DEVELOPMENT OF THE COMPACT INFRARED CAMERA (CIRC) FOR EARTH OBSERVATION

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ABSTRACT

The compact infrared camera (CIRC) is a technology demonstration instrument that Japanese Aerospace Exploration Agency (JAXA) is developing by using commercial-off-the-shelf (COTS) technology in recent years. CIRC is an infrared camera equipped with an uncooled infrared array detector (microbolometer). CIRC will be utilized for various technology demonstrations. This paper introduces the current development status of CIRC and the initial results of characteristics of the CIRC ground test model (Engineering Model; EM) that has been studied with laboratory experiments.

Keywords: remote sensing, thermal infrared imaging, uncooled infrared detector, microbolometer.

Ⅰ. 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 [1]. CIRC will be carried as a technology demonstration payload for the Advanced Land Observing Satellite-2 (ALOS-2), which is a successor satellite to the Advanced Land Observing Satellite (ALOS). The main purpose of the technology demonstration is to demonstrate the potential of microbolometers in thermal infrared imaging from space. The second purpose of the CIRC project is the low-cost and early development of the thermal infrared imager.
This paper introduces the details of CIRC, the current development status of CIRC, and the initial results of characteristics of the CIRC EM that has been studied with laboratory experiments to establish a prelaunch calibration method.

Ⅱ. ADVANCED LAND OBSERVING SATELLITE-2 (ALOS-2)

The Advanced Land Observing Satellite-2 (ALOS-2) [2] is a follow-on mission from ALOS. ALOS has been contributing to cartography, regional observation, disaster monitoring, and resource surveys, since its launch in 2006. JAXA is conducting research and development activities to improve wide and high-resolution observation technologies developed for ALOS in order 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 4) Global monitoring of tropical rain forests to identify carbon sinks.
ALOS-2 succeeds the L-band Synthetic Aperture Radar (SAR) observation of ALOS PALSAR with enhanced capabilities. Table 1 shows the baseline specifications of ALOS-2. CIRC will be carried as a technology demonstration instrument onboard ALOS-2. Fig.1 shows the mounting location of CIRC. CIRC will take images of the target area during the SAR pointing to the right at its off-nadir angle of 30 degrees.
Table 2 shows the mass budget of the ALOS-2 mission instruments. In comparison with the mass of the SAR instruments, that of the CIRC sensor system is much lighter. This demonstrates one of the advantages of CIRC when employing CIRC with other mission instruments of satellites.

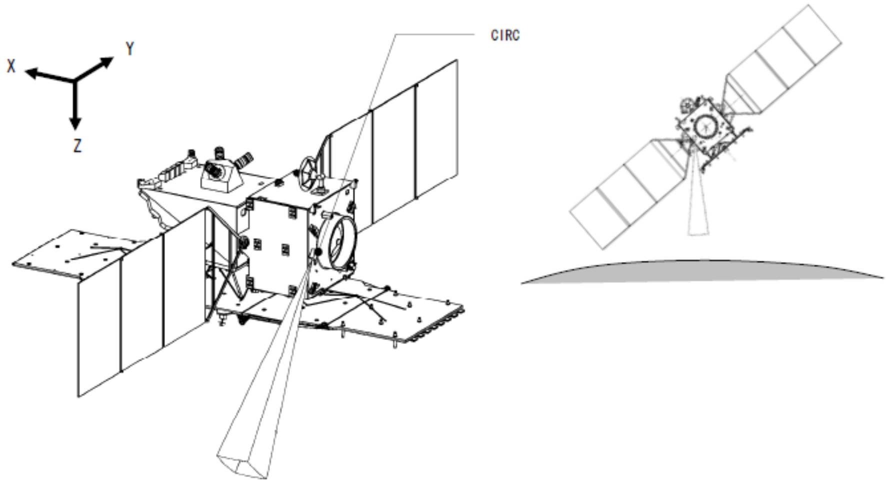


Fig. 1. Schematic view of ALOS-2 and the mounting location of CIRC

Table 1. Baseline specifications of ALOS-2

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

Table 2. Mass budget of the ALOS-2 mission instruments

Unit	Unit Mass (kg)
SAR-ANT	547.7
SAR-ELU	109.1
CIRC	2.6

Ⅲ. MISSION AND SPECIFICATION OF CIRC

The main mission of CIRC is a technology demonstration of a wildfire detection using the microbolometer. Wildfires are one of the major and chronic disasters affecting many countries in Asia-Pacific region, and some suggestions are that this will get worse with global warming and climate change. In Sentinel Asia project to share the disaster information in near real-time across the Asia-Pacific region, the wildfire detection is chosen as one of the important activities. It is possible to increase observational frequency of wildfires if CIRCs are carried on various satellites by taking advantages of small size, light weight and low power consumption. The other CIRC mission targets are volcanoes or heat island phenomena in a city. The observations of these targets with thermal infrared imager will become a useful tool to monitor volcanoes or to solve the heat island problem.

Ⅳ.HARDWARE DESIGN AND BASELINE SPECIFICATIONS OF CIRC

CIRC is based on a commercial infrared camera developed by Mitsubishi Electric Corporation (MELCO). In order to apply it for a space application, however, we add some modifications to the hardware design.
Baseline specifications of CIRC are shown in Table 3. We set the baseline specifications to meet requirements for the wildfire detection. The detector is a large format (640 × 480) to obtain a wide field of view. The spatial resolution is an important factor for the wildfire detection. The baseline specification of the spatial resolution is 200 m from the altitude of 600 km.
Fig. 2 shows a system block diagram of CIRC. In order to reduce the size, weight, and cost, we minimized the function of CIRC. The optics unit of CIRC is f/1.2 optics. We employ an athermal optics to keep the optical performance in a wide range of temperature. This will be an advantage of CIRC because we don’t need an active thermal control or a focus mechanism to the optics.

Table 3. Baseline specifications of CIRC

Parameter	Specification
Size	< 180mm x 100mm x 200mm
Mass	< 3kg
Detector	Uncooled infrared detector
Wavelength	8 - 12 μm
Number of pixels	640 × 480
Spacial resolution	< 200 m @ 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

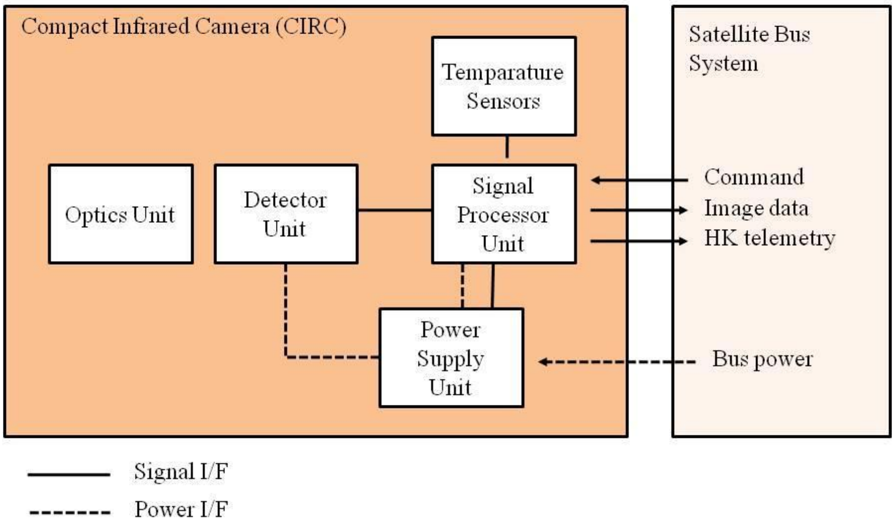


Fig. 2. System block diagram of the CIRC.

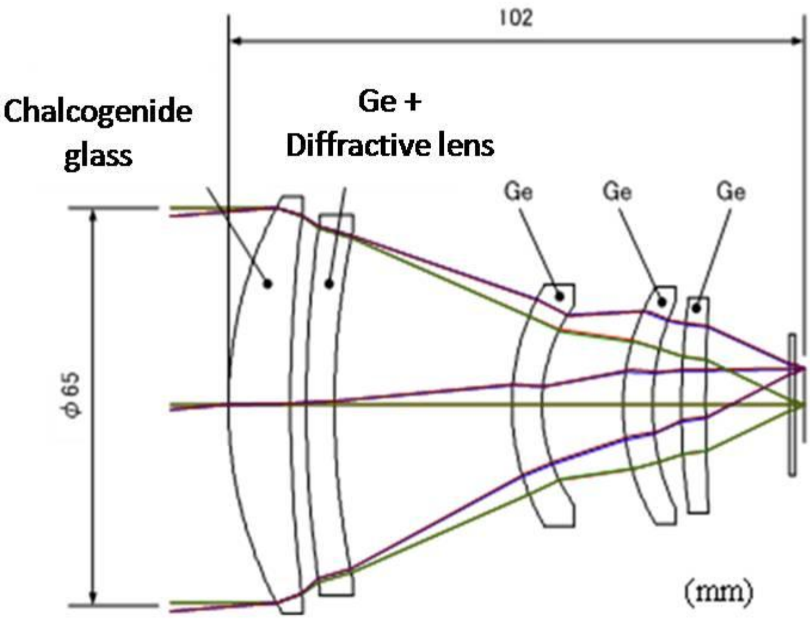


Fig. 3. Optical design of CIRC

The optics of the CIRC is a f/1.2 refractive optics. A focal 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. An athermal optics can compensate for the defocus due to the temperature change without such mechanisms. CIRC can operate in a temperature range from -15℃ to 50℃ while maintaining its performance. Fig. 3 shows the optical design of the CIRC. The athermal optics of the CIRC compensates for the defocus by a combination of different lens materials and diffractive lenses. The optics of the CIRC uses a germanium and a chalcogenide glass (GASIR) [3].

Ⅴ. LABORATORY EXPERIMENT OF THE CIRC ENGINEERING MODEL

In this section, we report the initial result of the laboratory experiment of the CIRC EM. The CIRC EM is shown in Fig.4.

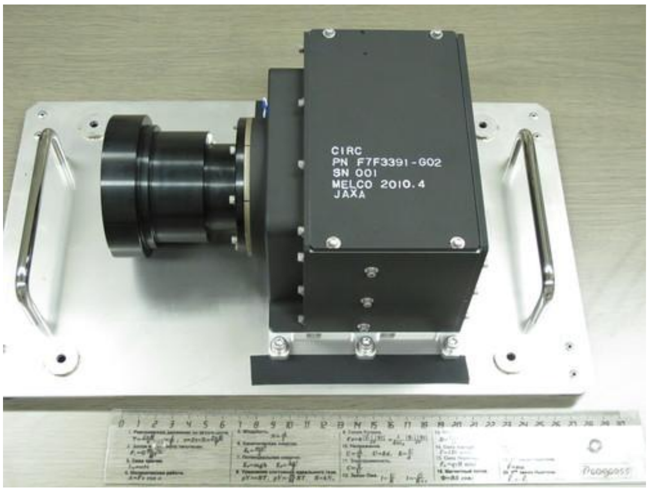


Fig.4. Picture of the CIRC EM

A. Measurement setup

In the laboratory experiment at JAXA Tsukuba Space center, we measured the Modulation Transfer Function (MTF), which is one of the important image capture performance parameters of the optical sensor systems, of the CIRC EM in both atmosphere and vacuum to evaluate the image capture performance of the sensor system. The schematic diagram of the experimental setup is shown in Fig.5 and the configuration of the measurement setup is shown in Fig.6.

CIRC is placed inside of the vacuum chamber in the laboratory and surrounded by a shroud which controls the ambient temperature of CIRC by using a heater and a cooler. The infrared-ray is emitted by the black body (CI Systems SR800) and passes through the 4-bar targets (shown in Fig.7) mounted inside of the reflective collimator system (CI Systems ILET-5-1.1). The intervals of the slits of the 4-bar targets is equivalent to 1-, 1/2-, 1/4- and 1/8-nyquist frequency. The collimated infrared-ray pass through a germanium window, which is mounted on to the side of the vacuum chamber and transmits the infrared-ray from outside of the vacuum chamber, and is detected by CIRC.

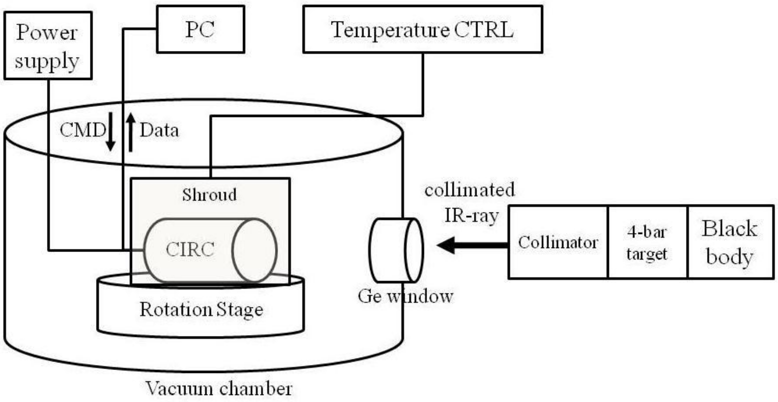


Fig.5. Schematic diagram of the experimental setup

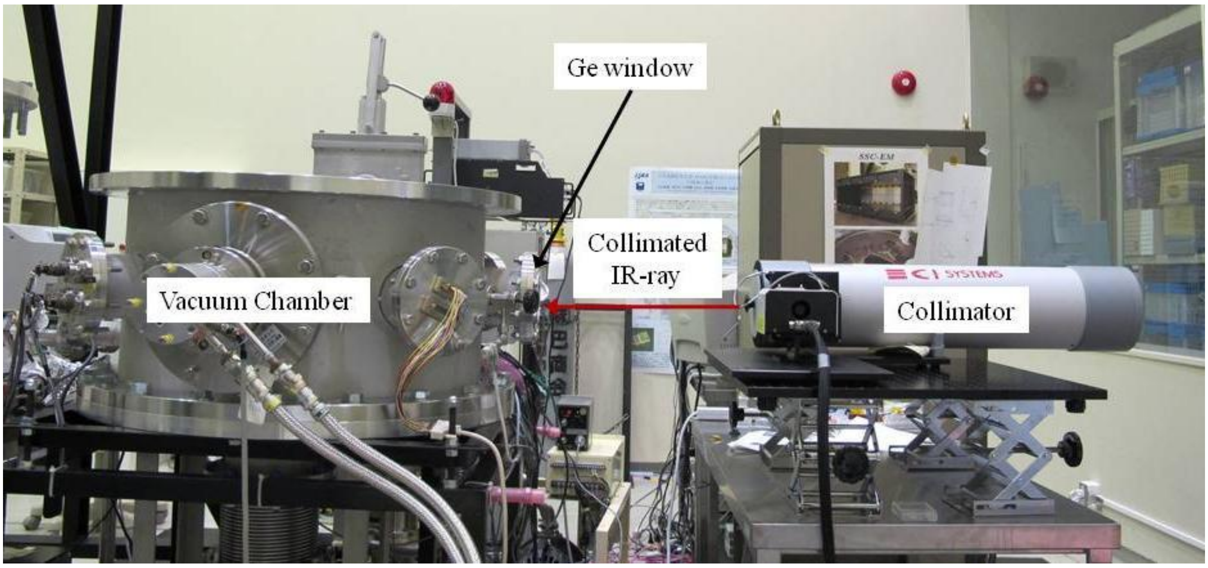
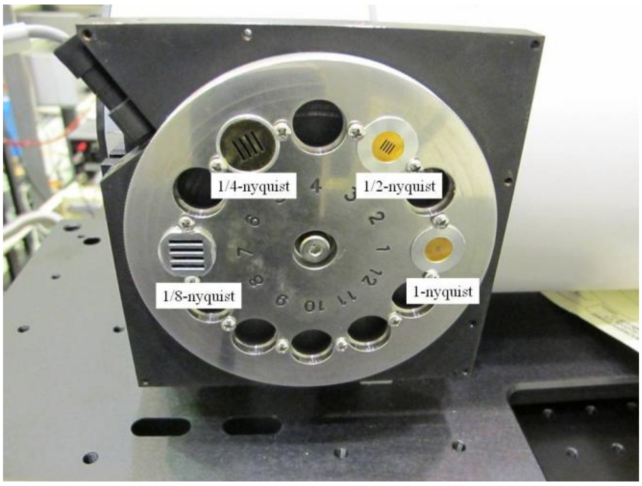


Fig.6. Configuration of the measurement setup



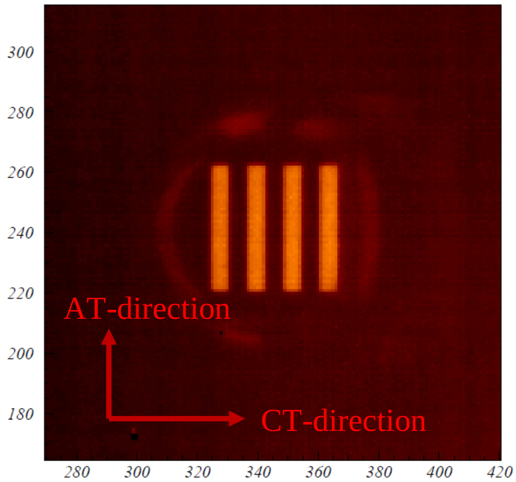


Fig.7. (left) 4-bar targets mounted on the collimator system. (right) Image of the 4-bar target taken with CIRC.

B. results

The MTF of CIRC corresponding to each nyquist frequency is measured for both the Along-Track (AT) and Cross-Track (CT) direction at the center of the field of view. Fig.8 (a) and Fig.8 (b) show the results of the MTF measurement for the AT and CT direction, respectively. The color of each line corresponds to the conditions of the measurements in Table 4. The ambient temperature of CIRC was changed from room temperature to 50℃. The difference in each measurement is large in the AT direction. One of the reasons for the difference is the accuracy of the alignment of the measurement. In the experiment setup, we can align the target position for the CT direction using the rotation stage under CIRC (see Fig. 6). However, there is no alignment mechanism for the AT direction.
As an initial result of the measurements, we confirmed the athermal characteristic of the lens of CIRC as we designed, though we need some improvement of the alignment for the MTF measurement in the AT direction.

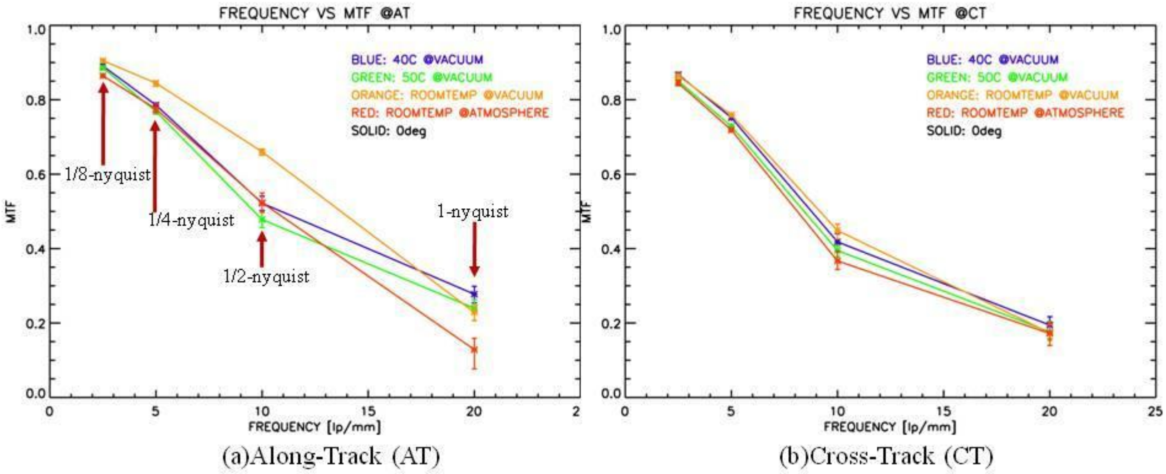


Fig.8. MTF of CIRC for the AT direction (a) and the CT direction (b).

Table 4. Conditions of the measurements

color of the line	measurement condition
blue	vacuum (P=10^{-5}Torr), 40℃
green	vacuum (P=10^{-5}Torr), 50℃
orange	vacuum (P=10^{-5}Torr), room temperature (~20℃)
red	atmosphere, room temperature (~20℃)

Ⅵ. SUMMARY

We measured the MTF characteristic of CIRC and confirmed the athermal characteristics of the lens of CIRC as it was designed. In a future experiment, we will measure the radiometric performance of the CIRC EM.
Through these experiments, we establish a prelaunch calibration method for the CIRC Proto-Flight Model (PFM) onboard ALOS-2.

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