

EO-1 Advanced Land Imager Overview and Spatial Performance

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Abstract - The Advanced Land Imager (ALI) is the primary instrument flown on the first Earth Observing mission (EO-1), which was developed under NASA's New Millennium Program (NMP). The ALI contains a number of innovative features. These include the basic instrument architecture which employs a push-broom data collection mode, a wide field of view optical design, compact multi-spectral detector arrays, non-cryogenic HgCdTe for the short wave infrared bands, silicon carbide optics, and a multi-level solar calibration technique. The sensor includes detector arrays that operate in ten bands, one panchromatic, six VNIR and three SWIR, spanning the range from 0.433 to 2.35 μm . This paper describes the instrument design, provides an overview of the ground testing and calibration of the instrument and a summary of the sensor performance in space. In particular, the spatial imaging performance of ALI is discussed. Sample images are shown that demonstrate the improved capability of the sensor in terms of Pan band resolution and signal-to-noise ratio in all bands. On-orbit images have been analyzed and the results are compared with pre-launch calibrations. The instrument performance appears to meet all expectations.

I. INTRODUCTION

The first Earth-Observing satellite (EO-1) in the New Millennium Program (NMP) of the National Aeronautics and Space Administration (NASA), launched on November 21, 2000, carries an Advanced Land Imager (ALI) with multispectral imaging capability [1,2]. The NMP missions are structured to accelerate the flight validation of advanced and enabling technologies that will enable dramatic improvements in performance, cost, mass, and schedule of future missions. The focus of EO-1 is the validation of technologies relevant to Landsat missions. The ALI has been designed to produce images directly comparable to those from the Enhanced Thematic Mapper Plus (ETM+) of Landsat 7. The EO-1 satellite is in a sun-synchronous, 705 km orbit with a 10:01 AM descending node. Thus, it flies "in formation" with the Landsat 7 satellite, covering the same ground track approximately one minute later than the Landsat 7 satellite. The wavelength limits and ground sampling distances (GSD) of the ALI sensing bands, listed in Table I, are mostly the same as those of ETM+. The exceptions are

that the ALI has no band 6 (thermal imaging), the panchromatic (Pan) band has a 10 m, rather than 15 m GSD, and the ALI has three additional bands, 1', 4', and 5'.

TABLE I

SPECTRAL BANDS OF THE ADVANCED LAND IMAGER

Band	Wavelength (μm)	GSD (m)
Pan	0.480-0.690	10
MS-1'	0.433-0.530	30
MS-1	0.450-0.515	30
MS-2	0.525-0.605	30
MS-3	0.630-0.690	30
MS-4	0.775-0.805	30
MS-4'	0.845-0.890	30
MS-5'	1.200-1.300	30
MS-5	1.550-1.750	30
MS-7	2.080-2.350	30

II. INSTRUMENT ARCHITECTURE

A conceptual sketch of the ALI illustrating the major design features is shown in Fig. 1. The telescope is a f/7.5 reflective triplet design with a 12.5 cm unobscured entrance pupil and a field-of-view (FOV) of 15° cross-track by 1.26° in-track. It employs reflecting optics throughout, to cover the fullest possible spectral range. At the focal plane, detectors are linearly arrayed in the cross-track direction. As the satellite moves along its track, the image of the ground is recorded in the "push-broom" mode. There are no moving scan mirrors. When not recording an image, a motorized cover closes the entrance aperture of the telescope housing. While the aperture cover is closed, detector dark currents are recorded, and an internal reference lamp assembly illuminates the detectors briefly with one, two, and three lamps to verify consistent operation of the detector system.

III. ADVANCED TECHNOLOGIES

The design of the telescope, with a FOV wide enough to cover the whole 185 km Landsat swath, enables the use of the "push-broom" imaging 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 incorporates silicon carbide mirrors and an Invar truss structure with appropriate mounting and attachment fittings. Silicon carbide possesses a high stiffness to weight ratio, a high thermal conductivity, and a low coefficient of thermal expansion. NMP Instrument

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Technology and Architecture team member SSG, Inc. supplied the telescope.

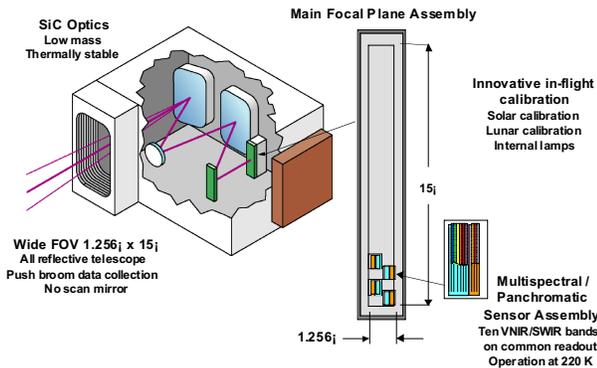


Fig. 1. A conceptual sketch of the ALI telescope and Focal Plane Assembly.

Although the optical system supports a 15° wide FOV, only 3° was populated with four sensor chip assemblies (SCA's) as illustrated in Fig. 2. 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. Each MS band on each SCA contains 320 detectors in the cross-track direction, while each Pan band contains 960 detectors. The ground swaths of the neighboring SCA's overlap by 300 m. The total cross-track coverage from the single MS/Pan module is 37.5 km.

The MS/Pan arrays use Silicon-diode VNIR detectors fabricated in the Silicon substrate of a Readout Integrated Circuit (ROIC). The SWIR detectors are Mercury-Cadmium-Telluride (HgCdTe) photo-diodes that are Indium-bump bonded onto the ROIC that services the VNIR detectors. The nominal focal plane temperature is 220 K and is maintained by the use of a passive radiator and heater controls.

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 closely together. This technology is extremely effective when combined with the wide cross-track FOV optical design being used on the ALI.

Both the array frame rate and the detector integration time can be set by commands to the Focal Plane Electronics (FPE). The nominal integration times are 4.05 msec for the MS detectors and 1.35 msec for the Pan. The frame rate can be adjusted in 312.5 nsec increments to synchronize frame rate with ground scan velocity variations due to altitude and velocity variations during orbit. The FPE samples the output of each detector with a 12-bit converter. Predicted signal-to-noise ratios (SNR's) for the ALI are shown in Fig. 3. NMP Instrument Technology and Architecture team member Raytheon Systems Santa Barbara Remote Sensing (SBRS) supplied the focal plane system.

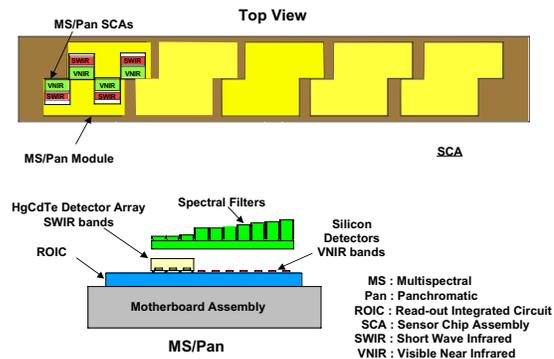


Fig. 2. Focal Plane Assembly.

In addition to extensive pre-flight calibrations [3-6], on-orbit absolute radiometry relies primarily on solar calibration [7]. For solar calibration there is motor-driven aperture selector in the aperture cover assembly. Just prior to solar calibration, a Spectralon diffuser plate is swung over the secondary mirror by a motor-driven mechanism. Then the aperture selector moves an opaque slide over a row of small to increasingly larger slit openings and then reverses the slide motion to block all light. In the process, the FPA receives irradiance equivalent to earth-reflected sunlight for an earth albedo ranging from 0 to 100%.

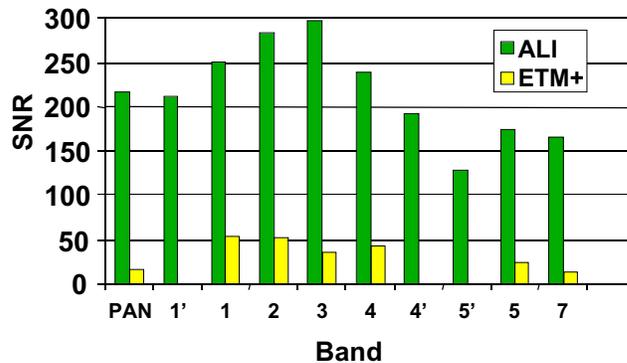


Fig. 3. Signal-to-noise ratios of the ALI bands compared with those of ETM+, for a solar zenith angle of 22.5° and 5% surface reflectance.

IV. PRE-FLIGHT CALIBRATIONS

Extensive calibration tests were performed before the instrument was integrated with the spacecraft [3-6]. Spectral calibrations were done with monochrometers [3]. Radiometric calibration employed a large integrating sphere and a calibrated reference lamp [4]. Spatial calibrations included knife-edge scans for modulation transfer function, and line-of-sight (LOS) calibrations, both performed with an imaging collimator [5]. The LOS calibrations began by recording images of Ronchi rulings oriented at various

angles. A set of parameters to describe optical distortions and SCA positions were then adjusted to match the predicted images to the measured images of the Ronchi rulings [5, 6].

V. IMAGING PERFORMANCE

Initial on-orbit data fulfill expectations for the ALI imaging performance. This is illustrated in Fig. 4, which is a Panchromatic image of Sutton, Alaska, acquired Nov 25, 2000. The solar elevation angle was only 5° . The area shown is 19.5 by 12.8 km.

A Panchromatic image of a 4.5 km square in the center of Washington, D. C. is seen in Fig. 5.

Fig. 6 shows Pan image of a 4.7 by 5.0 km area including the Colorado River and Imperial canal, near Yuma, Arizona. The observed signal-to-noise ratios are consistent with those of Fig. 3.

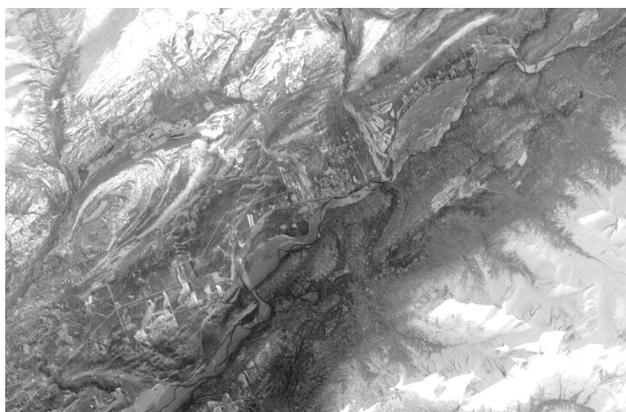


Fig. 4: Panchromatic image of Sutton, Alaska.



Fig. 5: Panchromatic image of Washington, D. C.



Fig. 6: Panchromatic image near Yuma, Arizona.

A. Lunar calibration scan

A lunar calibration scan offers a means of testing the optical MTF of the system. The angular speed of the scan was such that the image motion at the focal plane was one-eighth of the normal earth image speed. The Pan image of the first-quarter moon is in Fig. 7. We show a plot of the scaled Panchromatic radiance vs. focal plane distance near the moon's limb in Fig. 8.

Fig. 9 shows that the averaged Pan radiance profile normal to the lunar limb (symbols) is an excellent match to an edge-spread function computed from the spatial transfer function derived from our laboratory calibrations.



Fig. 7: Panchromatic image from a lunar calibration scan.

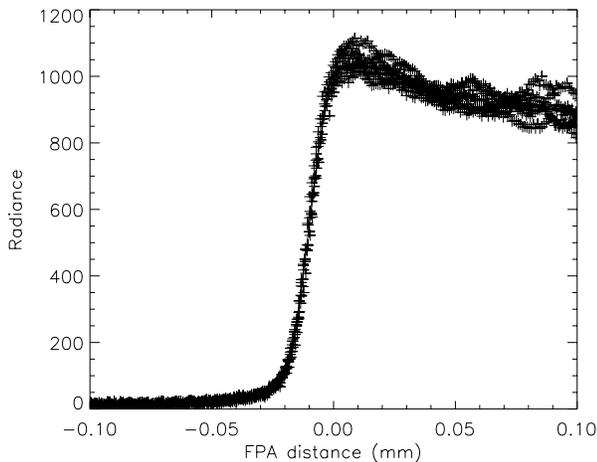


Fig. 8: Panchromatic detector signals crossing the lunar limb.

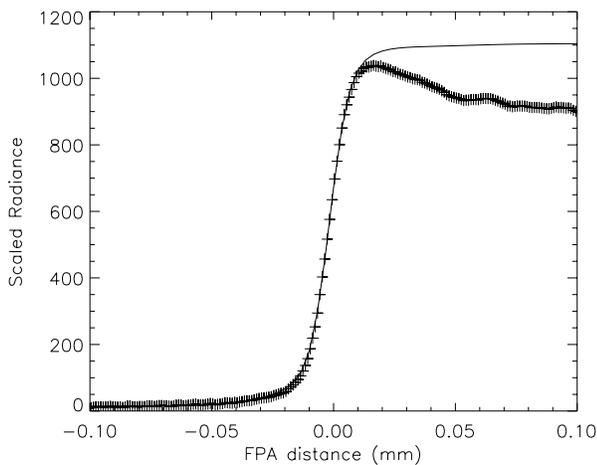


Fig. 9: Averaged Panchromatic lunar limb profile from Fig. 6 (symbols) compared with an edge-spread function (line) computed with the spatial transfer function from laboratory calibrations.

VI. ONGOING WORK

The spatial resolution of the Advanced Land Imager is being quantified using observations of long bridges, dams, canals, roads and observations of the Pleiades star cluster, as well as the limb of the Earth's moon. This effort is ongoing and initial results from these studies are to be presented in this conference.

VII. CONCLUSION

Initial results from the analysis of scenes collected by the Earth Observing-1 Advanced Land Imager indicate the instrument is healthy and functioning nominally. This instrument has demonstrated several technologies to improve the performance and lower the cost of future Landsat missions.

REFERENCES

- [1] J. A. Mendenhall et al., "Earth Observing-1 Advanced Land Imager: Instrument and Flight Operations Overview," MIT Lincoln Laboratory Project Report EO-1-1, 23 June 2000.
- [2] D. E. Lencioni, C. J. Digenis, W. E. Bicknell, D. R. Hearn, J. A. Mendenhall, "Design and performance of the EO-1 Advanced Land Imager," *SPIE Conference on Sensors, Systems, and Next Generation Satellites III*, Florence, Italy, 20 September 1999.
- [3] J. A. Mendenhall, and A. C. Parker, "Spectral calibration of the EO-1 Advanced Land Imager," *SPIE Conference on Earth Observing Systems IV*, Denver, Colorado, SPIE vol. 3750, July 1999, pp. 109-116.
- [4] J. A. Mendenhall, D. E. Lencioni, and A. C. Parker, "Radiometric calibration of the EO-1 Advanced Land Imager," *SPIE Conference on Earth Observing Systems IV*, Denver, Colorado, SPIE vol. 3750, July 1999, pp. 117-131.
- [5] D. R. Hearn, J. A. Mendenhall, and B. C. Willard, "Spatial calibration of the EO-1 Advanced Land Imager," *SPIE Conference on Earth Observing Systems IV*, Denver, Colorado, SPIE vol. 3750, July 1999, pp. 97-108.
- [6] D. R. Hearn, "Earth Observing-1 Advanced Land Imager: Detector Line-of-Sight Calibration," MIT Lincoln Laboratory Project Report EO-1-4, 29 December 2000.
- [7] D. E. Lencioni, J. A. Mendenhall, and D. P. Ryan-Howard, "Solar calibration of the EO-1 Advanced Land Imager," poster paper no. 740, this conference.