# IN-FLIGHT CALIBRATION PLAN OF FORMOSAT-5 REMOTE SENSING INSTRUMENT

Kuo-Hsien Hsu*[1], Cynthia Liu[2], Nai-Yu Chen[3], and Bo Chen[4]
[1]Assistant Researcher, National Space Organization,8F, 9, Prosperity 1st Road, Science-Based Industrial Park,
Hsin-Chu, Taiwan; Tel: + 886-3-5784208#1082;
Email: khhsu@nspo.narl.org.tw

2Associate Researcher, National Space Organization,8F, 9, Prosperity 1st Road, Science-Based Industrial Park,
Hsin-Chu, Taiwan; Tel: + 886-3-5784208#1086
E-mail: cynthia@nspo.narl.org.tw

[3] Research Fellow, National Space Organization,8F, 9, Prosperity 1st Road, Science-Based Industrial Park, Hsin-Chu,
Taiwan; Tel: + 886-3-5784208#1331
E-mail: nychen@nspo.narl.org.tw

[4]Senior Engineer, National Space Organization,8F, 9, Prosperity 1st Road, Science-Based Industrial Park, Hsin-Chu,
Taiwan; Tel: + 886-3-5784208#1592
E-mail: bochen@nspo.narl.org.tw

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**ABSTRACT:** The primary payload of Formosat-5 is optical Remote Sensing Instrument (RSI), which will provide high-spatial-resolution images. The RSI consists of one panchromatic and four multi-spectral (blue, green, red, NIR) bands with spatial resolutions of 2 and 4 meters, respectively. Formosat-5 is expected to be launched in 2014. Once Formosat-5 reaches its mission orbit and completes the system check-out procedures, in-flight RSI calibration and characterization activities will be carried out according to the in-flight RSI calibration plan. This plan is developed based on the valuable experiences gained from the Formosat-2 program, which describes the methodologies and strategies of in-flight calibration activities. Specifically, the in-flight RSI calibration and characterization activities of Formosat-5 include the measurements of Ground Sample Distance (GSD), Modulation Transfer Function (MTF), Signal-to-Noise (SNR) and gain number adjustment. In addition, determinations of RSI radiometric and geometric calibration parameters are also considered to ensure the optimal quality of image product.

## 1. INTRODUCTION

The primary payload of Formosat-5 is optical Remote Sensing Instrument (RSI) which provides high-spatial-resolution images. Pre-flight activities of Fromosat-5 RSI calibration should be accomplished before launch. In this paper, the pre-flight calibration plan of Fromosat-5 RSI will not be addressed. Once Formosat-5 reaches its mission orbit and completes the system check-out procedures, in-flight RSI calibration and characterization activities will be carried out according to in-flight RSI calibration plan. Considering the post-launch activities in satellite commissioning and routine operation phases, Initial Orbit and Regular Maintenance phases are defined throughout the in-flight RSI calibration plan. The period of Initial Orbit phase is six months after launch. In Initial Orbit phase, it is the first time that we will perform RSI characteristics examination and calibration parameters derivation. And, fine-tune adjustment of calibration parameters and monitoring of RSI system performance will be processed constantly in Regular Maintenance phase.

This paper is organized as follows: overview of Formosat-5 RSI is described in section 2. Section 3 provides the in-flight RSI calibration plan. Section 4 concludes this plan.

## 2. FORMOSAT-5 RSI OVERVIEW

Formosat-5 will be operated on a 720 km Sun-synchronous orbit with an inclination angle of 98.28 degrees. The RSI is capable of push-broom image formation. The swatch width of Formosat-5 image in the nadir direction is 24 km. Table 1 lists some important RSI specifications.

Table 1. Formosat-5 RSI spectral specifications.

| Spectral band | Pixel numbers | Spectral range(nm) | Spatial resolution(m) | Contrast Transfer Function (CTF) | Signal-to-Noise ratio (SNR) |
|---|---|---|---|---|---|
| Pan | 12,000 | 575±20 | 2 | ≧0.1 | ≧92 |
| B1 | 6,000 | 485±9 | 4 | ≧0.2 | ≧100 |
| B2 | 6,000 | 560±11 | 4 | ≧0.2 | ≧100 |
| B3 | 6,000 | 660±13 | 4 | ≧0.2 | ≧100 |
| B4 | 6,000 | 830±16 | 4 | ≧0.16 | ≧100 |

## 3. IN-FLIGHT CALIBRATION PLAN

This in-flight calibration plans provides the purposes and implementation approaches for radiometric calibration, geometric correction, and quality assessment. The detail of each activity in the plan is listed in table 2.

Table 2. The approaches and purposes of in-flight calibration plan of Formosat-5 RSI.

| Activity | Approach | Purpose |
|---|---|---|
| Radiometric calibration | Absolute radiometric calibration (e.g., vicarious & cross-calibrations) | Determination of absolute radiometric coefficients |
| | Relative radiometric calibration | Determination of relative radiometric coefficients (e.g., relative response & dark current) |
| Geometric correction | LOS reference frame adjustment | Determination of alignment bias between LOS and RSI frames |
| | LOS vector adjustment | Determination of polynomial coefficients of LOS vector |
| Quality assessment | Modulation Transfer Function (MTF) measurement | Determination of MTF value |
| | Signal-to-noise ratio (SNR) measurement | Determination of SNR value |
| | Ground sampling distance (GSD) measurement | Determination of GSD value |
| | Image dynamic range adjustment | Gain number adjustment of electronic gain |

### 3.1 Radiometric Calibration

Since the optics transmission and the dark current of RSI could be changed due to out-gassing and radiations effects. The radiometric calibration is planned to constantly derive the radiometric coefficients and monitor the RSI radiometric characteristics. Specifically, absolute and relative radiometric calibrations are used to determine the absolute radiometric, relative response and dark current coefficients. In addition, the trending data of radiometric calibration coefficients is expected to be very valuable for us to understand the further characteristics of Formosat-5 CMOS sensor.

The radiometric calibration is planned to be frequently performed in Initial Orbit phase, and to be performed in on a regular basis (e.g., at least once per six months) in Regular Maintenance phase.

#### Absolute Radiometric Calibration

Since the Formosat-5 dose not equip with any on-board calibrator, vicarious and cross- calibrations are both planned to be performed in absolute radiometric calibration [CNES, 2011]. The calibration sites should have the features of spatial uniformity, temporal stability, and lambertian-like surface.

Vicarious calibration is mainly performed by collected measurement results of ground-surface reflectance and atmosphere conditions, such as ground-surface radiance, direct sun irradiance, sky radiance/irradiance, and atmosphere contents. These results are characterized simultaneously at the time Formosat-5 overpass the calibration sites. Predicted Top of Atmosphere (TOA) reflectance is deduced by radiative transfer code using above measurement result as input data. Another predicted TOA reflectance is also deduced directly from Formosat-5 images of calibration sites for comparison pupose. The in-flight absolute radiometric coefficient could be estimated based on pre-flight absolute radiometric coefficient and above calculations.

For cross-calibration, we need to select other reference sensors (e.g., Formosat-2) for Formosat-5. In addition, in order to correctly estimate the results between Formosat-5 and reference sensors, the same (or closest) viewing and solar angles among Formosat-5 and reference sensors are strongly required. In cross calibration, spectral interpolation of different spectral band and atmospheric correction are further needed for reference sensors and Formosat-5.The in-flight absolute radiometric coefficient is estimated based on pre-flight absolute radiometric coefficient and above calculations.

### Relative Radiometric Calibration

Due to uneven response of sensor elements, remote sensing image acquired by a typical linear sensor array usually exhibits the vertical stripes in image raw data. To eliminate such defect, relative radiometric calibration is necessary to be performed. By assuming linear response of each sensor element, we perform this calibration by implementing proper relative radiometric coefficients (e.g., dark current (offset) and the relative response value) of each sensor element.

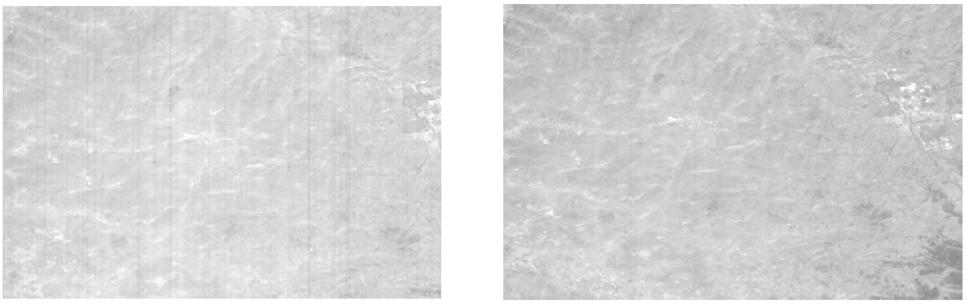

(a) (b)

Fig. 1. (a) Raw and (b) radiometrically calibrated FORMOSAT-2 images

The dark current images are planned to be acquired over Pacific Ocean in moonless nights. The sites acquired for relative response determination should have similar land-feature properties with those for radiometric calibration. By averaging sufficient of data, the dark current and relative response could be accurately estimated. As shown in fig. 1, the stripes in Formosat-2 raw image were removed by radiometric correction using coefficients of relative response and dark current.

### 3.2 Geometric Correction

The geometric correction is planned to be performed in order to improve the geo-location accuracy. The purpose of this work is to determine and fine-tune the geometric coefficients of the line-of-sight (LOS) reference frame and line-of-sight (LOS) vector used in geometric correction models.

### Line-of-sight (LOS) reference frame adjustment

This adjustment is planned to fine-tune the pre-flight measured transfer matrix (i.e., the alignment bias) between LOS ($R_{LOS}$) and body ($R_{PIP}$) frames by using Ground Control Points (GCP) database. In other words, misalignment between LOS ($R_{LOS}$) and body ($R_{PIP}$) frames leads to the unexpected geo-location error. As shown in Fig.2, there are at least 13 worldwide GCP sites used for Formosat-2, and they are useful for Formosat-5.

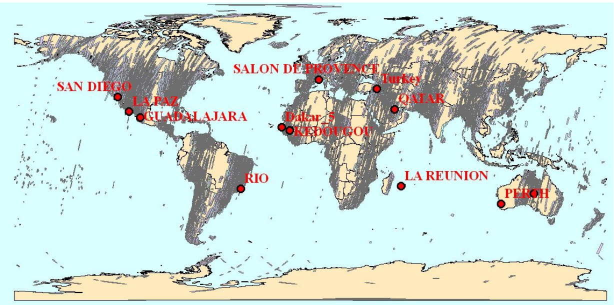


Fig. 2. Locations of worldwide GCP sites for the geo-location accuracy assessment.

In addition, Formosat-2 images would be considered as another one of the reference data source. Typically, there are three major steps proposed of this adjustment:

1. Identify GCP location ($X_{GCP,img}$) from image data,
2. Identify GCP location ($X_{GCP,gts}$) from GCP database,
3. Determine the bias coefficients to minimize the abs($X_{GCP,gts}$ - $X_{GCP,img}$) by using either optimization methods (e.g., least-square method) or statistic estimation.

### Line-of-sight (LOS) vector adjustment

The pixel $p$ on focal plane could be expressed by LOS vector in terms of two angles $\psi_{x,band}(p)$ and $\psi_{y,band}(p)$ in LOS ($R_{LOS}$) frame. Similar definition of two angles $\psi_{x,band}(p)$ and $\psi_{y,band}(p)$ could be referred from Formosat-2 RSI architecture in Fig.3.

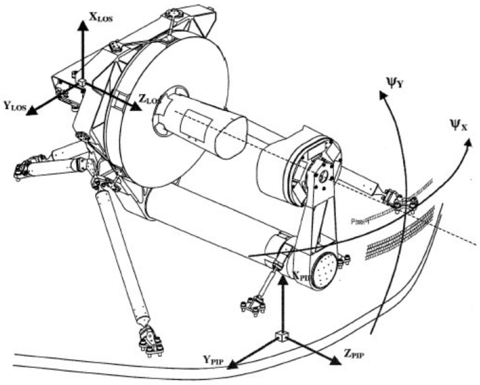


Fig. 3 Schematic diagram of Formosat-2 RSI.

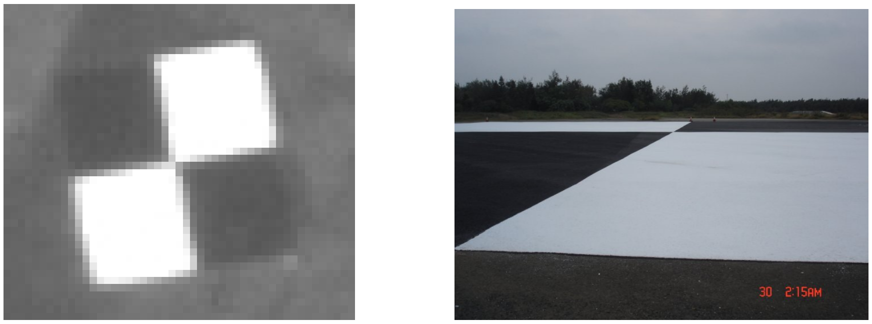
Typically, there are three major steps proposed of this adjustment:

1. Identify the location ($X_{img}$) from image data of each multispectral band,
2. Defining the reference location ($X_{ref,img}$) from image data of one of multispectral band,
3. Determine coefficients of polynomial equation to minimize the abs($X_{img}$ –$X_{ref,img}$) by using either optimization method (e.g., least-square method) or correlation method

## 3.3 Quality Assessment

### Modulation Transfer Function (MTF) Measurement

For an imaging system, measurement of spatial quality is typically preformed by calculating Modulation transfer function (MTF) or, equivalently, Contrast Transfer Function (CTF) of targets. Specifically, MTF is the normalized spatial frequency response of an imaging system, and it is defined as the normalized magnitude of the fast Fourier transform (FFT) of the point spread function (PSF). As shown in fig. 4, MTF site in Peng-Hu County constructed by NSPO is planned as the edge target of MTF measurement for yielding Knife Edge Function (KEF) which can be differentiated to obtain a PSF.



(a) (b)

Figure 4. (a) Formosat-2 image and (b) picture of NSPO’s MTF target site (60m X 60m) in Peng-Hu county.

The general steps of MTF measurement are proposed in the following description. Spatial qualities in along-track (X) and cross-track (Y) direction are planned to be examined simultaneously in MTF measurements.

1. Calculate the Knife Edge Function (KEF) by extracting the digital counts of MTF site image
2. Calculate Point Spread Function (PSF) by taking the first-derivative of KEF
3. Calculate the Fast Fourier Transform (FFT) of the PSF
4. Check the MTF value at the one half the sampling rate of the system (i.e., Nyquist frequency)

The MTF measurement is planned to be performed in Initial Orbit phase, and constantly be performed on a regular basis (e.g., at least once a year) in Regular Maintenance phase.

### Signal-to-Noise (SNR) Measurement

The SNR is defined as the ratio of mean to the standard deviation of digital counts extracted from images. In general, the noise source of optical remote sensing images consists of two parts, such as the RSI noise and variation of uniform landscape within images. Here, the RSI noise denotes all noises arose from hardware and software (e.g., compression). In addition, noise caused by the variation of landscape within image is due to no such a perfect site for SNR measurement. In order to understand the RSI performance from SNR result, numerical techniques for SNR measurement are proposed as follows:

1. Decompose an image into “*n*” images based on pre-flight SNR measurements,
2. Calculate SNR of each separate images considered samples within three standard deviation by:

$$\mathrm{SNR}= M/\sigma \tag{1}$$

   Where $M$: mean of digital counts, $\sigma$: Standard deviation of digital counts.

3. Calculate overall SNR of original image from SNR of $n$ separate images by,
   SNR= average (SNR of $n$ images)

The SNR measurement is planned to be performed in Initial Orbit phase, and constantly be performed on a regular basis (e.g., at least once a year) in Regular Maintenance phase.

### Gain Map Generation and Maintenance

For optimizing the image dynamics and avoiding the image saturation, a suitable gain number of on-board electronic gain (*G(spectral band, gain number)*) is a key parameter for image acquisition. An accurate gain number typically depends on scheduled location and date of image. Therefore, the concept of spatial decomposition and separate month for gain number selection is necessary by considering location and seasonal effects [CNES, 2007]. A database stores all worldwide gain numbers is named “Gain Map”. For example, Formosat-2 gain map contains more than 140 thousands gain numbers distributed globally and monthly.

The similar concept of spatial and seasonal distributions of gain number will still be adopted in Formosat-5 gain map. Basically, the spatial resolution of monthly gain number grid is at least 60km for compromising the swath (24 km) at nadir direction. The Formosat-5 gain map is planned to be generated either from Formosat-2 gain map or database of other optical remote sensing satellites (e.g., MODIS) by conversion method considering their differences of spatial and spectral bands.

### Ground Sampling Distance (GSD) Measurement

According to the specification of Formosat-5 RSI spatial resolution, GSD is 2m and 4m for panchromatic and multispectral band, respectively. This specification is planned to be examined in Initial Orbit phase by measuring the GSD target site (e.g., GCP, MTF). The ideal location of GSD target site should be in the nadir direction of Formosat-5 nominal orbit. Therefore, GSD could be simply determined by [NSPO,2007]:

$$\mathrm{GSD}= d_{real}/\, d_{img} \tag{2}$$

$$d_{img} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{3}$$

Where $d_{real}$ is the on-ground distance between targets, and $(x_i,y_i)$ is the location of corresponding target $i$ seen in the image.

## 4. CONCLUSIONS

In this paper, we present the methodologies and strategies of in-flight calibration activities of Formosat-5 RSI. This plan is developed based on valuable experience gained from Formosat-2 program. Specifically, radiometric calibration, geometric correction, and quality assessment of Formosat-5 RSI are described not only for determining the RSI radiometric, and geometric parameters, but also monitoring RSI system performance. In other words, all RSI characteristics and calibration parameters will be examined and deduced in Initial Orbit phase. And, these activities will be constantly performed during Formosat-5 operational life for monitoring the evolution of RSI performance. T the optimal quality of Formosat-5 image product is expected to be achieved after carrying out this plan,.

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