Ocean Scanning Multi-spectral Imager (OSMI) Pre-Launch Radiometric Performance Analysis*

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ABSTRACT

Ocean Scanning Multispectral Imager (OSMI) is a payload on the KOrean Multi-Purpose SATellite (KOMPSAT) to perform worldwide ocean color monitoring for the study of biological oceanography. KOMPSAT will be launched in the middle of November this year.

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 measurement data for 8 primary spectral bands of OSMI. The radiometric response linearity and dynamic range are analyzed for the image radiometric calibration and the estimation of OSMI image quality for the ocean remote sensing area. 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.

1. INTRODUCTION

The study of phytoplankton distribution on worldwide ocean can give the knowledge of ocean primary production (i.e. algae and some bacteria) and global biochemistry such as the ocean's role in the global carbon cycle. The concentration of phytoplankton 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. For example, chlorophytes and diatoms absorb light at wavelength below 550nm, phycocerythin absorption peaks around 490nm, and gelbstoffe absorbs below 550nm.

After the ocean data from Coastal Zone Color Scanner (CZCS) on Nimbus-7 (Leonard and McCLAIN, 1996; McCLAIN, 1993) are known to be useful for global research of ocean, several advanced ocean monitoring sensors were launched, are currently operating or to be launched in the near future, which are 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 ocean monitoring space-borne instrument developed by the Korean Aerospace Research Institute (KARI) and TRW, Inc (USA) and to be operated by Korea. The instrument is a payload on the KOrean Multi-Purpose SATellite (KOMPSAT) to be launched to a 685km sun synchronous orbit.

The mission goal of OSMI is to perform worldwide 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 (TRW, 1998).

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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 command. 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 for basic mission.

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

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 higher input had 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 imaging operation with a ground sample distance (GSD) of 1km and a cross-track ground swath of 800 km during 20% duty cycle. For 6 spectral bands the optical image collected by OSMI optics are converted to analog electric signal by Charge Coupled Device (CCD) on focal plane assembly (FPA). The analog signal is digitized to a 10-bit gray level digital signal after analog gain and offset signal adjustment and is lossless compressed before transfer to the payload data transmission subsystem (PDTS).

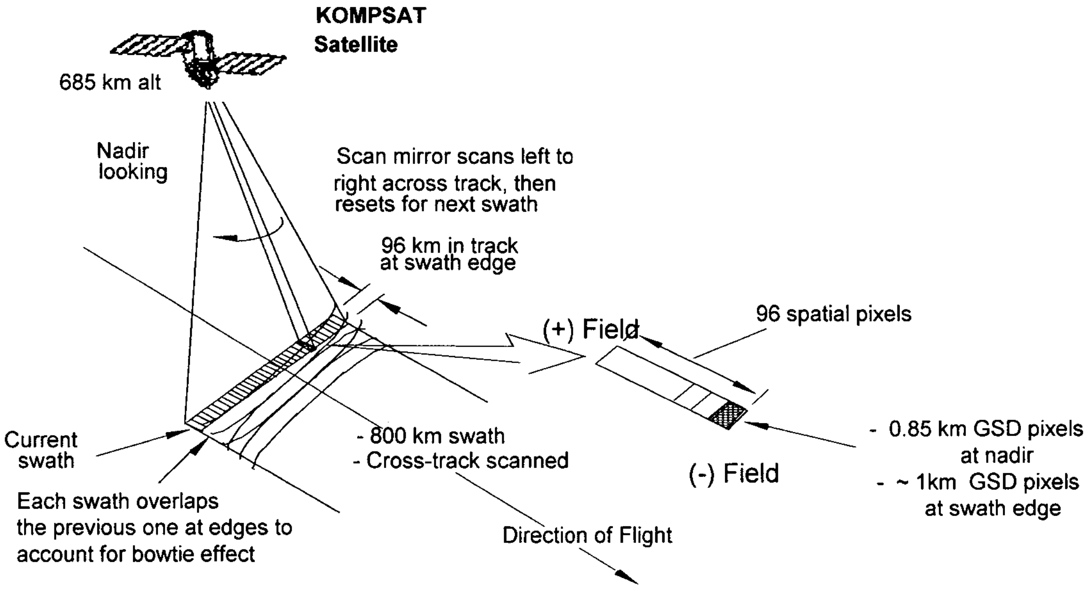

Fig. 1 OSMI Operation

OSMI has 2-dimensional CCD that 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 each other so that the radiometric response characteristics is different for two fields at all the bands.

3. RADIOMETRIC RESPONSIVITY

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

$$S_l = Ga \times (g1 \times R + g0) \tag{1}$$

where R is input light radiance (W/m^2/Sr/μm),

$g1$, $g0$ are linear coefficients for response gain and shift at the base gain setting respectively,

Ga is gain amplification parameter.

The gain amplification parameter is controlled by gain setting factor Ng which can be selected by command after launch (Table 2). 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 for the base gain setting of Ng = 0 (Ga=1 for all bands) (Fig. 2). The total radiometric responsivity is determined by the base gain coefficients and the gain amplification parameter.

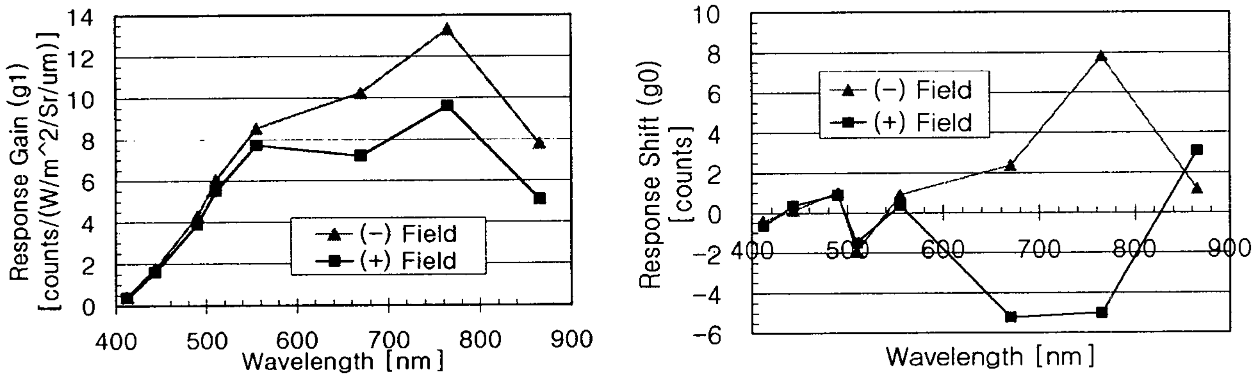

Fig. 2 The gain coefficients of OSMI radiometric response at the base gain setting (Ng=0)

Table 2. Gain Amplification Parameter (Ga)

Gain Setting Factor (Ng)	Blue Side Bands (B0, B1, B2, B3, B4)		Red Side Bands (B5, BX, B6)	
	(-)Field	(+)Field	(-)Field	(+)Field
0	1.000	1.000	1.000	1.000
1	1.543	1.529	1.521	1.579
2	2.085	2.057	2.042	2.158

4. RADIOMETRIC DYNAMIC RANGE

For the base 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 that is good for ocean monitoring and EOC (the primary payload of KOMPSAT) nominal input radiance for land observation (Fig. 3). The figure shows all bands of OSMI have enough wide dynamic range for ocean monitoring at the base gain setting. It is predicted that the OSMI signal for land can be saturated at the band of B5 and nearly saturated 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 irradiance point of the measured data to avoid uncertainty near zero input where there is high possibility for bad linearity (Fig. 4).

The radiometric accuracy of the linear model can be expressed by the radiometric linearity defined by the

Eq. (2). The maximum value of linearity is analyzed within the dynamic range of Fig. 3 and Fig. 4 and it is found that the linearity is less than 3% for all bands except for the (+) field of band BX whose linearity is as bad as 7.6% (Fig. 5).

$$\text{Linearity [\%]} = (\text{measured value} - \text{linear fitting value}) / \text{linear fitting value} * 100 \qquad (2)$$

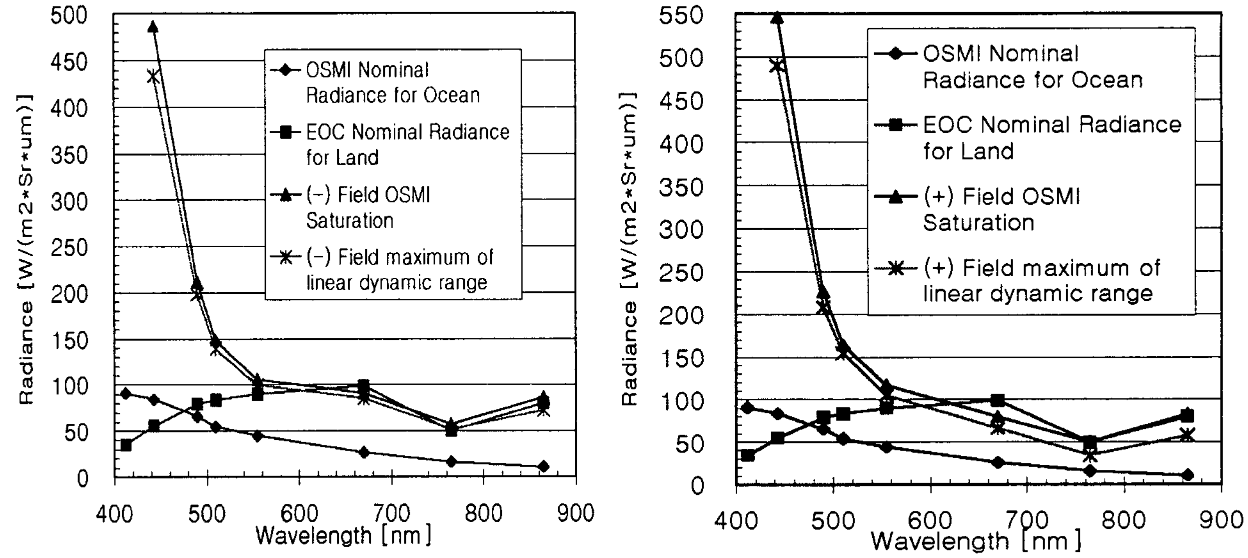

Fig. 3 Maximum of linear response dynamic range at the base gain (Ga=1, Ng=0)

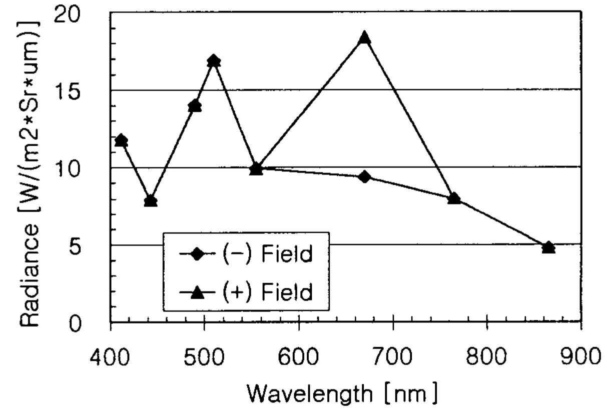

Fig. 4, Minimum of linear response dynamic range at the base gain (Ga=1, Ng=0)

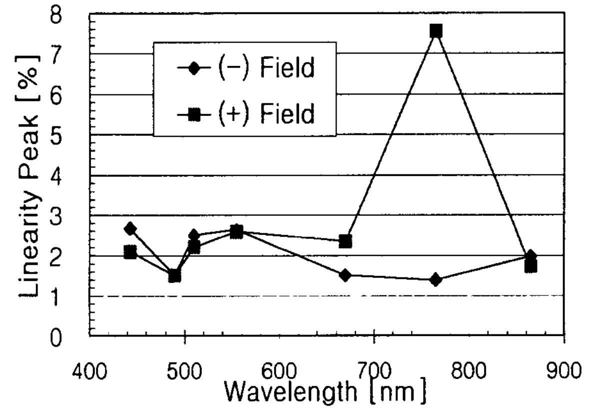

Fig. 5. The linearity within the dynamic range at the base gain (Ga=1, Ng=0)

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 is conserved. At high gain setting some input value can produce output value over 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 saturation radiance value which can be considered as draft criteria of the dynamic range for ocean observation (Fig 6). 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. For the case of Ng=2 (Ga ~2.0), in B3 and B4 the OSMI maximum radiance of the linear dynamic range are below the SeaWiFS saturation radiance values. Hence it is recommended that the upper limit of the gain setting factor should be Ng=1(Ga ~1.5) for sufficiently wide dynamic range for ocean monitoring.

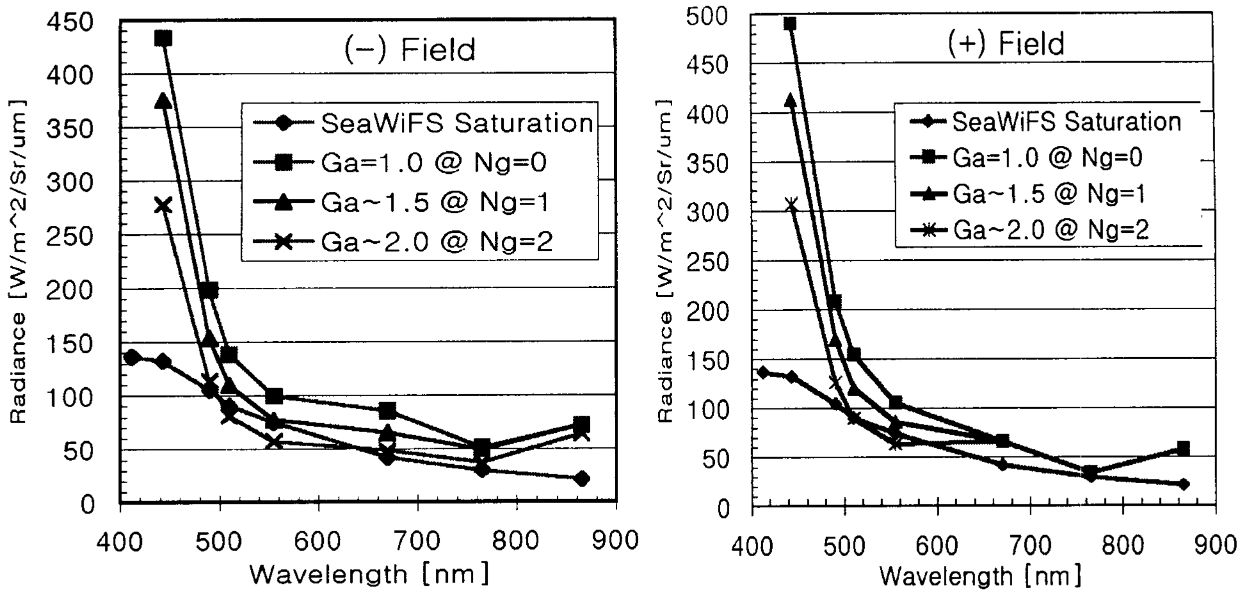

Fig. 6 Maximum of radiometric dynamic ranges for various gain amplifications (Ga)

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, atmosphere 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 radiance, the RMS noise at the OSMI nominal input radiance is analyzed by the curve fitting method of the Weibull model 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.

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

In general most of noise is from the parts before analog-to-digital (A/D) conversion. Assuming that all the instrument noise are come from the analog electronics before the gain setting circuit, the instrument noise at a gain setting is the gain amplification parameter (Ga) times the base gain (Ga=1). In this case NER and %NER is independent on the gain amplification parameter. This case can be considered as the worst noise case for the gain variation.

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 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 image. The relative value of 1CER, %1CER defined in Eq. (4) is useful for comparison with the linearity and %NER.

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

At the OSMI nominal radiance, the %1CER is analyzed for various gain settings and compared with %NER (Fig. 7). 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 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 base 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 first amplified gain (Ng=1), %1CER is less than 1.9% for the band of B0, 0.5% for B1~BX, and 1.2% for B6. Therefore the best radiometric resolution of digitization is achieved for the first amplified gain.

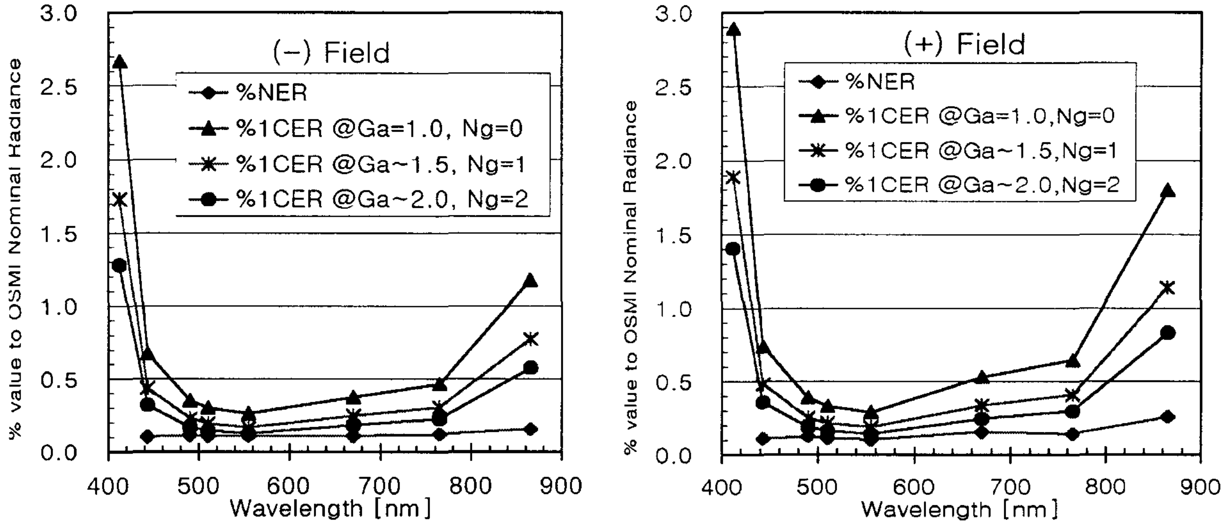

Fig. 7 Radiometric resolution of digitization (%1CER) for various gain amplifications (Ga) and Noise Equivalent Radiance (NER) for the instrument RMS noise at the OSMI nominal radiance

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 two gain settings (base and first amplified gain). The band B4, B5, BX, and B6 are not recommended for the land observation due to saturation. The radiometric response linearity is less than 3% for all the bands except for the (+) field of band BX whose linearity is less than 7.6% and B0 band whose measurement data are not enough. 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). Among the two gain settings the best radiometric resolution of digitization is obtained for the first amplified gain setting and its value is less than 1.9% of input at the nominal radiance for the band of B0, 0.5% for B1~BX, and 1.2% 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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