Development of the Compact Infrared Camera (CIRC) for earth observation

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ABSTRACT

We have developed Compact Infrared Camera (CIRC) with an uncooled infrared array detector (microbolometer) for space applications. The main mission of the CIRC is to demonstrate technology for wildfire detection. Wildfires are a major and chronic disaster that affects many countries, especially those in the Asia−Pacific region, and the situation may get worse with global warming and climate change. The CIRC detector has the largest format (640 × 480 pixels) ever used for observations of Earth from space. Microbolometers have the advantage of not requiring cooling systems such as a mechanical cooler and are suitable for resource-limited sensor systems or small satellites. In addition, the CIRC employs athermal optics and a shutter-less system, and hence, it is of a small size, is lightweight, and consumes low electrical power. The CIRC design was based on a commercial infrared camera and employs commercial-off-the-shelf (COTS) parts to reduce the cost and time for development. The CIRC will be carried as a technology demonstration payload of ALOS-2 and ISS/JEM, which will be launched in 2013 and 2014. We have developed the CIRC Proto Flight Model (PFM) and performed experiments for calibration in January 2012. In this paper, we present the verification results of the athermal characteristics and the calibration of the shutter-less system.
Keywords: remote sensing, thermal infrared imaging, uncooled infrared detector, wildfire

1. INTRODUCTION

Microbolometers are widely used in commercial and military applications. Their advantage is that they do not require a cooling system such as a mechanical cooler. Sensors without a detector cooling system can be made to have a small size, be lightweight, and consume low power. Although the sensitivity of a microbolometer is lower than that of an HgCdTe-based photonic infrared detectors, its advantage of not requiring a cooling mechanism makes it suitable for small satellites or resource-limited sensor systems.

JAXA has researched the application of microbolometers for observations of Earth[1]. The Compact Infrared Camera (CIRC) was developed as a technology demonstration payload for thermal infrared imaging from space using a microbolometer. The main mission of the CIRC is to detect wildfires. Wildfires are a major and chronic disaster that affects many countries, especially those in the Asia-Pacific region, and early detection is important. An effective means of early detection is to raise the observation frequency. Therefore, our aim is to realize frequent observations by loading CIRCs in many satellites in the future to take advantage of its small size, lightweight, and low power consumption. Other CIRC mission targets are volcanoes or heat island phenomena in a city. The CIRC will be carried as a technology demonstration payload of the Advanced Land Observing Satellite-2 (ALOS-2), and CALorimetric Electron Telescope (CALET), which will be attached to the Japanese Experiment Module (JEM-EF) of the International Space Station (ISS). In this paper, we present the verification results of the athermal characteristics and the calibration of the shutter-less system with the CIRC Proto Flight Model (PFM). In §2, we describe ALOS-2 and CALET. The mission and details of the CIRC are described in §3 and §4, respectively. In §5 and §6, we present the measurements and the initial calibration results of the CIRC PFM. The discussion and summary are given in §7.

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2. ALOS-2 AND CALET

2.1 ALOS-2

ALOS-2[2] is a follow-up mission to ALOS, which has been contributing to cartography, regional observation, disaster monitoring, and resource surveys since its launch in 2006. JAXA is conducting research and carrying out development activities to improve the wide and high-resolution observation technologies developed for ALOS to further fulfill social needs. These social needs include (1) disaster monitoring of damage areas, both in considerable detail and when these areas may be large; (2) continuous updating of data archives related to national land and infrastructure information; (3) effective monitoring of cultivated areas; and (4) global monitoring of tropical rain forests to identify carbon sinks. ALOS-2 will be launched in 2013.

ALOS-2 succeeds the L-band synthetic aperture radar (SAR) observation of ALOS PALSAR with enhanced capabilities. Table 1 lists the baseline specifications of ALOS-2. The mounting location of CIRC is shown in Figure 1. Basically, CIRC will take images of the target area when the SAR is pointing to the right at an off-nadir angle of 30°.

Table 1. Baseline specifications of ALOS-2.

Parameter	Specification
Size	9.9 m × 16.5 m × 3.4 m
Mass	<2000 kg
Bus power	>5200 W
Communication	<800 Mbps
Orbit	628 km

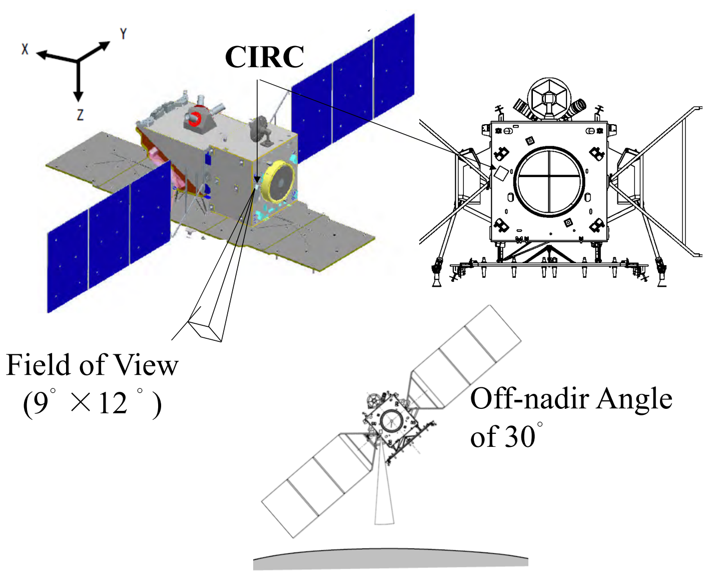

Figure 1. Schematic view of ALOS-2 and the mounting location of CIRC.

2.2 CALET

CALET[3] is an international program of the ISS that will search for signatures of dark matter and provide direct measurements of the highest energy of the cosmic ray electron spectrum to observe discrete sources of high-energy particle acceleration in our local region of the galaxy. CALET will address many outstanding questions, including (1) the nature of the sources of high-energy particles and photons through the high-energy spectrum, (2) the details of particle transportation in the galaxy, and (3) signatures of dark matter in either the high-energy electrons or the gamma ray spectrum. It will also be capable of monitoring gamma ray transients and solar modulation. CALET will be launched in 2013.

The baseline specifications of CALET are listed in Table 2. CIRC will be mounted on the bottom of CALET, which is shown in Figure 2.

Table 2. Baseline specifications of CALET.

Parameter	Specification
Mass	<500 kg
Bus power	>500 W
Communication	<300 kbps
Orbit	407 km (nominal)

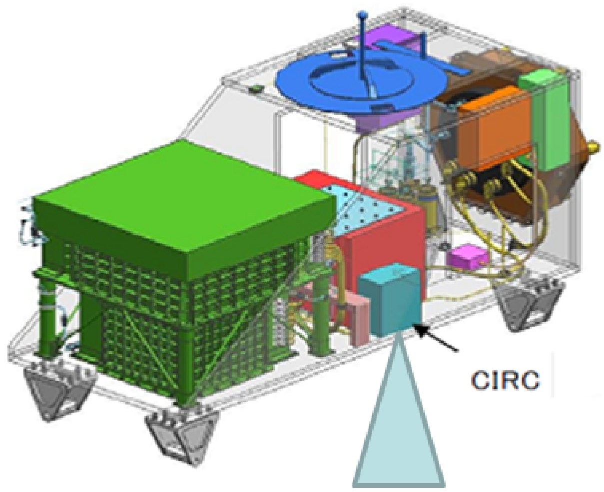

Figure 2. Schematic view of CALET and the mounting location of CIRC.

3. MISSION OF CIRC

The main mission of CIRC is to demonstrate technology for wildfire detection using a microbolometer. Wildfires are a major and chronic disaster that affects many countries in the Asia−Pacific region (see Figure 3), and there are suggestions that this will get worse with global warming and climate change. In the Sentinel Asia project, which will share disaster information in near real-time across the Asia−Pacific region, wildfire detection has been chosen as one of the important activities to be monitored. The other CIRC mission targets are volcanoes or heat island phenomena in a city. Observing these targets with a thermal infrared imager will be useful at monitoring volcanoes or solving the heat island problem.

The CIRC has the characteristics of athermal optical and shutter-less systems. The athermal optical system of the CIRC was designed by combining two infrared materials: germanium and chalcogenide. The temperature does not need to be controlled using a heater. Thus, we realized a CIRC with a small size, light weight, and low power consumption. Moreover, the CIRC design was based on a commercial infrared camera and employs commercial-off-the-shelf (COTS) parts to reduce cost and time for development.

It is possible to increase the observational frequency of wildfires if CIRCs are carried on various satellites, which can take advantage of its small size, lightweight, and low power consumption. If CIRCs are carried on ALOS-2 and ISS/CALET, the average observation interval becomes 39, 97, and 196 h in Russia, Japan (Tokyo), and Brunei, respectively (Figure 4).

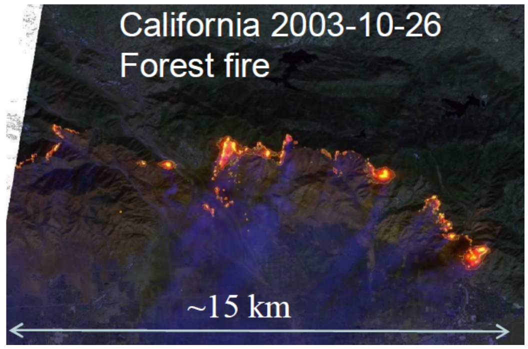

Figure 3. ASTER/TIR image of a forest fire in California.

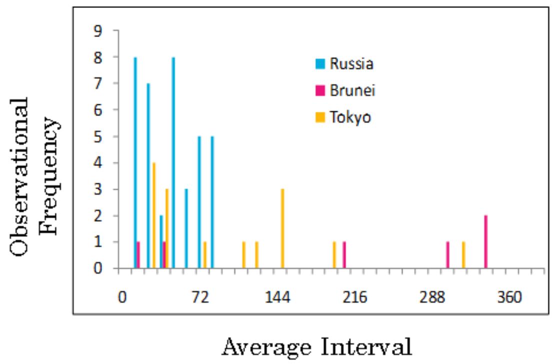

Figure 4. Average observing interval.

4. BASELINE SPECIFICATIONS OF THE CIRC

The baseline specifications of the CIRC are listed in Table 3. We set the baseline specifications to meet requirements for wildfire detection. The detector has a large format (640 × 480 pixels) to obtain a wide field of view. The spatial resolution is an important factor for wildfire detection. The spatial resolution is 200 m from an altitude of 600 km (ALOS-2) and 130 m from an altitude of 400 km (CALET). Eliminating the cooling system reduces the size (110 mm × 180 mm × 230 mm) and electrical power (<20 W).

Table 3. Baseline specifications of the CIRC.

Parameter	Specifications
Size	110 mm × 180 mm × 230 mm
Mass	3 kg
Detector	Uncooled infrared detector
Wavelength	8-12 μm
Number of pixels	640 × 480
Special resolution	<200 m @600 km (ALOS-2) <130 m @400 km (CALET)
Field of view	12° × 9°
Exposure	33 ms
Dynamic range	180−400 K
NEdT	0.2 K @300 K
FPN	0.3 K @300 K
Power	<20 W

5. CALIBRATION OF THE CIRC PFM

In this section, we present the calibration results of the CIRC PFM. Figure 5 shows a picture of the CIRC PFM.

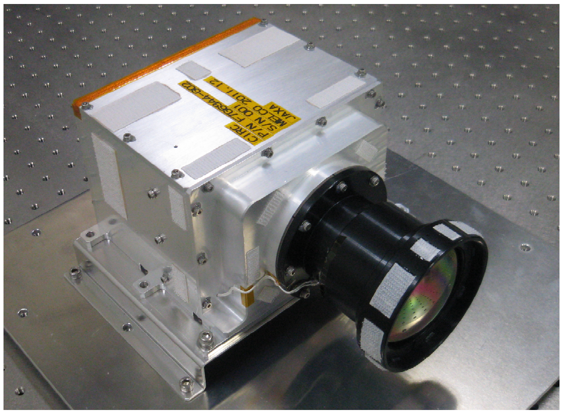

Figure 5. Picture of the CIRC PFM

In the laboratory experiment at the JAXA Tsukuba Space Center, we measured the Modulation Transfer Function (MTF) of the CIRC PFM in a vacuum to evaluate the image capture performance of the sensor system. We also carried out radiometric experiments.

5.1 Measurement setup of MTF experiments

The schematic diagram and configuration of the experimental setup are shown in Figures 6 and 7, respectively. The CIRC was placed inside the vacuum chamber in the laboratory and surrounded by a shroud to control its ambient temperature with a heater and cooler. The pressure in the vacuum chamber was ~10^{-5} Torr during the experiment. Infrared rays were emitted by a blackbody (CI Systems SR800) and passed through the four-bar targets (shown in Figure 8) mounted inside the reflective collimator system (CI Systems ILET-5-1.1). The intervals of the slits of the four-bar targets were equivalent to 1-, 1/2-, 1/4-, and 1/6-Nyquist frequencies. The collimated infrared rays passed through a germanium window mounted on to the side of the vacuum chamber that transmitted the infrared rays from outside the vacuum chamber to be detected by the CIRC.

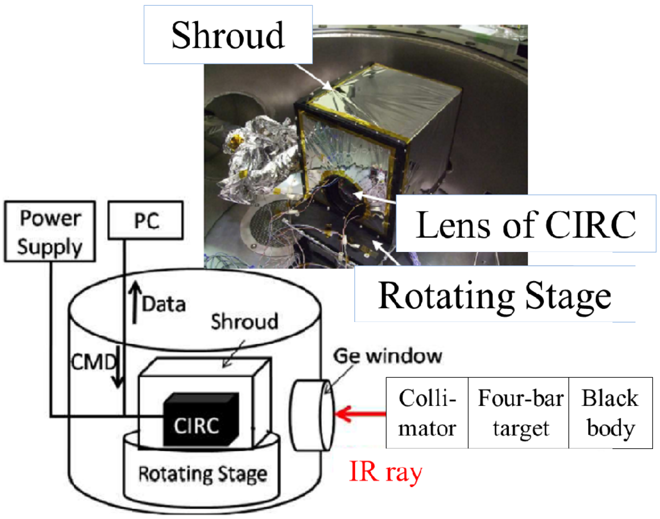

Figure 6. Schematic diagram of the MTF experimental setup.

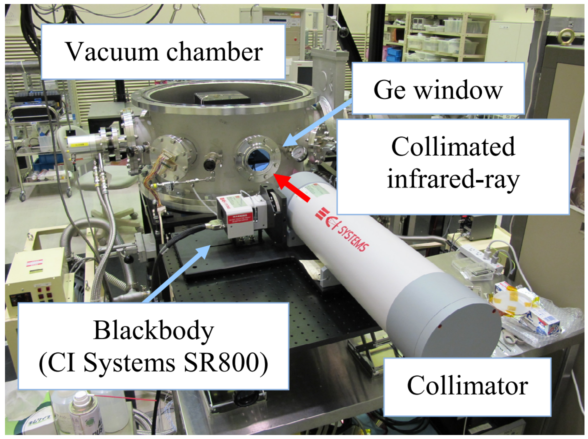

Figure 7. Experimental configuration

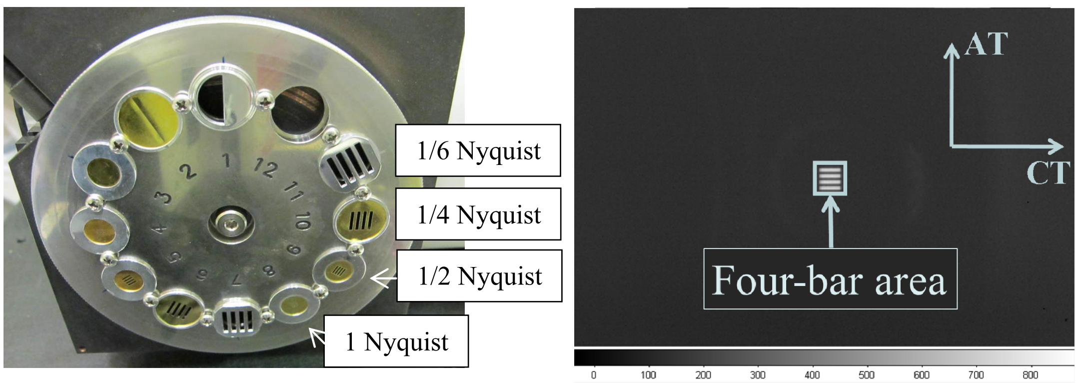

Figure 8. (left) Four-bar target mounted on the collimator system and (right) image of the four-bar target taken with CIRC.

5.2 Data of MTF measurement

We measured MTF in a vacuum environment. The detector positions for measurement were at the center, ±5° in the cross-track (CT) direction, and ±3.5° in the along-track (AT) direction, as shown in Figure 9. MTF for the CT/AT directions was measured by rotating the four-bar target. The temperature of the shroud was set to -15–50 °C. The procedure for MTF analysis was the same as that used by Nakamura et al. (2011)[4].

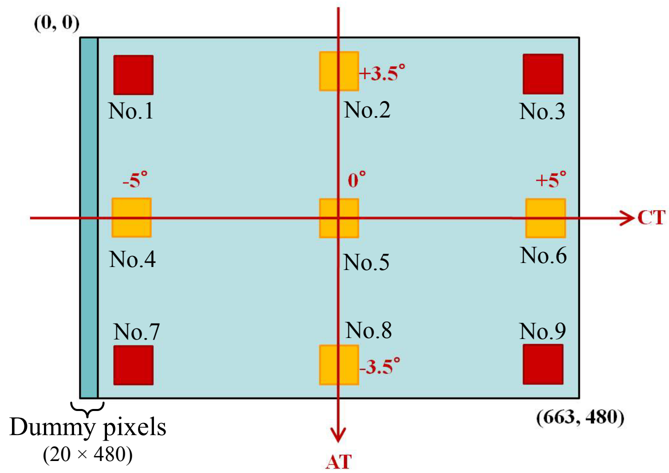

Figure 9. Positions of MTF measurement on the screen. The nine positions are marked as Nos. 1–9. Dummy pixels are optical black pixels, which mean non-photosensitivity and have the same electrical property as standard effective pixels.

5.3 Measurement setup of radiometric experiments

Figure 10 shows the schematic diagram of the radiometric experimental setup. The experimental configuration was the same as that for the MTF experiments. The blackbody was placed before the CIRC inside the vacuum chamber.

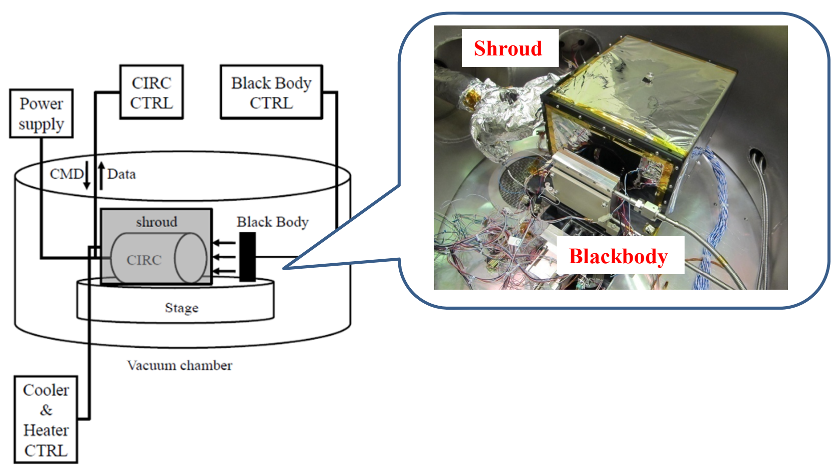

Figure 10. Schematic diagram of the radiometric experimental setup.

5.4 Data of radiometric measurement

We measured the radiometric performance of the CIRC in a vacuum environment. Table 4 lists the measurement conditions. For sensitivity correction, we measured data at blackbody temperatures of -10–50 °C when environmental temperature of the CIRC is -15, 5, 15, 30, and 45 °C. Moreover, the environmental temperature was changed from -15 to 50 °C under blackbody temperatures of 50, 30, 10, and -10 °C for stray-light correction.

Table 4. Measurement conditions for radiometric measurement.

Environmental temperature of the CIRC [°C]	Temperature of blackbody [°C]
-15, 5, 15, 30, 45	-10–50 (basically every 5 °C)
-15–50 (every 1 °C)	-10, 10, 30, 50

6. RESULTS

6.1 Results of MTF measurement

We measured MTF for the CT/AT directions at nine detector positions. Athermal characteristics when measuring the Nyquist frequencies are shown in Figure 11. MTF for the CT direction was constant regardless of the environmental temperatures on the whole. In contrast, MTF for the AT direction had a gradient and was lower in low-temperature environments.

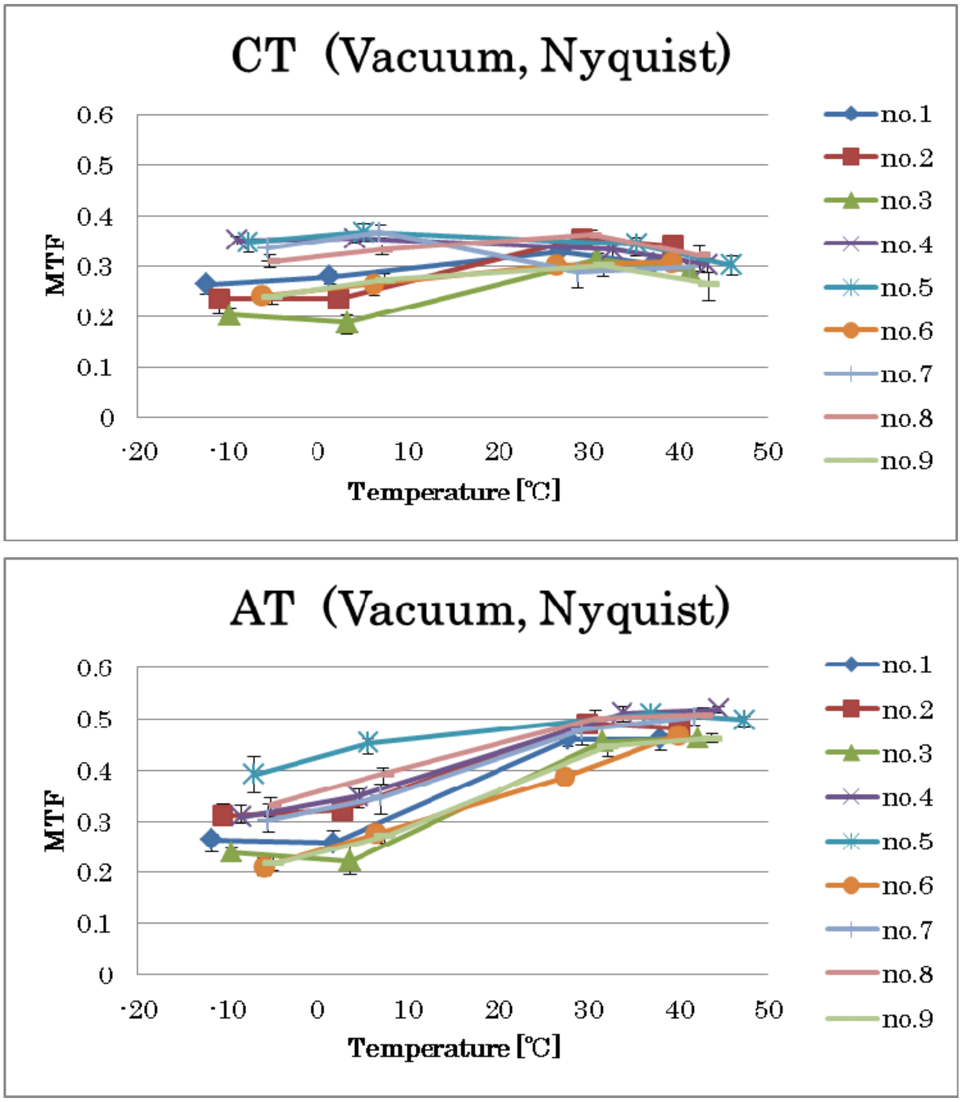

Figure 11. Athermal characteristics at Nyquist frequency for the CT/AT directions. Horizontal and vertical axes represent the environmental temperature and MTF, respectively. The upper and lower panels are for the CT and AT directions, respectively. Differences in color show the detector positions.

6.2 Results of radiometric measurement

We have verified the calibration in the case of shutter-less system. First, we analyzed noise equivalent differential temperature (NEdT) and flat pattern noise (FPN) with stray-light correction and thermal sensitivity by using the data at blackbody temperatures of 15/30/40 °C (TBB15, TBB30, TBB40). Table 5 lists the averages for NEdT and FPN. The procedures to calculate NEdT and FPN are given below:

◆ Procedures of NEdT and FPN

0. Perform dummy correction for all frames. Dummy correction is a process of subtracting the average of dummy pixels (20 × 480 pixels) from each effective pixel.
1. Correct amount of stray light by stray-light correction for all frames.

➢ NEdT

2. Estimate standard deviation (σ1 [DN]) of brightness variation using data at TBB30.
3. Calculate thermal sensitivity [DN/K] from data of TBB40 and TBB15.

$$\text{Thermal sensitivity} = \frac{Data_{TBB40} - Data_{TBB15}}{40 - 15} \tag{1}$$

4. Determine NEdT [K] as shown in the following equation.

$$\text{NEdT} = \sigma 1 \div \text{(thermal sensitivity)} \tag{2}$$

➢ FPN

2′. Calculate sensitivity correction factor (α) using data of TBB40 and TBB15.

$$\alpha = \frac{\frac{1}{N}\sum_{n=1}^{N}\left(Data_{TBB40} - Data_{TBB15}\right)}{Data_{TBB40} - Data_{TBB15}} \tag{3}$$

3′. Subtract average of data at TBB15 from data at TBB30 as offset correction ($Data_{TBB30,OC}$).

4′. Perform sensitivity correction for the offset-corrected data at TBB30 ($Data_{TBB30,OC,SC}$).

$$Data_{TBB30,OC,SC} = Data_{TBB30,OC} \times \alpha \tag{4}$$

5′. Estimate standard deviation (σ2 [DN]) of brightness using $Data_{TBB30,OC,SC}$.

6′. Determine FPN [K] as shown in the following equation:

$$\text{FPN} = \sigma 2 \div \text{(thermal sensitivity)} \tag{5}$$

Table 5. Average for NEdT and FPN.

Average NEdT [K]	Average FPN [K]
0.19	0.27

Next, we carried out background correction with stray-light correction and sensitivity correction. Figure 12 shows example images before and after the background correction. The corrected image (right in Figure 12) is smooth for all of the effective pixels. The procedure for background correction is given below:

- Procedure of background correction

    0. Perform dummy correction to all frames before background correction.

    1. Correct the amount of stray light corresponding to standard data by stray-light correction.

    2. Perform background correction by carrying out offset and sensitivity correction.

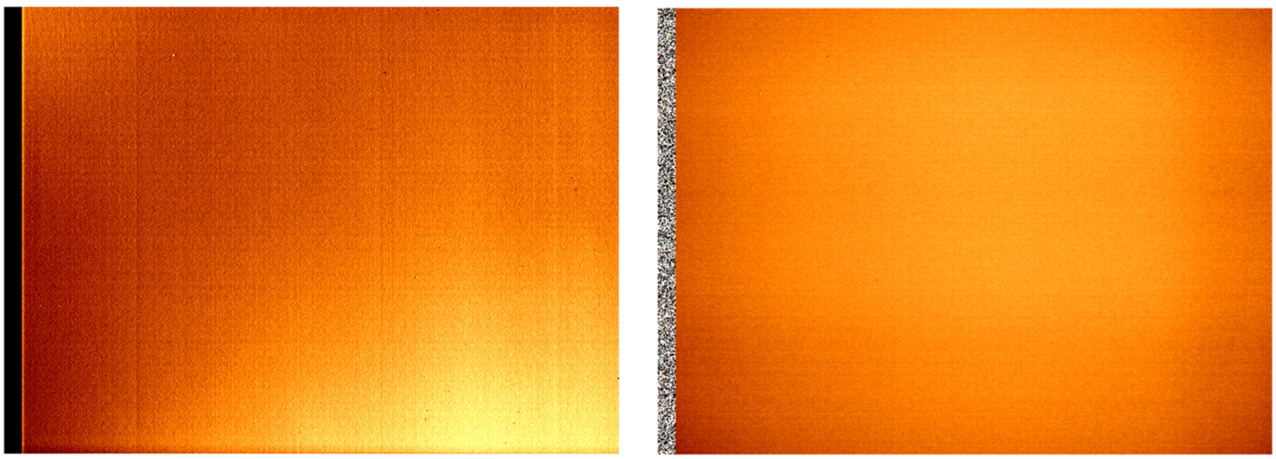

Figure 12. (left) Image before background correction. This is a stray-light corrected image of step 1. (right) Image after the background correction. The size of these images is 660 × 480 pixels.

7. DISCUSSION AND CONCLUSION

7.1 MTF

The results of the MTF measurement are summarized as follows:

- The MTF in the CT direction is constant regardless of environmental temperatures on the whole.
- The variation in the MTF in the AT direction was larger than that in the CT direction.

We measured the MTF characteristics of the CIRC as they are an important image capture performance parameter for optical sensor systems and confirmed the athermal characteristics of the CIRC.

7.2 Radiometry

From the analysis results, NEdT and FPN were estimated to be 0.19 and 0.27 K, respectively. These results satisfy the specifications for the CIRC. Using background correction with the shutter-less system, we can also get smooth images by stray-light correction and sensitivity correction. It is possible to correct background noise without using a shutter system. We will continue to search ways to correct images that would improve the correction accuracy.

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