Fraden Corporation

Use and Interface of Integrated Infrared Thermometer For Mobile Communication Devices

(Models HMM M13 L3.0-F5.5 T115/MLX90325)

San Diego, CA, USA
www.fraden.com

Datasheet Thermopile Module
Type HMM M13 L3.0-F5.5 T115 (PWM)

Features and Benefits

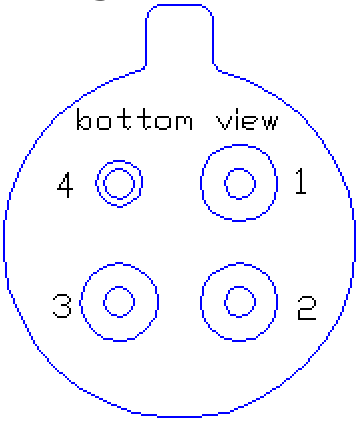
- Non-contact surface temperature detection with digital temperature output
- Thermopile Sensor and ASIC in TO-18/TO-46 housing with 4 leads
- Lens optics with 4:1 distance to spot ratio
- Digital temperature or voltage readout (SMBus compatible) or temperature output (PWM)
- Temperature resolution < 0.1°C at SMBus compatible operation
- High accuracy over wide sensor temperature and object temperature ranges
- Object temperature range -5°C .. 115°C ;
- 3V supply voltage ; higher supply voltage option by embedded shunt voltage regulator
- Complies with ROHS regulations

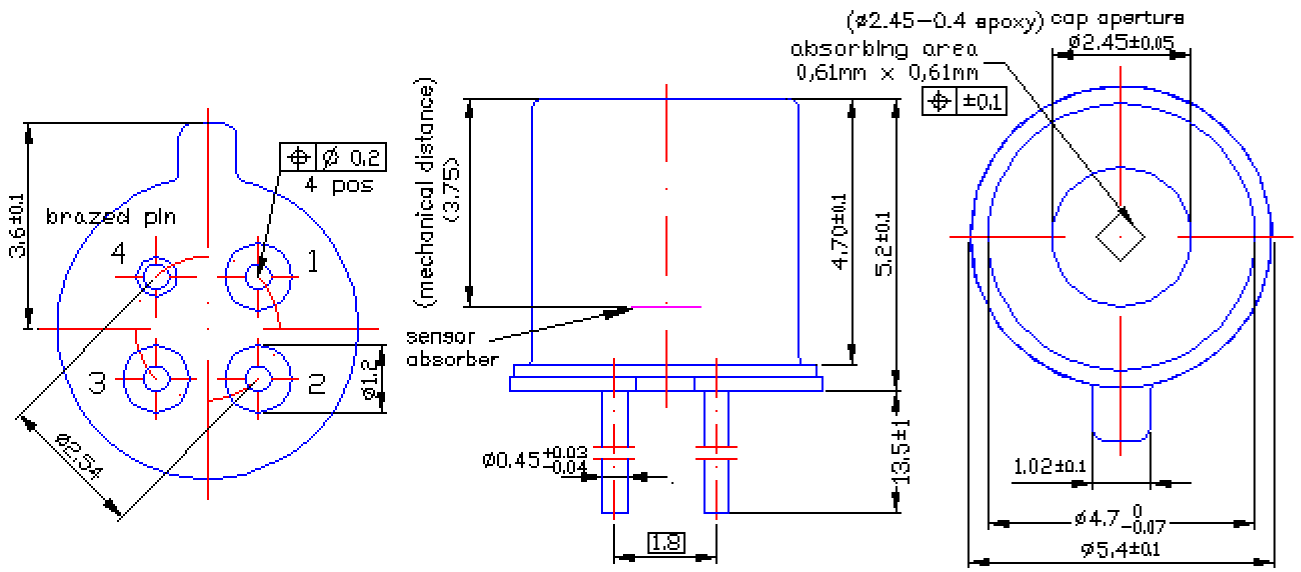
Ordering Information

HMM -> Heimann thermopile sensor and ASIC in TO-18/TO-46 housing
M13   -> „M"cap TO-46 for lens optics; „1" sensor chip TP1 ;
„3" small ASIC , supply voltage 3V
L3.0-F5.5 -> lens optics focal length 3mm , infrared transmission longwave pass cut on 5.5µm
T115 -> Object temperature range -5°C .. +115°C
(PWM) -> optional: „PWM" output , SDA/PWM-pin adusted to pulse width modulation

Pin Configuration and Dimensional Drawing

Pin	*Symb*	*Description*
1	SDA/ PWM	Digital I/O in SMBus compatible mode or pulse width modulated temperature(s) output in PWM mode
2	VDD	Positive supply voltage
3	SCL	Digital input , serial clock in SMBus compatible mode
4	VSS	Negative supply voltage / Ground (0V) (connected to housing)





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Maximum Ratings

Parameter	*Max. value*	*Unit*	*Condition*
Supply voltage VDD	5	V	Over voltage
Supply voltage VDD	3.6	V	Operation
Reverse voltage	0.5	V	Ground
ESD sensitivity	2	kV	Human body
Operating temperature	-40.. +85	°C	
Storage temperature	-40.. +125	°C	

Operating Conditions

Parameter	*Typical Value*	*Unit*	*Condition*
Supply voltage VDD	(2.6) .. 3 .. (3.6)	V	
Supply voltage VSS	0	V	Ground
Supply current	1.4 .. (2)	mA	Without load
Start up time after POR	0.15	sec	
Sensor absorbing area	0.61 x 0.61	mm²	Type TP1
Object temperature range	-5 .. +115	°C	
Response time	5	ms	Sensor chip
Refresh rate	ca. 100	ms	Temperature output
IR transmission (long wave pass)	>70	%	Within wavelength range 7.5µm to 13µm for LWP cut on 5.5µm
Operating temperature	-40 .. +85	°C	
Slave address	5B	hex	Factory default
Interface SM-Bus (default)	2-wire SMBus compatible, factory default without interface indication, output configured as open drain NMOS by default		
Interface PWM (type .. PWM)	1-wire PWM output on SDA/PWM, 10 bit resolution default settings: push-pull, single PWM, output of object temperature sensor 1		

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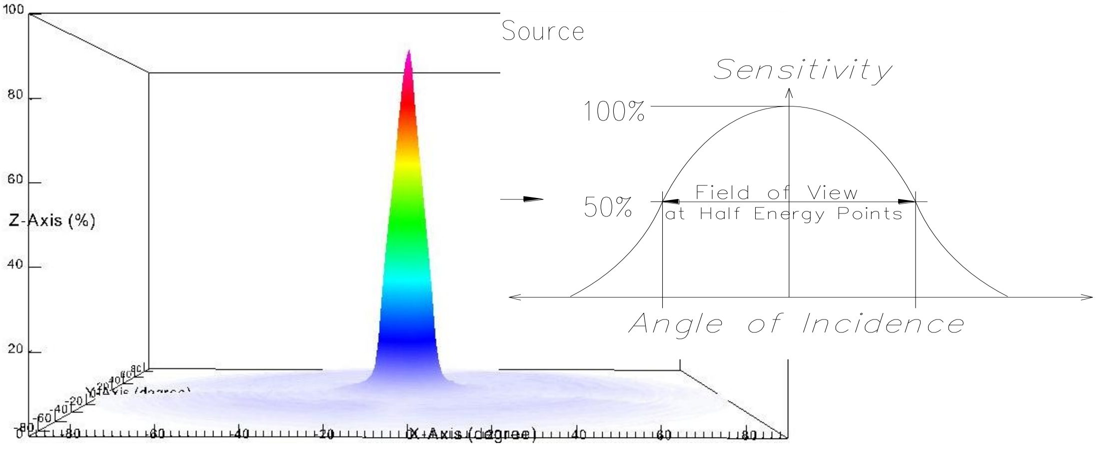
Type HMM M13 L3.0-F5.5 T115 (PWM)

Field of View



parameter	*limits*			*unit*	*conditions*
	Min	*Typ*	*Max*		
Optical axis	-3.5	0	+3.5	degree	Sensor view direction
Field of View		10	20	degree	energy points 50%
D:S Ratio		4:1			Distance to spot size

Temperature Performance

		Sensor (Ambient) Temperature [°C]			
		-40 .. 0	0 .. 40	40 .. 85	
Object Temperature [°C]	-30 .. 0	±3°C	±2.5°C	±3°C	Temperature Accuracy [°C]
	0 .. 60	±2°C	±1°C	±1.5°C	
	60 .. 115	±3°C	±2°C	±2.5°C	

Notes to the temperature performance:

- The specified temperature performance presents preliminary findings based on sample investigations using special test equipment.
- The temperature accuracies are achievable by following conditions
  - ➢ thermal equilibrium of the sensor
  - ➢ no temperature differences in the sensor package
  - ➢ the object fills the sensor field of view completely
  - ➢ homogenously distributed temperature on the object surface
  - ➢ high and uniform emissivity of the object surface in the interesting infrared range

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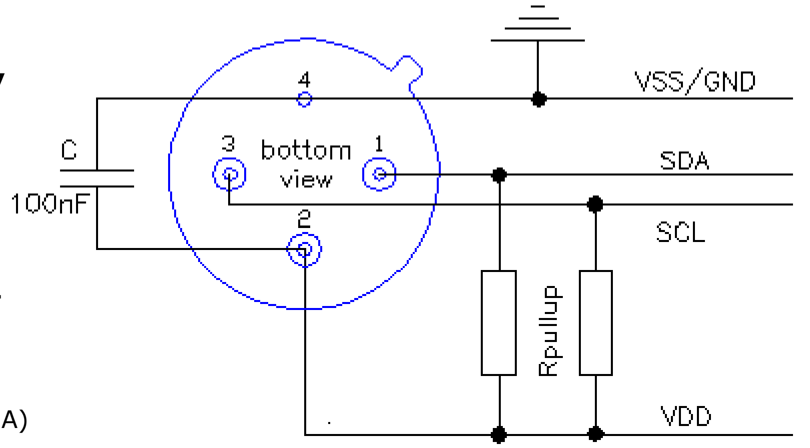
Applications Circuitry SM-Bus Operation

Pull-up resistor recommendation:

low power applications 20kOhm (SM-Bus DC specification Ipullup 100µA .. 350µA)

high power applications 1.5kOhm (SM-Bus DC specification Ipullup min. 4mA)



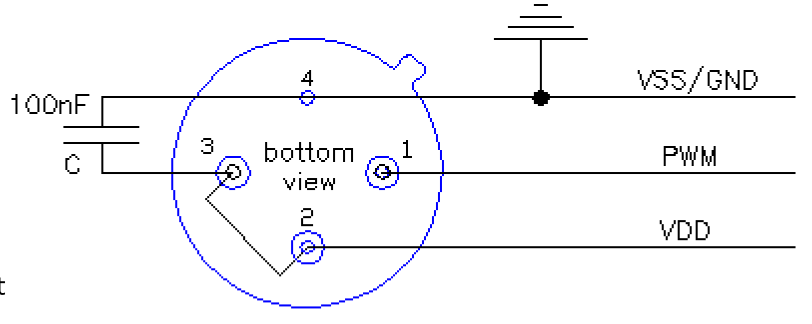
Applications Circuitry PWM Operation

PWM mode is free running after power on.

Pin 3 (SCL) must be forced high for PWM mode

PWM output is configured as push pull

Default PWM output of object temperature 1



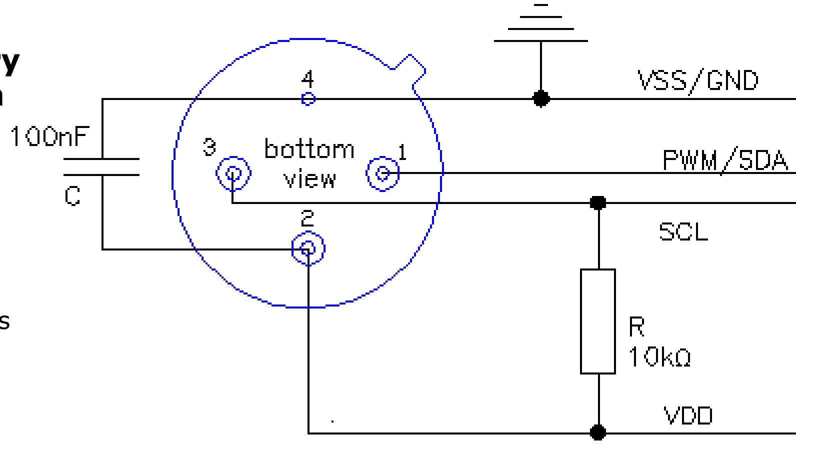
Applications Circuitry PWM Operation with SM-Bus Option

PWM mode is free running after power on.

SM-Bus operation available by added pull-up resistor

PWM output is configured as push pull

Default PWM output of object temperature 1



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General description (continued)

The MLX90615 is built from 2 chips, the Infra Red thermopile detector and the signal conditioning chip MLX90325, specially designed by Melexis to process the output of IR sensor.
The device is available in an industry standard TO-46 package.

Thanks to the low noise amplifier, high resolution 16-bit ADC and powerful DSP unit of the MLX90325, Melexis is able to deliver a high accuracy and high resolution infrared thermometer. The calculated object and ambient temperatures are available in the RAM memory of the MLX90325 with a resolution of 0.02˚C. The values are accessible by 2 wire serial SMBus compatible protocol with a resolution of 0.02℃ or via a 10-bit PWM (Pulse Width Modulated) signal from the device.

The MLX90615 is factory calibrated in standard temperature ranges from: -40...85˚C for the ambient temperature and from -40...115˚C for the object temperature.

As a standard, the MLX90615 is delivered with a programmed 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 MLX90615 can be battery powered.

An optical filter (5.5µm …14µm long-wave pass) that cuts off the visible and near infra-red radiant flux is integrated in the package to make the sensor insensitive to visible light.

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)
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
DC	**D**irect **C**urrent (for settled conditions specifications)
LPF	**L**ow **P**ass **F**ilter
FOV	**F**ield **O**f **V**iew
SDA, SCL	**S**erial **DA**ta, **S**erial **CL**ock – SMBus compatible communication pins
T_A	**A**mbient **T**emperature measured from the chip – (the package temperature)
T_O	**O**bject **T**emperature, 'seen' from IR sensor
ESD	**E**lectro-**S**tatic **D**ischarge
EMC	**E**lectro-**M**agnetic **C**ompatibility
TBD	**T**o **B**e **D**efined

Table 1: Glossary of Terms

5 Maximum ratings

Parameter	MLX90615
Supply Voltage, V_{DD} (over voltage)	5V
Supply Voltage, V_{DD} (operating)	3.6V
Reverse Voltage	0.5 V
Operating Temperature Range, T_A	-20…+85°C
Storage Temperature Range, T_S	-20…+125°C
ESD Sensitivity (AEC Q100 002)	2kV
DC sink current, SDA pin	25 mA
DC clamp current, SDA pin	10 mA
DC clamp current, SCL pin	10 mA

Table 2: Absolute maximum ratings for MLX90615

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

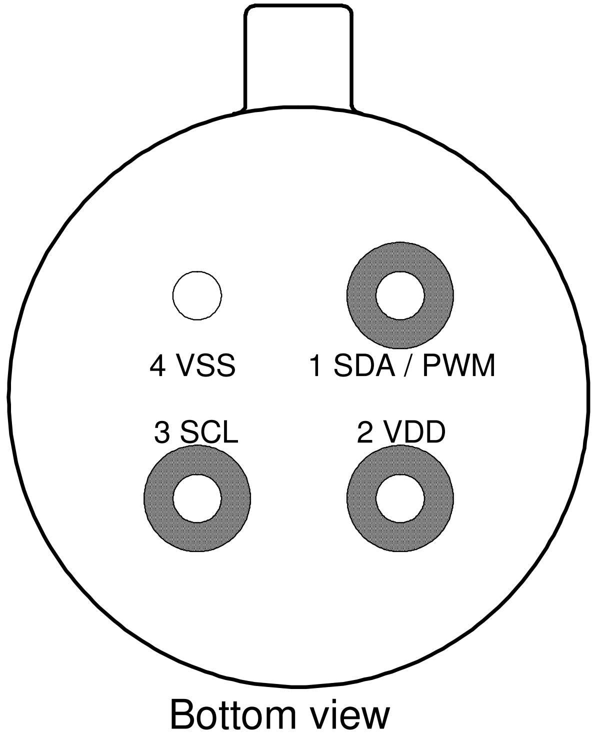

Figure 2: Pin description MLX90615

Pin Name	Function
SDA / PWM	Digital input / output open drain NMOS. In SMBus mode (factory default) Serial Data I/O. In PWM mode – PWM output. Weak pull-up (300kΩ typ) is present on this pin.
VDD	External supply voltage.
SCL	Serial clock input for 2 wire communications protocol. Weak pull-up (300kΩ typ) is present on this pin.
VSS	Ground. The metal can is also connected to this pin.

Table 3: Pin description MLX90615

Notes:
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.

Both SCL and SDA pin have input Schmidt trigger when the thermometer is operated in the 2-wire SMBus interface mode.

7 Electrical Specification

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	3.4	V
Supply current	I_{DD}	No load		1.3	1.5	mA
Supply current (programming)	I_{DDpr}	No load, erase / write EEPROM operations		1.5		mA
Power-down supply current	Isleep	No load, SCL and SDA high		1.1	3	µA
Power On Reset						
POR level	V_{POR}	Power-up, power-down and brown-out	0.8	1.5	1.9	V
V_{DD} rise time	T_{POR}	Ensure POR signal			20	ms
Output valid	Tvalid	After POR		0.5		s
EEPROM						
Data retention		T_A = +85℃	10			years
Erase/write cycles		T_A = +25℃	100,000			Times
Erase/write cycles		T_A = +85℃	40,000			Times
Erase cell time	Terase			5		ms
Write cell time	Twrite			5		ms
Pulse width modulation						
PWM resolution	PWMres	Data band		10		bit
PWM output period	$PWM_{T,H,def}$	Factory default high frequency PWM, HFO factory calibrated		1.024		ms
PWM output period	$PWM_{T,L}$	Low frequency PWM, HFO factory calibrated		102.4		ms
PWM period stability	$dPWM_T$	Internal oscillator factory calibrated, over the entire operation range and supply voltage	-15		+15	%
Output low Level	PWM_{LO}	I_{sink} = 2 mA			VSS+0.2	V
Output sink current	$Isink_{PWM}$	Vout,L = 0.5V		10		mA

Table 4 Electrical specification parameters of the MLX90615

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
SMBus compatible 2-wire interface*						
Input high voltage	$V_{IH}(T_A,V)$	Over temperature and supply	VDD-0.1			V
Input low voltage	$V_{IL}(T_A,V)$	Over temperature and supply			0.6	V
Output low voltage	V_{OL}	Over temperature and supply, Isink = 2mA			0.2	V
SCL,SDA leakage	I_{leak}	$V_{SCL}=V_{DD}$, $V_{SDA}=V_{DD}$, T_A =+85℃			0.25	µA
SCL capacitance	C_{SCL}				10	pF
SDA capacitance	C_{SDA}				10	pF
Slave address	SA	Factory default		**5B**		hex
WakeUp Request	t_{wake}	SCL low	8			ms
SMBus Request	t_{REQ}	SCL low	39			ms
Timeout, low	$T_{imeout,L}$	SCL low	21		39	ms
Timeout, high	$T_{imeout,H}$	SCL high	52		78	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

Table 5 Electrical specification parameters of the MLX90615 (continued)

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

**SMBus compatible interface is described in details in the SMBus detailed description section. Maximum number of MLX90615 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.*

MLX90615 is always a slave device on the bus. MLX90615 can work in both low-power and high-power SMBus communication.

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

8 Detailed description

8.1 Block diagram

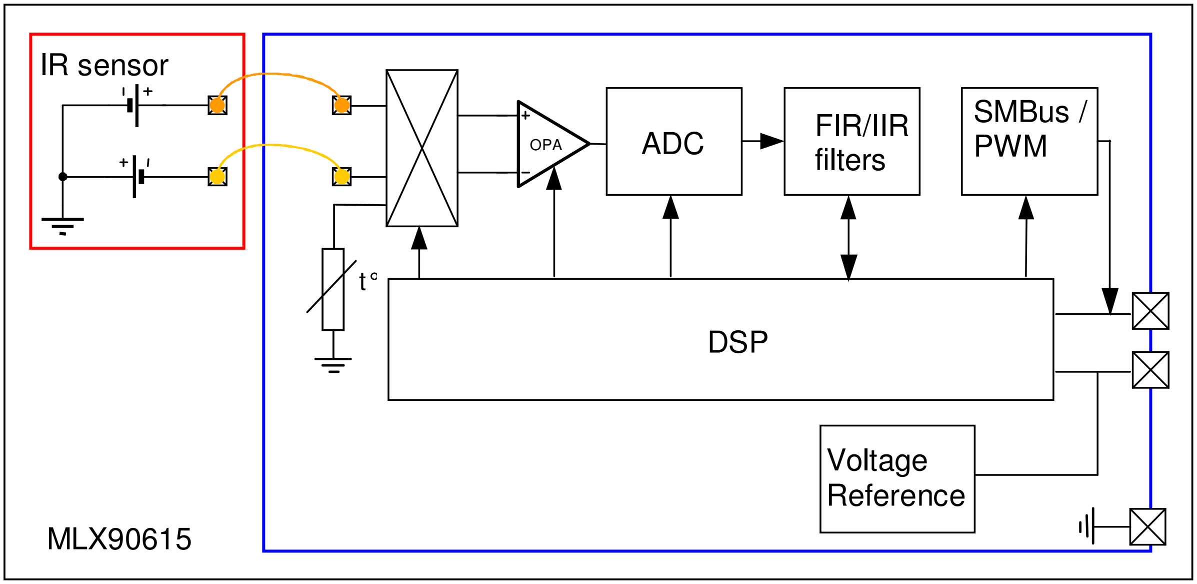

Figure 3: Block Diagram

8.2 Signal processing principle

A DSP embedded in the MLX90615 controls the measurements, calculates object and ambient temperatures and does the post-processing of the temperatures to output them through SMBus compatible interface or PWM (whichever activated).

The output of the IR sensor is amplified by a low noise, low offset chopper amplifier with programmable gain, then converted by a Sigma Delta modulator to a single bit stream and fed to the DSP for further processing. The signal passes a FIR low pass filter with fixed length of 65536. The output of the FIR filter is the measurement result and is available in the internal RAM. Based on results of the above measurements, the corresponding ambient temperature T_A and object temperatures T_O are calculated. Both calculated temperatures have a resolution of 0.02 ˚C.

An additional IIR LPF is programmable in EEPROM and allows customization of the thermometer output in order to trade-off noise versus settling time (refresh rate of the data in the RAM remain constant).

The IIR filter can also limit effect of spurious objects that may appear in the FOV in some applications.

The PWM output can be enabled in EEPROM as the POR default. Linearized temperatures (T_O or T_A, selectable in EEPROM) are available through the free-running PWM output.

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 a careful design of the input modulator and balanced input impedance, the max offset of the system is

0.5μV. As the device is factory calibrated any change of gain settings would require new calibration of object channel.

8.3.2 Power-On-Reset (POR)

The Power On Reset (POR) is connected to the Vdd supply. The on-chip POR circuit provides an active level of the POR signal when the Vdd voltage rises above approximately 0.5V and holds the entire MLX90615 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 a weak open drain (active high) at the SDA pin. After the MLX90615 exits the POR state, the functions programmed in the EEPROM take control of that pin.

8.3.3 EEPROM

A limited number of addresses in the EEPROM memory are of interest for the customer. The whole EEPROM can be read and written with the SMBus interface. The entire EEPROM content between addresses 0x04 and 0x0D must be kept unaltered or the factory calibration of the device will be lost.

EEPROM (16X16)		
Name	Address	Write access
PWM T min / SMBus slave address (SA)	0x00	Yes
PWM T range	0x01	Yes
Config	0x02	Yes
Emissivity	0x03	Yes
Melexis reserved (factory calibration)	0x04	Yes
…	…	…
Melexis reserved (factory calibration)	0x0D	Yes
ID number	0x0E	No
ID number	0x0F	No

Table 6 EERPOM table

SMBus slave address: 7 LSBs (6...0) contains the SMBus slave address that the MLX90615 will respond to. Note that all MLX90615 will respond to SA=0x00 and therefore this value is useless in a network. Factory default SA is 0x5B, max 127 devices on one line SA=0x01 …0x7F

PWM T min: 15 bit for the minimum temperature when PWM is used – right justified (factory default is 0x355B, which corresponds to +0.03℃)

PWM T range: 15 bit range for the PWM signal temperature (T_{MAX} – T_{MIN}) – right justified (factory default is 0x09C4, which corresponds to a PWM range of 50.01℃).

The **Config** register consist of control bits to configure the thermometer after POR:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	Config register bit meaning (0x02)
															0	- Comminucation type is PWM
															1	- Comminucation type is SMBus
														0		- PWM frequency = 1KHz
														1		- PWM frequency = 10KHz
													0			- PWM output = To
													1			- PWM output = Ta
																- 0…63 - Internal RC oscillator trimnming
																- MLXreserved - DO NOT alter
					0	0										- GAIN = 1 - Amplifier bypassed; MLX reserved - DO NOT alter
					0	1										- GAIN = 10; MLX reserved - DO NOT alter
					1	0										- GAIN = 40; MLX reserved - DO NOT alter
					1	1										- GAIN = 40; MLX reserved - DO NOT alter
				0												- Internal shunt regulatior disabled
				1												- Internal shunt regulatior enabled
	0	0	0													**- FORBIDDEN COMBINATION**
	0	0	1													- IIR (2) a1=1, b1=0
	0	1	0													- IIR (3) a1=0.5, b1=0.5
	0	1	1													- IIR (4) a1=0.333(3), b1=0.666(6)
	1	0	0													- IIR (5) a1=0.25, b1=0.75
	1	0	1													- IIR (6) a1=0.2, b1=0.8
	1	1	0													- IIR (7) a1=0.166(6), b1=0.833(3)
	1	1	1													- IIR (8) a1=0.14286, b1=0.87514
0																MLX reserved - DO NOT alter

Table 7 Config register meaning of the MLX90615 (continued)

**Note: IIR setting 000b must be avoided*

Emissivity: Contains the value for object emissivity correction. The MLX90615 will compensate for the emissivity of the object measured with respect to that value. The equation for that register is

$$Emissivity = dec2hex(round(16384 \times \varepsilon))$$

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. For details about the emissivity factor in IR measurements refer to the FAQ section of the current document.
Factory default is 0x4000, which sets the thermometer to an emissivity of 1.0 (emissivity correction is off).

8.3.4 RAM

RAM can be read through SMBus interface. Limited numbers of RAM registers, summarized below are of interest to the customer.

RAM (16x16)		
Name	**Address**	**Read access**
Melexis reserved	**0x00**	**Yes**
…	**…**	**…**
Melexis reserved	**0x04**	**Yes**
Raw IR data	**0x05**	**Yes**
T_A	**0x06**	**Yes**
T_O	**0x07**	**Yes**
Melexis reserved	**0x08**	**Yes**
…	**…**	**…**
Melexis reserved	**0x0F**	**Yes**

Table 8 RAM address list of the MLX90615

T_A is the MLX90615 package (ambient) temperature and T_O is the object temperature. The output scale is 0.02°K/LSB. To convert a read object temperature into degrees Celsius the equation is:

$$T_O[°C] = RAM(0x07) \times 0.02 - 273.15$$

Raw IR data is in sign (1 bit, the MSB) and magnitude (15 bits) format.

8.4 SMBus compatible 2-wire protocol

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

- SCL – digital input, used as the clock for SMBus compatible communication. A low pulse on that pin with duration t_{REQ} switches to the SMBus mode in case the PWM is selected in EEPROM. In case PWM operation is desired, the SCL pin should be kept high. SMBus is the factory default (via EEPROM settings).
- SDA / PWM – Digital input / NMOS open drain output, used for PWM and input / output for the SMBus. (SMBus is factory default function).

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 present at any given time [1]. The MLX90615 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 14 EEPROM cells (at addresses 0x00…0x0D). If the access to the MLX90615 is a read operation, it will respond with 16 data bits and 8 bit PEC only if its own SA, programmed in the internal EEPROM, is equal to the SA, sent by the master. The SA feature allows connecting up to 127 devices with 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 MLX90615 will always respond and will ignore the internal chip code information.

Note that EEPROM addresses 0x04…0x0D contain the factory calibration parameters and should not be altered.

Special care must be taken not to put two MLX90615 devices with the same SD addresses on the same bus as MLX90615 does not support ARP[1].
The MD can force the MLX90615 into low consumption mode “sleep mode”.

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

There are eleven command protocols for the standard SMBus interface. The MLX90615 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 SDA pin of the MLX90615 can operate also as a PWM output, depending on the EEPROM settings. If PWM is enabled, after POR the SDA pin is directly configured as a PWM output. The PWM mode can be avoided and the pin can be restored to its Serial Data function by issuing SMBus request condition. If SMBus mode is set, after POR, the request does not have to be sent.

8.4.3.1 Bus Protocol

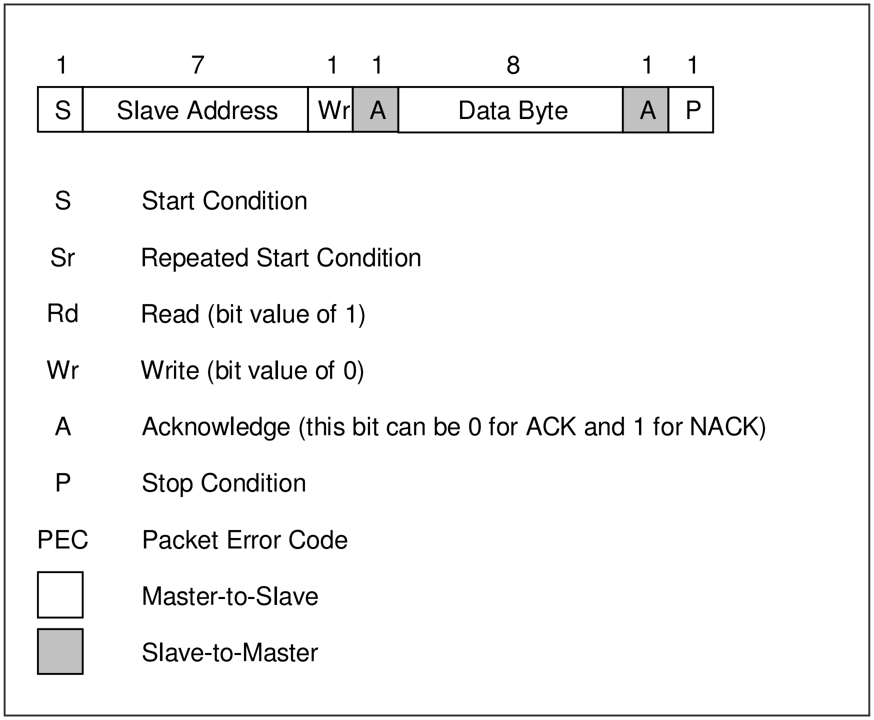

Figure 4: SMBus packet element key

After every 8 bits received by the SD an ACK/NACK is followed. When a MD initiates communication, it first sends the SA. Only the SD with recognized SA gives ACK, the rest will remain silent. If the SD does not ACK 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 transmitted first.

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

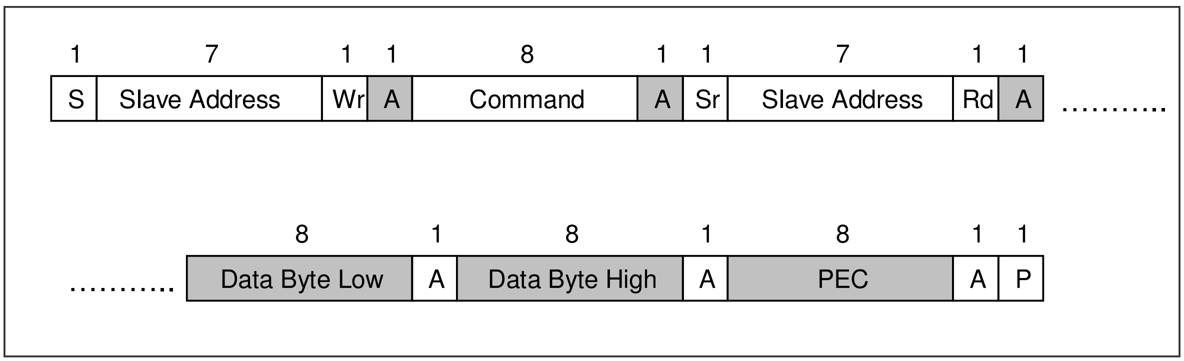

Figure 5: SMBus read word format

8.4.3.1.2 Write Word (EEPROM only)

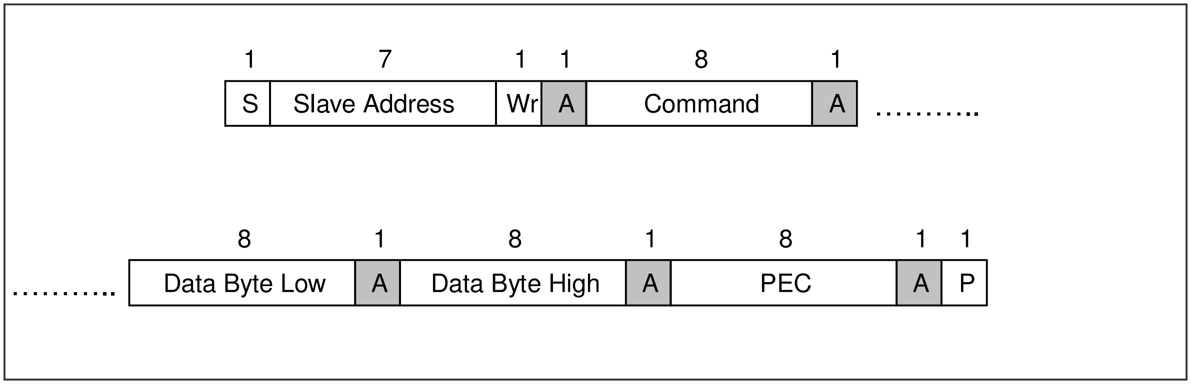

Figure 6: SMBus write word format

8.4.4 Bit transfer

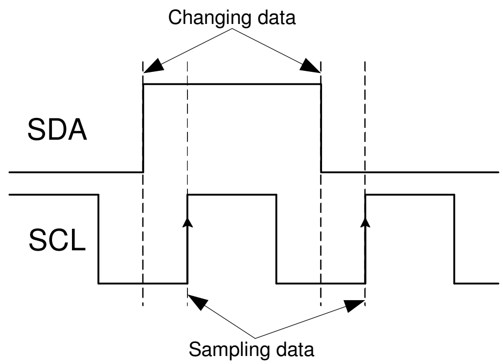

Figure 7: Bit transfer on SMBus

The data on 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

In application mode RAM and EEPROM can be read both with 16x16 sizes. (For example, T_O - RAM address 0x07 will sweep between 0x2D8A to 0x4BD0 as the object temperature rises from -40℃ to +115℃). The MSB read from RAM is an error flag (active high) for the linearized temperatures (T_O and T_A).

Opcode	Command
0001 aaaa*	EEPROM Access
0010 aaaa*	RAM Access
1100 0110	Enter SLEEP mode

Table 9 Command list for the MLX90615

NOTE*: The aaaa are the 4 LSBits of the memory map address to be read / written

8.4.6 SMBus Communication examples

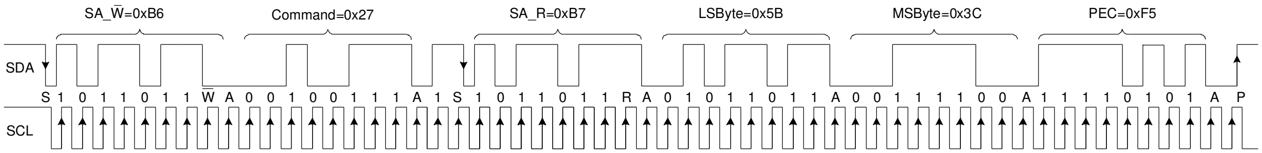

Figure 8: SMBus read word format (SA=0x5B, read RAM=0x07, result = 0x3C5B)

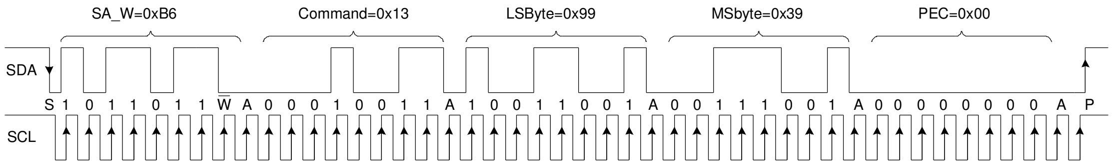

Figure 9: SMBus write word format (SA=0x5B, Write=0x3999 to EEPROM= 0x03)

Note: Before a write operation to takes place, the EEPROM cell needs to be erased. An erase operation is simply a writing of 0x0000 at the same EEPROM address. Care needs to be taken not to alter factory calibration (EEPROM addresses 0x04…0x0D).

8.4.7 Timing specification

The MLX90615 meets all the timing specifications of the SMBus [1] except the values given in the Electrical specifications section.The maximum frequency of the MLX90615 SMBus clock is 100 kHz and the minimum is 10 kHz.

The specific timings for the MLX90615's SMBus are:

SMBus Request (t_{REQ}) is the time that the SCL should be forced low in order to switch MLX90615 from thermal relay mode to SMBus mode – at least 39 ms

Timeout L is the maximum allowed time for SCL to be low. After this time the MLX90615 will reset its communication block and will be ready for new communication - not more than 21ms

Timeout H is the maximum time for which it is allowed for SCL to be high during communication. After this time MLX90615 will reset its communication block assuming that the bus is idle (according to the SMBus specification) - not more than 52µs

Tsuac(SD) is the time after the eighth falling edge of SCL during which the MLX90615 will force 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 during which the MLX90615 will release the 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 during which the MLX90615 will release 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 during which the MLX90615 will take control of the 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 the acknowledge; SD when the slave device is making the acknowledge). For other timings see [1].

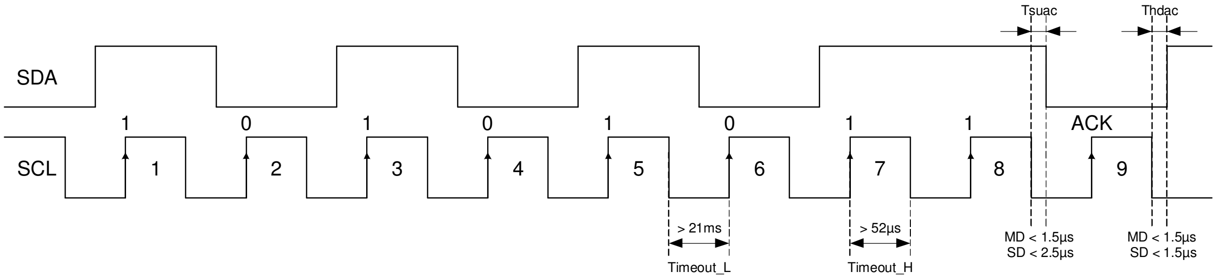

Figure 10: SMBus timing

8.4.8 Sleep Mode

Sleep mode is available in SMBus mode only.

MLX90615 can enter Sleep Mode via command "Enter SLEEP mode" sent via the SMBus interface. SCL needs to be high during Sleep. SDA can idle in each state at the same time, but the high state is recommended as the pull-up does not add current drain. There are weak pull-ups on both SCL and SDA pins.

8.4.8.1 Enter Sleep Mode

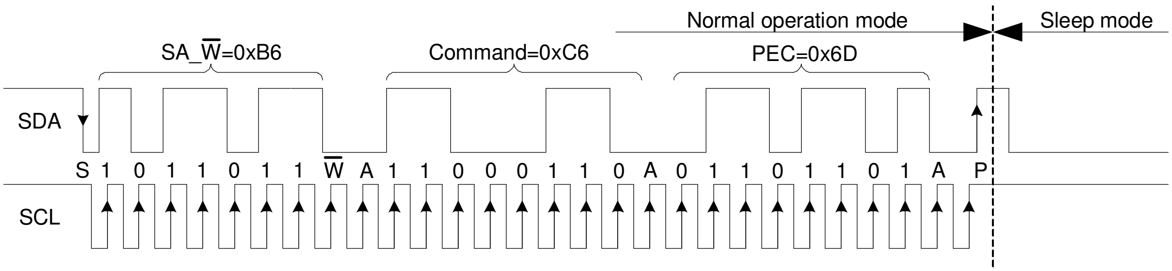

Figure 11: Enter sleep mode command (SA=0x5B, Command=0xC6,PEC=0x6D)

8.4.8.2 Exit Sleep Mode

MLX90615 goes back into power-up default mode by forcing the SCL pin low for at least t_{wake} > 8ms. Exit from Sleep is always in SMBus mode. Valid data will be available typically 0.3 seconds after the device has woken up.

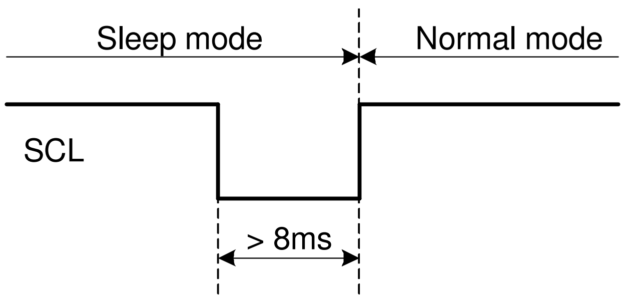

Figure 12 Exit Sleep Mode

8.5 Switching between PWM and SMBus

8.5.1 PWM to SMBus mode

The diagram below illustrates how to switch to SMBus if PWM is enabled. If PWM is enabled, the MLX90615's SMBus Request condition is needed to disable PWM and reconfigure SDA/PWM pin before starting SMBus communication. The MLX90615's SMBus request condition requires forcing the SCL pin LOW for a period longer than the request time (t_{REQ}>39ms). The SDA / PWM line value is ignored in this case. Note that after power ON / OFF the sensor will be in PWM mode if bit 0 from Config register is not set in SMBus mode.

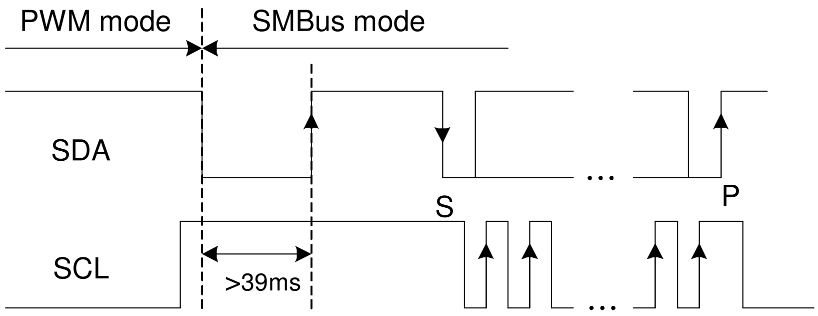

Figure 13: Switching from PWM to SMBus mode

8.5.2 SMBus to PWM mode

If SMBus mode is set by default, PWM mode can be set only by setting bit 0 from Config register to PWM mode and switching the supply OFF then ON.

8.6 PWM

The MLX90615 can be read via PWM or SMBus compatible interface. Selection of PWM output is done in EEPROM configuration (factory default is SMBus). Object or ambient temperature can be read through PWM. The PWM period is derived from the on-chip oscillator and is programmable in a low (10 Hz) or high (1 KHz) frequency mode.

Temperature ranges for the PWM output are determined by the contents of the cells 0x00, 0x01 in the EEPROM – PWM To_{MIN} and PWM_{RANGE} (To_{MAX} - To_{MIN}), scale is 0.02°K/LSB.

Note that in SMBus mode the EEPROM address 0x00 (LSByte) is used for Slave address SA.

Note that the SCL pin needs to be kept high in order to use the PWM function or to be left unconnected as there is a weak pull up build in.

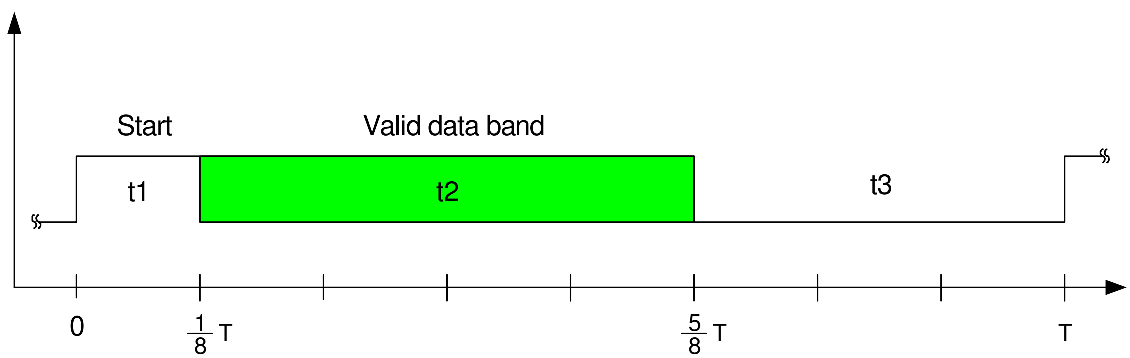

Figure 14 PWM format

8.6.1 PWM format

The temperature reading can be calculated from the signal timing as:

$$Tout = 2 \times \frac{t_2}{T} \times (T_{MAX} - T_{MIN}) + T_{MIN}$$

where Tmin and Trange are the corresponding rescale coefficients in EEPROM for the selected temperature output and T is the PWM period. Tout is T_O or T_A according to bit Config Register, 2.

The different time intervals t_1, t_2 and t_3 have the following functions:

t_1 : Start buffer. During this time the signal is always high. $t_1 = 0.125 \times T$ (T is the PWM period, refer to fig. 14).

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

t_3 : always low signal.

The maximum duty cycle is limited to $t_1 + t_2 = 0.625$ this means that the PWM line will never go static, allowing detection of fault on the line (disconnected device, short on the line).

8.6.2 Customizing the temperature range for PWM output

The calculated ambient and object temperatures are stored in RAM with a resolution of 0.02°C (15 bit). The PWM operates with a 10-bit number 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 temperature range, PWM T_{MIN} and PWM T_{RANGE}.

Thus the output range can be programmed with an accuracy of 0.02 °C.

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

$$T_{PWM} = \frac{T_{RAM} - T_{MIN_{EEPROM}}}{K_{PWM}}, K_{PWM} = \frac{T_{RANGE_{EEPROM}}}{1023}$$

The T_{RAM} is the linearized temperature, 15-bit (0x2D8A…0x4BD0, → -40 ..+115°C) and the result is a 10-bit word, in which 0x000 corresponds to PWM T_{MIN}[°C], 0x3FF corresponds to PWM T_{MAX}[°C] and 1LSB corresponds to:

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

$$T_{MAX} = T_{MIN} + T_{RANGE}$$

$$T_{MIN_{EEPORM}} = T_{MIN} \times 50LSB$$

$$T_{MAX_{EEPORM}} = T_{MAX} \times 50LSB$$

Example:

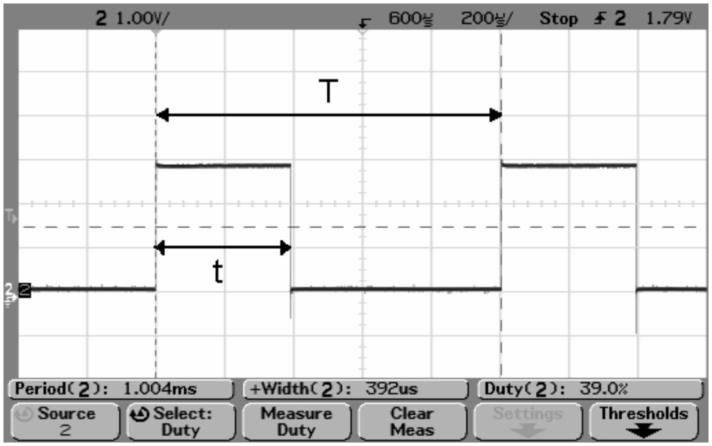

Figure 14: PWM example

$$To_{MIN} = 0°\text{C} \rightarrow To_{MIN}(\text{EEPROM}, 0\text{x}00) = 50 \times (To_{MIN} + 273.15) = 13658d = 0x355A$$

$$PWM_{RANGE}(To_{MAX} - To_{MIN}) = 50°\text{C}$$

$$PWM_{RANGE}(EEPROM, 0x01) = 50 \times PWM_{RANGE} \times (To_{MAX} - To_{MIN}) = 50 \times 50 = 2500d = 0x09C4$$

Captured PWM period is T = 1004µs (or frequency is 996 Hz i.e. high frequency mode is selected)
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:

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

Where 0.125 is START period (always high) which carry no temperature information and must be subtracted.

8.7 Principle of operation

The IR sensor consists of series connected thermo-couples with cold junctions placed at thick chip substrate and hot junctions, placed over thin membrane. The IR radiation absorbed from the membrane heats (or cools) it. The thermopile output signal is

$$V_{ir}(T_A, T_O) = A \times (T_O - T_A)$$

Where T_O is the object absolute temperature (Kelvin), T_A is the sensor die absolute (Kelvin) temperature, and A is the overall sensitivity.
An additional sensor is needed for the chip temperature. After measurement of the output of both sensors, the corresponding ambient and object temperatures can be calculated. These calculations are done by the internal DSP, which produces digital outputs, linearly proportional to measured temperatures.

8.7.1 Ambient temperature T_A

The Sensor die temperature is measured with a PTAT element. All the sensors conditioning and data processing is handled on-chip and the linearized sensor die temperature T_A is available in RAM (address 0x06).
The resolution of the calculated T_A is 0.02˚C. The sensor is factory calibrated for the range -20 … +85˚C.

Example:

$RAM(0x06) = 0x3171$ corresponding to -20.01˚C

$RAM(0x06) = 0x45F3$ corresponding to +84.99˚C

Conversion RAM content to real T_A is easy done with following expression:

$$T_A[°K] = 0.02 \times T_{A\_REG}$$

8.7.2 Object temperature T_O

The result has a resolution of 0.02˚C and is available in RAM (address 0x07). To is derived from RAM as:

$$T_O[°K] = 0.02 \times T_{O\_REG}$$

Example:

$RAM(0x07) = 0x2D89$ corresponding to -40.01˚C

$RAM(0x07) = 0x4BCF$ corresponding to +114.99˚C