Trans. JSASS Aerospace Tech. Japan
Vol. 8, No. ists27, pp. Tn_1-Tn_4, 2010

Topics

Development of the Compact Infrared Camera (CIRC) for Earth Observation

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(Received August 18th, 2009)

The Compact Infrared Camera (CIRC) is a technology demonstration payload of the Small Demonstration-Satellite type-2 (SDS-2). The CIRC is an infrared camera equipped with an uncooled infrared array detector (microbolometer). The main mission of the CIRC is to demonstrate the technology of wildfire detection using a microbolometer. The CIRC is a small, lightweight, and low-cost thermal infrared imager for space applications. We employ athermal optics and shutter-less image correction to reduce the size, weight, and cost of the CIRC. In this paper, we show the details of the design of the CIRC.

Key Words: Remote Sensing, Thermal Infrared Imaging, Wildfire, Uncooled Infrared Detector

1. Introduction

Microbolometers are widely used in commercial and military applications, such as night vision. Microbolometers have the advantage of not requiring a cooling mechanism, such as a mechanical cooler. Eliminating the detector cooling system reduces the size, cost, and electrical power of the sensor. Although the sensitivity of microbolometers is lower than that of HgCdTe-based photonic infrared detectors, the advantage of not requiring a cooling mechanism is suitable for small satellites or resource-limited sensor systems.

JAXA has researched the application of microbolometers for Earth observation since 2000. The Wide-Angle Multi-band Sensor-Thermal Infrared (WAMS-TIR) [1], aboard the station-keeping test airship (SPF-II) for the stratospheric platform project, is a thermal infrared multi-band radiometer using a microbolometer focal plane array.

In order to demonstrate the potential of microbolometers to thermal infrared imaging from space, the Compact Infrared Camera (CIRC) is chosen as a technology demonstration payload of the Small Demonstration Satellite (SDS) [2]. The SDS program is an activity of JAXA to demonstrate a variety of new technologies and new missions.

In this paper, we show the details of the design of the CIRC.

2. Small Demonstration Satellite Type-2

The SDS program aims to improve the reliability of practical artificial satellites by demonstrating a wide range of new space technologies covering everything from equipment and elements to system engineering. The SDS-1, the first satellite in the SDS program, was launched in 2009 as a piggyback satellite of the Greenhouse Gases Observing Satellite “IBUKI” (GOSAT). The mission payloads of the SDS-1 are Multi-mode integrated Transponder (MTP), Space Wire demonstration Module (SWIM), Advanced Micro processing In-orbit experiment equipment (AMI), and so on.

The SDS-2 is scheduled to be launched as a piggyback satellite in 2013 or later. Table 1 shows a baseline specification of the SDS-2. The specifications of the SDS-2 are similar to those of the SDS-1. The attitude control of the satellite is based on a three-axis stabilized attitude control. The SDS-2 is a sun-pointing attitude control in a nominal operation. However, it is possible to change to an earth-pointing attitude control during an experiment.

The CIRC has been selected as a mission payload of the SDS-2. Other mission payloads are a next-generation star tracker, a contamination monitor using quartz crystal microbalance, and others.

Table 1. Baseline specifications of the SDS-2.

Size	700 mm x 700 mm x 600 mm
Mass	< 90 kg
Bus power	> 110 W
Communication	S-band
Orbit	Sun-synchronous Orbit 600 km (TBD)
Mission resource	Size 600 mm x 550 mm x 250 mm Mass ~ 30 kg Power ~30 W (nominal)

3. Mission of the CIRC

The main mission of the CIRC is to demonstrate the technology of wildfire detection using a microbolometer. Wildfires are a major and chronic disaster affecting many countries in the Asia-Pacific region, and some predictions are that they will worsen with global warming and climate change.

In the Sentinel Asia[1] project to share disaster information in near real-time across the Asia-Pacific region, wildfire detection has been chosen as an important activity. It is possible to increase observational frequency of wildfires if CIRCs are carried on various satellites. The other CIRC mission targets are volcanoes and heat island phenomena in cities. The observations of these targets with a thermal infrared imager will become a useful tool in monitoring volcanoes or solving the heat island problem.

4. Baseline Specifications of the CIRC

The baseline specifications of the CIRC are shown in Table 2. We set the baseline specifications to meet requirements for the wildfire detection 3, 4). The detector uses a large format (640 × 480) to obtain a wide field of view. The spatial resolution is an important factor for wildfire detection. The baseline specification of the spatial resolution is 200 m from the altitude of 600 km. Noise Equivalent Differential Temperature (NEDT) is related to the contrast between a background area and a burning area. If NEDT is smaller, the detectability of the wildfire is increased. Considering the detector performance and the optical design, we set the NEDT is 0.2K at 300K background.

Figure 1 shows a system block diagram of the CIRC. To reduce the size, weight, and cost, we minimized the functions of the CIRC. The optics unit of the CIRC uses f/1.2 optics. We employ athermal optics to maintain optical performance in a wide range of temperatures. This will be an advantage of the CIRC for small satellites, because we do not need an active thermal control or a focus mechanism for the optics.

Table 2. Baseline Specifications of the CIRC.

Item	Characteristics
Size	< 150 mm × 100 mm × 200 mm
Mass	< 3 kg
Detector	Uncooled infrared detector
Wavelength	8 - 12 μm
Number of pixels	640 × 480
Spatial resolution	< 200 m observed from 600 km (< 0.33 mrad)
Field of View	12°× 9° (128 ×96 km)
Exposure	33 ms
Dynamic range	180 K - 400 K
NEDT	0.2 K@300 K

5. Hardware Designs of the CIRC

Figure 2 shows a schematic view of the CIRC. The CIRC is based on a commercial infrared camera developed by Mitsubishi Electric Corporation (MELCO). However, in order to utilize it for space applications, we added some modifications to the hardware design. In this section, we introduce the hardware design of the CIRC.

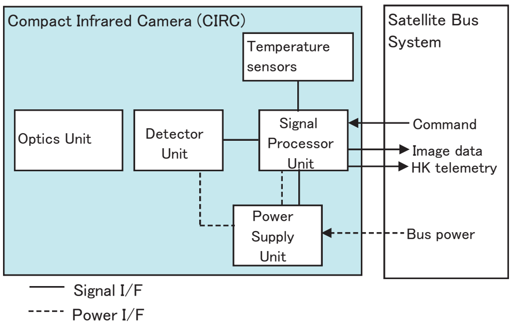

Fig 1. System block diagram of the CIRC.

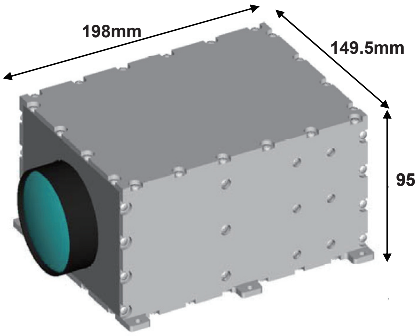

Fig. 2. Schematic view of the CIRC.

5.1 Detector unit

The Focal Plane Array (FPA) of the CIRC is a Silicon-On-Insulator (SOI) diode uncooled infrared (IR) FPA developed by MELCO 5, 6). The characteristic of the SOI diode uncooled IR FPA is its use of single-crystal silicon pn-junction diodes as a temperature sensor. The single-crystal sensor, which is based on silicon LSI technology, offers a low-noise characteristic.

We use a 640 × 480 pixel SOI diode uncooled IR FPA of which pixel size is 25 μm^2. The NEDT is 40 mK with f/1 optics. Drive and readout circuits are almost the same as those of a commercial IR camera. For space applications, we are planning to perform a radiation damage test, and a screening of commercial devices.

The thermal time constant of the SOI diode uncooled IR FPA is 24 ms. Although this thermal time constant is shorter than the exposure time of 33 ms, it affects the Modulation Transfer Function (MTF) due to the satellite motion. We estimate the effect of the thermal time constant to the MTF. The thermal time constant of 24 ms reduces the MTF in the along track direction by almost 40%. However, as the MTF of the optics is 0.6 (see next section), the total MTF including the detector MTF and the satellite disturbance effect is above 0.1 even in the along track direction.

5.2 Optics unit

The optics of the CIRC is f/1.2 refractive optics. The focal

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[1] http://dmss.tksc.jaxa.jp/sentinel/

length of the optics is 78 mm.

The temperature of the CIRC is changed on orbit. The temperature change of the optics will cause a defocus because refractive indices of lens materials are highly dependent on temperature. In order to compensate for this defocus, we have to employ a focus mechanism or a heater to keep the optics temperature constant. However, such mechanisms increase sensor resources. Athermal optics [7)] can compensate for the defocus due to the temperature change without such mechanisms.

Figure 3 shows the optical design of the CIRC. The athermal optics of the CIRC compensate for the defocus by utilizing a combination of different lens materials and diffractive lenses. The optics of the CIRC use a germanium and a chalcogenide glass (GASIR®1). Figure 4 shows the calculated MTF of the CIRC optics versus the ambient temperature from -15°C to 50°C. The MTF is constant over the wide range of temperatures.

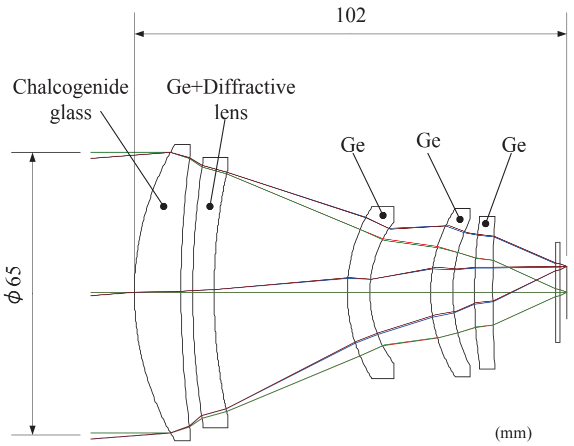

Fig. 3. Optical design of the CIRC.

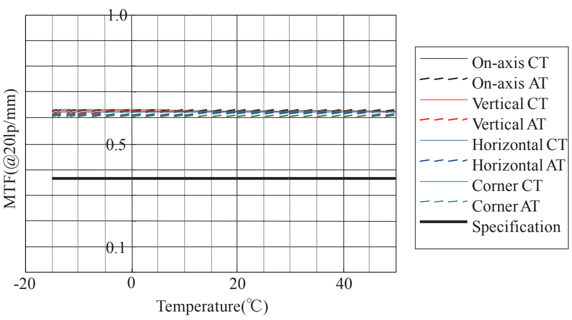

Fig. 4. Calculated MTF of the CIRC optics in the ambient temperature from -15°C to 50°C.

5.3 Signal processor unit

The CIRC has no calibration equipment, like a shutter or an onboard blackbody, to avoid the use of mechanical equipment. Commercial IR cameras correct a nonuniformity of an image using data while the shutter is closed. The onboard data corrections of the CIRC are a coarse correction of the analog offset level of the detector and a DC level correction to avoid a deviation from an ADC input range. Thus, the CIRC data is downlinked without compression and corrected on the ground using the data taken during a ground calibration. In order to correct effects of stray light or an analog drift of the CIRC electronics, we also monitor the temperatures of the optics, the detector, and the electrical circuit of the CIRC.

Image data of the CIRC are 14-bit images. The size of one frame data is 4.3M bits. The frame data is transferred to the satellite bus system with RS-422. The CIRC can also store 16-frame data in its frame memory.

6. On-orbit Operation Plan of the CIRC

The CIRC is a mission to demonstrate the potential of the microbolometer to thermal infrared imaging from space. We thus are planning to observe various targets, such as wildfires, volcanoes, and heat island phenomena. We are also planning to observe calibration targets, like deep space, the moon, and the ocean, to demonstrate the on-orbit performance of the CIRC. Although there is a restriction of downlinking resources of the SDS-2, we will be able to observe one target per day from these targets.

Figure 5 shows an observational sequence of the CIRC. In order to stabilize the temperature of the CIRC, the CIRC is turned on 30 minutes prior to the observation. After the heat run, we observe a calibration target that has a uniform temperature distribution, like deep space or the ocean. The satellite maneuvers from a sun-pointing attitude to an earth-pointing one to observe the target area. The frame rate of the CIRC is 30Hz (33ms/frame). The CIRC can store the image of the target area up to 16 frames on its memory. The time between stored frames (exposure interval) can be changed from 33 ms to 8.45 s as shown in Figure 6. If the exposure interval is 33 ms, the CIRC observes almost the same area displaced about 200 m with each exposure. By combining these data on the ground, the signal-to-noise ratio of the image can be increased. If we combined 16 frames data, the signal-to-noise ratio is expected to increase by 4 times. We are planning to confirm this on the ground calibration. This is an experiment of the Time Delay and Integration (TDI). If the exposure interval is longer, we can observe a wider area. The maximum area the CIRC can observe is about 128 km (cross track) × 1000 km (along track) in one observation.

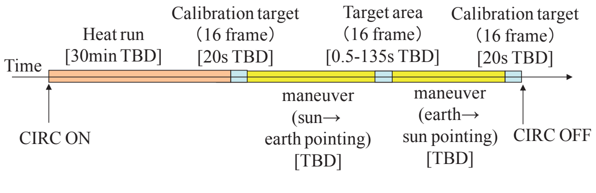

Fig. 5. Observational sequence of the CIRC.

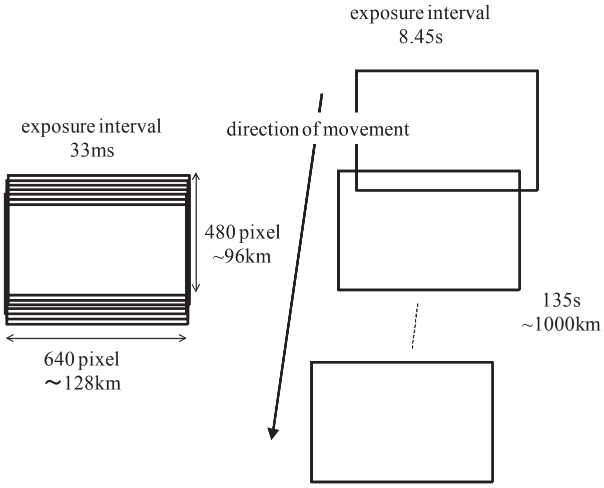

Fig.6. Observational area in case of the different exposure intervals (33 ms and 8.45 s).

7. Conclusion

The Compact Infrared Camera (CIRC) onboard the Small Demonstration Satellite type-2 (SDS-2) is a thermal infrared imager using a microbolometer. The main mission of the CIRC is to demonstrate the technology of wildfire detection using a microbolometer.

The hardware design of the CIRC is ongoing. The CIRC is a small, lightweight, and low-cost thermal infrared imager for space applications. We employ athermal optics and shutter-less image correction to reduce the size, weight, and cost of the CIRC.

We will finish the design of the CIRC and start fabrication of the ground test model (engineering model) of the CIRC by the end of FY 2009.

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