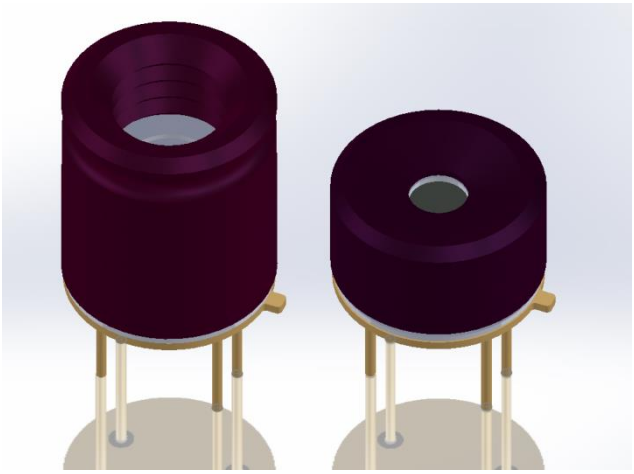
MLX90641 16x12 IR array

Datasheet

1. Features and Benefits

- Small size, low cost 16x12 pixels IR array
- Easy to integrate
- Industry standard four lead TO39 package
- Factory calibrated
- Noise Equivalent Temperature Difference (NETD) 0.1K @4Hz refresh rate
- I^2C compatible digital interface
- Programmable refresh rate 0.5Hz…64Hz
- 3.3V supply voltage
- Current consumption ≈ 12mA
- 2 FOV options – 55°x35° and 110°x75°
- Operating temperature -40°C ÷ 125°C
- Target temperature -40°C ÷ 300°C
- Complies with RoHS regulations



2. Application Examples

- High precision non-contact temperature measurements
- Microwave ovens
- Intrusion / Movement detection
- Temperature sensing element for residential, commercial and industrial building air conditioning
- Thermal Comfort sensor in automotive Air Conditioning control system
- Passenger classification
- Industrial temperature control of moving parts
- Visual IR thermometers
- Driver SW for MCU available at: https://github.com/melexis/mlx90641-library.git

3. Description

The MLX90641 is a fully calibrated 16x12 pixels thermal IR array in an industry standard 4-lead TO39 package with digital interface.
The MLX90641 contains 192 FIR pixels. An ambient sensor is integrated to measure the ambient temperature of the chip and supply sensor to measure the VDD. The outputs of all sensors IR, Ta and VDD are stored in internal RAM and are accessible through I^2C.

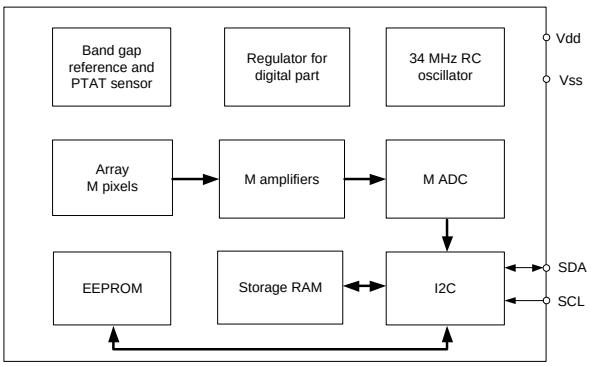


Figure 1 Block diagram

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4. Ordering Information

Product	Temperature	Package	Option Code	Custom Configuration	Packing Form	Definition
MLX90641	E	SF	BCA	000	TU	16x12 IR array
MLX90641	E	SF	BCB	000	TU	16x12 IR array
MLX90641	K	SF	BCA	000	TU	16x12 IR array
MLX90641	K	SF	BCB	000	TU	16x12 IR array

Legend:

Temperature Code:	**E: -40°C to 85°C** **K: -40°C to 125°C**
Package Code:	"SF" for TO39 package
Option Code:	xAx – TGC is disabled and may not be enabled xCx – TGC is enabled
Option Code:	xxA – FOV = 110°x75° xxB – FOV = 55°x35°
Custom configuration	000 – standard product
Packing Form:	"TU" - Tubes
Ordering Example:	"MLX90641KSF-BCA-000-TU"

Table 1 Ordering information

5. Glossary of Terms

TC	**T**emperature **C**oefficient (in ppm/°C)
POR	**P**ower **O**n **R**eset
IR	**I**nfra-**R**ed
Ta	**A**mbient **T**emperature – the temperature of the TO39 package
IR data	**I**nfrared **d**ata (raw data from ADC proportional to IR energy received by the sensor)
ADC	**A**nalog To **D**igital **C**onverter
TGC	**T**emperature **G**radient **C**oefficient
FOV	**F**ield **O**f **V**iew
nFOV	**F**ield **O**f **V**iew of the N-th pixel
I^2C	**I**nter-**I**ntegrated **C**ircuit communication protocol
SDA	**S**erial **Da**ta
SCL	**S**erial **Cl**ock
LSB	**L**east **S**ignificant **B**it
MSB	**M**ost **S**ignificant **B**it
Fps	**F**rames **p**er **S**econd – data refresh rate
MD	**M**aster **D**evice
SD	**S**lave **D**evice
ASP	**A**nalogue **S**ignal **P**rocessing
DSP	**D**igital **S**ignal **P**rocessing
ESD	**E**lectro **S**tatic **D**ischarge
EMC	**E**lectro **M**agnetic **C**ompatibility
NC	**N**ot **C**onnected
NA	**N**ot **A**pplicable

Table 2 Glosarry of terms

6. Pin Definitions and Descriptions

Pin #	Name	Description
1	SDA	I^2C serial data (input / output)
2	VDD	Positive supply
3	GND	Negative supply (Ground)
4	SCL	I^2C serial clock (input only)

Table 3 Pin definition

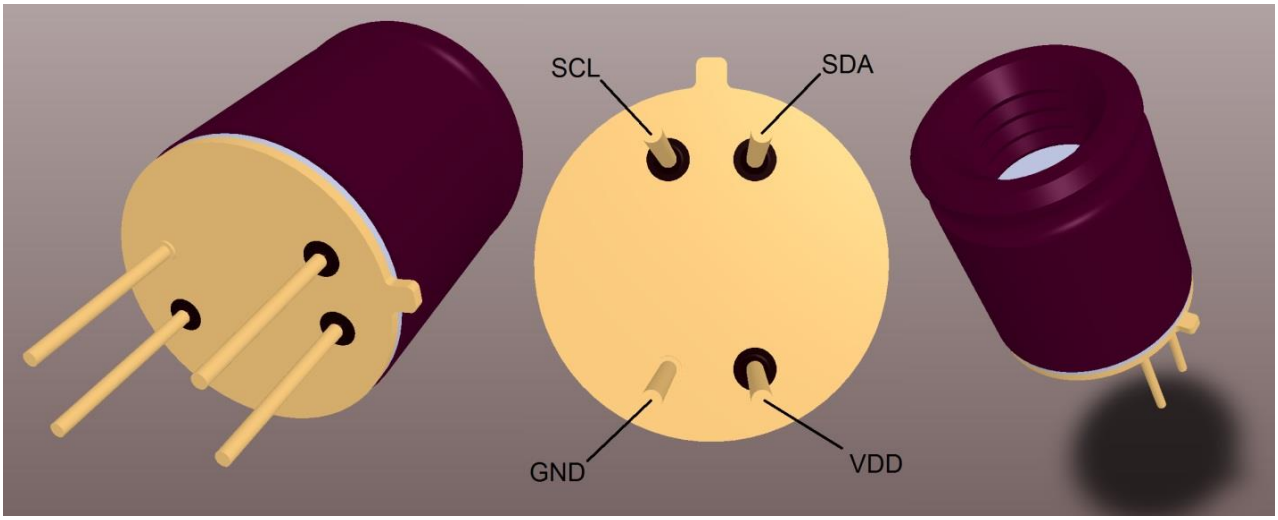


Figure 2 MLX90641 Overview and pin description

7. Absolute Maximum Ratings

Parameter	Symbol	Min.	Typ.	Max.	Unit	Remark
Supply Voltage (over voltage)	V_{DD}			5	V	
Supply Voltage (operating max voltage)	V_{DD}			3.6		
Reverse Voltage (each pin)				-0.3	V	
Operating Temperature	T_{AMB}	-40		+125	°C	
Storage Temperature	T_{ST}	-40		+150	°C	Not in plastic tubes
ESD sensitivity (AEC Q100 002)		4			kV	
SDA DC sink current				40	mA	

Table 4 Absolute maximum ratings

Exceeding the absolute maximum ratings may cause permanent damage. Exposure to absolute maximum-rated conditions for extended periods may affect device reliability.

8. General Electrical Specifications

Electrical Parameter	Symbol	Min.	Typ.	Max.	Unit	Condition
Supply Voltage	V_{DD}	3	3.3	3.6	V	
Supply Current	I_{DD}	10	12	14	mA	
POR level up analog	V_{POR_UP}	2.2		2.6	V	VDD rising
POR level down analog	V_{POR_DOWN}			2.55	V	VDD falling
POR hysteresis	V_{POR_hys}		50		mV	
I^2C address(NOTE 3)		0x01	0x33 (default)	0x7F		
Input high voltage (SDA, SCL)	V_{IH}	$0.7*V_{DD}$			V	Over Ta and V_{DD}
Input low voltage (SDA, SCL)	V_{LOW}			$0.3*V_{DD}$	V	Over Ta and V_{DD}
SDA output low voltage	V_{OL}			0.4	V	Over Ta and V_{DD} I_{SINK}=3mA
SDA leakage	I_{SDA_leak}			± 10	µA	V_{SDA}=3.6V, Ta=150°C
SCL leakage	I_{SCL_leak}			± 10	µA	V_{SCL}=3.6V, Ta=150°C
SDA capacitance	C_{SDA}			10	pF	
SCL capacitance	C_{SCL}			10	pF	
Acknowledge setup time	$T_{SUAC(MD)}$			0.45	µs	
Acknowledge hold time	$T_{DUAC(MD)}$			0.45	µs	
Acknowledge setup time	$T_{SUAC(SD)}$			0.45	µs	
Acknowledge hold time	$T_{DUAC(SD)}$			0.45	µs	
I^2C clock frequency	F_{I2C}		0.4	1	MHz	
Erase/write cycles				10	times	Ta = 25°C
Write cell time	T_{WRITE}	5			ms	

Table 5 Electrical specification

***NOTE 1**: For best performance it is recommended to keep the supply voltage as accurate and stable as possible to 3.3V ± 0.05V*

***NOTE 2**: When a data in EEPROM cell to be changed an erase (write 0x0000) must be done prior to writing the new value. After each write at least 5ms delay is needed in order to writing process to take place.*

***NOTE 3**: Slave address 0x00 must be avoided.*

***NOTE 4**: According to I^2C standard the max sink current is specified to be 20mA, however due to the thermal considerations (the dissipated power into the driver) the max current is limited to 10mA. This is the only parameter which does not comply with the FM+ specification.*

***NOTE 5**: Max EEPROM I^2C speed operations to be done at 400kHz.*

9. False pixel correction

The imager can have up to 1 defective pixel, with either no output or out of specification temperature reading. These pixels are identified in the EEPROM table of the sensor and can be read out through the I^2C. The defective pixel result can be replaced by an interpolation of its neighboring pixels.

10. Detailed General Description

10.1. Pixel position

The array consists of 192 IR sensors (also called pixels). Each pixel is identified with its row and column position as Pix(*i*,*j*) where ***i*** is its row number (from 1 to 12) and ***j*** is its column number (from 1 to 16)

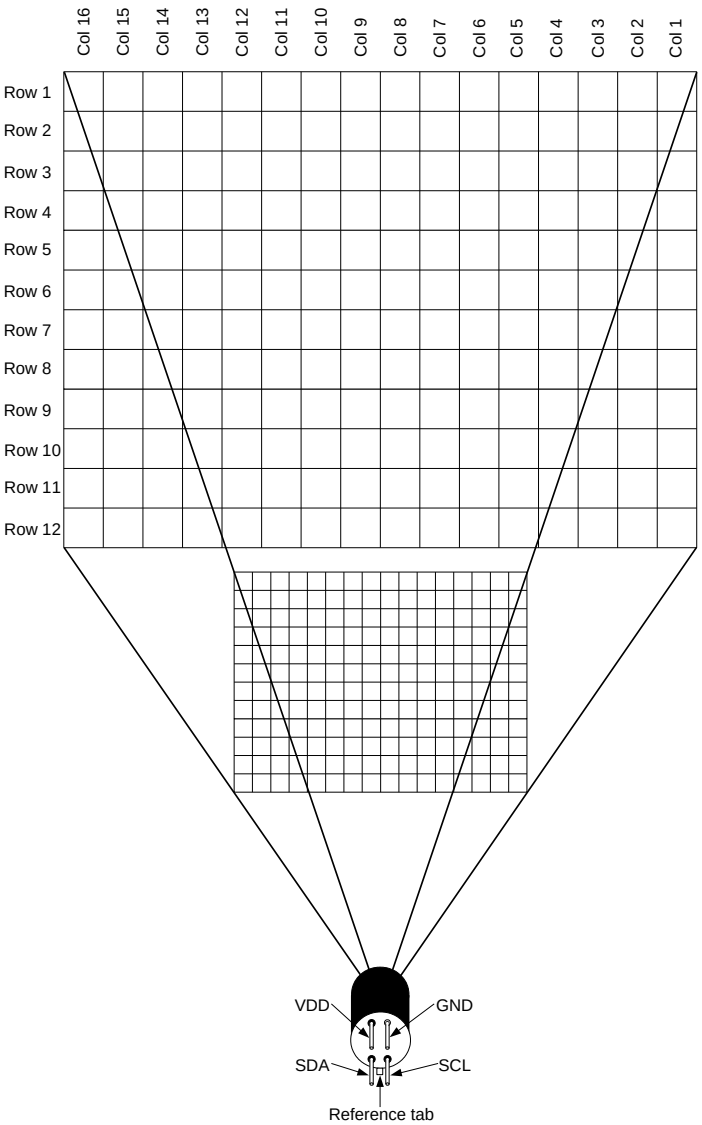


Figure 3 Pixel in the whole FOV

10.2. Communication protocol

The device use I²C protocol with support of FM+ mode (up to 1MHz clock frequency) and can be only slave on the bus.
The SDA and SCL ports are 5V tolerant and the sensor can be directly connected to a 5V I²C network.
The slave address is programmable and can have up to 127 different slave addresses (SA = 0x00 **must** be avoided).

10.2.1. Low level

10.2.1.1. Start / Stop conditions

Each communication session is initiated by a START condition and ends with a STOP condition. A START condition is initiated by a HIGH to LOW transition of the SDA while a STOP is generated by a LOW to HIGH transition. Both changes must be done while the SCL is HIGH.

10.2.1.2. Device addressing

The master is addressing the slave device by sending a 7-bit slave address after the START condition. The first seven bits are dedicated for the address and the 8th is Read/Write (R/W) bit. This bit indicates the direction of the transfer:

- Read (HIGH) means that the master will read the data from the slave
- Write (LOW) means that the master will send data to the slave

10.2.1.3. Acknowledge

During the 9th clock following every byte transfer the transmitter releases the SDA line. The receiver acknowledges (ACK) receiving the byte by pulling SDA line to low or does not acknowledge (NoACK) by letting the SDA 'HIGH'.

10.2.1.4. I²C command format

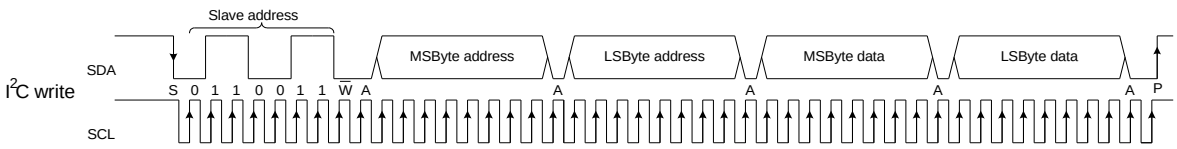


Figure 4 I²C write command format (default SA=0x33 is used)

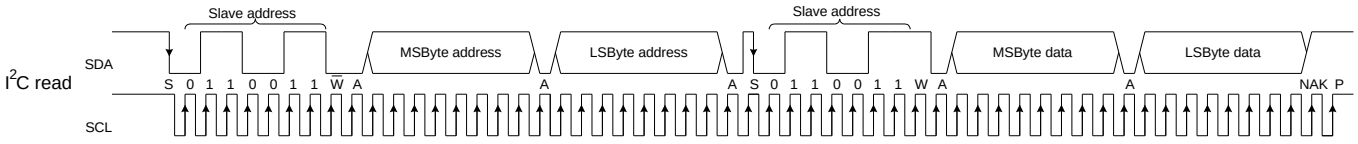


Figure 5 I²C read command format (default SA=0x33 is used)

10.3. Measurement mode

In this mode the measurements are constantly running. Depending on the selected frame rate Fps in the control register, the data for IR pixels and Ta will be updated in the RAM each $\frac{1}{F_{ps}}$ seconds. In this mode the external microcontroller has full access to the internal registers and memories of the device.

10.4. Refresh rate

The refresh rate is configured by “Control register 1” (0x800D) i.e. if “Refresh rate control” = 011 → 4Hz this would mean that each 250ms a new data (full frame) is available in the RAM.

NOTE: It is possible to program the desired refresh rate into device EEPROM eliminating the necessity to reconfigure the device every time it is powered on. The corresponding EEPROM cell is at address 0x240C (see Table 7)

Which subpage is updated is indicated by the “Last measured subpage” field.

It is important both subpages to be read as the necessary information for the Ta calculations is only available by combining the data from both subpages i.e. the Ta is refreshed with refresh rate twice as low as the one set in “Refresh rate control”.

When a new data (subpage) is available a dedicated bit is set to indicate this – bit 3 “New data available in RAM” in “Status register” (0x8000). It is up to the customer to reset the bit once the data is dumped.

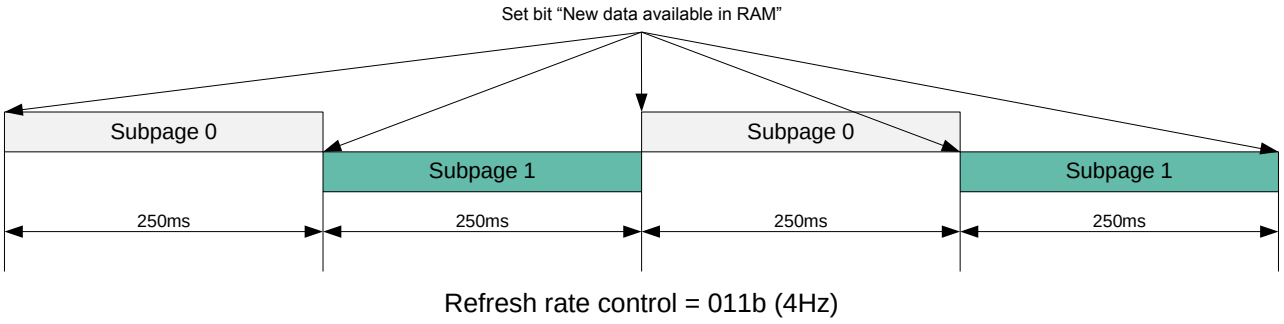


Figure 6 Refresh rate timing

10.5. Measurement flow

Following measurement flow is recommended:

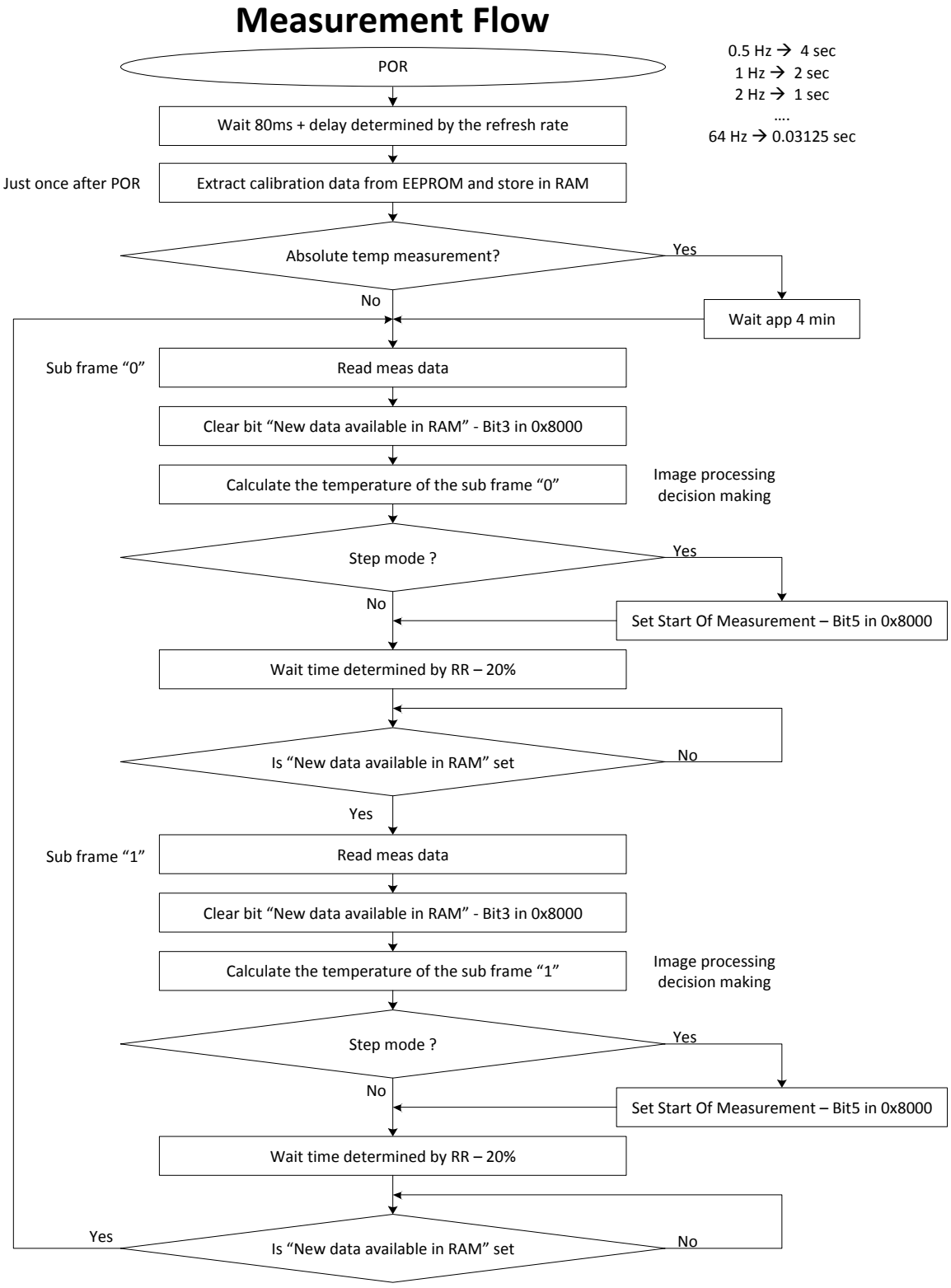


Figure 7 Recommended measurement flow

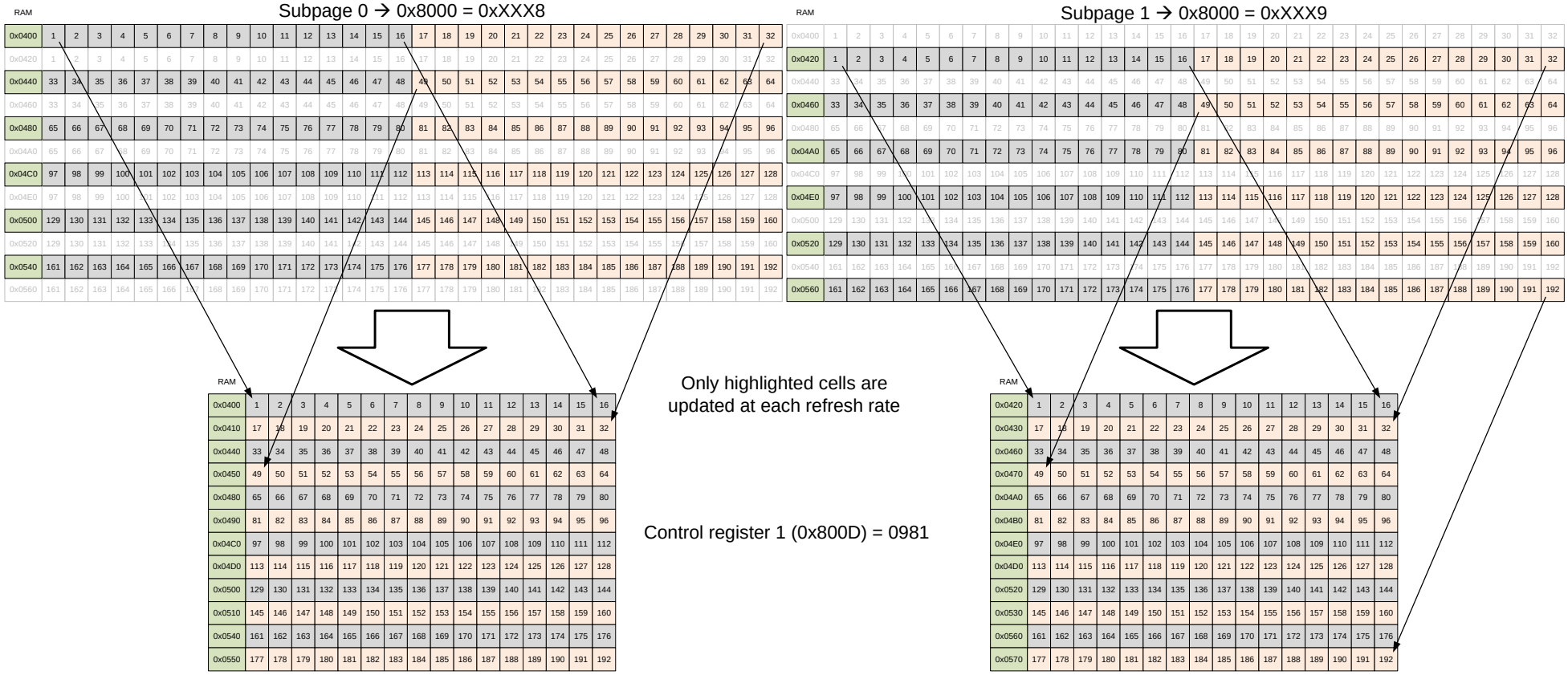


Figure 8 TV mode reading pattern

10.6. Address map

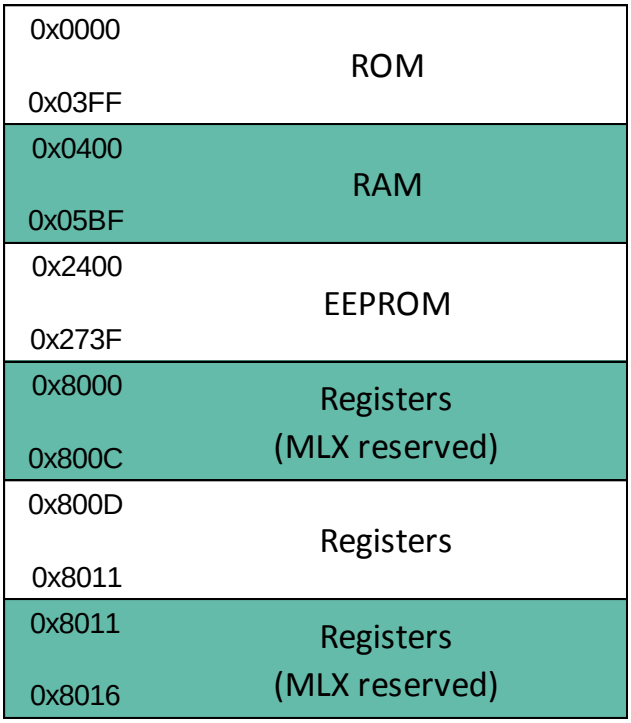


Figure 9 MXL90641 memory map

10.6.1. Internal registers

There are few internal register that are customer accessible through which the device performance may be customized:

B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0	Status register - 0x8000
Melexis reserved											Enable overwrite	New data available in RAM	Last measured subpage controlled by MLX90641			
													0	0	0	Measurement of subpage 0 has been measured
													0	0	1	Measurement of subpage 1 has been measured
													0	1	0	Melxis reserved
													0	1	1	Melxis reserved
													1	0	0	Melxis reserved
													1	0	1	Melxis reserved
													1	1	0	Melxis reserved
													1	1	1	Melxis reserved
												0	No new data is available in RAM (must be reset by the customer)			
												1	A new data is available in RAM			
											0	Data in RAM overwrite is disabled				
											1	Data in RAM overwrite is enabled				
-	-	-	-	-	-	-	-	-	-	-	Melexis reserved					

Figure 10 Status register (0x8000) bits meaning

B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0	Control register 1 - 0x800D
Melexis reserved			Reading pattern	Resolution control		Refresh rate control			Select subpage			Enable subpages repeat	Enable data hold	Melexis reserved	Enable subpages mode	
															0	No subpages, only one page will be measured
															1	Subpade mode is activated (default)
														0		Keep this bit = "0" (default)
													0			Transfer the data into storage RAM at each measured frame (default)
													1			Transfer the data into storage RAM only if en_overwrite = 1 (check 0x8000)
												0				Toggles between subpage "0" and subpage "1" if Enable subpages mode = "1" (default)
												1				Select subpage determines which subpage to be measured if Enable subpages mode = "1"
									0	0	0					Subpage 0 is selected (default)
									0	0	1					Subpage 1 is selected
									0	1	0					Not Applicable
									0	1	1					Not Applicable
									1	0	0					Not Applicable
									1	0	1					Not Applicable
									1	1	0					Not Applicable
									1	1	1					Not Applicable
						0	0	0								IR refresh rate = 0.5Hz
						0	0	1								IR refresh rate = 1Hz
						0	1	0								IR refresh rate = 2Hz (default)
						0	1	1								IR refresh rate = 4Hz
						1	0	0								IR refresh rate = 8Hz
						1	0	1								IR refresh rate = 16Hz
						1	1	0								IR refresh rate = 32Hz
						1	1	1								IR refresh rate = 64Hz
				0	0											ADC set to 16 bit resolution
				0	1											ADC set to 17 bit resolution
				1	0											ADC set to 18 bit resolution (default)
				1	1											ADC set to 19 bit resolution
			0													Interleaved (TV) mode (default)
			1													Chess pattern
-	-	-	Melexis reserved													

Figure 11 Control register 1 (0x800D) bits meaning

Enable subpage mode (Bit 0)	Enable subpage repeat (Bit 3)	Select subpage (Bit 4)	Working mode
0	0	-	measure subpage 0 only
0	1	-	measure subpage 0 only
1	0	-	0 → 1 → 0 → 1 …
1	1	0	measure subpage 0 only
1	1	1	measure subpage 1 only

Table 6 Priorities of subpage controls

B7	B6	B5	B4	B3	B2	B1	B0	B7	B6	B5	B4	B3	B2	B1	B0	
Melexis reserved												Melexis reserved	SDA driver current limit control	I2C threshold levels	FM+ disable	**I2C configuration register - 0x800F**
															0	FM+ mode enabled (default)
															1	FM+ mode disabled
														0		VDD reffered threshold (normal mode) (default)
														1		1.8V reffered threshold (1.8V mode)
													0			SDA driver current limit is ON (default)
													1			SDA driver current limit is OFF
												0				Melexis reserved
-	-	-	-	-	-	-	-	-	-	-	-					

Figure 12 I²C configuration register (0x800F) bits meaning

10.6.2. RAM

0x0400	Pixels 1…16 (subpage 0)	Pixels 17…32 (subpage 0)	0x041F
0x0420	Pixels 1…16 (subpage 1)	Pixels 17…32 (subpage 1)	0x043F
0x0440	Pixels 33…48 (subpage 0)	Pixels 49…64 (subpage 0)	0x045F
0x0460	Pixels 33…48 (subpage 1)	Pixels 49…64 (subpage 1)	0x047F
0x0480 … 0x0520	…	…	0x049F … 0x053F
0x0540	Pixels 161…176 (subpage 0)	Pixels 177…192 (subpage 0)	0x055F
0x0560	Pixels 161…176 (subpage 1)	Pixels 177…192 (subpage 1)	0x057F
0x0580	0x0580=Ta_Vbe, 0x0588=CP(SP 0), 0x058A=GAIN	Melexis reserved	0x059F
0x05A0	0x05A0=Ta_PTAT, 0x05A8=CP(SP1), 0x05AA=VDDpix	Melexis reserved	0x05BF

Figure 13 RAM memory map (Interleaved mode - default)

EEPROM

The EEPROM is used to store the calibration constants and the configuration parameters of the device

EEPROM address	Access	Meaning
0x2400	Melexis	Melexis reserved
0x2401	Melexis	Melexis reserved
0x2402	Melexis	Melexis reserved
0x2403	Melexis	Configuration register
0x2404	Melexis	Melexis reserved
0x2405	Melexis	Melexis reserved
0x2406	Melexis	Melexis reserved
0x2407	Melexis	Device ID1
0x2408	Melexis	Device ID2
0x2409	Melexis	Device ID3
0x240A	Melexis	Device Options
0x240B	Melexis	Melexis reserved
0x240C	Customer	Control register_1
0x240D	Customer	Control register_2
0x240E	Customer	I2CConfReg
0x240F	Customer	Melexis reserved / I2C_Address

Table 7 Configuration parameters memory

After POR the device read dedicated EEPROM cells and transfers their content to into the control and configuration register of the device. This way the device is configured and prepared for operation. The relation between EEPROM and register address is shown here after (explanation of the bit meaning can be found in section 10.6.1 Internal registers):

EEPROM address	Register address	Access	Name	Data [hex]
0x240C	0x800D	Customer	Control_register_1	0901
0x240D	0x800E	Customer	Control_register_2	0000
0x240E	0x800F	Customer	I2CConfReg	0000
0x240F	0x8010	Customer	Melexis internal use (8 bit) I2C_Address (8bit)	BE33

Figure 14 EEPROM to registers mapping

Address	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0x2400	Osc Trim	Ana Trim 1	MLX	Conf reg	Ana Trim 2	MLX	MLX	ID 1	ID 2	ID 3	MLX	MLX	Cont reg 1	Cont reg 2	I2C conf	I2C add
0x2410	Scale occ	Pix os R1		MLX		Kta_avg	Kta scales	Kv_avg	Kv scales	Scale_row 1…6			row1_max	row2_max	row3_max	row4_max
0x2420	row5_max	row6_max	KsTa	Emissivity	Gain		Vdd_25	K_vdd	PTAT_25		Kt_PTAT	Kv_PTAT	Alpha PTAT	Alpha CP	CP scale	OS 1 CP
0x2430	OS 2 CP	Kt CP	Kv CP	TGC	KsTo scale	KsTo_1	KsTo_2	KsTo_3	KsTo_4	KsTo_5	CT6	KsTo_6	CT7	KsTo_7	CT8	KsTo_8
0x2440	192 x Pixel offset - subpage 1															
0x2450																
0x2460																
0x2470																
0x2480																
0x2490																
0x24A0																
0x24B0																
0x24C0																
0x24D0																
0x24E0																
0x24F0																
0x2500	192 x Pixel sensitivity - α															
0x2510																
0x2520																
0x2530																
0x2540																
0x2550																
0x2560																
0x2570																
0x2580																
0x2590																
0x25A0																
0x25B0																
0x25C0	192 x Kta, Kv (i, j)															
0x25D0																
0x25E0																
0x25F0																
0x2600																
0x2610																
0x2620																
0x2630																
0x2640																
0x2650																
0x2660																
0x2670																
0x2680	192 x Pixel offset - subpage 2															
0x2690																
0x26A0																
0x26B0																
0x26C0																
0x26D0																
0x26E0																
0x26F0																
0x2700																
0x2710																
0x2720																
0x2730																

Table 8 EEPROM overview (words)

Address \ bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x2410	Hamming code					Scale_OCC_offset_range_1						MLX				
0x2411	Hamming code					Pix_offset_part_1										
0x2412	Hamming code					Pix_offset_part_2										
0x2413	Hamming code					MLX										
0x2414	Hamming code															
0x2415	Hamming code					Kta_avg										
0x2416	Hamming code					Kta_scale_1						Kta_scale_2				
0x2417	Hamming code					Kv_avg										
0x2418	Hamming code					Kta_scale_1						Kta_scale_2				
0x2419	Hamming code					Scale_row_1						Scale_row_2				
0x241A	Hamming code					Scale_row_3						Scale_row_4				
0x241B	Hamming code					Scale_row_5						Scale_row_6				
0x241C	Hamming code					Row_1_max										
0x241D	Hamming code					Row_2_max										
0x241E	Hamming code					Row_3_max										
0x241F	Hamming code					Row_4_max										
0x2420	Hamming code					Row_5_max										
0x2421	Hamming code					Row_6_max										
0x2422	Hamming code					KsTa (fixed scale 15)										
0x2423	Hamming code					Emissivity ± 2										
0x2424	Hamming code					GAIN - part 1										
0x2425	Hamming code					GAIN - part 2										
0x2426	Hamming code					Vdd_25 (fixed scale 5)										
0x2427	Hamming code					K_Vdd (fixed scale 5)										
0x2428	Hamming code					PTAT - part 1										
0x2429	Hamming code					PTAT - part 2										
0x242A	Hamming code					Kt_PTAT (fixed scale 3)										
0x242B	Hamming code					Kv_PTAT (fixed scale 12)										
0x242C	Hamming code					Alpha_PTAT (fixed scale 11)										
0x242D	Hamming code					Alpha CP										
0x242E	Hamming code					Alpha CP scale										
0x242F	Hamming code					Offset CP - part 1										
0x2430	Hamming code					Offset CP - part 2										
0x2431	Hamming code					Kt CP scale						Kt CP				
0x2432	Hamming code					Kv CP scale						Kv CP				
0x2433	Hamming code					Cal resolution		TGC coefficient ± 4								
0x2434	Hamming code					KsTo scale										
0x2435	Hamming code					± KsTo range 1 (-40°C ... -20°C)										
0x2436	Hamming code					± KsTo range 2 (-20°C ... 0°C)										
0x2437	Hamming code					± KsTo range 3 (0°C ... 80°C)										
0x2438	Hamming code					± KsTo range 4 (80°C ... 120°C)										
0x2439	Hamming code					± KsTo range 5 (120°C ... see 0x243A)										
0x243A	Hamming code					Corner temp range 6										
0x243B	Hamming code					± KsTo range 6 (see 0x243A ... see 0x243C)										
0x243C	Hamming code					Corner temp range 7										
0x243D	Hamming code					± KsTo range 7 (see 0x243C ... see 0x243E)										
0x243E	Hamming code					Corner temp range 8										
0x243F	Hamming code					± KsTo range 8 (see 0x243E ...)										
0x2440	Hamming code					Offset pixel (1, 1) - subpage 0										
0x2441	Hamming code					Offset pixel (1, 2) - subpage 0										
...	...					...										
0x244E	Hamming code					Offset pixel (1, 15) - subpage 0										
0x244F	Hamming code					Offset pixel (1, 16) - subpage 0										
0x2450	Hamming code					Offset pixel (2, 1) - subpage 0										
0x2451	Hamming code					Offset pixel (2, 2) - subpage 0										
...	...					...										
0x24FE	Hamming code					Offset pixel (12, 15) - subpage 0										
0x24FF	Hamming code					Offset pixel (12, 16) - subpage 0										
0x2500	Hamming code					Sensitivity (1, 1)										
0x2501	Hamming code					Sensitivity (1, 2)										
...	...					...										
0x250E	Hamming code					Sensitivity (1, 15)										
0x250F	Hamming code					Sensitivity (1, 16)										
0x2510	Hamming code					Sensitivity (2, 1)										
0x2511	Hamming code					Sensitivity (2, 2)										
...	...					...										
0x25BE	Hamming code					Sensitivity (12, 15)										
0x25BF	Hamming code					Sensitivity (12, 16)										
0x25C0	Hamming code					Kta (1, 1)						Kv (1, 1)				
0x25C1	Hamming code					Kta (1, 2)						Kv (1, 2)				
...	...					...						...				
0x25CE	Hamming code					Kta (1, 15)						Kv (1, 15)				
0x25CF	Hamming code					Kta (1, 16)						Kv (1, 16)				
0x25D0	Hamming code					Kta (2, 1)						Kv (2, 1)				
0x25D1	Hamming code					Kta (2, 1)						Kv (2, 1)				
...	...					...						...				
0x267E	Hamming code					Kta (12, 15)						Kv (12, 15)				
0x267F	Hamming code					Kta (12, 16)						Kv (12, 16)				
0x2680	Hamming code					Offset pixel (1, 1) - subpage 1										
0x2681	Hamming code					Offset pixel (1, 2) - subpage 1										
...	...					...										
0x268E	Hamming code					Offset pixel (1, 15) - subpage 1										
0x268F	Hamming code					Offset pixel (1, 16) - subpage 1										
0x2690	Hamming code					Offset pixel (2, 1) - subpage 1										
0x2691	Hamming code					Offset pixel (2, 2) - subpage 1										
...	...					...										
0x273E	Hamming code					Offset pixel (12, 15) - subpage 1										
0x273F	Hamming code					Offset pixel (12, 16) - subpage 1										

Table 9 Calibration parameters memory (EEPROM - bits)

***NOTE 1**: In case the pixel calibration data stored in EEPROM (Alpha, offset, Kta and Kv) is equal to 0x0000 this means that this particular pixels has failed and the calculation for To should not be trusted and avoided. Depending on the application, the To value for such pixels can be replaced with a default value such as -273.15°C, can be equal to Ta or one calculate an average value from the adjacent pixels.*

***NOTE 2**: The maximum number of deviating pixels is 1 (please check* False pixel correction*)*

11. Calculating Object Temperature

11.1. Restoring calibration data from EERPOM and calculations

NOTE: 1. All data in the EEPROM are coded as two's complement (unless otherwise noted)
2. All EEPROM cells are codded using Hamming code for proper data restoring stored in the 5 most significant bits
3. The calculation bellow are considering only the "valid" data in any particular cell ignoring the Hamming code bits
i.e. as the five significant bits of each word "0" for instance if the EEPROM content is "0x9A44" we will work with "0x0244"
In the example we are restoring calibration data for pixel (6, 9)

The polynom for the Hamming code is as follows:

P0 = D0 + D1 + D3 + D4 + D6 + D8 + D10
P1 = D0 + D2 + D3 + D5 + D6 + D9 + D10
P2 = D1 + D2 + D3 + D7 + D8 + D9 + D10
P3 = D4 + D5 + D6 + D7 + D8 + D9 + D10
P4 = D0 + D1 + D2 + D3 + D4 + D5 + D6 + D7 + D8 + D9 + D10 + P0 + P1 + P2 + P3

Where P4 is the MSBit in the word while D0…D10 are the data bits.

B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
P4	P3	P2	P1	P0	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0

Figure 15 EEPROM Hamming and data bit meaning

11.1.1. Restoring the VDD sensor parameters and VDD calculations

Following formula is used to calculate the VDD of the sensor:

$$V_{dd} = \frac{Resolution_{corr} * RAM[0x05AA] - V_{dd_{25}}}{K_{Vdd}} + 3.3$$

If $RAM[0x05AA] > 32767 \rightarrow RAM[0x05AA] = RAM[0x05AA] - 65536$

Where:

$K_{Vdd} = EE[0x2427]\ \&\ 0x07FF$

If $K_{Vdd} > 1023 \rightarrow K_{Vdd} = K_{Vdd} - 2048$

$K_{Vdd} = K_{Vdd} * 2^5$

$Vdd_{25} = EE[0x2426]\ \&\ 0x07FF$

If $Vdd_{25} > 1023 \rightarrow Vdd_{25} = Vdd_{25} - 2048$

$Vdd_{25} = Vdd_{25} * 2^5$

Where $Resolution_{corr}$ is restored in 11.1.18

11.1.2. Restoring the Ta sensor parameters

Following formula is used to calculate the Ta of the sensor:

$$T_a = \frac{\left(\frac{V_{PTAT_{art}}}{1+K_{V_{PTAT}}*\Delta V} - V_{PTAT_{25}}\right)}{K_{T_{PTAT}}} + 25, °C$$

Where:

$$K_{V_{PTAT}} = EE[0x242B] \,\&\, 0x07FF$$

If $K_{V_{PTAT}} > 1023 \rightarrow K_{V_{PTAT}} = K_{V_{PTAT}} - 2048$

$$K_{V_{PTAT}} = \frac{K_{V_{PTAT}}}{2^{12}}$$

$$K_{T_{PTAT}} = EE[0x242A] \,\&\, 0x07FF$$

If $K_{V_{PTAT}} > 1023 \rightarrow K_{V_{PTAT}} = K_{V_{PTAT}} - 2048$

$$K_{T_{PTAT}} = \frac{K_{T_{PTAT}}}{2^{3}}$$

$$\Delta V = \frac{RAM[0x05AA] - Vdd_{25}}{K_{Vdd}}$$

If $RAM[0x05AA] > 32767 \rightarrow RAM[0x05AA] = RAM[0x05AA] - 65536$

$$V_{PTAT_{25}} = 32 * (EE[0x2428] \,\&\, 0x07FF) + EE[0x2429] \,\&\, 0x07FF \text{ (unsigned)}$$

$$V_{PTAT_{art}} = \left(\frac{V_{PTAT}}{V_{PTAT} * Alpha_{PTAT} + V_{BE}}\right) * 2^{18}$$

Where:

$$V_{PTAT} = RAM[0x05A0]$$

If $V_{PTAT} > 32767 \rightarrow V_{PTAT} = V_{PTAT} - 65536$

$$V_{BE} = RAM[0x0580]$$

If $V_{BE} > 32767 \rightarrow V_{BE} = V_{BE} - 65536$

$$Alpha_{PTAT} = \frac{EE[0x242C] \,\&\, 0x07FF}{2^{7}}$$

11.1.3. Restoring the offset

There are two sets of offset data for each subpage.

$$pix_{OS_{ref_SP0}}(i,j) = Offset_{average} + offset_{SP0}(6,9) * 2^{Offset_{scale}}$$

$$pix_{OS_{ref_SP1}}(i,j) = Offset_{average} + offset_{SP1}(6,9) * 2^{Offset_{scale}}$$

$$Offset_{average} = 32 * (EE[0x2411] \,\&\, 0x07FF) + EE[0x2412] \,\&\, 0x07FF$$

If $Offset_{average} > 32767 \rightarrow Offset_{average} = Offset_{average} - 65536$

$$offset_{SP0}(6,9) = EE[0x2498] \,\&\, 0x07FF$$

If $offset_{SP0}(6,9) > 1023 \rightarrow offset_{SP0}(6,9) = offset_{SP0}(6,9) - 2048$

$$offset_{SP1}(6,9) = EE[0x26D8] \,\&\, 0x07FF$$

If $offset_{SP1}(6,9) > 1023 \rightarrow offset_{SP1}(6,9) = offset_{SP1}(6,9) - 2048$

$$Offset_{scale} = \frac{EE[0x2410] \,\&\, 0x07E0}{2^5} \text{ (unsigned)}$$

11.1.4. Restoring the Sensitivity $\alpha_{(i,j)}$

Sensitivity is divided into 6 ranges (1…32, 33…64 and so on) and for each range we store a reference value as follows:

Sensitivity Max value for row 1 (pixels 1…32) is stored at EEPROM address 0x241C

Sensitivity Max value for row 2 (pixels 33…64) is stored at EEPROM address 0x241D

Sensitivity Max value for row 3 (pixels 65…96) is stored at EEPROM address 0x241E

Sensitivity Max value for row 4 (pixels 97…128) is stored at EEPROM address 0x241F

Sensitivity Max value for row 5 (pixels 129…160) is stored at EEPROM address 0x2420

Sensitivity Max value for row 6 (pixels 161…192) is stored at EEPROM address 0x2421

$$\alpha_{(i,j)} = \frac{\alpha_{pixel}(6,9)}{2^{11}-1} * \alpha_{reference}$$

Where:

$$\alpha_{pixel}(6,9) = EE[0x2538] \,\&\, 0x07FF$$

$$\alpha_{reference_{row1}} = \frac{EE[0x241C] \,\&\, 0x07FF}{2^{\alpha_{scale_{row1}}}}$$

$$\alpha_{scale_{row1}} = \frac{EE[0x2419] \,\&\, 0x07E0}{2^5} + 20$$

$$\alpha_{reference_{row2}} = \frac{EE[0x241D] \,\&\, 0x07FF}{2^{\alpha_{scale_{row2}}}}$$

$$\alpha_{scale_{row2}} = EE[0x2419] \,\&\, 0x001F + 20$$

$$\alpha_{reference_{row3}} = \frac{EE[0x241E] \,\&\, 0x07FF}{2^{\alpha_{scale_{row3}}}}$$

$$\alpha_{scale_{row3}} = \frac{EE[0x241A] \,\&\, 0x07E0}{2^5} + 20$$

$$\alpha_{reference_{row4}} = \frac{EE[0x241F] \,\&\, 0x07FF}{2^{\alpha_{scale_{row4}}}}$$

$$\alpha_{scale_{row4}} = EE[0x241A] \,\&\, 0x001F + 20$$

$$\alpha_{reference_{row5}} = \frac{EE[0x2420] \,\&\, 0x07FF}{2^{\alpha_{scale_{row5}}}}$$

$$\alpha_{scale_{row5}} = \frac{EE[0x241B] \,\&\, 0x07E0}{2^5} + 20$$

$$\alpha_{reference_{row6}} = \frac{EE[0x2421] \,\&\, 0x07FF}{2^{\alpha_{scale_{row6}}}}$$

$$\alpha_{scale_{row6}} = EE[0x241B] \,\&\, 0x001F + 20$$

11.1.5. Restoring the Kta(i,j) coefficient

$$K_{Ta(6,9)} = \frac{K_{Ta_{EE}(6,9)} * 2^{K_{Ta_{scale2}}} + K_{Ta_{AVERAGE}}}{2^{K_{Ta_{scale1}}}}$$

Where:

$K_{Ta_{EE}(6,9)} = \frac{EE[0x2618] \,\&\, 0x07E0}{2^5}$ (depending on pixel number)

If $K_{Ta_{EE}(6,9)} > 31 \rightarrow K_{Ta_{EE}(6,9)} = K_{Ta_{EE}(6,9)} - 64$

$K_{Ta_{AVERAGE}} = EE[0x2415] \,\&\, 0x07FF$

If $K_{Ta_{AVERAGE}} > 1023 \rightarrow K_{Ta_{AVERAGE}} = K_{Ta_{AVERAGE}} - 2048$

$K_{Ta_{scale1}} = \frac{EE[0x2416] \,\&\, 0x07E0}{2^5}$ (unsigned)

$K_{Ta_{scale2}} = EE[0x2416] \,\&\, 0x001F$ (unsigned)

11.1.6. Restoring the Kv(i,j) coefficient

$$K_{V(6,9)} = \frac{K_{V_{EE}(6,9)} * 2^{K_{V\,scale2}} + K_{V_{AVERAGE}}}{2^{K_{V\,scale1}}}$$

Where:

$K_{V_{EE}(6,9)} = EE[0x2618] \,\&\, 0x001F$ (depending on pixel number)

If $K_{V_{EE}(6,9)} > 15 \rightarrow K_{V_{EE}(6,9)} = K_{V_{EE}(6,9)} - 32$

$K_{V_{AVERAGE}} = EE[0x2417] \,\&\, 0x07FF$

If $K_{V_{AVERAGE}} > 1023 \rightarrow K_{V_{AVERAGE}} = K_{V_{AVERAGE}} - 2048$

$K_{V\,scale1} = \frac{EE[0x2418] \,\&\, 0x07E0}{2^5}$ (unsigned)

$K_{V\,scale2} = EE[0x2418] \,\&\, 0x001F$ (unsigned)

11.1.7. Restoring the GAIN coefficient (common for all pixel)

$$\text{GAIN} = 32 * (EE[0x2424] \,\&\, 0x07FF) + EE[0x2425] \,\&\, 0x07FF \text{ (unsigned)}$$

11.1.8. Restoring the KsTa coefficient (common for all pixel)

$$KsTa = EE[0x2422] \,\&\, 0x07\text{FF}$$

$$\text{If } KsTa > 1023 \rightarrow KsTa = KsTa - 2048$$

$$KsTa = \frac{KsTa}{2^{15}}$$

11.1.9. Restoring corner temperatures (common for all pixel)

The information regarding corner temperatures is stored into device EEPROM and is restored as follows:

$$CT6 = EE[0x243\text{A}] \,\&\, 0x07\text{FF (unsigned)}$$

$$CT7 = EE[0x243\text{C}] \,\&\, 0x07\text{FF (unsigned)}$$

$$CT8 = EE[0x243\text{E}] \,\&\, 0x07\text{FF (unsigned)}$$

Or we can construct the temperatures for the ranges as follows:

CT1 = -40°C (hard codded) **< Range 1 >** CT2 = -20°C (hard codded) **< Range 2 >** CT3 = 0°C (hard codded) **< Range 3 >** CT4 = 80°C (hard codded) **< Range 4 >** CT5 = 120°C (hard codded) **< Range 5 >** CT6 **< Range 6 >** CT7 **< Range 7 >** CT8 **< Range 8**

11.1.10. Restoring the KsTo coefficient (common for all pixel)

$$KsTo_1 = \frac{EE[0x2435] \,\&\, 0x07\text{FF}}{2^{KsTo_{scale}}}$$

$$\text{If } KsTo_1 > 1023 \rightarrow KsTo_1 = KsTo_1 - 2048$$

$$KsTo_2 = \frac{EE[0x2436] \,\&\, 0x07\text{FF}}{2^{KsTo_{scale}}}$$

$$\text{If } KsTo_2 > 1023 \rightarrow KsTo_2 = KsTo_2 - 2048$$

$$KsTo_3 = \frac{EE[0x2437] \,\&\, 0x07\text{FF}}{2^{KsTo_{scale}}}$$

$$\text{If } KsTo_3 > 1023 \rightarrow KsTo_3 = KsTo_3 - 2048$$

$$KsTo_4 = \frac{EE[0x2438] \,\&\, 0x07\text{FF}}{2^{KsTo_{scale}}}$$

$$\text{If } KsTo_4 > 1023 \rightarrow KsTo_4 = KsTo_4 - 2048$$

$$KsTo_5 = \frac{EE[0x2439] \,\&\, 0x07\text{FF}}{2^{KsTo_{scale}}}$$

$$\text{If } KsTo_5 > 1023 \rightarrow KsTo_5 = KsTo_5 - 2048$$

$$KsTo_6 = \frac{EE[0x243\text{B}]\ \&\ 0x07\text{FF}}{2^{KsTo_{scale}}}$$

If $KsTo_6 > 1023 \rightarrow KsTo_6 = KsTo_6 - 2048$

$$KsTo_7 = \frac{EE[0x243\text{D}]\ \&\ 0x07\text{FF}}{2^{KsTo_{scale}}}$$

If $KsTo_7 > 1023 \rightarrow KsTo_7 = KsTo_7 - 2048$

$$KsTo_8 = \frac{EE[0x243\text{F}]\ \&\ 0x07\text{FF}}{2^{KsTo_{scale}}}$$

If $KsTo_8 > 1023 \rightarrow KsTo_8 = KsTo_8 - 2048$

Where:

$KsTo_{scale} = EE[0x2434]\ \&\ 0x07\text{FF}$ (unsigned)

11.1.11. Restoring sensitivity correction coefficients for each temperature range

$$Alpha_{corr_{range1}} = \frac{1}{\left(1 + KsTo1 * \left(CT2 - (CT1)\right)\right)} * Alpha_{corr_{range2}}$$

$$Alpha_{corr_{range2}} = \frac{1}{\left(1 + KsTo2 * \left(CT3 - (CT2)\right)\right)}$$

$$Alpha_{corr_{range3}} = 1$$

$$Alpha_{corr_{range4}} = \left(1 + KsTo3 * (CT4 - CT3)\right)$$

$$Alpha_{corr_{range5}} = \left(1 + KsTo4 * (CT5 - CT4)\right) * Alpha_{corr_{range4}}$$

$$Alpha_{corr_{range6}} = \left(1 + KsTo5 * (CT6 - CT5)\right) * Alpha_{corr_{range5}}$$

$$Alpha_{corr_{range7}} = \left(1 + KsTo6 * (CT7 - CT6)\right) * Alpha_{corr_{range6}}$$

$$Alpha_{corr_{range8}} = \left(1 + KsTo7 * (CT8 - CT7)\right) * Alpha_{corr_{range7}}$$

11.1.12. Restoring Emissivity

An emissivity parameter is stored into EEPROM and can have values from -2…1.999

$$Emissivity = EE[0x2423]\ \&\ 0x07\text{FF}$$

If $Emissivity > 1023 \rightarrow Emissivity = Emissivity - 2048$

$$Emissivity = \frac{Emissivity}{2^9}$$

Default value stored in EEPROM is $Emissivity = 1$

11.1.13. Restoring the Sensitivity α_{CP}

$$\alpha_{CP} = \frac{EE[0x242D] \,\&\, 0x07FF}{2^{\alpha_{scale_CP}}}$$

Where:

$$\alpha_{scale_CP} = EE[0x242E] \,\&\, 0x07FF$$

11.1.14. Restoring the offset of the CP

$$Off_CP = 32 * (EE[0x242F] \,\&\, 0x07FF) + EE[0x2430] \,\&\, 0x07FF \quad \text{(signed)}$$

If $Off_CP > 32767 \rightarrow Off_CP = Off_CP - 65536$

11.1.15. Restoring the Kv CP coefficient

$$K_{V_{CP}} = \frac{K_{V_{CP_EE}}}{2^{K_{V_{scale}}}}$$

$$K_{V_{scale}} = \frac{EE[0x2432] \,\&\, 0x07C0}{2^6} \text{ (unsigned)}$$

Where:

$$K_{V_{CP_EE}} = EE[0x2432] \,\&\, 0x003F \text{ (signed)}$$

If $K_{V_{CP_EE}} > 31 \rightarrow K_{V_{CP_EE}} = K_{V_{CP_EE}} - 64$

11.1.16. Restoring the Kta CP coefficient

$$K_{Ta_{CP}} = \frac{K_{Ta_{CP_EE}}}{2^{K_{Ta_{scale_1}}}}$$

$$K_{Ta_{scale_1}} = \frac{EE[0x2431] \,\&\, 0x07C0}{2^6} \text{ (unsigned)}$$

Where:

$$K_{Ta_{CP_EE}} = EE[0x2431] \,\&\, 0x003F \text{ (signed)}$$

If $K_{Ta_{CP_EE}} > 31 \rightarrow K_{Ta_{CP_EE}} = K_{Ta_{CP_EE}} - 64$

11.1.17. Restoring the TGC coefficient

$$TGC = \frac{TGC_{EE}}{2^6}$$

Where:

$$TGC_{EE} = EE[0x2433] \,\&\, 0x01FF \text{ (signed)}$$

If $TGC_{EE} > 255 \rightarrow TGC_{EE} = TGC_{EE} - 512$

11.1.18. Restoring calibration resolution control settings

For some calculation calibration resolution is needed that is why we store this parameter into EEPROM as well.

$$Resolution_{EE} = \frac{EE[0x2433]\ \&\ 0x0600}{2^9} \text{ (unsigned)}$$

11.2. Temperature calculation

11.2.1. Example input data

11.2.1.1. Example measurement data

Input data name	Input data value
Object temperature	80°C
Emissivity (ε)	0.95
Control register 1 (Res_{ctrl})	0x0901 (2 decimal)
RAM[0x0498] (pix(6, 9) data)	0x03CC (972)
Vbe - RAM[0x0580]	0x4C54 (19540)
CP - RAM[0x0588]	0xFF97 (-105)
GAIN - RAM[0x058A]	0x2606 (9734)
PTAT - RAM[0x05A0]	0x06D8 (1752)
VDD - RAM[0x05AA]	0xCB8A (-13430)

Table 10 Calculation example input data

11.2.1.2. Calibration data

EEPROM address	Calibration parameter name	Parameter value + Ham [hex]	Decoded value
0x2410	Scale_os_r1 - 6bits Scale_os_r2 - 5bits	0x0000	Scale_os_r1 = 0 Scale_os_r2 = 0
0x2411	Pix_os_r1_part_1 - 11 bits	0xB7E8	-746
0x2412	Pix_os_r1_part_2 - 11 bits	0xD016	NA
0x2413	MLX		
0x2414	MLX		
0x2415	Kta_avg - 11 bits	0xC2FD	0.00291824
0x2416	Kta_scale_1 - 6 bits Kta_scale_2 - 5 bits	0x1A43	Kta_scale_1 = 18 Kta_scale_2 = 3

0x2417	Kv_avg - 11bits	0xCA9A	0.325195313
0x2418	Kv_scale_1 - 6 bits Kv_scale_2 - 5 bits	0x5164	Kv_scale_1 = 11 Kv_scale_2 = 4
0x2419	Scale_row_1 - 6 bits Scale_row_2 - 5 bits	0x018C	Scale_row_1 = 32 Scale_row_2 = 32
0x241A	Scale_row_3 - 6 bits Scale_row_4 - 5 bits	0x018C	Scale_row_3 = 32 Scale_row_4 = 32
0x241B	Scale_row_5 - 6 bits Scale_row_6 - 5 bits	0x018C	Scale_row_5 = 32 Scale_row_6 = 32
0x241C	row1_max - 11 bits	0x9CB1	2.7962960E-07
0x241D	row2_max - 11 bits	0x956C	3.2316893E-07
0x241E	row3_max - 11 bits	0xA5CC	3.4552068E-07
0x241F	row4_max - 11 bits	0x7DD1	3.4668483E-07
0x2420	row5_max - 11 bits	0x6D7F	3.2759272E-07
0x2421	row6_max - 11 bits	0x3CD4	2.8777868E-07
0x2422	KsTa, fixed scale 15	0x27B8	-0.002197266
0x2423	Emissivity - ±2, 10 bits	0x19E6	0.94921875
0x2424	GainMeasRef_word1	0xF137	9972
0x2425	GainMeasRef_word2	0x7814	NA
0x2426	Vdd_25	0x2658	-13568
0x2427	K_Vdd	0xEF9E	-3136
0x2428	PTAT_25_W1	0x917F	12280
0x2429	PTAT_25_W2	0xF018	NA
0x242A	Kt_Ptat	0xE156	42.75
0x242B	Kv_Ptat	0x4817	0.005615234
0x242C	Alpha PTAT	0x1C80	9
0x242D	Alpha cyclops	0x233E	3.0195224E-09
0x242E	Alpha cyclop scale	0xC826	38
0x242F	Offset CP W1	0xCFFC	-119
0x2430	Offset CP W2	0xA009	NA
0x2431	Kta CP scale - 5 bits Kta CP - 6 bits	0xBB53	Kta CP scale = 13 Kta CP = -0.02319336
0x2432	Kv CP scale - 5 bits Kv CP - 6 bits	0xF194	Kv CP scale = 6 Kv CP = 0.3125

0x2433	Resolution control cal - 2 bits TGC - ±4, 9 bits	0xFC00	Resolution control cal = 2 TGC = 0
0x2434	KsTo scale - 11bits	0x7814	KsTo scale = 20
0x2435	KsTo_1 - 10 bits	0xED22	KsTo_1 = -0.0007
0x2436	KsTo_2 - 10 bits	0xED22	KsTo_2 = -0.0007
0x2437	KsTo_3 - 10 bits	0xED22	KsTo_3 = -0.0007
0x2438	KsTo_4 - 10 bits	0xED22	KsTo_4 = -0.0007
0x2439	KsTo_5 - 10 bits	0xED22	KsTo_5 = -0.0007
0x243A	CT6	0x80C8	CT6 = 200
0x243B	KsTo_6 - 10 bits	0xED22	KsTo_6 = -0.0007
0x243C	CT7	0x4190	CT6 = 400
0x243D	KsTo_7 - 10 bits	0xED22	KsTo_7 = -0.0007
0x243E	CT8	0xDA58	CT6 = 600
0x243F	KsTo_8 - 10 bits	0xED22	KsTo_8 = -0.0007

Table 11 Calculation example calibration data

11.2.2. Temperature calculation

After the parameters restore the temperature calculation is done using following calculation flow (assuming that the EEPROM data are already extracted):

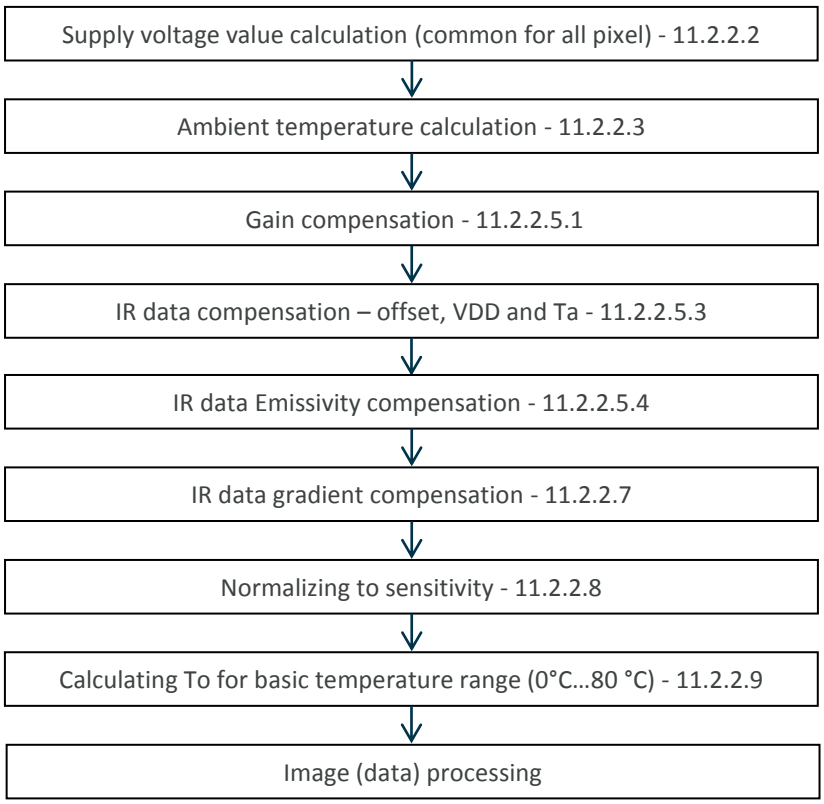


Figure 16 To calculation flow

For this example we calculate the temperature of pixel (12, 16) i.e. row=12 and the column=16.

Values marked with green are extracted from device EEPROM

Values marked with grey are final parameter values or are values to be used for next calculations

11.2.2.1. Resolution restore

The device is calibrated with default resolution setting = 2 (corresponding to ADC resolution set to 18bit see Fig 11) i.e. if the one choose to change the ADC resolution setting to a different one a correction of the data must be done. First we must restore the resolution at which the device has been calibrated which is stored at EERPOM 0x2433.

$$Resolution_{corr} = \frac{2^{Resolution_{EE}}}{2^{Resolution_{REG}}}$$

Where:

$$Resolution_{EE} = \frac{EE[0x2433] \,\&\, 0x0600}{2^9} = \frac{0xFC00 \,\&\, 0x0600}{2^9} = 0x0002 = 2 \text{ (unsigned)}$$

$$Resolution_{REG} = \frac{RAM[0x800D] \,\&\, 0x0C00}{2^{10}} = \frac{0x1901 \,\&\, 0x0C00}{2^{10}} = 0x0002 = 2 \text{ (unsigned)}$$

$$Resolution_{corr} = \frac{2^{Resolution_{EE}}}{2^{Resolution_{REG}}} = \frac{2^2}{2^2} = 1$$

In case the ADC resolution is changed the one must multiply the $Resolution_{corr}$ coefficient with the RAM data for VDD only. Please note that the data for Vbe, PTAT and IR pixels (including CP) ***must*** not be changed.

11.2.2.2. Supply voltage value calculation (common for all pixel)

$$V_{dd} = \frac{Resolution_{corr} * RAM[0x05AA] - V_{dd_{25}}}{K_{Vdd}} + V_{dd_0}$$

$$RAM[0x05AA] = 0xCB8A = 52106$$

If $52883 > 32767 \rightarrow RAM[0x05AA] = 52106 - 65536 = -13430$ LSB

Where:

$$K_{Vdd} = EE[0x2427] \,\&\, 0x07FF = 0xEF9E \,\&\, 0x07FF = 0x079E = 1950$$

If $1950 > 1023 \rightarrow K_{Vdd} = 1950 - 2048 = -98$

$$K_{Vdd} = K_{Vdd} * 2^5 = -98 * 32 = -3136$$

$$Vdd_{25} = EE[0x2426] \,\&\, 0x07FF = 0x2658 \,\&\, 0x07FF = 0x0658 = 1624$$

If $1624 > 1023 \rightarrow Vdd_{25} = 1624 - 2048 = -424$

$$Vdd_{25} = Vdd_{25} * 2^5 = -424 * 32 = -13568$$

$$V_{dd} = \frac{-13430 - (-13568)}{-3136} + 3.3 = \frac{138}{-3136} + 3.3 \approx -0.0440051 + 3.3 \approx 3.25599\ V$$

11.2.2.3. Ambient temperature calculation (common for all pixel)

$$T_a = \frac{\left(\frac{V_{PTAT_{art}}}{1+K_{V_{PTAT}}*\Delta V} - V_{PTAT_{25}}\right)}{K_{T_{PTAT}}} + 25,\ °C$$

Where:

$$K_{V_{PTAT}} = EE[0x242B] \,\&\, 0x07FF = 0x4817 \,\&\, 0x07FF = 0x0017 = 23$$

If $23 < 1023 \rightarrow K_{V_{PTAT}} = 23$

$$K_{V_{PTAT}} = \frac{K_{V_{PTAT}}}{2^{12}} = \frac{23}{4096} = 0.005615234$$

$$K_{T_{PTAT}} = EE[0x242A] \,\&\, 0x07FF = 0xE156 \,\&\, 0x07FF = 0x0156 = 342$$

If $342 < 1023 \rightarrow K_{T_{PTAT}} = 342$

$$K_{T_{PTAT}} = \frac{K_{T_{PTAT}}}{2^3} = \frac{342}{8} = 42.75$$

$$\Delta V = \frac{RAM[0x05AA] - Vdd_{25}}{K_{Vdd}}$$

$$RAM[0x05AA] = 0xCB8A = 52106$$

If $52883 > 32767 \rightarrow RAM[0x05AA] = 52106 - 65536 = -13430$ LSB

$$\Delta V = \frac{-13430 - (-13568)}{-3136} = \frac{138}{-3136} \approx -0.0440051$$

$$V_{PTAT_{25}} = 32 * (EE[0x2428] \,\&\, 0x07FF) + EE[0x2429] \,\&\, 0x07FF \text{ (unsigned)}$$

$$V_{PTAT_{25}} = 32 * (0x917F \,\&\, 0x07FF) + 0xF018 \,\&\, 0x07FF$$

$$V_{PTAT_{25}} = 32 * 0x017F + 0x0018 = 32 * 383 + 24 = 12256 + 24 = 12280$$

$$V_{PTAT_{art}} = \left(\frac{V_{PTAT}}{V_{PTAT} * Alpha_{PTAT} + V_{BE}}\right) * 2^{18}$$

Where:

$V_{PTAT} = RAM[0x05A0]$ = 0x06D8 = 1752

If $1752 < 32767 \rightarrow V_{PTAT} = 1752$

$V_{BE} = RAM[0x0580] =$ 0x4C54 $= 19540$

If $19540 < 32767 \rightarrow V_{BE} = 19540$

$$Alpha_{PTAT} = \frac{EE[0x242C] \,\&\, 0x07FF}{2^7} = \frac{0x1C80 \,\&\, 0x07FF}{2^7} = \frac{0x0480}{2^7} = \frac{1152}{128} = 9$$

$$V_{PTAT_{art}} = \left(\frac{V_{PTAT}}{V_{PTAT} * Alpha_{PTAT} + V_{BE}}\right) * 2^{18} = \left(\frac{1752}{1752 * 9 + 19540}\right) * 2^{18} = 13007.71$$

$$T_a = \frac{\left(\frac{V_{PTAT_{art}}}{1 + K_{V_{PTAT}} * \Delta V} - V_{PTAT_{25}}\right)}{K_{T_{PTAT}}} + 25 = \frac{\left(\frac{13007.71}{1 + 0.005615234 * -0.0440051} - 12280\right)}{42.75} + 25 = 17.022 + 25 \approx 42.02 \text{ °C}$$

11.2.2.4. Gain parameter calculation (common for all pixels)

$$K_{gain} = \frac{GAIN}{RAM[0x058A]}$$

$$RAM[0x058A] = 0x2606 = 9734$$

If $9734 < 32767 \rightarrow RAM[0x058A] = 9734$ LSB

$$GAIN = 32 * (EE[0x2424] \,\&\, 0x07FF) + EE[0x2425] \,\&\, 0x07FF \text{ (unsigned)}$$

$$GAIN = 32 * (0xF137 \,\&\, 0x07FF) + 0x7814 \,\&\, 0x07FF$$

$$GAIN = 32 * 0x0137 + 0x0014 = 32 * 311 + 20 = 9952 + 20 = 9972$$

$$K_{gain} = \frac{9972}{9734} = 1.02445038$$

11.2.2.5. Pixel data calculations

The pixel addressing is following the pattern described in Reading pattern as shown in Fig 5:

11.2.2.5.1. Gain compensation

$$pix_{gain}(6,9) = RAM[pixel\ data] * K_{gain} = RAM[0x0498] * K_{gain}$$

$$RAM[0x0498] = 0x03CC = 972$$

If $972 < 32767$ → $RAM[0x0498] = 972$

$$pix_{gain}(6,9) = 972 * 1.02445038 = 995.761767708547$$

11.2.2.5.2. Offset calculation

$$pix_{OS_{ref_SP0}}(6,9) = Offset_{average} + offset_{SP0}(6,9) * 2^{Offset_{scale}}$$

$$Offset_{average} = 32 * (EE[0x2411] \,\&\, 0x07FF) + EE[0x2412] \,\&\, 0x07FF$$

$$Offset_{average} = 32 * (0xB7E8 \,\&\, 0x07FF) + 0xD016 \,\&\, 0x07FF$$

$$Offset_{average} = 32 * 0x07E8 + 0x0016 = 32 * 2024 + 22 = 64768 + 22 = 64790$$

If $64790 < 32767$ → $Offset_{average} = 64790 - 65536 = -746$

$$offset_{SP0}(6,9) = EE[0x2498] \,\&\, 0x07FF = 0xF849 \,\&\, 0x07FF = 0x0049 = 73$$

If $73 < 1023$ → $offset_{SP0}(6,9) = 73$

$$Offset_{scale} = \frac{EE[0x2410] \,\&\, 0x07E0}{2^5} \text{ (unsigned)}$$

$$Offset_{scale} = \frac{0x0000 \,\&\, 0x07E0}{2^5} = \frac{0}{32} = 0$$

$$pix_{OS_{ref_SP0}}(6,9) = -746 + 73 * 2^0 = -673 \text{ LSB}$$

11.2.2.5.3. IR data compensation – offset, VDD and Ta

$$pix_{OS_SP0}(6,9) = pix_{gain}(6,9) - pix_{OS_{ref_SP0}} * \left(1 + K_{Ta(6,9)} * (T_a - T_{a0})\right) * \left(1 + K_{V(6,9)} * \left(V_{dd} - V_{dd_{V0}}\right)\right)$$

The same calculation must be done for the second subpage as well

$$pix_{OS_{ref_SP1}}(6,9) = Offset_{average} + offset_{SP1}(6,9) * 2^{Offset_{scale}}$$

$$offset_{SP1}(6,9) = EE[0x26D8] \,\&\, 0x07FF = 0xF847 \,\&\, 0x07FF = 0x0047 = 71$$

If $71 < 1023$ → $offset_{SP1}(6,9) = 71$

$$pix_{OS_{ref_SP1}}(6,9) = -746 + 71 * 2^0 = -671 \text{ LSB } (Offset_{average} \text{ and } Offset_{scale} \text{ are the same for both subpages})$$

$$pix_{OS_SP1}(6,9) = pix_{gain}(6,9) - pix_{OS_{ref_SP1}} * \left(1 + K_{Ta(6,9)} * (T_a - T_{a0})\right) * \left(1 + K_{V(6,9)} * \left(V_{dd} - V_{dd_{V0}}\right)\right)$$

NOTE: In the example bellow calculation are done for subpage 0 only

$$K_{Ta(6,9)} = \frac{K_{Ta_{EE}(6,9)} * 2^{K_{Ta_{scale2}}} + K_{Ta_{AVERAGE}}}{2^{K_{Ta_{scale1}}}}$$

Where:

$K_{Ta_{EE}(6,9)} = \frac{EE[0x2618] \,\&\, 0x07E0}{2^5}$ (depending on pixel number)

$K_{Ta_{EE}(6,9)} = \frac{0xB8C0 \,\&\, 0x07E0}{2^5} = \frac{0x00C0}{2^5} = \frac{192}{32} = 6$

If $6 < 31 \rightarrow K_{Ta_{EE}(6,9)} = 6$

$K_{Ta_{AVERAGE}} = EE[0x2415] \,\&\, 0x07FF = 0xC2FD \,\&\, 0x07FF = 02FD = 765$

If $765 < 1023 \rightarrow K_{Ta_{AVERAGE}} = 765$

$K_{Ta_{scale1}} = \frac{EE[0x2416] \,\&\, 0x07E0}{2^5}$ (unsigned)

$K_{Ta_{scale1}} = \frac{0x9A44 \,\&\, 0x07E0}{2^5} = \frac{0x0240}{2^5} = \frac{576}{32} = 18$

$K_{Ta_{scale2}} = EE[0x2416] \,\&\, 0x001F$ (unsigned)

$K_{Ta_{scale2}} = 0x1A43 \,\&\, 0x001F = 0x0003 = 3$

$$K_{Ta(6,9)} = \frac{K_{Ta_{EE}(6,9)} * 2^{K_{Ta_{scale2}}} + K_{Ta_{AVERAGE}}}{2^{K_{Ta_{scale1}}}} = \frac{6 * 2^3 + 765}{2^{18}} = 0.003101349$$

$$K_{V(6,9)} = \frac{K_{V_{EE}(6,9)} * 2^{K_{V_{scale2}}} + K_{V_{AVERAGE}}}{2^{K_{V_{scale1}}}}$$

Where:

$K_{V_{EE}(6,9)} = EE[0x2618] \,\&\, 0x001F$ (depending on pixel number)

$K_{V_{EE}(6,9)} = 0xB8C0 \,\&\, 0x001F = 0x0000 = 0$

If $0 < 15 \rightarrow K_{V_{EE}(6,9)} = 0$

$K_{V_{AVERAGE}} = EE[0x2417] \,\&\, 0x07FF$

$K_{V_{AVERAGE}} = 0xCA9A \,\&\, 0x07FF = 0x029A = 666$

If $666 < 1023 \rightarrow K_{V_{AVERAGE}} = 666$

$K_{Ta_{scale1}} = \frac{EE[0x2418] \,\&\, 0x07E0}{2^5}$ (unsigned)

$K_{Ta_{scale1}} = \frac{0x5164 \,\&\, 0x07E0}{2^5} = \frac{0x0160}{2^5} = \frac{352}{32} = 11$

$$K_{Ta_{scale2}} = EE[0x2418] \,\&\, 0x001F \text{ (unsigned)}$$

$$K_{Ta_{scale2}} = 0x5164 \,\&\, 0x001F = 0x0004 = 4$$

$$K_{V(6,9)} = \frac{K_{V_{EE}(6,9)} * 2^{K_{V scale2}} + K_{V_{AVERAGE}}}{2^{K_{V scale1}}} = \frac{0 * 2^4 + 666}{2^{11}} = 0.3251953$$

$$pix_{OS_SP0}(6,9) = pix_{gain}(6,9) - pix_{OS_{ref}} * \left(1 + K_{Ta(6,9)} * (T_a - T_{a0})\right) * \left(1 + K_{V(6,9)} * (V_{dd} - V_{dd_{V0}})\right)$$

$$pix_{OS_SP0}(6,9) = 995.761767708547 - (-673) * \left(1 + 0.00310135 * (42.02 - 25)\right) * \left(1 + 0.3251953 * (3.25599 - 3.3)\right)$$

$$pix_{OS_SP0}(6,9) = 995.761767708547 - (-673) * \left(1 + 0.00310135 * (42.02 - 25)\right) * \left(1 + 0.3251953 * (3.25599 - 3.3)\right)$$

$$pix_{OS_SP0}(6,9) = 1694.145767$$

11.2.2.5.4. IR data Emissivity compensation

$$Emissivity = EE[0x2423] \,\&\, 0x07FF = 0x19E6 \,\&\, 0x07FF = 0x01E6 = 486$$

If $486 < 1023 \rightarrow Emissivity = 486$

$$Emissivity = \frac{Emissivity}{2^9} = \frac{486}{512} = 0.949218$$

11.2.2.6. CP data calculations

11.2.2.6.1. Compensating the GAIN of CP pixel

$$pix_{gain}(6,9) = RAM[0x0588] * K_{gain}$$

$$RAM[0x0588] = 0xFF97 = 65431$$

If $65431 > 32767 \rightarrow RAM[0x0588] = 65431 - 65536 = -105$

$$CP\ pix_{gain} = -105 * 1.02445038 = -107.5672899$$

11.2.2.6.2. Compensating offset, Ta and VDD of CP pixel

$$CP\ pix_{OS} = CP\ pix_{gain} - pix_{OS_{ref_CP}} * \left(1 + K_{Ta_CP} * (T_a - T_{a0})\right) * \left(1 + K_{V_CP} * (V_{dd} - V_{dd_{V0}})\right)$$

$$pix_{OS_{ref_CP}} = 32 * (EE[0x242F] \,\&\, 0x07FF) + EE[0x2430] \,\&\, 0x07FF$$

$$pix_{OS_{ref_CP}} = 32 * (0xCFFC \,\&\, 0x07FF) + 0xA009 \,\&\, 0x07FF$$

$$pix_{OS_{ref_CP}} = 32 * 0x07FC + 0x0009 = 32 * 2044 + 9 = 65408 + 9 = 65417$$

If $65417 < 32767 \rightarrow pix_{OS_{ref_CP}} = 65417 - 65536 = -119$

$$K_{V_{CP}} = \frac{K_{V_{CP_EE}}}{2^{K_{V scale}}} = \frac{20}{2^6} = 0.3125$$

$$K_{V_{scale}} = \frac{EE[0x2432] \,\&\, 0x07C0}{2^6} = \frac{0xF194 \,\&\, 0x07C0}{2^6} = \frac{0x0180}{2^6} = \frac{384}{2^6} = 6 \text{ (unsigned)}$$

Where:

$K_{V_{CP_EE}} = EE[0x2432]$ & $0x003F$ (signed)

$K_{V_{CP_EE}} = 0xF194$ & $0x003F = 0x0014 = 20$ (signed)

If $20 < 31 \rightarrow K_{V_{CP_EE}} = 20$

$K_{Ta_{CP}} = \frac{K_{Ta_{CP_EE}}}{2^{K_{Ta_{scale_1}}}} = \frac{19}{2^{13}} = 0.0023193359$

$K_{Ta_{scale_1}} = \frac{EE[0x2431] \,\&\, 0x07C0}{2^6} = \frac{0xBB53 \,\&\, 0x07C0}{2^6} = \frac{0x0340}{2^6} = \frac{832}{2^6} = 13$ (unsigned)

Where:

$K_{Ta_{CP_EE}} = EE[0x2431]$ & $0x003F = 0xBB53$ & $0x003F = 0x0013 = 19$ (signed)

If $19 < 31 \rightarrow K_{Ta_{CP_EE}} = 19$

$CP\ pix_{OS} = -107.5672899 - (-119) * \left(1 + 0.0023193359 * (42.02 - 25)\right) * \left(1 + 0.3125 * (3.25599 - 3.3)\right)$

$CP\ pix_{OS} = 14.42901896$

11.2.2.7. IR data gradient compensation

$TGC = \frac{TGC_{EE}}{2^6} = \frac{0}{2^6} = 0$

Where:

$TGC_{EE} = EE[0x2433]$ & $0x01FF = 0xFC00$ & $0x01FF = 0x0000 = 0$ (signed)

If $0 < 255 \rightarrow TGC_{EE} = 0$

$V_{IR(6,9)_{COMPENSATED}} = \frac{pix_{OS_SP_0}(6,9) - TGC * CP\ pix_{OS}}{\varepsilon} = \frac{1694.145767 - 0 * 14.42901896}{0.949218} = 1784.78049 = 1785$

11.2.2.8. Normalizing to sensitivity

$\alpha_{(i,j)} = \frac{\alpha_{pixel}(6,9)}{2^{11}-1} * \alpha_{reference}$

The row for the pixel is calculated as follows:

$Pixel_{row} = int\left(\frac{((16*(row_{number}-1)+column_{number})-1)}{32}\right) + 1 = int\left(\frac{((16*(6-1)+9)-1)}{32}\right) + 1 = int\left(\frac{88}{32}\right) + 1 = 3$

$\alpha_{reference_{row3}} = \frac{EE[0x241E] \,\&\, 0x07FF}{2^{\alpha_{scale_{row3}}}}$

$\alpha_{scale_{row3}} = \frac{EE[0x241A] \,\&\, 0x07E0}{2^5} + 20 = \frac{0x018C \,\&\, 0x07E0}{2^5} + 20 = \frac{0x0180}{32} + 20 = \frac{384}{32} + 20 = 32$

$\alpha_{reference_{row3}} = \frac{EE[0x241E] \,\&\, 0x07FF}{2^{\alpha_{scale_{row3}}}} = \frac{0xA5CC \,\&\, 0x07FF}{2^{32}} = \frac{0x05CC}{2^{32}} = \frac{1484}{2^{32}} = 3.45520675182343E-07$

$\alpha_{pixel}(6,9) = EE[0x2558]$ & $0x07FF = 0xFFFF$ & $0x07FF = 0x07FF = 2047$

$\alpha_{(6,9)} = \frac{\alpha_{pixel}(6,9)}{2^{11}-1} * \alpha_{reference} = \frac{2047}{2047} * 3.45520675182343E-07 = 3.45520675182343E-07$

$$\alpha_{CP} = \frac{EE[0x242D] \,\&\, 0x07FF}{2^{\alpha_{scale_{CP}}}}$$

$$\alpha_{scale_{CP}} = EE[0x242E] \,\&\, 0x07FF = 0xC826 \,\&\, 0x07FF = 0x0026 = 38$$

$$\alpha_{CP} = \frac{EE[0x242D] \,\&\, 0x07FF}{2^{38}} = \frac{0x233E \,\&\, 0x07FF}{2^{38}} = \frac{0x033E}{2^{38}} = \frac{830}{2^{38}} = 3.01952240988612E-09$$

$$KsTa = EE[0x2422] \,\&\, 0x07FF = 0x27B8 \,\&\, 0x07FF = 0x07B8 = 1976$$

If $1976 > 1023 \rightarrow KsTa = 1976 - 2048 = -72$

$$KsTa = \frac{KsTa}{2^{15}} = \frac{-72}{2^{15}} = -0.002197265625$$

$$\alpha_{comp(6,9)} = \left(\alpha_{(6,9)} - TGC * \alpha_{CP}\right) * \left(1 + K_{sTa} * (T_a - T_{a0})\right)$$

$$\alpha_{comp(6,9)} = (3.45520675182343E-07 - 0 * 3.01952240988612E-09) * \left(1 + (-0.00219) * (42.02 - 25)\right)$$

$$\alpha_{comp(6,9)} = 3.32641806639731E-07$$

11.2.2.9. Calculating To for basic temperature range (0°C...80 °C)

$$KsTo_3 = EE[0x2437] \,\&\, 0x07FF = 0xED22 \,\&\, 0x07FF = 0x0522 = 1314$$

If $1314 > 1023 \rightarrow KsTo_3 = 1314 - 2048 = -734$

$$KsTo_3 = \frac{-734}{2^{20}} = -0.000699997$$

Where:

$KsTo_{scale} = EE[0x2434] \,\&\, 0x07FF$ (unsigned)

$KsTo_{scale} = 0x7814 \,\&\, 0x07FF = 0x0014 = 20$

As the IR signal received by the sensor has two components:

1. IR signal emitted by the object
2. IR signal reflected from the object (the source of this signal is surrounding environment of the sensor)

In order to compensate correctly for the emissivity and achieve best accuracy we need to know the surrounding temperature which is responsible for the second component of the IR signal namely the reflected part - T_r. In case this T_r temperature is not available and cannot be provided it might be replaced by $T_r \approx T_a - 5$.
Let's assume $T_r = 37$°C.

$$T_{a_{K^4}} = (T_a + 273.15)^4 = (42.02 + 273.15)^4 = 315.87^4 = 9866871831.80621$$

$$T_{rK4} = (T_r + 273.15)^4 = (37 + 273.15)^4 = 304.15^4 = 9253097577.685506$$

$$T_{a-r} = T_{rK4} - \frac{T_{rK4} - T_{aK4}}{\varepsilon} = 9253097577.685506 - \frac{9253097577.685506 - 9866871831.80621}{0.95} = 9899175739.92$$

$$S_{x(6,9)} = K_{sTo_3} * \sqrt[4]{\alpha_{comp(6,9)}{}^3 * V_{IR(6,9)_{COMPENSATED}} + \alpha_{comp(6,9)}{}^4 * T_{a-r}}$$

$$S_{x(6,9)} = -0.000699997 * \sqrt[4]{3.32641806639731E-07^3 * 1785 \; + 3.32641806639731E-07^4 * 9899175739.92}$$

$$S_{x(6,9)} = -8.18463664533495E-08$$

$$T_{O(6,9)} = \sqrt[4]{\frac{V_{IR(6,9)COMPENSATED}}{\alpha_{comp(6,9)} * \left(1 - K_{sTo_3} * 273.15\right) + S_{x(6,9)}} + T_{a-r}} - 273.15$$

$$T_{O(6,9)} = \sqrt[4]{\frac{1785}{3.32641806639731E-07 * \left(1 - (-0.000699997 * 273.15)\right) + -8.184636645335E-08} + 9899175739.92} - 273.15$$

$$T_{O(6,9)} = \sqrt[4]{\frac{1785}{3.143979442416E-07} + 9899175739.92} - 273.15$$

$$T_{O(6,9)} = \sqrt[4]{15576693779.3773} - 273.15 = 353.279812 - 273.15 = \mathbf{80.12}\ °C$$

11.2.2.9.1. Calculations for extended temperature ranges

In order to extent the object temperature range and get the best possible accuracy an additional calculation cycle is needed. We can identify 8 object temperature ranges (each temperature range has its own so called **C**orner **T**emperature – CT which is the temperature at which the range starts):

- Object temperature range 1 = -40°C … -20°C (Corner temperature for this range is -40°C and cannot be changed)
- Object temperature range 2 = -20°C … 0°C (Corner temperature for this range is -20°C and cannot be changed)
- Object temperature range 3 = 0°C … 80°C (Corner temperature for this range is 0°C and cannot be changed)
- Object temperature range 4 = 80°C … 120°C (Corner temperature for this range is 80°C and cannot be changed)
- Object temperature range 5 = 120°C … CT6°C(Corner temperature for this range is 120°C and cannot be changed)
- Object temperature range 6 = CT6°C … CT7°C
- Object temperature range 7 = CT7°C … CT8°C
- Object temperature range 8 = CT8°C …

In order to be able to carry out temperature calculation for the ranges outside of temperature range 3 (To = 0°C…80°C) an additional parameters are needed and must be extracted from the device EEPROM. Those parameters are:

- So called corner temperature (CTx) i.e. the value of temperature at the beginning of the range. Please note that the corner temperatures for range 1 is fixed to -40°C, corner temperatures for range 2 is fixed to -20°C, corner temperatures for range 3 is fixed to 0°C, corner temperatures for range 4 is fixed to 80°C , corner temperatures for range 5 is fixed to 120°C while CT6, CT7 and CT8 are adjustable
- Sensitivity slope for each range – $KsTo_x$
- $T_{O(x,y)}$ calculated in 11.2.2.9

11.2.2.9.1.1. Restoring corner temperatures

The information regarding corner temperatures is stored into device EEPROM and is restored as follows:

$$CT6 = EE[0x243A] \,\&\, 0x07FF = 0x80C8 \,\&\, 0x07FF = 0x00C8 = 200°C$$

$$CT7 = EE[0x243C] \,\&\, 0x07FF = 0x4190 \,\&\, 0x07FF = 0x0190 = 400°C$$

$$CT8 = EE[0x243E] \,\&\, 0x07FF = 0xDA58 \,\&\, 0x07FF = 0x0258 = 600°C$$

Or we can construct the temperatures for the ranges as follows:

CT1 = -40°C (hard codded) **< Range 1 >** CT2 = -20°C (hard codded) **< Range 2 >** CT3 = 0°C (hard codded) **< Range 3 >** CT4 = 80°C (hard codded) **< Range 4 >** CT5 = 120°C (hard codded) **< Range 5 >** CT6 **< Range 6 >** CT7 **< Range 7 >** CT8 **< Range 8**

11.2.2.9.1.2. Restoring the sensitivity slope for each range

$Ks_{To_{scale}} = 20$ has been extracted in 11.1.10

$KsTo_1 = EE[0x2435]\ \&\ 0x07FF = 0xED22\ \&\ 0x07FF = 0x0522 = 1314$

If $1314 > 1023 \rightarrow KsTo_1 = 1314 - 2048 = -734$

$$KsTo_1 = \frac{-734}{2^{20}} = -0.000699997$$

$KsTo_2 = EE[0x2436]\ \&\ 0x07FF = 0xED22\ \&\ 0x07FF = 0x0522 = 1314$

If $1314 > 1023 \rightarrow KsTo_2 = 1314 - 2048 = -734$

$$KsTo_2 = \frac{-734}{2^{20}} = -0.000699997$$

$KsTo_4 = EE[0x2438]\ \&\ 0x07FF = 0xED22\ \&\ 0x07FF = 0x0522 = 1314$

If $1314 > 1023 \rightarrow KsTo_4 = 1314 - 2048 = -734$

$$KsTo_4 = \frac{-734}{2^{20}} = -0.000699997$$

$KsTo_5 = EE[0x2439]\ \&\ 0x07FF = 0xED22\ \&\ 0x07FF = 0x0522 = 1314$

If $1314 > 1023 \rightarrow KsTo_5 = 1314 - 2048 = -734$

$$KsTo_5 = \frac{-734}{2^{20}} = -0.000699997$$

$KsTo_6 = EE[0x243B]\ \&\ 0x07FF = 0xED22\ \&\ 0x07FF = 0x0522 = 1314$

If $1314 > 1023 \rightarrow KsTo_6 = 1314 - 2048 = -734$

$$KsTo_6 = \frac{-734}{2^{20}} = -0.000699997$$

$KsTo_7 = EE[0x243D]\ \&\ 0x07FF = 0xED22\ \&\ 0x07FF = 0x0522 = 1314$

If $1314 > 1023 \rightarrow KsTo_7 = 1314 - 2048 = -734$

$$KsTo_7 = \frac{-734}{2^{20}} = -0.000699997$$

$KsTo_8 = EE[0x243F]\ \&\ 0x07FF = 0xED22\ \&\ 0x07FF = 0x0522 = 1314$

If $1314 > 1023 \rightarrow KsTo_8 = 1314 - 2048 = -734$

$$KsTo_8 = \frac{-734}{2^{20}} = -0.000699997$$

Now we can calculate sensitivity correction coefficients for each temperature range:

$$Alpha_{corr_{range1}} = \frac{1}{\left(1 + KsTo1 * \left(CT2 - (CT1)\right)\right)} * Alpha_{corr_{range2}}$$

$$Alpha_{corr_{range1}} = \frac{1}{\left(1 - 0.000699997 * \left(-20 - (-40)\right)\right)} * 1.014198721 = 1.014198721 * 1.014198721 = 1.028599$$

$$Alpha_{corr_{range2}} = \frac{1}{\left(1 + KsTo2 * \left(CT3 - (CT2)\right)\right)} = \frac{1}{\left(1 - 0.000699997 * \left(0 - (-20)\right)\right)} = 1.014198721$$

$$Alpha_{corr_{range3}} = 1$$

$$Alpha_{corr_{range4}} = \left(1 + KsTo3 * (CT4 - CT3)\right) = \left(1 - 0.000699997 * (80 - 0)\right) = 0.94400024$$

$$Alpha_{corr_{range5}} = \left(1 + KsTo4 * (CT5 - CT4)\right) * Alpha_{corr_{range4}}$$

$$Alpha_{corr_{range5}} = \left(1 - 0.000699997 * (120 - 80)\right) * 0.94400024 = 0.917568347$$

$$Alpha_{corr_{range6}} = \left(1 + KsTo5 * (CT6 - CT5)\right) * Alpha_{corr_{range5}}$$

$$Alpha_{corr_{range6}} = \left(1 - 0.000699997 * (200 - 120)\right) * 0.917568347 = 0.86618474$$

$$Alpha_{corr_{range7}} = \left(1 + KsTo6 * (CT7 - CT6)\right) * Alpha_{corr_{range6}}$$

$$Alpha_{corr_{range7}} = \left(1 - 0.000699997 * (400 - 200)\right) * 0.86618474 = 0.744919396$$

$$Alpha_{corr_{range8}} = \left(1 + KsTo7 * (CT8 - CT7)\right) * Alpha_{corr_{range7}}$$

$$Alpha_{corr_{range8}} = \left(1 - 0.000699997 * (600 - 400)\right) * 0.744919396 = 0.640631128$$

11.2.2.9.1.3. Extended To range calculation

The input parameter for this calculation is the object temperature calculated in Calculating To for basic temperature range (0°C…80 °C).

If $T_{O(i,j)}$ < -20°C we are in range 1 and we will use the parameters (Ks_{To1}, $Alpha_{corr_{range1}}$ and $CT1 = -40°C$)
If -20°C < $T_{O(i,j)}$ < -40°C we are in range 2 and we will use the parameters (Ks_{To2}, $Alpha_{corr_{range2}}$ and $CT2 = -20°C$)
If 0°C < $T_{O(i,j)}$ < 80°C we are in range 3 and we will use the parameters (Ks_{To3}, $Alpha_{corr_{range3}}$ and $CT3 = 0°C$)
If 80°C < $T_{O(i,j)}$ < 120°C we are in range 4 and we will use the parameters (Ks_{To4}, $Alpha_{corr_{range4}}$ and $CT4 = 80°C$)
If 120°C < $T_{O(i,j)}$ < CT6°C we are in range 5 and we will use the parameters (Ks_{To5}, $Alpha_{corr_{range5}}$ and $CT5 = 120°C$)
If CT6°C < $T_{O(i,j)}$ < CT7°C we are in range 6 and we will use the parameters (Ks_{To6}, $Alpha_{corr_{range6}}$ and $CT6 = 200°C$)
If CT7°C < $T_{O(i,j)}$ < CT8°C we are in range 7 and we will use the parameters (Ks_{To7}, $Alpha_{corr_{range7}}$ and $CT7 = 400°C$)
If CT8°C < $T_{O(i,j)}$ we are in range 8 and we will use the parameters (Ks_{To8}, $Alpha_{corr_{range8}}$ and $CT8 = 600°C$)

$$T_{O_{extra_range}(i,j)} = \sqrt[4]{\frac{V_{IR(i,j)_{COMPENSATED}}}{\alpha_{comp(i,j)} * ALpha_{corr_{rangeX}} * \left(1 + Ks_{ToX} * \left(T_{O(i,j)} - \mathrm{CT_X}\right)\right)} + T_{a-r}} - 273.15$$

12. Performance graphs

12.1. Accuracy

12.1.1. Pixel accuracy

All accuracy specifications apply under settled isothermal conditions only.
Furthermore, the accuracy is only valid if the object fills the FOV of the sensor completely.

Parameter definitions:
Frame accuracy is defined as average value of the all (768) pixels in the frame or for frame n can be expressed as:

$$\overline{T_o_frame(n)} = \frac{1}{768}\sum_{m=1}^{768} T_o(m,n)$$

$$Frame\ accuracy = \overline{T_o_frame(n)} - T_{target}$$

Non-uniformity is defined as the maximum deviation of each individual pixel reading vs. the absolute accuracy.

$$Non\ Uniformity = MAX\left(\left|T_o(m) - \overline{T_o_frame(n)}\right|\right)$$

Pixel absolute accuracy is defined as:

$$T_{O_{accuracy(n)}} = Frame\ accuracy + Non\ Uniformity$$

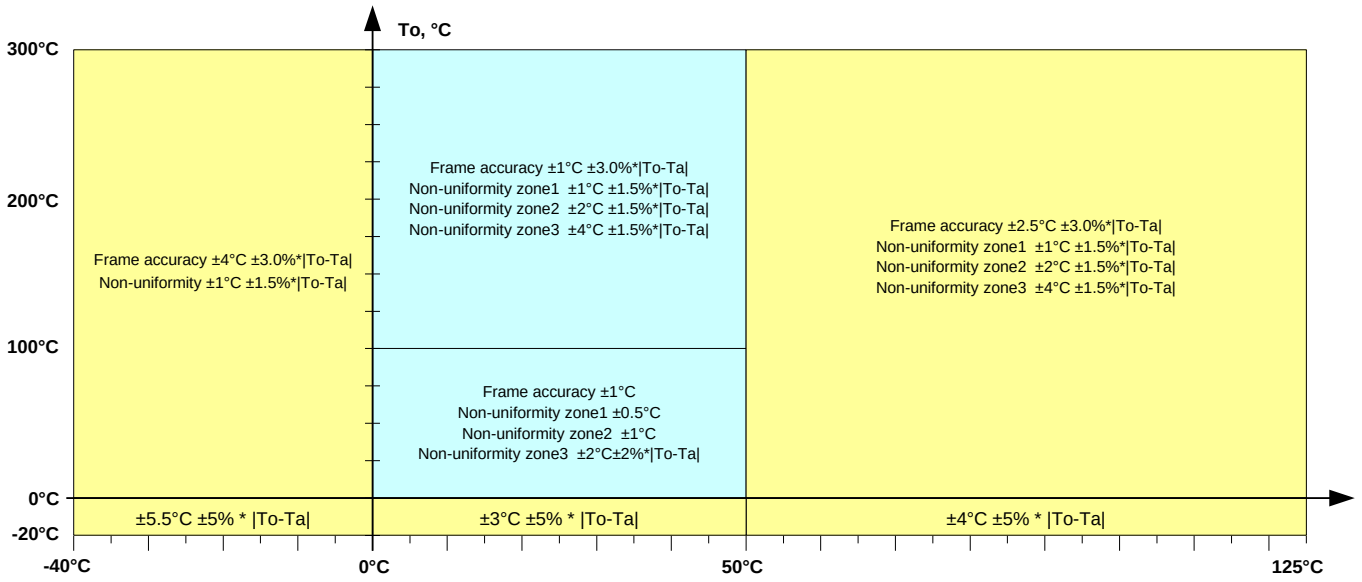


Figure 17 Temperature absolute accuracy - MLX90641BCA

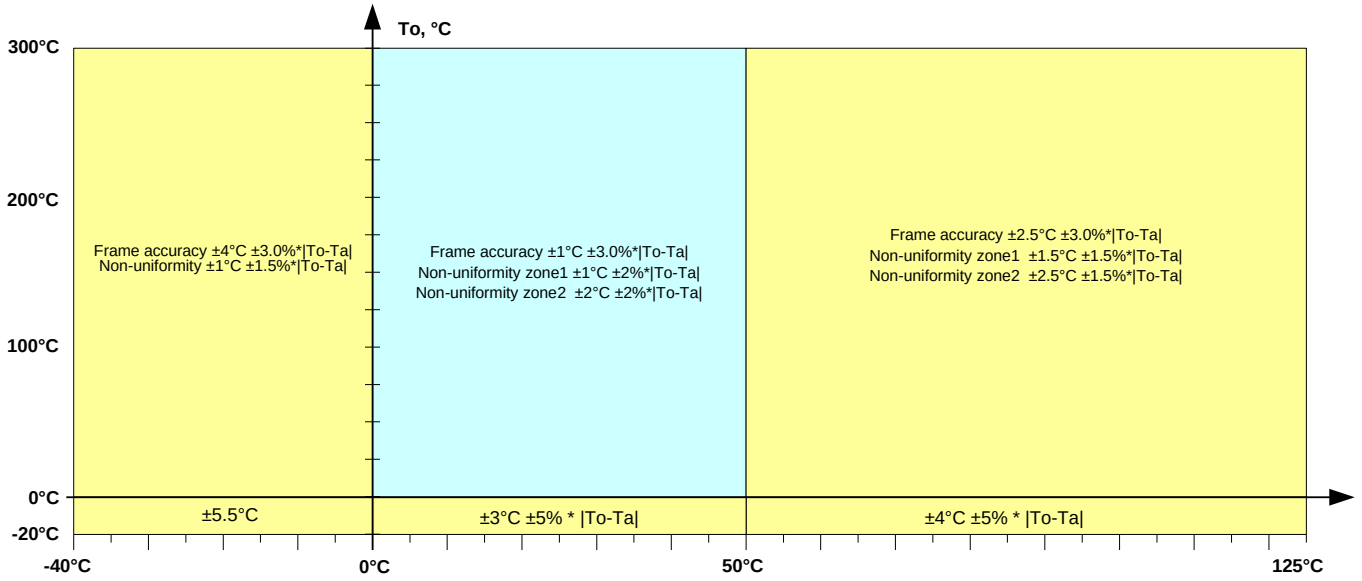


Figure 18 Temperature absolute accuracy - MLX90641BCB

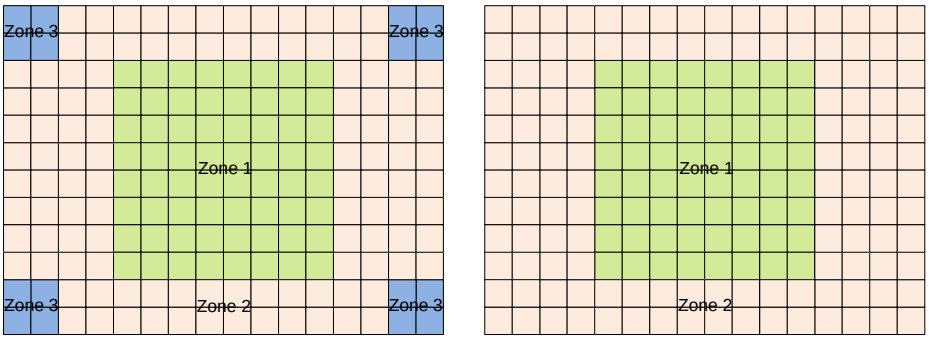


Figure 19 Different accuracy zones depending on device type (BCA on the left and BCB on the right)

Example: If we assume that the sensor (BCA type, zone 1) is measuring a target at 80°C that would mean that there should be no pixel with error bigger than:

$$T_{O_{accuracy(n)}} = Frame\ accuracy + Non\ Uniformity = \pm 1 \pm 0.5 = \pm 1.5°C$$

NOTES:

1) *For best performance it is recommended to keep the supply voltage as accurate and stable as possible to 3.3V ± 0.05V*
2) *As a result of long term (years) drift there can be an additional measurement deviation of ± 3°C for object temperatures around room temperature.*

12.1.2. Ta accuracy

Absolute accuracy for the Ta channel (die temperature):

$$T_{A_{accuracy}} = \pm 0.5°C$$

NOTE: Actual sensor surrounding temperature would be approximately 5°C lower

12.2. Startup time

12.2.1. First valid data

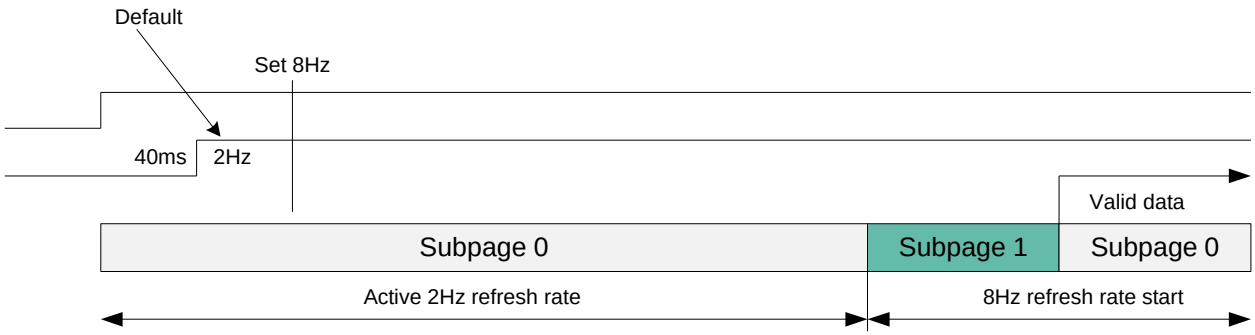
After POR the first valid data is available after (depending on the selected refresh rate) T_{valid_data} which is calculated as:

$$T_{valid_data} = 80 + 2 * 500, \text{ ms} \quad \text{(Example refresh rate is 2Hz – the default value)}$$

It is always subpage 0 to be measured first after POR then subpage 1 and so on alternating.

***NOTE1**: In case one changes the refresh rate on the fly (by writing new values into device register (0x800D)) the settings will take place only after the subpage under measurement is finished.*

***NOTE2**: Although the first subpage is ready after 500ms it is necessary to have data from both subpages in order to be able to calculate the Ta meaning that the valid data are only possible after twice the refresh rate after POR.*



12.2.2. Thermal behavior

Although electrically the device is set and running there is thermal stabilization time necessary before the device can reach the specified accuracy – up to 3 min.

12.3. Noise performance and resolution

There are two bits in the configuration register that allow changing the resolution of the MLX90641 measurements. Increasing the resolution decreases the quantization noise and improves the overall noise performance. Measurement conditions for the noise are: To=Ta=25°C

NOTE: Due to the nature of the thermal infrared radiation, it is normal that the noise will decrease for high temperature and increase for lower temperatures

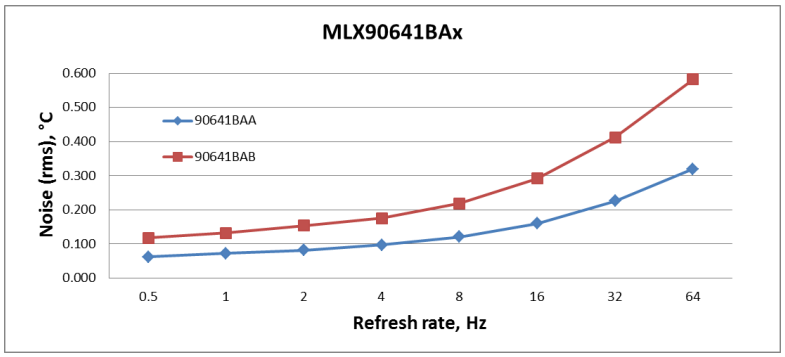


Figure 20 MLX90641BCx noise vs refresh rate for different device types

Not all pixels have the same noise performance. Because of the optical performance of the integrated lens, it is normal that the pixels in the corner of the frame are noisier in comparison with the pixels in the middle. The graphs bellow show the distribution of the noise density versus the pixel position in the frame (pixel number)

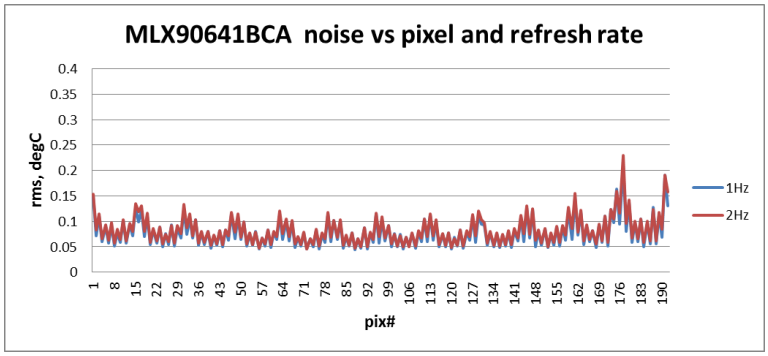


Figure 21 MLX90641BCA noise vs pixel and refresh rate at 1Hz and 2Hz

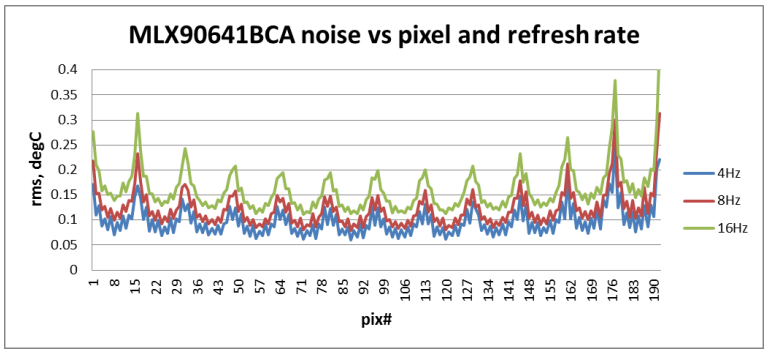


Figure 22 MLX90641BCA noise vs pixel and refresh rate at 4Hz, 8Hz and 16Hz

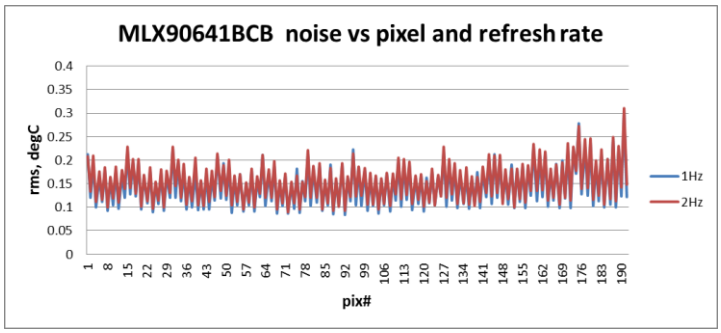


Figure 23 MLX90641BCB noise vs pixel and refresh rate at 1Hz and 2Hz

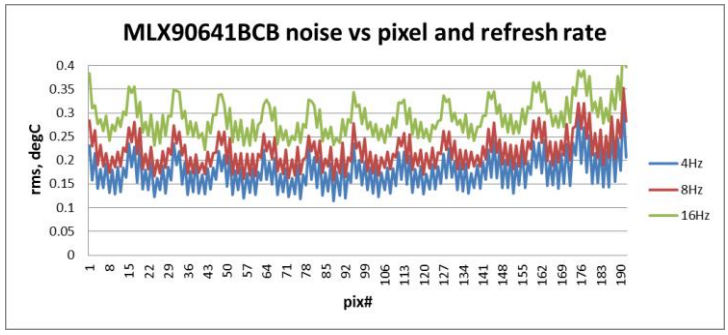


Figure 24 MLX90641BCB noise vs pixel and refresh rate at 4Hz, 8Hz and 16Hz

NETD (K)	1Hz RMS noise (temperature equivalent), all pixels		
MLX90641	Average	Min	Standard deviation
BCA	0.07	0.04	0.03
BCB	0.15	0.07	0.05

Table 12 Noise performance

12.4. Field of view (FOV)

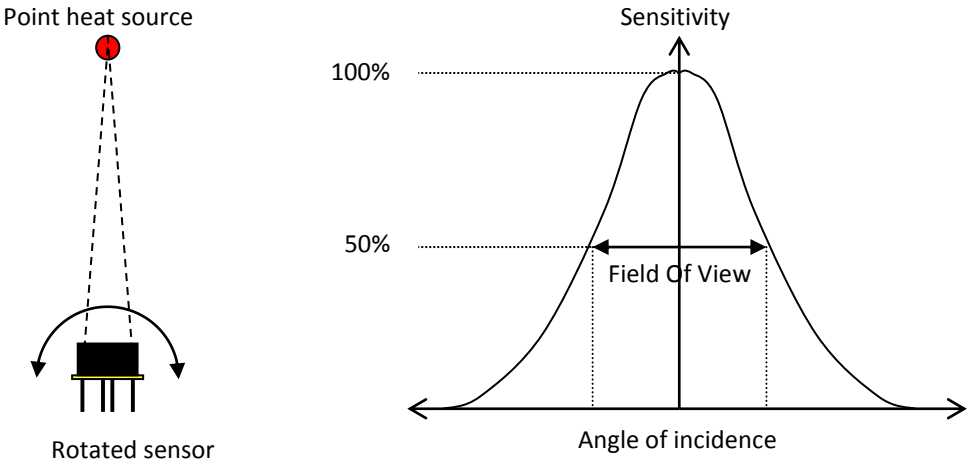


Figure 25 Field Of View measurement

The specified FOV is calculated for the wider direction, in this case for the 16 pixels.

FOV	X direction	Y direction	Central pointing from normal (X & Y direction)
	Typ	Typ	Max
MLX90641-ESF-BCA	110°	75°	5°
MLX90641-ESF-BCB	55°	35°	3°

Table 13 Available FOV options

13. Application information

13.1. Optical considerations

As this is an optical device a care must be taking such that the device performs according to the specification. One such parameter is FOV obstruction. It is paramount that the FOV in the optical path is kept clear. The external aperture is designed such to shape the FOV of the device and is installed prior calibration process thus cam be considered as part of the device which does not impact the performance but may be used as a reference for the so called “Optical free zone” – see Figure 27 hereafter.

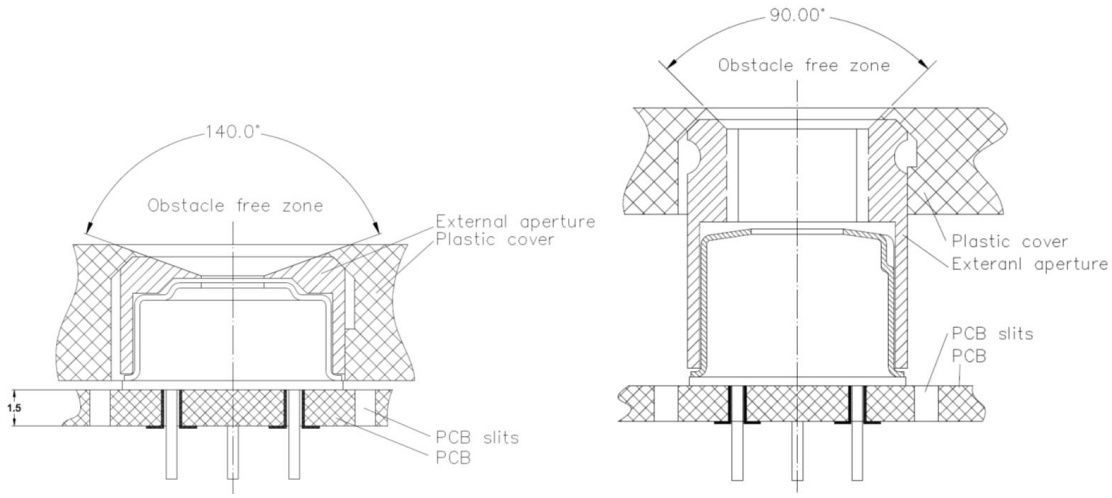


Figure 26 Application examples concerning the optical consideration

13.2. Electrical considerations

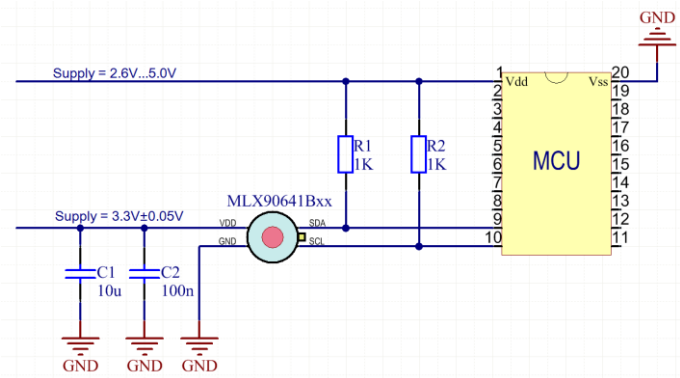


Figure 27 MLX90641Bxx electrical connections

As the MLX90641Bxx is fully I2C compatible it allows to have a system in which the MCU may be supplied with VDD=2.6V…5V while the sensor it’s self is supplied from separate supply VDD1=3.3V (or even left with no supply i.e. VDD=0V), **with the I2C connection running at supply voltage of the MCU.**

13.3. Using the device in “image mode”

In some applications may not be necessary to calculate the temperature but rather to have just and image (for instance in machine vision systems). In this case it is not necessary to carry out all calculations which would save computation time or allow the one to use weaker CPU.

In order to get thermal image only following computation flow is to be used:

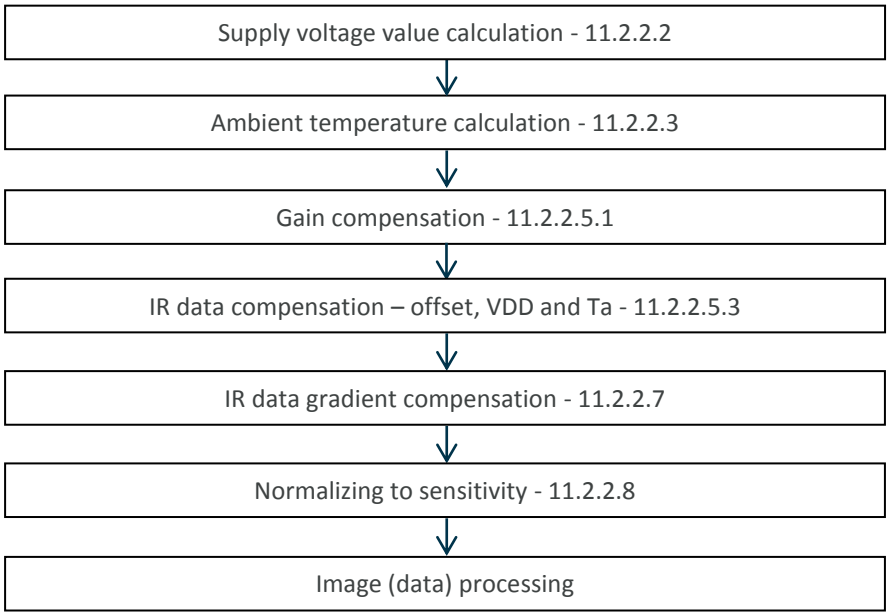


Figure 28 Calculation flow in thermal image mode

14. Application Comments

Significant **contamination** at the optical input side (sensor filter) might cause unknown additional filtering/distortion of the optical signal and therefore result in unspecified errors.

IR sensors are inherently susceptible to errors caused by **thermal gradients**. There are physical reasons for these phenomena and, in spite of the careful design of the MLX90641Bxx, it is recommended not to subject the MLX90641Bxx to heat transfer and especially transient conditions.

The MLX90641Bxx is designed and calibrated to operate as a non-contact thermometer in **settled conditions**. Using the thermometer in a very different way will result in unknown results.

Capacitive loading on an I2C can degrade the communication. Some improvement is possible with use of current sources compared to resistors in pull-up circuitry. Further improvement is possible with specialized commercially available bus accelerators. With the MLX90641Bxx additional improvement is possible by increasing the pull-up current (decreasing the pull-up resistor values). Input levels for I2C compatible mode have higher overall tolerance than the I2C specification, but the output low level is rather low even with the high-power I2C specification for pull-up currents. Another option might be to go for a slower communication (clock speed), as the MLX90641Bxx implements Schmidt triggers on its inputs in I2C compatible mode and is therefore not really sensitive to rise time of the bus (it is more likely the rise time to be an issue than the fall time, as far as the I2C systems are open drain with pull-up).

Power dissipation within the package may affect performance in two ways: by heating the “ambient” sensitive element significantly beyond the actual ambient temperature, as well as by causing gradients over the package that will inherently cause thermal gradient over the cap

Power supply decoupling capacitor is needed as with most integrated circuits. MLX90641Bxx is a mixed-signal device with sensors, small signal analog part, digital part and I/O circuitry. In order to keep the noise low power supply switching noise needs to be decoupled. High noise from external circuitry can also affect noise performance of the device. In many applications a 100nF SMD plus 10µF ceramic capacitors close to the Vdd and Vss pins would be a good choice. It should be noted that not only the trace to the Vdd pin needs to be short, but also the one to the Vss pin. Using MLX90641Bxx with short pins improves the effect of the power supply decoupling.

Check www.melexis.com for most recent application notes about MLX90641Bxx.

15. Mechanical drawings

15.1. FOV 55°

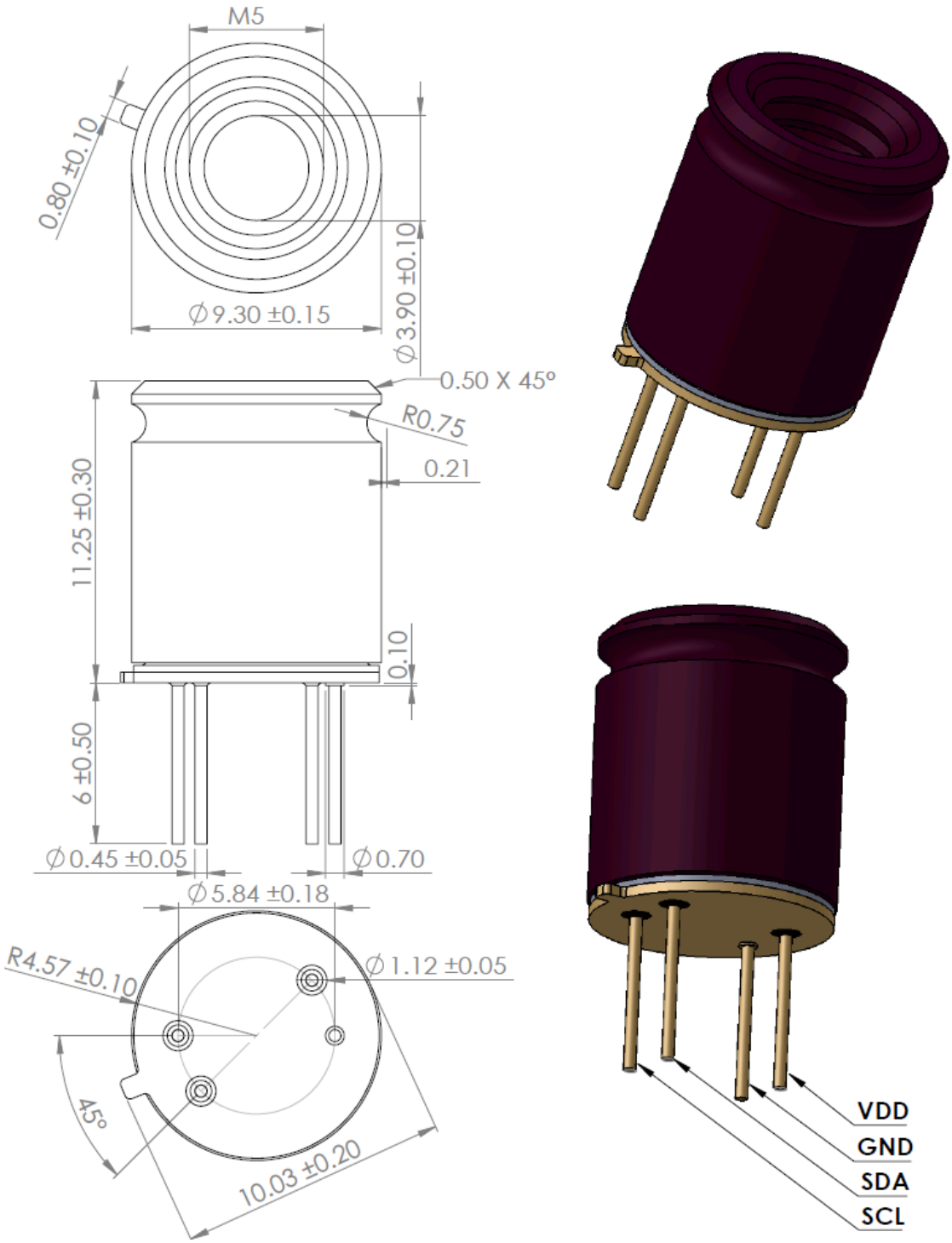


Figure 29 Mechanical drawing of 55° FOV device

15.2. FOV 110°

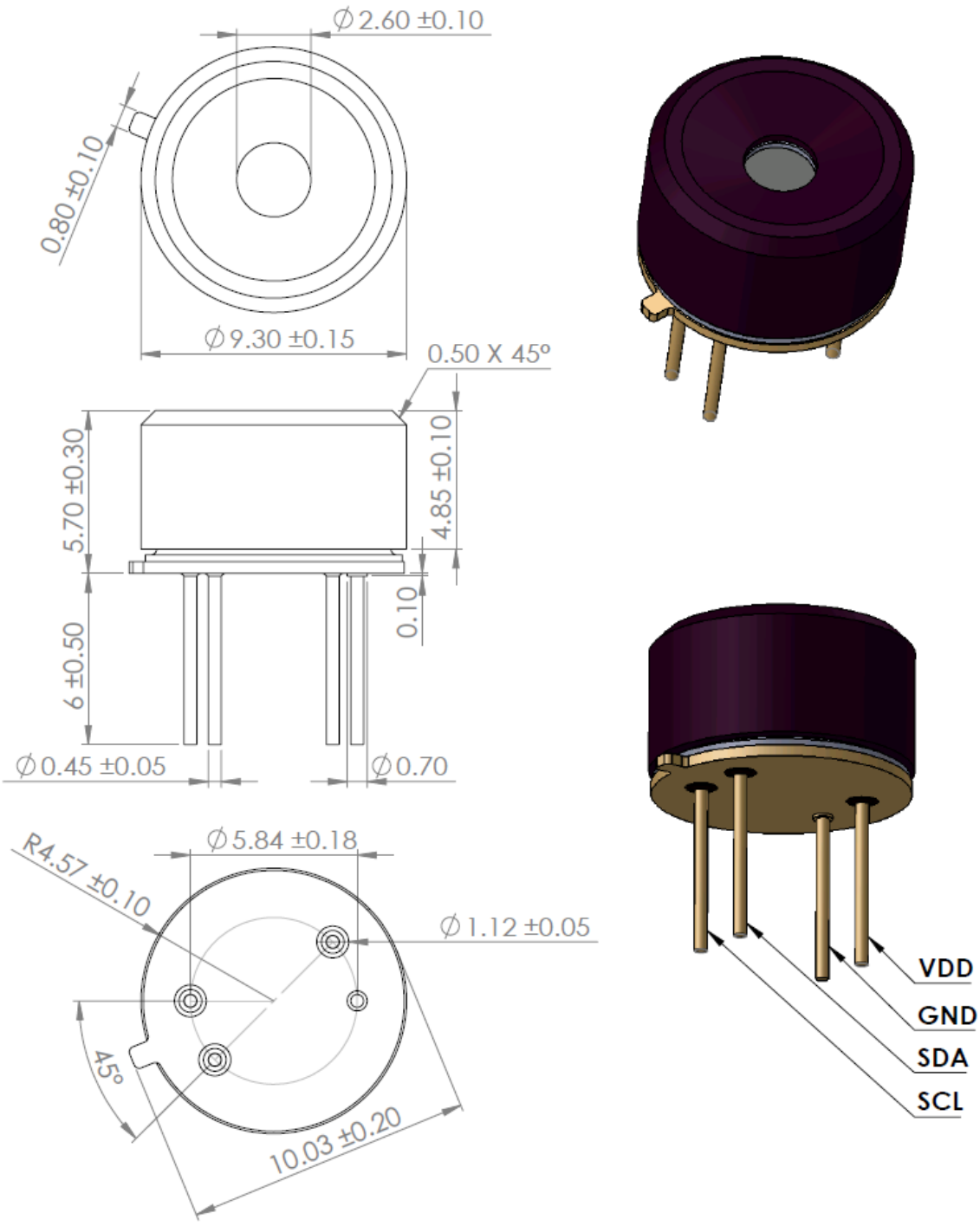


Figure 30 Mechanical drawing of 110° FOV device

15.3. Device marking

The MLX90641 is laser marked with 10 symbols as follows.

1	A	A	xxxxx	xx	**Laser marking**
					2 digits Split number
				5 digits LOT number	
		A	FOV = 110°		
		B	FOV = 55°		
	A	Device without thermal gradient compensation (TGC = 0 and may not be changed)			
	C	Device with thermal gradient compensation (TGC = -4…+3.992)			
1	MLX90641				

- Example: “1CA1052801” – Device type MLX90641BCA from lot 10528, sub LOT split 1 and Thermal Gradient Compensation activated.

16. Standard Information

Our products are classified and qualified regarding soldering technology, solderability and moisture sensitivity level according to standards in place in Semiconductor industry.

For further details about test method references and for compliance verification of selected soldering method for product integration, Melexis recommends reviewing on our web site the General Guidelines soldering recommendation. For all soldering technologies deviating from the one mentioned in above document (regarding peak temperature, temperature gradient, temperature profile etc), additional classification and qualification tests have to be agreed upon with Melexis.

For package technology embedding trim and form post-delivery capability, Melexis recommends to consult the dedicated trim&form recommendation application note: lead trimming and forming recommendations

Melexis is contributing to global environmental conservation by promoting **lead free** solutions. For more information on qualifications of **RoHS** compliant products (RoHS = European directive on the Restriction Of the use of certain Hazardous Substances) please visit the quality page on our website: http://www.melexis.com/en/quality-environment

17. ESD Precautions

Electronic semiconductor products are sensitive to Electro Static Discharge (ESD).
Always observe Electro Static Discharge control procedures whenever handling semiconductor products.

18. Revision History Table

25/07/2016	Initial release
12/08/2016	Calibration data stored into EEPROM, pixel reading modes explained
13/01/2017	Added CP data extraction, example updated, accuracy table
01/02/2017	Kta(i,j) and Kv(i,j) coefficients extraction from EEPROM corrected
15/12/2017	Overall rework
12/04/2018	extra temperature ranges calculations, new approach of Emissivity compensation
08/11/2018	Driver link, Max temp = 300°C, ESD = 4kV, step mode removed, FOV added,
06/02/2019	Emissivity compensation changed, added absolute accuracy for Ta
06/12/2019	Rev 3: long term accuracy note, optical consideration, package chamfer info, note regarding max current trough SDA driver, docserver number in the footer

Table 14 Revision history

19. Contact

For the latest version of this document, go to our website at www.melexis.com.

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