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MLX90614 family

Single and Dual Zone Infra Red Thermometer in TO-39

Features and Benefits

- ❑ Small size, low cost
- ❑ Easy to integrate
- ❑ Factory calibrated in wide temperature range:
  - -40…+125˚C for sensor temperature and
  - -70…+380˚C for object temperature.
- ❑ High accuracy of 0.5°C in a wide temperature range (0…+50°C for both Ta and To)
- ❑ High (medical) accuracy calibration
- ❑ Measurement resolution of 0.02°C
- ❑ Single and dual zone versions
- ❑ SMBus compatible digital interface
- ❑ Customizable PWM output for continuous reading
- ❑ Available in 3V and 5V versions
- ❑ Simple adaptation for 8…16V applications
- ❑ Sleep mode for reduced power consumption
- ❑ Different package options for applications and measurements versatility
- ❑ Automotive grade

Applications Examples

- ❑ High precision non-contact temperature measurements
- ❑ Thermal Comfort sensor for Mobile Air Conditioning control system
- ❑ Temperature sensing element for residential, commercial and industrial building air conditioning
- ❑ Windshield defogging
- ❑ Automotive blind angle detection
- ❑ Industrial temperature control of moving parts
- ❑ Temperature control in printers and copiers
- ❑ Home appliances with temperature control
- ❑ Healthcare
- ❑ Livestock monitoring
- ❑ Movement detection
- ❑ Multiple zone temperature control – up to 127 sensors can be read via common 2 wires
- ❑ Thermal relay / alert
- ❑ Body temperature measurement

Ordering Information

Part No.	Temperature Code	Package Code	- Option Code	Standard part	Packing form
MLX90614	E (-40°C...85°C) K (-40°C…125°C)	SF (TO-39)	- X X X (1) (2) (3)	-000	-TU

(1) Supply Voltage/ Accuracy
- A - 5V
- B - 3V
- C - Reserved
- D - 3V medical accuracy

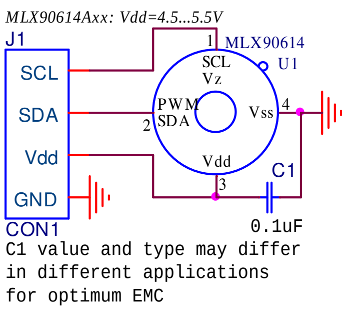
(2) Number of thermopiles:
- A – single zone
- B – dual zone
- C – gradient compensated*

(3) Package options:
- A – Standard package
- B – Reserved
- C – 35° FOV
- D/E – Reserved
- F – 10° FOV
- G – Reserved
- H – 12° FOV (refractive lens)
- I – 5° FOV

Example:
MLX90614ESF-BAA-000-TU

*** : See page 2**

1 Functional diagram



MLX90614 connection to SMBus

Figure 1: Typical application schematics

2 General Description

The MLX90614 is an Infra Red thermometer for non contact temperature measurements. Both the IR sensitive thermopile detector chip and the signal conditioning ASSP are integrated in the same TO-39 can.

Thanks to its low noise amplifier, 17-bit ADC and powerful DSP unit, a high accuracy and resolution of the thermometer is achieved.

The thermometer comes factory calibrated with a digital PWM and SMBus (System Management Bus) output.

As a standard, the 10-bit PWM is configured to continuously transmit the measured temperature in range of -20…120˚C, with an output resolution of 0.14˚C.

The factory default POR setting is SMBus.

General description (continued)

The MLX90614 is built from 2 chips developed and manufactured by Melexis:

- The Infra Red thermopile detector MLX81101
- The signal conditioning ASSP MLX90302, specially designed to process the output of IR sensor.

The device is available in an industry standard TO-39 package.

Thanks to the low noise amplifier, high resolution 17-bit ADC and powerful DSP unit of MLX90302 high accuracy and resolution of the thermometer is achieved. The calculated object and ambient temperatures are available in RAM of MLX90302 with resolution of 0.01˚C. They are accessible by 2 wire serial SMBus compatible protocol (0.02°C resolution) or via 10-bit PWM (Pulse Width Modulated) output of the device.

The MLX90614 is factory calibrated in wide temperature ranges: -40…125˚C for the ambient temperature and -70…380˚C for the object temperature.

The measured value is the average temperature of all objects in the Field Of View of the sensor. The MLX90614 offers a standard accuracy of ±0.5˚C around room temperatures. A special version for medical applications exists offering an accuracy of ±0.2˚C in a limited temperature range around the human body temperature.

It is very important for the application designer to understand that these accuracies are only guaranteed and achievable when the sensor is in thermal equilibrium and under 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.

This effect is especially relevant for thermometers with a small FOV like the xxC and xxF as the energy received by the sensor from the object is reduced. Therefore, Melexis has introduced the xCx version of the MLX90614. In these MLX90614xCx, the thermal gradients are measured internally and the measured temperature is compensated for them. In this way, the xCx version of the MLX90614 is much less sensitive to thermal gradients, but the effect is not totally eliminated. It is therefore important to avoid the causes of thermal gradients as much as possible or to shield the sensor from them.

As a standard, the MLX90614 is calibrated for an object emissivity of 1. It can be easily customized by the customer for any other emissivity in the range 0.1…1.0 without the need of recalibration with a black body.

The 10-bit PWM is as a standard configured to transmit continuously the measured object temperature for an object temperature range of -20…120˚C with an output resolution of 0.14˚C. The PWM can be easily customized for virtually any range desired by the customer by changing the content of 2 EEPROM cells. This has no effect on the factory calibration of the device.

The PWM pin can also be configured to act as a thermal relay (input is To), thus allowing for an easy and cost effective implementation in thermostats or temperature (freezing / boiling) alert applications. The temperature threshold is user programmable. In a SMBus system this feature can act as a processor interrupt that can trigger reading all slaves on the bus and to determine the precise condition.

The thermometer is available in 2 supply voltage options: 5V compatible or 3V (battery) compatible. The 5V can be easily adopted to operate from a higher supply voltage (8…16V, for example) by use of few external components (refer to "Applications information" section for details).

An optical filter (long-wave pass) that cuts off the visible and near infra-red radiant flux is integrated in the package to provide ambient and sunlight immunity. The wavelength pass band of this optical filter is from 5.5 till 14µm (except for xCH and xCI type of devices which incorporate uncoated silicon lens).

3 Table of Contents

4 Glossary of Terms

PTAT	**P**roportional **T**o **A**bsolute **T**emperature sensor (package temperature)
POR	**P**ower **O**n **R**eset
HFO	**H**igh **F**requency **O**scillator (RC type)
DSP	**D**igital **S**ignal **P**rocessing
FIR	**F**inite **I**mpulse **R**esponse. Digital filter
IIR	**I**nfinite **I**mpulse **R**esponse. Digital filter
IR	**I**nfra-**R**ed
PWM	**P**ulse **W**ith **M**odulation
DC	**D**uty **C**ycle (of the PWM) ; **D**irect **C**urrent (for settled conditions specifications)
FOV	**F**ield **O**f **V**iew
SDA,SCL	**S**erial **DA**ta, **S**erial **CL**ock – SMBus compatible communication pins
Ta	**A**mbient **T**emperature measured from the chip – (the package temperature)
To	**O**bject **T**emperature, 'seen' from IR sensor
ESD	**E**lectro-**S**tatic **D**ischarge
EMC	**E**lectro-**M**agnetic **C**ompatibility
ASSP	**A**pplication **S**pecific **S**tandard **P**roduct
TBD	**T**o **B**e **D**efined

Note: sometimes the MLX90614xxx is referred as "the module".

5 Maximum ratings

Parameter	MLX90614ESF-Axx	MLX90614ESF-Bxx MLX90614ESF-Dxx	MLX90614KSF-Axx
Supply Voltage, V_{DD} (over voltage)	7V	5V	7V
Supply Voltage, V_{DD} (operating)	5.5 V	3.6V	5.5V
Reverse Voltage	0.4 V		
Operating Temperature Range, T_A	-40…+85°C		-40…+125°C
Storage Temperature Range, T_S	-40…+125°C		-40…+125°C
ESD Sensitivity (AEC Q100 002)	2kV		
DC current into SCL / Vz (Vz mode)	2 mA		
DC sink current, SDA / PWM pin	25 mA		
DC source current, SDA / PWM pin	25 mA		
DC clamp current, SDA / PWM pin	25 mA		
DC clamp current, SCL pin	25 mA		

Table 1: Absolute maximum ratings for MLX90614

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

6 Pin definitions and descriptions

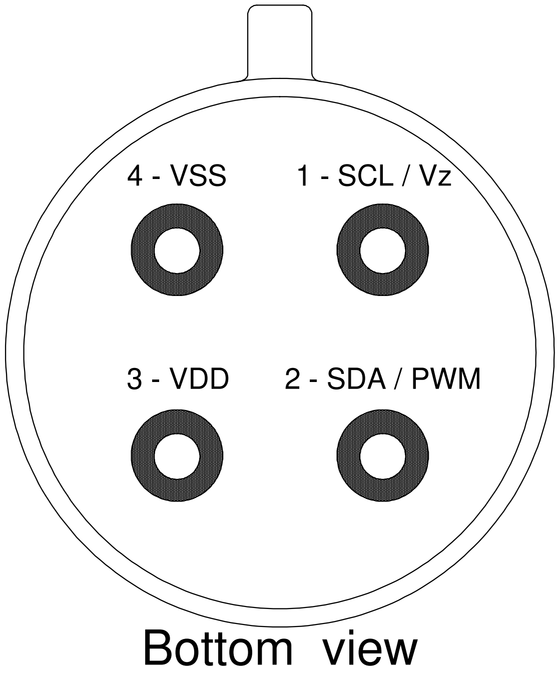


Figure 2: Pin description

Pin Name	Function
SCL / Vz	Serial clock input for 2 wire communications protocol. 5.7V zener is available at this pin for connection of external bipolar transistor to MLX90614Axx to supply the device from external 8 …16V source.
SDA / PWM	Digital input / output. In normal mode the measured object temperature is available at this pin Pulse Width Modulated. In SMBus compatible mode the pin is automatically configured as open drain NMOS.
VDD	External supply voltage.
VSS	Ground. The metal can is also connected to this pin.

Table 2: Pin description MLX90614

Note: for +12V (+8…+16V) powered operation refer to the Application information section. For EMC and isothermal conditions reasons it is highly recommended not to use any electrical connection to the metal can except by the VSS pin.
With the SCL / Vz and PWM / SDA pins operated in 2-wire interface mode, the input Schmidt trigger function is automatically enabled.

7 Electrical Specifications

7.1 MLX90614Axx

All parameters are valid for T_A = 25 ˚C, V_{DD} =5V (unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
Supplies						
External supply	V_{DD}		4.5	5	5.5	V
Supply current	I_{DD}	No load		1.3	2	mA
Supply current (programming)	I_{DDpr}	No load, erase/write EEPROM operations		1.5	2.5	mA
Zener voltage	Vz	Iz = 75…1000μA (Ta=room)	5.5	5.7	5.9	V
Zener voltage	Vz(Ta)	Iz = 70…1000μA, full temperature range	5.15	5.7	6.24	V
Power On Reset						
POR level	V_{POR_up}	Power-up (full temp range)	1.4	1.75	1.95	V
POR level	V_{POR_down}	Power –down (full temp range)	1.3	1.7	1.9	V
POR hysteresis	V_{POR_hys}	Full temp range	0.08	0.1	1.15	V
V_{DD} rise time (10% to 90% of specified supply voltage)	T_{POR}	Ensure POR signal			20	ms
Output valid (result in RAM)	Tvalid	After POR		0.25		s
Pulse width modulation[1]						
PWM resolution	PWMres	Data band		10		bit
PWM output period	$PWM_{T,def}$	Factory default, internal oscillator factory calibrated		1.024		ms
PWM period stability	$dPWM_T$	Internal oscillator factory calibrated, over the entire operation range and supply voltage	-10		+10	%
Output high Level	PWM_{HI}	I_{source} = 2 mA	V_{DD}-0.2			V
Output low Level	PWM_{LO}	I_{sink} = 2 mA			V_{SS}+0.2	V
Output drive current	$Idrive_{PWM}$	Vout,H = V_{DD} - 0.8V		7		mA
Output sink current	$Isink_{PWM}$	Vout,L = 0.8V		13.5		mA

Continued on next page

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
SMBus compatible 2-wire interface[2]						
Input high voltage	V_{IH} (Ta, V)	Over temperature and supply	3			V
Input low voltage	V_{IL} (Ta, V)	Over temperature and supply			0.6	V
Output low voltage	V_{OL}	Over temperature and supply, Isink = 2mA			0.2	V
SCL leakage	I_{SCL}, leak	V_{SCL}=4V, Ta=+85°C			30	µA
SDA leakage	I_{SDA}, leak	V_{SDA}=4V, Ta=+85°C			0.3	µA
SCL capacitance	C_{SCL}				10	pF
SDA capacitance	C_{SDA}				10	pF
Slave address	SA	Factory default		**5A**		hex
Wake up request	t_{wake}	SDA low	33			ms
SMBus Request	t_{REQ}	SCL low	1.44			ms
Timeout, low	$T_{imeout,L}$	SCL low	27		33	**ms**
Timeout, high	$T_{imeout,H}$	SCL high	45		55	**µs**
Acknowledge setup time	Tsuac(MD)	8-th SCL falling edge, Master			1.5	µs
Acknowledge hold time	Thdac(MD)	9-th SCL falling edge, Master			1.5	µs
Acknowledge setup time	Tsuac(SD)	8-th SCL falling edge, Slave			2.5	µs
Acknowledge hold time	Thdac(SD)	9-th SCL falling edge, Slave			1.5	µs
EEPROM						
Data retention		Ta = +85°C	10			years
Erase/write cycles		Ta = +25°C	100,000			Times
Erase/write cycles		Ta = +125°C	10,000			Times
Erase cell time	Terase			5		ms
Write cell time	Twrite			5		ms

Table 3: Electrical specification MLX90614Axx

Notes: All the communication and refresh rate timings are given for the nominal calibrated HFO frequency and will vary with this frequency's variations.

1. With large capacitive load lower PWM frequency is recommended. Thermal relay output (when configured) has the PWM DC specification and can be programmed as push-pull, or NMOS open drain. PWM is free-running, power-up factory default is SMBus, refer to section 8.6, "Switching between PWM and SMBus communication" for more details.

2. For SMBus compatible interface on 12V application refer to Application information section. SMBus compatible interface is described in details in the SMBus detailed description section. Maximum number of MLX90614 devices on one bus is 127, higher pull-up currents are recommended for higher number of devices, faster bus data transfer rates, and increased reactive loading of the bus.
MLX90614 is always a slave device on the bus. MLX90614 can work in both low-power and high-power SMBus communication.

All voltages are referred to the Vss (ground) unless otherwise noted.

Sleep mode is not available on the 5V version (MLX90614Axx).

7.2 MLX90614Bxx, MLX90614Dxx

All parameters are valid for T_A = 25 ˚C, V_{DD} =3V (unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
Supplies						
External supply	V_{DD}		2.6	3	3.6	V
Supply current	I_{DD}	No load		1.3	2	mA
Supply current (programming)	I_{DDpr}	No load, erase / write EEPROM operations		1.5	2.5	mA
Sleep mode current	Isleep	no load	1	2.5	5	μA
Sleep mode current	Isleep	Full temperature range	1	2.5	6	μA
Power On Reset						
POR level	V_{POR_up}	Power-up (full temp range)	1.4	1.75	1.95	V
POR level	V_{POR_down}	Power –down (full temp range)	1.3	1.7	1.9	V
POR hysteresis	V_{POR_hys}	Full temp range	0.08	0.1	1.15	V
V_{DD} rise time (10% to 90% of specified supply voltage)	T_{POR}	Ensure POR signal			20	ms
Output valid	Tvalid	After POR		0.25		s
Pulse width modulation[1]						
PWM resolution	PWMres	Data band		10		bit
PWM output period	$PWM_{T,def}$	Factory default, internal oscillator factory calibrated		1.024		ms
PWM period stability	$dPWM_T$	Internal oscillator factory calibrated, over the entire operation range and supply voltage	-10		+10	%
Output high Level	PWM_{HI}	I_{source} = 2 mA	V_{DD}-0.25			V
Output low Level	PWM_{LO}	I_{sink} = 2 mA			V_{SS}+0.25	V
Output drive current	$Idrive_{PWM}$	Vout,H = V_{DD} - 0.8V		4.5		mA
Output sink current	$Isink_{PWM}$	Vout,L = 0.8V		11		mA

Continued on next page

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
SMBus compatible 2-wire interface[2]						
Input high voltage	V_{IH}(Ta,V)	Over temperature and supply	VDD-0.1			V
Input low voltage	V_{IL}(Ta,V)	Over temperature and supply			0.6	V
Output low voltage	V_{OL}	Over temperature and supply, Isink = 2mA			0.25	V
SCL leakage	I_{SCL},leak	V_{SCL}=3V, Ta=+85°C			20	µA
SDA leakage	I_{SDA},leak	V_{SDA}=3V, Ta=+85°C			0.25	µA
SCL capacitance	C_{SCL}				10	pF
SDA capacitance	C_{SDA}				10	pF
Slave address	SA	Factory default		5A		hex
Wake up request	t_{wake}	SDA low	33			ms
SMBus Request	t_{REQ}	SCL low	1.44			ms
Timeout,low	$T_{imeout,L}$	SCL low	27		33	**ms**
Timeout, high	$T_{imeout,H}$	SCL high	45		55	**µs**
Acknowledge setup time	Tsuac(MD)	8-th SCL falling edge, Master			1.5	µs
Acknowledge hold time	Thdac(MD)	9-th SCL falling edge, Master			1.5	µs
Acknowledge setup time	Tsuac(SD)	8-th SCL falling edge, Slave			2.5	µs
Acknowledge hold time	Thdac(SD)	9-th SCL falling edge, Slave			1.5	µs
EEPROM						
Data retention		Ta = +85°C	10			years
Erase/write cycles		Ta = +25°C	100,000			Times
Erase/write cycles		Ta = +125°C	10,000			Times
Erase cell time	Terase			5		ms
Write cell time	Twrite			5		ms

Table 4: Electrical specification MLX90614Bxx, Dxx

Note: refer to MLX90614Axx notes.

8 Detailed description

8.1 Block diagram

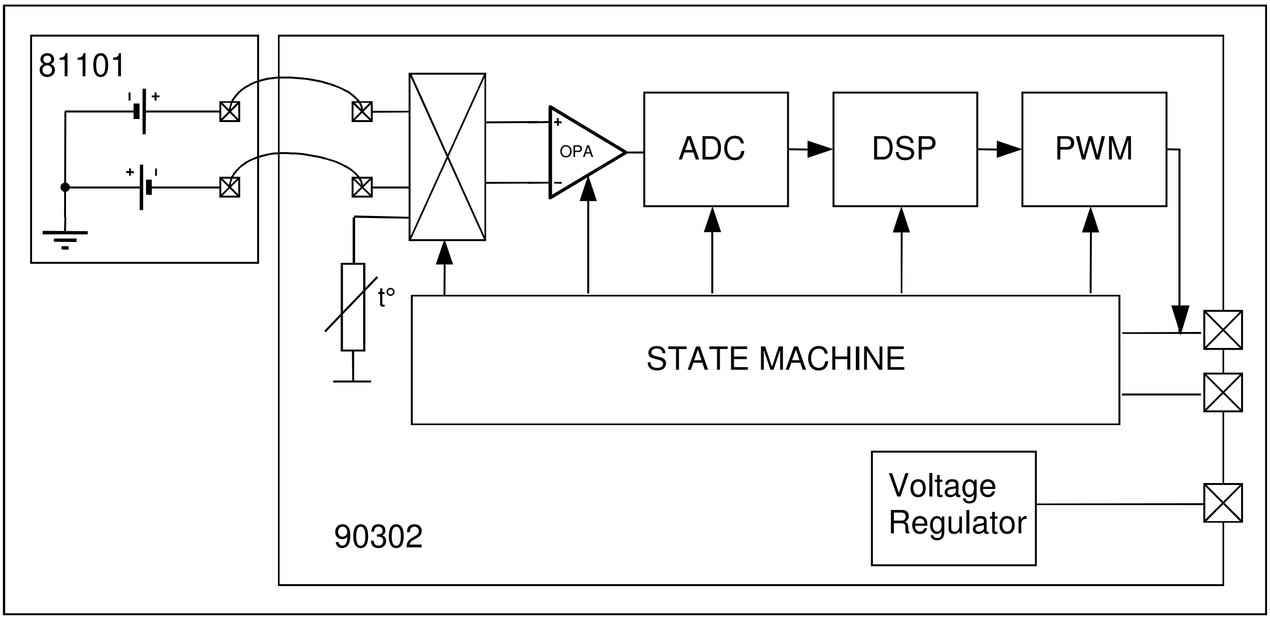


Figure 3: Block diagram

8.2 Signal processing principle

The operation of the MLX90614 is controlled by an internal state machine, which controls the measurements and calculations of the object and ambient temperatures and does the post-processing of the temperatures to output them through the PWM output or the SMBus compatible interface.

The ASSP supports 2 IR sensors (second one not implemented in the MLX90614xAx).The output of the IR sensors is amplified by a low noise low offset chopper amplifier with programmable gain, converted by a Sigma Delta modulator to a single bit stream and fed to a powerful DSP for further processing. The signal is treated by programmable (by means of EEPROM contend) FIR and IIR low pass filters for further reduction of the band width of the input signal to achieve the desired noise performance and refresh rate. The output of the IIR filter is the measurement result and is available in the internal RAM. 3 different cells are available: One for the on-board temperature sensor and 2 for the IR sensors.

Based on results of the above measurements, the corresponding ambient temperature Ta and object temperatures To are calculated. Both calculated temperatures have a resolution of 0.01˚C. The data for Ta and To can be read in two ways: Reading RAM cells dedicated for this purpose via the 2-wire interface (0.02°C resolution, fixed ranges), or through the PWM digital output (10 bit resolution, configurable range).
In the last step of the measurement cycle, the measured Ta and To are rescaled to the desired output resolution of the PWM) and the recalculated data is loaded in the registers of the PWM state machine, which creates a constant frequency with a duty cycle representing the measured data.

8.3 Block description

8.3.1 Amplifier

A low noise, low offset amplifier with programmable gain is used for amplifying the IR sensor voltage. By carefully designing the input modulator and balanced input impedance, the max offset of the system is 0.5µV.

8.3.2 Supply regulator and POR

The module can operate from 3 different supplies:

VDD = 5V → MLX90614Axx

VDD = 3.3V → MLX90614Bxx (battery or regulated supply)

VDD = 8…16V → MLX90614Axx few external components are necessary please refer to "Applications information" section for information about adopting higher voltage supplies.

The Power On Reset (POR) is connected to Vdd supply. The on-chip POR circuit provides an active (high) level of the POR signal when the Vdd voltage rises above approximately 0.5V and holds the entire MLX90614 in reset until the Vdd is higher than the specified POR threshold V_{POR} . During the time POR is active, the POR signal is available as an open drain at the PWM/SDA pin. After the MLX90614 exits the POR condition, the function programmed in EEPROM takes precedence for that pin.

8.3.3 EEPROM

A limited number of addresses in the EEPROM memory can be changed by the customer. The whole EEPROM can be read through the SMBus interface.

EEPROM (32X16)		
Name	Address	Write access
To_{max}	0x00	Yes
To_{min}	0x01	Yes
PWMCTRL	0x02	Yes
Ta range	0x03	Yes
Emissivity correction coefficient	0x04	Yes
Config Register1	0x05	Yes
Melexis reserved	0x06	No
…	…	…
Melexis reserved	0x0D	No
SMBus address (LSByte only)	0x0E	Yes
Melexis reserved	0x0F	Yes
Melexis reserved	0x10	No
…	…	…
Melexis reserved	0x18	No
Melexis reserved	0x19	Yes
Melexis reserved	0x1A	No
Melexis reserved	0x1B	No
ID number	0x1C	No
ID number	0x1D	No
ID number	0x1E	No
ID number	0x1F	No

Table 5: EEPROM table

The addresses To_{max}, To_{min} and Ta range are for customer dependent object and ambient temperature ranges. For details see section 8.5.3 below in this document

The address **Emissivity** contains the object emissivity (factory default 1.0 = 0xFFFF), 16 bit.

Emissivity = dec2hex[round(65535 x ε)]

Where dec2hex[round(X)] represents decimal to hexadecimal conversion with round-off to nearest value (not truncation). In this case the physical emissivity values are ε = 0.1…1.0.

<u>Erase (write 0) must take place before write of desired data is made.</u>

PWM period configuration: Period in extended PWM mode is twice the period in single PWM mode.
In single PWM mode period is T = 1.024*P [ms], where P is the number, written in bits 15…9 PWMCTRL. Maximum period is then 131.072 ms for single and 262.144 ms for extended. These values are typical and depend on the on-chip RC oscillator absolute value. The duty cycle must be calculated instead of working only with the high time only in order to avoid errors from the period absolute value deviations.
The address **PWMCTRL** consists of control bits for configuring the PWM/SDA pin as follows:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	PWM control bit meaning
															0	- PWM extended mode
															1	- PWM single mode
														0		- PWM mode disabled (EN_PWM)
														1		- PWM mode enabled (EN_PWM)
													0			- SDA pin configured as Open Drain (PPODB)
													1			- SDA pin configured as Push-Pull (PPODB)
												0				- PWM mode selected (TRPWMB)
												1				- Thermal relay mode selected (TRPWMB)
																- PWM repetition number 0…62 step 2 (bits 8…4)
																- PWM period 1.024*ms (Single PWM mode) or 2.048*ms (Extendet PWM mode) multiplied by the number written in this place (128 in case the number is 0) (bits 15…9)

* *Values are valid for nominal HFO frequency*

Table 6: PWM control bits

The address **ConfigRegister1** consists of control bits for configuring the analog and digital parts:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	Config register bit meaning
													1	0	0	- IIR (100%) a1=1, b1=0
													1	0	1	- IIR (80%) a1=0.8, b1=0.2
													1	1	0	- IIR (67%) a1=0.666, b1=0.333
													1	1	1	- IIR (57%) a1=0.571, b1=0.428
													0	0	0	- IIR (50%) a1=0.5, b1=0.5
													0	0	1	- IIR (25%) a1=0.25, b1=0.75
													0	1	0	- IIR (17%) a1=0.166(6), b1=0.83(3)
													0	1	1	- IIR (13%) a1=0.125, b1=0.875
												0				- Repeat sensor test "OFF"
												1				- Repeat sensor test "ON"
										0	0					- Ta, Tobj1
										0	1					- Ta, Tobj2
										1	0					- Tobj2
										1	1					- Tobj1, Tobj2
									0							- Single IR sensor
									1							- Dual IR sensor
								0								- Positive sign of Ks
								1								- Negative sign of Ks
					0	0	0									- FIR = 8 not recommended
					0	0	1									- FIR = 16 not recommended
					0	1	0									- FIR = 32 not recommended
					0	1	1									- FIR = 64 not recommended
					1	0	0									- FIR = 128
					1	0	1									- FIR = 256
					1	1	0									- FIR = 512
					1	1	1									- FIR = 1024
		0	0	0												- GAIN = 1 - Amplifier is bypassed
		0	0	1												- GAIN = 3
		0	1	0												- GAIN = 6
		0	1	1												- GAIN = 12,5
		1	0	0												- GAIN = 25
		1	0	1												- GAIN = 50
		1	1	0												- GAIN = 100
		1	1	1												- GAIN = 100
	0															- Positive sign of Kt2
	1															- Negative sign of Kt2
0																- Enable sensor test
1																- Disable sensor test

Note: The following bits / registers should not be altered (except with special tools – contact Melexis for such tools availability) in order to keep the factory calibration relevant:
Ke [15...0]; Config Register1 [14...11;7;3]; addresses 0x0F and 0x19.

Table 7: Configuration register 1

Check www.melexis.com for latest application notes with details on EEPROM settings.

On-chip filtering and settling time:

The MLX90614 features configurable on-chip digital filters. They allow customization for speed or noise. Factory default configurations and the typical settling time and noise for the MLX90614 family are given below.

Device	Settling time, sec	Typical noise, °C rms	Spike limit
MLX90614AAA, BAA, DAA	0.10	0.05	100%
MLX90614ABA, BBA	0.14	0.07	100%
MLX90614ACC, BCC, DCC	0.14	0.18	100%
MLX90614ACF, BCF	1.33	0.10	50%
MLX90614DCH, DCI, BCH, BCI	0.65	0.10	80%

Table 8: factory default IIR and FIR configuration, settling time and typical noise

Details on the filters are given in the application note "Understanding MLX90614 on-chip digital signal filters" available from www.melexis.com.

The evaluation board, EVB90614 supported by PC SW allows easy configuration of the filters, while not requiring in-depth understanding of the EEPROM.

The available filter settings and the settling times are listed below. Settling time depends on three configurations: single / dual zone, IIR filter settings and FIR filter settings. The FIR filter has a straight forward effect on noise (4 times decreasing of filter strength increases the noise 2 times and vice versa. The IIR filter provides an additional, spike limiting feature. Spike limit defines the level of magnitude to which the spike would be limited – for example, 25% denotes that if a 20°C temperature delta spike is measured the temperature reading by the MLX90614 will spike only 5°C.

IIR setting	FIR setting	Settling time (s)	Settling time (s)	Spike limit
		90614xAx	90614xBx, 90614xCx	
xxx	000…011	Not recommended		
100	100	0.04	0.06	100.00%
100	101	0.05	0.07	100.00%
100	110	0.06	0.10	100.00%
100	111	0.10	0.14	100.00%
101	100	0.12	0.20	80.00%
101	101	0.16	0.24	80.00%
101	110	0.22	0.34	80.00%
101	111	0.35	0.54	80.00%
110	100	0.24	0.38	66.70%
110	101	0.30	0.48	66.70%
110	110	0.43	0.67	66.70%
110	111	0.70	1.10	66.70%
111	100	0.26	0.42	57.00%
111	101	0.34	0.53	57.00%
111	110	0.48	0.75	57.00%
111	111	0.78	1.20	57.00%
000	100	0.30	0.47	50.00%
000	101	0.37	0.60	50.00%
000	110	0.54	0.84	50.00%
000	111	0.86	1.33	50.00%
001	100	0.70	1.10	25.00%
001	101	0.88	1.40	25.00%
001	110	1.30	2.00	25.00%
001	111	2.00	3.20	25.00%
010	100	1.10	1.80	16.70%
010	101	1.40	2.20	16.70%
010	110	2.00	3.20	16.70%
010	111	3.30	5.00	16.70%
011	100	1.50	2.40	12.50%
011	101	1.90	3.00	12.50%
011	110	2.80	4.30	12.50%
011	111	4.50	7.00	12.50%

Table 9: possible IIR and FIR settings

Note: Settling time is in seconds and depends on internal oscillator absolute value.
100% spike limit appears with the IIR filter bypassed, and there is no spike limitation.

8.3.4 RAM

It is not possible to write into the RAM memory. It can only be read and only a limited number of RAM registers are of interest to the customer.

RAM (32x17)		
Name	Address	Read access
Melexis reserved	**0x00**	**Yes**
…	**…**	**…**
Melexis reserved	**0x03**	**Yes**
Raw data IR channel 1	**0x04**	
Raw data IR channel 2	**0x05**	
T_A	**0x06**	**Yes**
T_{OBJ1}	**0x07**	**Yes**
T_{OBJ2}	**0x08**	**Yes**
Melexis reserved	**0x09**	**Yes**
…	**…**	**…**
Melexis reserved	**0x1F**	**Yes**

Table 10: Ram addresses

8.4 SMBus compatible 2-wire protocol

The chip supports a 2 wires serial protocol, build with pins PWM / SDA and SCL.

- SCL – digital input only, used as the clock for SMBus compatible communication. This pin has the auxiliary function for building an external voltage regulator. When the external voltage regulator is used, the 2-wire protocol is available only if the power supply regulator is overdriven.
- PWM / SDA – Digital input / output, used for both the PWM output of the measured object temperature(s) or the digital input / output for the SMBus. In PWM mode the pin can be programmed in EEPROM to operate as Push / Pull or open drain NMOS (open drain NMOS is factory default). In SMBus mode SDA is forced to open drain NMOS I/O, push-pull selection bit defines PWM / Thermal relay operation.

SMBus communication with MLX90614 is covered in details in application notes, available from www.melexis.com.

8.4.1 Functional description

The SMBus interface is a 2-wire protocol, allowing communication between the Master Device (MD) and one or more Slave Devices (SD). In the system only one master can be presented at any given time [1]. The MLX90614 can only be used as a slave device.

Generally, the MD initiates the start of data transfer by selecting a SD through the Slave Address (SA).

The MD has read access to the RAM and EEPROM and write access to 9 EEPROM cells (at addresses 0x00, 0x01, 0x02, 0x03, 0x04, 0x05*, 0x0E, 0x0F, 0x09). If the access to the MLX90614 is a read operation it will respond with 16 data bits and 8 bit PEC only if its own slave address, programmed in internal EEPROM, is equal to the SA, sent by the master. The SA feature allows connecting up to 127 devices (SA=0x00…0x07F) with only 2 wires, unless the system has some of the specific features described in paragraph 5.2 of reference [1]. In order to provide access to any device or to assign an address to a SD before it is connected to the bus system, the communication must start with zero SA followed by low R/$\overline{W}$ bit. When this command is sent from the MD, the MLX90614 will always respond and will ignore the internal chip code information.

Special care must be taken not to put two MLX90614 devices with the same SA on the same bus as MLX90614 does not support ARP [1].

The MD can force the MLX90614 into low consumption mode “sleep mode” (3V version only).

Read flags like “EEBUSY” (1 – EEPROM is busy with executing the previous write/erase), “EE_DEAD” (1 – there is fatal EEPROM error and this chip is not functional**).

Note: This address is readable and writable. Bit 3 should not be altered as this will cancel the factory calibration.*
*Note**: EEPROM error signaling is implemented in automotive grade parts only.*

8.4.2 Differences with the standard SMBus specification (reference [1])

There are eleven command protocols for standard SMBus interface. The MLX90614 supports only two of them. Not supported commands are:

- Quick Command
- Byte commands - Sent Byte, Receive Byte, Write Byte and Read Byte
- Process Call
- Block commands – Block Write and Write-Block Read Process Call

Supported commands are:

- Read Word
- Write Word

8.4.3 Detailed description

The PWM / SDA pin of MLX90614 can operate also as PWM output, depending on the EEPROM settings. If PWM is enabled, after POR the PWM / SDA pin is directly configured as PWM output. Even if the device is in PWM mode SMBus communication may be restored by a special command. That is why hereafter both modes are treated separately.

8.4.3.1 Bus Protocol

1	7	1	1	8	1	1
S	Slave Address	Wr	A	Data Byte	A	P

S	Start Condition
Sr	Repeated Start Condition
Rd	Read (bit value of 1)
Wr	Write (bit value of 0)
A	Acknowledge (this bit can be 0 for ACK and 1 for NACK)
S	Stop Condition
PEC	Packet Error Code
□ (white)	Master-to-Slave
■ (grey)	Slave-to-Master

Figure 4: SMBus packet element key

After every received 8 bits the SD should issue ACK or NACK. When a MD initiates communication, it first sends the address of the slave and only the SD which recognizes the address will ACK, the rest will remain silent. In case the SD NACKs one of the bytes, the MD should stop the communication and repeat the message. A NACK could be received after the PEC. This means that there is an error in the received message and the MD should try sending the message again. The PEC calculation includes all bits except the START, REPEATED START, STOP, ACK, and NACK bits. The PEC is a CRC-8 with polynomial X8+X2+X1+1. The Most Significant Bit of every byte is transferred first.

8.4.3.1.1 Read Word (depending on the command – RAM or EEPROM)

1	7	1	1	8	1	1	7	1	1	
S	Slave Address	Wr	A	Command	A	Sr	Slave Address	Rd	A	………..

	8	1	8	1	8	1	1
………..	Data Byte Low	A	Data Byte High	A	PEC	A	P

Figure 5: SMBus read word format

8.4.3.1.2 Write Word (depending on the command – RAM or EEPROM)

1	7	1	1	8	1	
S	Slave Address	Wr	A	Command	A	………..

	8	1	8	1	8	1	1
………..	Data Byte Low	A	Data Byte High	A	PEC	A	P

Figure 6: SMBus write word format

8.4.4 Bit transfer

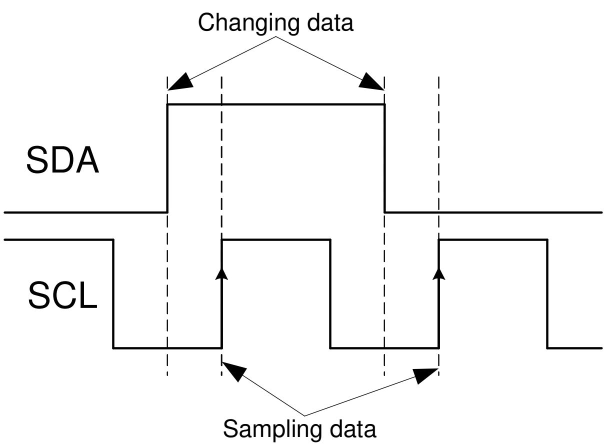


Figure 7: Recommended timing on SMBus

The data on PWM / SDA must be changed when SCL is low (min 300ns after the falling edge of SCL). The data is fetched by both MD and SDs on the rising edge of the SCL. The recommended timing for changing data is in the middle of the period when the SCL is low.

8.4.5 Commands

RAM and EEPROM can be read both with 32x16 sizes. If the RAM is read, the data are divided by two, due to a sign bit in RAM (for example, T_{O1} - RAM address 0x07 will sweep between 0x27AD to 0x7FFF as the object temperature rises from -70.01°C to +382.19°C). The MSB read from RAM is an error flag (active high) for the linearized temperatures (T_{O1}, T_{O2} and T_a). The MSB for the raw data (e.g. IR sensor1 data) is a sign bit (sign and magnitude format). A write of 0x0000 must be done prior to writing in EEPROM in order to erase the EEPROM cell content. Refer to EEPROM detailed description for factory calibration EEPROM locations that need to be kept unaltered.

Opcode	Command
000x xxxx*	RAM Access
001x xxxx*	EEPROM Access
1111_0000**	Read Flags
1111_1111	Enter SLEEP mode

Table 11: SMBus commands

Note: The xxxxx represent the 5 LSBits of the memory map address to be read / written.*
*Note**: Behaves like read command. The MLX90614 returns PEC after 16 bits data of which only 4 are meaningful and if the MD wants it, it can stop the communication after the first byte. The difference between read and read flags is that the latter does not have a repeated start bit.*
Flags read are:
Data[7] - EEBUSY - the previous write/erase EEPROM access is still in progress. High active.
Data[6] - Unused
Data[5] - EE_DEAD - EEPROM double error has occurred. High active.
Data[4] - INIT - POR initialization routine is still ongoing. Low active.
Data[3] - Not implemented.
Data[2...0] and Data[8...15] - All zeros.
Flag read is a diagnostic feature. The MLX90614 can be used regardless of these flags.

For details and examples for SMBus communication with the MLX90614 check the www.melexis.com

8.4.6 SMBus communication examples

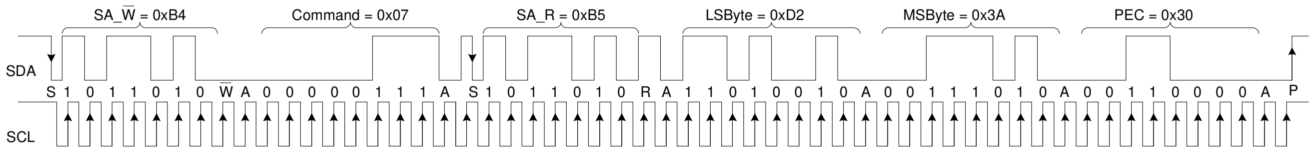


Figure 8: Read word format (SA=0x5A, read RAM=0x07, result=0x3AD2, PEC=0x30)

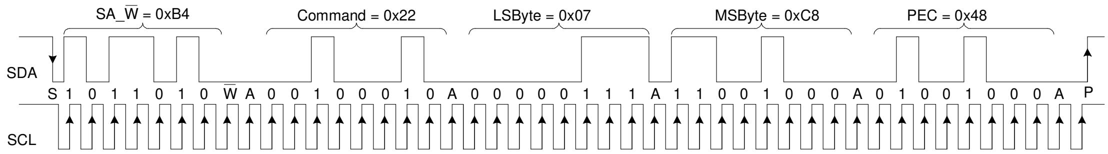


Figure 9: Write word format (SA=0x5A, write EEPROM=0x02, data=0xC807, PEC=0x48)

8.4.7 Timing specification

The MLX90614 meets all the timing specifications of the SMBus [1]. The maximum frequency of the MLX90614 SMBus is 100 KHz and the minimum is 10 KHz.

The specific timings in MLX90614's SMBus are:

SMBus Request (t_{REQ}) is the time that the SCL should be forced low in order to switch MLX90614 from PWM mode to SMBus mode – at least 1.44ms;

Timeout L is the maximum allowed time for SCL to be low during communication. After this time the MLX90614 will reset its communication block and will be ready for new communication – not more than 27ms;

Timeout H is the maximum allowed time for SCL to be high during communication. After this time MLX90614 will reset its communication block assuming that the bus is idle (according to the SMBus specification) – not more than 45µs.

Tsuac(SD) is the time after the eighth falling edge of SCL that MLX90614 will force PWM / SDA low to acknowledge the last received byte – not more than 2,5µs.

Thdac(SD) is the time after the ninth falling edge of SCL that MLX90614 will release the PWM / SDA (so the MD can continue with the communication) – not more than 1,5µs.

Tsuac(MD) is the time after the eighth falling edge of SCL that MLX90614 will release PWM / SDA (so that the MD can acknowledge the last received byte) – not more than 1,5µs.

Thdac(MD) is the time after the ninth falling edge of SCL that MLX90614 will take control of the PWM / SDA (so it can continue with the next byte to transmit) – not more than 1,5µs.

The indexes MD and SD for the latest timings are used – MD when the master device is making acknowledge; SD when the slave device is making acknowledge. For other timings see [1].

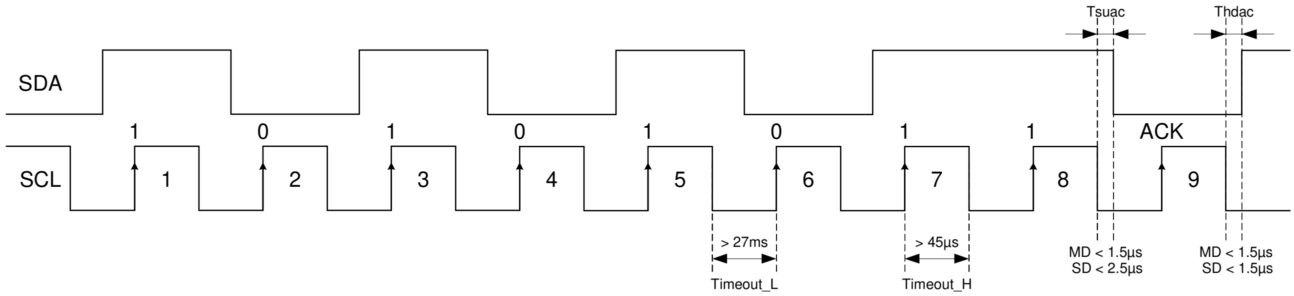


Figure 10: SMBus timing specification and definition

8.4.8 Sleep Mode

The MLX90614 can enter in Sleep Mode via the command "Enter SLEEP mode" sent via the SMBus interface. This mode is not available for the 5V supply version. There are two ways to put MLX90614 into power-up default mode:

- POR
- By Wake up request → SCL pin high and then PWM/SDA pin low for at least t_{DDQ} > 33ms

If EEPROM is configured for PWM (EN_PWM is high), the PWM interface will be selected after awakening and if PWM control [2], PPODB is 1 the MLX90614 will output a PWM pulse train with push-pull output.

NOTE: In order to limit the current consumption to the typical 2.5µA Melexis recommends that the SCL pin is kept low during sleep as there is leakage current trough the internal synthesized zener diode connected to SCL pin. This may be achieved by configuring the MD driver of SCL pin as Push-Pull and not having Pull-Up resistor connected on SCL line.

8.4.8.1 Enter Sleep Mode

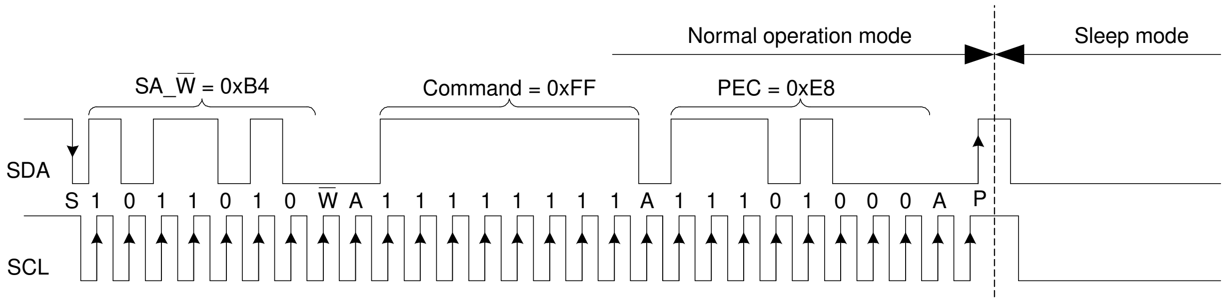


Figure 11: Enter sleep mode command (SA = 0x5A, Command = 0xFF, PEC = 0xE8)

8.4.8.2 Exit from Sleep Mode (Wake up request)

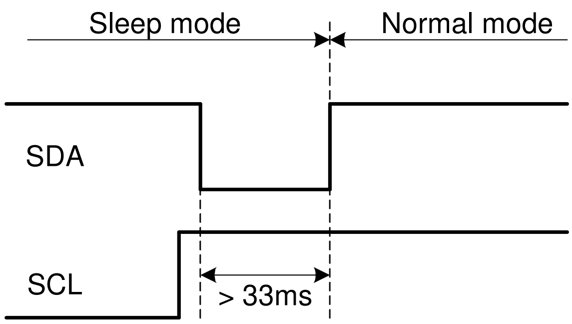


Figure 12: Exit Sleep Mode

After wake up the first data is available after 0.25 seconds (typ). On-chip IIR filter is skipped for the very first measurement. All measurements afterwards pass the embedded digital filtering as configured in EEPROM. Details on embedded filtering are available in application note "Understanding MLX90614 on-chip digital signal filters", available from www.melexis.com

8.4.9 MLX90614 SMBus specific remarks

The auxiliary functions of the SCL pin (zener diode) add undershoot to the clock pulse (5V devices only) as shown in the picture below (see Figure 13). This undershoot is caused by the transient response of the on-chip synthesized Zener diode. Typical duration of undershoot is approximately 15µs. An increased reactance of the SCL line is likely to increase this effect. Undershoot does not affect the recognition of the SCL rising edge by the MLX90914, <u>but may affect proper operation of non-MLX90614 slaves on the same bus</u>.

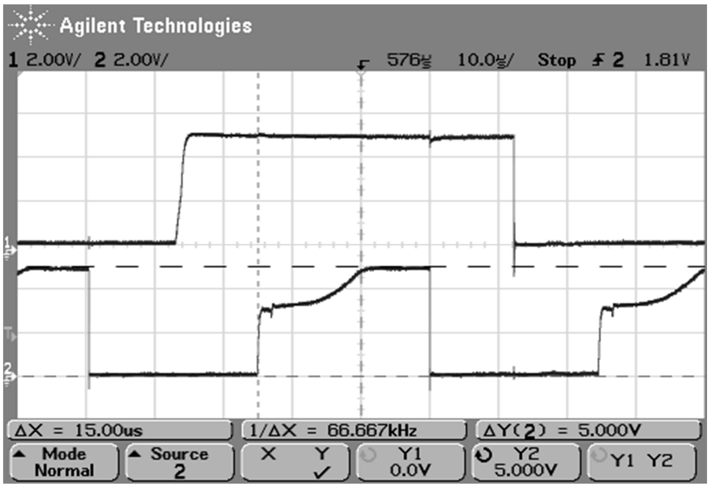


Figure 13: Undershoot of SCL line due to on chip synthesized Zener diode (5V versions only)

Continuous SMBus readings can introduce and error. As the SCL line inside TO39 package is passing relatively close to the sensor input and error signal is induced to the sensor output. The manifestation of the problem is wrong temperature readings. This is especially valid for narrow FOV devices. Possible solution is to keep SDA and SCL line quiet for period longer than refresh rate and settling time defined by internal settings of MLX90614 prior reading the temperature or switch to PWM signal and completely disconnect from SDA and SCL line.

8.5 PWM

The MLX90614 can be read via PWM or SMBus compatible interface. Selection of PWM output is done in EEPROM configuration (factory default is SMBus). PWM output has two programmable formats, single and dual data transmission, providing single wire reading of two temperatures (dual zone object or object and ambient). The PWM period is derived from the on-chip oscillator and is programmable.

Config Register[5:4]	PWM1 data	PWM2 data	Tmin,1	Tmax,1	Tmin,2	Tmax,2
00	T_A	T_{O1}	$T_{A\ range},L$	$T_{A\ range},H$	$T_{O\ MIN}$	$T_{O\ MAX}$
01	T_A	T_{O2}	$T_{A\ range},L$	$T_{A\ range},H$	$T_{O\ MIN}$	$T_{O\ MAX}$
11	T_{O1}	T_{O2}	$T_{O\ MIN}$	$T_{O\ MAX}$	$T_{O\ MIN}$	$T_{O\ MAX}$
10*	T_{O2}	**Undefined**	$T_{O\ MIN}$	$T_{O\ MAX}$	**N.A.**	**N.A.**

Table 12: PMW configuration table

Note: Serial data functions (2-wire / PWM) are multiplexed with a thermal relay function (described in the "Thermal relay" section).
** Not recommended for extended PWM format operation*

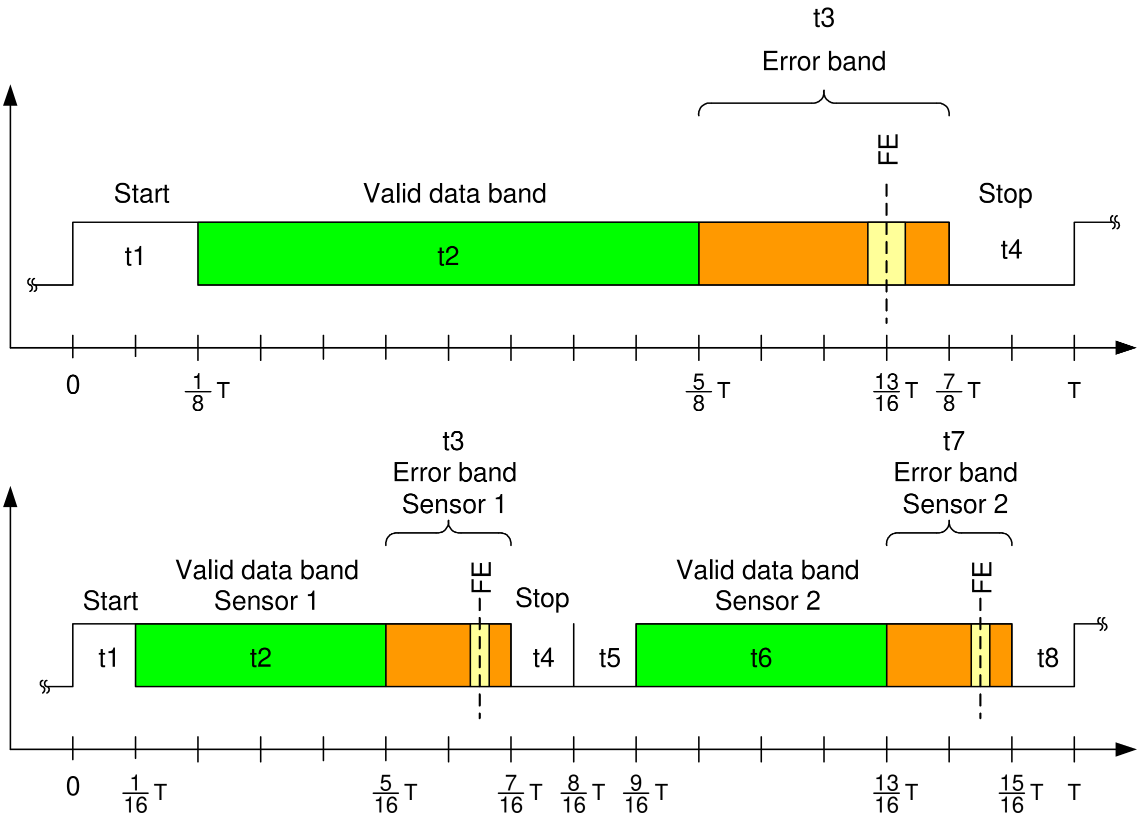


Figure 14: PWM timing single (above) and extended PWM (bellow)

PWM type	t1	t2	t3	t4	t5	t6	t7	t8
Single	1/8 – high	4/8 - var	2/8	1/8 – low	**NA**	**NA**	**NA**	**NA**
Extended - S1	1/16 - high	4/16 - var	2/16	1/16 - low	1/16 - low	4/16 – low	2/16 - low	1/16 - low
Extended - S2	1/16 - high	4/16 - high	2/16 - high	1/16 - high	1/16 - high	4/16 - var	2/16	1/16 - low

Table 13: PMW timing

8.5.1 Single PWM format

In single PWM output mode the settings for PWM1 data only are used. The temperature reading can be calculated from the signal timing as:

$$T_{OUT} = \left(\frac{2t_2}{T} \times \left(T_{O\_MAX} - T_{O\_MIN}\right)\right) + T_{O\_MIN}$$

where Tmin and Tmax are the corresponding rescale coefficients in EEPROM for the selected temperature output (Ta, object temperature range is valid for both Tobj1 and Tobj2 as specified in the previous table) and T is the PWM period. Tout is T_{O1}, T_{O2} or T_a according to Config Register [5:4] settings.
The different time intervals $t_1 \ldots t_4$ have following meaning:

t_1: Start buffer. During this time the signal is always high. t_1 = 0.125s x T (where T is the PWM period, please refer to Figure 14).

t_2: Valid Data Output Band, 0…1/2T. PWM output data resolution is 10 bit.

t_3: Error band – information for fatal error in EEPROM (double error detected, not correctable).
t_3 = 0.25s x T. Therefore a PWM pulse train with a duty cycle of 0.875 will indicate a fatal error in EEPROM (for single PWM format). FE means Fatal Error.

Example:

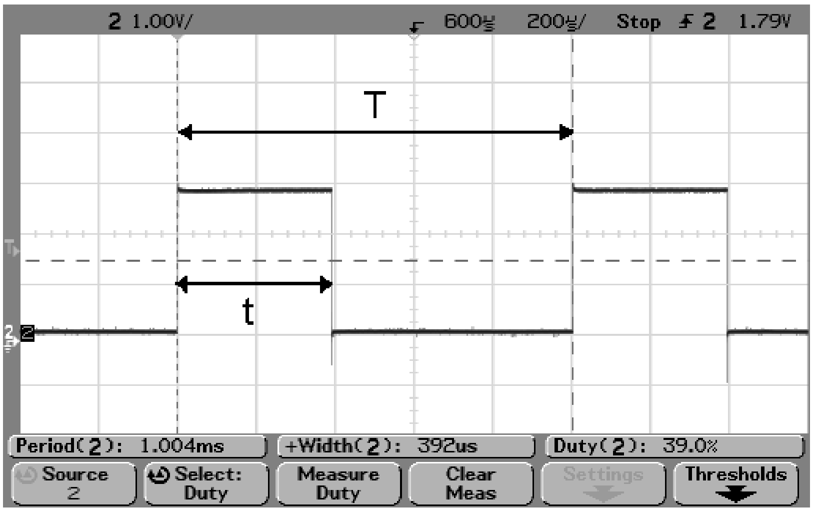


Figure 15: PWM example single mode

$$T_{O\_MIN} = 0°C \rightarrow T_{O\_MIN}(EEPROM, 0x01) = 100 \times (T_{O\_MIN} + 273.15) = 27315d = 0x6AB3$$

$$T_{O\_MAX} = 50°C \rightarrow T_{O\_MAX}(EEPROM, 0x00) = 100 \times (T_{O\_MAX} + 273.15) = 32315d = 0x7E3B$$

Captured PWM period is T = 1004µs
Captured high duration is t = 392 µs
Calculated duty cycle is:

$$D = \frac{t}{T} = \frac{392}{1004} = 0.3904 \text{ or } 39.04\%$$

The temperature is calculated as follows:

$$T_O = 2 \times (0.3904 - 0.125) \times (50 - 0) + 0 = 2 \times 0.2654 \times 50 = 26.54°C$$

8.5.2 Extended PWM format

The PWM format for extended PWM is shown in Figure 16. Note that with bits DUAL[5:1]>0x00 each period will be outputted 2N+1 times, where N is the decimal value of the number written in DUAL[5:1] (*DUAL[5:1] =PWM control & clock [8:4]*), like shown on Figure 16.

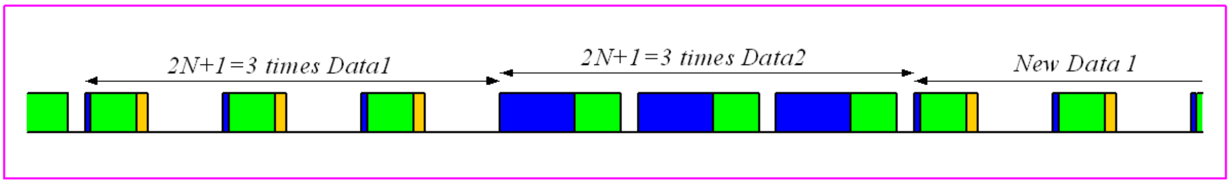


Figure 16: Extended PWM format with DUAL [5:1] = 01h (2 repetitions for each data)

The temperature transmitted in Data 1 field can be calculated using the following equation:

$$T_{OUT1} = \left(\frac{4t_2}{T} \times (T_{MAX1} - T_{MIN1}) \right) + T_{MIN1}$$

For Data 2 field the equation is:

$$T_{OUT2} = \left(\frac{4t_5}{T} \times (T_{MAX2} - T_{MIN2}) \right) + T_{MIN2}$$

Time bands are: t_1=0.0625 x T (Start1), t_3=0.125 x T and t_4=0.5625 x T (Start2 = Start1 + Valida_data1 + error_band1 + stop1 + start2). As shown in Figure 13, in extended PWM format the period is twice the period for the single PWM format. All equations provided herein are given for the single PWM period T. The EEPROM Error band signaling will be 43.75% duty cycle for Data1 and 93.75% for Data2.

Note: EEPROM error signaling is implemented in automotive grade parts only.

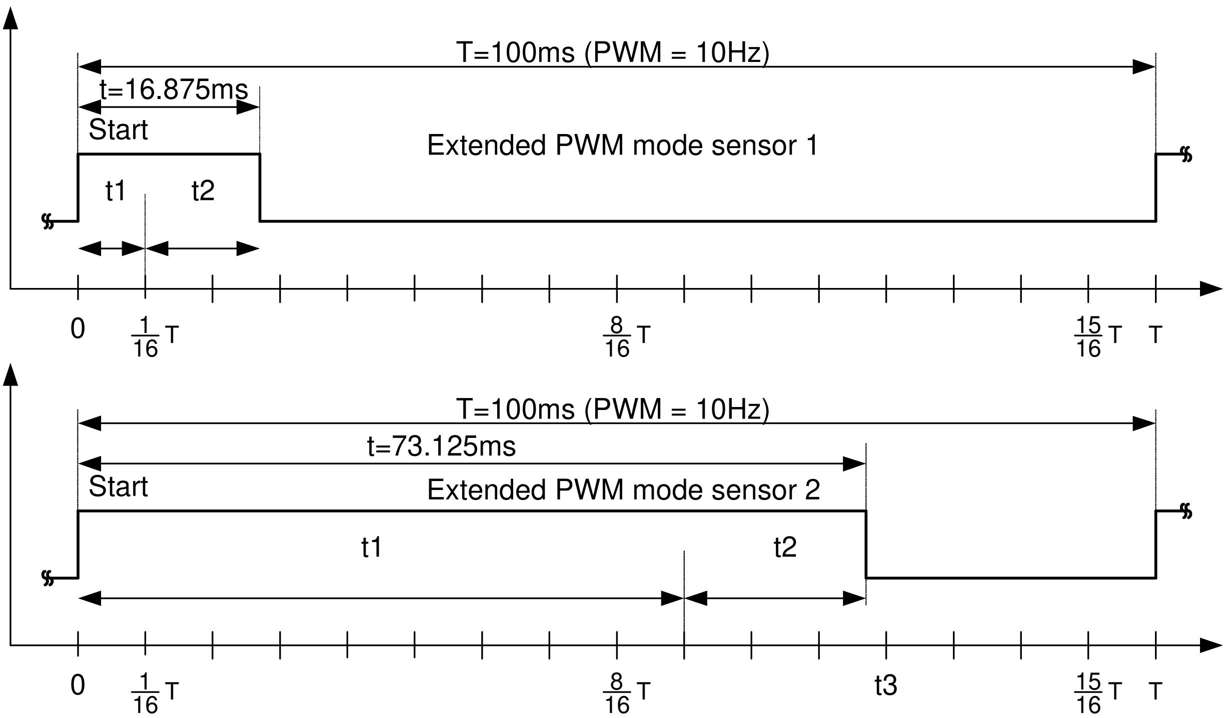


Figure 17: Example: Extended PWM mode readings – sensor 1 above and sensor 2 bellow

Example: (see Figure 17 above):

Configuration:

Sensor1 = Ta, Sensor2 = T_{obj1} → Config Reg[5:4] = 00b,

$$T_{A\_MIN} = 0°C \rightarrow T_{A\_RANGE\_L}(EEPROM) = 100 \times \frac{(T_{A\_min} + 38.2)}{64} = 59.6875 \approx 60d = 0x3C$$

$$T_{A\_MAX} = 60°C \rightarrow T_{A\_RANGE\_H}(EEPROM) = 100 \times \frac{(T_{A\_max} + 38.2)}{64} = 153.4375 \approx 153d = 0x99$$

$$T_{A\_RANGE}(EEPROM, 0x03) = \{T_{A\_RANGE\_H} : T_{A\_RANGE\_L}\} = 0x993C$$

$$T_{O\_MIN} = 0°C \rightarrow T_{O\_MIN}(EEPROM, 0x01) = 100 \times (T_{O\_min} + 273.15) = 27315d = 0x6AB3$$

$$T_{O\_MAX} = 50°C \rightarrow T_{O\_MAX}(EEPROM, 0x00) = 100 \times (T_{O\_min} + 273.15) = 32315d = 0x7E3B$$

Captured high durations are:

Sensor 1 – t = 16.875ms at period T = 100ms thus the duty cycle is $Duty_{S1} = \frac{16.875}{100} = 0.16875$

Sensor 2 – t = 73.125ms at period T = 100ms thus the duty cycle is $Duty_{S2} = \frac{73.125}{100} = 0.73125$

The temperatures are calculated as follows:

$$T_A = 4 \times (Duty_{S1} - Start1) \times (T_{A\_MAX} - T_{A\_MIN}) + T_{A\_MIN}$$

$$T_A = 4 \times (0.16875 - 0.0625) \times (60 - 0) + 0 = 25.5°C$$

$$T_{O1} = 4 \times (Duty_{S2} - Start2) \times (T_{O\_MAX} - T_{O\_MIN}) + T_{O\_MIN}$$

$$T_{O1} = 4 \times (0.73125 - 0.5625) \times (50 - 0) + 0 = 33.75°C$$

8.5.3 Customizing the temperature range for PWM output

The calculated ambient and object temperatures are stored in RAM with a resolution of 0.01°C (16 bit). The PWM operates with a 10-bit word so the transmitted temperature is rescaled in order to fit in the desired range.

For this goal 2 cells in EEPROM are foreseen to store the desired range for To (To_{min} and To_{max}) and one for Ta (Ta_{range}: the 8MSB are foreseen for Ta_{max} and the 8LSB for Ta_{min}).
Thus the output range for To can be programmed with an accuracy of 0.01°C, while the corresponding Ta range can be programmed with an accuracy of 0.64°C.
The object data for PWM is rescaled according to the following equation:

$$T_{PWM_{obj}} = \frac{T_{RAM} - T_{MIN_{EEPROM}}}{K_{PWM\,obj}}, K_{PWM\,obj} = \frac{T_{MAX_{EEPROM}} - T_{MIN_{EEPROM}}}{1023}$$

The T_{RAM} is the linearized Tobj, 16-bit (0x0000…0xFFFF, 0x0000 for -273.15°C and 0xFFFF for +382.2°C) and the result is a 10-bit word, in which 0x000 corresponds to To_{MIN}[°C], 0x3FF corresponds to To_{MAX}[°C] and 1LSB corresponds to $\frac{To_{MAX} - To_{MIN}}{1023}$ [°C].

$$T_{MIN_{EEPORM}} = T_{MIN} \times 100 \text{ LSB}$$

$$T_{MAX_{EEPORM}} = T_{MAX} \times 100 \text{ LSB}$$

The ambient data for PWM is rescaled according to the following equation:

$$T_{PWM_{ambient}} = \frac{T_{RAM} - T_{MIN_{EEPROM}}}{K_{PWM_{ambient}}}$$

Where:

$$K_{PWM\ ambient} = \frac{T_{MAX_{EEPROM}} - T_{MIN_{EEPROM}}}{1023}$$

The result is a 10-bit word, where 0x000 corresponds to -38.2°C (lowest Ta that can be read via PWM), 0x3FF corresponds to 125°C (highest Ta that can be read via PWM) and 1LSB corresponds to:

$$1LSB = \frac{T_{MAX} - T_{MIN}}{1023}, [°C]$$

$$T_{MIN_{EEPORM}} = (T_{MIN} - (-38.2)) \times \frac{100}{64} \text{ LSB}$$

$$T_{MAX_{EEPORM}} = (T_{MAX} - (-38.2)) \times \frac{100}{64} \text{ LSB}$$