Development of the Compact InfraRed Camera (CIRC) for wildfire detection

Haruyoshi Katayama[a*], Masataka Naitoh[a], Masahiro Suganuma[a], Masatomo Harada[a], Yoshihiko Okamura[a], Yoshio Tange[a], and Koji Nakau[a]
[a] Earth Observation Research Center, Japan Aerospace Exploration Agency, Tsukuba, Ibaraki, Japan 305-8505

ABSTRACT

The Compact InfraRed Camera (CIRC) is a technology-demonstration payload to be carried on the Small Demonstration Satellite type-2 (SDS-2). The SDS program is a JAXA activity to demonstrate a variety of new technologies and new missions. The CIRC is an infrared camera equipped with an uncooled infrared array detector (microbolometer). The mission of the SDS-2/CIRC project is to demonstrate the potential of the microbolometer, especially for wildfire detection but also for other applications. This paper introduces the detailed design and concept of CIRC. We also discuss preliminary results of the feasibility study on wildfire detection using thermal infrared images.

Keywords: remote sensing, thermal infrared imaging, wildfire, uncooled infrared detector

1. INTRODUCTION

Microbolometers are widely used in commercial and military applications such as night vision. Because of recent progress of microelectromechanical system (MEMS) technology, high-resolution, large-format devices are being developed by many companies.

Microbolometers have an advantage of not requiring cooling systems such as a mechanical cooler. Eliminating the detector cooling system can reduce the size, cost and electrical power consumption of the sensor. Although microbolometers are less sensitive than HgCdTe-based photonic infrared detectors, the advantage of not requiring a cooling system is suitable for small satellites or resource-limited sensor systems.

For this reason, microbolometers begin to be applied for various space applications. In planetary missions, the Thermal Emission Imaging System (THEMIS)[1] onboard Mars Odyssey spacecraft used a microbolometer focal plane array (FPA). The Longwave IR camera (LIR) onboard Venus Climate Orbiter (PLANET-C)[2], which is scheduled to be launched in 2010, also uses a microbolometer array.

In earth-observation missions, the Infrared Spectral Imaging Radiometer (ISIR)[3] experiment tests the potential of microbolometer for application to thermal infrared imaging. The ISIR was flown as a hitchhiker experiment on the space shuttle in 1997. Recent missions to measure the atmosphere vertical profiles like CALIPSO[4] and EarthCARE[5] also use a microbolometer as an imaging infrared instrument. JAXA began a research for application of microbolometer to earth observation since 2000. The Wide-Angle Multi-band Sensor - Thermal Infrared (WAMS-TIR)[6], aboard the station-keeping test airship (SPF-II) for the stratospheric platform project, is a thermal infrared multi-band radiometer using a microbolometer FPA.

In order to demonstrate the potential of microbolometer to the thermal infrared imaging from space, the compact infrared camera (CIRC) is chosen as one of the technology demonstration payloads of Small Demonstration Satellite (SDS). The SDS program is one of activities of JAXA, to demonstrate a variety of new technologies and new missions.

This paper introduces the details of the design and concept of the CIRC. We also discuss preliminary results of the feasibility study on wildfire detection using thermal infrared images.

Remote Sensing System Engineering II, edited by Philip E. Ardanuy, Jeffery J. Puschell,
Proc. of SPIE Vol. 7458, 745806 · © 2009 SPIE · CCC code: 0277-786X/09/$18 · doi: 10.1117/12.825445

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 element to system engineering. The SDS-1, the first satellite in the SDS program, was launched in 2009 as a piggybag 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), and Advanced Micro processing In-orbit experiment equipment (AMI).

The SDS-2 is scheduled to be launched as a piggybag 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 except for the attitude control. The attitude control of the satellite is based on a three axis stabilized attitude control, though that of the SDS-1 is a spin stabilized attitude control. The SDS-2 is a sun-pointing attitude control in a nominal operation. However, it is possible to change an earth-pointing attitude control during an experiment.

The CIRC is selected as one of mission payloads of the SDS-2. Other mission payloads are next generation star tracker, contamination monitor using quartz crystal microbalance.

Table 1. Baseline specifications of the SDS-2.

Size	700mm x 700mm x 600mm
Mass	< 90 kg
Bus power	> 110 W
Communication	S-band
Orbit	Sun-synchronous Orbit 600 km (TBD)
Mission resource	Size 600mm x550mm x 250mm Mass ~ 30kg Power ~30W (nominal)

3. MISSION OF THE CIRC

The main mission of the CIRC is the technology demonstration of the 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[7] 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 a various satellites by taking advantages of small size and light weight. 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.

4. BASELINE SPECIFICATIONS OF THE CIRC

A baseline specification of the CIRC is shown in Table 2. We set the baseline specification to meet requirements for the wildfire detection[8,9]. 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. 1 shows a system block diagram of the CIRC. In order to reduce the size, weight, and cost, we minimized the function of the CIRC. The optics unit of the 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 the CIRC for small satellites, because we don't need an active thermal control or a focus mechanism to the optics.

Table 2. Baseline specifications of the CIRC.

Item	Characteristics
Size	< 150mm × 100mm × 200mm
Mass	< 3kg
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

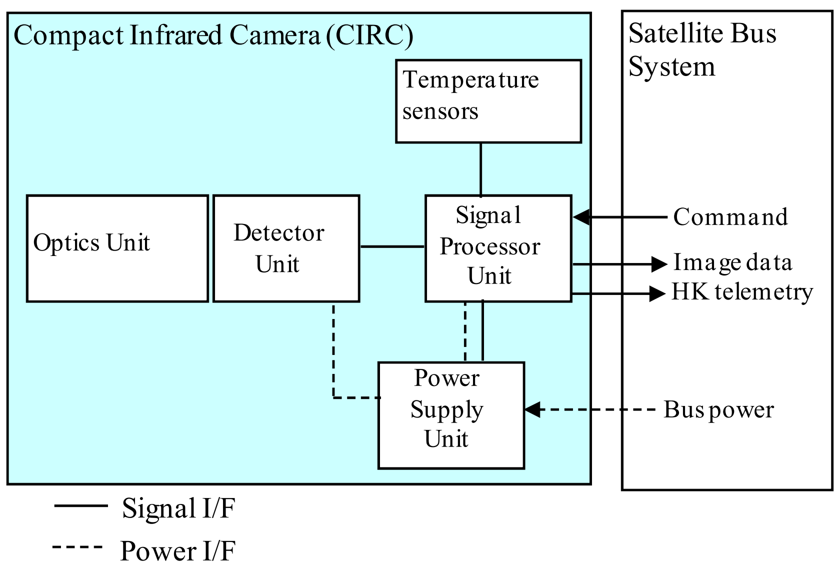

Fig. 1. System block diagram of the CIRC.

5. FEASIBILITY STUDY OF WILDFIRE DETECTION

For feasibility study of the wildfire detection and other possible application, we used Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) / thermal infrared (TIR)[10] data. ASTER has a significant advantage over previous datasets because of the combination of high spatial resolutions (15–90 m) and enhanced multispectral capabilities, particularly in the TIR. The spatial resolution and swath of the ASTER/TIR are 90m and 60km, respectively. The 90m spatial resolution in the thermal infrared band is useful to simulate various case of a spatial resolution.

In order to check the delectability of wildfire, we obtained the wildfire data taken by ASTER. Table 3 shows the list of wildfire data we checked. These are typical wildfire data including forest fires, tundra fires, and peat fires.

In order to investigate the difference of the wildfire detectability depending on the spatial resolution, we made simulated images of which spatial resolutions are 180m and 270m from the original ASTER/TIR image.

Table 3. Analyzed wildfire data of the ASTER/TIR.

Location	Date	Type
Alaska	2004-07-17	Forest fire
Alaska	2007-09-08	Tundra fire
California	2003-10-26	Forest fire
Indonesia	2006-10-12	Peat fire

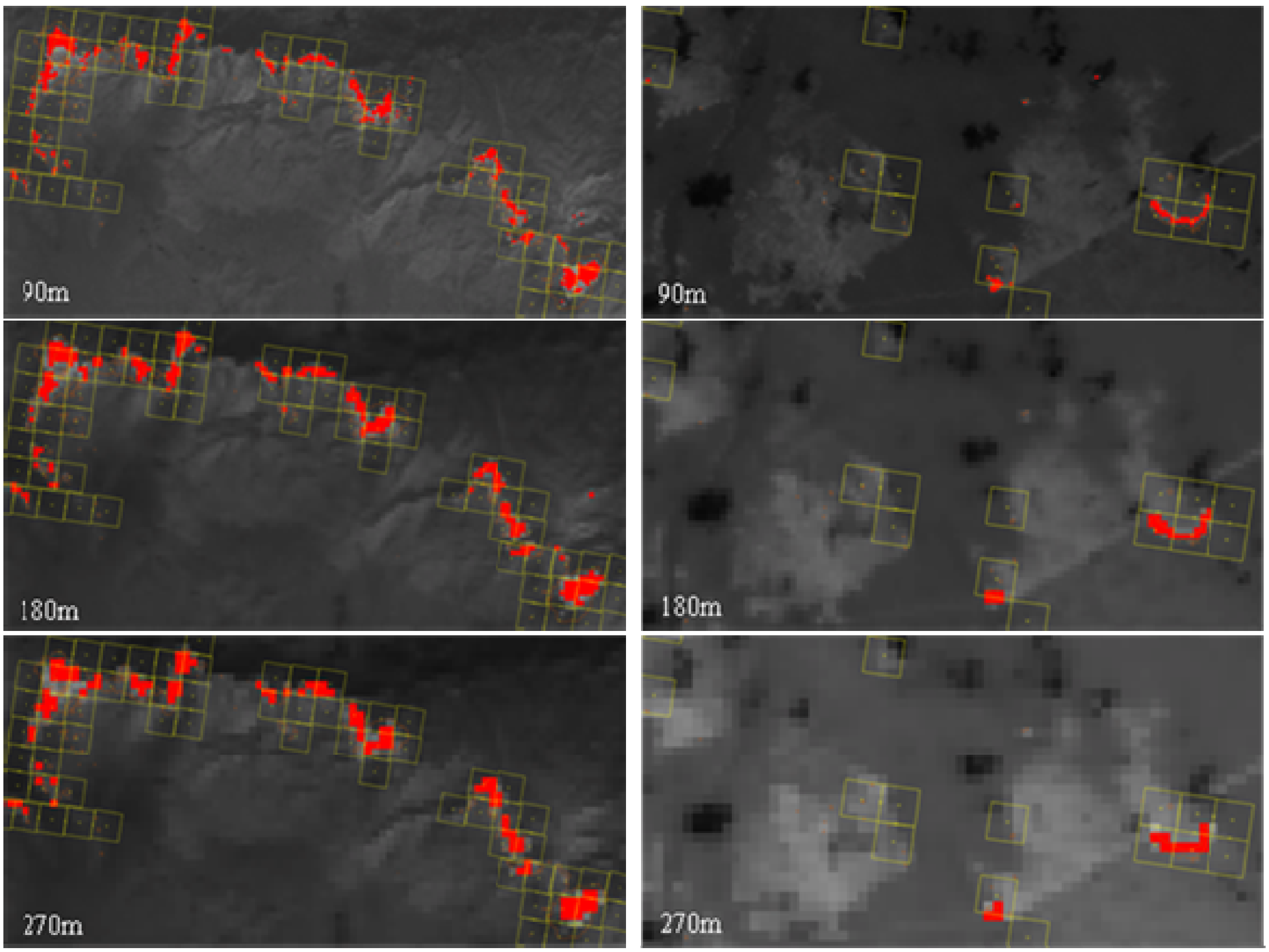

Fig. 2. ASTER/TIR images of forest fire in California on October 26, 2003 (left) and peat fire in Indonesia on October 12, 2006 (right). The spatial resolutions are 90m (top), 180m (middle), and 270m (bottom). Red filled squares are the results of wildfire detection using thermal infrared data only. Yellow open squares are the results using MOD14.

Fig. 2 show simulated images of the forest fire in California and the peat fire in Indonesia. We searched the image for regions of anomalously high brightness to detect wildfires. In general, the wildfire detection using satellite data uses short or medium infrared images in addition to the TIR image. However, by optimizing a threshold level, we can detect a wildfire only from the thermal infrared image. Hotspots are detected by contextual threshold method. A pixel is defined as hotspot if the anomaly in 11μm brightness is higher than 3σ, where σ is standard deviation of brightness in pixels within 1km radius.

In order to check the detectability, we used the MODerate-resolution Imaging Spectroradiometer (MODIS) Thermal Anomalies/Fire products (MOD14v4). MOD14 algorithm detects fire locations using 4μm and 11μm brightness temperatures with the spatial resolution of 1km.

From this simulation, we found that the detectability of forest fire or tundra fire using thermal infrared images of which spatial resolution of 180m is comparable to that of MOD14 algorithm. On the other hand, the detection of the peat fire needs higher spatial resolution. Because the burning temperature of peat fires is lower than that of other wildfires.

Although further improvements of the detection algorithm are needed especially for peat fires, we find that 200m spatial resolution is almost appropriate for the wildfire detection. The detectability of wildfires should have a dependency to the burning area. In addition to that, there is a possibility to detect a "false alarm" wildfire in a city due to various heat sources like heat power plants. So we are planning to apply this algorithm to other various dataset and check the detectability.

6. HARDWARE DESIGNS OF THE CIRC

Fig. 3 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 apply it for a space application, we add some modifications to the hardware design. In this section, we introduce the hardware design of the CIRC

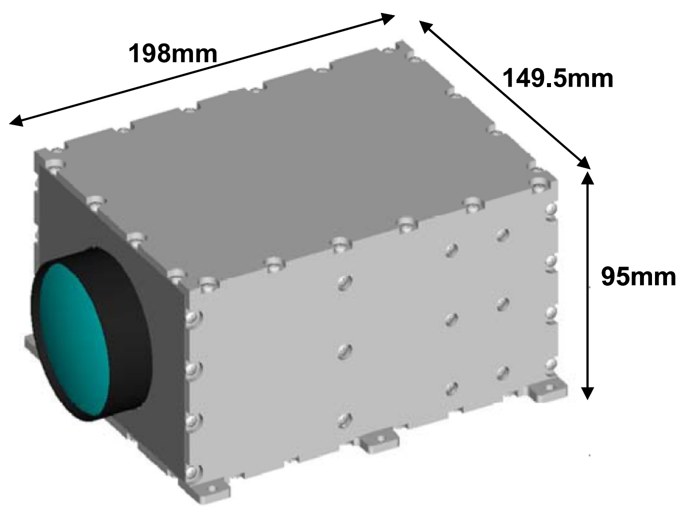

Fig. 3. Schematic view of the CIRC.

6.1 Detector Unit

A Focal Plane Array (FPA) of the CIRC is a Silicon-On-Insulator (SOI) diode uncooled infrared (IR) FPA developed by MELCO[11,12]. The characteristic of the SOI diode uncooled IR FPA is to use a single-crystal silicon pn-junction diodes as a temperature sensor. The single-crystal sensor based on silicon LSI technology offers a low-noise characteristic.

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

6.2 Optics Unit

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 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 [12] can compensate the defocus due to the temperature change without such mechanisms.

Fig. 4 shows the optical design of the CIRC. The athermal optics of the CIRC compensates the defocus by combination of different lens materials and diffractive lenses. The optics of the CIRC uses a germanium and a chalcogenide glass (GASIR®1). Fig. 5 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 temperature.

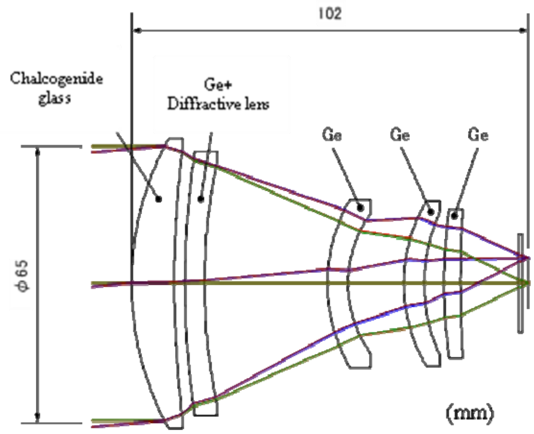

Fig. 4. Optical design of the CIRC.

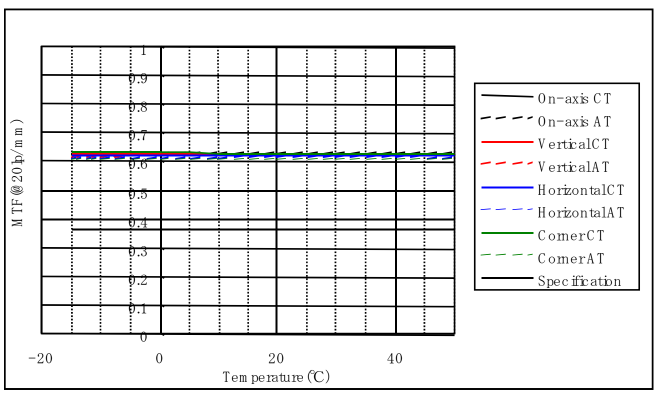

Fig. 5. Calculated MTF of the CIRC optics in the ambient temperature from -15 °C to 50 °C.

6.3 Signal Processor Unit

The CIRC has no calibration equipments like a shutter or an onboard blackbody to avoid mechanical equipments. The commercial IR camera corrects a nonuniformity of the image using data while a shutter is closed. The onboard data correction of the CIRC is 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 a 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 image. 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 a frame memory.

7. ON-ORBIT OPERATION PLAN OF THE CIRC

The CIRC is a mission to demonstrate the potential of microbolometer to the thermal infrared imaging from space. We thus are planning to observe various targets such as wildfires, volcanoes, 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 a downlink resource of the SDS-2, we will be able to observe one target per day from these targets.

Fig. 6 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 which has a uniform temperature distribution like deep space or the ocean. The satellite maneuvers form the sun-pointing to the earth-pointing to observe the target area. The CIRC can take the image of the target area up to 16 frames in one observation. The exposure time of one frame is 33ms. The time between exposures (exposure interval) can be changed from 33ms to 8.45s. If the exposure interval is 33ms, the CIRC observe almost the same area overlapped about 200m each exposure. By combining these data on the ground, the signal-to-noise ratio of the image can be increased. 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 128km (cross track) × 1000km (along track) in one observation.

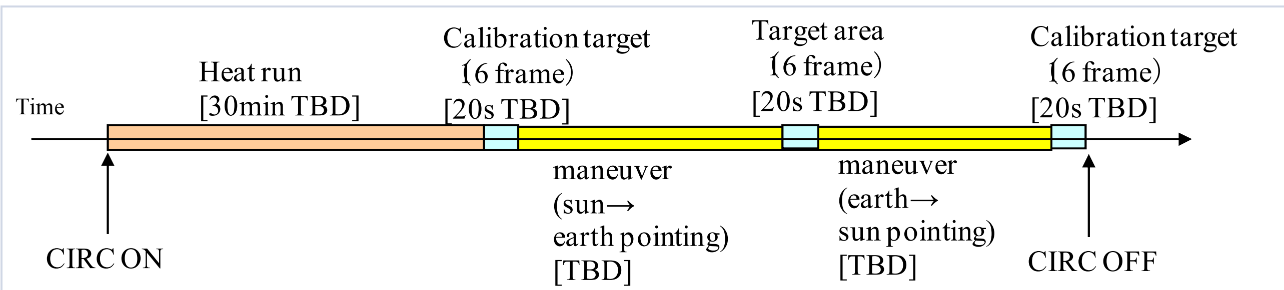

Fig. 6. Observational sequence of the CIRC.

8. SUMMARY

The Compact InfraRed Camera (CIRC) onboard the Small Demonstration Satellite type-2 (SDS-2) is a thermal infrared imager using microbolometer. The main mission of the CIRC is the technology demonstration of the wildfire detection. The feasibility study of the wildfire detection shows the CIRC's specification of the spatial resolution of 200m is almost appropriate for the wildfire detection.

The hardware design of the CIRC is ongoing. The feature of the CIRC is a small, light-weight, and low-cost thermal infrared imager for space application. We employ the athermal optics and the shutter-less image correction to reduce the size and weight of the CIRC. The athermal optics of the CIRC can keep the optical performance in the wide range of temperature from -15 °C to 50 °C.

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

REFERENCES

[1] Schueler, C. F, Silverman, S. H., and Christensen, P. R., "Thermal Emission Imaging System (THEMIS), " Proc. International Thermal Detectors Workshop, (2003)

[2] Fukuhara, T. et al., "Development of the longwave infrared imager (LIR) onboard PLANET-C," Proc. SPIE, 6940, 694030 (2008)

[3] Spinhirne, J. D., Scott, V. S., Cavanaugh, J. F., Palm, S., Manizade, K., Hoffman, J. W., and Grush, R. C., "Preliminary spaceflight results from the uncooled infrared spectral imaging radiometer (ISIR) on shuttle mission STS-85," Proc. SPIE 3379, 14-21 (1998).

[4] http://smsc.cnes.fr/CALIPSO/GP_iir.htm.

[5] http://esamultimedia.esa.int/docs/EEUCM/EarthCARE_TPA.pdf.

[6] Okamura, Y., Matsuyama, H., Kasahara. M., Yoshida, S., and Tange, Y., "Development of the WAMS-TIR instrument for SPF-II, "Proc. SPIE, 5659, 105-114 (2005).

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

[8] Katayama, H., Okamura. Y., Tange, Y., and Nakau, K., "Design and Concept of The Compact Infrared Camera (CIRC) with Uncooled Infrared Detector, " Proc. 26th ISTS, (2008).

[9] Katayama, H., Suganuma, M., Okamura. Y., Naioh, M., Tange, Y., and Nakau, K., "Design and Concept of The Compact Infrared Camera (CIRC) with Uncooled Infrared Detector," Proc. International Conference on Space Optics, (2008).

[10] Ohmae, H., Maekawa, T., Aoki, Y., and Kitamura, S., "Preflight test results of the ASTER TIR flight model," Proc. SPIE 3220, 210-219 (1997).

[11] Ueno, M. et al., "640 x 480 pixel uncooled infrared FPA with SOI diode detectors," Proc. SPIE 5783, 566-577 (2005).

[12] Tamagawa, Y., Wakabayashi, S., and Tajime, T., "New design method for athermalized optical systems, " Proc. SPIE 1752, 232-238 (1992)