In-Orbit Performance Result of KITSAT-3 Earth Imaging System (MEIS)

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Abstract

A compact imaging system, the Multi-spectral Earth Imaging System (MEIS) was developed and operated on an engineering test satellite, KITSAT-3 at the orbital altitude of 720 km. The MEIS takes multi-spectral images of the earth's surface with the swath width of 48 km and the ground sampling distance of 13.8 m in three spectral bands. A brief technical description of the KITSAT-3 MEIS and the result from its initial operation since early June, 1999 are presented. The quality of images produced by the KITSAT-3 MEIS was found comparable to that of images from existing commercial earth observation satellites from its preliminary assessment.

1. Introduction

There have been numerous satellites equipped with earth imaging payloads since US Vanguard and Explorer satellites. Many of them were developed and operated to meet the military and government needs especially during the Cold War. In 70's and 80's, LANDSAT and SPOT satellites produced enormous amount of valuable information on various characteristics and features of the earth's surface. Images produced by these satellites not only contributed to the advance of remote sensing technology and thus better understanding of the earth, but also made themselves recognized as a commercial entity. Since then, the remote sensing market has grown exponentially and the need for images of better quality has also grown rapidly. Many private enterprises world wide with advanced space technologies plan to develop or launch satellites that would produce high-resolution images of the earth's surface. However, high cost and limited access is inevitably associated with these satellites or their imaging payloads.

Based on its past experience from two micro-satellites, KITSAT-1 and 2, the Satellite Technology Research Center (SaTReC) has developed an engineering test satellite, KITSAT-3. In addition to new features such as common bus architecture, deployable solar panels, three-axis stabilized attitude control system, high-speed data transmission system, and solid-state mass memory, KITSAT-3 has the Multi-spectral Earth Imaging System (MEIS) as its primary payload. The MEIS is a pushbroom type imaging system with advanced features and was developed with proven technologies and design concepts.

Items	Specification
GSD @ altitude	13.5m @720km
Spectral Bands	510 ~ 590, 600 ~ 680, 710 ~ 890 nm
MTF	> 12 % for all bands and over the entire field of view
SNR	> 70 for all bands
Number of Pixels	3456 active pixels for each band
Dynamic Range	8 bits
Power Consumption	< 10 W camera, 12/18W thermal control heater
Overall Mass	6.5 kg
Temperature Range	Operational : -10 ~ 40 °C, Survival : -20 ~ 120 °C

Table 1. System Characteristics of the MEIS

2. Multi-spectral Earth Imaging System

2.1. Overview

At the operational orbital altitude of 720 km, the MEIS is able to take images of the earth's surface with the swath width of about 48 km and the ground sampling distance (GSD) of 13.5 m for three spectral bands at nadir. Its optical subsystem guarantees the system MTF (modulation transfer function) value greater than 12 % at the Nyquist frequency. With low-noise CCDs and readout electronics, it gives the SNR (signal-to-noise ratio) higher than 70 at the target reflectance of 0.25 and the sun elevation angle of 65 degrees for all spectral bands. The offset correction and gain control functions of the MEIS allow observation with a wide dynamic range for different levels of target brightness. The system characteristics of the MEIS are summarized in Table 1.

2.2. Optical Subsystem

The optical subsystem of the MEIS was designed and assembled in cooperation with the Center for Scientific and Industrial Research (CSIR) in the Republic of South Africa. It is a Mangin variant that consists of various lenses, prisms, and mechanical components. The design philosophy of the optical subsystem is to use the superior optical, thermal, mechanical, and radiation-resistant properties of fused silica for all critical optical and spacing components. All lenses and prisms are made with the Suprasil-1 (a top optical grade fused silica from Heraeus), while the spacing tube is made with fused silica of lower grade. The only component that is not made with silica is the internal baffle that is made with aluminum. The internal baffle is anodized using a qualified process and mounted in a manner to minize the thermal stress transferred to other optical components. The housing of the imaging group is mainly made with aluminum. The external baffle is made with glass fiber to reduce the weight and electromagnetic interference from communication antennas of KITSAT-3. The interface mechanism to the satellite bus provides the thermal coupling with the bus structure and prevents the raw shock from being propagated to the main spacing tube during launch.

The edges of lenses and the inside of the main spacing tube are painted with an all-solid 2-component low-outgassing epoxy paint. This paint is bead-blasted to achieve a mat finish on the internal surfaces to minimize the stray light. The backside of the main mirror and the disk baffle in front as well as the prism cluster are painted with the same material for the elimination of stray light. All active optical surfaces, which are not cemented, are coated with an

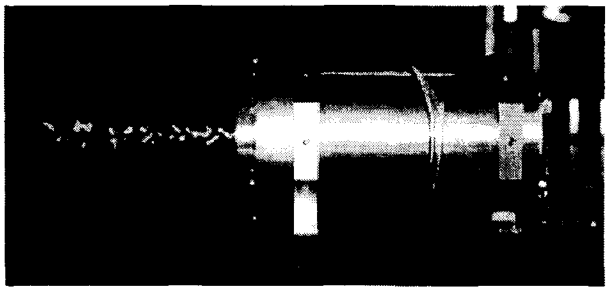

Figure 1. Photograph of KITSAT-3 MEIS

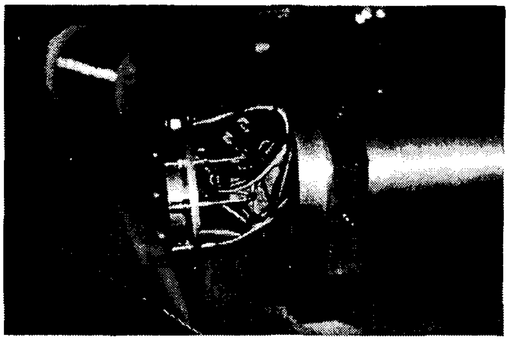

Figure 2. Photograph of Prism Cluster of KITSAT-3 MEIS

in-house developed multi-layer anti-reflection coating, providing low reflectance in the 500 ~ 900 nm waveband. The prism cluster is manufactured as a single unit with the use of a custom alignment microscope, which permits the alignment of three CCDs within 3 μm and the focusing of 20 μm (See Figure 2).

The optical subsystem was tested at the temperature range of −20 ~ 70 °C. Some components were tested at the temperature as low as −30 °C. Even though it was analyzed that the MEIS would not experience the temperature beyond this range during its normal operation, two protective heating devices are placed around the main spacing tube together with temperature sensors. The KITSAT-3 on-board computer (OBC) monitors the temperature at a predetermined interval and activates the heaters when the temperature is below a pre-defined level. In addition, the heaters can be used for cleaning up the optical surface in front, which can be contaminated by materials out-gassed during launch and /or in vacuum condition.

The weight of the optical subsystem is less than 1 kg including the prism cluster and is 3 kg in total including the housing and satellite interface mechanism. The photograph of its flight model is shown in Figure 1 and the prism cluster and CCDs are shown in Figure 2.

2.3. Electronics Subsystem

The electronics subsystem consists of the Focal Plane Assembly (FPA), the FPA control, analog signal processing, digital interface, and power supply units, and survival heaters. To achieve the GSD of 13.5 m and the swath width of 48 km, three TC104 linear CCDs from Texas Instrument with 3456 active pixels are used for three spectral bands. The FPA control unit consists of clock generator/drivers and the telecommand/telemetry interface. The clock generator/driver generates all necessary pulses for the operation of the CCDs, black level adjustment, and analog-to-digital conversion.

The video signal from the CCD detector is converted into digital data in the analog signal processing unit. It performs the automatic offset correction using optical black pixels of the CCD. Its wide range of signal gain allows to image various ground targets with different relfectances at different illumination angles. The analog-to-digital converter converts the processed video signal into 8-bit digital data, which is transferred to the digital interface unit. The digital interface unit transmits the image data to the solid-state mass memory through the RS-485 differential interface. The power supply unit converts the unregulated bus voltage into voltages necessary for the CCDs and other units.

Figure 3. MEIS Test Image-Las Vegas

Figure 4. MEIS Test Image – Chuncheon

3. In-Orbit Performance of KITSAT-3 MEIS

KITSAT-3 was launched successfully into a sun-synchronous circular orbit with the altitude of 720 km on the 26th of May, 1999. The first imaging operation of the MEIS was performed on the 31st of May, 1999, 5 days after the launch over the western coast of the Korean Peninsula. This operation was performed to verify the functionality of the complete imaging chain that consists of the MEIS, the mass memory, the X-band transmitter and antenna, the ground station, and the image receiving and archiving system. During this operation, quick-look images were transmitted to the ground station in real time. The complete images were received on the following day of operation. Even though most of the first image was covered by cloud, the Soheuksan-Do Island was identified beneath the cloud.

Since then, about 75 times of imaging operation were performed by the 9th of October, 1999 during the initial check-out period of the satellite. The quality of images acquired during the initial imaging operation was far superior to what had been anticipated. They revealed the details of the earth's surface in all three spectral bands. In addition, no degradation of images due to the instability of the satellite bus was identified with naked eyes. However, it was discovered that the green spectral band failed to produce valid image data with one of eight gain control steps. The degradation of the image quality was also observed when the UHF transmission system was turned on during the imaging operation, which is understood to be due to the electromagnetic interference between the transmission system and the MEIS. By turning off the transmission system during the imaging operation, the interference was avoided. In the preliminary assessment, one user group in Korea remarked that KITSAT-3 images deliver more information than those of SPOT multi-spectral bands or LANDSAT 2, 3, and 4 bands even when they are sharpened with 5 m panchromatic images. In-depth quantitative analysis must be performed in order to assess KITSAT-3 images qualitatively. Figure 3 and 4 are two false color images acquired during the initial operation.

A single scene is defined as an image of 3456 by 2048 pixels whose data size is about 170 Mbits (3 spectral bands and 8-bit quantization). The nominal image strip is defined as a collection of successive image scenes that is about 300 km long and 48 km wide. The maximum effective contact time with the ground station for image transmission is limited to about 10 minutes per day. Therefore, it takes about one and half days to downlink a single image strip to the ground station by the 3.3 Mbps X-band transmission system of KITSAT-3. In the nominal imaging operation mode, KITSAT-3 can give a single image strip in every the other day and the total imaging area is about 2,628,000 km^2 per year.

4. Conclusion

The quality of images produced by the KITSAT-3 MEIS was found comparable to that of existing commercial earth observation satellites from its preliminary assessment. The successful operation of KITSAT-3 and the MEIS has demostrated the possibility of acquiring high-quality earth images using micro-satellites. Considering that the development cost of KITSAT-3 and the MEIS was less than a tenth of that of other commercial satellites for earth observation, using micro-satellites can a cost-effective alternative to the traditional approach of remote sensing.

SaTReC plans to establish the database system and policy for the distribution of images from the KITSAT-3 MEIS through the Internet. These images will serve as a tool for academic research in remote sensing and as a platform for the development of more advanced imaging systems for micro-satellites. It is also anticipated that they will have competence in the commercial remote sensing market with some additional optimization and qualitative analysis.

Acknowledgement

The KITSAT-3 MEIS was developed as an international cooperative work with the University of Stellenbosch and the Center for Scientific and Industrial Research of the Republic of South Africa. SaTReC and these two bodies overcame the cultural difference and many technical challenges with the spirit of cooperation and genuine endeavor that brought forth the successful operation of the MEIS, which the authors would like to appreciate sincerely on behalf of SaTReC.

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