTH STEP(Delta lambda)- -- L3        25
  5          ORDER------------------------------m        1
  6          GROOVE DEPTH,  ANGSTROMS--------- h         1400
```

Appendix A.

PRELIMINARY

EG&G RETICON

RA1200J
Full Frame CCD Imager

General Description

The RA1200J is a full frame CCD sensor designed specifically for use in astronomy, spectroscopy and related scientific imaging applications. Its combination of very low noise and low dark current make it ideal for low light level, high dynamic range and high resolution applications.

The imager is structured in a serial parallel serial configuration. The charge packets (imaging data) in the vertical (parallel) registers can be shifted either up or down (not simultaneously) to two identical horizontal (serial) shift registers. One is at the top and another is at the bottom of the array. Four phase clocks are needed to drive both vertical and horizontal shift registers.

The array is available in a 48 pin ceramic package as shown in Figure 1. Package dimensions are shown in Figure 7. It is available with a quartz window or unwindowed. The device is indifferent to its orientation in a circuit due to the symmetry of the pinout (see Table I for complete pinout description).

Features

- 480,000 picture elements (pixels) in a 400 x 1200 configuration
- 27 µm square pixels
- Buried channel process
- On chip output amplifier for low noise and high speed readout
- High dynamic range: over 103 dB at -110 C (183 K)
- Serial parallel serial configuration for selectable bidirectional readout
- Usable spectral response from 450 nm to 1050 nm (greater than 5% of peak responsivity)

MPP Operation

A major source of dark current in devices such as this originates in surface states at the Si SiO interface. A unique design and process enables the RA1200J to be run in the Multi Pinned Phase* or MPP mode of operation. This helps eliminate dark current generation in the interface surface states. By holding the vertical clocks at negative potential during integration and horizontal signal readout, the surface of the sensing area is inverted. As a result, the surface will not be depleted and surface states will not generate dark current. Dark current densities of less than 0.1 na/cm have been achieved using the MPP mode of operation, resulting in integration times of more than 30 seconds at room temperature.

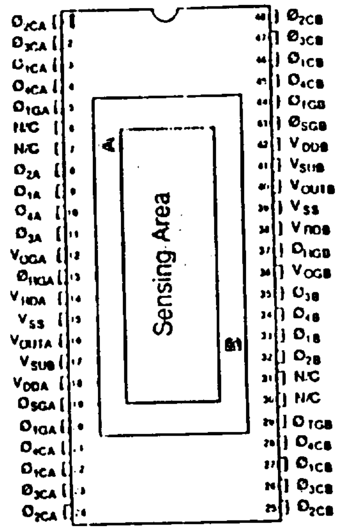


Figure 1. Pinout Configuration

Functional Description

Imaging Area

The imaging area is an array of 1200 columns (vertical CCD shift registers) which are isolated from each other by 5 µm channel stop regions. Each column has 400 picture elements. The pixel size is 27 µm x 27 µm. The imaging area is divided into two sections of 200 x 1200 pixels. Each section can be operated independently with its own four phase vertical clock. If both sections share the same clocks, the device operates as a full frame 400 x 1200 imager. Typical spectral response as a function of wavelength is shown in Figure 2.

In the vertical direction, each pixel corresponds to one stage (four electrodes) of the shift register. The four electrode groups are driven by four phase clocks brought in from both edges of the array for improving response time.

Charge packets (imaging data) in the vertical registers can be shifted either up or down to the top or bottom horizontal registers by interchanging two of the four phases (ø and ø). See Figure 3 for functional diagram.

Table II. Recommended Operating Conditions

Definition		Symbol	Normal Mode Low	Normal Mode Typ	Normal Mode High	MPP Mode Low	MPP Mode Typ	MPP Mode High	Units
DC Supply		V[illegible]	20	20.5	22	20	21.5	22	V DC
Output Gate Bias		V[illegible]	5	6	6	1	2	5	V DC
Reset Drain Bias		V[illegible]	12	13	14	12	13	14	V DC
Substrate Bias		V[illegible] V[illegible]	0	-0.3	-5.0	0	[illegible]	-5.0	V DC
Serial Clocks	High	[illegible]		12			9		V
	Low			[illegible]			[illegible]		V
Vertical Clocks	High	[illegible]		12			2		V
	Low			[illegible]			-8		V
	High	[illegible]		12			2		
	Low			[illegible]			-7		
Transfer Gate Clock	High	[illegible]		[illegible]			[illegible]		V
	Low			[illegible]			-5		
Reset Gate Clock	High	[illegible]		12			[illegible]		
	Low			[illegible]		[illegible]	[illegible]		
Summing Gate Clock	High	[illegible]		12			5		
	Low			[illegible]			[illegible]		

Table III. Typical Device Specifications

Die size	35.67 mm x 17.39 mm
Pixel size	27 μm x 27 μm
Imaging area	32.4 mm x 10.9 mm
Dark current at 25°C	2-10 nA/cm² 0.1 nA/cm² MPP mode
Charge transfer efficiency (CTE)	.99999
Readout noise (-110°C)	4e
Full well (pixel) signal	600 Ke
Sensitivity	75 microvolts/e
Dynamic range (-110°C)	100 dB

Typical IV. Typical Capacitance Values

Parameter	Symbol	[illegible]	[illegible]	
Parallel clocks	[illegible]	[illegible]	[illegible]	pF
	[illegible]	1, 24, 25, 46	660	pF
	[illegible]	2, 23, 26, 47	1310	pF
	[illegible]	4, 21, 28, 45	700	pF
Serial clocks	[illegible]	9, 33	185	pF
	[illegible]	8, 32	130	pF
	[illegible]	11, 35	275	pF
	[illegible]	10, 34	200	pF
Transfer clock	[illegible]	5, 20, 29, 44	125	pF
Video output	V[illegible]	16, 40	10	pF

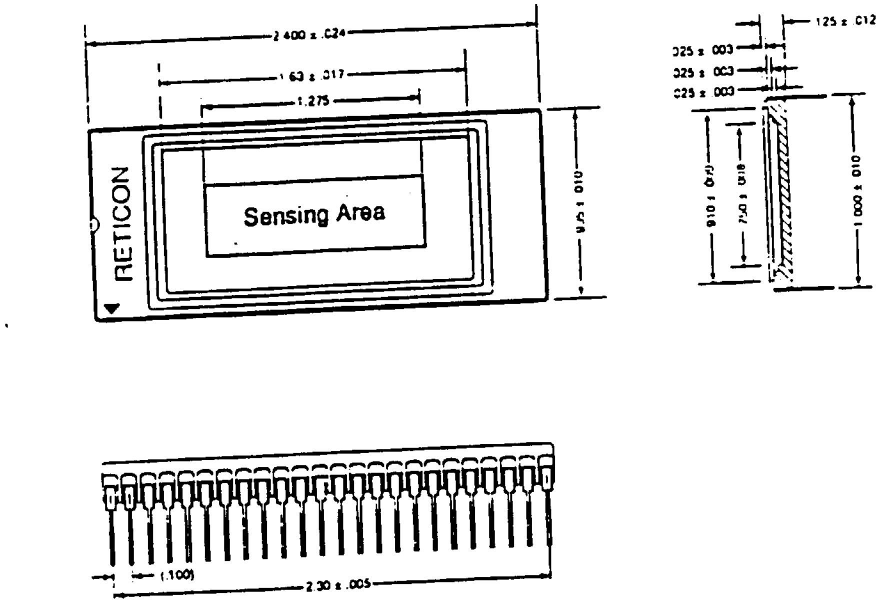
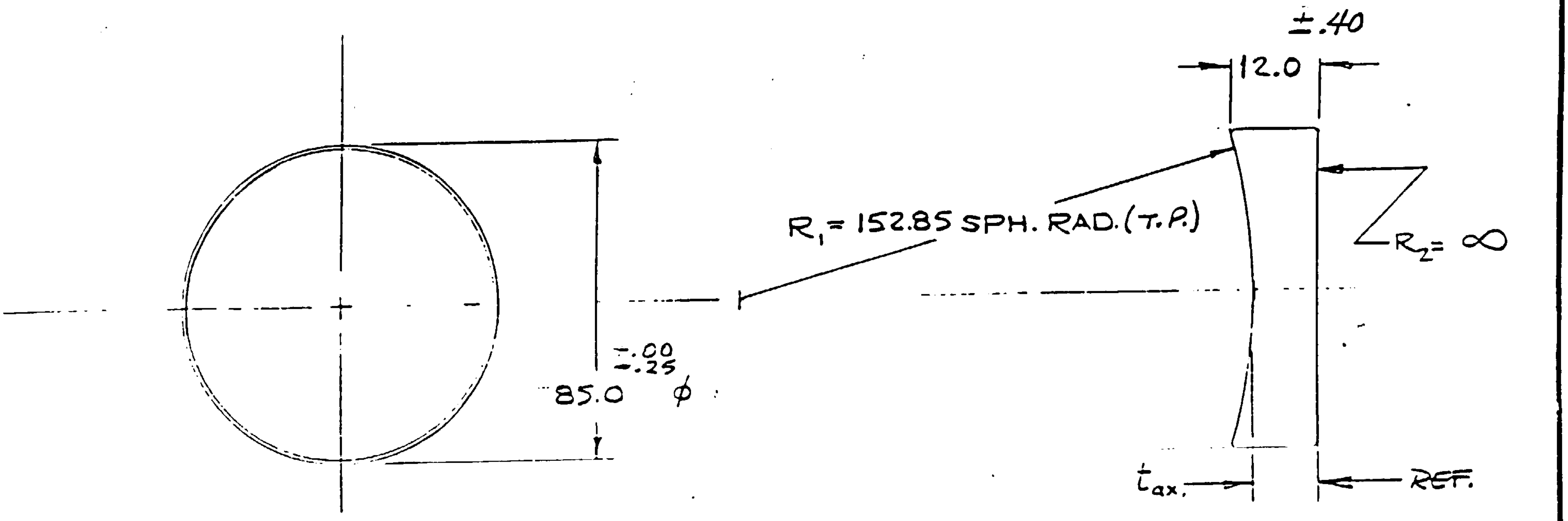


Figure 7. Package Dimensions

Appendix D.

FIGURE 8



1. ALL DIM IN *MM.*
2. TEST PLATE FIT: *10* FR.@*546.1*nm.
3. REGULARITY: *5* FR.@*546.1*nm.
4. SURFACE FINISH:
   a. CONCAVE SURF. (R_1): POL. TO *60/40* SCR./DIG
   b. BACKSIDE (R_2): *COMM'L. POL.*
   c. RIM: *FINE GND.*
5. PROT. CHAMF. EDGES 45° x *0.50* F.W. MAX.
6. CA= *80.0*
7. CONCAVE SURF. (R_1) MUST BE FREE OF BROKEN BUBBLES. WITHIN BLANK, BUBBLES, SEEDS, & INCLUSIONS SHALL NOT EXCEED — IN NUMBER & NONE SHALL EXCEED — IN DIAM.

447.01
450.02
USED ON

AMERICAN HOLOGRAPHIC

SCALE: N.T.S.
DATE: [illegible]
DRAWN BY
REV.

BLANK, CONCAVE GRATING, 85ϕ

MAT'L: *FINE ANNEALED PYREX*

DRAWING NUMBER
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This final report summarizes the design effort for the construction of a visible-infrared imaging spectrometer for planetary missions, funded by NASA under the Planetary Instrument Definition and Development Program. The goal was to design and develop a prototype brassboard pushbroom imaging spectrometer covering the 0.35 µm to 2.5 µm spectral region using a simplified optical layout that would minimize the size, mass and parts count of the instrument by using a single holographic grating to disperse and focus light from a single slit onto both the infrared and visible focal plane arrays. Design approaches are presented and analyzed, along with problems encountered and recommended solutions to those problems. In particluar, a new type of grating, incorporating two sets of rulings and a filter in a layered structure, is presented for further development.

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