NASA-CR-195254

First Year Report

Planetary Instrument Definition & Development Program (PIDDP)

Instrument for Future Planetary Flight Missions

A Visible-Infrared Imaging Spectrometer for Planetary Missions

Thomas B. McCord, Ph.D.
Principal Investigator

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(NASA-CR-195254) PLANETARY INSTRUMENT DEFINITION AND DEVELOPMENT PROGRAM (PIDDP). INSTRUMENT FOR FUTURE PLANETARY FLIGHT MISSIONS: A VISIBLE-INFRARED IMAGING SPECTROMETER FOR PLANETARY MISSIONS Final Report (SETS Technology) 13 p

Prepared by:

SETS Technology, Inc.
300 Kahelu Avenue, Suite 10
Mililani, HI, USA 96789

Reviewed by:

Principal Investigator: ____________

Operations Manager: Bruce D. ____________

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1.0 SUMMARY

The objective of this project is to develop and prove a small, light-weight, efficient imaging spectrometer design to cover the VIS/NIR spectral range for applications particularly but not exclusively to NASA inner solar system space missions. A design and a brassboard prototype will be developed and tested. Progress over the first year of this project includes design specification, optical design layout, grating specifications, infrared detector selection, and mechanical design. Mechanical and grating manufacturing drawings were begun. We developed an agreement in principle to cooperate with the German space group, DLR, to apply some of their electronics microminiaturization technology to this imaging spectrometer project, mostly or entirely at their expense. Funds from NASA for the second year of this effort have been received and the effort is on track. Release of funds for the third year of this award will be requested later this year in order to accelerate this work and bring it to a conclusion in time for new NASA missions considerations as well as to make effective use of the DLR contributions.

2.0 INTRODUCTION AND RELEVANCE

The objective of this project is to develop and prove a small, light-weight, efficient imaging spectrometer design to cover the VIS/NIR spectral range for applications to NASA space missions. A design and a brassboard prototype will be developed and tested.

The innovation focus is on the use of aberration-corrected holographic optics and the reduction of mass, size and cost. Other technical innovations involve the use of two-dimensional detectors, figured linear step filters, miniaturization, microelectronics, and automation. SETS has been working for about six years with this technology under other NASA and DoD projects and is driving the technology, particularly of holographic optics. In this project, SETS is concentrating to produce the most compact imaging spectrophotometer for covering a large spectral range. Recent NASA policy has clearly expressed a need for light-weight, simple instruments. This need is directly addressed by this PIDDP project, which was proposed and accepted before the recent NASA policy announcements.

The SETS approach, with aberration-corrected holographic optics, permits the use of only one optical element for the entire spectrometer. Normally, collimator, grating and camera optical elements are required, but the SETS approach is to perform all of these functions with just one element. Holography and etching produce a complex figure on a reflective surface which directs the rays of light to achieve the focusing and dispersion of the optical beam. This produces a spectrum for each of a line of pixels at a flat focal plane to be received by one or several two-dimensional detector arrays. Further, the simple, compact holographic grating optics are well suited to miniaturized instrument design.

This project effort has been directed primarily at serving the inner solar system missions, including Mercury, Venus, the Moon, Mars and the asteroids. The spectral range to be covered is 0.35 μm to 2.5 μm, where reflected sunlight is most important and where most materials composing the surfaces of these objects have significant absorption bands producing diagnostic spectral signatures and allowing identification and mapping of material units. This spectral range is also appropriate for outer solar system missions for focused science objectives and when cooling and other demands on the spacecraft and system need to be reduced. Alternatively, for outer solar system applications, where thermal emission is subdued and molecular absorption/emissions are more important, a third subsystem can be added to this instrument to cover the 2.5 to 5 μm spectral octave.

Our design meets a major specification for imaging spectrometry, that all spectral channels be measured simultaneously for each pixel or group of pixels. This means that some sort of spectrally dispersive device must be used. If a framing-type camera is used, the images for each spectral band must be spatially co-registered by spatial resampling to produce spectra for each pixel. This treatment inevitably reduces the spatial resolution and smears the spectral information differently at different spectral channels.

3.0 SUMMARY OF PROGRESS TO DATE

Tasks completed during the first year of this contract include:

- Review of project goals and objectives.
- Review of overall design approaches.
- Review of design specifications.
- Review of the design and performance of the existing SETS 1–2.5 μm prototype instrument at the telescope.
- Perform a detailed survey of available IR array detectors.
- Select the NICMOS3 HgCdTe 256 X 256 array as the baseline detector.
- Complete the science review of the specifications
- Finalize the system specifications
- Complete a baseline design of the electronics to control VIS/VNIR arrays.
- Obtain detailed specifications and operational information from Rockwell on the selected NICMOS3 detector already chosen for the NIR spectral range.
- Develop a preliminary optical design and layout of the optics and dewar optical bench.
- Develop a preliminary grating design with the manufacturer.
- Survey available guider camers and selected the baseline camera.
- Develop an agreement in principle to cooperate with the German Space Group DLR in applying some of their electronics microminiturization technolgoy to this imaging spectrometer project and at their expense.

Tasks begun but not completed during the first year of this contract include:

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

Work has progressed rapidly since early January 1993. The start of work was controlled by unexpected delays in receiving a contract and the resulting need to reschedule personnel onto other projects until the contract was put in place in October, 1992. Because the timing of the receipt of contract was uncertain up to the time it was received, it required several months to get personnel back from other projects to which they were assigned when the contract was not received as originally planned. However, we have completed the first-year effort on schedule and we see no problems in completing our second-year effort by September 1994.

In fact, the work could progress faster, but the incremental funding for each year is below that needed to keep work flowing continuously. We plan to request that funding for the third year of this project be provided by June 1994. This would allow an operating brassboard instrument to be available to qualify the design approach for evaluation for space mission applications and in time for new NASA missions.

4.0 DESCRIPTION OF PROGRESS TO DATE

4.1. Instrument Specification

In order to achieve the scientific goals, the design challenges of a visible-infrared imaging spectrometer for a deep space mission are:

- Simultaneity 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 the data in several modes using automated control
- Mechanical stability

The scientific advisory board, which we selected to assist in defining the science requirements, was used to clarify the criteria to which this instrument is being tailored. Working from the preliminary specification presented in the proposal, the specification has evolved to a point where detailed design can proceed. Rapidly changing detector technology is a primary driver of this specification, and the detector chosen for the NIR is the Rockwell HgCdTe NICMOS3 256 X 256 detector. A survey of VIS/VNIR detectors is currently under way. *Figure 1* shows the current system parameters for the spectrometer.

Spectral Range	0.35 - 2.5 μm
Range 1	0.35 - 1.05 μm
Range 2	0.95 - 2.5 μm
Spectral Resolution	1%
Range 1	5.5 nm/pixel
Range 2	12.1 nm/pixel
Number of Spectral Channels	256
Signal / Noise Ratio	> 300:1
IFOV	0.5 mrad
Number of Spatial Channels	64 (without scanning)
Platform	Spacecraft
Cooling Scheme	Passive (LN2)
Estimated Volume	14,400cm3 (30x30x16cm)
Estimated Mass	18kg

SUBSYSTEM SPECIFICATION

Foreoptics	
Type	All reflective Cassegrain
Aperture	5 cm
Focal Length	f 10
Focal Ratio	TBD
Spectrometer	
Slit Size	40 μm x 7.68 mm
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/8 or lower

Final Focusing Focal Ratio	f/8 or lower	
Detector		
Material	Range 1	Si CCD UV enhanced
	Range 2	HgCdTe
Array Dimensions	Range 1	TBD
	Range 2	256 x 256
Pixel Size	Range 1	TBD
	Range 2	40 μm HgCdTe
Quantum Efficiency	Range 1	TBD
	Range 2	>50% 1 - 2.5 μm
Operating Temperature	Range 1	TBD
	Range 2	77 K
Read Noise	Range 1	TBD
	Range 2	400 e-
Bias\DarkCurrent\Full Well	Range 1	TBD
	Range 2	\5 e-/sec @77K\ 2E7 - 4E7 e-

Figure 1. *SYSTEM PARAMETERS*

4.2 Selection of NIR detector

We performed a survey of available IR detectors suitable for this type of application while keeping in mind the practical use of this brassboard instrument in real groundbased telescope applications to demonstrate its operational effectiveness. The Rockwell NICMOS3 256 x 256 HgCdTe detector has been selected for the 0.95–2.5μm or SWIR spectral range. The results of our detector survey show the advantages of this array for low light level (and long integration applications, which are not necessarily important for space applications). Its low readout noise and insensitivity beyond 2.5 μm to thermal background radiation made it especially attractive. Since purchasing of the detector is not required until later in the project, we will review the available detector options at that time, building on the results of this survey. The results of the survey are included in *Figure 2*.

	Rockwell NICMOS3	SBFP InSb	SBRC InSb
Array Size	256 x 256	320 x 240/256 x 256	256 x 256
IR Sensor	PV, HgCdTe, PACE-1	PV, InSb	PV, InSb
Pixel Pitch	40μmx40μm	31μmx31μm	30μmx30μm
Fill Factor	90%	90%	90%
Operative Pixels	>98%	>99	>99%
Read Noise	40 e-	500 e-	70 e- @ 2Hz frame rate
Operating Temperature	60 - 77K	40 - 77K	40 - 77K
Dark Current	5 e-/sec @ 77K~1 e-/sec @ 60K	2000 e-/sec@40K ~250 e-/sec @ 40-50K	250 e-/sec @ 40-50K
Full Well	0.2 - 0.4 Me-	20 Me-	0.3 - 0.5 Me-
BLIP Dynamic Range*	125 - 250	80	60 - 100
Maximum Frame Rate	10 frames/sec	240 frames/sec	62.5 frames/sec

Non-Destructive Readout	No	No	Optional
Integration Mode	Rolling	Snapshot/Rolling	Rolling
Active Region	0.8 - 2.5 µm	0.7 - 5.3 µm	0.7 - 5.3 µm
	CdTe substrate limited	Passivity Required	Passivity Required
Quantum Efficiency	>50% 1-2.5 µm	>85% at 2.4 µm	>80% 1-5 µm
		>70% at 0.7 µm	>70% at 0.7 µm
Main Disadvantage	"LED" Effect	High Dark Current	High Dark Current
	Short Wave Cutoff	High Read Noise	Rolling Integration

Figure 2. *SWIR DETECTOR COMPARISON*

4.3 Optical and Grating Design

The grating to be used in this technological approach is an abberation-corrected holographic grating (ACHG). This device provides the function of the classical collimator, grating and camera optics all in one optical surface. The ACHG images the entrance slit and disperses the light into two spectral regions, VIS/VNIR and SWIR, because two different detector technologies must be used. Thus, the ACHG makes up most of the optical design. The resultant focal planes contain spatial information in one direction and spectral information in the orthognical direction. The ACHG is designed with two different holographic exposures, designed using software models, placed on a single substrate to specify the complex optical surface needed to perform all the focusing and dispersing functions. The surface is etched to match the hologram. The two sets of overlapping grooves cause the grating to act as two separate gratings. This provides the most efficient use of the input beam possible.

A preliminary grating design was developed early in this effort, to be used to control the early spectrometer design. It provides for the most efficient 1:1 magnification and minimizes stray light. This grating is undergoing slight redesign to accommodate the larger image size of the selected NIR NICMOS3 256 x 256 array detector from 7.5 mm square to 10.4 mm square. A target array size of 11.5 mm square is being used in the survey of the VNIR detector. The manufacturer has started to develop the final model to be used to create the grating.

In the grating and optical layout design, the VNIR spectra can be separated from the SWIR spectra so that the two detectors do not need to be butted together. The detectors are placed out of the grating normal to prevent re-imaging of scattered light by the grating, a problem in earlier designs. *Figure 3* shows the focal planes viewed from the center of the grating. *Figure 4* summarizes the grating design.

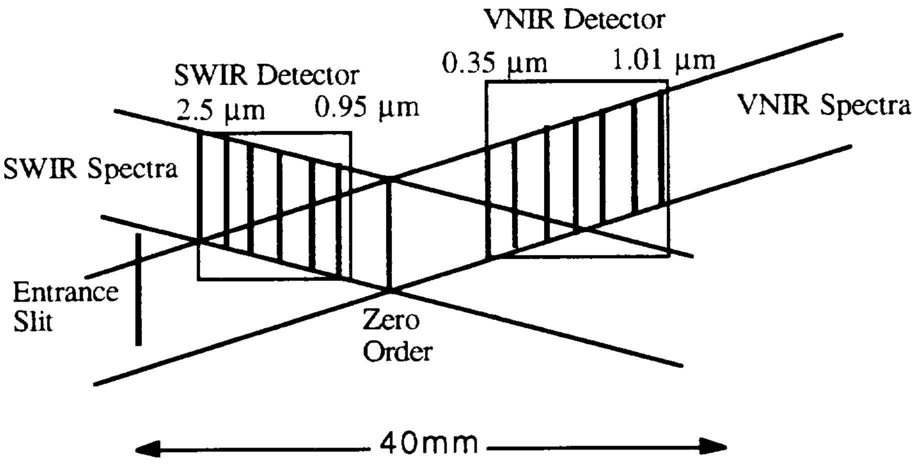


Figure 3. *GRATING SPECIFICATION*
Focal Plane Layout Viewed from Center of Grating

PARAMETERS	VNIR GRATING	SWIR GRATING
Wavelength Region	0.35-1.01 µm	0.95-2.5 µm
Length of Spectra	11.577	7.43
Groove Frequency (1/mm)	114	32.5
Order	-1	1
Radius of Curvature (mm)	152.4	152.4
Entrance Slit Distance (mm)	152.1	152.1
Angle of Incidence	3.25°	3.25°
Pinhole (source) 1		
Gamma	-43.4234	21.858°
Lc (mm)	354.538	1099.61
Pinhole (source) 2		
Delta	-39.4334	22.78006°
Ld (mm)	325.42	1143.712
Source Wavelength (mm)	457.93	457.93

Figure 4.*GRATING DESIGN SPECIFICATIONS*

4.4 VNIR Detector

With the current grating design, the VNIR detector needs to be on the order of 1.1 cm square and be sensitive across the 0.35 μm–1.1 μm range. The devices currently under consideration are listed in *Figure 5.*

CANDIDATE	PROPERTIES
Texas Instruments TC125	
Ford Aerospace (Loral) FA1024	
Tektronics TK1024	
JPL (Loral) Craf-Cassini CCD	control circuit developed by SETS providing readout of 10 Mpixels/sec. Circuit can be transferred into ASIC design

Figure 5. *VNIR SURVEY*

SETS has experience with the Ford Aerospace CRAF-Cassini detector. Also as part of our collaboration with the German organization, DLR Oberfaffenhafen has developed at SETS a control circuit which is also capable of controlling the Tektronics and Ford Aerospace device with little change. The CRAF-Cassini detector has been successfully flown in spacecraft and is a well documented device. It is being compared to the other available devices in an effort to obtain a detector optimized for our application. A decision on detector selection will be made within a few months. Since individual detector size will be much smaller than required and pixel binning will be practiced, the exact detector selected will not affect the optical design except for the overall physical size of the detector's active area.

4.5 VNIR Detector Analog Electronics

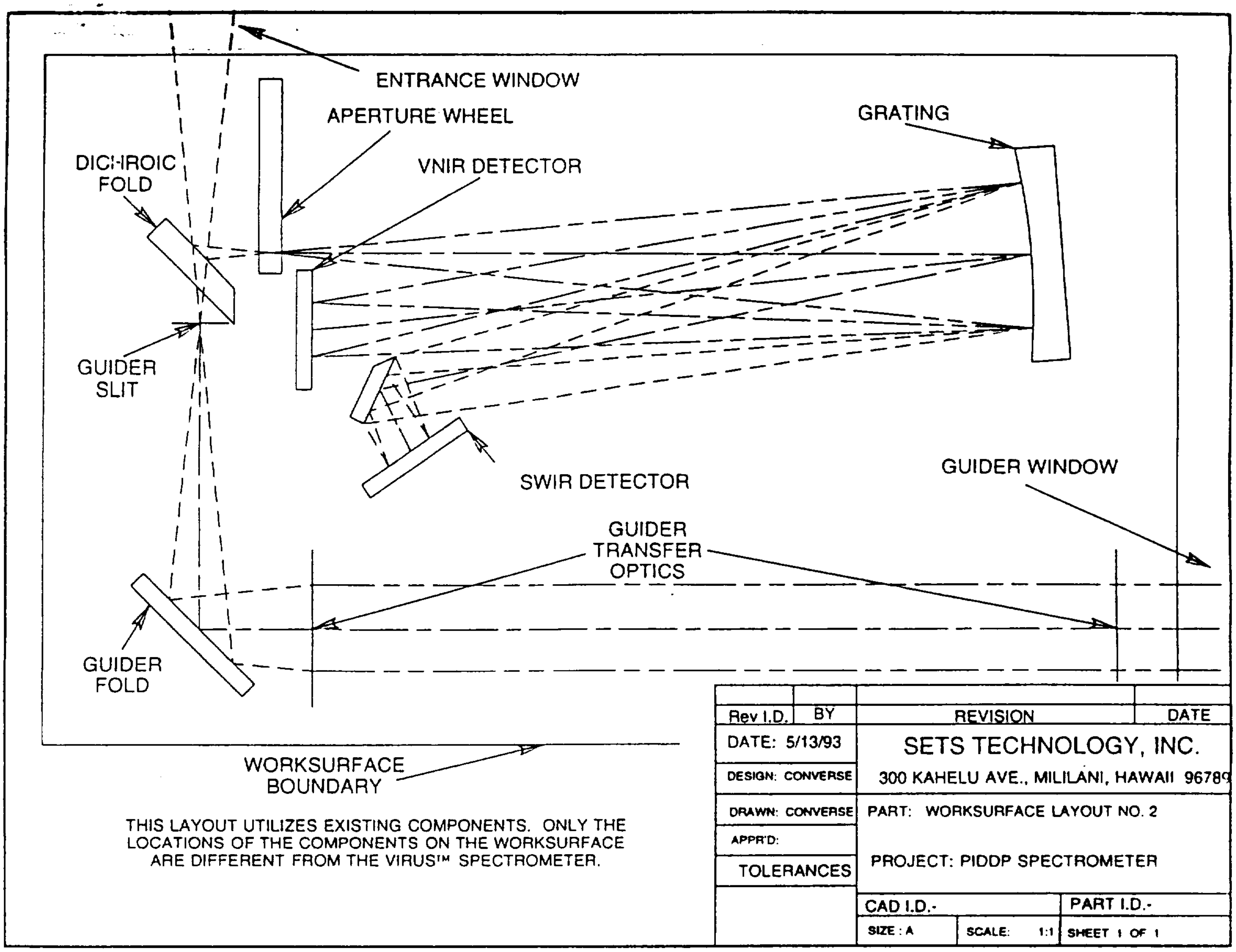
A circuit was designed and implemented on a board to control and read out a SiCCD array detector from several manufacturers. It was tested on the Cassini array and appeared to operate correctly. It is computer controlled using software. More extensive tests are planned when the final detector selection is made and the device is in-house.

4.6 Guider Camera

As a result of a review of available guider cameras, the Texas Instruments MG-780P black & white CCD camera was chosen for the guider portion of the spectrometer. This device has been used successfully in other SETS optical instrumentation projects, including for imaging spectrometers. Since upgraded models may be available when the brassboard is constructed and depending on the schedule of funding, we will review this selection for potential upgrade.

4.7 Dewar and Mechanical Subsystem Design

A benchmark grating design was first prepared and then a preliminary optical path was defined which satisfied the constraints of the design specifications. Challenges exist in providing enough room within the dewar for both the VNIR and SWIR detector packages as they are in close proximity to each other. Different configurations were investigated to minimize the space required to accommodate the optical path, thus minimizing the size and weight of the instrument. The various configurations studied are presented in *Figure 6.* The mechanical package and dewar design for the imaging spectrometer previously build was carefully studied with the new optical design in mind. The result is a mechanical design concept *Figure 7* which is now being implemented into detailed mechanical design and shop drawings. These drawings will then be used to fabricate the mechancial subsystem.



THIS LAYOUT UTILIZES EXISTING COMPONENTS. ONLY THE LOCATIONS OF THE COMPONENTS ON THE WORKSURFACE ARE DIFFERENT FROM THE VIRUS™ SPECTROMETER.

Figure 6. DEWAR LAYOUTS

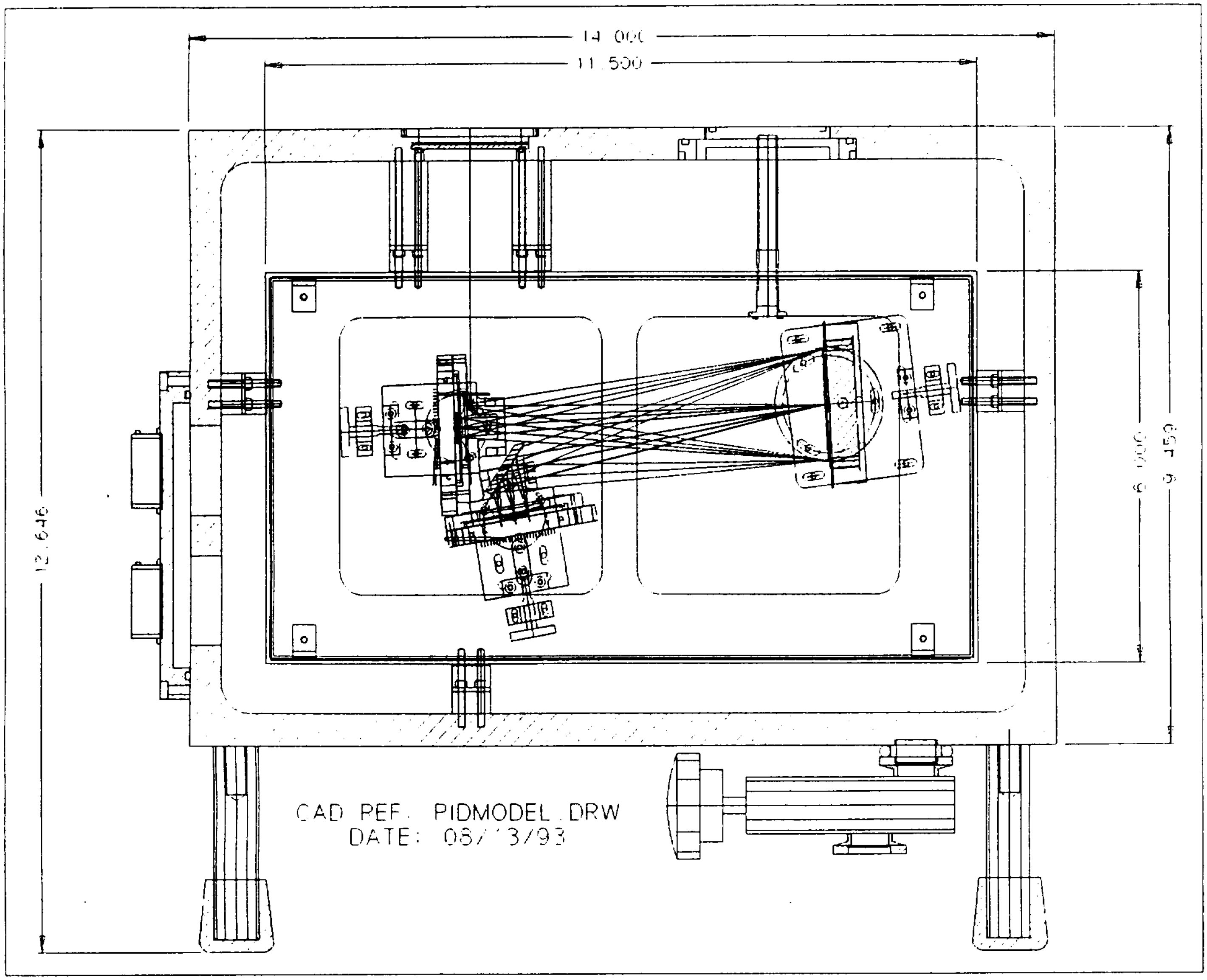


Figure 7. MECHANICAL DESIGN CONCEPT

4.8 Electronics and Teaming with DLR

A teaming arrangment has been explored with DLR, the German national government space organization, Deutsche Forschungsanstalt für Luft und Raumfahrt, under the German space ministry, DARA. Dr. Gerhard Neukum, Acting Director of the Planetary Research Institute at DLR in Berlin-Adlershof has agreed in principle to participate in this effort using German funds. DLR brings unique capabilities and technologies in microminiaturization of electronics and has been developing and applying these to the German High Resolution Stereo Camera (HRSC) and the Wide Angle Observing SubSystem (WAOSS) instrument they are building for the Russian Mars '94/96 missions. Joint efforts of SETS and DLR have revealed strong synergism between the SETS instrument design capability and the DLR microelectronics technologies, particularly ASICs. The approach is to specify the electronics DLR will prototype after SETS defines the interfaces. These prototype electronics will be used to operate the brassboard optical, mechanical, and focal plate subsystems. Already, DLR has assisted in the VNIR detector analog electronics design and prototype board fabrication and test effort. To apply their microelectronics expertise to this PIDDP effort, DLR has agreed to provide an electronic engineer to work at SETS's facility on the electronic package design.

5.0 TASKS FOR YEAR II

Year two will be devoted to completing the detailed design of the brassboard instrument (optically, mechanically and electrically), and fabricating at least the optical and mechanical subsystems. The goal is to have the core optical and mechanical subsystems together and set up in the laboratory by the end of the second year.

- Complete detailed mechanical design and shop drawings
- Complete mechanical fabrication
- Complete electronics design
- Control/acquisition software purchase/development
- Complete spectrometer assembly
- Integrate electronics and software

6.0 ACCELERATION OF THE PROJECT

The work to be accomplished in this project could be performed in a shorter period than the approved three years. Thus, the annual level of funding is the limiting factor in making this design approach available as a credible alternative for upcoming space mission instrumentation. We will request that the third year's funding be provided in the second half of the second year. Otherwise, it will be necessary to cycle personnel on and off the project and make the effort less efficient, as well as denying the space missions access to this technology in as timely a manner as possible. If this request were granted, brassboard testing could begin before the end of the second year.