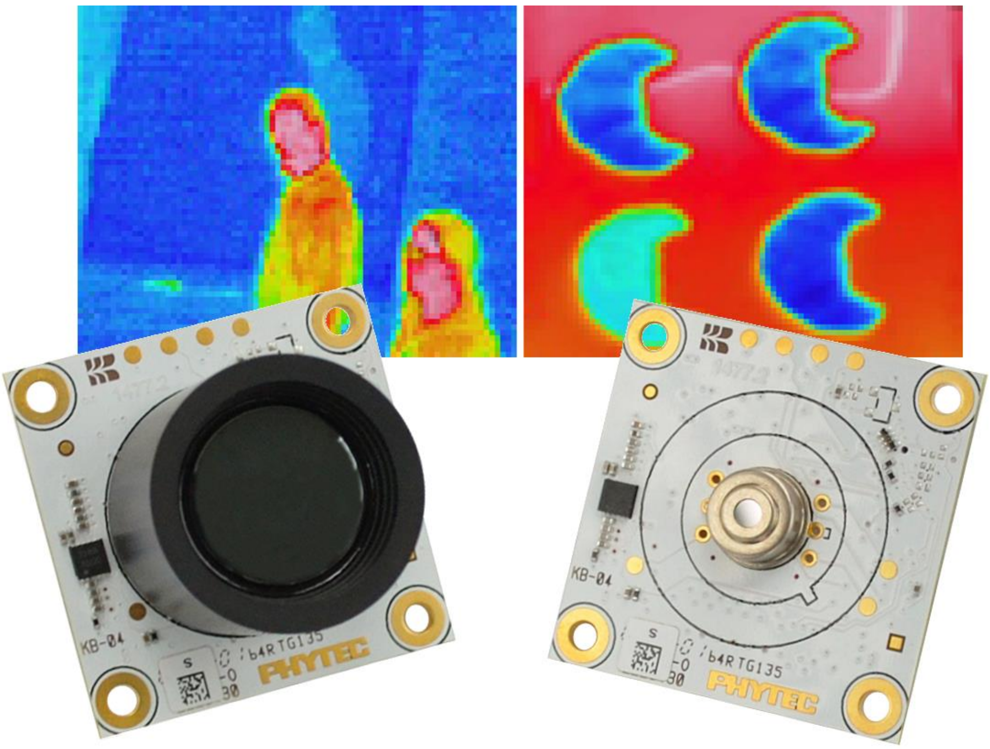
phyCAM® - VM-050 / VM-051

Digital Thermography Modules



Manual

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1 Introduction

With the phyCAM VM-050 / VM051 modules, PHYTEC introduces miniturized and inexpensive thermography camera modules for embedded applications. The VM-050 / VM-051 camera modules allow for the capture of infrared radiaton and process it as thermal images.

In connection with PHYTEC System on Modules (SOM) subassemblies, phyCAMs offer an easy and efficient way to add imaging capabilities to an embedded application.

The VM-05x thermal imaging modules integrate a fix-focus lens assembly. Several sensor and lens options are available.

phyCAM camera modules connect directly to the digital camera interface of PHYTEC SOMs. Many BSPs for PHYTEC SOMs already include appropriate software drivers for phyCAM digital camera modules. This enables easy deployment of phyCAMs into customized products. The phyCAM interface specification is open, allowing phyCAMs to be used with other microprocessors or hardware designs in addition to PHYTEC SOMs.

The interface definition of the each phyCAM family is identical for all products within each family. Thus, different camera modules can be connected to the same target hardware. This allows the system designer to interchange phyCAM camera modules during the design phase of the product as well as enable upgrades of camera modules without the need to redesign target hardware.

PHYTEC's phyCAM system consists of several sub-standards, like phyCAM-P, phyCAM-S or phyCAM-G.
The thermal imaging modules VM-050 / VM-051 are available with phyCAM-P interface only.

Note:
For detailed information about the phyCAM interface concept and specifications, please refer to the *phyCAM manual L-748*.

A wide range of powerful 32-bit microprocessors are supported by the phyCAM system, including the NXP i.MX processor series and the Texas Instruments OMAP family. Together with the numerous variants of phyCAM camera modules, embedded developers can choose the perfect combination of microprocessor and camera module for any given project.

1.1 phyCAM-P Interface Characteristics

The phyCAM-interface routes the following signals between the camera and microprocessor:

- Camera power supply
- Camera master clock
- Camera image data
- I²C control bus for camera configuration
- two multipurpose signals

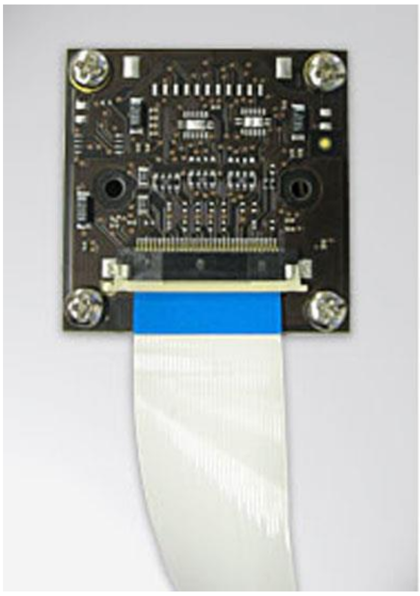


Figure 1: phyCAM-P - Interface

1.1.1 phyCAM-P

The phyCAM-P interface offers an easy and cost-efficient way to integrate a camera into an application.

Data and control signals are transmitted via a 33-pin flat-foil-cable (FFC). This minimizes the amount of components needed for the interface and still establishes compatibility between camera modules within the phyCAM-P family. Multipurpose pins allow the use of special functions on the individual camera module, such as a trigger input or LED light control.

Image data can be transmitted with up to 10-bit color or grey scale resolution (color depth per each color channel).

The phyCAM-P interface is especially suitable for applications where the camera is installed within the device housing. The maximum cable length is specified as 30 cm. Please note that the effective cable length depends on numerous parameters such as power consumtion, clock frequency, and data transfer mode. The overall system design also has an impact on the maximum camera cable length. PHYTEC recommends contacting our project engineers to discuss the maximum cable length in your specific design.

The phyCAM-P interface requires only a few components to connect to a microcontroller design. In the simplest case, direct wiring between camera connector and microcontroller interface is sufficient. However, the circuitry needed depends on some individual conditions. If a camera module and the microcontroller's camera interface have different voltage levels, level shifters have to be inserted to adapt the voltage levels. If a system design is to feature the interchangeability between various phyCAM-P models, the design will have to include level shifters and a variable voltage power source for the camera module.

In summary, the hardware can be adapted to the individual requirements of the application. The *phyCAM manual L-748* shows several design examples for the phyCAM-P interface.

The phyCAM-P interface includes two multipurpose signals. These signals can typically be configured by solder jumpers on the camera module. Examples of possible functions are Trigger- and strobe signals and I²C address select.

At higher quantities, the camera modules can be shipped with individual jumper settings so that the desired function is already configured. Please contact your PHYTEC sales person for more information.

Note:
Your PHYTEC sales team is happy to assist you with the selection and integration of your phyCAM-module.

1.2 Basics of Thermal Imaging

1.2.1 Fundamental Physics

Each object with a temperature greater than absolute zero (0 K) emits thermal radiation. The emissivity (ε) of the surface of the object defines its effectiveness in emitting energy as thermal radiation. Most non-metallic surfaces feature an emissivity of approximately ≈ 0,9. These materials can be easily measured with thermographic devices. Metals typically have an emissivity of < 0,2. This means that these materials –especially bare or polished metal surfaces – cannot be measured without further adjustments as the thermal radiation of the surroundings are reflected on the surfaces like in a mirror. Self-adhesive paper labels, paint, chalk, or heat conductive tape can be used to cover the surfaces that are to be measured for radiation.
Independent of the material, rough surfaces have a higher emissivity than smooth surfaces.

Thermal radiation of an object can be attentuated by gas molecules in between the object and the sensor. Attentuation is dependent on the characteristics of the specific gas or gas mixture. It takes effect if the gas has absorbtion lines within the infrared portion of the spectrum. This can be used, for example, to detect certain gases. The ambient atmosphere can already attentuate the transmission of thermal radiation. Water vapor (H_2O molecules) can especially cause significant attentuation. Vacuum features are best for thermal transmission. Many noble gases also have an excellent thermal transmisson.

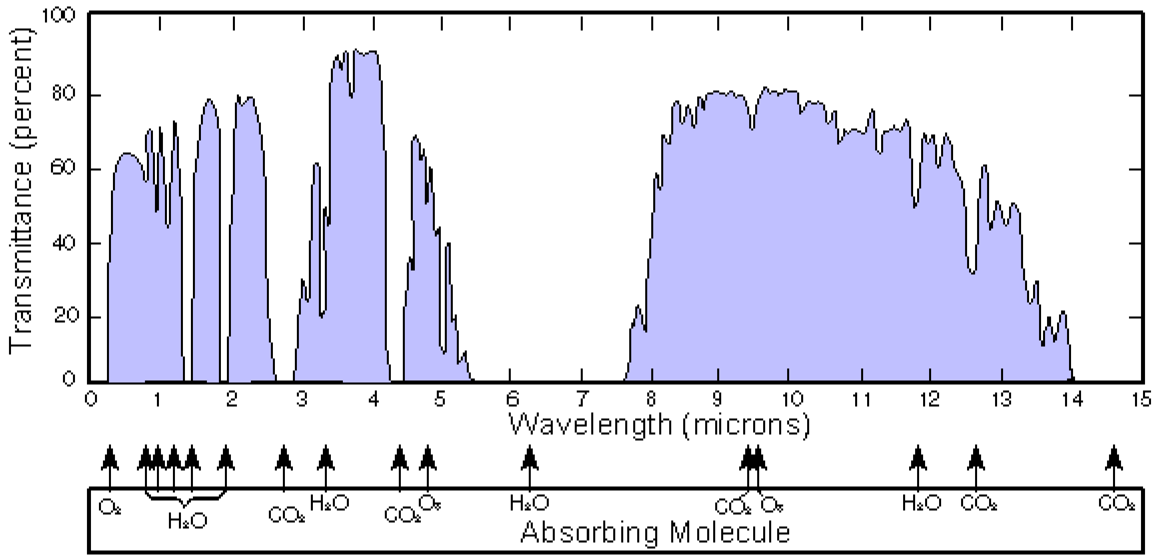


Figure 2: Atmospheric window (reference: Wikimedia)

1.2.2 Sensor Technologies

For thermal sensors, several different technologies are used. For area sensors that produce a two dimensional thermal image, the following technnologies are used:

Semiconductor arrays based on Phtotoelectrical effect

The functional principal of these sensors is similar to the one used for sensor arrays for visible light. However, as they are designed for a diffenent range of wavelengths, they also respond to thermal radiation.

This functional principle uses the photoelectrical effect: A photon of the thermal radiation absorbed by the semiconductor material increases the number of free electrons and electron holes and raises its electrical conductivity. This sopecific effect is called photoconductivity.

Thermal imagers that use this principle have to be cooled so that neither the ambient temperature nor the temperature of the sensor itself causes unwanted photoconductivity.

Bolometer

Bolometers take advantage of the temperature dependency of electrical resistors. A sensor element is heated by the absorbed thermal radiation. Thus, its electrial resistance is changed which can be measured by a change in voltage drop over the resistive element.
An absorptive element is connected to a thermal reservoir through a thermal link. The thermal reservoir is a body that remains at an (ideally) constant temperature. The ratio of the heat capacity of the absorptive element to the thermal conductance between the absorptive element and the reservoir is called thermal time constant. It defines the speed of the detector.

In order to obtain a high sensitivity of the pixel elements, materials with a high temperature coefficient have to be used. However, the variation of the electrical resistance caused by a change of the ambient temperature is significantly greater than the change caused by the thermal radiation to be measured. To eliminate this effect, a calibration of the sensor has to be executed frequently. Typically, this is done by closing a shutter for a short period of time.

Thermopile arrays

Thermopile sensors take advantage of the thermoelectric effect which occurs if two dissimilar electrical conductors are connected and their electrical junctions are exposed to different temperatures. As a result, a thermocouple produces a temperature-dependent voltage which is proportional to the temperature difference of the junction points (also known as the Seebeck effect).

Several thermocouple elements can be connected in series to increase the resulting output voltage. This device is called a thermopile. By choosing an appropriate operating point for the elements, temperatures below the object temperature of the thermopile element itself can also be measured.

The only required condition to operate a thermopile sensor is a stable ambient temperature. However, slow changes in ambient temperature can be compensated.

Calibration cycles ,as needed in bolometer technology, are not necessary for thermopile sensors because the output voltage depends on the temperature difference between the electrical junctions. Thus, it is sufficiant to determine the temperature of one of the junctions. The temperature of this reference side is measured by a dedicated temperature sensor. The temperature of the other junction point is affected by the incoming thermal radiation. By that, the quantity of the thermal radiation can be determined.

Note:
The image sensors of the thermal camera modules VM-050 / VM-051 are based on thermopile array technology.

1.2.3 Lenses for Thermal Imagers

Ordinary glass lenses do not feature a sufficient transmission for the long-wave infrared radiation used for thermal imaging. Therefore, lenses that are specifically designed for these wavelengths have to be used.

Various materials can be used for thermal lenses. These materials show significant differences in transmission, quality parameters like refractive index and dispersion, and in price. Special lens coatings can enhance the transmission ratio of a specific lens.
Typical lens materials for common applications are germanium and silicon.

Germanium lenses feature better transmission and higher refractive index compared to silicon lenses, which are less expensive. Germanium allows the construction of accuracte lenses with a low focal ratio (f#), which lets more radiation pass to the sensor.

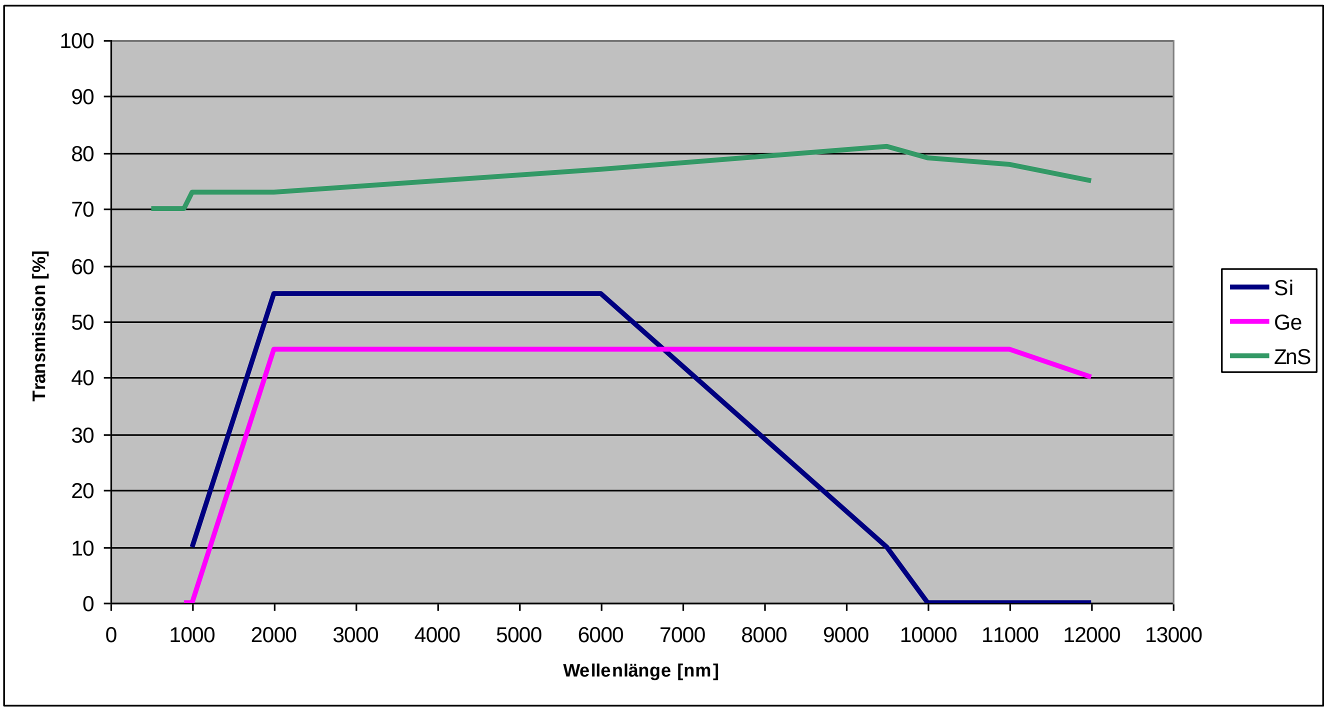


Figure 3: Transmission factors of different thermal lenses

Note:
Because numerous parameters affect the behavior of a lens in a given application, lenses always have to be selected according to the application's requirements.

Lenses often consist of several elements. As a rough rule of thumb, the *Noise Equivalent Temperature Difference* (NETD) doubles with a silicon lens construction of two lens elements, because only half of the emitted thermal radiation is transmitted to the sensor. A germanium single lens element with similar features has a lower NETD.

Our PHYTEC project engineers are happy to assist you in choosing the best lens for your application.

2 General Specifications of the phyCAM Modules

2.1 phyCAM-P Interface Specification

Main interface characteristics

- Parallel data interface for image data (camera to microcontroller)
- I²C interface for camera control (register settings)
- 33-pin FFC-connector 0.5mm pitch, matching cable thickness 0.3 mm
- Power supply and signal voltage levels depend on the camera sensor used on the camera module and may vary between the phyCAM-P models. Level translation is done on the PHYTEC Carrier Board or, if necessary, on the customized application board. The camera interface allows automatic detection of the required voltage level by the power voltage setup pin.
- Recommended maximum cable length < 30 cm

Note:
The maximum cable length strongly depends on numerous parameters like power consumption, clock frequency, and readout mode. The overall system design and EMI regulations to be applied also have an impact on the maximum camera cable length.

PHYTEC recommends contacting our project engineers to discuss the maximum cable length in your specific design.

Interface signals (overview)

- Power supply to the camera
- Master clock to the camera
- Image data and sync signals from the camera
- I²C–bus for camera control and control of additional functions (if available)
- Control signals (optional reset, output enable, ...)
- Multipurpose signals (optional trigger, strobe, I/O-signals, ...)

2.1.1 Connector

33-pin FFC/FPC, 0.5 mm pitch, contact position bottom.
Matching cable thickness: 0.3 mm

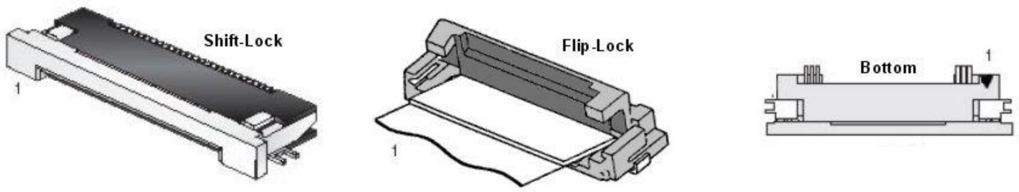


Figure 4: phyCAM-P FFC-connector types (top views and solder side – examples)

Matching cables:

Length	PHYTEC part no.
120 mm	WF062
200 mm	WF043
300 mm	WF046

(Contact type A: contacts are located on the same side of the cable)

Table 1: phyCAM-P Connector Cables

2.1.2 phyCAM-P – Interface Pin Assignment

phyCAM-P - Electrical Interface			
Pin	Dir.	Name	Function
1	PWR	Vcam	Power Supply Input
2		Vcam	
3	IN	CAM_RST	Reset Signal (optional – refer to camera description)
4	-	GND	Ground
5	I/O	CAM_SDA	SDA, I²C-Interface
6	IN	CAM_SCL	SCL, I²C-Interface
7	I/O	CAM_CTRL1	Multipurpose Pin 1 (refer to camera description)
8	-	GND	Ground
9	OUT	CAM_FV	VSYNC
10	OUT	CAM_LV	HSYNC
11	-	GND	Ground
12	OUT	CAM_DD9	D9
13	OUT	CAM_DD8	D8
14	-	GND	Ground
15	OUT	CAM_DD7	D7
16	OUT	CAM_DD6	D6
17	-	GND	Ground
18	OUT	CAM_DD5	D5
19	OUT	CAM_DD4	D4
20	-	GND	Ground
21	OUT	CAM_DD3	D3
22	OUT	CAM_DD2	D2
23	-	GND	Ground
24	OUT	CAM_DD1	D1
25	OUT	CAM_DD0	D0
26	-	GND	Ground
27	OUT	CAM_PCLK	Pixel Clock
28	-	GND	Ground
29	IN	CAM_MCLK	Master Clock (not required for VM-05x)
30	I/O	CAM_CTRL2	Multipurpose Pin 2 (refer to camera description)
31	OUT	CAM_VSET	Resistor to GND. Sets Supply and Signal Voltage Level
32	IN	CAM_OE	Data Lines Output Enable (optional)
33	PWR	Vcam	Power Supply Input

Note: PWR=Power, IN =Input, OUT =Output, I/O = bidirectional, with respect to the camera

Table 2: Pin Assignment phyCAM-P - Interface

Information

- The supply voltage V_{CAM} can be different for various camera models. Please refer to the detailed descriptions of specific phyCAMs. Carrier Boards that support multiple phyCAM modules must be equipped with an adaptive power supply. By reading the resistance value of pin 31, the appropriate voltage can be detected by the carrier board and the voltage regulator can be set to the required voltage (see design examples in the *phyCAM manual L-748*).

- Signal levels on the data- and control lines depend on the camera module used. Carrier boards that support multiple phyCAM modules must feature level shifters to adapt the signal levels to the signal levels of the microprocessor used in the design (see design examples in the *phyCAM manual L-748*).

- The signal levels of the I^2C interface are consistent with the levels of the data lines. Each I^2C bus requires pull-up-resistors on both SDA and SCL lines. Pull-up resistors must be installed on the Carrier Board unless they are already populated on the SOM.

- Depending on the camera model, the functions of the multipurpose pins CAM_CTRL1 / CAM_CTRL2 can vary. In the standard configuration, these pins are configured as inputs and should be left open or connected to Ground by a jumper (GND / VCAM) via a 200 series resistor. Default setting: GND.

- Typically, the default function of CAM_CTRL1 is to define the I^2C base address (address select line).The default use of CAM_CTRL2 is an additional ground connection (GND). If the camera supports other functions on these pins, ensure that this does not conflict with the default settings.

- Signal direction of the sync lines FV, LV und PCLK is output. This means that the camera controls the camera interface of the microprocessor. This is called "master mode". If the camera also supports slave mode, these signals can also be configured as inputs. However, this is an optional configuration and does not have to be considered when designing a custom application board.

- The control signal CAM_OE sets the data ,and optionally, the sync lines (FV, LV and PCLK) into tri-state mode if supported by the camera sensor. For more information, please refer to the camera module specification. The CAM_OE pin is not required for application board design. If not needed, this pin should be left open. This will enable the data and sync lines.

Note:
The pin numbers refer to the connector on the camera module.

Depending on the cable type and FFC connectors used, the pin numbering on the application board connector might be mirrored.

2.1.3 Voltage Selection – Resistor

Pin 31 of the camera connector supports the voltage setting for the camera on the application board. On the camera module, this pin is connected to Ground (GND) via a dedicated resistor.

The resistor value measured at Pin 31, relative to GND, specifies the voltage level of the power supply and the data lines of the camera module. This allows the application board to adapt to the required voltage level automatically.

The following table defines the resistor values and the corresponding operating and signal voltages:

Voltage Selection	
V_{CAM} and signal level	Resistance to GND at pin 31
3,3 V	0 Ω
2,8 V	220 Ω
1,8 V	1720 Ω

tolerance: +/- 4%

Table 3: Voltage-Selection - Resistor

Note:
The resistance values are defined in a way that they can be used as ground-end resistors in the feedback path of a variable voltage regulator. See design examples in the *phyCAM manual L 748.*

2.2 Specification of the Trigger/Strobe – Connector

Main Characteristics:

- 3 pin receptacle. Mating connector: JST SHR-03V-S-B
- Signal level on this connector depends on the specific camera module

Interface signals:

- Trigger
- Strobe / Sync

2.2.1 Connectors and Cables

Matching PCB-Headers for custom application boards:

- JST BM03B-SRSS-TB(LF)(SN) – top entry
- JST SM03B-SRSS-TB(LF)(SN) – side entry

Matching cables:

Length	PHYTEC order no.
250 mm	WK295
30 mm	WK295-0.03

Table 4: Cables for Trigger/Strobe-Header

Trigger/Strobe Header - Electrical Interface			
Pin	Dir.	Name	Function
1	IN	CAM_TRIG	Trigger Signal (optional – refer to camera description, internal 10 kΩ pull down resistor)
2	-	GND	Ground
3	OUT	CAM_STRO	Strobe Signal (optional – refer to camera description)

Table 5: Trigger/Strobe Connector – Pin Assignment

2.3 Mechanical Specifications

Tolerances:

PCB-dimensions: ±0,25 mm
Drill holes: ±0,1 mm
Plastic parts: ±0,5 mm

All information is subject to change.

2.3.1 PCB dimensions

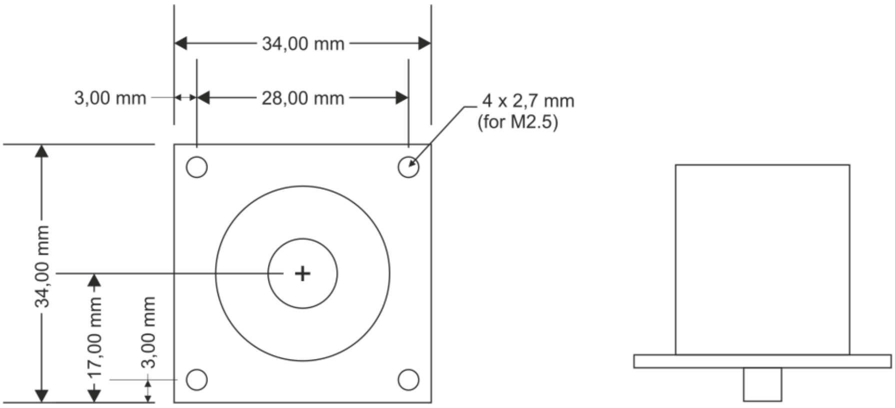


Figure 5: VM-050 / VM-051 PCB dimensions

The cable outlet is located on the top in relation to the standard sensor readout direction.

The outer mounting holes are surrounded by a metalized area 5 mm in diameter. Screw heads, washers or other mounting elements are allowed within this area. Please note that the position of electrical components on the camera modules is subject to change.

The connector for the trigger/strobe signals has a height of 4.9 mm (installed only if the camera module supports this feature).

Note:
Since optical lenses flip the image vertically (upside down), camera modules are usually mounted with the cable outlet located on the bottom. Many camera sensors allow reverting the readout direction via software. Therefore, other mounting positions are also possible (if supported by specific cameral module).

3 VM-050 / VM-051 Technical Specification

This section lists the specifications of each camera module in the VM-050 / VM-051 series. Special functions and configuration options are described separatly in *section 4*.

3.1 VM-050 – Thermopile-Imager 32x32 Pixel / SOC

3.1.1 Features

- 32x32-pixel thermopile-array
- phyCAM-P – interface
- export compliant
- framerate up tp 8.5 fps
- SOC – System on Chip: integrated pre-processing
- auto-scale option: measuring range can be controlled automatically
- integrated noise reduction
- dead pixel correction
- temperature tracking
- embedded data channel in the image (optional)
- external trigger and strobe signal (optional)

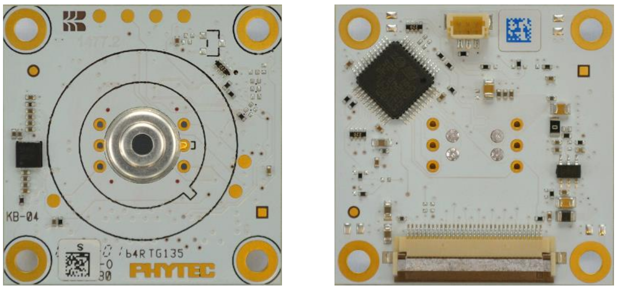


Figure 6: VM-050-021-0 (front / backside)

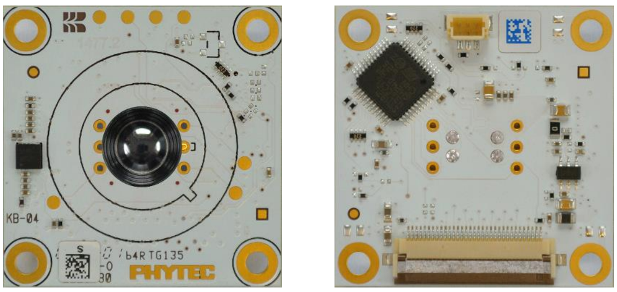


Figure 7: VM-050-050-0 (front / backside)

3.1.2 Parameters

VM-050	
Sensor Characteristsics	
Resolution	1024 pixels
Pixel Count (H x V)	32 x 32
Sensor Technoloy	Thermopile Array (n-poly/p-poly Si)
Image Sensor Type	Heimann Sensor HTPA32x32d
Thermal Pixel Time Constant	< 4 ms
Object Temperature Range	-20°C ... 1000°C
Accuracy	± 2 K ± 2 %
Sensitivity (without optics and filter)	450 V/W
Trigger	yes, by hardware or software
Sync	yes, strobe
Mirror	vertical, horizontal
ROI	yes
Special Functions	see *section 4*

Electrical Interface	
Video Output Type	digital
Interface	phyCAM-P
Data Format	8 / 10 / 12 / 16 (2x8) Bits parallel
Interface-Mode	Y8 / Y10 / Y12 / 2Y8
Camera Configuration	I^2C
Supply Voltage	3.3 V
Power Consumption	≈ 115 mW

Mechanical Parameters	
Lens Connector	integrated lens
Lenses	see *Table 7*
Housing	-
Dimensions (mm)	34 x 34
Mounting	4 x M2,5
Weight (PCB without sensor)	5 g
Operating Temperature	-20°C ... +85°C
Storage Temperature	-25°C ... +85°C

Connectors	
Data and Power	FFC 33 pin
Trigger / Sync	JST 3 pin (optional over phyCAM-P)

n/a: not applicable. All parameters are subject to changes.

Table 6: Parameters VM-050

	VM-050-021	VM-050-036	VM-050-050	VM-050-070
Focal Length	2.1 mm	3.6 mm	5.0 mm	7.0 mm
F# (Focal Ratio)	0.8	0.9	0.85	1.2
Field of View	90° x 90°	43° x 43°	33° x 33°	23° x 23°
Lens Coating	LWP 5.0	AR	LWP 7.7	AR
Filter characteristics	Tr. 5 % for λ > 5 µm ± 3 µm	Tr. < 3 % for 8 µm < λ <11.5 µm	Tr. 5 % für λ > 7,7 µm ± 3 µm	Tr. < 3 % for 8 µm < λ <11.5 µm
NETD @1Hz, @25°C	329 mK	512 mK	254 mK	590 mK
Precision[1]	±3 K or ± 0,03 × |ΔT|	±3 K or ± 0,03 × |ΔT|	±3 K or ± 0,03 × |ΔT|	±3 K or ± 0,03 × |ΔT|
Sensor Height	4.45 mm	6.65 mm	10.41 mm	9.51 mm
Sensor Diameter	8.15 mm	8.15 mm	9.3 mm	8.15 mm

Standard versions are printed bold. Tr. = Transmission ratio

Table 7: Lens Options for VM-050

3.1.3 Electrical Specifications

	Symbol	min	typ	max	Unit
Operating Voltage	V_{CAM}	3,0	3,3	3,6	V
Operating Current	I_{CAM}	-	36	-	mA
Input High Voltage	V_{IH}	2,3	-	3,6	V
Input Low Voltage	V_{IL}	-0,3	-	0,9	V
Output High Voltage	V_{OH}	2.9	-	-	V
Output Low Voltage	V_{OL}	-	-	0.4	V
Voltage Set Resistor	R_{31}	-	0	2	Ω
Operating Temperature	T_{OP}	-20	-	85	°C
Storage Temperature	T_{STG}	-25	-	85	°C

Table 8: VM-050 Electrical Specifications

	Symbol	min	typ	max	Unit
Pixel Clock Frequenncy	f_{PCLK}	-	1.6	-	MHz
PCLK to Data Valid	t_{PD}	150	160	-	ns
PCLK to FV High	t_{PFH}	150	1940	-	ns
PCLK to LV High	t_{PLH}	150	160	-	ns
I²C Clock Frequency	f_{I2C}	-	100	400	kHz

Table 9: VM-050 Timing Parameters

1: Depending on what's bigger

3.1.4 Data Formats

monochrome:

- Y8: 8 bits grey scale
- Y10: 10 bits grey scale
- Y12: 12 bits grey scale
- 2Y8: 16 bits grey scale (2 x 8 bits)

Note:
Any other desired, lower grey scale resolution can be configured by using a reduced subset of the data lines. To configure this, connect only the upper data lines (MSB) to the microprocessor interface. Some microprocessors also enable dynamic configuration of the camera interface input.

3.1.5 Pixel Order

The pixels of the array are read out in lines and columns. The pixel in the upper left corner is referred to as pixel no. 0.

The readout direction is line 0 left to right, followed by line 1 and so on (see *Figure 8* and *Figure 9*).

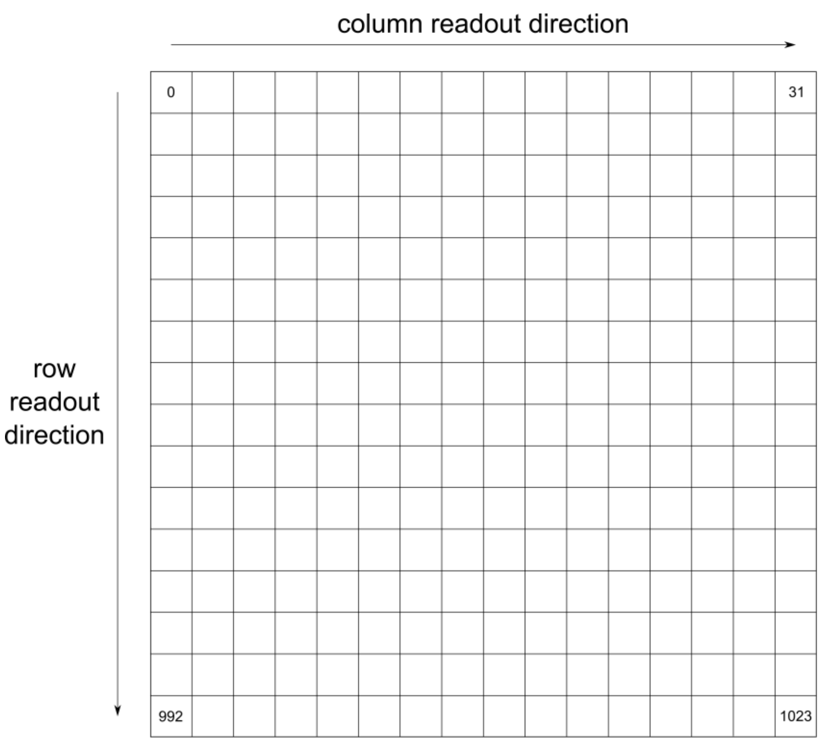


Figure 8: VM-050 Pixel Order

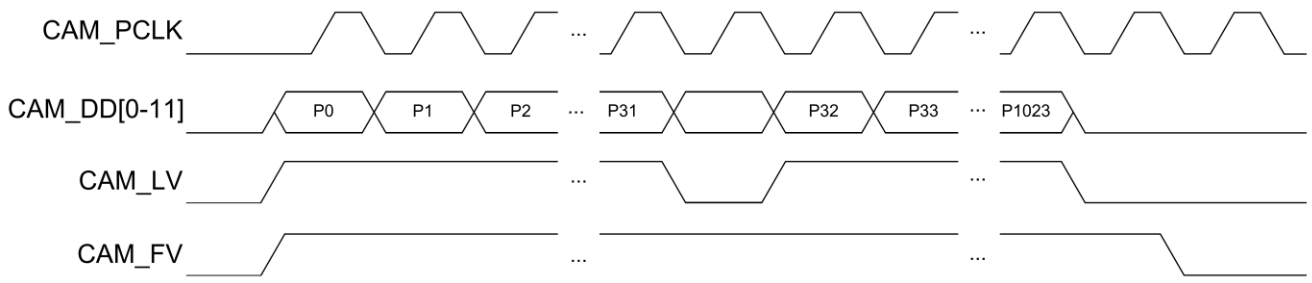


Figure 9: VM-050 Timing Diagram

3.2 VM-051 – Thermopile-Imager 80x64 Pixel / SOC

3.2.1 Features

- 80x64-pixel thermopile-array
- phyCAM-P – Interface
- export compliant
- Framerate up to 7.3 fps
- SOC – System on Chip: integrated pre-processing
- auto-scale option: measuring range can be controlled automatically
- integrated noise reduction
- dead pixel correction
- temperature tracking
- embedded data channel in the image (optional)
- external trigger and strobe signal (optional)

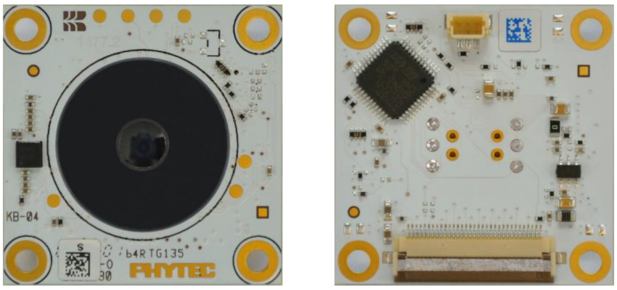


Figure 10: VM-051-050-0 (front / backside)

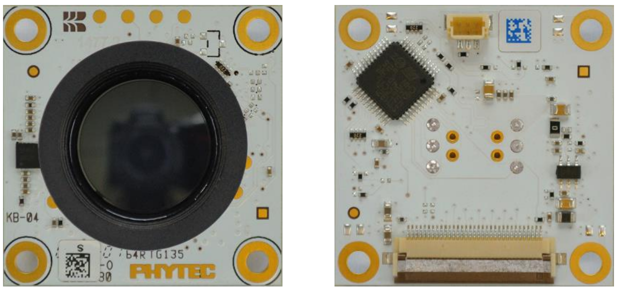


Figure 11: VM-051-100-0 (front / backside)

3.2.2 Parameters

VM-051	
Sensor Characteristsics	
Resolution	5120 pixels
Pixel Count (H x V)	80 x 64
Sensor Technoloy	Thermopile Array (n-poly/p-poly Si)
Image Sensor Type	Heimann Sensor HTPA80x64d
Thermal Pixel Time Constant	< 4 ms
Object Temperature Range	-20°C ... 1000°C
Accuracy	± 2 K ± 2 %
Sensitivity (without optics and filter)	450 V/W
Trigger	yes, by hardware or software
Sync	yes, strobe
Mirror	vertical, horizontal
ROI	yes
Special Functions	see *Section 4*

Electrical Interface	
Video Output Type	digital
Interface	phyCAM-P
Data Format	8 / 10 / 12 / 16 (2x8) Bits parallel
Interface-Mode	Y8 / Y10 / Y12 / 2Y8
Camera Configuration	I^2C
Supply Voltage	3.3 V
Power Consumption	≈ 250 mW

Mechanical Parameters	
Lens Connector	integrated lens
Lenses	see *Table 11*
Housing	-
Dimensions (mm)	34 x 34
Mounting	4 x M2,5
Weight (PCB without sensor)	5 g
Operating Temperature	-20°C ... +85°C
Storage Temperature	-25°C ... +85°C

Connectors	
Data and Power	FFC 33 pol.
Trigger / Sync	JST 3 pol. (optional FFC 33 pol.)

n/a: not applicable. All parameters are subject to changes..

Table 10: Parameters VM-051

	VM-051-039	VM-051-048	VM-051-100	VM-051-105
Focal Length	3.9 mm	4.8 mm	10.0 mm	10.5 mm
F# (Focal Ratio)	0.8	0.8	0.7	0.95
Field of View	120° x 90°	90° x 70°	41° x 33°	39° x 31°
Lens Coating	AR		LWP 7.7	LWP 7.7
Filter Characteristics	ARpS[2]< 3 % for 8 µm< λ <11.5 µm	ARpS[2] < 3 % for 8 µm < λ 11.5 µm	Tr. 5 % for λ > 7,7 µm ± 3 µm	Tr. 5 % for λ > 7,7 µm ± 3 µm
NETD @1Hz, @25°C	260 mK 87 mK[3]	390 mK 80 mK[3]	233 mK 70 mK[3]	333 mK 115 mK[3]
Precision[4]	±3 K or ± 0,03 × |ΔT|	±3 K or ± 0,03 × |ΔT|	±3 K or ± 0,03 × |ΔT|	±3 K or ± 0,03 × |ΔT|
Sensor Height	12.61 mm	14.59 mm	25.72 mm	24.14 mm
Sensor Diameter	20 mm	23 mm	23 mm	23 mm

Standard versions are printed bold. Tr. = Transmission ratio

Table 11: Lens Options for VM-051

3.2.3 Electrical Specifications

	Symbol	min	typ	max	Unit
Operating voltage	V_{CAM}	3.0	3.3	3.6	V
Operating current	I_{CAM}	-	70	-	mA
Input high voltage	V_{IH}	2.3	-	3.6	V
Input low voltage	V_{IL}	-0.3	-	0.9	V
Output high voltage	V_{OH}	2.9	-	-	V
Output low voltage	V_{OL}	-	-	0,4	V
Voltage Set Resistor	R_{31}	-	0	2	Ω
Operating temperature	T_{OP}	-20	-	85	°C
Storage temperature	T_{STG}	-25	-	85	°C

Table 12: VM-051 Electrical Specifications

	Symbol	min	typ	max	Unit
Pixel Clock Frequenncy	f_{PCLK}	-	1.6	-	MHz
PCLK to Data Valid	t_{PD}	150	160	-	ns
PCLK to FV High	t_{PFH}	150	1940	-	ns
PCLK to LV High	t_{PLH}	150	160	-	ns
I²C Clock Frequency	f_{I2C}	-	100	400	kHz

Table 13: VM-051 Timing Parameters

2: ARpS = Average Reflection per Surface
3: Sensor also available as "Ultra High Sensitiy" on request.
4: Depending on what's bigger

3.2.4 Data Formats

monochrome:

- Y8: 8 bits grey scale
- Y10: 10 bits grey scale
- Y12: 12 bits grey scale
- 2Y8: 16 bits grey scale (2 x 8 bits)

Note:
Any other desired, lower grey scale resolution can be configured by using a reduced subset of the data lines. To configure this, connect only the upper data lines (MSB) to the microprocessor interface. Some microprocessors also enable dynamic configuration of the camera interface input.

3.2.5 Pixel Order

The pixels of the array are read out in lines and columns. The pixel in the upper left corner is referred to as pixel no. 0.

The readout direction is line 0 left to right, followed by line 1 and so on (see *Figure 12* and *Figure 13*).

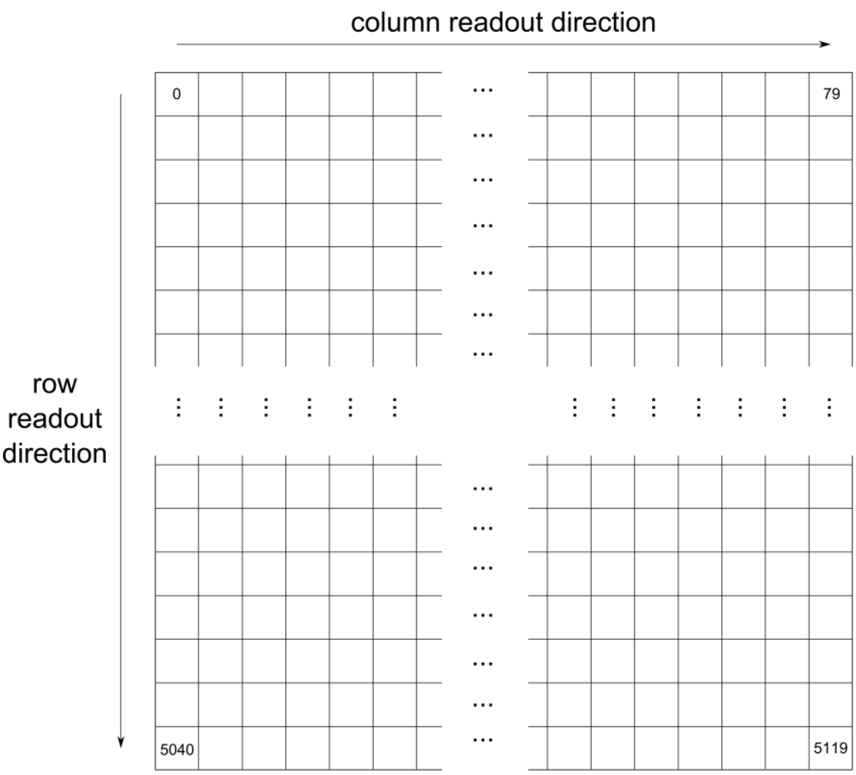


Figure 12: VM-051 Pixel Order

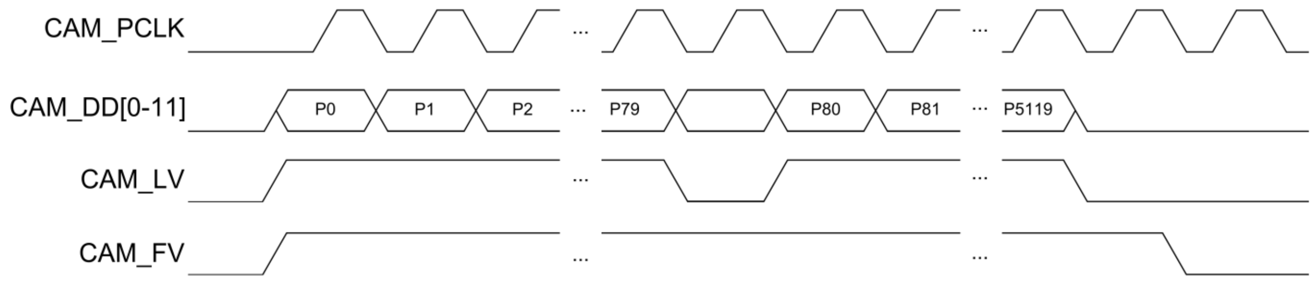


Figure 13: VM-051 Timing Diagram

3.3 I^2C Configuration Interface

3.3.1 I^2C Addresses

I^2C-Address	Configuration			
	CAM_CTRL1	J5	J4	J2
0x94	GND	1+2	2+4	1+2
	x	x	2+3	1+2
0x9C	VCAM	1+2	2+4	1+2
	x	x	1+2	1+2
0xB4	GND	1+2	2+4	2+3
	x	x	2+3	2+3
0xBC	VCAM	1+2	2+4	2+3
	x	x	1+2	2+3

Standard configuration is printed bold.

Table 14: I^2C Adressess VM-050 and VM-051

I^2C-addresses are shown in hexadecimal, 8-bit notation. Please note that Linux possibly uses 7-bit notation. If developing with 7-bit Linux notation, shift the address value one bit to the right. The table shows the write address (bit 0 = 0). To read from the device, add one to the address (bit 1 = 1).

3.3.2 I^2C Principle of Operation

For communication with the components on the camera module (like image sensor, EEPROM, etc.), the phyCAM interface features an I^2C interface. Via the I^2C interface, the CPU can read and write the registers of the camera sensor. This way, the configuration of the sensor can be set.

The I^2C interface of the VM-050 is organized in 8-bit data blocks:

- 8 bit device address
- 8 bit register address
- 2 x 8 bit data

I^2C access to the VM-050 / VM-051 is always carried out by a 16-bit write or 16-bit read protocol.

According to the I²C specification, the selection between read and write access is determined by the LSB of the device address.

- write access: LSB of the device address = 0
- read access: LSB of the device address = 1

3.3.2.1 16-Bit Write Sequence

Figure 14 shows a typical sequence for writing a value into a 16 bit register. The master initiates the sequence by a start bit, followed by the register address and two data bytes. The byte order is most significant byte first.

After each byte, an acknowledge (ACK) is sent by the camera module. After the transmission of all 16 data bits, the register content is updated. The master finishes the write cycle by sending a stop bit.

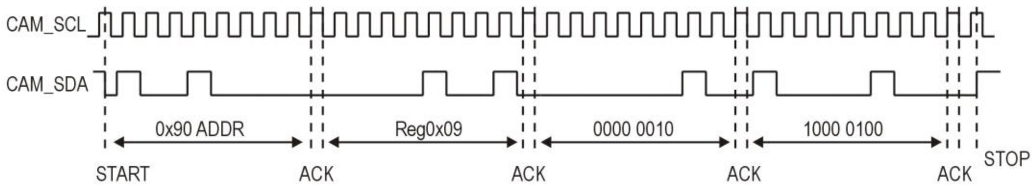


Figure 14: Example I²C Write Access: Writing 0x0284 into register 0x09 of device 0x90

3.3.2.2 16-Bit Read Sequence

A typical 16-bit read sequence is shown in *Figure 15*. First, the master has to write the register address, as in a write sequence. Then a start bit and the device address with LSB set specifies that a read is about to happen from the register. Note that the LSB set in the device address indicates read access.

With the following clocks, the camera module outputs two data bytes which contain the 16 bit register content, high-byte first. After each 8 bits, the master sends an acknowledge bit (ACK). The data transfer is finished by the master by sending a No-Acknowledge-Bit (NACK) after 16 bits of data have been transferred

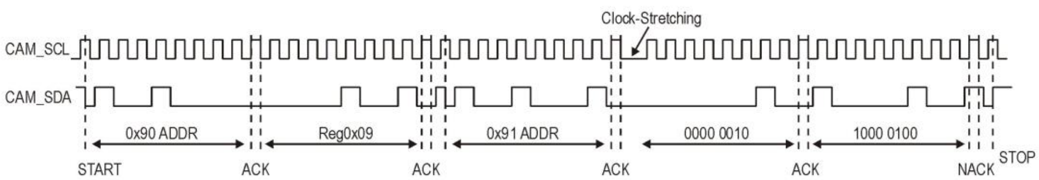


Figure 15: Example I²C Read Access: Reading 0x0284 from register 0x09 of device 0x90

Note:
After the internal microcontroller of the camera module has received the initial I²C write command and the device address with read bit set, it takes a short peroid of time to process the command internally.

The master of the I²C bus has to wait until this time is over before it can start reading the data from the camera module.

To signal this pause, the camera module uses the „*Clock-Stretching*“ method.
The I²C bus master must support Clock-Stretching“ in order to communicate properly with the camera module.

3.4 Multipurpose Pins

Signal	Pin	Function	I/O	Configuration
CAM_CTRL1	7	open	-	J5: NOMT
		I²C-Address-Select	I	J5: 1+2, J4: 2+4, J17: NOMT
		Strobe	O	J5: 2+4
		CAM_DD0	O	J5: 1+2, J4: nicht 2+4, J17: 1+2
CAM_CTRL2	30	open	-	J3: NOMT
		GND	-	J3: 2+4
		Trigger	I	J3: 1+2, J18: 1+2
		CAM_DD1	O	J3: 1+2, J18: 2+3
CAM_RST	3	Camera Reset (active low)	I	-
CAM_OE	32	Data Output Enable (active high)	I	-

Table 15: Configuration options of the Multipurpose Pins VM-050 and VM-051

Note:
Configuration: Internal Configuration of the camera module to activate / use this feature.
If more than one feature is available for one pin, the default configuration is printed in bold blue.

NOMT = not mounted

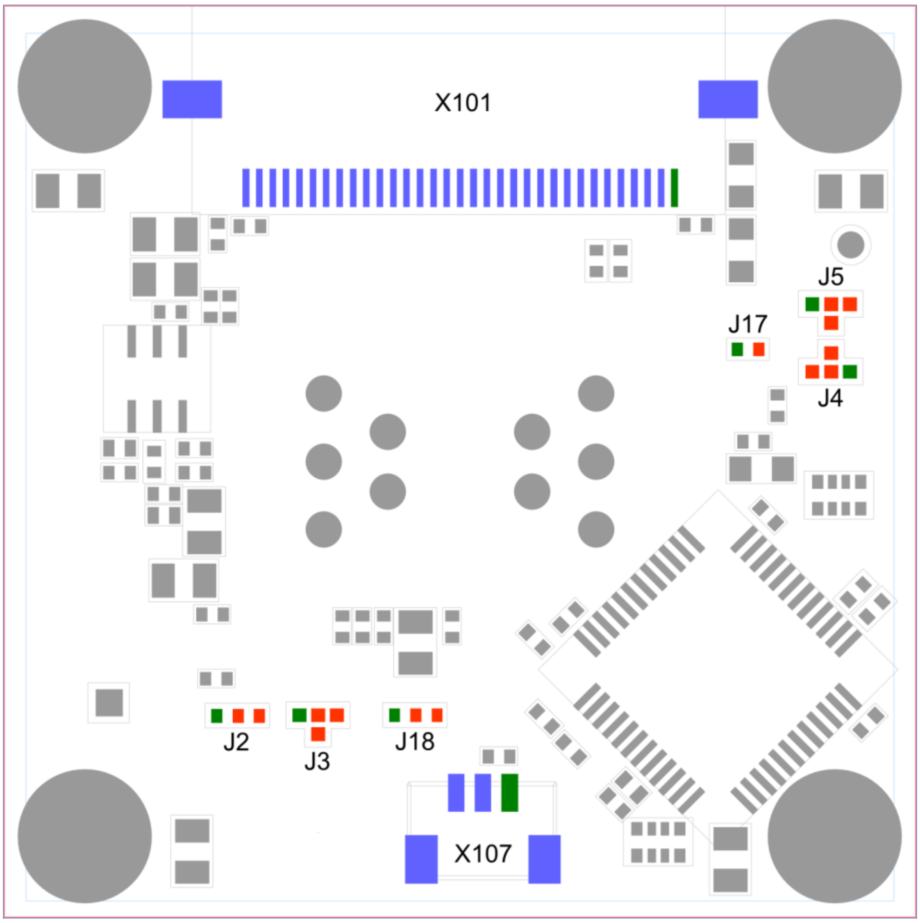
In order to best meet technical requirements and cost objectives, custom configurations are available for high volume deliveries of phyCAM modules. Please contact PHYTEC for additional information.

3.5 DataLine alignment

Bit	Data lines			
	8 Bit	10 Bit	12 Bit	16 Bit
0	CAM_DD2	CAM_DD0	CAM_CTRL1	CAM_DD2
1	CAM_DD3	CAM_DD1	CAM_CTRL2	CAM_DD3
2	CAM_DD4	CAM_DD2	CAM_DD0	CAM_DD4
3	CAM_DD5	CAM_DD3	CAM_DD1	CAM_DD5
4	CAM_DD6	CAM_DD4	CAM_DD2	CAM_DD6
5	CAM_DD7	CAM_DD5	CAM_DD3	CAM_DD7
6	CAM_DD8	CAM_DD6	CAM_DD4	CAM_DD8
7	CAM_DD9	CAM_DD7	CAM_DD5	CAM_DD9
8	-	CAM_DD8	CAM_DD6	CAM_DD2
9	-	CAM_DD9	CAM_DD7	CAM_DD3
10	-	-	CAM_DD8	CAM_DD4
11	-	-	CAM_DD9	CAM_DD5
12	-	-	-	CAM_DD6
13	-	-	-	CAM_DD7
14	-	-	-	CAM_DD8
15	-	-	-	CAM_DD9

Table 16: Data line alignment

3.6 Jumper Map VM-050 and VM-051



Pin 1 is shown green.

Figure 16: Jumper Map VM-050/VM-051

4 Special Features VM-050 and VM-051

4.1 Register Reference

The following sections describe the special features of the VM-050 / VM-051. For this, parts of the register reference are shown below. Please note that the full register reference is shown in a separate document.

Note:
Please refer to the document LAN-074e, "VM-050-VM051 Register Reference" for the complete description of all camera registers.

4.2 Trigger

The default mode is 'continuous mode', where the camera is free running and continuously outputs images. As soon as an image aquisition has been completed and frame data has been processed, the aquisition of the next frame is then started.

Using the trigger function allows to control the point in time at which an image aquisition takes place by an electrical signal or by software .

Two trigger modes are available at VM-050 / VM-051:

- Hardware Trigger: The image aquistion is controlled by an external signal which is applied to the CAM_TRIG input.
- Software Trigger: The image aquistion is controlled by software. It is started by setting the bit *Sensor Enable Sampling* in the CONTROL1 register.

Trigger mode is set by the bits 3:0 of the CONTROL2 register:

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x03 – CONTROL2						
3:0	Snapshot Mode	0 = Continuous Mode (Snapshot Mode disabled) 1 = Hardware trigger. Frame aquisition is started at a high-level applied to the CAM_TRIG input. 2 = Software trigger. Frame aquisition is started by setting the bit 'Sensor Enable Sampling' to 1. 'Sensor Enable Sampling' is reset automatically. 3...15 = Reserved	0	Y	0...2	R/W

Table 17: Trigger mode selection

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x02 – CONTROL1						
0	Sensor Enable Sampling	0 = Disable image sampling 1 = Enable image sampling (depends on ‘CONTROL_2’, ‘Snapshot Mode’)	1	Y	0,1	R/W

Table 17: Trigger mode selection (continued)

4.2.1 Hardware Trigger Mode

If the field *Snapshot Mode* in register CONTROL2 is set to 1, continuous frame aquisition is stopped and the camera is set to hardware trigger mode. In this mode, frame aquisition is started by a high-level on the CAM_TRIG input. An aquisition starts on a low-to-high transition of the signal on CAM_TRIG. If the high level is still persistent after the frame aquisition has ended, the next frame aquisition is carried out. If the signal level is low after an aquisition has ended, the camera stops frame aquisition until a new low-to-high transition occurs on CAM_TRIG or until aquisition mode is changed to *Continuos mode* by resetting the field *Snapshot Mode* to 0.

4.2.2 Software Trigger Mode

If the field *Snapshot Mode* in register CONTROL2 is set to 2, continuous frame aquisition is stopped and the camera is set to software trigger mode. In this mode, frame aquisition is started by setting the bit *Sensor Enable Sampling* in the register CONTROL1.

After the aquisition of one frame, the bit *Sensor Enable Sampling* is reset and the camera stops sampling frames until the bit *Sensor Enable Sampling* is set again or the aquisition mode is reset to *Continuous Mode* by writing a 0 to the *Snapshot Mode* field.

4.3 Strobe

The hardware output signal CAM_STRO reflects the aquisition state of the camera module. It shows a low-to-high transition at the beginning of a frame aquisition and stays at high level for a period of time while pixels are sampled and read out. After all pixels of this frame have been read, the Strobe signal returns to low state.

The strobe signal can be used to control external devices or to determine precisely the moment where the sampling of an image was started.

In hardware or software trigger mode, the strobe signal can be especially helpful to determine that an image aquisition has taken place.
The strobe signal is activated by writing a 1 to the field *Strobe Mode* in the register CONTROL2.

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x03 – CONTROL2						
7:4	Strobe Mode	0 = Disable strobe pulse 1 = Enable strobe pulse. Generates a high-pulse at STROBE-Pin while the sensor is sampling an image. 2…15 = Reserved (depends on 'CONTROL_1', 'Sensor Enable Sampling')	0	Y	0,1	R/W

Table 18: Strobe Mode Settings

4.4 Reset

4.4.1 Hardware Reset

Applying a low level to the reset input of the camera module initiates a reset cyle of the camera module. All registers are set to their default state and the initialization cycle of the sensor is carried out.

The reset input should be connected to the reset signal of the microcontroller circuit.
The reset input must held high during normal operation of the camera.

4.4.2 Software Reset

A reset of the camera module can be initiated by writing a 1 to the field *Module Reset* located in register CONTROL1.

All registers are set to their default state and the initialization cycle of the sensor is carried out.

The field *Module Reset* is self-cleared after the reset procedure has been carried out.

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x02 – CONTROL1						
3	Module Reset	Perform an automatic reset of the entire camera module. This is a self-resetting bit which should always read '0'. 0 = Normal operation 1 = Perform module reset	0	Y	0,1	R/W

Table 19: Reset Mode register

Note:
To ensure proper operation of the camera module, the CAM_RST input must held at high state during operation.

If the reset input is not used, CAM_RST has to be connected to V_{CAM} by a 10 kΩ pull up-resistor.

4.5 Output-Enable

The data lines CAM_DD[0...11] and the control signals CAM_LV, CAM_FV, CAM_PCLK und CAM_STRO can be tristated by applying a low-level to the CAM_OE input.

Note:
CAM_OE is held high by an internal pull up resistor of approx. 47 kΩ.

4.6 Temperature Window

The integrated preprocessor of the thermal camera converts the incoming thermal radiation measured by a pixel to a temperature value for the corresponding object. The effective measuring range is from -20°C to 1000°C. The internal data width of the camera module is 16 bits, which results in a temperature resoultion of 1 dK (deci-kelvin, 1/10 K). If the output is configured to 16 bit mode (2 x 8 bits) this resolution can be transmitted to the microcontroller.

However, in many applications only a part of the measurement range is needed.
For these cases, the camera module allows the application software to define a temperature window, which basically reduces the measurement range. The resulting measurement range is mapped on the selected output data width which can be 8, 10 or 12 bit width.
As a result, a smaller temperature range is available. The ratio between the temperature range and the number range given by the interface width defines the effective output resolution. The temperature range can be compressed, which results in a larger measurement range at lower temperature resolution or it can be stretched, which results in a smaller measurement range at a higher temperature resolution.

Figure 17 illustrates two examples for the use of the temperature window at an output resolution of 10 bits:

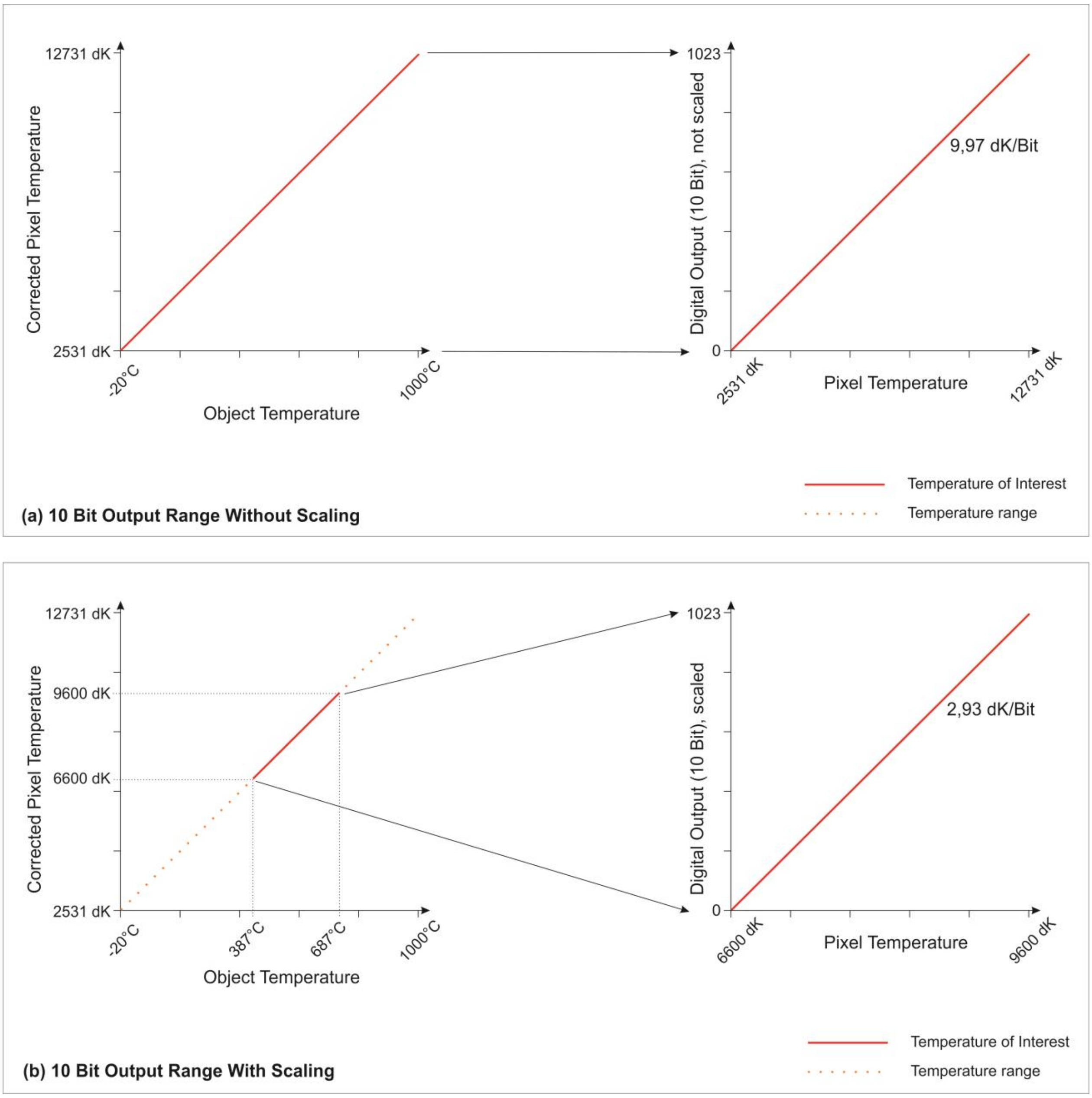


Figure 17: Two examples of scaling the temperature range

In *Figure 17a*, the complete temperature range of -20°C to 1000°C is scaled to the numeric output range of 0 to 1023. The output value 0 corresponds to a temperature of 2531 dK which is approx. -20 °C. The output value 1023 corresponds to a temperature of 12731 dK which is approx. 1000 °C in the centigrade scale.

Thus, one bit equals approximately 9.95 dK.

Figure 17b shows an example with a reduced measurement range. Only the object temperature range from 387°C to 687°C is mapped to the numeric output range of 0 to 1023. Now the output value 0 corresponds to a temperature of 6600 dk which is approx. 387°C. The output value 1023 corresponds to a temperature of 9600 dK which is approx. 687°C.

The measurment range is reduced to 300 K but the temperature resolution has increased to 2.93 dK/bit.

Using the temperature window has several advantages:

- The width of the data lane between the camera module and the microcontroller can be reduced to less than 16 bits but the temperature resolution can still be maintained in many use cases.
- In a given application, unwanted or unneccessary information can be removed from the temperature image.
- If the temperature range in an application is not too wide, the image processing can be carried out using 8-bit width, conserving memory and CPU power.

The output resolution of the interface can be set with the field *Temperature Resolution* in the OUTPUT_CONTROL-Register.

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x0F – OUTPUT_CONTROL						
3:0	Temperature Resolution	0 = 8 bits 1 = 10 bis 2 = 12 bits 4 = 16 bits (2x8 bits, big endian)	1	Y	0,1,2,4	R/W

Table 20: Temperature Resolution register

4.6.1 Manual and Semi-manual Window Control

4.6.1.1 Manual window control

The temperature window can be defined manually. First, the auto scale mode has to be disabled by writing a 0 to both the *Enable-Auto-Scale-Mode* field and the *Auto-Scale Metering* field in the CONTROL2 register.

After that, the upper and lower limit of the temperature window can be defined with the registers TEMP_WINDOW_MIN and TEMP_WINDOW_MAX.

TEMP_WINDOW_MIN holds the lower margin of the temperature window which is then the lowest temperature to be measured.
TEMP_WINDOW_MAX holds the upper margin of the temperature window which is then the highest temperature that can be measured.

If the highest temperature resolution is to be acheived, the size of the temperature window in decikelvin must be less or equal the output value range minus 1.
Example:
If the data interface is set to a data width of 10 bits, a numeric range of 0 to 1023 can be output. Therefore, to output maximum resolution, the width of the temperature window must be set to 1023 dK or less.

4.6.1.2 Semi-manual window control

This mode is helpful in applications where maximum temperature resolution is desired. In this mode, only the center temperature of the window has to be set. The window width (the corresponding upper and lower limits) is set automatically according to the current output data width so that the temperature resolution is best.

To use semi-manual window control:

- the *Tracking Mode* field in register TRACK_TEMP0_CONF must be not equal to 1
- the *Enable-Auto-Scale-Mode* field in register CONTROL2 must be set to 5
- the center temperature of the window has to be written to the TRACK_TEMP0 register

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x03 – CONTROL2						
11:8	Enable Auto-Scale-Mode	The camera module automatically scales the temperature values depending on 'Temperature Resolution' 0 = Reserved 1 = Full dynamic scale. 2 = Fixed Temp_Min scale. For this the 'TEMP_WINDOW_MIN' register has to be set. 3 = Fixed Temp_Max scale. For this the 'TEMP_WINDOW_MAX' register has to be set. 4 = Scale by mean temperature. (depends on 'Auto-Scale Metering') 5 = Scale by TRACK_TEMP0. 6…15 = Reserved	1	Y	0…5	R/W

Table 21: Semi-Manual Temperature Window Control

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x03 – CONTROL2						
15:12	Auto-Scale Metering	If Auto-Scale-Mode is used, a metering mode has to selected. 0 = Disable Auto-Scale-Mode. Temperature window is user defined by ‘TEMP_WINDOW_MIN’ and ‘TEMP_WINDOW_MAX’ registers. 1 = Auto scale by entire image. 2 = Center-weighted. Like entire image, but the central 25 % of the image are double-weighted. 3 = Spot. The central 64 Pixel are used only. 4...15 = Reserved	1	Y	0...3	R/W
0x19 – TEMP_WINDOW_MIN						
15:0	Temperature Window Min	Holds an unsigned value used to rescale the received data word back to a temperature value. Depending on ‘Enable Auto-Scale-Mode’. This register holds a fixed value (set by user) if ‘Enable Auto-Scale-Mode’ is set to 0 or 2. If ‘Enable Auto-Scale-Mode’ is set to 1 or 3 this registrer holds the value used to auto-scale the temperature values of each frame. In this case TEMP_WINDOW_MIN is updated on each frame.	-	Y	0...65 535	R/W

Table 21: Semi-Manual Temperature Window Control (continued)

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x1A – TEMP_WINDOW_MAX						
15:0	Temperature Window Max	Hold an unsigned value used to scale a sampled temperature value to the used data word width. Depending on 'Enable Auto-Scale-Mode'. This register holds a fixed value (set by user) if 'Enable Auto-Scale-Mode' is set to 0 or 2. If 'Enable Auto-Scale-Mode' is set to 1 or 3, this register holds the value used to auto-scale the temperature values of each frame. In this case TEMP_WINDOW_MAX is updated on each frame	-	Y	0…65535	R/W
0x20 – TRACK_TEMP0_CONF						
14:13	Tracking Mode	0 = disable Tracking 1 = 'TRACK_TEMP0' holds the temperature value of the pixel according to 'Pixel Number'. 2 = If one pixel in the whole image is equal or less 'TRACK_TEMP0'-value (set by user) the 'Tracking Flag' is set to '1'. 3 = If one pixel in the image is greater or equal 'TRACK_TEMP0'-value (set by user) the 'Tracking Flag' is set to '1'.	0	Y	0…3	R/W
0x24 – TRACK_TEMP0						
15:0	Track Temp 0	Depends on 'TRACK_TEMP0_CONF'	0	Y	0…65535	R/W

Table 21: Semi-Manual Temperature Window Control (continued)

Note:
Manual and Semi-manual window control is helpful especially in applications where defined object temperatures are to be measured.

4.6.2 Automatic Window Control

The VM-050 / VM-051 cameras feature an automatic control of the temperature window. If the automatic window control is activated, the window margins are automatically set by the camera according to the minimum and maximum temperatures measured in the thermal image.

Similar to cameras for visible light, several weight functions and metering modes can be seleceted.

Two parameters allow the developer to adapt the response of the automatic mode to the scene and the application:

- Definition of the measuring/weighting method (Scale Metering)
- Setting the automatic function (Scale Mode)

4.6.2.1 Selection of the Weight Function

In automatic window control mode, the camera module analyzes the current frame, determines the coldest and hottest temperature, and calculates the average temperature of the frame. By selection the weight function, the algorithm can be adapted to the scene.
The weight function can be selected with the field *Auto-Scale Metering* in the register CONTROL2.

- 0: Metering stopped. Settings are frozen and camera uses the last parameters.
- 1: Entire image: Each pixel of the image is considered the same way for metering.
- 2: Center-Weighted: The entire image is used for metering but the center 25 % of the pixels are double-weighted.
- 3: Spot: Only the inner 64 pixels of the sensor are used for metering.

4.6.2.2 Selection of the Metering Mode

The metering mode can be selected by the *Enable-Auto-Scale-Mode* field in register CONTROL2:

- 0 = Automatic mode disabled.
- 1 = Fill dynamic scale: The temperature window is continuously adapted to the lowest and highest temperature in the measuring field.
- 2 = Fixed lower temperature margin: The temperature window is continuously adapted to the hightest temperature found in the measuring field. The lower margin of the window is fixed and can be set by the TEMP_WINDOW_MIN register.
- 3 = Fixed higher temperature margin: The temperature window is continuously adapted to the lowest temperature found in the measuring field. The upper margin of the window is fixed and can be set by the TEMP_WINDOW_MAX register.
- 4 = Average temperature: The center of the temperature window is set to the average temperature of the measuring field. The average temperature is the arithmetic mean of the pixels after the weight function was applied to the pixels. The window width is set automatically according to the selected output data width.

Thus the maximum temperature resolution is obtained.

Note:
Automatic Window Control is used to track objects with different or changing temperatures. The Automatic Window Control can be used to quickly find a temperature window, with which, a separate temperature window can be defined for manual window adjustment.

In order to obtain a uniform image, the settings for automatic window control are filtered by a weak low pass filter.

The average temperature mode is helpful in applications where a thermal image is displayed on a HID. Because of the arithmetic average, the temperature window is not shifted much by the appearance of small objects. However, it should be considered that not all objects might be within the temperature window.

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x03 – CONTROL2						
11:8	Enable Auto-Scale -Mode	The camera module scales the calculated temperature values depending on 'Temperature Resolution' 0 = Reserved 1 = Full dynamic scale. 2 = Fixed Temp_Min scale. The register 'TEMP_WINDOW_MIN' has to be set. 3 = Fixed Temp_Max scale. The register 'TEMP_WINDOW_MAX' has to be set. 4 = Scale by mean temperature. (depends on 'Auto-Scale Metering') 5 = Scale by TRACK_TEMP0. 6…15 = Reserved	1	Y	0…5	R/W
15:12	Auto-Scale Metering	If Auto-Scale-Mode is used, a metering mode has to selected. 0 = Disable Auto-Scale-Mode. Temperature window is user defined by 'TEMP_WINDOW_MIN' and 'TEMP_WINDOW_MAX' registers. 1 = Auto scale by entire image. 2 = Center-weighted. Like entire image, but the central 25 % of the image are double-weighted. 3 = Spot. The central 64 Pixel are used only. 4…15 = Reserved	1	Y	0…3	R/W

Table 22: Auto Scale Mode Registers

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/Write
0x19 – TEMP_WINDOW_MIN						
15:0	Temperature Window Min	Holds an unsigned value used to rescale the received data word to a temperature value. Depending on 'Enable Auto-Scale-Mode' this Register hold a fixed Value (set by user) if 'Enable Auto-Scale-Mode' is set to 0 or 2. If 'Enable Auto-Scale-Mode' is set to 1 or 3 this value hold the value used to auto-scale the temperature values of each frame. In this case TEMP_WINDOW_MIN is updated each frame.	-	Y	0...65535	R/W
0x1A – TEMP_WINDOW_MAX						
15:0	Temperature Window Max	Holds an unsigned value used to scale a sampled temperature value to the used data word width. Depending on 'Enable Auto-Scale-Mode' this Register hold a fixed Value (set by user) if 'Enable Auto-Scale-Mode' is set to 0 or 2. If 'Enable Auto-Scale-Mode' is set to 1 or 3 this value hold the value used to auto-scale the temperature values of each frame. In this case TEMP_WINDOW_MAX is updated each frame	-	Y	0...65535	R/W

Table 22: Auto Scale Mode Registers (continued)

4.6.3 Retrieving Temperatures from Scaled Data

To obtain real temperatures from the data transmitted by the camera module, scaling has to be reverted.
The following equations can be used:

$$T_{Pix} = \frac{T_{PixScaled}}{f_{scale}} + T_{WinMin}$$

$$f_{scale} = \frac{2^{Bit} - 1}{T_{WinMax} - T_{WinMin}} \quad [float]$$

Figure 18: Temperature Scaling Equations

T_{Pix} = measured object temperature
$T_{PixScaled}$ = scaled value transmitted
T_{WinMin} = lower margin of the temperature window
T_{WinMax} = upper margin of the temperature window
f_{scale} = scale factor
Bit = selected data word width of the interface

The scale factor f_{scale} used by the camera can be read from the registers TEMP_WINDOW_SCALE_FACTOR1 (0x17) and TEMP_WINDOW_SCALE_FACTOR2 (0x18). The scale factor is stored as a 32 bit width integer (2x 16 bits) where TEMP_WINDOW_SCALE_FACTOR1 holds the MSB and TEMP_WINDOW_SCALE_FACTOR2 holds the LSB quantization error
Because the scaled temperature value is converted from Float to Integer, a quantization error occurs. Only if $f_{scale} = 1$, no quantization error will occur.

In case $f_{scale} > 1$, the temperature scale is spread. This is useful for pseudocolor images, because the entire color space can be used to visualize the given temperature range. In this case, the temperature values are not interpolated. Gaps will orccur in the output spectrum. The output values can be transformed back to the original values without any loss of accuracy.

In case $f_{scale} < 1$ the temperature scale is compressed. This leads to a loss of accuracy because two or more temperature values are mapped on the same output value.

The quantization error can be reduced to 0.5 LSB or less by setting the 'Interface Accuracy'-field in the 'OUTPUT_CONTROL'-Register to '1'.

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x0F – OUTPUT_CONTROL						
6	Interface Accuracy	Interface Accuracy 0 = min. 1 LSB. Coarse quantization results in a higher output speed. 1 = min. 0.5 LSB. Best quantization quality but lower output speed.	1	Y	0,1	R/W

Table 23: OUTPUT_CONTROL (Interface Accuracy Setting)

Example 1:

Temperature output resulution: 8 bits
Temperature Window Min: 2590 dK
Temperature Window Max: 2924 dK
Temperature measured: 2618 dK
Interface Accuracy: 1

➔ F_{scale} = 0,763473053892216 dK^{-1}

the internal scaling (compressing) results in:

➔ $T_{PixScaled}$ = 21

transforming the output value back to temperatures in the target device results in:

➔ T_{Pix} = 2618 dK (= 2618 dK)

Example2:

Temperature output resulution: 8 Bit
Temperature Window Min: 2590 dK
Temperature Window Max: 2924 dK
Temperature measured: 2617 dK
Interface Accuracy: 1

➔ F_{scale} = 0,763473053892216 dK^{-1}

the internal scaling (compressing) results in:

➔ $T_{PixScaled}$ = 21

transforming the output value back to temperatures in the target device results in:

➔ T_{Pix} = 2618 dK (≠2617 dK)

Note:
All parameters / factors needed to transform the output value back to the temperature of the pixel can be read out by the I^2C interface.

In addition, these parameters can also be obtained as embedded information from each frame. This is especially helpful if the parameters are changing dynamically (Auto Scale Mode). See *Section 4.11* for details.

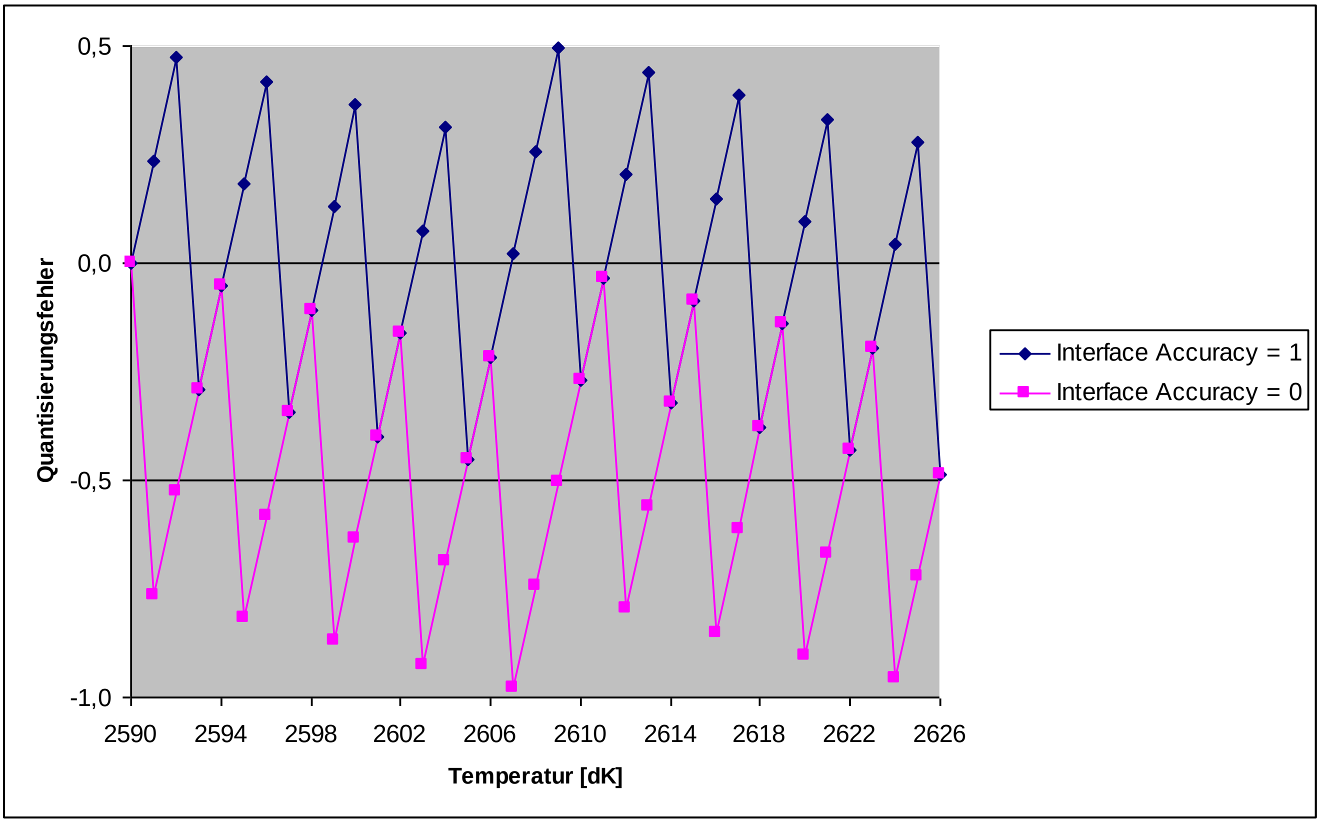


Figure 19: Quantization Error for Examples 1 and 2

4.6.4 Overflow-Flag

All temperature values in the image that fall below the temperature window are shown as 0, all values that are above the window are shown as full scale (e.g., 0xFF for 8 bits). The 'Overflow Flag' bit of the 'OUTPUT_CONTROL' register allows to determine for each frame if an overflow or underflow has occured.

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x0F – OUTPUT_CONTROL						
13	Overflow Flag	0 = All measured temperatures of the frame fit into the temperature window. 1 = Over-/Underflow occurred: At least one measured temperature of the current frame is outside the temperature window.	-	Y	0,1	R

Table 24: OUTPUT_CONTROL (Overflow Flag)

Note:
In addition, this parameter can also be obtained as embedded information from each frame. This is especially helpful, if the parameters are changing dynamically (Auto Scale Mode). See *Section 4.11* for details.

4.7 Temperature-Tracking

The camera module can calculate several statistics automatically. The following values are calculated for each frame:

- 'TEMP_MIN': the lowest temperature in the frame
- 'TEMP_MAX': the highest temperature in the frame
- 'TEMP_MEAN': the average temperature in the frame
- 'TEMP_CENTER': the temperature in the center of the frame

In addition, the camera has four tracking registers which can be configured individually with the 'Tracking Mode'-Bits in the 'TRACK_TEMPx_CONF' registers:

- 0: Tracking off
- 1: The 'TRACK_TEMPx' register stores the current temperature of the pixel defined by the 'Pixel Number' register.
- 2: The 'Tracking Flag' of the 'TRACK_TEMPx_CONF' register is set to 1 in case the temperature of one pixel of the current frame is equal or less the temperature value set in the 'TRACK_TEMPx' register. Otherwise, the 'Tracking Flag'-Bit is reset to 0.
- 3: The 'Tracking Flag' of the 'TRACK_TEMPx_CONF' registers is set to 1 in case the temperature of one pixel of the current frame is equal or greater the temperature value stored in the 'TRACK_TEMPx' register. Otherwise, the 'Tracking Flag'-Bit is reset to 0.

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x20 – TRACK_TEMP0_CONF						
12:0	Pixel Number	Number of the Pixel that is to be tracked if 'Tracking Mode' is set to 1.	0	Y	0...1023 / 5119	R/W
14:13	Tracking Mode	0 = disable Tracking 1 = 'TRACK_TEMP0' holds the temperature value of the pixel according to 'Pixel Number'. 2 = If one pixel in the whole image is equal or less 'TRACK_TEMP0'-value (set by user) the 'Tracking Flag' is set to '1'. 3 = If one pixel in the whole image is greater or equal 'TRACK_TEMP0'-value (set by user) the 'Tracking Flag' is set to '1'.	0	Y	0...3	R/W
15	Tracking Flag	Depends on 'Tracking Mode'	0	Y	0,1	R

Table 25: Temperature Tracking Registers

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x21 – TRACK_TEMP1_CONF						
12:0	Pixel Number	Number of the Pixel that is to be tracked if 'Tracking Mode' is set to 1.	0	Y	0...102 3 / 5119	R/W
14:13	Tracking Mode	0 = disable Tracking 1 = 'TRACK_TEMP1' holds the temperature value of the pixel according to 'Pixel Number'. 2 = If one pixel in the whole image is equal or less 'TRACK_TEMP1'-value (set by user) the 'Tracking Flag' is set to '1'. 3 = If one pixel in the whole image is greater or equal 'TRACK_TEMP1'-value (set by user) the 'Tracking Flag' is set to '1'.	0	Y	0...3	R/W
15	Tracking Flag	Depends on 'Tracking Mode'	0	Y	0,1	R
0x22 – TRACK_TEMP2_CONF						
12:0	Pixel Number	Number of the Pixel that is to be tracked if 'Tracking Mode' is set to 1.	0	Y	0...102 3 / 5119	R/W
14:13	Tracking Mode	0 = disable Tracking 1 = 'TRACK_TEMP2' holds the temperature value of the pixel according to 'Pixel Number'. 2 = If one pixel in the whole image is equal or less 'TRACK_TEMP2'-value (set by user) the 'Tracking Flag' is set to '1'. 3 = If one pixel in the whole image is greater or equal 'TRACK_TEMP2'-value (set by user) the 'Tracking Flag' is set to '1'.	0	Y	0...3	R/W
15	Tracking Flag	Depends on 'Tracking Mode'	0	Y	0,1	R

Fehler! Verweisquelle konnte nicht gefunden werden. (continued)

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x23 – TRACK_TEMP3_CONF						
12:0	Pixel Number	Number of the Pixel that is to be tracked if 'Tracking Mode' is set to 1.	0	Y	0…1023 / 5119	R/W
14:13	Tracking Mode	0 = disable Tracking 1 = 'TRACK_TEMP3' holds the temperature value of the pixel according to 'Pixel Number'. 2 = If one pixel in the whole image is equal or less 'TRACK_TEMP3'-value (set by user) the 'Tracking Flag' is set to '1'. 3 = If one pixel in the whole image is greater or equal 'TRACK_TEMP3'-value (set by user) the 'Tracking Flag' is set to '1'.	0	Y	0…3	R/W
15	Tracking Flag	Depends on 'Tracking Mode'	0	Y	0,1	R
0x24 – TRACK_TEMP0						
15:0	Track Temp 0	Depends on 'TRACK_TEMP0_CONF'	0	Y	0…65535	R/W
0x25 – TRACK_TEMP1						
15:0	Track Temp 1	Depends on 'TRACK_TEMP1_CONF'	0	Y	0…65535	R/W
0x26 – TRACK_TEMP2						
15:0	Track Temp 2	Depends on 'TRACK_TEMP2_CONF'	0	Y	0…65535	R/W
0x27 – TRACK_TEMP3						
15:0	Track Temp 3	Depends on 'TRACK_TEMP3_CONF'	0	Y	0…65535	R/W

Fehler! Verweisquelle konnte nicht gefunden werden. (continued)

Note:
All temperature tracking registers can also be transmitted as embedded information within an image frame. For more information, see *chapter 4.11.*

Dead Pixel are not used for tracking functions. If Pixel Number points to a dead pixel location, the register is not updated.

4.8 Dead Pixel Correction

Dead pixels may occur on the sensor array. During the production process, the locations of dead pixels are stored in a table. The camera does not use dead pixel. Their values are not used for any calculations. They cannot be used for temperature tracking.

The number of defective pixels of the individual sensor can be read from the 'Dead Pixel Count' field in the 'CONTROL3' register.

The positions of the dead pixel are stored in the register list 'DEAD_PIX_ADDR_xx'.

The camera module features an automatic dead pixel correction. The dead pixel correction uses the temperatures of suitable neighboring pixels to interpolate the temperature of the defective pixel.

The dead pixel correction can be enabled with the 'Enable Dead Pixel Correction' bit of the register 'CONTROL3'.

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x04– CONTROL3						
12:8	Dead Pixel Count	Number of defect pixels given from the sensor. Refer to sensor datasheet	-	N	0...24	R
13	Enable Dead Pixel Correction	Enable/ Disable Dead Pixel Correction. 0 = Disable Dead Pixel Correction 1 = Enable Dead Pixel Correction	-	Y	0,1	R/W
0x4A – DEAD_PIX_ADDR_00						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 00	-	N	0...65535	R
0x4B – DEAD_PIX_ADDR_01						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 01	-	N	0...65535	R
0x4C – DEAD_PIX_ADDR_02						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 02	-	N	0...65535	R
0x4D – DEAD_PIX_ADDR_03						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 03	-	N	0...65535	R
0x4E – DEAD_PIX_ADDR_04						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 04	-	N	0...65535	R

Table 26: Dead Pixel Address Map

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x4F – DEAD_PIX_ADDR_05						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 05	-	N	0...65535	R
0x50 – DEAD_PIX_ADDR_06						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 06	-	N	0...65535	R
0x51 – DEAD_PIX_ADDR_07						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 07	-	N	0...65535	R
0x52 – DEAD_PIX_ADDR_08						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 08	-	N	0...65535	R
0x53 – DEAD_PIX_ADDR_09						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 09	-	N	0...65535	R
0x54 – DEAD_PIX_ADDR_10						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 10	-	N	0...65535	R
0x55 – DEAD_PIX_ADDR_11						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 11	-	N	0...65535	R
0x56 – DEAD_PIX_ADDR_12						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 12	-	N	0...65535	R
0x57 – DEAD_PIX_ADDR_13						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 13	-	N	0...65535	R
0x58 – DEAD_PIX_ADDR_14						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 14	-	N	0...65535	R
0x59 – DEAD_PIX_ADDR_15						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 15	-	N	0...65535	R
0x5A – DEAD_PIX_ADDR_16						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 16	-	N	0...65535	R
0x5B – DEAD_PIX_ADDR_17						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 17	-	N	0...65535	R

Table 26: Dead Pixel Address Map (continued)

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x5C – DEAD_PIX_ADDR_18						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 18	-	N	0...65535	R
0x5D – DEAD_PIX_ADDR_19						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 19	-	N	0...65535	R
0x5E – DEAD_PIX_ADDR_20						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 20	-	N	0...65535	R
0x5F – DEAD_PIX_ADDR_21						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 21	-	N	0...65535	R
0x60 – DEAD_PIX_ADDR_22						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 22	-	N	0...65535	R
0x61 – DEAD_PIX_ADDR_23						
15:0	Dead Pixel Address	Contains the pixel number of Dead Pixel No. 23	-	N	0...65535	R

Table 26: Dead Pixel Address Map (continued)

Note:
The definition of a dead pixel can be found in the sensor datasheet.

4.9 Noise Reduction

The camera modules VM-050 and VM-051 feature different types of noise reducing filters. They are distinguished between time-variant and location-variant noise reduction. Both can be combined individually.

4.9.1 Time-variant Noise Reduction

The camera modules feature an effecive noise reduction which uses a moving average algorithm in the time domain on each individual pixel.

The noise reduction can be configured by the 'Average Mode' field located in the register 'CONTROL6' in 3 intensities:

- 0: noise reduction off
- 1: weak noise reduction (2 frames used)
- 2: medium noise reduction (3 frames used)
- 3: strong noise reduction (4 frames used)

Applying this filter reduces noise very well and causes no blurring at all. Moving objects can experience motion blur depending on intensity of the filter and the object's speed.

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x07– CONTROL6						
8:9	Average Mode	To reduce noise in the image, averaging of several images can be enabled. A moving average algorithm is used to get the fastest response time of the image. 0 = Disable average 1 = Weak average (2 images used) 2 = Medium average (3 images used) 3 = Strong average (4 images used)	1	Y	0...3	R/W

Table 27: Noise Filter Settings (Averaging)

4.9.2 Location-variant Noise Reduction

For further noise reduction, various filters are available that include the value of neighboring pixels in the calculation. A 3x3 area matrix is used for this. These filters can be addressed via 'Filter'-Bit in the 'CONTROL6'-register. Four filters are available: Box-Blur-Filter, Binominal-Filter, Gaussian-Filter and Median-Filter. All filters calculations are processed in parallel to the image acquisition. Therefore, the application of these filters only have a small effect on the frame rate.

- Box-Blur-Filter: Adds all values of the 3x3 neighboring pixels and calculates the arithmetic mean. All values are weighted equally. This will smooth out the image but blur on edges will occur.

  Box-Blur-Coefficients: $\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$

- Binominal-Filter: Works like the Box-Blur filter, but in contrast the weights differ on each position. The center pixel is weighted four-times, the edging pixels are weighted twice and corner pixels are weighted once. The smoothing is still in effect but blur is less severe.

  Binominal coefficients: $\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$

- Gaussian-Filter: The Gaussian-Filter weights are adjusted to the Gaussian curve with the center pixel matching the maximum value and other pixels, depending on their distance to the center, are symmetrically less weighted.

Compute Gaussian-Coefficients: $k(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$

Sigma: $\sigma = \sqrt{\frac{2}{\pi}} \approx 0.79788456$

Binominal and Gaussian-Filters normalize their output values so that the results match the original value range. This is carried out by dividing by the sum of the used weights.

i.e.: Binominal Dilter: $h(x, y) = \frac{1}{16}\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$

- Median-Filter: The Median-Filter sorts surrounding pixels by their temperature value and merely outputs the center (=median) value of the sorted list. This filter does not blur the picture but still reduces noise effectively. Due to the amount of lists to sort this, the filter slightly slows down the frame rate of the VM-051 camera module.

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x07– CONTROL6						
3:0	Filter	Different filters while processing a block to reduce noise in the image. 0 = Disable Filter 2 = Box-Blur 4 = Binominal 6 = Gaussian 8 = Median Gaussian filter comes with a constant sigma of √(2/π) = ~ 0.79788456	6	Y	0...8	R/W

Table 28: Noise Filter Settings (Location-variant)

4.10 Image Cropping / Region of Interest

The size of the temperature image (row and line count) can be reduced. This decreases the amount of pixels that are output by the sensor and only a certain region of the thermal sensor array is used. This can be helpful, if only a part of the image is interesting (ROI, Region of Interest).

The number of pixels in a line (image width) and the number of lines in an image (image heigth) can be defined independently.

The position of this rectangular field can be moved within the sensor array's borders by defining the position of the upper left corner of the ROI (horziontal and vertical offset):

RES_X : Number of Pixels in a row (horzizontal image size)
RES_Y : Number of lines per frame (vertical image size)
OFFSET_X : Horizontal displacement of the upper left corner of the ROI
OFFSET_Y : Vertical displacement of the upper left corner of the ROI

The offset is in relation to the upper left corner of the image sensor array.

Settings must respect the following restictions:

RES_X + OFFSET_X ≤ Sensor_Width
RES_Y + OFFSET_Y ≤ Sensor_Heigth

for VM-050:
Sensor_Width = 32
Sensor_Heigth = 32

for VM-051:
Sensor_Width = 80
Sensor_Heigth = 64

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x10 – RES_X						
15:0	Sensor X-Resolution	Number of pixels in a row to be output	32 / 80	Y	1...32 / 80	R/W
0x11 – OFFSET_X						
15:0	Sensor X-Offset	Position of first pixel in a row to be output relative to upper left corner of the sensor array	0	Y	0...31 / 79	R/W

Table 29: Cropping Registers

Bit	Field Name	Bit Description	Default Value (Dec)	Shdw	Range (Dec)	Read/ Write
0x12 – RES_Y						
15:0	Sensor Y-Resolution	Number of lines to be output. If is set to 34 (HTPA32x32d) or 66 (HTPA80x64d) the camera adds two additional rows to each frame that contain information about the current image. Only available at full X-resolution.	32 / 64	Y	1…32, 34 / 64, 66	R/W
0x13 – OFFSET_Y						
15:0	Sensor Y-Offset	Position of first line to be output relative to upper left corner of the sensor array	0	Y	0…31 / 63	R/W

Table 29: Cropping Registers (continued)

Note:
If the total number of active pixels and the offset in horizontal or verical direction exceeds the array size, the camera module will use the closest valid value.

This might lead to inconsistency between the pixel count output by the camera module and the pixel count expected by the CPU interface. Typically, this results in a disturbed image.

It is recommended that the value sets are checked before they are written to the registers.

If the field size is set to 32x34 (HxV) for VM-050 or 80 x 66 (HxV)for VM-051, the Embedded Information lines are activated (see *Section 4.11*).

This means that cropping / ROI cannot be used together with the Embedded Information function.

4.11 Embedded Data

In order to process the pixel data from the thermal camera – for example to transform the received image data back to temperature values - certain information like factors are needed. Other information might be helpful to efficiently perform certain tasks in an application (for example the contents of the Temperature Tracking registers).

All of this data can be obtained by read access to the corresponding registers.

However, a more convenient way in many applications is to obtain this data automatically with every captured frame, especially with parameters that can change from one frame to the next. It is very helpful to have the parameters stored within the image so that there is no need to keep track of the temporal correlation of two data streams.
Because the data is stored within the thermal image, this feature is called Embedded Data.
If this feature is activated, two extra lines are added to each image in order to transmit the

additional information within each image frame.

The embedded data is coded as 8 bits wide, regardless of the data format set for the pixel data. This means that a register, which is 16 bits wide, is transmitted in 2 x 8 bits (or in other words coded in two pixels). The data is transferred with the most significant byte first.

In case the data format is larger than 8 bits, the least significant bits (LSBs) of each data word are zero (0).

Embedded Data is activated by the image size settings. The data is added to the pixel data stream automatically, when the image size is set to a certain, fixed size:

VM-050:

- 'RES_X': 32
- 'OFFSET_X': 0
- 'RES_Y': 34
- 'OFFSET_Y': 0

VM-051

- 'RES_X': 80
- 'OFFSET_X': 0
- 'RES_Y': 66
- 'OFFSET_Y': 0

Example:

The full resolution of the camera model VM-050 is 1024 pixels in a square array. This means that the registers 'RES_X' and 'RES_Y' are both set to 32 and the registers 'OFFSET_X' and 'OFFSET_Y' are set to 0.

To enable the Embedded Data mode, a value of 34 has to be written to 'RES_Y' in this configuration. The camera module will then start with the next frame to output images with 34 lines (1088 pixels total).

The lines 33 and 34 do not contain pixel data but the binary encoded embedded informations as shown in the table below.

Note:
To display and process the thermal image, PHYTEC recomends splitting the data array received into an image section (lines 1…32) and a embedded data section (lines 33 and 34). Only the image section should be displayed or processed by imaging algorithms.

Embedded Data is activated only if RES_X is set to maximum horizontal resolution and RES_Y is set to the maximum vertical resolution +2.
OFFSET_X and OFFSET_Y must be set to 0.

4.11.1 Embedded Data Content

Pixel No. (VM-050)	Pixel No. (VM-051)	Register / Function
0 / 1	0 / 1	TEMP_MIN (MSB / LSB)
2 / 3	2 / 3	TEMP_MAX (MSB / LSB)
4 / 5	4 / 5	TEMP_MEAN (MSB / LSB)
6 / 7	6 / 7	TEMP_CENTER (MSB / LSB)
8 / 9	8 / 9	TRACK_TEMP0 (MSB / LSB)
10 / 11	10 / 11	TRACK_TEMP1 (MSB / LSB)
12 / 13	12 / 13	TRACK_TEMP2 (MSB / LSB)
14 / 15	14 / 15	TRACK_TEMP3 (MSB / LSB)
16	16	'Overflow Flag' of Register 'OUTPUT_CONTROL'
17	17	'Tracking Flag' of all 'TRACK_TEMPx_CONF' registers
18 / 19	18 / 19	TEMP_WINDOW_SCALE_FACTOR1 (MSB / LSB)
20 / 21	20 / 21	TEMP_WINDOW_SCALE_FACTOR2 (MSB / LSB)
22 / 23	22 / 23	TEMP_WINDOW_MIN (MSB / LSB)
24 / 25	24 / 25	TEMP_WINDOW_MAX (MSB / LSB)
26 – 63	26 – 159	Reserved

Table 30: Embedded Data Content

4.11.2 Dataline Assignment

Bit	Dataline
0	CAM_DD2
1	CAM_DD3
2	CAM_DD4
3	CAM_DD5
4	CAM_DD6
5	CAM_DD7
6	CAM_DD8
7	CAM_DD9

Table 31: Dataline Assignment for Embedded Data

Revision History

Rev.No.	Changes	Author	Date
0	Pre-release	H. Schwär	18.04.2017
1	Preliminary	H. Schwär	28.04.2017
2	Release	H.Schwär	03.11.2017
3	0: New feature ‚Overflow Flag' added	H. Schwär	15.11.2017
4	4.9: Chapter reorganization 4.9.1: New feature ‚Filter' added Figure 17: Figure corrected	A. Pitsch	26.02.2018
5	Aktualisierung der Abschnitte 3.1.2, 3.1.3, 3.2.2, 3.2.3 Wegen neuer Sensorrevision des Herstellers	H. Schwär	21.03.2019

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