MERIDIAN
Innovation

Improving Temperature Accuracy

Application Note MI.AN48

Revision 0.0.1 – March 2023

1. Introduction

The MI0802 is factory calibrated, so that all pixels report the same temperature value subject to some tolerance, when the entire field of view is flooded by a heat source at temperature. This is referred to as *factory level* calibration.

When the MI0802 is used in an application where not just thermal contrast is needed, but absolute temperature values are important, it may be useful to verify and fine tune the performance either per product (*product level calibration*), or per individual module (*unit level calibration*).

Below we describe a simplified approach to enable such calibration.

2. Methodology

The aim is to fine tune the sensitivity and offset for the nominal working distance and target size in mind. This involves the following steps, which are conveyed in Fig. 1.

2.1. Overview

2.1.1. Calibration

Find adjusted temperature offset and sensitivity value for a specific module, so that the readout from the module matches the desired reference values, for a representative target size and distance to the target.

2.1.2. Storage

Record the adjusted values of Sensitivity and Offset to the MI48 Flash Memory, so that they can be retrieved after power up. Note that the MI48 Registers – including the Sensitivity Factor and Temperature Offset registers are volatile – they do not persist after power down.

2.1.3. Normal Operation

Read the adjusted values of Sensitivity and Offset from the MI48 flash memory.

Write them to the corresponding registers – Sensitivity Factor (address 0xC2), and Temperature Offset (address 0xCB).

Start continuous acquisition of thermal data. The MI48 will use the adjusted values for Sensitivity and Offset.

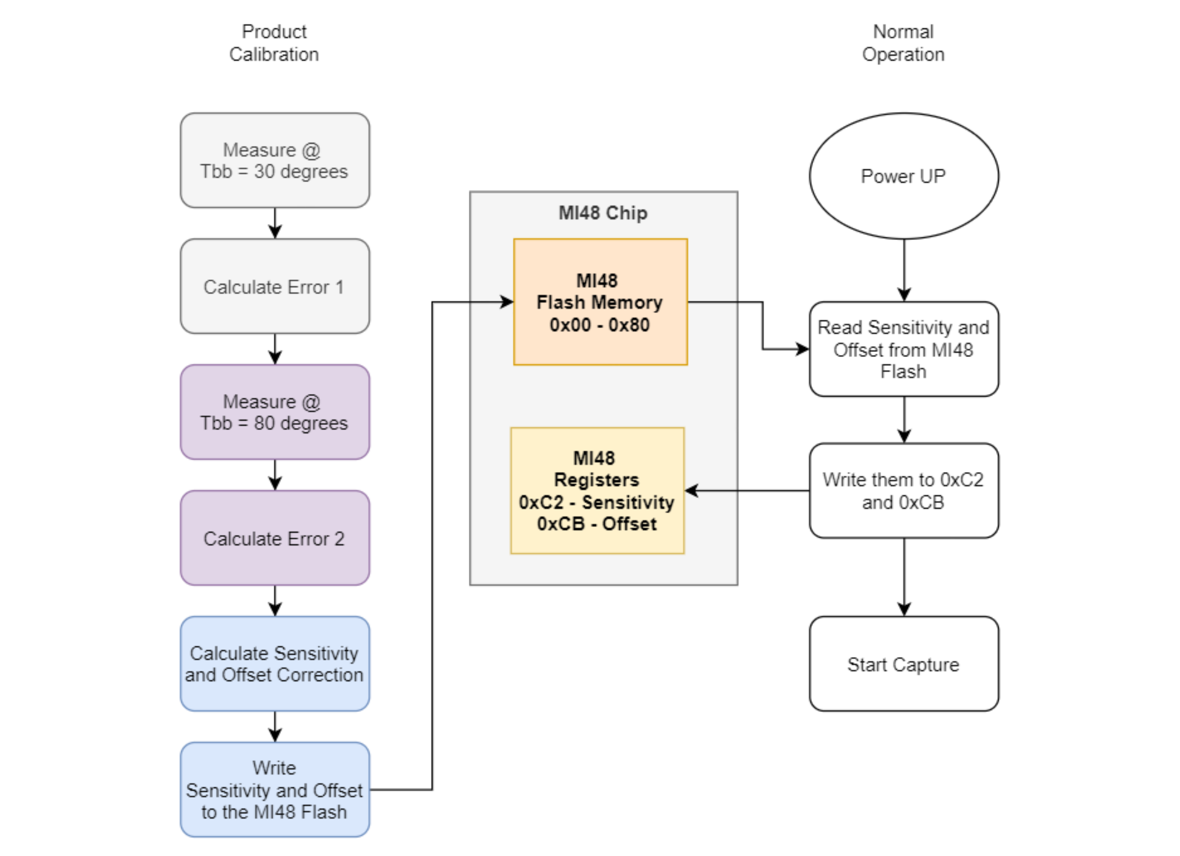


Fig. 1. Flowchart for realising product level calibration – the process of fine-tuning the sensitivity and offset of a given module, for a representative target and working distance, storing these parameters in the MI48 flash memory, and then retrieving them and setting up the MI48 to use them during normal data acquisition.

2.2. Calculations

2.2.1. Unit-level calibration

The correct Sensitivity Factor σ_i and Temperature Offset Δ_i are calculated individually for every module, based on data obtained from two measurements for each unit, while the Sensitivity Factor and the Temperature offset registers of the MI48 are set to 1.0 and 0.0 correspondingly.

First, a reference blackbody is set at 30°C and the sensor readout $T_{readout}(30)$ and its die temperature $T_{die}(30)$ are recorded.

Second, the reference blackbody is set at 80°C and the sensor readout $T_{readout}(80)$ and its die temperature $T_{die}(80)$ are recorded.

The correct Sensitivity Factor is:

$$\sigma_i = \frac{\left(T_{bb}(80) - T_{die}(80)\right) - \left(T_{bb}(30) - T_{die}(30)\right)}{\left(T_{readout}(80) - T_{die}(80)\right) - \left(T_{readout}(30) - T_{die}(30)\right)}$$

(EQ.1)

The correct Temperature Offset can then be calculated as:

$$\Delta_{\mathrm{i}} = \frac{\left(T_{bb}(80) - T_{die}(80)\right)}{\sigma_i} - \left(T_{readout}(80) - T_{die}(80)\right)$$

(EQ.2)

2.2.2. Product-Level Calibration

For product level calibration, an ensemble of N units is calibrated per-unit, and the values of the Sensitivity Factor and the Temperature Offset are averaged across the ensemble. Then, these values are used throughout each and every unit in the production. Mathematically, the product-level Sensitivity Factor σ_p and Temperature Offset Δ_p are obtained as:

$$\sigma_p = \frac{1}{N}\sum^{N} \sigma_i$$

(EQ.3)

$$\Delta_p = \frac{1}{N}\sum^{N} \Delta_i$$

(EQ.4)

3. PHYSICAL SETUP

The basic setup is illustrated in Fig. 2. The ambient temperature, in the range of 21 – 25 °C must remain constant, and no forced ventilation should be applied to the blackbody or the thermal imaging sensors. There should be no moisture on the lens of the module.

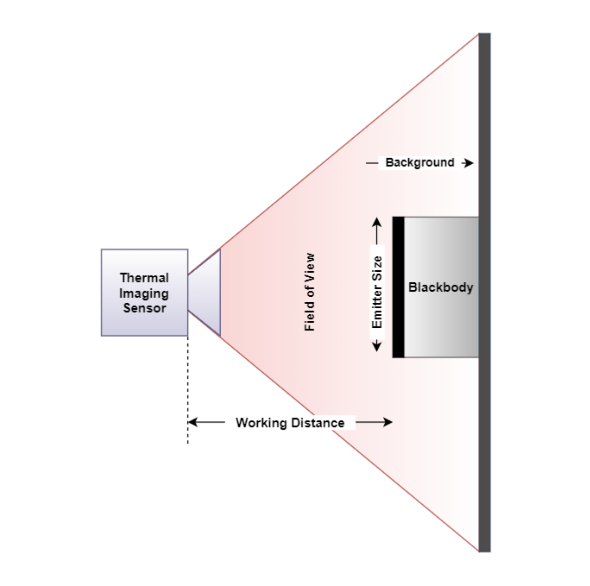


Fig. 2. The physical setup for product calibration typically involves working distance between the sensor and a reference heat object that are representative of the product application. Therefore, the heat object is likely to occupy only a fraction of the field of view of the sensor. However, to ensure good results of the calibration, the size should not be below 50 pixels, and ideally above 64 pixels.

The physical setup assumes that the working distance and the size of the blackbody are representative of the actual application of the thermal imaging sensor. Therefore, the indicated blackbody occupies only a fraction of the field of view of the imager.

3.1. Representative Results

3.1.1. Factory calibration

Figure 3 shows representative results from measurements without adjustments of Sensitivity or Offset, i.e. after *factory calibration*. Because of the small size of the heat source and the very wide angle of view of the lens of the MI0802M7G, the readout temperature – defined as the average of the 9 pixels in the centre of the hot-spot, where a green cross is seen – is lower than expected.

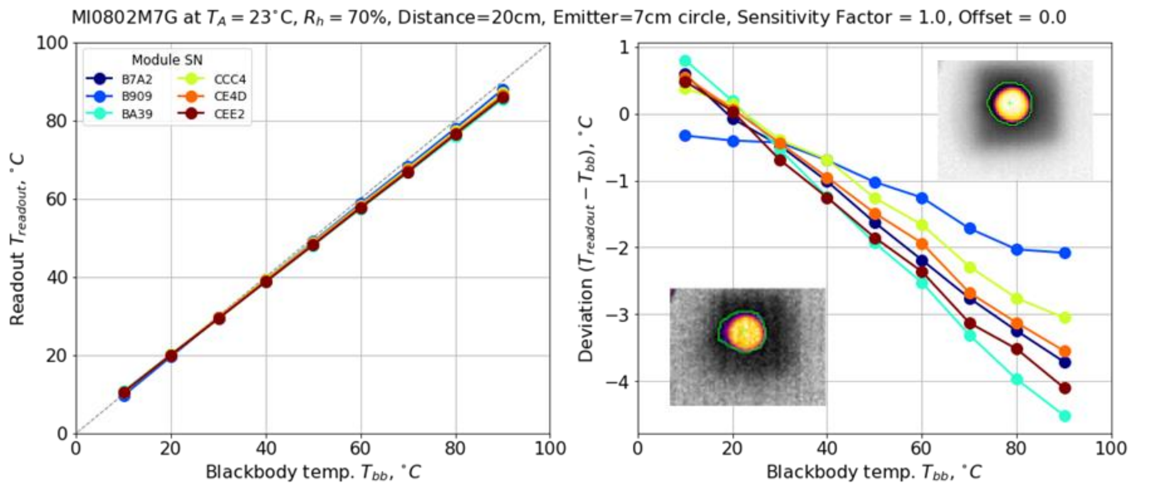


Fig. 3. Measured temperature (left) and temperature error (right) versus reference blackbody temperature. The blackbody is radiometrically calibrated, and we have used an emissivity of 1.0. The size of the emitter is 7 cm, and it is 20 cm away from the imager. The FOV is 105° and the hot spot occupies around 200 pixels. Dashed line on the left plot is the ideal relation of blackbody and measured temperature, for visual reference. The actual deviation of the readout from the reference temperature is shown in the right plot. The readout is the average of the 9 pixels in the centre of the hot spot shown in the thermograms, taken for one module at 30 and 80 °C.

3.1.2. Unit-level calibration

Figure 4 shows measurements after per unit calibration is done, i.e. Sensitivity Factor and Temperature offset have been tuned individually for each module, following EQ.1 and EQ.2.

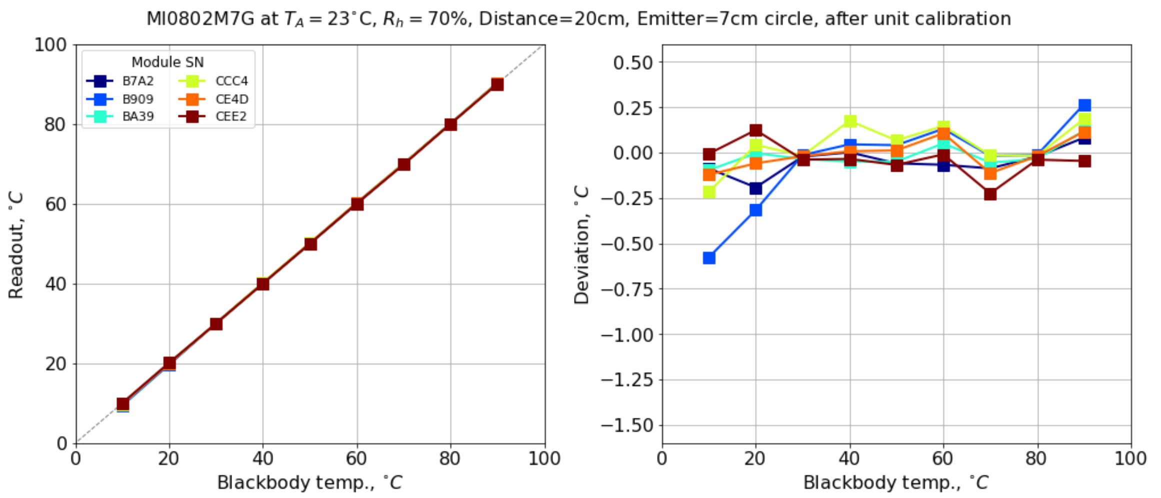


Fig. 4. Measured temperature (left) and temperature error (right) versus reference blackbody temperature after per-unit calibration, using the same setup as reported in Fig. 3. The adjustment of the Sensitivity Factor and Temperature Offset is done based on two points of the data reported in Fig. 3 – at blackbody temperature of 30, and 80 ℃, i.e. based on two measurements per each module. The error is reduced around 10 times over the range from 10 to 90 ℃.

3.1.3. Product-level calibration

The results for product level calibration are shown in Fig. 5. In this case σ_p and Δ_p are obtained from the ensemble of 6 devices measured above.

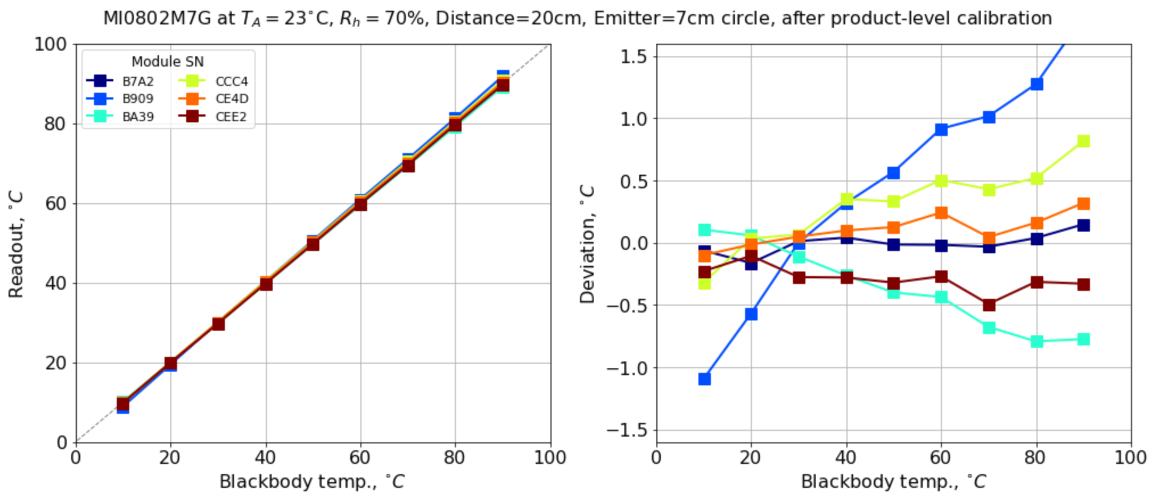


Fig. 5. Measured temperature (left) and temperature error (right) versus reference blackbody temperature after product-level calibration, using the same setup as reported in Fig. 3. The adjustment of the Sensitivity and Offset is based on the average values over the 6 modules shoen in Fig. 4. Although the error is reduced almost 5 times for most devices, there is an outlier (the blue line), for which the error is larger.

3.2. Procedure with EVK GUI Software

For preliminary investigation, one can use the EVK and EVK GUI without any calculation, to find the correct sensitivity and offset are. This is done by directly adjusting the Sensitivity Factor and the Temperature Offset registers of the MI48 in real time, following the procedure below. *Note that the values written to the MI48 during this procedure are not retained after power down or reset of the module*.

3.2.1. Setup

Use GUI Software version: 230117 or later

Set the distance between the blackbody and the sensor to the nominal working distance (or the average working distance, if a range is used).

Ensure that the optical axis of the thermal imager and the normal to the blackbody centre are collinear and as close as possible, i.e. aligned.

Ensure that the background is clean and not reflecting heat radiation:

- Do not use glass, as a background
- Black plastic board, a matt-painted wall or a curtain makes a good background

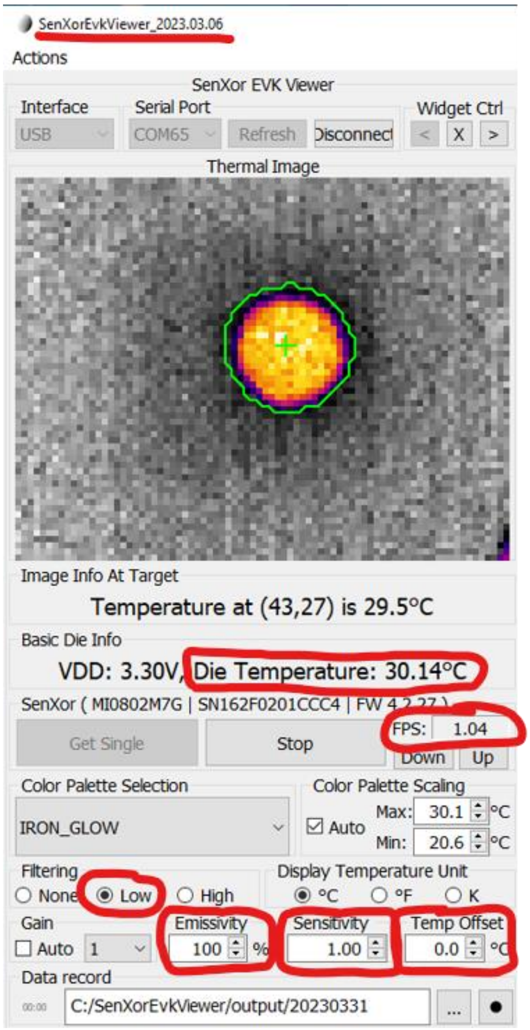
Prepare to record the following temperatures:

- Ambient temperature, T_{amb} – measured independently
- Blackbody temperature, T_{bb} – set temperature of the blackbody
- Senxor Die temperature, T_{die} – reported by the EVK GUI
- Readout temperature, $T_{readout}$ – reported by the EVK GUI

3.2.2. Warm up

- Set the **Blackbody to $\boldsymbol{T_{amb}} + \mathbf{6.0}$ ℃,** or to as close to that as possible.
  - Most blackbodies range from $T_{amb} + 10$℃ upwards.
- **Connect** the EVK and start **Continuous Capture**.
- Position the **green cursor in the middle of the hot stop** that represents your blackbody in the thermogram.
  - Ensure that the hot spot of the blackbody occupies at least 60 pixels or so.
- Set **Filtering to Low**
  - Use the radio button labelled Low
- Set **Frame rate to 1 FPS** or lower (Write 0xB4 = 0x20 – the EVK will display FPS = 1.04)
  - Use the Register Read/Write widget from the Actions menu of the GUI
- Set **Emissivity** to the value advertised by the manufacturer of your blackbody

  - If the blackbody is radiometrically calibrated, then Emissivity should be 1.0 (100 %)
  - If unknown, set to 98 %
- Set **Sensitivity to 1.0**
- Set **Temperature offset to 0.0** ℃
- **Wait until Die Temperature does not change** any more



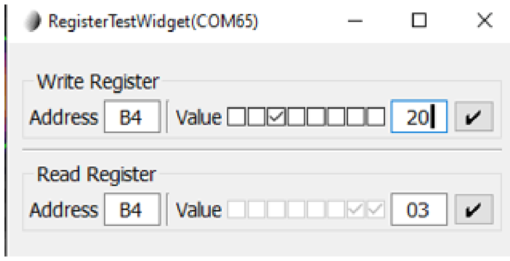


Fig. 6. GUI Setup at the end of the warmup stage, with important points highlighted:

- GUI Version > 2023.01.17 or later
- FPS set to 1
- Filtering set to Low
- Emissivity set to that of the blackbody in use
- Sensitivity set to 1.0
- Temperature offset set to 0.0 °C
- Die temperature should be stable.

The ambient temperature T_{amb} in this case was recorded to be 23 °C and the radiometric blackbody was set to $T_{bb} = 30$ °C. The sensor readout is seen to be $T_{readout} = 29.5$°C, i.e. 0.5°C lower than expected.

3.2.3. Offset Compensation

- Set the blackbody to the die temperature, or as close to that, and wait to stabilise
  - If the die temperature is not in the range of the blackbody, use the closest possible
- Change the Temperature Offset until the Readout off the Green Cursor matches the temperature of the blackbody. Record the temperature offset.

3.2.4. Sensitivity Correction

- Set the blackbody to 80 °C.
- Adjust the sensitivity until the readout off the green cursor matches the temperature of the blackbody. Record the sensitivity.

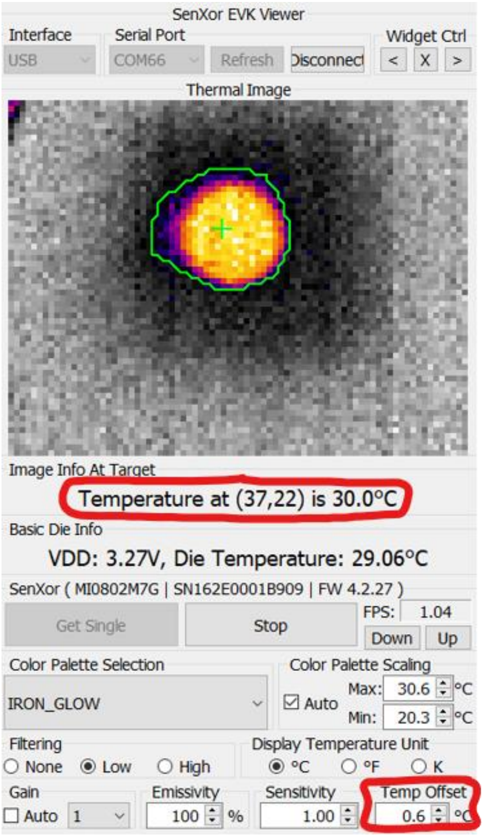


Fig. 7. Offset correction at temperature almost the same as the die temperature. The offset must be adjusted until the readout is the same as the set temperature of the blackbody.

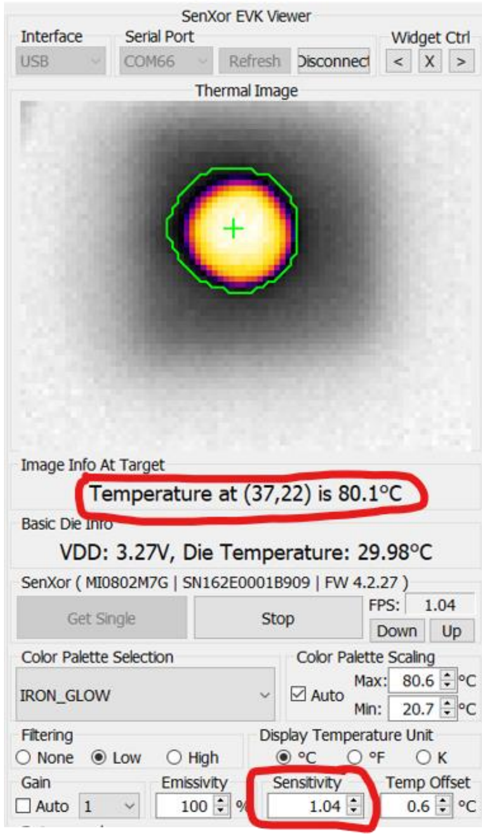


Fig. 8. Sensitivity compensation at temperature much higher than the die temperature. The sensitivity is adjusted until the readout is the sme as the set temperature of the blackbody.

3.2.5. Verification

Below, we show representative pictures for different temperatures, while maintaining the same settings as shown in Fig. 8.

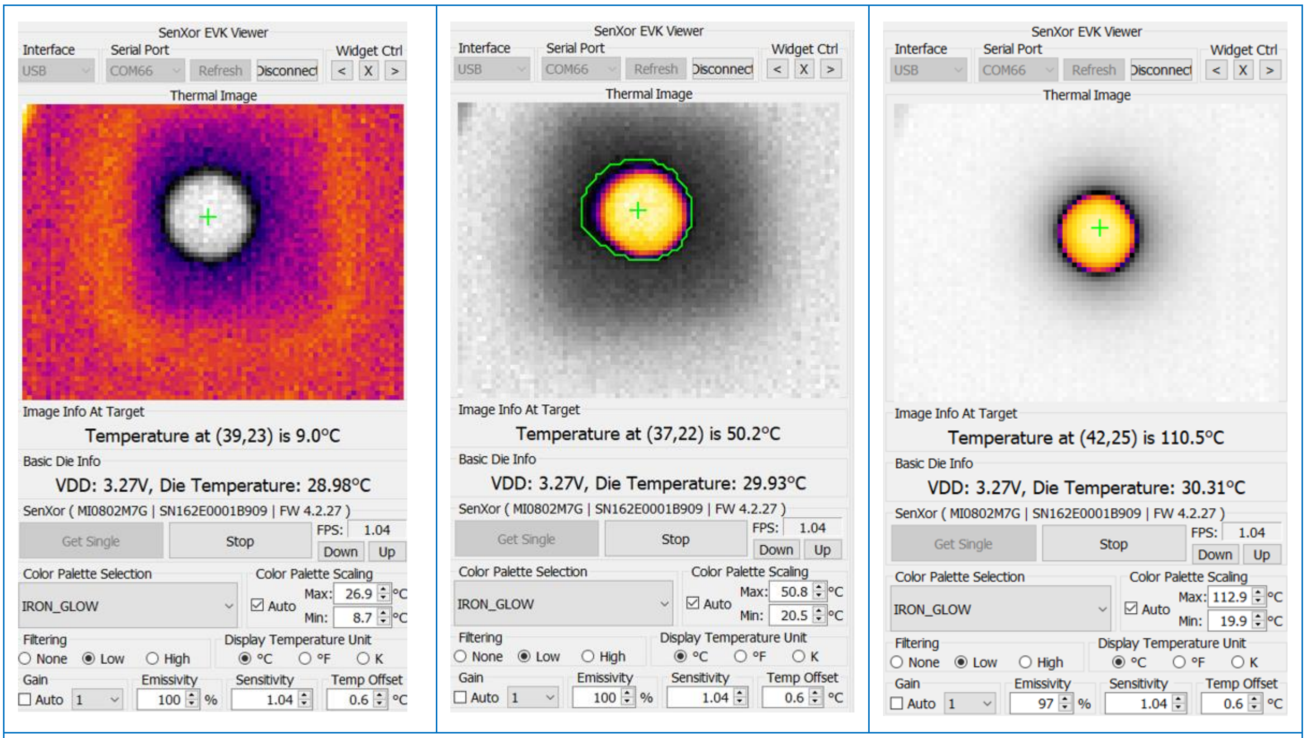


Fig. 9. Measurement with the same Sensitivity Factor and Temperature Offset, as established by *unit-level* calibration, for different blackbody temperatures. Note that for 110 °C the blackbody is different, non-radiometric, with advertised emissivity of 97 % (0.97).

4. Revision History

Revision	Date	Notes
0.0.1	Mar 2023	Initial Version

5. Legal Information

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6. Contacts Information

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