

**MERIDIAN**  
**Innovation**

# **Meridian Innovation MI48Ex Thermal Image Processor for MI16xx (Panther Senxor)**

**Data sheet 1.0.1**

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**Version 4.6.35 – Dec 2024**

**Firmware compatibility: 4.6.35 or higher**

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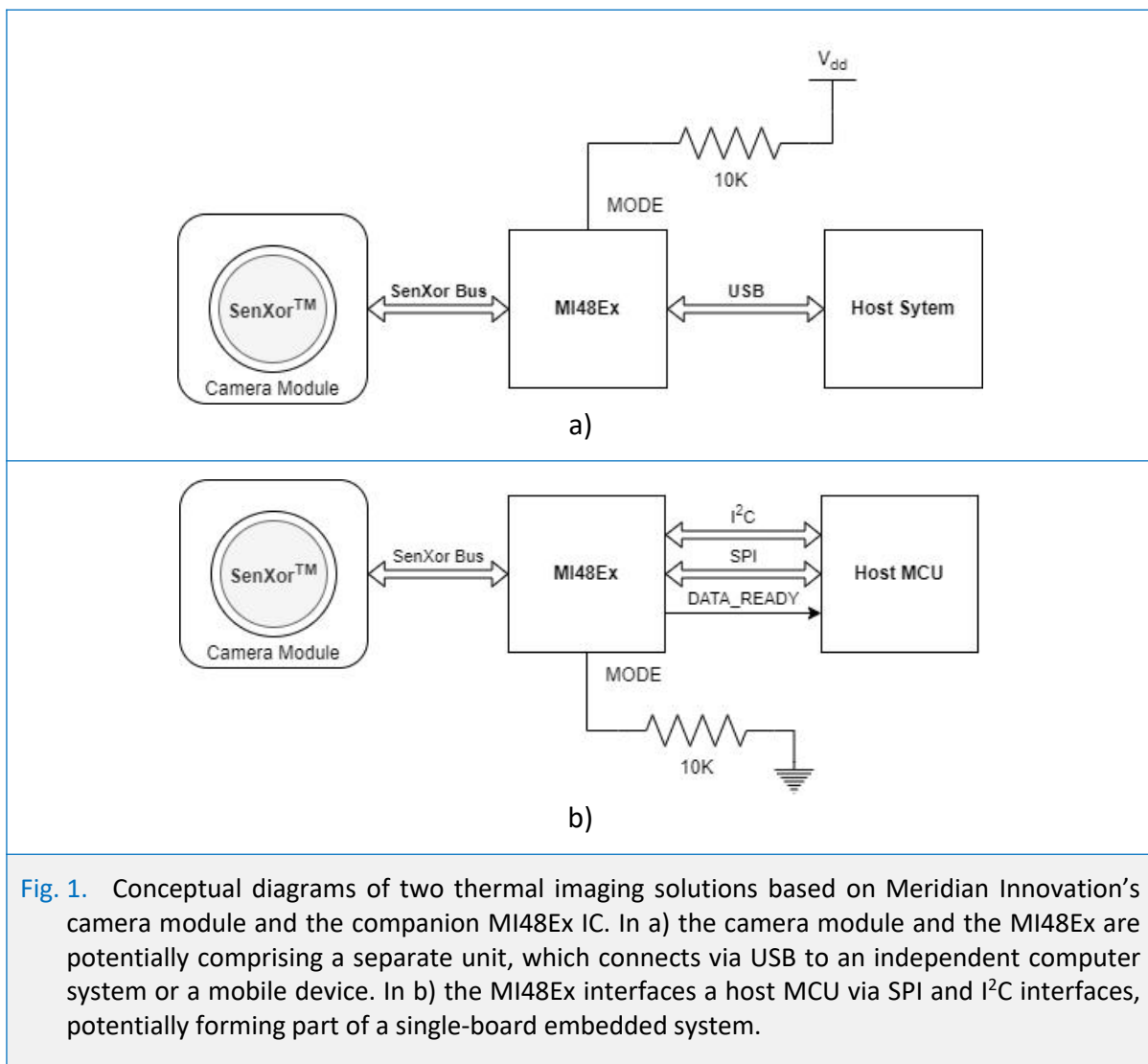
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## 1. DESCRIPTION

Meridian Innovation's MI48Ex is a specialised integrated circuit (IC) that is a companion to the MI16XX camera module featuring SenXor™ long-wave infrared (LWIR) imaging sensor. The MI48Ex handles the low-level control signalling necessary to capture raw sensor data from the thermal imaging array. It also provides standard interfaces for communication with a host controller.

The MI48Ex supports two different interfaces to the host system. One way to interface the host MCU is by the Inter-Integrated Circuit (I<sup>2</sup>C) bus – for conveying commands to the MI48Ex and obtaining status from it, and serial peripheral interface (SPI) – for readout of thermal data. The alternative way is to interface the MI48Ex is by USB interface for communicating both control/status and thermal data. The communication protocol that must be used by the host application layer to exchange command-acknowledge type of messages is specified elsewhere.

Fig. 1 shows conceptual diagrams of systems that embed the SenXor™ camera module and the MI48Ex with I<sup>2</sup>C and SPI interfaces, or alternatively, with USB interface.



**Fig. 1.** Conceptual diagrams of two thermal imaging solutions based on Meridian Innovation's camera module and the companion MI48Ex IC. In a) the camera module and the MI48Ex are potentially comprising a separate unit, which connects via USB to an independent computer system or a mobile device. In b) the MI48Ex interfaces a host MCU via SPI and I<sup>2</sup>C interfaces, potentially forming part of a single-board embedded system.

The MI48Ex also performs low-level processing of the data read out from the camera modules. Specifically, it handles the per-pixel calibration, performs bad pixel correction (BPC), converts the raw camera data to temperature, and suppresses the noise inherent to the signals coming from the pixels. In this way it greatly facilitates the development of applications embedding the SenXor™ thermal imaging sensor.

The MI48Ex is housed in a 7 mm by 7 mm, 64-pin leadless package low profile quad flat no-lead LQFP64.

## 2. ORDER INFORMATION

TABLE 1. ORDERING INFORMATION

Product Code	Package	Max FPS	Firmware Version	Interface	Min. Quantity
MI48E4	LQFP64 (plastic, low profile quad flat package, 64 terminals; 0.4 mm pitch; 7 mm x 7 mm x 1.4 mm body)	25 FPS	4.6.35 or higher	SPI/I <sup>2</sup> C and USB	100

### 3. PINOUT INFORMATION

#### 3.1. MI48Ex (LQFP64)

##### 3.1.1. Pin Configuration – MI48Ex (LQFP64)

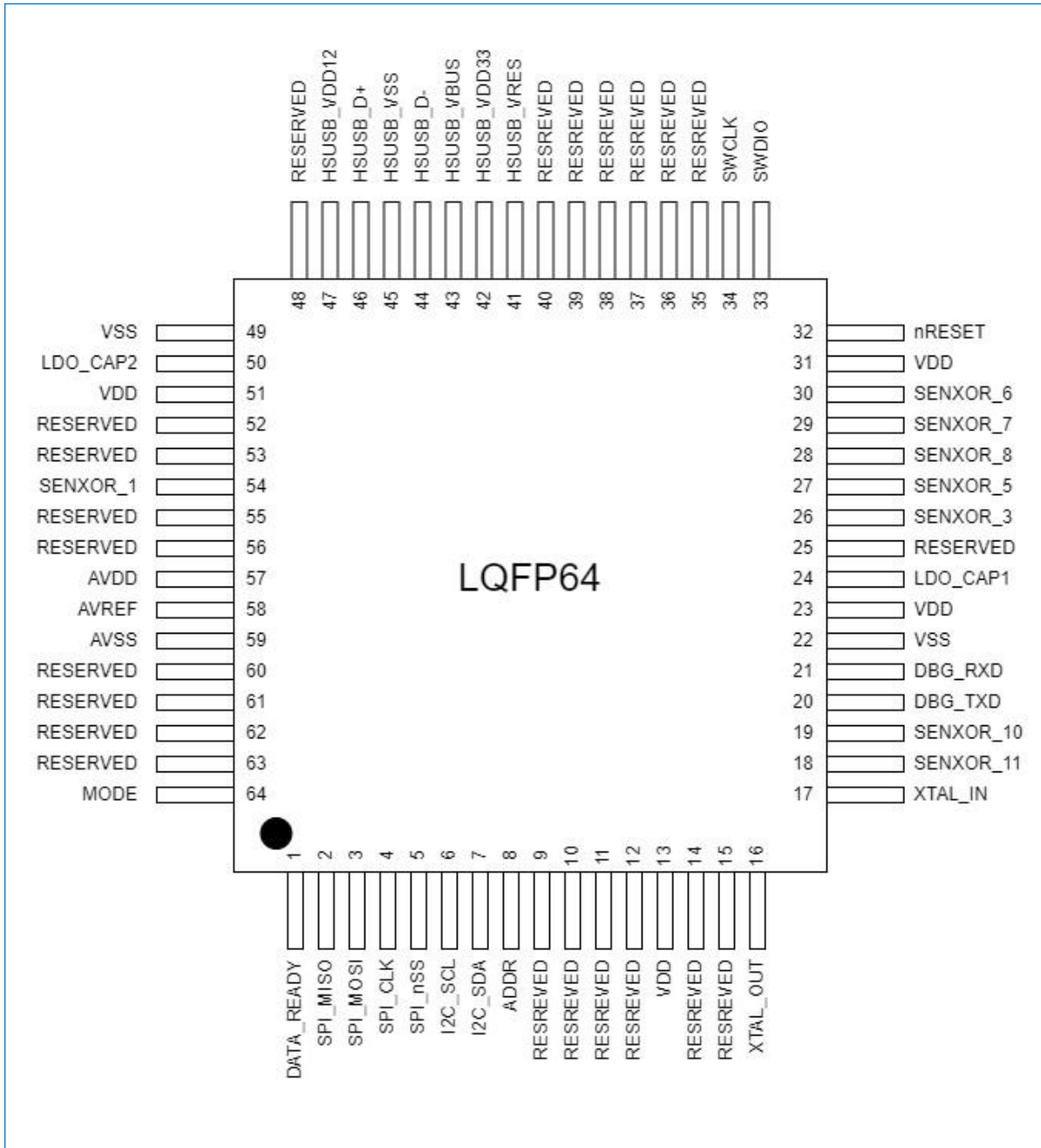


Fig. 2. MI48Ex LQFP64-pin Diagram. The pinout features both USB and SPI/I<sup>2</sup>C interfaces, only one of them must be configured for operation.

### 3.1.2. Pin Description

**TABLE 2. PIN DESCRIPTION OF MI48Ex<sup>1)</sup>**

PIN NO.	PIN NAME	TYPE	DESCRIPTION
1	DATA_READY	O	Data Ready output, active high.
2	SPI_MISO	O	Master Input Slave Output of the SPI bus.
3	SPI_MOSI	I	Master Output Slave Input of the SPI bus.
4	SPI_CLK	I	Serial Clock of the SPI bus.
5	SPI_nSS	I	Slave Select of the SPI bus.
6	I2C_SCL	I	Clock line of the I <sup>2</sup> C bus.
7	I2C_SDA	I/O	Data line of the I <sup>2</sup> C bus.
8	ADDR	I	I <sup>2</sup> C chip address select.
9	RESERVED	-	Reserved pin. Do not connect.
10	RESERVED	-	Reserved pin. Do not connect.
11	RESERVED	-	Reserved pin. Do not connect.
12	RESERVED	-	Reserved pin. Do not connect.
13	VDD	P	Power supply. Nominal 3.3 V.
14	RESERVED	-	Reserved pin. Do not connect.
15	RESERVED	-	Reserved pin. Do not connect.
16	XTAL_OUT	O	External 12MHz crystal output. Connect through a 18pF capacitor to ground, or as recommended for the specific external crystal in use.
17	XTAL_IN	I	External 12MHz crystal input. Connect through a 18pF capacitor to ground, or as recommended for the specific external crystal in use.
18	SENXOR_11	I	SenXor Bus. Connect directly to camera module pin: SENXOR_11 (DATA_AV).
19	SENXOR_10	O	SenXor Bus. Connect directly to camera module pin: SENXOR_10 (SSFLASHN).
20	DBG_TXD	O	UART TXD for output debug message, can be left NOT Connect if not use.
21	DBG_RXD	I	UART RXD for input debug message, can be left NOT Connect if not use.
22	VSS	P	Ground.
23	VDD	P	Power supply. Nominal 3.3 V.
24	LDO_CAP1	A	Internal LDO output pin. Connect through a 2.2uF capacitor to ground.
25	RESERVED	-	Reserved pin. Do not connect.
26	SENXOR_3	O	SenXor Bus. Connect directly to camera module pin: SENXOR_3 (RESET_N).
27	SENXOR_5	O	SenXor Bus. Connect directly to camera module pin: SENXOR_5 (SSN).
28	SENXOR_8	O	SenXor Bus. Connect directly to camera module pin: SENXOR_8 (SCK).
29	SENXOR_7	I	SenXor Bus. Connect directly to camera module pin: SENXOR_7 (MISO).
30	SENXOR_6	O	SenXor Bus. Connect directly to camera module pin: SENXOR_6 (MOSI).
31	VDDIO	P	Power supply. Nominal 3.3 V. Connect through a 1.0uF capacitor to ground.
32	nRESET	I	Active low hardware reset.
33	SWDIO	I/O	Firmware Upgrade or Debug Pins
34	SWCLK	I/O	Firmware Upgrade or Debug Pins
35	RESERVED	-	Reserved pin. Do not connect.

36	RESERVED	-	Reserved pin. Do not connect.
37	RESERVED	-	Reserved pin. Do not connect.
38	RESERVED	-	Reserved pin. Do not connect.
39	RESERVED	-	Reserved pin. Do not connect.
40	RESERVED	-	Reserved pin. Do not connect.
41	HSUSB_VRES	A	HSUSB reference resistor, connect to VSS via a 200Ω resistor.
42	HSUSB_VDD33	P	Power supply. Nominal 3.3 V, connects to VDD
43	HSUSB_VBUS	I	Power supply from USB host, connects to 5V VBUS of USB
44	HSUSB_D-	A	HS USB Data –.
45	HSUSB_VSS	P	Ground, connects to VSS.
46	HSUSB_D+	A	HS USB Data +.
47	HSUSB_VDD12_CAP	A	Internal USB LDO pin. Connect through a 1.0uF capacitor to ground.
48	RESERVED	-	Reserved pin. Do not connect.
49	VSS	P	Ground.
50	LDO_CAP2	A	Internal LDO output pin. Connect through a 2.2uF capacitor to ground.
51	VDD	P	Power supply. Nominal 3.3 V.
52	RESERVED	-	Reserved pin. Do not connect.
53	RESERVED	-	Reserved pin. Do not connect.
54	SENXOR_1	O	SenXor Bus. Connect directly to camera module pin: SENXOR_1 (SYSCLK).
55	RESERVED	-	Reserved pin. Do not connect.
56	RESERVED	-	Reserved pin. Do not connect.
57	AVDD	P	Power supply. Nominal 3.3 V, connects to VDD.
58	AVREF	A	Power supply. Nominal 3.3 V, connects to VDD
59	AVSS	P	Ground, connects to VSS.
60	RESERVED	-	Reserved pin. Do not connect.
61	RESERVED	-	Reserved pin. Do not connect.
62	RESERVED	-	Reserved pin. Do not connect.
63	RESERVED	-	Reserved pin. Do not connect.
64	MODE	I	Host Interface Mode Select, sensed during active low reset: Pull up (via 10kΩ resistor) – select USB interface Pull down (via 10kΩ resistor) – select SPI/I <sup>2</sup> C interface.

<sup>1)</sup> The term ‘camera module’ in Table 2 and Table 3 refers to the MI16XXX camera module.

### 3.1.3. Special Pin Handling

**TABLE 3. PIN TERMINATION – MI48EX**

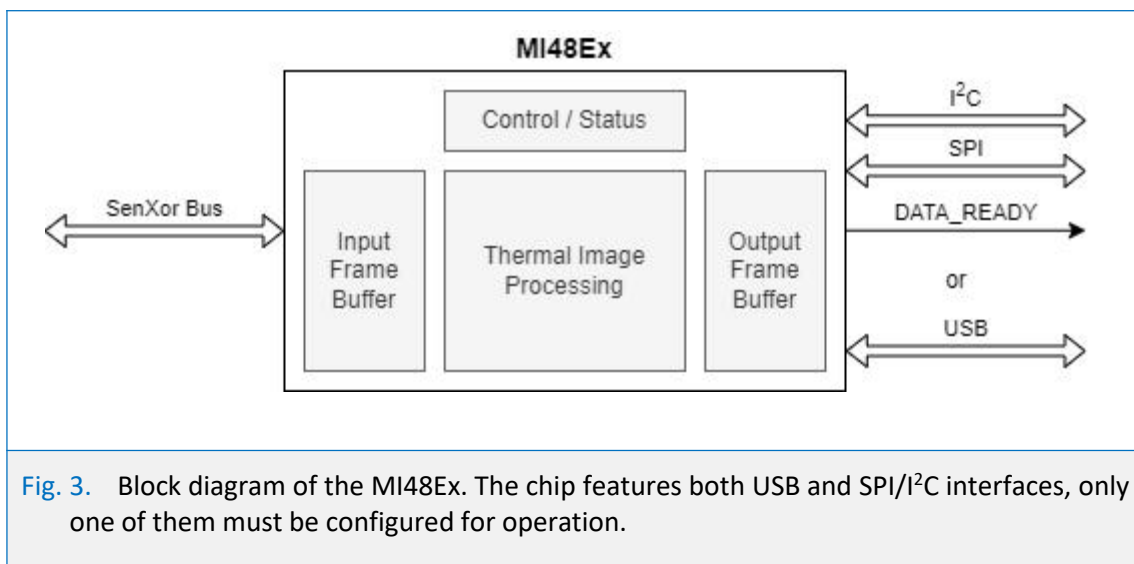
Pin No	Pin Name	Termination	Value
1	DATA_READY	Pull down	10 kΩ
6	I2C_SCL	Pull up	4.7 kΩ
7	I2C_SDA	Pull up	4.7 kΩ
24	LDO_CAP1	Connect to capacitor	2.2uF

31	VDDIO	Connect to capacitor	1.0uF
32	nRESET	Pull up resistor, plus a pull down capacitor to drive the line low during power up	10 kΩ, 10 μF
41	HSUSB_VRES	Connect to resistor to VSS	200Ω
47	HSUSB_VDD12_CAP	Connect to capacitor	1.0uF
50	LDO_CAP2	Connect to capacitor	2.2uF
64	MODE	Pull down or pull up	10 kΩ 10 kΩ

## 4. FUNCTIONAL DESCRIPTION

### 4.1. Architectural Overview

Fig. 3 shows the internal block diagram of the MI48Ex and the interfaces that enable the control of acquisition and readout of thermal data.



#### 4.1.1. SenXor Bus Interface

The SenXor Bus interface serves for capturing raw data from the thermal image sensor.

#### 4.1.2. I<sup>2</sup>C Bus Interface

In the MI48Ex the slave I<sup>2</sup>C interface provides software access to the internal registers of the Control and Status block of the MI48Ex.

#### 4.1.3. SPI Interface

In MI48Ex, the slave SPI interface serves to read out a temperature data frame from the Output Frame Buffer, indicated by DATA\_READY output signal, as shown in Fig. 3.

#### 4.1.4. USB Interface

In the MI48Ex the USB interface serves for conveying both control and status information, as well as readout of the temperature data from the Output Frame Buffer. The communication via USB relies on a specific protocol which must be implemented at the application layer of the host system; The reference manual can be found on Meridian Innovation's website.

#### 4.1.5. Data Frame Buffers and Thermal Image Processing

The Input and Output Frame Buffers allow the dynamics of thermal data capturing via the SenXor Bus to be decoupled from the dynamics of thermal data readout via the SPI interface, and to realise data frame averaging of software-controlled depth as an elementary noise reduction technique. The low-level Thermal Image Processing applies per-pixel calibration and bad pixel correction based on calibration data stored in the camera module and translates the raw sensor data to temperature in degrees Kelvin. Further noise reduction can be programmatically enabled to reduce the fluctuations in the temperature readout of individual pixels, which leads to a more stable readout and allows for an enhanced image upon visualisation of the thermal data.

## 4.2. MI48Ex Register Map

The MI48xx has several software-accessible registers that allow the control of thermal image capture and readout, the establishment of a power-down state, as well as obtaining relevant status information from the camera module and the MI48Ex itself.

The registers are summarized in Table 4 and are accessible via the I<sup>2</sup>C or USB interface. Refer to section 4.4 I<sup>2</sup>C Bus Interface for details on I<sup>2</sup>C access. Refer to [USB Interface Communication Protocol document](#) for USB access.

**TABLE 4. REGISTER MAP**

Register Name	Address	Access Type	Description
MCU_RESET	0x00	W	Software Reset of the MI48
HOST_XFER_CTRL	0x01	RW	Host DMA transfer control
STARK_CTRL	0x20	RW	STARK denoising filter control
STARK_CUTOFF	0x21	RW	STARK filter cutoff
STARK_GRAD	0x22	RW	STARK filter gradient
STARK_SCALE	0x23	RW	STARK filter scale
MMS_CTRL	0x25	RW	Min/Max Stabilization control
MEDIAN_CTRL	0x30	RW	Median denoising filter control
FRAME_FORMAT	0X31	RW	Temperature units of output frame

<b>SENSOR_GAIN</b>	0xB9	RW	Module ADC gain control
<b>SENSOR_TYPE</b>	0xBA	R	SenXor chip type
<b>MODULE_TYPE</b>	0xBB	R	Module type (chip-lens combination)
<b>TEMP_CONVERT_CTRL</b>	0xBC	RW	Temperature Conversion Control
<b>SENSITIVITY_FACTOR</b>	0xC2	RW	Sensitivity correction factor
<b>SELF_CALIBRATION</b>	0XC5	RW	Self-Calibration of column offset
<b>EMISSIVITY</b>	0xCA	RW	Emissivity value for temperature conversion
<b>OFFSET_CORR</b>	0xCB	RW	Offset correction to the entire frame
<b>OBJECT_TEMP_FACTOR</b>	0XCD	RW	Object temperature factor
<b>SENSOR_ID</b>	0xE0 – 0xE6	R	Serial number of the attached camera module
<b>FILTER_CONTROL</b>	0xD0	RW	Temporal domain denoising filter control
<b>FILTER_SETTING_1</b>	0xD1 – 0xD2	RW	Parameters for the temporal filter
<b>USER_FLASH_CTRL</b>	0xD8	RW	Enable/Disable host access to User Flash

### 4.3. Detailed Register Description

**TABLE 5. MCU\_RESET (0x00)**

Addr	0x00	Reset Value	0x00
Bits	Field Name	Access	Description
0	SW_RESET	W	Reset the MI48 by setting this bit to 1
1-7	Reserved	-	Not Accessible

**TABLE 6. HOST\_XFER\_CTRL (0x01)**

Addr	0x01	Reset Value	0x0
Bits	Field Name	Access	Description
0	DMA_TIMEOUT_ENABLE	RW	For SPI interface only. Enable DMA timeout monitoring for the SPI transfer. The value of timeout is determined by the TIMEOUT_PERIOD below.
1-2	TIMEOUT_PERIOD	RW	The value selects the timeout period as follows, in conjunction when bit 0 is set to 1: 0 – 500 ms 1 – 1000 ms 2 – 2000 ms 3 – 100 ms (default)
3	STOP_HOST_XFER	RW	For SPI interface only. For the host to reset the SPI transfer between the host and the MI48. Stop and reset host SPI DMA by setting to 1. This bit is self-cleared when the reset is complete.
4-7	Reserved	-	Not Accessible

The HOST\_XFER\_CTRL register can be used to set a timeout period of a timer to monitor the SPI transfer from the MI48 to the host. The timer is started when the MI48 drives the DATA\_READY signal high to notify the host to start the SPI transfer.

The host then starts the transfer by driving the SPI\_SS signal, driving the SPI\_CLK and sampling (read) the data on the SPI\_MISO signal driven by the MI48.

As the MI48 is an SPI slave and it has is no way to check the integrity of the data received at the host. The host has to implement CRC checking on the data received and drop the frame if the CRC of the data does not match the CRC value in the header.

If the SPI transfer is not completed when the timer expires (the timer expire period can be set to 100ms, 500ms, 1000ms or 2000ms, default at 100ms), the MI48 assumes the transmission is not successful and a reset to the SPI and DMA controller in the MI48 is performed. The same reset to SPI and DMA controller can be performed by setting the STOP\_HOST\_XFER in the HOST\_XFER\_CTRL register by the host.

**TABLE 7. STARK\_CTRL (0x20)**

Addr.	0x20	Reset Value	0x00
Bits	Field Name	Access	Description
0	STARK_ENABLE	RW	Enable STARK denoising filter (Spatio-temporal advanced rolling kernel). Preserves features

			without significant historical artefacts. Optimal filter for quasi-static scenes. However, for dynamic scene, the changing part of the scene will have noise penetration (which perceptually may be confused with motion blur/ghosting).
1-3	STARK TYPE	RW	000: Quick Stark (Lowest processing overhead) 001: StarkV1 (Auto, same as old Stark implementation) 010: StarkV2 011: StarkV1 Background Smooth (same as old Stark BG smooth implementation) 100: Full Stark (Higher process overhead) 101-111: Quick Stark
4	SPATIAL_KERNEL	RW	Kernel size for operations in spatial domain: 0 – 3x3 pixels (default) 1 – 5x5 pixels (lower noise, but there is some feature erosion and FPS drops for small FPS_DIVISOR of 1 to 3), significantly
5-7	RESERVED	-	Not accessible

**TABLE 8. STARK\_CUTOFF (0x21)**

Addr.	Field Name	Reset Value	Description
0x21		0x0A (decimal 10)	
Bits	Field Name	Access	Description
0-6	STARK_CUTOFF	RW	Noise suppression cutoff in units of dK. The higher the value, the better the noise suppression, except during change scene change.
7	Reserved	-	Not Accessible

**TABLE 9. STARK\_GRAD (0x22)**

Addr.	Field Name	Reset Value	Description
0x22		0x0A (decimal 10)	
Bits	Field Name	Access	Description
0-7	STARK_GRADIENT	RW	Unitless value that influences the steepness of filter output transition upon scene change. A higher value leads to more rapid transition, but also lowers the noise immunity of the output from the filter.

**TABLE 10. STARK\_SCALE (0x23)**

Addr.	Field Name	Reset Value	Description
0x23		0x50 (decimal 80)	

Bits	Field Name	Access	Description
0-7	STARK_SCALE	RW	Percentage of the input change that is ever allowed to reach the output during change.

**TABLE 11. MMS\_CTRL (0x25)**

Addr.	0x25	Reset Value	0x00
Bits	Field Name	Access	Description
0	KXMS	RW	KXMS is short for k-extrema median stabilization, which is turned ON when this flag is set to 1 (default). It operates on a per-frame basis, and thus has an instantaneous response to a dynamic scene. However, it is computationally more expensive and may lead to noticeable FPS drop for small values of FPS_DIVISOR. Disabled if this bit is cleared.
1	RA	RW	Min/Max stabilization based on a rolling average of FPS_DIVISOR-dependent depth, providing ~500 ms response time upon a change in scene range, is enabled if this bit is set to 1. Cleared (disabled) by default.

MMS is short for minimum and maximum stabilization. It realises elimination of extreme values (outliers) that are much lower than the true minimum or much higher than the true maximum of the scene temperature. This enables to estimate a stable scene range (frame to frame) which adapts rapidly if there is a genuine change in the scene. The outliers are eliminated from the frame data and replaced with the established stable minimum and maximum values. These values are readily obtained in the frame header too. This is advantageous for host image processing, especially for direct colour mapping, or other algorithms which require the knowledge of the scene temperature range at the onset of frame processing. The two available techniques – KXMS and RA – can be applied simultaneously for maximum effect, particularly at high FPS.

**TABLE 12. MEDIAN\_CTRL (0x30)**

Addr.	0x30	Reset Value	0x00
Bits	Field Name	Access	Description
0	MEDIAN_ENABLE	RW	Enable Median denoising filter operating in the spatial domain. This is a standard image processing filter, on a per-frame basis. It is great at removing very localised noise at the expense of computational cost (FPS drop) and erosion of small image features.
1	KERNEL_SIZE	RW	Sets the desired kernel size of the median filter:

			0 – 3x3 pixels (default) 1 – 5x5 pixels.
--	--	--	---

**TABLE 13. FRAME\_FORMAT (0x31)**

Addr.	0x31	Reset Value	0x00 (deci-Kelvin, 16-bit unsigned)																												
Bits	Field Name	Access	Description																												
0-2	TEMP_UNITS	RW	<p>These 3 bits select the temperature units of the frame output, and of the temperature items in the frame header. The supported units are deci-Kelvin [dK], Kelvin [K], Celsius [C] and Fahrenheit [F].</p> <p>The representation of the values can be unsigned integer, for [dK], two's complement, for [C] and [F], or half precision 16-bit floating point, for [K], [C], and [F].</p> <table border="1"> <thead> <tr> <th>TEMP_UNITS</th> <th>Unit</th> <th>16-bit Representation</th> <th>Unit</th> </tr> </thead> <tbody> <tr> <td>0 (default)</td> <td>dK</td> <td>Fixed point unsigned integer</td> <td>1 dK</td> </tr> <tr> <td>1</td> <td>dC</td> <td>Fixed point two's complement</td> <td>0.1 °C</td> </tr> <tr> <td>2</td> <td>dF</td> <td>Fixed point two's complement</td> <td>0.1 °F</td> </tr> <tr> <td>4</td> <td>K</td> <td>half precision floating point</td> <td>1 K</td> </tr> <tr> <td>5</td> <td>C</td> <td>half precision floating point</td> <td>1 °C</td> </tr> <tr> <td>6</td> <td>F</td> <td>half precision floating point</td> <td>1 °F</td> </tr> </tbody> </table> <p>Note: for the die temperature reported in the frame header, the unit with fixed point setting is 1 cK, or 0.01K or 0.01 °C, or 0.01 °F, while for floating point the unit is 1K, 1 °C or 1 °F.</p>	TEMP_UNITS	Unit	16-bit Representation	Unit	0 (default)	dK	Fixed point unsigned integer	1 dK	1	dC	Fixed point two's complement	0.1 °C	2	dF	Fixed point two's complement	0.1 °F	4	K	half precision floating point	1 K	5	C	half precision floating point	1 °C	6	F	half precision floating point	1 °F
TEMP_UNITS	Unit	16-bit Representation	Unit																												
0 (default)	dK	Fixed point unsigned integer	1 dK																												
1	dC	Fixed point two's complement	0.1 °C																												
2	dF	Fixed point two's complement	0.1 °F																												
4	K	half precision floating point	1 K																												
5	C	half precision floating point	1 °C																												
6	F	half precision floating point	1 °F																												
3-7	Reserved	-	Not accessible																												

**TABLE 14. FRAME\_MODE (0xB1)**

Addr.	0xB1	Reset Value	0x20
Bits	Field Name	Access	Description
0	GET_SINGLE_FRAME	RW	<p>Setting this bit to 1 leads to the acquisition of a single frame.</p> <p>This bit is automatically reset to 0 after the acquisition of one frame.</p> <p>Note that writing 1 to this bit prior to it being auto-reset and prior to DATA_READY going high will restart the frame acquisition. DATA_READY will remain low until the data from the restarted acquisition is available</p>

			in the output buffer.
1	CONTINUOUS_STREAM	RW	Setting this bit to 1 instructs the MI48xx to operate in Continuous Capture Mode, whereby it continuously acquires data from the camera module and updates the readout buffer accessible through the SPI interface. Resetting this bit to 0 instructs the MI48xx to stop continuous data acquisition. This also resets to 0 the DATA_READY pin and the corresponding bit 4 of the STATUS register.
2-4	READOUT_MODE	RW	Configure the readout mode of the output frame buffer, accessible through the SPI interface. Currently only Full-Frame Readout Mode is implemented, where the host controller can read out the frame only when it is captured and processed in its entirety. Values: 0 – Full-Frame Readout Mode 1 to 7 – Reserved.
5	NO_HEADER	RW	Setting this bit to 1 eliminates the Header from the Thermal Data Frame transferred through the SPI interface. Resetting this bit to 0 includes the HEADER in the Thermal Data Frame, as shown in Section 4.6.
6-7	RESERVED	-	Not accessible.

**TABLE 15. FW\_VERSION\_1 (0xB2)**

<b>Addr.</b>	0xB2	<b>Reset Value</b>	As per FW Version
<b>Bits</b>	<b>Field Name</b>	<b>Access</b>	<b>Description</b>
0-3	MINOR	R	Minor Firmware Version Number
4-7	MAJOR	R	Major Firmware Version Number

**TABLE 16. FW\_VERSION\_2 (0xB3)**

<b>Addr.</b>	0xB3	<b>Reset Value</b>	As per FW Version
<b>Bits</b>	<b>Field Name</b>	<b>Access</b>	<b>Description</b>
0-7	BUILD	R	Firmware build number

The Firmware version is represented as MAJOR.MINOR.BUILD. The three numbers are stored in FW\_VERSION\_1 and FW\_VERSION\_2, as per Table 9 and Table 10 above.

**TABLE 17. FRAME\_RATE (0xB4)**

<b>Addr.</b>	0xB4	<b>Reset Value</b>	0x03
<b>Bits</b>	<b>Field Name</b>	<b>Access</b>	<b>Description</b>
0-6	FRAME_RATE_DIVIDER	RW	The value of these bits establishes the rate at which

			<p>the host controller can read out thermal data frame from the Output Frame Buffer through the SPI interface.</p> <p>The value must be an unsigned integer representing the frame rate divisor of the maximum frame rate, FPS_MAX, of the attached camera module: FPS = FPS_MAX / FRAME_RATE_DIVIDER. Exception is FRAME_RATE = 0, which yields FPS_MAX.</p>
7	RESERVED	-	Not Accessible

This register should not be used if the MI48Ex is configured for USB communication with the host MCU.

**TABLE 18. STATUS (0xB6)**

Addr.	0XB6	Reset Value	0x00
Bits	Field Name	Access	Description
0	RESERVED	-	Not accessible
1	READOUT_TOO_SLOW	R	<p>Reads 1 if the last frame was not readout within the time-period reciprocal to the maximum frame rate of the attached camera module. Relevant only in Continuous Capture Mode (see bit 1, CONTINUOUS_STREAM, of register FRAME_MODE, 0xB1).</p> <p>Reads 0 otherwise. Auto-reset upon read. Supported only in SPI/I<sup>2</sup>C mode.</p>
2	SENXOR_IF_ERROR	R	Reads 1 if an error was detected on the SenXor interface during power up of the MI48xx.
3	CAPTURE_ERROR	R	Communication error on the SenXor interface during thermal data capture.
4	DATA_READY	R	<p>This bit reflects the state of the DATA_READY pin and is intended to be polled by a system that cannot have a hardware connection to the DATA_READY pin. Note however, that when this bit is polled continuously without delay it might cause a drop in the data frame rate. Therefore, it is recommended to introduce a few milliseconds delay between successive polls.</p>
5	BOOTING_UP	R	<p>Reads 1 if the MI48xx is still booting up. Reads 0 after the MI48xx completes its boot up process. Once it reads zero, write to other registers is allowed, and frame capture can start.</p>

Note: If any of the error flags above is raised, the frame capture stops. Upon reading the register, all error flags are cleared.

**TABLE 19. SENXOR\_GAIN (0xB9)**

Addr.	0xB9	Reset Value	0x00 *Not Implement Yet*
Bits	Field Name	Access	Description
0-3	MODULE_GAIN	RW	<p>These bits define the common amplification of the signal generated by each pixel in the SenXor array. The increased amplification improves signal to noise ratio but at the same time limits the range of scene temperatures that can be reported. By default, the sensor module is set at its maximum gain, considered to have a value of 1. Alternatively, the gain may be lowered to 0.5 or 0.25 times the maximum gain, in order to increase the observed scene temperature, according to the following:</p> <ul style="list-style-type: none"> <li>0 – Default, maximum gain of 1.</li> <li>1 – AUTO -- Automatic gain selection (one of 1.0, 0.5, 0.25), depending on the detected dynamic range of the input signal</li> <li>2 – Quarter gain of 0.25</li> <li>3 – Half gain of 0.5</li> <li>4 – Maximum gain of 1.0</li> <li>5 to 15 – Reserved.</li> </ul> <p>If MODULE_GAIN is set to AUTO, then reading this register will return the currently selected value.</p>
4-7	RESERVED	-	Not accessible.

**TABLE 20. SENXOR\_TYPE (0xBA)**

Addr.	0xBA	Reset Value	As per the SenXor chip in the attached module
Bits	Field Name	Access	Description
0-7	SENXOR_TYPE	R	<ul style="list-style-type: none"> <li>1 = MI0801-xxx</li> <li>4 = MI0802-xxx Revision 1</li> <li>5 = MI0802-xxx Revision 2</li> <li>6 = MI16XX Revision 1</li> </ul>

**TABLE 21. MODULE\_TYPE (0xBB)**

Addr.	0xBB	Reset Value	As per attached camera module
Bits	Field Name	Access	Description
0-7	MODULE_TYPE	R	<p>Module type, defined by the combination of SenXor chip type and specific lens, according to Appendix I. The value of this register is typically pre-set during factory calibration of the module.</p>

			However, for self-calibrated modules, the user must write the correct value before initiating the self-calibration process.
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**TABLE 22. TEMP\_CONVERT\_CTRL (0xBC)**

Addr.	Field Name	Reset Value	Description
0xBC		0x00	0x00 (bits 4-7 depend on the select LUT)
Bits	Field Name	Access	Description
0	LUT Source	RW	Select LUT Source: 0: Module flash (default) 1: FW
1-2	LUT Selector	RW	Interpretation depends on the LUT Source as follows:  <b>If LUT Source is Module flash:</b> 0x00 – Default LUT, module type-/lens- specific Other values are Reserved  <b>If LUT Source is FW:</b> 0x00 – not lens-specific, applicable only to a uniform blackbody size that fully covers and extends beyond the full FOV of the sensor. 0x10 – Extended LUT, for MI0802-M5S only, supporting Extended Scene Range Other values are reserved
3	Reserved	-	Not accessible
4 – 7	LUT Version	R	Look-up-table version

**TABLE 23. SENSITIVITY\_FACTOR (0xC2)**

Addr.	Field Name	Reset Value	Description
0xC2			Read back from attached camera module and depends on its calibration.
Bits	Field Name	Access	Description
0-7	CORR_FACTOR	RW	Multiplicative factor to the temperature readout of every pixel, allowing correction of the sensitivity, e.g. when a protective filter is placed in front of the thermal camera lens.

**TABLE 24. SELF-CALIBRATION (0xC5)**

Addr.	Field Name	Reset Value	Description
0xC5		0x00	0x00 <b>*Not Implement Yet*</b>
Bits	Field Name	Access	Description
0	RESERVED	R	Not used
1	START_COLOFFS_CALIB	RW	Setting this bit to 1 initiates column offsets calibration. The bit is automatically set during power up and upon a change in MODULE_GAIN (either manual or automatic).

2	COLOFFS_CALIB_ON	R	After setting START_COLOFFS_CALIB to 1, COLOFFS_CALIB_ON bit reads 1 throughout the process of column offsets calibration. Once the process is complete, this bit read 0.
3	RESERVED	R	Not used
4	USE_SELF_CALIB	RW	If set to 1, the module will not use module-specific calibration data. It will use instead the data obtained during column offset calibration, and predefined generic data for the given chip and lens combination. NOTE: the user must write the correct value of MODULE_TYPE to register 0xBB, in order to achieve a reliable self-calibration operation. In any case, the use of self-calibration cannot be as good as the factory calibration, which is done for each individual module
5-7	SAMPLE_SIZE	RW	These bits define the number of frames acquired during column calibration, according to the formula: $(SAMPLE\_SIZE + 1) \times 100$ . That is a value of 0 results in 100 frames being acquired, and a value of 7 results in 800 frames being acquired.

**TABLE 25. EMISSIVITY(0xCA)**

Addr.	Field Name	Reset Value	Description
0xCA			Read back from attached camera module and depends on its calibration.
Bits	Field Name	Access	Description
0-7	EMISSIVITY	RW	Emissivity value (percent) to be used in the conversion of raw data captured from SenXor to the temperature data that is readout through the SPI interface. The reset value reflects the emissivity of the black body source used for factory calibration of the camera module. If the target object is known to have a different emissivity, programming the correct value will lead to an accurate readout of the absolute temperature.

**TABLE 26. OFFSET\_CORR (0xCB)**

Addr.	Field Name	Reset Value	Description
0xCB			Read back from attached camera module and depends on its calibration.
Bits	Field Name	Access	Description
0-7	OFFSET	RW	This register represents a temperature offset that will be added to every pixel in the data frame before it is sent out to the host system. The value is expressed in 2's complement notation (8-bit signed integer) in units of 0.1 K. This allows for fine tuning any bias in the temperature readout by as much as $\pm 12.7$ K with,

			<p>with 0.1 K increments.</p> <p>For example, to correct an apparent bias of 0.7 K, we must add <math>-0.7</math> K to the data frame, hence write 241 (0xF9) to 0xCB. Conversely, if the apparent offset is <math>-0.75</math> we must add 0.75 K, hence write 7 (0x07) to 0xCB. The following Python code may be used as a reference for calculating the OFFSET value (n, below):</p> <pre>def value_0xCB(observed_error, unit=0.1):     """Calculate necessary value of 0xCB     to correct for observed error"""     # the offset to be applied is of     # opposite sign to the error     n = - int(round(observed_error/unit))     if n &lt; 0:         return 256 - abs(n)     else:         return n</pre>
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**TABLE 27. OBJECT\_TEMP\_FACTOR (0xCD)**

Addr.	0xCD	Reset Value	Description
Bits	Field Name	Access	Description
0-7	OTF	RW	<p>Read back from attached camera module and depends on its calibration.</p> <p>A decimal factor (multiplier) of the value of each pixel, applied before the frame is output via the host interface. This allows for the correction of size-of-source related optical phenomena, which typically result in attenuation (for high-temperature target) or enhancement (for low-temperature target) of the output temperature. Correction for these phenomena via the OTF permits one to maintain the calibrated sensitivity and avoid secondary errors that can manifest themselves as die-temperature or ambient temperature dependence. The value of the OTF is encoded in 2's complement notation, as an 8-bit signed integer, with resolution of 0.01. It is a unitless factor.</p> <p>For example. If the correction requires <math>OTF = -0.1</math> then the value of register 0xCD must be 246 (0xF6). If the correction requires <math>OTF = +0.1</math>, then the value of register 0xCD must be 10 (0x0A).</p> <p>Successful correction requires a knowledge of the application-level working distance, and must involve both OTF (register 0xCD) and Offset (0xCB). It is lens dependent too. For example, For MI0802-M7G module and a short working distance below 50 cm, the optimal values are: OTF register (0xCD) = 246 (0xF6), and OFFSET register (0xCB) = 33 (0x21).</p>

**TABLE 28.      SENXOR\_ID (0xE0—0xE6)**

Addr.	0xE0 – 0xE6	Reset Value	As per SenXor’s unique ID
Bits	Field Name	Access	Description
0 - 7	PRODUCTION_YEAR	R	Production year (19 – 99) – decimal offset since year 2000, i.e. 19 == 2019
8 – 15	PRODUCTION_WEEK	R	Production week (decimal 1 – 52)
16 – 23	MANUF_LOCATION	R	Manufacturing location (decimal 0 – 99)
24 – 63	SERIAL_NUMBER	R	Serial number of the camera module. This number may roll over, but only at the beginning of a new PRODUCTION_WEEK.

The SENXOR\_TYPE and SENXOR\_ID uniquely identify every single camera module produced by Meridian Innovation.

**TABLE 29.      FILTER\_CONTROL (0xD0)**

Addr.	0xD0	Reset Value	0x00
Bits	Field Name	Access	Description
0	TEMPORAL_ENABLE	RW	Enable data filtering in the temporal domain when set to 1. The effect of this filter is determined by the value of register FILTER_SETTING_1 (0xD1 – 0xD2). The higher the value – the more stable the readout temperature, but also – the more noticeable trailing artefacts in a dynamical scene. Note that the use of the temporal filter in conjunction with bit 0 of CLK_SPEED register, CLK_SLOW_DOWN, leads to a reduction in the data frame rate.
1	TEMPORAL_INIT	RW	Initialize temporal filter, when set to 1. This bit must be set to one whenever a new value is written to register FILTER_SETTING_1 (0xD1 – 0xD2), in order for the new setting to take effect. The bit will be automatically reset to 0 after the initialisation is complete, which typically takes around 40 ms.
2-7	RESERVED	-	Not accessible.

**TABLE 30.      FILTER\_SETTING\_1 (0xD1—0xD2)**

Addr.	0xD1 – 0xD2	Reset Value	0x0A (decimal 10)
Bits	Field Name	Access	Description
0 - 7	TEMPORAL_LSB	RW	Least significant 8 bits of the filter strength
8 – 15	TEMPORAL_MSB	RW	Most significant 8 bits of the filter strength

**TABLE 31. USER\_FLASH\_CTRL (0xD8)**

Addr.	0xD8	Reset Value	0x00
Bits	Field Name	Access	Description
0	USER_FLASH_ENABLE	RW	When set to 1, enable host to access User Flash via the I2C interface, using register-like byte-access, starting from address 0x00 to address 0x7F inclusive. Once User Flash access has been complete, the host must clear this bit to 0, to regain access to the standard MI48 registers.
1-7	RESERVED	-	Not accessible

## 4.4. I<sup>2</sup>C Bus Interface

The I<sup>2</sup>C interface provides access to the internal register map of the MI48Ex. The following communication protocol is implemented over the I<sup>2</sup>C interface of the MI48Ex, whereby communication is always initiated by the master device on the I<sup>2</sup>C bus, while the MI48Ex acts as a slave device on the I<sup>2</sup>C bus.

### 4.4.1. I<sup>2</sup>C Slave Address

The I<sup>2</sup>C slave address is composed of 7 bits – A6 to A0. For the MI48Ex bit A6 to A2 are hardwired to ‘10000’, while bit A0 depends on the value registered on the ADDR input pin (pin 22 of the QFN33 package) during hardware reset or power-on reset. Therefore, the MI48Ex can respond to one of two I2C slave addresses, as per Table 34.

**TABLE 32. SELECTION OF I<sup>2</sup>C SLAVE ADDRESS.**

ADDRESS state	I <sup>2</sup> C chip address
0 (Pull Low)	0x40
1 (Pull High)	0x41

### 4.4.2. I<sup>2</sup>C Command

The I<sup>2</sup>C command consists of 1 byte that includes the 7-bit I<sup>2</sup>C slave address (A6 to A0), followed by one-bit access type designator ( $R/\overline{W}$ ) – 1 for read access and 0 for write access:

A6	A5	A4	A3	A2	A2	A0	R/ $\overline{W}$
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Specifically, for the MI48Ex it is:

1	0	0	0	0	0	A0	R/ $\overline{W}$
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#### 4.4.3. Write Command

- Master initiates a write command by a Start Condition (S), followed by one byte containing Slave Address in the first 7 bits (A6 to A0), and 0 in the last bit.
- Upon acknowledge (A) from slave, master sends one byte with Slave Internal Register Address (B7 to B0) – the register it intends to write to.
- Upon acknowledge from slave (A), master sends one byte of register data (D7 to D0) to be written to the slave.
- Upon acknowledge from slave (A), master terminates the transfer with a Stop Condition (P).

This is summarised below – the shaded fields indicate Slave driving the I<sup>2</sup>C\_SDA line:

S	A6	A5	A4	A3	A2	A2	A0	0	A	B7	B6	B5	B4	B3	B2	B1	B0	A	D7	D6	D5	D4	D3	D2	D1	D0	A	P
---	----	----	----	----	----	----	----	---	---	----	----	----	----	----	----	----	----	---	----	----	----	----	----	----	----	----	---	---

#### 4.4.4. Read Command

- Master initiates a read command by a Start Condition (S), followed by one byte containing Slave Address in the first 7 bits, (A6 to A0) and 0 in the last bit.
- Upon acknowledge (A) from slave, master sends one byte with Slave Internal Register Address (B7 to B0) – the register it intends to read from.
- Upon acknowledge from slave (A), master sends a Repeated Start Condition (RS) followed by one byte containing Slave Address in the first 7 bits, (A6 to A0) and 1 in the last bit
- Slave then sends Acknowledge (A) followed by the one byte of data (D7 to D0).
- Once the master receives the number of bytes it expects from the slave, the master issues Not-Acknowledge (NA) and terminates the transfer with a Stop Condition (P).

This is summarised below – the shaded fields indicate Slave driving the I<sup>2</sup>C\_SDA line:

S	A6	A5	A4	A3	A2	A2	A0	0	A	B7	B6	B5	B4	B3	B2	B1	B0	A											
RS	A6	A5	A4	A3	A2	A2	A0	1	A	D7	D6	D5	D4	D3	D2	D1	D0	NA	P										

The MI48Ex supports multiple reads, whereby the internal register address is automatically incremented if the Master sends Acknowledge (A) instead of Not-Acknowledge (NA), indicating that it is ready to receive more data.

### 4.5. SPI Interface

The SPI interface enables the host processor to read out the thermal data frame assembled by the MI48Ex. The thermal data frame is held in the Output Frame Buffer of the chip and its availability is indicated by the DATA\_READY output signal.

#### 4.5.1. SPI Interface Operation

The MI48Ex acts as an SPI slave. The SPI interface master must be operated in Mode 0. Therefore, the SPI\_CLK idles at 0, and a clock cycle corresponds to a half cycle with the clock idle, followed by a half cycle with the clock asserted at 1. The leading and trailing edges of the clock are the rising and falling edges of SPI\_CLK correspondingly. This is illustrated in Fig. 4.

The SPI Interface master should be configured to use 16-bit data width, with the most significant bit (MSB) transferred first. It does not matter if the SPI master (on the host system) releases the SPI\_SS between reads of consecutive words of the same thermal data frame.

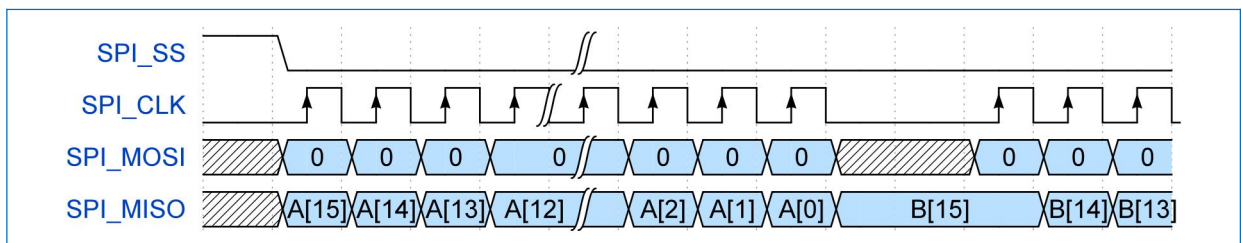


Fig. 4. Waveform diagram of the thermal data readout through the SPI Interface; A and B refer to the first and second 16-bit words of the data transfer. Vertical dotted lines delineate clock cycles.

Note that for every 2 bytes read from MI48Ex by the host controller over the SPI, the host must write two dummy bytes with the value 0x0000 over the MOSI pin in order to generate the clock for the SPI transfer.

#### 4.5.2. Thermal Data Frame Format

The format of the Thermal Data Frame depends on the value of bit 5 – NO\_HEADER of the FRAME\_MODE register (0xB1). If NO\_HEADER is set to 1, the Data Frame contains only the temperature data, and that is the only data transferred over the SPI interface. Alternatively, the data frame consists of a Frame Header, which is transferred first, followed by the temperature data. The data frame format in this case is shown in Table 35.

**TABLE 33. MI16XX THERMAL DATA FRAME FORMAT INCLUDING FRAME HEADER**

Frame Header	Frame counter	SenXor VDD	SenXor die temperature	Time stamp	Max pixel value	Min pixel value	CRC	Reserved
160 words (MI16XX)	1 word	1 word	1 word	2 words	1 word	1 word	1 word	152 words (MI16XX)
Temperature data	160 column * 120 row Pixel Data, i.e. 19,200 words (MI16XX Camera Module)							

#### 4.5.3. Thermal Data Frame Header Details

The header of the Thermal Data Frame consists of 160 words. Each word is composed of 16 bits, of which the most significant bit (MSB) is transferred first, and the least significant bit is transferred last. Only the first 8 words of the header are significant, as detailed in Table 36. Each word represents an unsigned integer.

**TABLE 34. THERMAL DATA FRAME HEADER**

Header Byte offset	Size, Bytes	Tag	Description
0	2	Frame counter	Number of frames taken from the since last power up. The value increments by 1 every time a frame is available for readout by the host.
2	2	SenXor VDD	Internal VDD sensed by the MI16XX Camera Module, in unit of 0.0001 V, i.e. 32945 equals 3.2945 V
4	2	SenXor die temperature	Internal die temperature of the connected MI16XX, in units of 0.01 K, i.e. 34001 = 340.01 K
6	4	Time stamp	Time elapsed since first frame was taken. Note that elapsed time is tracked using the external 12 MHz crystal oscillator, which is not as accurate as a standard 32kHz crystals for timing applications.
10	2	Max pixel value	Maximum pixel value of captured frame in units of 0.1 K, i.e. a decimal value of 3304 equals 330.4 K
12	2	Min pixel Value	Minimum pixel value of captured Frame in units of 0.1 K, i.e. a decimal value of 2735 equals 273.5 K
14	2	CRC	Check sum CRC-16/CCITT-FALSE calculated over the thermal data portion of the frame only. Note that the CCITT-FALSE variant of CRC-16 has the following parameters: width=16, poly=0x1021, <b>init=0xFFFF</b> , refin=False, refout=False, xorout=0x0000, check=0x29b1, residue=0x0000

#### 4.5.4. Temperature Data

The temperature data consists of 19200 words. Each word is composed of 16 bits, and the most significant bit is transferred first. Every word represents the temperature of a pixel, as a 16-bit unsigned integer in units of 0.1 K.

For example, the transfer of the 16-bit word 0x0BC1, represents 3009 in decimal and the corresponding temperature is 300.9 K.

#### 4.6. USB Interface Operation

The MI48Ex implements a USB interface that can be used as an alternative mode of communication to the host MCU. This mode of operation is select by pulling up the MODE pin (pin 31), which is sensed during reset. The host MCU must realise an interface protocol featuring command-acknowledge exchange of commands and data. The interface protocol is specified the document MI48xx-USB-Interface-Protocol by Meridian Innovation. The electrical signalling is compliant to the USB standard, which can be used as a reference, and the physical coupling can be done by USB-C a connector.

#### 4.7. Thermal Data Acquisition

The MI48xx supports two data acquisition modes – Single Frame Capture, and Continuous Frame Capture. The capture mode depends on how the capture mode is initiated.

Single Frame Capture mode is triggered by setting to 1 GET\_SINGLE\_FRAME (bit 0) of MODE\_REGISTER (0xB1) , and is appropriate when one needs to acquire thermal images at relatively large intervals from one another, e.g. once every 10 min. In such case, it is useful to also set the frame rate to a low value, e.g. by setting the FRAME\_RATE\_DIVIDER in the FRAME\_RATE register at address 0xB4 to the value of 0x20. In this way one can benefit from the noise reduction within the MI48xx itself, so that the obtained thermal data requires minimal processing. GET\_SINGLE\_FRAME is automatically reset to 0.

Continuous Capture mode is initiated by setting to 1 CONTINUOUS\_STREAM (bit 1) of MODE\_REGISTER (0xB1). MI48xx obtains a continuous stream of thermal images from the attached camera module and delivers the processed thermal data frames to the Output Frame Buffer at the frame rate specified by the FRAME\_RATE\_DIVIDER in the FRAME\_RATE register at address 0xB4. To stop the continuous data acquisition, one must reset CONTINUOUS\_STREAM to 0.

#### 4.8. Thermal Data Readout

##### 4.8.1. General Considerations

The MI48xx supports Full-Frame readout mode, in which the host processor can read the entire Thermal Data Frame – including Frame Header and the Temperature Data of the entire SenXor™ pixel array. In the case of the MI48Ex being configured to communicate via SPI/I<sup>2</sup>C interface this can happen upon the rise of the DATA\_READY output signal from the

MI48xx. This is illustrated in Fig. 5, where the data transfer over the SPI interface is abstractly represented.

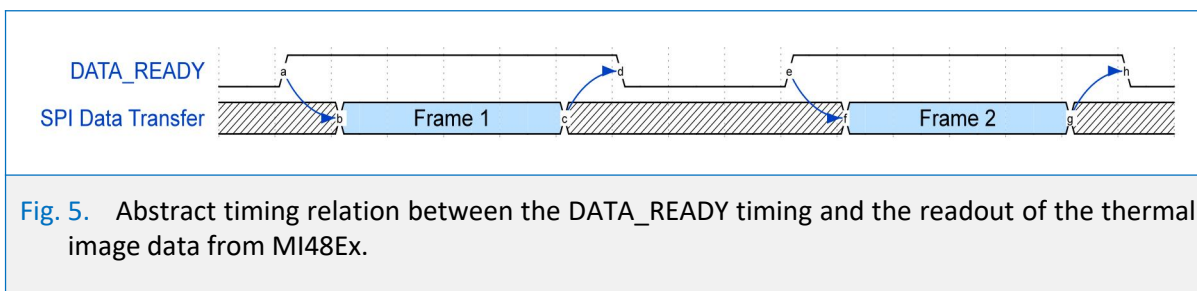


Fig. 5. Abstract timing relation between the `DATA_READY` timing and the readout of the thermal image data from MI48Ex.

Note that `DATA_READY` is lowered only after the host controller reads out the complete Thermal Data Frame.

In the case of the MI48Ex being configured to communicate via USB, the message containing the thermal data frame will be composed and sent out via the USB interface as soon as it is complete.

## 4.9. Low-level Thermal Data Processing

### 4.9.1. Per Pixel Calibration

Each SenXor™ module is factory-calibrated per pixel, so that accuracy and uniformity of temperature readout is achieved. The calibration data is accessed by the MI48xx, when connected to a camera module and used in the process of converting the output from the camera module into absolute temperature (in Kelvin).

### 4.9.2. Bad Pixel Correction

Each SenXor™ module is calibrated per pixel, and any bad pixel is identified during the calibration procedure. Within the MI48xx the readout value of the identified bad pixels is replaced by an appropriate estimate, based on the temperature of surrounding good pixels, automatically.

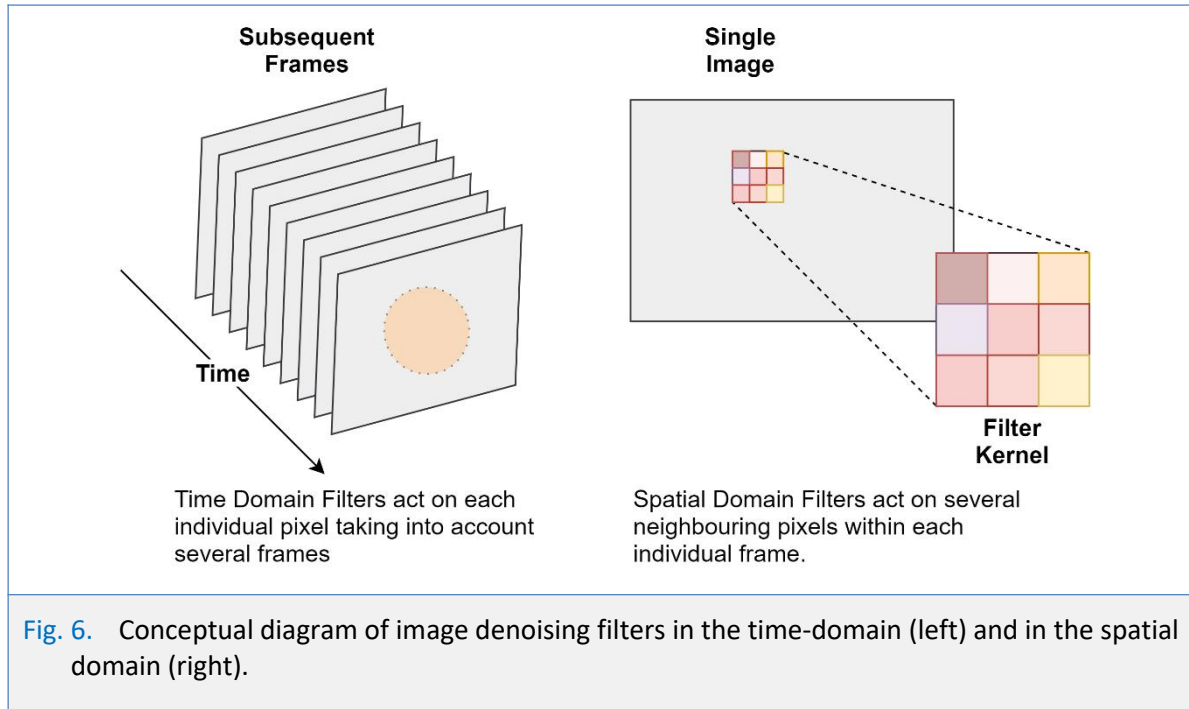
### 4.9.3. Camera Module Output to Temperature Conversion

The output of the camera module is readout by the MI48xx and converted into temperature after taking into account the calibration of the connected SenXor™, the emissivity value stored in the `EMISSIVITY` register at address `0xCA`, and the emissivity correction factor stored in the `EMISSIVITY_FACTOR` register at address `0xC2`.

### 4.9.4. Data Filtering

Data readout from each pixel of SenXor™ exhibit some fluctuations over time, particularly obvious at high frame rate. The MI48xx can smooth out these fluctuations to a different degree, depending on the application requirements for frame rate, readout stability and accuracy, and the anticipated dynamics of the scene to be observed by thermal imaging.

Image filtering can be performed in two distinct domains: in the time domain and in the spatial domain, as shown in the Fig. 6 below. The MI48 supports 2 different time-domain filters, Temporal Filter and Rolling Average Filter, as well as a Median Filter, for the spatial domain. Which one is turned on and off is dictated by the FILTER\_CONTROL register at 0xD0. The operation of the filters is independent of each other and they can be ON at the same time.



Time-domain filters maintain the sharpness and features of the image because the denoising algorithm is applied on each pixel individually. However, time-domain filters suffer from 'ghosting' effects. That means that a sudden or fast change in the scene will result in a 'ghost'-like movement or change in the image over consecutive frames. The strength of the Temporal Filter affects the amount of 'ghosting' and must be optimised for the specific application. This is done via the FILTER\_SETTING\_1 registers at address 0xD1 and 0xD2, for the Temporal Filter. By default, the filter strength is optimal for a slowly changing scene at 9 FPS. Note that the Temporal Filter must be initialised whenever its strength is changed, via the 0xD0 register, i.e. after a write to 0xD1 register, 0xD0 register write of 0x03 must follow.

The median filter, which is OFF by default (0xD3 is 0x00), is a spatial filter and does not introduce ghosting in the image, but smooths out subtle features, particularly if the features in the scene are resolved in too few pixels. The Median Filter supports a kernel of 3 x 3 or 5 x 5 pixels, to avoid excessive smoothing. The selection of the kernel size is done by bit 1 of register 0xD3, while the filter itself can be turned on by setting bit 0 of register 0xD3.

The MI48 features also a spatio-temporal filter, called STARK, which combines the information from both temporal and spatial domains in order to suppress the noise. Its ghosting effect is lesser than that of the temporal, and features are preserved, unlike when using the median filter. It has several empirical parameters to control its performance.

These has been optimized for different module types and the MI48 applies them automatically. Therefore, the user does not need to modify the associated registers (at address 0x20 to 0x23).

#### 4.9.5. Self-Calibration (Not Implement Yet)

If the MI48Ex is connected to a SenXor module that is provided without an external flash memory to store calibration information, then the MI48Ex performs a self-calibration routine upon module power up, in order to minimize temperature offset between individual columns of the array. Additionally, the MI48Ex can use a generic calibration data for a given module type (related to the type of lens being used). For this to happen, the host MCU must initialize register `MODULE_TYPE` at address 0xBB with the correct module type (see Appendix I) and then activate the use of self-calibration by setting to 1 bit 4 of the `SELF_CALIBRATION` register at address 0xC5.

#### 4.10. Module Gain Control (Not Implement Yet)

The module gain determines the range of scene temperatures that can be reported by the MI48Ex upon reading the data. The module gain is controlled via the MI48Ex, which supports two modes – manual and automatic gain control. By default, the chip is operating in manual gain control mode, with the gain that yields the highest sensitivity (lowest NETD) and best accuracy. This gain is normalized to a numerical value of 1. The user can reduce the gain to 0.5 (half-gain) or 0.25 (quarter gain) in order to expand the temperature range, via the `MODULE_GAIN` register at address 0xB9. The gain is controlled via the `MODULE_GAIN` register at address 0xB9 of the MI48Ex [2].

Note that the temperature ranges above are only roughly indicative. In practice, the actual range depends on the type of lens used (e.g. module type) and the operational die temperature of the sensor.

Note also that after changing the gain manually, frame capture will stop for a few seconds.

In Automatic Gain Control Mode, the chip will perform a seamless transition between the temperature ranges. However, during the transition and for a few seconds after, the image quality and temperature accuracy may be compromised.

When Automatic Gain Control is ON, the value of the current gain can be obtained by reading register 0xC5.

Note that lowering the gain to 0.5 or 0.25 increases the NETD and reduces the accuracy of the temperature readout. This is typically not a problem, since the NETD diminishes with the increase of target temperature, therefore, a high temperature target (observed with low gain) will exhibit lower NETD.

### 4.11. Accessing User Flash

The MI48 contains a 128-byte FLASH memory reserved for the user. This memory can be accessed byte-wise via the I2C interface. Its purpose is to store non-volatile data -- for example, end-product unit calibration data or identification codes. The byte addresses this flash memory enumerate from 0x00 to 0x7F, and is hereafter referred to as User Flash Address.

To access the User Flash for either read or write, the host must enable it by setting bit 0 of the USER\_FLASH\_CTRL register at address 0xD8. At that point, any attempt to access an address between 0x00 and 0x7F including will result in accessing the USER FLASH, i.e. any other MI48 registers that may be mapped to this address range will *not* be visible to the host. The memory map of the MI48 when User Flash access is enabled is shown in Fig. 7.

To resume access to all of the MI48 registers, the host must clear bit 0 of the USER\_FLASH\_CTRL register at address 0xD8, after completing the access (read or write) to the User Flash. Note that making the User Flash accessible to the host via the I<sup>2</sup>C interface implies a single byte access at a time, and the User Flash address and data are communicated just as any other access to the MI48 registers. Specifically, for read access, the corresponding byte from the User Flash is placed in the I<sup>2</sup>C data field.

For write access to the User Flash, the data from the I<sup>2</sup>C command is written to the MI48 internal memory, and then it is actually written to the User Flash using a read-update-write sequence. The actual process of writing to the flash involves the copying of the original 128-byte content of the flash to the internal memory of the MI48, updating the relevant byte, then erasing the user flash memory, and finally writing the updated 128-byte contents from the MI48 internal RAM to the User Flash. This process is obviously rather time consuming and should not be performed during continuous frame acquisition. In general, the usage of the User Flash should be avoided during data acquisition. The intended usage is to store some parameters that are end-product specific, during test and calibration of the unit. Then upon power up, the host should read these parameters if needed, before initiating data acquisition, and disable the User Flash thereafter.

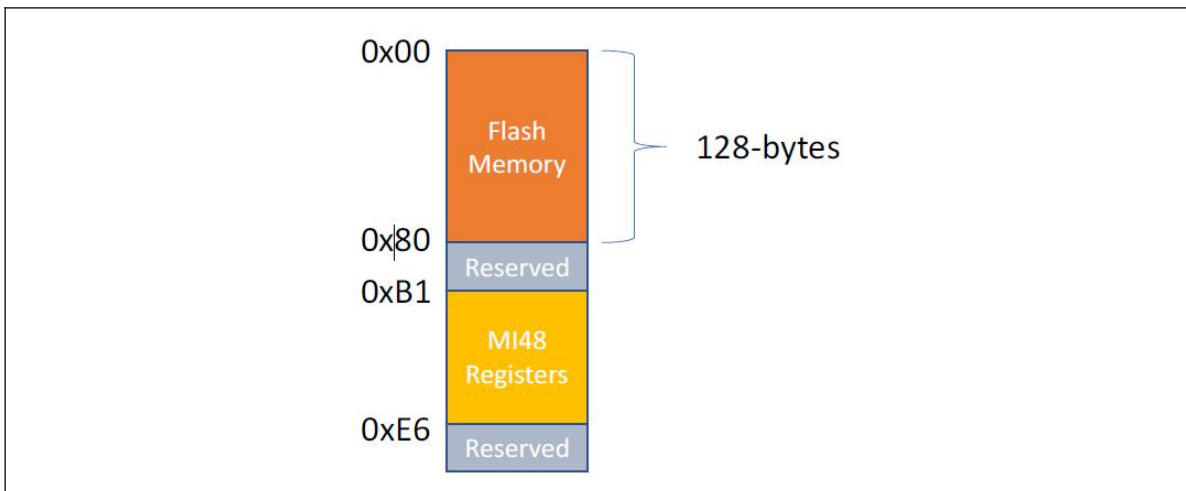


Fig. 7. Memory map of the MI48, showing the User Flash at address 0x00 – available only when bit 0 of the USER\_FLASH\_CTRL is set to 1.

## 5. ELECTRICAL AND THERMAL CHARACTERISTICS

### 5.1. Absolute Maximum Rating

Exceeding the values reported below at any time may lead to a performance deterioration, malfunction or destruction of the chip.

The values reported below are guaranteed by characterization results, not tested in production.

**TABLE 35. VOLTAGE CHARACTERISTICS**

Symbol	Parameter	MIN.	MAX.	Unit
$V_{DD}-V_{SS}$	DC Power Supply	-0.3	4	V
$ V_{DDX}-V_{DD} $	Variation between different power pins		50	mV
$V_{IN}$	Input Voltage on any other pin		$V_{DD}$	V

**TABLE 36. CURRENT CHARACTERISTICS <sup>1)</sup>**

Symbol	Parameter	MIN.	MAX.	Unit
$I_{DD}$	Maximum Current into $V_{DD}$		200	mA
$I_{SS}$	Maximum Current out of $V_{SS}$		100	
$I_{IO}$	Maximum Current Sunk by a I/O pin		20	
	Maximum Current Sourced by a I/O pin		20	
	Maximum Current Sunk by total I/O pins		100	
	Maximum Current Sourced by total I/O pins		100	
LU	Static latch-up class (at $T_A = 25^\circ\text{C}$ )		400	mA

<sup>1)</sup> All interface-related pins are referred to as IO pins.

**TABLE 37. THERMAL CHARACTERISTICS**

Symbol	Parameter	MIN.	MAX.	Unit
$T_A$	Operating Temperature	-40	85	°C
$T_J$	Junction Temperature	-40	125	
$T_{ST}$	Storage Temperature	-65	150	

### 5.2. Nominal Operating Conditions

The values below assume  $V_{DD} - V_{SS}$  is in the range of 3.0 to 3.6 V, and  $T_A = 25^\circ\text{C}$ , unless otherwise specified.

**TABLE 38. VOLTAGE CHARACTERISTICS**

Symbol	Parameter	Conditions	MIN.	TYP.	MAX.	Unit
$V_{DD}$	Operating Voltage		3.0	3.3	3.6	V
$V_{LDO}$	LDO output voltage	$C_{LDO}$ of 2.2 $\mu\text{F}$		1.26		

$T_{VDD}$	$V_{DD}$ rise time rate		10			$\mu\text{s}/\text{V}$
	$V_{DD}$ fall time rate		10			

**TABLE 39. CURRENT CONSUMPTION <sup>1)</sup>**

Symbol	Conditions	MIN.	TYP.	MAX.	Unit
$I_{DD}$	Capture mode		170		mA

<sup>1)</sup> Measured at  $V_{DD} = 3.3 \text{ V}$  and  $T_A = 25 \text{ }^\circ\text{C}$ .

## 6. DYNAMIC TIMING CHARACTERISTICS

### 6.1. MI48xx Clock

The MI48Ex timing is driven by a 12 MHz external oscillator. Internally, it generates all necessary timing for its operation and interfaces.

### 6.2. MI48xx Reset

The MI48xx is reset by asserting 0 to the nRESET pin 32 of the LQFP package.

The nRESET pin must be held low (below  $0.2 V_{DD}$ ) for at least  $32 \mu\text{s}$  in order to take effect. Similarly, nRESET is considered released after the pin is held high (above  $0.7 V_{DD}$ ) for at least  $32 \mu\text{s}$ .

An alternative way is to perform software reset by writing 0x01 to the MCU\_RESET register 0x00.

Either mode of resetting the MI48 is followed by a standard boot up sequence.

#### 6.2.1. Normal power up

The time between de-asserting the nRESET pin and attempting to acquire the first image from the connected camera module is 1.5 seconds. For a more precise timing budget, one could poll bit 5 of STATUS register at 0xB6, i.e. check the value of bit 5 of 0xB6 – if it is set to 1, capture is still in progress and data is NOT available; if it is 0, then temperature is available and can be readout.

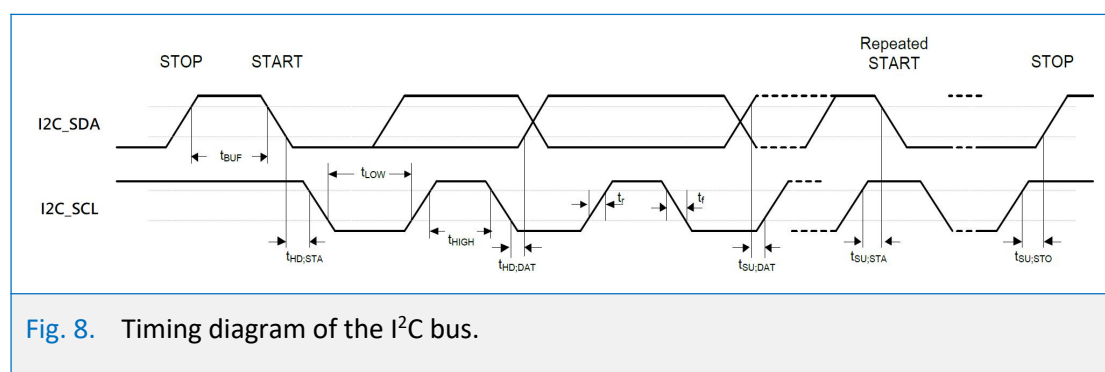
#### 6.2.2. First time power-up

When MI48xx detects that a new camera module has been attached, the power up sequence will take 5 seconds before the first image can be acquired.

## 6.3. I<sup>2</sup>C Characteristics

**TABLE 40. I<sup>2</sup>C TIMING PARAMETERS**

Symbol	Parameter	MIN.	MAX.	Unit
$t_{LOW}$	I <sup>2</sup> C_SCL LOW period	4.7	-	$\mu$ s
$t_{HIGH}$	I <sup>2</sup> C_SCL HIGH period	4	-	$\mu$ s
$t_{SU,STA}$	Repeated START condition setup time	4.7	-	$\mu$ s
$t_{HD,STA}$	START condition hold time	4	-	$\mu$ s
$t_{SU,STO}$	STOP condition setup time	4	-	$\mu$ s
$t_{BUF}$	Bus free time	4.7	-	$\mu$ s
$t_{SU,DAT}$	Data setup time	250	-	ns
$t_{HD,DAT}$	Data hold time	0	3.45	$\mu$ s
$t_r$	I <sup>2</sup> C_SCL/SDA rise time	-	1000	ns
$t_f$	I <sup>2</sup> C_SCL/SDA fall time	-	300	ns
$C_b$	Capacitive load for each bus line	-	400	pF



## 6.4. SPI Interface

**TABLE 41. SPI TIMING PARAMETERS**

Symbol	Parameter	MIN.	MAX.	UNIT
VDD=3.3V, 30pF Loading Capacitor				
$f_{CLK}$	Clock frequency	-	20	MHz
$t_{CLKH}$	Clock high time	-	$T_{SPI\_CLK} / 2$	ns
$t_{CLKL}$	Clock low time	-	$T_{SPI\_CLK} / 2$	
$t_{SS}$	Slave setup time	$T_{SPI\_CLK} + 2ns$	-	
$t_{SH}$	Slave hold time	$T_{SPI\_CLK}$	-	
$t_{DS}$	Data input setup time	0	-	
$t_{DH}$	Data input hold time	6	-	
$t_v$	Data output valid time	-	13	

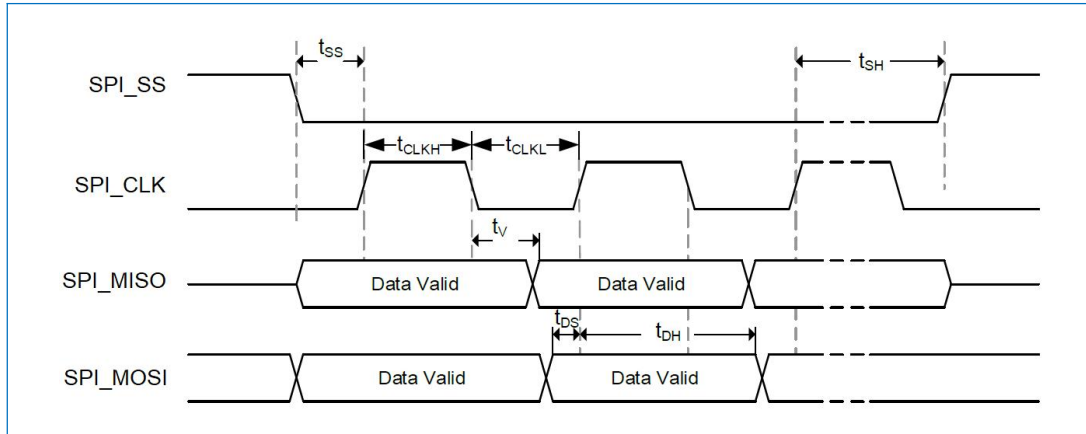


Fig. 9. SPI Interface timing diagram.

## 7. PACKAGE INFORMATION

### 7.1. Chip packaging for MI48Ex (LQFP64)

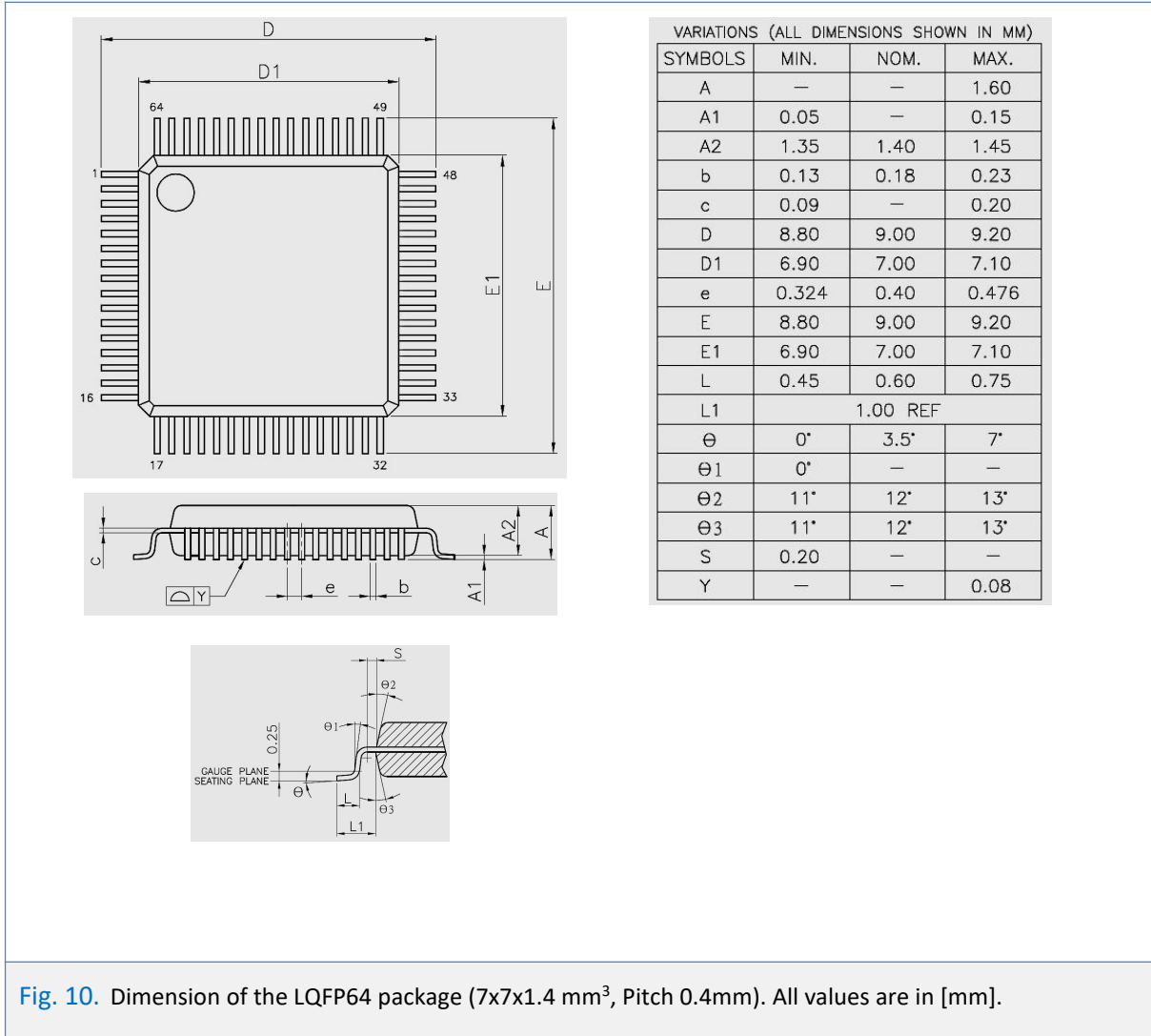


Fig. 10. Dimension of the LQFP64 package (7x7x1.4 mm<sup>3</sup>, Pitch 0.4mm). All values are in [mm].

## 8. REFERENCE DESIGN

### 8.1. Reference Circuit MI48Ex

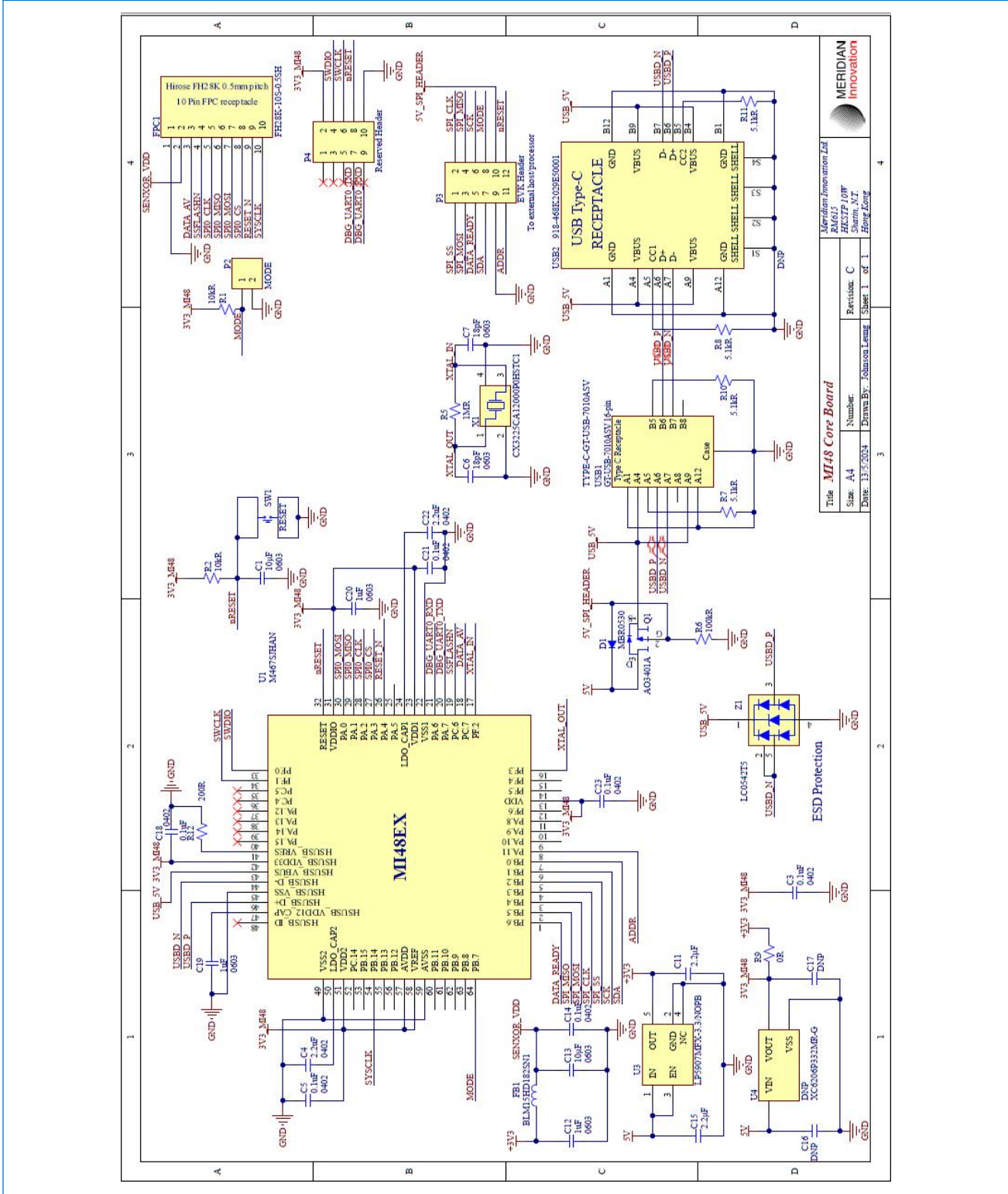


Fig. 11. Reference design circuit used for the MI16XX module evaluation board with MI48Ex

Note that the reference circuit includes both options for communication to the host MCU, and the header P2 is used to define which mode – USB or SPI/I2C, is being select. In an end-user application only one of these interfaces will be needed.

For MI48Ex, it is suggested that the USB\_D- and USB\_D+ pins are fanned out to a header or test pads, and that USB 5V (USB Vbus) and GND are connected to the MI48Ex HSUSB\_VBUS (pin 43) and GND correspondingly, even if the end system uses SPI/I<sup>2</sup>C communication interface to the host MCU. This is to enable potential firmware updates to the MI48Ex via the USB interface. Such an update can be realised with the help of Meridian Innovation DFU (Device Firmware Update) software, which can be run on a Windows PC or an Android device with USB connection to the system hosting the MI48Ex. Note that the system must be able to boot up independently and be able to operate correctly. Therefore, the system must provide the MI48Ex with a stable 3.3 V VDD and drive correctly the reset and clock signals.

## 8.2. Bill of Materials

**TABLE 42. BILL OF MATERIALS (MI48EX REFERENCE CIRCUIT)**

Designator	Value / Vendor Part Number	Description	Vendor	Quantity
C1, C13	10uF	Capacitor SMD, XCAM-C0603, 20%, 6.3V, X5R		2
C3, C5, C14, C18, C21, C23	0.1uF	Capacitor SMD, XCAM-C0402, 10%, 6.3V, X5R		6
C4, C22	2.2uF	Capacitor SMD, XCAM-C0402, 10%, 6.3V, X5R		2
C6, C7	18pF	Capacitor SMD, XCAM-C0603, 1%, 50V, COG		2
C12, C19, C20	1uF	Capacitor SMD, XCAM-C0603, 20%, 6.3V, X5R		3
C11, C15	2.2uF	Capacitor SMD, XCAM-C0603, 20%, 10V, X5R		2
D1	MBR0530	Surface Mount Schottky Power Rectifier, SOD123	OnSemi	1
FB1	BLM15HD182SN1	Inductor SMD, XCAM-R0402	Murata	1
FPC1	FH28K-10S-0.5SH	Hirose 0.5 mm Pitch, FPC Receptacle, 10P	Hirose	1
Q1	AO3401A	30V 4.0A P-Channel MOSFET, SOT23	Alpha & Omega Semicon.	1
R1, R2	10kR	Resistor SMD, XCAM-R0402, 5%		2
R5	1MR	Resistor SMD, XCAM-R0402, 5%		1
R6	100kR	Resistor SMD, XCAM-R0402, 5%		1
R7, R8, R10, R11	5.1kR	Resistor SMD, XCAM-R0402, 5%		4
R9	0R	Resistor SMD, R0805		1
R12	200R	Resistor SMD, XCAM-R0402, 1%		1
SW1	SKRPABE010	4-pin Tactile Switch, SKRP Series, TACT-SW-4P	Alps Alpine	1
U1	MI48EX	Thermal Image Processor for MI16XX Thermal Imaging Modules, LQFP64	Meridian Innovation	1

U3	LP5907MFX-3.3/NOPB	LP5907 250-mA, Ultra-Low-Noise LDO, SOT23-5 Package, LP5907 SOT-23	Texas Instruments	1
USB1	TYPE-C-GT-USB-7010ASV	5A 1 Surface Mount 16 Female -45°C~+85°C Type-C SMD USB Connectors ROHS, GT-USB-7010ASV		1
X1	CX3225CA12000P0 HSTC1	Passive 4-pin Oscillator, XTAL-4P, CX3225CA	KYOCERA	1
Z1	LC0542T5	Leiditech TVS Diode, TPD2E001DRLR, SOT553-TI	LEIDITECH	1

## 9. PCB DESIGN CONSIDERATIONS

Standard design rules should be considered to minimize noise and interference:

- Trace length, including FPC cable length to the camera module should not exceed 30 cm.
- Power related traces to the camera module (e.g. from LDO) should be as short as possible and as wide as possible to avoid any drop in  $V_{DD}$  to which temperature accuracy is sensitive.
- It is suggested to use Ultra Low Noise LDO with output voltage noise  $< 6.5 \mu\text{VRMS}$  to provide the VDD supply to the camera module. Recommended LDO is Texas Instruments, LP5907XXX-3.3/NOPB.
- Avoid ground loops, i.e. ground traces should form star connections only

## 10. REVISION HISTORY

<i>Version</i>	<i>Revision</i>	<i>Date</i>	<i>Comment</i>
1.0.1		16/12/2024	Initial release

## 11. LEGAL INFORMATION

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## 13. APPENDIX I

**TABLE 43. MODULE TYPE CODE AND PRODUCT CODE CORRESPONDENCE**

Module Type	Product Code	Resolution	FOV (H/V/D)	Comment
19	MI0802M5S	80 x 62	45/35/56	
20	MI0802M6S	80 x 62	90/67/122	
21	MI0802M7G	80 x 62	105/79/134	
40	MI1602M5S	160 x 120	45/34/56	
41	MI1602M6C	160 x 120	88/66/110	