The Ground Checkout Test of OSMI(Ocean Scanning Multispectral Imager) on KOMPSAT-1

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Abstract

Ocean Scanning Multispectral Imager (OSMI) is a payload on the KOMPSAT satellite to perform worldwide ocean color monitoring for the study of biological oceanography. The instrument images the ocean surface using a wisk-broom motion with a swath width of 800 km and a ground sample distance (GSD) of <1km over the entire field of view (FOV). The instrument is designed to have an on-orbit operation duty cycle of 20% over the mission lifetime of 3 years with the functions of programmable gain/offset and on-board image data compression/storage. The instrument also performs sun and dark calibration for on-board instrument calibration. The OSMI instrument is a multi-spectral imager covering the spectral range from 400nm to 900nm using CCD Focal Plane Array (FPA). The ocean colors are monitored using 6 spectral channels that can be selected via ground commands.

KOMPSAT satellite with OSMI was integrated and the satellite level environment tests and instrument aliveness/functional test as well, such as launch environment, on-orbit environment (Thermal/Vacuum) and EMI/EMC test were performed at KARI. Test results met the requirements and the OSMI data were collected and analyzed during each test phase.

The instrument is launched on the KOMPSAT satellite in the late 1999 and the image is scheduled to start collecting ocean color data in the early 2000 upon completion of on-orbit instrument checkout.

1. Introduction

The Ocean Scanning Multispectral Imager (OSMI) is a payload on the KOrean Multi-Purpose SATellite (KOMPSAT) to be launched in the late 1999. The instrument is the first ocean monitoring space-borne sensor developed and operated by Korea.

The mission goal of OSMI is to perform worldwide ocean color monitoring for the study of biological oceanography. The OSMI image data is collected for various researches and applications in the fields of worldwide ocean resources management and ocean environment monitoring.

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 400 nm to 700 nm) varies with the concentration of chlorophyll and other plant pigments in the water.

The study of phytoplankton distribution on ocean can give the knowledge of ocean primary production and global biochemistry. The "primary producers", i.e. algae and some bacteria, use sunlight or chemical energy as sources of energy. It is thought that marine plants remove carbon from the atmosphere at a rate equal to terrestrial plants, but the details of this biochemistry is poor.

A satellite sensor can provide worldwide view of cloud-free ocean and satellite ocean color data is a valuable for determining the abundance of ocean biota on a global scale. This information can then be used to assess the ocean's role in the global carbon cycle and the exchange of other critical elements and gases between the atmosphere and the ocean.

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 such as Sea-viewing Wide Field-of -view Sensor (SeaWiFS), Ocean Colour Imager(OCI) and MEdium Resolution Imaging Spectrometer (MERIS) are currently operating and will be launched in early future.

As a second generation of ocean color instrument, the OSMI designed to have on-orbit band selection capability for the flexible mission in ocean color monitoring has been developed and built by Korea Aerospace Research Institute(KARI) and TRW Inc.

After the OSMI was manufactured, integrated and verified through function and performance tests as unit level, the OSMI was integrated on KOMPSAT satellite and the satellite level environment tests as well as instrument aliveness/functional test were performed at KARI. All of test results were within the requirements and OSMI data of each test phase were collected and analyzed.

2. OSMI Instrument Description

The OSMI has been developed to provide 6 spectral image data with GSD less than 1km over swath width of 800 km by whisk-broom scanning method at the altitude of 685km. And primary 6 spectral bands for ocean color monitoring in the 400 nm to 900 nm range are selected and used to specify instrument performance as shown in Table 1.

Table 1. OSMI spectral channels

Ocean Color Spectral Band	B1	B2	B3	B4	B5	B6
Band Center (nm)	443	490	510	555	670	865
Bandwidth (nm)	20	20	20	20	20	40

The OSMI ocean color spectral bands B1 through B4 provides ocean color data while band B5 and B6 provide information for atmospheric (aerosol) corrections.

The OSMI instrument physically consists of two assembly, the electronics and the sensor unit shown in Figure 1. The sensor assembly includes optics chain, FPA, analog signal processing. The electronics assembly has digital data processing, control processor, motor driver and power converter. The OSMI instrument weight is about 30 lbs and the peak power consumption is about 30 watts.(Lee et al., 1997)

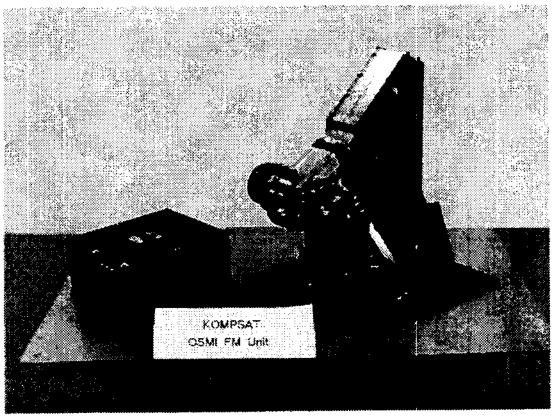


Figure 1. The OSMI electronics and sensor assembly (FM)

The OSMI instrument optics consists of an image scanner, an foreoptics and a multi-channel spectrometer (collimating lens, grating and reimaging lens group). The scanner consists of a scan mirror driven by a servo-motor. The scanner has a +/- 30 degrees scan angle with respect to nadir resulting in a 800 km swath at 685 km altitude. The foreoptics forms the primary image which is dispersed into its various colors by the spectrometer. The dispersed image is then focused onto and detected by the focal plane assembly (FPA).

The OSMI electronics shown in Figure 2 consists of the FPA electronics section providing timing and voltage bias for the CCD FPA which has four(4) quadrant output ports; the analog signal processing and analog-to-digital (A/D) conversion section providing analog gain (8 gain) and offset signal (256 offset) adjustment and a 10-bit A/D signal conversion; digital data processing and compression section providing 6 channels of data with the desired band centers and bandwidths, and USES data compression to reduce data volume(CCSDS 121.0 B-1 Bluebook, 1997); a control processor section to provide control, communication and house keeping; a motor drive section providing servo control for the scan motor and readout of the optical encoder for the position of the scan mirror; and the power converter section to regulate DC power.

For on-orbit calibration, the OSMI design employs a two level, black and white or solar, calibration scheme. The sensor black calibration level is provided by a dark cell while the white calibration level uses attenuated solar radiance. The solar calibration is performed over the north pole and the dark calibration is done at the beginning and end of each continuous image scan.

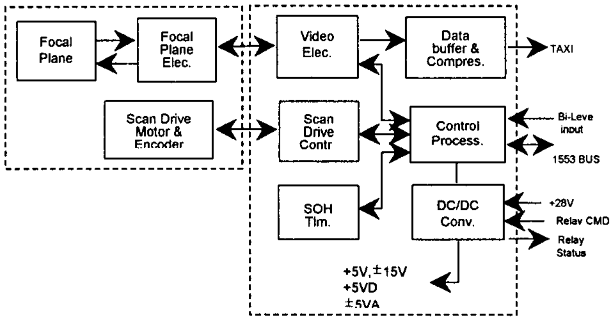


Figure 2. Block diagram of OSMI Electronics

The OSMI is a multi-spectral instrument covering the visible spectrum from 400nm to 900nm. In the OSMI design there is built-in flexibility to provide band center and bandwidth selection capability via ground station command. Any 6 spectral bands without overlap among the bands can be selected in the spectral range from 400nm to 900nm and the bandwidth of each band can be changed from the minimum value of 5.2 nm to the maximum value of 166.4nm in the step of 2.6nm. This flexibility in band selection provides research opportunities to support the next generation of sensor design.(Yong et al., 1998)

The six(6) OSMI ocean color bands performance requirements in signal-to-noise ratio (SNR), modulation transfer function (MTF), and ground sample distance (GSD) are as shown in Table 2. In addition to the requirements in SNR, MTF and GSD, the OSMI signal channels has a polarization requirement of less than +/-5%. The instrument is designed to meets all the requirements with some design margin and actual test results of MTF and SNR satisfy the requirement as shown in Figure 3 and Table 3.(Cho et.al., 1998)

Table 2. OSMI SNR, MTF and GSD requirements.

Ocean Color Spectral Channel	B1	B2	B3	B4	B5	B6
SNR	450	450	450	350	350	350
MTF (%)	20	20	20	18	18	15
GSD (km)	1.0	1.0	1.0	1.0	1.0	1.0

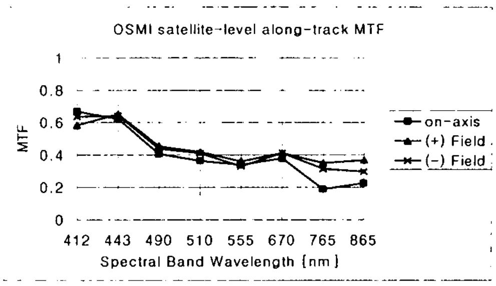


Figure 3. OSMI Satellite Level along-track MTF

Table 6. OSMI Radiometric Characteristics

Spectral Bands		Measured Value			
No.	Center Wavelength [nm]	Saturation Input Radiance[1]	Nominal Input Radiance[1]	SNR	Radiometric Linearity
B1	443	329	84.1	> 450	<10%
B2	490	206	65.6	> 450	<10%
B3	510	123	54.4	> 450	<10%
B4	555	80	44.5	> 350	<10%
B5	670	62	26.0	> 350	<10%
B6	865	68	10.9	> 350	<10%

(1. Radiance unit in $W/m^2/um/sr$)

3. OSMI Operation Description

The KOMPSAT OSMI was designed to provide worldwide ocean color data from 685 km altitude sun synchronous orbit. The orbit crossing time is at 10:50 AM and the inclination is 98.13 degree. 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. The ground track re-visit time is 28 days. The scan width of 96 along-track pixels provides 0.5sec image overlap between two adjacent cross-track scans considering the satellite speed of 6.78km/sec.

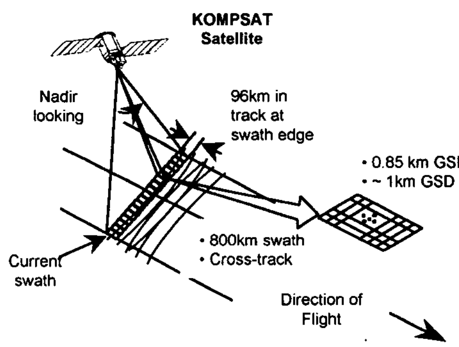


Figure 4. The operation concept of OSMI

The OSMI instrument was designed to perform imaging operation for 20% per orbit and to generate 6 spectral image data of each cross-track scanning frame. The image data are digitized and lossless compressed before being transfered to the payload data transmission subsystem (PDTS) as date rate of less than 1Mbps. PDTS will support worldwide imaging operation by providing data archive to on-board solid state recorder(data storage at the begin of life: 4Gbits) and X-band downlink of image data to the KARI ground station(KGS) at Taejon, Korea.

4. OSMI ground checkout Test

4.1. Ground checkout test sequence

The ground checkout test of OSMI started from instrument aliveness test to confirm the readiness of integration with spacecraft were performed for each test phase, such as initial Integrated Satellite Test(IST), formal IST, environment test and end-to-end test during ground test of KOMPSAT-1 as shown in Figure 5.

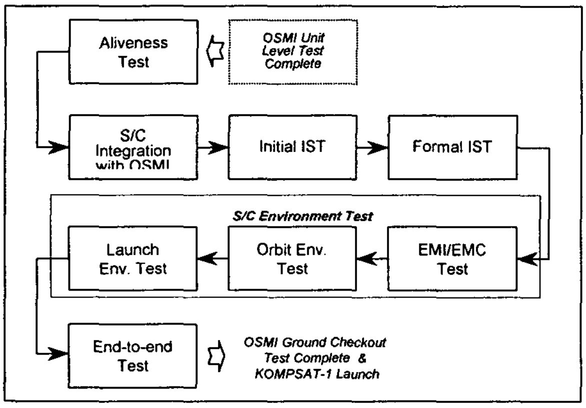


Figure 5. OSMI ground checkout test sequence

External electrical interface test between spacecraft and OSMI, like power interface, discrete command interfaces, 1553B command interface, and image interface and OSMI status test, such as power status, mirror status, temperature status and image data status were checked through these tests. In addition to external electrical interface and status checkout, cover open interface, band selection interface and image interface of different gain setting, and different offset setting were checked during ground checkout test.

The results of tests and analysis are described in the following section and these are indicated as each quadrant data of each 6 spectral bands to accurately analyze and characterize the captured data.

The 60^{th} pixel output of 96 spatial pixel output for quadrant A and quadrant C and the 12^{th} pixel output of 96 spatial pixel output for quadrant B and quadrant D is selected as sample data for analysis

4.2. Test result of different gain setting

The OSMI has capability of 8 different gain setting, 1 to 4.5 as 0.5 step for all quadrant output to amplify output signal during on-orbit operation based on the analyzed results. Three(3) different gain, 2, 4, 7 was tested during ground checkout test and the test result of collected dark calibration data were linear of gain step as shown in Figure 6.

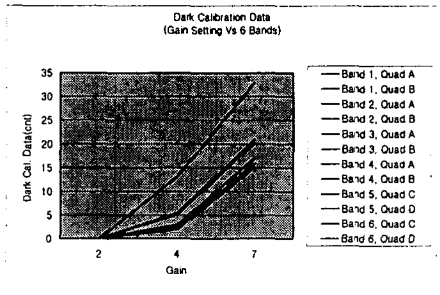


Figure 6. Test result of different gain setting

4.3. Test result of different offset setting

As above description, 256 different offset value of each of four(4) quadrant outputs can be selected by ground command to adjust OSMI signal level for the acquisition of the best ocean color information based on analyzed results. Fourteen dark calibration data was received under fourteen(14) different offset, 0 to 160. Because high offset values than 160 is out of OSMI A/D conversion range and the output was resulted in 1023 counts. The test results of each quadrant of six(6) bands in Figure 7 are analyzed and the output count values versus offset setting values is formulated in Table 4 through 4^{th} power polynomial fit.

This formula of each quadrant of six(6) bands will be used for effective control of OSMI signal during on-orbit operation

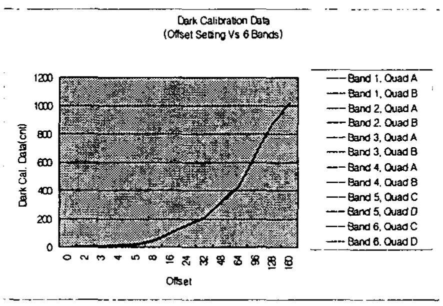


Figure 7. Test results of different offset setting (Gain = 0)

Table 4. The formula of the output count vs. offset setting

	Band 1		Band 2		Band 3	
	Quad A	Quad B	Quad A	Quad B	Quad A	Quad B
a	-8.11	-11.33	-8.09	-11.30	-8.09	-11.31
b	7.03	6.90	7.03	6.91	7.03	6.91
c	-1.1E-02	-8.0E-03	-1.2E-02	-8.2E-03	-1.2E-02	-8.3E-03
d	2.1E-04	1.8E-04	2.1E-04	1.8E-04	2.1E-04	1.8E-04
e	-9.9E-07	-9.2E-07	-9.9E-07	-9.3E-07	-9.9E-07	-9.3E-07

	Band 4		Band 5		Band 6	
	Quad A	Quad B	Quad C	Quad D	Quad C	Quad D
a	-8.07	-11.34	-10.45	-10.99	-10.50	-10.93
b	7.03	6.93	7.03	6.95	7.04	6.93
c	-1.2E-02	-8.5E-03	-1.2E-02	-9.2E-03	-1.2E-02	-9.3E-03
d	2.1E-04	1.8E-04	2.2E-04	1.9E-04	2.3E-04	1.9E-04
e	-9.9E-07	-9.3E-07	-1.1E-06	-9.2E-07	-1.1E-06	-9.4E-07

Output count = $a + bx + cx^2 + dx^3 + ex^4$

(a, b, c, d, e : constant, x : offset setting value)

The dark calibration data will also be collected and analyzed during early operation and before/after ocean scan & solar calibration imaging during normal operation to check data status and to process image data in Ground station. The following two(2) formula (5-1) and (5-2) are derived to calculated the dark calibration data and to estimated actual data. The dark calibration data of different offset test is used as a sample data to check the formula.

The difference between calculated data and actual data is shown in Figure 8 and data generated by formula (5-1) is closer to actual data than formula (5-2).

$$\text{Data} = (\text{Gain} \times I_d + O_h) + C_o \times \text{Offset} \qquad (5\text{-}1)$$

$$\text{Data} = (\text{Gain} \times I_d) + C_o \times \text{Offset} \qquad (5\text{-}2)$$

Where,

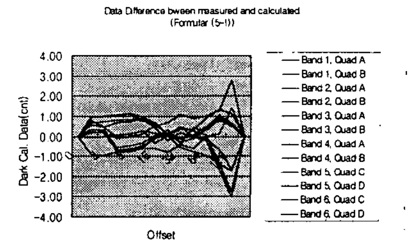
Gain : commanded gain, 1 ~ 4.5 as step 0.5
I_d : assumed dark current
O_h : assumed hardware offset
C_o : designed A/D count per one offset step 6.95 [A/D count /offset step]
Offset : commanded offset, 0 ~ 255

Assumed dark current(I_d) and hardware offset(O_h) is calculated by collected actual data and the values of each band is written in Table 5.

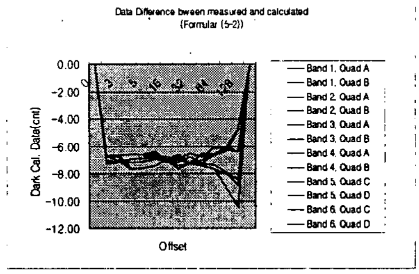
Table 5. Assumed dark current and hardware offset

	Band 1		Band 2		Band 3	
	Quad A	Quad B	Quad A	Quad B	Quad A	Quad B
I_d	12	8.53	12	8.40	12	8.33
O_h	-22.85	-23.25	-22.85	-22.65	-22.85	-22.45

	Band 4		Band 5		Band 6	
	Quad A	Quad B	Quad C	Quad D	Quad C	Quad D
I_d	11.87	8.47	8.67	8.00	9.27	8.00
O_h	-22.45	-22.55	-20.65	-21.85	-22.75	-21.85



(a) Formula (5-1) case



(b) formula (5-2) case

Figure 8. Difference of dark calibration data between calculated data and actual data

This formula will be checked and modified again by on-orbit data which is collected during early operation and then used to estimate dark calibration data under required gain and offset setting for on-orbit operation.

4.4. Dark calibration data for each checkout test phase

The OSMI readiness of integration on spacecraft was confirmed through aliveness test, one of checkout test. And the OSMI was integrated on spacecraft and checked through initial IST, formal IST, environment test, such as launch environment, on-orbit environment (Thermal/ Vacuum test) and EMI/EMC test, and end-to-end test with OSMI checkout test. The dark calibration data collected by the checkout test for each test phase are illustrated in Figure 9. The variation among test results is less then three(3) counts so that the range of dark calibration data under commanded gain and offset values can be predicted for on-orbit dark calibration data.

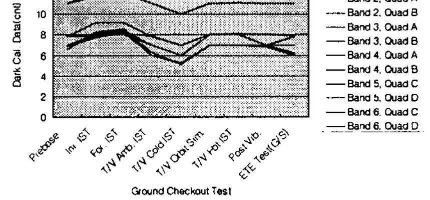


Figure 9. Dark calibration data of checkout tests

5. Summary

The KOMPSAT OSMI instrument was designed to perform worldwide ocean color monitoring in the 400 nm to 900 nm spectral range. The instrument has a 800 km ground swath at altitude of 685 km with sun synchronous orbit. The satellite ground track repeating time is 28 days and the orbit period is 98.5min. The instrument is designed to operate with a 20% duty cycle and has the capability to perform on-orbit selection of the imaging spectral band centers and bandwidths. This capability is able to provide the greatest flexibility to support the study of ocean color science from space.

The manufacturing and testing of the OSMI flight model (FM) was completed at the end of 1997. The instrument was integrated and tested with the spacecraft as well as interface test between satellite and ground station at KARI in the middle of 1999.
The integration and tests of satellite was completed to confirm the readiness of launch, and the satellite was transferred to launch site to be loaded on launch vehicle and to be checking the state of health (SOH). The satellite is scheduled to be launched on December 1999. On-orbit checkout and characterization of the OSMI instrument is performed during LEOP, about 3 month after launch. The OSMI image data designed to have the mission lifetime of at least 3 years is available for distribution at the early of 2000.

In this paper, test and analysis results of ground checkout test are described. The dark calibration data collected during several checkout tests are analyzed and formulated and these results are used for the check and estimation of OSMI data as well as providing the optimum operation environment by gain and offset setting as a reference.

Acknowledgements

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