Using Protective Windows with SenXor

Application Note

Revision 0.0.1 – Dec 2022

1. INTRODUCTION

Many applications require protection of the lens of the thermal imager from the actual environment of the objects of interest. Meridian Innovation offers suitable protective windows which are made of either Si or Ge, sufficiently transparent to LWIR. Depending on the application, these windows are of different thickness, and have a finite attenuation of the radiation reaching the sensor. The amount of attenuation depends on the thickness of the protective window. An additional challenge that must be considered is that the protective window itself is a source of radiation that reaches the sensor, and this radiation depends on the physical temperature of the protective window and specifically on its surface facing the sensor. Therefore, the use of a protective window compromises the accuracy of the temperature readout. In this application note, we discuss compensatory mechanisms that allow us to estimate the correct temperature of the object of interest despite the two challenges.

2. COMPENSATION OF THE ATTENUATION

2.1. Methodology

Fig. 1 a shows the spectral response of the MI0801M01, and the transmission spectra of several protective windows. AR stands for anti-reflective coating, which is typically applied to both sides, unless one side of the protective window has a diamond-like coating (DLC).

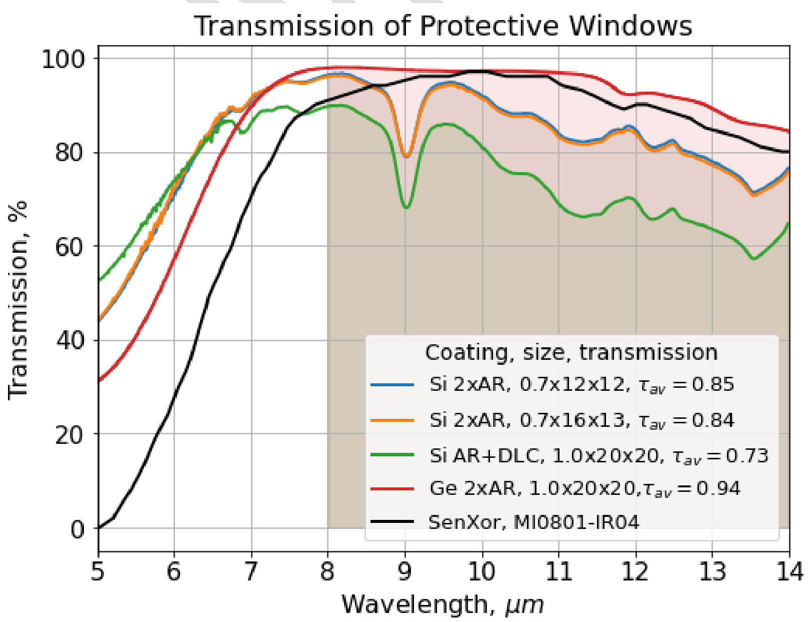


Fig. 1. Transmission spectra of different protective windows, with their average transmission τ_{av} over the shaded region. Black line is the spectral response of the MI0801M01 for comparison. The dimensions of the protective windows are thickness, width, height, in mm. Orange line overlaps the blue one, since the two windows have the same thickness and only differ in lateral extent.

Although the spectral response of the sensor and the transmission spectra of the windows differ in their features, the combined response of a system with a protective window represents that of the spectrally resolved product of the sensor response and the transmission spectrum of the protective window. Fig. 2 shows the combined spectral response for a system with 1 mm thick Si protective window. The integral average in the shaded region is 0.73 times the integral average of the sensor response without a window, which is equivalent to scaling the response of the sensor by the average transmission of the protective window – 73 %, in this instance. This suggests that the attenuation of the protective window can be compensated by a simple enhancement of the sensor sensitivity, which is a factor σ, representing the magnitude of sensor response S to a temperature difference ΔT between the observed object of interest and the sensor die temperature. The value of $\sigma = S/\Delta T$ is normalised to 1, during calibration, and used in the process of converting the sensor response in ADC codes to temperature values, as output by the thermal imaging processor chip MI48xx.

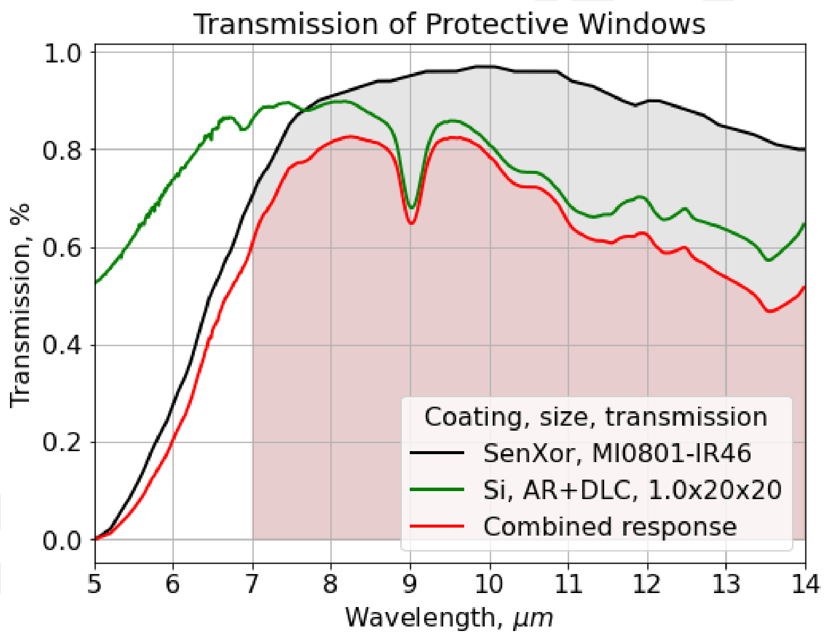


Fig. 2. Theoretical spectral response of the sensor, with and without a protective window. The integral average (the area under the curve in the shaded region, divided by the width of the range) of the response with protective window is 0.73 times that of the response without window, and the factor 0.73 corresponds to the average transmission of the protective window in the shaded region of the spectrum.

2.2. Compensation by Sensitivity Enhancement Factor

Fig. 3 shows temperature measurements with the MI0802M6S module *without* a protective window and *with* a protective window made of Si with 1.0 mm thickness, one sided AR and one sided DLC coating. Clearly, the temperature is attenuated significantly by the presence of the protective window.

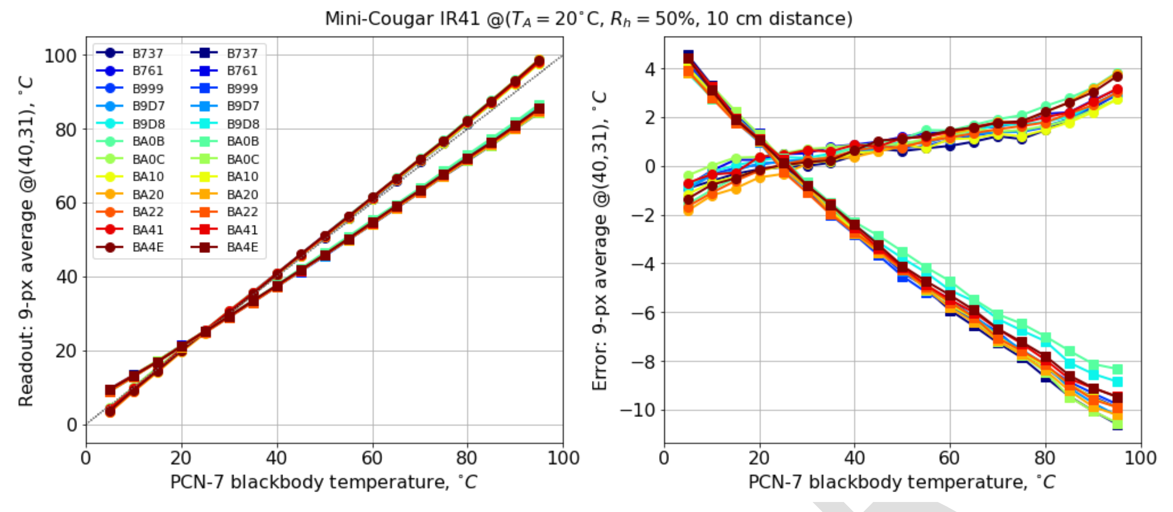


Fig. 3. Measured temperature and temperature error without protective window (disks) and with 1 mm thick Si protective window with AR+DLC (squares). The dashed line on the left plot is the ideal relation of blackbody and measured temperature, for visual reference. The actual deviation of the readout from the reference temperature is shown in the right plot, using corresponding symbols and colors.

Fig. 4 shows the results with protective window, obtained from measurements with sensitivity enhancement factor increased from 1.00 to 1.23. The error of attenuation is successfully compensated – the residual error over the range between 5 and 95 °C is within ±2 °C for the measured 18 modules.

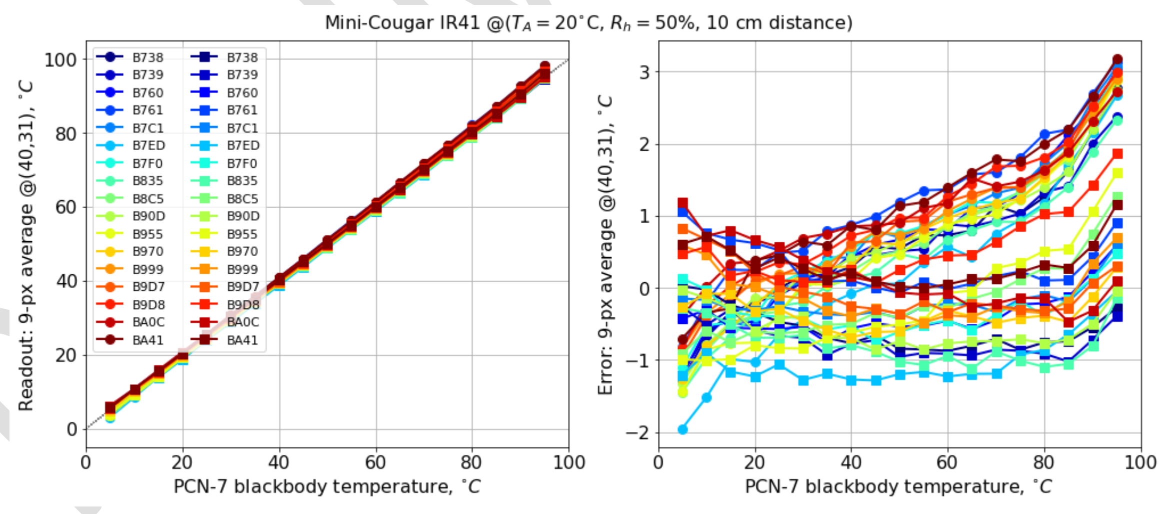


Fig. 4. Measured temperature and temperature error without protective window (disks) and with the same protective window as above (squares) but with compensation. The sensitivity enhancement factor is increased to 1.23 during the measurements with protective window. The error due to window attenuation is successfully compensated as seen in the right plot.

Fig. 5 shows that the same compensation approach and sensitivity factor of 1.23 work for a wider temperature range – in this case from 50 °C to 300 °C.

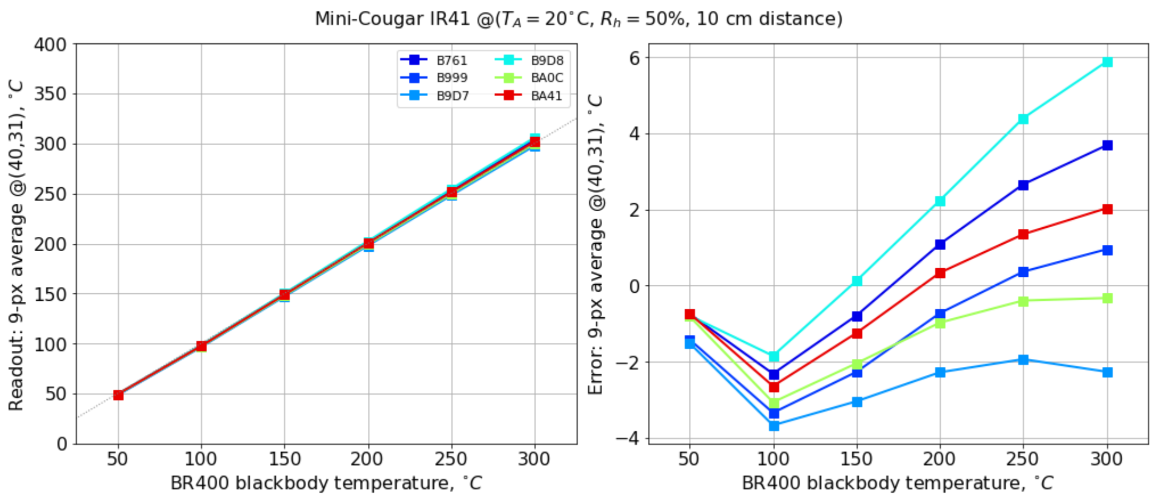


Fig. 5. Measured temperature (left) and temperature error (right) with protective window with sensitivity factor of 1.23 for a range of blackbody temperatures from 50 to 300 °C. The readout error is still within a few %, although sensitivity factor was established over a different temperature range.

The corrected sensitivity factor of 1.23 is established as follows. A linear fit on the readout versus reference temperature data without and with protective window from Fig. 3 yields the corresponding slopes $\alpha_{without}$ and α_{with}. The corrected sensitivity factor is $\sigma = \alpha_{without}/\alpha_{with}$.

This approach can be used to establish the correct sensitivity factor for other protective windows, based on the setup shown in Fig. 6. The recommended distance between the blackbody emitter and the sensor is around 10 to 20 cm, for a square emitter with 10 to 20 cm long side.

If a comprehensive measurement cannot be performed, a reasonable alternative is to use $\sigma = 1.0/\tau_{av}$, where the 1.0 in the numerator is the ideal slope of the readout data vs the reference blackbody temperature, and τ_{av} is the average transmission of the protective window in use, e.g. as reported in Fig. 1.

Note that the measurements above are performed at room temperature and the emission of the protective window itself are ignored, because the temperature of the window ≈ 20 °C, is quite close to the temperature of the sensor die (20 to 35 °C depending on the blackbody temperature, due to the physical proximity of the blackbody), which results in too small a signal.

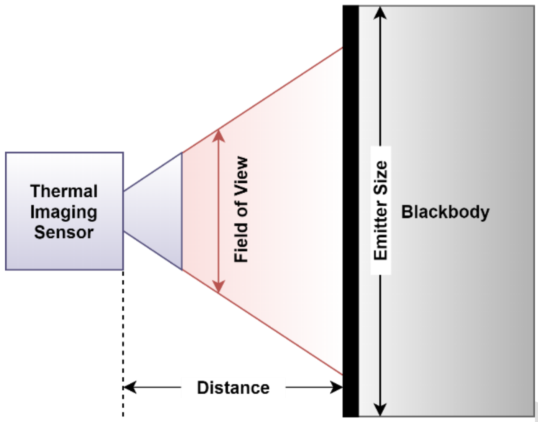


Fig. 6. Physical setup for measurement with and without protective window. The recommended distance between the protective window and the lens of the sensor is 1 to 2 mm and the distance between the sensor and the blackbody should be such that the field of view of the sensor is filled with the uniform emitter of the blackbody.

2.3. Changing the Sensitivity Factor

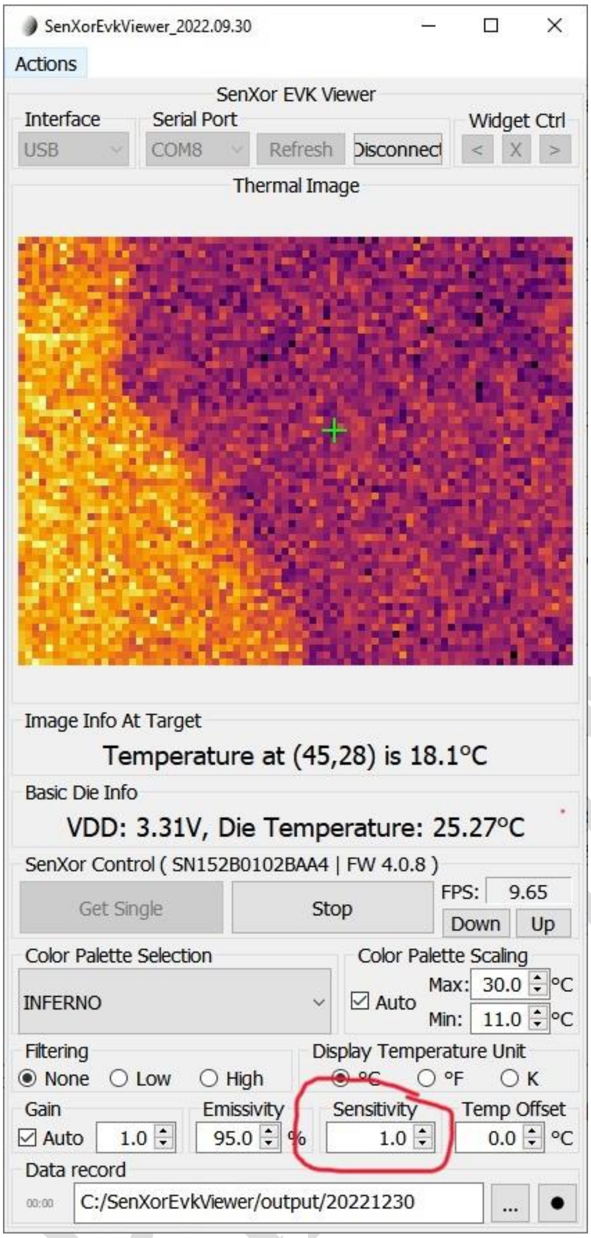
The conversion of the digital signal of the sensor in ADC codes to temperature values is performed within the MI48xx thermal imaging processor. This is where the sensitivity factor σ plays a role. Changing the value of σ is done via a write access to the SENSITIVITY_FACTOR register at address 0xC2. Depending on the SW used for characterisation, there are two approaches.

2.3.1. Using the EVK GUI

Subsequent to versions 2023.01.07 of the EVK GUI software, there is a dedicated control for the sensitivity factor in the main user interface window. This is shown in Fig. 7a).

For prior versions of the EVK GUI interface, a read and write access to the SENSITIVITY_FACTOR is realised through the Read/Write Register widget, accessed via the Actions menu:

1. Ensure you have SenXor EVK Viewer version 2022.04.06 or later.
2. Connect to the thermal imaging module and start continuous transfer.
3. Wait for the die temperature to reach steady state, i.e. observe a very slow change, or no change at all.
4. Set **Filtering** to **None**, after connecting to the sensor, as seen in Fig. 6.
5. Use the Register Read/Write Action (from Actions drop-down menu) to set register 0xC2 to the integer value corresponding to $100 \times \sigma$. For example, to set sensitivity factor to 1.23, as above, we must write the hex(123)=0x7B, to the register at address 0xC2.



a)

b)

Register Address	Register Value
0xB4	0x19
0xCA	0x64
0xC2	0x7B
0xCB	0x00

c)

Fig. 7. a)—EVK GUI version 2023.01.07 (or later) showing dedicated control of **Sensitivity** – set to the default value of **1.0.** b)—The RegisterTestWidget, selected from *Actions →Registers Read/Write*, showing a write of the value of 0x7B to register 0xC2. c)—Table of the register addresses and corresponding values that must be set during the measurements reported in Fig. 4 and Fig. 5, with the 1 mm thick Si protective window with AR+DLC coating.

2.3.2. Using PySenXor Library

PySenXor library abstracts the communication with the MI48xx by an instance of the class MI48. The class has a method `set_sens_factor(value)`, which can be called to set the value of the SENSITIVITY_FACTOR register (0xC2) of the MI48. The value can be a float, or an integer in decimal or hex number, representing the100 $\times$ σ. For sample, both `set_sens_factor(1.23)` and `set_sens_factor(0x7B)` achieve the same.

3. Revision History

Revision	Date	Notes
0.0.1	Dec 2022	Initial Version

4. Legal Information

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5. Contacts Information

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