

EO-1 Advanced Land Imager In-Flight Calibration¹

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ABSTRACT

The EO-1 Advanced Land Imager (ALI) is the first earth-orbiting instrument to be flown under NASA's New Millennium program. The ALI employs novel wide-angle optics and a multispectral and panchromatic spectrometer. EO-1 is a technology verification project designed to demonstrate comparable or improved Landsat spatial and spectral resolution with substantial mass, volume, and cost savings. This paper provides an overview of in-flight calibration and performance assessment of the Advanced Land Imager. Included are techniques for calibrating and assessing focus and MTF using long, straight man-made objects and monitoring of radiometric linearity and offsets using an internal calibration source, standard Earth reference scenes, and solar and lunar observations.

Keywords: remote sensing, Landsat, spatial calibration, spectral calibration, radiometric calibration

1. INTRODUCTION

The Earth Orbiter I Advanced Land Imager is a technology verification instrument under the New Millennium program (Figure 1, Lencioni and Hearn (1998), Digenis et al.(1998)). The focal plane for this instrument is partially populated with four sensor chip assemblies (SCA) and covers 3° by 1.625°. Operating in a pushbroom fashion at an orbit of 705 km, the ALI will provide Landsat type images across a 36 km contiguous swath of the Earth's surface. Each SCA contains 9 multispectral bands and a single panchromatic band (Table 1). These bands have been designed to mimic four Landsat bands (Lauer et al., 1997) with three additional bands covering 0.433-0.453, 0.845-0.890, and 1.20-1.30 μm. The ALI also contains wide-angle optics designed to provide a continuous 15° x 1.625° field of view for a fully populated focal plane with 30-meter resolution for the multispectral pixels and 10 meter resolution for the panchromatic pixels.

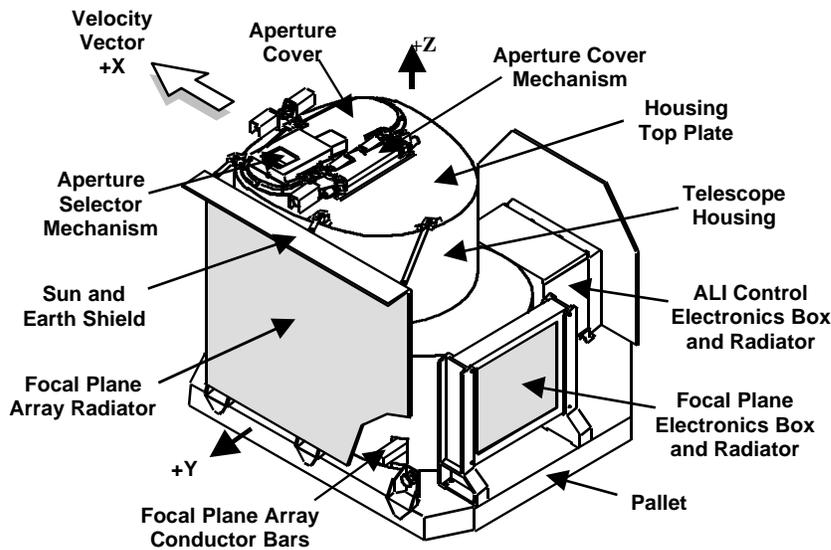


Figure 1: Earth Orbiter 1 Advanced Land Imager.

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Band	Wavelength (μm)	Ground Sampling 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	0.633 – 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

Table 1: Spectral and spatial definitions for the ten EO-1 ALI bands.

Ground calibration of the Advanced Land Imager is scheduled to begin in September 1998 at the Massachusetts Institute of Technology Lincoln Laboratory. For three months, the ALI will be subjected to a series of tests designed to examine and calibrate the spatial, spectral, and radiometric properties of this instrument (Mendenhall et al., 1998). Following ground calibration, the EO-1 is currently scheduled for launch in late May 1999 and will fly one minute behind Landsat-7. This paper provides a description of the procedures that will be followed to verify and calibrate the spatial and radiometric performance of the Advanced Land Imager in orbit.

2. SPATIAL CALIBRATION

Verification of the EO-1 ALI spatial characteristics on-orbit includes the measurement of the modulation transfer function across the focal plane and the determination of the pixel lines of sight.

Modulation Transfer Function

The modulation transfer function of the Advanced Land Imager may be checked in flight by observing long, straight, man-made objects such as bridges and roads (Schowengerdt et al., 1985). These objects serve as knife-edges which, when inclined, cut through various portions of many pixels and provide an over-sampling of the spatial resolution of the instrument. As a result, reconstructed images of these objects at $>20^\circ$ inclination to the in-track direction may be used for in-flight MTF determination.

A demonstration of the technique to be employed during ALI in-flight MTF verification is depicted in Figure 2. The upper left panel depicts a portion of an image taken by the Landsat Thematic Mapper of a bridge in the Boulder Colorado region. Analysis of this image begins by fitting a straight line to the bridge. Pixel intensity versus distance from the point perpendicular to the line is then plotted. An edge-spread function is then generated by binning the distance data into 0.25 pixel wide bins (upper right panel). In order to suppress artifacts introduced by spatial fluctuations far from the bridge, data locations more than two pixels from the bridge line have been fixed to either the minimum or the maximum intensity values. This is depicted in the lower left panel. The line-spread function of the bridge is calculated by taking the derivative of the edge-spread function (lower middle panel). Finally, the modulation transfer function is simply the normalized Fourier transform of the line spread function. The MTF calculated for this example is depicted in the lower right panel.

Pixel Lines of Sight

Complex spatial scenes will be used to verify the pixel lines of sights of the ALI while in orbit. These scenes will contain well-known features such as complex freeway intersections, city streets, airport runways, rivers, canyons, and farms.

Periodically, portions of a future observation will be designated ground control points. Data collected by the ALI over ground control points will be processed using the calibration pipeline to produce radiometrically and geometrically corrected images of the region for each

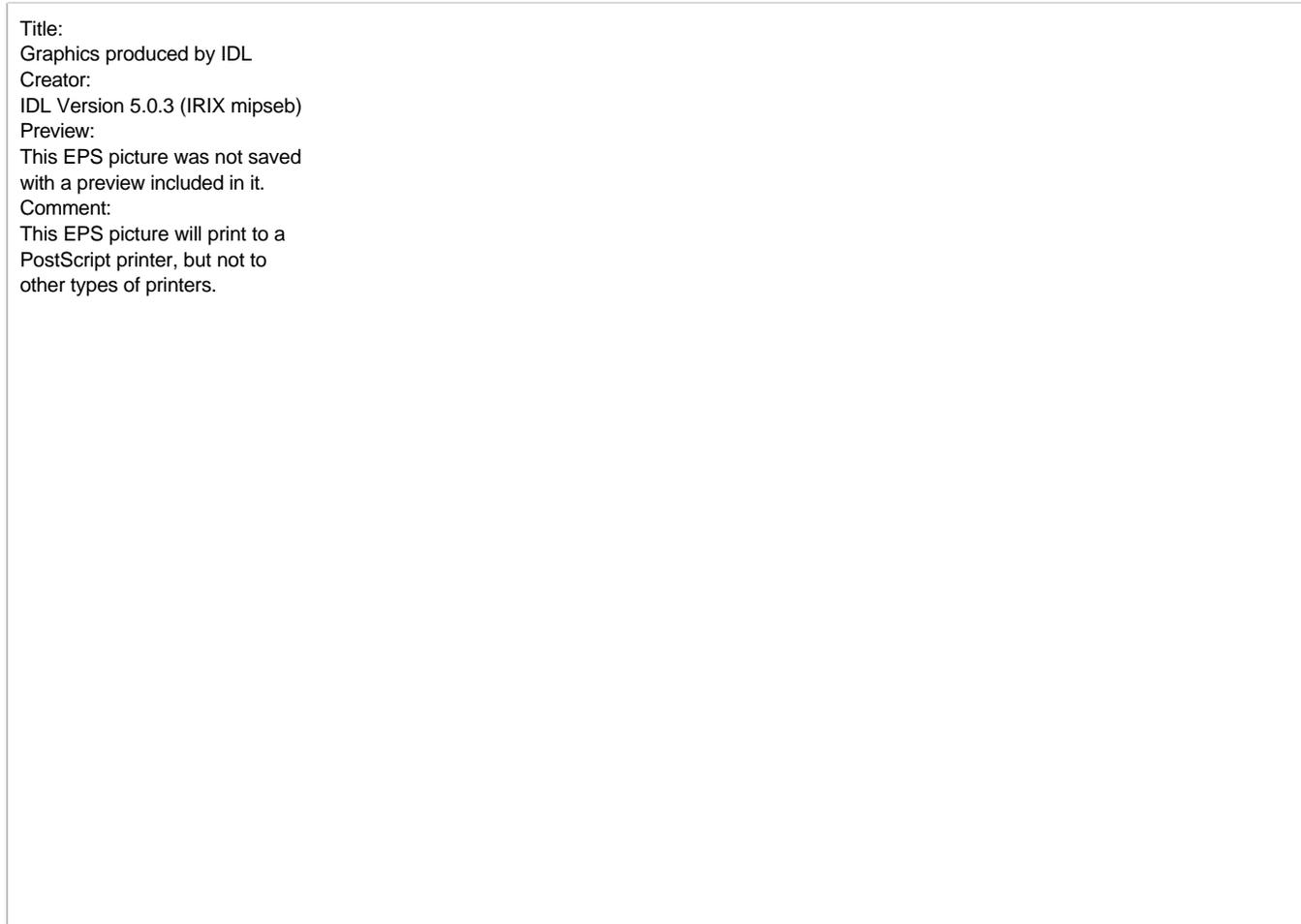


Figure 2: Sample modulation transfer function determination for a Landsat scene of a bridge near Boulder, Colorado. Upper left panel shows the original image. Lower left panel depicts the edge spread function derived from the original image. Lower middle panel indicates the line spread function, obtained by taking the derivative of the edge spread function and the lower right panel is the modulation transfer function derived by taking the fourier transform of the line spread function.

MS/PAN band. These images will then be compared to the accurately known geometric features of the ground control points. Any corrections necessary to account for lines of sight shifting due to launch stresses or the thermal migrating (deformation) of the telescope will be reflected in updated pixel lines of sight mapping used during subsequent geometric ground processing.

3. RADIOMETRIC CALIBRATION

In-flight radiometric calibration provides a verification of pre-flight calibration coefficients after the stresses of launch and also monitors changes in focal plane response as a function of mission lifetime. For the EO-1 program, in-flight radiometric calibration includes regular data collection from an on-board internal calibration source, periodic solar observations, and repeated viewing of standard Earth and Lunar scenes.

Internal Calibration Source

Daily in-flight radiometric calibration checks of the Advanced Land Imager will be conducted by observing the on-board internal calibration source (Figure 3). This source consists of three Welch Allyn 997418-7 (modified) gas-filled lamps mounted on a small, 0.8-inch diameter integrating sphere. Light emerging from the exit slit of the sphere passes through a BK 7 lens and infrared filter, is reflected off the ALI M2 mirror, and floods the focal plane. This source should provide better than 2% absolute radiometric calibration for the instrument. Extensive stability and lifetime testing of the internal calibration source for spaceflight operation is under way at Lincoln Laboratory.

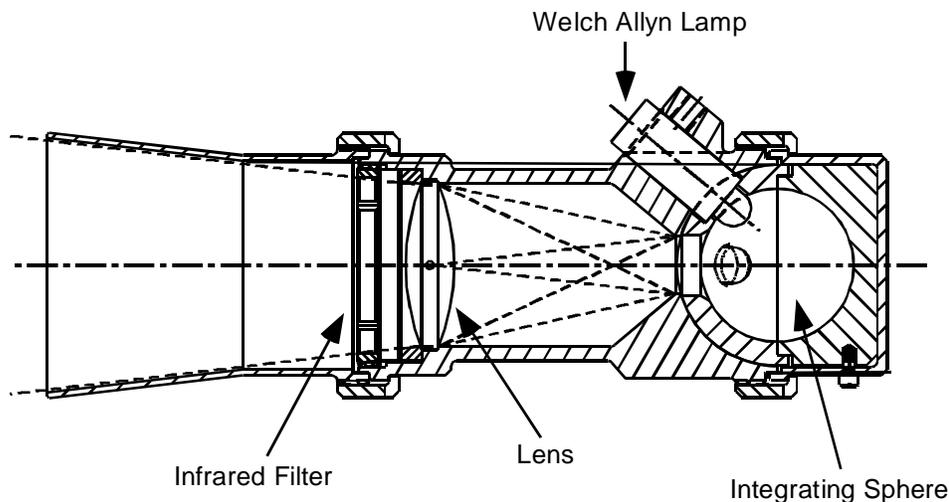


Figure 3: EO-1 ALI internal calibration source.

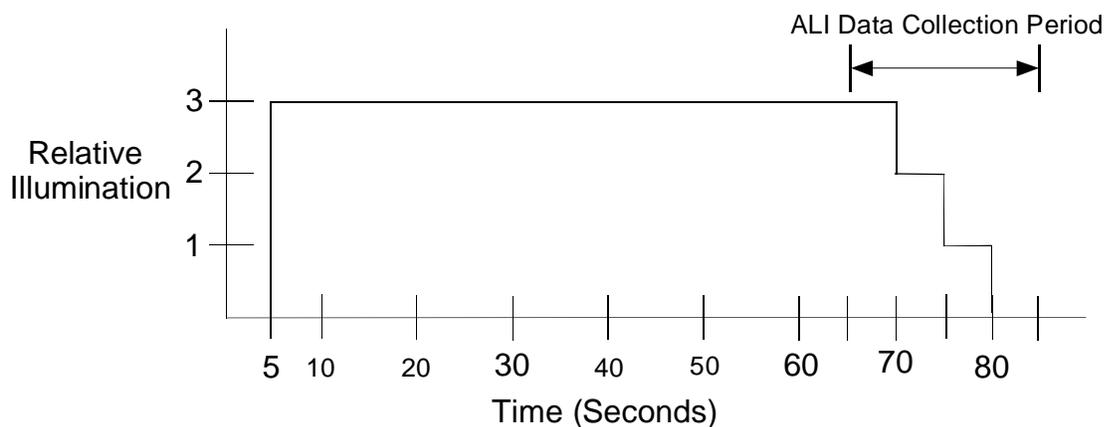


Figure 4: In-flight internal calibration source exposure sequence.

Following each observation, the three internal calibration lamps are powered by the ALI Control Electronics board. After a sixty-second stabilization period after the aperture cover has been closed, the lamps are sequentially powered down in a staircase fashion, with two-second exposures between each step (Figure 4). In this manner, the focal plane will receive a three point radiometric calibration prior to each observation.

Solar Calibration

The primary source of in-flight absolute radiometric calibration of the EO-1 Advanced Land Imager is based on indirect viewing of the Sun. Periodically, the instrument aperture cover will be closed, a *Labsphere* space-grade *Spectralon* diffuser (Leland and Arcchi, 1998) will be placed in front of the ALI M2 mirror, and the instrument pointed in the direction of the Sun. After a brief stabilization period, a slide will be withdrawn at a constant velocity, to expose a slotted mask (Figure 5), filling a portion of the aperture cover. This mask contains seven reference slots designed to provide a piecewise linear increase (decrease) of signal level from 0% to 90% equivalent diffuse Earth reflectance. As the mask is withdrawn, the solar flux entering through the exposed slot(s) will be diffusely scattered off the Lambertian *Spectralon* reflector, producing uniform scenes of incrementing radiance. Reference bars, located between the slots will provide a constant signal level for 0.5 seconds for each radiance level. Periodic absolute radiometric calibration of the focal plane will be maintained by recording the output of the focal plane as a function of calibration mask position (assuming constant solar irradiance from 400-2500 nm and stable *Spectralon* diffuser). Adopting this technique, monthly absolute radiometric calibration of the ALI will be maintained and compared against other sources of in-flight calibration (internal calibration lamps, Lunar scans, ground reference scenes).

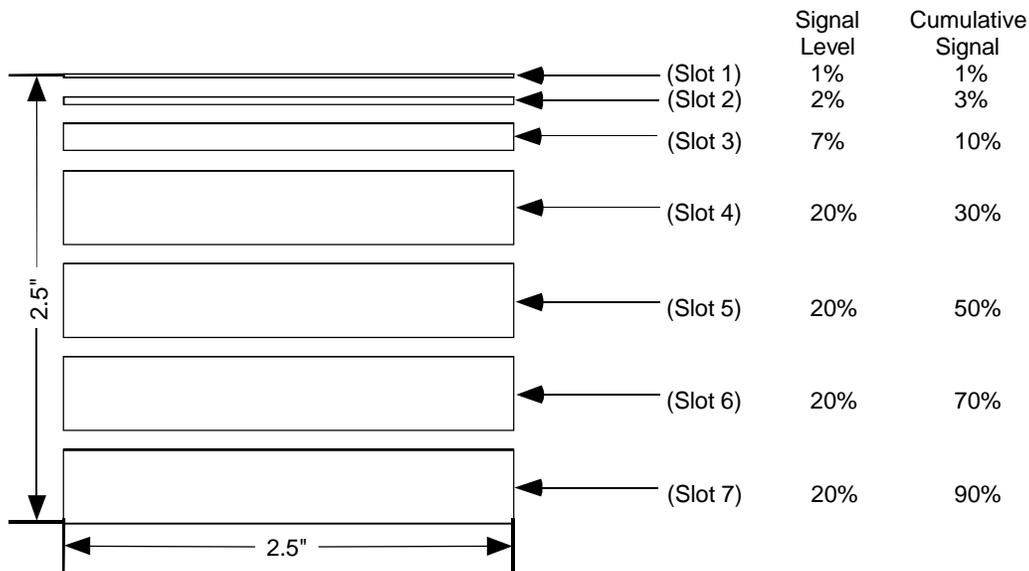


Figure 5: Aperture cover mask used during solar calibration

Lunar Observations

Another radiometric standard that will be used during in-flight calibration of the ALI is the surface of the Moon. The absence of a Lunar atmosphere and minimal geological activity results in a very stable source, only affected by rare meteoroidal impacts (10^{-9} /year, Kieffer and Wildey, 1996). As a result, reflected sunlight from the surface of the Moon will be used as a relative and absolute radiometric calibration standard, periodically monitored by the Advanced Land Imager.

Observations of the Moon have two advantages over solar calibration. First, direct pointing of the instrument towards the Sun is not required. Additionally, the contamination of solar diffusers during ground calibration and launch are avoided by

directly imaging the Moon. However, Lunar irradiance will change substantially as a function of Solar illumination and viewing geometry. As a result, radiometric calibration of the ALI using the Lunar surface will require careful planning. Although no restriction is placed on which phase of the Moon to observe, equivalent phases and similar instrument-Lunar-solar angles must be adhered to when comparing calibrations from two separate observations. Similarly, the same region on the lunar surface must be scanned across the same pixels for all observations.

Figure 6 depicts a typical Lunar scan sequence for the ALI. Initially, the instrument is pointed near the Moon and observes deep space. The Lunar surface is then scanned across the central portion of the first MS/PAN sensor chip assembly (SCA) at a rate of 0.5 degrees/second, maintaining the same attitude control/jitter requirements as during Earth viewing science data acquisition. Once this observation is complete, a second scan of the Moon, over the central portion of the second SCA is performed. This raster scan continues until each SCA has been covered.

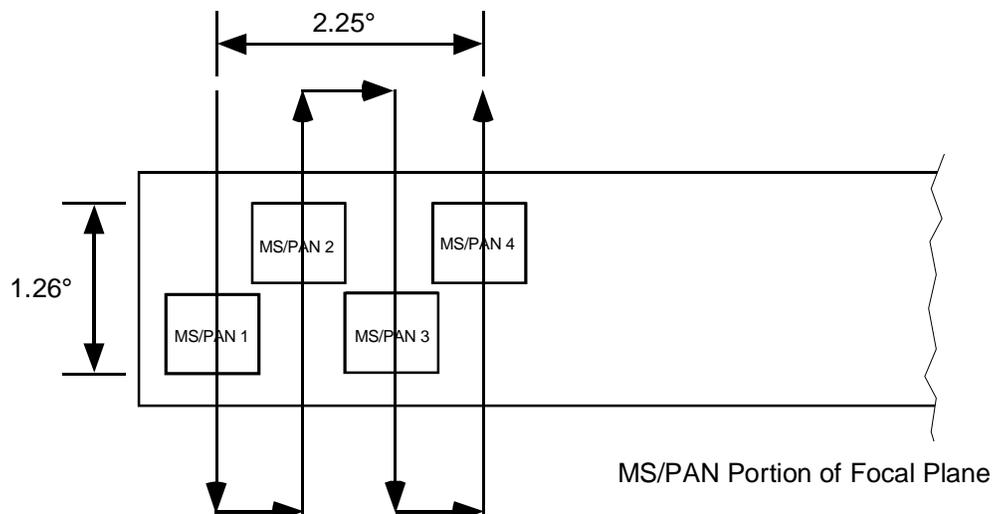


Figure 6: Lunar scan sequence to be used during in-flight calibration of the Advanced Land Imager. Each sensor chip assembly will be covered using a raster scanning technique.

Simultaneous Standard Earth Scene Observations with Landsat-7

Finally, in-flight radiometric performance of Advanced Land Imager will be directly verified and monitored by the periodic, near-simultaneous observation of well-characterized targets with Landsat-7. Currently, the ALI is scheduled to fly in a similar orbit but one minute behind Landsat-7. This will provide a unique opportunity to directly compare the radiometric performance and calibration of the two instruments throughout the 1-year mission lifetime of the EO-1 program. Observations of spatially flat or diffuse scenes (e.g. White Sands, New Mexico) will be used to directly compare the radiometric calibration of the two instruments. Any discrepancy between the Landsat-7 and ALI instrument calibrations may be resolved using a more detailed *reflectance-based* calibration technique.

The *reflectance-based* calibration technique relies on the accurate determination of the ground reflectance and atmospheric conditions near the scene at the time of the observation (Slater et al., 1987). For ALI calibration, we will rely on the ground measurements performed for Landsat-7 (ETM+). A prediction of the upwelling radiance observed by both instruments will be calculated based on an estimated solar irradiance, a MODTRAN radiative transfer model (based on the measured

atmospheric conditions), and reflectance measurements of the standard scene. Next, instrument calibration coefficients will be derived by dividing the estimated radiance by the detector output in DN. These coefficients are then checked against previously calculated values in an effort to understand the nature of the Landsat-7 – ALI discrepancy.

4. SUMMARY

In-flight spatial calibration of the EO-1 Advanced Land Imager will be accomplished by observing carefully selected ground targets. These observations will allow researchers to correct for any postlaunch changes in the instrument modulation transfer function and pixel lines of sight. In-flight radiometric calibration and monitoring of the EO-1 ALI will be accomplished prior to each observation using an internal calibration source and periodically using carefully selected solar, lunar, and Earth observations. In-flight calibration, along with knowledge of the instrument performance obtained during ground calibration, will allow for direct verification of ALI performance throughout the EO-1 mission.

5. ACKNOWLEDGEMENTS

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