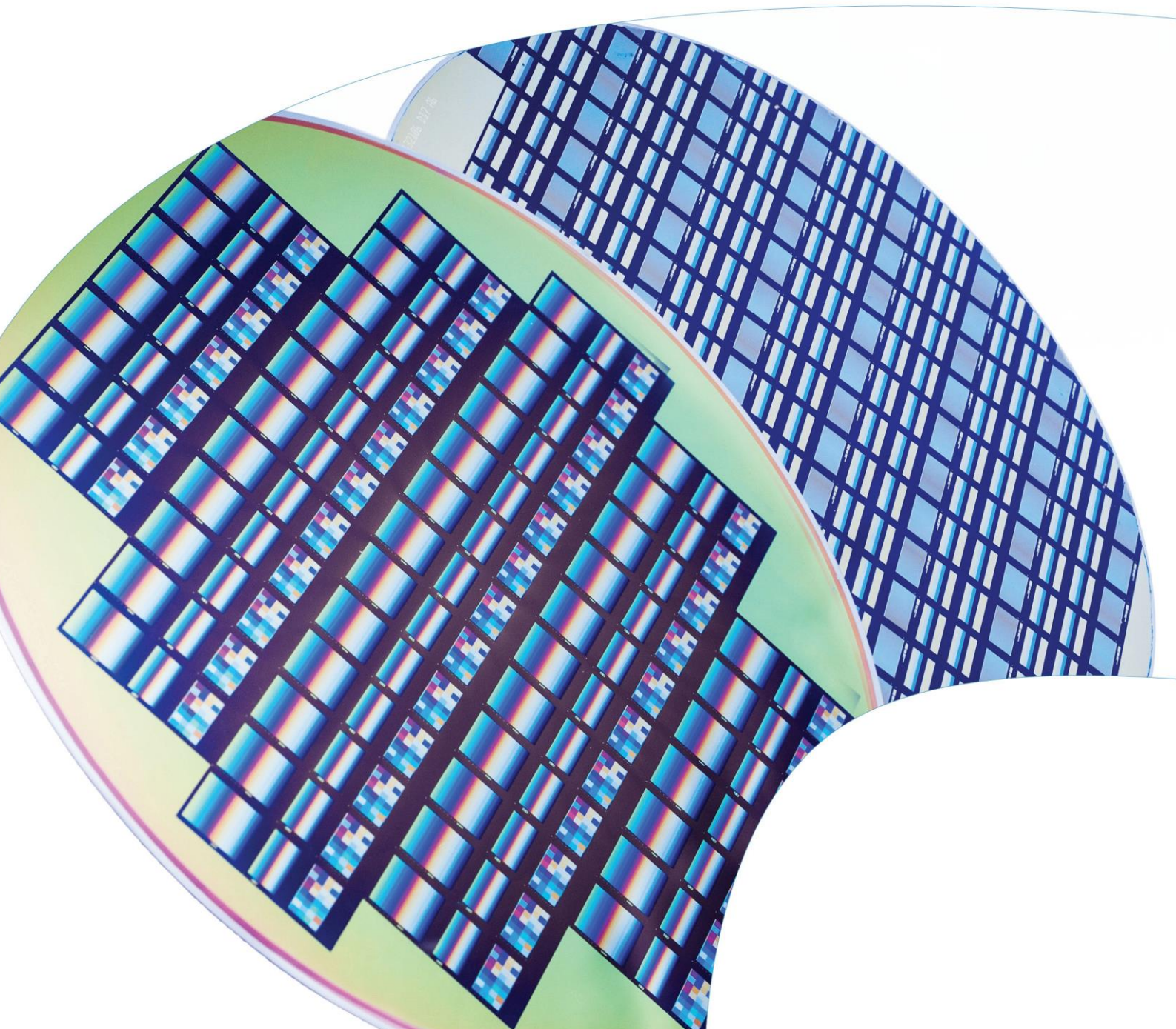




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# **HYPERSENSITIVE SENSORS**

TECHNOLOGY OVERVIEW





## Revision history

|             |                |                                                         |
|-------------|----------------|---------------------------------------------------------|
| <b>V1.0</b> | Sept. 20, 2017 | First draft of the document                             |
| <b>V1.1</b> | Okt. 25, 2017  | Final draft of the document                             |
| <b>V1.2</b> | Feb. 9, 2018   | Added specs on new SSM4x4 REDNIR and SSM5x5 NIR mosaics |
| <b>V1.3</b> | Jul. 15, 2019  | Updated filter spec and ranges                          |
| <b>V1.5</b> | Oct. 15, 2019  | Updated support contact.                                |



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## I Introduction

This document provides an overview of the hyperspectral imaging technology and sensors, developed by imec vzw, Belgium.

The manual is organized as follows: Section 2 gives an overview of the working principle of the hyperspectral filters and important properties of the sensors. The typical filter patterns and calibration files are also described. Section 3 focuses on the system aspects of hyperspectral imaging. More specifically, the influence of correct illumination and optical components is described. The section is finalized by an introduction to reflectance calculations and spectral correction. Section 4 gives an overview of all different hyperspectral sensors that are currently available, including their filter properties, spectral performance and preferred optical components.

## 2 General information

### 01 Working principle

Imec's hyperspectral filters are based on Fabry-Pérot structures. Such structures consist of two reflective surfaces with a cavity between them, as shown in Figure 1.

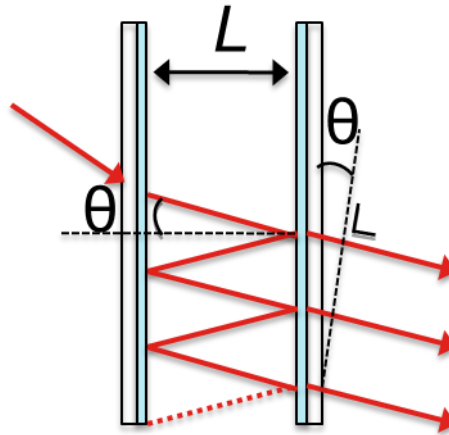


Figure 1: A Fabry-Pérot structure

The filter transmits wavelengths satisfying the equation

$$k\lambda = 2nL \cos \theta, \quad (1)$$

where  $L$  equals the thickness of the cavity between the two mirrors,  $\theta$  equals the angle of the light inside the cavity,  $n$  equals the refractive index of the material in the cavity,  $\lambda$  equals the central wavelength of the filter and  $k$  equals the order of the harmonic. Equation 1 shows that given a certain thickness  $L$  and refractive index  $n$ , the transmission of the filter also depends on:

- the angle  $\theta$  of the light inside the cavity, which is directly related to the chief ray angle (CRA) and the cone angle of the optical system;
- the harmonic number  $k$  of the wavelength for which it is designed.

Since the angular dependence is introduced through a cosine, the response is relatively insensitive to small angles of incidence.

### 02 Filter response

The sensor is designed to work in a specific spectral range. This range is called the active range. The typical active ranges for the hyperspectral sensors are:

- the visual spectrum (VIS): 470-630 nm
- the near infrared spectrum (NIR): 600-975 nm
- the combined visual and near infrared spectrum (VIS-NIR): 470-900 nm

The response of an ideal filter has narrow peaks centered around each harmonic wavelength with no response in the spectral range outside of these peaks. The width at half of the maximum of the peak

is called the full width at half maximum (FWHM). The peak's central wavelength  $\lambda_0$  is located in the center of the FWHM. As such the central wavelength is not always equal to the peak wavelength.

The response curve of a filter is the combination of the quantum efficiency (QE) of the sensor and the quantum efficiency of the filter. The maximal response of a filter equals the quantum efficiency of the sensor. An example of the quantum efficiency of the CMOSIS CMV2000 sensor without microlenses is given in Figure 2.

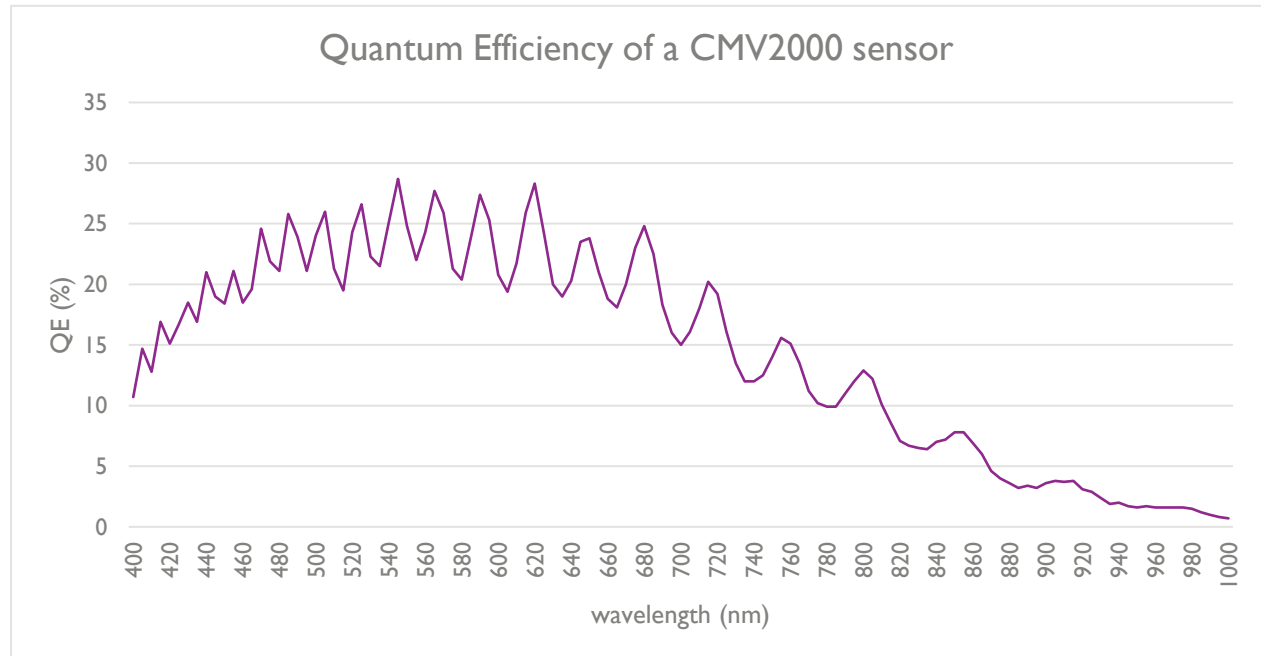


Figure 2: Example of the quantum efficiency of a CMOSIS CMV2000 sensor in function of the wavelength.

Due to physical constraints, some impurities are introduced into the response curve of a real filter. These effects can be summarized as a spectral shift, spectral leaking, and crosstalk and are explained in more detail later.

The spectral shift is introduced by the distributed Bragg stacks used to create the mirrors in imec's implementation of the Fabry-Pérot filter. The theoretic case of equation (1) assumes a phase shift of 180 degrees on every reflection. In the case of the Bragg stack, this assumption is not valid. Consequently, the wavelength of the second order harmonics is slightly shifted.

The response of the filters is not defined outside the active range. If light with wavelengths outside this range leaks into the filter, this is called spectral leakage. The response to wavelengths outside of the active range originates from the selection of materials used to create the Bragg stacks. Different materials will result in a different spectral range for which high reflectivity can be obtained, and the behavior is undefined outside of this range.

Crosstalk happens when the signal on one pixel influences the signal on another pixel. It plays an important role at the boundary of filters as electrons that belong to the pixel of one filter influence the response of another filter. This causes an unwanted response outside of the filter's response peaks. For this reason, it has a stronger influence on the data of sensors with a high spatial variation of filters.

The effects are illustrated in Figure 3, which shows the response curve of a filter designed for a wavelength of 913nm on a sensor designed for a range of 600-975 nm. The figure shows a second order response at 603 nm, wavelengths leaking into the filter outside of the active range and crosstalk from spatially nearby filters around 680, 760, 815 and 870 nm.

These effects must be removed or compensated to get good spectral data, which is the topic of Section 0.

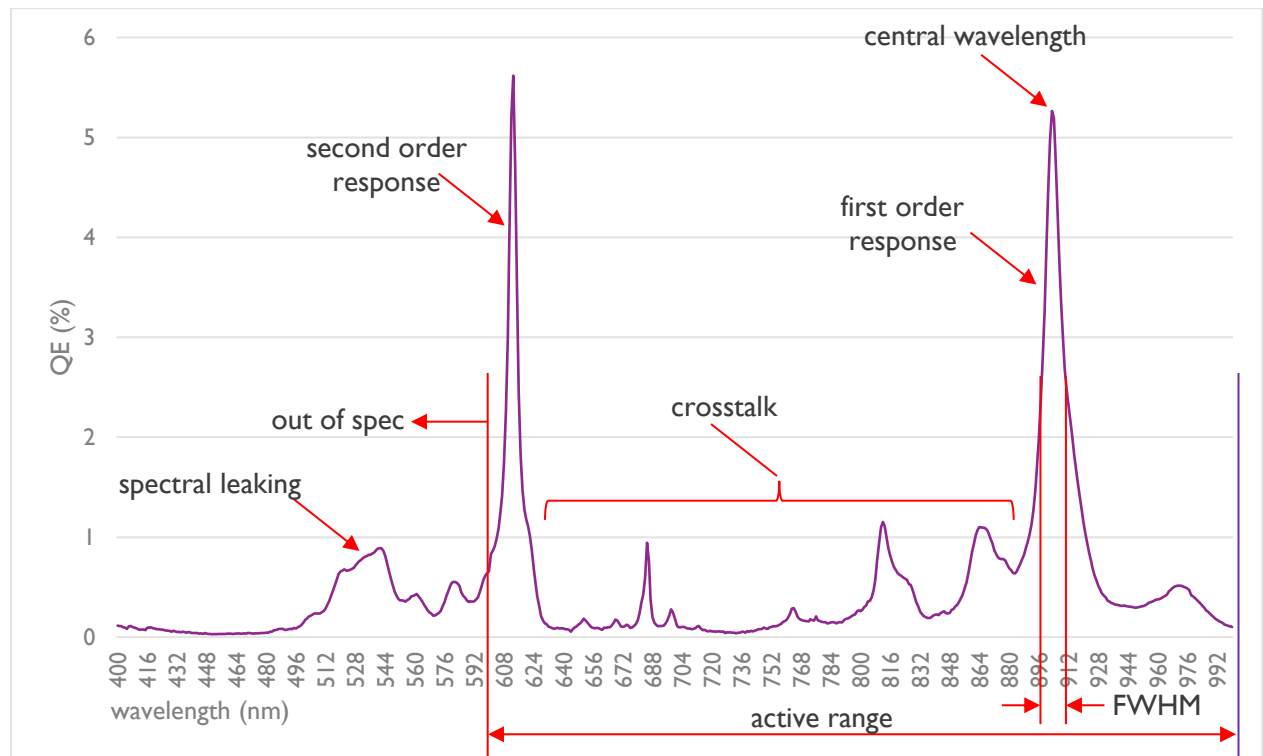


Figure 3: Example response of a hyperspectral filter with annotations. Noisy data taken from a snapshot mosaic 5x5 sensor.

### 03 Filter Layout

The filter layout describes the pattern in which the filters are deposited on the sensor. Typically, the filters do not cover the entire surface of the sensor. The area on the sensor covered with filters is called the active area. The positioning of the active area on the sensor is illustrated in Figure 4. The hyperspectral sensors can have one of the following filter layouts:

- Linescan Wedge (LS)

- Snapshot Tiled (SST)

- Snapshot Mosaic (SSM)

For each layout, there are variations depending on the type of the sensor, the active range of the sensor and the number of different filters in the layout. The position of the active area on the sensor depends on both the filter layout and the variant of the filter layout. Within each variation, the position of the active area on the sensor and the ordering of the filters is always the same. Moreover, the position of the filters in the pattern is always from left to right, up to down.

Each different filter layout is discussed in more detail in the following subsections.

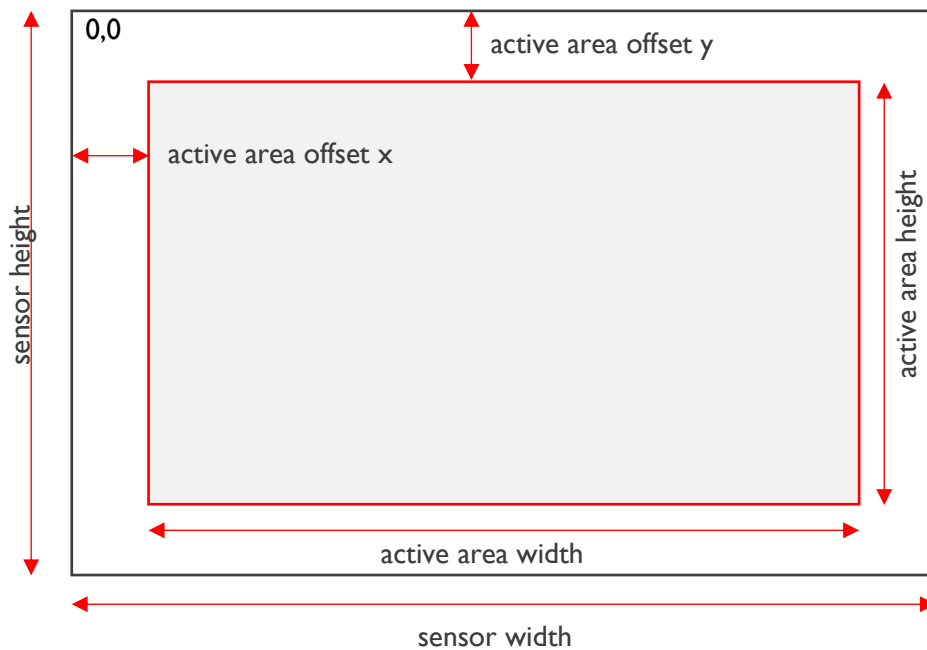


Figure 4: Positioning of the active area on the sensor.

#### Linescan

The linescan filter layout has a wedge design. The  $n$  filters in the linescan layout are organized in  $n$  bands of a fixed height over the full width of the active area. Typically, the width of the active area equals the width of the sensor. The height of the active area equals  $n$  times the height of the bands in pixels (e.g., 8 pixels). The band at the top of the active area has position index 0. The position index is incremented to the bottom of the active area, with the band at the bottom of the active area has position index  $n - 1$ . The linescan wedge layout is summarized in Figure 5.

Because of the organization of the filters in bands over the whole width of the sensor, this filter layout is best suited for linescan applications.

The filter layout is denoted by LS followed by the number of bands available. E.g., LS100 denotes the linescan layout with 100 spectral bands available. Note that the number of available bands does not necessarily coincide with the actual number of bands on the sensor. This is because some bands are used for production quality checks and future product development.

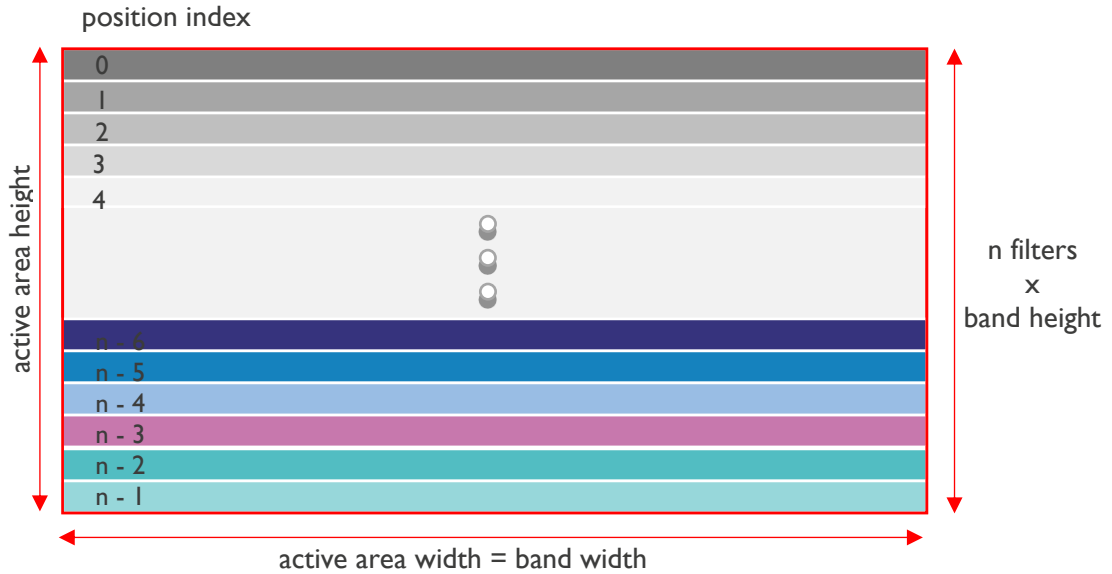


Figure 5: Filter organization in the linescan wedge layout.

### Snapshot Tiled

The snapshot tiled filter layout has an area design. The filters in the snapshot tiled layout are organized in  $n$  rows and  $m$  columns of tiles, all with a fixed width  $w$  and height  $h$ . The width and height of the active area equal  $m$  times  $w$  and  $n$  times  $h$  respectively. Typically, the width of the active area equals the width of the sensor. Each band image of a filter corresponds to one tile on the active area. The band at the top-left of the active area has position index 0. The position index is incremented from left to right and from the top to the bottom of the active area. The band at the bottom-right of the active area has position index  $nm - 1$ . The snapshot tiled layout is summarized in Figure 6.

The filter layout is denoted by SST followed by the number of tiles on the sensor. E.g., SST32 denotes the snapshot tiled layout with 32 spectral bands.

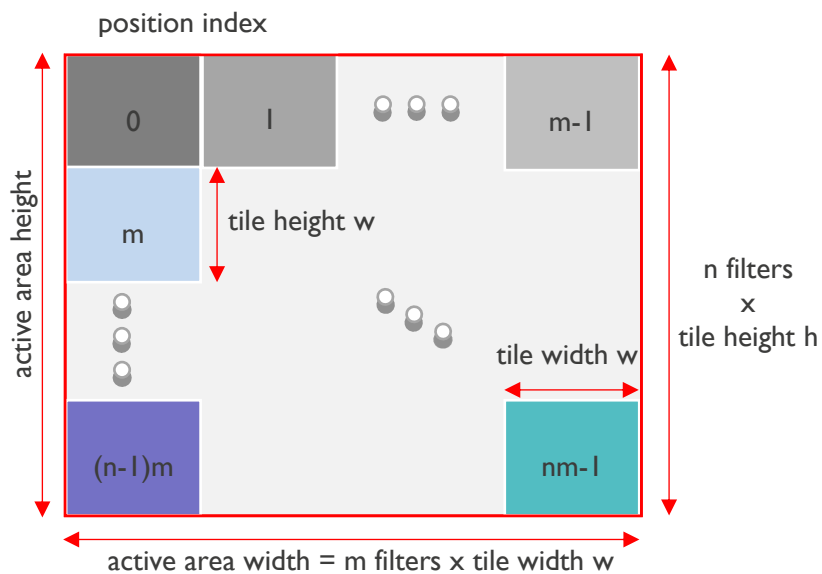


Figure 6: Filter organization in the snapshot tiled layout.

## Snapshot Mosaic

The snapshot mosaic filter layout has a per-pixel design. The filters in the snapshot mosaic layout are organized in a mosaic pattern of  $n$  rows and  $m$  columns. The mosaic pattern is repeated  $w$  times over the width and  $h$  times over the height of the active area. Each band image corresponding to a filter thus has width  $w$  and height  $h$ , distributed over the active area. For this reason, one mosaic pattern is also called one macro pixel or sub pixel. The filter at the top-left in the mosaic pattern has position index 0. The position index is incremented from left to right and from the top to the bottom in the mosaic pattern. The band at the bottom-right of the mosaic pattern has position index  $nm - 1$ . The organization of the filters in the mosaic pattern is summarized in Figure 7. The layout of the mosaic pattern over the active area is summarized in Figure 8.

The filter layout is denoted by SSM followed by the size of the mosaic pattern. E.g., SSM4x4 denotes the snapshot mosaic layout with 16 spectral bands arranged in mosaic pattern of four rows and four columns.

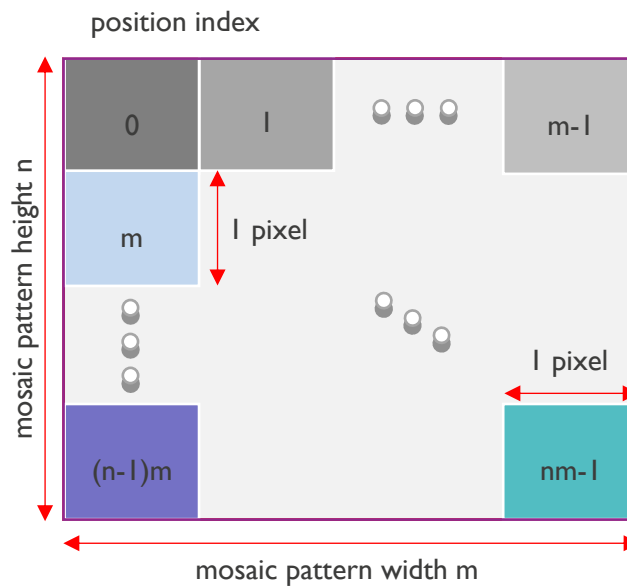


Figure 7: Filter organization in one mosaic pattern of the snapshot mosaic filter layout.

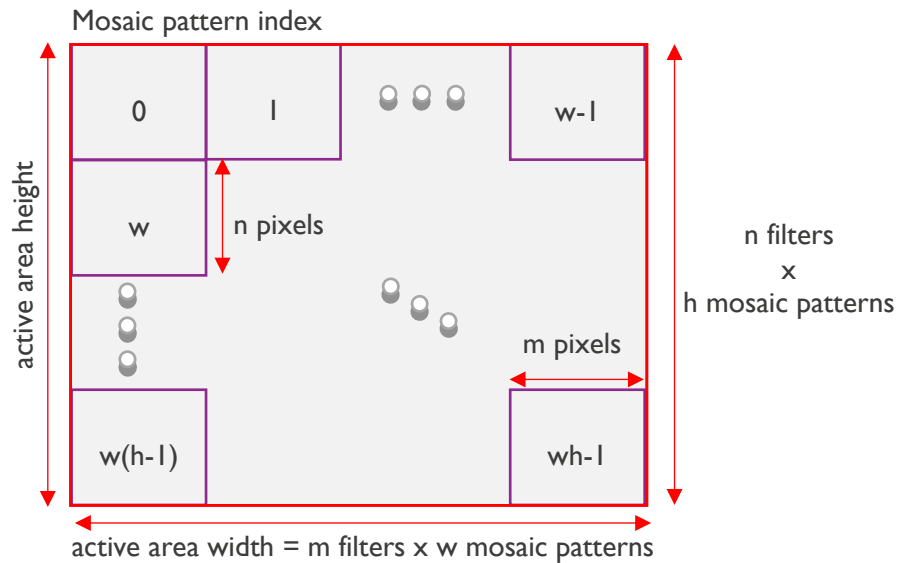


Figure 8: Mosaic pattern organization in the active area of the snapshot mosaic filter layout.

## 04 Sensor identification

A sensor is uniquely defined by a part number and a serial number. The part number describes the type of sensor, and the serial number is specific for each sensor. The full name of the sensor is then:

<part number>-<serial number>

The part number is composed of the base sensor type, the filter layout type and the active range of the filters on the sensor as follows:

<base sensor type>-<filter layout>-<active range>

Examples:

- Base sensor type:
  - CMV2K: CMOSIS 2K sensor
  - CMV4K: CMOSIS 4K sensor
- Filter layout:
  - LS100: linescan wedge layout with at least 100 bands available
  - SST32: snapshot tiled layout with 32 tiles
  - SSM4x4: snapshot mosaic with 16 filters in a 4x4 mosaic pattern
- Active range: <min>\_<max>
  - 470\_620: active range of 470 to 620 nm
  - 600\_1000: active range of 600 to 1000 nm

The sensor serial number is composed of four digits that link the sensor back to the production process. This enables the traceability of the sensor and to retrieve all information about a sensor. The serial number has the following format:

<X0>.<X1>.<X2>.<X3>

For example, CMV2K-SSM4x4-470\_600-3.1.7.7 has 4x4 mosaic filters in the range 470-600 nm on a CMOSIS 2K sensor with serial number 3.1.7.7.

## 05 Sensor calibration

Besides the different filter layouts on the sensors, the characteristics of the filters on a sensor slightly vary from sensor to sensor. To calibrate the sensor model, the response curve of each filter on the sensor is measured after production. The response curve is measured under ortho-collimated light at discrete wavelengths from 400-1000 nm in steps of one nanometer using a monochromator setup. The result of the calibration is the sensor model in the form of a response matrix. Each row of the response matrix contains the contribution of each wavelength from 400-1000 nm to one filter's total response. Given a spectrum of 601 samples, the response matrix is the transform that converts the spectrum to what would be measured by the sensor. The number of rows of the response matrix equals the number of filters on the sensor and the number of columns equals the number of measurement points used during calibration (i.e., 601 samples from 400-1000 nm).

The response matrix can be considered as the model of the sensor and is the primary source of information about the filters on the sensor. Specific filter characteristics, such as first and second order responses, the full width of the response peaks at half the maximum of the peak (FWHM), etc., are extracted from the response matrix. This sensor model can be used as the basis of a system model for e.g., a system level calibration.

An example of the response curves over the whole calibration range of a SST NIR hyperspectral sensor is given in Figure 9.

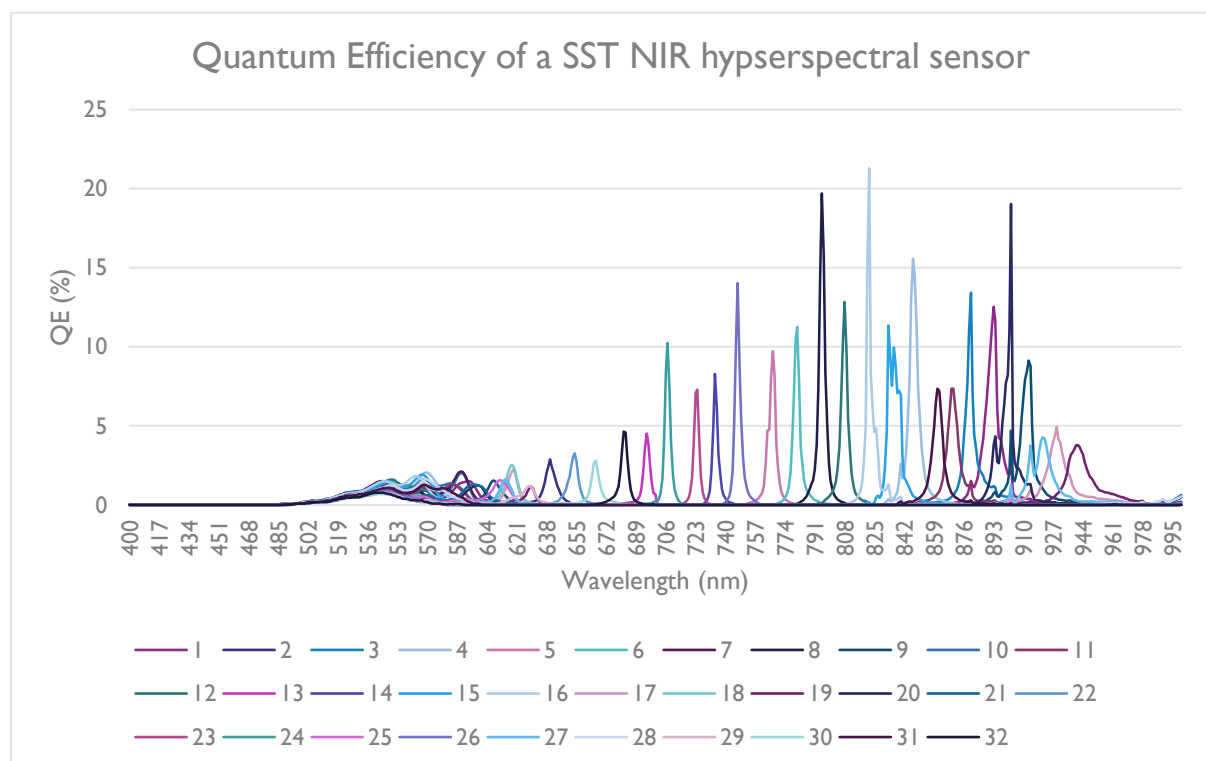


Figure 9: Example of a sensor's response curves.

### *Sensor calibration files*

The characteristics of the sensor that were measured during the calibration process are contained in a calibration file in xml format. Each sensor has its own calibration file containing data specific for this sensor. Using the calibration file of a different sensor to interpret captured data will result in wrong spectral information and render the data useless even when the filter layout of the sensor is the same. Because of this link between the sensor and the calibration data, the filename of each sensor calibration files equals the full sensor identifier. For example, the calibration file named “*CMV2K-SST32-600\_1000-1.2.3.4.xml*” belongs to sensor CMV2K-SST32-600\_1000-1.2.3.4.

The content of the calibration files is split over a sensor, a filter and a system element.

The sensor element contains all relevant information about the base sensor. This information is amongst others:

- width: the full width / number of columns of the sensor
- height: the full height / number of rows of the sensor

The filter element contains all relevant information about the filters on the sensor. This information consists of amongst others:

- active area: the position of the active area on the sensor
- bands: specific information for each band on the sensor, such as first order response, position index in the filter layout, response, etc.

The system element contains information about the system the sensor is intended to be used in and system dependent spectral correction / calibration matrices. This system information is primarily a list of additional optical components, such as rejection filters and/or light source spectra.

### 3 System aspects

As explained in Section 2, the response of the sensor is a mixture of wavelengths around the first order response, the second order response and wavelengths leaked into the filter. The raw sensor measurements or irradiance is the combination of this response with system aspects such as the illumination spectrum, the lens, optical filters, etc. This section focusses on the required conditioning of the input of the sensor (i.e., the incident light) and/or the data post-acquisition.

 **Note:** When not used correctly, this can result in incorrect spectral information in the measurements.

#### 01 Illumination

An illumination source is needed to illuminate the scene. The light generated by this source reflects on the objects in the scene after which it is measured by the sensor. Consequently, the spectrum of the illumination source has a strong impact on which wavelengths can be measured and on the signal strength.

A proper illumination source meets the following requirements:

1. The light spectrum covers the sensor's active range.
2. The light spectrum is smooth over the sensor's active range.
3. The light source illuminates the scene uniformly.

Besides these requirements, it is beneficial if the source emits more light in the spectral range where the QE of the sensor is lower. **The theoretical spectrum of an ideal light source is the inverse of the envelope of the response curves of the filters on the sensor.** This ideal light source does not exist in practice, but better approximations show to provide better results.

figure gives an overview of the spectra of several different illuminants.

Recommended illuminants:

- Visual range (450-650 nm):
  - Halogen (either cool fit or cool beam) combined with white and green LED
  - Xenon
  - Daylight
- Near infra-red range (600-1000 nm):
  - Halogen (cool fit) with aluminium or gold coating. To enhance illumination in the 600-700 nm range, combine with white or red LED
- Full range (450-1000 nm):
  - Combination of Halogen (cool fit) with aluminium or gold coating and Xenon or blue and green LED lamps

 **Note:** It is strongly advised to shield the setup from foreign light and to remove reflective surfaces around the setup.

#### 02 Lens

Not every lens is suited for use with a hyperspectral sensor. The main reasons are the angular dependency of the Fabry-Pérot filter transmission (see Equation 1) and the active range of the sensors (i.e., between 400-1000 nm).

The lens system fixes the angularity of the incident light on the sensor. For best performance, the angle of the incident light on the filters must be minimized. The determinant lens properties for the angle of the incident light are the chief ray angle (CRA) and the aperture. The CRA is the angle of incidence of the chief ray on the sensor. Best performance is achieved when the chief ray is orthogonal to the sensor. For standard lenses this is only the case for one ray, causing variations in CRA depending on the position of the object in the field of view of the lens. For this reason, the lens must be (near) image side telecentric. The angle of the light cone around the chief ray is controlled by the aperture. Closing the aperture will reduce the angle of the light cone as the opening of the lens to the sensor is limited. The effect of the F-number of the lens on a filter's response peak is illustrated in Figure 10.

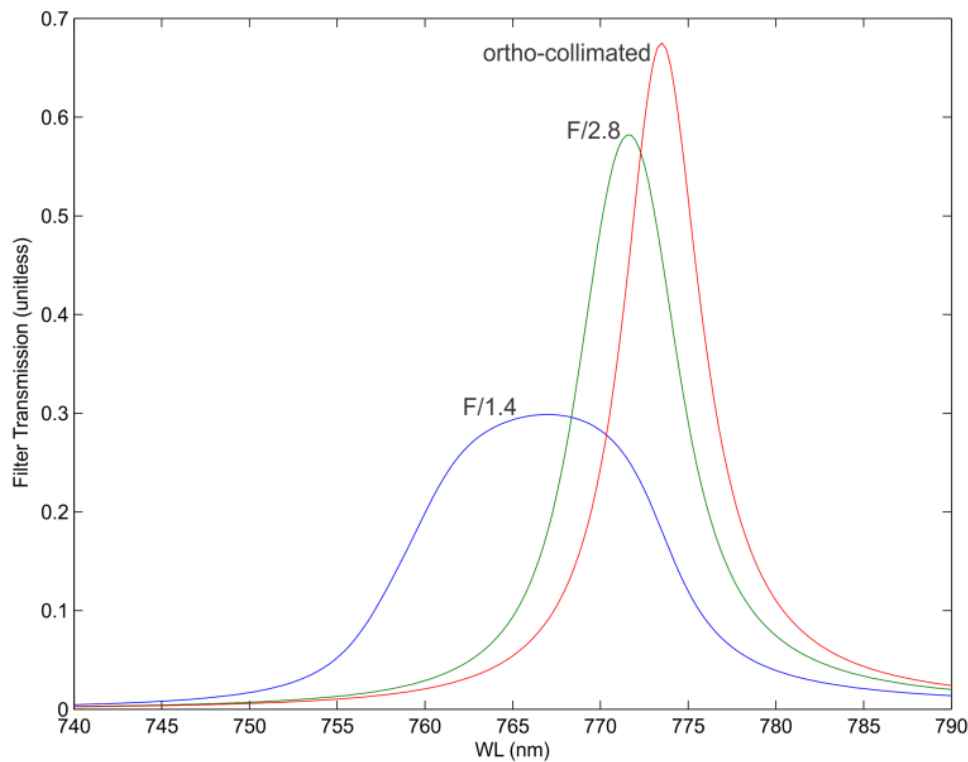


Figure 10: Effect of the F-number on a filter's response peak.

Closing the aperture also controls the transmission of the lens. Smaller F-numbers allow more light to pass through the lens and hence shorter integration times for the same illumination of the scene. At the same time the filter's peak transmission drops, the peak wavelength decreases and the FWHM of the peak increases. The combined effect of the F-number on the total lens and filter transmission is shown in Figure 11. Consequently, selecting the actual aperture opening is a trade-off between the quality of the spectral data and the acquisition speed. **Tests show that for most applications the optimal trade-off is an F-number of F/2.8.**

The lens must also be suited to capture wavelengths in both the visible light and the near infrared range. This means that the lens must have an appropriate anti-reflective coating (ARC) for light in the full range of 400 to 1000 nm. A good lens will also reduce the focus error for light in the full range of 400 to 1000 nm. Standard lenses limit the focus error only in the range of the visible light. More advanced lenses better reduce the focus error and over larger spectral ranges as illustrated in Figure 12. These lenses are called achromat, apochromat and superapochromat lenses in order of increasing performance. When focusing the lens for one wavelength, the focus error causes the lens to defocus on other wavelengths.

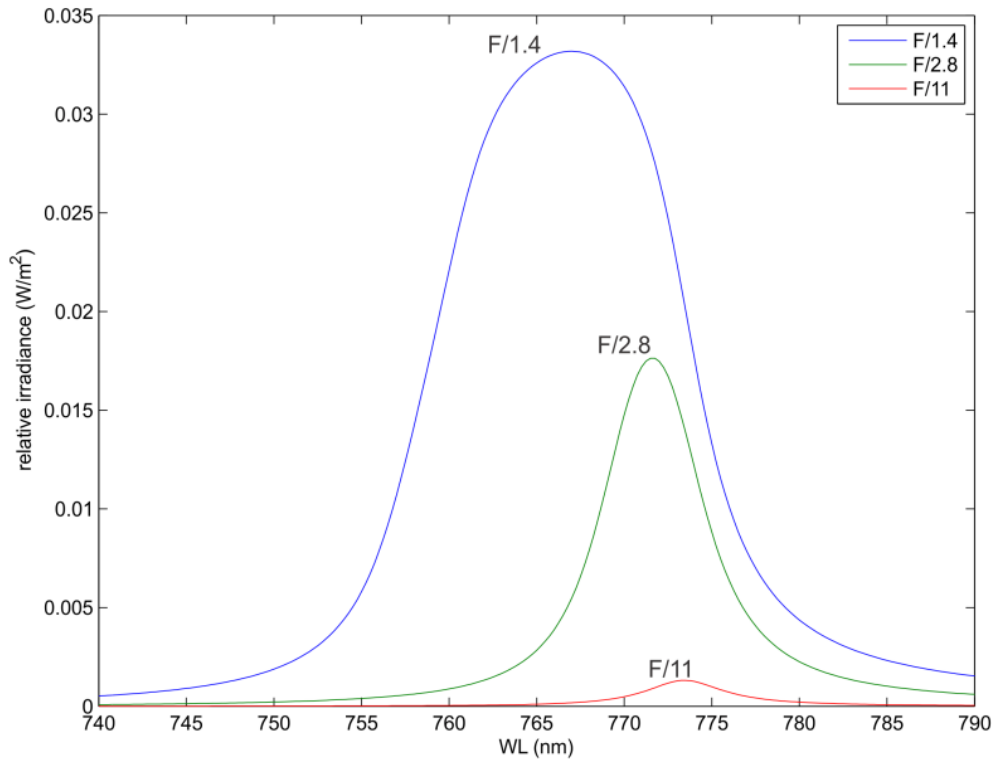


Figure 11: Effect of the F-number on the light transmission of the filter and lens.

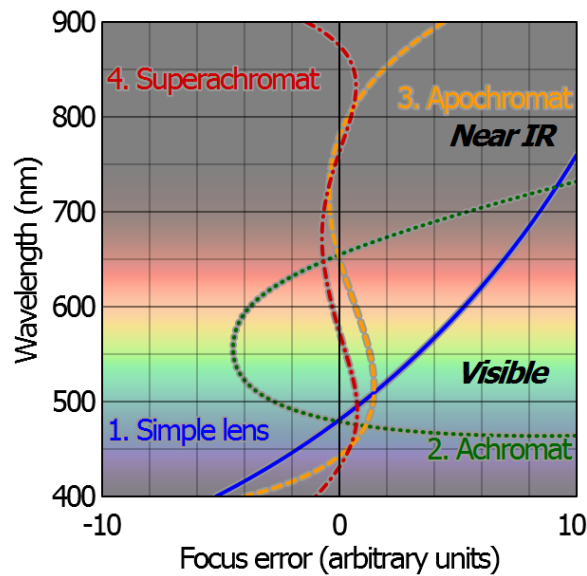


Figure 12: Lens focus error in function of the wavelength for different types of lenses.

**⚠ Note:** The SST sensors require an optical duplicator in the optical path. The optical duplicator duplicates the image on each tile of the sensor.

### 03 Band pass filters

The incident light is conditioned using an appropriate band pass or rejection filter in front of the sensor. The primary goal of the rejection filter is to block all wavelengths outside of the active range. Hence the filters will remove spectral leaking and unwanted second order responses outside of the sensor's active range.

The effect on the data of the rejection filter is illustrated in Figure 13, which contains the spectra of green vegetation. The green curve is the true spectrum of green vegetation, recognizable by the steep 'red edge' at 700 nm. The blue curve is the spectrum captured by the sensor when no rejection filter is installed in front of the sensor. The red curve is the spectrum as captured by the sensor with a rejection filter. A drop of intensity at 900 nm is observed due to a second order response peak in the active range of the sensor.

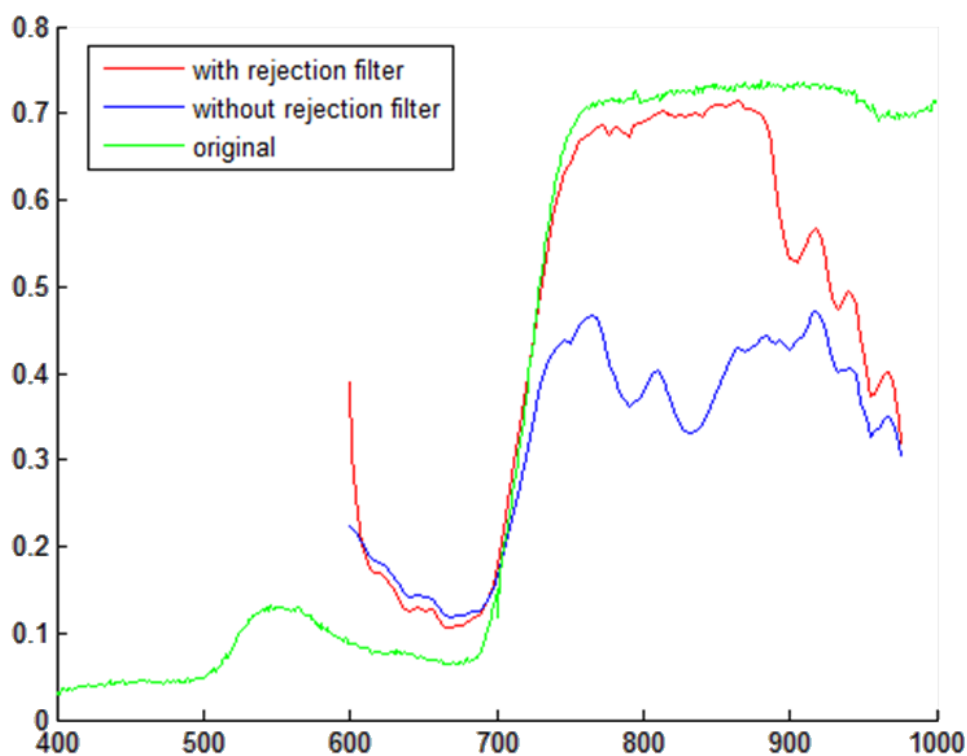


Figure 13: spectral responses of vegetation

The red curve in Figure 13 doesn't represent the actual spectrum because of crosstalk and a second order response peak in the sensor's active range. A possible solution is to narrow the band pass filter such that the second order responses are blocked. This is however doesn't remove the crosstalk and is also not always possible because the band pass filter must be selected to transmit light for at least one order of response of each filter on the sensor. If the band pass filter is too narrow some filters on the sensor will not function correctly and will produce invalid information in the captured data. A better solution is to remove the unwanted response using the spectral correction algorithm (see Section 2 Subsection 05).

## 04 Reflectance calculation

Reflectance calculation or white balancing computes the reflectance signal from the captured radiance of an object. This removes the influence of the sensor characteristics (QE, transmission efficiency, etc.) and the illumination from the spectrum of an object. The computed reflectance enables the comparison of spectra with available databases.

To compute the reflectance of an object the maximal response of a spectrally and spatially uniform white surface must be known for every pixel on the sensor. This image is called the white reference. The reflectance is computed by rescaling the radiance with respect to the white reference as

$$v = \frac{\rho}{\rho_{ref}},$$

where  $\rho_{ref}$  is the radiance of the white reference,  $\rho$  is the radiance of the object and  $v$  is the computed reflectance of the object, with  $v \in [0, 1]$ .

Often the radiance of the object is much lower than the radiance of the white reference. Consequently, only a fraction of the sensor's dynamic range is utilized. The dynamic range of the sensor is maximized assuming the radiance varies linearly with the integration time. The above formula is then changed to

$$v = \frac{\rho}{\rho_{ref}} \frac{\tau_{ref}}{\tau},$$

where  $\tau_{ref}$  is the integration time used to create the white reference and  $\tau$  is the integration time optimized to capture the object.

Additionally, bias correction will remove static noise from the data. This operation requires dark images of the sensor captured with both integration times  $\tau$  and  $\tau_{ref}$ . A dark image or bias image is an image created with the shutter closed or lens covered. The formula for reflectance calculation then becomes

$$v = \frac{(\rho - \rho_{0,\tau})}{(\rho_{ref} - \rho_{0,\tau_{ref}})} \frac{\tau_{ref}}{\tau},$$

where  $\rho_{0,\tau}$  is the bias image acquired with integration time  $\tau$ .

The assumption of linearity is key to compute reflectance using the above formulas. If this assumption is violated, the shape of the measured spectrum will depend on the integration time used, hence corrupting the measurement. It is recommended to validate the linearity of the response during the configuration of the setup. This is done by imaging a typical scene with increasing integration times. The maximum integration time to be used is then the integration time at which one band's response starts to deviate from the expected linear response. Note that from each image a corresponding bias image must be subtracted to achieve linearity.

## 05 Spectral correction

Unlike the wavelengths outside of the active range some unwanted responses cannot be removed using rejection filters. These unwanted responses typically are second order responses, response to wavelengths leaking into the filters and response to filter crosstalk (see Section 2 Subsection 02). These wavelengths contribute to the filter's total response and will be present in the captured data. Their contribution to the signal can be suppressed by the spectral correction algorithm. An example

is given in Figure 14. The green curve is the expected spectrum of vegetation. The red curve is the captured spectrum with a band pass filter installed. The unwanted responses create an erroneous spectrum. The blue curve is the spectrum after applying the spectral correction algorithm to the data and coincides with the expected spectrum of vegetation.

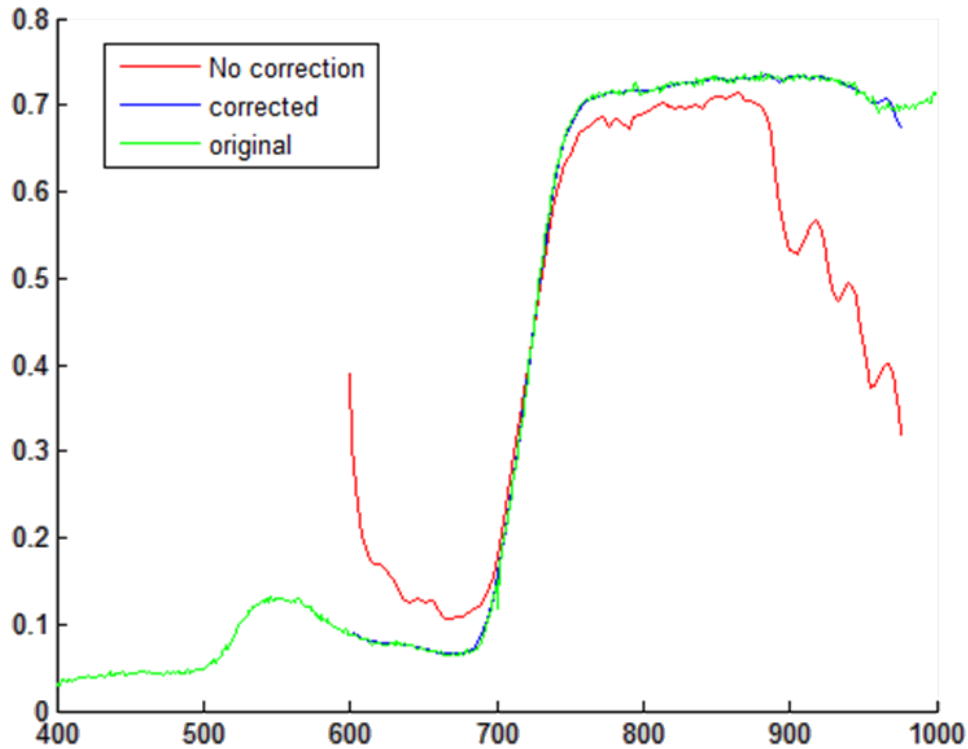


Figure 14: effect of removing second order harmonics in post-processing

Spectral correction consists of a linear combination of the raw responses to remove the unwanted signal. Hence the correction is formulated as a correction matrix and is applied to the signal by multiplying the signal with the correction matrix. The correction matrix always has a number of columns equal to the number of bands on the sensor, and a number of rows equal to the number of virtual or ideal bands. While in theory the number of virtual bands is unlimited, in practice this number is always smaller or equal to the number of physical bands. In some cases, there are fewer virtual bands than physical bands. This might be due to large correlations between the responses of some physical bands or a lack of signal captured by one or more physical bands.

The spectral correction must be applied after reflectance calculation. The spectral correction matrix is computed specifically for each combination of sensor and optical components (i.e., rejection filters, light source, etc.) and is provided in the sensor's calibration file.

The complete formula to compute spectrally corrected reflectance from the raw measurements is

$$v = C \frac{(\rho - \rho_{0,\tau})}{(\rho_{ref} - \rho_{0,\tau_{ref}})} \frac{\tau_{ref}}{\tau},$$

where  $C$  is the correction matrix.

## 4 Hyperspectral sensors

### 01 CMV2K LSI00+ NIR (600-975 nm)

|                                        |                                                                                                                   |
|----------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| <b>Sensor type</b>                     | <b>CMV2K LSI00+ NIR</b>                                                                                           |
| <b>Wavelength range</b>                | 600-975 nm                                                                                                        |
| <b>Filter pattern</b>                  | Wedge                                                                                                             |
| <b># bands</b>                         | 100+ (max 128)                                                                                                    |
| <b>Recommended lens</b>                | <u>35 mm VIS-NIR Compact Fixed Focal Length Lens</u>                                                              |
| <b>Recommended filters<sup>1</sup></b> | <u>Edmund Optics 600 nm long pass filter (#62-985)</u><br><u>Edmund Optics 975 nm short pass filter (#86-108)</u> |
| <b>Recommended mount</b>               | <u>M25.5 x 0.5 mount for 25 mm diameter filters</u>                                                               |
| <b>Calibration file format</b>         | CMV2K-LSI00-600_1000-X.X.X.X.xml                                                                                  |

The CMV2K LSI00 NIR sensor is a CMOSIS CMV2K sensor with 128 filters in a wedge pattern, active in the near infrared (600-975 nm). Each band is 8 rows high, covering in total 1024 rows of the sensor. An example of the filter responses in the active range is given in Figure 15.

**⚠ Note:** At least 100 of the 128 bands are available for use on the sensor. The remaining bands are used for production quality checks and future product development. Typically, the available bands are band 13 to band 114.

In the evaluation kits a custom made 600-975 nm band pass filter is built into the Ximea camera.

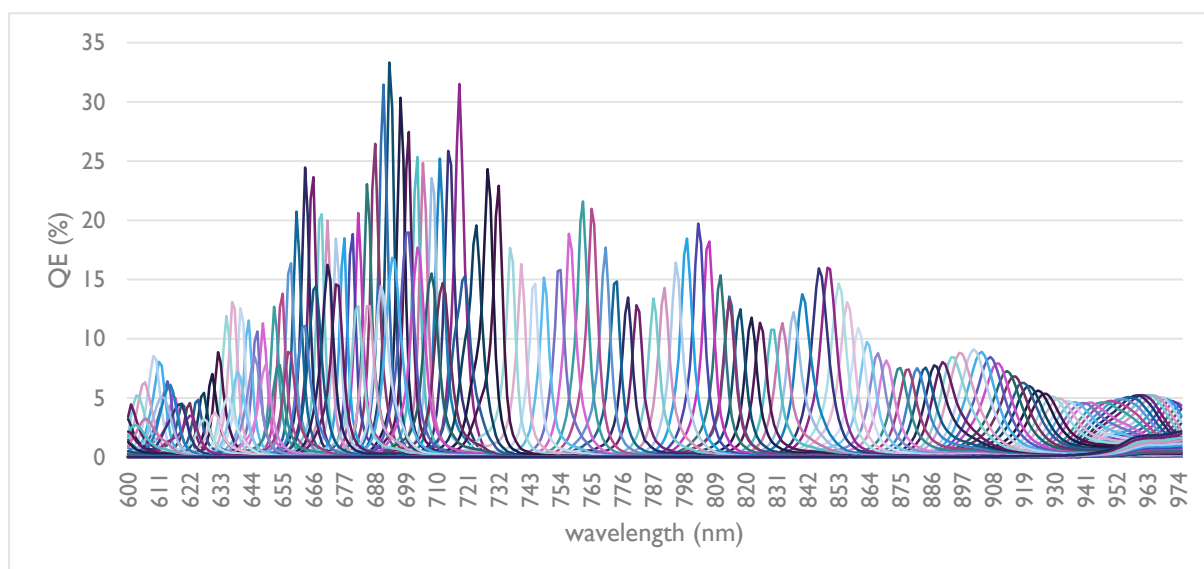


Figure 15: Example filter responses of the LS 100+ NIR sensor in the active range of 600-1000 nm.

**Note:** Increased measurement precision may be achieved by constraining the spectral range to 950 nm using shortpass filter [Edmund Optics 950nm short pass filter \(#64-336\)](#)

## 02 CMV2K LSI50+ VIS-NIR (470-900 nm)

|                                        |                                                                                                                   |
|----------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| <b>Sensor type</b>                     | <b>CMV2K LSI50+ VIS-NIR</b>                                                                                       |
| <b>Wavelength range</b>                | 470-900 nm                                                                                                        |
| <b>Filter pattern</b>                  | Wedge                                                                                                             |
| <b># bands</b>                         | 150+ (max 192)                                                                                                    |
| <b>Recommended lens</b>                | <u>35 mm VIS-NIR Compact Fixed Focal Length Lens</u>                                                              |
| <b>Recommended filters<sup>1</sup></b> | <u>Edmund Optics 475 nm long pass filter (#84-743)</u><br><u>Edmund Optics 900 nm short pass filter (#64-335)</u> |
| <b>Recommended mount</b>               | <u>M25.5 x 0.5 mount for 25 mm diameter filters</u>                                                               |
| <b>Calibration file format</b>         | CMV2K-LSI50-470_900-X.X.X.X.xml                                                                                   |

The CMV2K LSI50 VIS-NIR sensor is a CMOSIS CMV2K sensor with 64 filters active in the visual range (470-600 nm) and 128 filters active in the near infrared (600-900 nm). The filters are distributed over two separate active areas. Within each active area, the filters are organized in a wedge pattern in which each band covers 5 rows. The active areas are separated from each other by an empty interface zone of 120 rows. An overview of the filter layout is given in Figure 16.

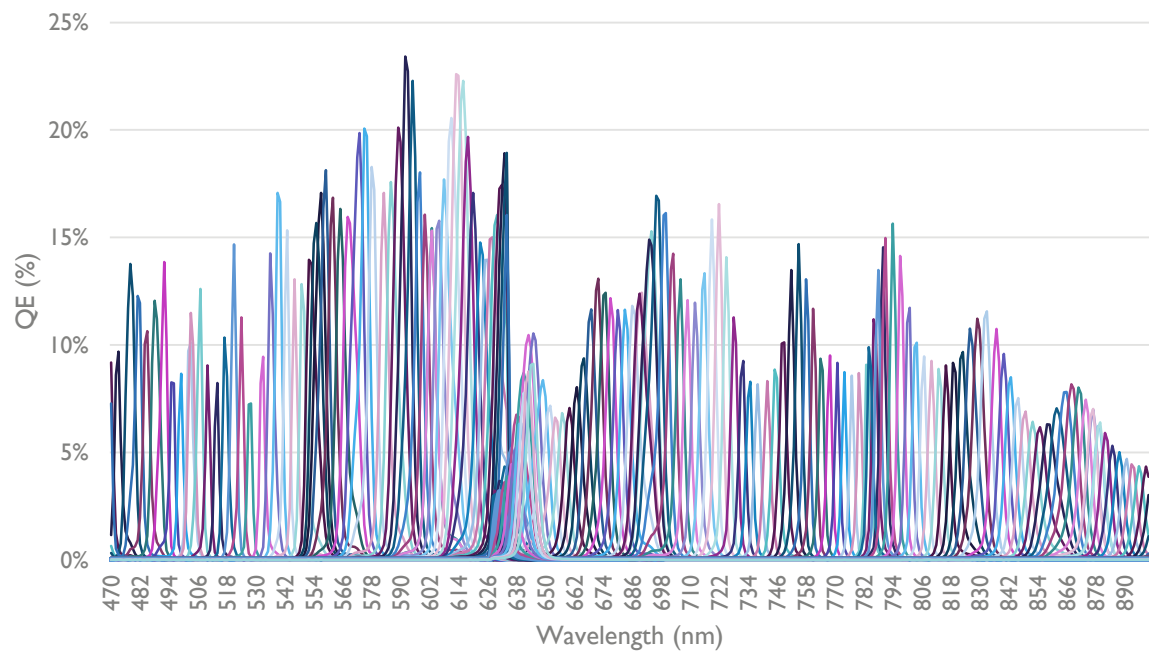
**⚠ Note:** At least 150 of the 192 bands are available for use on the sensor. The remaining bands are used for production quality checks and future product development.

In the evaluation kits a custom made 460-910 nm band pass filter is built into the Ximea camera.

|                      |     |
|----------------------|-----|
| 0                    | VIS |
| 1                    | VIS |
| ...                  |     |
| 62                   | VIS |
| 63                   | VIS |
| empty interface zone |     |
| 64                   | NIR |
| 65                   | NIR |
| ...                  |     |
| 190                  | NIR |
| 191                  | NIR |

Figure 16: Filter layout in the wedge filter layout of the CMV2K LSI50+ VIS-NIR sensor.

An example of the responses of the filters is given in Figure 17 for wavelengths in the range of 400 to 1000 nm. The sensor is designed for an active range of 470-900 nm. All filters have one response peak in the active range.



*Figure 17: Example filter responses of the LSI 50+ VIS-NIR sensor.*

### 03 CMV2K SST32 NIR (600 – 950 nm)

**Sensor type** **CMV2K SST32 NIR**

**Wavelength range** 600 – 950 nm

**Filter pattern** Tiled

**# bands** 32

**Recommended lens** 16 mm VIS-NIR Compact Fixed Focal Length Lens

**Recommended filters** Edmund Optics 600 nm long pass filter (#62-985)  
Edmund Optics 975 nm short pass filter (#86-108)

**Recommended mount** M25.5 x 0.5 mount for 25 mm diameter filters

**Calibration file format** CMV2K-SST32-600\_1000-X.X.X.X.xml

The CMV2K SST32 NIR sensor is a CMOSIS CMV2K sensor with 32 filters active in the near infrared (600-1000 nm) in a snapshot tiled filter layout organized in 4 rows of 8 columns as illustrated in Figure 18. The sensor is designed for an active range of 600-950 nm. An example of the filter responses in the active raonge is given in Figure 19.

**⚠ Note:** An optical duplicator must be installed between the sensor and the lens.

|    |    |    |    |    |    |    |    |
|----|----|----|----|----|----|----|----|
| 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  |
| 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 |
| 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |

Figure 18: Position of the filters in the snapshot tiled filter layout of the CMV2K SST32 NIR sensor.

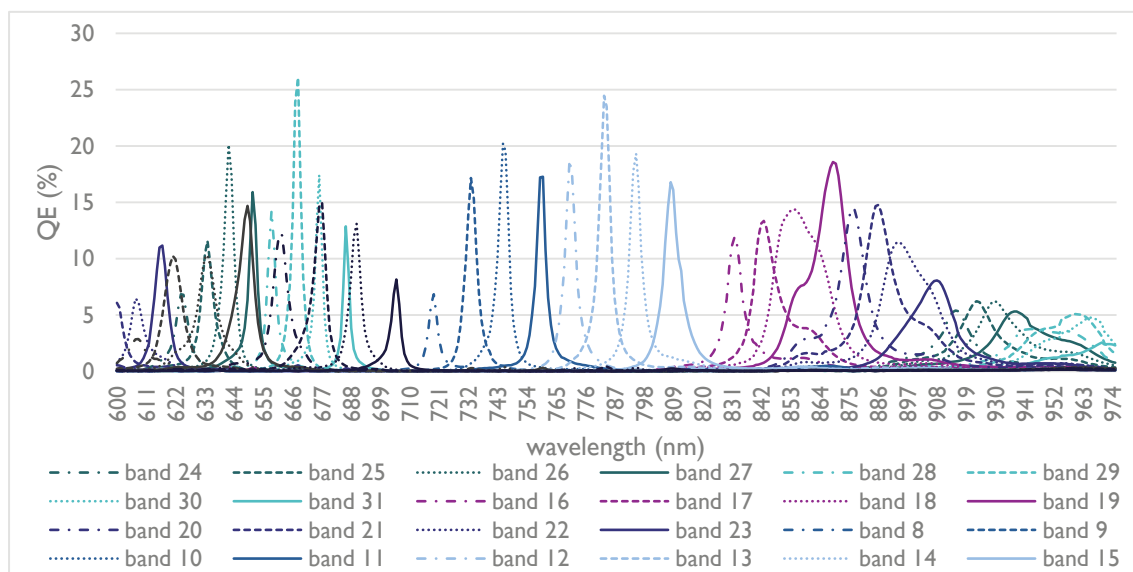


Figure 19: Example of the filter responses of a SST32 NIR hyperspectral sensor with the band pass filter of 600-975nm.

## 04 CMV2K SSM4x4 VIS (470 – 620 nm)

|                                        |                                                                                                                    |
|----------------------------------------|--------------------------------------------------------------------------------------------------------------------|
| <b>Sensor type</b>                     | <b>CMV2K SSM4x4 VIS</b>                                                                                            |
| <b>Wavelength range</b>                | 470 – 620 nm                                                                                                       |
| <b>Filter pattern</b>                  | Mosaic                                                                                                             |
| <b># bands</b>                         | 16                                                                                                                 |
| <b>Recommended lens</b>                | <u>35 mm VIS-NIR Compact Fixed Focal Length Lens</u>                                                               |
| <b>Recommended filters<sup>1</sup></b> | <u>Edmund Optics 475 nm long pass filter (#84-743)</u><br><u>Semrock 650 nm short pass filter (FF01-650-SP-25)</u> |
| <b>Recommended mount</b>               | <u>M25.5 x 0.5 mount for 25 mm diameter filters</u>                                                                |
| <b>Calibration file format</b>         | CMV2K-SSM4x4-470_620-X.X.X.X.xml                                                                                   |

The CMV2K SSM4x4 VIS sensor is a CMOSIS CMV2K sensor with 16 filters active in the visual spectrum in a snapshot mosaic filter layout organized in patterns of 4 rows and 4 columns as illustrated in Figure 20. The sensor is designed for an active range of 470 – 620 nm. An example of the filter responses in the active range is given in Figure 21.

In the evaluation kits a custom-made bandpass filter is built into the Ximea camera.

|    |    |    |    |
|----|----|----|----|
| 0  | 1  | 2  | 3  |
| 4  | 5  | 6  | 7  |
| 8  | 9  | 10 | 11 |
| 12 | 13 | 14 | 15 |

Figure 20: Position of the filters in the mosaic pattern on the CMV2K SSM4x4 VIS sensor.

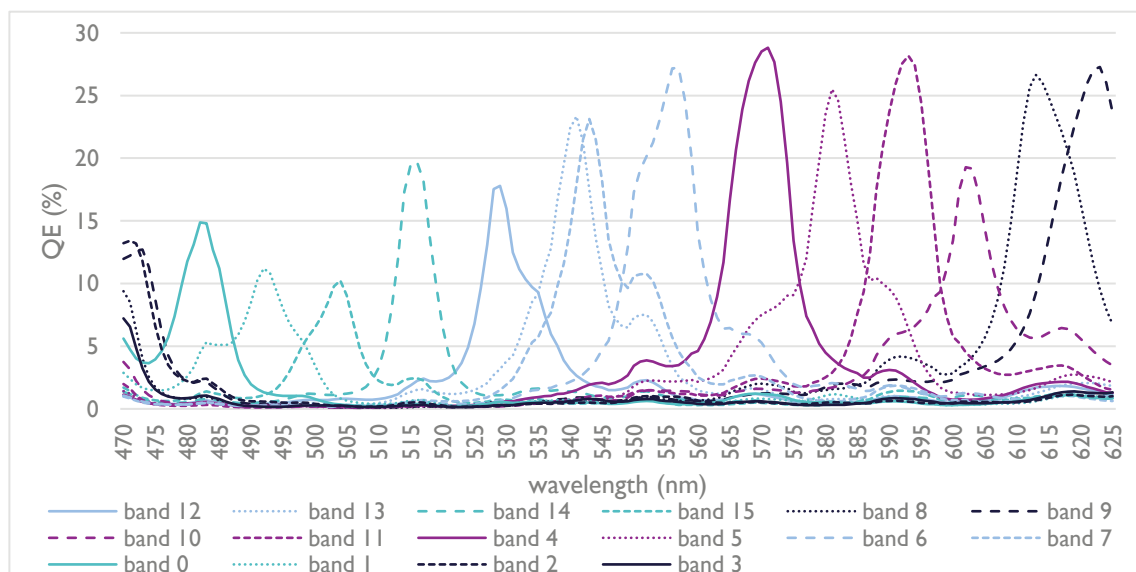


Figure 21: Example filter responses of the SSM 4x4 VIS sensor in the active range of 470 – 620 nm.

## 05 CMV2K SSM4x4 REDNIR (600 – 860 nm)

|                                |                                                                                                                   |
|--------------------------------|-------------------------------------------------------------------------------------------------------------------|
| <b>Sensor type</b>             | <b>CMV2K SSM4x4 REDNIR</b>                                                                                        |
| <b>Wavelength range</b>        | 600 – 860 nm                                                                                                      |
| <b>Filter pattern</b>          | Mosaic                                                                                                            |
| <b># bands</b>                 | 16                                                                                                                |
| <b>Recommended lens</b>        | <u>35 mm VIS-NIR Compact Fixed Focal Length Lens</u>                                                              |
| <b>Recommended filters</b>     | This filter set is still under evaluation<br><u>Omega 590LP rapidedge</u><br><u>Edmund optics 875SP (#86-106)</u> |
| <b>Recommended mount</b>       | <u>M25.5 x 0.5 mount for 25 mm diameter filters</u>                                                               |
| <b>Calibration file format</b> | CMV2K-SSM4x4-595_860-X.X.X.X.xml                                                                                  |

The CMV2K SSM4x4 VIS sensor is a CMOSIS CMV2K sensor with 16 filters active in the NIR spectrum in a snapshot mosaic filter layout organized in patterns of 4 rows and 4 columns as illustrated in Figure 22. The sensor is designed for an active range of 595 – 860 nm. An example of the filter responses in the active range is given in Figure 23. Error! Reference source not found..

The evaluation kits are provided with the recommended filter set.

|    |    |    |    |
|----|----|----|----|
| 0  | 1  | 2  | 3  |
| 4  | 5  | 6  | 7  |
| 8  | 9  | 10 | 11 |
| 12 | 13 | 14 | 15 |

Figure 22: Position of the filters in the mosaic pattern on the CMV2K SSM4x4 redNIR sensor.

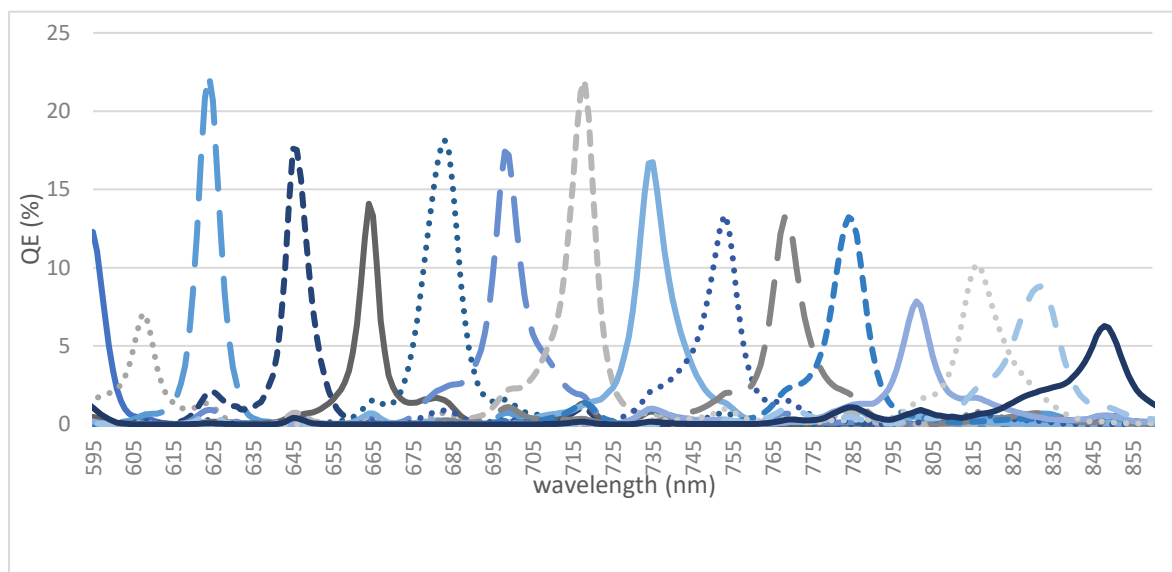


Figure 23: Example filter responses of the SSM 4x4 redNIR sensor in the active range of 595 – 860 nm.

## 06 CMV2K SSM5x5 NIR (665-975 nm)

|                                |                                                                                                                                     |
|--------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| <b>Sensor type</b>             | <b>CMV2K SSM5x5 NIR</b>                                                                                                             |
| <b>Wavelength range</b>        | 665-975 nm                                                                                                                          |
| <b>Filter pattern</b>          | Mosaic                                                                                                                              |
| <b># bands</b>                 | 25                                                                                                                                  |
| <b>Recommended lens</b>        | <u>35 mm VIS-NIR Compact Fixed Focal Length Lens</u>                                                                                |
| <b>Recommended filters</b>     | This filter set is still under evaluation<br><a href="#">Omega 660LP rapidedge</a><br><a href="#">Edmund Optics 975SP (#86-108)</a> |
| <b>Recommended mount</b>       | <u>M25.5 x 0.5 mount for 25 mm diameter filters</u>                                                                                 |
| <b>Calibration file format</b> | CMV2K-SSM5x5-665_975-X.X.X.X.xml                                                                                                    |

The CMV2K SSM4x4 VIS sensor is a CMOSIS CMV2K sensor with 25 filters active in the NIR spectrum in a snapshot mosaic filter layout organized in patterns of 5 rows and 5 columns as illustrated in Figure 24. The sensor is designed for an active range of 655 – 970 nm. An example of the filter responses in the active range is given in Figure 25.

The evaluation kits are provided with the recommended filter set.

|    |    |    |    |    |
|----|----|----|----|----|
| 0  | 1  | 2  | 3  | 4  |
| 5  | 6  | 7  | 8  | 9  |
| 10 | 11 | 12 | 13 | 14 |
| 15 | 16 | 17 | 18 | 19 |
| 20 | 21 | 22 | 23 | 24 |

Figure 24: Position of the filters in the mosaic pattern on the CMV2K SSM5x5 NIR sensor.

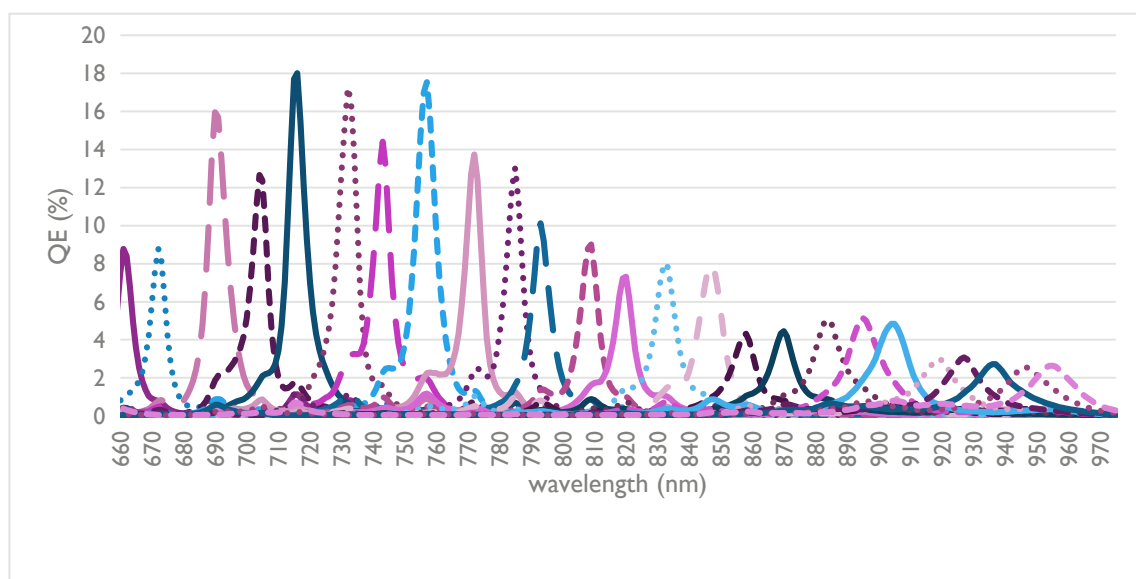


Figure 25: Example filter responses of the SSM 5x5 NIR sensor in the active range of 665-975 nm.

## 07 CMV2K SSM5x5 NIR (600-975 nm) – Discontinued

### Sensor type

**CMV2K SSM5x5 NIR**

### Wavelength range

600-875 nm

675-975 nm

### Filter pattern

Mosaic

### # bands

25

### Recommended lens

35mm VIS-NIR Compact Fixed Focal Length Lens

### Recommended filters<sup>1</sup>

Edmund Optics 600 nm long pass filter (#62-985)

Edmund Optics 875 nm short pass filter (#86-106)

Edmund Optics 675 nm long pass filter (#84-747)

Edmund Optics 975 nm short pass filter (#86-108)

### Recommended mount

M25.5 x 0.5 mount for 25 mm diameter filters

### Calibration file format

CMV2K-SSM5x5-600\_1000-X.X.X.X.xml

The CMV2K SSM5x5 NIR sensor is a CMOSIS CMV2K sensor with 25 filters active in the near infrared in a snapshot mosaic filter layout organized in patterns of 5 rows and 5 columns as illustrated in Figure 26. The sensor is designed for an active range of 600-975 nm. An example of the filter responses in the active range is given in Figure 27.

In the evaluation kits a custom made 600-975 nm band pass filter is built into the Ximea camera.

|    |    |    |    |    |
|----|----|----|----|----|
| 0  | 1  | 2  | 3  | 4  |
| 5  | 6  | 7  | 8  | 9  |
| 10 | 11 | 12 | 13 | 14 |
| 15 | 16 | 17 | 18 | 19 |
| 20 | 21 | 22 | 23 | 24 |

Figure 26: Position and peak responses of the filters in the mosaic pattern on the CMV2K SSM5x5 NIR sensor.

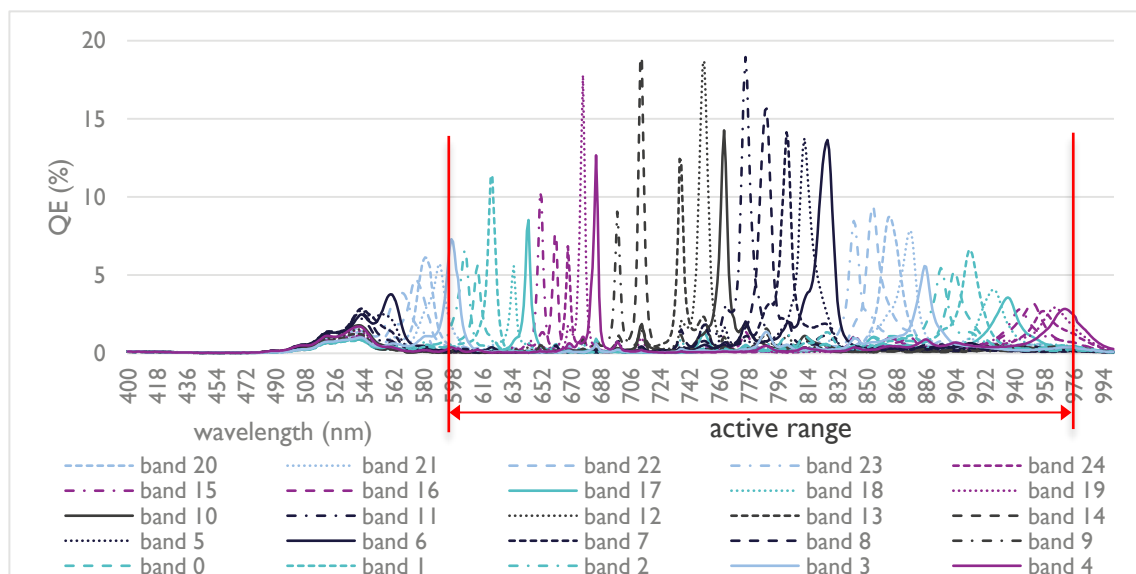


Figure 27: Example filter responses of the SSM 5x5 NIR sensor.

The filters with first order responses in the range of 875-975 nm have strong second order responses in the range of 600-700 nm. The responses of these filters are shown in Figure 28. The second order responses have a quantum efficiency of the same magnitude as the first order responses of the filters in the range of 675-750 nm.

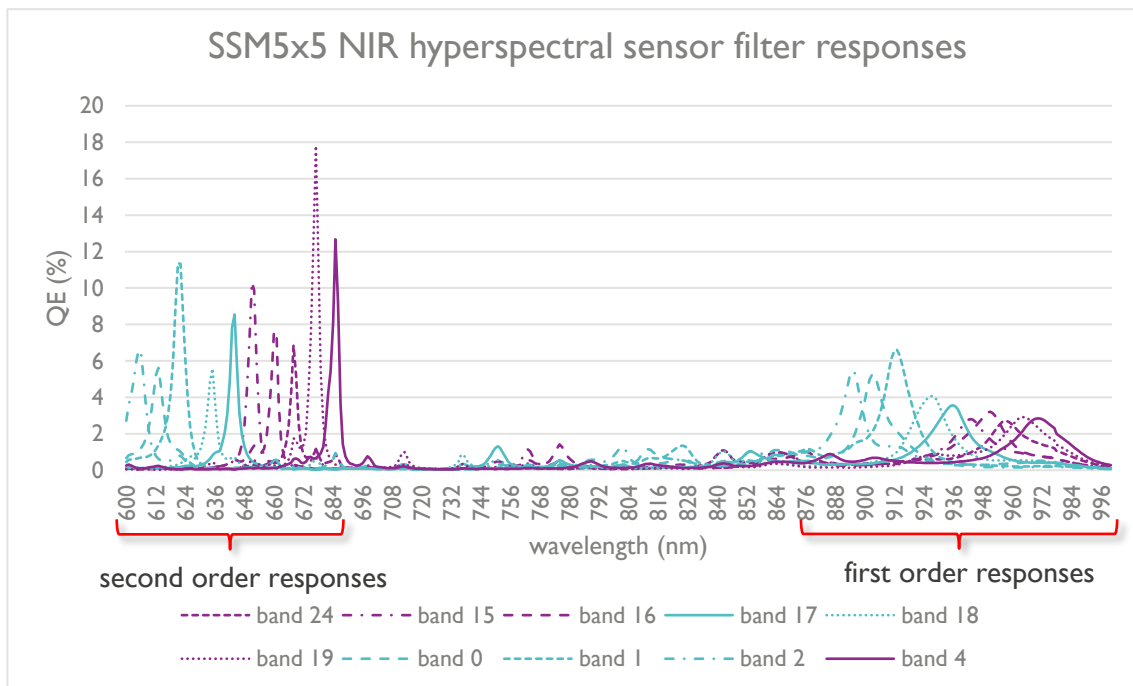


Figure 28: Example of second order filter responses of the SSM5x5 NIR sensor in the active range. The first order responses are situated in the range of approx. 875-975 nm. The second order responses are situated in the range of 600-700 nm.

Two **band pass filters** have been selected to condition the incident light w.r.t. the strong second order responses of some filters on the sensor. Each band pass filter is created as a combination of a high pass filter and a low pass filter.

Alternatively the band pass filters are created using a broad band pass filter of 600-975nm in combination with either the [Edmund Optics 675 nm long pass filter \(#84-747\)](#) or the [Edmund Optics 875 nm short pass filter \(#86-106\)](#).<sup>1</sup>

The band pass filter of 600-875 nm will retain the second order responses and reject those filter's first order responses as shown in Figure 29. The band pass filter of 675-975 nm will retain the first order responses and reject those filter's second order responses as shown in Figure 30.

**⚠ Note:** in setups where the responses of the SSM4x4 and SSM5x5 sensor are combined to create a full range spectrum from 450 to 875 nm, it is advised to use long pass rejection filter

[Semrock 593 nm long pass filter \(FF01-593-LP-25\)](#)

Contact the support for more information on how to successfully combine the spectral measurements.

<sup>1</sup> This is done in the evaluation kits, where a custom made 600-975 nm band pass filter is built into the Ximea camera.

**Note:** The two band pass filters are selected because of the second order responses in the active range of the sensor. For this reason, the sensor calibration file contains **two correction matrices**, where each matrix must be used in combination with the corresponding band pass filter:

- 600-875 nm band pass filter: hsi\_600-875
- 675-975 nm band pass filter: hsi\_675-975

For applications that do not require spectral analysis, such as classification, the full active range can be used with a band pass filter of 600-975 nm.

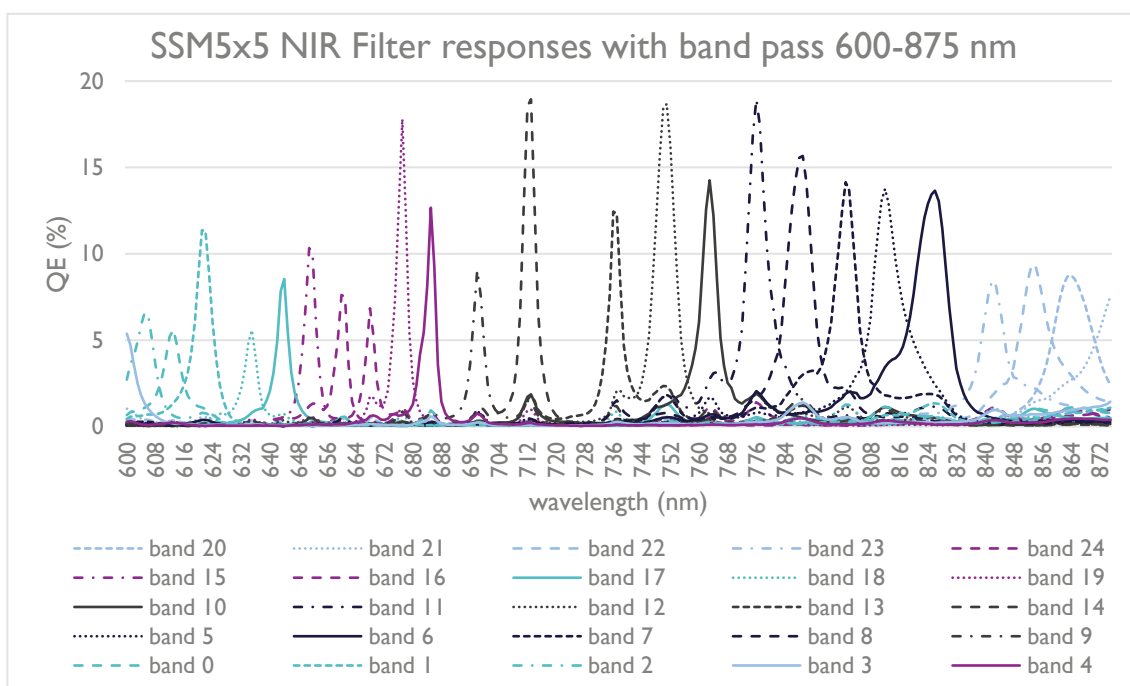


Figure 29: Example of the filter responses of a SSM 5x5 NIR hyperspectral sensor with the band pass filter of 600-875 nm.

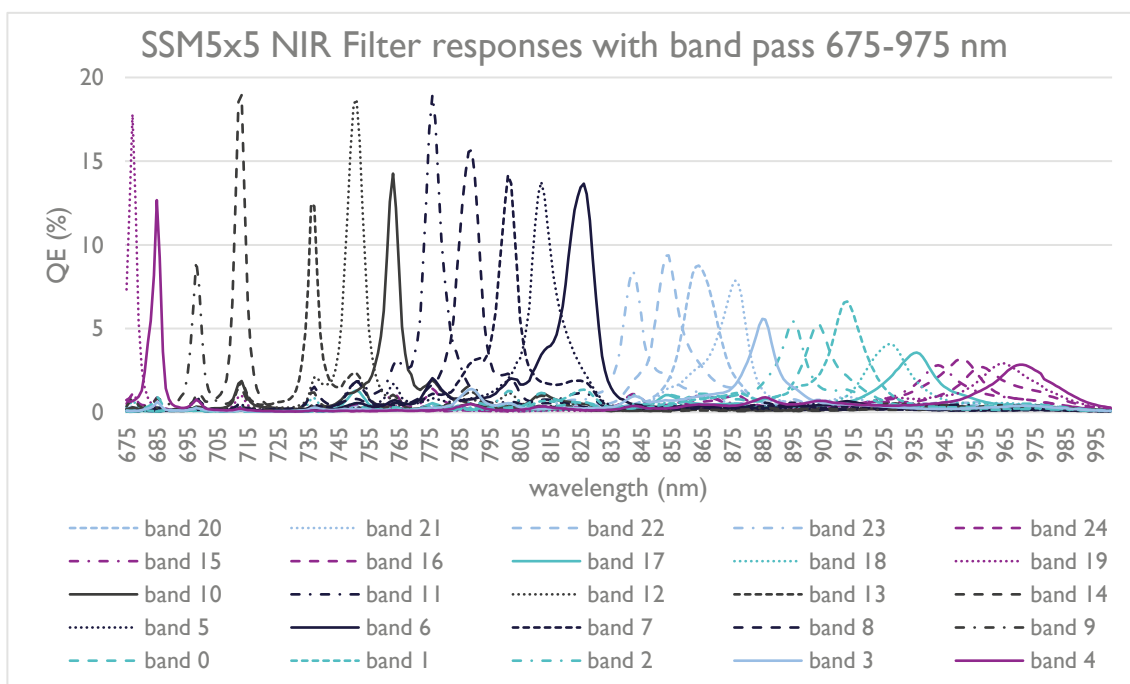


Figure 30: Example of the filter responses of a SSM 5x5 NIR hyperspectral sensor with the band pass filter of 675-975 nm.

## 08 CMV2K SSM2x2 RGB+NIR (RGB + 810 nm)

|                                |                                                      |
|--------------------------------|------------------------------------------------------|
| <b>Sensor type</b>             | <b>CMV2K SSM2x2 RGB+NIR</b>                          |
| <b>Wavelength range</b>        | 400-850 nm                                           |
| <b>Filter pattern</b>          | Mosaic                                               |
| <b># bands</b>                 | 4                                                    |
| <b>Recommended lens</b>        | <u>35 mm VIS-NIR Compact Fixed Focal Length Lens</u> |
| <b>Recommended filters</b>     | No additional filters required                       |
| <b>Recommended mount</b>       | <u>M25.5 x 0.5 mount for 25mm diameter filters</u>   |
| <b>Calibration file format</b> | CMV2K-SSM2x2-400_850-X.X.X.X.xml                     |

The CMV2K SSM2x2 RGB+NIR sensor is a CMOSIS CMV2K sensor with three RGB filters and one filter active in the NIR. The filters are organized similar to an RGBG pattern on conventional RGB sensors, in which one of the G filters is replaced by an 810 nm filter as illustrated in Figure 31. The sensor is designed for an active range of 400-850 nm. An example of the filter responses in the active range is given in Figure 32.

An additional rejection filter to reject all light outside of the spectral range of interest is integrated in the cover glass of the sensor. No additional filters are required.

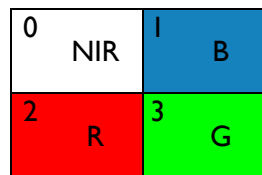


Figure 31: Position of the filters in the mosaic pattern on the CMV2K SSM2x2 RGB-NIR sensor.

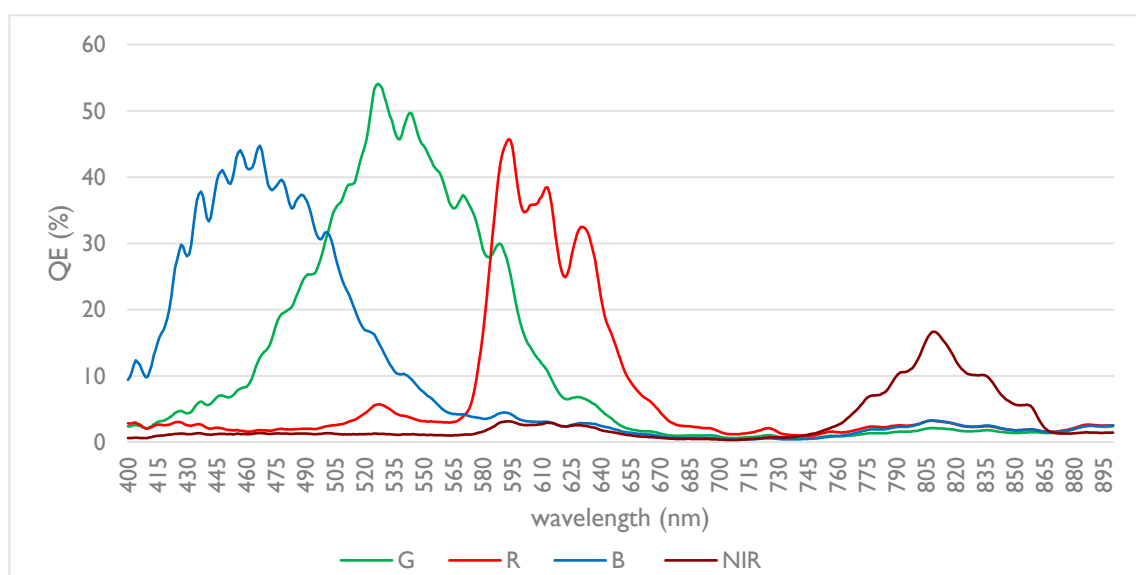


Figure 32: Example filter responses of a SSM2x2 RGB-NIR sensor.