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MLX90621

16x4 IR array

Datasheet

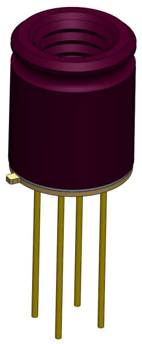
Features and Benefits

- Small size, low cost 16x4 pixels IR array
- Easy to integrate
- Industry standard four lead TO39 package
- Factory calibrated infrared temperature measurement.
  Calibration parameters stored in EEPROM.
- Noise Equivalent Temperature Difference (NETD) 0.20K RMS @4Hz refresh rate
- I^2C compatible digital interface
- Programmable frame rate 0.5Hz…512Hz
- 2.6V supply voltage
- Current consumption less than 9mA
- Sleep mode consumption less than 7µA
- Measurement start trigger for synchronization with external control unit
- 3 FOV - 40°x10°, 60°x16° and 120°x25°
- Ta -40°C to 85°C
- To -20°C to 300°C
- Complies with RoHS regulations

Applications Examples

- High precision non-contact temperature measurements;
- Temperature sensing element for residential, commercial and industrial building air conditioning;
- Microwave ovens
- Home appliances with temperature control;
- Thermal Comfort sensor in automotive Air Conditioning control system;
- Passenger classification
- Automotive blind angle detection;
- Industrial temperature control of moving parts;
- Identifying thermal leaks in homes
- Thermal scanners
- Security / safety gates
- Intrusion / Movement detection;
- Presence detection / Person localization

Ordering Information



Part No.	Temperature Code	Package Code	Option Code - X X X	Standard part	Packing form
MLX90621	E (-40°C to 85°C)	SF (TO-39)	(1) (2) (3)	-000	-TU

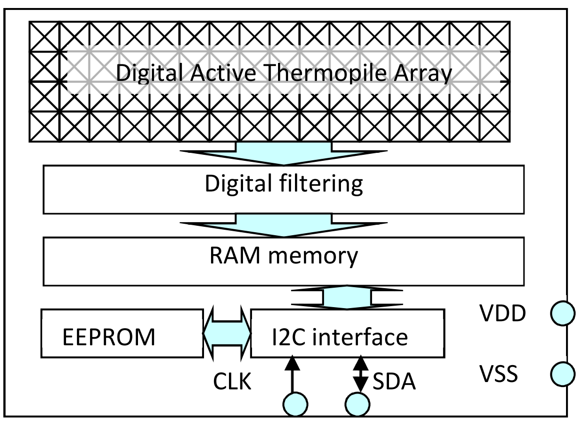
(1) Supply Voltage
B = 2.6V

(2) Number of thermopiles:
A = 16X4

(3) Package options:
A = 120°x25° FOV
B = 60°x16° FOV
C = reserved
D = 40°x10° FOV

Example:
MLX90621ESF-BAB-000-TU

Functional diagram



General Description

The MLX90621 is a fully calibrated 16x4 pixels IR array in an industry standard 4-lead TO-39 package. It contains 2 chips in one package: the MLX90670 (IR array with signal conditioning electronics) and the 24AA02 (256x8 EEPROM) chip.

The MLX90621 contains 64 IR pixels with dedicated low noise chopper stabilized amplifier and fast ADC integrated. A PTAT (Proportional To Absolute Temperature) sensor is integrated to measure the ambient temperature of the chip. The outputs of both IR and PTAT sensors are stored in internal RAM and are accessible through I^2C.

General Description (continued)

The results of the infrared sensor measurements are stored in RAM:

- 15...18-bit result of IR measurement for each individual sensor (64 words)
- 15…18-bit result of PTAT sensor

Depending on the application, the external microcontroller can read the different RAM data and, based on the calibration data stored in the EEPROM memory, compensate for difference between sensors to build up a thermal image, or calculate the temperature at each spot of the imaged scene.
These constants are accessible by the user microcontroller through the I2C bus and have to be used for external post processing of the thermal data. This post processing includes:

- Ta calculation
- Pixel offset cancelling
- Pixel to pixel sensitivity difference compensation
- Object emissivity compensation
- Object temperature calculation

The result is an image with NETD better than 0.1K RMS at 1Hz refresh rate.
The refresh rate of the array is programmable by means of register settings or directly via I2C command. Changes of the refresh rate have a direct impact on the integration time and noise bandwidth (faster refresh rate means higher noise level). The frame rate is programmable in the range 0.5Hz…512Hz and can be changed to achieve the desired trade-off between speed and accuracy.
The MLX90621 requires a single 2.6V…3.2V although the device is calibrated and performs best at VDD=2.6V.

The MLX90621 is factory calibrated in following temperature ranges:

- -40˚C…85˚C for the ambient temperature sensor
- -50˚C…300˚C for the object temperature.

NOTE: The sensor can detect higher temperatures, but is not calibrated for temperatures above 300°C.
See Table 21 for configuration specific properties.

Each pixel of the array measures the average temperature of all objects in its own Field Of View (called nFOV).

It is very important for the application designer to understand that the accuracy of the temperature measurement is very sensitive to the thermal equilibrium isothermal conditions (there are no temperature differences across the sensor package). The accuracy of the thermometer can be influenced by temperature differences in the package induced by causes like (among others): Hot electronics behind the sensor, heaters/coolers behind or beside the sensor or by a hot/cold object very close to the sensor that not only heats the sensing element in the thermometer but also the thermometer package.

1. Table of contents

2. Glossary of terms

POR	**P**ower **O**n **R**eset
PTAT	**P**roportional **T**o **A**bsolute **T**emperature sensor (package temperature)
IR	**I**nfra **R**ed
IR_data	**I**nfrared **data** (raw data from ADC proportional to IR energy received by the sensor)
ADC	**A**nalog To **D**igital **C**onverter
Ta	**A**mbient **T**emperature measured from the chip – (the package temperature)
To	**O**bject **T**emperature, 'seen' from IR sensor
TGC	**T**emperature **G**radient **C**oefficient
FOV	**F**ield **O**f **V**iew
nFOV	**F**ield **O**f **V**iew of N-th pixel
ESD	**E**lectro-**S**tatic **D**ischarge
EMC	**E**lectro-**M**agnetic **C**ompatibility
I^2C	**I**nter-**I**ntegrated **C**ircuit communication protocol
SDA	**S**erial **Da**ta
SCL	**S**erial **Cl**ock
FpS	**F**rames **per** **S**econd – data refresh rate
MD	**M**aster **D**evice
SD	**S**lave **D**evice
TBD	**T**o **B**e **D**efined
NA	**N**ot **A**pplicable

Table 1 Glossary of terms

3. Absolute Maximum ratings

Parameter	MLX90621
Supply Voltage, V_{DD} (over voltage)	5.5V
Supply Voltage, V_{DD} (operating max)	3.6V
Reverse Voltage (each pin)	-0.3 V
Operating Temperature Range, T_A	-40…+85°C
Storage Temperature Range, T_S	-40…+125°C
ESD Sensitivity (AEC Q100 002)	4kV
DC sink current, SDA	50 mA
DC source current, SDA	NA (open drain)
DC clamp current, SDA	25 mA
DC source current, SCL	NA (input only)
DC clamp current, SCL	25 mA

Table 2 Absolute maximum ratings for MLX90621

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

4. Pin definition and description

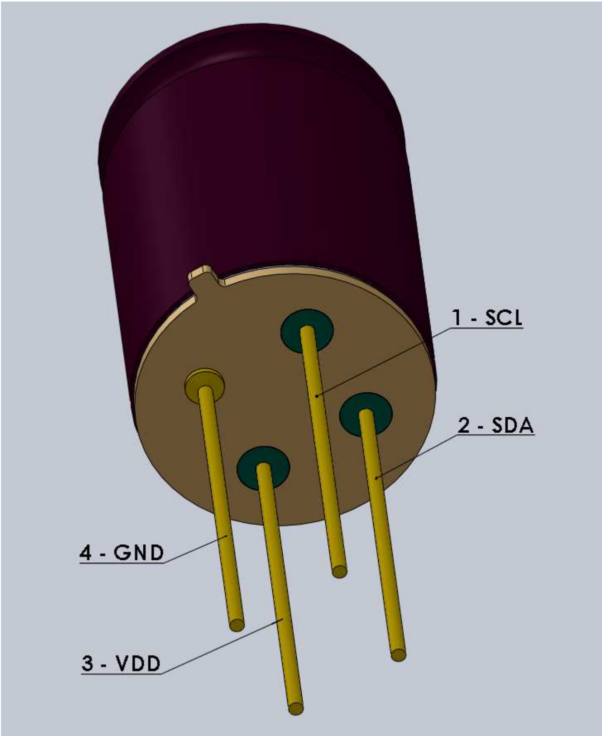


Figure 1 Pin description

Pin Name	Function
SCL	Serial clock input for 2 wire communications protocol
SDA	Digital input / output 2 wire communications protocol.
VDD	External supply voltage
VSS	Ground (case)

Table 3 Pin description for MLX90621

5. Electrical characteristics

All parameters are valid for T_A = 25˚C, V_{DD} =2.6V (unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
Supplies						
External supply[1]	V_{DD}		2.5	2.6	3.3	V
Supply current	I_{DD}	No load		5	9	mA
Sleep current	I_{slp}	No load			7	µA
Power On Reset						
POR level	V_{POR_up}	Power-up (full temp range)	2	2.2	2.4	V
POR level	V_{POR_down}	Power –down (full temp range)	1.9	2.1	2.3	V
POR hysteresis	V_{POR_hys}	Full temp range		0.1		V
V_{DD} rise time (10% to 90% of specified supply voltage)	T_{POR}	Ensure POR signal	100			µs
I^2C compatible 2-wire interface Sensor chip						
Slave address	SA	Factory default		60		hex
Input high voltage	V_{IH} (Ta, V)	Over temperature and supply	0.7VDD			V
Input low voltage	V_{IL} (Ta, V)	Over temperature and supply			0.3VDD	V
Output low voltage	V_{OL}	SDA over temperature and supply, Isink = 6mA (FM mode)			0.6	V
Output low voltage	V_{OL}	SDA over temperature and supply, Isink = 20mA (FM+ mode)			0.4	V
SCL leakage	I_{SCL}, leak	V_{SCL}=4V, Ta=+85°C			2	µA
SDA leakage	I_{SDA}, leak	V_{SDA}=4V, Ta=+85°C			2	µA
SCL capacitance	C_{SCL}	Two dies MLX90670 + EEPROM			20	pF
I^2C clock frequency	SCL_{IR}	MLX90621 (FM+ mode)			1	MHz
Acknowledge setup time	Tsuac(MD)	8-th SCL falling edge, Master			0.45	µs
Acknowledge hold time	Thdac(MD)	9-th SCL falling edge, Master			0.45	µs
Acknowledge setup time	Tsuac(SD)	8-th SCL falling edge, Slave			0.45	µs
Acknowledge hold time	Thdac(SD)	9-th SCL falling edge, Slave			0.45	µs
EEPROM						
Slave address	SA	Factory default		50		hex
I^2C clock frequency	SCL_{EEPROM}	EEPROM (FM mode)			400	kHz
Data retention		Ta = +85°C	200			years
Erase/write cycles		Ta = +25°C	1M			Times
Erase/write cycles		Ta = +125°C	100K			Times
Erase cell time	T_erase				5	ms
Write cell time	T_write				5	ms

Table 4 Electrical specification parameters of MLX90621

1) The device can be supplied with VDD = 2.6…3.3V but the best performance is achieved at VDD=2.6V. For supply voltages above 2.7V a compensation algorithm should be applied for compensating the temperature readings.

6. Block diagram

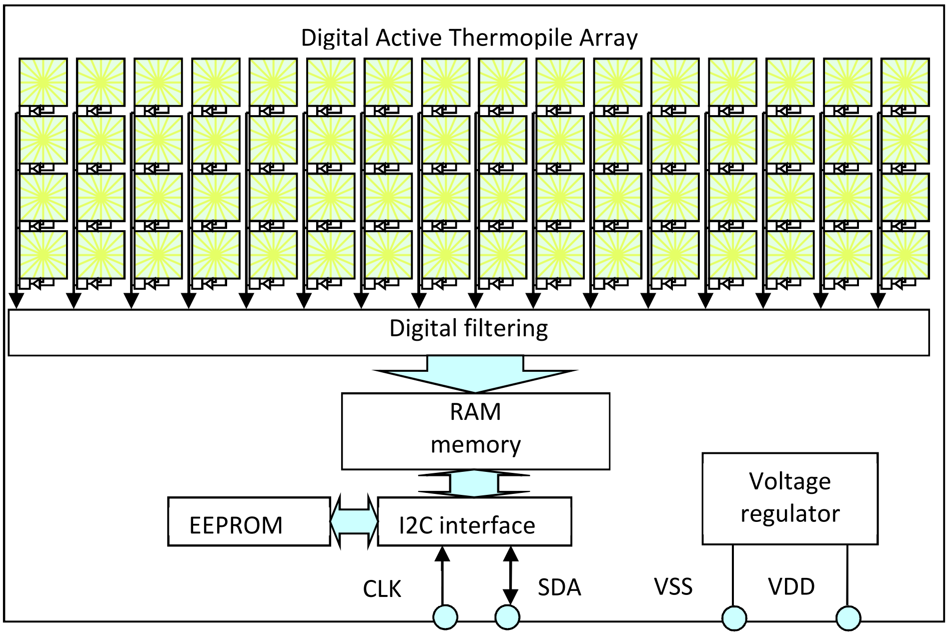


Figure 2 Block diagram

The device consists of 2 chips packed in single TO-39 package

- IR array and processing electronics
- EEPROM chip

7. Principle of operation

The output of all IR sensors and absolute temperature sensors is scanned according to the programmed refresh rate. Using their output data as well as calibration constants written in EEPROM the absolute chip temperature and object temperature, 'seen' by each pixel can be calculated. For this goal several sequential calculations must be done according to the Figure 3 Operation block diagram

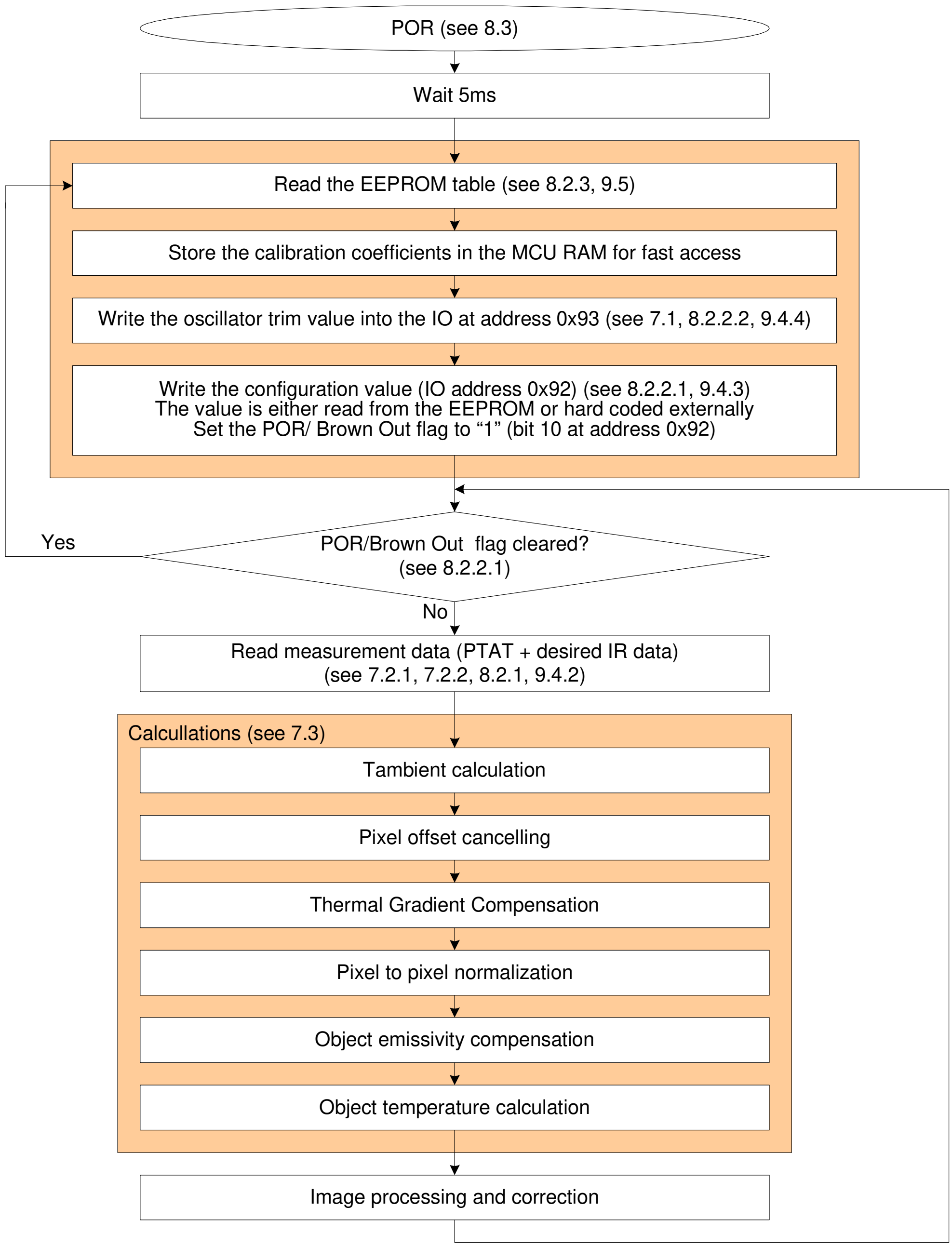


Figure 3 Operation block diagram

7.1. Initialization

After the POR is released the external MCU must execute an initialization procedure.
This procedure must start at least 5ms after POR release.

- **Read the whole EEPROM** (see Figure 4). For maximum speed performance MELEXIS recommends that the whole calibration data is stored into the client MCU RAM. However it is possible to read the calibration data from the EEPROM only when needed during calculations. This will result in increased time for temperature calculation i.e. low refresh rate.

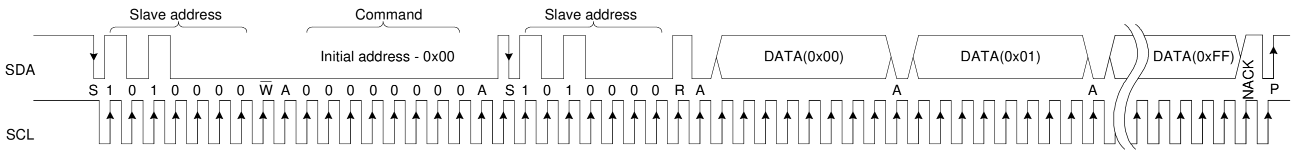


Figure 4 Whole EEPROM dump (SA = 0x50, command = 0x00)

- **Store the EEPROM content into customer MCU RAM** – This step could be omitted resulting in more data processing time because calibration data needs to be reread for each calculation

- **Write the oscillator trimming value** (extracted from EEPROM content at address 0xF7) into the corresponding register (0x93).

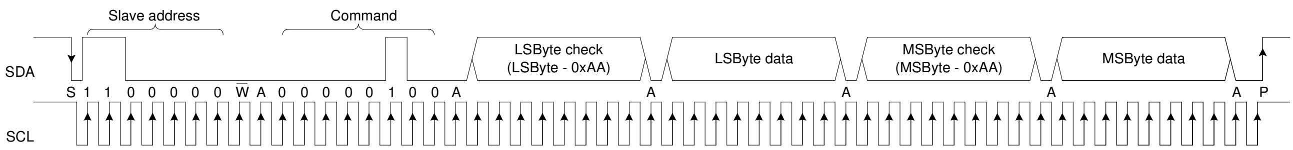


Figure 5 Write oscillator trimming (SA = 0x60, command = 0x04)

Example: If the value that has to be uploaded is 0x0052 the following sequence must be sent:

1. Start condition (Falling edge of SDA while SCL is high)
2. Slave address (SA=0x60) plus write bit = 0xC0
3. Command = 0x04
4. LSByte check = LSByte – 0xAA = 0x52 – 0xAA = 0xA8
5. LSbyte = 0x52
6. MSByte check = MSByte – 0xAA = 0x00 – 0xAA = 0x56
7. MSbyte = 0x00
8. Stop condition (Rising edge of SDA while SCL is high)

- **Write device configuration value**. In EEPROM addresses (0xF5 and 0xF6) MELEXIS provides a typical value of the configuration register (0x463E). So it is up to the user to copy that value or hardcode a new value to be loaded into the configuration register. If the EEPROM value is to be used the 16 bits are combined as follows:

  For example: if EEPROM 0xF5 = 0x3E and 0xF6 = 0x46, the Configuration register value is:

$$Configuration\ Register\ value = \{0xF6: 0xF5\}$$

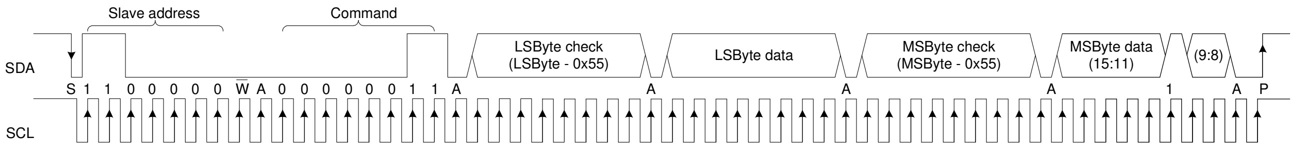


Figure 6 Write configuration register (SA = 0x60, command = 0x03)

NOTE: The user must ensure that the bit 10 (POR or Brown-out flag) in Configuration register is set to "1" by the MD. Furthermore, this bit must be checked regularly and if it is cleared it indicates that the device has been reset and the initialisation procedure must be redone.

Example: If the value that has to be uploaded is 0x463E the following sequence must be sent:

1. Start condition (Falling edge of SDA while SCL is high)
2. Slave address (SA=0x60) plus write bit = 0xC0
3. Command = 0x03
4. LSByte check = LSByte – 0x55 = 0x3E – 0x55 = 0xE9
5. LSbyte = 0x3E
6. MSByte check = MSByte – 0x55 = 0x46 – 0x55 = 0xF1
7. MSbyte = 0x46
8. Stop condition (Rising edge of SDA while SCL is high)

The default configuration is:

- IR and Ta refresh rate = 1Hz;
- Normal mode (no sleep);
- I^2C FM+ mode enabled (maximum bit transfer up to 1000 Kbit/s);
- ADC low reference enabled;

7.1.1. Reading configuration

7.1.1.1 Reading configuration register (EEPROM data)

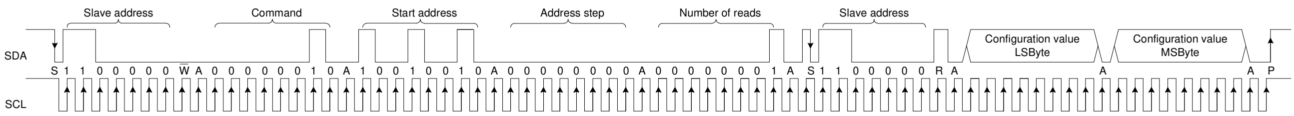


Figure 7 Reading configuration register (SA = 0x60, command = 0x02,

Start address = 0x92, Address step = 0x00, Number of reads = 0x01)

7.1.1.2 Reading oscillator trimming register (EEPROM data)

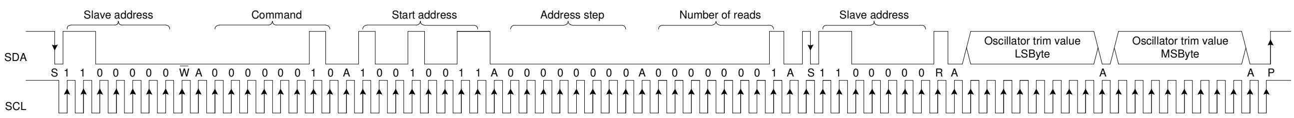


Figure 8 Reading configuration register (SA = 0x60, command = 0x02,

Start address = 0x93, Address step = 0x00, Number of reads = 0x01)

7.2. Read measurement data (RAM data)

7.2.1. PTAT data read

Absolute ambient temperature data of the device itself (package temperature) can be read by using following command:

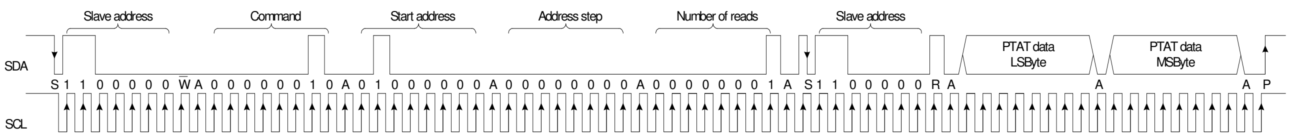


Figure 9 PTAT (SA = 0x60, command = 0x02, Start address = 0x40,

Address step = 0x00, Number of reads = 0x01) measurement result read

$$PTATdata = \{PTATdata_{MSByte} : PTATdata_{LSByte}\}$$

7.2.2. IR data read

There are four options available for reading IR data: (See section 8.2.1 for an overview of the RAM addresses).

- **Whole frame read** (MELEXIS recommends the whole frame read for maximum refresh rate)

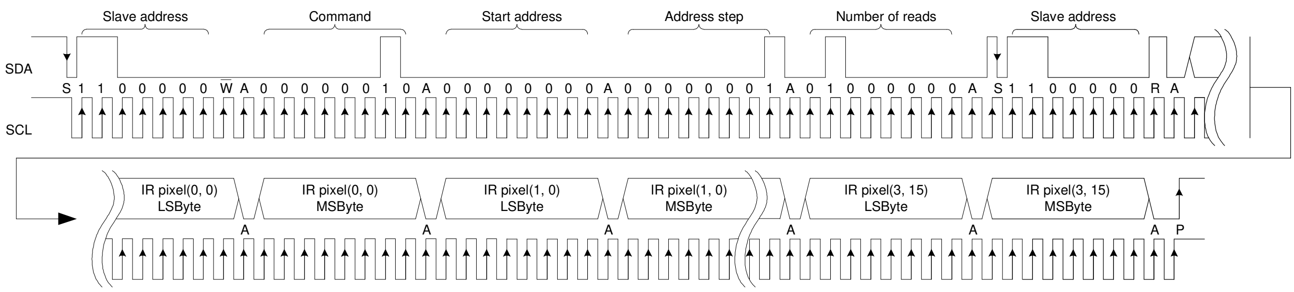


Figure 10 Whole frame (SA = 0x60, command = 0x02, Start address = 0x00,

Address step = 0x01, Number of reads = 0x40) measurement result read

- **Single column read**

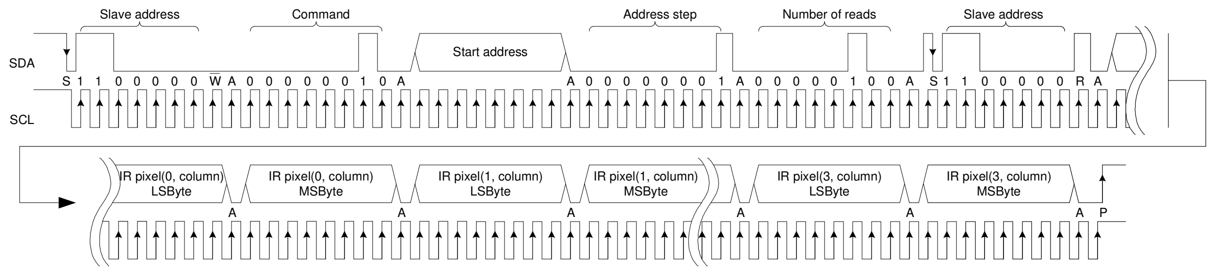


Figure 11 Single column (SA = 0x60, command = 0x02, Start address = 0x00…0x3C (step 0x04),

Address step = 0x01, Number of reads = 0x04) measurement result read

- **Single line read**

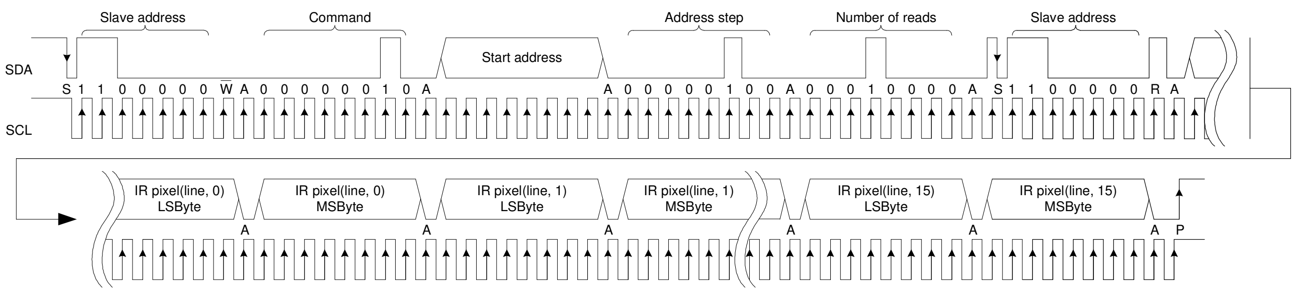


Figure 12 Single line (SA = 0x60, command = 0x02, Start address = 0x00…0x03 (step 0x01),

Address step = 0x04, Number of reads = 0x10) measurement result read

- **Single pixel read**

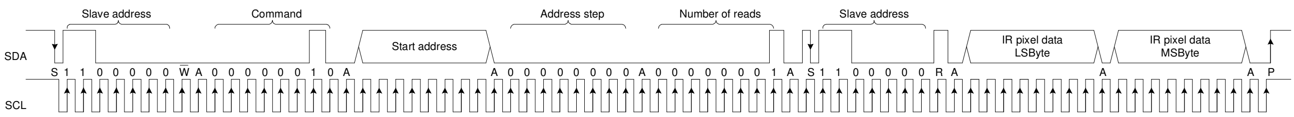


Figure 13 Single pixel (SA = 0x60, command = 0x02, Start address = 0x00…0x3F,

Address step = 0x00, Number of reads = 0x01) measurement result read

- **Compensation pixel read**

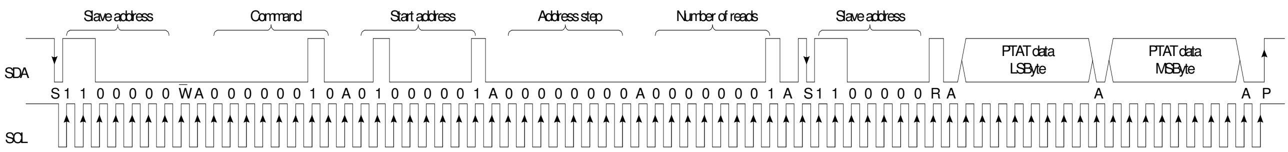


Figure 14 Compensation pixel (SA = 0x60, command = 0x02, Start address = 0x41,

Address step = 0x00, Number of reads = 0x01) measurement result read

The 16bit data for each pixel is:

$$IRdata(i,j) = \{IRdata(i,j)_{MSByte} : IRdata(i,j)_{LSByte}\}$$

7.3. Calculation

7.3.1. Calculation of absolute chip temperature Ta (sensor temperature)

The output signal of the IR sensors is relative to the cold junction temperature. That is why we need to know the temperature of the die in order to be able to calculate the object temperature 'seen' by each pixel.

The Ta can be calculated using the formula:

$$T_a = \frac{-K_{T1} + \sqrt{K_{T1}^2 - 4K_{T2}[V_{TH}(25) - PTAT\_data]}}{2K_{T2}} + 25, [°C]$$

Constants $V_{TH}(25)$, K_{T1} and K_{T2} are stored in EEPROM at following addresses as two's complement values:

EEPROM address	Cell name	Stored as	Parameter
0xDA	V_{TH}_L	2's complement	V_{TH0} of absolute temperature sensor
0xDB	V_{TH}_H		
0xDC	K_{T1}_L	2's complement	K_{T1} of absolute temperature sensor
0xDD	K_{T1}_H		
0xDE	K_{T2}_L	2's complement	K_{T2} of absolute temperature sensor
0xDF	K_{T2}_H		
0xD2	K_T_scale	unsigned	[7:4] – K_{T1}_scale [3:0] – K_{T2}_scale

Table 5 EEPROM parameters for Ta calculations

$$V_{TH}(25) = 256 * V_{TH\_H} + V_{TH\_L}$$

$$If\ V_{TH}(25) > 32767 \rightarrow V_{TH}(25) = V_{TH}(25) - 65536$$

$$V_{TH}(25) = \frac{V_{TH}(25)}{2^{3-ConfigReg[5:4]}}$$

$$K_{T1} = 256 * K_{T1\_H} + K_{T1\_L}$$

$$if\ K_{T1} > 32767 \rightarrow K_{T1} = K_{T1} - 65536$$

$$K_{T1} = \frac{K_{T1}}{2^{EERPOM\ 0xD2[7:4]} * 2^{3-ConfigReg[5:4]}}$$

$$K_{T2} = 256 * K_{T2\_H} + K_{T2\_L}$$

$$if\ K_{T2} > 32767 \rightarrow K_{T2} = K_{T2} - 65536$$

$$K_{T2} = \frac{K_{T2}}{2^{EERPOM\ 0xD2[3:0]+10} * 2^{3-ConfigReg[5:4]}}$$

7.3.2. Example for Ta calculations

Let's assume that the values in EEPROM are as follows
(Derived using maximum resolution – ConfigRegister[5:4] = 11b):

EEPROM address	Cell name	Cell values (hex)
0xDA	V_{TH}_L	0x20
0xDB	V_{TH}_H	0x64
0xDC	K_{T1}_L	0x89
0xDD	K_{T1}_H	0x55
0xDE	K_{T2}_L	0x7E
0xDF	K_{T2}_H	0x5E
0xD2	K_T_scale	0x8B

Table 6 EXAMPLE for Ta calibration values

Let's assume that the maximum resolution is set in the configuration register:

ConfigRegister[5:4] = 11b

$$V_{TH}(25) = 256 * V_{TH\_H} + V_{TH\_L} = 256 * 100 + 32 = 25632$$

Sign check: 25632 $< 32768 \rightarrow V_{TH}(25) = 25632$

$$V_{TH}(25) = \frac{V_{TH}(25)}{2^{3-ConfigReg[5:4]}} = \frac{25632}{2^{3-3}} = 25632$$

$$K_{T1} = 256 * K_{T1_H} + K_{T1_L} = 256 * 85 + 137 = 21897$$

Sign check: $21897 < 32768 \rightarrow K_{T1} = 21897$

$$K_{T1} = \frac{K_{T1}}{2^{EERPOM\ 0xD2[7:4]} * 2^{3-ConfigReg[5:4]}} = \frac{21897}{2^8 * 2^{3-3}} = 85.53515625$$

$$K_{T2} = 256 * K_{T2_H} + K_{T2_L} = 256 * 94 + 126 = 24190$$

Sign check: $24190 < 32768 \rightarrow K_{T2} = 24190$

$$K_{T2} = \frac{K_{T2}}{2^{EERPOM\ 0xD2[3:0]+10} * 2^{3-ConfigReg[5:4]}} = \frac{24190}{2^{11+10} * 2^{3-3}} = 0.01153469085$$

Let's assume that the input data is:

$PTAT\_data =$ **0x67DE = 26590 dec**

Thus the ambient temperature is:

$$T_a = \frac{-K_{T1} + \sqrt{K_{T1}^2 - 4K_{T2}[V_{TH}(25) - PTAT\_data]}}{2K_{T2}} + 25$$

$$T_a = \frac{-85.53515625 + \sqrt{7316.26295471 - 4 * 0.01153469085 * [25632 - 26590]}}{0.0230693817} + 25$$

$$T_a = \frac{-85.53515625 + \sqrt{7316.26295471 - 0.0461387634 * (-958)}}{0.0230693817} + 25$$

$$T_a = \frac{-85.53515625 + \sqrt{7360.46389005}}{0.0230693817} + 25 \approx \frac{-85.53515625 + 85.7931459386}{0.0230693817} + 25 \approx 11.1832077 + 25$$

$$T_a \approx 36.18\ °C$$

The calculated values for the different resolution settings are given in the table below:

ConfigRegister[5:4] (bin)	PTAT data (hex)	VTH(25)	KT1	KT2	Ta, °C
00	0x0CFB	3323.750	10.69189453125	0.0014418363571167	36.18
01	0x19F7	6647.500	21.38378906250	0.0028836727142334	36.18
10	0x33EF	13295.000	42.76757812500	0.0057673454284668	36.18
11	0x67DE	26590.000	85.53515625000	0.0115346908569336	36.18

Table 7 Calculated values at different resolution settings

7.3.3. Calculation of To

Following formula is used to calculate the temperature seen by specific pixel in the matrix:

$$T_{O(i,j)} = \sqrt[4]{\frac{V_{IR(i,j)COMPENSATED}}{\alpha_{comp(i,j)}*(1-K_{s4}*273.15)+S_{x(i,j)}} + T_{a_{K^4}}} - 273.15,\ \ [^{\circ}\ C]$$

Where:

$V_{IR(i,j)\_COMPENSATED}$ is the parasitic free IR compensated signal as calculated in 7.3.3.1

$\alpha_{comp(i,j)}$ is the compensated sensitivity coefficient for each pixel

K_{s4} is the compensation factor for the sensitivity – for BAB and BAD, $K_{s4} = 0$, resulting in a simplified formula

$T_{a_{K^4}} = (T_a + 273.15)^4$ where T_a is the ambient temperature calculated in 7.3.2

$$S_{x(i,j)} = K_{s4} * \sqrt[4]{{\alpha_{comp(i,j)}}^3 * V_{IR(i,j)_{COMPENSATED}} + {\alpha_{comp(i,j)}}^4 * T_{a_{K^4}}}$$

7.3.3.1 Calculating $V_{IR(I,j)\_COMPENSATED}$

1. **Offset compensation**

$$V_{IR(i,j)_{OffsetCompensated}} = V_{IR(i,j)} - \left(A_{i(i,j)} + B_{i(i,j)} * (T_a - T_{a0})\right)$$

Where:

$V_{IR(i,j)}$ is an individual pixel IR_data readout (RAM read)
$A_{i(i,j)}$ is an individual pixel offset restored from the EEPROM using the following formula:

$$A_{i(i,j)} = \frac{A_{common} + \Delta A_{i(i,j)} * 2^{\Delta A_{i_{scale}}}}{2^{3-ConfigReg[5:4]}}$$

A_{common} is the minimum offset value stored in the EEPROM at addresses 0xD0 and 0xD1 as 2's complement value

ΔA_i is the difference between the individual offset and the minimum value. It is stored in the EEPROM as unsigned values.

$\Delta A_{i_{scale}}$ is the scaling coefficient for the ΔA_i values and is stored in the EEPROM at address 0xD9[7:4] as an unsigned value

$B_{i(i,j)}$ is an individual pixel offset slope coefficient

$$B_{i(i,j)} = \frac{B_{i(i,j)_{EEPROM}}}{2^{B_{i_{scale}}} * 2^{3-ConfigReg[5:4]}}$$

$B_{i(i,j)_{EEPROM}}$ is the value stored in EEPROM as two's complements

$B_{i_{scale}}$ is a scaling coefficient for the slopes of IR pixels offset and is stored in the EEPROM at address 0xD9[3:0] as an unsigned value
T_a is the ambient temperature calculated in 7.3.2
$T_{a0} = 25°C$ is a constant

NOTE: This applies to the compensation pixel as well (A_{CP} and B_{CP} while $B_{i_{scale}}$ is the same) with the only difference being that A_{CP} is stored in the EEPROM at addresses 0xD3 and 0xD4 as an unsigned value but not calculated

2. **Thermal Gradient Compensation (TGC)**

$$V_{IR(i,j)_{TGCCompensated}} = V_{IR(i,j)\_OffsetCompensated} - TGC * V_{IRcp_{OffsetCompensated}}$$

Where:

$V_{IRcp_{OffsetCompensated}}$ is the offset compensated IR signal of the thermal gradient compensation pixel

$$TGC = \frac{TGC_{EEPROM}}{32}$$

TGC_{EEPROM} is a coefficient stored at EEPROM address 0xD8 as a two's complement value

3. **Emissivity compensation**

$$V_{IR(i,j)_{COMPENSATED}} = \frac{V_{IR(i,j)_{TGCCompensated}}}{\varepsilon}$$

Where:

ε is the emissivity coefficient. The scaled value is stored into EEPROM as unsigned value

$$\varepsilon = \frac{256 * \varepsilon_H + \varepsilon_L}{32768}$$

7.3.3.2 Calculating $\boldsymbol{\alpha_{comp(i,j)}}$

$$\alpha_{comp(i,j)} = \left(1 + KsTa * (T_a - T_{a0})\right) * \left(\alpha_{(i,j)} - TGC * \alpha_{CP}\right)$$

Where:

T_a is the ambient temperature calculated in 7.3.2

T_{a0} is a constant = 25°C

$KsTa$ is Ta dependence of $\alpha_{comp(i,j)}$ stored in EEPRPOM at addresses 0xE6 and 0xE7 as two's complement value and the scale coefficient is fixed to be 20.

$$KsTa = \frac{256 * KsTa_H + KsTa_L}{2^{20}}$$

$$\alpha_{(i,j)} = \frac{\frac{256 * \alpha_{0_H} + \alpha_{0_L}}{2^{\alpha_{0_{scale}}}} + \frac{\Delta\alpha_{(i,j)}}{2^{\Delta\alpha_{scale}}}}{2^{3-ConfigReg[5:4]}}$$

$$\alpha_{CP} = \frac{256 * \alpha_{CP_H} + \alpha_{CP_L}}{2^{\alpha_{0_{scale}}} * 2^{3-ConfigReg[5:4]}}$$

$\alpha_{0_H}, \alpha_{0_L}, \alpha_{CP_H}, \alpha_{CP_L}, \Delta\alpha_{(i,j)}, \alpha_{0_{scale}}$ and $\Delta\alpha_{scale}$ are stored in the EEPROM as unsigned values

7.3.3.1 Calculating K_{s4}

$K_{s4} = \frac{K_{s4\_EE}}{2^{(K_{s\_}scale+8)}}$, stored in EEPRPOM at addresses 0x9E as two's complement value

All parameters necessary to calculate To are stored into EEPROM at following addresses:

EEPROM address	Cell name	Stored as	Parameter
0x00…0x3F	ΔA_i	unsigned	IR pixel individual offset delta coefficient
0x40…0x7F	$B_{i(i,j)}$	2's complement	Individual Ta dependence (slope) of IR pixels offset
0x80…0xBF	$\Delta\alpha_{(i,j)}$	unsigned	Individual sensitivity coefficient
0xC0	K_s_scale	unsigned	[7:4] – NA [3:0] – K_s_scale - 8
0xC4	K_{s4_EE}	2's complement	Sensitivity To dependence (slope)
0xD0	A_{common_L}	2's complement	IR pixel common offset coefficient
0xD1	A_{common_H}		
0xD3	A_{CP_L}	2's complement	Compensation pixel individual offset coefficient
0xD4	A_{CP_H}		
0xD5	B_{CP}	2's complement	Individual Ta dependence (slope) of the compensation pixel offset
0xD6	α_{CP_L}	unsigned	Sensitivity coefficient of the compensation pixel
0xD7	α_{CP_H}		
0xD8	TGC	2's complement	Thermal gradient coefficient
0xD9	$\Delta A_{i_{scale}}, B_{i_{scale}}$	unsigned	[7:4] – Scaling coeff for the IR pixels offset [3:0] – Scaling coeff of the IR pixels offset Ta dependence
0xE0	α_{0_L}	unsigned	Common sensitivity coefficient of IR pixels
0xE1	α_{0_H}		
0xE2	$\alpha_{0_{scale}}$	unsigned	Scaling coefficient for common sensitivity
0xE3	$\Delta\alpha_{scale}$	unsigned	Scaling coefficient for individual sensitivity
0xE4	ε_L	unsigned	Emissivity
0xE5	ε_H		
0xE6	$KsTa_L$	2's complement	KsTa (fixed scale coefficient = 20)
0xE7	$KsTa_H$		

Table 8 EEPROM parameters for To calculations

7.3.4. Example for To calculations

Let’s assume that we have following EEPROM data for pixel i=2, j=8:

EEPROM address	Cell name	Stored as	Cell values (hex)
0x22	ΔA_i	unsigned	0x21
0x62	$B_{i(i,j)}$	2’s complement	0xBC
0xA2	$\Delta\alpha_{(i,j)}$	unsigned	0xCD
0xC0	K_s_scale	unsigned	0x99
0xC4	K_{s4}	2’s complement	0x9E
0xD0	A_{common_L}	2’s complement	0x8A
0xD1	A_{common_H}		0xFF
0xD3	A_{CP_L}	2’s complement	0x9D
0xD4	A_{CP_H}		0xFF
0xD5	B_{CP}	2’s complement	0xA2
0xD6	α_{CP_L}	unsigned	0xA8
0xD7	α_{CP_H}		0x0F
0xD8	TGC	2’s complement	0x18
0xD9	$\Delta A_{i_{scale}}, B_{i_{scale}}$	unsigned	0x07
0xE0	α_{0_L}	unsigned	0xAE
0xE1	α_{0_H}		0x4E
0xE2	$\alpha_{0_{scale}}$	unsigned	0x26
0xE3	$\Delta\alpha_{scale}$	unsigned	0x1F
0xE4	ε_L	unsigned	0x00
0xE5	ε_H		0x80
0xE6	$KsTa_L$	2’s complement	0x0C
0xE7	$KsTa_H$		0x02

Table 9 EXAMPLE for To calibration values

Let’s assume that we have the following input data:

$V_{IR(2,8)} = 0x01B7 = 439$, decimal value

Sign check $439 < 32768 \rightarrow V_{IR(2,8)} = 439$ LSB

$V_{CP} = 0xFFDC = 65500$, decimal value (compensation pixel readings)

Sign check $65500 > 32767 \rightarrow V_{CP} = 65500 - 65536 = -36$ LSB

$T_a \approx 36.18$ °C (as calculated in 7.3.2)

Reference routine for To computation:

$$T_{O(i,j)} = \sqrt[4]{\frac{V_{IR(i,j)COMPENSATED}}{\alpha_{comp(i,j)}*(1-K_{S4}*273.15)+S_x} + T_{a_{K^4}}} - 273.15, \quad [°C]$$

$$V_{IR(2,8)_{OffsetCompensated}} = V_{IR(2,8)} - \left(A_{i(2,8)} + B_{i(2,8)} * (T_a - T_{a0})\right)$$

$$A_{i(2,8)} = \frac{A_{common}+\Delta A_{i(2,8)}*2^{\Delta A_{i_{scale}}}}{2^{(3-ConfigReg[5:4])}}$$

$A_{common} = 256 * A_{common_H} + A_{common_L} = 256 * 255 + 138 = 65418$ LSB decimal value

Sign check $65418 > 32767 \rightarrow A_{common} = 65418 - 65536 = -118$ LSB

$\Delta A_i = 33$ LSB

$$A_{i(2,8)} = \frac{A_{common}+\Delta A_{i(2,8)}*2^{\Delta A_{i_{scale}}}}{2^{(3-ConfigReg[5:4])}} = \frac{-118+33*2^0}{2^{(3-3)}} = -85 \text{ LSB}$$

$$B_{i(2,8)} = \frac{B_{i(2,8)}}{2^{B_{i_{scale}}}*2^{(3-ConfigReg[5:4])}}$$

$B_{i(2,8)\_EE} = 188$

Sign check $188 > 127 \rightarrow B_{i(2,8)} = 188 - 256 = -68$

$$B_{i(2,8)} = \frac{B_{i(2,8)}}{2^{B_{i_{scale}}}*2^{(3-ConfigReg[5:4])}} = \frac{-68}{2^7*2^{(3-3)}} = -0.53125$$

$V_{IR(2,8)_{OffsetCompensated}} = 439 - (-85 - 0.53125 * (36.18 - 25)) \approx 529.939375$ LSB

$A_{CP} = 256 * A_{CP_H} + A_{CP_L} = 65437$, decimal value

Sign check $65437 > 32768 \rightarrow A_{CP} = 65437 - 65536 = -99$ LSB

$$A_{CP} = \frac{A_{CP}}{2^{(3-ConfigReg[5:4])}} = \frac{-99}{2^{(3-3)}} = -99$$

$B_{CP\_EE} = 162$

Sign check $162 > 127 \rightarrow B_{CP} = 162 - 256 = -94$

$$B_{CP} = \frac{B_{CP}}{2^{B_{i_{scale}}}*2^{(3-ConfigReg[5:4])}} = \frac{-94}{2^7*2^{(3-3)}} = -0.734375$$

$$V_{IRCP_{OffsetCompensated}} = V_{CP} - \left(A_{CP} + B_{CP} * (T_a - T_{a0})\right) = -36 - (-99 - 0.734375 * (36.18 - 25))$$

$V_{IRCP_{OffsetCompensated}} \approx 71.2103125$ LSB

$TGC_{EEPROM} = 0x18 = 24$, decimal value

Sign check $24 < 128 \rightarrow TGC\_EEPROM = 24$

$$TGC = \frac{TGC_{EEPROM}}{32} = \frac{24}{32} = 0.75$$

$$V_{IR(2,8)_{TGCCompensated}} = V_{IR(2,8)\_OffsetCompensated} - TGC * V_{IRcp_{OffsetCompensated}}$$

$$V_{IR(2,8)_{TGCCompensated}} = 529.939375 - 0.75 * 71.2103125 \approx 475.531640625 \text{ LSB}$$

$$\varepsilon = \frac{256 * \varepsilon_H + \varepsilon_L}{32768} = \frac{256 * 128 + 0}{32768} = \frac{32768}{32768} = 1$$

$$V_{IR(2,8)_{COMPENSATED}} = \frac{V_{IR(2,8)_{TGCCompensated}}}{\varepsilon} = 476.531640625 \text{ LSB}$$

$$\alpha_{comp(2,8)} = \left(1 + KsTa * (T_a - T_{a0})\right) * \left(\alpha_{(2,8)} - TGC * \alpha_{CP}\right)$$

$$KsTa = 256 * KsTa_H + KsTa_L = 256 * 2 + 12 = 524 \text{ , decimal value}$$

Sign check $524 > 32768 \rightarrow A_{CP} = 524$ LSB

$$KsTa = \frac{524}{2^{20}} = 4.9972534.10^{-4} \text{ decimal value}$$

$$\alpha_{(2,8)} = \frac{\frac{256 * \alpha_{0_H} + \alpha_{0_L}}{2^{\alpha_{0_{scale}}}} + \frac{\Delta\alpha_{(2,8)}}{2^{\Delta\alpha_{scale}}}}{2^{(3 - ConfigReg[5:4])}} = \frac{\frac{256 * 78 + 174}{2^{38}} + \frac{205}{2^{31}}}{2^{(3-3)}} = \frac{\frac{20142}{2^{38}} + \frac{205}{2^{31}}}{2^{(3-3)}} \approx 1.68736733031.10^{-7}$$

$$\alpha_{CP} = \frac{256 * \alpha_{CP_H} + \alpha_{CP_L}}{2^{\alpha_{0_{scale}}} * 2^{3 - ConfigReg[5:4]}} = \frac{256 * 15 + 168}{2^{38} * 2^{(3-3)}} = \frac{4008}{2^{38}} \approx 1.45810190588.10^{-8}$$

$$\alpha_{comp(2,8)} = \left(1 + 4.9972534.10^{-4} * (36.18 - 25)\right) * (1.68736733031.10^{-7} - 0.75 * 1.45810190588.10^{-8})$$

$$\alpha_{comp(2,8)} = 1.58682591595.10^{-7}$$

$$K_{s4} = 158 \text{ decimal value}$$

Sign check $158 > 127 \rightarrow K_{s4} = 158 - 256 = -98$

$$K_{s4} = \frac{K_{s4}}{2^{(K_{s}\_scale + 8)}} = \frac{-98}{2^{(9+8)}} = -7.476806640625.10^{-4}$$

$$T_{a_{K^4}} = (T_a + 273.15)^4 = (36.18 + 273.15)^4 = 9155628583$$

$$S_x = K_{S4} * \sqrt[4]{{\alpha_{comp(2,8)}}^3 * V_{IR(2,8)_{COMPENSATED}} + {\alpha_{comp(2,8)}}^4 * T_{a_{K^4}}}$$

$$S_x = -7.476806640625.10^{-4} * \sqrt[4]{(1.58682591595.10^{-7})^3 * 476.531640625 + (1.58682591595.10^{-7})^4 * 9155628583}$$

$$S_x = -3.93973510355.10^{-8}$$

$$T_{O(2,8)} = \sqrt[4]{\frac{V_{IR(2,8)_{COMPENSATED}}}{\alpha_{comp(2,8)} * (1 - K_{S4} * 273.15) + S_x} + T_{a_{K^4}}} - 273.15 \text{ °C}$$

$$T_{O(2,8)} = \sqrt[4]{\frac{476.531640625}{1.58682591595.10^{-7} * (1 - (-7.476806640625.10^{-4}) * 273.15) + (-3.93973510355.10^{-8})} + 9155628583} - 273.15 \text{ °C}$$

$$T_{O(2,8)} = 59.8546263694257 \approx 59.85 \text{ °C}$$

The calculated values for the different resolution settings are given in the table below:

ConfigRegister[5:4] (bin)	$V_{IR(2,8)}$	V_{CP}	$V_{IR(2,8)COMPENSATED}$	$\alpha_{comp(2,8)}$	S_x	To, °C
00	0x0036	0xFFFB	59.066455078125	1.98353239494464E-08	-4.9221144181793E-09	59.67
01	0x006D	0xFFF7	118.38291015625	3.96706478988929E-08	-9.8455068127298E-09	59.72
10	0x00DB	0xFFEE	237.7658203125	7.93412957977857E-08	-1.9696122547076E-08	59.81
11	0x01B7	0xFFDC	476.531640625	1.58682591595571E-07	-3.9397351035512E-08	59.85

Table 10 Calculated values at different resolution settings

8. Detailed description, Block description

8.1. Pixel position

The array consists of 64 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 0 to 3) and *j* is its column number (from 0 to 15)

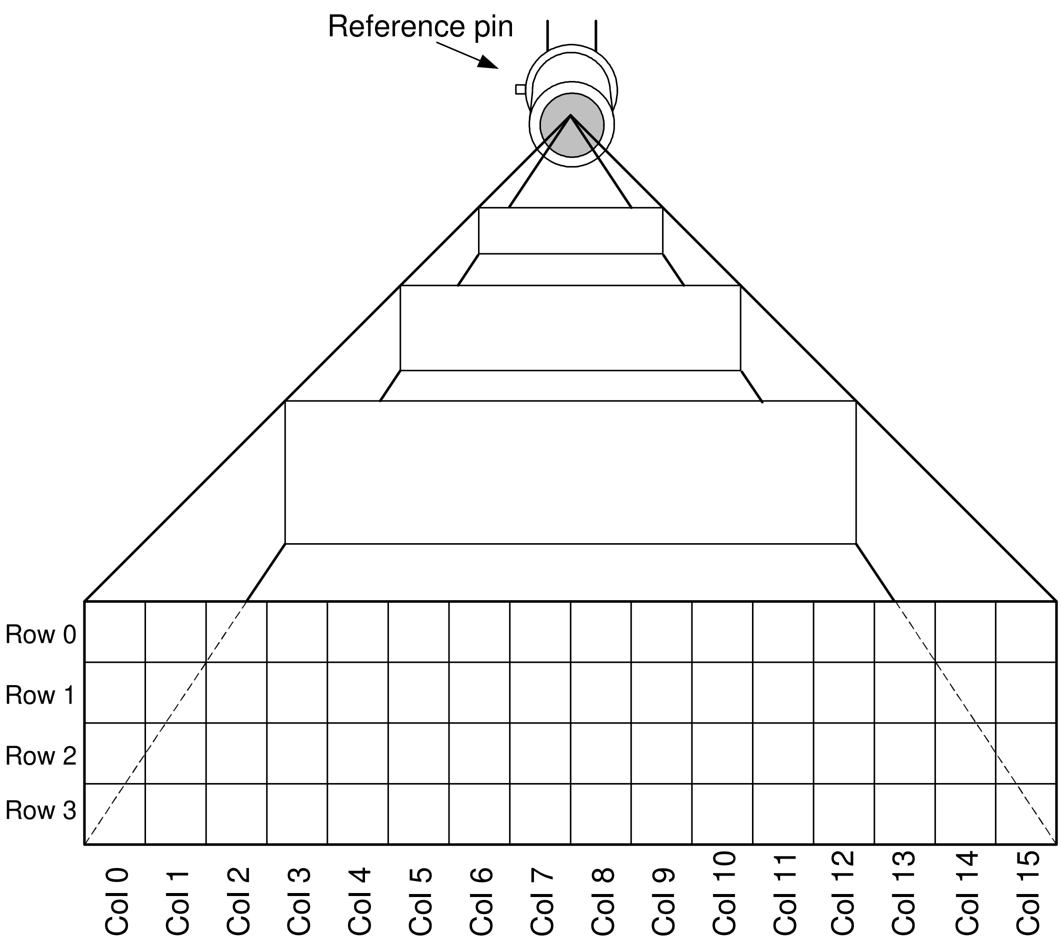


Figure 15 Pixel position in the whole FOV

8.2. MLX90621 address map

The MLX90621 address map is shown below:

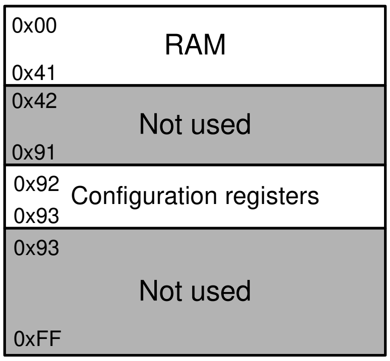


Figure 16 Address map

8.2.1. RAM

The on chip 146x16 RAM is accessible for reading via I^2C. The RAM is used for storing the results of measurements of pixels and Ta sensor and is distributes as follows:

- 64 words for IR sensors. The data is in 2's complement format (see 7.2.2)
- 1 word for measurement result of PTAT sensor. The data is 16 bit without sign. (see 7.2.1)

The memory map of the RAM is shown below:

RAM Address	RAM variable description
0x00	IR sensor (0,0) result
0x01	IR sensor (1,0) result
0x02	IR sensor (2,0) result
0x03	IR sensor (3,0) result
0x04	IR sensor (0,1) result
0x05	IR sensor (1,1) result
…	…
0x3B	IR sensor (3,14) result
0x3C	IR sensor (0,15) result
0x3D	IR sensor (1,15) result
0x3E	IR sensor (2,15) result
0x3F	IR sensor (3,15) result
0X40	PTAT sensor result
0x41	Compensation pixel result

Table 11: Result address map

For IR sensors results, the addressing can be summarized:
IR(x,y) is on address:

$$IR(x, y)address = x + 4.y$$

8.2.2. Internal registers

8.2.2.1 Configuration register (0x92)

The configuration register defines the chip operating modes.
It can be read and written by the I^2C MD.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	Configuration register bit meaning (0x92)
												0	0	0	0	- IR Refresh rate = 512Hz
												0	0	0	1	- IR Refresh rate = 512Hz
												0	0	1	0	- IR Refresh rate = 512Hz
												0	0	1	1	- IR Refresh rate = 512Hz
												0	1	0	0	- IR Refresh rate = 512Hz
												0	1	0	1	- IR Refresh rate = 512Hz
												0	1	1	0	- IR Refresh rate = 256Hz
												0	1	1	1	- IR Refresh rate = 128Hz
												1	0	0	0	- IR Refresh rate = 64Hz
												1	0	0	1	- IR Refresh rate = 32Hz
												1	0	1	0	- IR Refresh rate = 16Hz
												1	0	1	1	- IR Refresh rate = 8Hz
												1	1	0	0	- IR Refresh rate = 4Hz
												1	1	0	1	- IR Refresh rate = 2Hz
												1	1	1	0	- IR Refresh rate = 1Hz (default)
												1	1	1	1	- IR Refresh rate = 0.5Hz
										0	0					ADC set to 15 bit resolution*1
										0	1					ADC set to 16 bit resolution*1
										1	0					ADC set to 17 bit resolution*1
										1	1					ADC set to 18 bit resolution*1
									0							- Continuous measurement mode (default)
									1							- Step mode
								0								- Normal operation mode (default)
								1								- Sleep mode
							x									- NA
						0										- No IR measurement running (flag only cannot be written)
						1										- IR measurement running (flag only cannot be written)
					0											- POR or Brown-out occurred - Need to reload Configuration register
					1											- MD must write "1" during uploading Configuration register (default)
				0												- I^2C FM+ mode enabled (max bit transfer rates up to 1000 kbit/s) (default)
				1												- I^2C FM+ mode disabled (max bit transfer rates up to 400 kbit/s)
			0													- EEPROM enabled
			1													- EEPROM disabled
		0														- Melexis reserved
	0															- ADC high reference enabled*2
	1															- ADC low reference enabled (default)
0																- Melexis reserved

Table 12: Configuration register bit meaning

*1 – does not impacting the calibration of the device (may be changed and the calibration remain valid)
*2 – does impact the calibration of the device (if changed the calibration is no longer valid)