Calibration Results of the Compact Infrared Camera (CIRC) Ground Test Model

(9mm)

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The compact infrared camera (CIRC) is a technology demonstration instrument equipped with an uncooled infrared array detector (microbolometer). Eliminating the cooling system reduces the size, cost, and electrical power of the sensor. The CIRC also achieves small size and light weight by employing athermal optics and shutter-less system. The main mission of the CIRC is the technology demonstration of the wildfire detection. Wildfires are major and chronic disasters affecting many countries in the Asia-Pacific region. The second purpose is the low-cost and early development of a thermal infrared imager. The CIRC is designed based on a commercial infrared camera and is employing commercial-off-the-shelf (COTS) parts to reduce cost and time for development. The CIRC ground test model was made to establish a prelaunch calibration method. The main calibration items are imaging quality (Modulation Transfer Function; MTF), and radiometric quality. We have measured MTFs in a vacuum environment. Nyquist MTF at center positions is from 0.1 to 0.3. We also measured athermal characteristics in the temperature range from -10 to 50 degrees C. We confirmed the athermal characteristics. In this paper, we show the current status of the CIRC development, and the calibration results of the CIRC ground test model.

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 [1]. In order to demonstrate the potential of microbolometers to thermal infrared imaging from space, the Compact Infrared Camera (CIRC) is developed 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 show the current development status of CIRC. In §2, we briefly describe ALOS-2 and CALET. The mission and the details of the CIRC are shown in §3 and §4, respectively. In §5, we show the initial calibration results of the CIRC ground test model that has been studied with laboratory experiments to establish a prelaunch calibration method. Discussion and Summary are shown in §6.

2. ALOS-2 and CALET

2.1 ALOS-2

ALOS-2 [2] is a follow-on mission from ALOS, which 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 will be launched in 2013.

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. The mounting location of CIRC is shown in figure 1. CIRC will take images of the target area during the SAR pointing to the right at its off-nadir angle of 30 degrees.

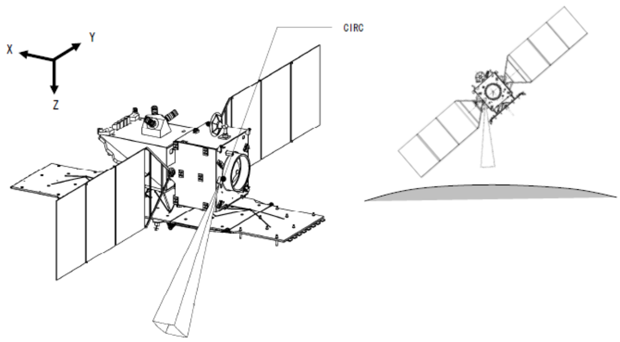

Fig. 1 Schematic view of ALOS-2 and the mounting location of CIRC

Table 1. Baseline specifications of ALOS-2

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

2.2 CALET

CALET [3] is an international program for the ISS that will search for signatures of Dark Mater and provide the highest energy direct measurements of the cosmic ray electron spectrum in order to observe discrete sources of high energy particle acceleration in our local region of the Galaxy. CALET will address many of the 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 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 shown in table 2. CIRC will be mounted on the bottom of CALET, shown in figure 2.

Table. 2 baseline specifications of CALET

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

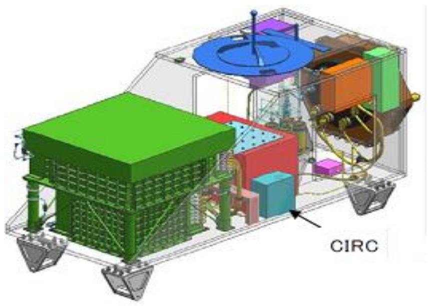

Fig. 2 Schematic view of CALET and the mounting location of CIRC

3. Mission of the 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.

4. Baseline specifications of the CIRC

Baseline specifications of the 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 spatial resolution is 200 m from the altitude of 600 km (ALOS-2), and 130 m from the altitude of 400 km (CALET), respectively. Eliminating the cooling system reduces the size (110mm x 180mm x 230mm) and electrical power (<20 W).

Table 3. Baseline specifications of the CIRC

Parameter	Specification
Size	110mm x 180mm x 230mm
Mass	~3kg
Detector	Uncooled infrared detector
Wavelength	8 - 12 µm
Number of pixels	640 × 480
Special resolution	< 200 m @ 600 km (ALOS-2) < 130m @ 400km (CALET) (< 0.33 mrad)
Field of View	12°× 9°
Exposure	33 ms
Dynamic range	180 K - 400 K
NEdT	0.2 K@300 K
Power	< 20W

5. Calibration of the CIRC ground test model

In this section, we present the calibration results of the CIRC ground test model. Figure 3 shows the picture of the CIRC ground test model.

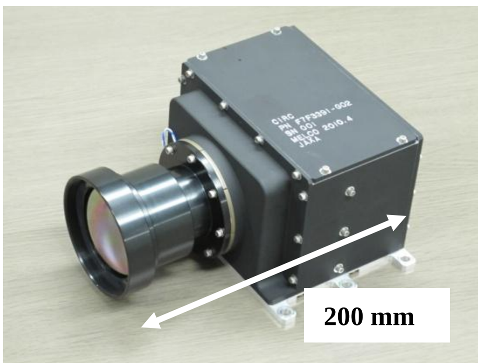

Fig. 3 Picture of the CIRC ground test model

In the laboratory experiment at JAXA Tsukuba Space center, we measured the Modulation Transfer Function (MTF) of the

CIRC ground test model in a vacuum to evaluate the image capture performance of the sensor system.

5.1 Measurement Setup

The schematic diagram and the configuration of the experimental setup are shown in Fig. 4 and 5, respectively.

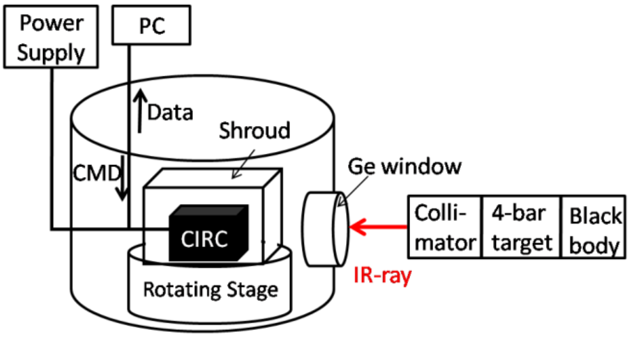

Fig. 4 Schematic diagram of the experimental setup

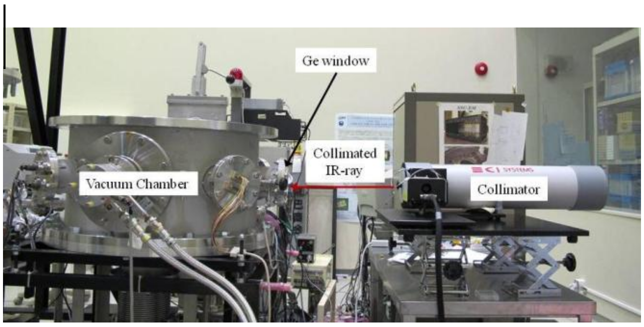

Fig. 5 Configuration of the experimental setup

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.6) mounted inside of the reflective collimator system (CI Systems ILET-5-1.1). The intervals of the slits of the 4-bar targets are equivalent to 1-, 1/2-, 1/4- and 1/6-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.

5.2 Data

We have measured MTF under a vacuum environment. The detector positions of measurements are at the center, ±5 degrees in the Cross-Track (CT) direction, and ±3.5 degrees in the Along-Track (AT) direction, shown in figure 7. In order to measure the MTF at ±3.5 degrees, the CIRC is able to be replaced to the side panel of the shroud, because only one rotating stage is set in the vacuum chamber (see figure 4). MTF for CT/ AT direction were measured by rotating the 4-bar target. The environments of measurement are shown in table 4. The temperatures of the shroud are set to -10 to 50 degrees C.

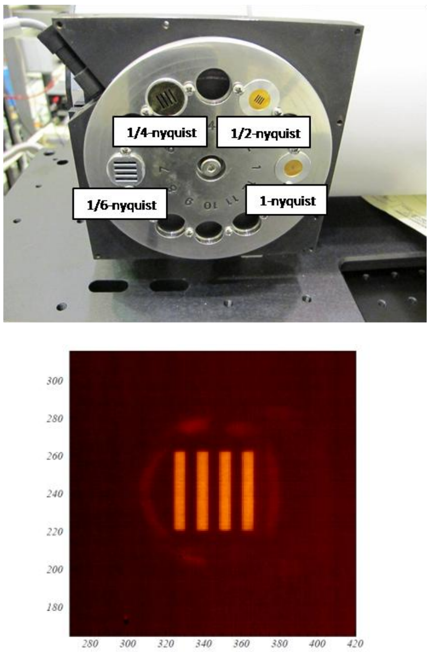

Fig. 6 (top) 4-bar target mounted on the collimator system. 1/6-, 1/4-, 1/2-, 1-nyquist frequency from the left. (bottom) image of the 4-bar target taken with CIRC

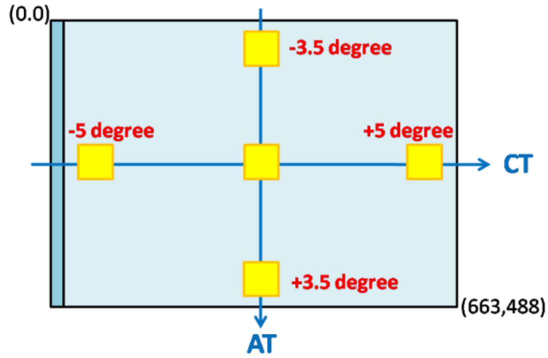

Fig. 7 The positions of MTF measurement

Table 4. The environments of the measurement

	-10 degrees C	22 degrees C	40 degrees C	50 degrees C
± 5 degrees 0 degree *	○	○	○	○
± 3.5 degrees 0 degree #	○	○	---	○

* CIRC is on the bottom panel of the shroud

\# CIRC is on the side panel of the shroud

5.3 Measurement environment

The pressure in the vacuum chamber is ~ 10^{-5} Torr. We have monitored the temperature of the CIRC and shroud with platinum-resistant. The position of resisters are shown in figure 8

Figure 9 shows the temperatures during the experiment. In the room temperature case, the temperature of CIRC increases from 22 to 35 degrees C due to the heat from electrical circuit . The temperature variation between each position is ~ 5 degrees C. The temperature of channel 5, 6 and 8, which are mounted on the lens and body of the CIRC, are higher than

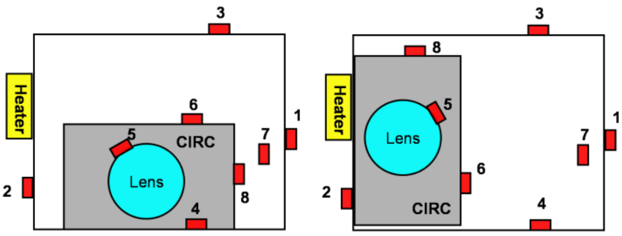

Fig.8. Position of the platinum-resistant. (right) For the case that CIRC is on the bottom panel of the shroud. (left) For the case that CIRC is on the side panel of the shroud.

that of others. Although the temperature variation is larger than the room temperature case, same trend is seen in low and high temperature environment. In order to keep the temperature, we turned off and on again in the high temperature case.

CIRC have other own thermometers near the lens and the detector. The difference between lens and channel5 temperature is less than 1 degrees C.

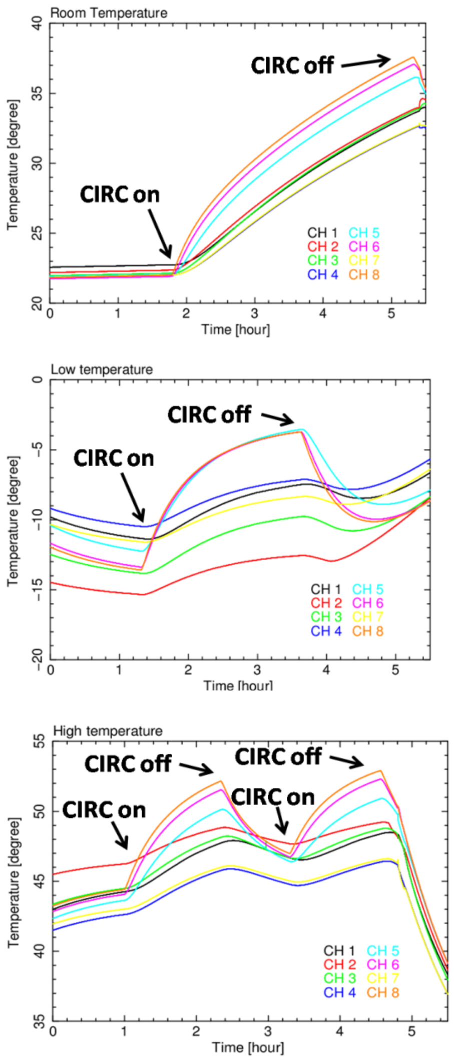

Fig. 9 Obtained temperatures of each position with platinum-resistant. (top) In the room temperature. (middle) In the low temperature. (bottom) In the high temperature.

5.4. Procedure of measurement and analysis

The procedures of measurement are;

1. Obtain a dark image by covering the Ge window with aluminum cover.
2. Target images (1-, 1/2-, 1/4-, 1/6-nyquist frequency) are taken.

One cycle of this procedure take about 7 minutes.

We analyzed the data with target and dark images. The flow chart of the MTF analysis is shown in figure 10. Figure 11 is additional figure to explain the analysis. First of all, we subtract a dark image from a target image to correct an offset. As a second step, 4-bar-target area of an image is chosen. We sum digital number (DN) of each pixel along y-direction in figure 11 (top), and calculate standard deviation as shown in figure 11 (middle). The image is chosen with the area above one third of maximum standard deviation. Next we integrate DN of pixels along x-direction in figure 11 (top) in order to reduce random noise. We correct offset again to remove remaining dark level, by using the target image with no 4-bar area. Finally, we calculate MTF. A peak and a bottom of DN (V_{max}, V_{min}) are detected, shown in figure 11 (bottom). MTF is derived with V_{max} and V_{min} as shown below;

$$MTF = (V_{max} + V_{min}) / (V_{max} - V_{min}) .$$

We can calculate 6 MTFs from 4-bar image, and derive the average ($MTF_{average}$), the maximum (MTF_{max}), and the minimum (MTF_{min}) of 6 MTFs. The errors of the MTF are defined as differences between MTF_{max} (MTF_{min}) and $MTF_{average}$.

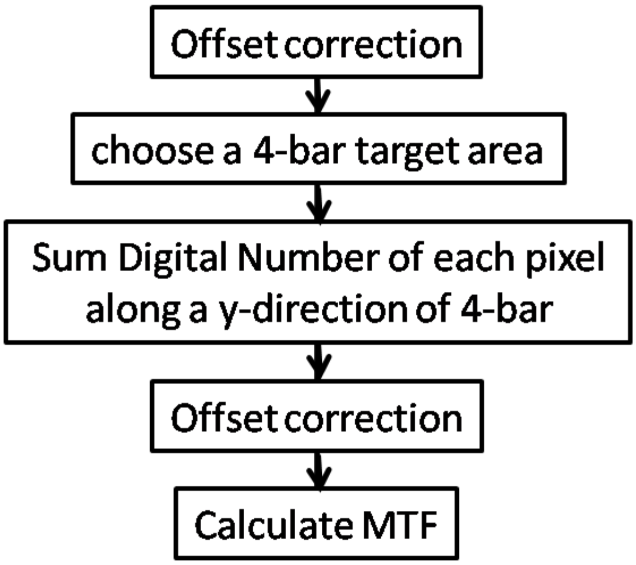

Fig. 10 Flow chart of the MTF analysis

5.5. Results

We have measured MTF for CT/AT direction at 5 detector positions. Results are shown in figure 12. Color means temperature difference; blue, black, magenta, and red represent results -10, 22, 40, and 50 degrees C, respectively. CT- and AT-direction MTF are shown in left and right panel. Top panels show the results at the detector center. Solid and dash lines mean MTF with different configuration that CIRC is on the bottom and side panel, respectively. MTF for

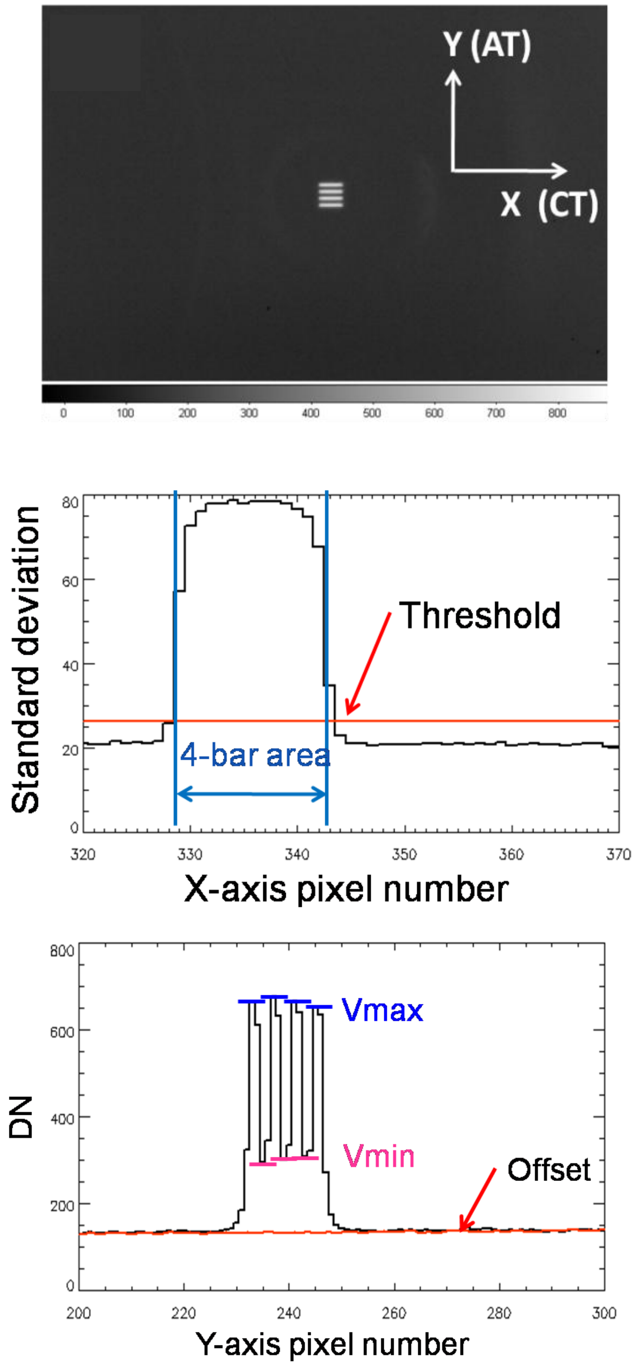

Fig. 11 Additional figure to explain the MTF analysis. (Top) Image of 4-bar target at the detector center. (Middle) Standard deviation of integrated image for Y (AT) direction. We set the threshold (red line) and choose the 4-bar target area. (Bottom) DN of 4-bar target. We correct the offset (red line), and calculate MTF with Vmax and Vmin shown in blue line.

CT-direction has same trend with several temperature and configurations. Middle and bottom panels show the results at the edge of the detector, ±5 degrees for CT and ±3.5 degrees for AT direction, respectively. Except for low temperature case at -5 degrees position, CT-direction MTFs are same within error. On the other hand, AT-direction MTFs vary with different temperature and positions. Nyquist MTFs of low temperature environments are lower than that of room and high temperature case for CT/AT-direction and all detector positions.

Figure 13 shows athermal characteristics at nyquist frequency measurement. Difference in color means the detector position; black, red, blue, magenta, and cyan represent at the center, +5, -5, +3.5, and -3.5 degrees, respectively. Top and bottom panels show the results at CT and AT direction. CT direction MTF at the detector center and ±5 degrees are constant regardless of temperatures. CT at ±3.5 degrees and AT direction MTF has gradient, lower in low temperature environment.

6. Discussion and Conclusion

Results of MTF measurement are summarized as follows;

- MTF is lower at low temperature environment
- The variation of AT-direction MTF is large

Possible reason for small MTF at low temperature case is due to the gap of focal length. Although an alignment of focal length of CIRC ground test model was adjusted in atmosphere, focal length changes due to the variation of reflective index in the vacuum environment. We are planning to adjust focal length of CIRC PFM for vacuum environment. We could not find out the reason that the variation of AT-direction MTF. It seems that misalignment of measurement setup is not a reason. We need a future work for this problem.

We measured the MTF characteristic of CIRC, which is one of the important image capture performance parameters of the optical sensor systems, and confirmed the athermal characteristics of the CIRC. We input the results to development process of CIRC PFM. In a future experiment, we will measure the radiometric performance of the CIRC ground test model. Through these experiments, we establish a prelaunch calibration method for the CIRC PFM onboard ALOS-2 and CALET.

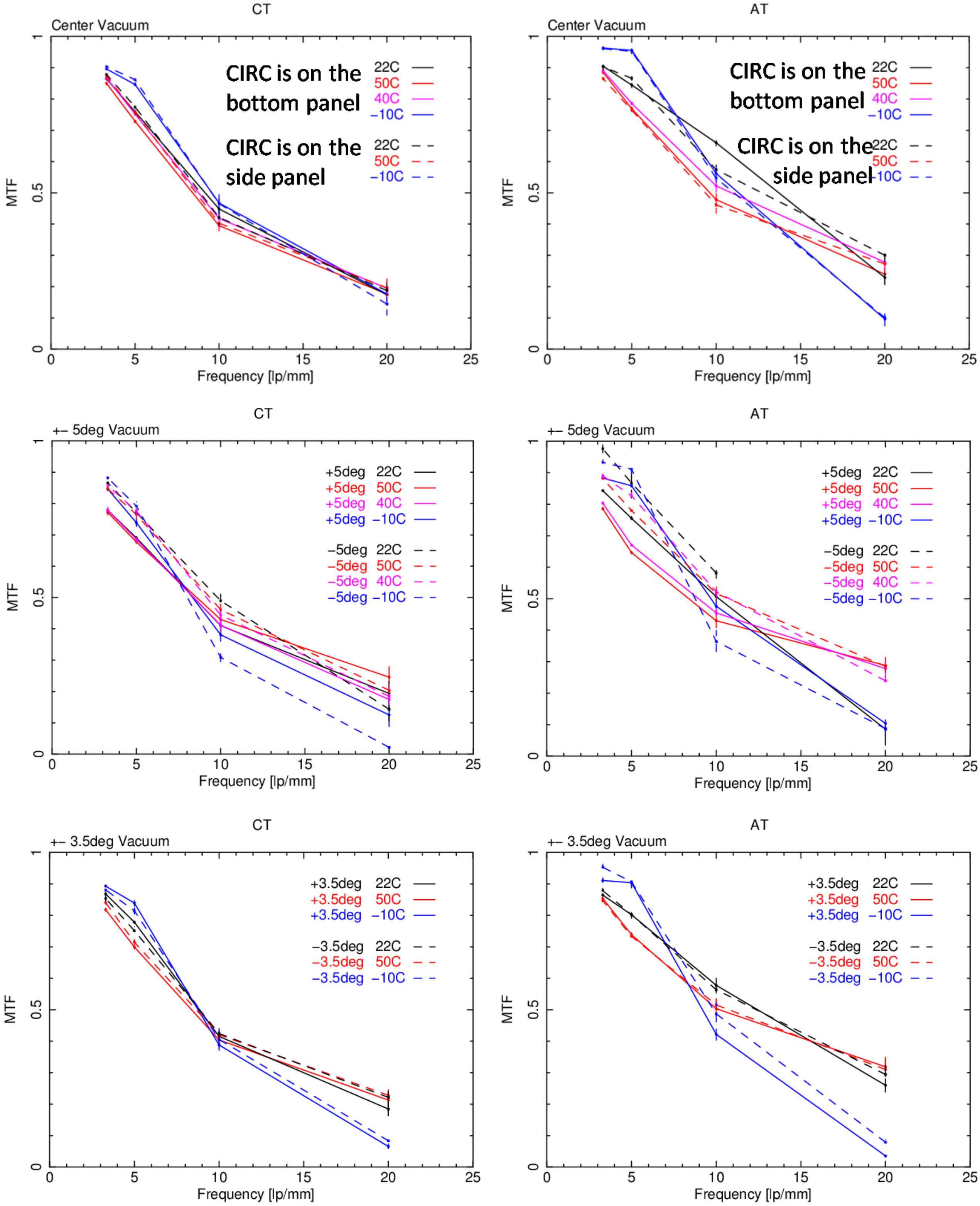

Fig. 12 Results of MTF measurement. In the room temperature (black), low temperature (blue) and high temperature (magenta or red) environment results are shown. Left panels are CT-direction, and right panels are AT-direction MTF. (Top) Results at the detector center. Solid line shows under the configuration that CIRC is on the bottom panel. Dash line is corresponds to the result with CIRC on the side panel. (Middle) Results at ± 5 degrees positions. Solid and dash line are correspond to the results at + 5 and -5 degrees, respectively. (Bottom) Results at ± 3.5degrees positions. Solid and dash line are correspond to the results at + 3.5 and -3.5 degrees, respectively.

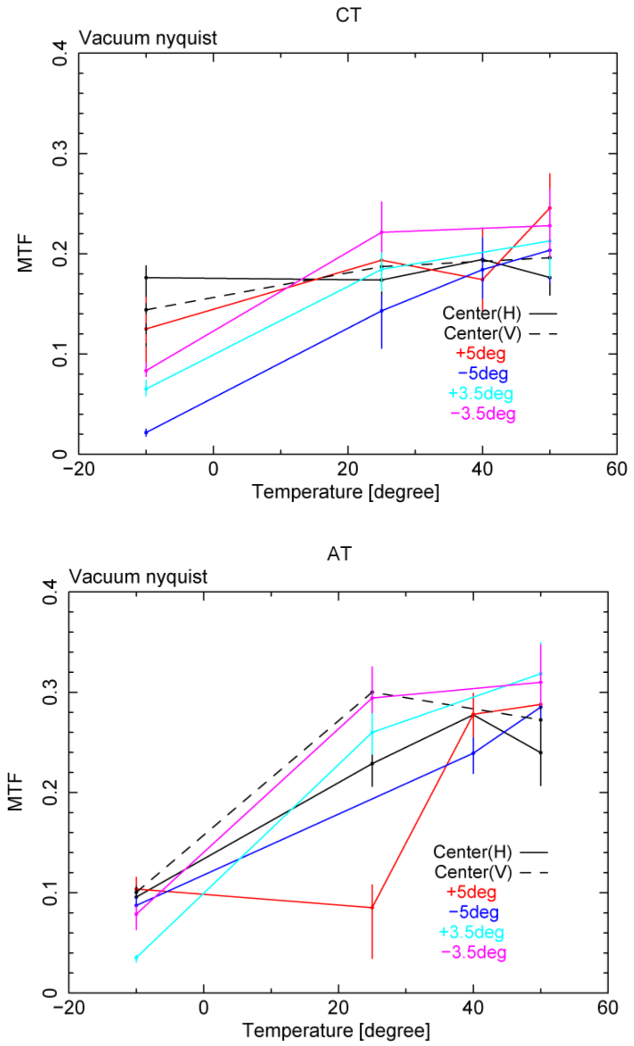

Fig. 13 Athermal characteristics at nyquist frequency. Difference in color shows the detector position; center is in black (solid and dash lines are correspond to the CIRC installed conditions of bottom and side panel), +5 degrees is in red, -5 degrees is in blue, +3.5 degrees is in cyan, and -3.5 degrees is in magenta, respectively. (Top) CT-direction. (Bottom) AT-direction.

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