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Prelaunch Radiometric Performance Analysis of Ocean Scanning Multi-spectral Imager (OSMI)

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Abstract : Ocean Scanning Multispectral Imager (OSMI) is a payload on the KOrean Multi-Purpose SATellite (KOMPSAT) to perform global ocean color monitoring for the study of biological oceanography. KOMPSAT was launched 21 December 1999.

The radiometric performance of OSMI is analyzed for various gain settings in the viewpoint of the instrument developer for OSMI calibration and application based on its ground performance data measured before launch. The radiometric response linearity and dynamic range are analyzed and the dynamic range is compared with the nominal input radiance for the ocean and the land. The noise equivalent radiance (NER) corresponding to the instrument radiometric noise is compared with the radiometric resolution of signal digitization (1-count equivalent radiance). The best gain setting of OSMI for ocean monitoring is recommended. This analysis is considered to be useful for the OSMI mission and operation planning, the OSMI image data calibration, and users' understanding about OSMI image quality.

Key Words : KOMPSAT, Ocean Scanning Multispectral Image

1. INTRODUCTION

The study of phytoplankton distribution in the global ocean can give the knowledge of ocean primary production and global biochemistry such as the ocean's role in the global carbon cycle. The concentration of phytoplankton cells can be derived from satellite observation of ocean color. This is because ocean color in the visible light region (wavelengths from 400nm to 700nm) varies with the concentration of chlorophyll and other plant pigments in the water (Hooker, Esaias, Feldman, Gregg, and McClain, 1992).

After the ocean data from Coastal Zone Color Scanner (CZCS) on Nimbus-7 (Leonard and McCLAIN, 1996; McCLAIN, 1993) are proved to be useful for global research of ocean, several advanced ocean monitoring sensors were launched and are currently operating or to be launched in the near future such as OCTS (Japan), MOS (German), SeaWiFS (USA), OCI (Taiwan), MODIS (USA), MERIS (ESA), GLI (Japan).

The Ocean Scanning Multi-spectral Imager (OSMI) (Cho, 1998) is the first Korean ocean

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monitoring space-borne instrument developed by the Korean Aerospace Research Institute (KARI) and TRW, Inc (USA) and is being operated by KARI. The instrument is a payload on the KOrean Multi-Purpose SATellite (KOMPSAT) launched to a 685km sun synchronous orbit on December 21, 1999 (Lee and Kim, 1996; Baek and Chang, 1996).

The mission goal of OSMI is to perform global ocean color monitoring for the study of biological oceanography. For flexible mission OSMI has on-orbit spectral band selectability and programmable gain and offset. To know pre-launch instrument performance for various instrument parameters is the starting point for the OSMI mission and operation planning, the OSMI image data calibration, and understanding about OSMI image quality. OSMI pre-launch radiometric performance is investigated for various gain settings at the base offset setting through the analysis of the laboratory performance measurement data taken under the ambient environment by TRW before launch (Frink, 1998).

2. SPECTRAL BAND AND MISSION OPERATION

OSMI has on-orbit spectral band selectability, i.e. after launch any 6 spectral band can be selected in the spectral range from 400nm to 900nm via ground station commands. Since it is practically impossible to measure performance for all possible bands more than 1000, the instrument performance was measured for the 8 primary spectral bands (Table 1) during its development. The OSMI ocean color spectral bands B0 through B4 provide ocean color data while band B5, BX and B6 provide information for atmospheric (aerosol) corrections. During routine on-orbit operation, 6 bands (4 bands for ocean color and 2 bands for atmospheric correction) will be selected among the 8 bands.

Unfortunately, in the shortest wavelength band B0 enough reliable measurement data could not be obtained for some reasons. The radiometric performance at B0 was measured at only two input points within low and narrow dynamic range and the measurement shows that the higher input generates lower noise than the other. This is why some radiometric characteristics are not analyzed for the band of B0 in the following study.

The OSMI instrument performs whisk-broom scan with a ground sample distance (GSD) of 1km and a ground swath width of 800 km during 20% duty cycle. For the 6 spectral bands, the optical image collected by OSMI optics are converted to analog electric signal by Charge Coupled Device

Table 1. OSMI Primary Spectral Bands

Spectral Band	Band Center (nm)	Bandwidth (nm)	Sensing Objective
B0	412	20	Desolved Organic Material, Aerosol
B1	443	20	Concentration of chlorophyll
B2	490	20	Concentration of pigment
B3	510	20	Turbidity of chlorophyll
B4	555	20	Turbidity
B5	670	20	Calibration of atmospheric effect
BX	765	40	Calibration of atmospheric effect
B6	865	40	Calibration of atmospheric effect

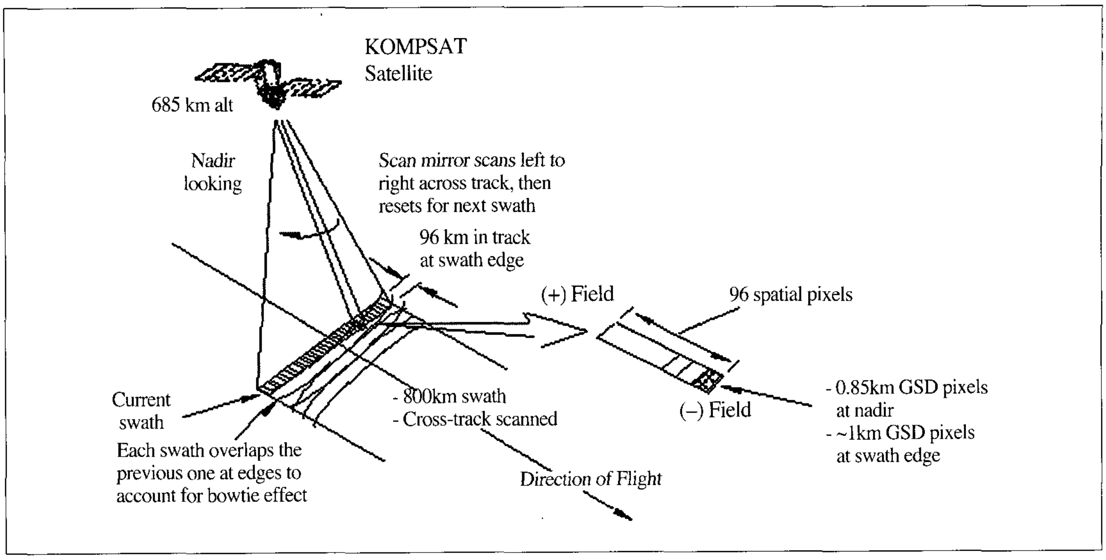

Fig. 1 OSMI Operation

(CCD) on focal plane assembly (FPA). The analog signal is digitized to a 10-bit gray level digital signal after analog gain and offset adjustment and then is lossless-compressed before transfer to the payload data transmission subsystem (PDTS), which downloads the OSMI data to the Ground Station.

OSMI has a 2-dimensional CCD which has 96 pixels along spatial direction and 192 pixels along spectral direction. The CCD pixels are divided into 2 groups along spatial direction. One is called as '(–) field' which includes 48 forward spatial pixels to the satellite velocity direction, the other is '(+) field' which includes 48 backward spatial pixels (Fig. 1). Each field has different quantum efficiency from each other so that the radiometric response characteristics are different for the two fields at all the bands.

3. RADIOMETRIC RESPONSIVITY

Since photon detector CCD has almost linear response to input light amount, OSMI radiometric response signal can be modeled by the following linear equation after dark signal correction.

$$S_l = Ga \times (g1 \times R + g0) \qquad (1)$$

where R is input light radiance ($W/m^2/Sr/\mu m$),
$g1$, $g0$ are the linear gain coefficients for responsivity and the response offset at the minimum gain setting respectively,
Ga is the gain amplification parameter.

The OSMI total radiometric responsivity is determined by the minimum gain coefficients and the gain amplification parameter. It was reported by TRW that the gain coefficients g1 and g0 are obtained for each spectral band and each field by linear curve fitting to the laboratory performance measurement data at the minimum gain setting of $Ng = 0$ (Ga=1 for all bands) (Fig. 2). OSMI has 8 steps of gain setting to control the radiometric responsivity after launch, that is 8 sets of the gain amplification parameter (Ga) are available at each band and each field. The gain amplification parameter (Ga) is controlled by gain setting factor

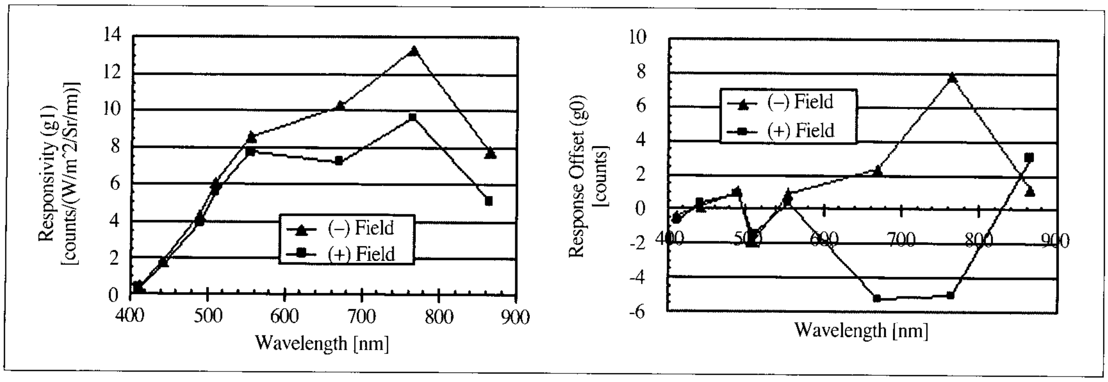

Fig. 2. The gain coefficients of OSMI radiometric response at the minimum gain setting (Ng=0)

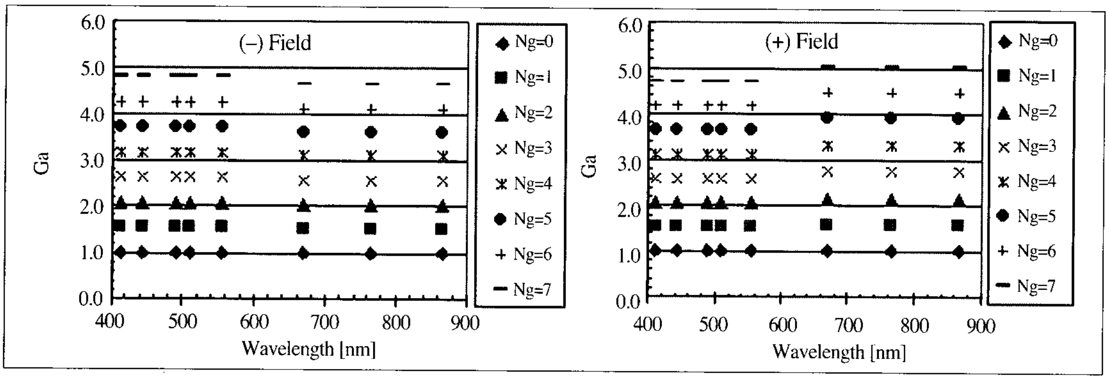

Fig. 3. Gain Amplification Parameters (Ga) at various Gain Setting Factors (Ng)

Ng which can be selected by ground station command after launch (Fig. 3).

4. RADIOMETRIC DYNAMIC RANGE

For the minimum gain setting, the radiometric dynamic range of linear response where the linear model of Eq. (1) can be a good approximation is investigated from the interpretation of the laboratory measurement data. The maximum value of the dynamic range is compared with OSMI nominal input radiance which is good for ocean monitoring and EOC (the primary payload of KOMPSAT) nominal input radiance for land observation (Fig. 4)(Lee, Shim, and Paik, 1998). The figure shows all bands of OSMI have enough wide dynamic range for ocean monitoring at the minimum gain setting. It is predicted that the OSMI signal from land can be saturated at the band of B5 and very close to the saturation at B4, BX, and B6 band. So these bands are not good for the land observation. The minimum value of the dynamic range is taken from the minimum radiance point of the measured data to avoid uncertainty near zero input where there is high possibility for bad linearity (Fig. 5).

The radiometric accuracy of the linear model can be expressed by the radiometric linearity error defined by the Eq. (2). The maximum value of linearity error is analyzed within the dynamic range of Fig. 4 and Fig. 5 and it is found that the linearity error is less than 3% for all bands except for the (+) field of band BX whose linearity error is

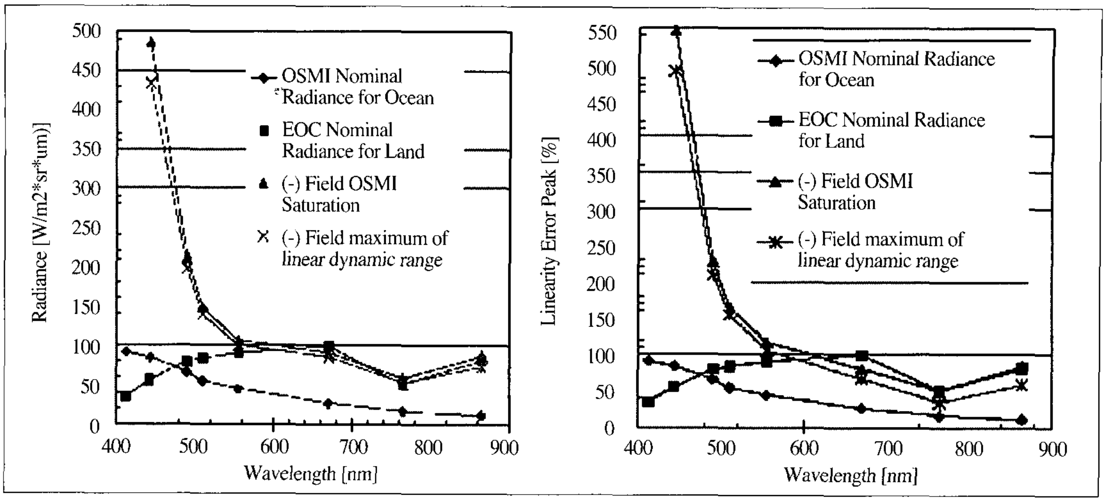

Fig. 4. Maximum of linear response dynamic range at the minimum gain (*Ga*=1, *Ng*=0)

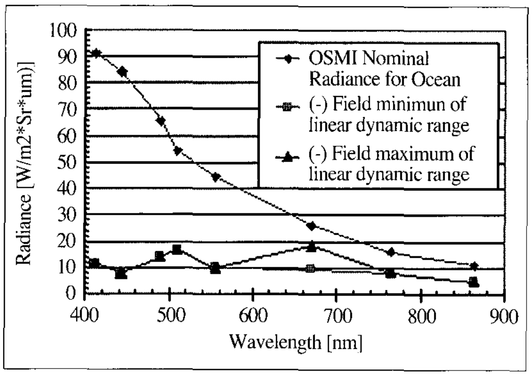

Fig. 5. Minimum of linear response dynamic range at the minimum gain (*Ga*=1, *Ng*=0)

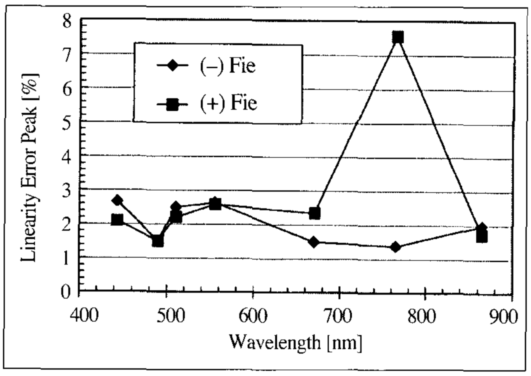

Fig. 6. The linearity error within the dynamic range at the minimum gain (*Ga*=1, *Ng*=0)

as bad as 7.6% (Fig. 6).

linearity error [%] = (measured value − linear fitting value) / linear fitting value * 100   (2)

The maximum of dynamic range can be altered for various gain amplifications (*Ga*). At low gain setting, the maximum value of dynamic range can be determined by the maximum input point up to which the given linearity error is conserved. At high gain setting, some high input value can produce output value higher than the digitization limit of 10-bit gray level (1023), although it generates output value less than the digitization limit at low gain, so that the digitization limit can determine the maximum value of dynamic range. Considering these two aspects, the maximum value of dynamic range is investigated for various gain settings at each band and is compared with the SeaWiFS Knee 1 radiance values (Barnes, Holmes, Barnes, Esaias, McClain, and Svitek, 1994; Johnson, Early, Eplee, Jr., Barnes, and Caffrey, 1999) which can be considered as a criteria of the dynamic range for ocean observation (Fig 7). For the bands of B1~B4, it is clear that the higher the gain is, lower the maximum of the dynamic range due to the digitization limit. It is noted that, for the

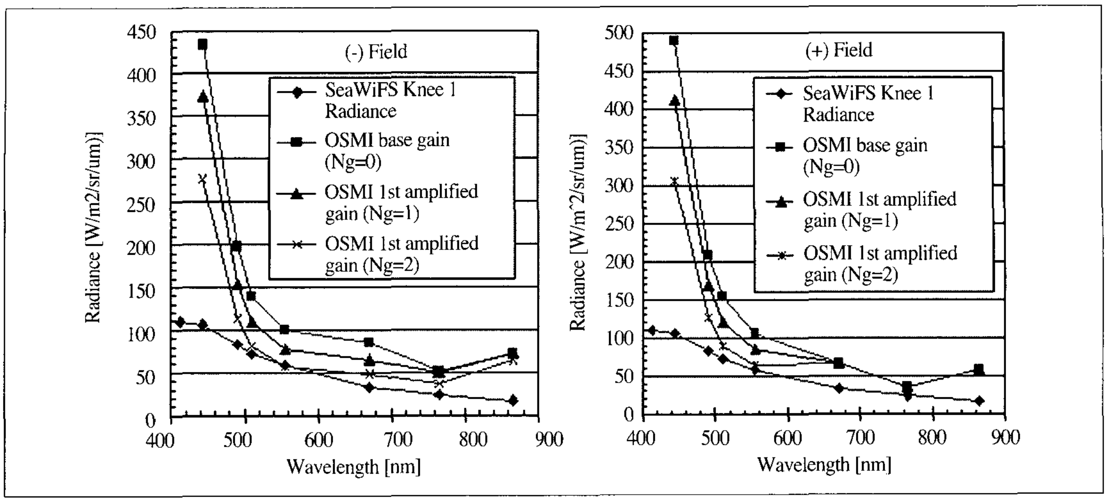

Fig. 7. Maximum of radiometric dynamic ranges for various gain amplifications (*Ng*)

case of *Ng*=2 (*Ga*~2.0), band B4 has the maximum radiances of the linear dynamic range very close to the SeaWiFS Knee 1 radiance values, although the other bands have the maximum radiances above the SeaWiFS radiance. Hence it is recommended that the upper limit of the gain setting factor should be *Ng*=2 (*Ga*~2.0) in order to keep sufficiently wide dynamic range for ocean monitoring at all the bands.

5. RADIOMETRIC RESOLUTION OF DIGITIZATION AND NOISE EQUIVALENT RADIANCE (NER)

The radiometric resolution of remote-sensing image is determined by the digitization of the radiometric dynamic range and all the noises which affect the image quality such as instrument noise, atmospheric noise, and background noise. It can be a staring point of understanding the image quality to investigate its scene-independent components such as the radiometric resolution of the digitization and the instrument noise.

Based on the laboratory measurement data of the root mean square (RMS) noise at several input radiances, the RMS noise at the OSMI nominal input radiance is analyzed by curve fitting method to calculate the Noise Equivalent Radiance (NER) at the nominal radiance using Eq. (1). The % value of NER to input radiance (%NER) is introduced as the Eq. (3) for the comparison with the radiometric linearity error.

$$\%NER = \text{Noise Equivalent Radiance (NER) / Input Radiance} * 100 \qquad (3)$$

In general most of noise is from the parts before analog-to-digital (A/D) conversion. Assuming that all the instrument noise are coming from the analog electronics before the gain setting circuit, the instrument noise at a gain setting is the corresponding gain amplification parameter (*Ga*) times the noise at the minimum gain setting (*Ga*=1). In this case NER and %NER is independent on the gain amplification parameter.

OSMI output signal is digitized into 10-bit gray level so that the signal range is 0~1023 counts. The radiometric resolution of the signal digitization

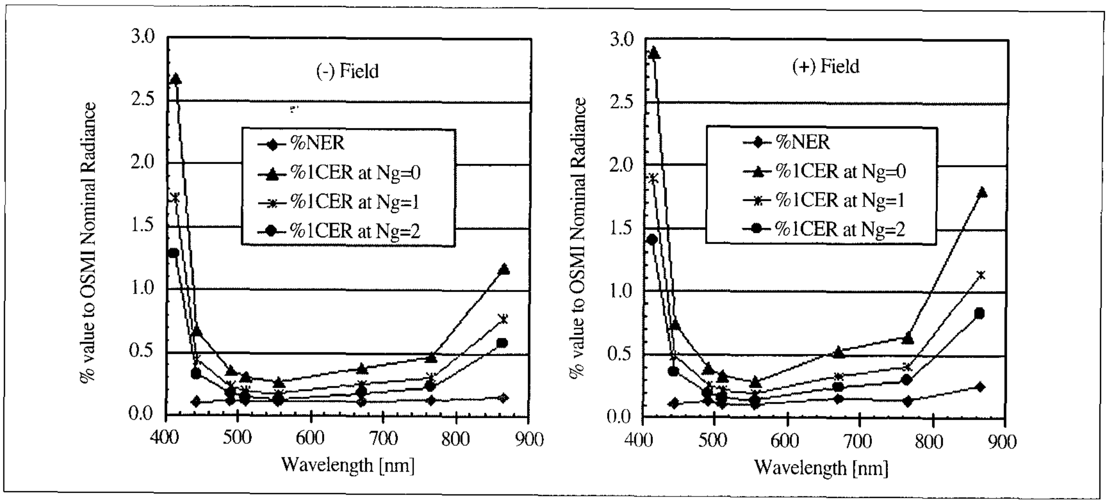

Fig. 8. Radiometric resolution of digltization (%1CER) for various gain amplifications (*Ga*) and Noise Equivalent Radiance (NER) for the instrument RMS noise at the OSMI nominal radiance

can be expressed the1-Count Equivalent Radiance (1CER) which is defined as the input radiance variation corresponding to 1 count change in output signal. The variation of input radiance within 1CER can not be distinguished in the digital image. The relative value of 1CER, %1CER *defined in Eq. (4) is useful for comparison with* the linearity error and %NER.

$$\%1CER = 1\text{–Count Equivalent Radiance (1CER) / Input Radiance} * 100 \quad (4)$$

At the OSMI nominal radiance, the %1CER is analyzed for various gain settings and compared with %NER (Fig. 8). The higher the gain is, the lower 1CER is. It is noticed that %1CER is larger than %NER at all bands (except for B0) for the gain settings of *Ng*= 0, 1, 2 which give wider dynamic range than the SeaWiFS. This means that OSMI has the instrument noise (RMS value) which is less than its radiometric resolution of digitization within the dynamic range suitable for ocean monitoring. In other words, the resolution of signal digitization determines OSMI radiometric resolution at the OSMI nominal radiance considering the instrument RMS nose.

At the minimum gain (*Ng*=0), %1CER is less than 2.9% for the band of B0, 0.8% for B1~BX, and 1.8% for B6. At the second amplified gain (*Ng*=2), %1CER is less than 1.5% for the band of B0, 0.4% for B1~BX, and 1.0% for B6. Among the three gain settings suitable for ocean at all the bands, the best radiometric resolution of digitization is achieved for the second amplified gain.

6. CONCLUSION

OSMI pre-launch radiometric performance is investigated for various gain settings at the base offset setting through the analysis of the laboratory performance measurement data taken under the ambient environment. This study shows that all bands of OSMI have enough wide dynamic range for ocean monitoring at three gain settings (minimum, first amplified gain, and second amplified gain). The band B4, B5, BX, and B6 are not recommended for the land observation due to saturation. The radiometric response linearity error is less than 3% for all the bands except for the B0 band and the (+) field of band BX. The linearity error of BX band at (+) field is less than 7.6% and that of B0 band is unknown at present due to lack of prelaunch measurement data. The OSMI radiometric resolution at the OSMI nominal radiance is determined by the radiometric resolution of signal digitization considering the instrument RMS noise (except for B0 band). It is found that three low gain settings have dynamic range enough for ocean monitoring at all the bands. Among the three gain settings the best radiometric resolution of digitization is obtained for the second amplified gain setting and its value is less than 1.5% of input at the nominal radiance for the band of B0, 0.4% for B1~BX, and 1.0% for B6.

In order to understand on orbit instrument performance fully, this analysis shall be followed by the study on the other instrument-related parameters such as band selection and the performance shift after launch due to the environment change. It is expected that the OSMI on-orbit calibration, dark and solar calibration, will be useful for understanding the on-orbit performance.

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