Characteristics of COMS MI Radiometric Calibration

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Abstract: Communication Ocean Meteorological Satellite (COMS) is planned to be launched onto Geostationary Earth Orbit in 2008. The meteorological imager (MI) is one of COMS payloads and has 5 spectral channels to monitor meteorological phenomenon around the Korean peninsular intensively and of Asian-side full Earth disk periodically. The MI has on-board radiometric calibration capabilities called "blackbody calibration" for infrared channels and "space look" for infrared/visible channels, and radiometric response stability monitoring device called "albedo monitor" for visible channel. Additionally the MI has on-board function called "electrical calibration" for the check of imaging path electronics of both infrared and visible channels. The characterization of MI performance is performed to provide the pre-launch radiometric calibration data which will be used for in-orbit radiometric calibration with the on-board calibration outputs. The radiometric calibration of the COMS MI is introduced in the view point of instrument side in terms of in-orbit calibration devices and capabilities as well as the pre-launch calibration activities and expected outputs.

Keywords: Communication Ocean Meteorological Satellite, COMS, meteorological imager, MI, radiometric calibration.

1. Introduction

Communication Ocean Meteorological Satellite (COMS) for the hybrid mission of meteorological observation, ocean monitoring, and telecommunication service is planned to be launched onto Geostationary Earth Orbit in 2008 according to the Korea national space program[1]. The mission orbit for COMS will be selected in the range from 116° East to 138° East. The meteorological payload of COMS is an imager which will monitor meteorological phenomenon around the Korean peninsular intensively and of Asian side full Earth disk periodically[2].

Korea Meteorological Administration (KMA) is the principal user of the image data of the meteorological imager (MI) of COMS and supports the development of the MI in the financial aspect. KMA has defined the user requirements for the MI of the COMS. The COMS development is performed by the joint team of KARI and Astrium under Astrium's responsibility. As a part of the COMS program, the MI is provided by ITT and delivered to KARI under monitoring by Astrium and KARI. COMS MI will be operated per mission request by KMA.

The MI is a five-spectral channel two-axis scanning imaging radiometer to sense radiant and solar reflected energy from the Earth simultaneously and to provide imagery and radiometric information of the Earth's surface and cloud cover. The MI has 1 visible and 4 infrared (IR) channels as shown in the Table 1. The MI is required to operate its mission through normal Earth imaging and in-orbit calibration continuously all the life time including the satellite eclipse periods during which minimum performance degradation is required.

Table 1 MI Spectral Channels
(IFOV: Instantaneous Field Of View,
IGD@N: Instantaneous Ground Distance at Nadir)

No.	Channel	Wavelength (㎛)	IFOV (μrad)	IGD@N (km)
1	VIS	0.55 – 0.80	28	1
2	SWIR	3.5 – 4.0	112	4
3	WV	6.5 – 7.0	112	4
4	WIN1	10.3 –11.3	112	4
5	WIN2	11.5 -12.5	112	4

The purpose of the paper is to introduce the COMS MI radiometric calibration, which will be characterized in the following sections in the view point of instrument side in terms of in-orbit calibration devices and capabilities as well as the pre-launch calibration activities and expected outputs for IR and visible channels respectively.

2. Infrared Channel Calibration

The MI sweeps a swath along EW direction and step along NS direction for one visible and four IR channels using its 2-axis rotation scan mirror. During imaging operations, a scan line is generated by rotating the scan mirror in the East-to-West direction. At the end of the line, the scan mirror elevation is changed by a stepped rotation in the North-to-South direction. The next scan line is then acquired by rotating the scan mirror in the West-to-East direction after turn around at the end of the scan line. This process continues to the end scan line of the imaging area. This scanning method provides flexible scan control enabling coverage of small areas as well as full earth disk and continuous observation of severe storms and of dynamic weather phenomena.

During imaging the frame of observation area the MI looks cold space at the either (East or West) side end of EW scan line to update zero radiance reference value periodically. For this activity, the MI has two modes of scanning, scan clamp mode and space clamp mode (Fig. 1, 2). The scan clamp mode scans the full earth width (the EW direction) with over-scan on the side toward the designated space position (normally 10.4° away from the satellite nadir point). Imaging scan of the scan clamp is kept going to the space position in the every other scan line every 2.2 sec.. The scan clamp mode is used when scanning the full disk or a sector of the earth having full E-W width. The space clamp mode is the choice for scanning a small frame within Earth's disk. This mode interrupts the frame imaging scan process every designated time interval for a scan to space. Two space clamp intervals are used normally. The fast space clamp mode scans to space every 9.2 sec. and the slow space clamp mode scans to space every 36.6 sec..

The MI carries an on-board blackbody target inside of the sensor module for the blackbody calibration which is full aperture, end-to-end path (from input to output of instrument), full focal plane calibration for in-orbit radiometric calibration of the IR channels. The on-board blackbody target, called Internal Calibration Target (ICT), is located at the opposite direction to the nadir, so that the scan mirror is rotated 180 degrees in the NS direction from imaging mode to the blackbody calibration mode (Fig. 3). The full-aperture blackbody calibration can be performed by the scan mirror's looking at the ICT via ground command or automatically.

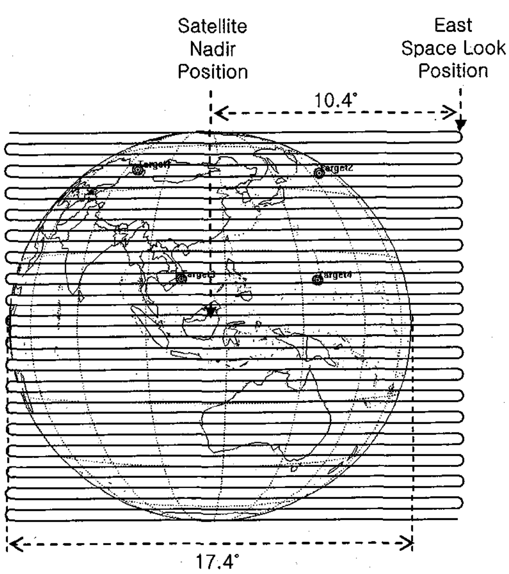

Fig. 1 Schematic Diagram of Scan Clamp

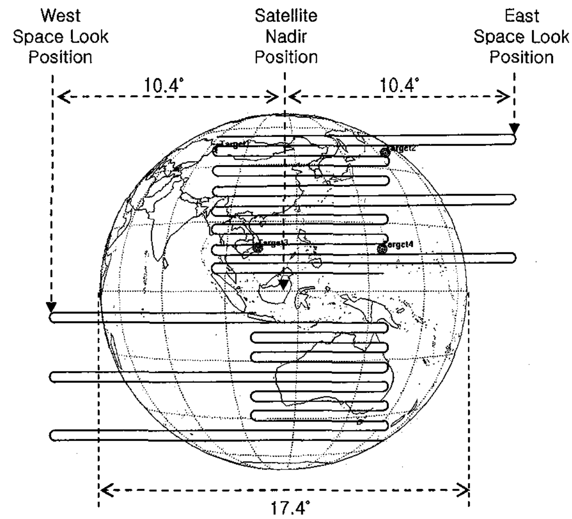

Fig. 2 Schematic Diagram of Space Clamp

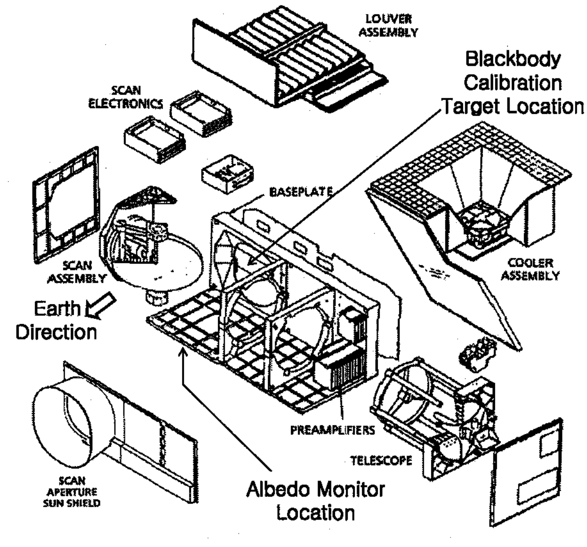

Fig. 3 MI Sensor Module

The IR blackbody calibration can be performed automatically every 19.4 minutes or manually by ground command with the maximum valid interval of 30 minutes. Dwell time at the blackbody (ICT) is about 2 seconds. The blackbody calibration does not interrupt an earth scan. In case of the full Earth disk imaging, normally the blackbody calibration follows the imaging. A blackbody calibration sequence requires less than 1 minute. Each blackbody calibration sequence includes scans to space for zero radiance reference before and after the blackbody dwell. The temperature of the ICT is measured precisely by the imbedded thermistors and is sent through telemetry to ground station. The ICT fills the optical aperture of the MI. The calibration process includes all parts of the imaging path from scan mirror to digital signal output end. The temperature of the ICT will vary with time of day and year in orbit within the controlled range.

The IR on-board calibration capabilities of the MI have the same process used successfully on GOES[3] and MTSAT-2. The IR radiometric quality of the MI image data is maintained by frequent looks of space and timely view of the full-aperture on-board blackbody for in orbit calibration.

The pre-launch instrument radiometric performance parameters of the IR channels are measured during Final Thermal Vacuum (FTV) testing which is to be carried out on ground by ITT. The performance parameters to be tested in the FTV chamber include IR channel radiometric response, response non-linearity, noise, response dynamic range, traceability of calibration to the US National Institute of Standards and Technology (NIST), and data quantization as well as the IR channel on-board calibration characterization parameters. The pre-launch IR radiometric calibration is established based on the performance parameters measured during the FTV test.

The FTV radiometric test is done using two accurate extended-area blackbodies in a thermal vacuum chamber. The chamber is used to avoid atmospheric signal loss and to better simulate the space environment in which the instrument must operate. The blackbodies are used as two infrared sources which generate the range of radiances expected from the Earth and deep space respectively. The IR blackbody sources fill the instrument optical aperture. The blackbody targets are high emissivity sources and contain precision thermal sensors. The blackbody target used for the Earth, called External Calibration Target (ECT), is controlled to have several temperature levels varied from cold to hot and stabilized at each calibration temperature level. The space target temperature is kept at less than 90K and therefore is below the lowest noise equivalent absolute temperature for any channel. It is noted that the calibration traceability to NIST is done via the temperature of the blackbody. During FTV testing the instrument internal temperatures as well as the detector temperature are controlled and maintained. This test performs all instrument control, data collection and computations necessary to produce the IR calibration data.

Calibration of a satellite radiometer is the finding of a transfer function from digital counts output of the instrument to scene input spectral radiance for all the channels. In order to find the transfer function called calibration equation, the output of the instrument is collected during the FTV testing while the instrument is viewing the ECT at a series of several temperature levels. Since the IR detectors and preamplifiers show almost linear response to input radiance, the quadratic fit of the output counts to the input radiance has been used for the calibration equation in the GOES imagers[4] and is to be used in the COMS MI for the pre-launch radiometric calibration of all the IR channels. The calibration equation can be expressed as the following:

$$R = qX^2 + mX + b \qquad (1)$$

where R is input radiance from scene,

X is output count of the instrument,

q, m, b are radiometric calibration coefficients.

During the FTV test, with respect to the ECT and the space target, pre-launch radiometric calibration coefficients (q, m, b) will be established by ITT with the assessment of the linearity of the calibration equation. The coefficients for each detector in the IR channels will be provided by ITT at several combinations of operating temperatures of instrument interior and detector.

After the calibration of the instrument imaging path response to the ECT, the ICT is also calibrated with respect to the ECT in terms of the temperature of the blackbodies while the scan mirror of the instrument looks at the ICT during the FTV testing before launch. The pre-launch ICT calibration provides the conversion from the ICT temperature to the ICT emitted radiance, which will be expressed as the following cubic polynomial equation.

$$R_{BB} = a_3 T_{BB}^3 + a_2 T_{BB}^2 + a_1 T_{BB} + a_0 \qquad (2)$$

where R_{BB} is the radiance emitted from ICT,

T_{BB} is the ICT temperature measured by the thermistors,

a_0, a_1, a_2, a_3 are conversion coefficients.

The conversion coefficients of ICT radiance will be provided by ITT with the ICT calibration error traceable to the ECT.

The COMS MI will be calibrated before launch to have the absolute calibration accuracy equal to or better than 1K(rms) at 300K for the IR channels.

The quadratic equation of Eq. (1) is also used for in-orbit radiometric calibration, where the in-orbit quadratic term coefficient (q) is taken from the pre-launch values, the in-orbit slop term coefficient (m) is obtained from the in-orbit blackbody calibration output counts, and the in-orbit intercept term coefficient (b) is calculated from in-orbit space look data. Pre-launch MI characterization data will be provided from ITT to support the in-orbit calibration. For example, scan mirror emissivity measurement data and instrument 1/f noise test data will be provided before launch to support the correction of the scan mirror emissivity variation and the normalization (destriping), if needed, during in-orbit calibration respectively, which have been performed at the in-orbit calibration process of the GOES[5].

3. Visible Channel Calibration

For the visible channel there is no on-board device dedicated to the in-orbit calibration except for the space look functionality. The space look data will be taken for the visible channel as those for the IR channels.

The pre-launch instrument radiometric performance parameters of the visible channel are measured during post-vibration bench testing at ambient temperature and pressure and the FTV testing which are to be carried out on ground by ITT. The visible pre-launch calibration of the MI will be accomplished by the use of an integrating sphere device during the post-vibration bench testing. The integrating sphere is used to generate a visible spectral radiance which is traceable to the NIST.

Since the visible detectors and preamplifiers have good linearity of response to input radiance, the quadratic equation of Eq. (1) is used for the pre-launch calibration equation of the visible channel and the calibration coefficients (q, m, b) will be provided by ITT for each detector in the visible channel with the assessment of the linearity of the calibration equation.

An assembly called the albedo monitor is mounted in the sensor module of the MI to monitor the in-orbit response change of the visible channel over the mission life. It uses sunlight through a small aperture as a source. Albedo monitor is not a calibrator because it only uses a partial instrument aperture. Only monitoring information about the electrical path (including detectors) of the visible channels can be obtained through the albedo monitor observations. Albedo monitor is mainly to determine the degradation of detector.

The albedo monitor observations occur once per day, every day of the year. Observation occurs during a 35-minute period centered at 06:00 AM satellite time. During an observation, the MI scans the sun as seen through a small hole. The process uses the entire optical system path (from scan mirror through telescope to relay optics) and detectors. This process also includes all electronics from preamplifier to digital signal output end. While the responsivity of the instrument's visible channel may change with time, sunlight through the albedo monitor path, corrected for some systematic errors such as Sun-Earth distance variation effect, remains a consistent reference for the stability monitoring of visible channel. The albedo monitor of the MI is designed to have the same process used on MTSAT-2.

4. Electrical Calibration

In addition to radiometric calibration, for both IR and visible channels, electrical calibration is provided to check stability and linearity of the output data of the image signal processing electronics by using internal reference signal. During in-orbit operation electronic calibration is performed by inserting an electrical reference signal into the imaging path electronics after the detectors. The results are part of the raw image data. The reference signal source is a 12-bit digital-to-analog converter and a precision voltage reference. The output of the converter connects to the amplifier system through ultra-stable, high-precision resistors. Since only electronics path after detector is checked, the output data of electronic calibration can not be used for in-orbit radiometric calibration purpose. The electrical calibration of the MI has the same process used successfully on GOES[3] and MTSAT-2.

5. Conclusions

The characteristics of the COMS MI radiometric calibration is introduced in the view points of instrument side in terms of in-orbit calibration devices and capabilities as well as the pre-launch calibration activities and expected outputs.

The MI has on-board radiometric calibration capabilities called "blackbody calibration" for infrared channels and "space look" for infrared/visible channels, and radiometric response stability monitoring device called "albedo monitor" for visible channel. Additionally the MI has on-board function called "electrical calibration" for the check of imaging path electronics of both infrared and visible channels. The MI uses an internal blackbody source and cold space for IR channel calibration, solar radiation for visible channel monitoring, and an internal test signal for the electronic calibration. The MI on-board calibration is designed to have the same process used successfully on GOES or MTSAT-2.

The characterization of MI performance is performed to provide the pre-launch radiometric calibration data which will be used for in-orbit radiometric calibration with the on-board calibration outputs.

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