New Millennium EO-1 Advanced Land Imager

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ABSTRACT

The primary instrument of the first Earth Orbiter satellite (EO-1) under NASA's New Millennium Program will be an Advanced Land Imager (ALI), with multispectral and imaging spectrometer capabilities. The principal motivation for this mission is to flight-validate advanced technologies which are relevant to the next-generation of Earth Science Systems Program Office science needs. The ALI telescope is a reflective triplet design employing silicon carbide mirrors with a 15° cross-track field of view. There are three imaging technologies in the ALI. The first is a multispectral panchromatic array with 10 spectral bands in the visible and near infrared and short wave infrared. The two additional imaging technologies are the Wedge Imaging Spectrometer (WIS) and the Grating Imaging Spectrometer (GIS) that each provides a continuous range of wavelength selections from 0.4 to 2.5 μm. Elements of the WIS and GIS were developed but due to budgetary and schedule constrains, and some performance issues, were not included in the flight assembly. The paper will present details of the ALI design and status.

Keywords: Imaging spectrometer, multispectral imaging

1. INTRODUCTION

The primary instrument of the first Earth Orbiter satellite (EO-1) under the New Millennium Program (NMP) of the National Aeronautics and Space Administration (NASA) is an Advanced Land Imager (ALI), with multispectral and imaging spectrometer capabilities. Overall direction of the EO-1 mission and acquisition of the spacecraft is being carried out by the Goddard Space Flight Center (GSFC) of NASA. MIT Lincoln Laboratory is developing the Advanced Land Imager with NMP instrument team members: Raytheon/Santa Barbara Remote Sensing (SBRS) for the focal plane system, SSG Inc. for the optical system, and Jet Propulsion Laboratory for grating fabrication. This instrument comprises an optical system, a focal plane system, a calibration system, and the structural, thermal, and electrical components required to form an integrated unit. Lincoln Laboratory is responsible for the design, fabrication, test and development of the instrument, the software and databases for calibration, and for on-orbit performance assessment.

NMP is an initiative to demonstrate advanced technologies and designs that show promise for dramatically reducing the cost and/or improving the quality of instruments and spacecraft for future space missions. Under this program, missions are intended primarily to validate such technologies and designs in flight by providing useful science data to the user community. The goal is to make future operational spacecraft "faster, cheaper and better", through incorporation of the technologies validated in the NMP. The Earth Orbiter missions will flight-validate advanced technologies for the next generation Earth Science Systems Program Office science needs.

ALI will produce images directly comparable to those from the Enhanced Thematic Mapper Plus (ETM+) of Landsat 7. ALI will also establish data continuity with previous Landsats and demonstrate advanced capability and innovative approaches to future land imaging. The EO-1 satellite will fly "in formation" with the Landsat 7 satellite in a sun-synchronous, 705 km orbit with a 10:01 am descending node. That is, it will be in an orbit which covers the same ground track as Landsat 7, approximately one minute later than that satellite. The objective is to obtain images of the same ground areas at nearly the same time, so that they may be directly compared. Accordingly, the basic field of view, angular resolution, and spectral bands are matched to those of the ETM+. The EO-1 satellite is co-manifested with Argentina's SAC-C (Scientific Applications Satellite) and is scheduled for launch from the Western Test Range on a Delta 7320 in December 1999. [1]

2. INSTRUMENT DESCRIPTION

The essential features of the instrument are schematically depicted in Figures 1 and 2.

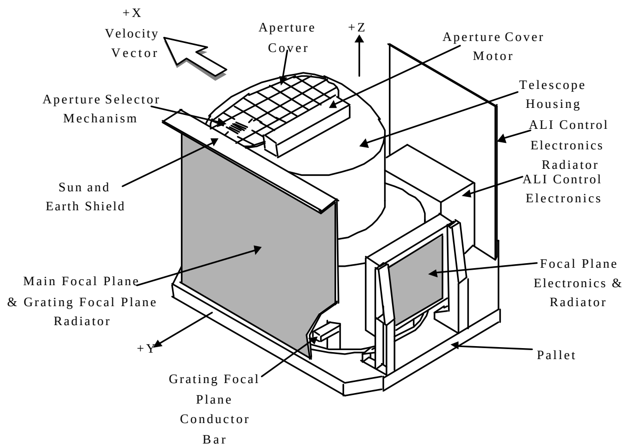


Figure 1. ALI instrument configuration showing the main thermal, mechanical, and electronic components. The instrument pallet will be mounted on the nadir deck of the EO-1 spacecraft.

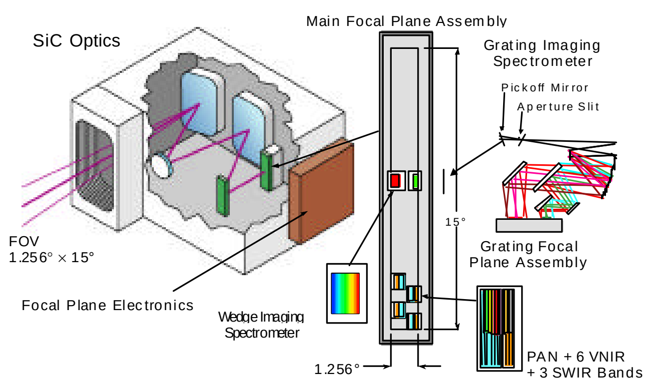


Figure 2. Conceptual layout of the ALI optical system and focal plane detector arrays.

2.1 Wide Field of View (15°) All-Reflective Optical System

The telescope is a reflective triplet design with a 12.5 cm unobscured aperture diameter and a field of view (FOV) of 15° by 1.256°. It employs reflecting optics throughout, to cover the fullest possible spectral range. The design uses four mirrors; the primary is an off-axis asphere, the secondary is an ellipsoid, and the tertiary is a concave sphere; the fourth mirror is a flat folding mirror. Additional optical elements make up the grating imaging spectrometer subsystem. This technology will enable the use of large arrays of detectors at the focal plane, for covering an entire 185 km swath equivalent to Landsat in a "push broom" mode. The optical design features a flat focal plane and telecentric performance, which greatly simplifies the placement of the filter and detector array assemblies.

The design features silicon carbide mirrors and Invar structure with appropriate mounting and attachment fittings. Silicon carbide has many favorable properties for space optical systems. It possesses high stiffness, high thermal conductivity, and low thermal expansion. Although it has been used for space optical elements previously, it has not been used for such large mirrors. Although silicon carbide was initially considered for the optics structure, the EO-1 schedule and cost constraints were not consistent with its use and Invar was used instead. The grating imaging spectrometer was made of aluminum to limit costs and delivery schedule. A photograph of the silicon carbide mirrors held in place by the Invar metering truss is shown in Figure 3.

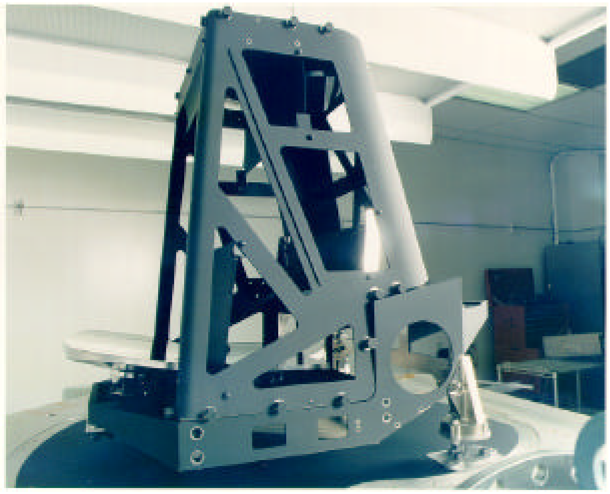


Figure 3. Photograph of the silicon carbide mirrors held in place by the Invar metering truss.

2.2 Multispectral Panchromatic (MS/Pan) Array

Although the optical system supports a 15° wide FOV, only a small fraction was populated with detector arrays, as illustrated in Figure 4. The intent is to provide adequate flight validation of the imaging technologies but within the program cost and schedule constraints. The multispectral panchromatic (MS/Pan) array has 10 spectral bands in the visible, near infrared (VNIR) and short wave infrared (SWIR). The pan detectors subtend 10 m square pixels on the ground and are sampled every 10 m as the earth image moves across the array. The MS detectors subtend 30 m and are sampled every 30 m. Four sensor chip assembles (SCA's) populate a 3° cross-track segment of the focal plane. Each MS band on each SCA contains 320 detectors in the cross-track direction, while the pan band contains 960 detectors. The total cross-track coverage from the MS/Pan module is 37 km.

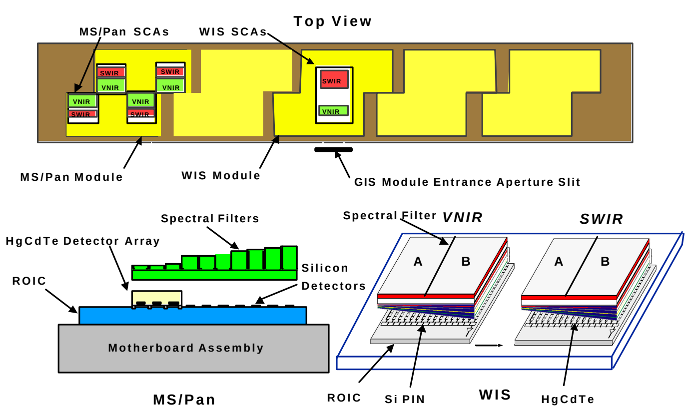


Figure 4. Main focal plane array assembly and illustrations of the NMP imaging technologies.

The MS/Pan arrays use VNIR detectors integrated with the Readout Integrated Circuit (ROIC). The SWIR detectors made of mercury-cadmium-telluride (HgCdTe) promise high performance over the 0.9 to 2.5 μm wavelength region at temperatures which can be reached by passive or thermoelectric cooling. The nominal focal plane temperature is 220°K and is maintained by the use of a radiator. Application of detectors of different materials to a single readout integrated circuit (ROIC) enables a large number of arrays covering a broad spectral range to be placed close together. This technology is extremely effective when combined with the WFOV optical design being used on ALI. This is due to the fact that although this optical design provides a large FOV in the cross-track dimension, the FOV in the in-track dimension is much smaller.

2.3 Imaging Spectrometers

The two additional imaging technologies are the imaging spectrometer arrays. Two wedge imaging spectrometer (WIS) arrays, one for 0.4 to 1.0 μm wavelengths, and one for 0.9 to 2.5 μm, were located near the center of the focal plane, and arranged to view a common ground swath of 0.78°, centered on nadir.. Linear variable wedge filters above the arrays provide a continuous range of wavelength selections. The spectral rows are read out and recorded to provide a complete sampling of the spectrum of each ground pixel in the path of the WIS arrays. The combination of a two-dimensional detector array and a linear-wedge spectral filter is a novel approach to imaging spectrometers (see Figure 4). It offers good relative spectral resolution (of order 100:1) in a light, simple, compact and rugged package.

Grating imaging spectrometer (GIS) arrays with the same wavelength coverage were arranged to view a common ground swath with the WIS. The GIS and main optical layout is shown in Figure 5. The pixel pitches of the imaging spectrometers in the in-track direction are commensurate with those of the MS arrays.

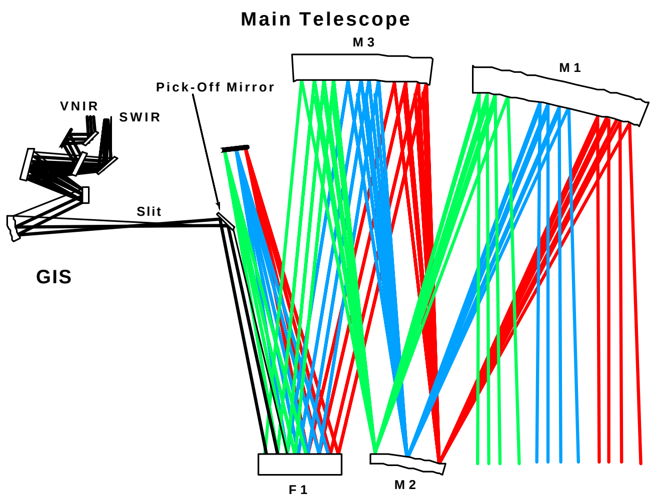


Figure 5. The grating imaging spectrometer (GIS) and main optical system layout

The spectral coverages, spectral sampling, and ground sample distances are summarized in Table 1. Elements of the WIS and GIS were developed but due to budgetary and schedule constraints, and some performance issues, were not included in the flight assembly.

Band	Wavelength (µm)	Spectral Sampling (nm)	Ground Sample Distance (m)
Pan	0.48 – 0.69	—	10
MS-1'	0.433 – 0.453	—	30
MS-1	0.45 – 0.515	—	30
MS-2	0.525 – 0.605	—	30
MS-3	0.63 – 0.69	—	30
MS-4	0.775 – 0.805	—	30
MS-4'	0.845 – 0.89	—	30
MS-5'	1.2 – 1.3	—	30
MS-5	1.55 – 1.75	—	30
MS-7	2.08 – 2.35	—	30
WIS/VNIR-A (40 bands)	0.41 – 0.66	6.3	30
WIS/VNIR-B (62 bands)	0.59 – 1.00	6.6	30
WIS/SWIR-A (112 bands)	0.93 – 1.54	5.4	30
WIS/SWIR-B (95 bands)	1.52 – 2.50	10.3	30
GIS/VNIR (100 bands)	0.4 – 1.0	6.0	30
GIS/SWIR (133 bands)	0.9 – 2.5	12.0	30

Table 1. Summary of the ALI spectral coverage, spectral sampling intervals, and ground sample distances.

2.4 In-Flight Calibration

The Advanced Land Imager will demonstrate an innovative approach toward accurate radiometric calibration on orbit, using precisely controlled amounts of the incident solar irradiance. The goals are to achieve 5% absolute and 2% relative radiometric calibration accuracy. The calibration will be performed by using a carefully controlled variable aperture and a Spectralon diffuser deployed in front of the secondary mirror.

3. MEASURED PERFORMANCE

A photograph of the MS/PAN module comprising four SCA's is shown in Figure 6. The module has been tested in a dewar at 220°K together with the flight Focal Plane Electronics. The average pixel operability of the four SCA's is 99.97% in Pan, 99.99% in MS-VNIR and 99.77% in MS-SWIR. The signal-to-noise ratio (S/N) of each SCA has been calculated in each one of the bands from the measured performance, for 5% earth surface reflectance. The resulting S/N of one of the SCA's is shown in Figure 7 where it is compared to the S/N measured for the ETM+ instrument of Landsat 7.

The measured telescope wavefront error at 0.6328 µm is 0.083λ on axis, with an average value of 0.111 λ over the field of view (twelve points).

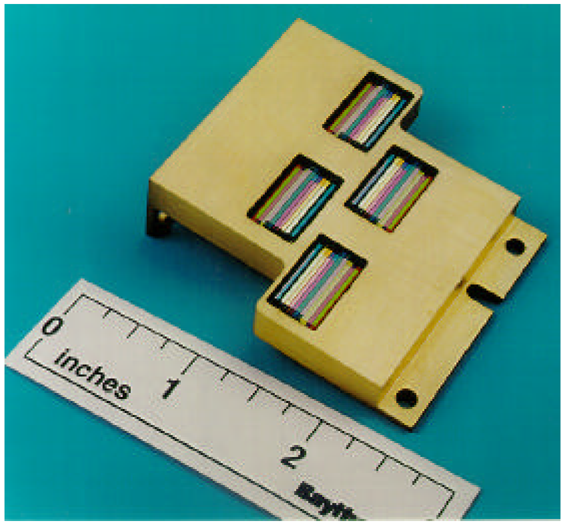


Figure 6. Photograph of the MS/Pan module.

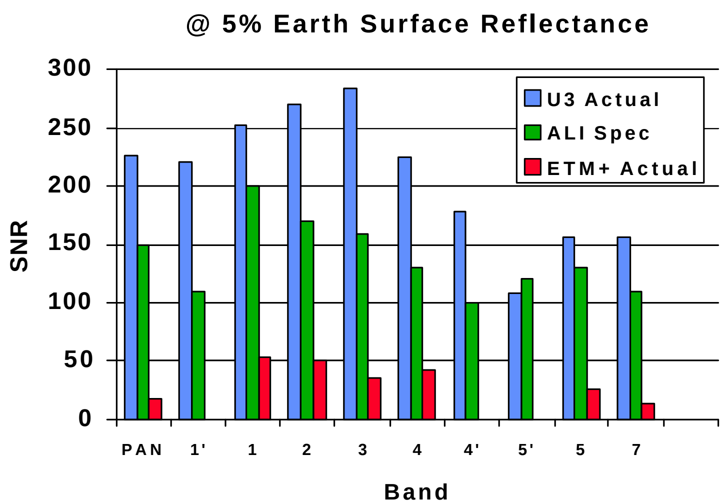


Figure 7. MS/Pan signal to noise ratio at 5% earth reflectance compared with the ETM+.

4. APPLICATIONS TO OTHER MISSIONS

The technologies which will be flight validated on the EO-1 mission are directed towards next generation Earth Science Systems Program Office science needs and in particular the applicability for use in an advanced Landsat instrument. An ALI based concept for a future Landsat instrument is illustrated in Figure 8. Here the advanced instrument employs a fully populated MS/Pan focal plane array. A comparison with the ETM+ of some key parameters is shown. Note that for both sensors the ground swath is 185 km. The ETM+ optical diameter is 41 cm and the 185 km swath is achieved by scanning a turning flat at a 7 Hz rate. The ALI concept uses a 12.5 cm optical diameter and operates in a pushbroom mode (no scan mirror).

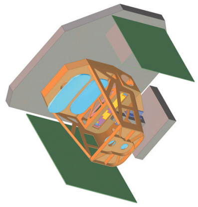
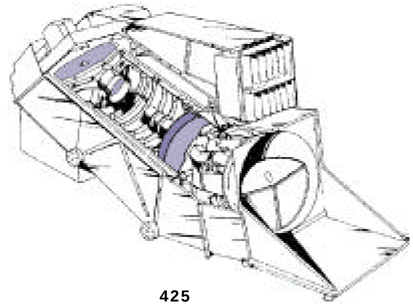
ALI Based Concept for Future Landsat Instrument		Enhanced Thematic Mapper (ETM)
		
100	Mass (kg)	425
100	Power (W)	545
80 × 50 × 50	Size (cm)	196 × 114 × 66
10	VNIR/SWIR Bands	7
6200	Detectors Per Band	16
None	Thermal Bands	1
300	Data Rate (Mbps)	150
10	Pan Resolution (m)	15
4	Relative SNR	1

Figure 8. An ALI based concept for a future Landsat instrument compared with the ETM+.

5. ACKNOWLEDGEMENT

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6. REFERENCES

1. Lencioni, D. E. and Hearn, D. R., “New Millennium EO-1 Advanced Land Imager”, *International Symposium on Spectral Sensing Research*, San Diego, Dec. 13-19, 1997.

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